United Nations Development Programme
World Bank
Bangladesh Water Development Board
Ministry of Irrigation, Water Development and Flood Control
Government of the People's Republic of Bangladesh

South East Region Water Resources Development Programme BGD/86/037

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Noakhali North Drainage and Irrigation Project Feasibility Study

Volume 2 - Annex B and C

Hydrology and Hydraulic Modelling/Hydrogeology

October, 1993

Sir M MacDonald and Partners Limited, UK
in association with
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ANNEX B

HYDROLOGY AND HYDRAULIC MODELLING

4

NOAKHALI NORTH DRAINAGE AND IRRIGATION PROJECT
FEASIBILITY STUDY

ANNEX B - HYDROLOGY AND HYDRAULIC MODELLING

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CHAPTER B.1

INTRODUCTION

B.1.1 Objectives

The hydrological and hydraulic studies have a central role in the assessment of the impact of the river and drainage engineering proposals in the Noakhali North Project. These studies involve the use of the computer based hydrological model NAM and the hydraulic model MIKE11. The model studies are not an end in themselves but should be viewed as a tool to provide quantitative predictions of the changes in flow patterns, rates and levels that may arise from the implementation of the engineering proposals. The modelling also provides parameters for the design of the engineering works.

The objectives of the hydrodynamic modelling in the project are threefold,

i) to assess the nature and extent of the existing flood problem, and to provide the basis for quantifying present flood-depth-area-frequency relationships, which can be used in project planning and evaluation;

ii) to provide the basis for assessing the impacts of flood mitigation measures, both inside and external to the project area, and for comparing pre- and post-development conditions;

iii) to provide design characteristics in the form of peak flood levels, discharges and velocities, for flood mitigation measures.

The hydrodynamic model provides a simulation of water levels and discharges, at each node in the schematisation of the river system, in response to a set of boundary conditions which effectively comprise upstream flows and downstream water level controls.

B.1.2 Study Area Location, Climate and Hydrology

The Noakhali North project area is bounded by the existing Chandpur Irrigation Project and Lower Meghna on the west, the Dakatia river in the north, the slight ridge bordering the Little Feni river basin on the east, and the old coastal embankment separating the coastal char lands to the south.

The project area is 108,718 hectares in size with a net cultivatable area (NCA) of 122,103 hectares. The dominant feature of the area is the Begumganj depression which is more or less centred on Begumganj. The land elevation in the depression is not in fact remarkably low (about 3mPWD), but it is almost completely encircled by higher ground.

The project area experiences a typical monsoon climate, with hot wet summers from May to October and cooler dry winters. Mean annual rainfall at Noakhali is of the order of 3200mm, and decreases northwards to about 2000mm at Comilla.

In an average year, potential evapotranspiration exceeds rainfall between the months of October and March throughout the region. Rainfall in the early and late monsoon periods is highly variable however, and the average conditions do not give a representative indication of requirements for irrigation. There is a requirement for irrigation between the months of October and April, even under average rainfall conditions.

The region is affected by severe tropical cyclones which develop in the Bay of Bengal. Cyclones most commonly occur in the periods before and after the main monsoon season in the months of May and October. In recent times, cyclones have affected the region in 1970, 1985 and 1991. Tropical cyclones are generally accompanied by very strong winds, high rainfall and storm surges, which in coincidence with high tides can have disastrous consequences in coastal regions.

The area south of the Daudkandi to Comilla road has three principal drainage features,

- the Dakatia River
- the Rahmatkhali Khal
- the Little Feni River.

These rivers are in fact interconnected by a complex system of channels, but they do provide primary drainage routes. The Dakatia River has its source with the Sonaichari and Pagli Rivers which drain small catchments in the Tripura Hills. The Little Feni collects drainage from the Kakri and a number of catchments in the Tripura hills, but these are all significantly smaller than those north of the Gumti.

Rahmatkhali khal forms the principal drainage route in the south of the region. Formerly, before completion of the Meghna cross dams, the coastal embankments and polders, the Noakhali Khal was a more important drainage route. However, with land accretion in the south, the primary drainage routes from the South Noakhali area are through the Rahmatkhali regulator to the west and Kazirhat regulator to the east.

The Little Feni which drains into the Bay of Bengal via Kazirhat regulator suffers from siltation in the outfall channel. Clearing of the channel and gates causes delays in the opening of the regulator in the early part of the monsoon season with associated upstream flooding and occasional spilling into the Begumganj depression. However, the volume of spilling appears too small to cause any significant increases in water levels in the project area.

The general categories under which flooding in the region can be considered are,

- monsoon floods from the River Meghna and Lower Meghna
- flash floods from those rivers rising in the Tripura Hills to the east
- localised flooding as a result of heavy and intense rainfall
- floods resulting from storm surges in the Bay of Bengal.

It is clear that any flood control and drainage proposals therefore have to take account of these distinct flooding problems.

B.1.3 Scope of Report

This report covers the hydrological and hydraulic studies carried out during the Noakhali North study. A description is given of the methodology used in these studies. The development and calibration of the hydraulic model is described. The application of the model to investigate existing conditions and future conditions with proposed developments is presented.

The report does not cover the assessment of any non-hydraulic impacts of the various options and scenarios studied, these are described in the main report and other annexes.

B.1.4 Report Structure

Following this chapter which gives an introduction to the hydrological and hydraulic studies there are two chapters which describe respectively the hydrometeorology and the drainage conditions. Chapter 4 outlines the modelling methodology and Chapter 5 describes the model development and calibration. Chapters 6 and 7 describe the baseline testing and the investigation of various flood control and drainage development options whilst Chapter 8 describes the modelling of irrigation developments. Chapter 9 describes the final With Project testing. Chapter 10 draws conclusions and gives recommendations for future investigations.

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CHAPTER B.2

HYDROMETEOROLOGY

B.2.1 General

The hydrometeorology of the study area has been described to some degree in several publications, the most note worthy of which are "The Agro-Climatic Survey of Bangladesh" (Manalo, Ref. 1), and "Net Irrigation Requirement of Rice and Evapotranspiration of Wheat and Potato for Different Locations in Bangladesh" (Karim and Akland, Ref 2). For completeness of the present study, some further analysis of climatic conditions of particular relevance to the project area has been carried out. In the case of rainfall, more extensive analysis has been carried out than in previous studies, utilising records up to the 1989-90 water year. The analysis of basic climatic data has been based on the readily available published data for stations in the project area, generally covering the period 1965-80.

The monsoonal climate which affects the South East Region, and indeed the whole of Bangladesh, is part of a system which affects the whole of the Indian sub-continent. There are three main seasons:

i)	the south-west monsoon:	lasting approximately from May to October, and producing the main rainy season; almost 90% of the annual rainfall total in the study area occurs during this period, when both temperatures and relative humidity are high;
ii)	the north-east monsoon:	extending from November through to March, establishes the cool dry season of winter; only occasional rainfall occurs, associated with weak cyclonic disturbances;
iii)	a short hot season	this precedes the south-west monsoon and can extend from late March through till May; the highest maximum daily temperatures can occur at this time, and the season is associated with variable convective storm activity which can occasionally develop into severe cyclonic storms; during this season, flash flooding from the rivers draining the Tripura hills to the east of the region can be a problem.

The region is affected by severe tropical cyclones which develop in the Bay of Bengal. Cyclones most commonly occur in the periods before and after the main monsoon season in the months of May and October. In recent times, severe cyclones have affected the region in 1970, 1985 and 1991. Tropical cyclones are generally accompanied by very strong winds, high rainfall, and storm surge, which in coincidence with high tides can have disastrous consequences in coastal regions.

B.2.2 Climatic Norms

The locations of climatic stations in the South East Region are shown in Figure B.2.1. The climate stations of relevance to the study are at Chandpur and Noakhali. Data at each station date from 1965, although there is some variability in the parameters recorded, and the completeness of records. The key parameters of temperature, relative humidity and wind speed are recorded at each of the climate stations. Neither hours of bright sunshine or radiation are recorded at any of the stations, however, a reference has been made to data for the stations at Dhaka and Chittagong. This is a limitation in the existing network, and it is recommended that efforts be made to upgrade each of the stations. Significant variations exist in rainfall across the region, and there will therefore be variability in insolation.

Climatic norms for Chandpur and Noakhali are summarised in Figures B.2.2 and B.2.3, and in Tables B.2.1 and B.2.2. From these, the general characteristics in climate described in the introduction above are obvious, with very similar patterns being observed at each station. Wind speeds are lowest in the north-east monsoon period, but then pick up during the pre-monsoon hot season when Nor' westers and localised storm activity can occur. Wind speeds tend to level off during the south-west monsoon. In collecting climatic data for the present study it was noted that discrepancies exist in the units of wind speed measurement at several stations. It is recommended that original records at the existing climate stations are completely standardised. The mean monthly wind speeds are significantly higher than those recorded in some other parts of the country.

Mean daily temperatures in the region are fairly constant between the months of April and September, and show little variation across the region, being of the order of 28°C. From October, temperatures begin to decline, and mean daily temperatures reach a minimum of about 19-19.5°C in January. In April, maximum daily temperatures in the region can often exceed 35°C, while in January, minimum daily values can be below 10°C. Increased cloud cover during the south-west monsoon period prevents extremes of temperature when the sun is at its maximum declination. This is reflected clearly from the plots of sunshine hours. There is a dramatic fall in the hours of bright sunshine during the main monsoon period.

Relative humidity is high throughout the year. Maximum values occur in July, when the mean is of the order of 87.5% throughout the region. February generally produces the lowest values of 71% at Chandpur and Noakhali.

Potential evapotranspiration has been calculated using the modified Penman Method, and these estimates are included in Tables B.2.1 and B.2.2.

Potential evapotranspiration at Noakhali and Chandpur are more or less in the same range. Pan evaporation measurements are made at a number of stations in Bangladesh, but must be treated with caution. There are few countries in which practical use can be made of pan measurements. A comparison of evaporation estimates for Noakhali is presented in Table B.2.3. Differences in the dry season are of rather more significance than differences in the wet season when irrigation is not required. The reliability that can be attached to the evaporation estimates is not particularly high.

In an average year, potential evapotranspiration exceeds rainfall between the months of October an March throughout the region. Rainfall in the early and late monsoon periods is highly variable however, and the average conditions do not give a representative indication of requirements for irrigation. It is clear from Figures B.2.1 to B.2.3 that there is a requirement for irrigation between the months of October and April, even under average rainfall conditions. Rainfall and effective rainfall for agriculture are considered in greater detail in sections B.2.3 and B.2.4.

The peak rainfall months in the region are June, July and August. During these three months, about 55-60% of the annual rainfall total can be expected.

Figure B 2.1
Hydrometric Stations in the South East Region

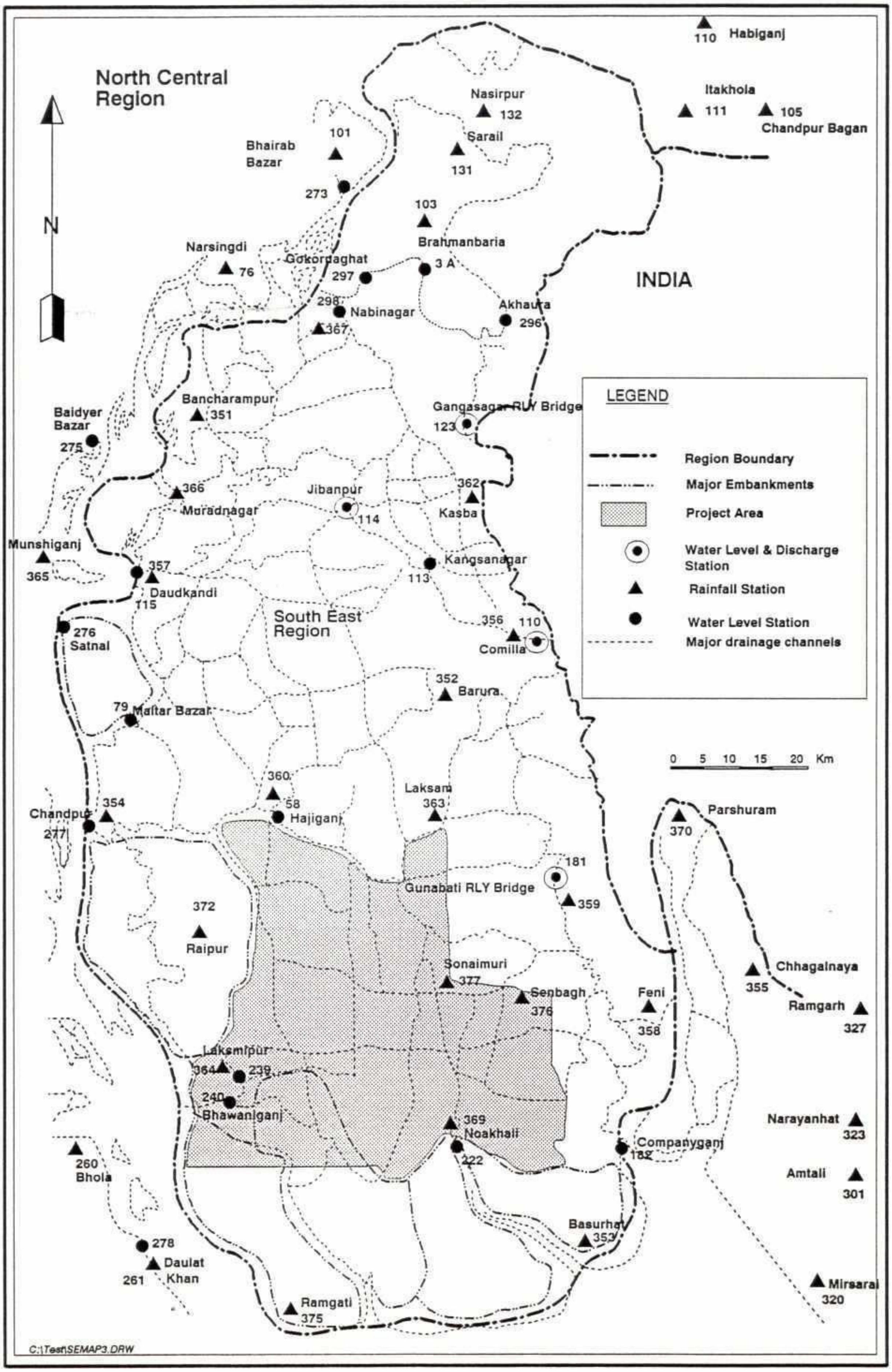

Figure B.2.2

Climatic Norms at Chandpur

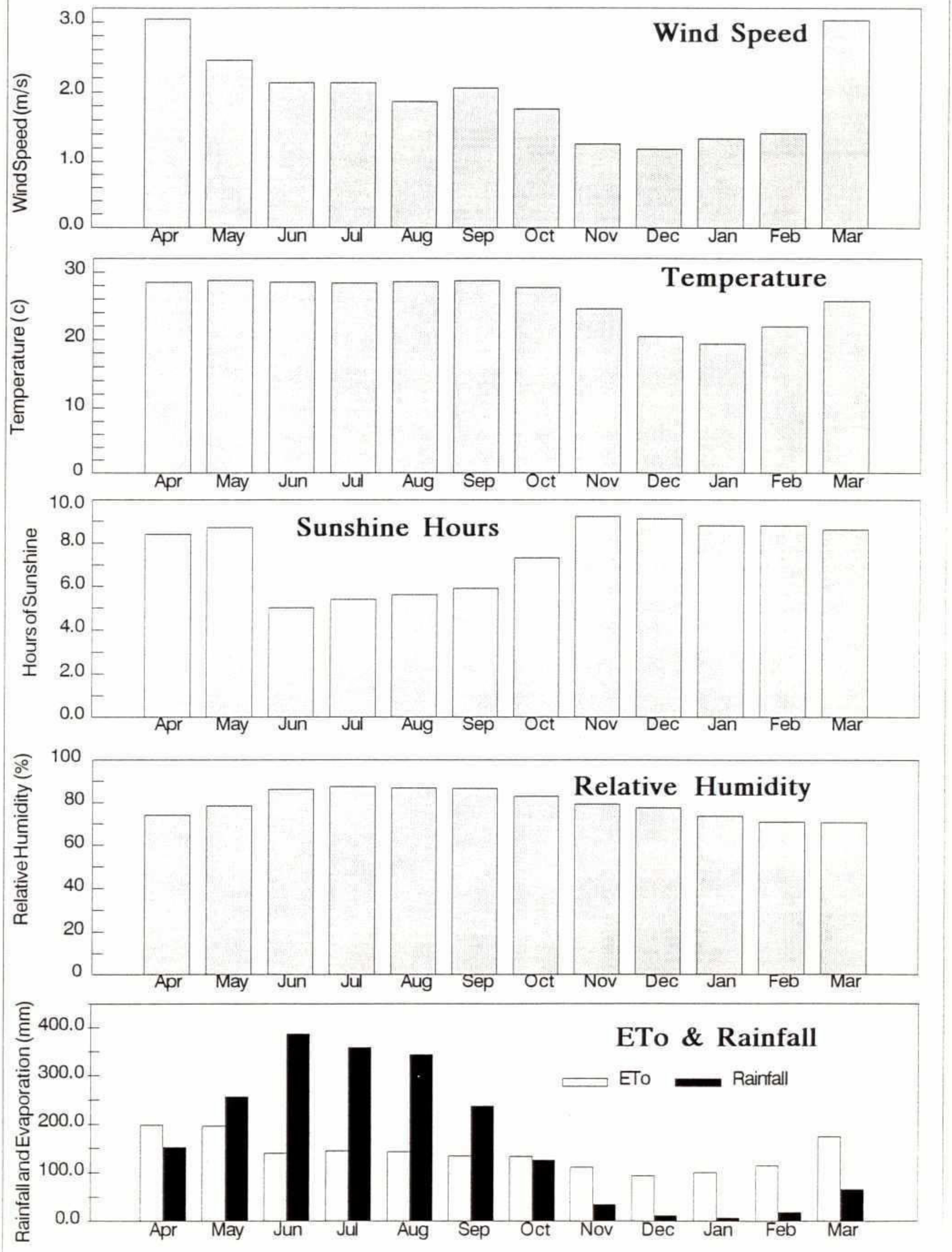

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Figure B.2.3
Climatic Norms at Noakhali

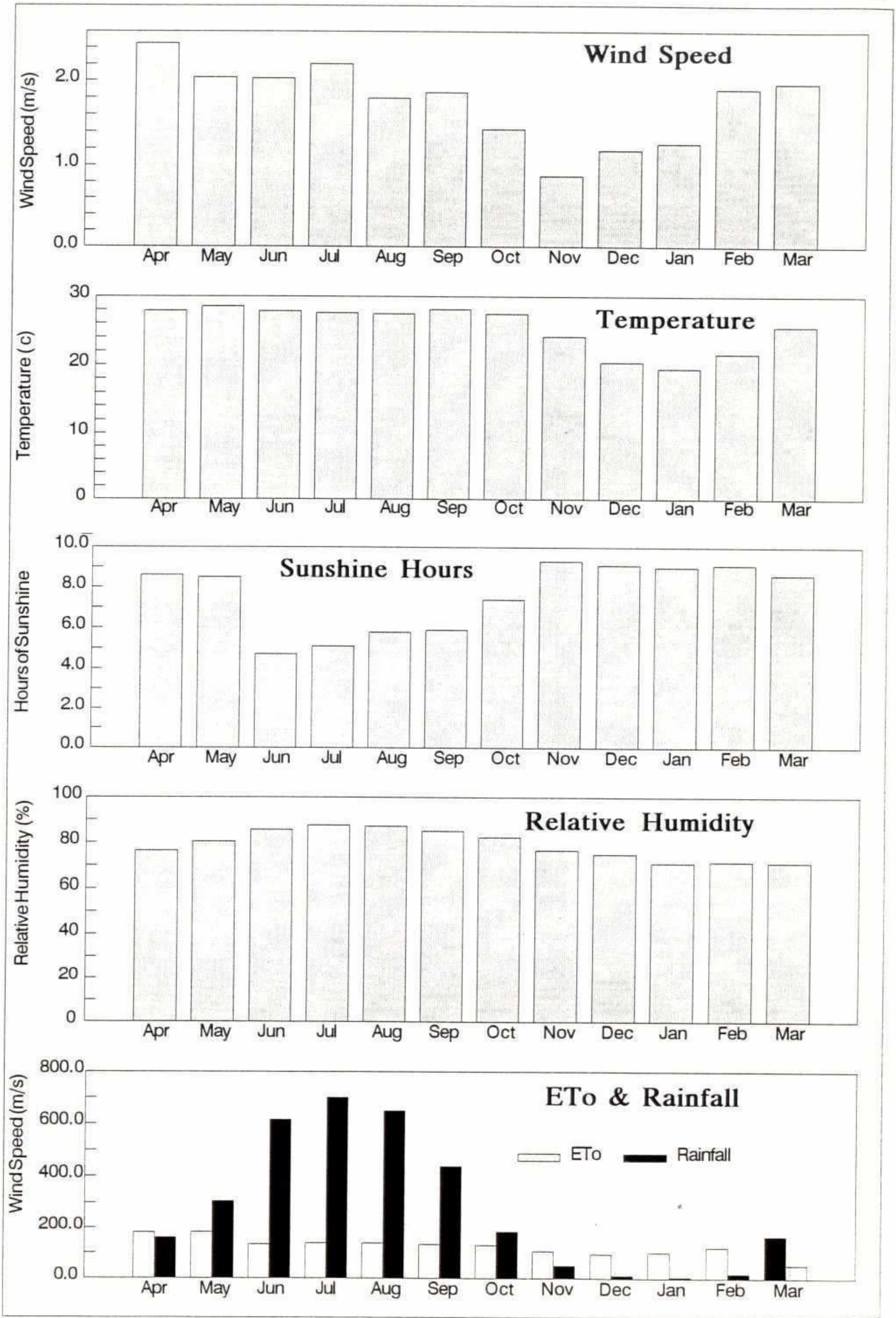

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TABLE B.2.1

Climatic Norms at Chandpur

Parameter	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
Mean Temperature (c)	28.5	28.8	28.5	28.4	28.6	28.7	27.7	24.5	20.4	19.3	21.9	25.7	25.9
Relative Humidity	74.1	78.3	86.2	87.4	86.7	86.5	82.9	79.2	77.6	73.8	71.0	70.7	79.5
Windspeed (m/s)	3.0	2.5	2.1	2.1	1.9	2.1	1.8	1.3	1.2	1.3	1.4	3.0	2.0
Sunshine (hrs/d)	8.4	8.7	5.0	5.4	5.6	5.9	7.3	8.8	9.1	8.8	8.8	8.6	75
Peanman Eto (mm)	195	196	140	145	143	134	134	97	94	100	115	174	1670
Rainfall (mm)	152.0	257.0	387.0	358.0	343.0	237.0	126.0	7.0	12.0	7.0	18.0	66.0	1970

TABLE B.2.2

Climatic Norms at Noakhali

Parameter	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
Mean Temperature (c)	27.9	28.5	27.8	27.6	27.4	28.1	27.4	24.1	20.4	19.5	21.6	25.5	25.5
Relative Humidity	76.6	80.4	85.6	87.5	87.2	85.0	82.3	76.7	74.9	71.0	71.5	71.3	79.2
Windspeed (m/s)	2.5	2.0	2.0	2.2	1.8	1.9	1.4	0.9	1.2	1.3	1.9	2.0	1.8
Sunshine (hrs/d)	8.6	8.5	4.7	5.1	5.8	5.9	7.4	9.3	9.1	9.0	9.1	8.6	7.0
Peanman Eto (mm)	183	183	135	140	140	134	131	108	96	103	123	169	1645
Rainfall (mm)	161.0	306.0	614.0	700.0	648.0	439.0	186.0	49.0	13.0	6.0	19.0	53.0	3194

TABLE B.2.3

Comparison of Evaporation Values for Noakhali Area

Method	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
Pan Evaporation	124	119	95	69.0	60	63	90	81	83	85	115	138	1122
Karim & Akland Evaporation	102	102	69	62	56	63	71	57	53	53	76	102	866
Manalo (mean monthly)	129	133	89	90	78	84	86	71	65	65	82	121	1093
SERM *	108	101	93	74	85	80	86	88	73	67	73	104	1032

* Based on Brahmanbaria Pan Evaporation

B.3 Regional Rainfall

B.2.3.1 General

The locations of raingauges of relevance to the study have been indicated in Figure B.2.1. The general availability of daily data for these stations is indicated in Table B.2.4. In general terms the continuity of records is fairly good. A total of 22 daily gauges have been used on the study, and a data base created with a common record period of covering the 1962-1991 water years. These 22 stations were selected on the basis of their data availability and are highlighted in Table B.2.4.

B.2.3.2 Data Reliability

A number of forms of analyses have been carried out to test the reliability of the data, including cross correlation and double mass.

Cross correlations for ten day and monthly rainfall totals between the months of April and October were presented in the South East Regional Plan Report. The correlation coefficients are generally higher for the monthly totals than for the ten day totals, as would be expected, and the indication is of general consistency. The exception however, is at station R-375 where correlation coefficients between station R-375 and its neighbours are low. There is therefore reason to suspect data quality at this station.

Double mass curve analysis has been carried out on the station identified through cross correlation analysis as having suspect data quality, and on a further station which was considered to be typical from the correlation analysis. The stations tested, and the groupings of check stations used are summarised in Table B.2.5.

Station R-375, Ramgati, appears to have experienced some change in regime between 1966 and 1980 (Figure B.2.4). The slope of the mass curve before and after this period is similar, but seems to have undergone progressive change in between. The mean annual rainfall total at this station is particularly high, and it could be important to the design of drainage facilities in the south of the region. The data are apparently unreliable and should not be used in any detailed analysis until the station history can be verified and reasons, if any, for the apparent unreliability defined.

Figure B.2.5 presents a double mass curve for station R-376, this is a more typical plot for reliable data. The indications are that the rainfall data quality is, on the whole, good.

B.2.3.3 Time Series Analysis

Time series analysis has been carried out on the annual rainfall data for station R-376. The records are too short and have too many gaps to permit detection of any long term trends, but the analysis does assist in giving an understanding of the inter-annual variations in rainfall data that exist. The missing values in the annual totals for each of these stations also restricts the usefulness of any statistical interpretation.

TABLE B.2.4

Availability of Rainfall Data for Noakhali North Project

Figure B.2.4

Double Mass Curve Analysis, Station R-375

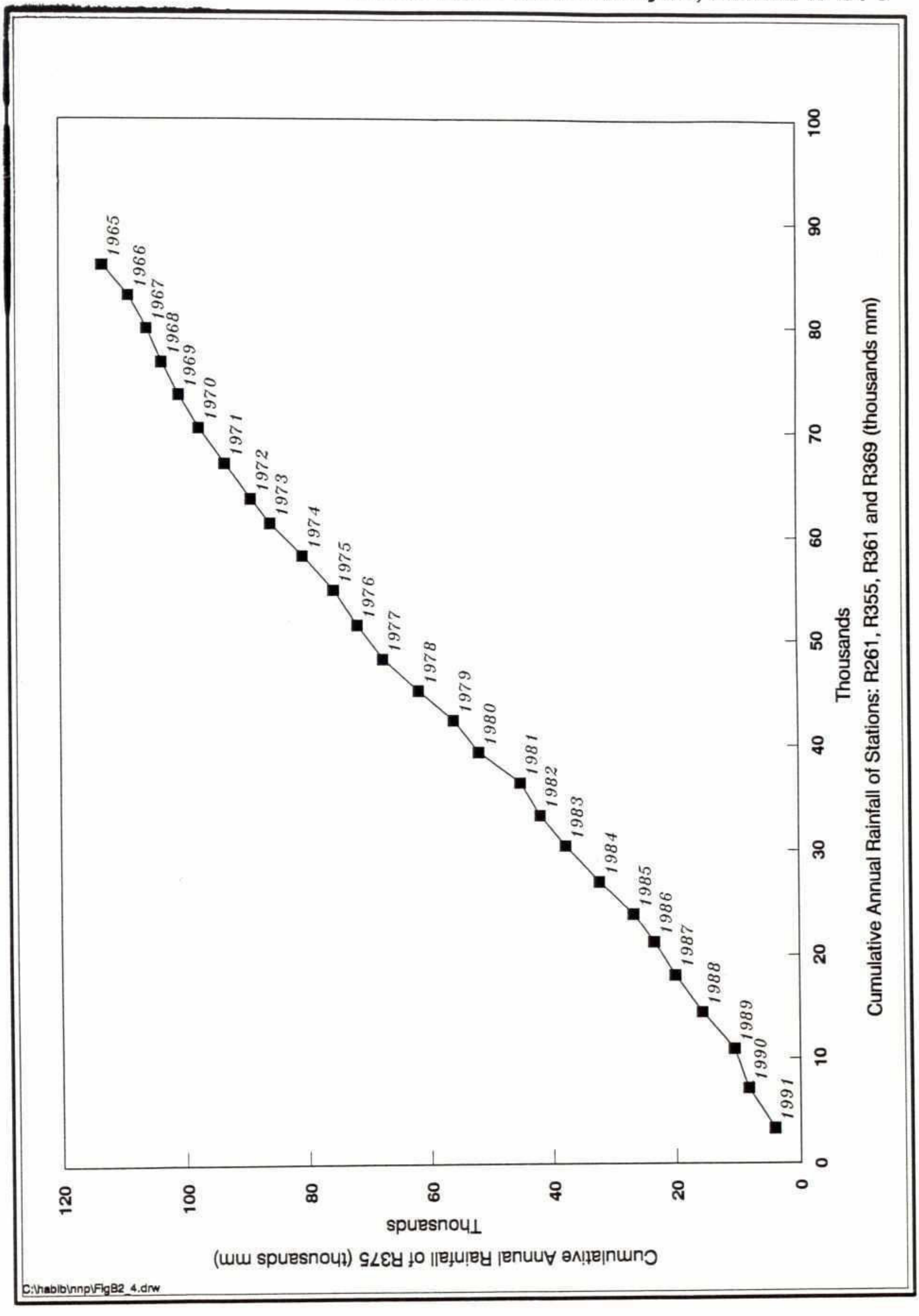


Figure B.2.5

Double Mass Curve Analysis, Station R-376

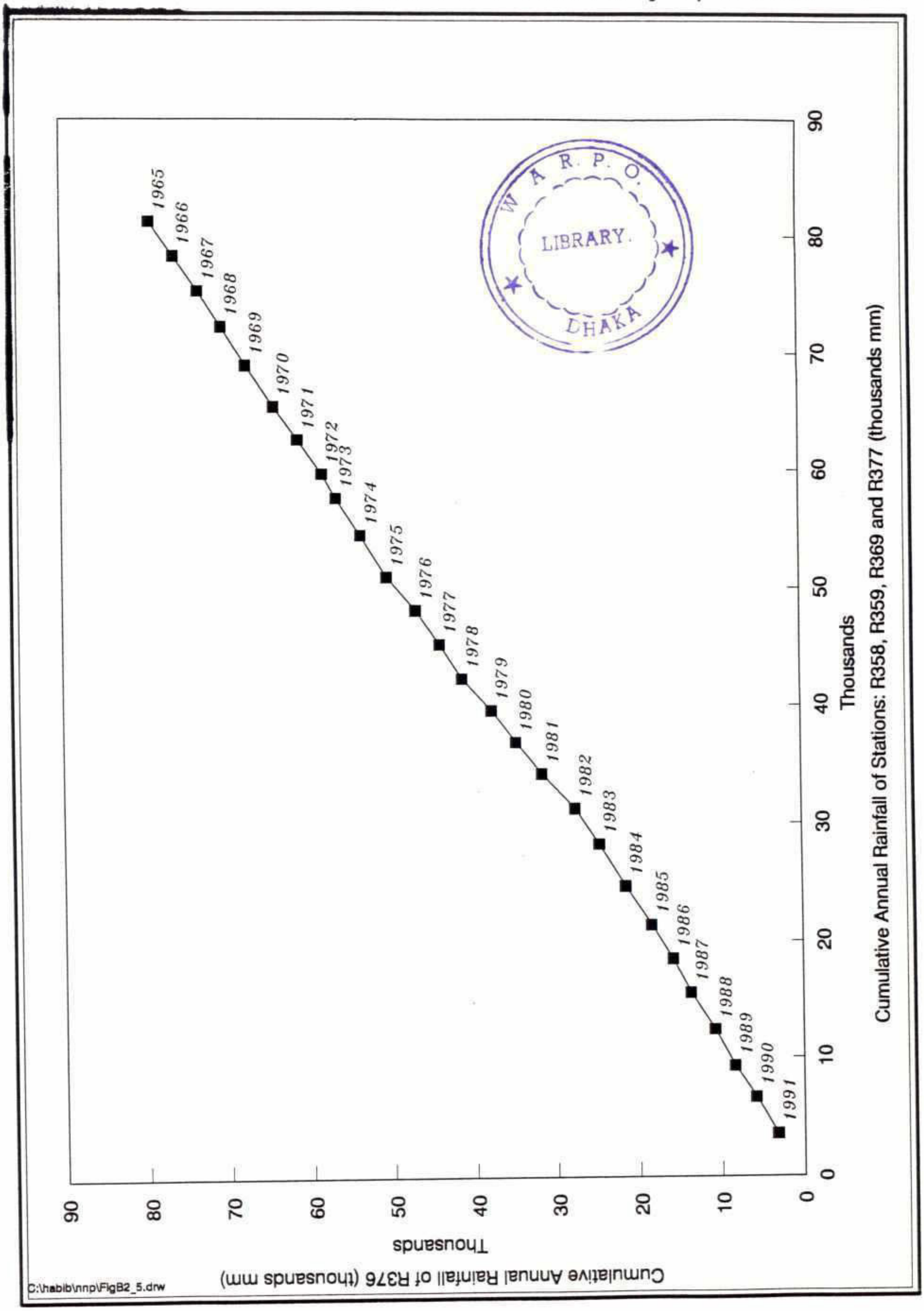


Figure B.2.6
Annual Rainfall Deviations
at Senbagh R-376

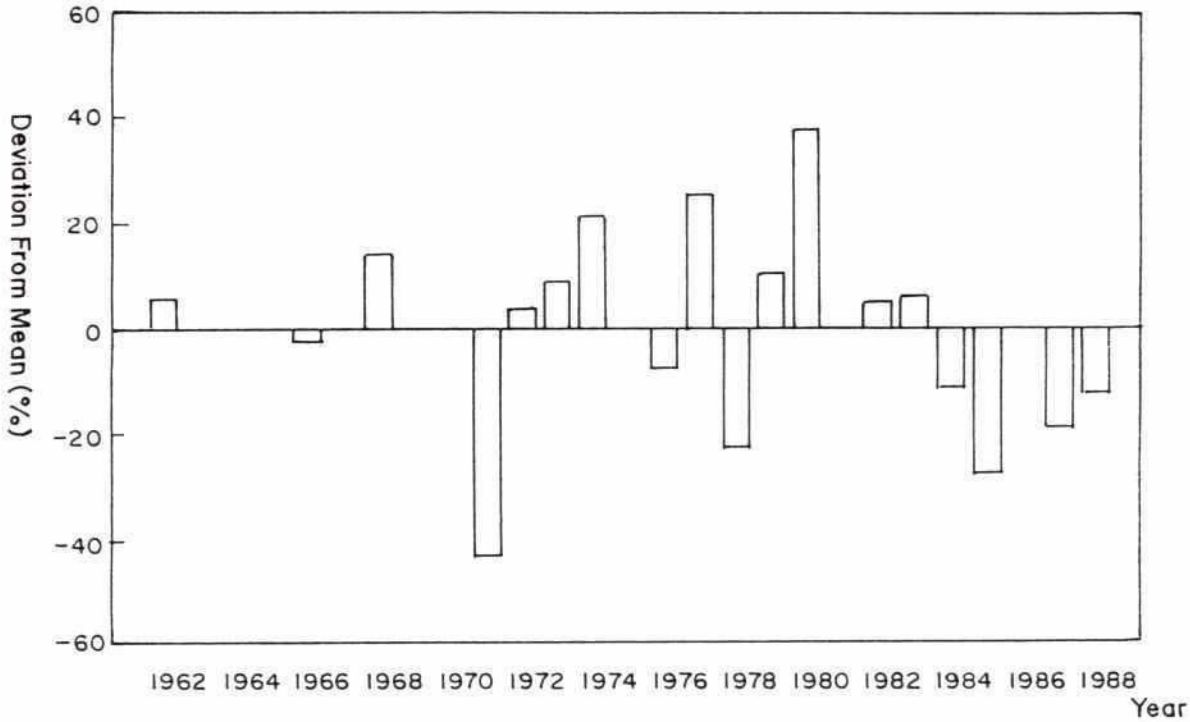


TABLE B.2.5

Raingauges Used in Double Mass Analysis

Test Station	Check Stations
R-375	R-261, R-369, R-353, R-361
R-376	-377, R-359, R-369, R-358

Figure B.2.6 presents the deviations from the long term mean of annual rainfalls at station R-376. Direct comparison is difficult because of differences in the years of missing data at the station, and the influence of the very dry 1972 at station R-376. The results of a series of statistical tests for randomness, trend and persistence, on the records of station are presented in Table B.2.6. At station R-376 the general randomness tests are biased by the number of missing years of record. There is evidence of weak persistence, probably caused by the bias introduced by the influence of the very dry 1972 on the long term mean.

It is difficult to draw any particular conclusions from the time series analysis, and much longer homogeneous records would be required for any meaningful evaluation of non-stationarity to be made.

TABLE B.2.6

Statistical Tests on Annual Rainfall

R-376, Senbag

Statistical Test	Expected	Observed
Randomness		
Median Crosses	8 +/- 5	5
Turning Points	7 +/- 3	3
Persistence		
First Order Serial Correlation	-0.06+/-0.49	0.01
Spearman Rank	-0.09+/-0.56	0.56
Trend		
Rank Order	-0.06+/-0.47	-1.43
Mann-Whitney U Test	36 +/- 20	35
Wald-Wolfowitz Runs Test	9 +/- 4	10

B.2.3.4 Annual Rainfall Distribution

Isohyetal maps of mean annual rainfall, and of annual rainfall equalled or exceeded in 80 per cent of years have been prepared and are presented in Figures B.2.7 and B.2.8. The maps have been prepared on the basis of the available data at 22 stations in the region for the 1962-91 period. In filling of missing years of data at individual stations has not been carried out, but this does not limit the usefulness of the maps as the general data availability is good. It should be noted that the isohyets do not represent a homogeneous pattern, and that in any particular year, the regional distribution of rainfall may be quite different to that shown.

Figure : B.2.7

Mean Annual Rainfal (mm)

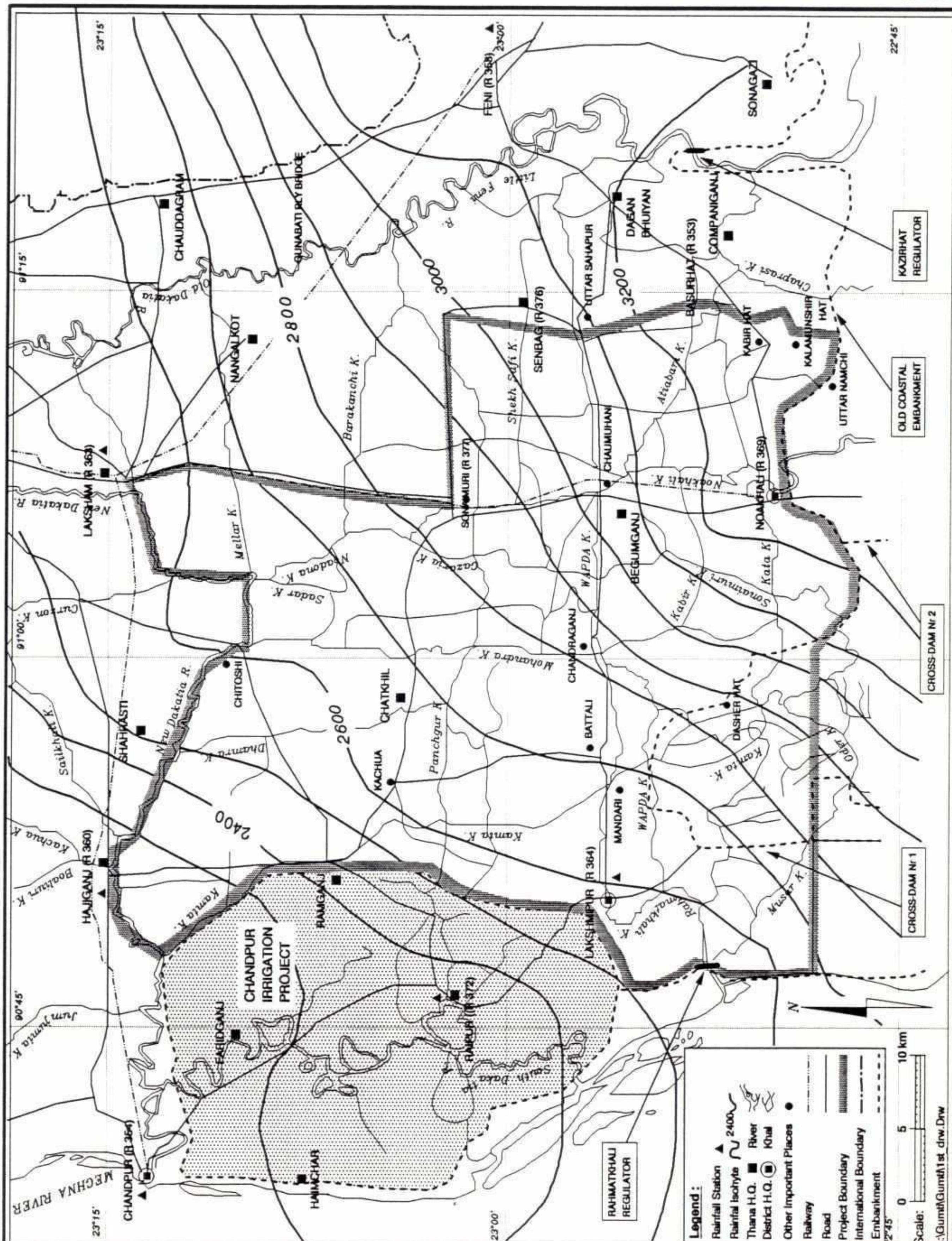
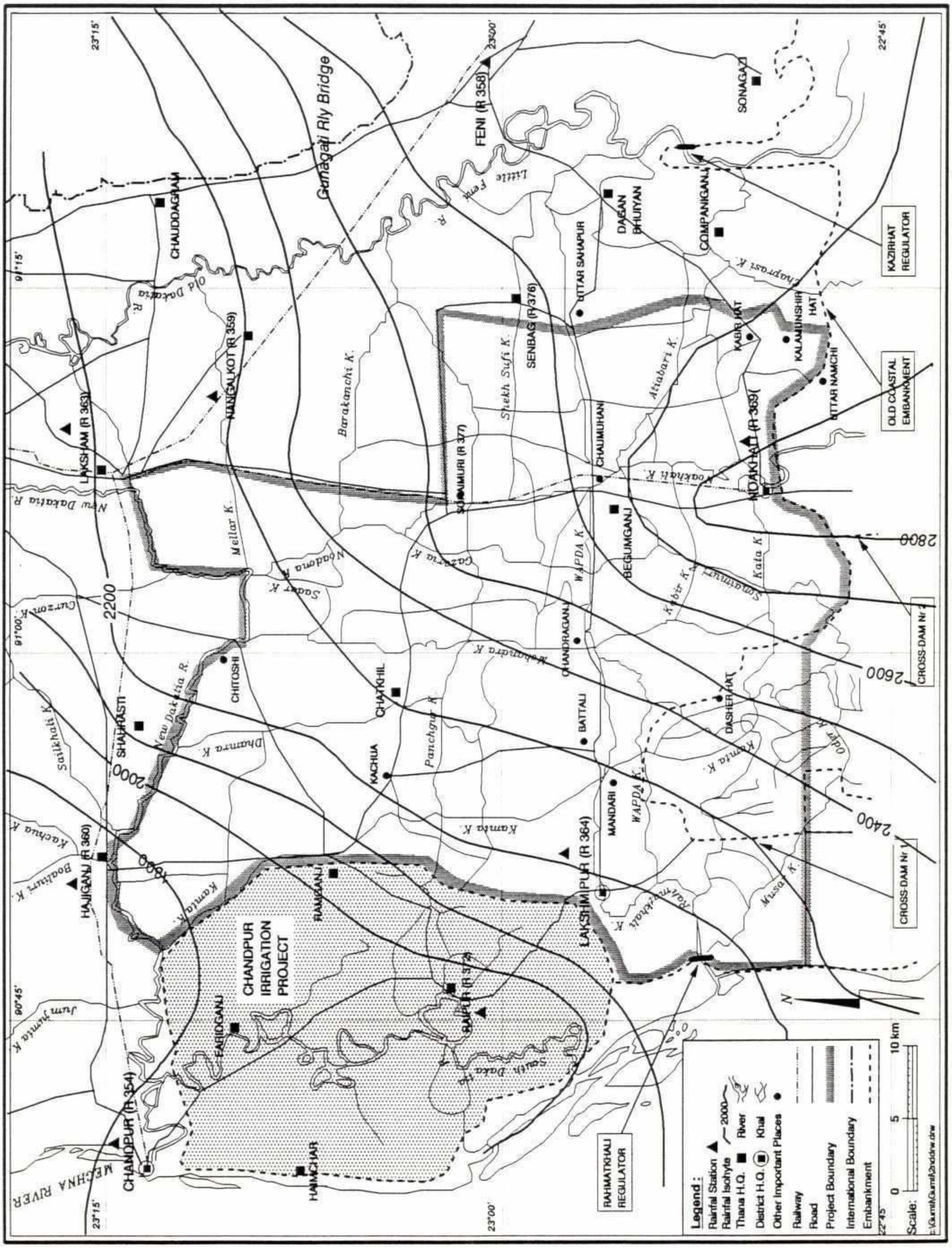


Figure : B.2.8

Annual Rainfall Exceeded in 80% of Years (mm)



The isohyets have been prepared by fitting a multi-quadratic surface to the irregularly spaced rainfall data points. Unlike mathematical surfaces based on low-order polynomials, orthogonal polynomials or double Fourier series which are generally fitted by least squares, multi-quadratic surfaces exactly fit the data points. In order to permit plotting, the surface has been output on a 5 km grid, and a further automatic routine interpolating between grid points, used to plot the contours.

The highest rainfalls occur in the south of the region, particularly around stations R-375, Ramgati. There has been some discussion about data quality at this station in the preceding section, but for the purposes of isohyetal mapping, this and the other stations at which problems were highlighted have been included. Mean annual rainfall at Noakhali is of the order of 3200 mm, and decreases northwards to about 2000 mm at Comilla.

The pattern of annual rainfall distribution at 80 per cent exceedance probability is similar to that for the mean condition, and annual totals are generally about 500 mm lower.

B.2.4 Decad Rainfalls at 80 Per Cent Exceedance

Decad rainfalls at 80 per cent exceedance probability have been evaluated for every station in the region, and are presented in Table B.2.7. The purpose of this analysis is to provide an indication of possible irrigation water demand throughout the year in different parts of the region. The methodology adopted has been to rank each series of decad totals, and to calculate the rank corresponding to 80 per cent exceedance probability using the Blom formula; the corresponding rainfall is then computed through linear interpolation between the ranks. It should be noted that the values presented in Table B.2.7 do not represent a homogeneous series, and there is no dependence between decad values. It is also recommended that the values for the stations identified as being of suspect data quality be ignored. Station with suspect data quality is flagged in Table B.2.7.

Table B.2.7, gives a clear indication of the length of the irrigation season throughout the region. In the south of the region, it is early May before there is any significant rainfall at the 80 per cent exceedance level.

B.2.5 Pentad Analysis

An analysis has been carried out of 5 day rainfalls in order to give an indication of the periods for which supplemental irrigation could be required. For the purposes of the present analysis, a wet pentad is defined as follows:

- the central 5 days of a fifteen day period in which the total rainfall exceeds 45 mm;
- the rainfall in at least one of the pentads other than the one containing the maximum rainfall in the 15 days must exceed 9 mm.

A typical output from the analysis is presented in Table B.2.8 for station R-377. Appendix B.I contains the results for each of the daily raingauges in the study area. It is emphasised that the results are indicative only, taking no account of soil conditions, water table position, or crop requirements. They are therefore only a first level planning tool to help identify areas in which further more detailed forms of analysis are likely to be required. The analysis does give a good indication of the frequency with which supplemental irrigation will be required at any location.

TABLE B.2.7

Decad Rainfalls at 80% Exceedance Probability (mm)

STATION	APR			MAY			JUN			JUL			AUG			SEP			OCT			NOV			DEC			JAN			FEB			MAR			80% ANN.	ANN. MEAN
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3		
R-260	0	0	6	4	8	36	44	102	79	79	52	86	62	76	81	42	39	24	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2227	2460
R-261	0	0	0	5	0	20	68	89	80	83	90	71	126	111	94	108	33	20	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2299	2872
R-301	0	0	4	0	12	19	67	106	48	44	57	63	33	60	80	28	24	12	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2224	2900
R-320	0	0	0	14	17	38	68	71	66	105	100	114	71	85	132	58	53	36	40	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2832	3437
R-323	0	0	8	8	16	39	77	76	39	67	41	70	61	58	97	41	32	34	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2342	2784
R-327	0	2	1	17	23	31	64	90	42	82	62	56	77	68	74	46	37	36	29	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2188	2858
R-352	0	0	2	11	6	14	51	57	55	41	70	58	23	37	66	22	25	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1445	2009
R-353	0	0	4	6	32	25	70	63	64	76	90	96	98	80	130	41	23	40	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2479	3320
R-354	0	1	8	5	16	30	60	70	46	53	36	70	53	34	36	25	5	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1765	1987
R-355	0	3	0	16	43	26	66	79	50	73	55	75	44	50	111	58	41	37	16	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2667	2867
R-358	0	1	4	12	24	25	61	109	74	74	118	99	52	35	75	54	30	23	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2825	3245
R-359	0	0	0	0	9	11	70	65	74	70	65	54	38	45	72	42	28	19	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2177	2585
R-360	0	7	7	10	1	19	34	72	36	43	55	51	42	32	49	34	33	11	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1704	2074
R-361	0	0	2	7	4	26	91	63	91	134	89	112	124	93	113	81	37	21	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2739	3161
R-363	0	1	3	7	19	26	41	91	80	37	57	83	62	47	74	28	33	4	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2168	2506
R-364	0	2	5	7	14	18	85	69	62	88	72	91	68	58	84	54	30	35	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2073	2554
R-369	0	0	1	10	15	53	81	105	117	103	112	105	104	92	124	70	55	26	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2856	3182
R-370	0	2	7	12	6	21	57	74	31	46	59	77	48	59	94	55	24	26	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2075	2441
R-372	0	6	15	10	5	17	41	51	78	72	62	68	67	72	57	52	43	18	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1805	2162
R-375	0	0	0	3	2	31	62	96	128	173	128	141	116	120	119	77	19	33	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2975	4185
R-376	0	0	0	4	24	30	31	80	83	103	116	74	53	55	84	41	19	12	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2356	2829
R-377	0	0	2	0	11	26	65	68	55	109	91	98	59	43	93	65	49	19	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2482	2713

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TABLE B.2.8

Pentade Analysis of Sonaimuri (R-377)

YEAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
1962	------	------	------	------	------	------	-*****	******	******	******	******	******
1963	******	......	......	......	......	*.....	.***..	******	******	******	*****.	.****-
1964	------	------	------	------	------	------	------	------	------	------	------	------
1965	-*****	...***	......	......	......	......	******	******	******	******	******	******
1966	******	****..	......	......	......	.-----	******	******	******	******	******	******
1967	****..	.***..	......	......	......	......	..****	******	******	******	******	******
1968	*.*.**	**....	......	......	......	......	******	******	******	******	******	***..*
1969	**...*	*****.	......	......	......	.....*	******	******	******	******	******	******
1970	*...**	***...	......	......	......	......	.**..*	******	******	******	******	******
1971	*..***	..****	......	......	......	...*..	..***.	.*****	******	******	******	******
1972	****.*	****..	**....	......	......	.***..	..****	******	******	******	****..	.*****
1973	*****.	......	......	......	......	......	.***..	....**	******	******	******	****..
1974	.****.	...**.	......	......	......	......	.**...	******	******	******	******	******
1975	******	***...	..**..	......	......	.....*	...**.	..****	******	******	******	******
1976	******	...*..	....--	-.....	......	....*.	...***	******	******	******	******	******
1977	......	......	......	......	......	......	.****.	.*****	******	******	******	******
1978	**..**	......	......	......	......	...**.	...***	******	******	******	******	****..
1979	.*****	******	*.....	......	......	..**..	.*****	****.*	******	******	**.***	******
1980	*****.	......	......	......	......	....**	..****	******	******	******	******	***.*.
1981	....**	*.....	..**..	......	......	....**	******	******	******	******	******	******
1982	**...*	*****.	......	..*...	......	....**	******	******	******	******	*****.	....**
1983	*.....	......	***...	......	......	......	...***	******	******	******	******	******
1984	*****.	......	......	......	......	.....*	******	******	******	******	******	******
1985	****..	..*...	......	......	......	......	******	******	******	******	******	******
1986	*.***.	...*.*	**....	......	......	......	.*****	******	******	******	******	******
1987	***...	..***.	......	......	......	......	...***	******	******	******	*****.	.*****
1988	**...*	***...	......	......	......	.....*	..****	******	******	******	******	******
1989	******	****..	......	......	.**...	......	......	******	******	******	******	***...
1990	..**..	.....*	***...	......	......	.*....	..****	*.****	******	******	******	*****.
1991	..**..	......	......	......	......	......	...***	******	******	******	******	*****-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

B.2.6 Drainage Design Rainfalls

Frequency analyses have been carried out on all daily rainfall stations in the project area, with the exception of the one station identified as being unreliable. The objective has been to provided the basic data for drainage design purposes. EV1 (Gumbel) distributions have been fitted to the annual maximum series rainfalls of the following durations:

- 1 day;
- 2 day;
- 3 day;
- 4 day;
- 5 day;
- 7 day;
- 10 day.

The seasonality of rainfall extremes is also important and forms part of the drainage design analysis. This is to account for the different stages of crop growth that are likely at different times of the year, as well as the influence different drainage conditions in terms of main river levels and outfall controls. In accordance with practice in Bangladesh, rainfall extremes have been evaluated at each of the above durations for the following periods:

- pre-monsoon (April to June inclusive);
- mid-monsoon (July and August);
- post-monsoon(September and October).

A sample of results is presented in Table B.2.9. The results for all stations are included in Appendix B.II. Summary results for 1 day, 3 day and 5 day durations at return periods of 2, 5 and 10 years of the annual maximum rainfall are presented in Table B.2.10. These give a good indication of how conditions vary across the region. The rainfall extremes are high by world standards. The results of the analysis are consistent with the annual rainfall distribution, with greater extremes in areas of highest rainfall. Of particular note are the extremely high annual maxima at stations R-301, R-315, R-320 and R-327, which are in the Chittagong Hills to the south east of the study area.

B.2.7 Storm Reduction Factors

An attempt has been made to investigate likely storm reduction factors in the region. Guidelines do exist in the BWDB design manual for aerial reduction factors. These are appropriate for project design, but for the analysis of regional events, it was considered appropriate to attempt an investigation of the order of storm reduction factors likely to be experienced. This proved to be less successful than had been hoped, partly as a result of missing records at some of the stations being used in analysis. The results may serve as a starting point for further analysis at some future date.

TABLE B.2.9

Seasonal and Annual Maximum Rainfall Frequency of Sonaimuri, R-377

Annual Maximum Pre-Monsoon Rainfall
R-377, Sonaimuri; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	107	148	174	200	233
2	149	203	238	272	316
3	177	240	281	320	371
4	199	269	315	359	416
5	223	302	354	405	470
7	261	359	424	487	567
10	322	450	535	616	721

Annual Maximum Mid-Monsoon Rainfall
R-377, Sonaimuri; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	129	171	199	226	260
2	180	240	279	317	367
3	217	286	331	374	431
4	243	317	366	413	474
5	267	344	396	445	509
7	321	430	503	572	662
10	392	524	611	695	804

Annual Maximum Post-Monsoon Rainfall
R-377, Sonaimuri; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	103	142	167	191	223
2	145	202	240	276	323
3	171	243	290	335	394
4	186	255	301	344	401
5	199	266	311	353	409
7	222	300	351	400	464
10	247	328	382	433	499

Annual Maximum Rainfall
R-377, Sonaimuri; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	153	193	220	246	279
2	219	275	312	348	394
3	260	326	370	412	467
4	287	356	402	445	502
5	315	391	441	489	552
7	376	476	543	607	689
10	451	582	669	752	860

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TABLE B.2.10

Summary of Annual Maximum Rainfalls (mm) at Few Stations in Noakhali Area

Duration	1 Day			3 Day			5 Day		
Return Period	2	5	10	2	5	10	2	5	10
Station									
R - 354	131	173	202	200	261	301	237	309	357
R - 358	180	218	243	315	386	432	393	484	545
R - 360	116	161	191	199	253	289	254	315	355
R - 363	127	167	194	235	302	345	299	385	442
R - 369	180	217	242	291	342	376	349	421	469
R - 377	153	193	220	260	326	370	315	391	441

A Theissen polygon network was prepared, and storm reduction factors evaluated for annual maximum 1 day, 2 day, 3 day, 4 day, 5 day, 7 day and 10 day rainfalls at stations R-363, R-369 and R-377. The stations used in the analysis and the relative areas were:

Station R-363, Laksham

Level 1 R-352, R-360, R-377, R-359, 2121 km^2

Level 2 R-352, R-360, R-377, R-3359, R-110, R-354, R-372, R-376, R-370, 4090 km^2

Level 3 R-352, R-360, R-377, R-3359, R-110, R-354, R-372, R-376, R-370, R-364, R-369, R-358, R-355, 6409 km^2

Station R-369, Noakhali

Level 1 R-377, R-376, 1195 km^2

Level 2 R-377, R-376, R-358, R-353, R-375, R-364, 3988 km^2

Level 3 R-377, R-376, R-358, R-353, R-375, R-364, R-372, R-360, R-363, R-359, R-370, R-355, R-361, R-261, 8044 km^2

Station R-377, Sonaimuri

Level 1 R-376, 642 km^2

Level 2 R-376, R-359, 969 km^2

Level 3 R-376, R-359, R-369, R-363, 2023 km^2

Level 4 R-376, R-359, R-369, R-363, R-360, R-3372, R-364, R-375, R-353, R-358, R-355, R-370, R-352, 7475 km^2

A summary of the results is presented in Figure B.2.9, from which the general reduction of storm intensity with area is apparent. As might be expected, aerial reduction factors during the mid monsoon season are higher than in the pre-monsoon period, indicating the more widespread nature of rainfall occurrence in the mid-monsoon period. The results are in broad agreement with what would be expected. Considerably more work would be required before the results could be used as the basis of any design criteria for larger project areas. The analysis has been based on annual maximum values, and a missing value at any one of the chosen stations on the date or dates of annual maximum occurrence at the key station causes a null result, and is indicated by an asterisk. The sample size is therefore limited. In future analyses it will be necessary to use a greater selection of events, and to prepare isohyets for each event considered, such that a better assessment of storm distribution is obtained.

B.2.8 NAM model of the South East Region

B.2.8.1 Introduction

The NAM hydrological model allows runoff (discharge) to be estimated from a knowledge of rainfall, evaporation and groundwater abstraction.

It is required to provide discharge hydrographs for input into the hydrodynamic model, MIKE11-HD. NAM is used to generate lateral inflows along different reaches of the main rivers, runoff in the flood storage areas and discharge hydrographs at discharge boundaries in the hydrodynamic model where discharge observations are not available.

NAM input is most important in areas where the flood regime depends on the river flows, rather than being as a result of backwater effects from the main rivers.

Set-up, calibration and verification of the NAM model was carried out by the Surface Water Modelling Centre, SWMC (Ref. 5.1).

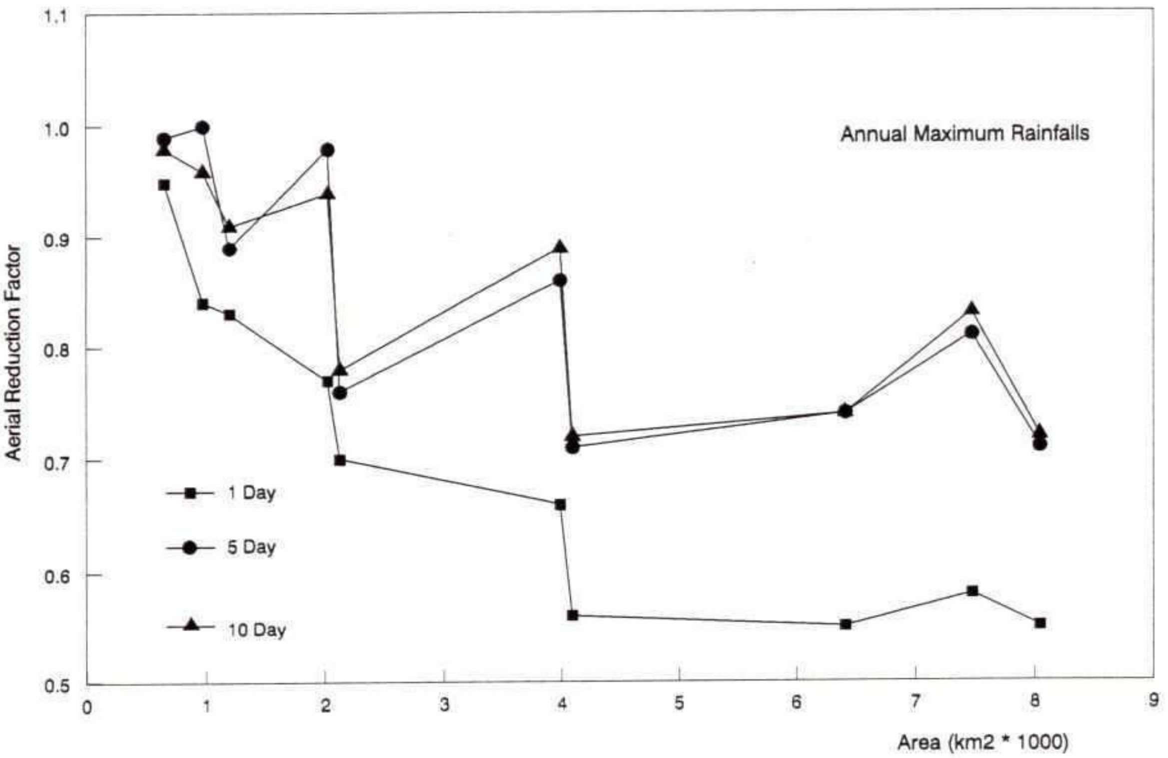
B.2.8.2 Model Set-up

For the purposes of the NAM modelling, the South East region was divided into 24 catchments Figure B.2.10. The catchment boundaries are delineated on what may be loosely considered watersheds, along natural topographic features or artificial embankments. At least one rainfall station and one groundwater observation well with a continuous record were available for each sub-catchment.

B.2.8.3 Model data

Rainfall data : A total of 24 rainfall stations were used in the NAM modelling. A Thiessen polygon was constructed connecting all the rainfall stations in the region with the weightage of each station being used to compute the mean areal rainfall. Missing data are covered by increasing the weightage of the neighbouring stations.

Figure B.2.9
Areal Reduction Factors



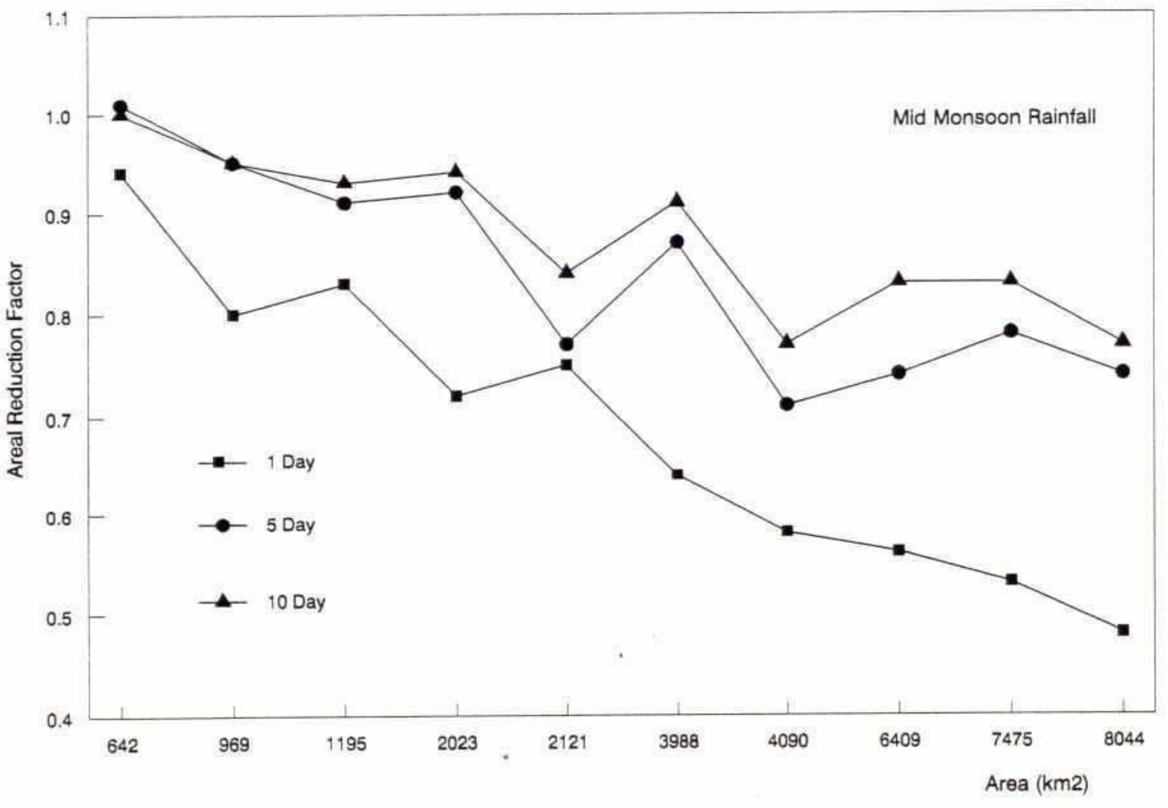


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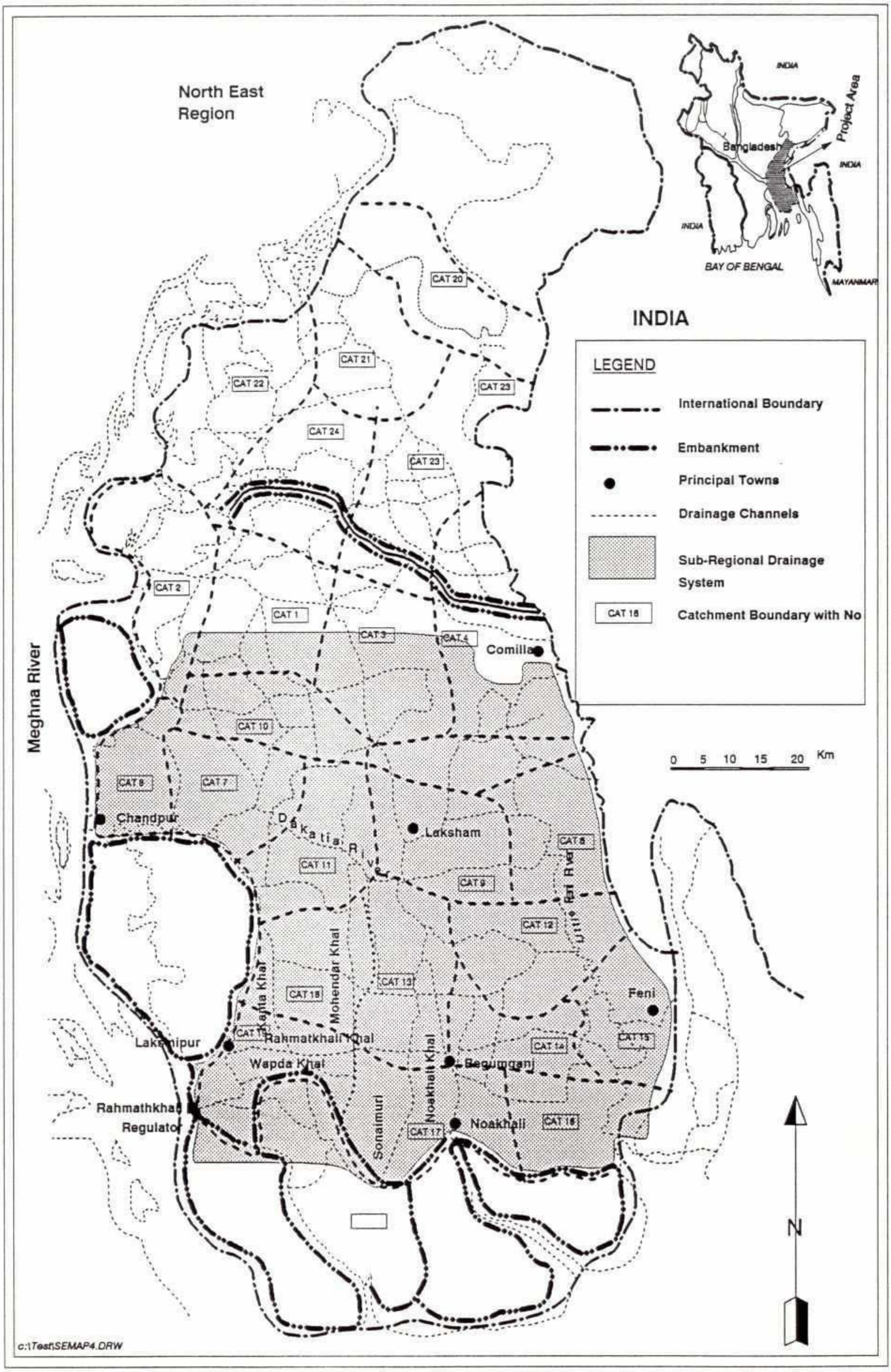
Figure B 2.10
South East Region NAM Model Sub Catchments



Evaporation data : Evaporation data is only available at the Brahmanbaria climatological station. This is in fact pan evaporation with a pan coefficient of 0.7. The Brahmanbaria station was assumed to be representative of the entire region.

Groundwater abstractions : There is no direct reliable data available on groundwater abstractions. The estimated abstractions were based on an estimate of the number of tubewells on a Thana basis and an assumed average abstraction rate per working day.

B.2.8.4 Model calibration

Model calibration was carried out over the hydrological years 1986, 1987 and 1988. The parameter values in the model were changed until a good match was achieved between the simulated and observed groundwater level hydrographs. There are no discharge gauging stations in the region against which the runoff estimates from NAM can be calibrated.

Details of the calibration results and an assessment of the calibration can be found in the South East Region Model Verification Report 1990 which was produced by the SWMC in November 1991 (Ref. 5.1).

B.2.8.5 Verification

The model was verified from April 1989 to March 1991. The verification was good in areas where the groundwater level fluctuations were accurately recorded.

B.2.8.6 25 year NAM simulation

In order to provide discharges for the 25 year hydrodynamic model simulations a 25 year NAM simulation is required. This simulation was carried out for the period 1965 to 1989.

Missing rainfall data was infilled by using the 'Normal Ratio' method. Data quality was initially checked by serial correlation of monthly values among the surrounding stations. Where the correlation was poor stations were checked by the Double Mass Method. Inconsistent data was made consistent and reviewed.

Since the annual variation in evaporation is small the same set of evaporation data was used for each year of NAM calculation.

For the purposes of the 25 year NAM simulation the most recent estimate of groundwater abstraction rate was used for each year of NAM calculation.

The NAM 25 year simulation was run for the period 1965 to 1989 in two blocks, the first consisting of 15 years and the second 10 years.

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CHAPTER B.3

THE DRAINAGE SYSTEM

B.3.1 Introduction

A general map of the drainage system in South East region and Noakhali Study area is presented in Figure B.3.1. The South East region is bounded to the west by the River Meghna, and it is this that dominates drainage of the greater part of the region. The Meghna is joined by the Padma about 100 km downstream of Bhairab Bazar. The Padma carries the combined discharges of the Ganges and Jamuna (Brahmaputra) Rivers. Mean annual runoff in the Padma is of the order of 30,000 m^3/s, and on average varies between 75,000 m^3/s in August and 6000 m^3/s in February. The annual rainfall on the South East region, in volume terms, is less than 2% of the annual runoff in the lower Meghna, and contributes little to the runoff in the latter. The coincidence of seasonal rainfall with peak flood discharges in the Meghna does, however, exacerbate internal drainage problems especially in the Begumganj depression. Figure B.3.2 shows hydrographs of decade water levels with 1 in 5 year return period in the Padma and Meghna Rivers at Rahmat Khali and Chandpur, along with mean decade rainfalls at Sonaimuri. The basic parameters of the internal drainage problem of the region, are the same as those for the country as a whole.

The Meghna is the outfall water level control on drainage for almost the entire region. The seasonal range in Meghna water levels reduces in a southerly direction towards the Bay of Bengal. Seasonal water surface profiles between Bhairab Bazar and Daulat Khan are shown in Figure B.3.3. The profiles shown are for 1981, but the chosen year is of no significance. At Bhairab Bazar, the seasonal range of water levels is of the order of three metres, and there is very little tidal influence in the dry season. At Chandpur the seasonal range in water levels is of the order of 1.5 - 2.0 m, with a tidal range in the monsoon season of the order of 0.6 m. At Daulat Khan towards the south of the region, and close to the outfall of Rahmatkali Khal, the tidal range is much larger, of the order of two and a half metres, and the difference in seasonal water levels much lower, being of the order of 0.5 metres. This variability in the range of Meghna water levels across the region does result in different drainage problems in different parts of the region. These are discussed further in section 3.2. Drainage of the Noakhali area is further complicated by the morphological changes of the coastal area resulting from the construction of the coastal cross dam No. 1 on the Meghna in the late 1950's.

General topography is indicated in Figure B.3.4. Comparison with Figure B.3.3 gives an indication of the areas most susceptible to flooding, particularly to the north of the Gumti River. Figure B.3.4 is at a macro level and is included only to help illustrate the general problems. Micro relief is of regional importance and is discussed in some detail in section B.3.3, where the approach to regional flood risk and susceptibility is discussed.

The internal drainage of the **South East region** may be considered under three general areas:

i) the area north of the railway line at Brahmanbaria

ii) the area between the Gumti River and the railway line at Brahmanbaria

iii) the area to the south of the Gumti River which includes the Noakhali Study area.

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Figure B.3.1
Sub-Regional Drainage Systems

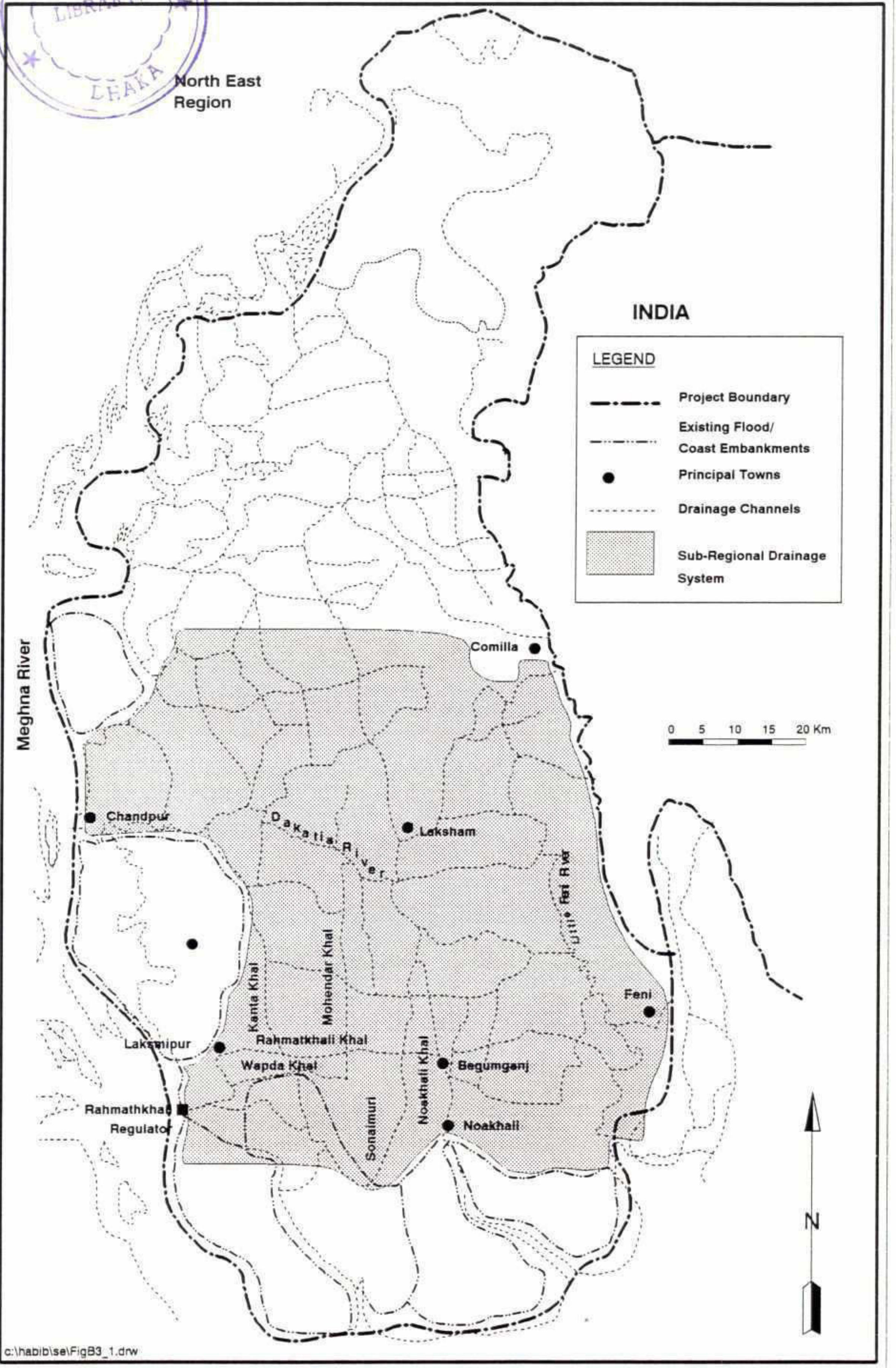

Figure B.3.2
Relationship Between Rainfall Evapotranspiration, Floods and Crops

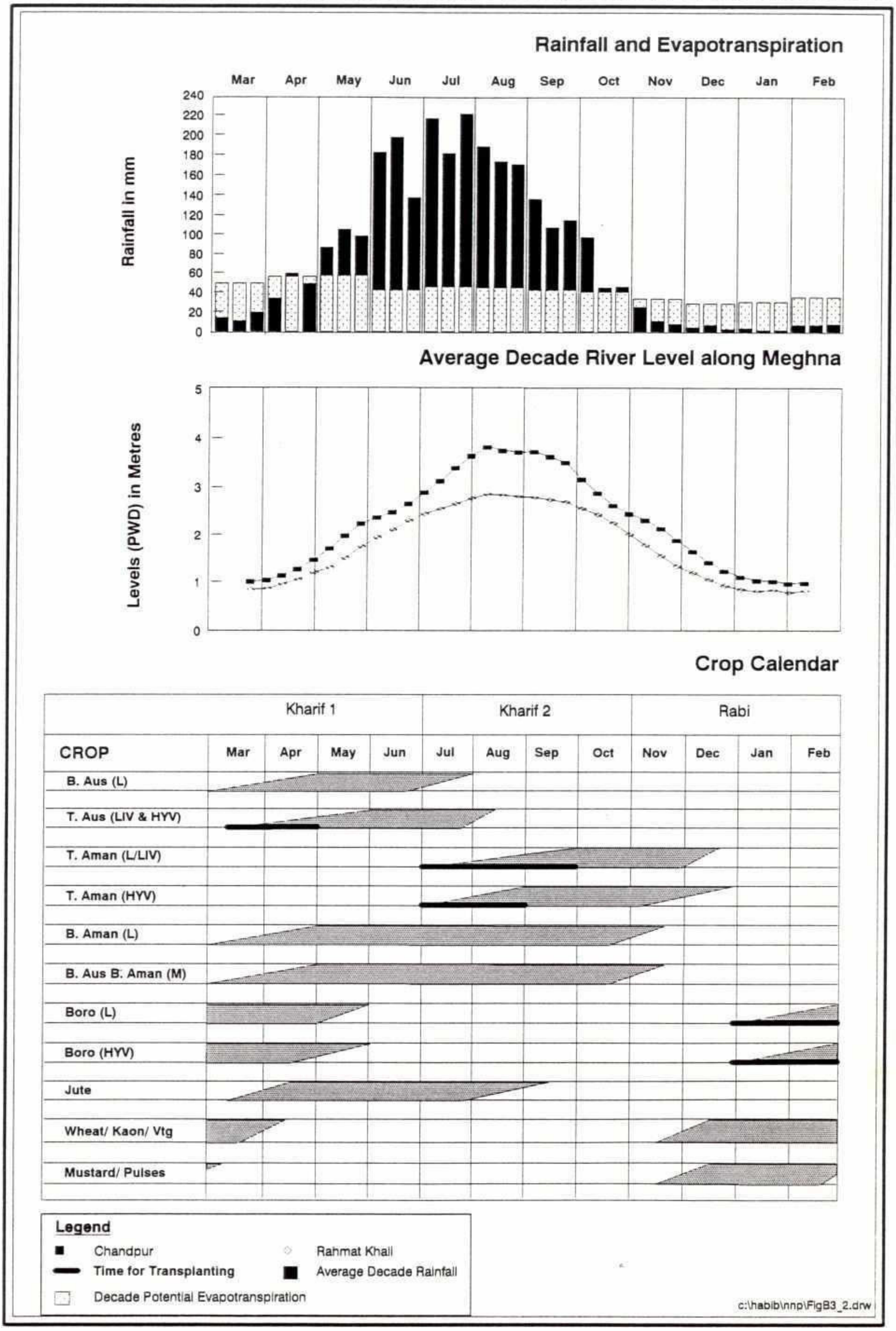

Figure B.3.3

Meghna Water Surface Profiles

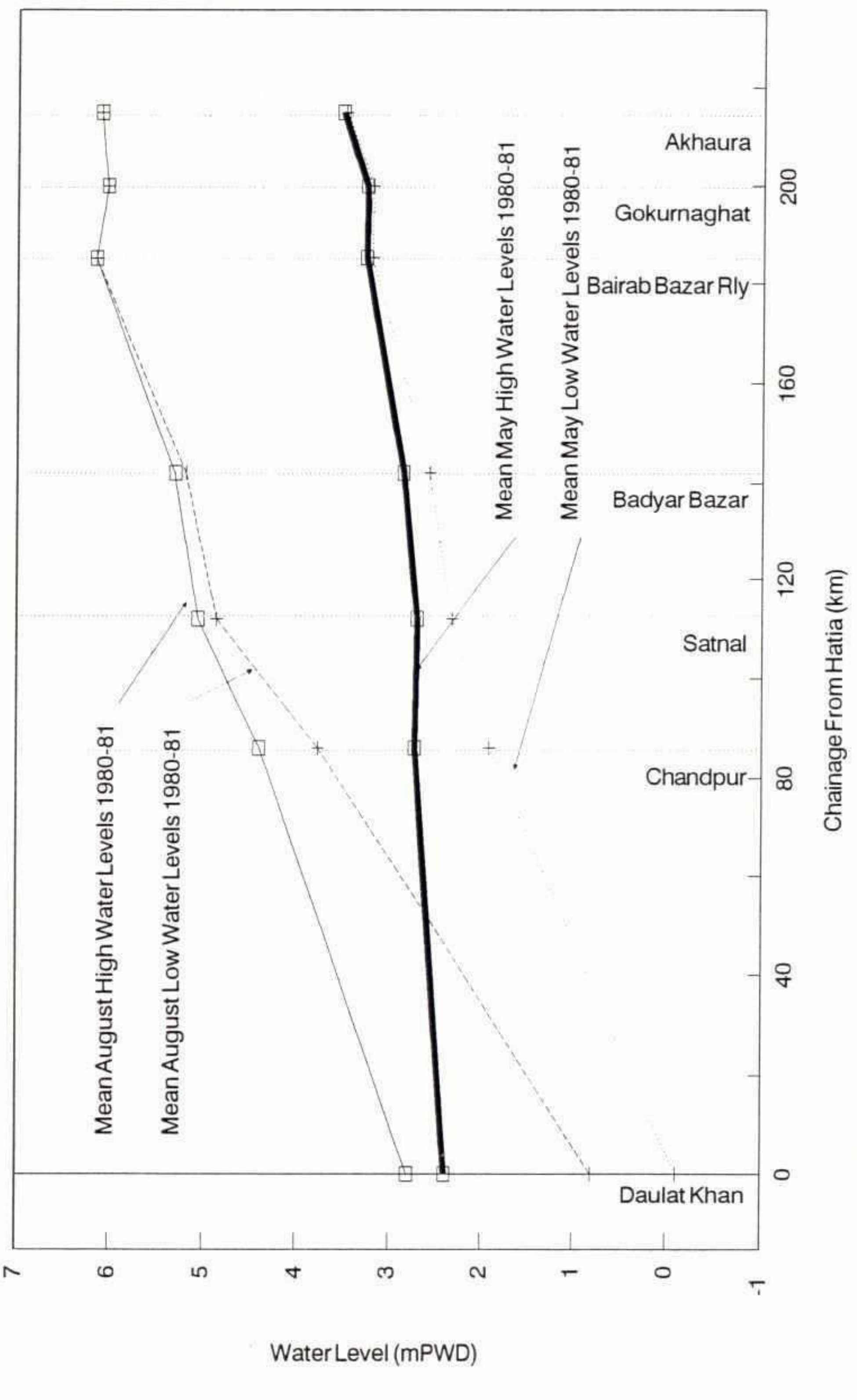

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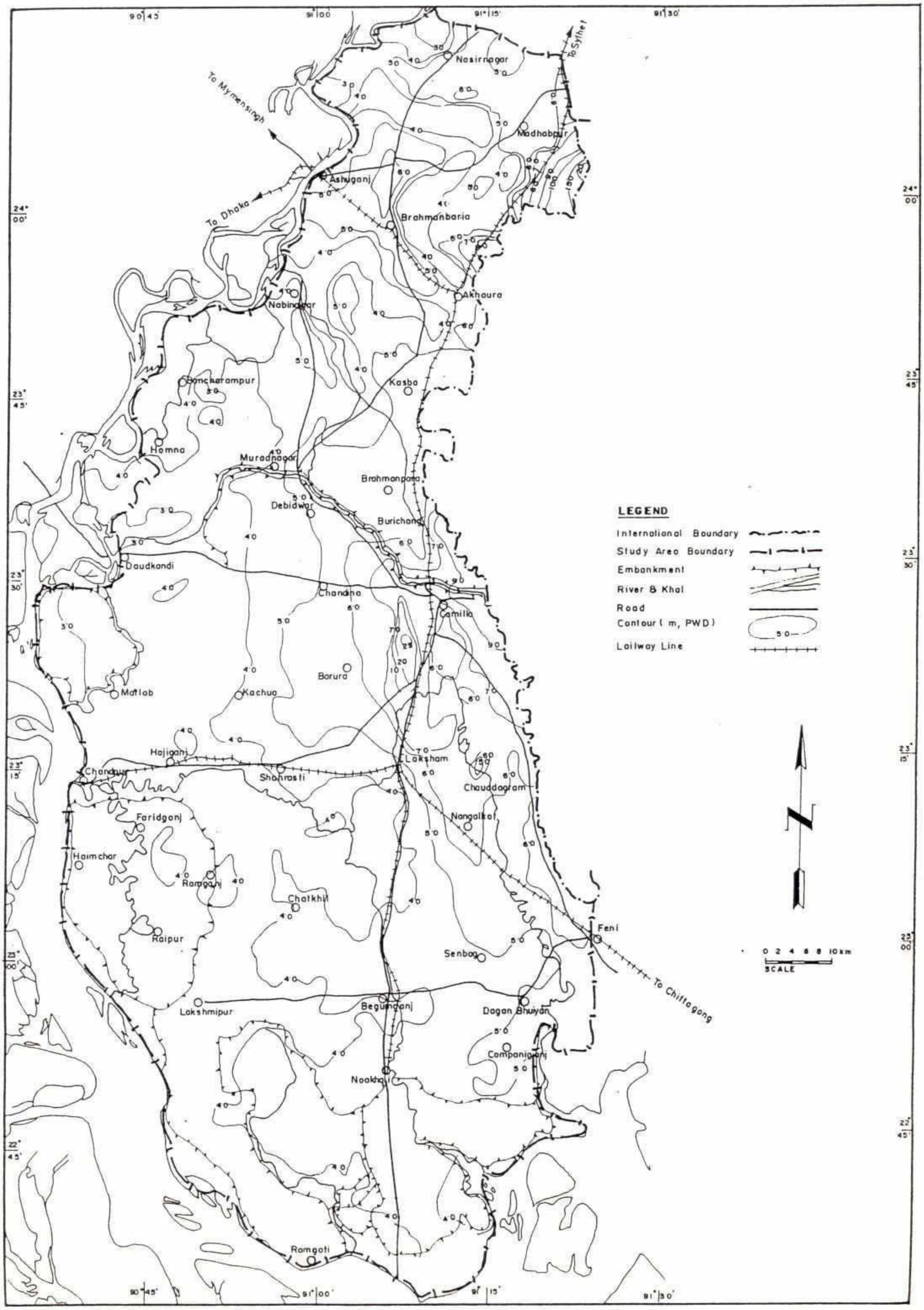
Figure B.3.4

Generalised Regional Topography



Area (iii) is of special interest for this report and is high lighted here.

iii) Immediately south of the Gumti River, the Daudkandi to Comilla road and Gumti Phase I project embankments isolate a significant area, from which drainage is mainly west to the lower Gumti and Meghna. The area south of the Daudkandi to Comilla road has three principal drainage features:

- the Dakatia River,
- the Rahmatkali Khal, and
- the Little Feni River.

These rivers are in fact interconnected by a complex system of channels, but they do provide primary drainage routes. The Dakatia River has its source with the Sonaichari and Pagli Rivers which drain small catchments in the Tripura Hills. The Little Feni collects drainage from the Kakri (and occasionally from the Pagli) and a number of catchments in the Tripura hills, but these are all significantly smaller than those north of the Gumti. The hill catchments draining into the area south of the Gumti River are listed in Table B.3.1 below.

TABLE B.3.1

External Catchments South of the Gumti

Catchment	Area (km^2)
Pagli North (Chowara)	64
Pagli South (Shuagazi)	56
Kakri	76
Kakri South	45
K2	66
Total	307

The catchment marked as K2 in fact contains diffuse drainage over a length of some 27.0 km of the Little Feni. These catchments, although small, do bring in significant sediment loads to the river system, and also cause flash floods. Unfortunately none are gauged.

B.3.1.1 Principal Drainage Routes to Sea (Bay of Bengal)

Rahmatkali khal forms the principal drainage route in the south of the region. Formerly, before completion of the Meghna cross dams (cross dam No. 1 1957 and cross dam No.2 1965), the coastal embankments and polders, the Noakhali Khal was a more important drainage route. However, with land accretion in the south, the primary drainage routes from the South Noakhali area are through the Rahmatkahli regulator to the west and Kazirhat regulator to the east. The peak monsoon discharge out of Noakhali khal is between 20 and 25 m^3/s: a small proportion of the flow discharged by the regulators (approximately 381 m^3/s from Kazirhat and 383 m^3/s from Rahmatkhali).The effects of siltation in the **Noakhali** khal are shown on Figure B.3.5. Following construction of the second cross dam tidal influence is progressively reduced by siltation of the outfall channel to the present conditions after a period of 4 to 5 years (1968- 1973). At present water levels in the khal are controlled by levels in the Begumganj depression and flows in the khal. Noticeable is the increase in mean daily peak monsoon levels from 1965 to 1973-74 by approximately 0.7 metres.

The **Little Feni** which drains into the east Bay of Bengal via the Kazirhat regulator suffers from siltation in the outfall channel. The silt accumulates during the dry season when the regulator is closed to retain water in the upstream areas for irrigation. Clearing of the channel and gates causes delays in the opening of the regulator in the early part of the monsoon season which associated upstream flooding and occasional spilling into the Begumganj depression. However, the volume of spilling appears to be too small to cause any significant increase in water levels in the Noakhali. Details are presented in Chapters B.3 and B.5. Water levels at Kazirhat regulator are shown in Figure B.3.6.

The general drainage system is a complex network of interconnected channels, in which flow directions often reverse. Almost the entire system is inter-linked, and changes to one part of the system have an impact else where. The evaluation of project impacts on flood levels thus requires the use of sophisticated hydrodynamic modelling techniques.

B.3.2 The Present Flood Problems

B.3.2.1 Seasonal Flood Characteristics

Much of the land in the project area is regularly flooded. On the basis of the MPO flood phase classification system, 7% of the project area is flood free, almost all of this is in the south west of the project near the Rahmatkhali regulator. The flood problem cannot be considered in terms of depth of flooding alone, however. The timing, rate of rise, and duration of flooding are, in addition to the flood peak attained, very important factors influencing agricultural damage and cropping patterns and indeed general disruption caused. Seasonality of flooding is therefore a key variable.

In terms of seasonality, the flood problems are:

pre-monsoon	April-June	rapid rise in water level before boro crops are harvested, and kharif I crops planted; loss of young crops and seedlings;
monsoon	July-August	the rate of rise of flood levels exceeding the rate of growth of rice; peak main river levels and prolonged flooding partly through backing up from the main rivers and reduced gradients for local rainfall; duration of flood inundation is important, and whether flood water is clear or sediment laden;
post-monsoon	Sept.-Oct.	drainage at too slow a rate to permit timely planting of certain crops;

Figure B.3.5

Water Levels in the Noakhali Khal

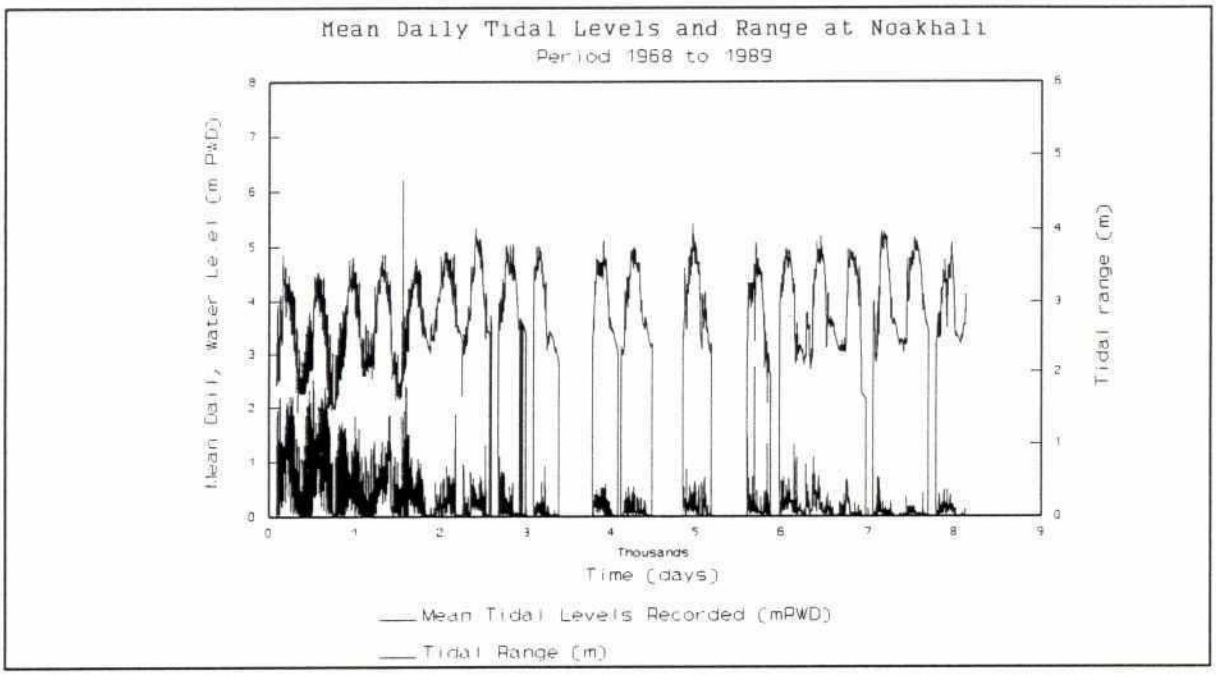
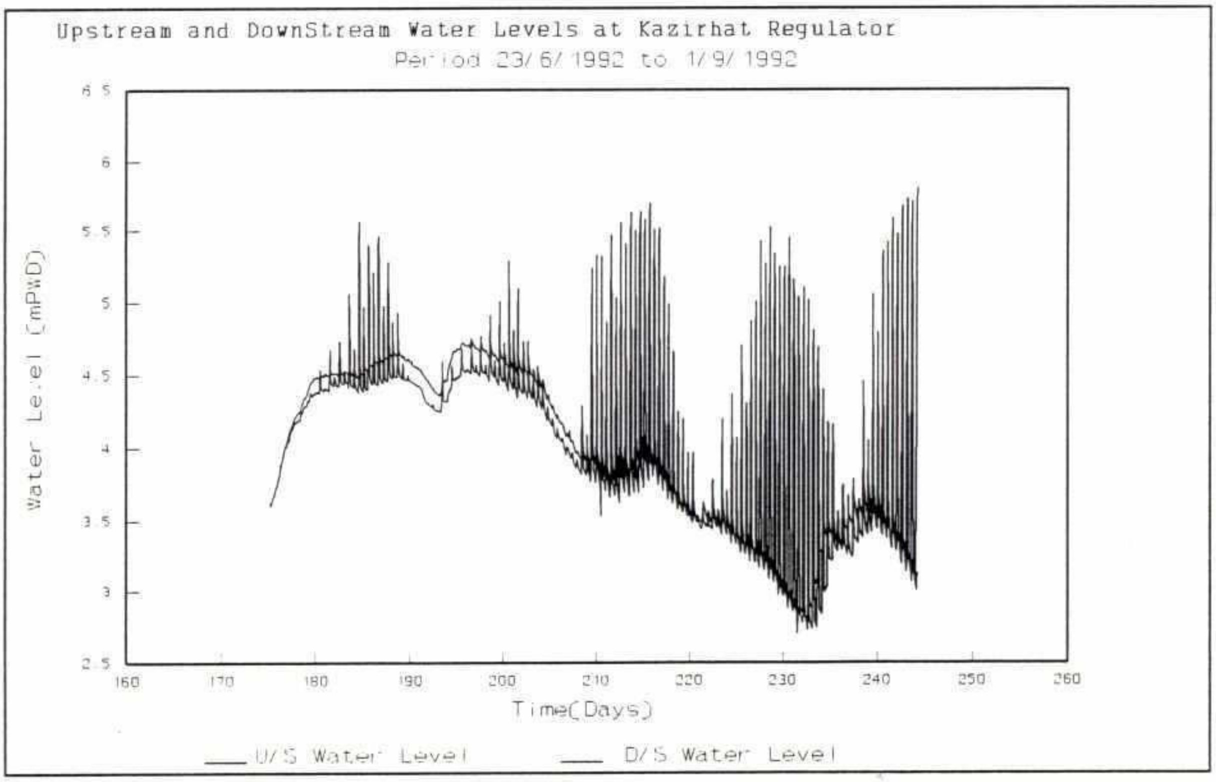


Figure B.3.6

Water Levels at Kazirhat Regulator



In addition to the above flood periods, the general categories under which flooding in the region can be considered are:

- monsoon floods from the River Meghna and Lower Meghna;
- flash floods from those rivers rising in the Tripura Hills to the east of the region;
- localised flooding as a result of heavy and intense rainfall;
- floods resulting from storm surges in the Bay of Bengal.

B.3.2.2 Noakhali Flood Characteristics

The above categories of flooding affect different parts of the region to different degrees, as has been stated in section 3. B.1. Following from that introduction, it is apparent that for the purposes of flood assessment, and for the definition of design approaches, the sub-regional area might best be considered under three zones:

i) the area between the Gumti and the Dakatia rivers;
ii) the Little Feni catchment;
iii) the area south of the Dakatia river.

South of the Gumti to the Dakatia river, the flood problems are less directly associated with inundation from the Meghna, than with impediment to the drainage of local rainfall caused by high outfall water levels in the Meghna. It has been noted by some observers that flood waters are relatively clear in this area, indicating their main origin to be local rainfall rather than the Meghna. It is, however, the Meghna which ultimately does form the control on the potential drainage of the area. There are areas of deep flooding to the east of the Meghna Dhonagoda project area, but there is less susceptibility to flash flooding than in the areas to the north of the Gumti, or in the Little Feni catchment. A number of roads also form natural drainage barriers in the region. These include the road from Chandpur to Daudkandi-Comilla road (not yet completed), and the Chandpur to Comilla road. These roads apparently have adequate cross drainage provision, but they do impede floodplain flow. The Dakatia River forms the main arterial drainage for the area, discharging westwards to the Meghna at Chandpur. There is, however, a very complex interconnected network of channels.

The Little Feni River drains to the south from Comilla, collecting drainage laterally from the Tripura Hills, and from its own catchment area in Bangladesh. The hill catchments draining in to the Little Feni have a total area of 307 km^2. The catchment area of the Little Feni in Bangladesh is some 570 km^2. There are flash flooding problems from the Tripura Hill catchments, some of which (notably the Kakri) carry substantial sediment loads. Sediment deposition results in further drainage problems. The Little Feni is regulated at its lower end by Kazirhat regulator. This prevents the ingress of saline tidal water during the dry season, and provides a reservoir for irrigation. During the monsoon the regulator is kept open, but problems can occur in the pre-monsoon season as estuarine silts deposited downstream of the regulator during the dry season require excavation before the tidal flaps can be operated. There are a number of drainage connections from the Little Feni system to the Dakatia system, and to the Noakhali area, although the primary drainage is southwards through the main channel.

In the area to the south of the Dakatia River, the drainage is provided primarily by the WAPDA Khal and the Rahmatkali Khal. This area is generally considered to suffer from congested drainage, and one of the most notable features is the Begumganj depression which is seasonally flooded. There has been some deterioration in drainage of the area following the completion of the coastal embankment and polder projects. At Noakhali for example, the tidal range has declined from 2.0 m in the 1960's to about 0.2 m at present, indicating the general loss of channel capacity, and the impact of accretion and land formation to the south (see Figure B.3.5).

The nature of the drainage system throughout the region is such that specific areas cannot be considered in isolation. Although division into zones is useful in the definition of primary flood mechanisms and design requirements, the holistic view of the system and its seasonal flood response must not be lost. It was for this purpose that the South-East Regional Model (SERM) was created. The model is discussed in Chapter B.4 and B.5.

B.3.3 Data Availability

B.3.3.1 General

The locations of water level and discharge measurement stations in the region are given in Figure B.2.1. Data availability for these, and for the main river stations is summarised in Table B.3.2. A considerable volume of additional field data was collected for the region as part of the Surface Water Simulation Modelling Programme (SWSMP). Additional topographic data were collected as part of the regional study and all reference levels were checked.

B.3.3.2 Discharge Measurement

There are very few relevant discharge measurement stations in the region. Table B.3.2 indicates a total of 9 stations in the region. Some of the stations have been installed by SWMC and they have collected a few years data which are used for the South East Regional Model (SERM) set up and calibration.

The Little Feni River is gauged at Gunabati Railway Bridge, but in effect there is only one year of monsoon discharge data at this station. The record is thus of little value.

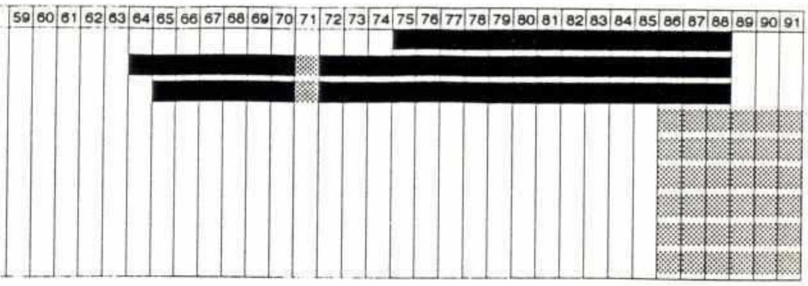
The stations at Kaliachari (84.1) and Parshuram (212) are in the Muhuri catchment. They are indicative of runoff conditions from Tripura Hill catchments, and are also of direct relevance to investigations of Muhuri Reservoir.

There is effectively very little discharge data for the study area, and the majority of inflows from the Tripura Hills are ungauged. Most of the discharge data indicated in Table B.3.2 are available in digital form. The stations G-17, Miarbazar on Kakri, G-52, Chowara on Sonaichari and G-129 Shuagazi on Pagli carry cross-boundary flow from Tripura hills from India, as the record is of short duration for the 25 year boundary, the flows are generated from Comilla with catchment area ratio.

TABLE B.3.2

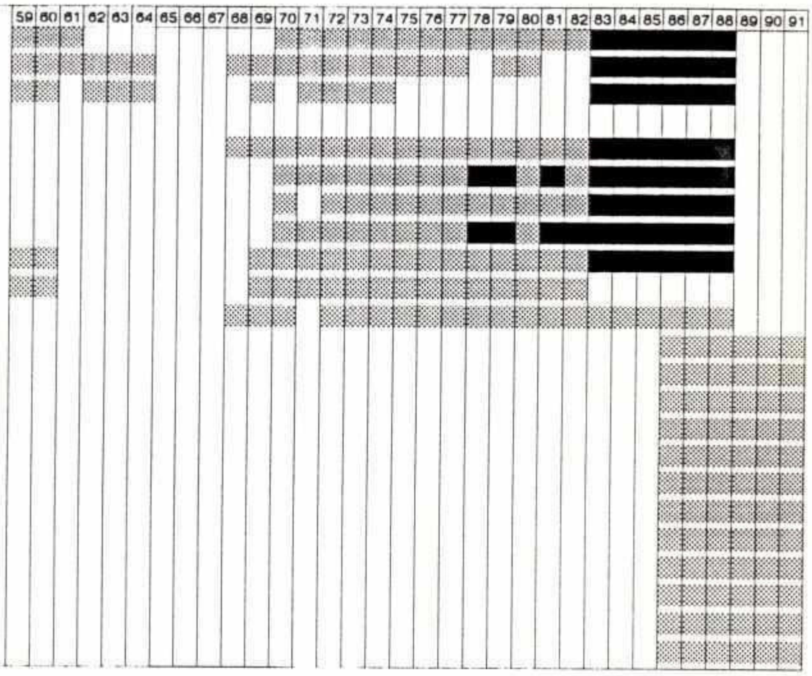
Mean Daily Discharge Availability for Noakhali Sub-project

No.	Station Name		Type
84.1	Kaliachari		
181	Gunabati Railway Bridge	T	
212	Parshuram		
G−10	Dakatia at Bagmara		Df/S/W
G−17	Kakri at Miarbazar		S/W
G−22	Dakatia at Chitoshi		S/W
G−38	WAPDA Kl at Chandraganj		Df/S/W
G−52	Sonaichari at Chowara		Df/S/W
G−129	Pagli at Suagazi		S/W



Average Daily Water Level Availability for Noakhali Sub-project

No.	Station Name		Type
58	Haziganj	T	
79	Matlab Bazar	T	
115	Daudkandi	T	
181	Gunabati Railway Bridge (d/s)	T	
182	Companiganj	T	
222	Noakhali	T	
239	Lakshmipur	T	
240	Bhawaniganj	T	
276	Satnal	T	
277	Chandpur	T	
278	Daulatkhan	T	
G−1	Elliotganj Khal at Elliotganj		
G−2	Harikhola Khal at harikhola		
G−15	Little Feni at Kashinagar		
G−22	Chitoshi		
G−36	WAPDA Khal at Piarapur	T	
G−38	Chandraganj	T	
G−40	Noakhali Khal at Begumganj		
G−42	Little Feni at Selonia	T	
G−76	Curzon Khal at Mudaffarganj		
G−91	Mohendra Khal in Dasherhat		
G−92	Noakhali Khal at Naodona		
	Rahmatkhal in Rahmatkhali (u/s&d/s)	T	



Sources:
- (i) Surface Water Hydrology, BWDB, e.g. 212
- (ii) Surface Water Modelling Centre, e.g. G−10

Legend:
- Dw : discharge (weekly)
- Df : discharge (fortnightly)
- S : discharge with suspended sediment

Water Level:
- W Non−tidal
- T Tidal

B.3.3.3 Water Level Data

Water level data in the study area is generally more widely available than streamflow, as indicated in Figure B.2.1 and Table B.3.2. For the Noakhali area, many of the data are tidal, however, and usual practice is to record daily maximum and minimum levels. Unfortunately, daily data are only available from 1983 in digital form. Resources were not available to the present project to encode all of the available daily water level records. Maximum 10 day water levels for the period April to October have been encoded, however, and combined with similar data extracted from the existing digital daily water level data base. These data are presented in Appendix B.III. At tidal stations, the data base includes daily tidal range, and these data have been available for preliminary engineering evaluations of tidal drainage structures.

The water level data base is adequate to give an indication of historical flood problems over the region. There are notable gaps in the data coverage, however, particularly in the area to the south of the Gumti River. There are generally fewer problems associated with water level data than river flow data, although problems have been noted with gauge datums at a number of locations, notably Daulat Khan. Such problems stem from difficulties in transferring bench marks across large expanses of water, and of course from the usual problems of gauge settlement or gauge re-establishment following damage.

Surface Water Modelling Centre has installed a water level gauge station at Selonia on the Little Feni river. The water level data of this station was previously used as boundary for the south east regional model by SWMC. At present the record of this station is used for calibration for the Noakhali Sub-Model.

B.3.3.4 Sediment Data

Sediment deposition from rivers rising in the Tripura Hills is a problem in several areas. There are, however, very few sediment data available for the region. There is no routine sediment or water quality sampling at any location in the region. Some data have been collected by the Surface Water Modelling Centre, on the Gumti at Comilla and on the Buri Nadi at Jibanpur. Sediment data were also collected as part of the "Hydrological and Morphological Studies of the Gumti-Titas and Atrai Basins" (Ref. 4). Sampling points included the Gumti at Comilla and the Howra at Ganga Sagar. Data are available for one complete wet season, and their use on the present study is discussed in section B.3.5.

B.3.3.5 Tidal Records

Short tidal records are available at Chital Khali on the Meghna and at Sandwip south of the Little Feni outfall for 1990 and 1991. At Sandwip records do not cover the night periods. Sandwip tide is semidiurnal with an average tidal range of 5.5 m. The maximum spring tide level is +5.8-6.0 mPWD and minimum level -0.3 MPWD. At Chital Khali/Daulat Khan the average tidal range is 2.5 m approximately. Tidal range is not affected by flows in the Meghna. The mean daily water level in the Meghna is shown at Daulat Khan in Figure B.3.7. Typical tidal fluctuations at Chital Khali and Sandwip are shown in Figures B.3.8 to B.3.10. At the outfall of the Little Feni (Sandwip) there is very little variation in the mean sea level which remains at about 2.8 MPWD.

At Chandpur, the major drainage outfall route for the Dakatia, tidal range and travel time are dependent on the flow conditions in the Meghna. Travel time between Daulat Khan and Chandpur is about 2 hours in the dry season and between two and a half and three during peak flood monsoon. Figure B.3.11 shows mean daily water levels and tidal fluctuations for 1990 as recorded at Chandpur.

Figure B.3.7

A Mean Daily Water Levels at Daulat Khan

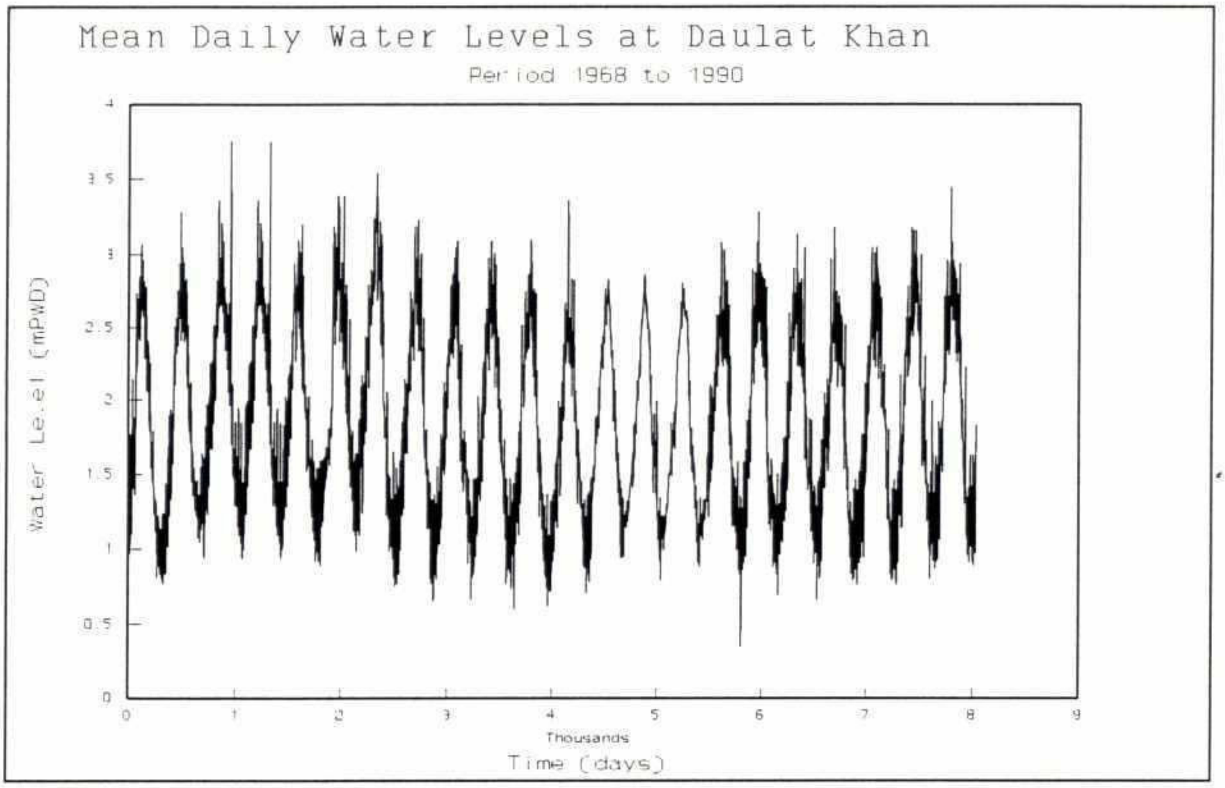


Figure B.3.8

Chital Khali Tide

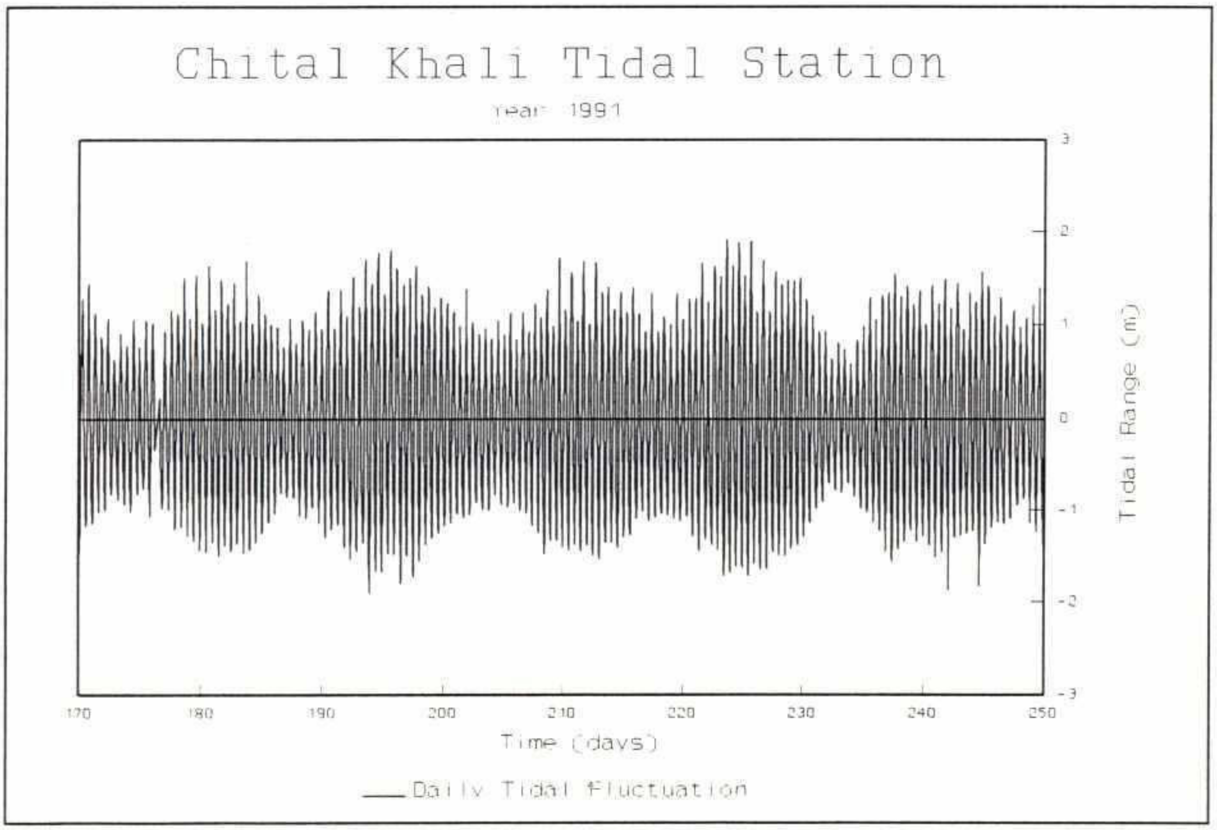


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Figure B.3.9

Sandwip Daily Tidal Oscillations

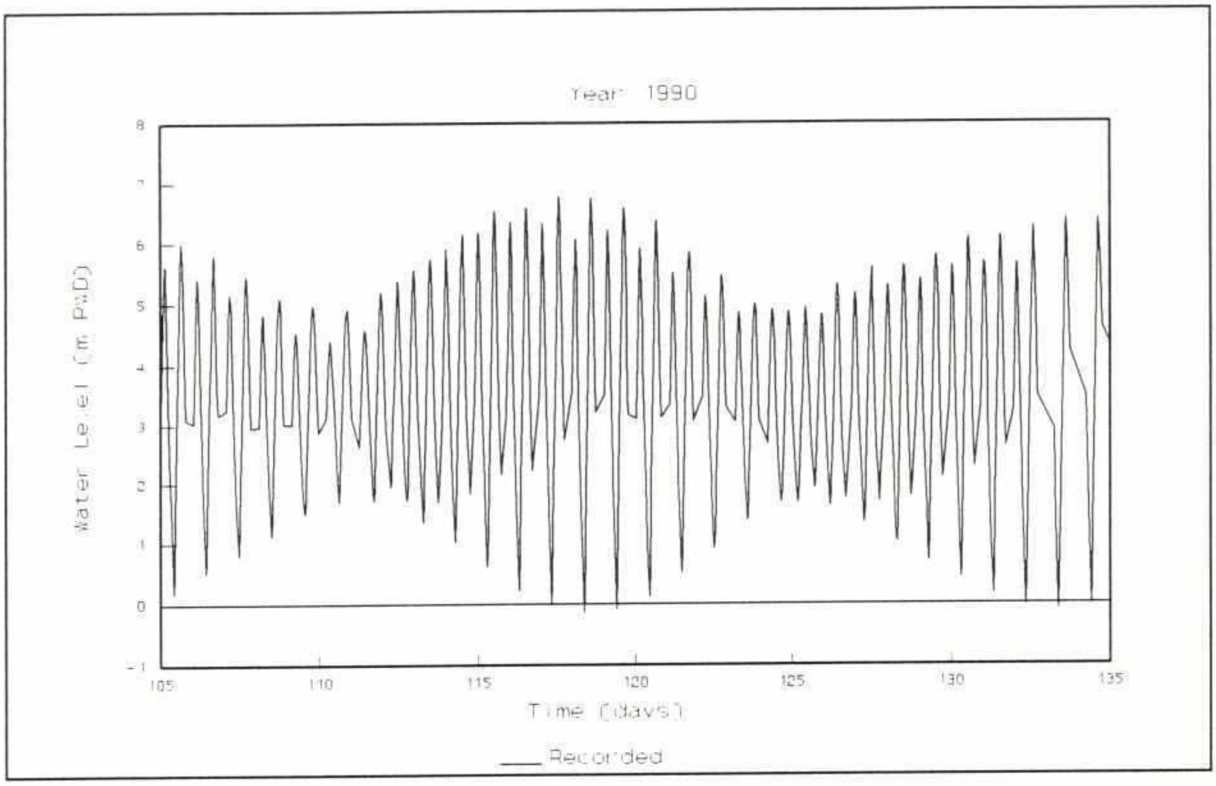

Figure B.3.10

Synthetic Tidal Levels at Sandwip

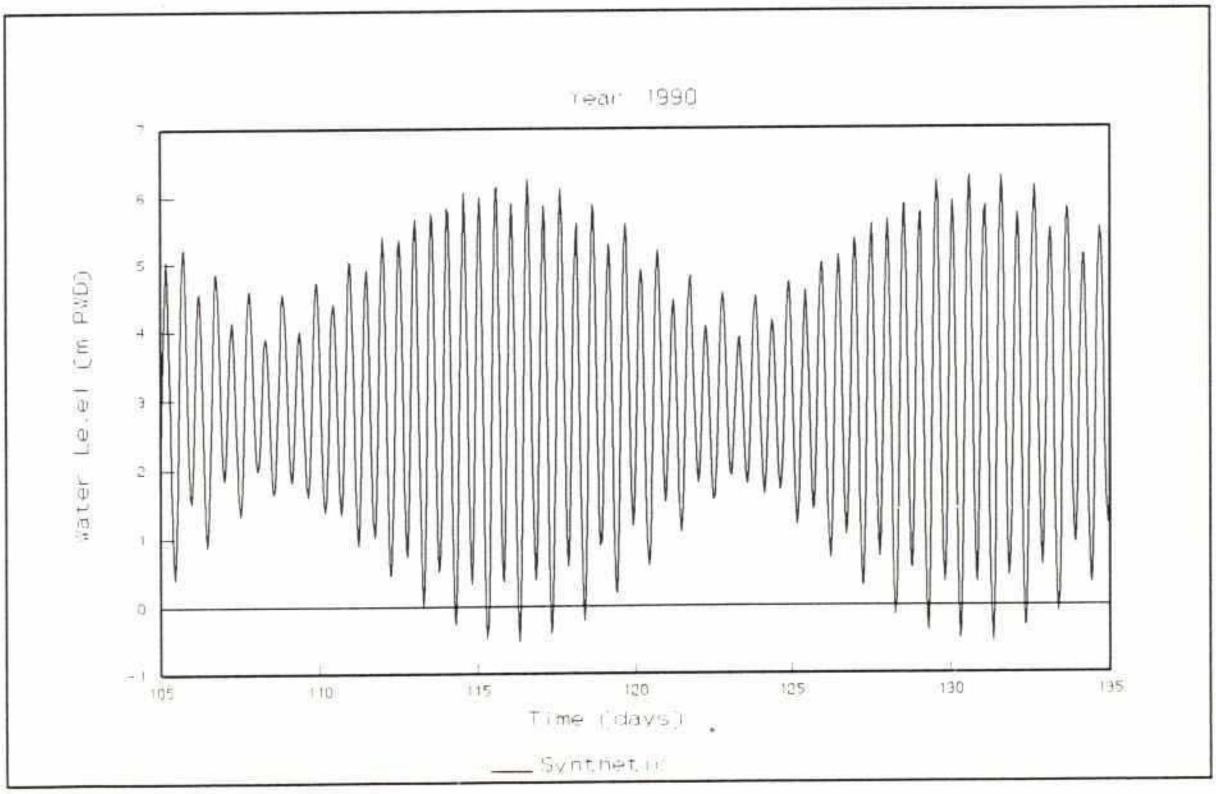

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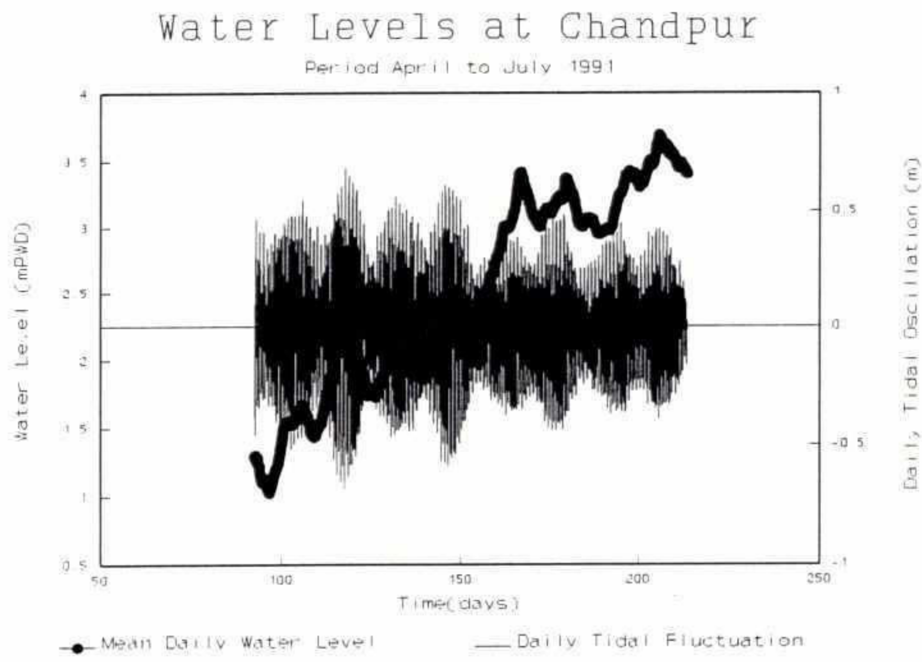
Figure B.3.11

Tidal and Mean Daily Levels at Chandpur



B.3.4 Analysis of Available Data

B.3.4.1 General

The analysis of flood conditions within the project area has been largely based on computational hydraulic modelling, in view of the complexities of the system. The extent of more traditional forms of analysis in flood hydrology, has therefore been at a fairly general level, and is discussed in the following sections.

Analyses have been made of all primary streamflow and water level data relevant to the project area. The focus has been on water level data, which is most widely available and which for the flood alleviation aspects of the project, is of most relevance. Some analysis has also been carried out of the water levels and discharges on the main river systems in order to help put the recent floods into perspective, to assist in defining appropriate distributions for regional multi-station analysis, and to test the data for non-stationarity. Much of this analysis preceded FAP-25 (Ref. 6).

B.3.4.2 Analysis of Main River Data

In view of the fact that the study area is bounded by the Meghna, and that flooding through much of the project area is controlled by the Meghna, either directly or indirectly, an analysis and understanding of the boundary conditions is important.

The manner in which the boundary conditions could change in the future under different scenarios of flood mitigation upstream of the study area is an output of the hydrodynamic modelling studies undertaken by FAP-25 (Ref. 6). It was considered important, however, to try and assess whether or not there were any underlying trends of increasing flood magnitude or frequency resulting from upper catchment activity, which should be incorporated in the analyses. In order to ascertain this, trend analysis has been carried out on the series of annual maximum water levels at Baruria. The results of a number of statistical tests are presented in Table B.3.3. These are on the basis of the common data period 1964-1988, the maximum record available at the time of the analysis.

The annual maxima series indicates that there is no detectable trend of increasing flood frequency at Baruria, although at Baruria, 1987 and 1988 provided the two highest events on record. For the purposes of the South-East Regional Study, the evidence of the Baruria record is sufficient to indicate the absence of any trends of increasing flood levels at the present time. This is not to say that trend does not exist, only that it is not detectable with the present data set, which is in any case rather short for this form of analysis.

General Extreme Value distributions have been fitted to the series of annual maximum water levels at Baruria. It is generally preferable to work with discharges in order to avoid stage induced influences when rivers go out of bank, but the analysis was intended to be preliminary and would in itself indicate whether or not considering a single population is appropriate. At Baruria the best fit is provided by a Type I distribution. Plots of the fitted distributions are presented in Figure B.3.12. Good fits have been achieved in all cases. At Baruria, which is the station of most relevance to the present study, the 1988 flood was the highest on record, with a return period of about 50 years. The return period of the 1987 flood at Baruria was about 20 years. A fuller treatment of main river flood characteristics has been provided under FAP-25. The analysis presented here was carried out in order to gain a preliminary understanding of the importance of different aspects of the flood problem, rather than as a possible basis for any design or evaluation work.

Figure B.3.12

Annual Maximum Water Level Frequencies at Baruria

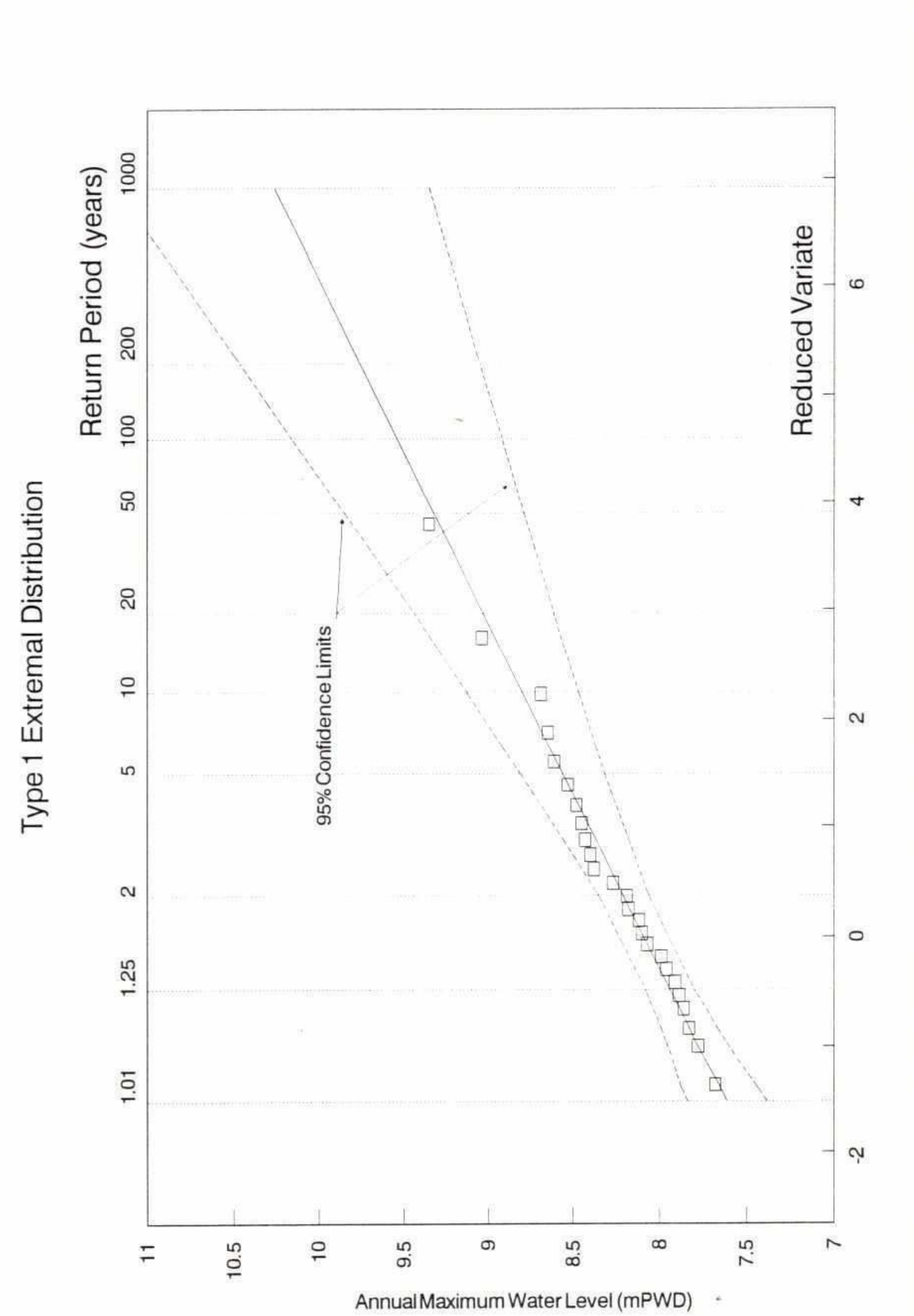


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TABLE B.3.3

Statistical Tests on Annual Maximum Water Levels

	Baruria	
Statistical Test	Expected	Observed
Randomness		
Median Crosses	11 +/- 6	11
Turning Points	14 +/- 3	14
Persistence		
First Order Serial Correlation	-0.04 +/- 0.41	0.13
Spearman Rank	-0.05 +/- 0.41	0.17
Trend		
Mann-Whitney U Test	72 +/- 34	69
Wald-Wolfowitz Runs Test	13 +/- 5	15

B.3.4.3 Analysis of Water Levels in the Noakhali Area

There has been discussion at various stages during the Flood Action Programme about the most appropriate choice of statistical distribution for frequency analysis of both water levels and discharges. The analysis for the South East Regional Study preceded much of this discussion, and it was considered that at a regional planning level it was not appropriate to go into great detail in assessing the most appropriate statistical distribution for each station or group of stations, although this could be a requirement where the data of particular stations are being used at full feasibility level, or in detailed design. Analysis showed that application of Extreme Value Type I distributions provided good fits to the main station data on the Meghna, and this distribution was therefore used throughout. The fitted distributions to the series of annual maximum daily water levels at Chandpur and Satnal are shown in Figures B.3.13 to B.3.14. The EV1 distribution apparently fits the data well, and for the purposes of regional analysis it has been considered appropriate to adopt this. Tabulated values of estimated water levels at these locations are presented in Table B.3.4. It is of particular interest to note the range of variability in levels at different locations. At Chandpur, the 50 year flood level is only 0.61 m above the 2 year flood level.

Figure B.3.13

Annual Maximum Water Level Frequencies at Chandpur

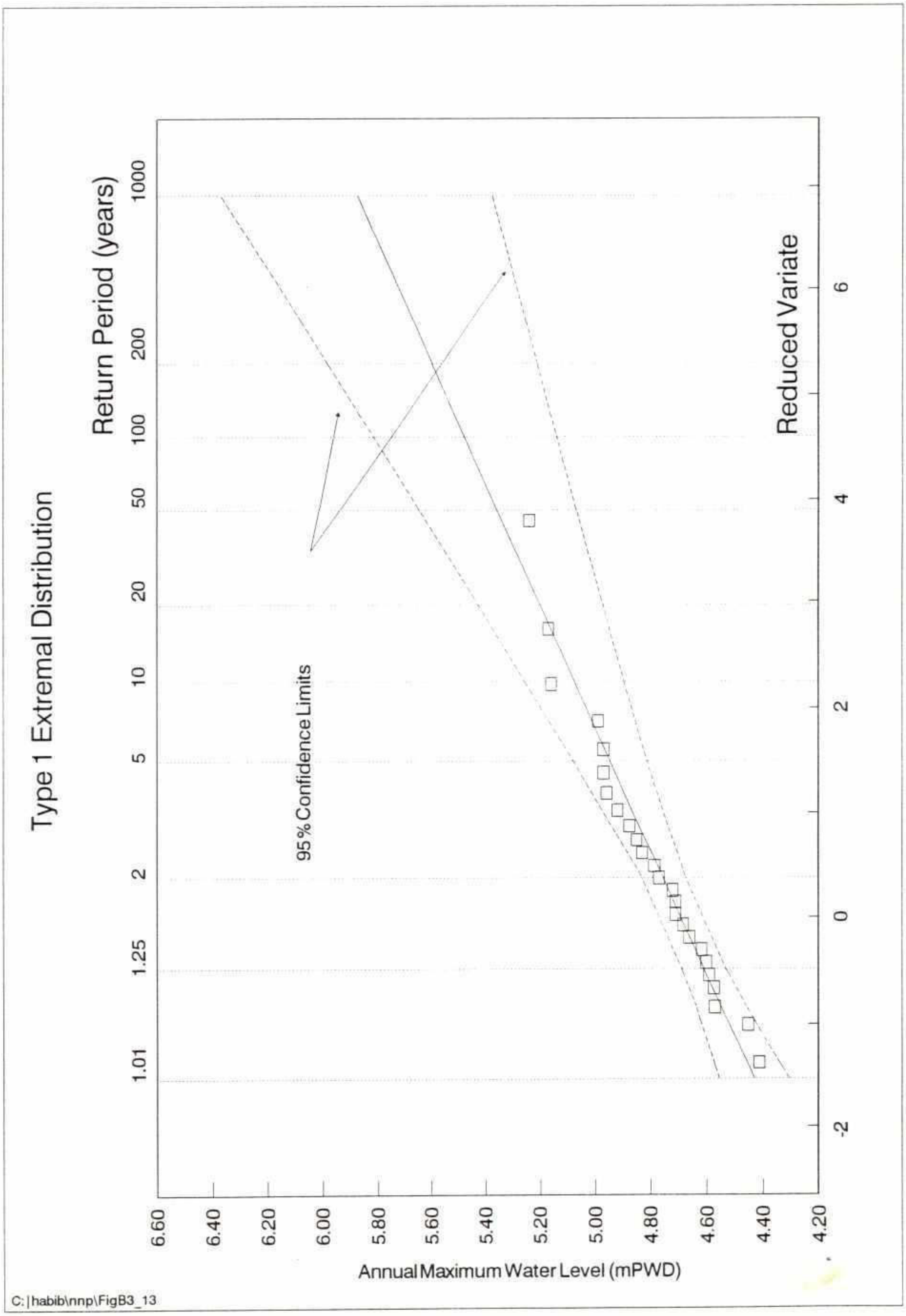

Figure B.3.14

Annual Maximum Water Level Frequencies at Satnal

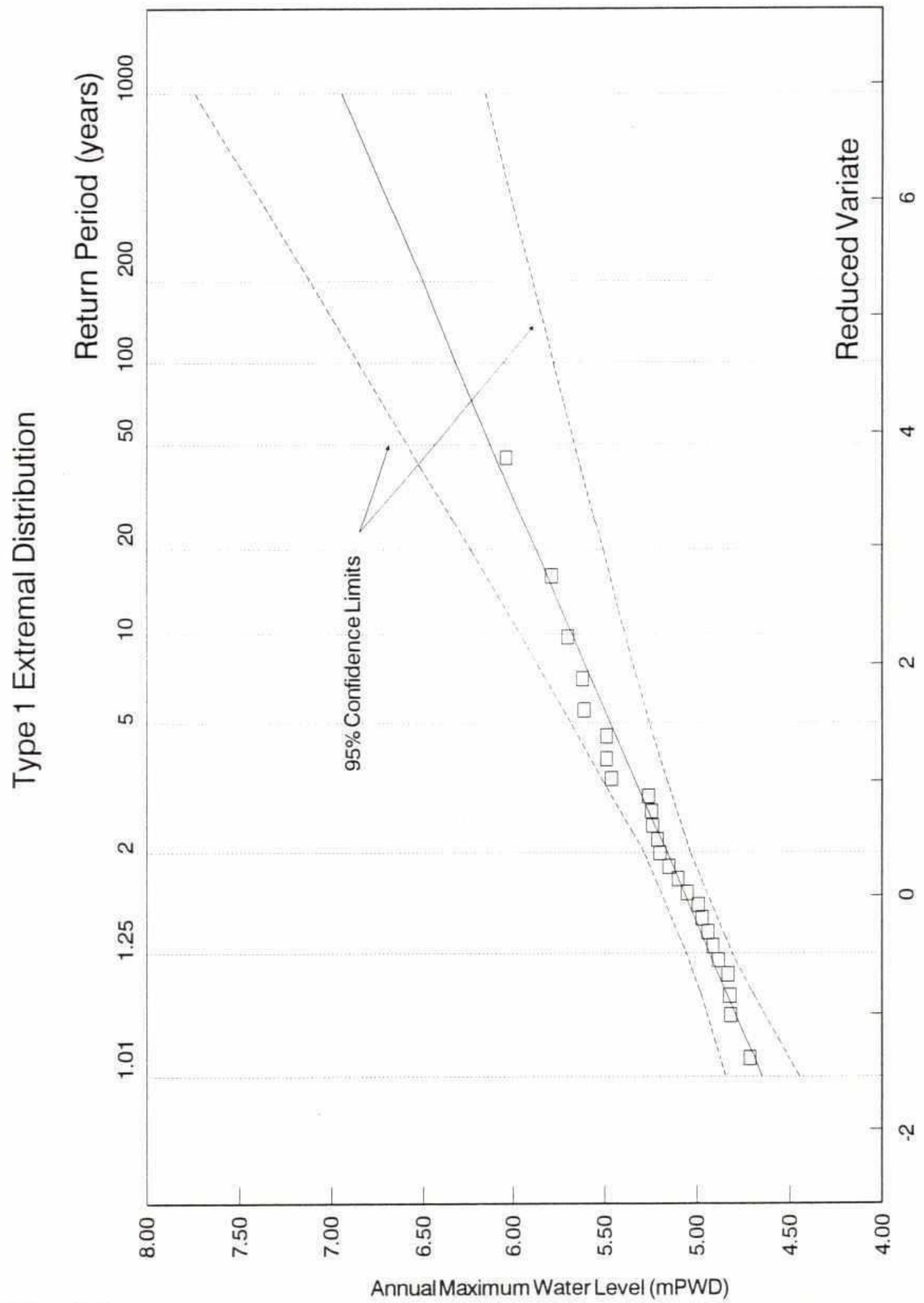

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TABLE B.3.4

Annual Maximum Water Levels

Annual Max. Water Level (mPWD)

Return Period (years)	Meghna River			Noakhali Khal	Companyganj (Little Feni)
	Satnal	Chandpur	Daulat Khan		
1.01	5.64	4.42	3.82	4.95	5.30
1.25	4.94	4.61	3.87	5.06	5.45
2	5.18	4.78	3.98	5.33	5.81
5	5.47	4.96	4.13	5.69	6.28
10	5.7	5.1	4.22	5.93	6.60
20	5.88	5.22	4.32	6.16	6.90
50	6.13	5.39	4.44	6.46	7.29

Typical mean high and low water surface profiles for the Meghna between Daulat Khan and Bhairab Bazar have been shown in Figure B.3.3, for the months of May and August. These give an indication of the range in water levels that can be expected in different parts of the region. It should be noted that the stations used upstream of Bhairab Bazar are not main river stations, and in real terms are at a similar chainage to Bhairab Bazar. It is thus to be expected that the seasonal variation in flooded areas in the north of the region will be much greater than in the areas south of the Gumti. Similarly, the impact of flood extremes could be greater in the northern areas, subject of course to the overall distribution of land levels relative to flood levels.

Regionally, frequency analysis has been carried out on all available records of 10 day water levels. For the period April to October, frequency distributions have been fitted to each 10 day period, resulting in a series of independent seasonal water level frequency estimates. The full results of the analysis are presented in Appendix B.IV, and a sample table shown in Table B.3.5 for Chanpur. The analysis provides a preliminary basis for the evaluation of embankment design for both full polder and submersible embankments. In conjunction with local topographic data it will also give an indication of flood risk on different land types. The seasonal presentation of results permits flood levels to be related directly to cropping conditions.

TABLE B.3.5

Seasonal Water Level Frequency Analysis at Station T-277 (Chandpur)

Annual Maximum Water Levels
T-277, Chandpur

; Maximum 10 day Levels April - October

Return Period (Years)	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1.11 *	1.93	2.03	2.12	2.23	2.51	2.89	3.04	3.34	3.49	3.83	3.98	4.15	4.26	4.24	4.20	4.16	4.20	3.99	3.78	3.50	3.08	4.55
1.25	2.00	2.12	2.20	2.36	2.61	2.97	3.12	3.42	3.59	3.90	4.04	4.22	4.34	4.31	4.29	4.24	4.26	4.07	3.86	3.60	3.19	4.61
2	2.17	2.34	2.39	2.67	2.85	3.15	3.33	3.61	3.83	4.05	4.19	4.40	4.51	4.40	4.50	4.43	4.40	4.24	4.06	3.86	3.47	4.76
5	2.40	2.63	2.65	3.08	3.17	3.39	3.60	3.86	4.14	4.26	4.39	4.64	4.75	4.70	4.78	4.69	4.59	4.48	4.34	4.21	3.83	4.95
10	2.55	2.83	2.82	3.35	3.39	3.55	3.78	4.02	4.35	4.39	4.52	4.80	4.91	4.85	4.97	4.86	4.71	4.63	4.52	4.44	4.07	5.08
20	2.69	3.01	2.98	3.61	3.60	3.71	3.95	4.18	4.56	4.52	4.65	4.95	5.06	5.00	5.15	5.02	4.83	4.78	4.69	4.66	4.30	5.20
50	2.88	3.25	3.19	3.94	3.86	3.91	4.17	4.38	4.82	4.69	4.82	5.15	5.26	5.18	5.38	5.23	4.98	4.98	4.91	4.94	4.60	5.36

It was also considered important to prepare flood level frequency duration tables, from which an indication of the duration of inundation to certain flood depths could be obtained. The results of the analysis could also be related to elevation area characteristics for different parts of the region in order to give preliminary indications of flood depth area frequency relationships. Flood level frequency duration tables have been prepared for each of the water level stations in the area. The full results of the analysis are presented Appendix B.V. Table B.3.6 presents the results for Companyganj, Noakhali and Daulat Khan. A summary of the of results for selected flood durations and return periods is presented in Table B.3.7, and serves to give an indication of variability across the project area.

With the exception of the main river station data, the analysis discussed above is not based on homogeneous record periods, but utilises all available data at each station. It will be noted from Table B.3.2 that at some stations record periods are very short. Caution must therefore be exercised in the use of any the results. The purpose of the analysis was broad level planning and this must be borne in mind.

Frequency analysis based on historic water levels are of value in identifying appropriate design events, or preliminary outline design criteria. The statistical analysis of the historic record cannot however, be used as any form of predictor for flood levels that might be expected under future embanked river or polder conditions. The evaluation of such situations requires the use of hydrodynamic modelling techniques. These are discussed in Chapter B.4.

TABLE B.3.6

Flood Level Duration-Frequency Analysis

Flood Level Duration / Frequency
T-182, Companyganj, ; Maximum 10 day levels, Apr. - Oct.

Duration Days	Return Period (years) 1.11	1.25	2	5	10	20	50
20	5.03	5.13	5.34	5.63	5.83	6.01	6.25
30	4.90	4.99	5.19	5.48	5.66	5.84	6.07
40	4.84	4.93	5.13	5.40	5.58	5.75	5.97
50	4.75	4.84	5.06	5.34	5.53	5.72	5.95
60	4.73	4.82	5.03	5.32	5.51	5.69	5.92
80	4.53	4.64	4.90	5.24	5.47	5.69	5.98
100	4.28	4.39	4.67	5.04	5.29	5.52	5.83
120	4.17	4.27	4.51	4.83	5.04	5.24	5.50
150	3.77	3.90	4.20	4.61	4.88	5.14	5.47

Flood Level Duration / Frequency
T-222, Noakhali, ; Maximum 10 day levels, Apr. - Oct.

Duration Days	Return Period (years) 1.11	1.25	2	5	10	20	50
20	4.93	4.97	5.05	5.16	5.23	5.31	5.40
30	4.91	4.94	5.02	5.13	5.21	5.28	5.37
40	4.87	4.91	4.99	5.11	5.19	5.27	5.37
50	4.85	4.89	4.98	5.11	5.19	5.27	5.37
60	4.82	4.86	4.95	5.06	5.14	5.21	5.31
80	4.71	4.75	4.84	4.97	5.05	5.13	5.24
100	4.70	4.72	4.77	4.84	4.88	4.92	4.98
120	4.43	4.48	4.58	4.71	4.80	4.89	5.00
150	3.76	3.86	4.09	4.39	4.59	4.78	5.03

Flood Level Duration / Frequency
T-278, Daulat Khan, ; Maximum 10 day levels, Apr. - Oct.

Duration Days	Return Period (years) 1.11	1.25	2	5	10	20	50
20	3.42	3.47	3.60	3.76	3.87	3.98	4.11
30	3.32	3.38	3.50	3.66	3.77	3.87	4.01
40	3.26	3.31	3.43	3.59	3.69	3.79	3.92
50	3.22	3.27	3.38	3.54	3.64	3.74	3.87
60	3.16	3.21	3.32	3.48	3.58	3.68	3.81
80	3.05	3.10	3.20	3.34	3.44	3.53	3.65
100	2.93	2.97	3.07	3.21	3.30	3.39	3.51
120	2.51	2.60	2.80	3.07	3.25	3.42	3.64
150	2.31	2.39	2.58	2.83	3.00	3.16	3.37

TABLE B.3.7

Summary of Flood Level Duration Frequencies

Duration		20 Days			40 Days			60 Days		
Return Period		2	5	10	2	5	10	2	5	10
Station No.	Station Name									
T-79	Matlab	4.75	4.98	5.12	4.58	4.81	4.95	4.45	4.62	4.74
T-115	Daudkandi	5.11	5.48	5.73	4.90	5.22	5.44	4.79	5.10	5.30
T-240	Bawaniganj	3.45	3.88	4.17	3.37	3.78	4.06	3.21	3.65	3.94
T-276	Satnal	4.86	5.16	5.36	4.67	4.93	5.10	4.51	4.74	4.88
T-277	Chandpur	4.43	4.64	4.78	4.31	4.49	4.60	4.23	4.38	4.48

B.3.4.4 Analysis of Discharge Data

There are no discharge measurement stations inside Noakhali North area having long term recorded discharge data. Gunabati Raily Bridge (181A) has got a short period of data. Surface Water Modelling Centre has collected data at a few locations for a few years for the calibration of South East Model. For reasons of data limitations no discharge analysis has been done on observed data. Of course discharge data has been analysed for the simulated data for the 25 year simulation for the present and with project conditions through the post processing of the model data.

The analysis of discharge data has effectively been limited to that of the Gumti at Comilla, for reasons of data availability and quality. The main objective of analysing the Gumti record has been to gain some understanding of the likely typical flood response of those rivers draining from the Tripura Hills into the sub-regional area.

The Kakri, Pagli and Sonaichari are flashy types of river, and drain from the Tripura Hills. Figure B.3.15 shows a typical annual hydrograph for the Kakri at Miarbazar. This is quite different to those of the main rivers, exhibiting direct rainfall response.

Other records which were thought to be of potential value in assessing flood frequency for cross boundary rivers were those at Parshuram (212), and Kaliachari (84.1).

At Parshuram there is also apparently a trend of increasing flood discharge (Figure B.3.16), although the possible reasons for this are unknown. It has not been possible to investigate this. At Kaliachari there are problems with the streamflow record, and in August 1982, the equivalent runoff depth over a four day period from the catchment was over 1500 mm. The maximum rainfall recorded in the area at this time was 357 mm at Parshuram and there are therefore problems with this record.

Figure B.3.15

Hydrograph of Daily Discharge at Miarbazar on Kakri River for the Year 1991

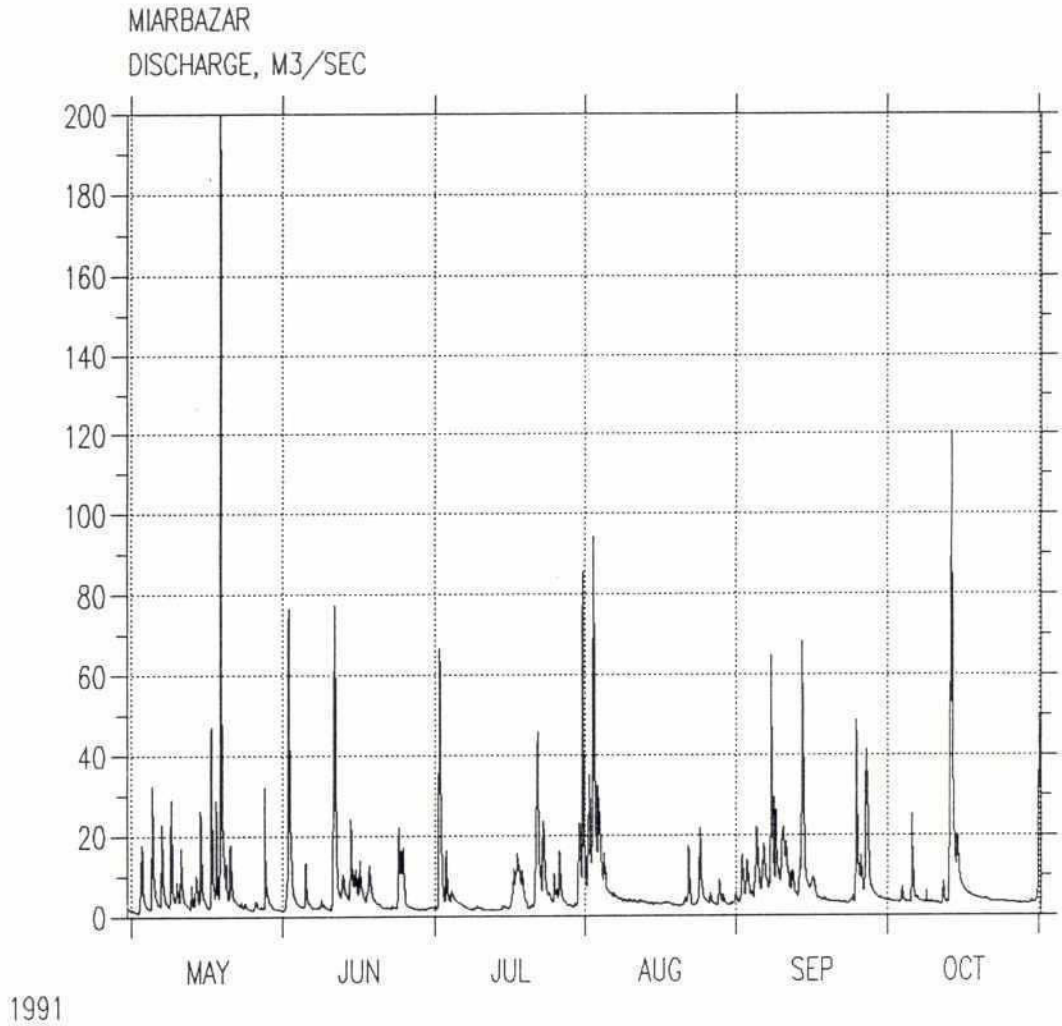
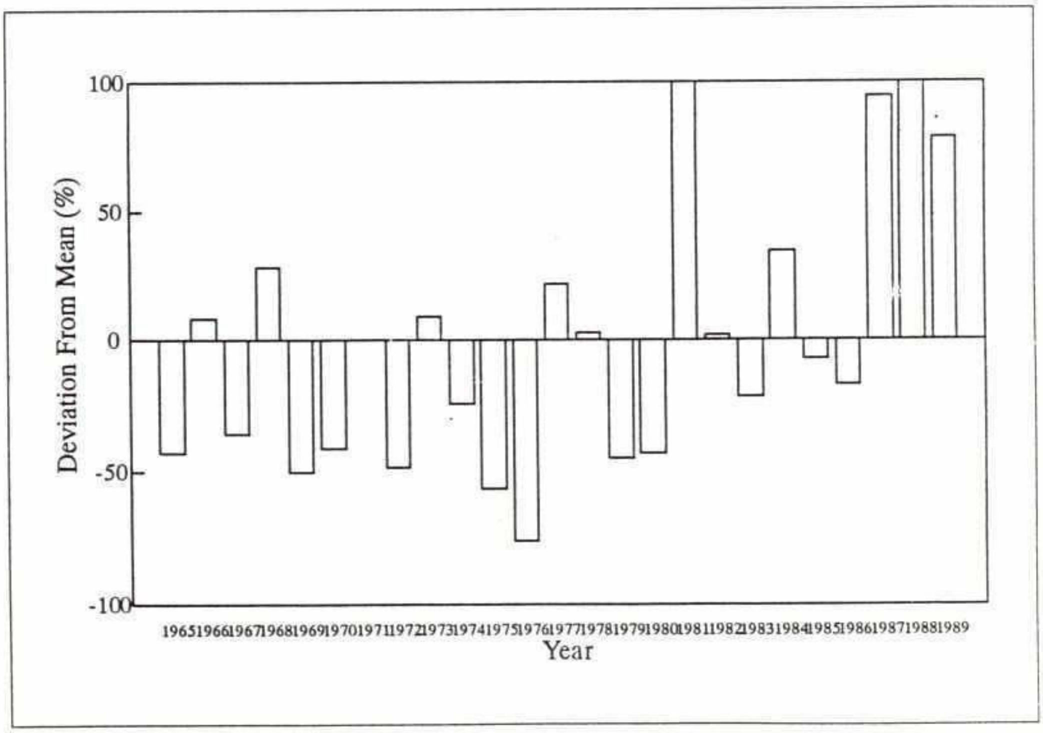


Figure B.3.16

Annual Maximum Discharge at Parshuram



The difficulty remaining is in evaluating a mean annual flood for any particular catchment area, given that only the Gumti is gauged. The mean annual flood on the Gumti has a specific peak mean daily discharge of 0.26 $m^3/s/km^2$. On the Muhuri at Pashuram the mean annual flood has a specific peak mean daily discharge of 0.52 $m^3/s/km^2$. Rainfall over this area is significantly higher than at Comilla, and this combined with a smaller catchment area, results in a higher specific discharge. This analysis has not therefore resulted in any quick assessments for flood peaks from ungauged catchments. The data available are annual maximum mean daily flood discharges, and not instantaneous flood peaks. It is not considered appropriate to use the specific discharge approach for any of the smaller ungauged catchments. It is recommended that for investigations of specific areas, a synthetic unit hydrograph approach be adopted. An appropriate methodology for the hill catchments would be the USSCS method (Ref. 7). This could be used with rainfall estimates from Bangladesh, and catchment characteristics estimated from available mapping or imagery.

B.3.5 Sediment Discharges

The availability of sediment discharge data for the region is quite limited, as discussed in section B.3.3.4. Work on the Hydrological and Morphological Study of the Gumti, Titas and Atrai Basins (Ref. 4), has however, given some general figures on typical size fractions and annual sediment yields, and these are considered to be appropriate for outline planning purposes in the region. The annual sediment yield from the Gumti was estimated to be 770 $tonnes/km^2/year$, which compared well with a previous estimate for a catchment in north-east India of 700 $tonnes/km^2/year$ (Ref. 8). Studies of reservoir sedimentation in India have indicated sediment yields of the order of 600 to 1400 $tonnes/km^2/year$ for catchments in Southern India of less than 150 km^2. Similar measurements for mountain catchments in Northern India indicated annual yields of the order of 1200 to 2000 $tonnes/km^2$. For smaller catchments draining from the Tripura Hills, sediment yields could be in excess of those estimated for the Gumti. Annual sand extraction from the Kakri River is equivalent to a yield of 490 $tonne/km^2$.

The composition of Gumti sediment was 700 $tonnes/km^2/year$ of silt, and 70 $tonnes/km^2/year$ of sand. Morphological modelling runs carried out on the Gumti adopted a sand size of 0.2 mm, and a silt size of 0.03 mm.

B.3.6 Tidal Analysis

B.3.6.1. Introduction

A general expression for the tide as a function of time is:

$$h(t) = h_0 + \sum f_n \, H_n \cos(\omega_n \, t + V_n + u_n - g_n) \quad (1)$$

where:
- h_0 mean daily water level in (mPWD);
- f_n node factor;
- H_n amplitude of tidal component in (m);
- ω_n period of tidal component in (degrees/hour)
- g_n phase lag of tidal component in (degrees);
- V_n, u_n astronomical argument from the equilibrium tide theory in (degrees).

The tidal signal is the linear superposition of a series of harmonic terms, called constituents. Each constituents, for a given place and interval, is characterized by three factors: i) amplitude h_j, period ω_j and phase lag α_j. There are more than two hundred components in a tidal signal.

The contribution to the total tidal level is for some components relatively small and therefore neglected in many practical applications.

The simplified harmonic analysis considers a limited number of constituents: diurnal and semi-diurnal and shallow water (optional). The principal components considered are listed in Table B.3.8. Correction factors compensate for the contributions of the less important tidal constituents.

TABLE B.3.8

Principal Tidal Components for Simplified Method

Symbol	Cause	ω_j (Degrees/hr)	T (hour)
M_2	Main lunar tide (semi-diurnal)	28.98410	12.42
S_2	Main solar tide (semi-diurnal)	30.00	12.00
K_1	Sun/moon declination tide (diurnal)	15.04107	23.93
O_1	Moon declination tide (diurnal)	13.94303	25.82

B.3.6.2. Tidal Analysis

The general expression for the horizontal or vertical tide as function of time is given in equation 1. Tidal analysis aims at the determination of constants, amplitude and phase of each constituent. In general the problem is classified under the theory of the most likely estimates and in particular the regression analysis. The parameters of the function are determined by the method of the least squares. For details see Ref. 2.

The series g(t) is the measured tidal signal during a certain period of time (t1 to t2) and h(t) is the basic expression (Eq. 1)> The function h(t) contains a number of parameters a_1,..a_n which have to be determined from the observations. The method of least squares requires that the difference F between measured signal g(t) and function h(t) is minimal.

$$F(a1,....an) = \int [h(t)-g(t)]^2 dt \quad (2)$$

$$\frac{\partial F}{\partial a_1} = 0, \frac{\partial F}{\partial a_2} = 0,......, \frac{\partial F}{\partial a_n} = 0 \quad (3)$$

This procedure allows to write an equation for each unknown a1 to an.

$$h(t) = \sum h_i \cos(\omega_i t - \alpha_i) = h_1 \cos\omega_1 t \cos\alpha_1 + h_1 \sin\omega_1 t \sin\alpha_1 + h_2 \cos\omega_2 t \cos\alpha_2 + h_2 \sin\omega_2 t \sin\omega_2 + ... \quad (4)$$

By introducing the following new unknowns:

$$h_1\cos\alpha_1 = A_1 \qquad h_2\cos\alpha_2 = A_2 \qquad h_1\sin\alpha_1 = B_1 \qquad h_2\sin\alpha_2 = B_2 \quad (5)$$

Equation 1 and 2 can be written in the following form:

$$h(t) = A_1\cos\omega_1 t + B_1\sin\omega_1 t + A_2\cos\omega_2 t + B_2\sin\omega_2 t + ... \quad (6)$$

$$F(A_1,B_1,A_2,B_2,....) = \sum_{i=0}^{k} [h(t_i) - g(t_i)]^2 \Delta t \quad (7)$$

$$F(A_1,B_1,A_2,B_2,...) = \sum_{i=1}^{k} [A_1\cos\omega_1 t_i + B_1\sin\omega_1 t_i + A_2\cos\omega_2 t_i + B_2\sin\omega_2 t_i + ... - g(t_i)]^2 \Delta t \quad (8)$$

By differentiating with respect to $A_1, B_1, \ldots A_n, B$ and equating the derivatives to zero we obtain a system of linear equations. In matrix form for the case of two constituents, this can be expressed as:

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} A_1 \\ B_1 \\ A_2 \\ B_2 \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} \quad (9)$$

The unknowns $A_1, B_1, \ldots A_n, B_n$ can be solved by inverting the matrix. This approach can be extended for a case with any number of tidal constituents.

B.3.6.3 Tidal Constituents: Chital Khali and Sandwip.

The simplified harmonic method applied to tidal record at Chital Khali and Sandwip provided the following parameters for tidal constituents M_2, S_2, K_1 and O_1. In the present analysis only four components are considered. Higher order and shallow water components are not included because of low quality of the recorded signal. Tide at both Chital Khali and Sandwip is predominantly semi-diurnal with values of the ratio γ of 0.096 and 0.144 respectively. The ratio λ is defined as:

$$\gamma = \frac{h_{K_1} + h_{O_1}}{h_{M_2} + h_{S_2}} \qquad (10)$$

Results of the analysis are presented in Table B.3.9.

TABLE B.3.9

Harmonic Analysis: Tidal Components

i) Dealt Khan (Chital Khali)

HM2	**HS2**	**HK1**	**HO1**
1.262	0.32	0.096	0.076
gM2	**gS2**	**gK1**	**gO1**
245.0	90.0	341.0	328.0

ii) Sandwip Island

HM2	**HS2**	**HK1**	**HO1**
2.199	0.954	0.3327	0.1226
gM2	**gS2**	**gK1**	**gO1**
302.0	349.0	357.0	342.0

B.3.6.4. Tidal Prediction

The general equilibrium tide (Eq.1) as observed in Greenwich, United Kingdom, forms the base of the prediction of tide all over the world. For a location at latitude L the equilibrium tide is corrected by a factor -pL where p is a species number depending on the type of the tidal constituent (p=0,1,2,..). In general this location uses another time as GMT and a correction ω_n S will be required (where S is hours earlier than Greenwich). The node factors for middle of the year and equilibrium argument for the period 1965 to 1993 are listed in Table B.3.10.

TABLE B.3.10

Node actors f_{M2} and equilibrium argument for years 1965 to 1993

YEAR		M_2 f_{M2}	S_2 f_{S2}	K_1 f_{K1}	O_1 f_{O1}	M_2 V_o+u	S_2 V_o+u	K_1 V_o+u	O_1 V_o+u
1965		0.989	1.000	1.051	1.081	327.900	0.000	2.100	44.600
1966	0.978	1.000	1.079	1.128	69.100	0.000	3.000	142.700	
1967	0.969	1.000	1.100	1.161	246.400	0.000	5.500	241.000	
1968	0.964	1.000	1.110	1.178	346.900	0.000	7.800	339.800	
1969		0.963	1.000	1.113	1.182	64.000	0.000	11.200	52.600
1970	0.966	1.000	1.105	1.170	165.400	0.000	13.400	150.700	
1971	0.973	1.000	1.088	1.143	266.800	0.000	15.500	249.000	
1972		0.983	1.000	1.063	1.101	8.000	0.000	17.100	347.800
1973	0.995	1.000	1.029	1.047	84.500	0.000	19.000	61.700	
1974	1.008	1.000	0.990	0.984	185.300	0.000	19.200	162.000	
1975	1.020	1.000	0.951	0.920	285.800	0.000	18.200	263.500	
1976	1.029	1.000	0.916	0.863	26.000	0.000	16.200	6.500	
1977	1.035	1.000	0.891	0.822	101.800	0.000	14.100	85.700	
1978	1.038	1.000	0.882	0.806	201.800	0.000	10.500	191.300	
1979	1.036	1.000	0.890	0.819	301.900	0.000	6.800	296.900	
1980	1.030	1.000	0.913	0.858	42.000	0.000	3.700	41.600	
1981		1.021	1.000	0.948	0.915	117.900	0.000	2.500	119.400
1982	1.009	1.000	0.987	0.979	218.400	0.000	1.500	221.100	
1983	0.997	1.000	1.026	1.041	319.100	0.000	1.500	321.400	
1984		0.984	1.000	1.060	1.096	60.000	0.000	2.400	60.800
1985		0.974	1.000	1.086	1.140	136.800	0.000	4.900	134.200
1986		0.967	1.000	1.104	1.168	238.100	0.000	6.900	232.600
1987		0.964	1.000	1.112	1.182	339.100	0.000	9.200	330.700
1988		0.964	1.000	1.111	1.180	81.000	0.000	11.600	68.800
1989		0.969	1.000	1.100	1.161	158.100	0.000	14.800	141.600
1990		0.977	1.000	1.079	1.128	259.400	0.000	16.700	240.100
1991		0.988	1.000	1.051	1.081	0.500	0.000	18.000	339.000
1992		1.000	1.000	1.015	1.024	101.300	0.000	18.700	78.700
1993		1.013	1.000	0.976	0.960	177.600	0.000	19.400	154.000

B.3.6.5. Tide on the Meghna River

Prediction of tidal levels on the Meghna river needs to take into account the interaction between flow conditions in the Meghna and tidal oscillations in the Bay of Bengal. Tidal components derived for Chital Khali are attenuated and delayed as they travel upstream the Meghna river. Such attenuation and lag are related to gradients in the Meghna and vary seasonally. In the dry season gradients are very small and difference in mean daily water levels between Chandpur and Chital Khali are of the order of 0.20 to 0.3 m. During this period the tide penetrates into Meghna system up to Nabinagar with spring tides of the order of 0.30 metres. In the monsoon season, tidal amplitudes are gradually reduced and delayed with the rising of water levels (and gradients) in the Meghna. Recorded levels show that tidal amplitude, for the same period of the year, reduce gradually moving upstream the Meghna from the Bay of Bengal. At Chandpur wet season spring tide amplitude is about 60% of dry season values. Recorded mean daily levels and daily tidal oscillations measured about mean water levels for Chandpur (April to November 1991) are shown in Figure B.3.11.

As this affects each tidal component, daily tidal oscillations can be expressed in the following form:

$$\eta_n(t) = h_0 + e^{\lambda x} f_n H_n \cos(\omega t + V_n + u_n + kx) \quad (11)$$

where

$e^{\lambda x}$	attenuation term
kx	lags term
x	distance along river from origin (where tidal components were derived: Chital Khali)
$f_n H_n$	amplitude of nth tidal components
λ and k	attenuation and lag factors.

The attenuation and lag factors and celerity are related by the following expressions 12, 13 and 14. They can be derived from the basic momentum equation applied to sections of the river.

$$\lambda = \frac{\omega \sqrt{-1 + \sqrt{1 + \frac{m^2A^2}{\omega^2}}}}{c_0\sqrt{2}} \qquad (12)$$

$$k = \frac{\omega \sqrt{1 + \sqrt{1 + \frac{m^2A^2}{\omega^2}}}}{c_0\sqrt{2}} \qquad (13)$$

$$c = \frac{\omega}{k} = \frac{c_0\sqrt{2}}{\sqrt{1 + \sqrt{1 + \frac{m^2A^2}{\omega^2}}}} \qquad (14)$$

where

mA proportional to $\frac{g|Q|}{C^2AR}$ (15)

C Chezy's roughness coefficient

R hydraulic radius

Q discharge

B.3.6.6 Noakhali regional Model: Tidal Boundary Conditions for 25 Year Simulations

Simulations with the Noakhali sub-regional model require boundary conditions on the Meghna at Chandpur and Rahmatkhali regulator, and in the Bay of Bengal downstream Kazirhat regulator. Flows through the regulators as well as the Dakatia river are affected by mean water levels and tidal ranges at their downstream end. It was therefore important to establish accurate mean water levels and tidal shape (amplitude and timing) at the three major outfall links of the Noakhali drainage system. The Noakhali khal also drains into the Bay of Bengal however, due to siltation which occurred after the construction of the Meghna's cross dams in the late 60s, its capacity is greatly reduced and tidal influence is negligible. Figure B.3.5 shows mean daily water levels and tidal range at Noakhali gauging station covering the period 1968 to 1989. Simulations also showed that flows through the khal are of the order of 20 m^3/sec in the monsoon season and its effect on water levels in the Begunganj depression is minimal.

To correctly simulate flows through the Rahmatkhali regulator it is necessary to provide water levels at half hourly intervals at the regulator on the Meghna side. The time step being dictated by stability conditions in the Noakhali model. At present the General Model (GM) provides only mean daily water levels for the 25 year simulation period along the Meghna river. Recorded water levels at these locations could be used to provide boundary levels for simulations. Unfortunately, these are not available and, in addition, changes in the Meghna system, resulting from any of the other FAP projects, would be difficult to incorporate. The Noakhali model in fact needs to take into account these effects which are supposedly built into the GM model.

To generate half hourly water levels there are two possible alternative methods:

i) run GM in tidal mode for 25 year period;

ii) add daily tidal fluctuation on simulated mean daily water levels;

With method i) the distortion and delay affecting tide travelling along the Meghna river is taken into account by the hydrodynamic model. The drawback of this method is that it requires calibration of the GM model in "tidal mode" and run time will be very high because of the small time step required. For this task more detailed information of the geometry and hydraulic roughness conditions of the Meghna would also be required.

Method ii) relies on a simpler method to estimate distortion and delay of tide along the Meghna. It uses the output from the GM model to calculate attenuation and lag factors λ and k with which new tidal components are calculated (Eq. 10). Tidal fluctuations are then added to the mean daily water level. The model therefore uses calibrated and verified simulated water levels.

After careful examination of the data available and the time constraints for the study, it was decided that method ii) would be the most appropriate. The method, which relies on the GM to provide mean daily water levels and the hydraulic factors and a reasonably long tidal record at Chital Khali, is considered sufficiently accurate for the scope of the study.

To this end a computer programme has been prepared to read Mike11 result files and cross sectional hydraulic parameters from the GM model and, calculate attenuation and lag terms according to the methodology previously presented. The tidal levels produced are then superimposed to the "non-tidal" results from the GM model. The output is prepared in a format compatible with Mike11 boundary files. The method is able to reproduce tidal range and seasonal variations. Calibration against recorded levels at Piarapur showed good agreement between recorded and simulated levels. Synthetic tidal oscillations against GM model mean daily water levels for year 1965 are presented in Figure B.3.17, Figures B.3.18 and B.3.19 show tidal signals at Daulat Khan and Chandpur for dry and wet season.

Tidal levels at this location relate to mean sea level with no seasonal variation.

Figure B.3.17

Simulated Tidal Fluctuations and Mean Daily Water Levels at Chandpur

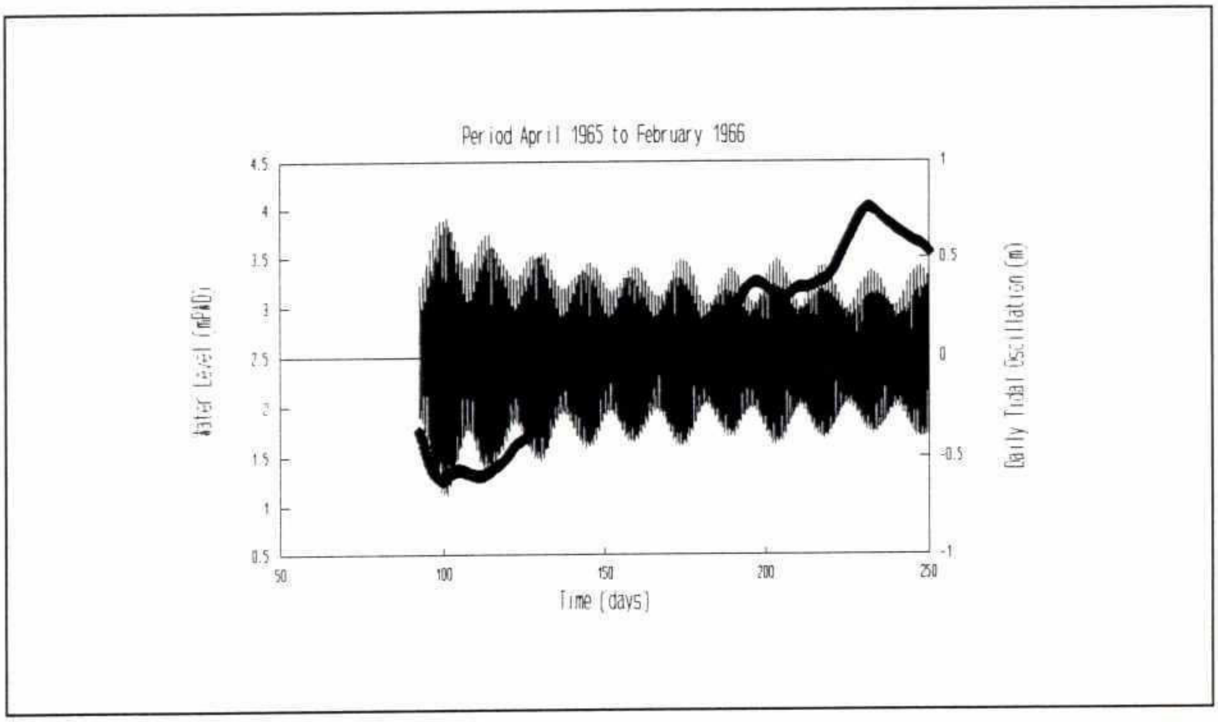


Figure B.3.18

Tidal Levels at Daulat Khan and Chandpur for Dry Season Period

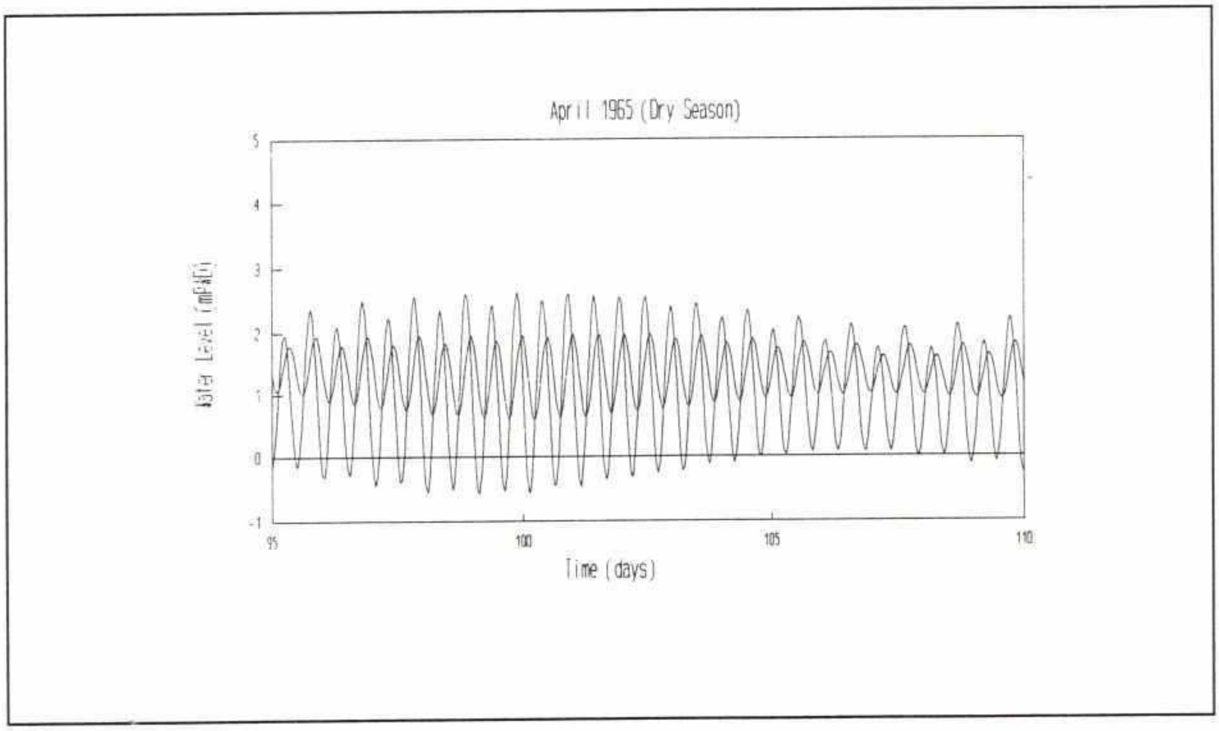


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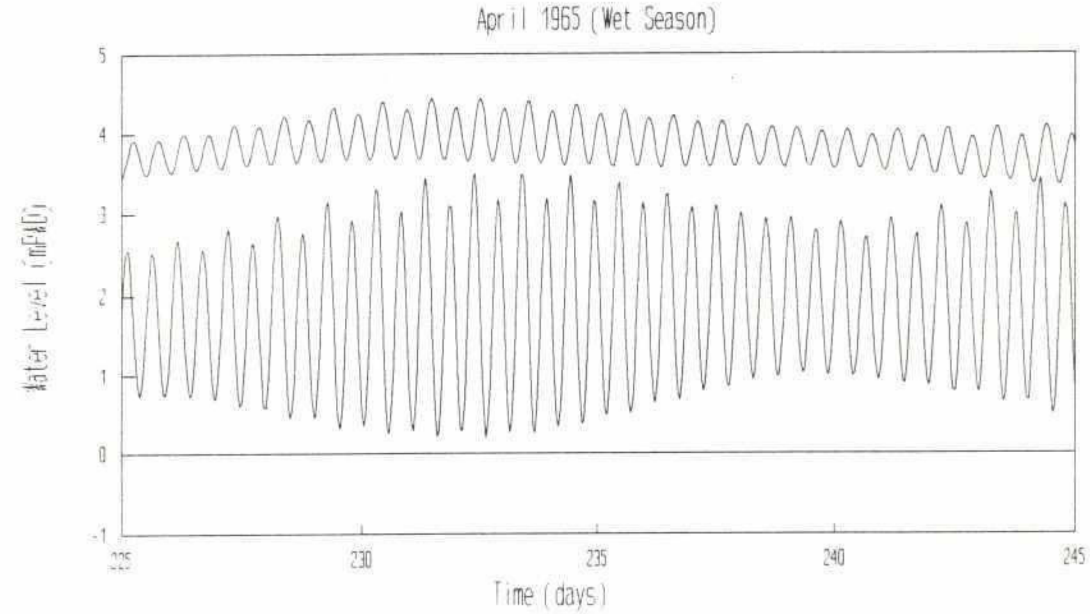
Figure B.3.19

Tidal Levels at Daulat Khan and Chandpur for Wet Season



CHAPTER B.4

MODELLING METHODOLOGY

B.4.1 NAM modelling

NAM is a deterministic model of the lumped, conceptual type. NAM operates on a daily time step, taking in data on rainfall, evaporation and groundwater abstractions, and producing as output river flows at the catchment outfall and values for its internal state parameters. The principal restrictions of NAM are that it does not couple surface inundation from river flow or irrigation into the sub-surface water balance and that it contains only a restricted amount of attenuation for high values of runoff (floods). Technical details concerning NAM can be found elsewhere (Ref. 4.1).

The NAM model used in this study was that developed and calibrated by the SWMC.

The application of NAM was divided into two stages:

Stage 1 : The NAM model, for the entire South East region, was calibrated for the period April 1986 to March 1988. Calibration was based on simulating variations in groundwater levels since there are no internal discharge gauging points within the region. Verification of the model, against observed groundwater depth, was carried out for the period from April 1989 to March 1991.

Stage 2 : Following calibration and verification, a 25 year simulation for the period from 1965 to 1989 was carried out.

NAM was used to define runoff inputs along river reaches of the hydrodynamic model or to provide boundary condition discharges at locations where gauged discharges were not available. Further details of NAM together with its application to the South East region are given in Chapter B.2.

B.4.2 Development of the Hydrodynamic Model

B.4.2.1 The Hydrodynamic Model

The simulation of water levels, flow rates and flow velocities in the river system is carried out with the MIKE11-HD hydrodynamic model (hereafter called MIKE11). The model is well tried on rivers in Bangladesh through the efforts of the SWMC and other FAP studies.
MIKE11 is a deterministic model based on the St. Venant equations of open channel flow and the Abbott-Ionescu finite difference scheme. It represents flow in river channels, through structures and over flood plains. Technical details of MIKE11 can be found elsewhere (Ref. 2.1). Like all mathematical models it is based on a variety of assumptions and numerical approximations which determine its scope of application.

The development of models, by the SWMC, is following a programme in which first a pilot model is set up using readily available data from the Master Planning Organisation (MPO) and the Bangladesh Water Development Board (BWDB). The pilot models may be somewhat coarse in many areas pending the collection of further topographic, survey and hydrometric data. Once the full survey information is available the full model is established and finally, following the successful application to a number of flood seasons, the full model achieves the status of the verified model.

B.4.2.2 Collaboration with Surface Water Modelling Centre

The surface water simulation modelling programme in Bangladesh commenced in 1986, and the Surface Water Modelling Centre (SWMC) now exists as part of the River Research Institute (RRI). There is active support from the Bangladesh University of Engineering Technology (BUET), and from the Danish Hydraulics Institute (DHI) who are consultants to the programme.

The South East Regional Model (SERM) was the first hydrodynamic model to be developed in Bangladesh by the SWMC, and is therefore in a more advanced state of calibration and verification than any of the other regional models. Outputs from the model include water levels, discharges and velocities at each node in the network, for each modelled time step. The most recent report by the SWMC on the SERM is their 1990 Verification Report. This report showed, in general, a good calibration of the model.

The SERM was originally developed in two parts because of the computer memory allocation limitations of the DOS operating system on the computers on which the model was being run. The division of the models was at the Daudkandi to Comilla road, which does form a reasonable divide across the region although transfers between the northern and southern systems do exist. The SWMC now operate their models under the UNIX operating system, which overcomes the memory allocation limitations associated with DOS. The SERM model has been transferred to the UNIX system and there is now a single model for the entire South East region.

The SERM team at the SWMC are currently carrying out a thorough verification exercise on the model, which has effectively evolved to its present form over a six year period. Full verification of the model is not expected until after the completion of the present project. For this study the latest version of the model available was used; this is not expected to change significantly as a result of the current verification process.

The project initially carried out its modelling activities in the SWMC offices, working closely with the SERM team. A connection was established to the SWMC computer network, and UNIX installed on the Noakhali North modelling computer. This ensured that full compatibility was maintained and was of mutual benefit to both modelling teams.

Once production runs of the model commenced the modelling team moved back to the Noakhali North project offices to ensure closer involvement of engineering and other staff in the formulation of model runs and the evaluation of results. For the production runs the latest version of the model, available at the time of the move, was used although further changes have been made to the Noakhali model, see Chapter B.5.

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The production runs of the Noakhali North model were carried out using the southern part of the SERM. The division was taken at the Daudkandi to Comilla road. The split was carried out to ensure acceptable run times for the 25 year model simulations. Since the Noakhali North study area is to the south of the embankment on the right bank of the Gumti river there is little possibility of the developments in this area having a significant impact on conditions to the north of the river, or vice versa.

B.4.3 Application of Hydraulic Models

B.4.3.1 Guidance from FAP25

Due to the complexity of the Bangladeshi Delta and the interaction of the various flood causing factors, the definition of design events of a given return period in terms of standardised boundary conditions is impossible. In an attempt to overcome these problems FAP-25 recommended a rationale which involves long term simulations of hydraulic models for the period 1965-89. In detail the rationale required,

- the preparation of boundary conditions required to run models for the period 1965-89.
- running the models for the full 25 year period, at least once for the present (baseline) conditions and once for the ultimately adopted scheme(s).
- combinations of various options to reach the final plan may be studied on the basis of simulations for a reduced number of selected seasons, the selections being based on the analysis of the 25 year baseline run.
- sensitivity analysis of ultimately adopted scheme considering changed boundary conditions in the major rivers due to proposed schemes outside the region.
- statistical analysis of the results, aimed at assigning return periods to historic peak, seasonal or sub-seasonal values of selected design variables.

B.4.3.2 Approach Adopted

In keeping with the FAP-25 guidelines, the application of the Noakhali North model was divided into five stages,

Stage 1 : Calibration and verification. The model was calibrated against observed water level and discharge data at gauging stations. The calibration concentrated on simulating water level variations. Comparison with observed discharges was used to ensure that flow splits between major river channels were correctly simulated. The model was verified over a number of seasons to ensure that reasonable variations in water level and discharge were being produced. This stage of the work was carried out mainly by the SWMC.

Stage 2 : Without Project (present / baseline) simulation. The Without project simulation used the 25 years of hydrological data from 1965 to 1989. The objective of the model was to produce data on water level and discharge variations over a period of 25 hydrological years. This information would form the baseline data for investigating the impact of proposed developments in the modelled area. The objective of the Without Project simulation was not to simulate observed water level and discharge variations over the 25 year period from 1965 to 1989.

Stage 3 : Once the Without Project simulation had been completed the results were used to select a design year for investigating proposed developments. The design year was selected to give an approximate 1 in 5 years return period event over the whole of the modelled area. The model was run for the design year to investigate the impact of design options or scenarios (set of options). This was done by comparing the results of the design option simulations with the results of the Without Project simulation for the same year.

Stage 4 : With Project simulation. Following the design option, or scenario, simulations a development plan for the modelled area was formulated. A With Project simulation was carried out with this development plan in place. The With Project simulation used the hydrological data for the period from 1965 to 1989. The impact of the proposed development plan was investigated by comparing the results of the With Project simulation with the results of the Without Project simulation.

Stage 5 : Sensitivity analysis to investigate the impact, on the proposed development plan, of changed external conditions were carried out in this final stage.

B.4.3.3 Modelling Constraints

The Noahkhali model was run with tidal boundaries to ensure that the results from the model reliably represented the prototype conditions. As a tidal model, a small time step is required to be able to depict the tidal variations to a sufficient degree of accuracy. In the Noahkhali study a 15 minute time step was used for all model runs.

Using a 15 minute time step, the results file for a single hydrological year is in the order of 30 Mbytes. A 25 year simulation would therefore require over 750Mbytes of disk space plus a further 2-300 Mbytes for database files, workspace, etc. This was beyond the means of the project computer hardware and alternatives had to be found to ease this problem.

The monsoon model runs were undertaken for a 7 month period only, from May to November, with a short 10 day period at the beginning of each simulation to allow the model to settle down from its initial conditions. In addition, the results were saved at selected nodes only and at hourly time intervals thereby reducing the size of the output files further. Using this approach the results files became more manageable, about 5Mbyte.

The savings on space also had substantial savings in terms of run times and these were kept to around 2 hours for a seven month simulation.

Figure B.4.1

Post-Processing Analysis

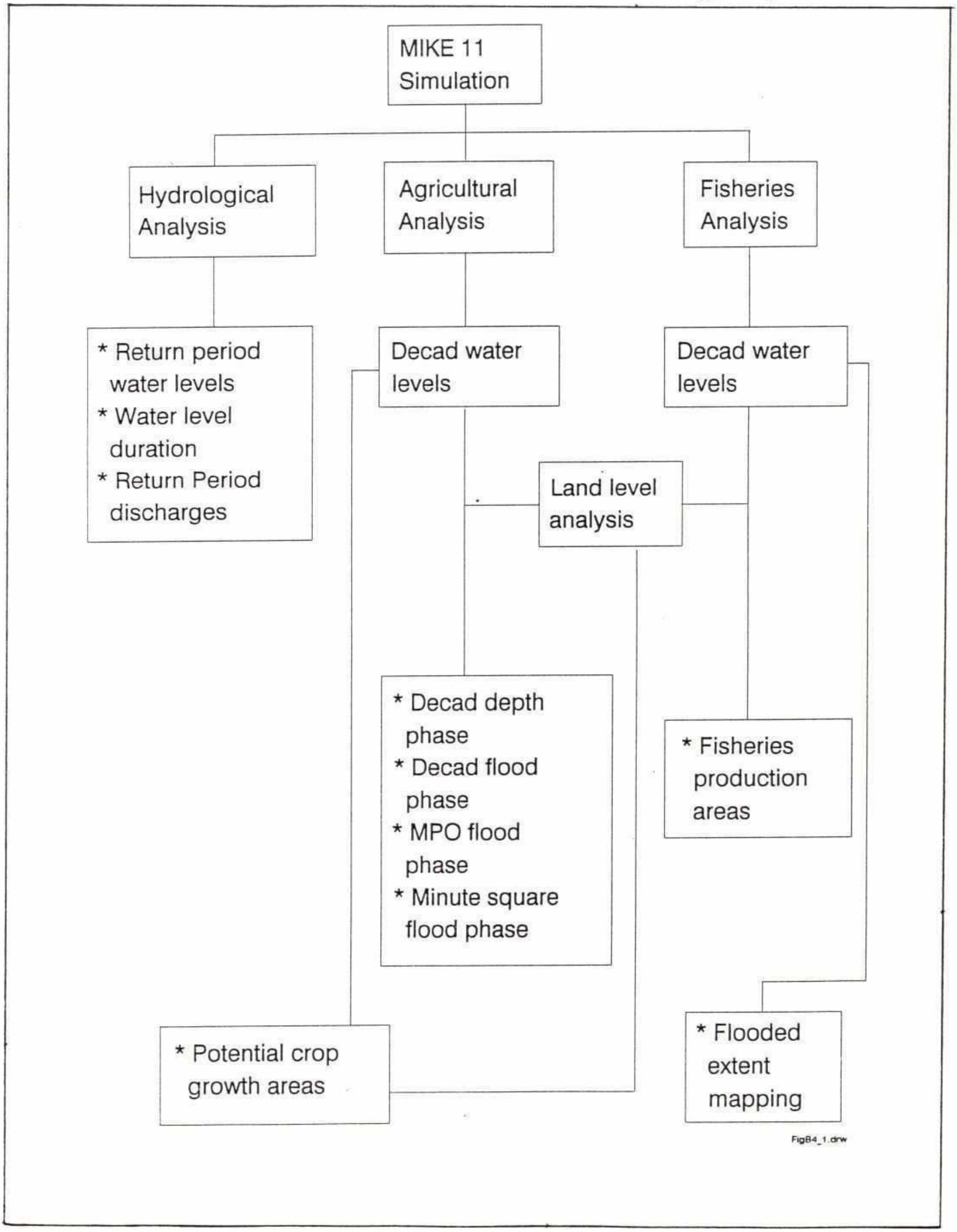
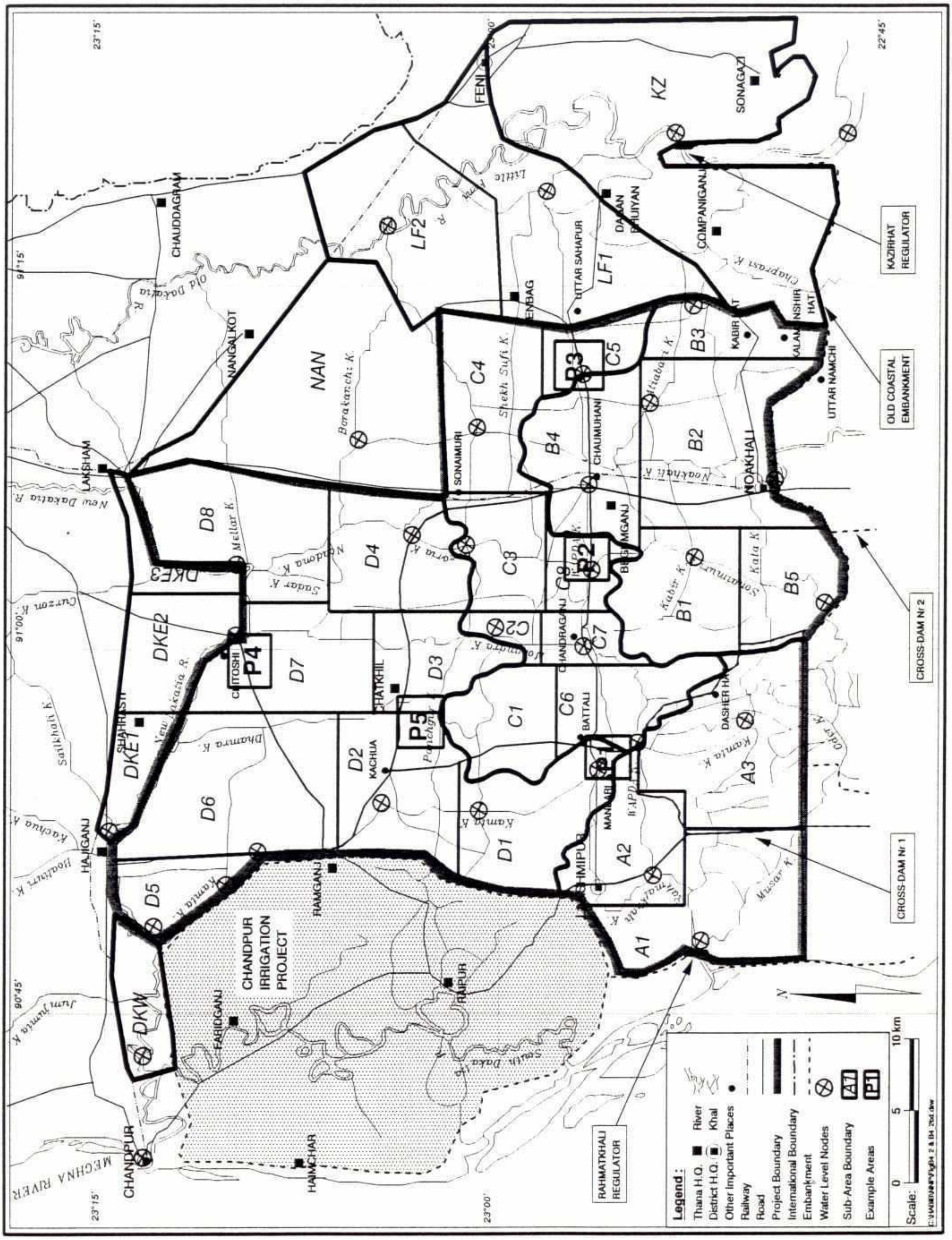


Figure B.4.2
Hydrodynamic Model Sub-Areas



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B.4.4. Post-Processing of Results from 25-year Hydraulic Model Simulations

B.4.4.1 Introduction

The 25 year MIKE11 simulations generate 25 years of daily water levels and discharges at the model nodes. This is a vast amount of information which in its raw form is of limited use, hence there is a need for post-processing. The output required from this post-processing will depend on the use to which it is to be put. The MIKE11 results are to be used for three forms of analysis; engineering, agriculture and fisheries / environment. This section describes the post-processing of MIKE11 results for each of these disciplines; Figure B.4.1 is a flow diagram illustrating the procedure used.

The engineering analysis requires information at key points within the hydraulic system whereas for the agricultural and fisheries analysis information is required for areas. For this purpose the Noakhali North study area was divided into 32 analysis areas, see Figure B.4.2. These analysis areas were based on the four zones of flooding and agricultural type; they also took into account the proposed interventions.

B.4.4.2 The Meaning of Return Period

The return period for an event (occurrence or exceedance of water level, discharge or any other hydrological parameter) is a convenient label to characterise the frequency of occurrence of that event. Return period is conventionally quoted in years. Since the analysis is in terms of annual occurrence of level exceeding a certain amount, there is no direct meaning of return period of less than two years. For large values (say 5 years or more) the return period becomes the average frequency of occurrence of the event in a very long sequence. This of course begs the question of whether the processes which force the event (climate, river morphology, anthropogenic development) are statistically stationary. There is a danger in the use of the notion of return period for non-specialists, in that it can be misinterpreted as implying some form of regularity of occurrence, that is a five year level occurs every five years ie if it has occurred this year it will not do so next year or if it has not done so for four years it will do so next year. Floods are random.

Return period is defined in terms of the annual probability of exceedance, P, by

$$T = 1.0 / P$$

Return periods of less than two years should really be expressed as a convenient ratio such as 4 in 5 years for $P = 0.8$ rather than $T = 1.25$, or, 9 in 10 years for $P = 0.9$ rather than $T = 1.11$.

The return period associated with a given level depends upon several factors,

- the representative nature of the sample used in the estimation (ie are there "too many" wet or dry years?)
- the number of observations (ie record length)
- the statistic analysed (annual peak value, decad mean, peak over threshold etc)

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- the statistical model (or probability *distribution*) used for the random process (eg GEV type 1 distribution - the Gumbel plot)

- the "plotting rule" used to assign probability values to the observations as each distribution is associated with a particular plotting rule to minimise bias

- the method of fitting the distribution to the observed probability values.

These factors are considered in setting up the hydrological analysis software.

B.4.4.3 Engineering

The engineering discipline uses the MIKE11 results for a number of purposes, these include,

- definition of channel / khal dimensions
- definition of structure details including sill levels and gate sizes

In order to make these decisions water levels and discharges with different return periods at key points within the system are required. The procedure utilised to obtain this information is as follows,

Definition of locations : The key locations for which information on water levels and /or discharges was required were identified by the engineers.

Output of MIKE11 results : The standard MIKE11 water level and/or discharge results were output to text files in five year blocks. The output was on a daily basis. This was done for each required location.

Analysis of MIKE11 results : The daily values were analysed to obtain decad, 10 day, values. The average over the decad was used to represent the decad. Hydrological analysis was carried out on the decad values to give minimum, mean and maximum values for each decad. In addition, return period decad values were calculated for 2, 5, 10, 20, 50 and 100 year return periods. Output from a typical water level analysis is shown in Table B.4.1. A Blom formula was used for the lower return periods, up to 1 in 20 year for a 25 year simulation, and a Gumbel Extreme Value analysis for the higher return period events. Estimates of events with return periods greater than the length of run analysed should be viewed with caution because they result from extrapolation beyond the period of model simulation.

TABLE B.4.1

Decad Water Level Analysis at Begumganj for With Project Condition

! DATA FILE : N-FN.RDF BOUNDARY FILE: N-65-FN.BSF !
! Boundary Fil : N-65-FN.RRF CALCULATED : 5-MAY-1993, 23:09 !
MIKE-11 file : N65-F-FL.TXT (all files also R70...., R75.... etc)
This analysis file: FLWP4000.00S

ANALYSIS OF 10-DAY MEAN WATER LEVELS
(Model output for 24 years - run F)

WAPDA K4 (WP4) Chainage 0.000

	Min.	Mean	Max.	Return Period (years)					
				2	5	10	20	50	100
Apr 1	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90
2	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90
3	-99.90	-98.63	-89.76	-99.90	-99.90	-89.78	-89.77	-88.01	-85.50
May 1	0.64	1.52	2.75	1.49	1.95	2.55	2.64	2.85	3.08
2	1.07	1.91	3.02	1.70	2.71	2.93	2.97	3.40	3.68
3	1.07	2.13	3.13	1.99	2.87	3.06	3.12	3.41	3.61
Jun 1	0.97	2.49	3.93	2.50	3.11	3.27	3.58	3.79	3.99
2	1.58	2.92	3.67	2.95	3.38	3.57	3.64	3.76	3.87
3	2.11	3.21	4.04	3.28	3.66	3.74	3.87	4.01	4.12
Jul 1	2.84	3.45	4.04	3.47	3.80	3.85	3.94	4.04	4.12
2	3.18	3.70	4.24	3.62	4.07	4.15	4.21	4.41	4.54
3	3.26	3.85	4.56	3.78	4.19	4.22	4.38	4.54	4.67
Aug 1	3.49	4.00	4.81	3.99	4.20	4.24	4.48	4.62	4.74
2	3.41	4.05	4.82	4.05	4.29	4.31	4.53	4.67	4.77
3	3.18	4.06	4.75	4.01	4.34	4.42	4.61	4.73	4.85
Sep 1	3.22	4.06	4.66	4.01	4.37	4.51	4.60	4.74	4.85
2	3.46	4.02	4.60	3.95	4.30	4.52	4.56	4.70	4.83
3	3.46	3.94	4.50	3.84	4.33	4.44	4.47	4.69	4.82
Oct 1	3.22	3.80	4.39	3.74	4.07	4.30	4.36	4.49	4.60
2	2.61	3.57	4.16	3.55	4.04	4.14	4.15	4.33	4.44
3	1.84	3.15	3.92	3.03	3.71	3.90	3.91	4.21	4.37
Nov 1	1.26	2.59	3.58	2.60	3.25	3.36	3.47	3.73	3.91
2	0.97	2.14	3.26	2.12	2.78	2.89	3.10	3.30	3.46
3	-8.44	0.37	2.65	1.31	1.98	2.34	2.55	2.75	2.97
Dec 1	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90
2	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90
3	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90
Jan 1	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90
2	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90
3	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90
Feb 1	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90
2	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90
3	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90
Mar 1	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90
2	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90
3	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90	-99.90

Note: Estimates for return periods of more than 20 years should be viewed with particular caution because they result from extrapolation beyond the period of model simulation.

Return periods up to 20 years from Blom formula; 50 and 100 years by Gumbel Extreme Value Analysis on upper half of points.

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B.4.4.4 Agriculture

This section presents the form of analysis to determine the probability of crop success or failure in any given area of land due to a flood event. The analysis must be carried out for each crop type taking into account the susceptibility to damage in each phase of its growth. Each sub-division of the analysis areas was analysed separately and this information was combined to give results for the analysis area. The procedure utilised is as follows,

- a water level node in the MIKE11 model is assigned as being representative of the area.
- output of MIKE11 results as described in Section B.4.4.3.
- decad analysis of water levels
- statistical analysis of decad water levels
- calculation of depth and flood phases subject to FPCO and MPO rules
- the land-level database is used to determine the area subject to each phase of flooding
- analysis determines the water level, subject to agricultural rules, which is critical for the success of the crop and this is in turn related to a minimum ground level which can be planted without failure.
- the land-level database is used to determine the area of land over which the crop can be grown without damage.

(a) Decad Analysis of the Model Results

In each decad (with three decads per calendar month), crop failure occurs on the fourth day on which the level exceeds the critical value. Hence each decad should be represented as the maximum of a running four day minimum level, starting by looking three days backwards into the previous decad. The water levels ,from the MIKE11 model, at each representative node, were analysed in terms of four-day exceedances.

Thus a representative water level is produced for each decad and these can be analysed using standard statistical techniques as a 25-year sequence for the same decad in each year. The hydrological analysis software described in Section B.4.4.3 was used for this purpose. Thus return periods for water level in each decad can be produced.

For most of the Noakhali North project area the analysis was based on mean daily water levels. In the areas immediately upstream of Rahmatkhali and Kazirhat regulators there were significant tidal fluctuations which make mean daily values of little use. In these areas the representative daily value was taken to be 10 cm below the maximum value which occurred during the day.

(b) **Depth Phases**

The new draft rules from FPCO define depth phases for flooding analysis. These categories allow the former MPO phases to be reconstituted by addition. For these feasibility studies the following categorisation is used.

Depth Category	MPO Phase	Depth Range (m)		
D1	F0	0.0	to	< 0.2
D2	F0	0.2	to	< 0.3
D3	F1	0.3	to	< 0.5
D4	F1	0.5	to	< 0.7
D5	F1	0.7	to	< 0.9
D6	F2	0.9	to	< 1.8
D7	F3	1.8	to	< 3.6
D8	F4	3.6	and deeper	

Based on the decad water level analysis and land-level analysis, areas flooded to different depth categories were calculated for each decad through the hydrological year. Typical output from this analysis is given in Table B.4.2 which gives the areas flooded to different depth categories for each decad. This information can also be supplied as a percentage of the total area, Table B.4.3. This information can be supplied for the different return periods for which statistical analysis was carried out.

(c) **Flood Phases**

The widely quoted MPO flood phase figures are not quoted with respect to a time element whereas the model output and flood levels at each node are produced as a time series. The depth categories for the flood phases are also defined differently from those for the depth phase analysis, the depth phases have a higher resolution.

Based on the decad water level analysis and land-level analysis, areas in the different flood phase categories were calculated for each decad through the hydrological year. Typical output from this analysis is given in Table B.4.4 which gives the areas in the different flood phase categories for each decad. This information can also be supplied as a percentage of the total area, Table B.4.5. This information can be supplied for the different return periods for which statistical analysis was carried out. However, this does not eliminate the time dependent nature of the depth phase information.

Sensitivity analysis carried out by the North-West Regional Study (FAP-2) showed the most suitable method for obtaining the MPO flood phases was to select the 1 in 5 year return period level and take the peak decad flood level. Typical output for this analysis is given in Table B.4.6 which gives the flood phase distribution.

The percentage of the net cultivatible land which falls into flood phase categories F0 and F1 for the decad of worst flooding was plotted on a minute square basis to give the overall areal distribution of flood phasing.

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TABLE B.4.2

Areas Flooded to Different Depths for the Sub-Unit B.4 With Project Condition

Depth and Flood Phase analysis

Analysis for B4

NCA = 4457.00 (ha)

GCA = 8086.00 (ha)

Water levels based on 1:5 year levels

Area flooded in depth categories - Total Area

Month	10 day	Depth categories (m) 0.0-0.2	0.2-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.8	1.8-3.6	>3.6
4	1	4457.	0.	0.	0.	0.	0.	0.	0.
4	2	4457.	0.	0.	0.	0.	0.	0.	0.
4	3	4457.	0.	0.	0.	0.	0.	0.	0.
5	1	4457.	0.	0.	0.	0.	0.	0.	0.
5	2	4457.	0.	0.	0.	0.	0.	0.	0.
5	3	4457.	0.	0.	0.	0.	0.	0.	0.
6	1	4457.	0.	0.	0.	0.	0.	0.	0.
6	2	4449.	7.	1.	0.	0.	0.	0.	0.
6	3	4379.	66.	11.	0.	0.	0.	0.	0.
7	1	4043.	236.	168.	10.	0.	0.	0.	0.
7	2	2224.	976.	992.	250.	15.	0.	0.	0.
7	3	1247.	976.	1472.	621.	132.	7.	0.	0.
8	1	1138.	792.	1617.	732.	168.	10.	0.	0.
8	2	848.	363.	1892.	1040.	287.	28.	0.	0.
8	3	631.	363.	1523.	1328.	510.	103.	0.	0.
9	1	464.	312.	1155.	1617.	732.	178.	0.	0.
9	2	703.	363.	1646.	1232.	435.	78.	0.	0.
9	3	594.	363.	1462.	1376.	547.	115.	0.	0.
10	1	1247.	976.	1472.	621.	132.	7.	0.	0.
10	2	1931.	976.	1136.	361.	50.	2.	0.	0.
10	3	3944.	310.	191.	11.	0.	0.	0.	0.
11	1	4449.	7.	1.	0.	0.	0.	0.	0.
11	2	4457.	0.	0.	0.	0.	0.	0.	0.
11	3	4457.	0.	0.	0.	0.	0.	0.	0.
12	1	4457.	0.	0.	0.	0.	0.	0.	0.
12	2	4457.	0.	0.	0.	0.	0.	0.	0.
12	3	4457.	0.	0.	0.	0.	0.	0.	0.
1	1	4457.	0.	0.	0.	0.	0.	0.	0.
1	2	4457.	0.	0.	0.	0.	0.	0.	0.
1	3	4457.	0.	0.	0.	0.	0.	0.	0.
2	1	4457.	0.	0.	0.	0.	0.	0.	0.
2	2	4457.	0.	0.	0.	0.	0.	0.	0.
2	3	4457.	0.	0.	0.	0.	0.	0.	0.
3	1	4457.	0.	0.	0.	0.	0.	0.	0.
3	2	4457.	0.	0.	0.	0.	0.	0.	0.
3	3	4457.	0.	0.	0.	0.	0.	0.	0.

Note : all areas in hectares

TABLE B.4.3

Areas Flooded to Different Depths by Percentage for the Sub-Unit B.4
With Project Condition

Depth and Flood Phase analysis

Analysis for B4

NCA = 4457.00 (ha)

GCA = 8086.00 (ha)

Water levels based on 1:5 year levels

Area flooded in depth categories - Total Area

Depth categories (m)

Month	10 day	0.0-0.2	0.2-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.8	1.8-3.6	>3.6
4	1	100	0	0	0	0	0	0	0
4	2	100	0	0	0	0	0	0	0
4	3	100	0	0	0	0	0	0	0
5	1	100	0	0	0	0	0	0	0
5	2	100	0	0	0	0	0	0	0
5	3	100	0	0	0	0	0	0	0
6	1	100	0	0	0	0	0	0	0
6	2	100	0	0	0	0	0	0	0
6	3	98	1	0	0	0	0	0	0
7	1	91	5	4	0	0	0	0	0
7	2	50	22	22	6	0	0	0	0
7	3	28	22	33	14	3	0	0	0
8	1	26	18	36	16	4	0	0	0
8	2	19	8	42	23	6	1	0	0
8	3	14	8	34	30	11	2	0	0
9	1	10	7	26	36	16	4	0	0
9	2	16	8	37	28	10	2	0	0
9	3	13	8	33	31	12	3	0	0
10	1	28	22	33	14	3	0	0	0
10	2	43	22	25	8	1	0	0	0
10	3	88	7	4	0	0	0	0	0
11	1	100	0	0	0	0	0	0	0
11	2	100	0	0	0	0	0	0	0
11	3	100	0	0	0	0	0	0	0
12	1	100	0	0	0	0	0	0	0
12	2	100	0	0	0	0	0	0	0
12	3	100	0	0	0	0	0	0	0
1	1	100	0	0	0	0	0	0	0
1	2	100	0	0	0	0	0	0	0
1	3	100	0	0	0	0	0	0	0
2	1	100	0	0	0	0	0	0	0
2	2	100	0	0	0	0	0	0	0
2	3	100	0	0	0	0	0	0	0
3	1	100	0	0	0	0	0	0	0
3	2	100	0	0	0	0	0	0	0
3	3	100	0	0	0	0	0	0	0

Note : all figures in percent

TABLE B.4.4

Areas Flooded to Different Flood Phases for the Sub-Unit B.4 With Project Condition

Depth and Flood Phase analysis

Analysis for B4

NCA = 4457.00 (ha)

GCA = 8086.00 (ha)

Water levels based on 1:5 year levels

Area flooded in flood categories - Area

Month	10 day	F0	F1	F2	F3	F4
		Flood categories				
4	1	4457.	0.	0.	0.	0.
4	2	4457.	0.	0.	0.	0.
4	3	4457.	0.	0.	0.	0.
5	1	4457.	0.	0.	0.	0.
5	2	4457.	0.	0.	0.	0.
5	3	4457.	0.	0.	0.	0.
6	1	4457.	0.	0.	0.	0.
6	2	4456.	1.	0.	0.	0.
6	3	4446.	11.	0.	0.	0.
7	1	4280.	178.	0.	0.	0.
7	2	3200.	1257.	0.	0.	0.
7	3	2224.	2226.	7.	0.	0.
8	1	1931.	2517.	10.	0.	0.
8	2	1211.	3219.	28.	0.	0.
8	3	993.	3361.	103.	0.	0.
9	1	776.	3504.	178.	0.	0.
9	2	1066.	3314.	78.	0.	0.
9	3	957.	3385.	115.	0.	0.
10	1	2224.	2226.	7.	0.	0.
10	2	2907.	1548.	2.	0.	0.
10	3	4255.	203.	0.	0.	0.
11	1	4456.	1.	0.	0.	0.
11	2	4457.	0.	0.	0.	0.
11	3	4457.	0.	0.	0.	0.
12	1	4457.	0.	0.	0.	0.
12	2	4457.	0.	0.	0.	0.
12	3	4457.	0.	0.	0.	0.
1	1	4457.	0.	0.	0.	0.
1	2	4457.	0.	0.	0.	0.
1	3	4457.	0.	0.	0.	0.
2	1	4457.	0.	0.	0.	0.
2	2	4457.	0.	0.	0.	0.
2	3	4457.	0.	0.	0.	0.
3	1	4457.	0.	0.	0.	0.
3	2	4457.	0.	0.	0.	0.
3	3	4457.	0.	0.	0.	0.

Note : all areas in hectares

TABLE B.4.5

Areas Flooded to Different Flood Phases by Percentage for the Sub-Unit B.4
With Project Condition

Depth and Flood Phase analysis

Analysis for B4

NCA = 4457.00 (ha)

GCA = 8086.00 (ha)

Water levels based on 1:5 year levels

Area flooded in flood categories - Area

Month	10 day	F0	F1	F2	F3	F4
				Flood categories		
4	1	100	0	0	0	0
4	2	100	0	0	0	0
4	3	100	0	0	0	0
5	1	100	0	0	0	0
5	2	100	0	0	0	0
5	3	100	0	0	0	0
6	1	100	0	0	0	0
6	2	100	0	0	0	0
6	3	100	0	0	0	0
7	1	96	4	0	0	0
7	2	72	28	0	0	0
7	3	50	50	0	0	0
8	1	43	56	0	0	0
8	2	27	72	1	0	0
8	3	22	75	2	0	0
9	1	17	79	4	0	0
9	2	24	74	2	0	0
9	3	21	76	3	0	0
10	1	50	50	0	0	0
10	2	65	35	0	0	0
10	3	95	5	0	0	0
11	1	100	0	0	0	0
11	2	100	0	0	0	0
11	3	100	0	0	0	0
12	1	100	0	0	0	0
12	2	100	0	0	0	0
12	3	100	0	0	0	0
1	1	100	0	0	0	0
1	2	100	0	0	0	0
1	3	100	0	0	0	0
2	1	100	0	0	0	0
2	2	100	0	0	0	0
2	3	100	0	0	0	0
3	1	100	0	0	0	0
3	2	100	0	0	0	0
3	3	100	0	0	0	0

Note : all figures in percent

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TABLE B.4.6

Flood Phase by Percentage Similar to MPO for the Sub-unit B.4 With Project Condition.

Flood phase analysis

Analysis for B4

NCA = 4457.00 (ha)

GCA = 8086.00 (ha)

Water levels based on 1:5 year levels

Total F0 land	17.
Total F1 land	79.
Total F2 land	4.
Total F3 & F4 land	0.

(d) **Cropping Analysis**

Following agronomic principles water depth limitations can be defined for each stage of the growth cycle of a crop. This can be done for each crop of interest as illustrated in Figures B.4.3(a),(b) and (c).

Using the decad water levels together with the cropping water depth limitations, the lowest land level on which the crop can grow in each year can be determined. Having determined the lowest land level, the land area associated with that level can be determined by using the land-level database.

From the information on the lowest land level on which each crop can survive in each year water level statistics can be produced and the levels for various return periods established using the method described.The cultivable land for each crop at any required return period can be derived from the land-level database. An example output for the crops investigated during this feasibility study is given in Table B.4.7. This information can also be supplied as a percentage of the total area, Table B.4.8.

B.4.4.5 Fisheries/Environment

This section presents the form of analysis used to post-process the MIKE11 results for use by the fisheries / environmental discipline. The procedure utilised is as follows,

- a water level node in the MIKE11 model is assigned as being representative of the area.
- output of MIKE11 results as described in Section B.4.4.3.
- decad analysis of water levels
- statistical analysis of decad water levels
- calculation of decad flood phases with different return periods
- the land-level database is used to determine the area subject to each phase of flooding

Decad Analysis of Water Levels

For the purposes of the fisheries / environmental analysis the minimum over the decad was used to represent the decad. Hydrological analysis, as described in Section B.4.4.3, was carried out on the decad values to give minimum, mean and maximum values for each decad. In addition, return period decad values were calculated for 2, 5, 10, 20, 50 and 100 year return periods.

Figure B.4.3 (A)
Crop Water Depth Limitations

(Sheet 1 of 3)

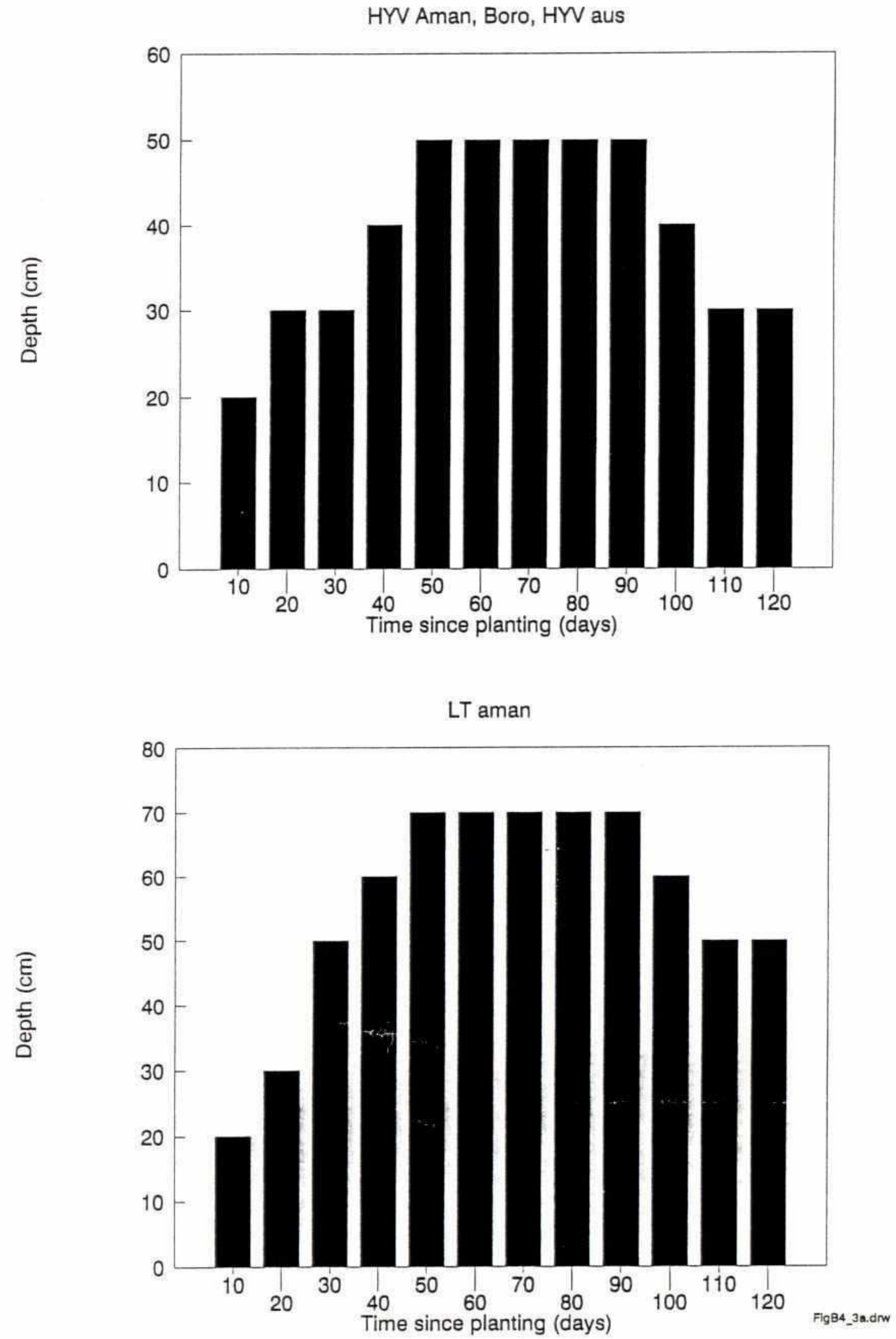
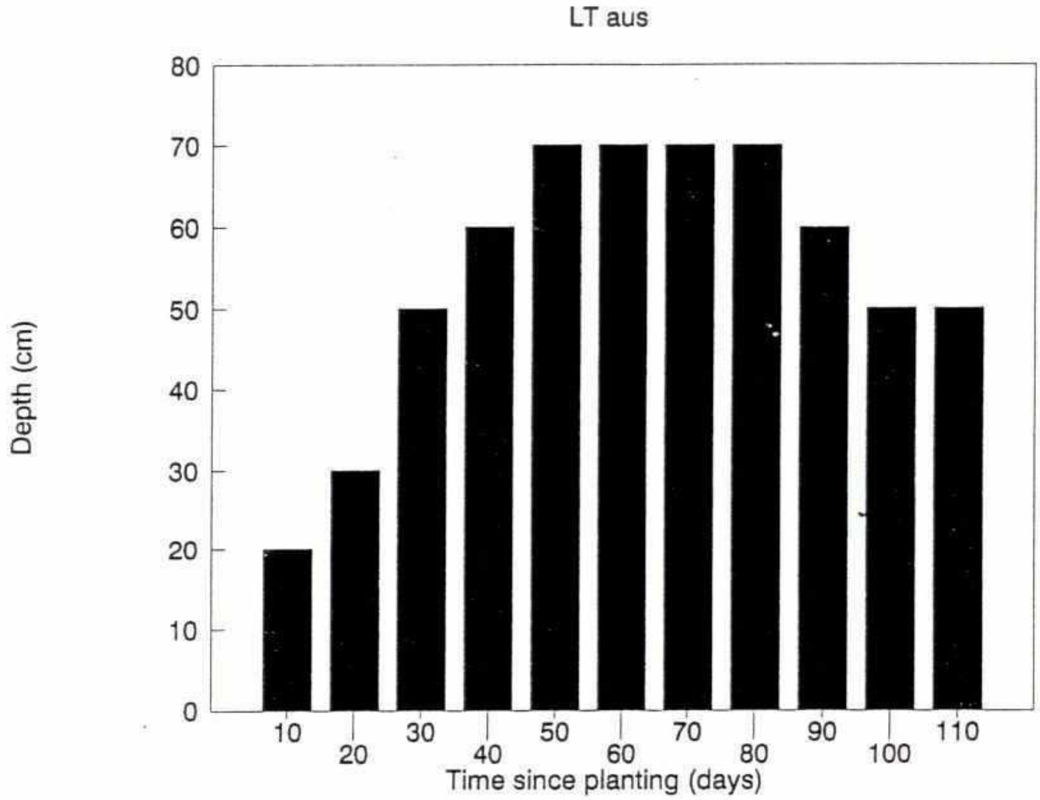


Figure B.4.3 (B)

(Sheet 2 of 3)

Crop Water Depth Limitations



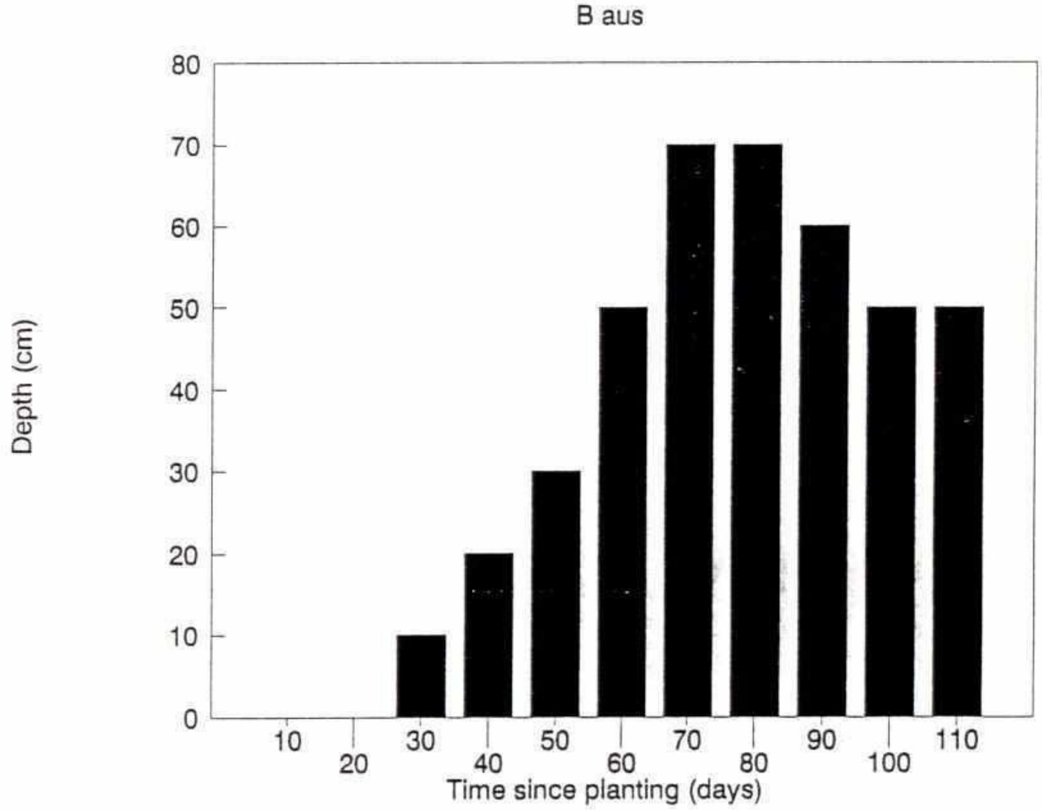


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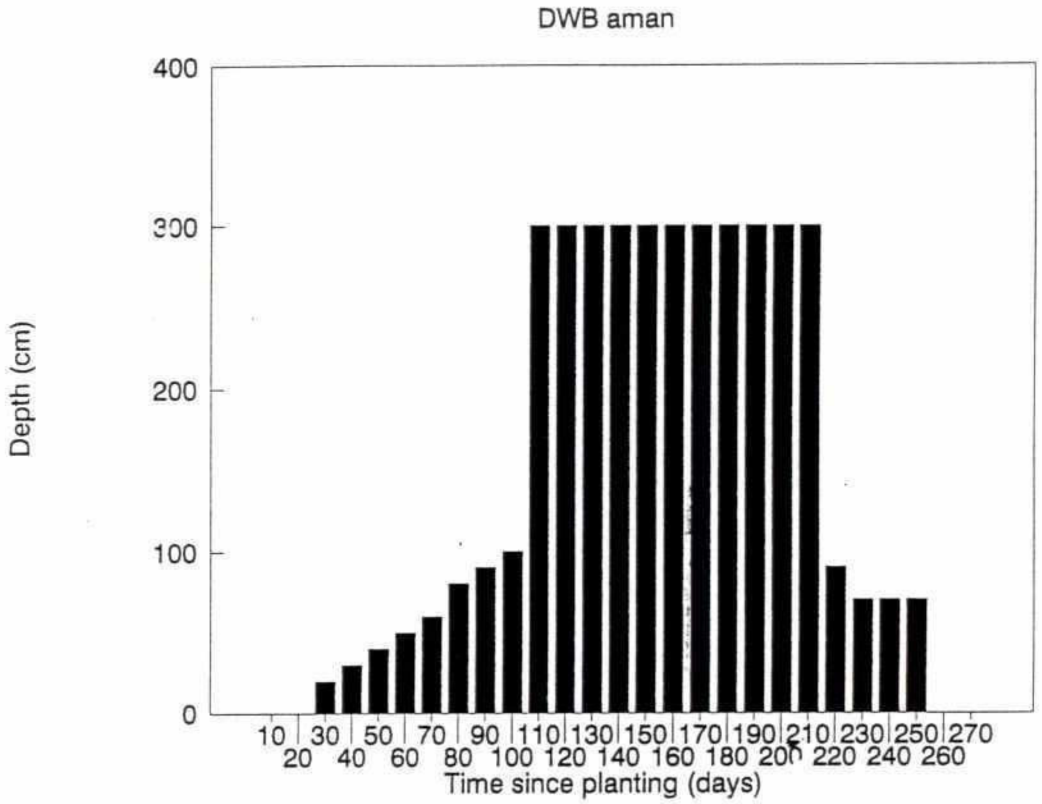
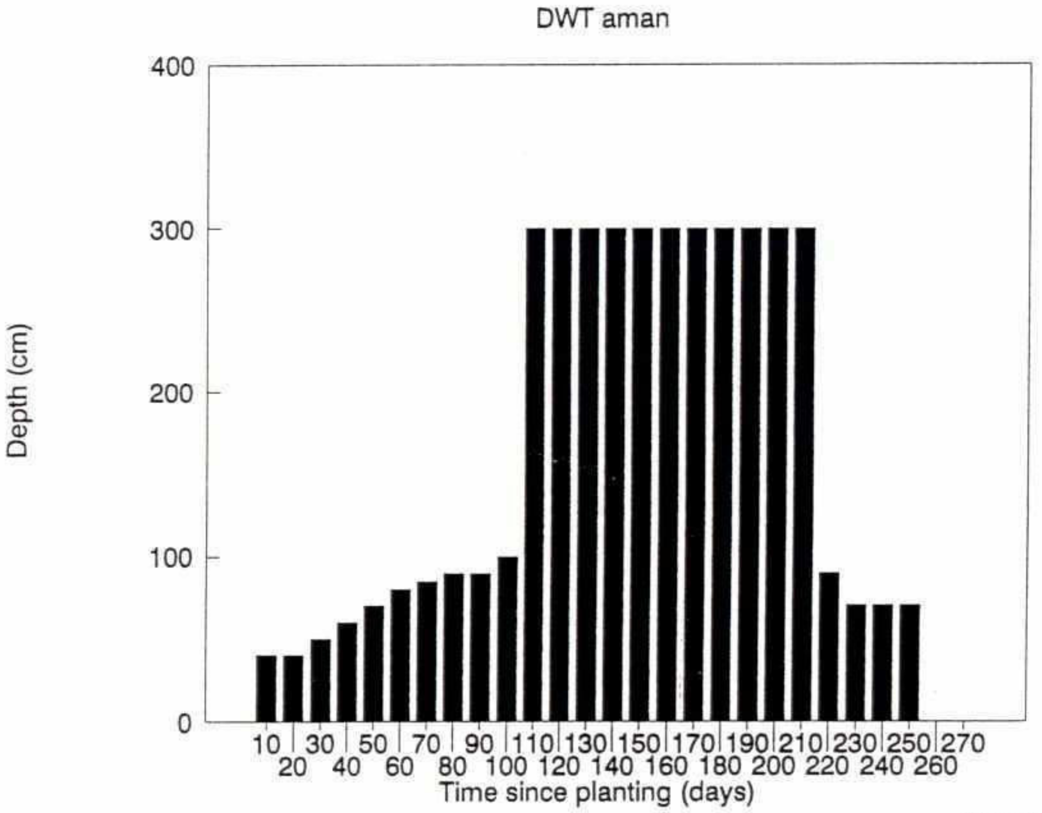
Figure B.4.3 (C)

(Sheet 3 of 3)

Crop Water Depth Limitations





figb4_3c.drw

TABLE B.4.7

Maximum Cultiviable Land Area(ha) on Which Different Crops Can be Grown for Different Return Period for Sub-unit B.4(with Project Condition).

Project area B4

NCA = 4457.00 (ha)
GCA= 8086.00 (ha)

Maximum land area (ha) on which crop can be safely grown

	Min .	Mean	Max.	Return Period (years) 2	3	4	5	8	10
HYV AMAN 1	4447.	1957.	70.	2780.	1233.	514.	415.	375.	288.
HYV AMAN 2	4447.	1938.	18.	2101.	1139.	812.	666.	435.	362.
HYV AMAN 3	4407.	2551.	66.	2282.	1222.	1141.	1071.	668.	554.
HYV AMAN 4	4417.	3273.	125.	3478.	1931.	1558.	1236.	942.	825.
BORO 1	4457.	4457.	4457.	4457.	4457.	4457.	4457.	4457.	4457.
BORO 2	4457.	4457.	4457.	4457.	4457.	4457.	4457.	4457.	4457.
BORO 3	4457.	4457.	4457.	4457.	4457.	4457.	4457.	4457.	4457.
BORO 4	4457.	4457.	3889.	4457.	4457.	4457.	4450.	4446.	4443.
HYV AUS 1	4457.	4457.	3359.	4454.	4322.	4297.	4278.	4218.	4164.
HYV AUS 2	4457.	4362.	1579.	4442.	3908.	3278.	3069.	2895.	2554.
HYV AUS 3	4457.	4052.	299.	4252.	3298.	2221.	2143.	1585.	1224.
HYV AUS 4	4457.	3494.	66.	3284.	2094.	1978.	1909.	1006.	868.
HYV AUS 5	4447.	3279.	66.	3146.	1973.	1686.	1236.	868.	736.
LT AUS 1	4457.	4457.	4246.	4457.	4457.	4457.	4452.	4451.	4448.
LT AUS 2	4457.	4457.	4232.	4457.	4450.	4448.	4447.	4444.	4435.
LT AUS 3	4457.	4452.	3369.	4457.	4370.	4212.	4125.	4037.	3864.
LT AUS 4	4457.	4407.	826.	4446.	4217.	3695.	3655.	3372.	3137.
LT AUS 5	4457.	4266.	291.	4213.	3630.	3571.	3536.	2551.	2178.
LT AMAN 1	4452.	3642.	393.	3875.	2806.	1573.	1176.	984.	839.
LT AMAN 2	4447.	3126.	258.	3775.	2379.	1172.	453.	604.	466.
LT AMAN 3	4457.	2059.	70.	2780.	1236.	677.	415.	384.	298.
LT AMAN 4	4383.	2579.	16.	2287.	1176.	1142.	1088.	631.	507.
LT AMAN 5	4450.	3586.	291.	3567.	2378.	2142.	1499.	1149.	1031.
LT AMAN 6	4457.	4005.	483.	3919.	3074.	2606.	2477.	1791.	1513.
B AUS 1	4457.	4457.	4366.	4457.	4457.	4457.	4457.	4457.	4457.
B AUS 2	4457.	4457.	4246.	4457.	4457.	4457.	4452.	4451.	4448.
B AUS 3	4457.	4457.	4232.	4457.	4450.	4448.	4447.	4444.	4435.
B AUS 4	4457.	4452.	3369.	4457.	4370.	4212.	4125.	4037.	3864.
B AUS 5	4457.	4457.	4246.	4457.	4457.	4457.	4452.	4451.	4448.
DWB AMAN 1	4457.	4457.	4233.	4457.	4451.	4391.	4369.	4376.	4340.
DWB AMAN 2	4457.	4457.	4233.	4457.	4451.	4391.	4369.	4376.	4340.
DWB AMAN 3	4457.	4457.	4233.	4457.	4451.	4391.	4369.	4376.	4341.
DWT AMAN 4	4457.	4457.	4233.	4457.	4451.	4391.	4369.	4376.	4341.
DWT AMAN 5	4457.	4457.	4233.	4456.	4451.	4391.	4369.	4372.	4341.
DWT AMAN 6	4457.	4455.	4113.	4451.	4446.	4371.	4369.	4335.	4306.

TABLE B.4.8

Percentage of Net Cultivable Area (NCA) on Which Different Crops Can be Grown for Different Return Period for Sub-unit B.4 (with Project Condition)

Project area B4
NCA = 4457.00 (ha)
GCA= 8086.00 (ha)

Percentage of NCA on which crop can be safely grown

	Min.	Mean	Max.	Return Period (years) 2	3	4	5	8	10
HYV AMAN 1	100.	44.	2.	62.	28.	12.	9.	8.	6.
HYV AMAN 2	100.	43.	0.	47.	26.	18.	15.	10.	8.
HYV AMAN 3	99.	57.	1.	51.	27.	26.	24.	15.	12.
HYV AMAN 4	99.	73.	3.	78.	43.	35.	28.	21.	19.
BORO 1	100.	100.	100.	100.	100.	100.	100.	100.	100.
BORO 2	100.	100.	100.	100.	100.	100.	100.	100.	100.
BORO 3	100.	100.	100.	100.	100.	100.	100.	100.	100.
BORO 4	100.	100.	87.	100.	100.	100.	100.	100.	100.
HYV AUS 1	100.	100.	75.	100.	97.	96.	96.	95.	93.
HYV AUS 2	100.	98.	35.	100.	88.	74.	69.	65.	57.
HYV AUS 3	100.	91.	7.	95.	74.	50.	48.	36.	27.
HYV AUS 4	100.	78.	1.	74.	47.	44.	43.	23.	19.
HYV AUS 5	100.	74.	1.	71.	44.	38.	28.	19.	17.
LT AUS 1	100.	100.	95.	100.	100.	100.	100.	100.	100.
LT AUS 2	100.	100.	95.	100.	100.	100.	100.	100.	100.
LT AUS 3	100.	100.	76.	100.	98.	94.	93.	91.	87.
LT AUS 4	100.	99.	19.	100.	95.	83.	82.	76.	70.
LT AUS 5	100.	96.	7.	95.	81.	80.	79.	57.	49.
LT AMAN 1	100.	82.	9.	87.	63.	35.	26.	22.	19.
LT AMAN 2	100.	70.	6.	85.	53.	26.	10.	14.	10.
LT AMAN 3	100.	46.	2.	62.	28.	15.	9.	9.	7.
LT AMAN 4	98.	58.	0.	51.	26.	26.	24.	14.	11.
LT AMAN 5	100.	80.	7.	80.	53.	48.	34.	26.	23.
LT AMAN 6	100.	90.	11.	88.	69.	58.	56.	40.	34.
B AUS 1	100.	100.	98.	100.	100.	100.	100.	100.	100.
B AUS 2	100.	100.	95.	100.	100.	100.	100.	100.	100.
B AUS 3	100.	100.	95.	100.	100.	100.	100.	100.	100.
B AUS 4	100.	100.	76.	100.	98.	94.	93.	91.	87.
B AUS 5	100.	100.	95.	100.	100.	100.	100.	100.	100.
DWB AMAN 1	100.	100.	95.	100.	100.	99.	98.	98.	97.
DWB AMAN 2	100.	100.	95.	100.	100.	99.	98.	98.	97.
DWB AMAN 3	100.	100.	95.	100.	100.	99.	98.	98.	97.
DWT AMAN 4	100.	100.	95.	100.	100.	99.	98.	98.	97.
DWT AMAN 5	100.	100.	95.	100.	100.	99.	98.	98.	97.
DWT AMAN 6	100.	100.	92.	100.	100.	98.	98.	97.	97.

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Calculation of Flood Phases

Flood phases for the decad water levels with different return periods were calculated using the procedure outlined in Section B.4.3.2.

For the purposes of the analysis the areas in flood phases F1, F2, F3 and F4 are potentially suitable for fisheries. Results were presented by giving the amount of F0 land and the amount of land greater than F0, see Table B.9. This information can also be supplied as a percentage of the total area, Table B.4.10.

Mapping for Fisheries Analysis

For fisheries analysis the land areas flooded to depths greater than 30 cm need to be mapped. This was done for different return period water levels and different decads by considering the representative water level in the model and the variation in topographic level. Figure B.4.4 is an example of a map produced for the fisheries analysis.

Figure B.4.4
Differential Flood Modelling by Decad (3rd Decad in September)

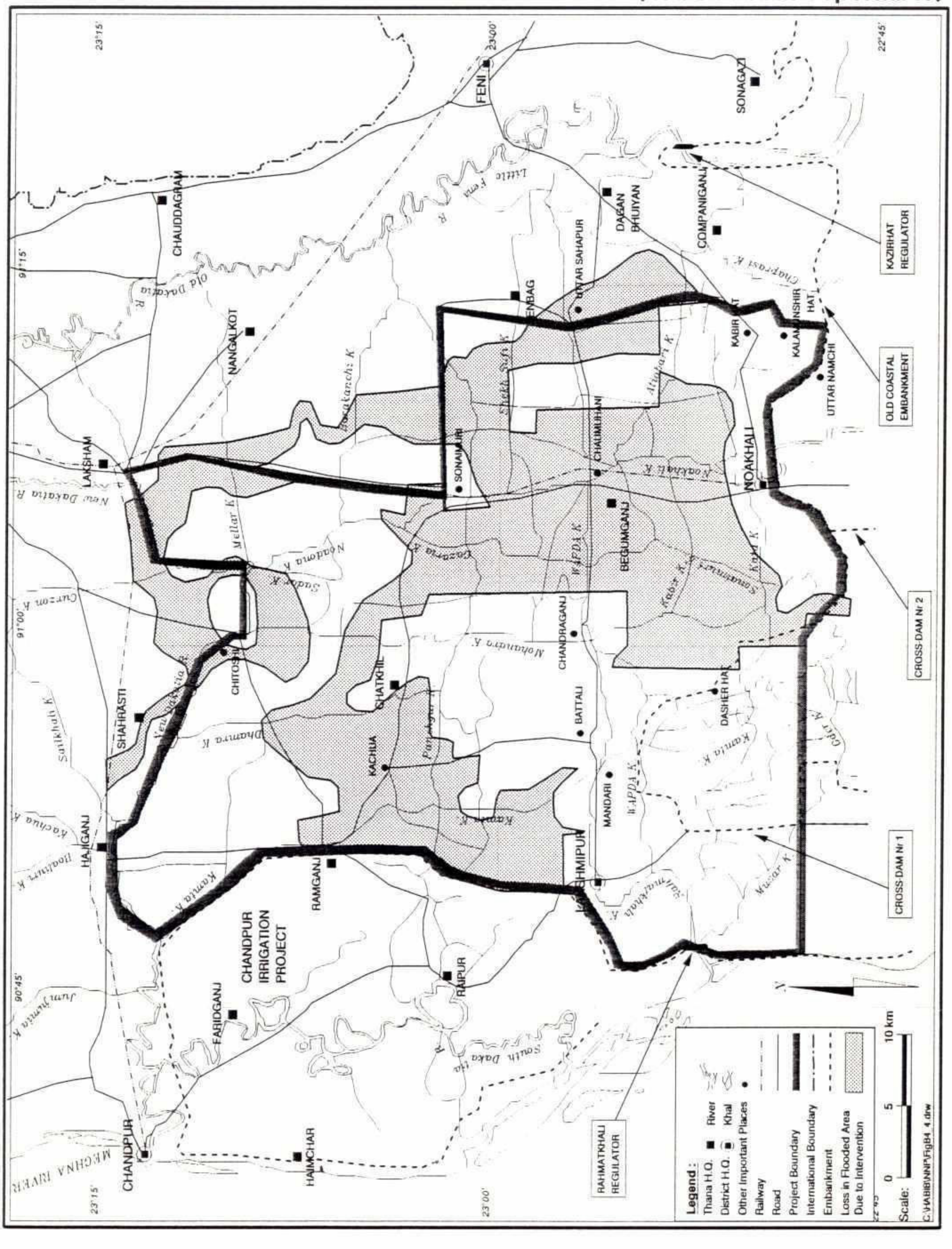

TABLE B.4.9

Flood Phase Analysis by Area for Fisheries Purpose for Sub Unit B.4 (With Project Condition)

Flood Phase analysis

Analysis for B4

NCA = 4457.00 (ha)

GCA = 8086.00 (ha)

Water levels based on 1:2 year levels

Area flooded in flood categories - Area
Flood categories

Month	10 day	F0	>F0
4	1	4457.	0.
4	2	4457.	0.
4	3	4457.	0.
5	1	4457.	0.
5	2	4457.	0.
5	3	4457.	0.
6	1	4457.	0.
6	2	4457.	0.
6	3	4457.	0.
7	1	4457.	0.
7	2	4451.	6.
7	3	4444.	13.
8	1	4093.	364.
8	2	3646.	811.
8	3	3696.	761.
9	1	3795.	662.
9	2	4230.	228.
9	3	4329.	128.
10	1	4445.	12.
10	2	4457.	0.
10	3	4457.	0.
11	1	4457.	0.
11	2	4457.	0.
11	3	4457.	0.
12	1	4457.	0.
12	2	4457.	0.
12	3	4457.	0.
1	1	4457.	0.
1	2	4457.	0.
1	3	4457.	0.
2	1	4457.	0.
2	2	4457.	0.
2	3	4457.	0.
3	1	4457.	0.
3	2	4457.	0.
3	3	4457.	0.

Note : all areas in hectares

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TABLE B.4.10

Flood Phase Analysis by Percentage of Area for Fisheries Purpose for Sub Unit B.4 (With Project Condition)

Flood Phase analysis

Analysis for B4

NCA = 4457.00 (ha)

GCA = 8086.00 (ha)

Water levels based on 1:2 year levels

Area flooded in flood categories - Area
Flood categories

Month	10 day	F0	>F0
4	1	100	0
4	2	100	0
4	3	100	0
5	1	100	0
5	2	100	0
5	3	100	0
6	1	100	0
6	2	100	0
6	3	100	0
7	1	100	0
7	2	100	0
7	3	100	0
8	1	92	8
8	2	82	18
8	3	83	17
9	1	85	15
9	2	95	5
9	3	97	3
10	1	100	0
10	2	100	0
10	3	100	0
11	1	100	0
11	2	100	0
11	3	100	0
12	1	100	0
12	2	100	0
12	3	100	0
1	1	100	0
1	2	100	0
1	3	100	0
2	1	100	0
2	2	100	0
2	3	100	0
3	1	100	0
3	2	100	0
3	3	100	0

Note : all figures in percent

CHAPTER B.5

DEVELOPMENT AND CALIBRATION OF NOAKHALI MODEL

B.5.1 Introduction

This Chapter covers the development and calibration of the Noakhali North hydraulic model. The modelled area is bounded to the south by the old coastal embankment, to the west by the existing Chandpur irrigation project, to the north by the Comilla to Daudkhandi road and to the east by the slight ridge bordering the Little Feni river basin. The initial development and calibration of the model was carried out by the SWMC as part of their work on the South East Regional Model (Ref. 5.1); further development and a calibration check was undertaken by the Noakhali North modelling team.

The modelled area is shown in Figure B.5.1. Hydraulic conditions in the modelled area are dominated by the Meghna river. In the east most of the rivers coming from India are flashy in nature. With the exception of the Dakatia and Little Feni the rivers in the modelled area do not generate any significant discharge during the dry period.

The model was originally calibrated for the period from the monsoon 1986 to December 1987; calibration was against both wet and dry season conditions. Subsequently the calibration period was extended to the end of the 1988 monsoon season. The model was verified for the period January 1990 to March 1991.

B.5.2 Data Sources

The Bangladesh Water Development Board (BWDB) maintains a countrywide data collection network. In order to calibrate the hydrodynamic model a more uniform and denser distribution of collection stations was established by the SWMC.

B.5.2.1 Topographic

Cross section surveys were carried out on behalf of the SWMC during 1986; a large number of these were remeasured during 1987. Important cross-sections were updated further during 1988, 1990 and 1991.

The flood plain levels were obtained from the MPO square kilometre grid. During the river survey spot levels were taken on the flood plain adjacent to the rivers to ensure continuity of datums between the river sections and the flood plain levels.

Cross-sectional surveys have also been carried out by the Noakhali study team during the 1992/3 dry season. These supplement the surveys carried out by the SWMC but also duplicate them along reaches such as the Rahmatkhali and Wapda khals and can be used for comparison purposes.

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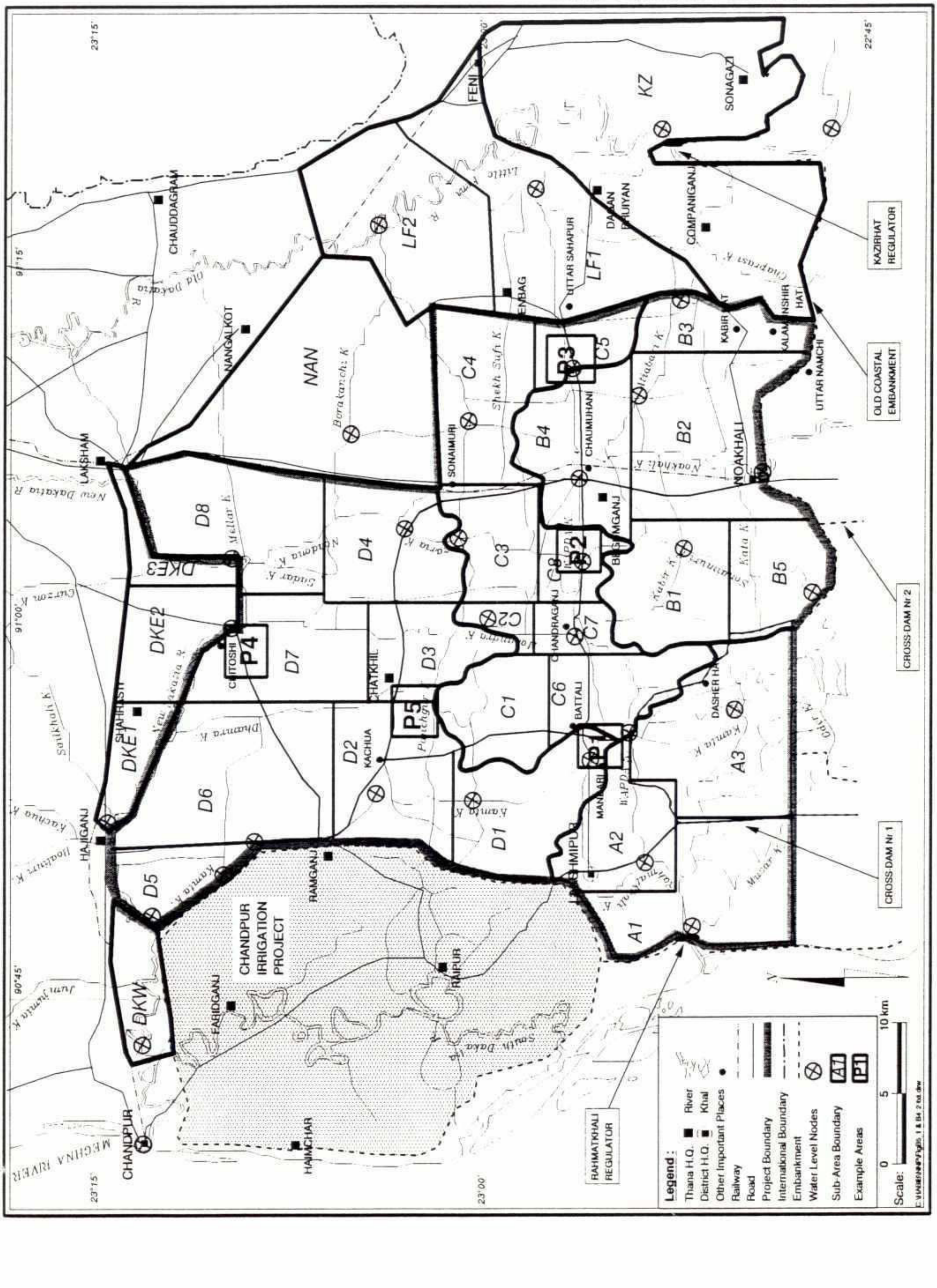
Figure B.5.1

Hydrodynamic Model Sub-Areas



B.5.2.2 Hydrometric

Water level gauging stations were established by the SWMC during 1986, 1987, 1988 and 1990 to augment the BWDB monitoring stations. The water level collection programme was predominantly during the monsoon season. The number of water level monitoring points was reduced by eliminating locations where water level fluctuations were small or the channels were frequently dry.

Most of the water level stations record 3 hourly readings but at some locations tidal records are maintained. At these locations 2 hourly records are maintained together with the recording of daily HW and LW levels.

B.5.3 Model Set-Up

B.5.3.1 Channel and Flood Plain Network

To select the channels for the model several criteria were applied,

- the importance of the channel in terms of drainage
- the possibility that the channel serves as an important route for flood water from outside the area
- the importance of channels in relation to nearby channels
- the importance of the channels in future developments

The schematisation was based on topographic maps with reference to aerial photographs and satellite images to give more up to date information.

Flood plain geometry is attached to the river cross-sections to represent overland flow and storage available at high flood levels. The boundaries of the flood plain cells are selected on the basis of the flow direction in the flood plain determined from land contours and the orientation of road, rail and flood defence embankments. The resistance to flow on the flood plain is higher than that of the river owing to the irregular surface and vegetation.

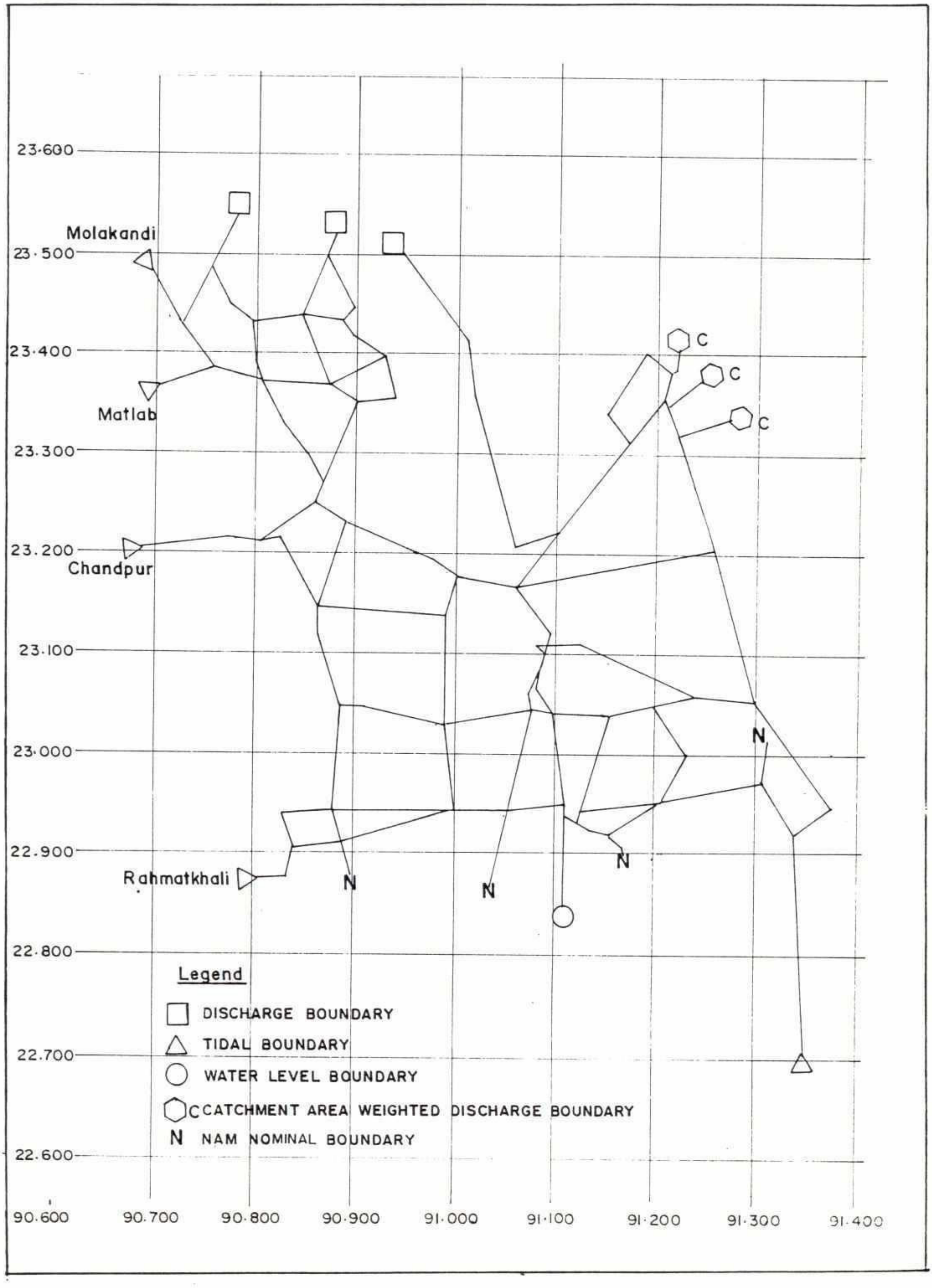
The scheme plan of the Noakhali North model is shown in Figure B.5.2. While the basic information is one dimensional, the construction of a dense network based on the rivers and khals of the region introduces a quasi two dimensional aspect to the model. This allows the simulation of the one dimensional dry season flow and the more two dimensional monsoon season flow.

B.5.3.2 NAM Connection

The hydrodynamic model includes the NAM generated runoff in terms of discharge from the NAM catchments in its computations. The runoff is distributed among a particular reach or reaches of the river system, or throughout the entire river system within the catchment area.

Figure B.5.2

Schematic Boundary Location of Noakhali Sub-Model



B.5.3.3 Flows from Ungauged Catchments

The 25 year baseline simulation requires an estimate of the inflows from the catchments in the Tripura Hills in India. Flows entering from the east were required at three boundary locations; Chowara, Shuagari and Miarbazar.

Two options are available for estimating these flows,

1. NAM -the NAM rainfall-runoff model generates the hydrological response based on the catchment characteristics. Assumptions are necessary in developing NAM for the catchments concerned given the paucity of data available from the Indian side of the border. Some preliminary estimates of inflow using NAM showed a less flashy response than would be expected. Experiences on the North West Regional Study (FAP2) indicated that large margins of uncertainty are possible when NAM is applied with insufficient calibration data. Theoretically adjustment of the shape of the response of the smaller catchments could be based on physical characteristics of the drainage basins but there is insufficient information readily available to do this.

2. Catchment area weighting - A complete 25 year discharge record exists at Comilla on the Gumti which also drains from the Tripura Hills. Flows from the other catchments can be estimated by catchment area weighting of these flows. Some criticism of this method may be justified in that it assumes that the rainfall, percentage runoff and time of concentration for each of the catchments is effectively the same.

The uncertainties introduced by using catchment area weighting are, in our view, no greater than that introduced by the assumptions necessary in developing NAM hydrological response models for the catchments concerned given the paucity of data available from the Indian side of the border. The catchment area ratios used for the eastern tributaries to the Noakhali North project area are given in Table B.5.1.

TABLE B.5.1

Catchment Area Ratios

Catchment	Area (km^2)	Ratio to Comilla
Gumti	2173	1.000
Chowara	64	0.030
Shuagari	56	0.026
Miarbazar	76	0.035

Two model simulations were carried out to investigate the different treatment of the inflow from the Tripura Hills in India. In one this is estimated using NAM and in the other it is computed on a catchment area basis from the recorded flows for the Gumti at Comilla. These simulations indicated that catchment area weighting method gave a much more flashy response than the use of NAM; this is what is expected.

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B.5.3.4 Model Boundaries

The River Meghna forms an important boundary condition for the Noakhali model. Four water level boundaries on the western side of the model are dictated by levels in the Meghna; Matlab, Molakandi, Chandpur and Rahmatkhali. In the south, the Little Feni outfalls to an area dominated by tidal fluctuations and the tidal recording station at Sandwip was used as a basis for this boundary. Again in the south, Noakhali khal used to be a major drainage route but this has now become severely restricted due to siltation and tidal influence at the outfall is minimal.

In the north, across the Daudkandi-Comilla highway, discharge boundaries were taken from model runs of the Gumti II model. To the west, however, rainfall-runoff was used (NAM) to estimate the flows entering the Little Feni from the Tripura hills.

The generation of tidal boundaries was discussed in Chapter B.3.

B.5.3.5 Structures

There are a number of bridges and structures in the Noakhali North area. During the 1986 data collection period water level gauges were installed upstream and downstream of major bridges over the schematised channels. At the majority of these the observed head losses were negligible and the structures were omitted.

The exceptions to this are two structures on the upper reaches of the Dakatia and the Rahmatkhali and Kazirhat regulators. These two regulators are of great importance since they control outflow from the Noakhali North area.

B.5.4 SWMC Calibration and Verification

The model was originally calibrated for the period from the monsoon 1986 to December 1987; calibration was against both wet and dry season conditions. Subsequently the calibration period was extended to the end of the 1988 monsoon season.

The detailed results of the model calibration are presented in the SWMC South East Regional Model Verification Report (Ref. 5.1). In general the monsoon season calibration of the model is good both in terms of water levels and, at the few locations where data is available, in terms of discharges. Most minor channels dry up during the dry period and numerous temporary cross dams are built in the medium channels to lift water by low lift pumps for irrigation. The calibration for the dry season is difficult to ascertain. The model can become unstable during a sudden shift from a dry to wet condition. This can only be overcome by running the model for short time steps for these short transition periods.

The model was verified for the period January 1990 to March 1991. The model shows a good comparison with the observations at most of the calibration points. The results of the verification are presented in the SWMC report.

Much of the initial work by the SWMC was based on non-tidal conditions. Recently, however, the SWMC have been working on the tidal calibration of the model.

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B.5.5 Modifications to the SWMC Model

B.5.5.1 Meghna tidal Boundaries

It is understood that the SWMC used Chitalkhali with a positive datum shift of 0.15m as a basis for their tidal boundary condition at Rahmatkhali. Based on the General Model (GM) mean daily results along the Meghna, and the water surface slopes, this underestimates peak levels along the Meghna by about 45cm. This is likely to have a significant influence on the potential discharge through Rahmatkhali regulator and hence the internal calibration of the modelled area.

Chandpur was included in the SWMC model as a mean daily level, based on GM results, as were Molakandi and Matlab. In the Noakhali model all three boundaries were represented as full tidal boundaries.

In the 25 year simulations of the GM, problems in calibrating the Lower Meghna reach were encountered by the FAP 25 team. A vertical shift of 25cm at the downstream boundary of the Meghna, Daulat Khan, was introduced and led to a much improved calibration in this reach.

The GM model simulation of the Lower Meghna assumed the length of the Lower Meghna to be 85km from its confluence with the Upper Meghna to its downstream boundary at Daulat Khan. River chainage measurements made by the study team indicated that this reach of the Lower Meghna should in fact be 90km.

This is likely to be the reason that problems were encountered in calibrating the General Model and why a shift of 25cm in the downstream boundary was required. Assuming the river slope is in the order of 2-3cm/km the additional 5km of river reach would account for 10-15cm of the shift made by the SWMC. However, the SOB have also acknowledged that a datum error existed in the bench mark used at Daulat Khan of about 12cm. Together these lead to an overall shift of some 22-27cm correction which is of the same order of magnitude as that required to improve the General Model calibration, see Figure B.5.3.

Mean daily data for the generation of tidal boundaries along the Meghna was taken from the GM results (Run6/2) but with the locations of the boundaries adjusted so that they concurred with the correct chainage of their relative positions.

Based on the mean daily water levels from the General Model, tidal boundaries were generated at four boundary location; Molakandi, Matlab, Chandpur and Rahmatkhali. An additional tidal boundary at the outfall of the Little Feni was based on analysis of tidal records at Sandwip.

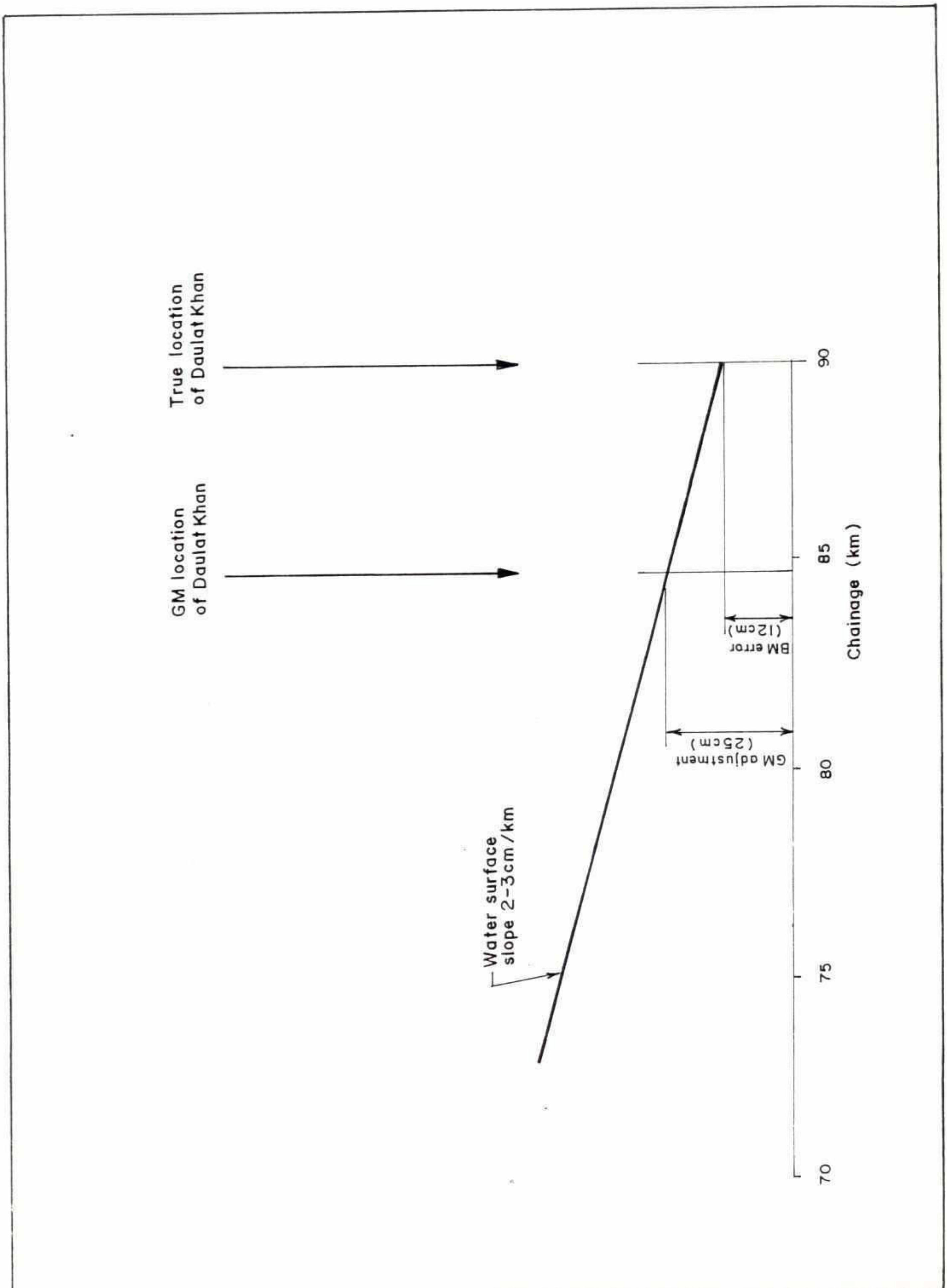
B.5.5.2 Channel Roughness

Channel roughness values were taken from the SWMC calibration runs. In general these vary between Mannings' **n** values of 0.025-0.033.

Some of the Manning's n values associated with the lower regions of the Wapda and Rahmatkhali khals may be slightly high. Investigation of these reaches suggests that the channel lengths used in the SWMC model under-estimate the actual channel lengths and that the roughness coefficient may have needed to be raised to compensate for this fact. However, no changes to the channel reach lengths were made for the Noakhali model studies but these should be verified and adjusted during any further model development.

Figure B.5.3

Justification of Daulat Khan Datum Correction



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B.5.5.3 Rahmatkhali Regulator

Problems in the representation of control structures by making use of culvert routines in the Mike 11 system were experienced at both Rahmatkhali and Kazirhat.

Initially, Rahmatkhali was represented as a culvert opening with the valve operation set to give positive flow only, ie tide flapped. This gave a very peaky discharge response through the structure with high peak discharges not necessarily coinciding with the largest driving heads across the structure.

Desk calculations carried out as check indicated that the discharges generated using the undershot gate (control structure) representation in Mike 11 gave much closer agreement. The undershot gate representation also allowed the failure of one or more of the tide flaps, which occurs annually in the prototype, to be included in the representation of the present conditions.

It was interesting to note that the volumes of water discharged through the structure in trial runs for both the culvert and undershot gate representation were very similar over the monsoon period. This would therefore mask the effect of using a culvert representation of the structure in the model as drainage rates and water levels further upstream would remain very similar.

B.5.5.4 Kazirhat Regulator

As with Rahmatkhali, Kazirhat regulator has been replaced by a control structure (undershot gate) as the peak discharges through the structure were over-estimated, double those expected, when using the culvert representation. The culvert representation was also found to be unsatisfactory because it gave negative discharges despite having a flap gate (ie valving set to positive flow only) and caused unrealistic water level spikes to be generated on the upstream face.

The headloss through the barrel of the culvert at Kazirhat is relatively small compared with the entry and exit losses, accounting for only 20% of the total losses, and could therefore be neglected in the simulations without significantly influencing the model results.

B.5.5.5 Kazirhat Blockage/Siltation

At Kazirhat regulator the pre-monsoon flows are restricted due to siltation on its downstream side. The siltation is eroded gradually during May and June before full discharge capacity is reached in July. This pre-monsoon blockage due to siltation was represented as a moveable weir in the Noakhali model. The crest level was reduced during the pre-monsoon period, to represent erosion of the blockage, before being finally lowered to the channel bed level.

B.5.5.6 Channel Downstream of Piarapur

During initial runs of the Noakhali model it was found that levels at Piarapur, and further upstream, were overestimated by about 0.5m despite a reasonable match being attained at the upstream face of Rahmatkhali regulator.

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The SWMC channel cross-sections between Rahmatkhali and Piarapur were compared with those from the recent FAP5 field survey. It was found that the SWMC sections and conveyances were much smaller than those indicated by the FAP 5 survey. Introducing the new sections in to the model greatly enhanced the model results and lead to a much closer correlation between modelled and observed levels in the reach from Piarapur to Begumganj.

B.5.5.7 Flows from the Gumti Area

Discharge boundaries in the northern half of the Noakhali model, immediately south of the Daudkandi-Comilla highway, were based on flows generated from the Gumti II model.

B.5.6 Calibration/Verification of the Noakhali Model

B.5.6.1 General

The modifications outlined in Section B.5.5 were incorporated in to the Noakhali model and run for the 1991 monsoon season. This was effectively a verification run, to ensure that the changes incorporated in to the model gave a good match between observed and modelled water levels.

The results of this run, see below, suggested that no further recalibration of the model was necessary.

B.5.6.2 Water Levels

Some comparisons between observations and model results for 1991 are shown in Figures B.5.4 to B.5.11.

Rahmatkhali and Begumganj Depression

Modelled and observed levels upstream and downstream of the regulator site show a only reasonable agreement. Unfortunately, there is only a short observed record at both sites and a full comparison throughout the monsoon season cannot be made. However, a good agreement is found at Piarapur and this suggests that the model representation of the structure and its operation approximate to that in the prototype.

Further upstream, at Chandraganj and Begumganj, a good match is found between observed and modelled results. This is also true at Noakhali where the water levels are seen to be very similar to those at Begumganj and display no obvious tidal influence.

It is interesting to note that many of the water level observations, under the influence of Rahmatkhali regulator, display an early peak at the beginning of the monsoon period; for example, Piarapur, Chandraganj and Begumganj. This response is not observed in the modelled results and this was during the period when the regulator was being mended following damage from the 1991 cyclone. During this period some of the regulator gates would have remained closed and prevented drainage from the area thereby resulting in a ponding of water upstream. Following the repair works, drainage would once again be possible and levels brought to their normal monsoon levels. The model has assumed the regulator functions throughout the entire monsoon season and is not therefore expected to predict such features.

Figure B.5.4
Observed and Modelled Water Levels
at Rahmatkhali Regulator U/S.

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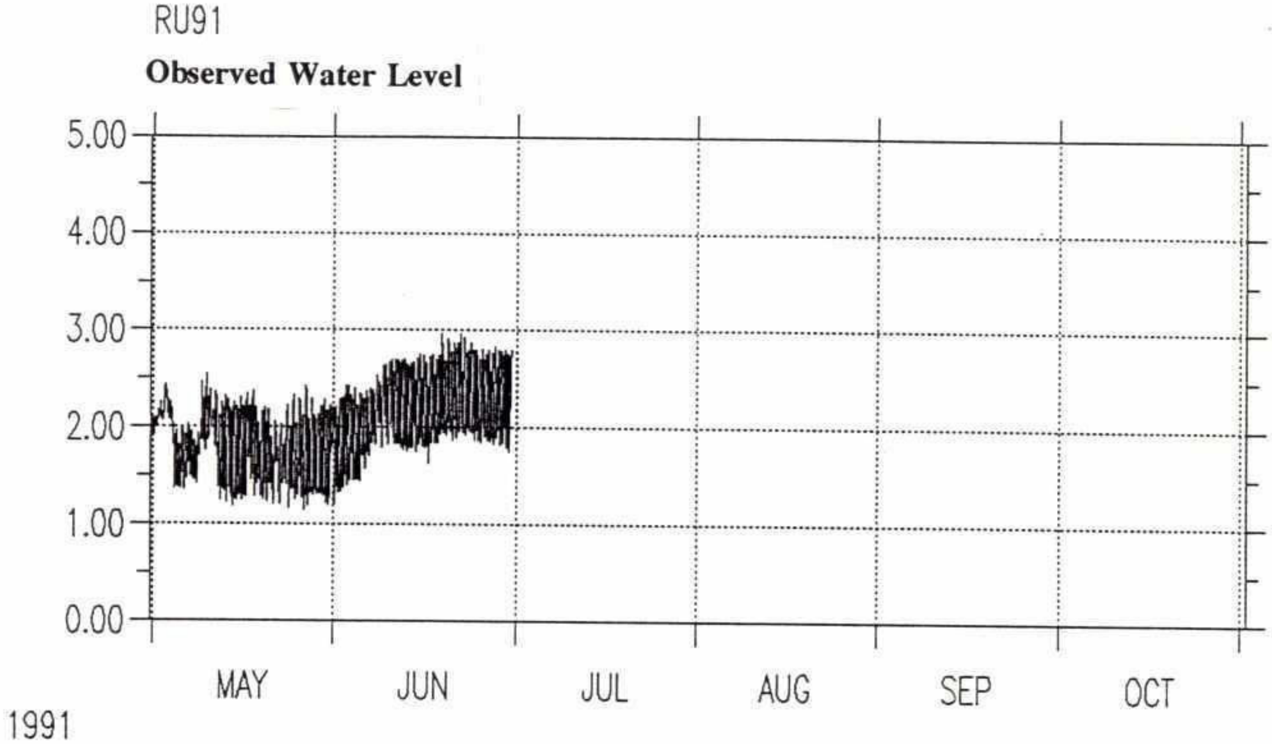


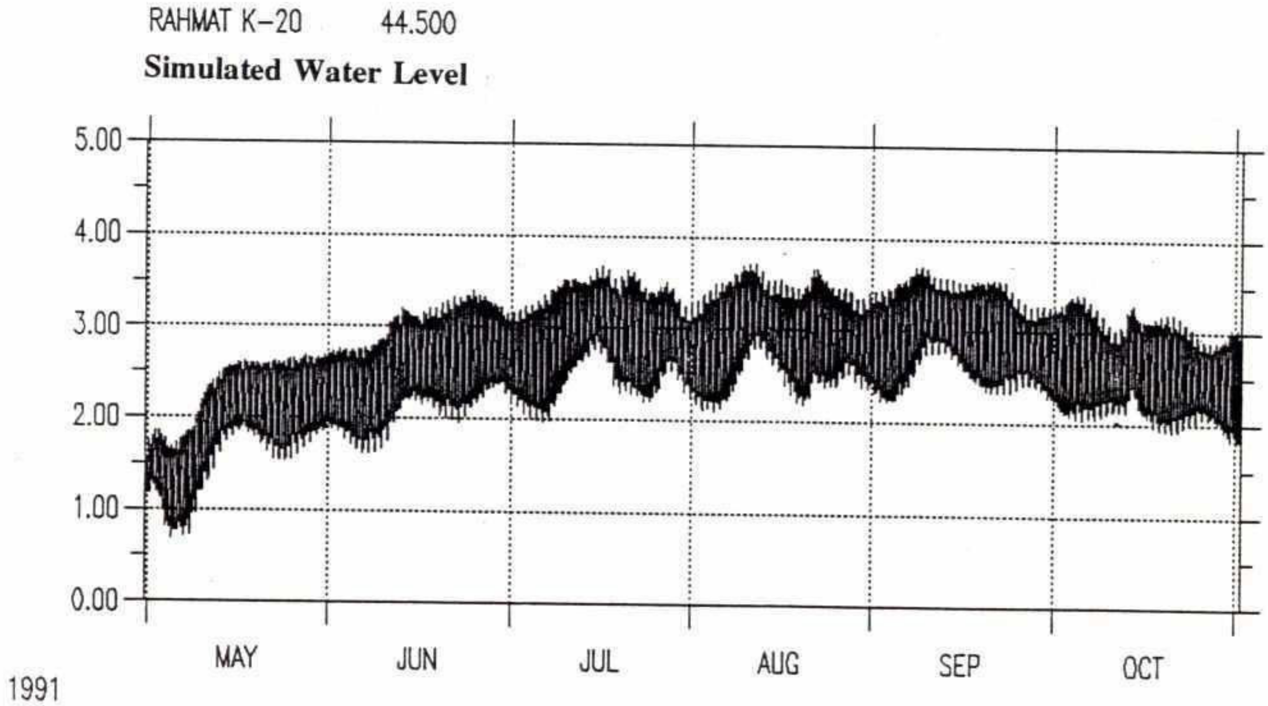
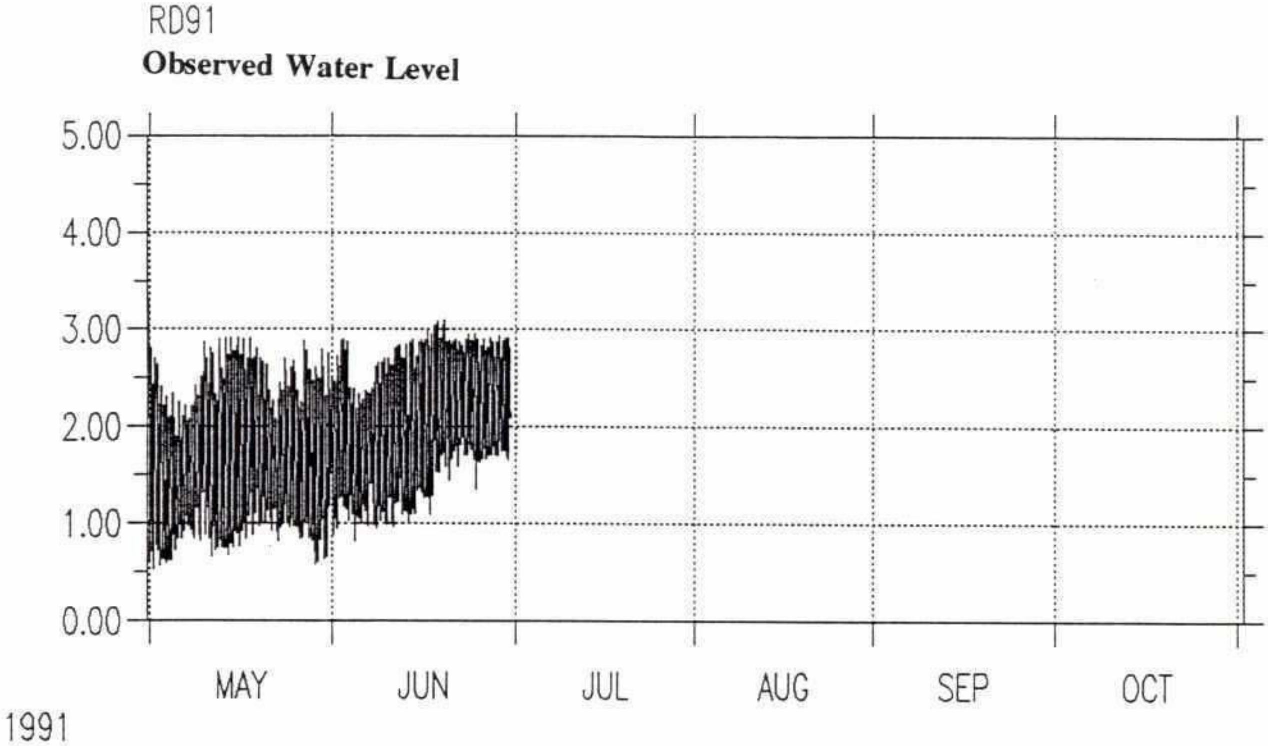


Figure B.5.5
Observed and Modelled Water Levels at Rahmatkhali Regulator D/S.



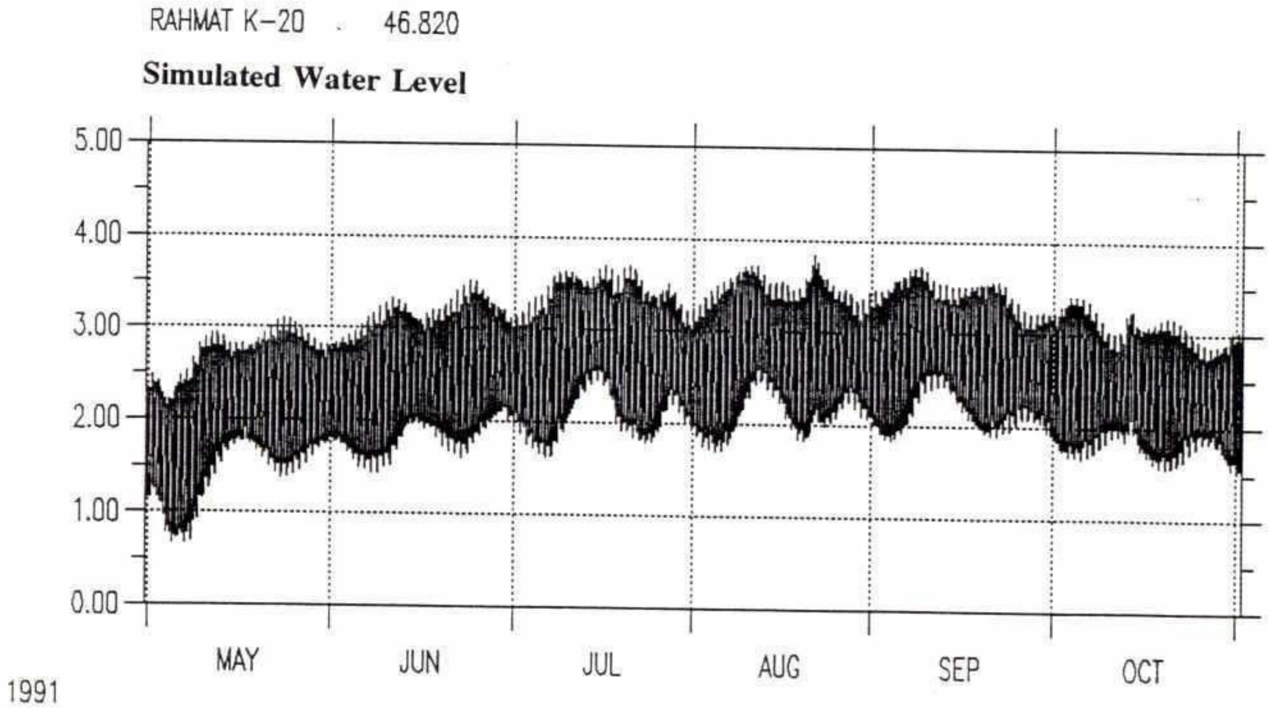
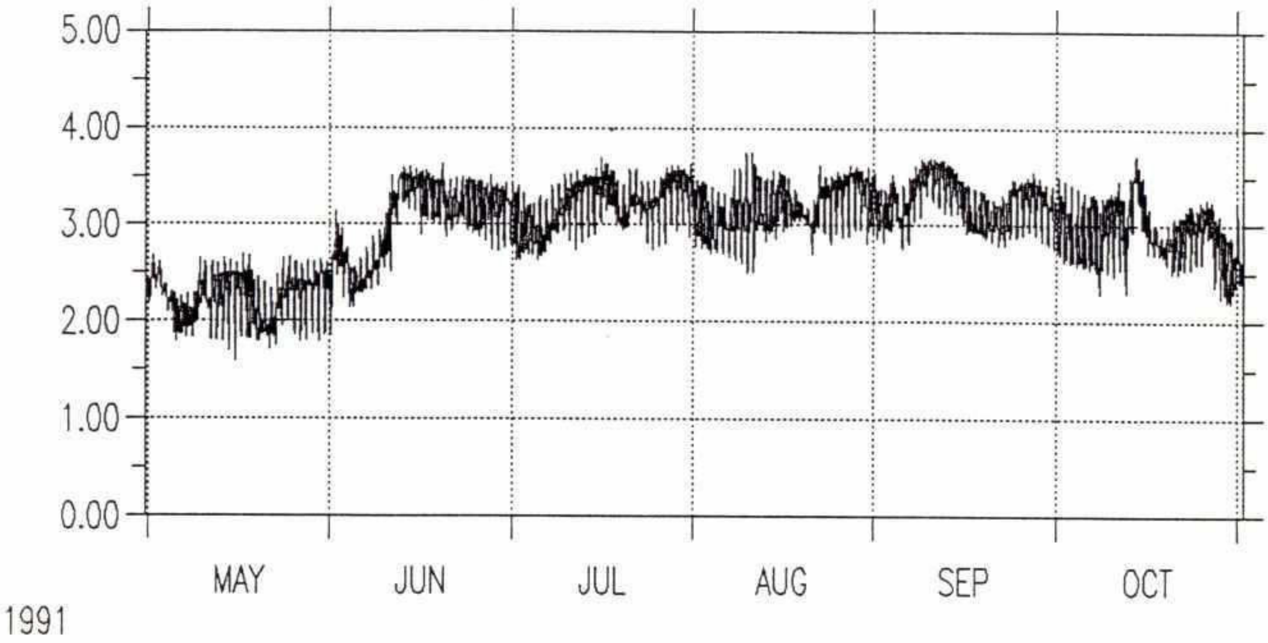


Figure B.5.6

Observed and Modelled Water Levels at Piarapur

PIARAPUR

Observed Water Level



RAHMAT K20 39.000

Simulated Water Level

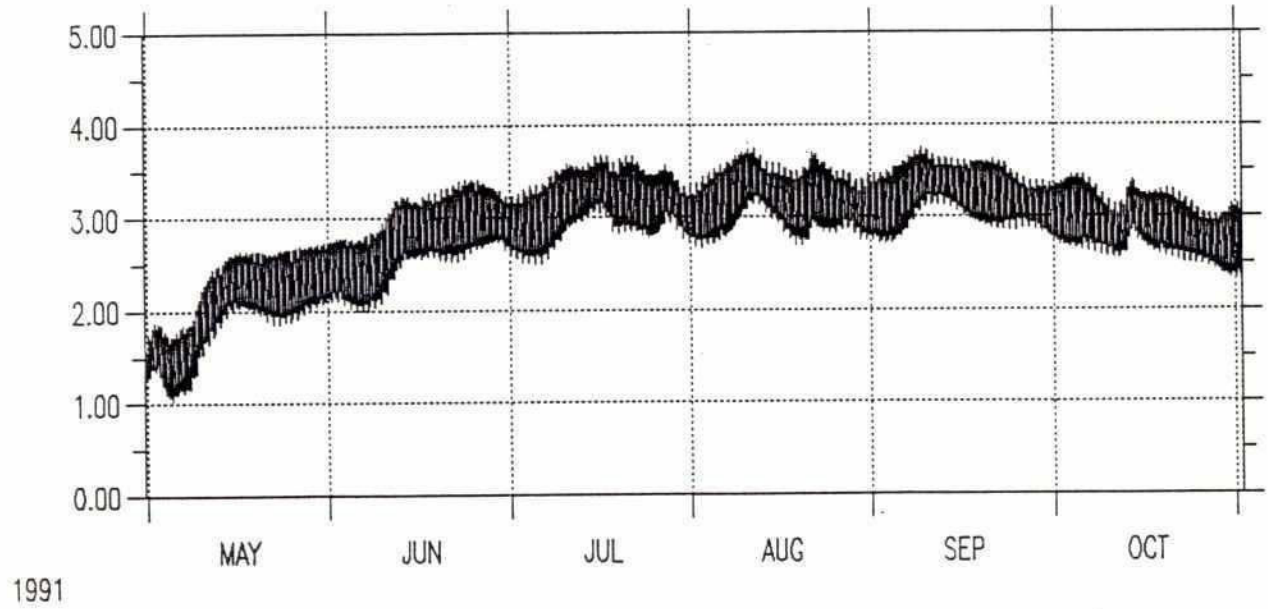


Figure B.5.7
Observed and Modelled Water Levels
at Noakhali and Begumganj

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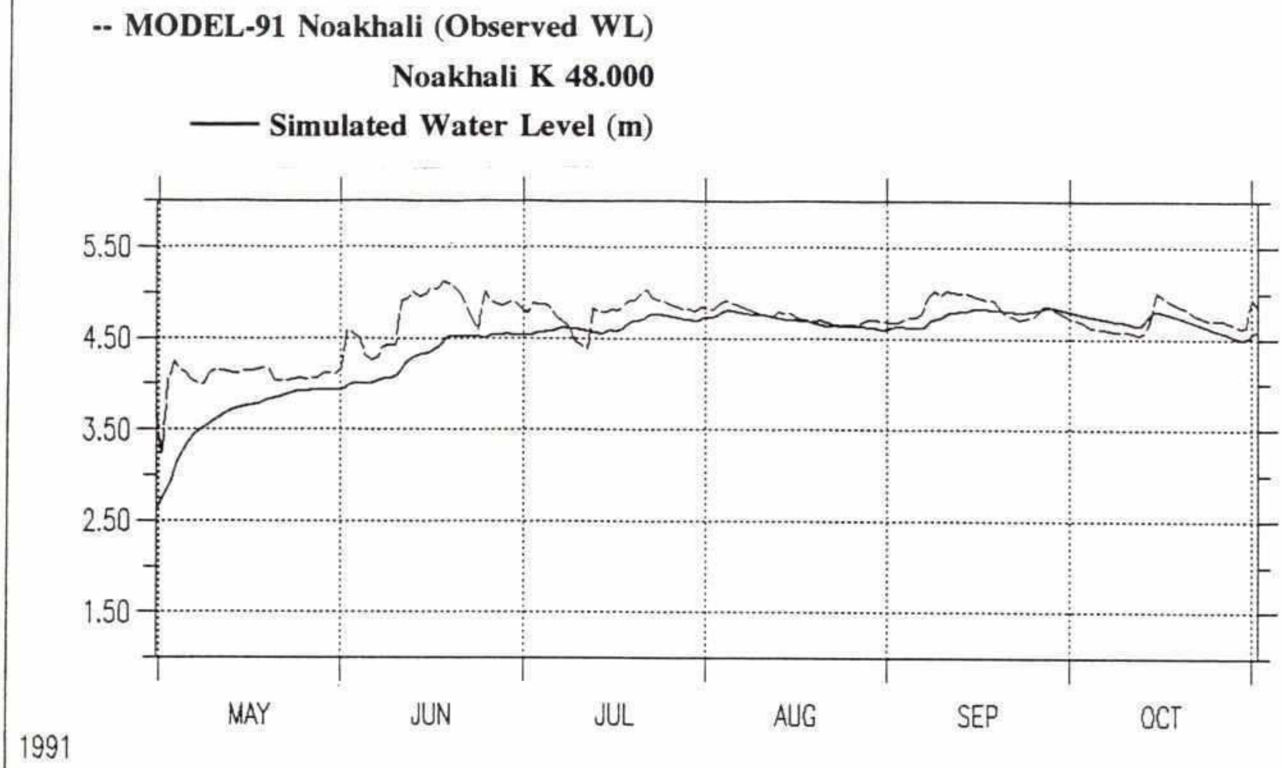

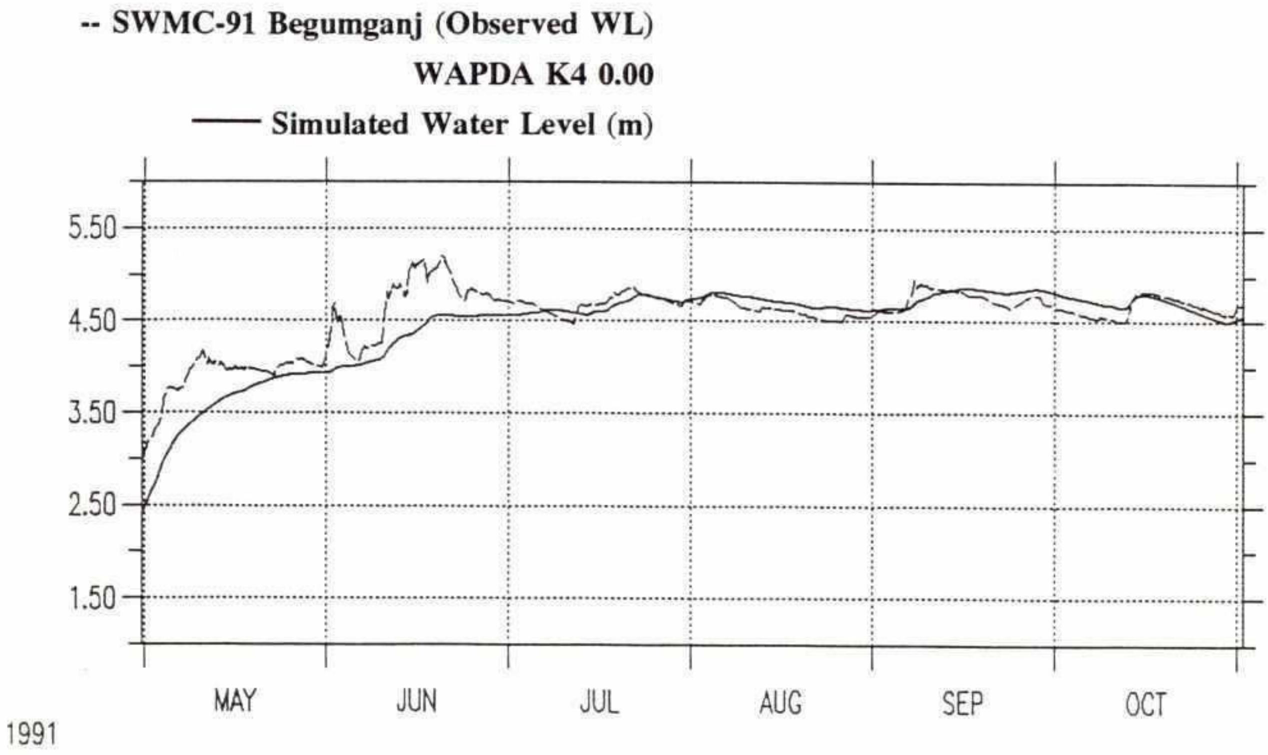

Figure B.5.8

Observed and Modelled Water Levels at Chandraganj and Chitoshi

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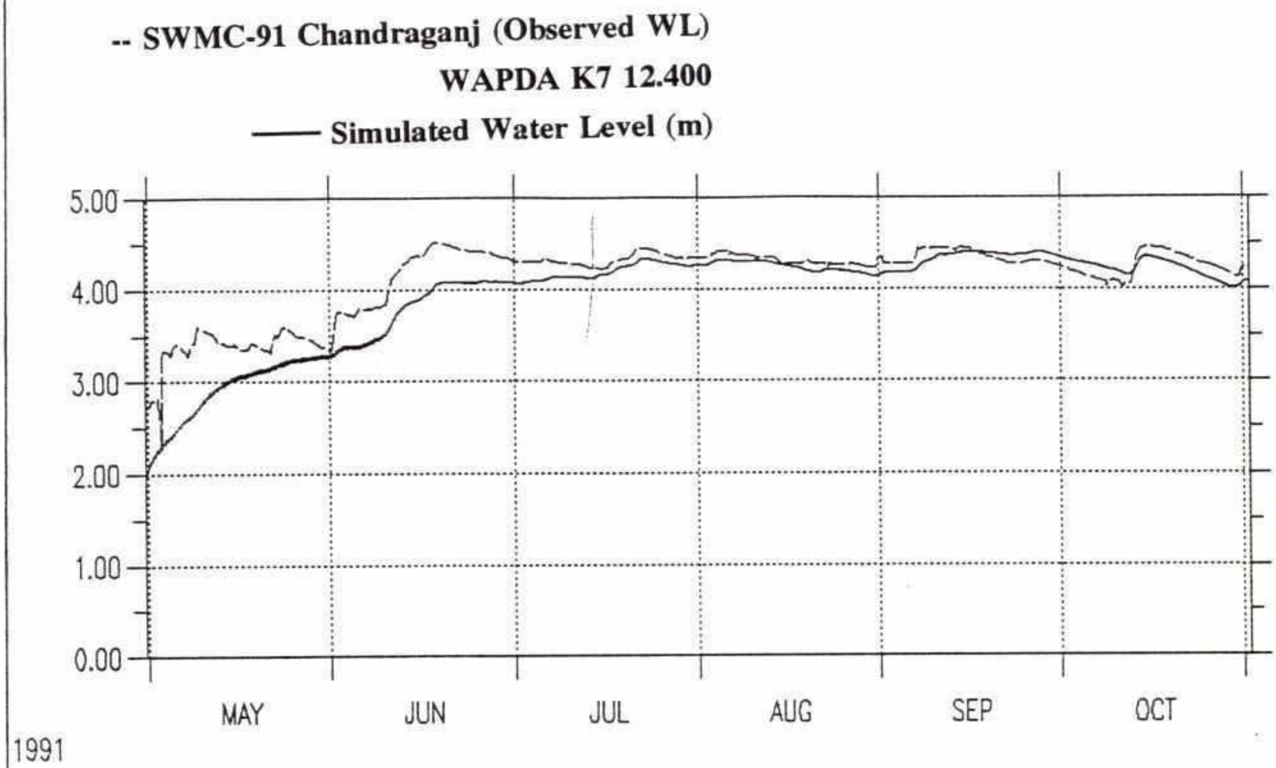


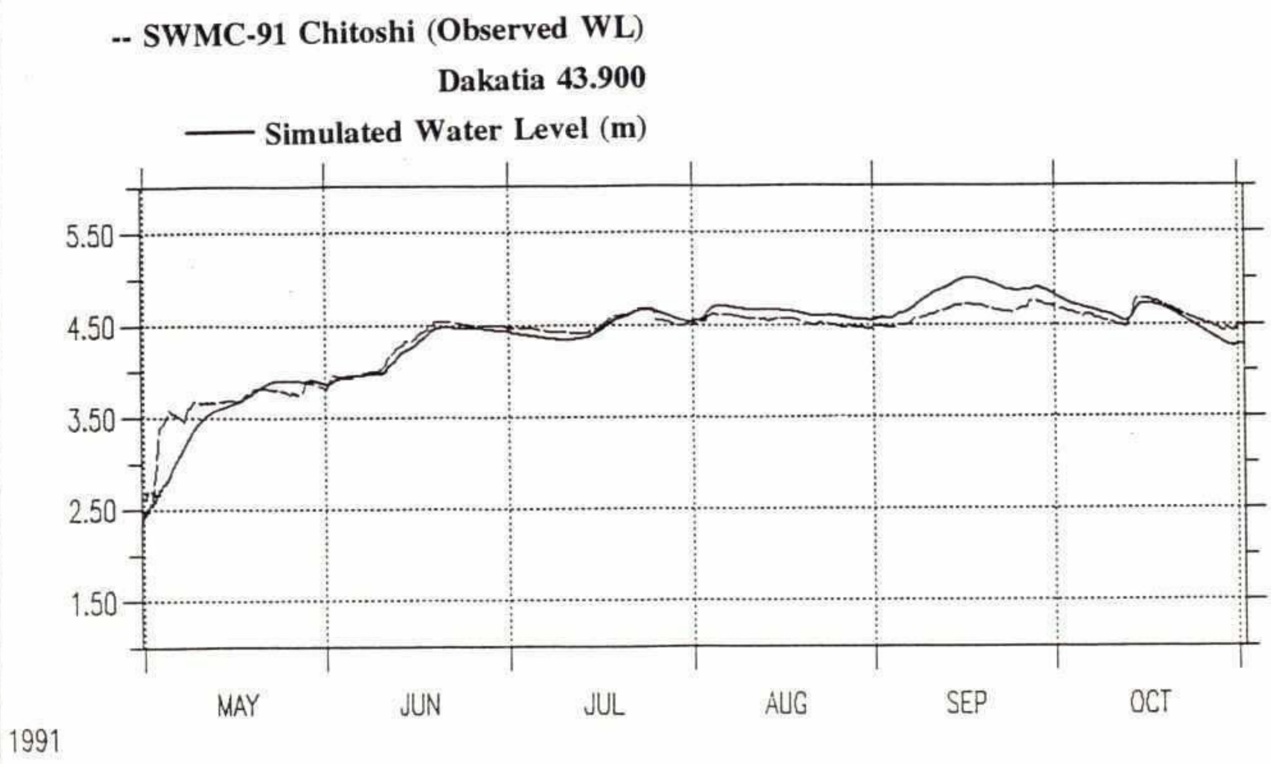
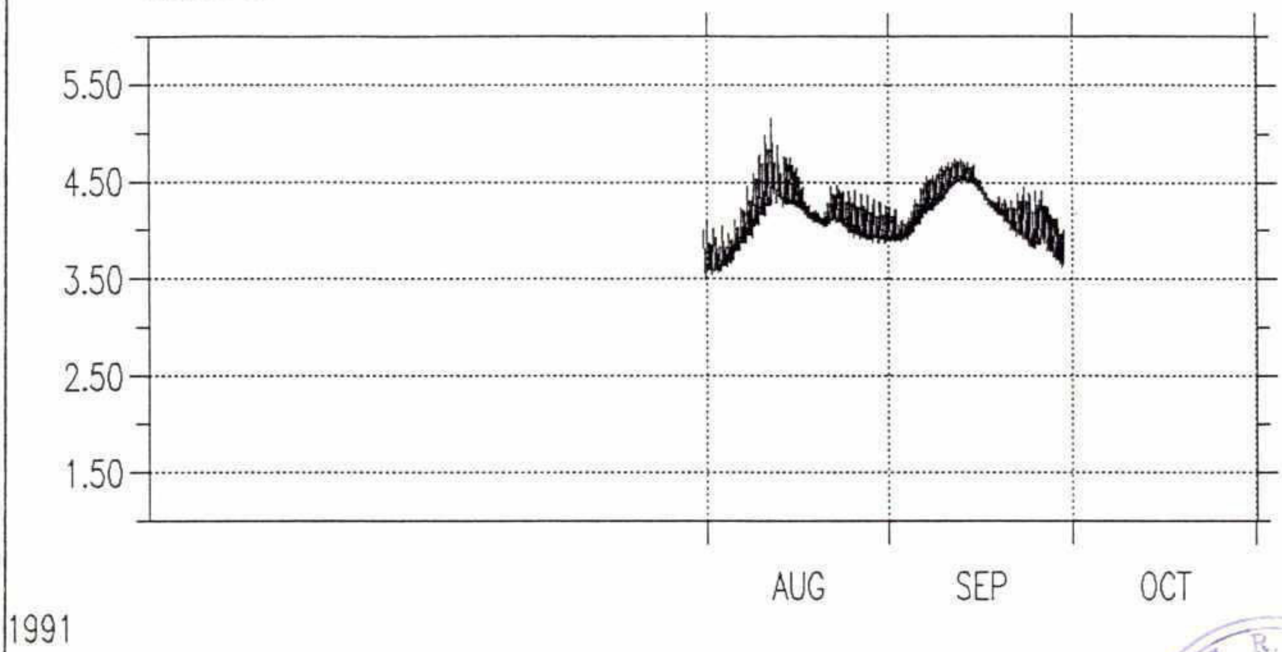


Figure B.5.9

Observed and Modelled Water Levels at Chandrapur

CHANDPUR–TI

Observed Water Level



DAKATIA 120.500

Simulated Water Level

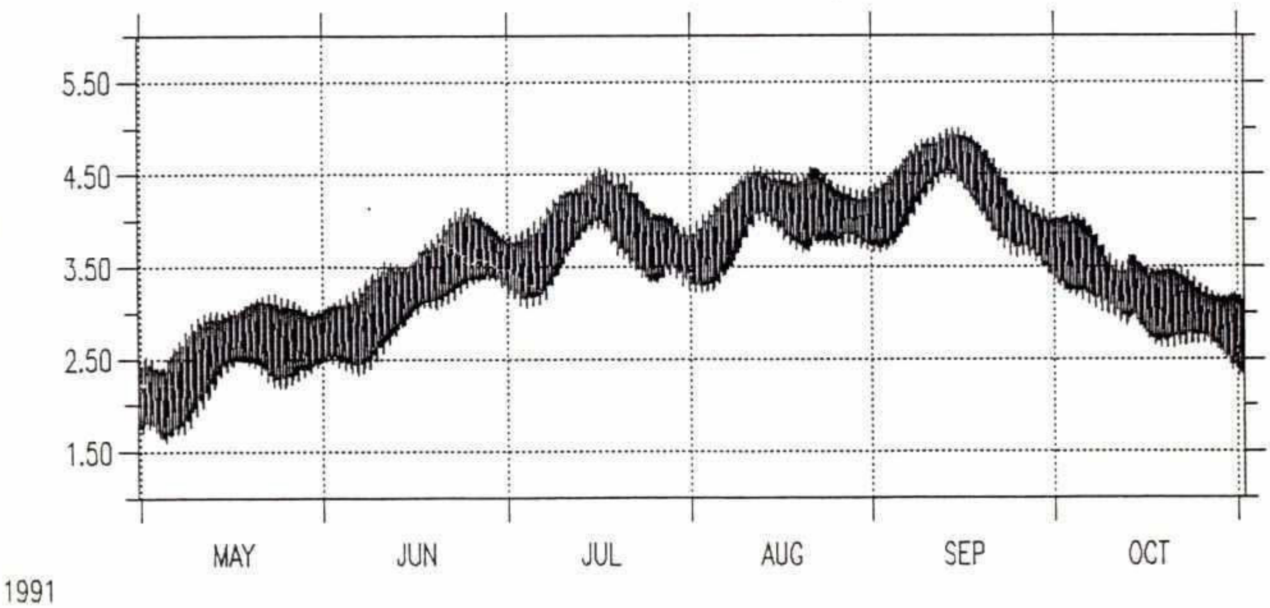
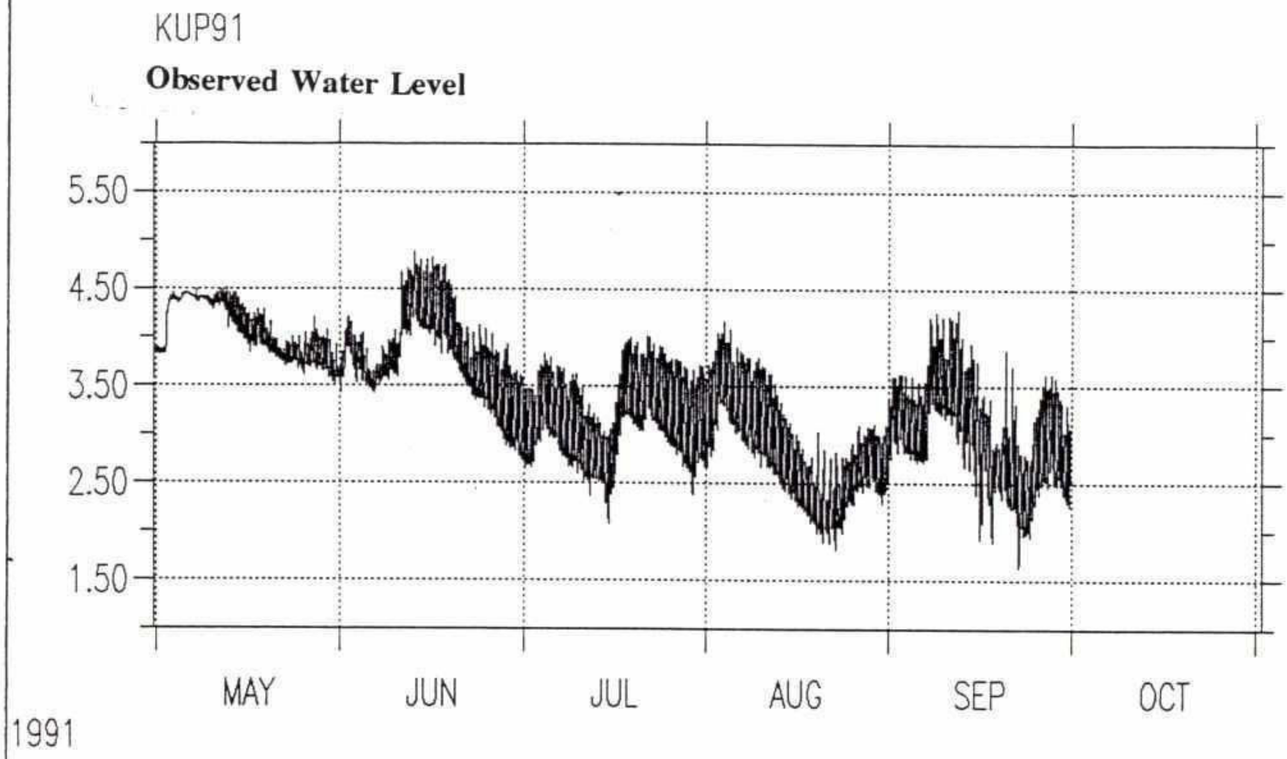


Figure B.5.10
Observed and Modelled Water Levels
at Kazirhat Regulator U/S.



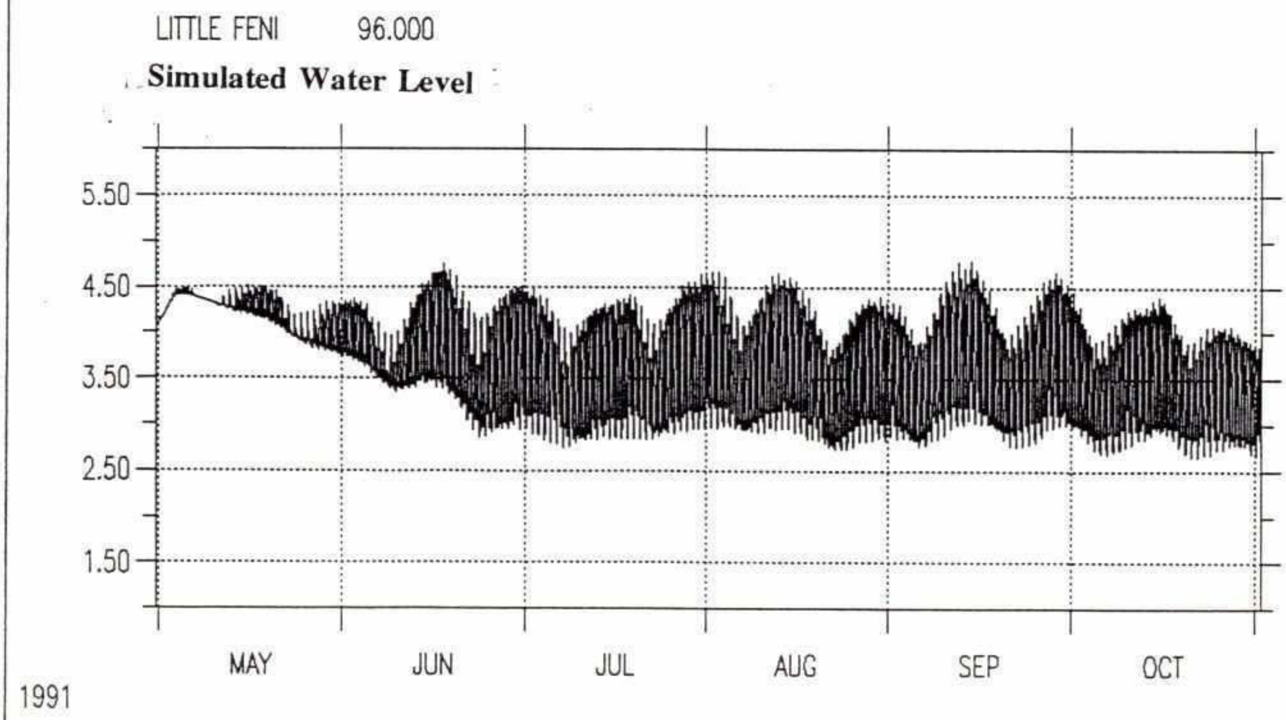
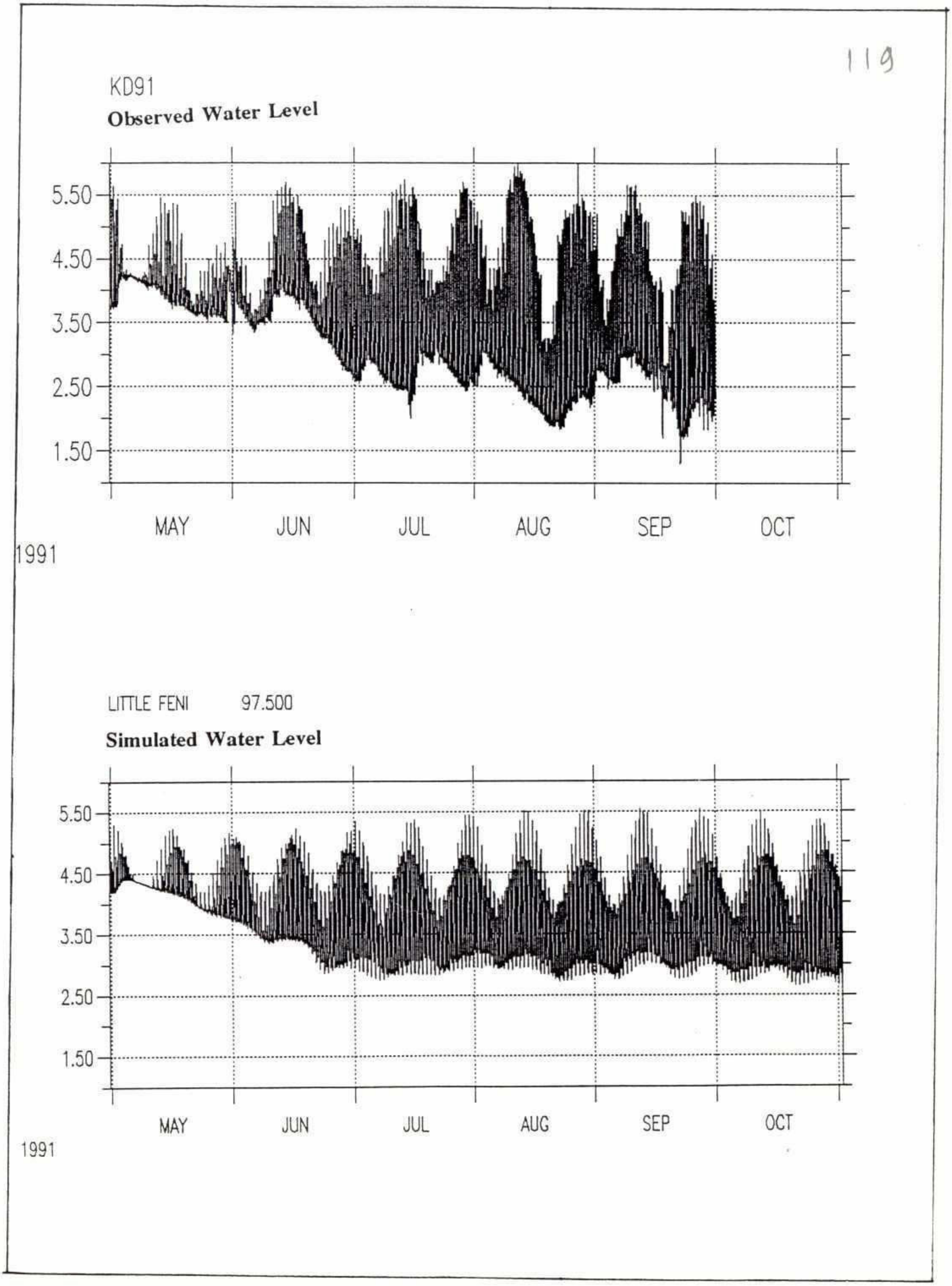


Figure B.5.11
Observed and Modelled Water Levels
at Kazirhat Regulator D/S.



Dakatia

At Chandpur the tidal variations correlate well with the model boundary condition and give confidence in the tidal boundaries generate for the study. Further upstream, at Chitoshi, the tidal influence of the Meghna is only seen at very low stages and again a good match between modelled and observed levels is found.

Little Feni

The model results immediately downstream of Kazirhat show a good match with the observed levels. The troughs tend to be over-estimated but the peaks agree much more closely. The influence of the siltation on the downstream side during the early monsoon period is clearly seen in the observations. The model has also been able to reproduce this effect.

Upstream of the regulator, peak levels are predicted reasonably but the timing of the peaks is very different between the model and observations. The troughs predicted by the model are also too high. This may be accounted for by morphological changes in the bed profiles during the monsoon season whereas the model assumes a fixed channel geometry, which is generally the dry season bed profile.

B.5.6.3 Discharges

The discharge through Rahmatkhali regulator is shown in Figure B.5.12 for the 1991 monsoon season. The variation of discharge over the spring neap cycle is clearly seen. Peak discharges are about $275m^3/s$. During height of the monsoon the tide flaps would normally remain open almost throughout the tidal cycle whereas in the pre-monsoon they close fully.

Annually the regulator suffers damage to one or more tide flaps. The single links or hinges are prone to fracture and this prevents the flaps operating as designed. The broken flaps remain open and allow flow to enter from the Meghna.

In the model simulation as shown on Figure B.5.12, three of the 14 tide flaps were assumed to cease working at the end of June. With the broken tide gates, the model indicates the magnitude of the negative flows enter the project area. These are relatively small, less than $40m^3/s$, in comparison with the overall outflow and would not have a significant effect on the internal levels.

Figure B.5.12
Discharge Hydrograph Through Rahmatkhali Regulator for Existing Condition

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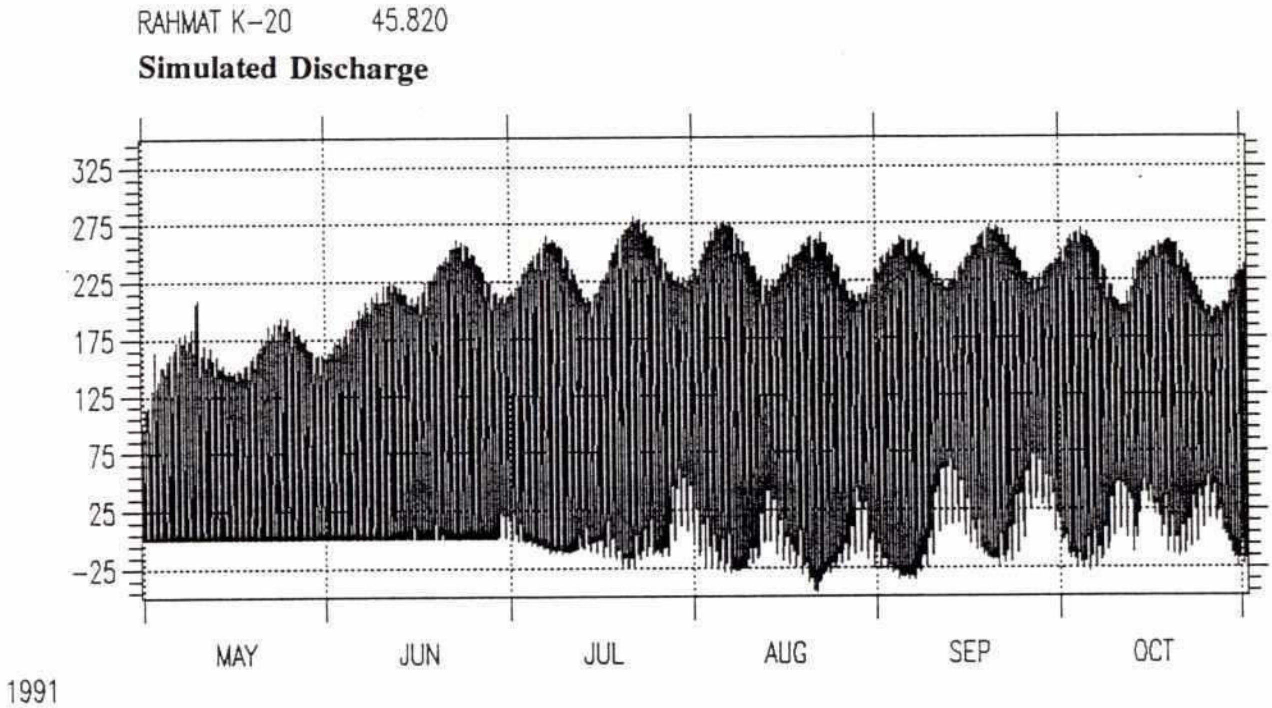

CHAPTER B.6

NOAKHALI NORTH MODEL - WITHOUT PROJECT CONDITIONS

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B.6.1 Introduction

The calibrated and verified model described in the previous chapter was used in the 25 year simulation run for a future 'without' project condition. This simulation was of present conditions in the modelled area; it incorporates all existing developments.

It must be stressed that the objective of the Without Project simulation was not to simulate observed water level and discharge variations over the 25 year period from 1965 to 1989. It was to produce data on water level and discharge variations over a period of 25 hydrological years.

This simulation provides baseline data for investigating and comparing the impacts of developments proposed as part of the Noakhali North project.

B.6.2 Analysis of Results of Without Project Simulation

B.6.2.1 Water Levels

Hydrological analysis was carried out on the 25 year time series of water levels at key locations within the Noakhali project area. The results were analysed on a decad (10 day) basis to give minimum, mean and maximum water levels for each decad. In addition, return period water levels were calculated for 2, 5, 10, 20, 50 and 100 year return periods. These return period levels were compared to the Without Project simulation to ascertain the impact of the developments.

The tidal range at Rahmatkhali regulator is about 1.5-2.0m during the monsoon season. Immediately upstream of the regulator, the tidal influence reduces to about 1.0m and this reduces to around 0.5m at Piarpur. Further upstream the tidal influence deminishes rapidly and at Chandraganj no tidal fluctuations are evident during high monsoon season levels.

Water levels in the Begumganj depression rise rapidly during May and June. High water levels and ponding in the area begins in July. The levels remain high until the end of October due to inadequate drainage of the area and the intensive monsoon rainfalls. The recession continues relatively slowly during November and extends in to December.

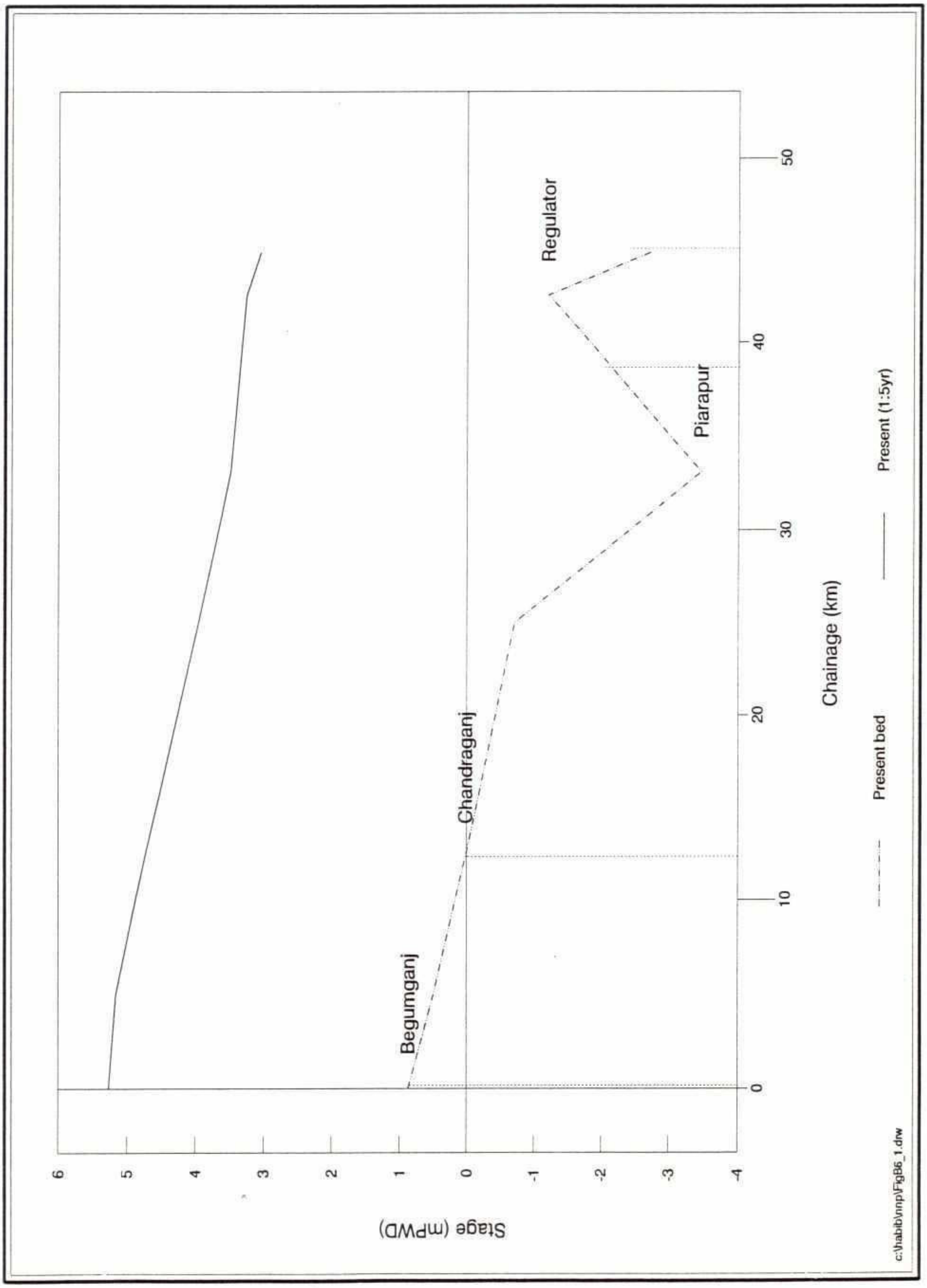
The 1:5 year long profile of levels along the Wapda khal are shown in Figure B.6.1.

B.6.2.2 Discharges

The 1:5 year discharge through Rahmatkhali regulator is 310m^3/s. Maximum discharges through the regulator are in the region 380m^3/s.

Figure B.6.1

Long Profile along WAPDA Khal
1:5 Year Levels



B.6.2.3 Flood Phases

Table B.6.1 presents the model predicted flood phases, for Without Project conditions, for each of the post-processing sub-areas in the Noakhali project area. These flood phases are based on the 4-day maximum, 1:5 year decad level which gives the deepest flooding. The sub-areas listed in Table B.6.1 correspond to those given in Figure B.4.2.

The flood phases are based on an analysis of mean daily levels and in areas influenced by large tidal fluctuations the flood phase figures will generally underpredict the percentage area of flooding.

TABLE B.6.1

Without Project Simulation Flood Phases for Noakhali Project Area

Area	Flood phase (%)			
	F0	F1	F2	F3+F4
A1	92	8	0	0
A2	78	21	1	0
A3	100	0	0	0
B1	0	15	80	5
B2	9	46	44	1
B3	1	43	56	0
B4	0	7	92	1
B5	9	70	21	0
C1	24	65	11	0
C2	2	73	25	0
C3	2	22	76	0
C4	7	21	71	1
C5	6	26	67	1
C6	61	37	2	0
C7	7	74	19	0
C8	1	29	70	0
D1	0	12	84	4
D2	5	12	81	2
D3	1	31	68	0
D4	0	4	95	1
D5	0	17	77	6
D6	0	3	83	14
D7	0	8	90	2
D8	0	3	92	5

In Zone A, Piarpur to Rahmatkhali, there is little inundation at present. The channel conveyance in this reach is relatively large and the area is drained rapidly due to its close proximity to the regulator site. The severity of the flooding increases further up the Wapda/Rahmatkhali system with the deepest flooding occurring in and around the Begumganj depression. This area is effectively a lake during the height of the monsoon season.

Immediately south of the Dakatia, the area suffers from relatively deep inundation, high percentage of F2 land, as do the central and western parts of the region.

Model predicted flood phases for the areas adjacent to the Noahkhali project area are given in Table B.6.2. The flood phases are based on mean daily levels and in areas influenced by large tidal fluctuations the flood phase figures will generally underpredict the percentage area of flooding.

TABLE B.6.2

Without Project Simulation Flood Phases
Adjacent to Noakhali Project Area

Area	Flood phase (%)			
	F0	F1	F2	F3+F4
KZ	95	4	1	0
LF1	22	69	9	0
LF2	54	21	23	2
NAN	35	25	39	1
DKW	1	53	43	3
DKE1	0	7	85	8
DKE2	1	36	62	1
DKE3	0	2	94	4

In the area immediately north of the Dakatia flood depths fall primarily into the F1 and F2 categories with little or no F0 land. In the Little Feni, the area immediately upstream of Kazirhat regulator does not suffer heavily from flooding but further upstream drainage congestion results in inundation with up to 30% F2 land. Bed levels in the Little Feni indicate that there may be a constriction to flow in the middle reaches of the Little Feni and this is supported by the flood phase results.

Flood phase figures were also produced for each minute square within the project area. These give an indication of the areal distribution of the flood phases and are shown in Figure B.6.2.

These flood phase figures form the baseline against which proposed developments and scenarios may be assessed.

Figure B.6.2

Noakhali North - Without Project 1 in 5 Year Peak Flood Phasing

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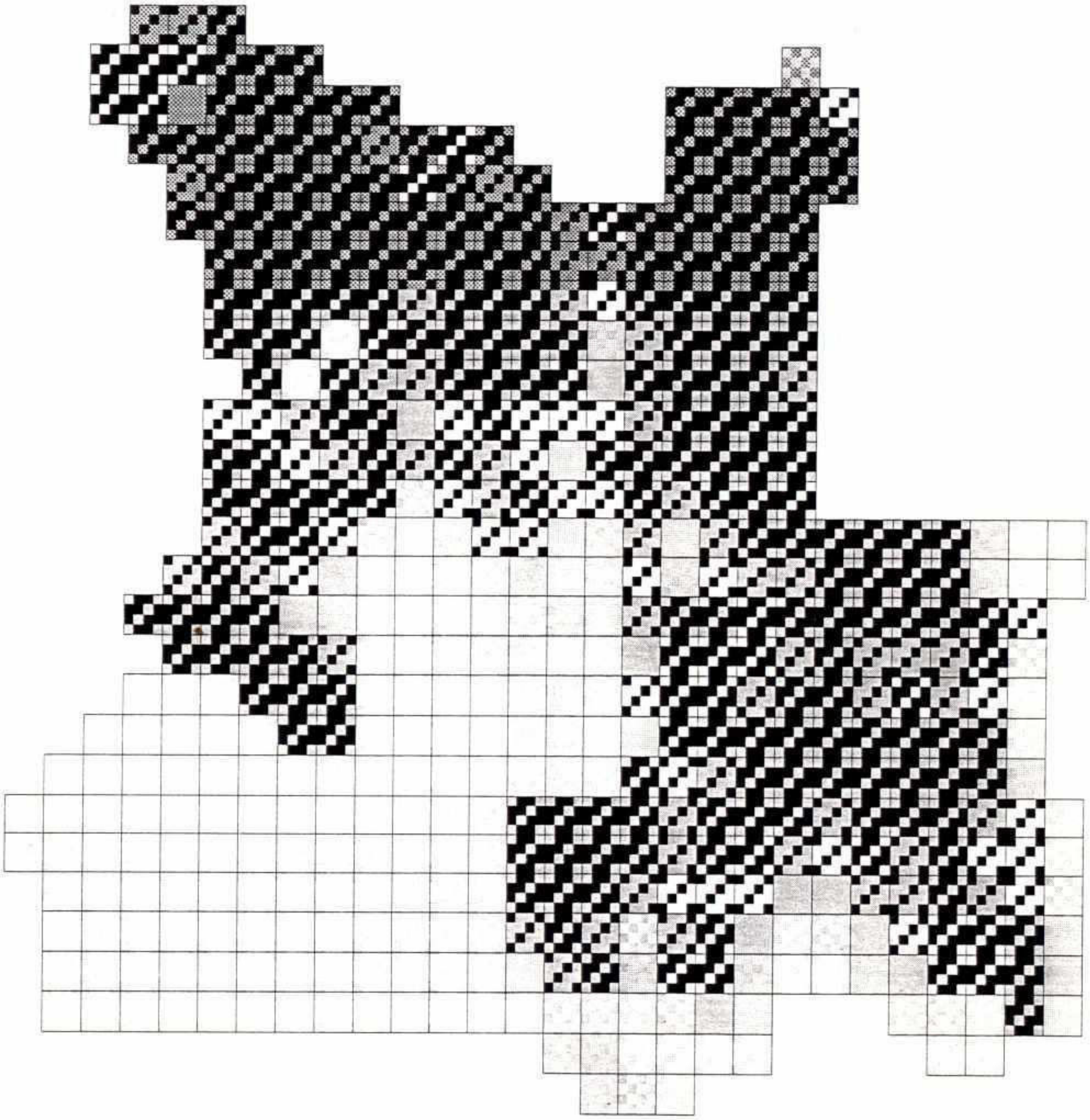


% of NCA with Flood Phase F2 or F3/F4 (1 in 5 year Peak Flood Depth > 0.9m)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
% of NCA with Flood Phase F0 or F1 (1 in 5 year Peak Flood Depth < 0.9m)	90-100	80-90	70-80	60-70	50-60	40-50	30-40	20-30	10-20	0-10

CHAPTER B.7

NOAKHALI NORTH MODEL - DESIGN OPTION SIMULATIONS

B.7.1 Introduction

The Noakhali model area is a complex network of khals with three major drainage routes; Rahmatkhali, Dakatia and Little Feni. Each of these three river basins are interlinked and the division of the area in to isolated catchments is not possible. The model was used to assess the influence each of these major drainage routes has on the Noakhali project area and to assess the effectiveness of different development scenarios.

The model was used to assess not only changes in the hydraulic regime within the project boundaries but also in the adjacent areas, to ensure there were no significant disbenefits in these areas as a result of benefits within the project area.

Four main elements were considered in the design option simulations:

- capacity and operation of Rahmatkhali regulator and its constriction to effective drainage of the area
- khal excavation and regrading and the constriction to drainage due to insufficient channel conveyance
- a new regulator at the mouth of the Dakatia to prevent tidal inflows from the Meghna
- a new regulator at the outfall of the Little Feni, south of the existing Kazirhat regulator

Investigations of the different developments were undertaken for the 1983 monsoon period, May to November inclusive. 1983 was selected as the design year as this was approximately a 1:5 year event throughout most of the model area.

The options were assessed primarily through changes in water levels between the development scenarios and present conditions and between the development scenarios themselves. Changes in discharge and velocity in key channels and through the regulating structures were also considered.

B.7.2 Rahmatkhali Options

A summary of the runs undertaken is shown in Table B.7.1 and the conclusions drawn during the analyses summarised.

TABLE B.7.1

Summary of Option Runs for Rahmatkhali

Run No.	Regulator No.	Sill (mPWD)	Channel sections	Other changes
PP	14	-1.5	Present	
R0	20	-1.5	Present	
R1	14	0.0	Present	
R2	14	-1.5	Excavated	
R3	14	-0.5	Excavated	
R4	20	-0.5	Excavated	
R5	28	-0.5	Excavated	
R6	28	-0.5	Excavated	Dakatia reg
R7	28	-0.5	Excavated	10m Widening in Wapda khal
R8	28	-0.5	Excavated	20m Widening in Wapda khal
R9	24	-0.5	Excavated	Widening in Wapda khal, Musapur regulator
R9P	24	-0.5	Excavated	Widening in Wapda khal, Musapur regulator, pump station ($50m_3/s$).

Run PP : Baseline simulation for present conditions.

Run R0 : Increasing the number of gates at Rahmatkhali to 20 gave no reduction in the peak levels in the Begumganj depression. This indicated that the major constriction to drainage in the area was due to insufficient conveyance capacity in the Rahmatkhali and Wapda khals rather than the capacity of the regulator.

Run R1 : The initial option run investigated the impact of raising the sill level at Rahmatkhali regulator by 1.5m to 0.0mPWD, with all other conditions remaining the same, that is, the present channel geometry. Peak water levels in the system were unaffected, same as at present, but minimum levels were raised upstream of the regulator.

Run R2 : Excavation of the channels increases their conveyance capacity thereby increasing drainage from the Begumganj depression. Peak levels at Begumganj reduced by some 0.5m. However, this led to drainage congestion at the existing regulator site where peak levels were increased.

Run R3 : Raising the sill level by 1.0m, compared with R2, to -0.5mPWD did not lead to any decrease in peak levels and suggested that the peak levels were relatively insensitive to variations in the sill level. It was clear that the regulator capacity itself, however, was now a constriction to the drainage.

Run R4 : Increasing the number of gates at the regulator, to 20 in total, improved outflows from the area and removes the drainage congestion at the regulator site by reducing peak levels immediately upstream by 0.1 to 0.2m. The water surface profile was flattened upstream of the regulator but there was no significant improvement in the Begumganj depression itself compared to R2 and R3.

Run R5 : Increasing the number of gates further, to 28 in total, gave a slight lowering of peak levels, by 0.05m, in the reach between Chandraganj and Piarapur. The results indicated that further increasing the number of gates at the structure would not have any significant impacts with the currently modelled sizes of channels.

Run R6 : As R5 but with a regulator on the Dakatia to investigate the impact of reducing inflows from the Meghna at Chandpur. The Dakatia regulator was found to have no impact on peak levels in the Rahmatkhali/Wapda khal drainage system.

Run R7 : Widening of the excavated khals, by 10m, in the middle reaches of the Wapda khal reduced peak levels, compared with R5, by 0.15m at Begumganj, but levels remained the same at Piarapur.

Run R8 : Widening the channels by a further 10m had only a minor impact with peak levels falling by a mere 0.05m at Begumganj compared with R7. This further widening could not therefore be justified.

Run R9 : Runs R4 and R5 suggested that there was an optimum number of gates at the regulator site beyond which no further significant improvement in peak levels could be achieved. With the number of gates reduced to 24 (in total) peak levels remained similar to those in R7 (28 gates).

Musapur regulator, located on the Little Feni downstream of the existing Kazirhat regulator, was included in this run. The results indicated peak levels in the Begumganj depression were not influenced by this development.

Run R9P : In comparison with R9, the run showed that pumped drainage at Rahmatkhali caused minor reduction in peak levels (0.05m) at the regulator but that no impacts were produced upstream of Piarapur. As this area does not suffer from any severe flooding the pumped drainage is of little benefit.

Improving the drainage conditions in the Begumganj depression not only gave reduced peak levels in this area but also as far north as the Dakatia. For example, Runs R7 and R9 reduced peak levels in the Dakatia by 0.1-0.2m in the reach between Hajiganj and Chitoshi. Upstream of Chitoshi the impact diminishes rapidly.

B.7.3 Chandpur Options

The option of a regulator on the Dakatia was dropped after the results of R6 were analysed. The regulator provides only a small reduction in levels along the lower reaches of the Dakatia and these diminished rapidly further upstream. The regulator has no significant benefits in the Begumganj depression or at Rahmatkhali regulator. The only time the regulator would provide a significant impact would be during extreme events when the levels in the Meghna were exceptionally high.

B.7.4 Little Feni Options

Kazirhat regulator suffers from sediment deposition on its downstream side which severely inhibits drainage flows during the early monsoon period. This causes levels upstream of Kazirhat to be high during this period. The introduction of a new regulator, approximately 15km downstream of Kazirhat, will prevent this deposition and help to reduce the high early monsoon levels. Furthermore it provides protection from high tidal levels to the area between the two regulators.

A summary of the runs undertaken for a new regulator on the Little Feni is given in Table B.7.2 and the conclusions drawn during the analyses summarised below.

TABLE B.7.2

Summary of Option Runs for Little Feni

Run No.	Regulator No.	Regulator Sill (mPWD)	Other
PP	-	-	
K1	20	0.0	Gates 3.0m x 3.5m
K2	20	0.8	Gates 3.0m x 3.5m
K3	22	1.0	Gates 3.0m x 3.0m

The incorporation of a regulator downstream of Kazirhat significantly improved the flow conditions through Kazirhat itself. Peak water levels immediately upstream were reduced substantially and the regulator was able to discharge fully during the early monsoon period as no siltation occurs on the downstream side.

Further upstream, outside the influence of Kazirhat regulator, levels still remained high. This suggested that there is a constriction to the flow in this area. This was not investigated further as the model requires updating and improving along the Little Feni reach before it can be used with confidence in further studies. This will be discussed in the final regional plan.

B.7.5 Conclusions

The conclusions drawn from the option runs can be summarised as follows:

- Rahmatkhali regulator would not restrict drainage from the area if the existing regulator was supplemented by an additional regulator of 10 gates. A common sill level of -0.5mPWD gives improved flow conditions in the channels upstream.

- Channel excavation/regrading improves drainage from the Begumganj depression; discharges from the depression are increased and significant reductions in water levels, throughout the monsoon season are achieved.

- Pumped drainage does not give any significant benefits to peak levels in the Begumganj depression

- A new regulator on the Dakatia would have little impact on levels in the project area and does not have a large impact on levels in the Dakatia as tidal variations are small during the monsoon season.

- The proposed developments in the Noakhali project area are not influenced significantly by the introduction of a new regulator site on the Little Feni at Musapur. There is little cross flow between the two drainage systems and they function almost entirely as separate drainage basins.

Based on the findings of the option simulations the preferred option was selected and a 25 year simulation undertaken as the With Project condition. This is described in detail in Chapter B.9.

CHAPTER B.8

IRRIGATION MODEL

B.8.1 Introduction

Hydrodynamic models to look at dry season flow conditions and developments for irrigation within the project area were developed.

Two areas were considered for irrigation development. These would also improve the drainage characteristics in these areas. The two models covered the Wapda/Rahmatkhali drainage system and the Dakatia drainage system.

B.8.2 Rahmatkhali Irrigation Model

B.8.2.1 Introduction

At present Rahmatkhali regulator is principally a one way flow structure allowing outflow to the Lower Meghna. The structure can be used, with appropriate modification, to operate in a reversed manner during the dry season with the aim of retaining water for irrigation purposes. In this case, the structure would allow only one-way flow but this being from the Lower Meghna in to the project area.

The regulator was modelled as for the 'With Project' conditions, see Chapter B.9. In comparison with present conditions, the increase in the number of gates allows an increase in the volume of water that can be taken in to the system over a tidal cycle.

A five month irrigation period from December to April, inclusive, was modelled. Irrigation offtakes were lumped together at selected offtake locations, with a total command area of some 30,000ha.

B.8.2.2 Model Set-Up

(a) River System

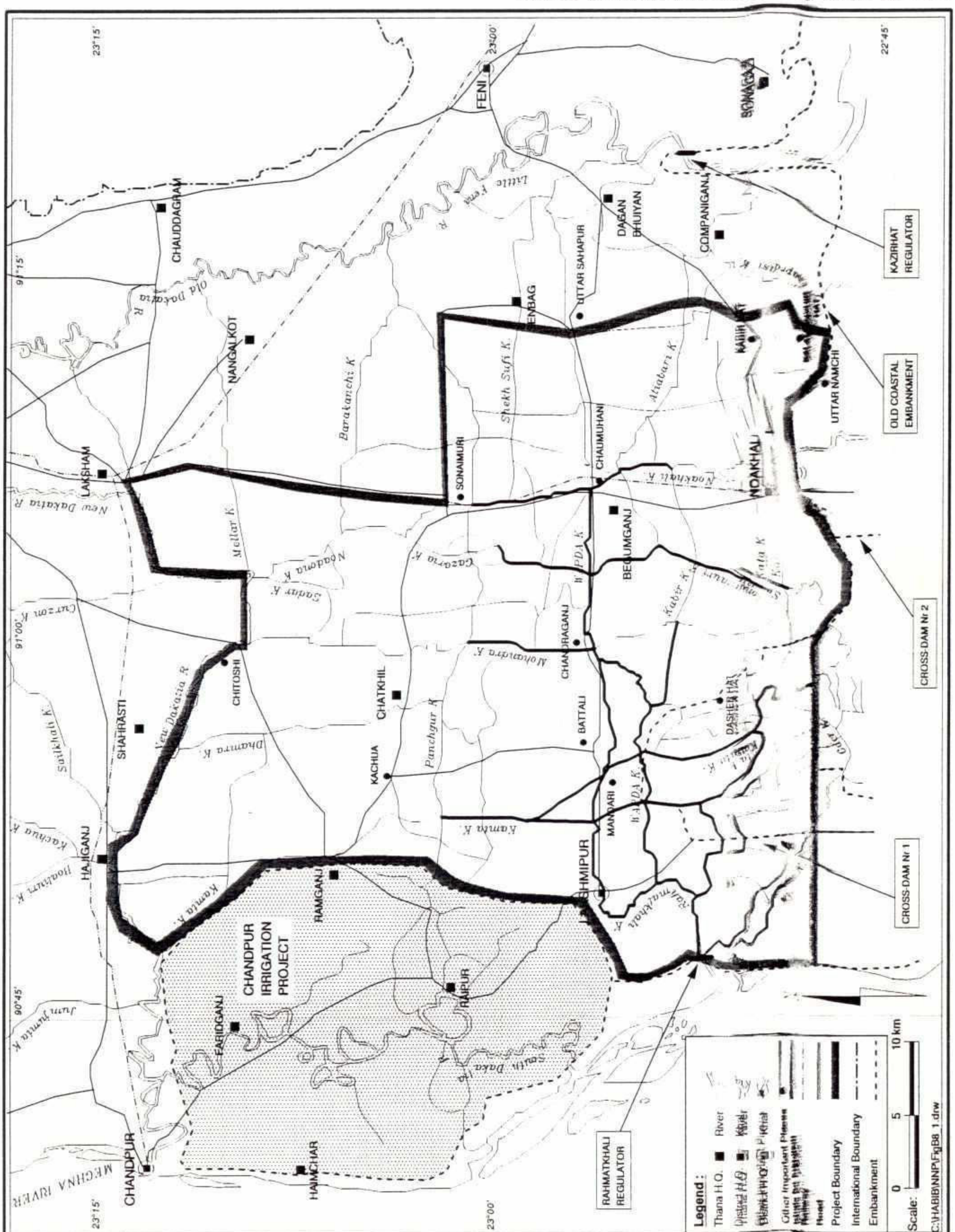
The command area for the Rahmatkhali irrigation model includes the Wapda and Rahmatkhali khals together with its tributaries and distributaries. The model extends to the Panchgur khal to the north and to Noakhali khal in the east. Additional minor khals, not included in the flood season flow model, were also incorporated, Figure B.8.1.

(b) Khal Excavation

Storage of irrigation water in the river system was increased by re-grading and re-sectioning the existing khals. This included both the main drainage system and other associated minor khals.

Figure B.8.1

Khals in Rahmatkhali Irrigation Model



In the minor khals, revised sections included a minimum bed level of -0.5mPWD, 2:1 side slopes and a minimum bed width of 1-2m. Only those khals which could accommodate such a section, in general sections with top widths greater than 20m, were considered. This avoids land acquisition and the problems which this introduces.

Along Wapda khal top widths varied from 40m at Begumganj to over 100m upstream of the regulator. Re-grading was also included with bed levels varying from -0.5mPWD to less than -3.0mPWD. Similarly, Rahmatkhali khal was re-graded and re-sectioned. Maximum top widths varied between 24-50m.

(c) Tidal Boundary

The FAP 25 General Model simulations are calibrated for monsoon season flows with little emphasis put on the dry season flows and levels. Checks were therefore undertaken to ensure that the tidal boundary at Rahmatkhali, based on the GM results, was representative of that in the dry season.

Comparisons with observed data, Figure B.8.2, indicated that the General Model results superimposed with a tidal variation gave a good match with observed HWL and LWL for the 1986/87 dry season. This gave confidence that the GM results could be used during the dry season modelling in the irrigation model.

(d) Irrigation Demand

Irrigation demand for a total area of 30,000ha was considered. Low lift pump (LLP) operation was considered over a 12 hourly period each day. Peak decad abstraction rates, over the entire area, were about 90m^3/s during the first and second decads of March. The total abstraction was distributed along the khal network as point outflows at approximately 4 km intervals.

B.8.2.3 Model Results

Tidal variations at Rahmatkhali regulator allow peak discharges of about 300m^3/s to enter the project area on spring tidal cycles in late February/early March.

The water level hydrographs throughout the 5 month period (December to April) are shown in Figures B.8.3 for Piarapur and Begumganj. Water levels reach a minimum during the months of February and March when Meghna levels are low and the irrigation demand is highest. As expected, at locations furthest from the regulator site the draw down in level is greatest (ie Begumganj) but remains sufficiently high to provide the irrigation demand without drying out the channels.

The general operation of the regulator during a 48 hour period is demonstrated in Figure B.8.4.

Figure B.8.2

Dry Season Tidal Boundary at Rahmatkhali

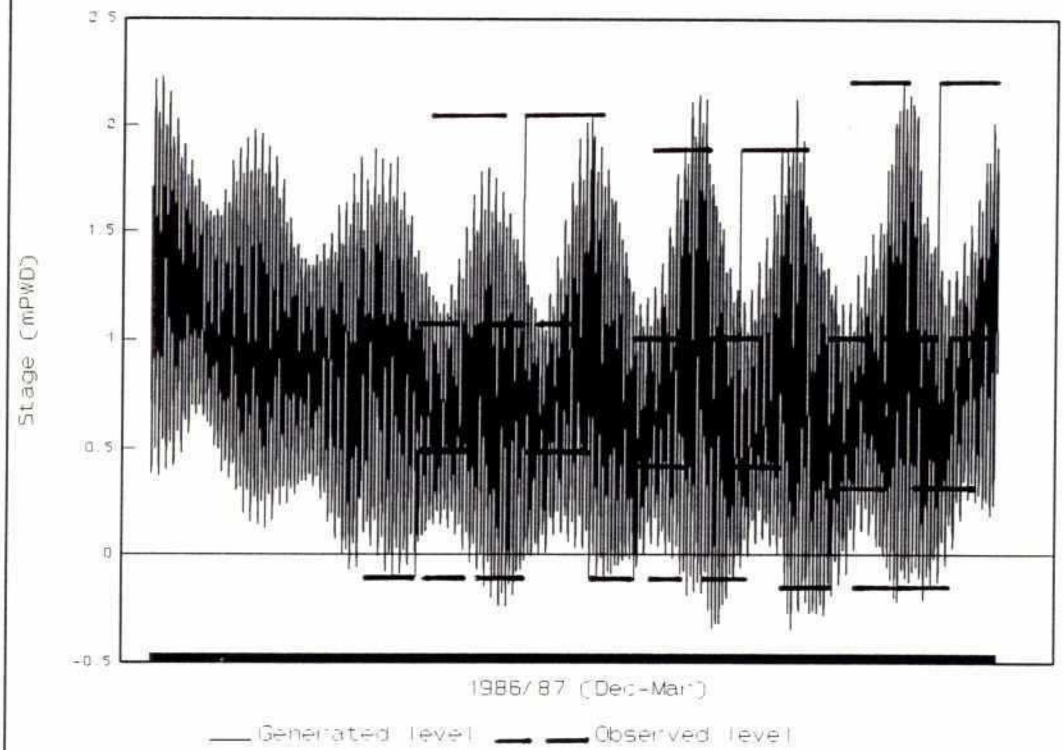
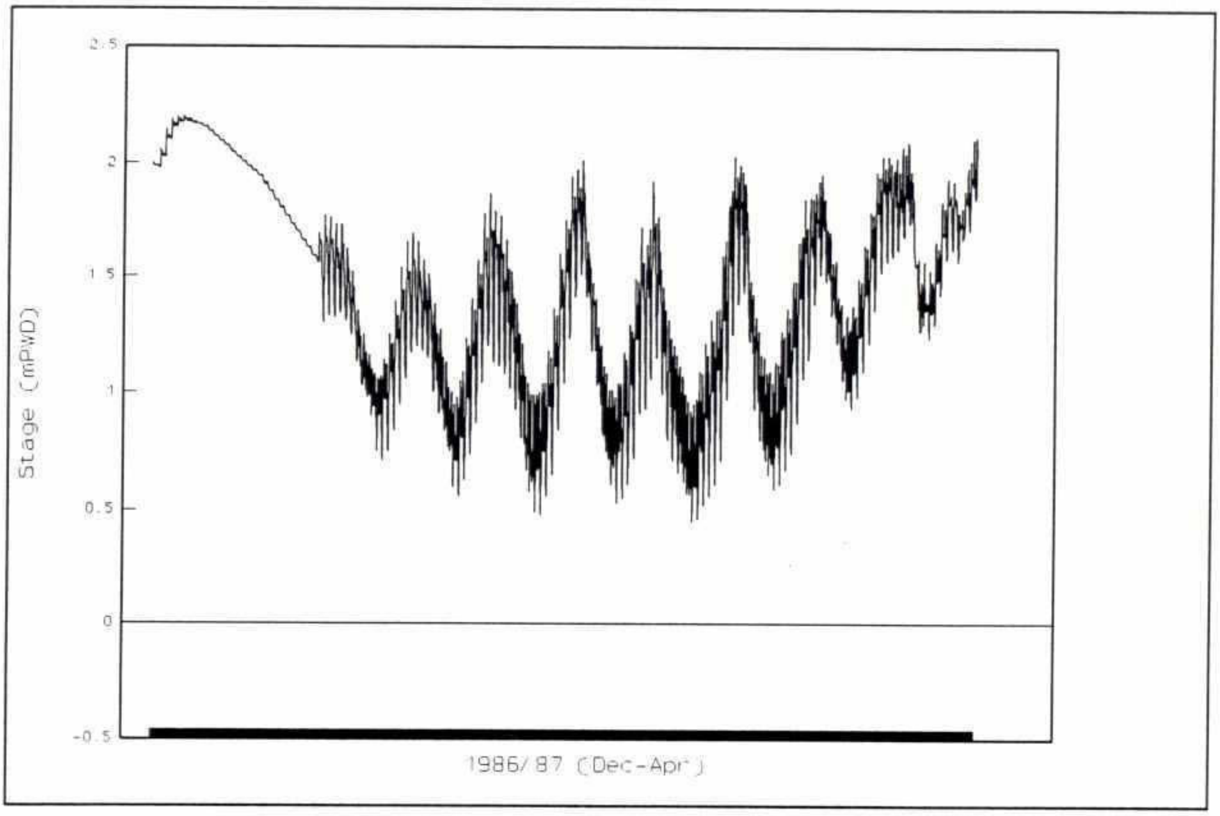


Figure B.8.3

Model Results

Water Levels at Piarapur



Water Levels at Begumganj

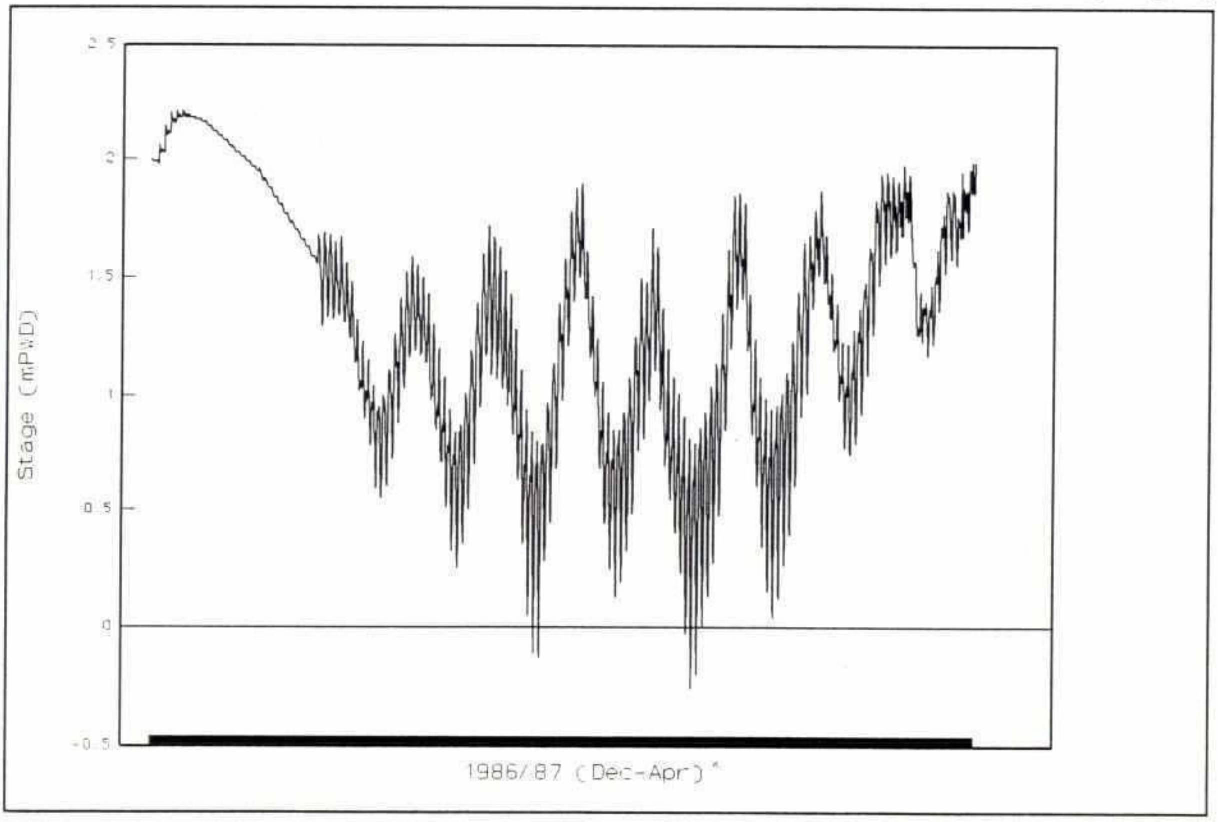
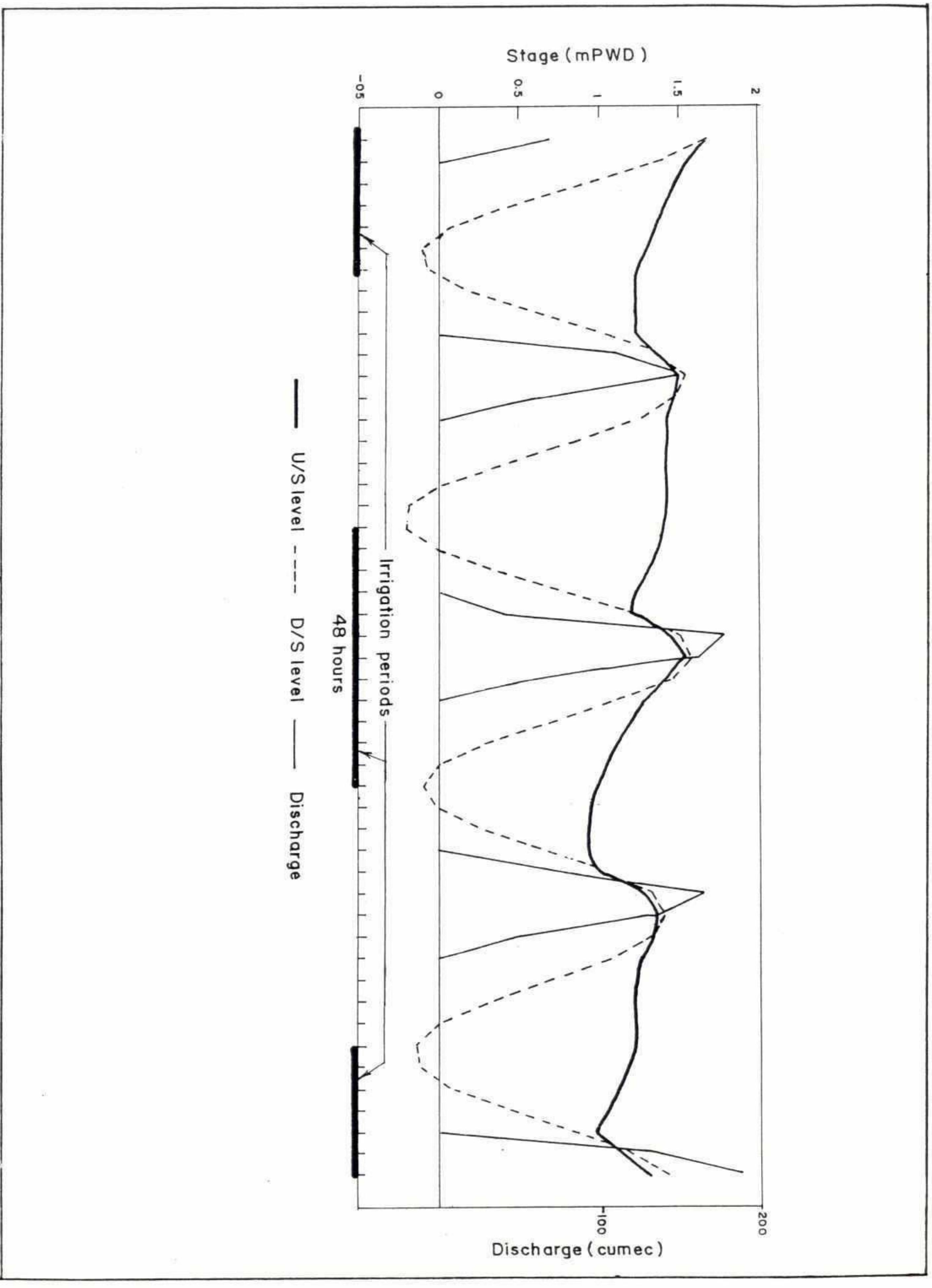


Figure B.8.4

Rahmatkhali Regulator Irrigation Inflow



B.8.3 Dakatia/Chandpur Irrigation

A model was also developed to investigate the potential of irrigation water supply, similar to that at Rahmatkhali, for the area between the Dakatia and Panchgur rivers. Channel excavation was considered along those khals which had an existing top width capable of taking a trapezoidal channel (1:2 side slope) with a minimum bed level of -0.5mPWD and a minimum bed width of 1-2m. Effectively, this requires a top width in the region of 20m, as ground levels are around 4.0mPWD.

The channel excavations were possible along the northern reaches of Noakhali khal, Mohanandra, Naogaon khal and parts of the Frider khal. In addition, some further khals linking to the Dakatia were introduced in to the model, which were not included in the flood flow model.

The irrigated area was about 30,000ha, requiring a peak decad abstraction rate in the region of $90m^3/s$. Irrigation offtakes were located as point outflows at a 2.5km spacing along the channel network. Operation was over a 12 hourly period per day.

Modelling options undertaken for the monsoon season (Chapter 7) indicated that the viability of a regulating structure at the outfall of the Dakatia was not viable. The differential head generated throughout the tidal cycle is small and is barely sufficient to operate the tide flaps. It would only provide benefits during extreme high tides. Furthermore, the structure cannot be justified purely on gravity irrigation. The irrigation model simply considered an open outfall, as at present, and was used to test whether the volume of water entering the Dakatia, and its associated tributaries/distributaries, during the dry season were sufficient to supply the irrigation demand.

The model was run over a 5 month period (Dec-Apr) for the 1986/87 dry season. The results indicated firmly that this level of irrigation could not be satisfied and that the network of irrigation channels would begin to run dry in early January. Sensitivity tests also indicated that even a 50% reduction in the irrigation demand would still lead to a drying of the system in late January.

Further investigations of the potential for full scale irrigation development in this area were therefore not considered during this study.

CHAPTER B.9

NOAKHALI MODEL - WITH PROJECT CONDITION

B.9.1 Description

B.9.1.1 General

Following the design option simulations and the irrigation analysis a development plan for the Noakhali project area was formulated. A With Project simulation was carried out for this development plan.

The With Project simulation was based on a 25 year simulation for the period 1965-89 and considered the monsoon season only, from May to November inclusive. The impact of the proposed developments was investigated by comparing the results of the With Project simulation with those from the Without Project simulation.

B.9.1.2 Proposed Developments

The key components of the development plan simulated in the With Project conditions were as follows:

Rahmatkhali Regulator

- existing regulator upgraded to ensure tide flaps functioned throughout the whole season without failure, and additional flap gates for dry season irrigation

- sill level at the existing Rahmatkhali regulator raised to -0.5mPWD

- additional regulator added in parallel with the existing regulator; 10 vents, 3m wide gates (including dual tide flaps) and sill level at -0.5mPWD

Channel Excavation

- re-grading and re-sizing (to trapezoidal section) of Wapda and Rahmatkhali khals, minimum bed levels varying from -0.5mPWD in the Begumganj depression to less than -3.0mPWD near the regulator site

- excavation of tributaries and distributaries of the Wapda and Rahmatkhali khals to a bed level of -0.5mPWD with trapezoidal section and minimum bed width of 1-2m

- all tributary and distributary khal excavations carried out within the existing top width dimensions to minimise loss of agricultural land

Musapur Regulator

- new regulator, downstream of the existing Kazithat regulator, with 22 no. 3mx3m gates, tide flapped, and sill level set at +1.0m

B.9.2 Results of the With Project Simulation

B.9.2.1 Water levels

Hydrological analysis was carried out on the 25 year time series of water levels at key locations within the Noakhali project area. The results were analysed on a decad (10 day) basis to give minimum, mean and maximum water levels for each decad. In addition, return period water levels were calculated for 2, 5, 10, 20, 50 and 100 year return periods. These return period levels were compared to the Without Project simulation to ascertain the impact of the developments.

The operation of Rahmatkhali regulator is demonstrated in Figure B.9.1. As tide levels fall the tide gates open and water is drained from within the project area, with levels dropping rapidly immediately upstream. Peak discharges occur at or around low water. As the tide rises the discharge reduces as the head differential across the gates is reduced, until the tide flaps finally close. During closure, internal levels rise until internal levels exceed the tide level and the tide flaps open once more.

Figure B.9.2 shows a long-profile of 1:5 year levels (based on mean daily values) along the Wapda khal with and without the interventions. In the vicinity of the Begumganj depression levels are reduced by almost 0.8m. At Chandraganj the level is reduced by over 0.7m and at Piarapur by almost 0.2m. Immediately upstream of the regulator there is only a small change in peak levels but this is an area which does not suffer from inundation even under present conditions.

Comparison of the hydrographs (1983) with and without the project at Chandraganj is shown in Figure B.9.3. It indicates that the tidal influence extends further upstream under the proposed developments although this becomes insignificant at higher levels, when the flows are out of bank. This is due to the re-sectioning and re-grading of the bed profile.

An important feature of the hydrographs is the recession rate at which excess monsoon water can be evacuated from the area. The recession to inbank conditions is much earlier in the With Project situation and would lead to an improved situation for agriculture.

B.9.2.2 Discharges

During the monsoon season, under present conditions, the Begumganj depression becomes a lake and agricultural benefits can only be gained by draining this area more rapidly. Figure B.9.4 shows the discharge hydrographs at Chandraganj for With and Without project conditions.

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Figure B.9.1

Rahmatkhali Regulator Monsoon Season Operation

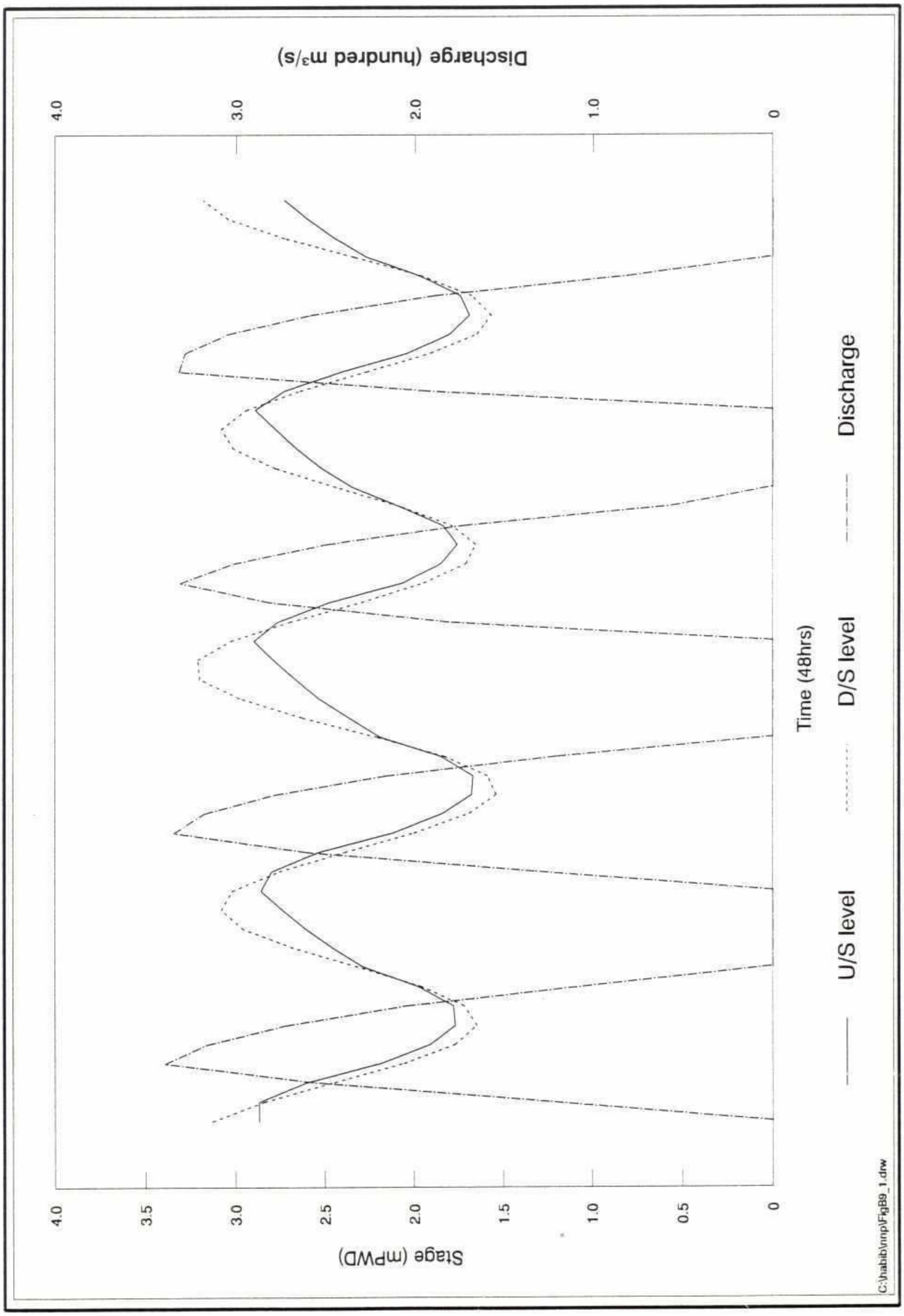


Figure B.9.2

Water Level Profiles along WAPDA Khal
1:5 Year Levels

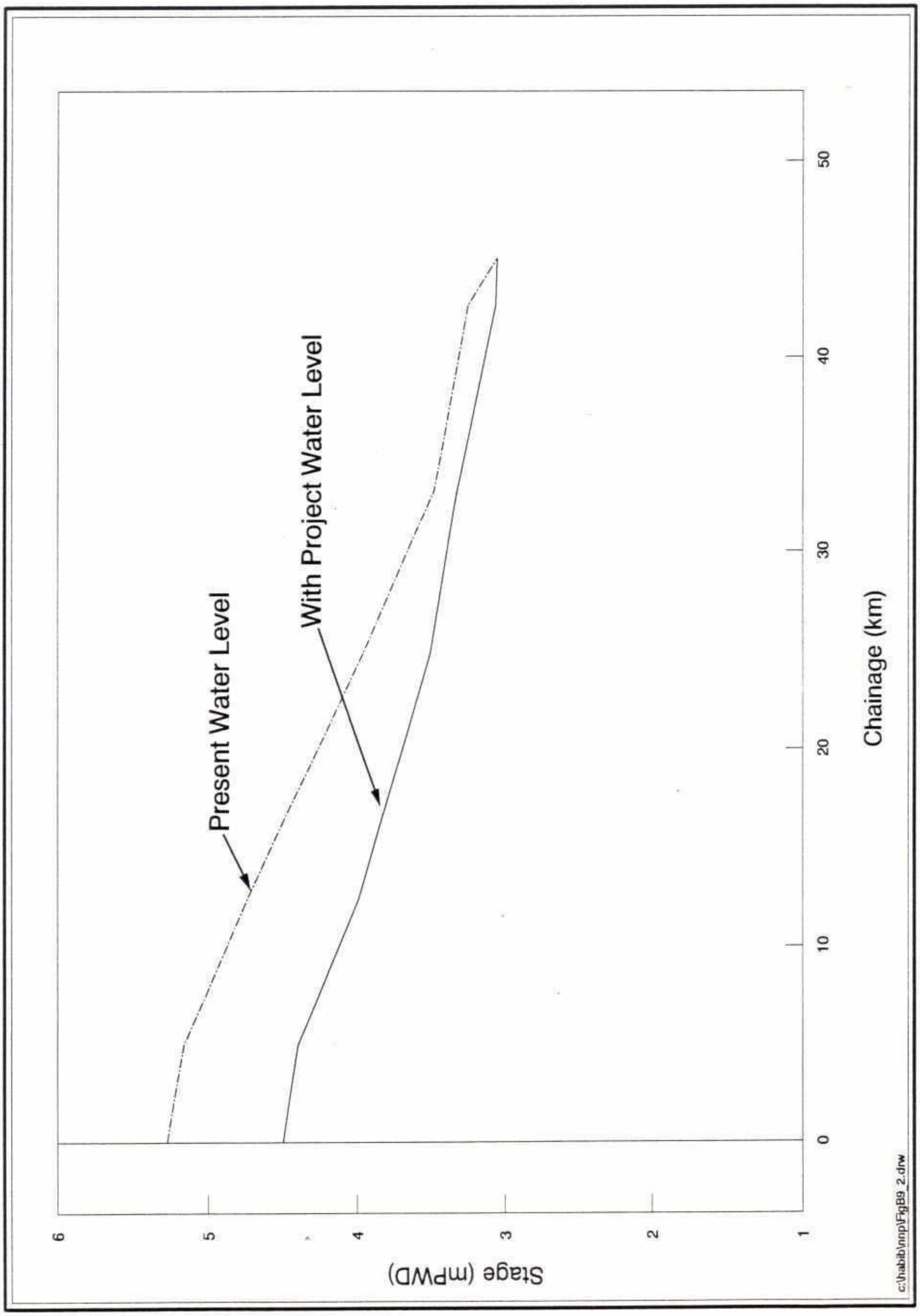


Figure B.9.3

Monsoon Season Water Level at Chandraganj

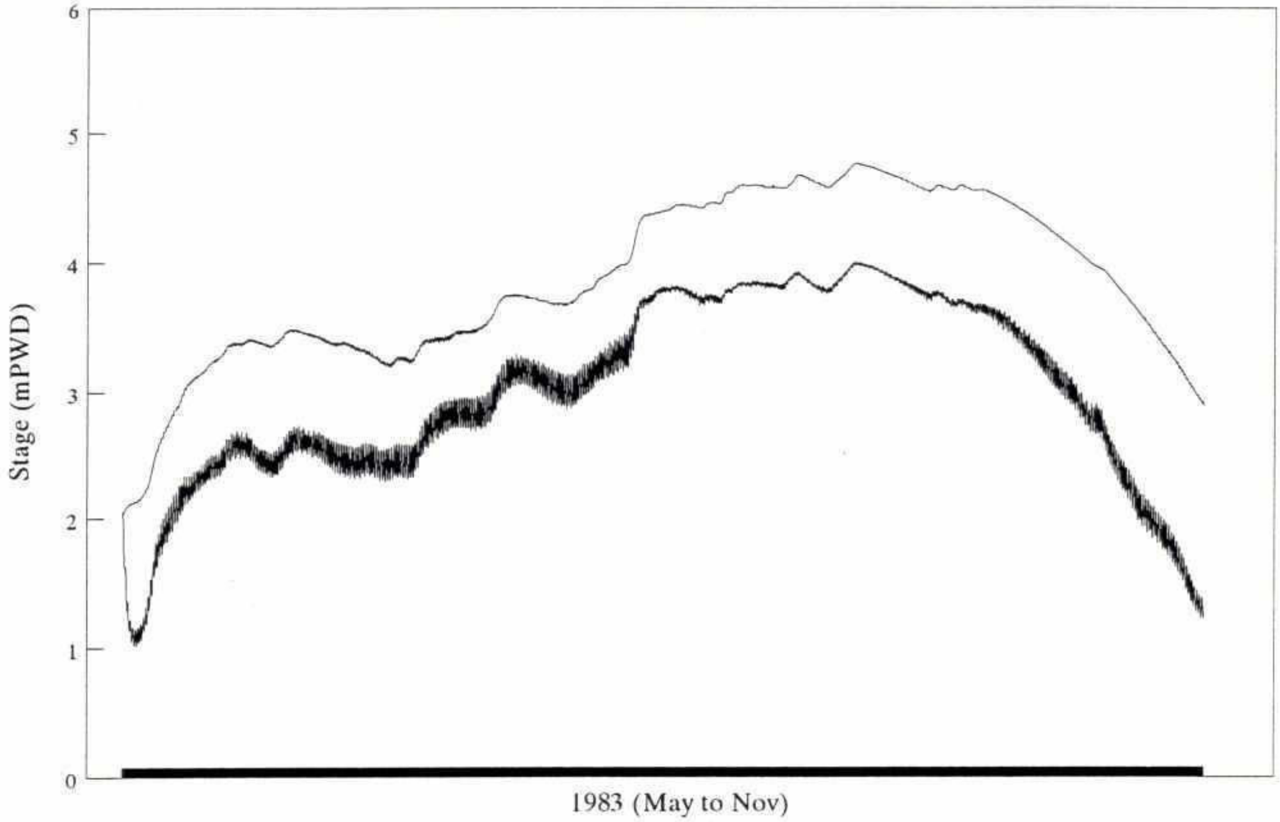
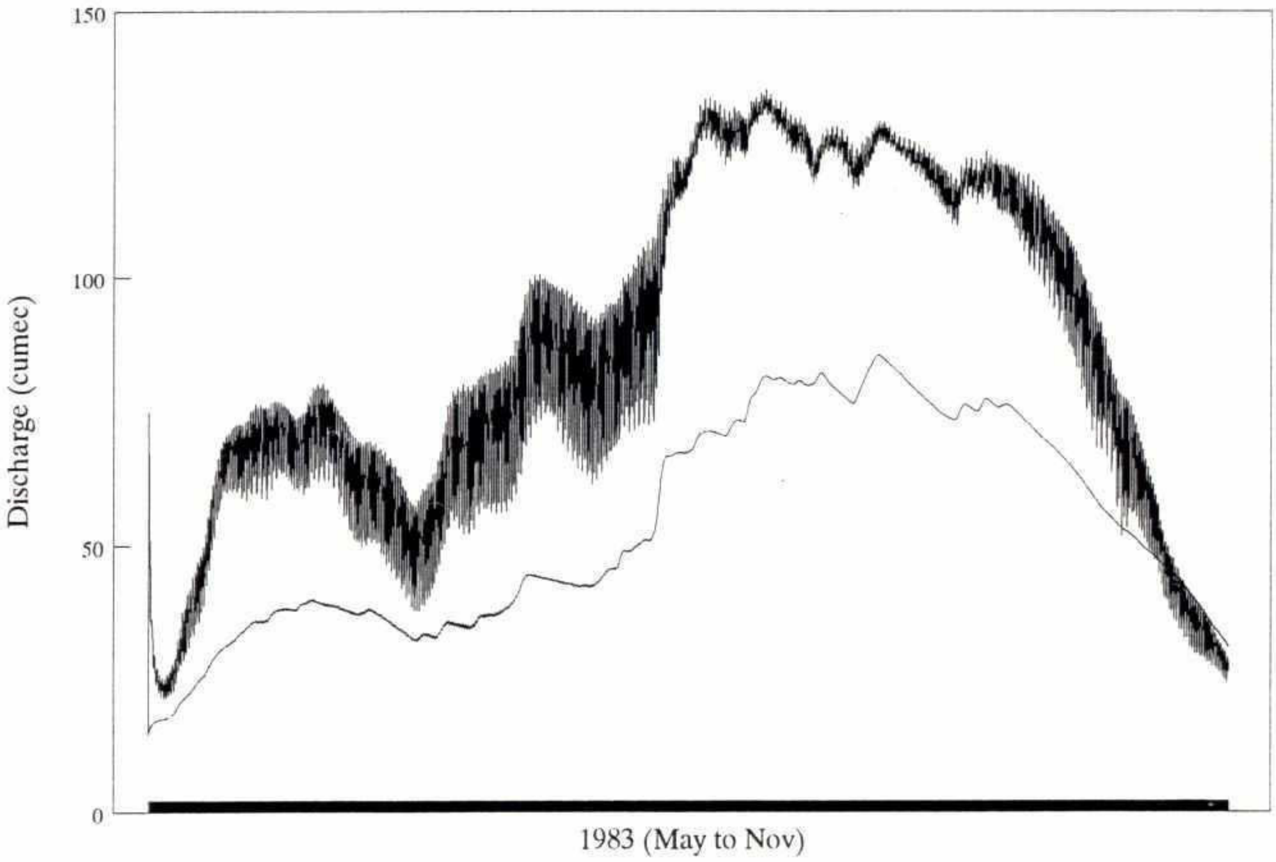


Figure B.9.4

Monsoon Season Discharges Upstream of Chandraganj



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Under With Project conditions discharges are increased significantly, more than 50% at the peak, which leads to improved drainage of the area upstream. Again, Figure 9.4 demonstrates how the tidal influence has extended further upstream in the With Project conditions.

The 1:5 year discharge through Rahmatkhali regulator is about 500m³/s whereas under present conditions the 1:5 year discharge is 310m³/s. The maximum discharge through the regulator is about 540m³/s.

B.9.2.3 Flood Phases

The most effective means of summarising the benefits and disbenefits of the proposed interventions is by considering the impact these have on flood phases throughout the project area.

A comparison between the flood phases for With and Without conditions within the project area is presented in Table B.9.1; figures in brackets refer to Without Project conditions.

TABLE B.9.1

With Project Simulation Flood Phases for Noakhali Project Area

Area	Flood phase (%)			
	F0	F1	F2	F3+F4
A1	94(92)	6(8)	0(1)	0(0)
A2	90(78)	10(21)	0(1)	0(0)
A3	100(100)	0(0)	0(0)	0(0)
B1	31(0)	57(15)	12(80)	0(5)
B2	59(9)	40(46)	1(44)	0(1)
B3	2(1)	54(43)	44(56)	0(0)
B4	17(0)	79(7)	4(92)	0(1)
B5	94(9)	6(70)	0(21)	0(0)
C1	69(24)	31(65)	0(11)	0(0)
C2	23(2)	74(73)	3(25)	0(0)
C3	14(2)	56(22)	30(76)	0(0)
C4	15(7)	36(21)	49(71)	1(1)
C5	11(6)	37(26)	52(67)	0(1)
C6	93(61)	7(37)	0(2)	0(0)
C7	93(7)	7(74)	0(19)	0(0)
C8	59(1)	40(29)	1(70)	0(0)
D1	4(0)	48(12)	48(84)	0(4)
D2	7(5)	48(12)	45(81)	0(2)
D3	10(1)	82(31)	8(68)	0(0)
D4	2(0)	20(4)	78(95)	0(1)
D5	0(0)	24(17)	71(77)	5(6)
D6	0(0)	8(3)	88(83)	4(14)
D7	0(0)	24(8)	76(90)	0(2)
D8	0(0)	9(3)	90(92)	1(5)

Note : Figures in brackets are for Without Project situation

In the With Project situation there is a reduction in the depth of inundation throughout the entire Noakhali project area. The greatest shifts in flood phases occur in the Begumganj depression although this in turn has beneficial effects along the tributaries and distributaries which drain through this area. The area immediately to the east of the Begumganj depression shows a less marked improvement in flood phases as it lies on the ridge of slightly higher ground which divides the Begumganj depression from the Little Feni.

In the northern part of the project area there has been some improvement in the flooding regime but this much less than that in the central and southern areas.

An areal plan of the flood phase distribution based on a minute square analysis is shown in Figure B.9.5 (for comparison with the equivalent Without Project analysis see Figure B.6.2). The relative change in flood phase is given in Figure B.9.6.

A listing of model predicted flood phases for the areas adjacent to the Noahkhali project area are given in Table B.9.2.

TABLE B.9.2

With Project Simulation Flood Phases
Adjacent to Noakhali Project Area

Area	Flood phase (%)			
	F0	**F1**	**F2**	**F3+F4**
KZ	100(95)	0(4)	0(1)	0(0)
LF1	40(22)	58(69)	2(9)	0(0)
LF2	61(54)	18(21)	20(23)	1(2)
NAN	42(35)	28(25)	30(39)	0(1)
DKW	3(1)	58(53)	37(43)	2(3)
DKE1	0(0)	11(7)	84(85)	5(8)
DKE2	7(1)	50(36)	43(62)	0(1)
DKE3	0(0)	10(2)	90(94)	0(4)

Note : Figures in brackets are for Without Project situation

Along the north bank of the Dakatia there is a slight increase in the area of F0 and F1 land due to the lowering of water levels in the Dakatia. Along the little Feni, again there is an improvement but this is not as significant as within the project area itself.

The flood phase figures for the adjacent areas indicate that the flooding regime outside the project area has not been made worse at the expense of improvements within the project area itself.

Figure B.9.5

With Project 1 in 5 Year Peak Flood Phasing

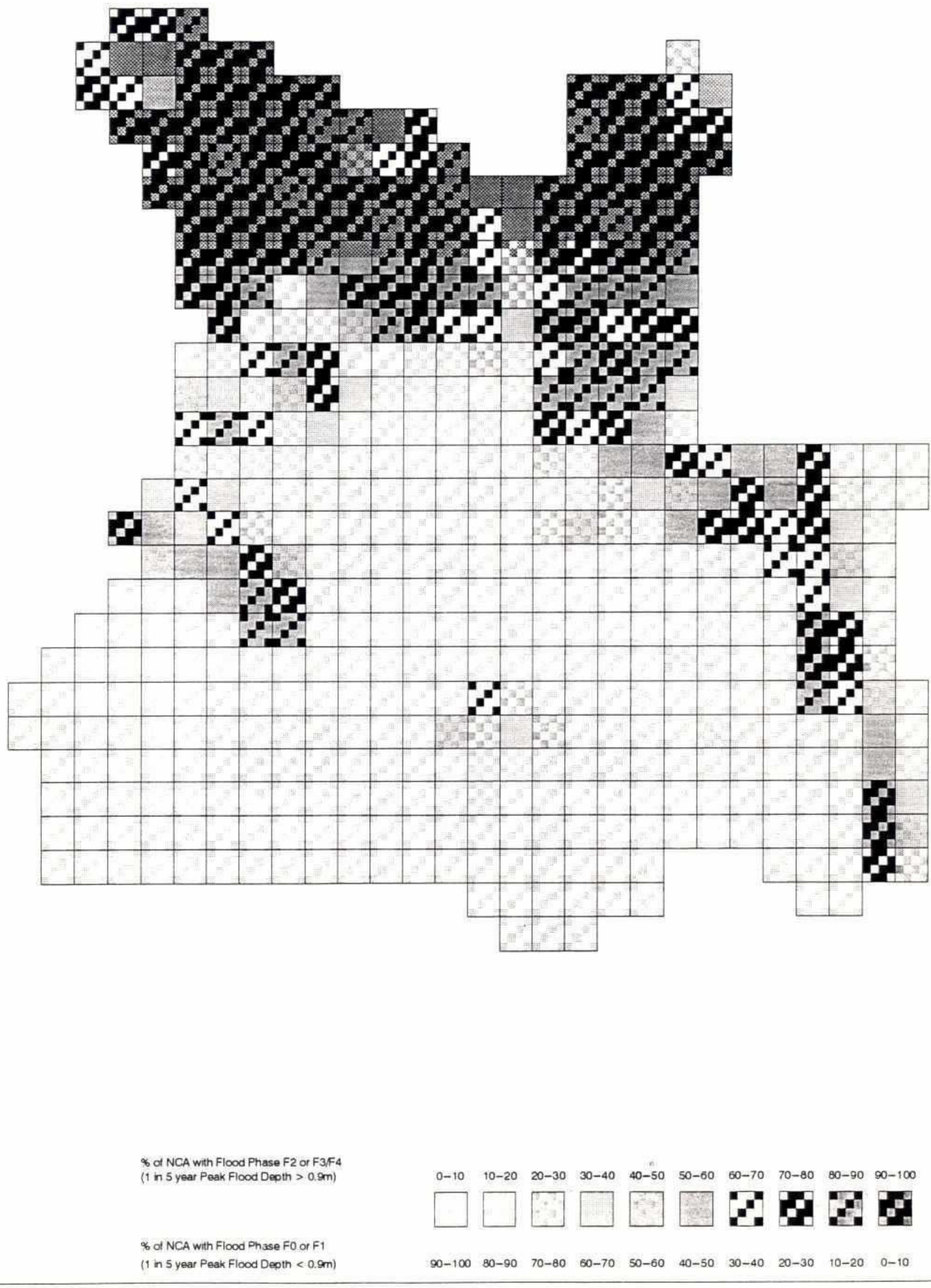

Figure B.9.6

With vs Without Changes in 1 in 5 Year Peak Flood Phasing

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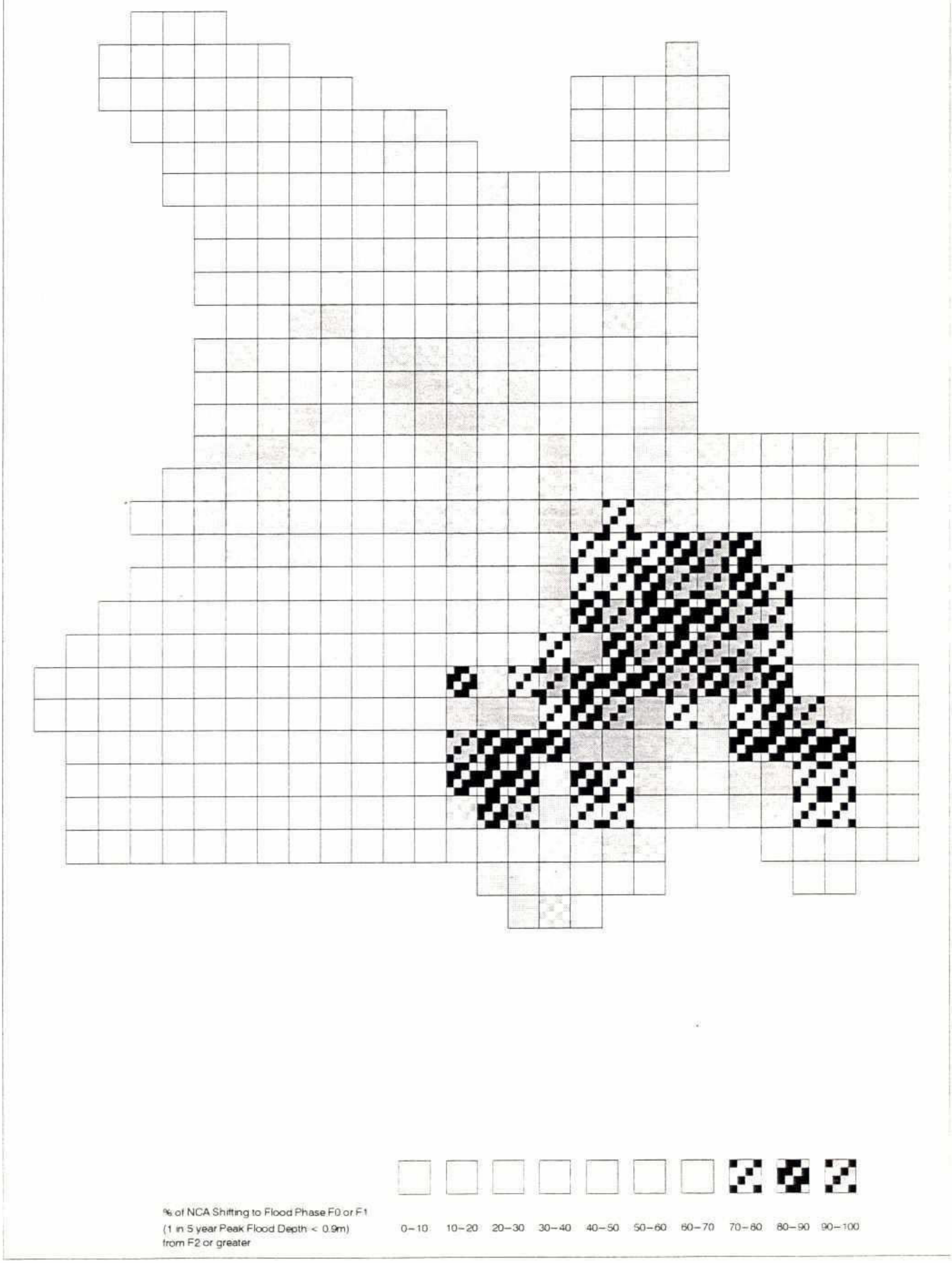


B.9.3 Sensitivity Analysis

B.9.3.1 Introduction

The final stage of the hydrodynamic modelling methodology outlined in Chapter 4 is to carry out sensitivity analysis to investigate the impact, on the proposed development plan, of changed external conditions. For the Noakhali North area these changed external conditions are changes in the water level in the Meghna as a result of various flood control options elsewhere in Bangladesh.

The Flood Modelling and Management project, FAP-25, have carried out General Model simulations to investigate the impact of a range of scenarios which are a combination of some of the following external developments:

- Sealed Brahmaputra Right embankment
- Jamuna Left embankment
- Ganges Left embankment
- Ganges Right embankment
- Padma Left embankment
- Padma Right embankment
- Old Brahmaputra embankments
- Dhaleswari Left embankment
- Dhaleswari Right embankment
- Upper Meghna Left embankment
- Upper Meghna right embankment
- Lower Meghna Left embankment
- Lower Meghna Right embankment
- Jamuna bridge
- Sea level rise

Most of the simulated developments produce changes in mean daily water level in the reach of the Meghna adjacent to the northern part of the Noakhali project area of less than +/-10cm. The maximum predicted change is 17cm, at Chandpur. These changes in level diminish downstream of Chandpur with little or no change indicated at Rahmatkhali.

B.9.3.2 Rise in Level at Chandpur

A model simulation was carried out to investigate the impact of changes in Meghna level and considered a rise in water level of 15cm at Chandpur, Molakandi and Matlab. Levels at the outfall of Rahmatkhali regulator were assumed to remain the same. This gives an increase of 15cm in the diffential head between the upper and lower reaches of the project area. This has little impact on levels in the Rahmatkhali/Wapda khal system, Figure B.9.7. Levels increase slightly but these would not threaten the viability of the proposed interventions.

Along the lower part of Dakatia river, peak levels increase by 10-15cm for some 80km from the outfall partially negating the limited with project benefits in this area. Upstream of Hajiganj, the rise in Meghna levels would largely negate the benefits along the Dakatia which were introduced by carrying out the Rahmatkhali drainage improvements.

B.9.3.3 Effect of Musapur Regulator

The Musapur regulator, located downstream of the existing Kazipur regulator, on the little Feni has an impact on levels upstream of Kazipur regulator. A simulation run was undertaken to assess whether this had any significant impact on water levels in the project area, in the vicinity of the Begumganj depression.

Long profiles of peak water levels (1983) along the Wapda khal, with and without Musaprur in place, indicate that there is no significant change, see Figure B.9.8. Maximum changes are in the order of 1-2cm. Analysis of discharges in the link channels between the Little Feni and the Begumganj depression show these to be small which further substantiates these results.

The developments associated with the Rahamatkhali drainage system are therefore not dependent on those in the Little Feni and can be carried out independently.

Figure B.9.7

Sensitivity Analysis Long Profile along WAPDA Khal

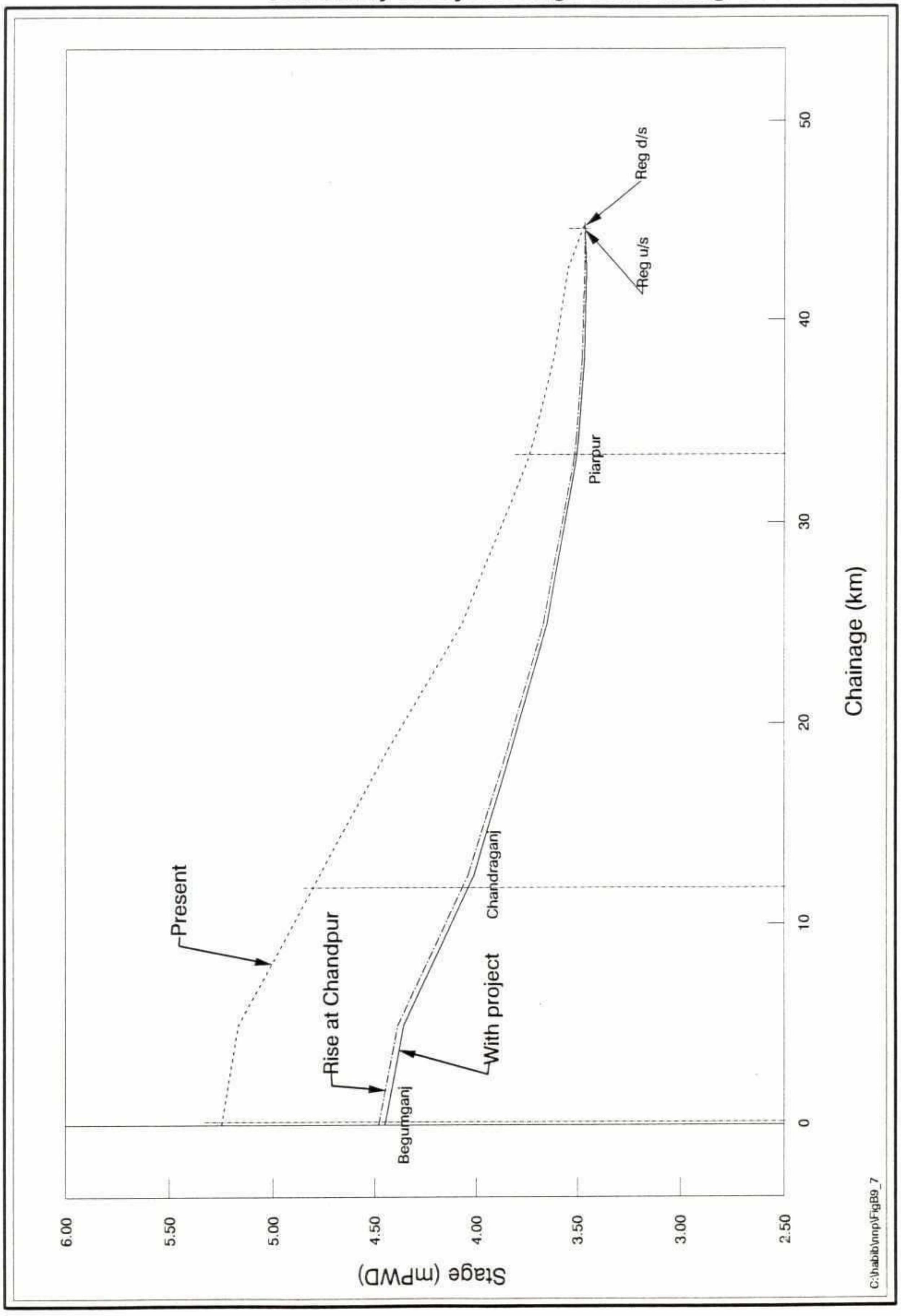
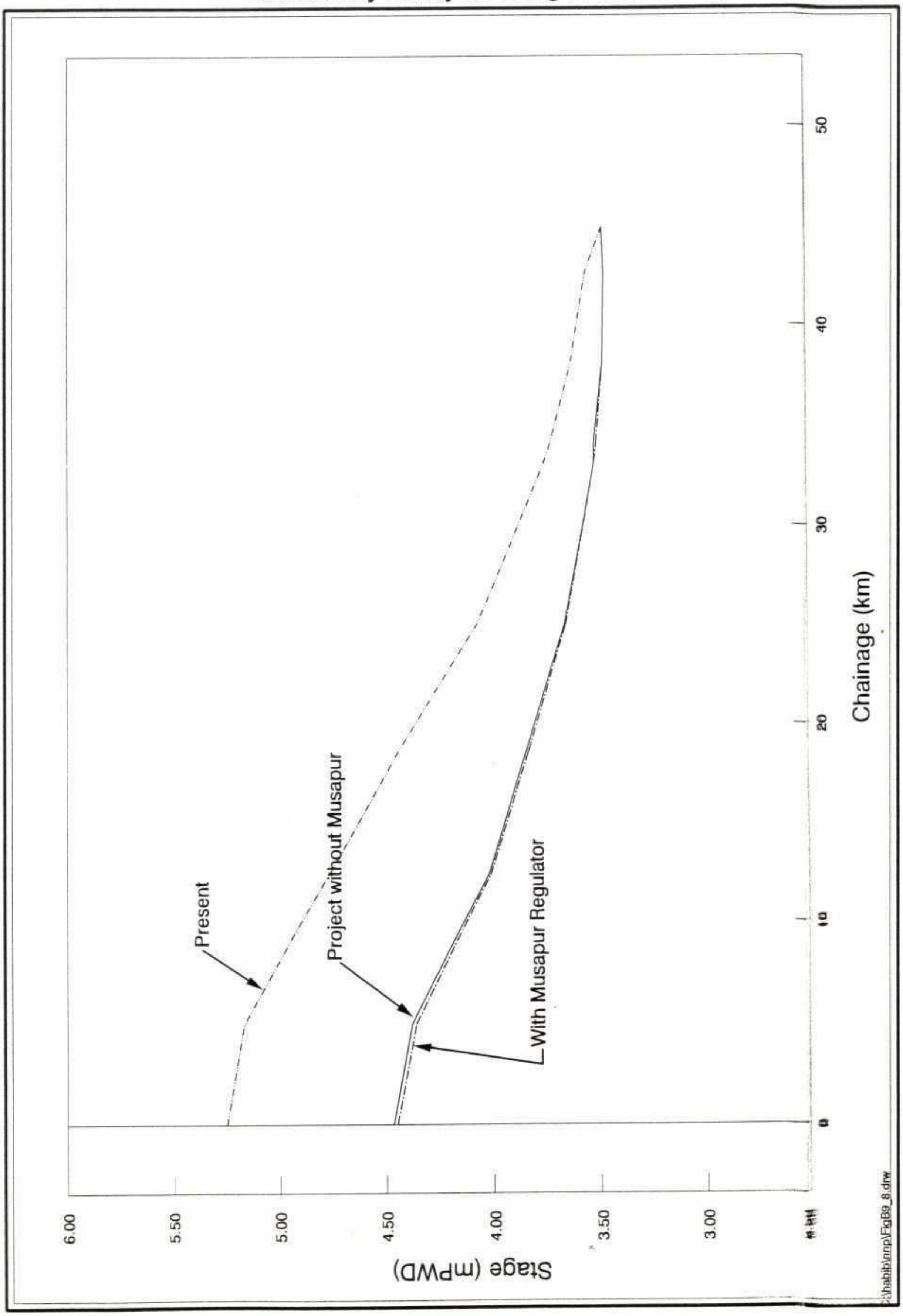


Figure B.9.8

Sensitivity Analysis Long Profile along WAPDA Khal



CHAPTER B.10

CONCLUSIONS AND RECOMMENDATIONS

B.10.1 Conclusions

Hydrodynamic modelling of the Noakhali North area has brought the complex hydraulic regime into an analytical framework. It has to be an invaluable tool with which to assess and understand and present flooding problems and to assess the impacts of measures to alleviate these problems.

Catchment area weighting method were used to estimate the flows from the ungauged catchments in India. This method gave discharge hydrographs with the expected flashy response. The NAM estimated discharges gave much smoother discharge hydrographs.

Tidal analysis was used to generate tidal boundary conditions along the River Meghna, based on the General Model results. Comparison with both dry season and monsoon conditions gave a reasonable correlation between generated and observed water levels.

Irrigation development in the Rahmatkhali drainage system can be greatly enhanced by the retention of tidal inflows behind t he regulator and the deepening of the khal network.

A similar development by the provision of a regulator on the Dakatia is not viable. without this regulator, the volumes of water entering the Dakatia and its associated khal system are insufficient to provide the same level of irrigation development as that in the Rahmatkhali basin.

Increasing the number of vents at the Rahmatkhali regulator site whilst raising the sill level improves flow conditions upstream of the regulator. In association with re-sectioning/re-grading of the khal system, these measures have significant benefits in terms of reduced levels of flooding.

Flood control options elsewhere in Bangladesh are unlikely to affect the impact of the recommended developments.

The developments in the Rahmatkhali basin are basin are effectively independent of those for the Little Feni as there is interaction between the two.

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B.10.2 Recommendations

Further detailed hydrodynamic modelling should be carried out at the detailed design stage; the boundary conditions for these models should be provided by the most appropriate hydrodynamic model which is available at the time.

At the detailed design stage the hydrodynamic model should be updated using the latest hydrometric and topographic information, including the FAP 5 cross-sectional surveys. To obtain the maximum benefits the model should be linked to a digital elevation model. it is suggested that the most recent mapping should be used to generate a DEM using the FAP 19 system.

Linking the model output results to other post-processing programs has enabled the models to be used in a much wider context than that of simply predicting water levels and discharges within the modelled river reaches and drainage channels. Further work should be undertaken on these applications.

REFERENCES

- The Agro-Climatic Survey of Bangladesh - by Manalo
- Net Irrigation Requirement of Rice and Evapotranspiration of Wheat and Potato for Different Locations in Bangladesh" - by Karim and Akland
- South East Regional Study Draft Final Report, 1992 - by Mott MacDonald and Associating Companies
- MPO Water Balance Study
- Bureau of Consulting Engineers in Association with Sir William Halcrow and Partners Gumti Phase II sub-project Feasibility Study Final Report, March 1990
- Hydrological and Morphological Modelling of the Gumti-Titas and Atrai River Basins Final Report, April 1990 - by Howard Humphreys and Partners
- "Use of Storm and Watershed Characteristics in Synthetic Hydrograph Analysis and Application - by U.S. Soil Conservation Service
- Sediment in India - by Howard Humphreys and Partners
- MIKE 11 Scientific Documentation - by Danish Hydraulics Institute
- South East Regional Model Verification Report, November 1991 - by Surface Water Modelling Centre
- Admiralty Manual of Tides - A.T. Doodson and H.D. Warburg, Hydrographic Department, Admiralty, London, United Kingdom 1941.
- Theory of Tides - J.P. Kalwijk - IHE, Delft, The Netherlands.
- Shore Protection Manual - U.S. Corps of Army Engineers - Coastal Erosion Center, U.S.A.

APPENDIX - B.1

Pentade Analysis

Analysis of Pentades
R-260, Bhola; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-***....**.........*..................***********************************
1963	**..............**....................**********************************-
1964	---
1965	-******..**..........*..............*************************************
1966	******..***.........**.................******************************..**
1967	*************..........................**************************..***..*
1968	*.******......................**.......*******************************..*
1969	***...*****.........................*************************************
1970	**********........................**......**---**************************
1971	*..***...**...........................****..*****************..**********
1972	*************....................**....***************************...****
1973	******.*..............................****....************************...
1974	..****...**...........................***********************************
1975	********................................**....***************************
1976	****................................*************************************
1977	....................**.............**************************************
1978	*....*................................***********************************
1979	**.**********.....................**...************************.***..****
1980	*******............................*..********************************...
1981	.....***.*........................*****************************..********
1982	**....*****.........*.............***.***********************************
1983	*..................................**....********************************
1984	****......*........................**....********************************
1985	****........**................**.....************************************
1986	****.......***..........................***..****************************
1987	***....****.........................***.*************************..*.*.**
1988	***..**.............................***..********************************
1989	********.....................*........*...**********************...****.-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-261, Daulatkhan; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-****...**.........**........**.......***********************************
1963	***......*.---------.........---------***---------------****************-
1964	---
1965	-*****......*.......................ъ*************************************
1966	******...**..........................************************************
1967	***...*******...**.....................**********************************
1968	********..............*........*.***..***********************************
1969	***********........................**************************************
1970	**.....------...................****..**..**---**************************
1971	*****............................**..***-------------------------********
1972	***..*********...**.............*****.***********************************
1973	*****.................................****....**************************.
1974	..****...*.............................*.********************************
1975	********...........................********...***************************
1976	******....**.........**---..**...********************************..******
1977	....................................*************************************
1978	.....**..........................*.*.************************************
1979	************.....................**...*************************.***..****
1980	******...........................***.....*****************************...
1981	....*****........................**..************************************
1982	**....*****.......................**...**********************************
1983	*.....*............................**....********************************
1984	****...............................***...********************************
1985	**.*.....**.........................*********..**************************
1986	****...................................**********************************
1987	****....****.........................*...****************************..**
1988	*****.................................***********************************
1989	*********...*..............................******************.......***..
1990	.******................................*********************************-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-301, Amtali; Daily Rainfall (mm).

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-.***..*****.............*............***.*******************************
1963	*.....***...................*****...****.*******************************-
1964	---
1965	-********.*....**....**..........**...***********************************
1966	**********...........***.............*..*********************************
1967	****....******........***..............**********************************
1968	********....*..................*.......*******************************..*
1969	**...*****.............................**************************..******
1970	*...*****.............................**......**************************-
1971	---****************************
1972	----*****..........*.........*...**....***************************..*****
1973	****.................................*****....************************...
1974	.****....*........................***************************************
1975	**..***..................**..............*...****************************
1976	*..****..***......................*...*.*********************************
1977	....**............................***************************************
1978	********..........*........**......**************************************
1979	*****.....***..........***.......***.************..**************---****-
1980	---
1981	---
1982	---
1983	-**............................*.****...*********************************
1984	*****....................*.......***..********************************..*
1985	*****.......................******..*************************************
1986	**.....................................**********************************
1987	***.*.******.....*.......**.....*...*************************************
1988	*******..................................********************************
1989	********....*................**...........**************************.*.*-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-320, Mirsari; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-*********.........*...................**..******************************
1963	******........................*.........*.*.*********************...****-
1964	---
1965	-**.................**...............************************************
1966	**................................***...**********..****************...**
1967	*.****.....**..........................**********************************
1968	**....**...---.........................******************************....
1969	*...*****...........................*****************************..******
1970	*********..............................***..*****************************
1971	*....*.***.............................****...***************************
1972	****...**..***....**...........****....**************************...*****
1973	*****......----........................****....***********************...
1974	**......***.......................**.....********************************
1975	********..................*............**********************************
1976	.........***.......................**.*.*********************************
1977	**..**.................................**********************************
1978	******.............*..................***********************************
1979	*****.*.*****....................**...*********.*******************..****
1980	*...**.................................*******************************...
1981	***.****..........................***************************************
1982	......******...........---.............**************************......**
1983	****.....****....................****....********************************
1984	..**..............................**.....*****************************..*
1985	***....................................*********************************-
1986	---
1987	-*...*..***.....**....................***************************....***.
1988	.****.....................................*******..*********************-
1989	------**..................*...............**********************...*.*..-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-323, Narayanhat; Daily Rainfall (mm).

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-****..***........**....***............*...*****************************-
1963	-------......................*..........********************************-
1964	---
1965	-****....**..........................***...******************************
1966	******...**..........***............*********************************....
1967	****...**..***........***.......***...********************************...
1968	...*****..............**...............**********************************
1969	**...******............................**************************..******
1970	*...*****.............................**......***************************
1971	...****...***.....**................******..*****************************
1972	.*.*.****...**....***..........**********************************.*.*****
1973	****...............***...............*****.....***********************...
1974	..***...***...........................**..*******************************
1975	***..****......*..............................***************************
1976	***.**..........................***...***********************************
1977	....**********************************
1978	**..***............................*.************************************
1979	*******...***..........**..........*.**********.*****************---*****
1980	*****....................................******************************..
1981	.....***......*....................**************************************
1982	**....***---......*....................*.************************....****
1983	............***.........................*********************************
1984	****..............................**..********************************..*
1985	*****..........................***..***..********************************
1986	**...............................*.....**********************************
1987	***.....***..............**...........*.****************************.****
1988	**...***.................................********************************
1989	********....*............****............*************************.*.*..-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-327, Ramgarh; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-****..***........**.....*.............*****************************..***
1963	.....****....................---------.....****---------**********.*****-
1964	---
1965	-******..***.........................***...******************************
1966	*******..***.*......****............*********************************.***
1967	****....******........**..........*....*******************************...
1968	********...............................*******************************..*
1969	**....***...........................*************************************
1970	*********.............................**...******************************
1971	...**--*************.
1972	...*...***........***........*.****....**************************...*****
1973	****...............*.................***......************************...
1974	.*****...*................................*******************************
1975	***...***************..**********
1976	******..................................*********************************
1977	....**********************************
1978	*******................................**---*****************************
1979	*******...***..........................*******...**************.***..****
1980	***.*..............................*.*...******************************..
1981	....***..........................**
1982	**....*..***......***.............**...***************************......*
1983	............***..........................********************************
1984	****..............................**..********************************..*
1985	**.*...........................***..***..*******************************-
1986	---
1987	-**.....***......*.............**....*****************************...****
1988	**...**..................................********************************
1989	********..***...**........***............***************************.*..-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-352, Barura; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-*****..***---------------...---------------****************-------------
1963	-*..........................*****..**..**---------**********************-
1964	---
1965	-*****...***......................***************************************
1966	*******..............**................*****************************...**
1967	****...*******...*.....................*******************************...
1968	*.*****........................*.....************************************
1969	**.....****.........................****************************---*****.
1970	....******.............................*..*******************************
1971	....*.....**.....................*********..*********************---*****
1972	...*.*.***...*....**...........**********************************...*****
1973	****..................................*****...*************************..
1974	..***..................................*.********************************
1975	****.***......******.....*.........***...**..****************************
1976	******.*.***.........**.........*******.*********************************
1977	...........*.....*.............**..**************************************
1978	**..**............**......*......***.**********************************--
1979	-************...........**.......*....***********************************
1980	***..**.........****.......****.***
1981	**..*****...***.................***
1982	****..********.............***....***********************************...*
1983	*...........****..................**.....********************************
1984	*****....**........................***.**********************************
1985	*****..***.....................*.....************************************
1986	*.........**--------...........*........*********************************
1987	***.....*****...*........**...........*.**************************.*.****
1988	***...***..........................*.*...********************************
1989	*********................**...............*****************************..
1990	.**............................***.....****..****************************
1991	..***...................................*************..*****************-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-353, Basurhat; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	---********************************
1963	....*.......*****************---------------*****************************
1964	*****.*.***......................****.....************-------------------
1965	-******..........................**..***....*****************************
1966	****...**...............................*****************************....
1967	..******...............................*******************************..*
1968	**.......**....................**......**********************************
1969	*...*****.............**.............****************************..******
1970	*..**.................................***..******************************
1971	.....****...**..................**....****..*****************************
1972	******.............*..........******...**************************...*****
1973	*.****.......................*........****.....***********************...
1974	***..****.*******.....................***********************************
1975	******...**........................***....*.*****************************
1976	......*..............**.......**........*******..************************
1977	**..**................................***********************************
1978	*******.*****......................*.************************************
1979	********..........................**..*********.*****************---*****
1980	*...***.......**...........**...*****************************..********..
1981	......*******............----......**************************************
1982	*...................*.......*.....*************************************.*
1983	.***...............................**...*********************************
1984	***....................................*******************************...
1985	*...........**.....................****..********************************
1986	***.....***......................*......***..****************************
1987	**...**..............................*****************************...****
1988	*************......................***...*******************************-
1989	--------------------........*............*************************.*.*..-
1990	---
1991	---

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-354, Chandpur; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-*.......*........**.........---------******************************..***
1963	**..............**.......................*******************************-
1964	---
1965	-****....***.........*..............*************************************
1966	******..***.........**............**...******************************..**
1967	****...******....*.....................*******************************...
1968	..******..........................***..**********************************
1969	***..*******..........*****...**....************************************.
1970	..********.......................***..**..*******************************
1971	***......***......................*...****..******************.*********.
1972	...*.*****..**.................**********************************...*****
1973	******.............*.......*...*......****....*************************..
1974	.****....**...............*............**..*****************************-
1975	---
1976	-********.............**.......**********************************..******
1977	...................***.....**..***.
1978	.**..**............*........*....**..************************************
1979	*******.*.........................**...********.*************************
1980	*****...........**...*............************************************...
1981	....****.....****.......**....********************************..*********
1982	**.......***........*...............********..********************.....**
1983	*...........***.....**.............*....*********************************
1984	*****....**........................***.*.********************************
1985	**.*....*............................************************************
1986	****...*.*.***.........................**********************************
1987	*.......*................**.........***.*************************..*.****
1988	**....**..........................****...********************************
1989	********....................***.......*...*****************************..
1990	..**..**...............................**********************************
1991	...**...........***................*.*.**********************...********-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-355, Chhagalnaya; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-.***..***.........................---------*****************************
1963	**.........---------........*.***......*...*****************************-
1964	---
1965	-*****...**.........**...............************************************
1966	*******..**...........*................*********.*.*****************...**
1967	*********..***.........................*******************************...
1968	*.******..................**.***......********************************..*
1969	**....******..........**............*****************************..*****.
1970	.**..***..............................**...*****************************-
1971	--.****...........................***...**...****************************
1972	......***...**.....**..........******..**************************...*****
1973	****---............**................*****....************************...
1974	..****....................**...*****...*.********************************
1975	***......***..******.....*.........**....*....*************..************
1976	******................**......**........*************************..******
1977	..................................*....***..*****************************
1978	******......................*......*...**********************************
1979	*******...***.........................*********.***************.*********
1980	***.*..............................*.**********************************..
1981	....****..........................***************************************
1982	*.......***.......................**..***************************...***.*
1983	............****.........................********************************
1984	****..............................**...*******************************...
1985	.*.*...--------.................**..*************************************
1986	*.........******.......................******************************..**
1987	***....****.....**............***...*************************************
1988	**....*.*...............................*********************************
1989	**********......**.......******...........*****************************.-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-358, Feni; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-..*...****.............---------**
1963	*...---.....................*******---------------------**************..-
1964	---
1965	-******..****........................****...*****************************
1966	*******..**.........................********************************...**
1967	****........*.........................********************************...
1968	...*****..............*........**.....********************************..*
1969	**....***.............**.........**..***********************************.
1970	.********.............................**...******************************
1971	*.........*........**...........**********..*****************************
1972	**********..**....***..........***********************************...****
1973	****..............**.........*.......*****.....************************..
1974	.****....*...............**.......**...**********************************
1975	*******..***..**............*...........***...**********************.****
1976	******.............................*.****************************..******
1977	..................................**..*********************************..
1978	.**................................*.************************************
1979	*************.........................*********.*************************
1980	*****......*....**.....................**..*******************.*******.*.
1981	*...****..........................***************************************
1982	*---.....***.........................*******..****************.*....*****
1983	*..********************************
1984	*****.................................***********************************
1985	**.*................................*************************************
1986	.........*****.........................******************************..**
1987	***.....***.....*...............*...***.**************************.******
1988	**...**..................................********************************
1989	********..................**..............************************..***..
1990	....****..****************..*********.
1991	..***.....................*.........********************..******..******-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-359, Gunabati; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-***...***........**.................************************************
1963	***..***********************..****-
1964	---
1965	-*****...***.........................***...******************************
1966	***.*******.............................********.*.**********************
1967	****...**...**.........................*******************************...
1968	*.******............---...............****.*.*************************..*
1969	**...*******.........*........*...---****************************..******
1970	*********.............................**...******************************
1971	******...**..--------------**----.......**..*****************************
1972	*****..***.......***.*.*........**.....**************************.*******
1973	****.........................*....*...**********************************.
1974	..*********.......*...............**..***********************************
1975	*****************.......******..........***..***************************-
1976	---
1977	-------------.....................**..****...****************************
1978	******.............*..............*.*.***********************************
1979	*************...........**.......***..*********..************************
1980	*****...........**..................*******************..***************.
1981	....***..................**...***
1982	*........**................**.....*******************************...****-
1983	---
1984	-*****.................................*******************************..*
1985	******..............................***..********************************
1986	.........*.*****.......................**********************************
1987	*........***..........................*.**************************...****
1988	**...***.............................*...********************************
1989	********..**.............**.........***.*******************************..
1990	..******..**..........................*****..****************************
1991	..***................................*.**************..*****************-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-360, Hajigang; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-***...***.........*.....*............**********************************
1963	**............................**.........************************..****-
1964	--
1965	-*****...***.......................*************************************
1966	***.*******.............................********.*.*********************
1967	**********..**........**...............******************************...
1968	...*****..............................*******************************.**
1969	**....****......................*......*******************************..
1970	....********...........................*..*****************************-
1971	------*****...........................****...**************************.
1972	..***..***..*......*..**......****..*.**************************....****
1973	*****.............**...................***....************************..
1974	.****................................***..***************************..*
1975	****.***.................***.......*....***..***************************
1976	*..***................*...........**************************************
1977	.............*.................**..***.*********************************
1978	*******..........*..........*....***.*********************************..
1979	**************.........****.......*...*********..***********************
1980	*****....**..........*.*.*.*......************************************..
1981	....******....*..........*.........*************************************
1982	**.....******..............**.....******************************...*****
1983	*.........*****.....**....**............********************************
1984	*****..............................***.******************************..*
1985	**.*.............*.......***....**...***********************************
1986	*...*.***********............***.......*********************************
1987	***....*****....***......**..........****************************...****
1988	**...***.............................**..*******************************
1989	**********........****...................****************************.*.
1990	*.*...**...................***.***.....****..***************************
1991	..***...........*****..............*.*.*********************...********-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-361, Hatia; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-------****..................**.......**********************************
1963	.......***......**.................*.**********************************-
1964	--
1965	-******...*..........................*......****************************
1966	******..***............................******************************.**
1967	****...******..........................******************************...
1968	*.******..............................**********************************
1969	********...............................*********************************
1970	**********............................**..**---*************************
1971	....*.............---...........***..***---.****************************
1972	**.....***..**..................**....***************************..*****
1973	*****................................****....************************...
1974	.**********..................---........********************************
1975	********...............................***...***************************
1976	******...............................***************************..******
1977	.....................................***********************************
1978	**..***............................*...*********************************
1979	*************...................**...***************************---*****
1980	*******..........................**..*****************..**************..
1981	....***...........................**************************************
1982	***...******.........................****************************.***..*
1983	*...*.....*.........**..................********************************
1984	****......*......................****...********************************
1985	**.*................................************************************
1986	**........***...................*....***********************************
1987	****....***.*.......................***.********************************
1988	*******.................................******.************************-
1989	--

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-363, Laksam; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-.....****........********...**....---------**********-------------------
1963	--------------------------------.....***********************************-
1964	---
1965	-*****...****......****.........*.***************************************
1966	***********..........**...........***********************************..**
1967	****...***..**.........................*******************************...
1968	*.******..........................***..**********************************
1969	**....*.*.*.........................*****************************..******
1970	...*******........................**...*..*******************************
1971	*........***.......**...........***.....**..*****************************
1972	*..*******..**................*******..**************************.*******
1973	***................**.................****....*************************..
1974	..***....**...............*...........***********************************
1975	****----------------------..*...........**...****************************
1976	******.............................**...*********************************
1977	.................................***.*****..*****************************
1978	**..**.................................********************************..
1979	*******.*****..........**.........**..*********..****************---*****
1980	****..................................********************************...
1981	.....***..........................***************************************
1982	**.......***........*.............********************************.....**
1983	*..................**....................********************************
1984	*****.....*.......................************************************..*
1985	*****...*............................************************************
1986	..........******.......................**********************************
1987	***.....***.....*.........*.........******************************....***
1988	***...............................***************************************
1989	*********...................***.........****************************.*...
1990	.***............................**....*****..**************************..
1991	...**..............................*....*********************...*.******-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-364, Lakshmipur; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-**.....**....................***.....***********************************
1963	*...---................................*.---****************************-
1964	---
1965	-**.*....***........................*************************************
1966	*****...***.............................****************************..***
1967	*************....................---..********************************...
1968	..******......................**...*.*********************************..*
1969	***.....*...........................*************************************
1970	*...*****.........................*.......*******************************
1971	*...*....***..........................****..*****************..**********
1972	**...****...**...................*....***************************...*****
1973	******................................****....*************************..
1974	..***....*............................***********************************
1975	*********.*..............*........**....**...****************************
1976	****...*.........................*.****.*************************..******
1977	................................*......***..*****************************
1978	******..........................**...************************************
1979	.*....*******....................***..***************************---.****
1980	*******.........**...........*......*************************.*********..
1981	......*...........................**.************************************
1982	**.....*.*........................********************************..*****
1983	...........***......**...................********************************
1984	*******...*.......................**...*********************************
1985	***********....................*.....************************************
1986	******...*.*............................***...***************************
1987	*.......****........................**...********************************
1988	********..............................*..********************************
1989	********.................****..............***************************...
1990	....**********************************
1991	...**...................................********************************-

Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-369, Noakhali; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-***...***.........*.................***********************************-
1963	-------...............................****************************..****-
1964	---
1965	-****....**.........................*****...*****************************
1966	**********..........**.................*****************************...**
1967	****...***.............................*******************************...
1968	*.******...........................*...**..***************************..*
1969	***...***...........................*************************************
1970	*...*****.............................**...******************************
1971	*..***...**......................**....***..*****************************
1972	**...****...**...................****..**************************....****
1973	*****.................................**......************************...
1974	.****....**............................*.*******************************-
1975	---
1976	-*****..................................*********************************
1977	...................................*******..*****************************
1978	*...**...........................*.*...********************************..
1979	*******.*****.....................**..********...**************.*---*****
1980	*****.................................*********************************..
1981	....***..............................************************************
1982	**....******........*................***************************---****.*
1983	............*......................**...*********************************
1984	*****..............................**....********************************
1985	**.*................................***..********************************
1986	..**.........*.........................**********************************
1987	***.....***..........................*****************************.*.****
1988	**....*..................................******************************.*
1989	*********..**.............................*********************.....***..
1990	......**...............................****..****************************
1991	...**..............................*.......******************.....******-

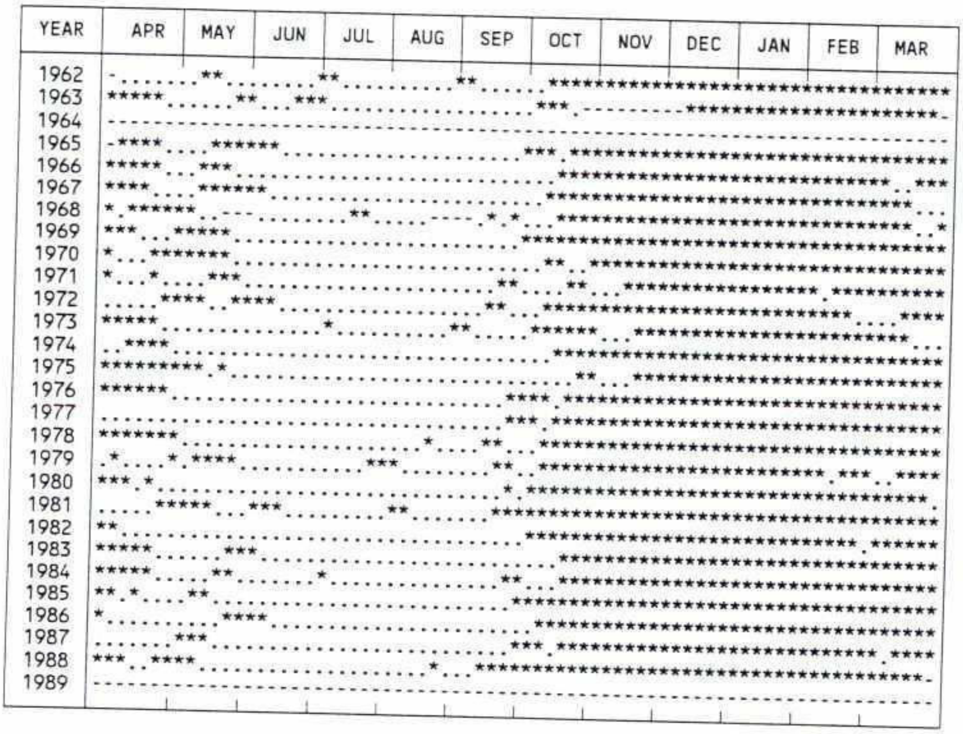
Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-370, Parshuram; Daily Rainfall (mm)

YEAR	APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
1962	-***...***...........................*******************************..***
1963	....*....****************************-
1964	---
1965	-*****...***........................*************************************
1966	************......................**********************************..***
1967	****....******........................********************************...
1968	*.******.............---.......*...*.*********************************..*
1969	**....****......................**..************************************.
1970	.*.******.......................*.....**...*..***************************
1971	...***..---......................*.....**********************************
1972	****.*****..**....**...........*****...**************************...*****
1973	****.........................*........****....*************************..
1974	.****.....---..---..................****...******************************
1975	***..****.*....***.......*............*.***...*************************--
1976	-*****....**..........**......*****..************************************
1977	.................................***...****.*****************************
1978	**...*.............................*.*.**********************************
1979	**.**********..........****......**...********...************************
1980	****............**................**.***********************************.
1981	....****.....**...................***************************************
1982	***..**..***.......................*..***--------------------------------
1983	-...................**...................********************************
1984	****........*.........................********************************..*
1985	**.................................**************************************
1986	..........****..........................*********************************
1987	***.....***......*.......**....*......*.**************************...****
1988	**...**............................***...********************************
1989	*********............**...*.***..........*************************.*.*..-

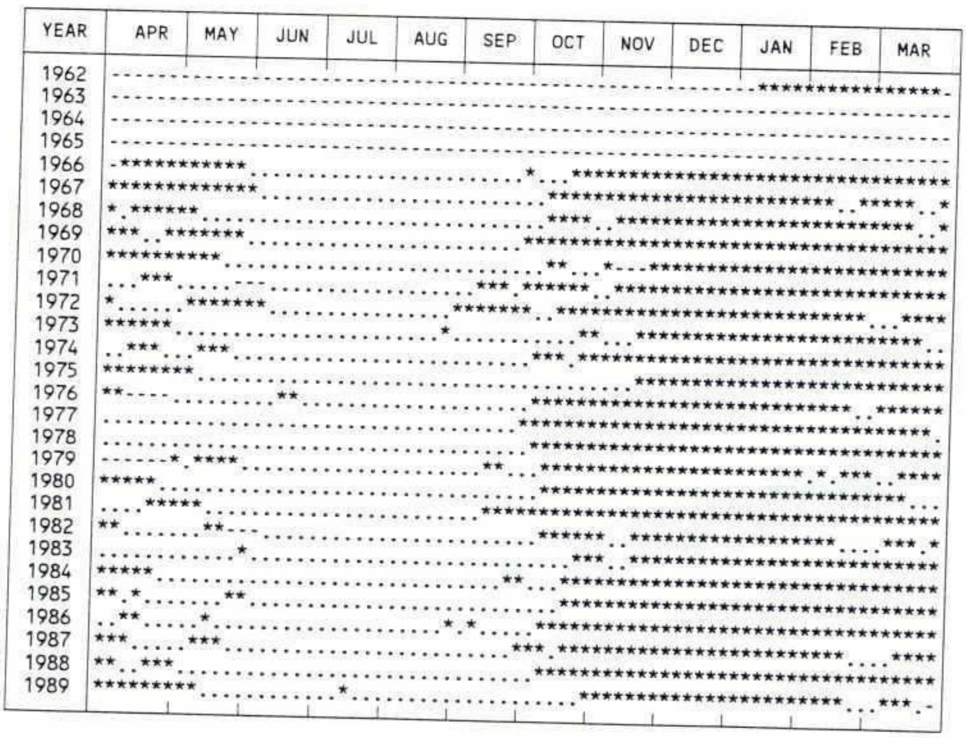
Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-372, Raipur (Noakhali); Daily Rainfall (mm)



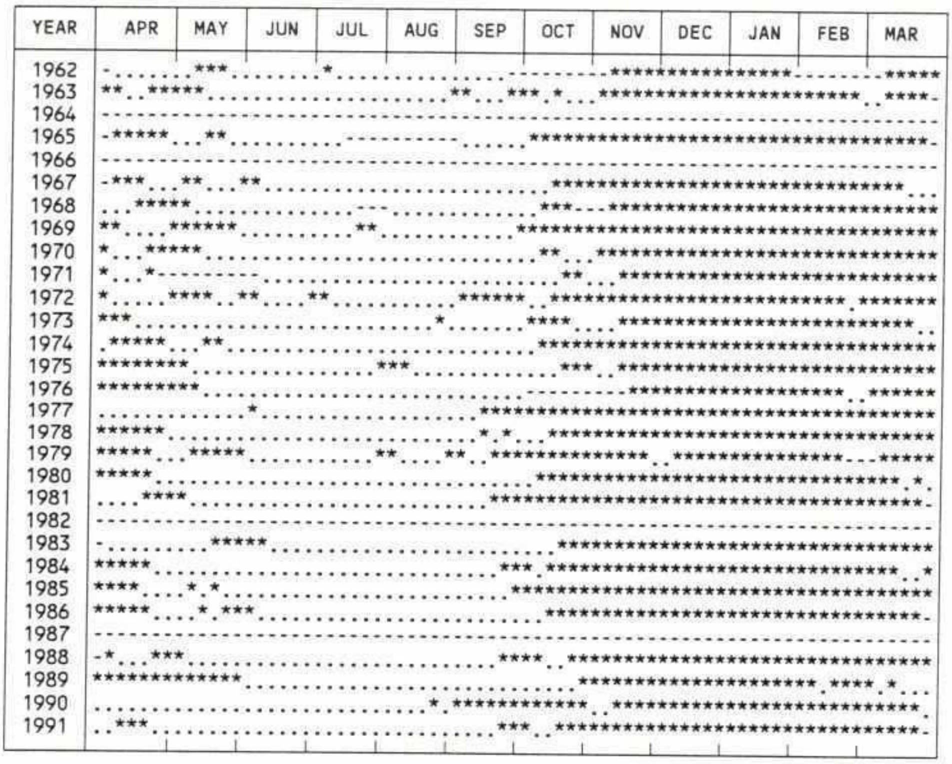
Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-375, Ramgati; Daily Rainfall (mm)



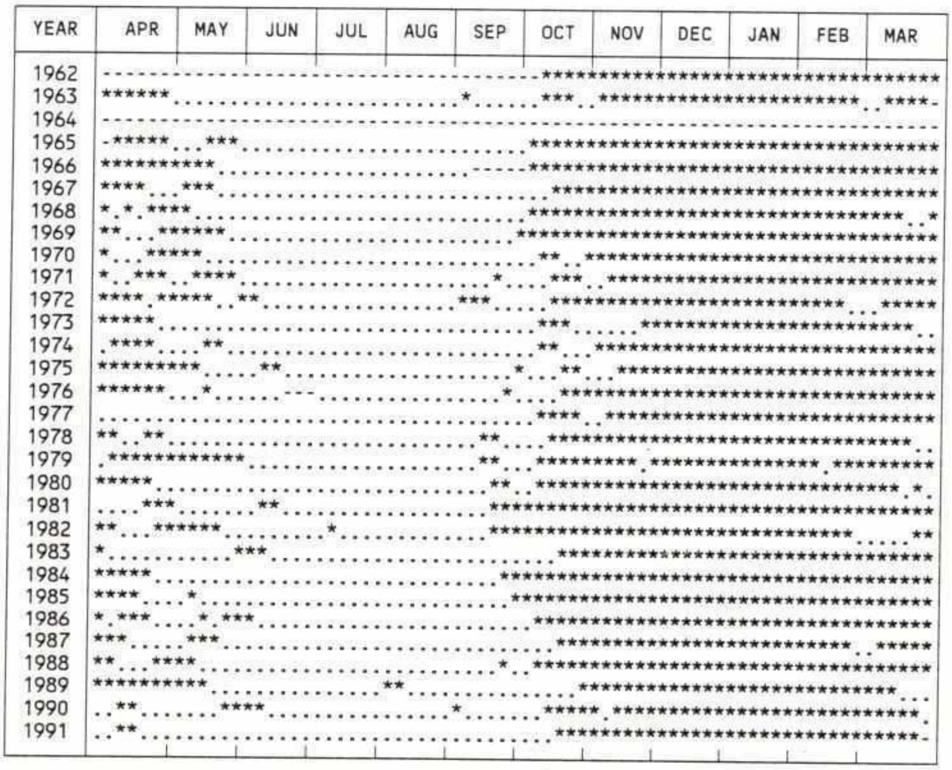
Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-376, Senbag; Daily Rainfall (mm).



Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

Analysis of Pentades
R-377, Sonaimuri; Daily Rainfall (mm)



Note: * represents a dry pentade
Note: . represents a wet pentade
- represents missing data

APPENDIX - B.2

Frequency Analysis of Seasonal and Annual Maximum Rainfall

Annual Maximum Pre-Monsoon Rainfall
R-260, Bhola; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	109	141	162	183	209
2	150	188	213	236	267
3	179	228	261	292	332
4	203	270	314	357	412
5	223	302	355	405	470
7	258	353	416	476	553
10	314	415	481	545	628

Annual Maximum Mid-Monsoon Rainfall
R-260, Bhola; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	109	145	169	193	223
2	151	205	241	276	321
3	181	252	300	345	404
4	205	289	345	398	467
5	228	315	373	428	500
7	266	360	422	481	558
10	315	423	495	564	653

Annual Maximum Post-Monsoon Rainfall
R-260, Bhola; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	104	148	177	205	242
2	140	196	233	268	314
3	156	222	266	308	363
4	167	232	275	317	370
5	175	244	289	333	389
7	192	274	328	380	447
10	216	311	373	433	511

Annual Maximum Rainfall
R-260, Bhola; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	154	185	205	225	250
2	205	248	277	305	340
3	241	299	338	375	422
4	266	338	386	433	492
5	292	370	421	470	534
7	343	427	483	537	606
10	402	495	557	616	692

Annual Maximum Pre-Monsoon Rainfall
R-261, Daulatkhan; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	101	136	159	181	209
2	142	194	229	262	305
3	173	238	280	322	375
4	203	273	319	363	421
5	224	302	354	404	469
7	271	368	431	493	572
10	320	436	513	587	682

Annual Maximum Mid-Monsoon Rainfall
R-261, Daulatkhan; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	104	138	161	183	211
2	168	229	269	308	358
3	214	296	350	402	470
4	244	337	398	457	534
5	271	370	436	499	581
7	319	437	515	589	686
10	389	516	600	680	784

Annual Maximum Post-Monsoon Rainfall
R-261, Daulatkhan; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	104	153	186	217	258
2	155	257	325	391	475
3	183	295	369	440	532
4	199	320	400	477	576
5	213	336	418	497	598
7	234	355	436	514	614
10	269	401	489	573	683

Annual Maximum Rainfall
R-261, Daulatkhan; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	136	179	207	233	268
2	216	301	357	410	480
3	262	360	425	488	568
4	300	404	472	538	623
5	325	433	505	573	662
7	379	494	569	642	736
10	452	574	655	733	833

Annual Maximum Pre-Monsoon Rainfall
R-301, Amtali; Daily Rainfall (mm).

Duration Days	Return Period (years)				
	2	5	10	20	50
1	151	235	290	343	411
2	214	325	398	469	560
3	261	414	515	612	738
4	297	480	600	716	866
5	324	518	647	771	931
7	366	575	714	846	1018
10	417	642	791	934	1120

Annual Maximum Mid-Monsoon Rainfall
R-301, Amtali; Daily Rainfall (mm).

Duration Days	Return Period (years)				
	2	5	10	20	50
1	153	202	235	266	306
2	230	315	370	424	493
3	301	406	476	543	629
4	357	486	571	653	759
5	395	540	636	728	848
7	459	629	741	849	989
10	537	752	895	1031	1208

Annual Maximum Post-Monsoon Rainfall
R-301, Amtali; Daily Rainfall (mm).

Duration Days	Return Period (years)				
	2	5	10	20	50
1	78	124	154	183	220
2	105	157	191	224	266
3	122	193	240	285	343
4	130	206	257	305	367
5	140	219	271	322	387
7	151	234	288	341	409
10	173	260	318	374	446

Annual Maximum Rainfall
R-301, Amtali; Daily Rainfall (mm).

Duration Days	Return Period (years)				
	2	5	10	20	50
1	184	262	313	362	426
2	264	374	446	516	607
3	336	486	585	680	804
4	393	575	694	809	958
5	425	626	759	887	1052
7	486	700	842	978	1155
10	568	813	976	1132	1333

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Annual Maximum Pre-Monsoon Rainfall
R-320, Mirsari; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	155	212	250	287	334
2	221	303	357	410	477
3	259	352	413	472	548
4	295	395	461	524	606
5	329	434	504	571	658
7	366	482	559	632	728
10	430	578	675	768	889

Annual Maximum Mid-Monsoon Rainfall
R-320, Mirsari; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	153	197	227	255	291
2	245	323	375	424	489
3	302	405	473	539	623
4	355	475	554	630	729
5	391	520	605	686	792
7	453	586	674	759	868
10	526	674	772	866	988

Annual Maximum Post-Monsoon Rainfall
R-320, Mirsari; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	119	178	218	255	304
2	169	240	287	332	391
3	197	279	333	385	452
4	219	310	371	429	504
5	234	333	399	462	543
7	258	380	461	538	638
10	282	415	503	587	696

Annual Maximum Rainfall
R-320, Mirsari; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	203	251	283	314	354
2	289	366	417	465	529
3	354	450	514	575	654
4	407	518	591	662	753
5	446	560	636	708	802
7	511	626	702	774	868
10	592	723	809	892	1000

Annual Maximum Pre-Monsoon Rainfall
R-323, Narayanhat; Daily Rainfall (mm).

Duration Days	Return Period (years) 2	5	10	20	50
1	138	191	226	259	302
2	195	265	311	355	413
3	237	318	372	424	491
4	268	355	413	469	541
5	291	390	455	518	600
7	316	430	505	578	671
10	359	494	584	671	782

Annual Maximum Mid-Monsoon Rainfall
R-323, Narayanhat; Daily Rainfall (mm).

Duration Days	Return Period (years) 2	5	10	20	50
1	145	185	211	237	270
2	224	299	349	397	459
3	282	381	447	510	592
4	325	436	510	581	673
5	357	476	555	630	728
7	407	545	637	726	840
10	472	630	735	835	965

Annual Maximum Post-Monsoon Rainfall
R-323, Narayanhat; Daily Rainfall (mm).

Duration Days	Return Period (years) 2	5	10	20	50
1	93	139	169	198	236
2	132	207	256	304	365
3	153	233	286	338	404
4	161	242	296	347	414
5	169	251	305	357	424
7	184	271	328	383	454
10	204	290	347	401	472

Annual Maximum Rainfall
R-323, Narayanhat; Daily Rainfall (mm).

Duration Days	Return Period (years) 2	5	10	20	50
1	175	218	246	273	308
2	264	330	373	415	468
3	330	412	466	518	585
4	374	463	522	578	652
5	402	499	564	625	705
7	449	570	650	727	827
10	512	658	754	847	967

Annual Maximum Pre-Monsoon Rainfall
R-327, Ramgarh; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	145	204	243	280	328
2	196	269	317	363	422
3	238	343	413	480	566
4	268	399	485	569	676
5	292	444	545	642	767
7	330	496	605	710	846
10	374	558	680	797	948

Annual Maximum Mid-Monsoon Rainfall
R-327, Ramgarh; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	150	203	239	273	317
2	237	336	401	464	545
3	291	416	499	579	682
4	324	462	554	642	756
5	357	506	604	699	821
7	405	577	691	800	941
10	467	651	773	890	1041

Annual Maximum Post-Monsoon Rainfall
R-327, Ramgarh; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	89	122	144	165	192
2	120	172	206	238	281
3	140	203	245	285	337
4	151	218	262	304	359
5	158	226	272	316	372
7	175	245	292	336	394
10	198	282	338	392	461

Annual Maximum Rainfall
R-327, Ramgarh; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	184	239	276	311	357
2	274	360	416	471	541
3	336	457	537	614	713
4	372	515	610	701	819
5	402	568	678	783	920
7	460	641	762	877	1026
10	519	714	842	966	1126

Annual Maximum Pre-Monsoon Rainfall
R-352, Barura; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	96	142	173	202	239
2	125	189	231	271	323
3	150	225	275	323	385
4	172	261	321	378	452
5	191	292	359	424	507
7	218	335	411	485	581
10	259	383	465	543	645

Annual Maximum Mid-Monsoon Rainfall
R-352, Barura; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	90	123	144	165	192
2	133	176	204	231	265
3	157	201	231	259	296
4	177	225	257	287	327
5	194	247	282	316	360
7	226	287	327	365	414
10	265	346	399	451	517

Annual Maximum Post-Monsoon Rainfall
R-352, Barura; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	75	114	140	164	196
2	111	178	222	265	319
3	130	219	279	336	409
4	143	239	302	363	441
5	150	245	308	368	447
7	168	267	333	396	478
10	192	296	365	430	516

Annual Maximum Rainfall
R-352, Barura; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	122	165	193	221	256
2	174	240	284	325	379
3	202	289	346	401	472
4	227	324	389	451	531
5	247	350	417	482	567
7	279	392	467	539	632
10	324	445	525	601	700

Annual Maximum Pre-Monsoon Rainfall
R-353, Basurhat; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	131	173	201	228	262
2	193	251	290	327	375
3	236	323	381	436	508
4	261	359	425	487	568
5	286	401	477	550	645
7	322	452	538	620	727
10	381	528	625	718	839

Annual Maximum Mid-Monsoon Rainfall
R-353, Basurhat; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	149	199	231	263	304
2	228	301	350	396	457
3	284	368	424	478	547
4	328	418	478	535	609
5	362	451	511	568	641
7	425	526	593	657	740
10	516	636	716	792	891

Annual Maximum Post-Monsoon Rainfall
R-353, Basurhat; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	115	175	215	253	302
2	158	249	308	365	439
3	188	295	366	434	522
4	206	321	398	471	566
5	216	335	414	489	587
7	242	368	451	531	634
10	273	405	493	577	686

Annual Maximum Rainfall
R-353, Basurhat; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	169	223	259	293	338
2	249	327	379	428	492
3	309	411	477	542	625
4	354	461	532	600	688
5	384	500	577	651	746
7	445	573	657	738	843
10	532	674	768	859	976

Annual Maximum Pre-Monsoon Rainfall
R-354, Chandpur; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	97	135	160	184	215
2	127	165	191	216	248
3	151	196	225	254	291
4	178	237	276	314	362
5	195	261	304	346	400
7	226	299	347	393	452
10	266	340	389	435	496

Annual Maximum Mid-Monsoon Rainfall
R-354, Chandpur; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	92	129	154	178	209
2	130	185	221	256	301
3	148	208	248	286	336
4	171	234	276	316	369
5	185	249	291	332	384
7	214	285	333	378	436
10	251	336	392	446	516

Annual Maximum Post-Monsoon Rainfall
R-354, Chandpur; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	76	127	161	194	236
2	99	167	212	254	310
3	112	187	237	284	346
4	122	199	249	298	361
5	130	211	265	316	382
7	141	232	292	350	424
10	164	272	343	411	499

Annual Maximum Rainfall
R-354, Chandpur; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	131	173	202	229	264
2	176	230	265	300	344
3	200	261	301	339	389
4	224	291	335	378	433
5	237	309	357	403	462
7	273	352	403	453	517
10	326	407	461	512	579

Annual Maximum Pre-Monsoon Rainfall
R-355, Chhagalnaya; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	118	154	178	201	230
2	170	220	253	284	325
3	209	267	305	342	390
4	229	290	330	369	419
5	250	317	361	404	459
7	284	367	421	473	541
10	331	421	480	537	611

Annual Maximum Mid-Monsoon Rainfall
R-355, Chhagalnaya; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	143	203	242	280	329
2	217	296	349	399	465
3	268	359	420	478	553
4	307	399	460	518	594
5	332	419	477	532	604
7	382	483	550	614	698
10	443	559	635	709	804

Annual Maximum Post-Monsoon Rainfall
R-355, Chhagalnaya; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	97	153	191	227	273
2	127	209	263	314	381
3	148	233	288	342	411
4	162	248	305	359	430
5	173	260	317	372	444
7	197	292	354	414	492
10	223	319	382	442	521

Annual Maximum Rainfall
R-355, Chhagalnaya; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	171	229	267	303	350
2	248	327	380	430	495
3	298	383	439	493	562
4	334	416	471	523	591
5	353	434	487	538	604
7	406	497	558	616	691
10	470	573	642	708	794

Annual Maximum Pre-Monsoon Rainfall
R-358, Feni; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	134	177	206	233	268
2	188	247	286	324	372
3	226	291	334	376	429
4	253	334	388	439	506
5	277	372	434	495	573
7	327	442	518	591	685
10	387	524	615	702	815

Annual Maximum Mid-Monsoon Rainfall
R-358, Feni; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	153	198	228	257	295
2	239	307	353	396	453
3	293	374	428	479	546
4	334	428	490	549	626
5	364	467	535	600	685
7	431	548	625	699	794
10	500	657	760	860	988

Annual Maximum Post-Monsoon Rainfall
R-358, Feni; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	98	140	169	196	231
2	138	196	235	272	320
3	172	251	304	354	420
4	191	277	334	388	459
5	204	295	355	412	487
7	229	325	388	448	527
10	256	356	422	486	568

Annual Maximum Rainfall
R-358, Feni; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	180	218	243	267	298
2	261	317	354	389	435
3	315	386	432	476	534
4	359	440	493	544	611
5	393	484	545	603	678
7	455	558	627	692	777
10	545	686	779	869	985

Annual Maximum Pre-Monsoon Rainfall
R-359, Gunabati; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	102	133	154	173	199
2	142	196	231	266	310
3	170	241	288	333	391
4	201	290	349	406	479
5	227	328	394	458	540
7	268	393	477	557	660
10	313	449	538	624	736

Annual Maximum Mid-Monsoon Rainfall
R-359, Gunabati; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	122	167	197	225	262
2	174	239	282	324	377
3	212	299	357	413	484
4	243	341	407	470	551
5	266	371	441	508	595
7	312	427	504	577	671
10	381	537	641	740	868

Annual Maximum Post-Monsoon Rainfall
R-359, Gunabati; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	94	147	183	217	261
2	137	221	277	330	399
3	162	265	334	399	484
4	177	289	363	435	527
5	191	305	379	451	544
7	217	338	418	495	594
10	235	359	442	521	623

Annual Maximum Rainfall
R-359, Gunabati; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	154	194	220	246	278
2	226	296	343	388	446
3	273	367	430	490	568
4	303	414	488	558	649
5	329	446	523	598	694
7	381	510	596	678	784
10	443	592	690	784	906

Annual Maximum Pre-Monsoon Rainfall
R-360, Hajigang; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	90	122	143	162	188
2	126	164	190	215	247
3	153	193	219	245	278
4	178	228	261	292	333
5	198	257	296	334	382
7	234	308	357	404	465
10	278	358	412	462	528

Annual Maximum Mid-Monsoon Rainfall
R-360, Hajigang; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	92	141	173	205	245
2	129	186	223	259	306
3	155	213	252	289	337
4	173	233	273	311	360
5	193	261	305	348	404
7	226	308	363	415	483
10	265	356	417	475	551

Annual Maximum Post-Monsoon Rainfall
R-360, Hajigang; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	73	106	127	148	174
2	112	169	206	242	289
3	132	195	237	277	328
4	146	215	262	306	364
5	155	233	284	333	397
7	176	272	336	398	477
10	196	309	383	454	547

Annual Maximum Rainfall
R-360, Hajigang; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	116	161	191	220	257
2	172	224	259	292	334
3	199	253	289	323	367
4	228	282	318	352	396
5	254	315	355	394	444
7	297	377	430	480	546
10	344	430	487	542	613

Annual Maximum Pre-Monsoon Rainfall
R-361, Hatia; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	121	169	200	230	268
2	174	237	278	318	370
3	212	279	323	365	420
4	240	313	362	409	470
5	269	356	414	470	542
7	313	411	475	538	618
10	367	487	566	642	741

Annual Maximum Mid-Monsoon Rainfall
R-361, Hatia; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	138	177	203	228	260
2	214	282	327	370	426
3	266	351	408	462	532
4	297	392	455	515	594
5	334	440	511	578	666
7	393	508	585	659	754
10	464	588	670	748	850

Annual Maximum Post-Monsoon Rainfall
R-361, Hatia; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	108	157	189	220	260
2	157	227	274	318	376
3	192	276	331	385	454
4	208	295	353	408	480
5	221	313	374	432	507
7	246	343	406	468	547
10	268	369	436	500	583

Annual Maximum Rainfall
R-361, Hatia; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	174	222	253	283	323
2	257	323	367	409	463
3	308	388	442	493	559
4	338	425	482	537	609
5	375	470	533	593	671
7	427	527	593	657	739
10	505	614	687	756	846

Annual Maximum Pre-Monsoon Rainfall
R-363, Laksam; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	103	144	172	198	231
2	150	195	225	254	292
3	183	243	282	320	369
4	205	277	325	371	431
5	231	316	373	426	496
7	272	373	441	505	589
10	323	439	516	590	685

Annual Maximum Mid-Monsoon Rainfall
R-363, Laksam; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	98	133	156	178	207
2	156	208	243	276	318
3	191	256	300	341	395
4	218	292	341	387	448
5	239	318	370	420	485
7	279	370	431	488	563
10	325	426	493	557	639

Annual Maximum Post-Monsoon Rainfall
R-363, Laksam; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	75	112	136	159	189
2	113	171	209	246	294
3	141	214	262	308	367
4	154	243	301	358	430
5	165	256	317	375	450
7	182	275	337	396	472
10	207	311	381	447	533

Annual Maximum Rainfall
R-363, Laksam; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	127	167	194	219	252
2	192	241	274	305	346
3	235	302	345	387	442
4	270	352	406	458	525
5	299	385	442	497	568
7	346	442	506	567	645
10	400	509	581	650	740

Annual Maximum Pre-Monsoon Rainfall
R-364, Lakshmipur; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	90	128	154	178	209
2	128	174	205	234	273
3	158	218	257	295	344
4	180	247	291	334	389
5	206	278	325	371	429
7	244	336	397	456	532
10	295	402	473	541	629

Annual Maximum Mid-Monsoon Rainfall
R-364, Lakshmipur; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	89	128	154	180	212
2	139	201	242	281	332
3	175	252	303	352	416
4	200	284	340	394	464
5	222	317	379	439	517
7	264	376	451	523	615
10	316	453	544	632	744

Annual Maximum Post-Monsoon Rainfall
R-364, Lakshmipur; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	88	130	158	185	219
2	131	193	233	272	323
3	158	224	268	311	366
4	177	251	300	347	408
5	195	276	330	382	448
7	221	314	376	435	512
10	249	351	418	483	566

Annual Maximum Rainfall
R-364, Lakshmipur; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	122	165	193	220	256
2	187	245	284	321	369
3	227	299	347	393	452
4	258	336	388	438	502
5	284	371	429	484	556
7	334	445	517	587	678
10	398	529	616	699	807

Annual Maximum Pre-Monsoon Rainfall
R-369, Noakhali; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	129	174	203	232	269
2	174	233	273	310	359
3	206	278	326	372	432
4	227	309	363	415	482
5	254	346	406	464	540
7	299	410	484	555	646
10	356	482	566	646	750

Annual Maximum Mid-Monsoon Rainfall
R-369, Noakhali; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	131	172	199	225	258
2	194	235	263	289	323
3	232	283	317	350	392
4	265	318	353	386	430
5	292	347	384	419	465
7	338	401	443	482	534
10	420	515	579	639	718

Annual Maximum Post-Monsoon Rainfall
R-369, Noakhali; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	125	170	200	229	266
2	172	239	283	326	381
3	198	272	321	368	428
4	219	302	356	409	477
5	229	316	374	429	500
7	247	337	397	454	529
10	285	386	453	517	599

Annual Maximum Rainfall
R-369, Noakhali; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	180	217	242	265	296
2	252	291	317	341	373
3	291	342	376	409	451
4	323	384	424	462	512
5	349	421	469	514	574
7	402	489	547	602	674
10	489	591	659	724	808

Annual Maximum Pre-Monsoon Rainfall
R-370, Parshuram; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	130	169	195	221	253
2	175	231	267	303	348
3	204	276	325	371	430
4	227	306	358	408	473
5	245	332	390	445	517
7	272	367	431	491	570
10	324	433	505	575	664

Annual Maximum Mid-Monsoon Rainfall
R-370, Parshuram; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	128	166	191	215	246
2	186	240	276	310	355
3	231	302	348	393	451
4	258	329	377	422	481
5	284	365	419	471	538
7	331	417	473	528	598
10	385	485	551	615	698

Annual Maximum Post-Monsoon Rainfall
R-370, Parshuram; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	68	100	120	140	166
2	95	141	173	202	241
3	113	174	214	252	302
4	127	191	233	274	327
5	136	200	243	283	336
7	150	216	260	302	356
10	168	238	285	330	388

Annual Maximum Rainfall
R-370, Parshuram; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	153	189	212	235	265
2	212	268	306	342	388
3	259	331	379	424	484
4	284	358	407	454	515
5	312	396	452	505	574
7	357	443	500	555	626
10	417	512	576	636	715

Annual Maximum Pre-Monsoon Rainfall
R-372, Raipur (Noakhali); Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	91	137	167	196	233
2	127	183	220	256	302
3	158	219	259	298	348
4	182	250	295	339	395
5	199	273	321	367	428
7	232	312	365	415	481
10	274	364	423	479	553

Annual Maximum Mid-Monsoon Rainfall
R-372, Raipur (Noakhali); Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	83	111	130	147	170
2	132	176	206	234	270
3	156	209	244	277	321
4	185	248	289	328	380
5	201	271	317	361	419
7	234	313	365	415	480
10	281	369	426	482	554

Annual Maximum Post-Monsoon Rainfall
R-372, Raipur (Noakhali); Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	78	117	143	168	201
2	107	154	185	215	253
3	128	183	220	255	301
4	138	195	232	268	314
5	146	206	245	283	333
7	168	235	280	323	378
10	190	271	324	375	442

Annual Maximum Rainfall
R-372, Raipur (Noakhali); Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	115	156	184	210	244
2	166	217	251	283	324
3	199	250	283	316	358
4	226	284	322	359	407
5	250	313	355	395	447
7	289	363	411	458	518
10	336	420	476	530	600

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Annual Maximum Pre-Monsoon Rainfall
R-375, Ramgati; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	108	141	163	185	212
2	176	232	269	305	351
3	221	300	352	402	467
4	266	366	432	496	578
5	307	428	508	584	684
7	370	524	626	724	851
10	450	649	781	907	1071

Annual Maximum Mid-Monsoon Rainfall
R-375, Ramgati; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	124	159	183	205	234
2	218	275	313	349	396
3	296	375	427	477	541
4	357	454	518	580	660
5	412	530	608	683	780
7	499	653	755	853	979
10	604	800	931	1055	1217

Annual Maximum Post-Monsoon Rainfall
R-375, Ramgati; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	99	134	157	179	207
2	165	235	282	327	385
3	204	292	350	406	478
4	239	345	415	482	569
5	259	371	446	517	609
7	282	398	475	548	644
10	318	454	544	630	741

Annual Maximum Rainfall
R-375, Ramgati; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	136	174	200	224	256
2	231	300	345	389	446
3	300	392	453	511	587
4	359	472	547	619	712
5	415	552	643	729	842
7	516	691	807	919	1063
10	633	845	986	1121	1296

Annual Maximum Pre-Monsoon Rainfall
R-376, Senbag; Daily Rainfall (mm).

Duration Days	Return Period (years) 2	5	10	20	50
1	121	167	197	226	263
2	160	211	244	276	317
3	194	260	303	345	399
4	216	300	356	409	478
5	235	327	388	446	522
7	278	388	462	532	623
10	337	468	554	636	743

Annual Maximum Mid-Monsoon Rainfall
R-376, Senbag; Daily Rainfall (mm).

Duration Days	Return Period (years) 2	5	10	20	50
1	146	208	248	287	338
2	210	283	331	377	437
3	257	349	409	467	542
4	287	386	452	515	596
5	312	417	487	555	642
7	372	479	550	618	707
10	429	554	637	716	819

Annual Maximum Post-Monsoon Rainfall
R-376, Senbag; Daily Rainfall (mm).

Duration Days	Return Period (years) 2	5	10	20	50
1	110	170	210	248	298
2	150	229	281	332	397
3	174	270	333	394	472
4	192	294	361	426	510
5	201	308	379	447	535
7	222	335	410	482	575
10	245	370	453	533	636

Annual Maximum Rainfall
R-376, Senbag; Daily Rainfall (mm).

Duration Days	Return Period (years) 2	5	10	20	50
1	179	230	264	296	338
2	241	306	348	389	442
3	293	384	444	502	577
4	326	432	502	570	657
5	350	467	544	618	714
7	405	529	610	689	791
10	475	617	711	801	918

Annual Maximum Pre-Monsoon Rainfall
R-377, Sonaimuri; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	107	148	174	200	233
2	149	203	238	272	316
3	177	240	281	320	371
4	199	269	315	359	416
5	223	302	354	405	470
7	261	359	424	487	567
10	322	450	535	616	721

Annual Maximum Mid-Monsoon Rainfall
R-377, Sonaimuri; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	129	171	199	226	260
2	180	240	279	317	367
3	217	286	331	374	431
4	243	317	366	413	474
5	267	344	396	445	509
7	321	430	503	572	662
10	392	524	611	695	804

Annual Maximum Post-Monsoon Rainfall
R-377, Sonaimuri; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	103	142	167	191	223
2	145	202	240	276	323
3	171	243	290	335	394
4	186	255	301	344	401
5	199	266	311	353	409
7	222	300	351	400	464
10	247	328	382	433	499

Annual Maximum Rainfall
R-377, Sonaimuri; Daily Rainfall (mm)

Duration Days	Return Period (years) 2	5	10	20	50
1	153	193	220	246	279
2	219	275	312	348	394
3	260	326	370	412	467
4	287	356	402	445	502
5	315	391	441	489	552
7	376	476	543	607	689
10	451	582	669	752	860

APPENDIX - B.3

10-Day Maximum Water Level for the Period April to October

T-58 , Hazigang ; Maximum 10 day levels, Apr. - Oct.

YEAR	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1978	1.768	1.737	2.027	2.286	2.499	3.475	3.719	3.749	4.054	4.039	4.039	4.161	4.237	4.343	4.404	4.282	4.222	4.206	4.115	3.810	3.429	4.404
1979	1.981	1.920	2.072	2.072	2.499	2.560	2.346	3.124	3.474	3.688	3.764	3.932	4.175	4.267	4.175	4.145	4.160	3.840	3.932	3.855	3.489	4.267
1980	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1981	2.225	3.322	3.277	2.743	2.972	3.139	3.337	3.261	3.444	3.962	4.099	4.343	4.526	4.496	4.435	4.373	4.237	4.145	3.977	3.535	3.048	4.526
1982	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1983	2.150	2.700	2.850	3.350	3.250	3.290	3.050	3.290	3.630	3.750	3.840	4.050	4.510	4.540	4.490	4.570	4.650	4.700	4.620	4.510	4.130	4.700
1984	2.050	2.370	2.310	3.110	3.550	3.510	3.750	3.930	4.180	4.180	4.510	4.650	4.820	4.700	4.550	4.570	4.570	4.650	4.500	4.080	3.700	4.820
1985	2.200	2.250	2.220	2.310	2.250	3.100	3.450	3.480	3.650	3.930	4.060	4.160	4.420	4.290	4.270	4.300	4.280	4.180	3.940	4.030	3.810	4.420
1986	2.060	2.300	2.550	2.420	2.360	2.700	2.350	2.600	3.320	3.590	3.680	4.080	4.180	4.230	4.070	4.040	4.080	4.170	4.170	4.110	3.900	4.230
1987	1.650	2.520	2.770	2.390	2.290	2.190	2.990	3.080	3.300	3.850	4.080	4.390	4.540	4.700	5.060	4.950	4.910	4.820	4.680	4.510	3.960	5.060
1988	2.080	2.640	2.360	2.220	3.060	3.490	3.600	3.730	3.830	4.110	4.510	4.510	4.620	4.600	4.990	5.520	5.490	5.160	4.600	4.200	3.940	5.520
1989	2.000	1.950	2.050	2.200	2.570	2.990	3.160	3.690	3.780	3.810	4.020	4.180	4.230	4.140	4.050	3.960	4.070	3.990	4.020	4.170	4.050	4.230

T-79 ,Matlab Bazar ; Maximum 10 day levels, Apr. - Oct.

YEAR	April 1	April 2	April 3	May 1	May 2	May 3	June 1	June 2	June 3	July 1	July 2	July 3	August 1	August 2	August 3	September 1	September 2	September 3	October 1	October 2	October 3	Annual
1959	-99.000	-99.000	-99.000	-99.000	-99.000	3.220	3.250	3.580	4.130	4.260	4.350	4.130	4.350	4.530	4.740	4.410	4.190	4.100	4.010	3.950	3.920	4.740
1960	1.090	1.210	1.420	1.450	1.660	1.660	2.550	2.670	3.280	3.680	3.650	4.220	4.830	4.860	4.770	4.770	4.740	4.990	4.900	4.560	3.980	4.990
1961	2.420	2.300	2.260	3.880	2.780	3.240	3.420	3.450	3.790	3.720	4.050	4.050	3.990	4.420	4.820	4.630	4.480	4.330	4.210	4.150	3.810	4.820
1962	2.590	2.130	2.320	2.560	2.650	3.230	3.260	3.510	3.780	4.360	4.420	4.360	4.360	4.690	5.090	5.090	5.060	4.880	4.540	3.870	3.320	5.090
1963	1.950	2.010	2.380	2.380	2.380	2.800	3.660	3.900	3.960	4.210	4.510	4.630	4.750	4.750	4.770	4.980	4.790	4.340	4.150	3.540	3.350	4.980
1964	2.160	2.820	2.380	3.050	3.190	2.870	3.200	3.630	3.960	4.360	4.450	4.750	5.360	5.440	4.880	4.790	4.690	4.910	4.690	4.010	3.930	5.440
1965	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1966	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1967	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1968	2.070	2.680	2.410	2.560	2.990	3.050	3.380	3.570	4.070	4.570	4.600	5.060	5.040	4.820	4.600	4.400	4.340	4.080	4.330	4.250	3.660	5.060
1969	2.180	2.530	2.230	2.560	2.360	3.050	3.140	3.630	4.020	4.040	4.570	4.940	4.880	4.710	5.000	4.950	4.770	4.630	4.240	3.960	3.190	5.000
1970	2.470	2.440	2.470	2.960	3.260	3.380	3.540	3.660	4.270	4.300	4.720	4.970	5.110	5.240	5.150	4.790	4.560	4.590	4.850	4.390	4.210	5.240
1971	2.190	2.470	2.440	2.960	2.740	2.800	3.250	4.020	4.270	4.190	4.600	4.750	5.180	5.180	5.330	5.380	5.110	4.910	4.790	4.280	4.150	5.380
1972	2.350	2.670	2.610	2.680	3.000	3.170	3.280	3.290	4.180	4.270	4.160	4.510	4.800	4.690	4.360	4.510	4.570	4.270	3.610	3.410	3.260	4.800
1973	2.220	2.620	2.550	2.990	3.110	3.260	3.200	4.150	4.960	4.750	4.360	4.630	4.790	5.180	5.000	4.630	4.630	5.090	4.570	4.600	3.750	5.180
1974	2.440	2.440	2.580	3.140	3.030	3.320	3.320	3.600	4.160	4.560	4.720	5.090	5.530	5.610	5.360	5.040	4.910	4.690	4.680	4.070	3.520	5.610
1975	2.240	2.550	2.800	2.940	2.910	2.960	3.290	3.310	3.730	3.950	4.270	4.540	4.940	4.880	4.400	4.770	4.590	4.590	4.300	4.130	3.660	4.940
1976	2.010	2.700	2.390	2.620	2.960	2.960	3.230	3.600	3.720	4.510	4.600	4.360	4.330	4.540	4.800	4.630	4.510	4.500	3.660	3.340	3.410	4.800
1977	2.880	2.530	2.510	3.020	3.600	3.320	3.580	3.870	4.110	4.180	4.420	4.740	4.690	4.770	4.920	4.950	4.540	4.050	3.930	3.960	3.140	4.950
1978	-99.000	2.073	2.377	2.499	3.246	3.414	3.322	3.795	4.054	4.115	4.176	4.404	4.496	4.816	4.816	4.267	4.496	4.420	4.313	3.551	3.261	-99.000
1979	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1980	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1981	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1982	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1983	2.340	2.640	2.820	2.920	3.040	2.960	3.190	3.250	3.750	4.140	4.190	4.210	4.630	4.640	4.420	4.720	4.830	4.890	4.630	4.290	3.960	4.890
1984	2.450	2.820	2.650	2.720	3.200	3.630	3.860	3.970	4.270	4.280	4.880	5.000	5.190	4.670	4.530	4.490	4.700	4.980	4.440	4.210	3.640	5.190
1985	2.560	2.410	2.580	2.800	2.440	3.000	3.660	3.660	3.980	4.260	4.390	4.600	4.850	4.460	4.580	4.600	4.600	4.260	4.180	4.480	3.780	4.850
1986	2.320	2.340	2.860	2.580	2.550	2.910	2.560	3.130	3.480	3.780	4.080	4.410	4.490	4.450	4.100	4.260	4.300	4.510	4.130	3.960	3.790	4.510
1987	2.220	2.680	2.760	2.520	2.730	2.880	3.250	3.450	3.710	4.570	4.650	4.750	4.890	5.200	5.330	5.090	5.140	5.050	4.650	4.350	3.640	5.330
1988	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1989	2.290	2.110	2.300	2.870	2.850	3.490	3.530	4.070	4.160	4.110	4.590	4.980	4.610	4.530	4.490	4.410	4.510	4.360	4.260	4.510	3.760	4.980

T-278, Daulat Khan, ; Maximum 10 day levels, Apr. - Oct.

YEAR	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1968	1.950	2.680	2.470	2.680	2.990	2.740	3.140	3.510	3.140	3.510	3.600	3.750	3.570	3.660	3.410	3.380	3.260	2.990	3.020	2.590	2.990	3.750
1969	2.100	2.290	1.950	2.410	2.380	2.680	3.170	3.050	3.170	3.470	3.470	4.080	3.810	3.690	3.660	3.320	3.290	3.510	2.710	3.080	2.410	4.080
1970	2.470	2.260	2.470	2.870	2.620	2.830	2.930	2.990	3.170	3.450	4.120	4.210	3.510	3.870	3.570	3.600	3.350	2.990	3.140	2.960	3.110	4.210
1971	1.900	2.450	2.670	2.790	2.510	2.820	3.120	3.020	3.410	3.320	3.600	3.660	4.300	3.810	3.600	4.240	3.260	-99.000	-99.000	2.970	2.820	-99.000
1972	2.510	2.830	2.600	2.410	2.840	2.780	2.840	3.180	3.360	-99.000	3.490	3.430	3.640	3.760	3.820	3.940	3.730	3.610	2.820	2.510	2.670	-99.000
1973	1.740	1.810	1.720	1.860	1.860	1.860	1.920	1.970	1.970	3.810	3.870	3.750	3.720	4.020	3.930	3.630	3.410	3.510	3.170	3.960	2.800	4.020
1974	2.680	2.260	2.680	3.080	2.500	3.080	3.140	3.510	3.630	3.320	3.810	3.870	3.870	4.150	3.750	3.510	3.870	3.600	3.600	3.350	2.930	4.150
1975	1.890	2.560	2.800	2.620	2.870	2.710	2.960	3.050	3.630	3.320	3.470	3.050	3.990	-99.000	3.140	4.050	3.380	3.380	3.600	3.170	2.590	-99.000
1976	1.890	2.650	2.190	2.350	3.110	2.870	2.930	3.230	3.080	3.170	3.600	3.540	3.350	3.660	3.750	3.260	3.660	3.350	2.410	2.590	-99.000	-99.000
1977	2.740	2.040	2.010	2.650	2.950	2.930	3.290	3.250	3.200	3.750	3.320	3.840	3.840	3.350	3.720	3.660	3.570	3.080	2.770	3.080	2.350	3.840
1978	2.010	1.680	2.320	2.190	2.710	3.230	2.770	3.260	3.540	3.080	3.050	3.470	3.540	3.780	3.900	3.290	3.510	3.260	3.810	2.800	2.410	3.900
1979	1.830	2.130	2.260	2.130	2.740	2.590	2.740	2.830	3.050	3.200	3.440	3.260	4.110	3.510	3.140	3.720	3.080	2.770	3.440	2.590	2.500	4.110
1980	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1981	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1982	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1983	2.100	2.650	2.850	2.800	2.850	2.620	2.710	2.720	3.170	3.170	3.230	3.420	3.600	3.550	3.070	3.700	3.230	3.300	3.530	2.770	3.160	3.700
1984	2.400	2.800	2.450	2.580	2.850	3.000	3.750	3.510	3.610	3.700	3.900	4.120	4.060	3.610	3.750	3.370	3.600	3.550	2.820	3.700	3.300	4.120
1985	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1986	2.450	2.380	2.890	2.430	2.400	3.030	2.950	3.560	3.410	3.030	3.460	4.170	3.470	3.490	3.370	3.200	3.120	3.170	3.170	2.620	2.470	4.170
1987	2.050	2.490	2.300	2.200	2.500	2.520	2.850	3.080	2.930	3.690	3.930	3.260	3.750	3.750	3.740	3.700	3.560	3.560	3.430	2.960	2.750	3.930
1988	2.560	2.910	2.000	2.520	3.020	3.100	3.400	3.180	2.950	3.180	3.810	3.890	4.100	3.410	3.950	3.800	3.330	3.540	3.170	3.430	2.740	4.100

T-277 , Chandpur ; Maximum 10 day levels, Apr. - Oct.

YEAR	April 1	April 2	April 3	May 1	May 2	May 3	June 1	June 2	June 3	July 1	July 2	July 3	August 1	August 2	August 3	September 1	September 2	September 3	October 1	October 2	October 3	Annual
1959	2.120	2.150	2.660	2.760	2.790	2.970	3.210	3.940	4.400	4.400	4.400	4.400	4.370	4.710	4.680	4.340	4.340	4.070	4.430	3.730	3.760	4.710
1960	1.930	1.900	1.870	1.870	2.080	3.210	3.370	3.520	3.520	4.010	3.910	4.580	4.680	4.520	4.460	4.580	4.430	4.710	4.340	4.100	3.790	4.710
1961	2.260	2.010	2.040	4.360	2.710	3.570	3.510	3.570	3.380	3.630	3.870	4.210	4.150	4.270	4.600	4.510	4.480	4.150	3.930	3.840	3.630	4.600
1962	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1963	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1964	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1965	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1966	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1967	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1968	1.580	2.380	2.290	2.070	3.080	2.960	3.540	3.690	3.990	4.540	4.400	4.830	4.750	4.540	4.450	4.270	4.270	4.050	4.250	4.130	3.790	4.830
1969	2.210	2.610	2.150	2.390	2.380	3.170	3.910	3.580	4.040	3.950	4.460	4.830	4.770	4.590	4.850	4.710	4.570	4.540	4.070	4.010	3.320	4.850
1970	2.450	2.470	2.480	2.940	2.960	3.520	3.490	3.780	4.270	4.180	4.560	4.800	4.850	4.970	4.920	4.630	4.390	4.280	4.470	4.160	4.280	4.970
1971	2.450	2.470	2.480	3.000	3.370	3.490	3.550	3.780	4.270	4.160	4.250	4.250	4.280	4.240	5.070	5.170	4.820	4.690	4.690	4.590	4.360	5.170
1972	2.330	2.670	2.640	2.670	3.090	3.280	3.350	3.940	3.870	4.190	4.220	4.400	4.590	4.570	4.370	4.470	4.540	4.210	3.630	3.200	2.350	4.590
1973	2.190	2.620	2.440	2.930	3.200	3.260	3.320	4.050	4.600	4.510	4.240	4.330	4.560	4.970	4.750	4.360	4.390	4.510	4.390	4.570	3.570	4.970
1974	2.100	2.290	2.530	2.800	2.900	3.140	3.350	3.660	4.020	4.270	4.510	4.820	5.120	5.240	4.940	4.690	4.790	4.330	4.390	3.780	3.290	5.240
1975	2.030	1.420	1.660	2.320	2.620	2.990	3.320	3.320	3.540	4.050	4.050	4.240	4.920	4.630	4.240	4.630	4.300	4.210	4.330	4.180	3.600	4.920
1976	1.910	2.680	2.550	2.410	3.280	2.940	3.100	3.600	3.660	4.210	4.390	4.210	4.020	4.330	4.450	4.150	4.270	4.330	3.380	3.260	3.540	4.450
1977	2.870	2.510	2.390	2.970	3.230	3.340	3.750	3.840	3.960	4.020	3.990	4.990	4.480	4.420	4.690	4.820	4.420	3.990	3.840	3.990	3.110	4.990
1978	2.087	1.996	2.453	2.499	3.246	3.581	3.398	3.855	4.130	4.008	4.191	4.099	4.312	4.617	4.602	4.251	4.312	4.160	4.404	3.642	3.398	4.617
1979	2.027	2.271	2.576	2.819	2.941	3.063	2.880	3.124	3.185	3.871	4.054	3.901	4.785	4.328	3.871	4.130	4.084	3.658	4.145	3.444	3.307	4.785
1980	1.981	2.682	2.713	2.926	3.230	3.200	3.185	3.474	3.871	4.023	3.901	4.480	4.297	4.389	4.876	4.480	4.572	4.115	3.810	3.596	3.932	4.876
1981	2.529	2.770	2.438	2.865	2.774	2.926	3.444	3.414	3.444	3.947	3.962	4.389	4.541	4.572	4.450	4.267	4.236	4.358	3.840	3.689	2.987	4.572
1982	2.290	2.200	2.900	2.780	2.660	2.920	3.070	3.590	3.980	3.880	4.120	4.340	4.570	4.500	4.340	4.530	4.480	4.480	4.040	3.400	3.150	4.570
1983	2.207	2.634	2.862	2.725	2.999	2.908	3.304	3.289	3.792	3.853	4.127	4.020	4.462	4.478	4.301	4.499	4.590	4.682	4.468	4.139	3.883	4.682
1984	2.530	2.850	2.670	2.870	3.800	3.670	3.800	4.110	4.330	4.220	4.350	4.520	4.960	4.340	4.410	4.380	4.410	4.550	3.930	4.070	3.790	4.960
1985	2.460	2.400	2.460	3.140	2.550	3.110	3.690	3.830	4.050	4.150	4.280	4.420	4.720	4.220	4.380	4.280	4.380	4.000	3.980	4.560	3.540	4.720
1986	2.300	2.490	2.680	2.610	2.510	2.930	2.610	3.140	3.530	3.700	3.950	4.410	4.240	4.150	4.030	4.070	4.050	4.070	3.990	3.750	3.610	4.410
1987	2.080	2.640	2.570	2.240	2.740	2.690	2.940	3.380	3.390	4.440	4.600	4.440	4.600	4.660	4.770	4.570	4.670	4.640	4.270	4.090	3.490	4.770
1988	2.140	2.660	2.160	2.560	3.020	3.720	3.790	3.740	3.810	4.110	4.590	4.530	4.590	4.410	5.160	5.140	4.870	4.320	4.000	3.770	3.590	5.160
1989	2.260	2.080	2.280	3.050	2.590	3.260	3.550	4.140	4.090	3.920	4.300	4.660	4.310	4.300	4.180	4.060	4.160	4.050	3.860	4.450	3.260	4.660

T-276 , Satnal ; Maximum 10 day levels, Apr. - Oct.

YEAR	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1958	1.930	1.690	1.780	2.330	2.690	3.240	3.240	2.940	3.360	3.570	3.610	3.700	4.660	4.820	5.070	5.100	4.730	4.340	4.060	4.090	3.670	5.100
1959	1.800	1.950	2.650	2.650	2.620	2.960	3.140	3.750	4.450	4.390	4.360	4.330	4.420	4.850	4.880	4.390	4.300	4.080	4.300	3.870	3.690	4.880
1960	1.890	2.260	2.100	2.130	2.190	2.960	3.170	3.350	3.350	3.750	4.080	4.750	4.720	4.660	4.570	4.750	4.750	4.970	4.570	4.020	3.750	4.970
1961	2.190	2.130	2.130	4.050	2.870	3.320	3.540	3.570	3.870	3.810	4.150	4.210	4.180	4.600	4.940	4.910	4.820	4.570	4.420	4.420	4.050	4.940
1962	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1963	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1964	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1965	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1966	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1967	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1968	1.870	2.410	2.160	2.440	2.830	2.830	3.470	3.660	4.360	4.850	4.940	5.390	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	5.490
1969	1.900	2.270	2.030	2.180	2.000	2.850	2.970	3.700	4.020	4.110	4.690	5.030	5.490	5.150	4.940	4.790	4.630	4.330	4.570	4.510	3.670	5.210
1970	2.330	2.150	2.210	2.800	3.140	3.290	3.460	3.640	4.370	4.370	4.680	5.170	5.030	4.880	5.210	5.180	4.970	4.720	4.330	3.990	3.200	5.460
1971	1.940	2.240	2.240	2.870	2.740	2.930	3.350	4.330	4.510	4.690	5.120	5.240	5.460	5.350	4.920	4.920	4.620	4.650	4.850	4.470	4.310	5.700
1972	2.160	2.560	2.380	2.440	2.800	3.050	3.110	3.110	4.110	4.330	4.210	4.510	5.460	5.520	5.700	5.700	5.460	5.210	5.060	4.690	4.750	4.820
1973	2.090	2.550	2.210	2.910	2.940	2.970	3.140	4.020	4.720	4.750	4.360	4.600	4.820	4.790	4.360	4.510	4.570	4.270	3.570	3.410	3.110	5.240
1974	2.270	2.240	2.330	2.760	2.760	2.790	3.550	3.440	4.150	4.660	4.790	5.380	4.850	5.240	5.030	4.660	4.630	4.850	4.630	4.600	3.750	5.790
1975	2.180	2.150	2.390	2.190	2.620	2.700	3.010	3.250	3.740	3.920	4.320	4.650	5.670	5.670	5.430	5.090	5.790	4.850	4.690	4.080	3.580	5.050
1976	1.630	2.270	1.910	2.420	2.530	2.590	3.140	3.700	3.730	4.590	4.710	4.470	5.050	4.870	4.470	4.750	4.620	4.560	4.140	3.950	3.650	4.830
1977	2.710	2.530	2.440	2.870	3.570	3.410	3.840	3.930	4.220	4.190	4.430	4.920	4.310	4.470	4.830	4.710	4.590	4.590	3.760	3.350	3.140	5.200
1978	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	4.860	4.940	5.110	5.200	4.680	4.160	4.070	4.150	3.440	-99.000
1979	2.040	2.010	2.230	2.040	2.770	2.800	2.620	2.930	3.540	4.150	4.180	4.720	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	5.150
1980	1.960	2.450	2.610	2.760	2.970	3.090	2.970	3.890	3.990	4.080	4.270	4.970	5.150	4.910	4.510	4.630	4.540	4.270	4.270	4.240	3.470	5.490
1981	2.743	2.621	2.469	2.530	2.713	2.804	3.383	3.383	3.475	4.511	4.511	4.907	4.880	5.150	5.490	5.210	5.000	4.540	4.210	3.870	3.750	5.243
1982	2.377	2.256	2.804	2.530	2.621	3.018	3.109	3.871	3.993	4.145	4.420	4.481	5.182	5.243	4.968	4.968	4.785	4.603	4.267	3.719	2.926	4.816
1983	1.900	1.900	2.840	2.740	3.770	2.960	3.740	3.990	4.420	4.710	4.470	4.480	4.816	4.633	4.603	4.663	4.694	4.724	4.115	3.200	2.987	5.260
1984	2.330	2.600	2.400	2.600	3.350	3.780	3.920	4.160	4.470	4.420	5.130	5.290	4.930	4.880	4.720	4.930	5.160	5.260	4.800	4.330	4.130	5.620
1985	2.630	2.420	2.520	3.220	2.810	3.130	3.720	3.720	4.170	4.470	4.470	4.820	5.620	4.940	4.570	4.670	5.020	5.210	4.590	4.190	3.730	4.990
1986	2.200	2.100	2.970	2.950	2.750	3.000	2.300	3.050	3.500	3.840	4.160	4.490	4.990	4.490	4.620	4.690	4.670	4.320	4.250	4.520	4.000	4.710
1987	1.850	2.290	2.290	2.190	2.390	2.540	2.790	3.180	3.560	4.430	4.630	4.880	4.710	4.610	4.280	4.340	4.370	4.600	4.210	4.050	3.810	5.610
1988	2.170	2.670	2.150	2.400	3.050	3.950	3.870	3.840	4.020	4.800	5.170	4.920	5.330	5.570	5.610	5.250	5.320	5.250	4.750	4.280	3.540	6.040
1989	2.200	2.000	2.280	2.680	2.430	3.170	3.370	3.980	4.030	4.330	4.550	4.910	5.070	5.030	5.940	6.040	5.690	4.760	4.120	3.970	3.610	4.910
													4.690	4.490	4.460	4.400	4.530	4.370	4.270	4.460	3.560	

W-181, Gunabati Railway Bridge (d/s) ; Maximum 10 day levels, Apr. - Oct.

YEAR	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1983	-99.000	-99.000	-99.000	5.430	5.388	4.862	4.250	4.858	4.912	5.092	5.004	4.790	5.878	5.610	4.998	4.850	4.754	4.760	4.527	4.838	4.610	-99.000
1984	1.910	1.850	2.090	3.950	5.610	5.388	4.290	4.720	5.010	5.230	5.626	5.288	4.826	4.864	4.858	4.836	4.776	4.728	3.940	3.810	3.706	5.626
1985	-99.000	-99.000	-99.000	2.920	3.160	4.746	5.368	5.430	4.860	5.310	5.328	4.620	4.630	4.650	5.160	4.774	4.380	4.266	3.900	3.290	3.470	-99.000
1986	-99.000	-99.000	-99.000	4.138	4.240	4.278	4.156	4.254	4.760	5.034	5.038	5.484	5.310	4.836	4.696	4.346	3.792	4.558	4.720	4.688	3.910	-99.000
1987	-99.000	-99.000	4.620	4.620	4.362	3.410	3.858	3.968	3.810	4.620	5.058	5.508	5.586	4.880	5.608	5.486	4.746	5.050	4.900	4.218	3.774	-99.000
1988	3.186	3.438	3.522	3.470	4.240	5.292	5.326	5.016	4.810	5.618	5.716	5.120	4.430	5.068	5.046	5.386	5.302	4.730	4.040	3.910	4.098	5.716
1989	-99.000	-99.000	-99.000	-99.000	4.080	4.080	4.160	5.190	5.166	5.312	4.940	4.700	4.720	3.850	3.180	4.010	4.426	4.276	4.850	5.470	5.120	-99.000

T-182, Companyganj, ; Maximum 10 day levels, Apr. - Oct.

YEAR	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1968	4.300	5.120	4.210	4.310	5.300	4.720	5.210	5.850	4.940	5.240	5.880	5.640	5.580	5.610	5.390	5.580	5.330	5.390	5.520	4.180	5.360	5.880
1969	4.410	4.450	4.110	4.420	4.360	4.680	4.870	4.480	4.870	5.160	5.070	6.040	5.800	5.500	5.430	5.170	5.430	5.680	4.500	6.240	4.630	6.240
1970	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1971	4.000	4.300	4.180	4.360	3.750	4.060	4.420	4.790	5.000	4.730	5.490	4.790	4.120	4.180	3.570	3.870	4.910	4.790	-99.000	4.390	4.790	-99.000
1972	4.570	4.880	4.720	4.720	5.000	4.880	4.880	5.120	5.460	5.380	5.650	5.720	5.320	5.620	5.620	6.080	5.530	5.830	5.340	4.800	4.980	6.080
1973	4.680	4.590	4.180	4.830	4.680	4.370	4.270	4.300	5.460	5.520	5.610	5.520	5.160	5.920	5.800	5.310	5.310	5.400	4.660	5.830	5.490	5.920
1974	4.310	4.310	4.770	5.040	4.440	4.650	5.260	4.650	5.380	5.170	5.790	5.790	6.860	7.160	6.130	5.790	6.710	5.820	5.880	5.520	5.520	7.160
1975	3.240	3.640	2.080	-99.000	4.800	4.800	-99.000	4.610	5.010	5.770	5.620	5.370	4.920	4.550	5.100	-99.000	5.070	4.830	5.190	5.160	-99.000	-99.000
1976	2.850	3.370	3.400	3.610	4.830	4.860	4.800	5.350	5.350	5.320	5.440	5.650	5.470	5.560	5.870	4.590	5.780	5.810	5.320	5.170	5.290	5.870
1977	4.620	4.620	4.620	4.620	5.680	5.830	5.440	5.320	5.260	5.470	5.230	5.470	5.530	5.320	5.500	4.980	5.530	5.140	4.970	5.360	4.910	5.830
1978	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1979	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1980	3.660	3.840	4.020	4.450	4.210	4.360	4.330	4.690	4.330	4.740	5.260	5.500	5.410	5.530	4.950	5.290	5.400	4.890	4.800	4.740	4.770	5.530
1981	4.207	3.963	3.201	4.268	4.146	4.024	4.268	4.268	4.115	5.243	5.487	5.456	5.487	5.304	5.304	5.091	5.774	5.792	4.176	5.152	5.030	5.792
1982	3.963	3.658	4.268	4.725	3.963	3.658	4.789	4.877	5.091	4.725	5.182	5.091	5.182	5.365	5.274	5.182	5.182	4.633	4.451	4.877	4.268	5.365
1983	3.871	4.359	4.481	4.481	4.511	4.877	4.115	4.359	5.182	4.968	4.785	5.121	4.724	3.962	4.633	5.243	4.572	4.663	5.182	4.572	4.572	5.243
1984	4.237	4.572	4.267	4.572	4.938	4.877	4.968	5.182	5.243	5.029	4.877	5.334	5.304	5.121	5.334	5.182	5.395	5.029	4.877	4.877	4.816	5.395
1985	3.709	3.496	3.740	4.877	4.572	7.010	5.639	4.785	4.572	5.486	5.029	4.816	5.486	4.877	4.572	4.938	5.334	5.090	4.785	6.706	4.572	7.010
1986	3.709	3.591	3.834	3.834	3.834	4.481	4.176	4.206	5.182	5.182	4.572	5.243	5.182	4.785	5.182	5.304	5.243	4.724	4.633	4.572	4.023	5.304
1987	3.690	3.190	3.220	3.400	3.520	3.200	4.110	4.700	4.770	5.190	5.130	5.210	5.930	6.210	6.070	5.390	5.290	6.050	6.230	5.350	6.010	6.230
1988	4.590	4.480	3.390	4.580	4.580	4.210	4.550	4.490	4.490	4.550	4.490	3.970	5.120	5.210	5.410	4.610	4.880	5.650	4.670	5.120	5.100	5.650
1989	3.650	3.600	3.670	3.500	3.800	4.000	4.800	5.300	5.200	5.330	5.700	5.300	5.330	5.330	5.210	5.000	4.700	5.100	5.000	5.200	5.100	5.700

T-239 , Laksh-mipur ; Maximum 10 day levels, Apr. - Oct.

YEAR	April 1	April 2	April 3	May 1	May 2	May 3	June 1	June 2	June 3	July 1	July 2	July 3	August 1	August 2	August 3	September 1	September 2	September 3	October 1	October 2	October 3	Annual
1978	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	3.200	3.048	3.353	3.231	3.170	3.261	3.231	3.200	3.353	3.444	3.231	3.109	3.170	2.652	2.957	-99.000
1979	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	2.317	2.865	3.353	3.170	3.139	3.536	3.597	3.292	3.231	3.231	3.292	2.987	3.079	-99.000
1980	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1981	1.494	2.835	2.743	1.829	2.530	3.200	0.000	0.000	0.000	3.536	3.353	3.322	3.353	3.353	3.231	3.353	3.200	3.048	3.048	3.109	2.987	3.536
1982	0.975	1.036	0.300	1.180	1.260	1.640	2.130	2.780	2.980	2.890	3.020	3.180	3.770	3.680	3.490	3.330	3.350	3.280	-99.000	2.730	2.790	-99.000
1983	1.340	1.890	2.660	3.020	2.890	2.510	2.660	2.590	2.780	3.240	3.110	3.450	3.780	3.680	3.680	3.670	3.710	3.780	3.610	3.580	3.360	3.780
1984	1.460	1.410	1.450	1.890	2.390	2.470	3.420	3.420	3.520	3.520	3.500	3.600	3.690	3.710	3.720	3.720	3.680	3.570	3.520	3.170	2.790	3.720
1985	1.270	1.700	1.600	1.520	1.510	2.770	3.080	3.060	3.080	3.280	3.290	3.250	3.250	3.500	3.620	3.530	3.420	3.280	3.270	3.220	2.940	3.620
1986	1.450	1.490	1.530	1.880	2.400	2.380	2.330	2.330	3.210	3.310	3.100	3.820	3.530	3.360	3.340	3.250	3.260	3.380	3.630	3.560	3.270	3.820
1987	1.280	1.990	1.840	1.710	1.670	1.710	1.850	1.840	1.830	2.360	2.840	3.590	3.640	3.630	4.360	4.230	3.980	3.740	3.620	3.570	3.400	4.360
1988	1.150	1.190	2.000	1.350	0.840	2.760	2.770	2.770	3.030	3.100	3.490	3.470	3.620	3.670	3.730	3.810	4.000	3.990	3.740	3.340	3.360	4.000
1989	1.260	0.880	0.850	2.380	2.340	2.940	2.830	3.170	3.330	2.860	2.840	3.260	3.020	2.850	2.740	3.340	3.530	3.350	3.580	3.770	3.550	3.770

T-240 , Bhawaniganj ; Maximum 10 day levels, Apr. - Oct.

YEAR	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1960	1.830	2.290	2.290	1.980	2.690	3.200	2.500	3.290	2.500	2.690	3.200	3.390	3.600	3.780	3.780	3.840	3.690	3.690	3.810	3.420	2.990	3.840
1961	2.530	2.380	2.440	2.930	2.360	3.520	3.220	3.730	3.730	4.130	3.920	4.160	4.220	4.250	4.280	4.160	4.280	3.830	3.790	3.760	3.670	4.280
1962	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1963	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1964	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1965	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1966	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1967	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1968	2.470	2.960	2.680	2.620	3.470	3.660	3.600	3.930	3.960	3.960	3.960	3.790	3.760	3.580	3.730	3.400	3.490	3.580	3.940	3.060	3.280	3.960
1969	2.500	2.960	2.190	2.590	2.530	2.870	3.200	3.510	3.570	3.630	3.750	4.080	4.050	3.930	3.840	3.690	3.960	3.810	3.350	3.380	3.200	4.080
1970	2.800	2.500	2.650	3.050	2.800	3.080	3.110	3.170	3.200	3.320	3.660	4.020	3.810	3.870	3.840	3.810	3.750	3.440	3.440	3.470	3.600	4.020
1971	2.230	2.410	2.290	2.440	2.410	2.440	3.230	3.230	3.350	3.230	3.870	3.600	3.840	3.660	3.960	4.080	3.840	3.750	3.660	3.630	3.350	4.080
1972	2.160	2.960	2.680	2.870	2.960	3.080	2.620	2.800	2.560	3.350	3.050	3.440	3.260	3.840	3.750	3.440	3.350	2.870	2.680	2.590	2.500	3.840
1973	1.800	2.440	2.740	2.960	2.960	2.960	2.950	3.140	3.230	3.510	3.660	3.690	3.600	3.930	3.810	3.690	3.410	3.510	3.320	3.600	3.290	3.930
1974	2.740	2.530	2.530	2.900	2.990	2.990	3.290	2.990	3.290	3.630	3.660	3.930	4.020	4.360	4.420	3.900	3.660	3.570	3.750	3.350	3.320	4.420
1975	2.070	2.440	2.620	2.960	3.080	2.900	2.900	3.020	3.020	3.020	3.350	3.750	3.780	3.750	3.840	3.990	3.510	3.470	3.350	3.630	3.410	3.990
1976	1.920	1.890	1.800	1.860	1.860	1.740	2.230	2.990	3.200	3.170	3.230	3.870	3.870	3.600	3.840	3.870	3.690	3.750	3.660	3.600	3.570	3.870
1977	3.080	3.140	2.830	2.620	3.080	2.680	2.900	2.900	3.020	3.140	3.080	3.290	3.690	3.440	3.900	3.900	3.600	3.780	3.690	3.630	3.380	3.900
1978	-99.000	1.341	1.311	1.615	2.317	3.322	3.353	3.200	3.353	3.231	3.200	3.292	3.109	3.109	3.139	3.231	3.048	3.261	3.109	2.926	2.926	-99.000
1979	0.792	0.732	0.762	0.671	0.853	0.823	0.945	1.158	1.341	1.554	2.621	3.322	3.079	2.835	2.804	2.804	2.713	2.469	2.134	1.829	1.768	3.322
1980	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1981	1.311	1.219	1.311	1.372	1.341	2.042	2.347	2.195	2.317	2.499	2.652	2.652	2.652	3.139	3.261	3.322	3.170	3.139	2.774	2.225	2.103	3.322
1982	1.460	1.300	2.300	2.300	2.100	2.120	2.390	2.940	3.490	4.360	4.200	3.680	3.410	3.400	3.260	3.180	3.060	3.020	3.000	2.950	2.910	4.360
1983	2.070	1.420	1.370	1.520	1.260	1.060	1.020	1.000	0.980	1.090	1.930	2.050	2.820	2.340	2.320	3.400	2.900	2.600	2.800	2.800	2.570	3.400
1984	1.200	1.140	1.140	1.160	1.470	1.220	1.970	2.020	2.160	2.120	2.120	2.080	2.090	2.200	2.170	2.140	2.200	2.120	2.170	2.120	2.100	2.200
1985	1.720	1.370	1.170	1.020	0.920	3.020	2.690	2.690	2.800	3.120	3.180	3.200	3.410	3.370	3.380	3.350	3.310	3.350	3.390	3.320	3.330	3.410
1986	2.170	2.100	2.060	1.920	2.030	2.070	2.030	2.060	2.100	2.450	2.930	3.900	3.700	3.410	3.380	3.380	3.330	3.450	3.550	3.370	3.170	3.900
1987	1.200	1.220	1.550	1.180	1.180	1.230	1.270	1.200	1.170	2.350	3.270	3.640	3.800	3.680	4.000	3.930	3.800	3.690	3.620	3.590	3.580	4.000
1988	1.250	1.270	1.230	1.260	1.300	1.740	2.200	2.650	2.720	3.350	3.550	3.600	3.700	3.750	3.640	3.650	3.700	3.720	3.530	3.070	2.550	3.750
1989	2.150	2.080	1.720	2.100	2.130	2.530	2.410	2.730	2.980	2.830	2.730	2.830	2.730	2.630	2.640	2.940	3.450	3.380	3.180	3.830	3.170	3.830

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T-222, Noakhali, ; Maximum 10 day levels, Apr. - Oct.

YEAR	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1959	4.180	4.270	5.390	5.700	4.420	4.720	4.480	4.480	4.790	5.390	5.240	5.180	5.150	5.240	5.030	5.300	4.830	4.560	5.070	4.530	4.830	5.700
1960	3.580	4.620	3.920	4.130	4.800	4.920	5.070	5.140	4.680	5.200	4.980	4.920	5.380	4.980	5.170	5.010	4.430	5.140	5.440	4.590	4.710	5.440
1961	4.040	4.220	3.950	5.670	4.400	5.290	5.200	4.950	5.140	5.070	4.920	5.230	4.890	4.920	5.140	4.830	5.040	5.230	4.620	4.590	5.070	5.670
1962	4.570	3.960	4.330	4.720	4.180	4.330	4.850	4.920	4.910	4.690	4.750	4.940	4.910	5.120	4.750	4.690	5.390	4.750	4.720	4.820	5.030	5.390
1963	2.410	2.500	2.610	2.700	2.960	4.080	4.360	4.650	4.660	4.660	4.690	4.720	4.970	4.820	4.850	4.880	4.690	4.630	5.210	4.180	4.180	5.210
1964	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1965	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1966	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1967	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1968	3.730	4.650	3.870	3.840	4.890	4.330	4.740	5.200	4.910	5.210	5.200	5.110	5.110	5.060	5.070	5.040	4.950	4.950	5.000	4.420	4.800	5.210
1969	4.290	4.670	4.040	4.430	4.030	4.460	4.990	4.760	4.820	5.070	5.070	5.230	5.160	5.190	5.170	4.910	4.910	5.190	4.850	4.930	4.590	5.230
1970	4.230	3.760	4.110	4.410	3.980	4.410	4.460	4.460	4.300	4.720	4.760	5.040	4.720	5.100	5.100	5.190	5.040	4.840	5.070	4.850	4.610	5.190
1971	3.400	3.310	3.860	4.370	4.600	4.220	4.540	4.660	4.750	4.750	4.970	5.180	5.360	4.850	4.940	5.360	4.750	4.750	4.910	4.850	4.750	5.360
1972	6.630	4.450	3.990	3.990	4.720	3.930	4.750	4.660	4.570	4.750	4.750	4.750	4.750	4.750	5.000	4.910	5.000	4.910	4.910	4.910	4.880	6.630
1973	3.730	4.110	3.730	4.110	4.190	4.190	4.430	5.040	4.800	4.650	4.950	5.170	5.110	5.040	5.260	5.170	5.040	5.010	5.040	5.040	4.740	5.260
1974	3.660	3.510	3.700	4.040	3.840	4.890	4.800	4.650	4.860	4.860	5.170	5.530	5.260	5.260	5.200	5.230	5.320	5.180	5.260	5.060	4.370	5.530
1975	-99.000	-99.000	-99.000	4.040	4.340	4.500	4.720	4.500	4.620	4.770	5.070	5.150	5.010	5.000	4.710	5.170	5.010	4.830	5.230	5.070	4.680	-99.000
1976	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	4.720	4.750	4.910	5.070	4.910	5.090	5.060	5.000	4.970	4.970	4.630	4.540	4.540	4.570	-99.000
1977	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1978	-99.000	-99.000	-99.000	3.688	3.932	4.541	4.907	4.755	4.876	4.877	4.724	4.861	4.907	4.846	4.907	5.305	4.953	4.983	4.983	4.526	4.343	-99.000
1979	3.155	3.063	3.079	3.932	4.298	4.420	4.572	4.542	4.389	4.633	5.029	5.029	5.029	5.151	5.182	5.029	5.090	4.694	4.724	4.846	4.846	5.182
1980	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1981	3.490	4.709	4.526	4.160	4.404	4.374	4.953	4.618	5.227	5.075	5.532	5.289	5.318	5.258	5.318	5.227	4.831	4.709	4.922	4.541	3.490	5.532
1982	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
1983	-99.000	-99.000	-99.000	4.380	4.500	4.380	4.400	4.420	4.650	4.780	4.840	4.270	5.130	4.830	4.810	4.690	4.650	4.580	4.580	4.540	4.120	-99.000
1984	-99.000	-99.000	-99.000	-99.000	4.410	4.410	4.660	4.910	5.100	4.800	5.100	5.170	5.150	4.890	5.200	5.070	4.900	4.740	4.500	4.500	4.450	-99.000
1985	3.640	3.650	3.050	3.120	3.130	4.600	5.000	4.900	4.900	5.250	5.070	5.100	5.220	5.120	5.320	5.070	4.940	4.870	4.720	4.490	4.000	-99.000
1986	3.260	3.230	3.340	3.210	3.220	3.410	3.210	3.920	5.080	4.950	4.890	5.050	4.950	4.820	4.930	4.800	4.820	4.870	4.810	4.610	4.480	5.320
1987	-99.000	-99.000	-99.000	3.780	3.670	3.000	3.820	4.050	4.330	5.100	5.300	5.350	5.320	5.040	5.300	5.200	5.260	5.220	5.000	4.810	4.630	5.080
1988	3.170	3.200	3.300	3.230	4.330	4.830	4.260	4.880	4.760	4.930	4.970	4.930	5.080	5.250	5.050	5.120	5.040	5.030	4.950	4.760	4.720	-99.000
1989	-99.000	-99.000	-99.000	3.770	3.740	3.870	3.760	4.290	4.310	4.630	4.550	4.840	4.670	4.370	4.470	4.710	4.740	4.730	5.140	5.170	4.990	5.250

APPENDIX - B.4

Frequency Analysis of 10-Day Maximum Water Level for the Period April to October

Annual Maximum Water Levels
T-58 , Hazigang ; Maximum 10 day levels, Apr. - Oct.

Return Period (YEARS)	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1.11	1.82	1.86	2.00	2.05	2.24	2.56	2.62	2.95	3.34	3.68	3.76	4.00	4.19	4.21	4.07	3.96	3.97	3.92	3.92	3.75	3.38	4.16
1.25	1.87	1.99	2.11	2.16	2.36	2.68	2.76	3.06	3.42	3.74	3.83	4.06	4.25	4.26	4.16	4.09	4.10	4.04	4.00	3.83	3.47	4.27
2	1.99	2.30	2.38	2.44	2.66	2.97	3.09	3.33	3.62	3.86	4.01	4.21	4.39	4.40	4.39	4.39	4.39	4.32	4.20	4.03	3.69	4.55
5	2.15	2.70	2.74	2.81	3.05	3.36	3.54	3.68	3.88	4.03	4.26	4.41	4.58	4.58	4.70	4.81	4.79	4.69	4.48	4.30	3.99	4.92
10	2.25	2.97	2.98	3.06	3.31	3.62	3.84	3.92	4.05	4.14	4.42	4.54	4.71	4.69	4.90	5.08	5.06	4.93	4.66	4.47	4.18	5.16
20	2.36	3.23	3.22	3.30	3.57	3.87	4.12	4.14	4.22	4.24	4.58	4.66	4.83	4.81	5.10	5.35	5.31	5.17	4.83	4.64	4.37	5.40
50	2.49	3.56	3.51	3.60	3.89	4.19	4.49	4.43	4.44	4.38	4.78	4.82	4.99	4.96	5.35	5.69	5.64	5.48	5.05	4.86	4.61	5.70

Annual Maximum Water Levels
T-79 ,Matlab Bazar ; Maximum 10 day levels, Apr. - Oct.

Return Period (YEARS)	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1.11	1.88	2.02	2.13	2.28	2.40	2.65	2.97	3.23	3.62	3.92	4.11	4.27	4.39	4.47	4.43	4.40	4.39	4.22	3.96	3.68	3.32	4.75
1.25	1.98	2.12	2.22	2.40	2.51	2.75	3.06	3.32	3.72	4.00	4.18	4.36	4.49	4.56	4.52	4.48	4.45	4.31	4.06	3.78	3.41	4.82
2	2.20	2.36	2.41	2.69	2.78	3.01	3.25	3.54	3.94	4.18	4.36	4.56	4.73	4.78	4.74	4.67	4.61	4.53	4.29	4.02	3.61	4.99
5	2.50	2.67	2.67	3.07	3.14	3.34	3.52	3.84	4.23	4.42	4.61	4.84	5.05	5.07	5.03	4.93	4.83	4.82	4.60	4.34	3.88	5.22
10	2.70	2.88	2.85	3.32	3.38	3.57	3.69	4.04	4.43	4.58	4.77	5.02	5.26	5.26	5.23	5.10	4.97	5.01	4.81	4.55	4.05	5.37
20	2.90	3.08	3.01	3.56	3.61	3.78	3.86	4.23	4.61	4.74	4.92	5.19	5.46	5.44	5.41	5.26	5.11	5.20	5.01	4.75	4.23	5.52
50	3.14	3.34	3.23	3.88	3.91	4.06	4.08	4.47	4.85	4.94	5.12	5.42	5.72	5.68	5.66	5.47	5.29	5.44	5.26	5.01	4.45	5.70

Annual Maximum Water Levels
T-278, Daulat Khan, ; Maximum 10 day levels, Apr. - Oct.

Return Period (YEARS)	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1.11	1.83	2.02	2.01	2.17	2.35	2.45	2.56	2.69	2.77	3.11	3.29	3.31	3.49	3.46	3.29	3.29	3.18	3.04	2.74	2.55	2.43	3.82
1.25	1.93	2.12	2.11	2.25	2.43	2.53	2.66	2.80	2.88	3.18	3.37	3.41	3.56	3.52	3.37	3.37	3.24	3.11	2.84	2.67	2.51	3.87
2	2.14	2.35	2.33	2.45	2.64	2.74	2.91	3.05	3.14	3.34	3.55	3.64	3.73	3.66	3.56	3.56	3.39	3.28	3.10	2.94	2.70	3.98
5	2.43	2.66	2.64	2.72	2.91	3.01	3.25	3.39	3.48	3.57	3.80	3.94	3.97	3.84	3.81	3.82	3.58	3.51	3.44	3.31	2.96	4.13
10	2.62	2.86	2.83	2.90	3.09	3.19	3.47	3.61	3.71	3.71	3.96	4.15	4.12	3.97	3.97	3.99	3.71	3.66	3.67	3.55	3.13	4.22
20	2.80	3.06	3.03	3.08	3.27	3.36	3.69	3.82	3.93	3.85	4.12	4.34	4.27	4.09	4.13	4.15	3.83	3.81	3.89	3.78	3.29	4.32
50	3.04	3.31	3.27	3.30	3.49	3.59	3.96	4.10	4.22	4.03	4.32	4.59	4.47	4.24	4.33	4.37	3.99	3.99	4.17	4.08	3.50	4.44

B:\APP.B4

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Annual Maximum Water Levels
T-277 , Chandpur ; Maximum 10 day levels, Apr. - Oct.

Return Period (YEARS)	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1.11	1.93	2.03	2.12	2.23	2.51	2.89	3.04	3.34	3.49	3.83	3.98	4.15	4.26	4.24	4.20	4.16	4.20	3.99	3.78	3.50	3.08	4.55
1.25	2.00	2.12	2.20	2.36	2.61	2.97	3.12	3.42	3.59	3.90	4.04	4.22	4.34	4.31	4.29	4.24	4.26	4.07	3.86	3.60	3.19	4.61
2	2.17	2.34	2.39	2.67	2.85	3.15	3.33	3.61	3.83	4.05	4.19	4.40	4.51	4.48	4.50	4.43	4.40	4.24	4.06	3.86	3.47	4.76
5	2.40	2.63	2.65	3.08	3.17	3.39	3.60	3.86	4.14	4.26	4.39	4.64	4.75	4.70	4.78	4.69	4.59	4.48	4.34	4.21	3.83	4.95
10	2.55	2.83	2.82	3.35	3.39	3.55	3.78	4.02	4.35	4.39	4.52	4.80	4.91	4.85	4.97	4.86	4.71	4.63	4.52	4.44	4.07	5.08
20	2.69	3.01	2.98	3.61	3.60	3.71	3.95	4.18	4.56	4.52	4.65	4.95	5.06	5.00	5.15	5.02	4.83	4.78	4.69	4.66	4.30	5.20
50	2.88	3.25	3.19	3.94	3.86	3.91	4.17	4.38	4.82	4.69	4.82	5.15	5.26	5.18	5.38	5.23	4.98	4.98	4.91	4.94	4.60	5.36

Annual Maximum Water Levels
T-276 , Satnal ; Maximum 10 day levels, Apr. - Oct.

Return Period (YEARS)	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1.11	1.82	1.99	2.03	2.17	2.37	2.68	2.84	3.19	3.57	3.93	4.10	4.34	4.55	4.58	4.44	4.46	4.42	4.26	3.98	3.67	3.20	4.84
1.25	1.90	2.06	2.11	2.28	2.48	2.78	2.95	3.30	3.68	4.03	4.20	4.45	4.65	4.67	4.57	4.57	4.52	4.36	4.07	3.78	3.31	4.93
2	2.09	2.23	2.29	2.56	2.73	2.99	3.21	3.55	3.94	4.26	4.44	4.70	4.91	4.89	4.86	4.83	4.77	4.59	4.30	4.03	3.58	5.16
5	2.34	2.45	2.54	2.93	3.07	3.28	3.56	3.89	4.29	4.57	4.76	5.05	5.25	5.20	5.25	5.18	5.11	4.89	4.60	4.38	3.95	5.47
10	2.50	2.59	2.71	3.17	3.30	3.47	3.79	4.12	4.52	4.77	4.97	5.28	5.48	5.40	5.50	5.41	5.34	5.09	4.80	4.60	4.19	5.68
20	2.66	2.73	2.87	3.41	3.52	3.66	4.01	4.33	4.74	4.97	5.17	5.50	5.70	5.59	5.75	5.64	5.55	5.28	4.99	4.82	4.42	5.87
50	2.87	2.92	3.08	3.71	3.80	3.90	4.30	4.61	5.02	5.23	5.44	5.79	5.98	5.83	6.07	5.92	5.83	5.53	5.24	5.10	4.72	6.13

Annual Maximum Water Levels
W-181, Gunabati Railway Bridge (d/s) ; Maximum 10 day levels, Apr. - Oct.

Return Period (YEARS)	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1.11	112.57	112.67	113.43	3.12	3.53	3.80	3.82	4.21	4.28	4.83	4.90	4.66	4.46	4.24	3.95	4.24	4.08	4.31	3.93	3.51	3.46	115.69
1.25	84.65	84.75	85.51	3.37	3.76	4.00	3.99	4.35	4.40	4.92	4.98	4.77	4.61	4.39	4.16	4.38	4.21	4.39	4.05	3.72	3.62	87.77
2	18.97	19.07	19.84	3.94	4.30	4.46	4.39	4.69	4.69	5.12	5.19	5.01	4.97	4.74	4.67	4.73	4.52	4.58	4.34	4.20	4.00	22.10
5	-69.39	-69.29	-68.53	4.72	5.04	5.09	4.92	5.15	5.08	5.40	5.47	5.34	5.44	5.20	5.34	5.19	4.93	4.83	4.73	4.85	4.51	-66.27
10	-127.89	-127.80	-127.03	5.23	5.52	5.50	5.27	5.45	5.34	5.58	5.66	5.56	5.76	5.51	5.79	5.50	5.20	4.99	4.98	5.27	4.85	-124.77
20	-184.01	-183.92	-183.15	5.73	5.99	5.89	5.61	5.74	5.58	5.75	5.84	5.77	6.06	5.80	6.22	5.79	5.47	5.15	5.23	5.69	5.17	-180.89
50	-256.65	-256.56	-255.79	6.36	6.59	6.41	6.05	6.11	5.90	5.97	6.07	6.04	6.46	6.19	6.78	6.17	5.80	5.35	5.55	6.22	5.59	-253.53

Annual Maximum Water Levels
T-182, Companyganj, ; Maximum 10 day levels, Apr. - Oct.

Return Period (YEARS)	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1.11	3.47	3.50	3.19	3.84	3.85	3.72	4.20	4.32	4.57	4.82	4.83	4.82	4.77	4.54	4.64	4.61	4.83	4.77	4.44	4.47	4.43	5.30
1.25	3.61	3.65	3.38	3.97	4.01	3.94	4.33	4.44	4.68	4.91	4.95	4.95	4.92	4.74	4.80	4.75	4.96	4.90	4.59	4.64	4.57	5.45
2	3.93	4.02	3.81	4.29	4.38	4.47	4.64	4.73	4.93	5.12	5.21	5.24	5.28	5.20	5.19	5.07	5.26	5.20	4.93	5.05	4.88	5.81
5	4.37	4.51	4.38	4.71	4.87	5.19	5.05	5.13	5.27	5.40	5.57	5.64	5.75	5.83	5.70	5.49	5.67	5.61	5.38	5.59	5.30	6.28
10	4.66	4.83	4.77	4.99	5.20	5.66	5.33	5.39	5.50	5.58	5.81	5.91	6.06	6.25	6.05	5.77	5.94	5.89	5.68	5.96	5.58	6.60
20	4.94	5.14	5.14	5.26	5.52	6.12	5.59	5.63	5.71	5.76	6.03	6.16	6.37	6.65	6.38	6.04	6.20	6.15	5.97	6.31	5.85	6.90
50	5.29	5.54	5.61	5.61	5.92	6.71	5.93	5.96	6.00	5.99	6.33	6.49	6.76	7.17	6.80	6.39	6.53	6.49	6.35	6.76	6.19	7.29

Annual Maximum Water Levels
T-239 , Laksh-mipur ; Maximum 10 day levels, Apr. - Oct.

Return Period (YEARS)	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1.11	1.12	0.95	0.80	1.25	1.23	1.91	1.35	1.41	1.56	2.73	2.93	3.17	3.16	3.18	3.10	3.22	3.18	3.10	3.19	2.85	2.84	3.54
1.25	1.16	1.11	1.02	1.41	1.42	2.06	1.62	1.69	1.84	2.83	3.00	3.23	3.24	3.25	3.21	3.30	3.27	3.19	3.26	2.95	2.92	3.62
2	1.27	1.50	1.54	1.77	1.87	2.40	2.27	2.34	2.51	3.05	3.15	3.36	3.41	3.43	3.47	3.49	3.46	3.38	3.41	3.18	3.09	3.78
5	1.42	2.03	2.23	2.26	2.47	2.86	3.13	3.21	3.40	3.36	3.35	3.55	3.65	3.66	3.82	3.76	3.72	3.65	3.62	3.50	3.32	4.01
10	1.51	2.38	2.68	2.59	2.87	3.17	3.71	3.79	4.00	3.56	3.49	3.67	3.81	3.81	4.05	3.93	3.89	3.82	3.75	3.72	3.48	4.16
20	1.61	2.71	3.12	2.90	3.26	3.47	4.26	4.34	4.57	3.75	3.62	3.78	3.96	3.96	4.28	4.09	4.06	3.99	3.88	3.92	3.63	4.30
50	1.73	3.14	3.69	3.31	3.75	3.85	4.97	5.06	5.30	4.00	3.79	3.93	4.15	4.16	4.56	4.31	4.28	4.21	4.05	4.18	3.82	4.49

Annual Maximum Water Levels
T-240 , Bhawaniganj ; Maximum 10 day levels, Apr. - Oct.

Return Period (YEARS)	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1.11	1.32	1.22	1.28	1.27	1.32	1.54	1.73	1.86	1.90	2.18	2.62	2.82	2.91	2.86	2.88	3.01	2.94	2.85	2.74	2.58	2.45	3.29
1.25	1.49	1.42	1.46	1.47	1.54	1.77	1.94	2.08	2.13	2.40	2.78	2.98	3.05	3.02	3.04	3.14	3.06	2.98	2.88	2.73	2.60	3.42
2	1.88	1.89	1.88	1.96	2.05	2.31	2.42	2.59	2.65	2.90	3.16	3.35	3.39	3.38	3.43	3.45	3.36	3.28	3.21	3.09	2.95	3.73
5	2.40	2.52	2.44	2.62	2.74	3.04	3.07	3.28	3.36	3.59	3.67	3.86	3.85	3.87	3.94	3.86	3.75	3.69	3.65	3.58	3.41	4.14
10	2.75	2.93	2.82	3.05	3.19	3.53	3.50	3.74	3.83	4.04	4.00	4.19	4.16	4.19	4.28	4.14	4.01	3.96	3.94	3.90	3.72	4.42
20	3.09	3.33	3.18	3.47	3.63	3.99	3.91	4.18	4.28	4.48	4.33	4.52	4.45	4.50	4.61	4.40	4.27	4.22	4.22	4.21	4.02	4.68
50	3.52	3.85	3.64	4.00	4.20	4.59	4.44	4.75	4.86	5.04	4.75	4.93	4.83	4.91	5.03	4.74	4.59	4.56	4.58	4.61	4.40	5.02

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Annual Maximum Water Levels
T-222, Noakhali, ; Maximum 10 day levels, Apr. - Oct.

Return Period (YEARS)	April			May			June			July			August			September			October			Annual
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
1.11	2.86	3.14	3.11	3.28	3.56	3.82	4.05	4.33	4.48	4.66	4.74	4.76	4.85	4.77	4.80	4.82	4.71	4.65	4.66	4.44	4.18	5.03
1.25	3.10	3.33	3.29	3.48	3.71	3.95	4.18	4.41	4.55	4.72	4.80	4.83	4.91	4.83	4.86	4.87	4.77	4.70	4.73	4.51	4.28	5.13
2	3.69	3.77	3.71	3.95	4.04	4.27	4.49	4.62	4.72	4.87	4.95	5.00	5.04	4.96	5.00	5.00	4.91	4.84	4.89	4.68	4.52	5.36
5	4.47	4.35	4.27	4.58	4.50	4.70	4.90	4.89	4.94	5.06	5.14	5.22	5.21	5.15	5.19	5.18	5.09	5.03	5.10	4.89	4.84	5.68
10	4.99	4.74	4.65	5.00	4.80	4.99	5.17	5.08	5.09	5.19	5.27	5.37	5.33	5.27	5.31	5.30	5.22	5.15	5.24	5.04	5.05	5.89
20	5.49	5.12	5.00	5.40	5.09	5.26	5.43	5.25	5.23	5.31	5.40	5.51	5.44	5.38	5.43	5.41	5.34	5.27	5.38	5.17	5.25	6.09
50	6.13	5.60	5.47	5.92	5.47	5.62	5.77	5.48	5.42	5.47	5.56	5.69	5.58	5.53	5.59	5.56	5.49	5.42	5.55	5.35	5.52	6.35

APPENDIX - B.5

Water Level Duration and Frequency Analysis

Flood Level Duration / Frequency
T-58 , Hazigang ; Maximum 10 day levels, Apr. - Oct.

Duration Days	Return Period (years) 1.11	1.25	2	5	10	20	50
20	4.09	4.18	4.42	4.73	4.94	5.14	5.39
30	4.06	4.15	4.36	4.64	4.82	5.00	5.23
40	4.08	4.14	4.30	4.51	4.65	4.79	4.96
50	3.99	4.06	4.24	4.48	4.65	4.80	5.00
60	3.95	4.02	4.20	4.45	4.61	4.76	4.96
80	3.86	3.93	4.09	4.31	4.45	4.59	4.77
100	3.67	3.72	3.86	4.04	4.16	4.28	4.42
120	3.33	3.40	3.55	3.77	3.91	4.04	4.21
150	2.41	2.55	2.87	3.30	3.59	3.87	4.23

Flood Level Duration / Frequency
T-79 ,Matlab Bazar ; Maximum 10 day levels, Apr. - Oct.

Duration Days	Return Period (years) 1.11	1.25	2	5	10	20	50
20	4.52	4.59	4.75	4.98	5.12	5.26	5.45
30	4.39	4.46	4.64	4.87	5.02	5.17	5.36
40	4.35	4.42	4.58	4.81	4.95	5.10	5.28
50	4.31	4.37	4.52	4.71	4.84	4.97	5.13
60	4.27	4.32	4.45	4.62	4.74	4.85	4.99
80	4.10	4.15	4.29	4.47	4.58	4.70	4.84
100	3.80	3.86	4.00	4.19	4.31	4.43	4.58
120	3.47	3.54	3.71	3.93	4.08	4.23	4.42
150	2.76	2.84	3.02	3.27	3.44	3.59	3.80

Flood Level Duration / Frequency
T-278, Daulat Khan, ; Maximum 10 day levels, Apr. - Oct.

Duration Days	Return Period (years) 1.11	1.25	2	5	10	20	50
20	3.42	3.47	3.60	3.76	3.87	3.98	4.11
30	3.32	3.38	3.50	3.66	3.77	3.87	4.01
40	3.26	3.31	3.43	3.59	3.69	3.79	3.92
50	3.22	3.27	3.38	3.54	3.64	3.74	3.87
60	3.16	3.21	3.32	3.48	3.58	3.68	3.81
80	3.05	3.10	3.20	3.34	3.44	3.53	3.65
100	2.93	2.97	3.07	3.21	3.30	3.39	3.51
120	2.51	2.60	2.80	3.07	3.25	3.42	3.64
150	2.31	2.39	2.58	2.83	3.00	3.16	3.37

Flood Level Duration / Frequency
T-277 , Chandpur ; Maximum 10 day levels, Apr. - Oct.

Duration Days	Return Period (years) 1.11	1.25	2	5	10	20	50
20	4.21	4.27	4.43	4.64	4.78	4.91	5.08
30	4.16	4.22	4.35	4.54	4.66	4.78	4.93
40	4.13	4.18	4.31	4.49	4.60	4.71	4.85
50	4.10	4.16	4.29	4.46	4.58	4.69	4.84
60	4.06	4.11	4.23	4.38	4.48	4.57	4.70
80	3.90	3.95	4.06	4.22	4.33	4.43	4.55
100	3.70	3.75	3.89	4.06	4.18	4.29	4.44
120	3.37	3.45	3.62	3.85	4.01	4.16	4.35
150	2.85	2.92	3.10	3.34	3.50	3.65	3.85

Flood Level Duration / Frequency
T-276 , Satnal ; Maximum 10 day levels, Apr. - Oct.

Duration Days	Return Period (years) 1.11	1.25	2	5	10	20	50
20	4.54	4.63	4.86	5.16	5.36	5.55	5.79
30	4.42	4.51	4.72	4.99	5.17	5.35	5.58
40	4.39	4.47	4.67	4.93	5.10	5.27	5.49
50	4.34	4.42	4.60	4.85	5.02	5.17	5.38
60	4.27	4.34	4.51	4.74	4.88	5.03	5.21
80	4.06	4.14	4.32	4.56	4.72	4.88	5.08
100	3.77	3.85	4.04	4.28	4.45	4.61	4.81
120	3.34	3.44	3.67	3.98	4.19	4.39	4.64
150	2.62	2.71	2.93	3.22	3.41	3.59	3.83

Flood Level Duration / Frequency
W-181, Gunabati Railway Bridge (d/s) ; Maximum 10 day levels, Apr. - Oct.

Duration Days	Return Period (years) 1.11	1.25	2	5	10	20	50
20	115.14	87.22	21.55	-66.82	******	******	******
30	115.07	87.15	21.47	-66.89	******	******	******
40	114.83	86.91	21.24	-67.13	******	******	******
50	114.83	86.91	21.24	-67.13	******	******	******
60	114.83	86.91	21.24	-67.13	******	******	******
80	114.45	86.53	20.86	-67.51	******	******	******
100	114.45	86.53	20.86	-67.51	******	******	******
120	114.45	86.53	20.86	-67.51	******	******	******
150	113.93	86.01	20.34	-68.03	******	******	******

Flood Level Duration / Frequency
T-182, Companyganj, ; Maximum 10 day levels, Apr. - Oct.

Duration Days	Return Period (years) 1.11	1.25	2	5	10	20	50
20	5.03	5.13	5.34	5.63	5.83	6.01	6.25
30	4.90	4.99	5.19	5.48	5.66	5.84	6.07
40	4.84	4.93	5.13	5.40	5.58	5.75	5.97
50	4.75	4.84	5.06	5.34	5.53	5.72	5.95
60	4.73	4.82	5.03	5.32	5.51	5.69	5.92
80	4.53	4.64	4.90	5.24	5.47	5.69	5.98
100	4.28	4.39	4.67	5.04	5.29	5.52	5.83
120	4.17	4.27	4.51	4.83	5.04	5.24	5.50
150	3.77	3.90	4.20	4.61	4.88	5.14	5.47

Flood Level Duration / Frequency
T-239 , Laksh-mipur ; Maximum 10 day levels, Apr. - Oct.

Duration Days	Return Period (years) 1.11	1.25	2	5	10	20	50
20	3.37	3.43	3.58	3.78	3.91	4.03	4.19
30	3.32	3.38	3.50	3.67	3.78	3.89	4.03
40	3.27	3.32	3.46	3.64	3.76	3.87	4.02
50	3.24	3.29	3.42	3.60	3.72	3.83	3.98
60	3.07	3.14	3.33	3.58	3.74	3.90	4.10
80	3.02	3.09	3.25	3.48	3.63	3.77	3.96
100	2.84	2.91	3.07	3.29	3.44	3.58	3.76
120	1.27	1.58	2.31	3.29	3.94	4.57	5.37
150	1.13	1.39	2.01	2.84	3.39	3.91	4.60

Flood Level Duration / Frequency
T-240 , Bhawaniganj ; Maximum 10 day levels, Apr. - Oct.

Duration Days	Return Period (years) 1.11	1.25	2	5	10	20	50
20	2.98	3.12	3.45	3.88	4.17	4.45	4.80
30	2.96	3.09	3.40	3.82	4.10	4.36	4.71
40	2.94	3.07	3.37	3.78	4.06	4.32	4.66
50	2.85	2.99	3.30	3.73	4.01	4.28	4.63
60	2.74	2.88	3.21	3.65	3.94	4.22	4.58
80	2.63	2.77	3.11	3.57	3.87	4.16	4.53
100	2.39	2.54	2.89	3.37	3.69	3.99	4.39
120	1.84	2.05	2.54	3.20	3.64	4.06	4.61
150	1.48	1.68	2.16	2.81	3.24	3.65	4.18

Flood Level Duration / Frequency
T-222, Noakhali, ; Maximum 10 day levels, Apr. - Oct.

Duration Days	Return Period (years) 1.11	1.25	2	5	10	20	50
20	4.90	4.94	5.03	5.15	5.23	5.30	5.40
30	4.86	4.90	5.00	5.12	5.21	5.29	5.40
40	4.82	4.86	4.96	5.10	5.19	5.28	5.39
50	4.79	4.84	4.94	5.08	5.17	5.26	5.38
60	4.77	4.81	4.91	5.03	5.12	5.20	5.30
80	4.69	4.73	4.82	4.94	5.02	5.10	5.19
100	4.65	4.68	4.74	4.83	4.88	4.94	5.01
120	4.44	4.48	4.59	4.73	4.82	4.91	5.03
150	3.87	3.96	4.17	4.45	4.64	4.82	5.05

ANNEX C

HYDROGEOLOGY

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NOAKHALI NORTH DRAINAGE AND IRRIGATION PROJECT
FEASIBILITY STUDY

ANNEX C - GROUNDWATER

CONTENTS

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GROUND WATER

CHAPTER C1

INTRODUCTION

C.1.1 Background

This report forms part of the Noakhali North Feasibility Study, and follows on from the work carried out for the Hydrogeology Annex of the Draft South East Region Water Resources Development Plan. The report also contains supporting data relevant to the Final Regional Plan. Figure C.1.1 shows the study area, the main khals and existing embankments.

C.1.2. Objectives

The report addresses two, largely separate, issues related to groundwater. First, even though the feasibility study is concerned with surface water development, it recognises that the Draft Regional Plan was drawn up on the basis of a deficient database on minor irrigation development, and wrongly concluded that there was no groundwater potential in much of the project area. Recent irrigation developments implemented through BADC have proven that there is some potential throughout the area. Secondly, the report examines the possibility of any interaction between shallow saline groundwater and surface water in khals that it has been proposed to excavate.

C.1.3 Previous Work

No detailed groundwater resources evaluation of the Noakhali region has ever been carried out. No provision was made for addressing this under FAP:5 (nor has there under any other FAP project).

In preparing this report, the following reports (in chronological order) were found to contain reference to groundwater in the study area:

IECO. 1972. Meghna - Muhuri Transfer. Planning Report.

> On groundwater potential, the report notes " The Lower Little Feni and Noakhali area is a zone of possible seawater intrusion." The report also doubts that the grain size of the sediments would be sufficient to form aquifers. It is also interesting to record the changing policy over twenty years, *viz*: "... if a surface water shortage becomes apparent, a limited need for groundwater may develop. At that time, detailed investigations ..... will determine the comparative economy .... ".

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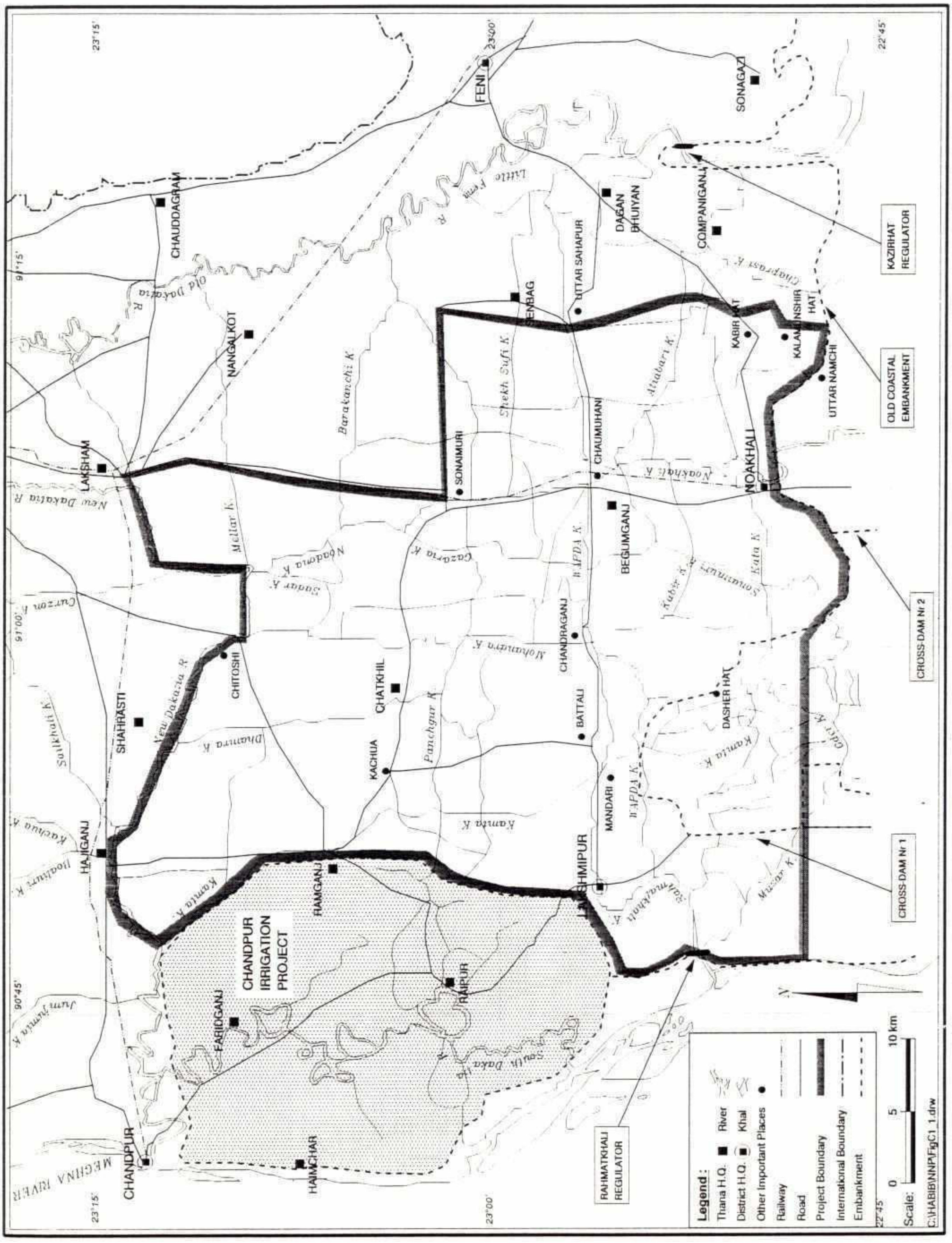
Figure C.1.1
The Study Area



Morton and Khan. 1979. Groundwater in the Coastal Zone and Offshore Islands of Bangladesh. UNDTCD. BWDB WSP 416.

To date this is the only systematic description of the coastal aquifers. It is essentially a compilation of the existing data. The report takes pains to point out the inadequate database, and emphasises that "the potential of the aquifer ...... cannot be determined without further field studies", and recommended a major programme of exploratory drilling, aquifer testing, data analysis and salinity monitoring. It is worth noting that the major national resource studies (e.g. the Water Balance Studies, and the National Water Plan) appear to have based their assessment of the coastal aquifers on this study.

BWDB. 1982. Noakhali North Irrigation Project.

The report contains no information on groundwater.

MPO. 1988. Planning Area Analysis. Vol IVA - Southeast Region. Planning Area 33.

The report refers to the 1985 NWP baseline data which showed there were hardly any DTWs or STWs, but large numbers of MOSTI's (far more than in the 1991 AST survey):

Thana	MOSTI	STW	DTW
Laksmipur	437	1	0
Chatkil	299	0	0
Ramganj	236	1	0
Begumganj	721	150[1]	1

On planning constraints, the report indicates a 100% salinity constraint for Noakhali Sadar, and a 45% constraint for Laksmipur, and zero elsewhere. The NWP recommended zero incremental numbers of both DSSTWs and DTWs.

DANIDA. 1989. 'Water under the bridge'. Noakhali RDP Phase II. Irrigation and Drainage Component.

Mainly concerned with evaluation of surface water irrigation, but draws attention to the strong demand for groundwater irrigation, stating (p151) "... the theme is hardly touched on in the official documents. Still, ever since the inception of NRDP-1 pressure has increasingly been applied to the project to establish a programme of DTW irrigation. It is of importance in areas where surface water for irrigation is in short supply ....". The project included three sub-studies of Noakhali, Feni and Laksmipur districts:

- Laksmipur District. *Prokashali Sangshad*. The report noted "groundwater data are too insufficient to describe ...... aquifer characteristics, water quality, potential ...."

- Feni District. *Sarm Associates*. The report notes "Groundwater data are also sparse here."

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[1] curiously three times the number in 1991

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- Noakhali District. *Development Consultancy Services*. On Senbag thana it notes "7 DTWs reported as failed due to high water salinity, non-maintenance, non-payment of water charges, and conflicts .... ". It also notes that STWs are not functioning due to "gas interception" and a "high incidence of salt water intrusion", and in general that "the hydrogeology is not clearly understood ..... and calls for further studies". On Chatkil thana it noted "DTWs and STWs may be the answer, but investigation into hydrogeology is paramount". On Noakhali Sadar "Groundwater is likely to be saline in the upper layers.

DANIDA. 1989. Groundwater Investigation Reports: Laksmipur, Maijdee and Choumohani Pourashavas.
The three valuable short reports give details of existing (especially DPHE) wells in the municipalities. Sample basic aquifer test and chemical data are given. The most useful information are the electrical resistivity logs of two test holes in each pourashava, which show clearly the vertical distribution of salinity.

DPHE/DANIDA. 1990. Rural Water Supply and Sanitation Programme. 1988-93.
This contains a useful compilation (at union and thana level) of all DPHE hand tubewells for drinking water in the coastal zone, including depths, and iron and chloride concentrations.

SERS. 1991. Draft Regional Plan. Hydrogeology Annex.
The report is mainly a reworking of the MPO data, updated with information from the DTW II project and limited field studies in the Comilla Region. It includes a development and detailed application of the MPO style recharge model and depth storage analyses. It gave attention to the possible effects of FCD/I interventions on potential recharge. However, the report did not identify the mode of occurrence of fresh groundwater in Laksmipur District. The study relied on 1989/90 MPO irrigation data, which missed the recent rapid increase in DTW irrigation.

CHAPTER C.2

MINOR IRRIGATION

C.2.1 Available Data

Until the mid-1980's when irrigation was provided through Government agencies, reliable estimates of minor irrigation (operating numbers at least) could be obtained through BADC and BKB and to a lesser extent BWDB and BRDB. Following deregulation, LLP and STW irrigation has been increasingly dominated by the private sector. This makes monitoring more difficult, especially since the changes have been accompanied by a rapid growth in numbers and diversification of the types and capacities of equipment. BADC, however, still provides the best data on DTW irrigation. Recognising that major changes were occurring, the (CIDA funded) Agriculture Sector Team (AST) organised national inventories of minor irrigation in 1989 and 1991. In 1989 they recorded only numbers of STWs and LLPs, but in 1991 they included all types of irrigation equipment and their command areas. These data are recorded by DAE block level, of which there may be around 20 to 40 in a thana. While far from perfect, the 1991 AST data are widely considered to be the best available. This study, has used the AST data updated with information from BADC on the number of DTWs drilled up to March 1993. The growth of DTWs since 1990 has occurred since it has only recently been widely recognised that DTWs screened below about 130 metres produce fresh water.

Table C.2.1 shows the original AST 1991 data, where the thana totals have been adjusted to count only those DAE blocks within the study area, while the data in Table C.2.2 include the latest DTW numbers and DTW irrigated areas that have been synthesised from the 1991 average command area to give an indication of the probable current irrigation coverage. Full details of the AST data, by block, are given in Appendix C.I. Despite the recent increase in groundwater irrigation, the area is still dominated by LLP irrigation. Traditional irrigation is also important, providing nearly a quarter of all irrigation. Groundwater irrigation is constituted by approximately one third STWs and two thirds DTWs. The MPO data mentioned in Chapter C.1 suggest that manual tubewells may be more important than shown in Table C.2.2, but would still not exceed more than a few hundred hectares.

2.2 Surface Water Irrigation

Figure C.2.1 shows the major concentrations (>100 ha and >300 ha in a DAE block) of surface water irrigation in the Noakhali North area. The main concentrations are along the Dakatia River in the north of the study, adjacent to the western section of the WAPDA khal, and along the northern and southern ends of Noakhali Khal. Surface irrigation is discussed in Appendix I.

C.2.3 Groundwater Irrigation

The total irrigation by groundwater is also shown in Figure C.2.1 (AST data only). Most areas have no groundwater irrigation, however, those that do also tend to have relatively intensive surface water irrigation. The northern part of the boundary between Begumganj and Senbag is the only part of the study area that is dominated by groundwater irrigation.

Figure C.2.1
Distribution of Minor Irrigation in 1991

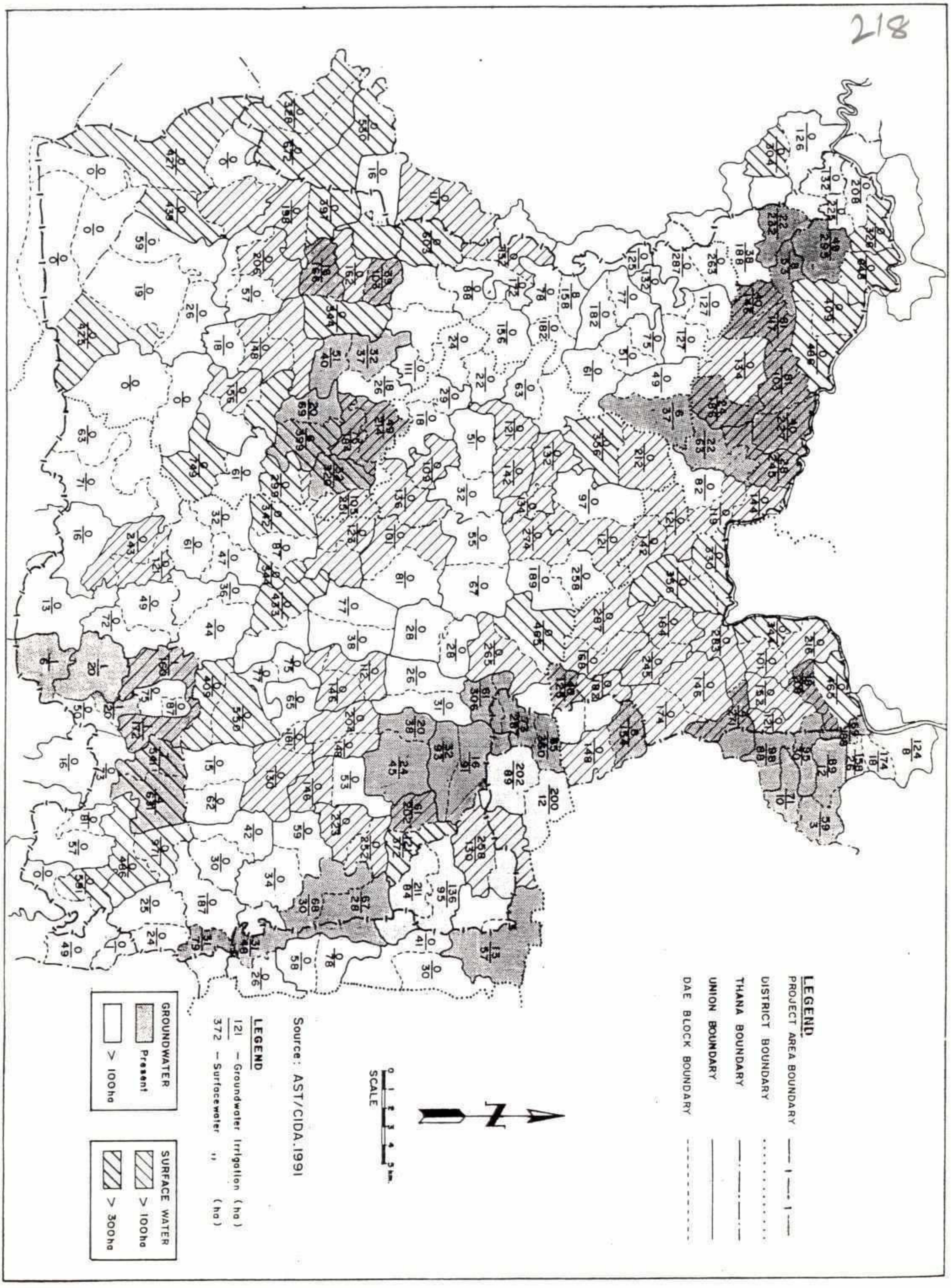

Figure C.2.2 shows the distribution of STWs by DAE block. Most of the area has no STW irrigation, implying that their development is constrained by either salinity or gas (or both). As with the overall distribution of groundwater irrigation, the main concentration is in the extreme east of the area. A minor concentration of STWs occurs in the east of Laksmipur Sadar. The status of gas as a constraint on STW development is the area is unknown.

The main concentration of DTWs is in Chatkil and Laksmipur north of WAPDA Khal. This was seen earlier (Figure C.2.1) to be an area of low total irrigation coverage, and hence probably represents an area of strong demand for irrigation, coupled with regulated supply mechanism. It is also noticeable that most of the DTWs are sited more than 1 Km away from any major Khal.

Figure C.2.2
Distribution of STWs in 1991

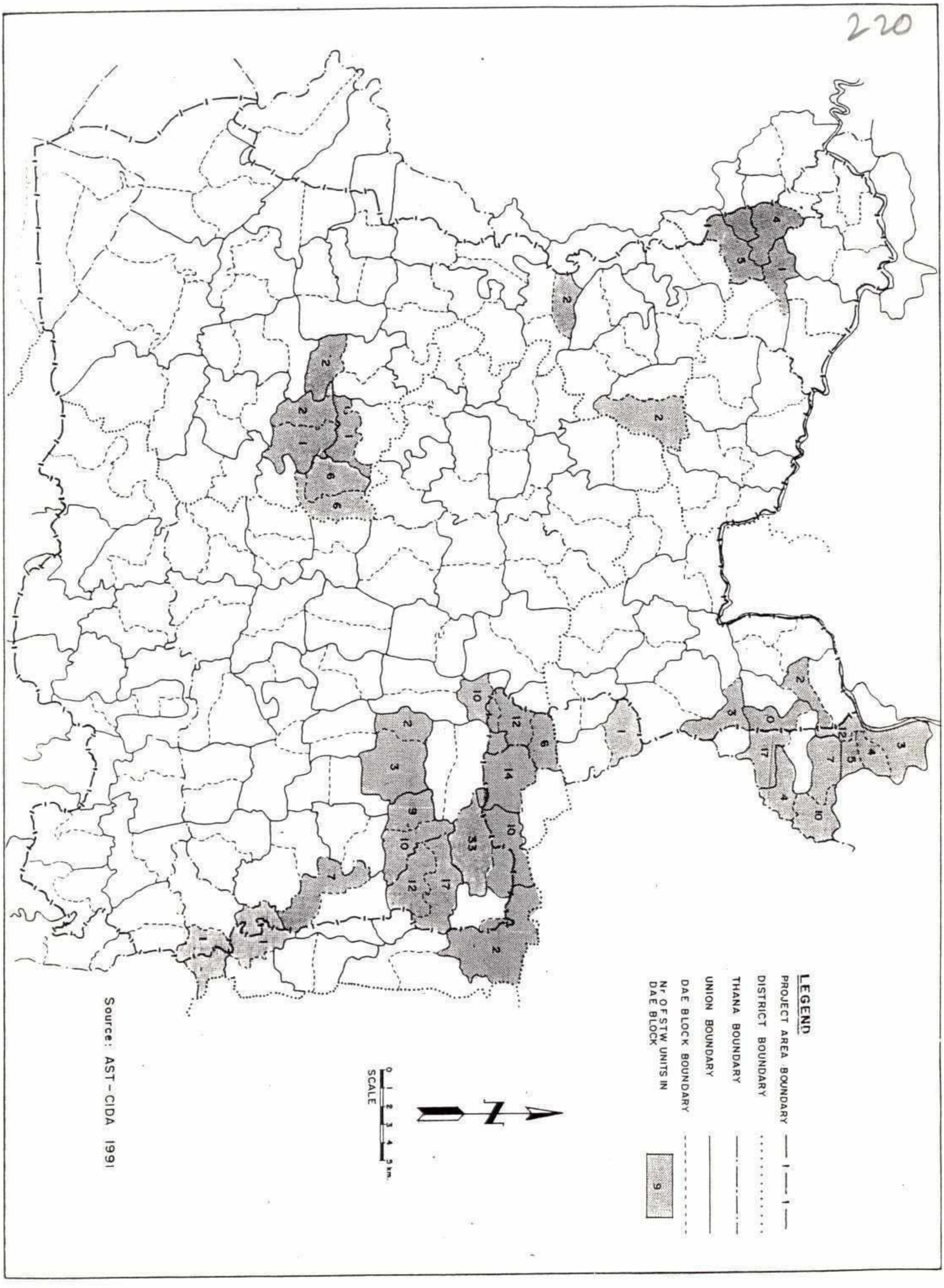

TABLE C.2.1

Inventory of Minor Irrigation in the Noakhali North Area

Thana	DTW	STW	MTW	LLP <1 cs	LLP 1 cs	LLP 2 cs	LLP 3-5 cs	DTW	STW	MTW	LLP <1 cs	LLP 1 cs	LLP 2 cs	LLP 3-5 cs	Tradit- -ional	Total Irrigation	Surface Water	Groundwater (suction)	Groundwater (Total)
	nr	nr	nr	nr	nr	nr	nr	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
Noakhali	0	0	21	84	46	6	1	0	0	17	1,469	1,286	271	73	1,591	4,707	4,690	17	17
Begumganj	1	52	20	549	192	55	1	28	397	49	2,199	1,418	762	51	4,219	9,123	8,649	446	474
Chatkhil	0	0	4	428	24	2	0	0	0	1	1,915	153	14	0	157	2,240	2,239	1	1
Senbag	14	70	2	74	11	2	0	384	453	1	258	89	31	0	296	1,512	674	454	838
Laksam	0	22	1	311	99	63	0	0	63	0.2	1,522	736	1,327	0	1,019	4,667	4,604	63	63
Hajiganj	7	1	0	9	52	73	0	174	4	0	61	645	2,032	0	168	3,084	2,906	4	178
Shahrasti	9	0	0	45	55	22	1	196	0	0	211	544	384	1	117	1,453	1,257	0	196
Faridganj	0	9	0	0	15	45	0	0	61	0	0	125	656	0	22	864	803	61	61
Ramganj	0	4	4	301	131	41	0	0	14	1	924	869	536	0	250	2,594	2,579	15	15
Laksmipur	14	18	3	211	171	413	0	342	101	0.4	773	1,519	6,490	0	1,064	10,289	9,846	101	443
Ramgati	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	45	176	55	2,012	796	722	3	1,124	1,093	70	9,332	7,384	12,503	125	8,903	40,534	38,247	1,163	2,287

Source : AST/CIDA (1991), WITHOUT DTW UPDATE

TABLE C.2.2

Estimated Current Irrigation Coverage

Thana	DTW Command	Revised DTW Nrs	Estimated DTW Irri. ha	Estimated Groundwater ha	Estimated Irrigation ha
Noakhali		0	0	17	4,707
Begumganj	28.0	3	76	522	9,171
Chatkhil		20	506	507	2,746
Senbag	27.4	14	354	808	1,482
Laksam		0	0	63	4,667
Hajiganj	24.9	7	177	181	3,087
Shahrasti	21.8	9	228	228	1,485
Faridganj		0	0	61	864
Ramganj		3	76	91	2,670
Laksmipur	24.4	25	632	734	10,580
Ramgati		0	0	0	0
Total	25.3	81	2,049	3,212	41,459

Table assumes 1991 (AST) irrigation plus revised DTW Numbers, with 1991 average DTW command area.

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CHAPTER C.3

HYDROGEOLOGY

C.3.1 Geology

The geology of the southeast region in general is reviewed in Annex V of the Draft Regional Plan, but pays little attention to the alluvial geology of the Noakhali North area. This is mainly because hardly any research has been done on the area. The only available information is on the deep subsurface from boreholes in the Begumganj Gas Field. It is surprising that the Holocene deposits have not attracted more interest, since it is the area of most active land formation.

The surface deposits are assigned to the Meghna River and Tidal Floodplains (FAO/UNDP, 1988). However, sediments of the shallow sub-surface must belong to what Bakr (1976) has called the Chandina Formation. This concept has been extended by MMI (1992) in the Comilla Region to describe the sediments deposited following the last glacial maximum (18,000 years BP) that filled the incised channels of the Brahmaputra river system. The deposits are mainly grey, unweathered highly micaceous sands and sandy silts. Further north (Muradnagar thana) the sediments have been assigned an estuarine origin, and so it must be expected that sediments in the study area will have more marine affinities. The thickness of the Chandina Formation (or the depth of incision of the late Pleistocene channels) is not known, but is not likely to greatly exceed 130 metres. This is important because in some areas the Chandina Formation contains connate water which constrains groundwater development. The persistence of connate waters appears to be related to the interaction of low lateral hydraulic gradients and the occurrence of deeper silt or clay (aquitard) horizons. These very recent sediments also contain abundant organic matter that decomposes to produce discharges of gas.

The Chandina Formation is presumed to be underlain by the Plio-Pleistocene Dupi Tila Formation, which is well known in Sylhet and the Eastern Hills where it is usually consists of yellowish brown, highly weathered fine to medium sands. The Dupi Tila Formation is generally hundreds to more than a thousand metres thick. These old sands are well flushed.

C.3.2 Occurrence of Aquifers

The aquifer configurations and properties are not well known. Unfortunately most of the potential aquifers in the top hundred metres are brackish or saline, and therefore not useful. The clearest descriptions are given by the electrical resistivity logs from DANIDA investigations. An example from Laksmipur is shown in Figure C.3.1. All of the logs show an extremely sharp increase in resistivity at a depth between about 150 and 180 metres. The aquifers below this depth, down to 300 m at least are very fresh. A selection of characteristic logs and the salinity distribution are shown in Figure C.3.2. The logs often show around 3 to 8 clay layers within the drilled sequence. The importance of each of these layers is not clear, but they must reduce the overall vertical permeability, and slow the natural flushing process. On almost logs, thick clay just above the dramatic increase in resistivity is particularly clear.

Figure C.3.1

Electrical Resistivity Profile at Lakshmipur

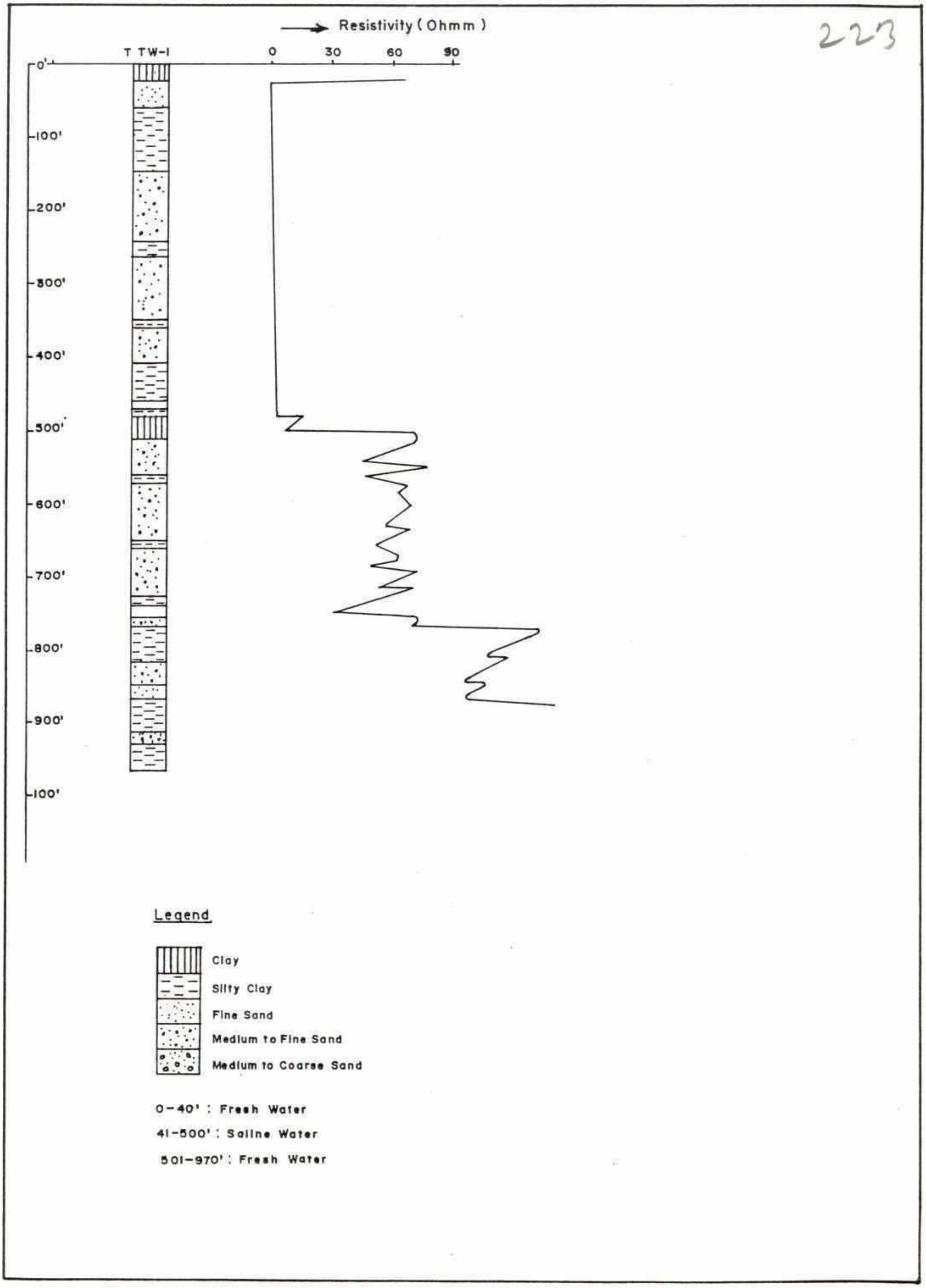
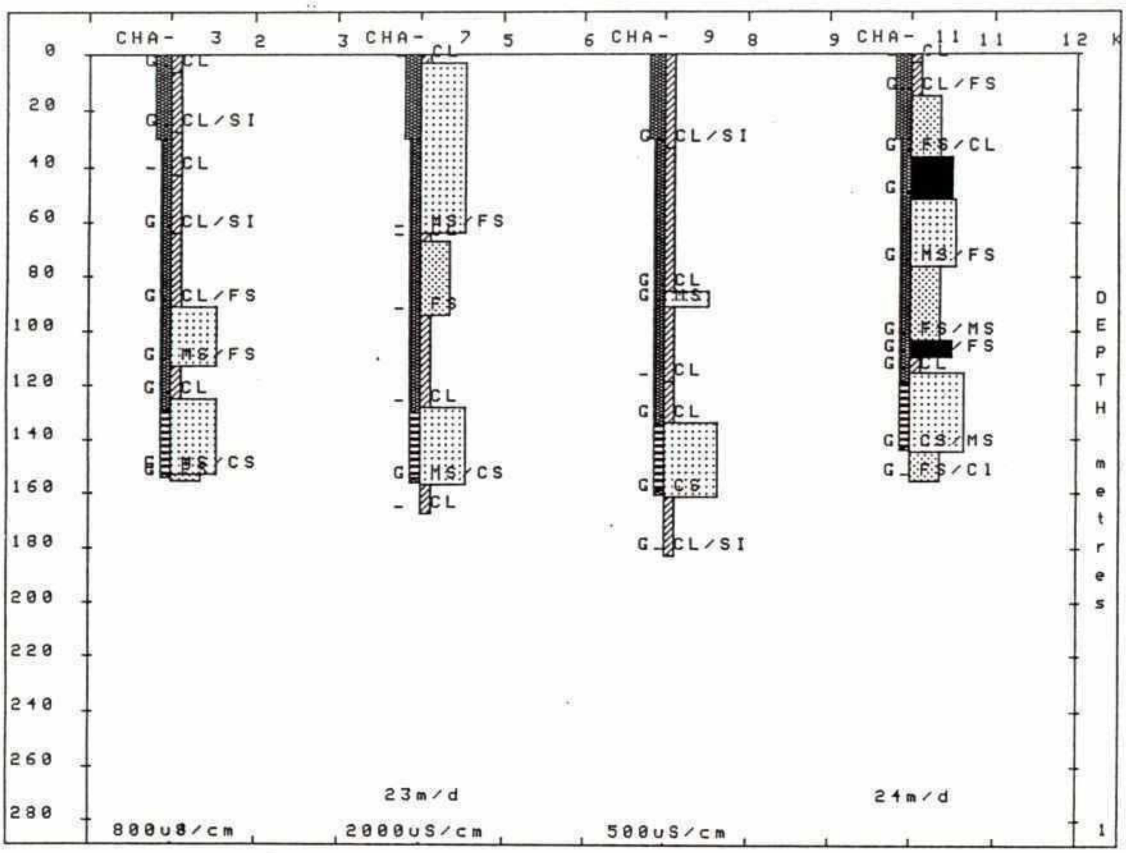


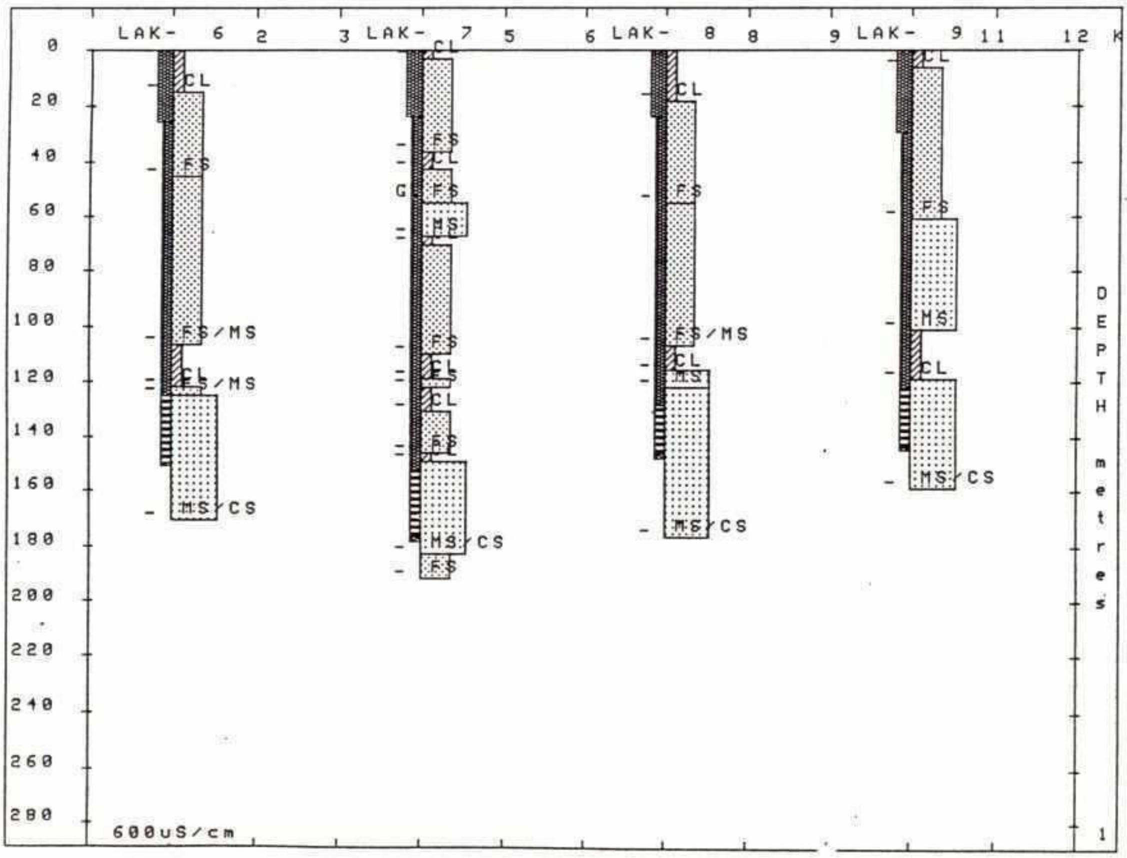
Figure C.3.2

Selected Lithological Profiles in Chatkhil and Lakshmipur

(a) Chatkhil



(b) Lakshmipur



It is observed that below 150 metres salinity generally reduces with depth. In fact, the groundwater reduces to a useable level before the sharp inflection shown on the resistivity logs. This is shown by Table C.3.1 which shows the screen setting depths and operational electrical conductivities of BADC DTWs in Laksmipur, Chatkil, Senbag and Begumganj thanas. Figure C.3.3 and Table C.3.2 shows the distribution of EC in operating DTWs while shallow aquifer Table C.3.1 salinity is presented in Figure C.3.4 and Table C.3.3.

The resistivity logs also show that the depth of the fresh water in the shallow aquifer is generally 10 to 15 metres. This is consistent with the results of the shallow aquifer salinity survey (Figure 3.4) which shows that there is shallow fresh water throughout the area, but that saline water may also be intercepted over large areas presumably due to variations of screened well depth and local geological factors.

The few data on the deep aquifer properties in the area have been compiled in Table C.3.4. There are anomalous results that probably result from poor well construction, but transmissivity is generally in the range of 500 to 800 m^2/d, with an average permeability of 20 - 25 m/d, which is typical of the Dupi Tila Formation where it is extensively exploited by DTWs further north (MMI, 1992).

The aquifer configuration, whereby fresh water is drawn from beneath saline, also means that fresh water recharge to these aquifers must occur by horizontal groundwater flow. Therefore conventional resource potential models, such as the MPO recharge model, are not relevant. Simulation with a distributed parameter numerical model is required.

C.3.3 Water Levels

BWDB maintains a limited groundwater level monitoring network in the area. With the exception of one autorecorder (depth 85 metres) in Noakhali (Figure C.3.5), it comprises only shallow piezometers. This is valuable in its own right, but it should be a high priority to install piezometers and monitor levels in the deep aquifer. Further in order to calibrate a groundwater model it is highly desirable to also monitor water levels in the brackish zone just above the exploited aquifer.

Predictably, the hydrographs in Figures C.3.5 to C.3.7 show little evidence of impact from groundwater development. The total annual fluctuations are typically 3 to 4 metres, and show the characteristic seasonal pattern of dry season recession, and rise to a period of 'rejected recharge' in the monsoon.

C.3.4 Water Quality

With the exception of total salinity, chloride and iron there are insufficient chemical data to draw any firm conclusions about the potential use of the deep aquifer. Conducting such analyses should be done as a matter of some urgency.

Figure C.3.3

Distribution of EC in Operating DTWs

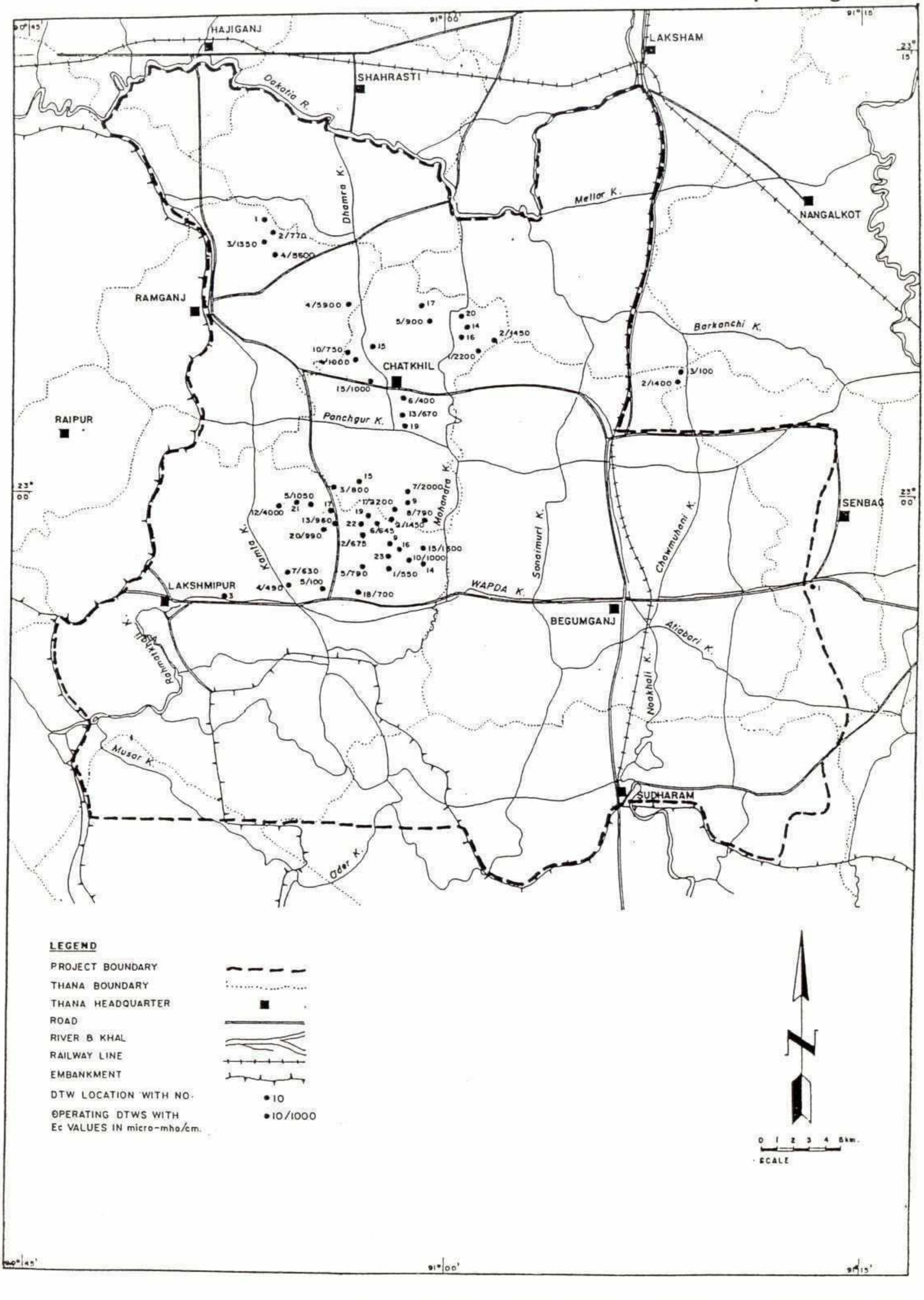


Figure C.3.4

Distribution in the Shallow Aquifer

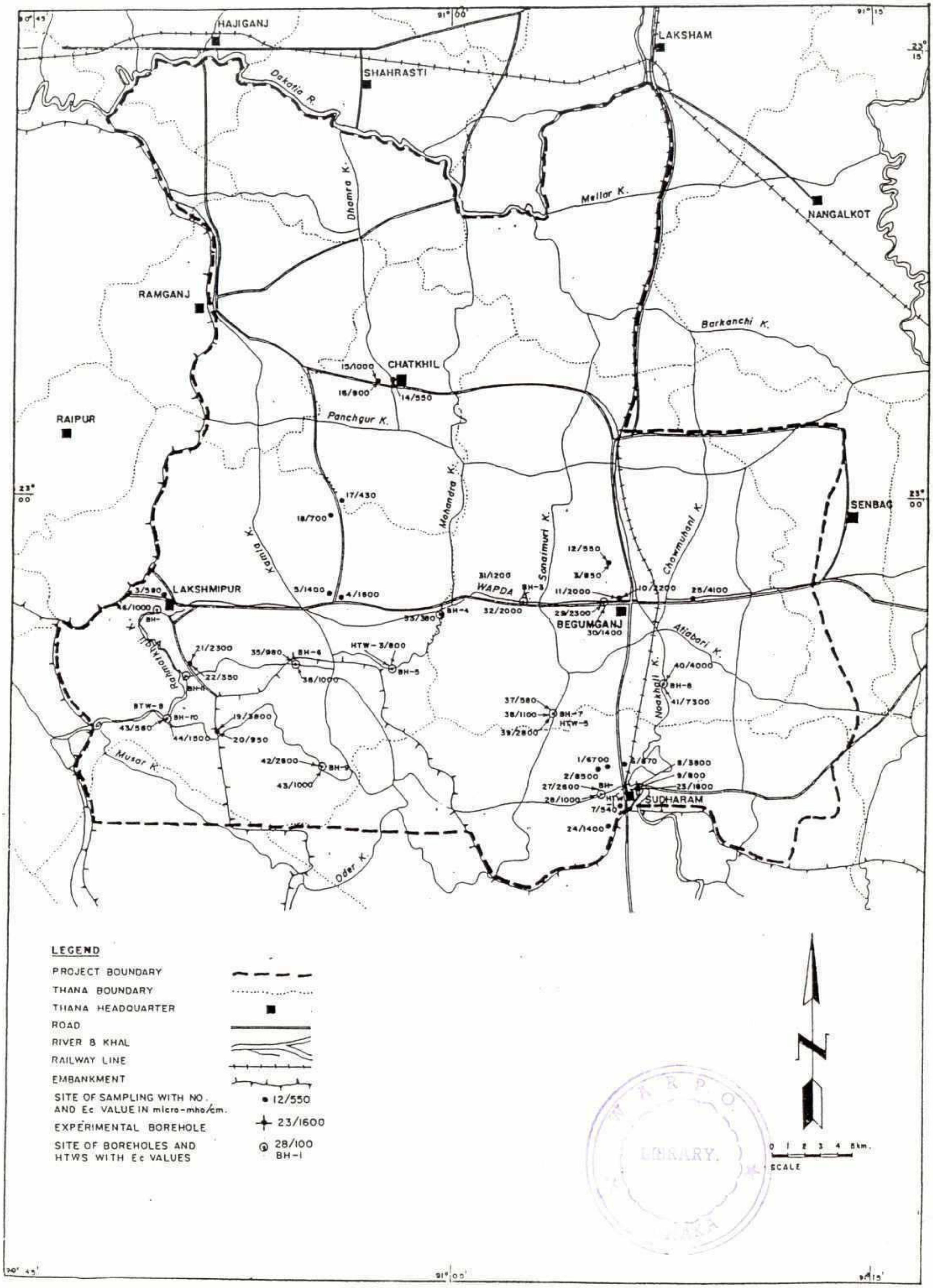


Figure C.3.5

Groundwater Hydrograph from Noakhali

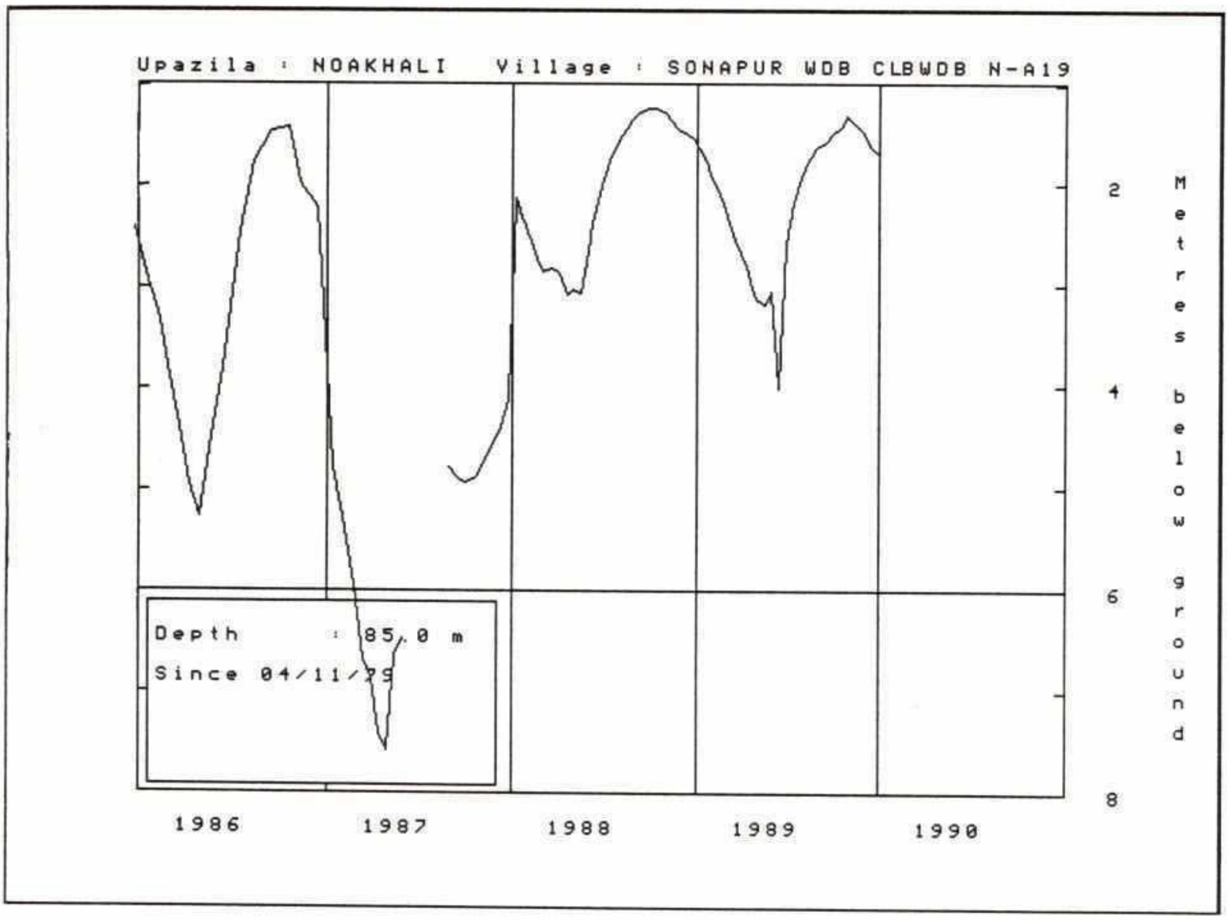


Figure C.3.6

Groundwater Hydrograph from Lakshmipur

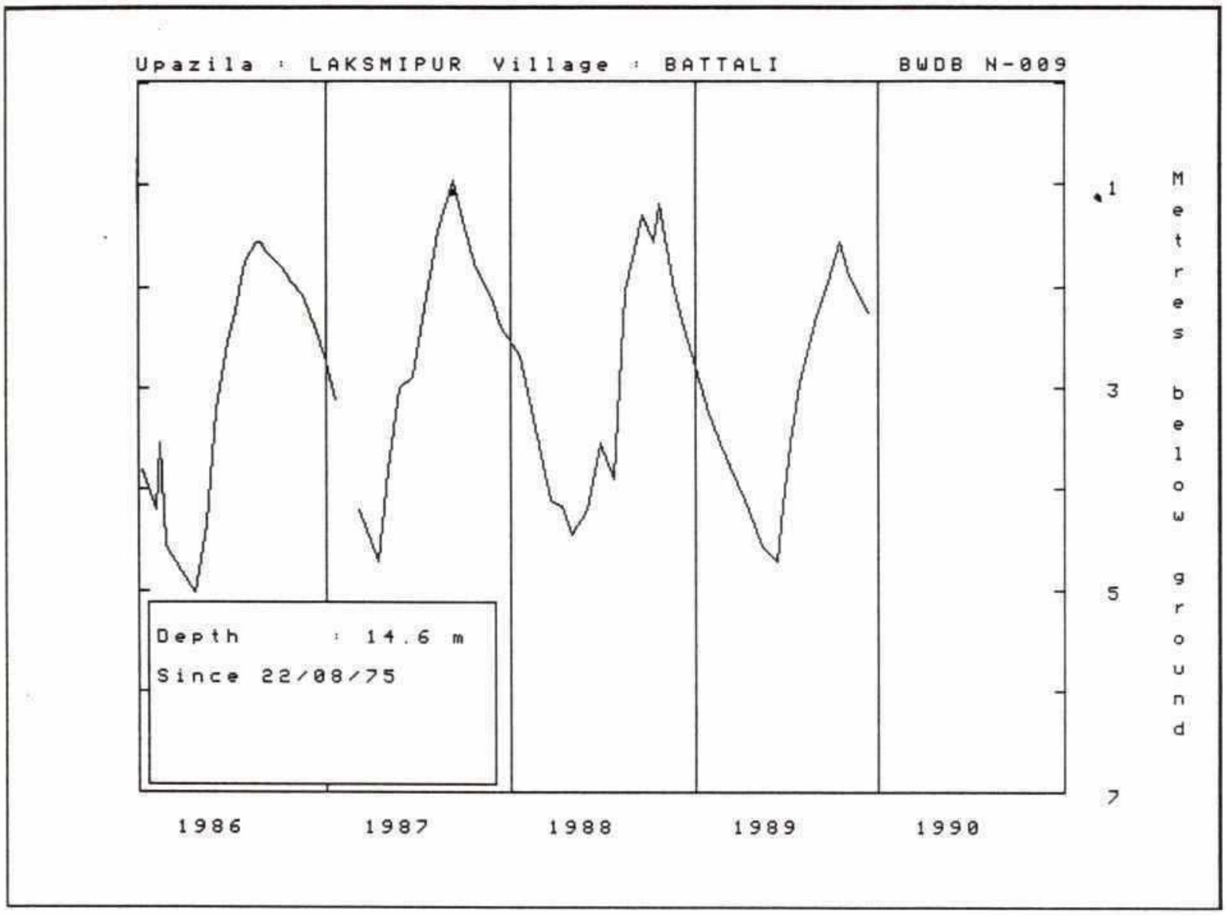


Figure C.3.7

Groundwater Hydrograph from Begumganj

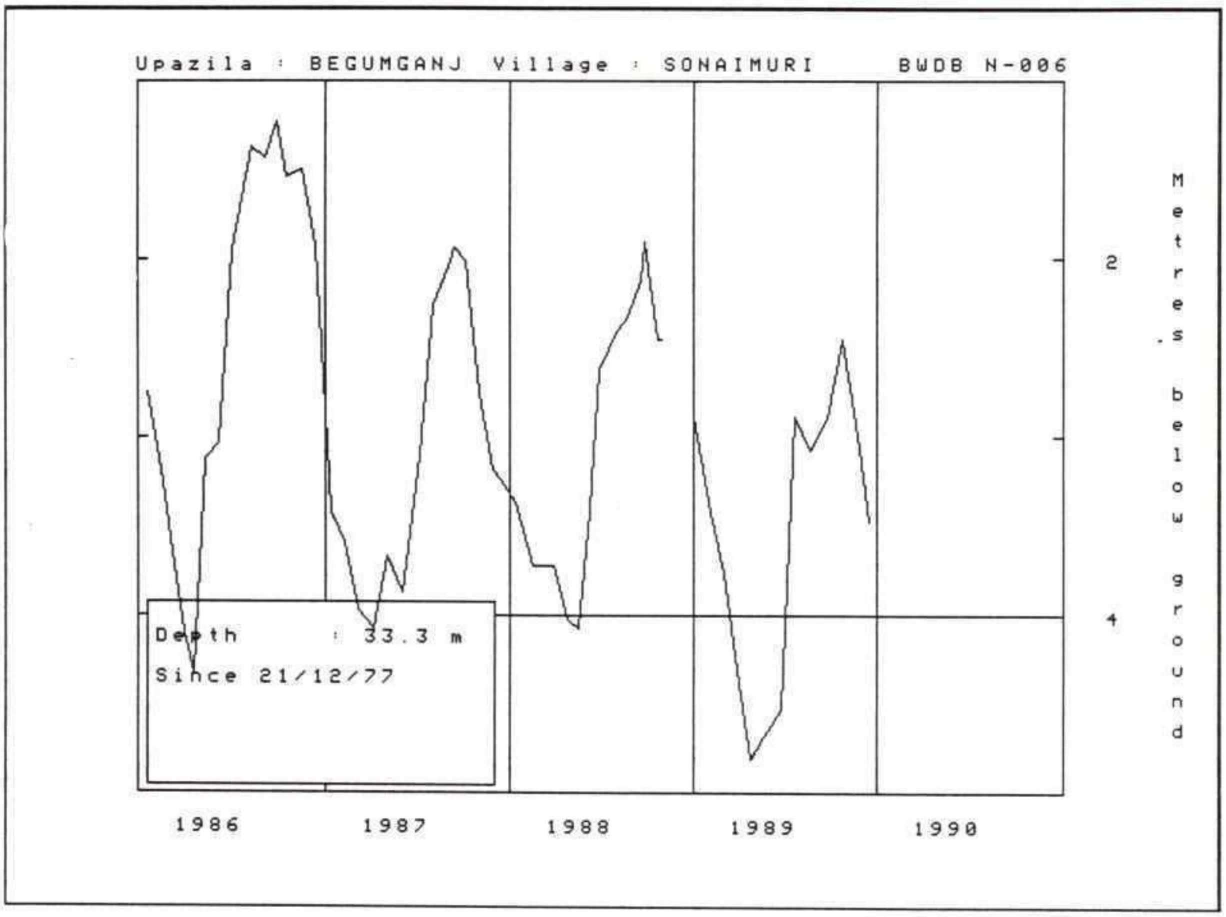


TABLE C.3.1

Screen Settings, Specific Drawdown and Salinity of BADC DTWs

Thana	Well Nr	JL nr	Village	Screened Section From m	To m	Specific Drawdown m/l/s	Electrolytic Conductivity µS/cm
BEGUMGANJ	3	127	KAIYA	101	137		1400
CHATKHIL	3	100	MADHABP	129	153		800
CHATKHIL	6	207	DAULATP	137	158		400
CHATKHIL	7	237	U SHANKA	130	155	0.25	2000
CHATKHIL	9	237	U SHANKA	135	159		500
CHATKHIL	10	133	BAISH SHI	129	150		
CHATKHIL	11	199	DHAINAYK	119	143	0.24	
CHATKHIL	13	211	TOBGA	138	162		670
CHATKHIL	19	211	TOBGA	135	161	0.24	
LAKSMIPUR	6	153	RAIPUR HA	125	150		600
LAKSMIPUR	7	117	KARAITAL	152	177		630
LAKSMIPUR	8	152	DEBINAGA	128	146		790
LAKSMIPUR	9	157	JOYPUR	122	143		990
LAKSMIPUR	16	185	PALPARA	128	152		565
LAKSMIPUR	17	111	DATTAPAR	146	171		1000
SENBAG	?	310	LADHUA	43	62		
Average				125	149	0.24	862

TABLE C.3.2

Deep Aquifer Salinity Survey (1992-1993)

Noakhali North Project Area

(25°c Temperature)

Sl. No.	DTW No	Thana	Union	Date Sampled	Date Tested	Time	EC µs/cm	TDS	Depth of Sampling ft	Remarks
1	DPHE well	Chatkhil	-	10-3-1993	10-3-1993	6.30 P.M	6400	4500	8500-950	
2	Chat-13	Chatkhil	Tobga	10-3-1993	10-3-1993	2.30 P.M	670	480	443-528	
3	Chat-6	Chatkhil	Daulatpur	10-3-1993	10-3-1993	3.30 P.M	400	280	-	
4	Chat-12	Chatkhil	Uttar Shimbaora	10-3-1993	10-3-1993	4.30 P.M	250	170	580-640	
5	Chat-1	Chatkhil	Gomatali-1	01-4-1992	01-4-1992	-	2200	-	-	
6	Chat-2	Chatkhil	Gomatali-2	01-4-1992	01-4-1992	-	1450	-	-	
7	Chat-3	Chatkhil	Madhabpur	01-4-1992	01-4-1992	-	800	-	-	
8	Chat-4	Chatkhil	North Ramdevpur	01-4-1992	01-4-1992	-	1000	-	-	
9	Chat-5	Chatkhil	Basna	01-4-1992	01-4-1992	-	900	-	-	
10	Chat-7	Chatkhil	North Shankarpur-1	01-4-1992	01-4-1992	-	2000	-	-	
11	Chat-10	Chatkhil	Bais Sindhur	01-4-1992	01-4-1992	-	750	-	-	
12	Lax-1	Lakshmipur	Monoharpur	10-3-1992	31-3-1993	9 .00 A.M	550	385	430-530	
13	Lax-2	Lakshmipur	Kangsa Narayanpur	10-3-1992	31-3-1993	9.10 A.M	675	475	450-550	
14	Lax-4	Lakshmipur	Narsinghpur	16-3-1992	31-3-1993	9.20 A.M	490	345	521-591	
15	Lax-6	Lakshmipur	Rajaram Ghosh	12-3-1992	31-3-1993	9.25 A.M	645	450	411-491	
16	Lax-7	Lakshmipur	South Karoitola	13-3-1992	31-3-1993	9.30 A.M	630	440	510-590	
17	Lax-8	Lakshmipur	Debinagar	12-3-1992	31-3-1993	9.35 A.M	790	550	420-500	
18	Lax-10	Lakshmipur	Pachpara-3	10-3-1992	31-3-1993	9.45 A.M	1000	700	463-543	
19	Lax-12	Lakshmipur	Gangashibpur	-	31-3-1993	9.50 A.M	4000	2800	463-543	
20	Lax-13	Lakshmipur	Dattapara K.SS	16-3-1992	31-3-1993	10.A.M	960	675	493-593	
21	Lax-15	Lakshmipur	Pachpara-2	-	31-3-1993	3.0 P.M	16000	11000	480-560	
22	Lax-18	Lakshmipur	Hasanpur	14-3-1992	31-3-1993	10.15	700	490	423-503	
23	Lax-20	Lakshmipur	Chartara	10-3-1992	31-3-1993	10.40	990	695	400-470	
24	Beg-1	Begumganj	Kabinpur	01-4-1992	-	-	1400	-	-	
25	Beg-2	Begumganj	Koya	01-4-1992	-	-	1000	-	-	
26	Ram-2	Ramganj	Naogaon Purbapara	30-3-1993	30-3-1993	12.00 Noon	770	540	-	
27	Ram-3	Ramganj	Naogaon Madhya Dakhinpara	30-3-1993	30-3-1993	1.00 P.M	1350	950	-	
28	Ram-4	Ramganj	Naogaon Dakhinpara	30-3-1993	30-3-1993	3.0 P.M	5650	4000	-	
29	Ram-5	Ramganj	Bhatra Union	31-3-1993	30-3-1993	5 P.M	5900	4150	-	

TABLE C.3.3

Shallow Aquifer Salinity Survey

The Noakhali North Planning Unit (1992-1993)

(Temperature 25°C)

Sl. No	Site No.	Thana	Union	Mouza	J.L	Date of Sampling	Time	EC (/ws/cm)	TDS	Type of Well with depth (feet)	Depth of Sampling (feet)
1	1	Sudharam	Maijdee Court P.S		BADC Complex	28-10-1992	10.30 A.M	6700	4900	150 HTW 26	180'-200
2	2	Sudharam	Maijdee Court P.S		BADC Complex	28-10-1992	12.30 A.M	8500	6000	HTW 30	20'-26
3	3	Lakshmipur	Pourashava		BADC Complex	28-10-1992	01.30 P.M	580	395	HTW 36	25'-30
4	4	Lakshmipur	15, Matbi		Botali Mosque	28-10-1992	01.45 P.M	1600	1020	HTW 36	30'-36
5	5	Lakshmipur	15, Matbi		Botali Bazar	28-10-1992	04.30 P.M	1400	1000	HTW 60	30'-36
6	6	Sudharam	Maijdee Court		DPHE Complex	28-10-1992	08.30 P.M	870	610	HTW 26	40'-60
7	7	Sudharampur	Sonapur P.S		BWDB Complex	29-10-1992	09.00 A.M	540	380	HTW 36	20'-26
8	8	Sudharampur	Sonapur P.S		Homestead	29-10-1992	09.15 A.M	3800	270	26	30'-36
9	9	Sudharampur	Sonapur P.S		Homestead	29-10-1992	09.45 A.M	800	550	HTW 26	20'-26
10	10	Begumganj	Pourashava		Homestead	29-10-1992	09.50 A.M	2200	1600	HTW 26	20'-26
11	11	Begumganj	Pourashava		Homestead	29-10-1992	10.15 A.M	2000	1400	HTW 26	20'-26
12	12	Begumganj	Pourashava		Mir Warishpur'	29-10-1992	10.20 A.M	550	380	HTW 26	20'-26
13	13	Begumganj	Pourashava		Mir Warishpur	29-10-1992	12.30 A.M	800	600	HTW 26	20'-26
14	14	Chatkhil	Pourashava		BADC Complex	29-10-1992	12.45 P.M	550	385	HTW 32	26'-30
15	15	Chatkhil	Pourashava		Chatkhil High School	29-10-1992	12.50 P.M	100	750	-DPHE 750	750'-750
16	16	Chatkhil	Pourashava		Chatkhil High School	29-10-1992	02.30 P.M	900	630	HTW 26	20'-26
17	17	Chatkhil	Dakhin Dalea		9, Khilpara	29-10-1992	02.30 P.M	430	300	HTW 530	410'-510
18	18	Chatkhil	Dakhin Dalea		9, Khilpara	29-10-1992	02.35 P.M	760	530	HTW 32	26'-32
19	19	Lakshmipur	18, Bhabaniganj (Within Embankment)			29-10-1992	05.30 P.M	3800	2700	HTW 24	18'-24
20	20	Lakshmipur	18, Bhabaniganj (Canal, Non-tidal)			29-10-1992	05.45 P.M	950	700	Canal	
21	21	Lakshmipur	Piyarapur (Crossing of WAPDA Khal and Road)			29-10-1992	06.00 P.M	2300	1600	HTW 32	26'-62
22	22	Lakshmipur	Piyarapur (Crossing of WAPDA Khal and Road)			29-10-1992	06.10 P.M	350	250	Canal Water (Tidal)	
23	23	Sudharampur	Sonapur Pourashava			30-10-1992	10.00 A.M	1600	1050	Ext. Borehole 35	28'-32
24	24	Sudharampur	Sonapur Homstead			30-10-1992	12.30 P.M	1400	1000	HTW 26	20'-26
25	25	Begumgaj	Setubhanga (Jonaki Industry)			30-10-1992	01.30 P.M	4100	2900	HTW 30	24'-30
26	26	Begumgaj	Sunaimuri No. 3			10-10-1993	04.30 P.M	6500	4600	HTW	35'-45

TABLE C.3.4
Estimates of Aquifer Properties

TABLE C.3.4
Estimates of Aquifer Properties

Thana	Well Nr	Screen Position		Transmissivity	Permeability	Storage	Method	Water Quality			Reference
		From	To (m)	m2/d	m/d	Coefficient		EC	Cl	Fe	
Lakshmipur	DPHE-1	186	216	242	8		Jacob (pumping well)		222	5.1	Danida (1989a)
"	"			907	30		Jacob (obs. well)				Danida (1989a)
"	"			50	2		Logan approximation				This study
Lakshmipur	DPHE-2	171	195	233	10		Jacob (pumping well)		130	3.5	Danida (1989a)
"	"			131	5		Logan approximation				This study
Lakshmipur	BADC	c. 275m		50			Logan approximation		22	1.8	After Danida (1989a)
Begumganj	BCIC	219	256	553	15		Jacob (pumping well)			>10	Danida (1989b)
				605	16		Theis recovery				Danida (1989b)
				94	3		Logan approximation				This study
Noakhali	Sundarpur	26	59	1,122	34		Jacob ?				Morton & Khan (1979)
	BWDB-32			674	20		Logan approximation				This study
Noakhali	NO-1			1050		0.0011	Jacob ?				UNDP (1982)
Noakhali	NO-2			770		0.0013	Jacob ?				UNDP (1982)
Chatkhil	DTW-7	130	155	560	22		Logan approximation	2,000			This study
Chatkhil	DTW-11	119	143	588	25		Logan approximation				This study
Chatkhil	DTW-19	135	161	586	23		Logan approximation				This study

CHAPTER C.4

GROUNDWATER AND KHAL EXCAVATION

C.4.1 Conceptual Model of Groundwater - Khal Interactions

There is known to be saline groundwater at relatively shallow depths in the areas where it has been proposed to excavate existing khals. Concern has been expressed that excavation might cause salinisation of the intended irrigation water in the khals. Theoretically, this might occur three ways.

(i) direct interception of the saline zone, or

(ii) inducing an increased rate of baseflow by enlarging the contact area between the surface water body and the aquifer, and/or removing low permeability material from the bed of khal, or

(iii) causing "upcoming" of saline water in response to lower water levels in the khals.

On the other hand, it is also possible that increasing the quantity of fresh water in the khals during the dry season could have the exact opposite effect, and actually improve the shallow groundwater conditions by increasing the slow, natural processes of flushing connate water from the recent sediments.

Of these possibilities (iii) has been negated by adopting as a principle of design and operation that "dry season" water lands should not be allowed to fall below their present average dry season levels. Given that the proposed excavation depths do not generally exceed about 2 metres below existing excavation levels possibilities (i) and (ii) presuppose that there is saline groundwater present in the shallow subsurface. Project investigations have aimed at determining the lithology and pore water salinity of the top 5 to 10 metres through a programme of shallow drilling and sampling existing hand tubewells.

C.4.2 Drilling Investigations

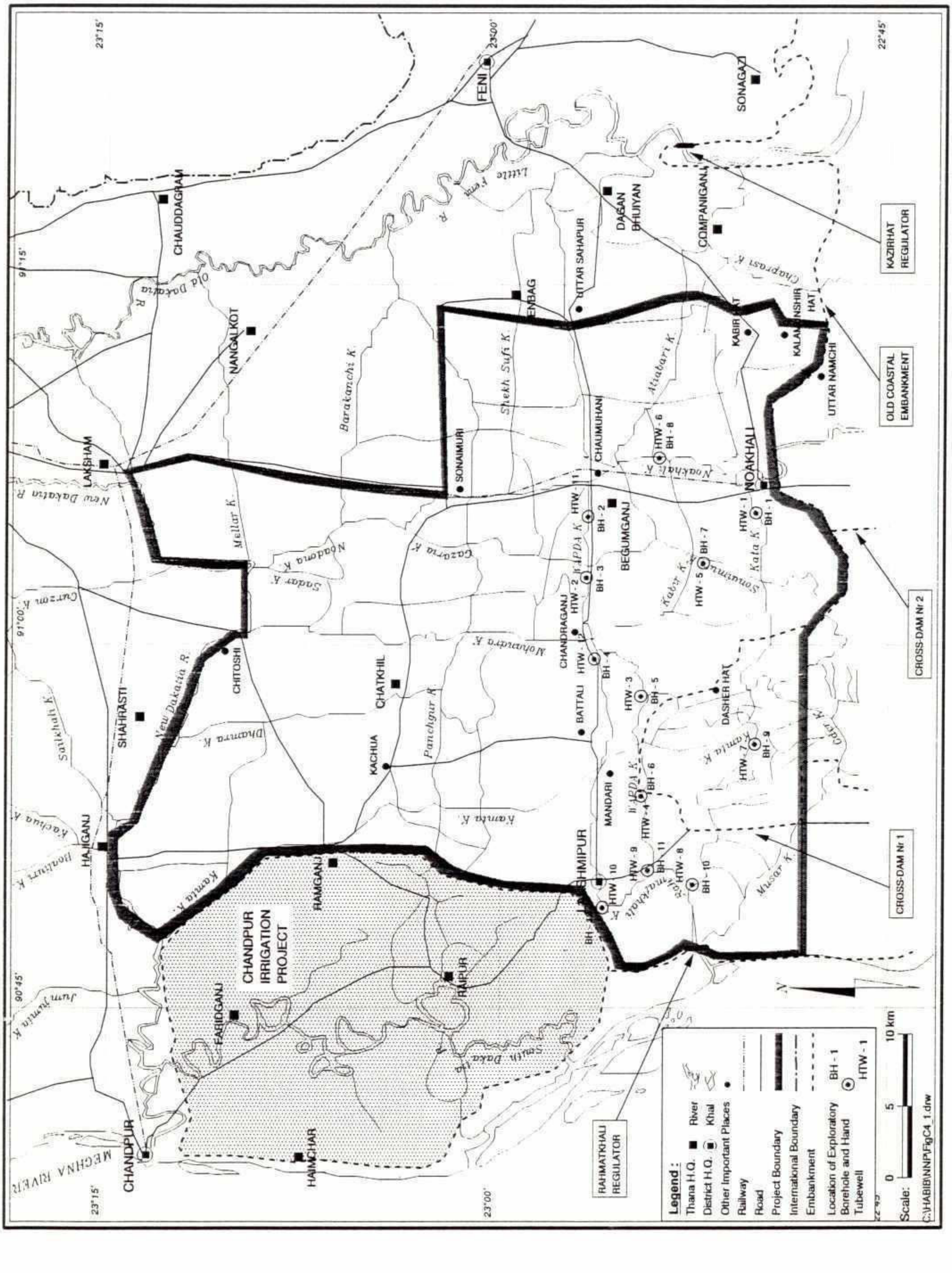
Twelve boreholes were drilled to depths of between 4 and 7 metres at the locations shown in Figure C.4.1 These holes were drilled for a number of purposes as follows:-

- to obtain information concerning soil properties in terms of their suitability for cropping if spread on the land (eg salinity and organic properties).
- to identify the nature of the sub-soils to be excavated (sand, silt, clay).
- to obtain groundwater salinity data which is combined with data collected from the shallow aquifer survey.

Full details of the individual boreholes are given in Appendix C.II.

Figure C.4.1

Location of Exploratory Boreholes



C.4.3 Laboratory Analyses

During drilling soil samples were collected at various depths (see Appendix C.II) and were analysed at sedmentological laboratory Deptt. of Geology and Chemical laboratory of the Deptt. of soil Science, Dhaka University fro the following parameters:

a) Grain size
b) PH
c) soil Salinity in Ec μ-mho/cm
d) Organic content
e) Content of Na, K and D

The soil testing results are given in Appendix C.III.

C.4.4 Discussion

The soil quality and engineering aspects of the boring programme are discussed in Annex I. The intention here is to attempt to answer the concerns which have been expressed concerning possible salinisation of khal waters by the khal deepening programme.

There are a number of factors here which must be considered. Firstly as stated in section C.4.1 the design of the irrigation system is such that for the vast majority of the dry season water levels in the khals will actually be substantially higher than those presently maintained. Only for one or two hours at the end of irrigation periods during neap tides may water levels fall below those presently encountered. (For details see Annex B).

Secondly the results of the tests conducted suggest that with a few exceptions the ground water quality whilst not ideal is not very saline. Four boreholes (BH 1,7,8 and 9) showed poorer water quality. It is interesting to note that three of these boreholes are located in the extreme south east of the areas demarkated as possible irrigation areas. They are in the area close to the tidal access route of Noakhali khal and the khal water itself near BH7 had the highest salinity reading. the proposal to gate off Noakhali Khal in the dry season should eliminate this problem.

The fourth borehole (BH 9) is at Piarapur where two adjacent readings from the shallow aquifer survey show similarly high readings (see tables C.3.3 site nos 19 and 21). However at both these locations EC readings of the khal water were taken which showed very good quality water. It may be noted that the WAPDA khal is already very deep at this location and these readings clearly demonstrate how the fresh water in the khals is unaffected by higher salinity levels in the groundwater. This is assumed to be because the khal water levels remain above the groundwater levels and being fresh keep the saline water out of the khals. The design condition would maintain this state or improve it by generally raising khal water levels at these locations.

Thirdly the ground water levels in the dry season generally fall to about 4 m below ground level. (see figures C.3.5 to C.3.7)

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This approximately corresponds to the design bed level of the secondary khals which are designed never to dry out. Where the main khals are deeper (downstream of Chandraganj) ground water quality is shown to be of a quality not good as can be expected to be obtained from the Meghna but about or less than 2000 μs/cm, and frequently below 1000 μs/cm. These levels are generally satisfactory (see boreholes nos 8 to 12 excluding 7 and 8).

The groundwater data collected suggests that neither groundwater levels nor quality pose a threat to sustainability of the irrigation system.

CHAPTER C.5

CONCLUSIONS AND RECOMMENDATIONS

C.5.1 Existing Groundwater Development

Deep aquifers in the Noakhali North area are a major long term source of fresh water for potable, industrial and agricultural purposes. In the last four years there has been a rapid increase in the quantity of fresh water withdrawn from these aquifers.

The configuration of fresh and salt water in the aquifers means that the sustainability of groundwater irrigation in the area is questionable. This is not to say that salinisation is expected but simply that there is no reliable basis for answering this question.

since the first general study of the coastal area by Morton and Khan (1979) all workers have emphasised the inadequacy of the data base on groundwater conditions in the coastal belt. That study stated that it was impossible the evaluate the potential of the aquifers. That remains equally true today. All studies stressed the need for additional field work, but sadly hardly any of their recommendations have been acted upon. The major change is that previously the concern was that a potential resource had not quantified and hence restricted planned development, but now the existing abstraction and the resource itself must be considered at risk.

C.5.2 Groundwater Resource Assessment

A fundamental field programme consisting of exploratory drilling and geophysical logging to determine the geological conditions, followed by aquifer testing and water quality sampling, and the installation and monitoring of piezometer network. Following a period of monitoring, and routine data analysis the results of the field investigations should be integrated into a digital groundwater model.

C.5.3 Monitoring Network

A detailed monitoring strategy should be developed during the course of the above resource evaluation programme. The network will need to include both groundwater levels and quality. Water level monitoring will need to include both the shallow and deep groundwater levels, as well as a very carefully designed programme of monitoring levels in the saline zones in order to provide advance waning of any intrusion of upconing (or "down-coning") of saline water.

TABLE C.5.1

Components of a Programme to Evaluate the Groundwater Resource Potential

Phase 1 (first dry season)

- Review existing data
- Prepare drilling contract
- Drill 10 slim hole (c. 200 mm) exploratory boreholes to an average of around 250 metres, conduct geophysical logging, install piezometers, conduct permeability tests and collect water samples.
- Implement intensive water monitoring,
- Preliminary evaluation of results
- Determine groundwater modelling requirements

Phase 2 (second dry season)

- on the basis of the Phase 1 results, select 5 sites for test pumping.
- prepare drilling contract.
- install test production wells adjacent to piezometers and conduct long term pumping tests. Collect water samples for chemical and isotopic analysis.
- Evaluate results
- Preliminary groundwater modelling to simulate existing conditions.
- Continue groundwater level monitoring.

Phase 3

- Estimate long term water requirements for each thana, distinguishing between potable supplies, irrigation demand, and known and planned industrial development.
- Through additional modelling, determine the impact of satisfying potable demands, and then identify areas and quantify with residual potential for agricultural and industrial development.
- Develop a groundwater development plan for each thana.
- Institutionalise groundwater level and water quality monitoring.

APPENDIX C.I

MINOR IRRIGATION STATISTICS

Than Code	Thana name	DAE Block Nr & Name	DTW (ha)				STW (ha)				DSSTW (ha)				MTW (ha)				Traditional Irrigation (ha)				LLP (ha)				All Modes (ha)
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
406	Begumganj	1 Joyag	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	0	0	0	227	274
406	Begumganj	2 Junukbpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51	0	0	0	138	189
406	Begumganj	3 Machtala	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51	0	0	0	208	258
406	Begumganj	4 Kaluai	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	26	0	0	35	200	265
406	Begumganj	5 Panchbaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	121	0	0	0	344	465
406	Begumganj	6 Rampur	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	0	0	0	0	98	0	0	0	31	162
406	Begumganj	8 Sonaimuri	0	0	0	0	0	0	61	0	0	0	0	0	0	0	0	0	0	0	255	0	0	0	51	0	366
406	Begumganj	9 Razibpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	20	0	0	0	71	0	107
406	Begumganj	10 Daulatpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	24	0	0	0	69	0	125
406	Begumganj	11 Oasefpur	0	0	0	0	0	0	61	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	182	0	263
406	Begumganj	12 Aumbarnagar	0	0	0	0	0	0	121	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	344	0	494
406	Begumganj	13 Nateshar	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	28	0	69
406	Begumganj	14 Ghoskamta	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	24	0	59
406	Begumganj	15 Chandpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	23	0	31
406	Begumganj	16 Bazra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	20	0	26
406	Begumganj	17 Sanapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	16	0	28
406	Begumganj	18 Daulatpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	20	0	28
406	Begumganj	19 Baghpachra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	14	0	0	15	31	67
406	Begumganj	20 Deauti	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	9	0	0	11	32	55
406	Begumganj	21 Amishapara	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61	0	0	0	20	0	81
406	Begumganj	22 Abirpara	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	0	0	0	30	0	101
406	Begumganj	23 A.K.G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	119	0	123
406	Begumganj	24 Amanullahpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	105	0	134
406	Begumganj	25 Miraznagar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	35	0	38
406	Begumganj	26 Betuabag	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	0	0	0	20	0	77
406	Begumganj	27 Nazartali	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	49	0	79
406	Begumganj	28 Bengla Bazar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61	182	0	0	48	143	0	433
406	Begumganj	29 Bhababadri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	121	0	0	0	221	0	342

NOAKHALI NORTH PROJECT

Than Code	Thana name	DAE Block Nr & Name	DTW (ha)				STW (ha)				DSSTW (ha)				MTW (ha)				Traditional Irrigation (ha)				LLP (ha)				All Modes (ha)
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
405	Noakhali	1 Charmatua (Pash)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	57	0	0	0	63
405	Noakhali	2 Charmatua (Purb)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	65	0	0	0	71
405	Noakhali	3 Dadpur (Uttar)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	111	0	0	121
405	Noakhali	4 Dadpur (Dakhin)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	223	0	0	243
405	Noakhali	5 Noyannai (Uttar)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	20	0	0	49
405	Noakhali	6 Noyannai (Dakhi)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38	0	0	0	34	0	0	73
405	Noakhali	7 Kadir Hafiz (Pu)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	20	0	0	0	152	0	0	173
405	Noakhali	8 Kadir Hafiz (Pa)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	40	0	0	0	119	0	0	161
405	Noakhali	9 Binodpur (Dakhi)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0	0	0	26	0	0	75
405	Noakhali	10 Binodpur (Uttar)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0	0	0	27	0	0	87
405	Noakhali	11 Noakhali (Uttar)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	10	0	0	0	10	0	0	21
405	Noakhali	12 Noakhali (Dakhi)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	0	0	5
405	Noakhali	13 Aozbalia (Dakhi)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6	0	0	0	0	0	0	7
405	Noakhali	14 Aozbalia (Uttar)	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	8	0	0	0	12	0	0	21
405	Noakhali	15 Kaladrap (Uttar)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	8	0	0	1	3	0	0	16
405	Noakhali	16 Kaladrap (Dakhi)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	2	0	0	13
405	Noakhali	17 Ashadia (Uttar)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	63	0	0	73
405	Noakhali	19 Newazpur (Purba)	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	405	0	0	0	227	0	0	635
405	Noakhali	20 Newazpur (Pashi)	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	324	0	0	0	218	0	0	549
405	Noakhali	21 Narattompur (Da)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	320	0	0	0	166	0	0	486
405	Noakhali	22 Narattompur (Ut)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	121	0	0	0	850	0	0	971
405	Noakhali	23 Sandalpur (Purb)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	53	0	0	57
405	Noakhali	24 Sandalpur (Pash)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	75	0	0	81
405	Noakhali	25 Goshbag (Uttar)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	550	0	0	591
405	Noakhali	26 Goshbag (Dakhin)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
405	Noakhali	29 Batya (Purba)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	16	0	0	24
405	Noakhali	30 Batya (Pashim)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	13	0	0	25
		Sub-Total	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	16	1559	0	0	123	2974	0	0	4690

Than Code	Thana name	DAE Block Nr & Name	DTW (ha)				STW (ha)				DSSTW (ha)				MTW (ha)				Traditional Irrigation (ha)				LLP (ha)				All Modes (ha)
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
406	Begumganj	30 Alaiyarpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	47	0	87
406	Begumganj	31 Aminbazar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	20	0	0	152	152	0	344
406	Begumganj	32 Chayani	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	26	0	0	47
406	Begumganj	33 Bhabani Jibonpu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	2	0	0	18	4	0	32
406	Begumganj	34 Khalishpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	30	0	0	61
406	Begumganj	35 Dakhin Rajgaon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	20	0	0	36
406	Begumganj	36 Uttra Rajgaon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	32	0	0	44
406	Begumganj	37 Anantapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	364	0	0	0	45	0	0	409
406	Begumganj	38 Aklashpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	486	0	0	0	65	0	0	550
406	Begumganj	39 Muzahidpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61	0	0	0	16	0	0	77
406	Begumganj	40 Amanatpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	10	0	0	26	9	0	75
406	Begumganj	41 Mir Alipur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	0	0	0	70	0	112
406	Begumganj	42 Mir Oarishpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	138	0	0	146
406	Begumganj	43 Narottampur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	125	0	0	0	22	0	0	148
406	Begumganj	44 Narottampur (Pa)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	190	0	0	0	14	0	0	204
406	Begumganj	45 Razapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	40	0	0	53
406	Begumganj	46 Durgapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	81	0	0	0	65	0	0	146
406	Begumganj	47 Kutubpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	121	0	0	0	101	0	0	223
406	Begumganj	48 Abdulpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	89	109	0	0	24	29	0	252
406	Begumganj	49 Rantali /(Lowtala)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	7	0	0	10	6	0	34
406	Begumganj	50 Rasulpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	29	0	0	59
406	Begumganj	53 Khanpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	57	0	0	62
406	Begumganj	54 Sharifpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	10	0	0	15
406	Begumganj	55 Earpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	14	0	0	42
406	Begumganj	56 Kadirpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	10	0	0	30
406	Begumganj	57 Golabaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	121	0	0	0	9	0	0	130
406	Begumganj	58 Nazirpur (Paura)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	45	0	0	65
406	Begumganj	59 Ganipur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	152	0	0	0	9	0	0	161
		Sub-Total	0	0	0	0	0	0	287	33	0	0	0	0	0	0	49	0	0	2128	1216	417	0	1074	1969	1211	8383

Than Code	Thana name	DAE Block Nr & Name	DTW (ha)				STW (ha)				DSSTW (ha)				MTW (ha)				Traditional Irrigation (ha)				LLP (ha)				All Modes (ha)
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
407	Chatkhil	1 Sahapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	22
407	Chatkhil	2 Sompara	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	19	24
407	Chatkhil	3 Ramnarayanpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	0	29
407	Chatkhil	4 Baikubnthapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	19
407	Chatkhil	5 Dashgharia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	42	63
407	Chatkhil	6 Narkopt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35	35
407	Chatkhil	7 Badalkot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	344	356
407	Chatkhil	8 Manikpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	192	212
407	Chatkhil	9 Mohammadpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	101	121
407	Chatkhil	10 Kamalpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	81	97
407	Chatkhil	11 Palla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	210	211
407	Chatkhil	12 Panchgaon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	134	134
407	Chatkhil	13 Sundarpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	132	132
407	Chatkhil	14 Chatkhil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	121	142
407	Chatkhil	15 Gobondrapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	101	121
407	Chatkhil	16 Noakhola	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	0	0	31	13	51
407	Chatkhil	17 Shreenagar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	29	32
407	Chatkhil	18 Karihati	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48	0	48
407	Chatkhil	19 Khilpara	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	101	0	109
407	Chatkhil	20 Daliai	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	142	0	146
407	Chatkhil	21 Naharkhil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	72	59	136
		Sub-Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	19	138	0	0	445	1637	2240

Than Code	Thana name	DAE Block Nr & Name	DTW (ha)				STW (ha)				DSSTW (ha)				MTW (ha)				Traditional Irrigation (ha)				LLP (ha)				All Modes (ha)
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
408	Senbag	3 Kesherpara	0	0	45	0	0	0	214	0	0	0	0	0	0	0	0	0	0	0	67	0	0	0	64	0	389
408	Senbag	6 Moyshari	0	0	67	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	38	0	107
408	Senbag	9 Argumtala	0	0	134	0	0	0	78	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	44	0	295
408	Senbag	10 Batakandi	0	0	20	0	0	0	83	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	46	0	174
408	Senbag	11 Kabilpur	0	0	67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	8	0	95
408	Senbag	12 Earpur	0	0	22	0	0	0	45	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	10	0	98
408	Senbag	17 Bishnapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	101	0	0	0	86	0	0	187
408	Senbag	18 Nabipur	0	12	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	34	0	0	55
	Senbag 8	4 Birkot	0	0	34	0	0	0	33	0	0	0	0	0	0	0	0	0	0	0	36	0	0	0	41	0	143
	Senbag 15	15 Begbag	0	0	10	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	13	0	31
		Sub-Total	0	12	397	0	0	3	454	0	0	0	0	0	0	0	1	0	0	107	216	0	0	120	263	0	1574
398	Faridganj	31 Basara	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	122	132
398	Faridganj	32 Lakshmipur	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	223	255
398	Faridganj	33 Sree Kalia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	251	251
398	Faridganj	34 Ghaniamanuri	0	0	0	0	0	0	0	38	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	186	227
		Sub-Total	0	0	0	0	0	0	0	61	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	781	864
403	Ramgati	3 Motirhat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
403	Ramgati	4 Char Lauranch	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
403	Ramgati	5 Char Martin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Sub-Total	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Than Code	Thana name	DAE Block Nr & Name	DTW (ha) A	DTW B	DTW C	DTW D	STW (ha) A	STW B	STW C	STW D	DSSTW (ha) A	DSSTW B	DSSTW C	DSSTW D	MTW (ha) A	MTW B	MTW C	MTW D	Traditional Irrigation (ha) A	Traditional B	Traditional C	Traditional D	LLP (ha) A	LLP B	LLP C	LLP D	All Modes (ha)
390	Laksam	43 Ramarbagh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	81	0	0	0	40	121
390	Laksam	45 Manoharganj	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	111	0	0	0	233	344
390	Laksam	46 Amtoli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	192	216
390	Laksam	47 Ashirpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	79	101
390	Laksam	48 Dakhin Chandpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61	0	0	0	91	152
390	Laksam	49 Gobindapur	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0	0	126	0	0	0	82	227
390	Laksam	50 Mohammedpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	445	465
390	Laksam	55 Baishgaon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45	0	0	0	312	356
390	Laksam	56 Jolipur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	0	0	0	295	330
390	Laksam	57 Hasnabad	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	0	0	0	65	121
390	Laksam	58 Naotala	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	121	142
390	Laksam	59 Lakshmanpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63	0	0	0	182	245
390	Laksam	60 Maraha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	152	164
390	Laksam	61 Vanpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	273	287
390	Laksam	62 Shahapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	140	168
390	Laksam	63 Baralla	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0	0	142	174
390	Laksam	64 Uttar Haula	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	121	146
390	Laksam	65 Khila	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	89	0	0	0	182	275
390	Laksam	66 Tairpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	101	0	0	0	182	283
390	Laksam	67 Bipulasar	0	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	109	166
390	Laksam	68 Kachi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	0	0	0	146	182
		Sub-Total	0	0	0	0	0	0	0	63	0	0	0	0	0	0	0	0	0	0	0	1019	0	0	0	3584	4666

Than Code	Thana name	DAE Block Nr & Name	DTW (ha)				STW (ha)				DSSTW (ha)				MTW (ha)				Traditional Irrigation (ha)				LLP (ha)				All Modes (ha)
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
396	Hajijganj	17 Barkul	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	0	0	0	591	648
396	Hajijganj	18 Sonaimuri	0	0	0	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	255	344
396	Hajijganj	19 Ramchandrapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	208	208
396	Hajijganj	20 Jhakni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	223	225
396	Hajijganj	21 Nachathara	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38	0	0	0	287	326
396	Hajijganj	27 Ahmmadpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	405	409
396	Hajijganj	28 Kakairtala	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	471	486
396	Hajijganj	29 Deshgaon	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	140	180
396	Hajijganj	30 Rashimpur	0	0	0	81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	109	198
396	Hajijganj	31 Panchai Black	0	0	0	4	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	49	61
		Sub-Total	0	0	0	174	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	168	0	0	0	2738	3084
397	Shahrasti	16 Chitoshi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	142	144
397	Shahrasti	17 Kashba	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	107	119
397	Shahrasti	18 Kadra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	73	82
397	Shahrasti	19 Ugharia	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	47	85
397	Shahrasti	20 Pathair	0	0	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	225	273
397	Shahrasti	21 Suchipara	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	214	267
397	Shahrasti	22 Sursak	0	0	0	81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	79	184
397	Shahrasti	23 Raghai	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	121	134
397	Shahrasti	24 Naringpur	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	178	210
		Sub-Total	0	0	0	196	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	117	0	0	0	1186	1499

Than Code	Thana name	DAE Block Nr & Name	DTW (ha) A	B	C	D	STW (ha) A	B	C	D	DSSTW (ha) A	B	C	D	MTW (ha) A	B	C	D	Traditional Irrigation (ha) A	B	C	D	LLP (ha) A	B	C	D	All Modes (ha)
401	Ramganj	1 Joipura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0	239	263
401	Ramganj	2 Bigha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	65	0	0	0	223	287
401	Ramganj	3 Noagaon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	130	132
401	Ramganj	4 Paniwala	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	125	127
401	Ramganj	5 Saisai	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	123	127
401	Ramganj	6 Bhadur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	69	77
401	Ramganj	7 Morondi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	178	182
401	Ramganj	8 Sonapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	123	125
401	Ramganj	9 Lamchar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	0	0	0	95	152
401	Ramganj	10 Kalikapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	168	172
401	Ramganj	11 Darbashpur	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	150	166
401	Ramganj	12 Sosholia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	180	182
401	Ramganj	13 Jagatpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	70	78
401	Ramganj	14 Dumuria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	84	88
401	Ramganj	15 Kanpara	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	148	156
401	Ramganj	16 Nagmut	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	73	75
401	Ramganj	17 Tiori	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	34	51
401	Ramganj	18 Bholakot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	40	61
401	Ramganj	19 Vatra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	38	49
401	Ramganj	20 Daulta	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	43
		Sub-Total	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	1	0	0	0	250	0	0	0	2329	2593

Than Code	Thana name	DAE Block Nr & Name	DTW (ha)				STW (ha)				DSSTW (ha)				MTW (ha)				Traditional Irrigation (ha)				LLP (ha)				All Modes (ha)
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
402	Laksmipur	2 Bijoynagar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	597	603
402	Laksmipur	4 Hamchadi (South)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	389	389
402	Laksmipur	8 Sjasherabad	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	190	0	0	0	198
402	Laksmipur	9 Mijupur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	376	0	0	0	397
402	Laksmipur	10 Parbatanagar	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	8	19	0	0	74	142
402	Laksmipur	11 Khilbaicha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	8	73	0	0	73	162
402	Laksmipur	12 Bhangakha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	336	344
402	Laksmipur	13 Rajabpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	1	168	0	0	42	217
402	Laksmipur	14 Rashedpur	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	81	0	0	0	85	182
402	Laksmipur	15 Bashikpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	30	0	0	25	25	111
402	Laksmipur	16 Rokanpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	81	0	0	0	61	142
402	Laksmipur	17 Sattapara	0	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	24	0	45
402	Laksmipur	18 Saidpur	0	0	0	40	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	29	91
402	Laksmipur	19 Totarakhal	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	33	69
402	Laksmipur	20 Joypur (North)	0	0	73	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0	154	0	259
402	Laksmipur	21 Chaupalli	0	0	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	57	0	0	0	158	0	263
402	Laksmipur	22 Latiapur	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	299	0	352
402	Laksmipur	23 Ram Krishnapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	297	0	299
402	Laksmipur	24 Pachpara	0	0	75	0	0	0	30	0	0	0	0	0	0	0	0	0	0	0	63	0	0	0	188	0	356
402	Laksmipur	25 Hajirpara	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	378	0	405
402	Laksmipur	26 Char Chamita	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	61	0	89
402	Laksmipur	27 Char Shahi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	277	0	0	0	471	0	749
402	Laksmipur	28 Rampur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	20	0	61
402	Laksmipur	29 Dhighali	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	154	0	0	0	156
402	Laksmipur	30 Khagdia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	6	0	33	0	33	0	79
402	Laksmipur	31 Jamintala	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	356	0	356
402	Laksmipur	32 Mandari	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	138	0	0	0	148
402	Laksmipur	33 Ratanpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	29	0	0	88	118
402	Laksmipur	34 Gandabpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	16	0	0	0	18
402	Laksmipur	35 Laharkandi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	196	0	0	0	206
402	Laksmipur	36 Jabir nagar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	0	0	0	36

Than Code	Thana name	DAE Block Nr & Name	DTW (ha)				STW (ha)				DSSTW (ha)				MTW (ha)				Traditional Irrigation (ha)				LLP (ha)				All Modes (ha)
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
402	Laksmipur	37 Ramanandi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	53	0	0	0	57
402	Laksmipur	38 Shakchar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
402	Laksmipur	39 Tumchar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	125	0	0	0	134
402	Laksmipur	40 Char Ramani	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0	0	0	391	0	0	0	439
402	Laksmipur	41 Kalirchar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	411	0	0	0	427
402	Laksmipur	42 Char Manasha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	0	0	0	19
402	Laksmipur	43 Hossainpur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	24	0	0	0	26
402	Laksmipur	44 Piarapur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	58	0	0	0	59
402	Laksmipur	45 Char Ubuti	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	417	0	0	0	425
402	Laksmipur	46 Kathali	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
402	Laksmipur	47 Goranbag	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Sub-Total	38	0	214	89	0	0	91	10	0	0	0	0	0	0	0	0	162	0	556	239	2926	0	2467	1831	8626
Total (ha)			38	12	611	459	0	3	833	185	0	0	0	0	0	17	50	1	179	3794	2007	2369	3050	4168	5144	15298	38218
Additional DTWs			290	0	154	432																					
Total	by Mode		1997				1021				0				68				8349				27659				38218

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APPENDIX C.II

BOREHOLE LOGS

BOREHOLE NO : BH-1
HTW NO. HTW-1
WATER QUALITY

Water from Kata Khal adj to BH-1
EC = 450 μs/cm
TDS = 310

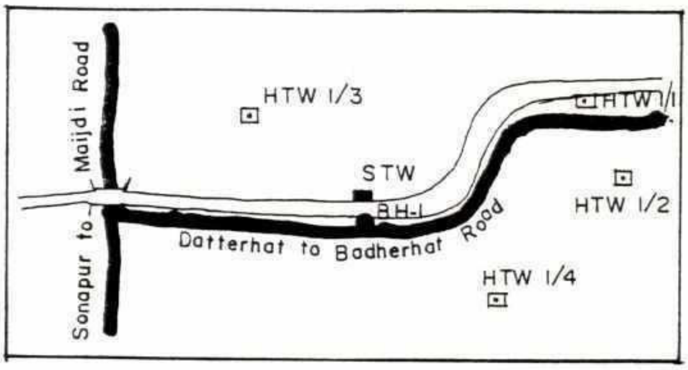
HTW 1/1. 200'-0" NE of BH-1
EC = 1200 μs/cm
TDS = 1900

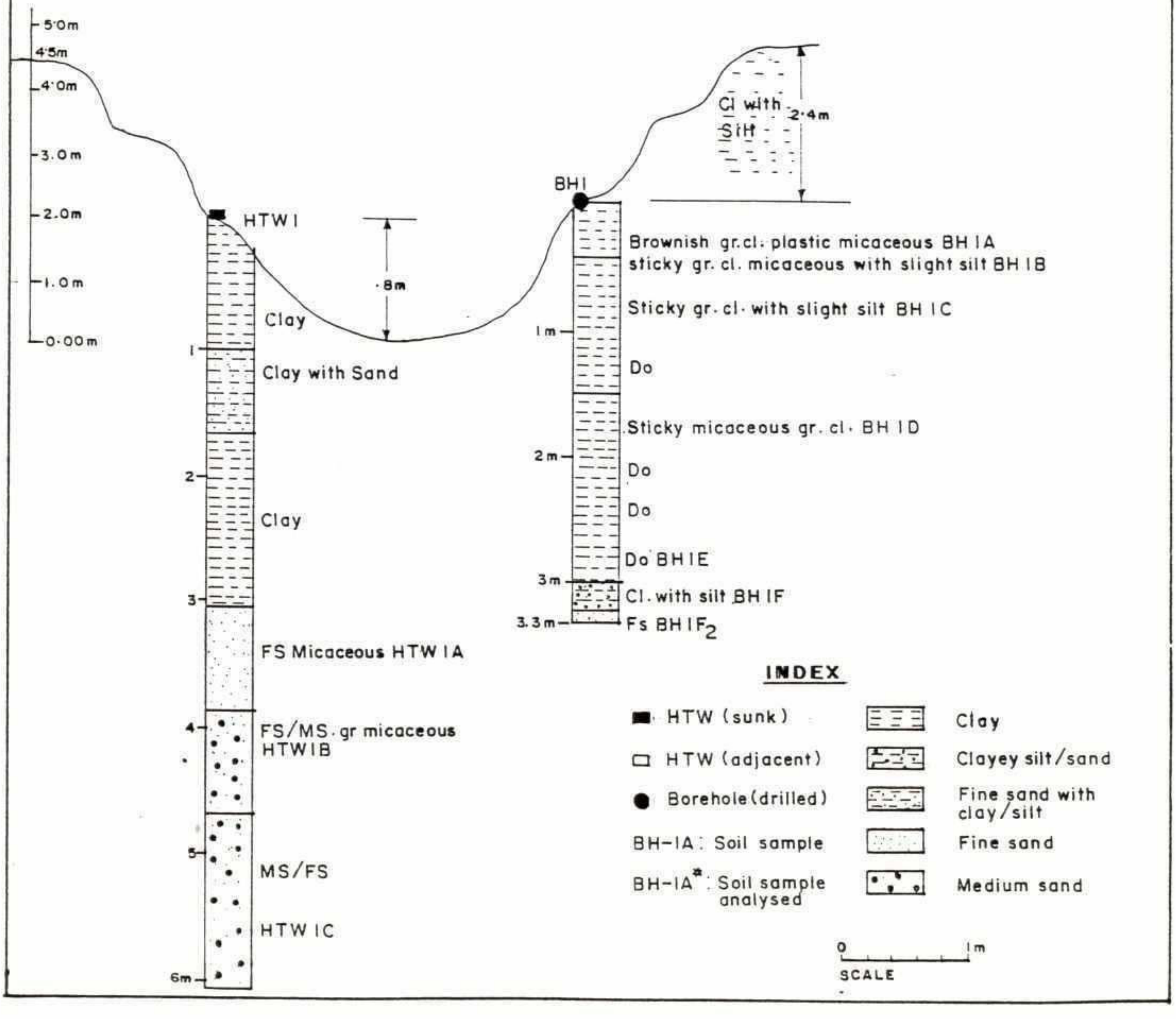
HTW 1/2. 200'-0" NE of BH-1
EC = 1200 μs/cm
TDS = 900

HTW 1/3. 100'-0" N of BH-1
EC = 1000 μs/cm
TDS = 700

HTW 1/4. 200'-0" SE of BH-1
EC = 1000 μs/cm
TDS = 700

SITE LOCATION





BOREHOLE NO: BH-2

HTW NO. HTW-11

WATER QUALITY

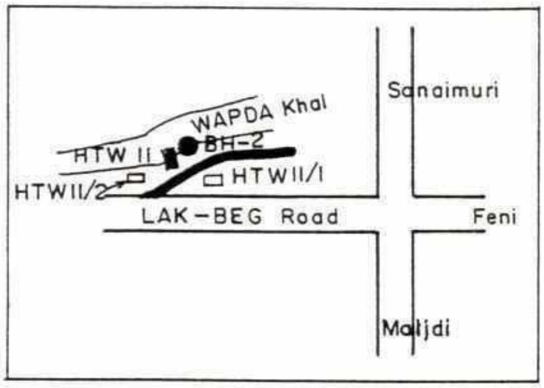
HTW 11/1 = Adj to BH-2
EC = 2300 µs/cm, TDS = 1600

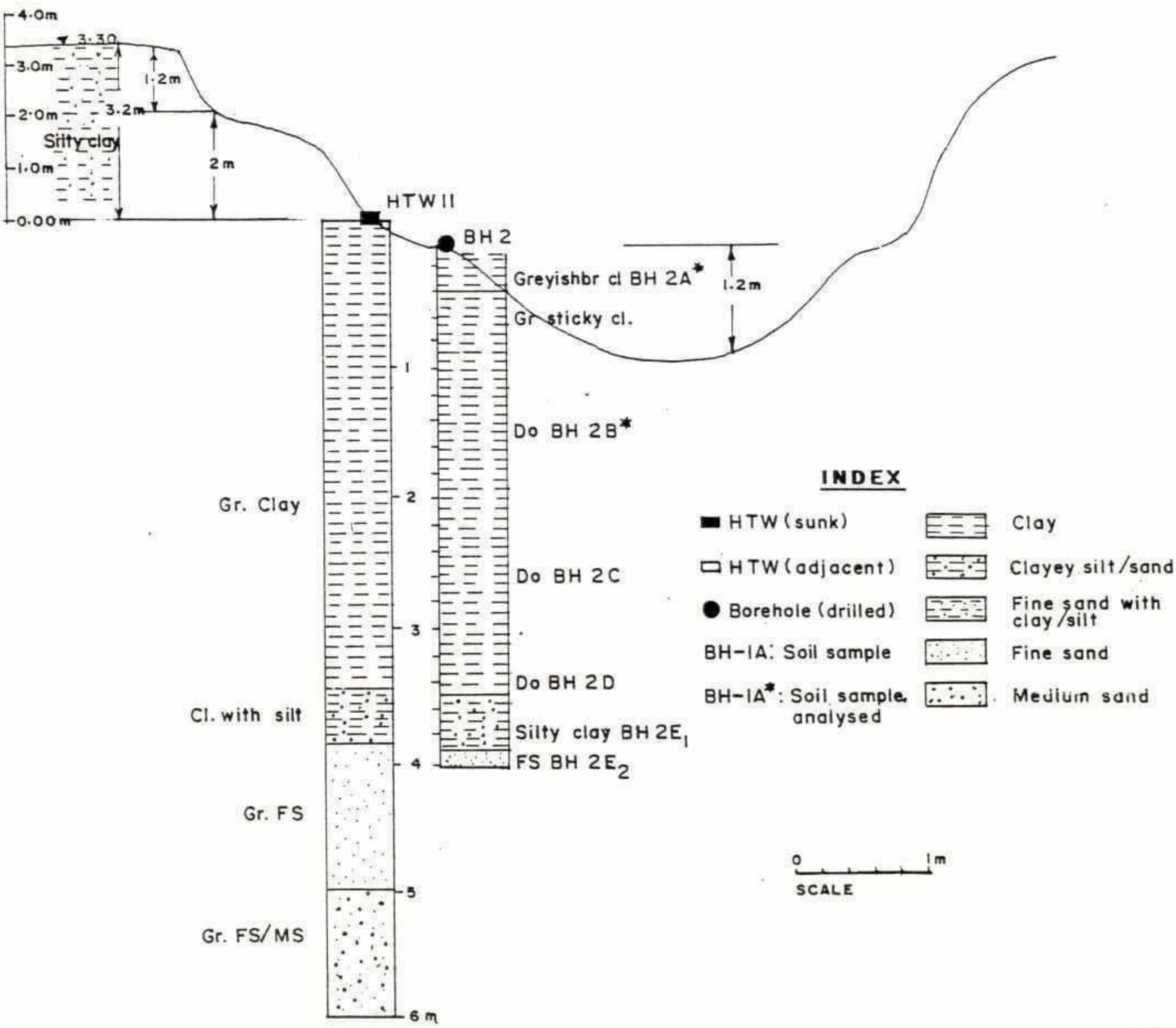
HTW 11/2 200' w of HB-2
EC = 2300 µs/cm TDS = 1600

Pond water, adj to HB-2
EC = 260 µs/cm, TDS = 210

Khal water, adj to HB-2
EC = 1400 µs/cm
TDS = 1000

SITE LOCATION





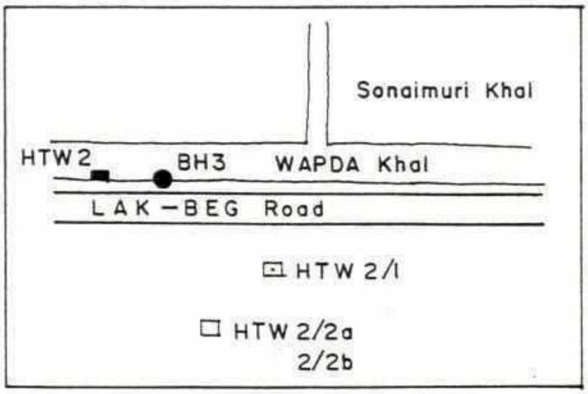
BOREHOLE NO: BH-3

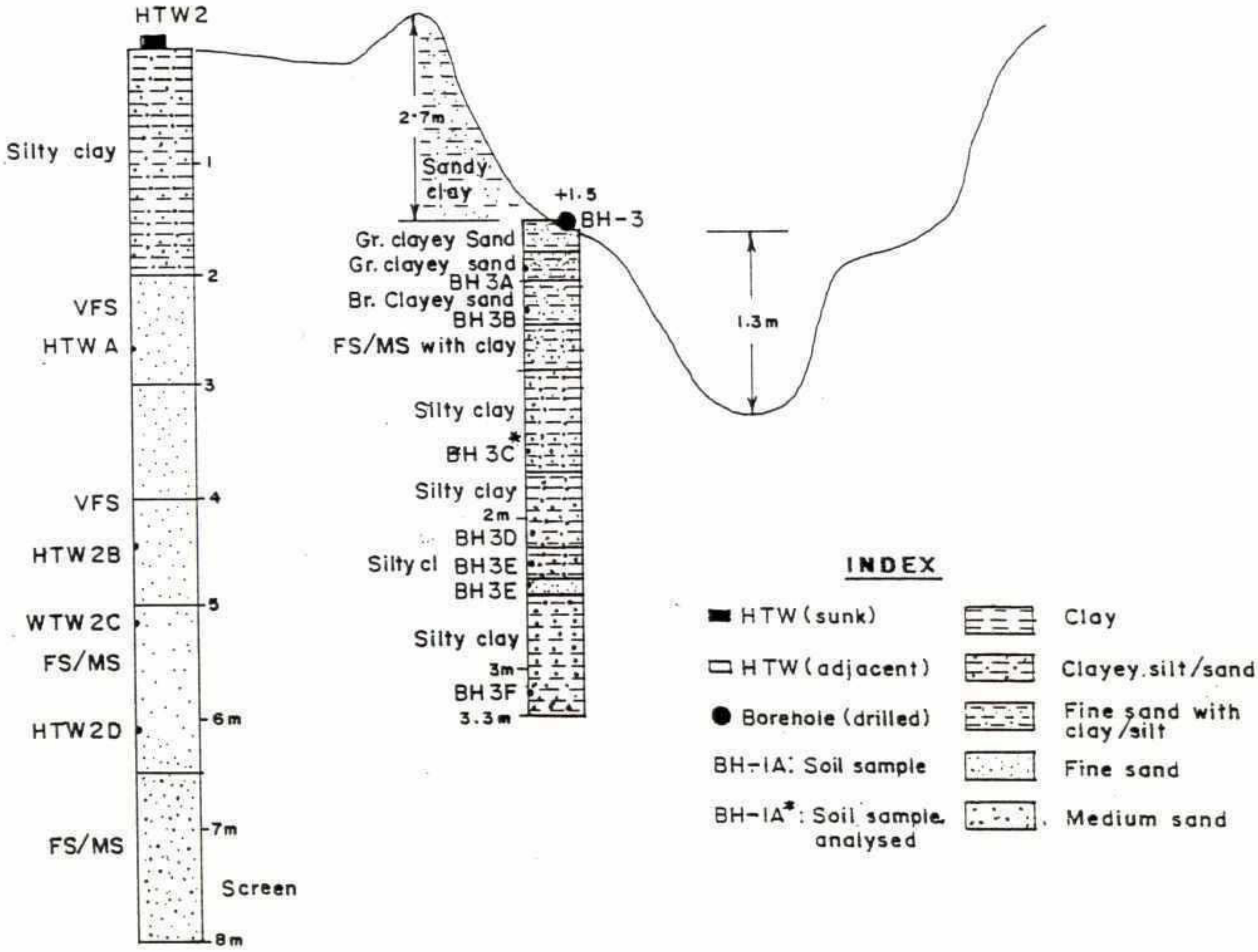
HTW NO. HTW-2

WATER QUALITY

WAPDA Khal water adj to BH-3
EC= 900 μs/cm, TDS= 600
HTW 2/1 100' SE of BH=3
EC= 1200 μs/cm, TDS= 850
HTW 2/2a 200' SE of BH-3
EC= 650 μs/cm, TDS= 450
HTW 2/2b 200' SE of BH-3
EC= 2000 μs/cm, TDS= 1400

SITE LOCATION

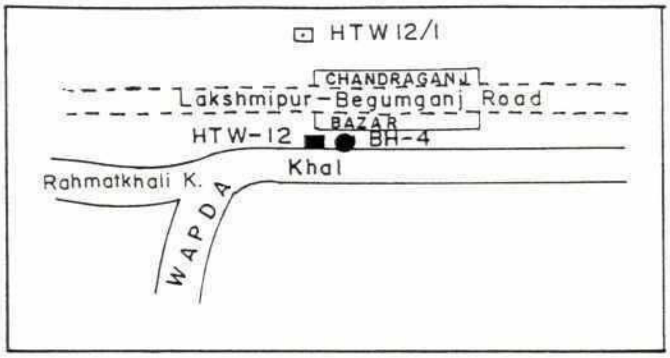


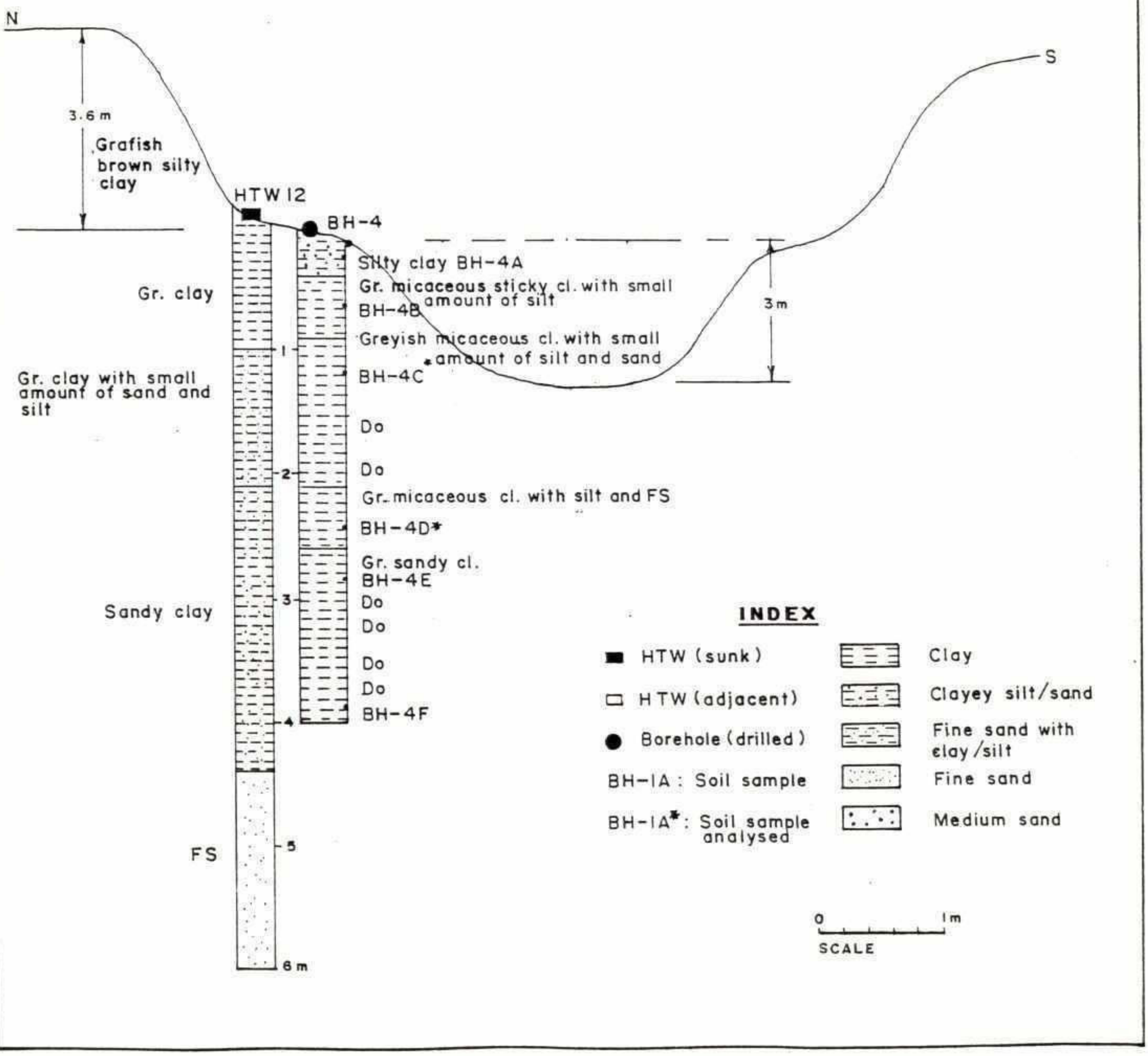


BOREHOLE NO. BH-4
HTW NO. HTW-12
WATER QUALITY

WAPDA Khal water Adj to BH-4
EC = 410 µs/cm
TDS = 290
HTW12/1 = 300' N of BH-4
EC = 380 µs/cm
TDS = 275

SITE LOCATION

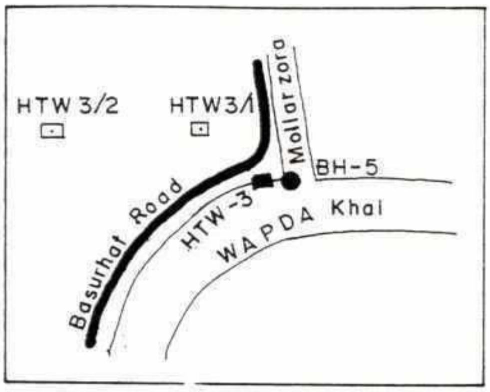


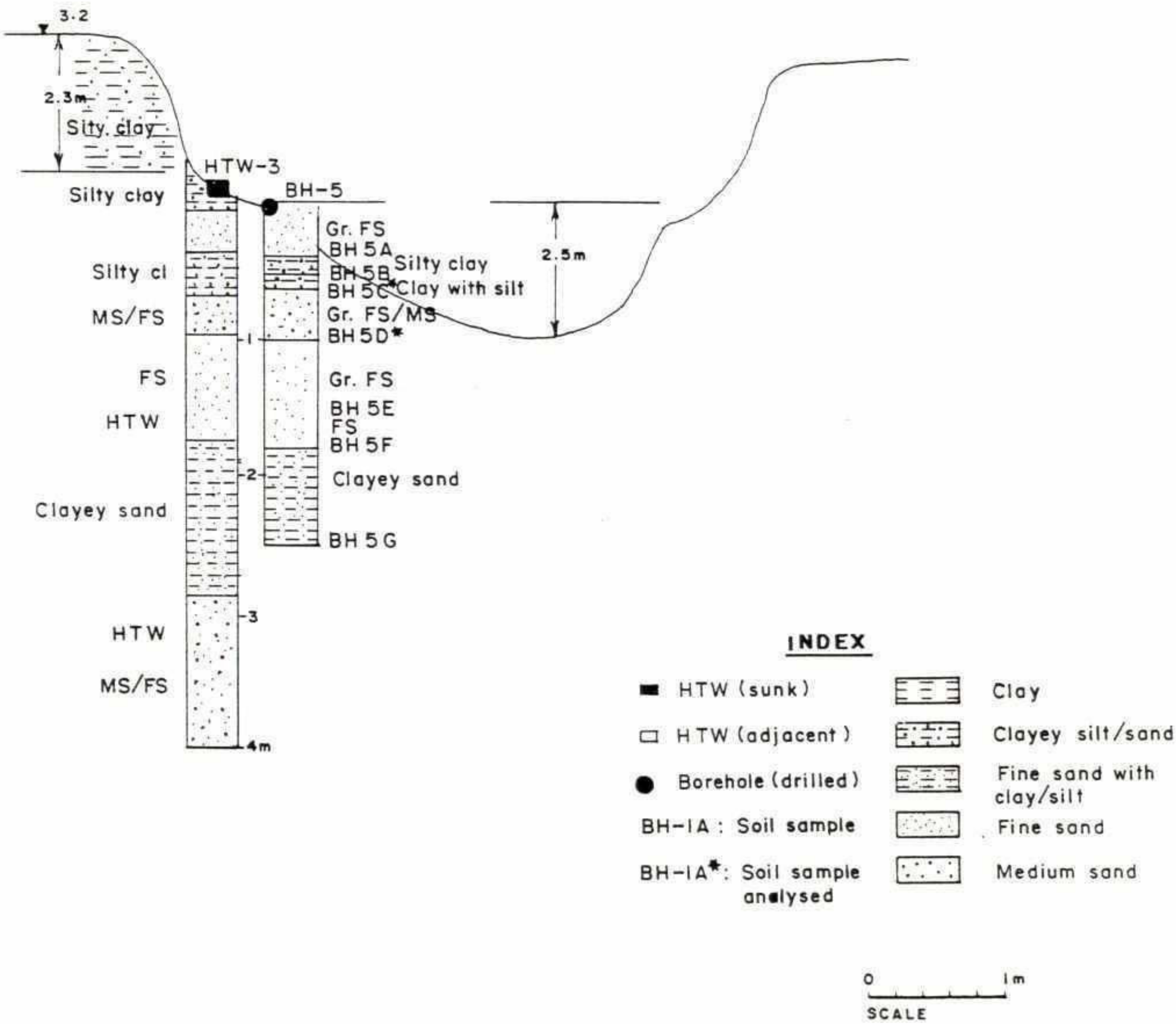


BOREHOLE NO. BH-5
HTW NO. HTW-3
WATER QUALITY

WAPDA Khal Water:
EC = 360 µs/cm
TDS = 260
HTW 3/1 100' NW of BH-5
EC = 800 µs/cm
TDS = 600
HTW 3/2 300' W of BH-5
EC = 450 µs/cm
TDS = 320

SITE LOCATION

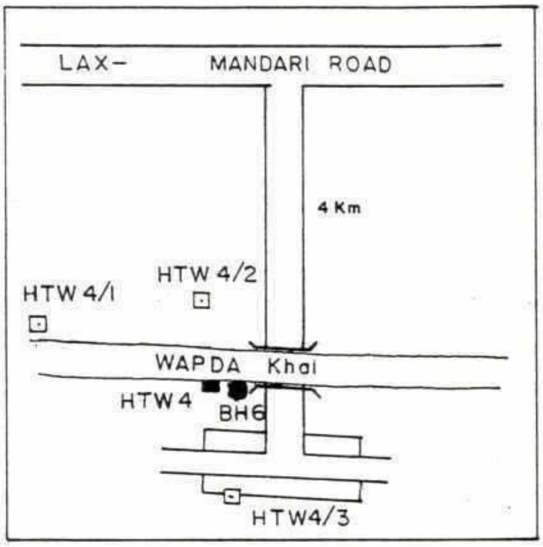


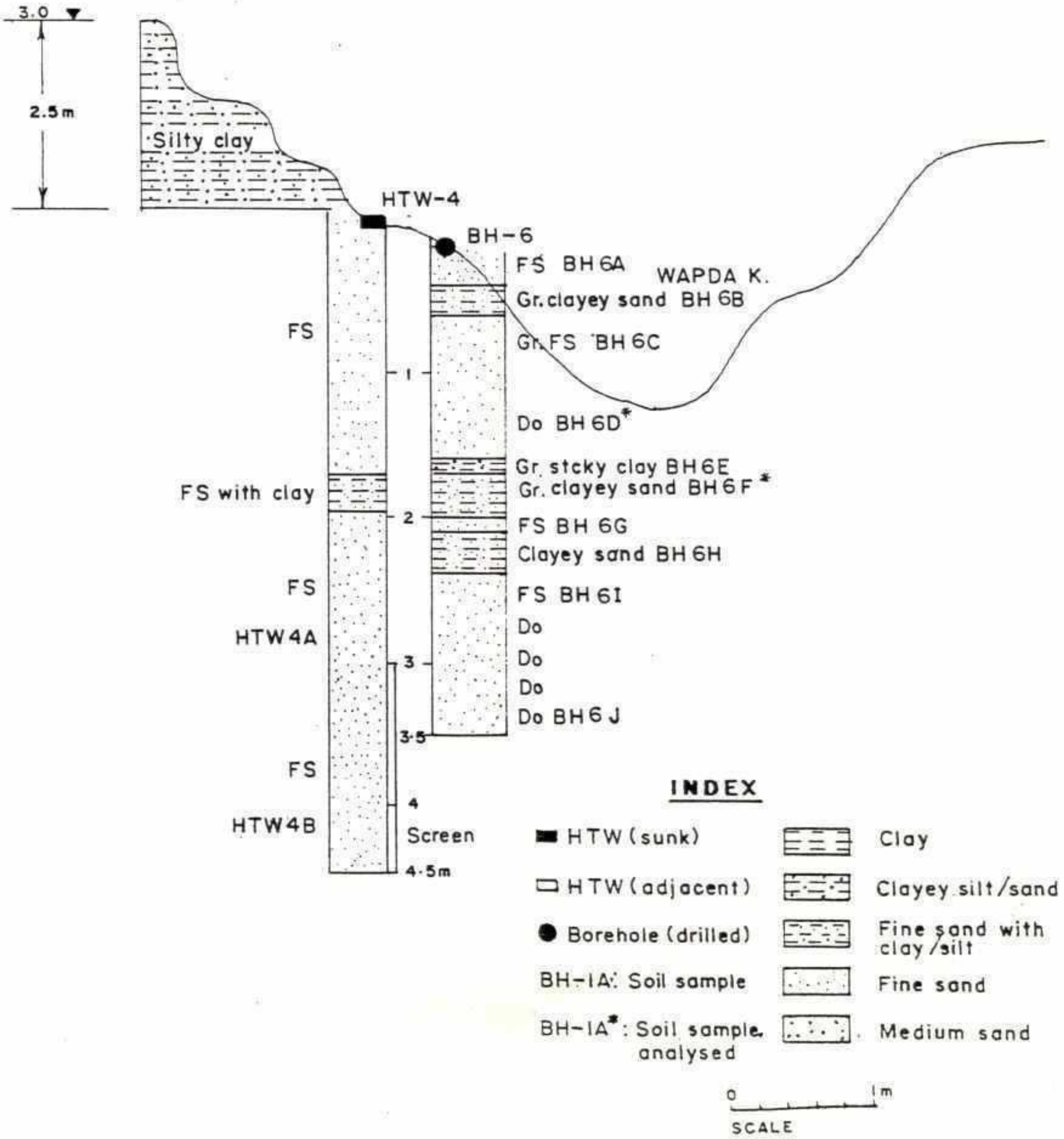


BOREHOLE NO. BH-6
HTW NO. HTW-4
WATER QUALITY

WAPDA Khal Water adj to BH-6
EC = 290 µs/cm, TDS = 250
HTW 4/1 300' W of BH-6
EC = 980 µs/cm, TDS = 680 — Time 4.15 PM
HTW 4/2 100' NW of BH-6
EC = 1000 µs/cm, TDS = 700 — Time 4.30 PM
HTW 4/3 100' SW of BH-6
EC = 810 µs/cm, TDS = 565
Water from HTW-4
EC = 820 µs/cm, TDS = 580 — Time 4.45 PM, Temp. 25°C

SITE LOCATION

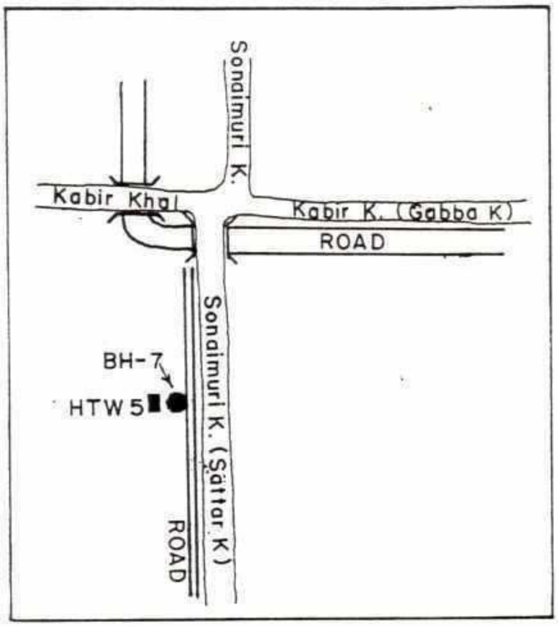


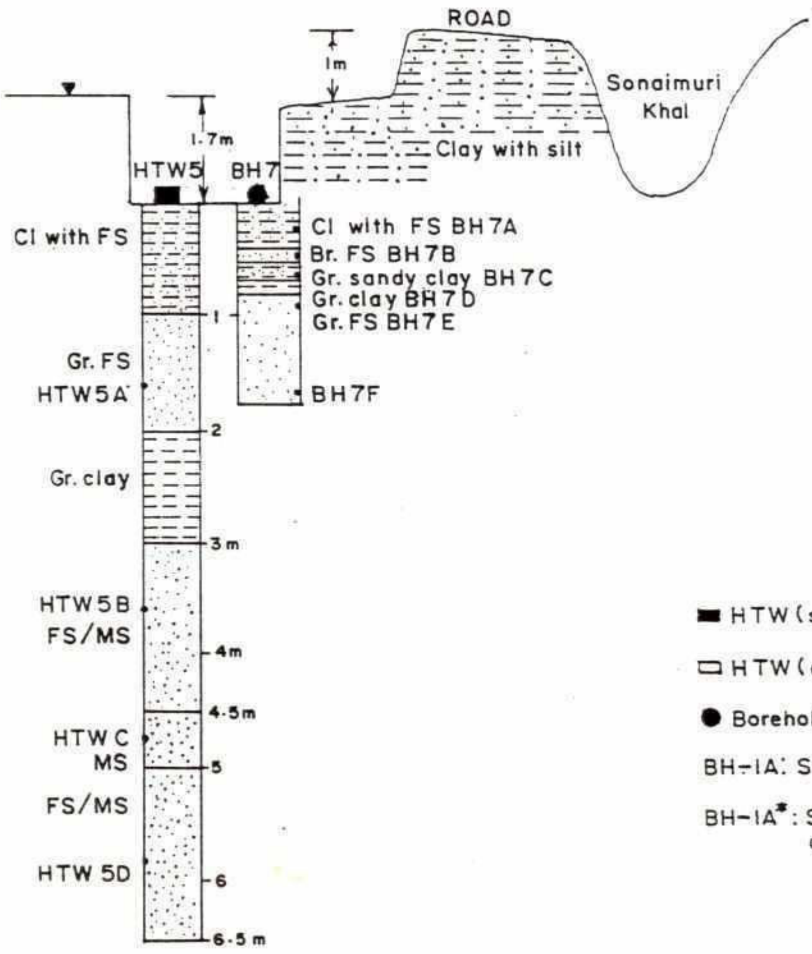


BOREHOLE NO. BH-7
HTW NO. HTW-5
WATER QUALITY

HTW-5
5A EC= 570 μs/cm, TDS= 400
5B EC= 580 μs/cm, TDS= 410
Khal Water, EC= 1250 μs/cm, TDS= 850
H_1, EC= 470 μs/cm, TDS= 330
H_2, EC= 2800 μs/cm, TDS= 2000
H_3, EC= 570 μs/cm, TDS= 400
HTWX_1, EC= 1100 μs/cm, TDS= 750
HTWX_2, EC= 3500 μs/cm, TDS= 2450

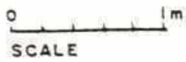
SITE LOCATION





INDEX

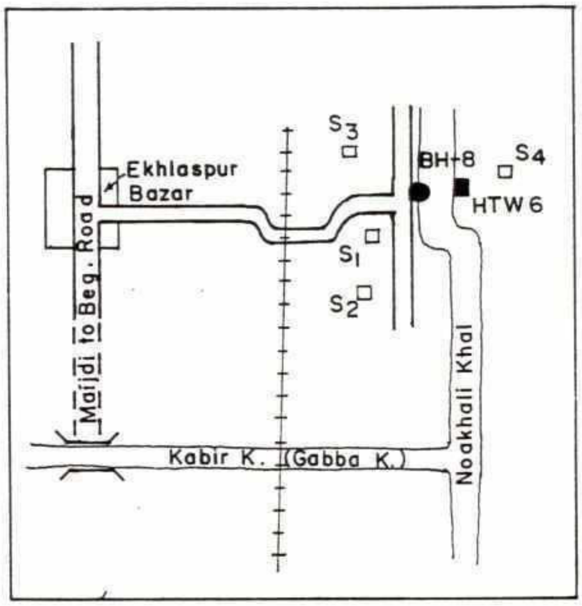
■ HTW (sunk)	Clay
▭ HTW (adjacent)	Clayey silt/sand
● Borehole (drilled)	Fine sand with clay/silt
BH-1A: Soil sample	Fine sand
BH-1A*: Soil sample analysed	Medium sand

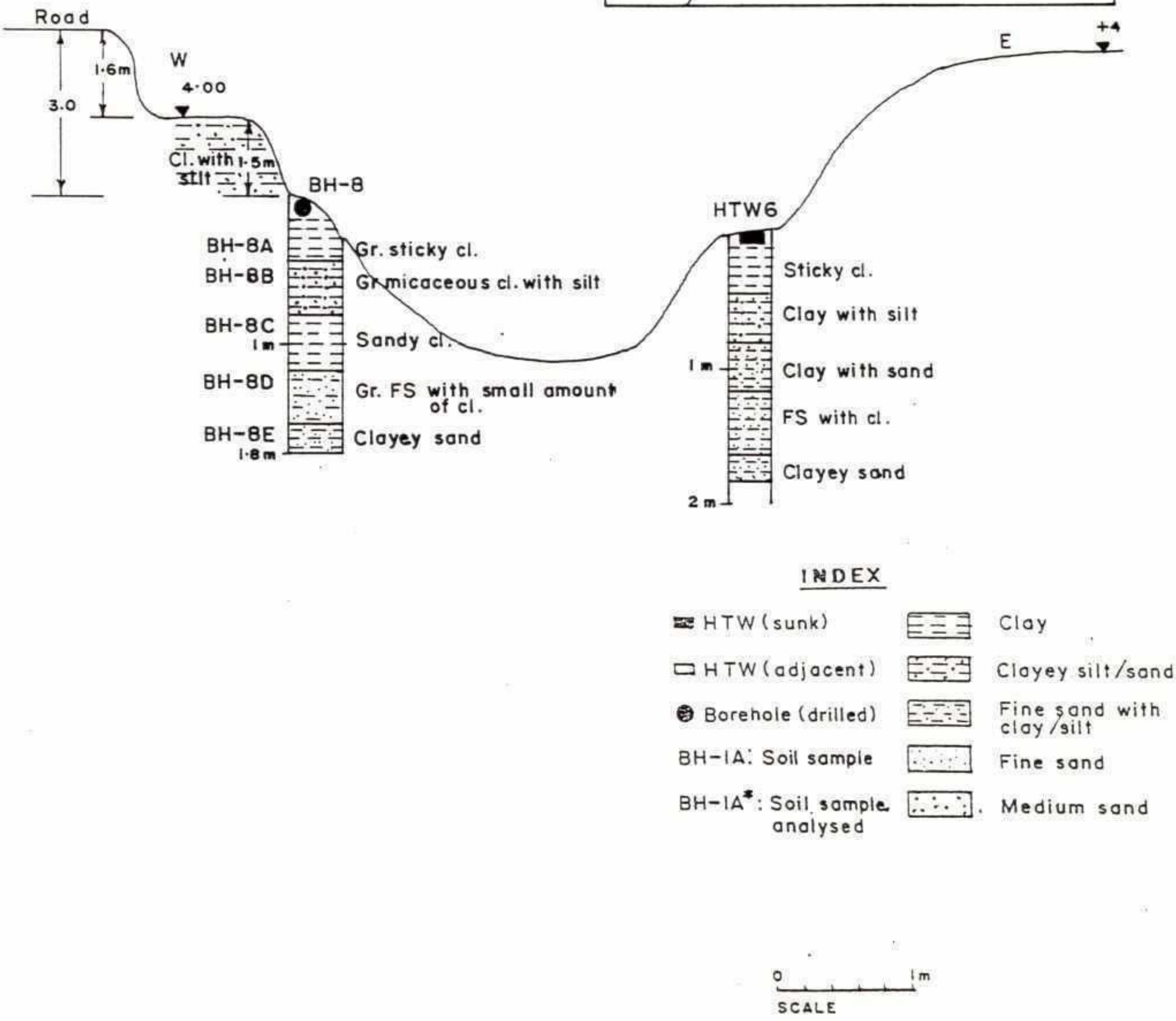


BOREHOLE NO. BH-8
HTW NO. HTW-6
WATER QUALITY

S_1, 100' SW of BH-8
EC = 4000 μs/cm
TDS = 2800
S_2, 300' SW of BH-8
EC ≡ 2500 μs/cm, TDS = 1750
S_3, 100' NW of BH-8
EC = 530 μs/cm, TDS = 370
Khal Water adj to BH-8
EC = 7300 μs/cm, TDS = 5100
S_4, Adj to HTW-6
EC = 6700 μs/cm, TDS = 4700

SITE LOCATION





BOREHOLE NO. BH-9

HTW NO. HTW-7

WATER QUALITY

HTW X_1, 50' N of BH-9

EC = 440 µs/cm, TDS = 310, Time - 10·30 AM

HTW X_2, 100' E of BH = 9

EC = 1000 µs/cm, TDS = 700 — Time - 11·20 AM

Khal Water adj. to BH-9

EC = 430 µs/cm, TDS = 300

Water from

HTW-7

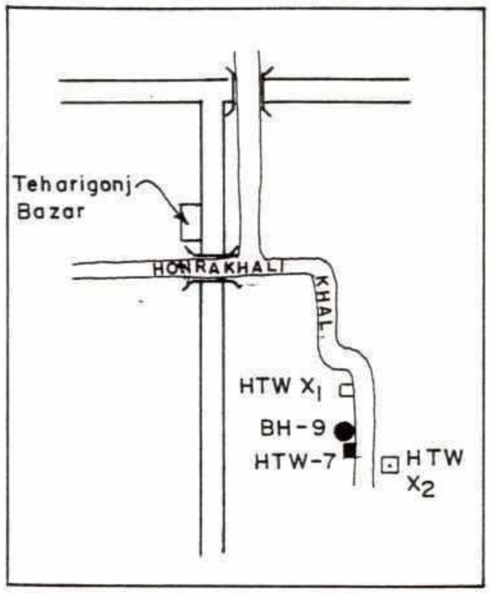
Test no. 1 EC = 2800 µs/cm

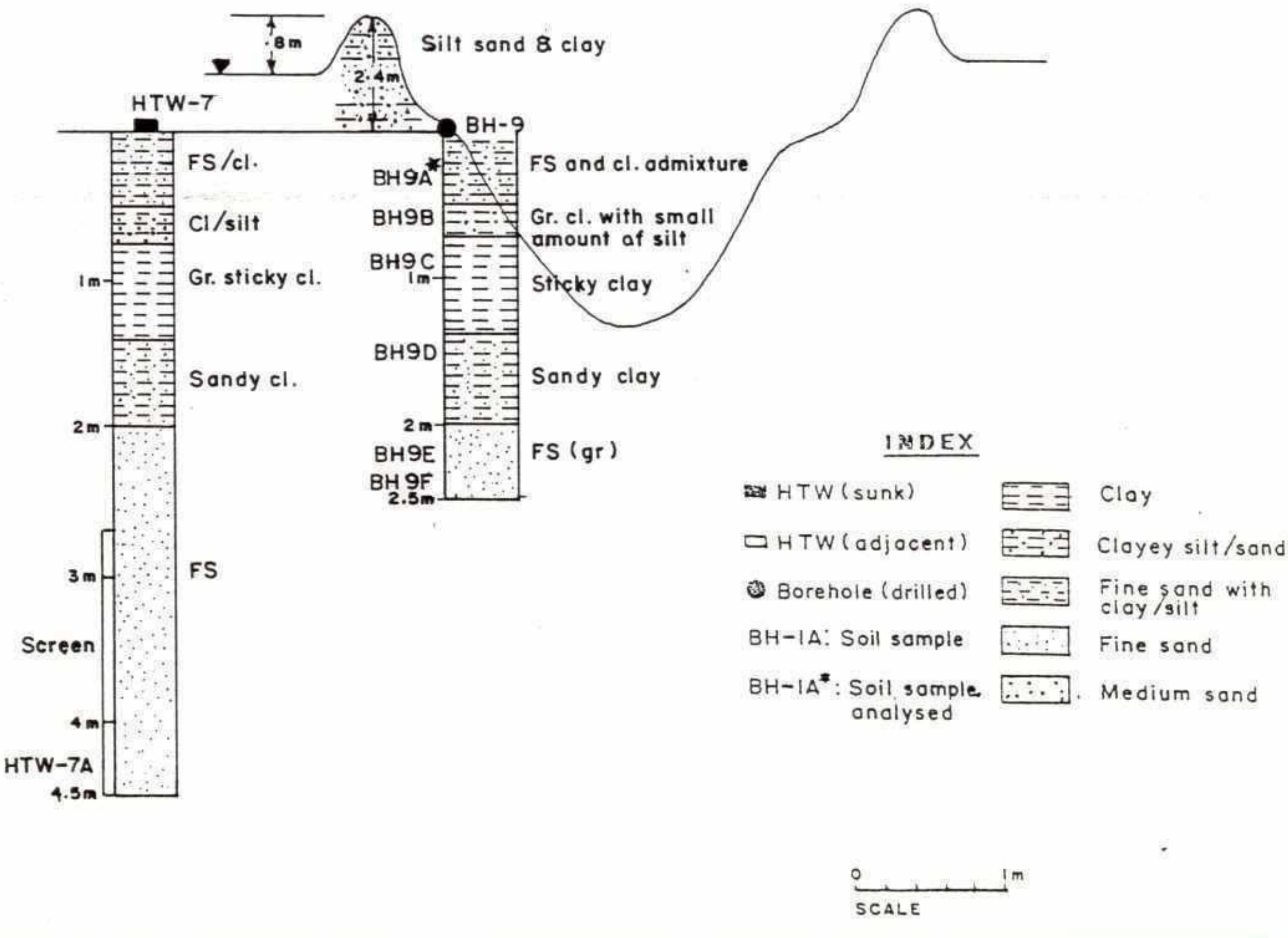
Time 11.28 TDS = 1950

2nd. Test EC = 3300 µs/cm

Time 11·30 TDS = 2300

SITE LOCATION





BOREHOLE NO. BH-10

HTW NO. HTW-8

WATER QUALITY

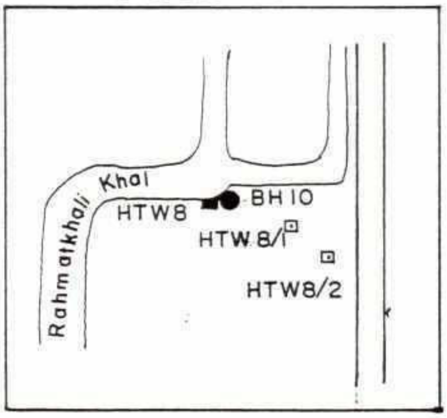
HTW 8/1, 100 SE of BH-10
EC = 1500 µs/cm, TDS = 1000 — Time 1·45 PM

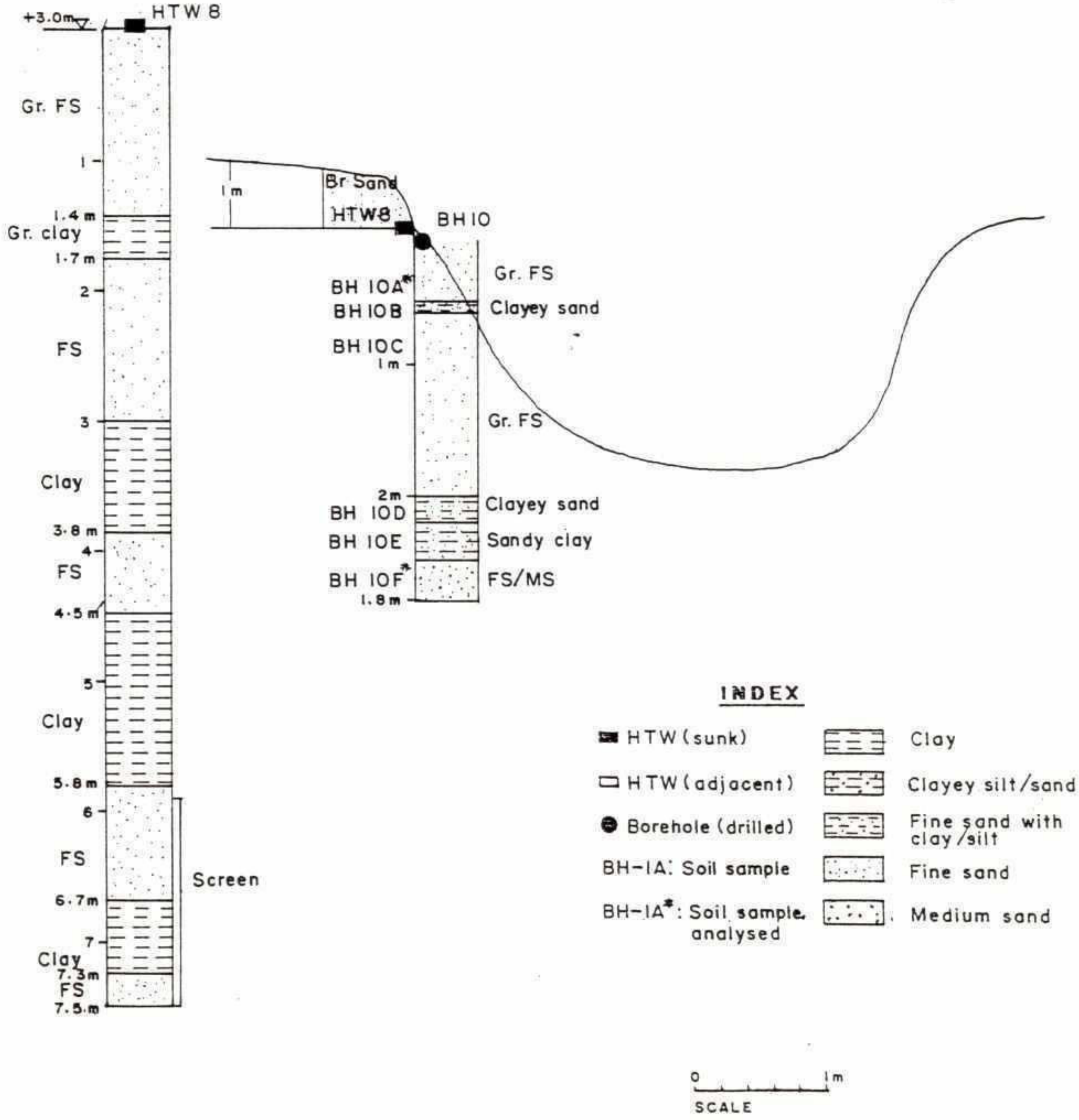
HTW 8/2, 200' SE of BH-10
EC = 985 µs/cm, TDS = 690 — Time 1·46 PM

Khal Water, EC = 290 µs/cm
Time - 1·30 PM. TDS = 200

Water from HTW-8
EC = 560 µs/cm, TDS = 390 — Time 1·35 PM

SITE LOCATION

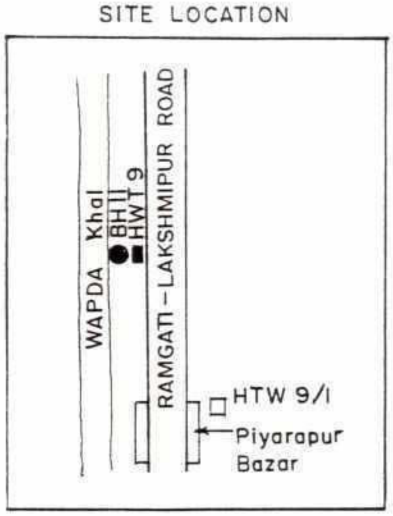


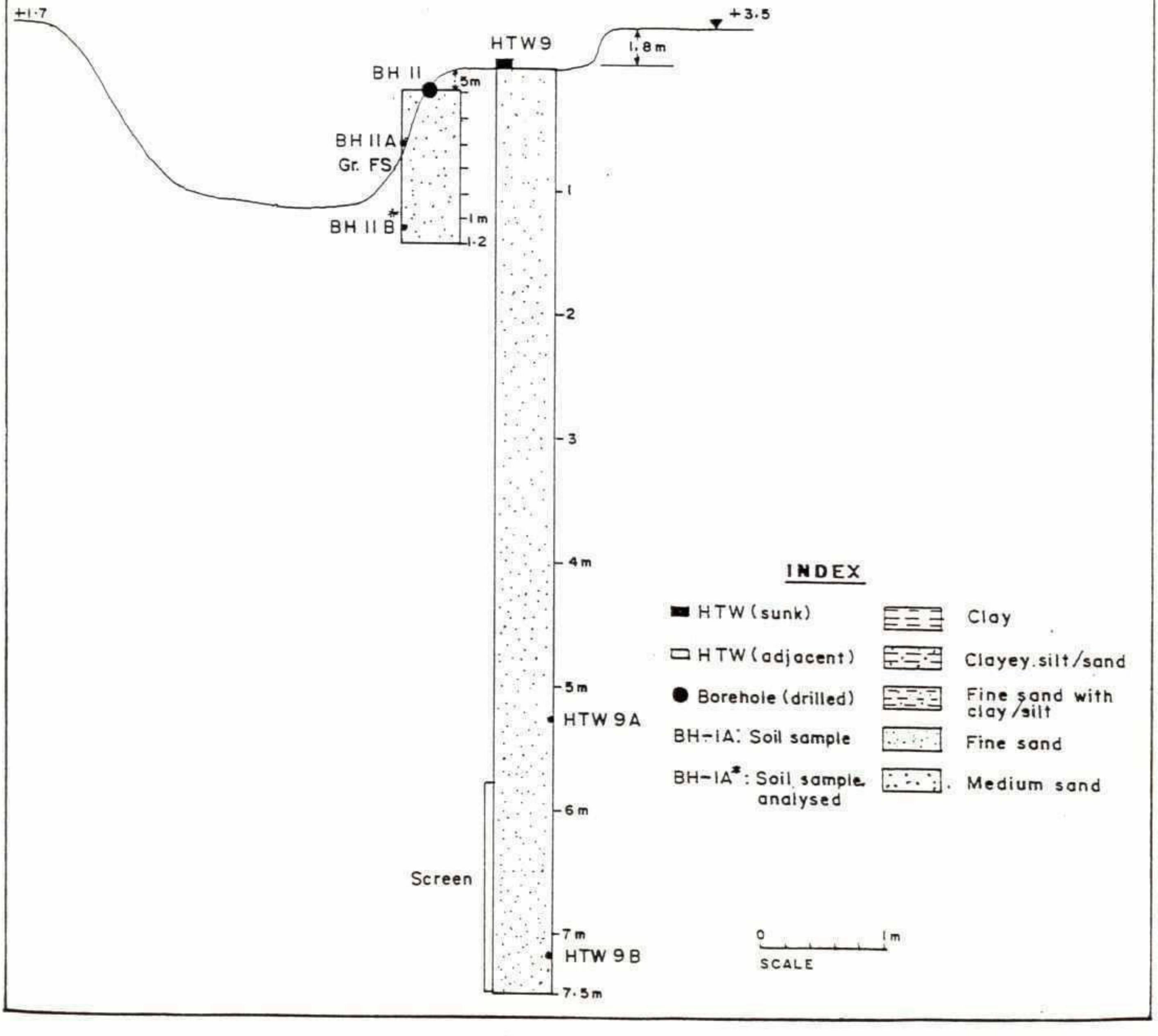


BOREHOLE NO. BH-II
HTW NO. HTW-9
WATER QUALITY

Water from WAPDA Khal
EC= 290 μs/cm
TDS = 200
HTW 9/I 200' SE of BH 9-II
EC= 710 μs/cm
TDS= 500
Time 2.35 PM
Water from HTW 9
Ist test: EC= 430 μs/cm
TDS=300
2nd test: EC= 440 μs/cm
TDS = 310

SITE LOCATION

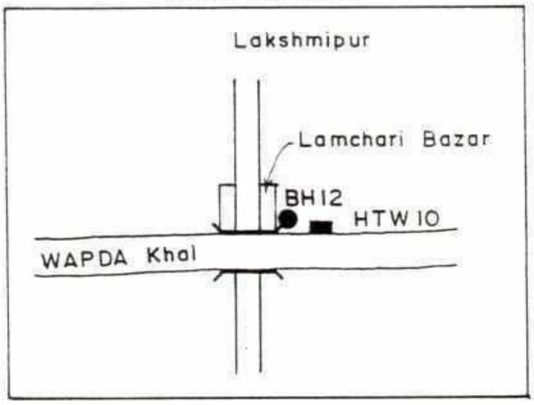


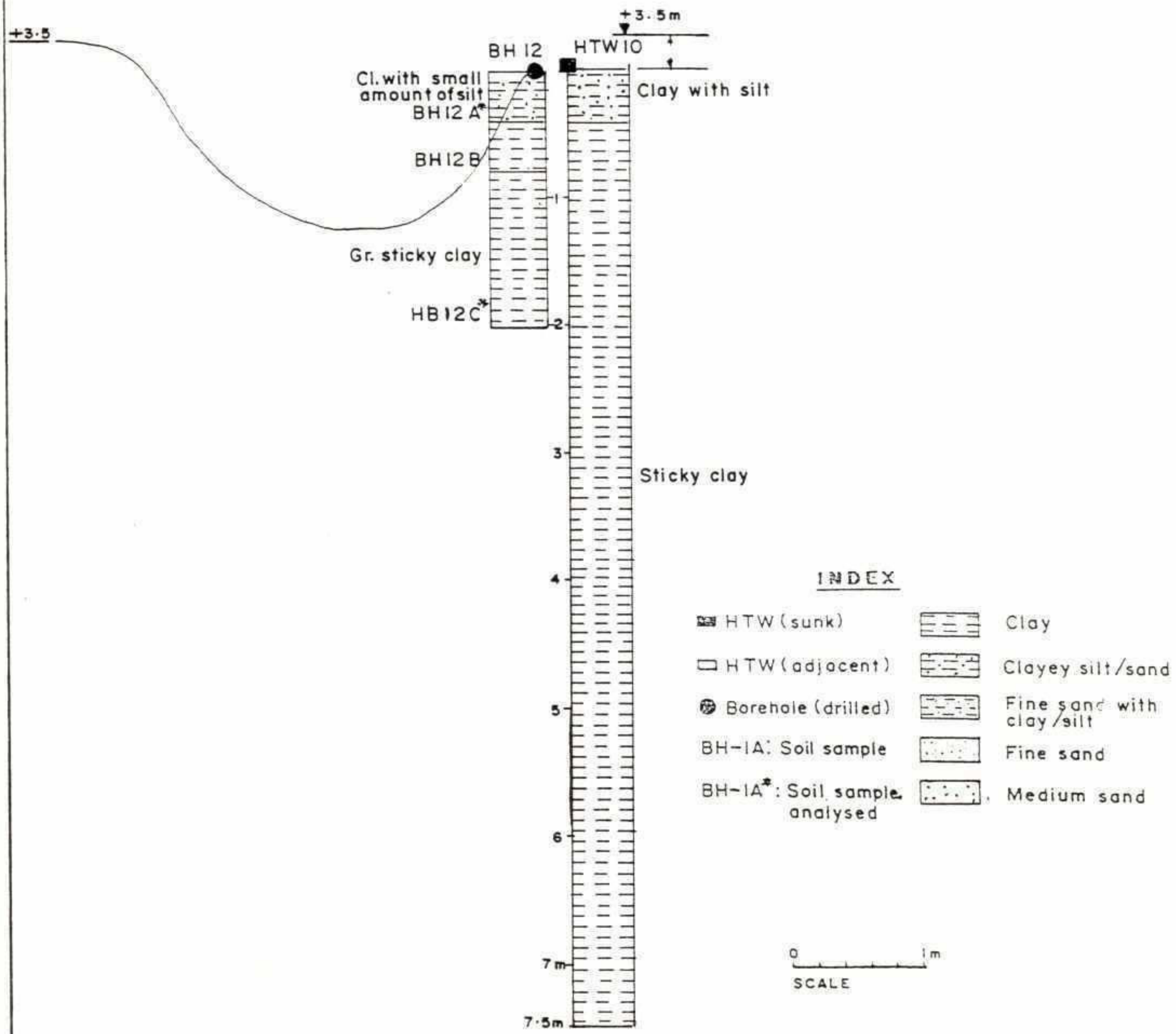


BOREHOLE NO: BH-12
HTW NO. HTW-10
WATER QUALITY

Khal water adj to BH-12
EC= 250 µs/cm] Time 4.45
TDS=160
HTW adjacent to BH-12
EC=1000 µs/cm
TDS= 200

SITE LOCATION





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APPENDIX C.III

RESULTS OF BOREHOLE TESTS

TABLE C.III.1
Borehole Salinity Survey in the
Noakhali North Area (1992-1993)

Sl. No.	Site No.	Thana	Location	Date of Sampling	Ec in pus/cm	TDS	Type of well	Depth of Sampling (m)
27	BH-1	Sudharam	200' NE of BH-1	10-03-1993	2600	1900	HTW	4-6
28	BH-1	Sudharam	200' ASE of BH-1	10-03-1993	1000	700	HTW	4-6
29	BH-2	Begumganj	Adj.to BH-2	12-03-1993	2300	1600	HTW	5-6
30	BH-2	Begumganj	Adj.to BH-2	12-03-1993	1400	1000	Khal Water	
31	BH-3	Begumganj	100' SE of BH-3	12-03-1993	1200	850	HTW	6-8
32	BH-3	Begumganj	200' SE of BH-3	12-03-1993	2000	1400	HTW	6-8
33	BH-4	Begumganj	300' N of BH-4	13-03-1993	380	275	HTW	5-6
34	BH-5 & HTW-3	Lakshmipur	-	13-03-1993	800	600	HTW-3	5-6
35	BH-6 & HTW-4	Lakshmipur	-	20-03-1993	980	680	HTW-4	3-4.5
36	BH-6	Lakshmipur	100' NW of BH-6	20-03-1993	1000	700	HTW	3-4.5
37	BH-7 & HTW-5	Begumganj	On site of HTW-5	20-03-1993	580	410	HTW	5-6
38	BH-7 & HTW-5	Begumganj	Adj.to BH-7	20-03-1993	1100	750	HTW	5-6
39	BH-7	Begumganj	Adj.to BH-7	20-03-1993	2800	2000	Khal Water	
40	BH-8	Begumganj	100' SE of BH-8	20-03-1993	4000	2800	HTW	5-6
41	BH-8	Begumganj	Adj.to BH-8	20-03-1993	7300	5100	Khal Water	
42	BH-9 & HTW-7	Lakshmipur	On site	21-03-1993	2800	1950		3-5m
43	BH-9	Lakshmipur	Adj.to BH-9	21-03-1993	1000	700		3-5
44	BH-10 & HTW-8	Lakshmipur	On site	21-03-1993	560	390		6-8
45	BH-10	Lakshmipur	100' SE of BH-10	21-03-1993	1500	1000		6-8
46	BH-11 & HTW-9	Lakshmipur	On site	21-03-1993	440	310		5-6
47	BH-12 & HTW-10	Lakshmipur	Adj.to BH-12	21-03-1993	1000	700		?

TABLE C.III.2

Grain Size Analysis of Samples Collected from
Exploratory Noakhali North Area

Sample No.	% sand	% of silt	% of clay	Total
2A	0.667	77.56	21.776	
2B	0.667	69.720	29.613	
3C	6.87	89.51	3.62	
4C	6.48	84.09	9.43	
4D	3.89	86.16	9.95	
5C	6.89	76.29	16.82	
5D	82.10	14.81	3.09	
6D	50.20	44.55	5.25	
6F	37.0	55.01	7.99	
9A	92.06	5.29	2.65	
10A	42.08	49.05	8.87	
10F	92.22	4.66	3.12	
11B	71.87	23.55	4.58	
12A	0.16	85.95	13.89	
12C	24.05	58.62	17.33	

TABLE C.III.3

Chemical Analysis of Soil Samples Collected from Exploratory Boreholes in the Noakhali North Project Area

No of Samples	pH	Ec us/cm	% organic carbon	% organic matter	Phosphorus PPM
BH-2A	7.55	710	0.5780	0.9964	570
BH-2B	7.66	810	0.5866	1.0112	630
BH-3C	7.62	480	0.5176	0.8923	570
BH-4C	7.42	740	0.6039	1.0411	600
BH-4D	7.57	620	0.3105	0.5353	530
BH-5C	7.00	280	0.3278	0.5651	530
BH-5D	7.33	120	0.0690	0.1189	660
BH-6D	7.26	270	0.2760	0.4758	650
BH-6F	7.22	260	0.3019	0.5204	700
HTW-9A	7.21	100	0.0862	0.1486	950
BH-10A	7.27	260	0.2847	0.4908	630
BH-10F	7.37	240	0.2502	0.4313	810
BH-11B	7.35	160	0.1294	0.2230	650
BH-12A	7.60	270	0.3019	0.5204	680
BH-12C	7.50	370	0.3537	0.6097	650