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CONTENTS

SECTION E : CONCLUSIONS AND RECOMMENDATIONS

TABLES

Section B - Regional Assessment

Section C - Sub-Regional Model

Section C - Sub-Regional Model

Section D - Gaibandha Model

FIGURES (Following each chapter)

Section A - General

Section B - Regional Assessment

Section C - Sub-Regional Model

Section D - Gaibandha Model

EXECUTIVE SUMMARY

SECTION A : GENERAL

0.1 The report is divided into five Sections as follows:

Section A	:	Gives an introduction to the hydraulic studies and the methodologies adopted in carrying out the work.
Section B	:	Gives a hydrological and morphological assessment of the North West region with particular emphasis on areas which are not included in the hydraulic modelling areas.
Section C	:	Presents the development and calibration of a sub-regional model covering the Lower Atrai and Middle/Lower Bangali river basins. Included is the application of the model in simulating present conditions and future situations, including development scenarios. Morphological assessments are also presented.
Section D	:	Presents the development and calibration of a model of the Priority Project area, Gaibandha. The application of this model to investigate a wide range of development scenarios is described and Morphological assessments of the preferred options presented
Section E	:	Conclusions and recommendations are given in this section.

0.2 Hydraulic models were developed for priority areas in the region. The sub-regional model covered the Lower Atrai, Lower/Middle Bangali basins; this area suffers the most severe flooding in the region and has a particularly complex hydraulic characteristics. A model was also developed of the Gaibanda Improvement Project area. A third model was also developed for the Bangali Floodway, a version of the shortened interceptor.

In modelled areas the FAP-25 guidelines were followed . In non-modelled areas alternative approaches were undertaken based on discharge assessments from observations or the NAM rainfall-runoff model.

SECTION B : REGIONAL ASSESSMENT

0.3 The region is bounded by the Jamuna (Brahmaputra) to the east and the Ganges to the south. These two rivers, into which the entire area drains play a dominant role in constraining its drainage. Despite the construction of flood embankments the region still suffers flooding from the major rivers due to regular breaching of the embankments. Backwater influence from the Brahmaputra plays a dominant role in determining the flooding regime in the lower prts of the region. Levels in the external rivers are often higher than those in the internal rivers thereby restricting drainage from the area for long periods. The rivers of the region are heavily meandering and have limited capacity for passing flood discharges.

0.4 The rivers in the North West region are currently not truly in equilibrium and modest changes

in their dimensions and plan shape are discernable from year to year. Ongoing and new projects will induce morphological responses and the rivers will react to the changes imposed. The reactions could take the form of aggradation, degradation, changes in size or changes in plan shape. A full analysis of river morphology as affected by ongoing and new projects has not been possible during the North West Regional Study. However, an indication is given of the time which could elapse before re-adjustment is achieved and what the nature of that re-adjustment is likely to be.

SECTION C : SUB-REGIONAL MODEL

0.5 A model of the Lower Atrai and Middle/Lower Bangali river basins (sub-regional model) was developed in close co-operation with the SWMC. The model was calibrated for the 1990 and 1991 flood seasons and verified for the five year period 1985-89. The calibration results were, in general, within the guidelines given by the Flood Action Plan Model Coordinating Committee (FAPMCC) for pre-feasibility modelling; peak water levels are matched to within 0.5m and peak discharges within 25 %.

0.6 A suite of post-processing software was developed to enable the hydraulic model results to be used in a much wider context than purely predicting levels and discharges in the main river and drainage system. The suite of programs were set-up to calculate water phases, flood phases, cropping patterns, and potential fisheries areas. The approach developed was applicable to all project areas covered by the hydraulic models and could also be applied in non-modelled areas where a more simplified drainage analysis had been carried out.

0.7 A major external feature of the North West region is the Brahmaputra Right Embankment. At present the BRE is repeatedly breached and this has a significant impact on flooding in the region. For the purposes of the NWRS it was assumed that the BRE would be effectively sealed. Model simulations indicated that sealing of the BRE would have a significant impact on flood levels and discharges in the Middle Bangali basin; flood levels are significantly reduced to such an extent that it would almost elliminate flooding as a major restriction on agriculture.

0.8 A 25 year simulation of the future Without Project project conditions was undertaken. This assumed that on-going or near completion internal developments would go ahead to completion; such as Naogaon Polder and the Barnai project.

Model simulations showed that completion of the Naogaon would have little impact on peak water levels in the Atrai river. On the other hand, the completion of Barnai Project may cause a substantial rise in levels along the Shib-Barnai thereby worsening the flooding and drainage situation on the western embankment of Chalan Beel Polder D; which, even under present river levels, is subject to regular public cutting.

The Without Project simulation formed the baseline conditions against which proposed project developments or scenarios could be assessed. The Future Without conditions showed a level of flooding close to that for present conditions apart from along the Shib-Barnai (see above) and in the Middle Bangali, where the sealing of the BRE has had a significant impact.

0.9 The Green River concept for the Lower Atrai basin was proposed to attain a more natural drainage conditions; similar to those that occured prior to embanking and empoldering. In

addition, partial protection is provided some of the lower lying areas; designed to prevent damage to crops due to rapid rises in water level. Results of model simulations for variations on this concept showed that benefits to the flooding regime could be achieved by having partially protected areas on the low land and CFD measures in the upper reaches.

In the middle Karatoya, CFD measures were investigated but these resulted in an increase in discharge and water levels along the Bangali river thereby worsening the flooding situation in this latter area. Relief could be gained in Middle Bangali by the construction of a new outfall to the Brahmaputra; the Bangali Floodway. Hydraulically the Bangali floodway is feasible and it was shown to have a beneficial hydraulic impact but these are not the only criteria on which the Bangali floodway should be assessed.

0.10 A 25 year With project simulation undertaken based on the Green River concept but with a higher level of partial protection than had been assessed in the option simulations. The partial protection level was set such that it protected the low lying areas up to the second decad in July; giving protection to the TDW aman crop.

Whilst this scenario showed significant benefits, in comparison with the Without Project situation, it does also have disbenefits in that the high level of partial protection is achieved at the expense of raising peak levels in the Atrai river, and its tributaries and distributaries.

SECTION D : GAIBANDHA MODEL

0.11 A model of the GIP study area was developed and calibrated for the 1990 and 1991 flood seasons and verified for the five year period 1985-89. The model includes all the major rivers in the area and also includes a flood cell representation of the area internal to the GIP area.

0.12 A 25 year Without Project simulation was carried out to form a baseline against which varios design options and scenarios could be measured.

0.13 Thirteen initial options were conceived for the GIP area which considered structural measures such as sealing the Teesta Right Embankment (TRE), extensions of the Ghagot left embankment, a Ghagot right embankment, removal of the Manas regulator, provision for new regulators, drainage improvements and compartmentalisation.

The findings of these simulations showed that the most beneficial impact on flooding in the area would come from sealing the TRE.

0.13 Three refined design options were brought forward for futher study. The first considered the removal of current Manas regulator. Backwater embankment to prevent spillage on the Ghagot right bank when Brahmaputra levels are high. Sealing of the TRE upstream and downstream of Kaunia. Extension of the Ghagot left embankment from Bamandanga to Jafarganj. Regulator at the tail of the Manas and head of the Alai Nadi. The second was as above but included compartmentalisation within the GIP area, and the final option was without compartmentalisation and was with the New Manas regulator removed.

Of the three options the compartmentalised option was found to give the greatest benfits and this was carried forward as the With Project formulation.

0.14 In comparison with the Without Project simulation the proposed developments result in a significant improvement in the situation in the southern parts of the GIP area with an significant increase in the percentage of F0+F1 land in this area. Elsewhere in the GIP area the proposed developments have had a limited impact on the flood regime although the reduction in losses due to crop damage from spilling from the rivers is likely to be high.

SECTION E : CONCLUSIONS AND RECOMMENDATIONS

0.15 The primary conclusions to be drawn from the Hydraulic Studies were :

- the completion of the Barnai project will raise river levels in the Shib-Barnai river and the lower reaches of the Fikirni river.

- full confinement in the Lower Atrai is not a feasible development option.

- the Green River concept of the Lower Atrai basin is designed to bring the river system closer to its original drainage conditions and hydraulic characteristics; prior to the development of the area by empoldering and embanking.

- the concept of partial protection in the low lying areas adjacent to the Atrai and CFD measures in the upper reaches were found to give overall benefits in terms of increasing the shifts in flood phase. Depending on the level of partial protection, however, they can result in a rise in water level in the middle reaches of the Lower Atrai.

- the cause of the flooding problems in the Middle Bangali basin derives from breaches in the BRE. If these breaches can be prevented flooding will not restrict development in the Middle Bangali basin. If spillage from the Jamuna through breaches cannot be prevented the problems of the Middle Bangali must be reassessed.

- CFD developments in the Upper Karatoya basin will result in increases in discharge in the Bangali river and produce a worsening of the flooding situation. The construction of a new outfall to the Brahmaputra, the Bangali Floodway, could alleviate these problems.

- the impact of the sealing the Teesta right embankment upstream of Kaunia is to lead to a marked reduction in peak flows in the Ghagot and a reduction in the peak water levels, by more than 1 m. Sealing the Teesta downstream of Kaunia will reduce inflows to this area and help to alleviate some of the drainage congestion in the southern part of the area.

- compartmentalisation redistributes the volumes of flood waters in the GIP area and has an overall beneficial impact on the flood regime. In particular, it was found that there were substantial benefits in the southern part of the area.

- the constructing of a regulator at the head of the Alai Nadi river results in a decrease in peak water levels of more than 1 m in the upper reaches of this river and will also

help to reduce the flood flows which enter the Bangali basin further downstream.

- the opening of internal rivers to the Brahmaputra creates potential route for the Brahmaputra to flow into region and great care must be taken to reduce this risk to a minimum.

The following recommendations are made for any future studies which may be undertaken :

- further, detailed, hydrodynamic modelling of project areas should be carried out at the feasibility stage of all projects. The boundary conditions for these models should be provided by the most appropriate hydrodynamic model of the area which is available at the time.

- 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.

- if further detailed design studies are carried out physical models should be used to investigate the risk posed by opening internal rivers to the Brahmaputra.

- more detailed analyses should be carried out, at the design stage, to quantify, as far as possible, the morphological changes which will be induced by projects in the North West region.

- where complex structures are being proposed, such as submersible embankments, further research into the hydraulics of these structures and their representation in hydrodynamic models is required.

SECTION A

GENERAL

CHAPTER 1

INTRODUCTION

1.1 Objectives

The hydraulic studies have a central role in the assessment of the impact of the river and drainage engineering proposals in the development of the regional plan for the North West region of Bangladesh. These studies involve the use of a computer-based hydraulic model, MIKE11, and an assessment of the morphological effects of the flood control and drainage proposals. 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 hydraulic studies are laid down in the Terms of Reference (ToR) and may be summarised as follows:

- assess current flooding and drainage problems in the North West region;
- predict the hydraulic performance of flood control and drainage (FCD) works in the North West region and assist with their design;
- demonstrate the effectiveness of the proposed designs for a range of design flow conditions;
- assess the downstream impacts of the FCD works; and
- assess the long term effectiveness of the proposed FCD measures by considering channel stability and morphological response of the river system.

Within the ToR several specific watercourses and developments are mentioned. These and others are taken up in the text of the main report and the discussion below.

1.2 Scope of report

This report covers the hydraulic studies which have been carried out in the second phase of the North West Regional Study, that is, the hydraulic studies since the submission of the Interim Report. A description is given of the methodology used in these studies. The development and calibration of the hydraulic models are described. The application of these models to investigate existing conditions and future conditions with imposed developments is presented. Morphological problems associated with the rivers of the North West Region are also addressed.

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.

1.3 Report Structure

The report is divided into five Sections as follows:

Section A	:	Gives an introduction to the hydraulic studies and the methodologies adopted in carrying out the work.
Section B	:	Gives a hydrological and morphological assessment of the North West region with particular emphasis on areas which are not included in the hydraulic modelling areas.
Section C	:	Presents the development and calibration of a sub-regional model covering the Lower Atrai and Middle/Lower Bangali river basins. Included is the application of the model in simulating present conditions and future situations, including development scenarios. Morphological assessments are also presented.
Section D	:	Presents the development and calibration of a model of the Priority Project area, Gaibandha. The application of this model to investigate a wide range of development scenarios is described and morphological assessments of the preferred options presented
Section E	:	Conclusions and recommendations are given in this section.

CHAPTER 2

METHODOLOGY

2.1 Introduction

2.1.1 General approach

For the basis of overall Regional Planning, the North West regional was divided into 15 planning units, see Figure 2.1. For the hydraulic studies, the region can also be broken down into areas for which hydraulic models were developed to assist in the planning and those that were not. These areas are shown in Figure 2.2

The methodologies adopted in the hydraulic studies can be broken down depending on the 'tools' that were available to carryout the studies. Essentially, there were two clear distinctions which divide between areas of the North West region which were covered by a hydraulic model and those that were not.

In the areas where models were developed, model simulations and output were used extensively in the assessment of development options and scenarios. In other parts of the region the hydraulic problems were assessed using non-modelling approaches. Discharge assessment in these areas was based on observations and design discharges based on rainfall-runoff estimations from the NAM model.

The general methodologies adopted for the hydraulic studies in the North West region are described in this Chapter. Details of the application of these methodologies are given in appropriate Chapters of the report.

2.1.2 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 (Ref. 2.1) 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. 2.2)

The NAM model used in this phase of the study was that developed and calibrated by the SWMC with minimum changes.

The application of NAM was divided into two stages:

<u>Stage 1</u> : The NAM model, for the entire North West region, was calibrated for the period 1985 - 1991. Calibration was mainly based on simulating variations in groundwater levels but also included comparisons between simulated and observed discharges and accumulated discharges at 14 observation stations.

<u>Stage 2</u> : Following calibration, a 25 year simulation for the period from 1965 to 1989 was carried out.

In the modelled areas, NAM was used to define runoff inputs along river reaches of the hydrodynamic models or to provide boundary condition discharges at locations where gauged discharges were not available. Outside model areas, the NAM discharges enable estimates of the river channel discharges to be made for individual years or for a specific return period. Further details of NAM together with its application to the North West region are given in the Hydrology Annexe.

2.2 Methodologies applied in modelled areas

2.2.1 Development of models

Role of the Surface Water Modelling Centre

The Surface Water Modelling Centre (SWMC) was established in the mid 1980's with assistance from the Danish Hydraulics Institute (DHI), initially with funding from UNDP and later from DANIDA. It is under the ultimate control of the Ministry of Irrigation Water Development and Flood Control (MIWDFC) in Dhaka. DHI has provided software, training and expatriate staffing at SWMC under these contracts. The SWMC are now engaged on setting up models of the water movement in each region of the country based on the MIKE11 modelling system. SWMC has a team of locally recruited engineers working on each regional model with overall direction and support from specialists from DHI. The SWMC started developing the North West Regional Model (NWRM) as a series of sub-models in early 1990 with a planned work programme lasting over two years before the completion of the verified model of the region.

During the first phase of the NWRS a pilot model of the entire North West region was used to assist in the hydraulic studies. It was stressed during the reporting of this first phase that the pilot model was known to have limitations and that an improved model should be used during the second phase of the hydraulic studies. At the commencement of phase two of the study, the full model for the whole North West region was not available and it was evident that it would not be available in sufficient time for use in the study. In view of this, it was decided to concentrate modelling efforts in the areas which would most benefit the study as a whole.

The modelling staff of the FAP-2 team have worked closely with the SWMC throughout the studies. In particular, the development of the sub-regional model was carried out jointly with the SWMC. Final calibration of this model was completed by FAP-2 modelling staff. The Gaibandha Improvement Project (GIP) model was developed by the FAP-2 modelling staff with data, support and advice being supplied by the SWMC.

Modelled areas

Hydraulic models were developed for the priority areas in the region. Firstly, a sub-regional model was developed covering the Lower Atrai, Lower/Middle Bangali basins. This area is the most severely flood affected area in the region and has the most complex hydraulic regime due to its outfall to the major rivers, extensive runoff from the northern and middle reaches of the region, and major spillage due to breaches in the Brahmaputra Right Embankment (BRE). A second model was developed of the Gaibandha Improvement Project (GIP) area which formed the Priority Project area of the region. Finally, a model of the Bangali Floodway was also developed. This was a variation of a shortened Interceptor Drain which was initially investigated during the Interim studies.

The hydrodynamic model

The simulation of flood season water levels and flow rates in the river system is carried out with the MIKE11-HD hydrodynamic model (called hereafter MIKE11). This model is well tried on rivers in Bangladesh through the efforts of the SWMC. 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. 2.2). Like all mathematical models it is based on a variety of assumptions and numerical approximations which determine its scope of application; these and the implications for the study are described separately (Ref. 2.3).

The development of all the regional models, by the SWMC, is following a programme in which first of all 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 at least two flood seasons data, the full model achieves the status of the verified model.

2.2.2 Application of the hydraulic models

Guidance from FAP 25

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 involved long term simulations of regional 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 regional flood alleviation scheme(s).

- combination of various options to reach the final plan may be studied on the basis of simulations for a reduced number selected flood seasons, the selections being based on the analysis of the 25 year run.

- sensitivity analysis of ultimately adopted regional 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.

Approach adopted

In keeping with the FAP-25 guidelines, the application of each of the hydrodynamic models was divided into six stages,

Stage 1 : Calibration and validation. The models were calibrated against observed water level and discharge data at gauging stations. The calibration concentrated on simulating water level variations during the monsoon season. Comparison with observed discharges was used to ensure that flow splits between the major river channels were correctly simulated. The models were validated over a five year period to ensure that reasonable variations in water level and discharge were being produced.

Stage 2 : Simulation to investigate impact of external developments. Once the models had been calibrated and validated a simulation to investigate the impact of external developments was carried out. This simulation assumed no developments in the modelled area together with certain, assumed, external developments, such as sealing the BRE. The external developments to be simulated were agreed following discussions with FPCO and FAP-25. This 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 with the existing developments in the modelled area. The objective of this simulation was not to simulate observed water level and discharge variations over the 25 year period from 1965 to 1989.

Stage 3 : Without Project simulation. This simulation includes the known internal developments in the modelled area together with the external developments simulated in Stage 2. 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 with known future developments in the modelled area. This information would form the baseline data for investigating the impact of proposed developments in the modelled areas. The objective of the Without Project simulation was not to simulated observed water level and discharge variations over the 25 year period from 1965 to 1989.

Stage 4 : Once the Without Project simulation had been completed the results were used to select design years for investigating proposed developments. Design years were selected to give a range of return period events over the whole of the modelled area. The models were run for the design years to investigate the impact of design options or scenarios (set of options). This was done by comparing the results of the design option simulations, which were run for 10 years, with the results of the Without Project simulation. The design options, or scenarios, only looked at developments within the modelled area. For the design option simulations the same known internal developments and external developments as for the Without Project simulation were assumed.

Stage 5 : 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.

State 6 : Sensitivity analysis to investigate the impact of changed external conditions were carried out in this final stage.

2.2.3 Analysis of hydraulic model results

MIKE11 produces water level and discharge hydrographs at all model nodes at a preselected time interval. Purpose written software was developed to analyse this information to produce return period levels and discharges for differing time durations; 1-day, 3-day, 10-day, etc. intervals. This information was extensively used by the engineering team to investigate the impact proposed developments had on the level and timing of flood events and to define engineering work design levels.

In addition, the results of the model simulations were analysed on a 10 day (decade) basis to give minimum, mean and maximum water levels for each decade. Return period water levels have been calculated for 2, 5, 10, 20, 50 and 100 years. This output can be obtained for any cross-section location, or water level node, within the modelled area.

2.2.4 Morphological analysis

Sediment transport calculations

One approach to morphological analysis is to carry out calculations of sediment transport at various points throughout the river system. By comparing the quantity of sediment transported at adjacent points conclusions can be drawn about the quantity of sediment that may be eroded or deposited. The results can also be used in a comparative way to determine the impact of proposed schemes.

Morphological river models

The comparison of sediment transport rates at adjacent points forms the basis for all computer morphological models. Such models, however, require some form of assumption about the shape of the channel and how it might change in time. While morphological models can provide information on locations and rates of erosion or deposition and hence changes in bed level, regime analysis still provides the most reliable way of predicting changes in channel width and plan form.

A morphological module is currently being developed for MIKE11 to predict long-term changes in bed level. Unfortunately at the time of the present study this module was not available. A sediment transport module, however was available. This module uses sediment transport formulae together with flow data to calculate the quantity of sediment that passes each cross-section within the model. The impact that this has on bed levels had to be determined separately and the feedback that this change in bed level has on the flow could not be determined. The sediment transport module could only be applied to reaches were MIKE11 flow results were available. The Surface Water Modelling Centre is currently working on applying the sediment transport module to the results of their simulations of the North West region. Unfortunately their results were not available in time for this study.

The use of alternative morphological models was not possible within the time and financial constraints of the NWRS.

Regime theory

Regime theory considers the problem of determining the cross-sectional geometry and slope of a stable alluvial channel flowing through an alluvium. The theory was originally developed at the end of the nineteenth century by engineers working in the Indo-Gangetic plain for the design of irrigation canals. These are normally characterised by fairly constant discharges. Initially the approach was empirical. Observed data from stable canals were collected and used to derive relationships for such variables as velocity and depth of flow. The range of applicability of such an empirical theory, however, is governed by the range of the data on which it was developed.

Although the theory was originally developed for irrigation canals, it was recognised more recently that the theory could apply also to natural rivers. In regime theory, the discharge is an important parameter in determining the channel dimensions and slope. Whilst this is normally well defined in the case of an irrigation canal, in a river there is normally a much larger range of discharges. Research has shown that the theory can be applied to rivers if the canal discharge is replaced by a dominant discharge which is representative of the natural variations in the river. Much work has been done on the definition of this dominant discharge and satisfactory results can be obtained by using a discharge with a specific frequency.

More recently the foundations of regime theory have been placed on a firmer footing by the development of rational regime theories based on equations describing sediment transport, alluvial friction and channel width processes. The advantage of this rational approach is that it does not suffer from the same restrictions on the range of applicability that the empirical theories do. White, Betters and Paris (Ref. 2.4) developed a rational regime theory based on the Ackers and White (Ref. 2.5) sediment transport relationship and the White, Paris and Betters method (Ref. 2.6) to calculate alluvial friction. This was combined with the extremal hypothesis that the channel width adjusts to maximise the transport rate. It was demonstrated that this regime theory gave good agreement with observations for a wide range of conditions.

It has also been shown that the slope predictions of regime theory can also be used to provide information on the plan form of rivers and the impact of changes on the plan form.

Impact of diverting flows from one internal river to another

Water level and bed level data was examined to determine whether there was evidence for long-term change under existing conditions. From the hydrological data the dominant discharge was determined and the regime width, depth and slope were determined. These were compared with the observed values of these variables. An estimate was then made of the revised, with-scheme dominant discharge. Revised regime conditions were then determined and any change in slope was interpreted in terms of its impact on plan form.

2.2.5 Assessment of morphological impacts

Impact on internal rivers of preventing spillage from major rivers

Firstly, the existing situation was studied in both the major river and the receiving river:

Major river : The sediment concentrations were determined either from observations or by calculation.

Receiving river : Water level and bed level data was examined to determine whether there was evidence for long-term change under existing conditions. Results from the sediment transport module of MIKE11 were examined to determine if erosion or deposition was taking place along the river under existing conditions. From the hydrological analysis the dominant discharge was determined and the regime width, depth and slope were determined. These were compared with the corresponding observed values.

Secondly, conditions under the proposed scheme were then investigated:

Receiving river : A revised estimate of the dominant discharge was determined from the MIKE11 results. The revised sediment load in the river was determined taking into account the cessation of the supply of sediment from major river. The regime width depth and slope were then determined. Any change in regime slope was interpreted in terms of its impact on plan form.

Impact of embanking

The results from the sediment transport module of MIKE-11 for hydraulic model runs which included with and without embanking were interpreted to give an indication of the impact of embanking on the channel morphology.

2.3 Methodologies applied in non-modelled areas

2.3.1 Design discharge assessment

Design discharges at key points in the region were estimated using the runoff results from the NAM model. The details of this analysis together with the results are given in the Hydrology Annexe.

The standard design condition for engineering considerations was taken as the 20-year return period flows and levels for the internal CFD embankments with 100 year return period levels associated with protection levels on the major rivers and for their associated backwater levees. Design levels for partial protection embankments varied depending on the level of protection being investigated.

To obtain estimates of these flood discharges, frequency analyses have been undertaken using the Gumbel Distribution on the annual peak flows calculated by the NAM model because the NAM series is generally longer and/or more complete than observed flows. This was preceded by cross checks between the model results and observed data.

2.3.2 Drainage analysis

Drainage analysis involves the routing of drainage across an area to the drainage basin outlet. Rainfall information was used to provide the input to the system. Where possible the water level control at the drainage basin outlet was taken from the hydraulic models; in other areas observed water levels were used. Given the rainfall inputs and the water levels at the outlet the drainage and ponding in an area can be assessed and water levels estimated.

2.3.3 Morphological analysis

Regime theory

Regime theory, which is described in Section 2.2, was also used for morphological analysis in the non-modelled areas.

Impact of diverting flows from one internal river to another

Water level and bed level data was examined to determine whether there was evidence for long-term change under existing conditions. From the hydrological data the dominant discharge was determined and the regime width, depth and slope were determined. These were compared with the observed values of these variables. An estimate was then made of the revised, with-scheme dominant discharge. Revised regime conditions were then determined and any change in slope was interpreted in terms of its impact on plan form.

The above analysis was supplemented by consideration of the results from the sediment transport module for both with and without the scheme.

2.4 Post-processing

2.4.1 Flood phase analysis

Flood levels on the flood plains can be represented by water levels at one or more model modes. Utilising these water levels and area/elevation relationships for the flood plains allows the flood/water phases to be calculated on the flood plains. For a particular project area the sum of the flood/water phases of the sub-areas which make up its full area gives the total flood/water phases for the project area as a whole.

Observed flood phase figures are not quoted with respect to time whereas the model output and flood levels at each node are produced as a time series. Post-processing software was developed to calculate water phases (time dependent) at the following depth categories; 0-0.3, 0.3-0.7, 0.7-1.0, 1.0-1.5, 1.5-3.0 and > 3.0 m. These can easily be converted into the more widely used flood phase categories (see Chapter 6).

2.4.2 Cropping pattern analysis

Based on the water phase results described above software was written to generate potential cropping patterns. This software was based on the limitations flooding causes to crop growth; these limitations were defined by the project agriculturist. Once it had been confirmed that the generated cropping patterns agreed reasonably with observations this analysis was used to investigate how the cropping patterns in the project areas would be affected by the proposed developments.

2.4.3 Fisheries analysis

Based on the water phase results, software was written to generate potential fisheries areas. This software was based on the flooding requirements of fish; these requirements were defined by the project fisheries expert. This analysis was used to investigate how the fisheries areas in the project areas would be affected by the proposed developments.

Figure 2.1
NWRS PLANNING UNITS

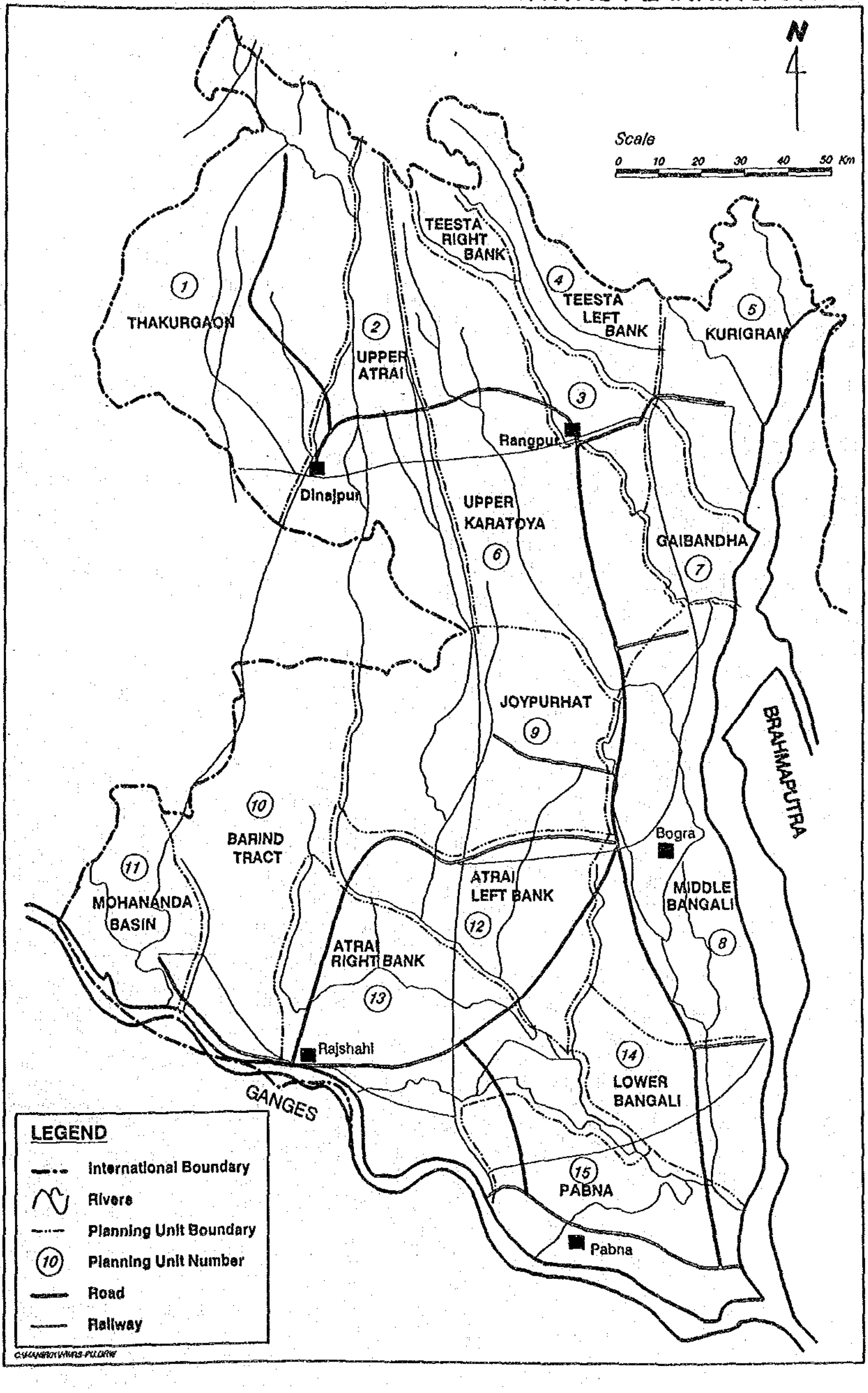
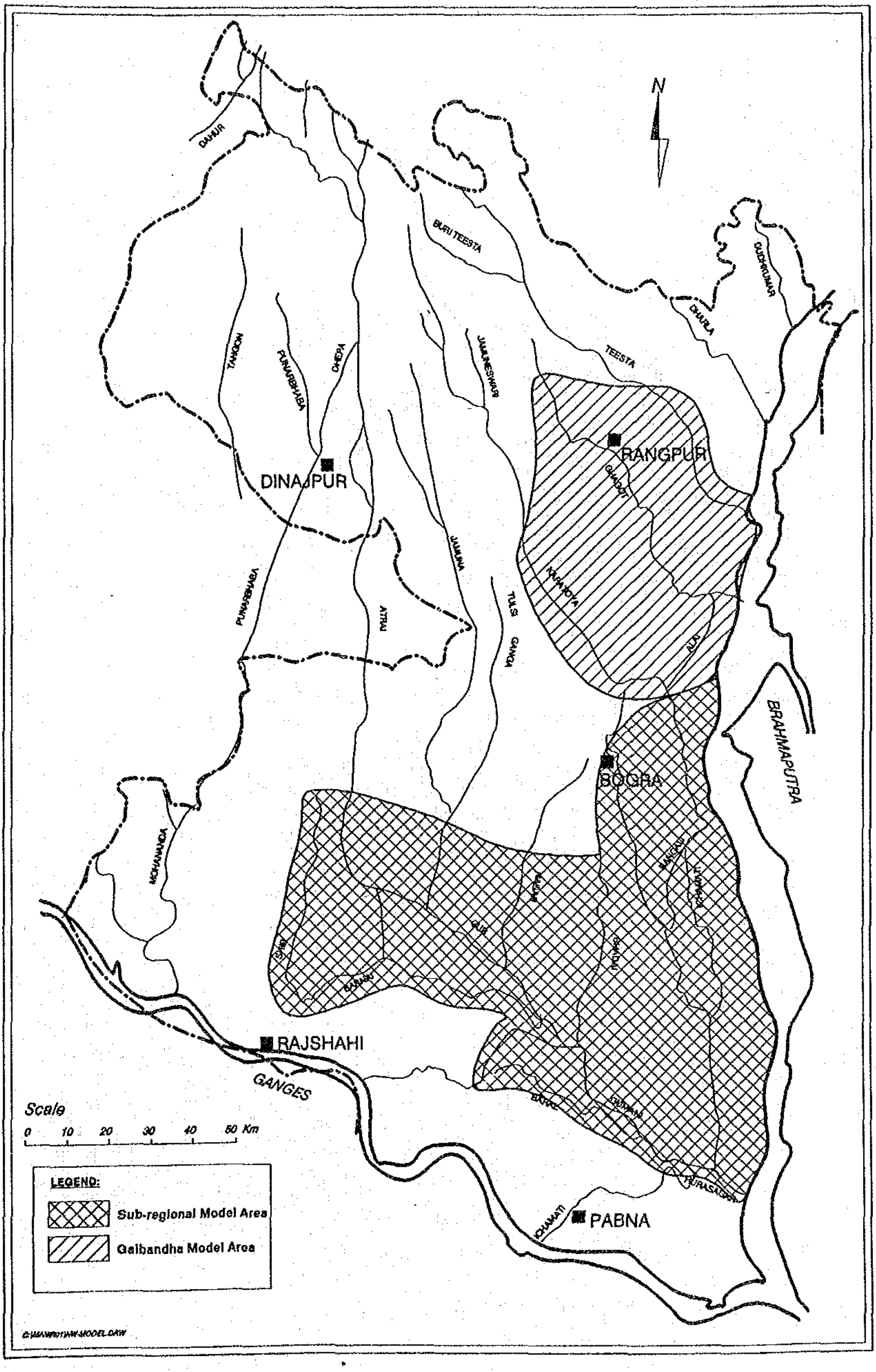


Figure 2.2
Modelled Area



SECTION B

REGIONAL ASSESSMENT

CHAPTER 3

HYDROLOGICAL ASSESSMENT

3.1 Introduction

The North West Region of Bangladesh lies between latitudes 23°50' and 26°40' N, i.e. just outside the tropics. A brief description of the hydrology of the region is given in this Chapter; further details can be found in the Hydrology Annexe.

The region has a typical monsoon climate. With the exception of rainfall, the main climatic parameters generally vary relatively little across the region.

Average annual rainfall ranges from less than 1500 mm to just over 3000 mm, with a regional average of about 1900 mm. Well over 80% of the annual rainfall occurs during the five month monsoon season between May and September, and this rises to an average of 97% for the seven months from April to October.

In addition to the climate, the hydrology of the area is influenced by the topography and the drainage network, and in particular by the major rivers which bound it. The characteristic topographical feature of the region is its flatness. Elevations vary from less than 10 m above sea level in the south east corner to just under 100 m in the far north west; most of the region lies below 30 masl. In the southern part 1m contours are typically up to 5 km apart, and even in the north west of the region average slopes rarely exceed 1 in 1000. As a consequence of the low gradients, the rivers and drainage channels within the region are generally heavily meandered and braided, and capacity for rapidly passing substantial flood peaks is very limited.

The region is bounded on its lower sides (south and east) by two of the world's great rivers, the Ganges and Brahmaputra; the latter is known as the Jamuna within Bangladesh. These rivers, which join to form the Padma at the south east corner of the region, drain a total area of nearly 1.5 million km^2, of which only about 7% lies within Bangladesh. The catchments cover some of the wettest areas in the world, together with the major part of the Himalayan mountains. Snowmelt from the Himalayas combines with runoff from the monsoon rains to produce very large flood peaks on the lower reaches of both rivers. Besides the potential for spillage from breaches of the embankments, high levels on the main rivers (particularly the Jamuna) make a significant contribution to flooding problems within the region because drainage from regional rivers is severely impeded.

3.2 Climate

There are two main seasons, separated by transition seasons. The monsoon season lasts from May/June until September and shows the typical monsoon characteristics of heavy rain and very high humidity. The dry season from November to February is sunny and relatively cool, with only occasional scattered showers. The transition from monsoon to dry seasons in October-November is relatively smooth, with declining temperature, humidity and storm frequency. The start of the transition period at the end of the dry season is also smooth, but the pre-monsoon period in April and May has somewhat unstable atmospheric conditions. This period is very hot and is characterized by thunderstorms and squalls, known as Nor'westers. This is also the peak season for cyclones in the Bay of Bengal which sometimes have catastrophic consequences in the coastal regions of Bangladesh. Cyclones themselves do not reach as far inland as the North West Region, but the area may be affected by associated storms.

Humidity levels are consistently very high during the monsoon season, and only drop significantly for a relatively short period at the end of the dry season. Sunshine levels are of course low during the monsoon, but from November to May are consistently high. Wind speeds are at a maximum in the early part of the monsoon, but drop substantially by the beginning of the dry season.

Evapotranspiration reaches a maximum in April when temperature, sunshine and wind are all at or close to their maxima for the year, while humidity is a little below its peak. Evapotranspiration drops substantially thereafter as the humidity reaches very high levels and the other significant parameters all also become less favourable for evapotranspiration. Evapotranspiration is exceeded by average rainfall from May to October, while for the remaining months it is substantially higher than rainfall.

3.3 Rainfall

The North West Region has an average annual rainfall of a little over 1900 mm; this is significantly below the estimated average for the whole of Bangladesh of 2320 mm (MPO, Technical Report Nr. 10, 1985). The driest area is in the south-west of the region where the annual rainfall of around 1400 mm is the lowest in the country. The highest rainfall is in the far north of the region, where annual rainfall averages around 3000 mm; however, this is much lower than in parts of the North East region of Bangladesh where the annual average reaches nearly 6000 mm.

Annual rainfall shows considerable variability from one year to another as well as between different parts of the region in a single year. Over the period from 1962 to 1990 the regional average annual rainfall ranged from 1350 mm in 1972/73 to 2600 mm in 1987/88. The extreme annual rainfall totals at individual stations in this period were 554 mm at Bagdogra in 1962/63 and 5633 mm at Bhitargarh in 1974/75. There is some suggestion of a trend of increasing annual rainfall since 1962, but the available longer term records show that the variations in this period are of a similar magnitude to variations observed earlier in the century, so a continuation of the apparent recent trend cannot necessarily be expected.

Storm rainfalls can be very heavy in all parts of the region. At almost all of the stations daily falls of 200 mm have been recorded, with the absolute maximum being 485 mm at Rajshahi (which is one of the driest places on the basis of long-term average rainfall) in 1965. 10-day totals of 700 mm or more are not uncommon, with the most extreme recorded value being over 1100 mm at Kaunia in 1987. Whilst heavy 1-day rainfalls can occur right across the region, the highest 10-day rainfalls are not surprisingly concentrated in the wetter northern part of the region. It may also be noted that at more than one third of the rainfall stations in the region the highest recorded 10-day rainfall occurred in 1987, which has already been noted as the wettest recorded year over the region as a whole.

3.4 The River System

The region is bounded, and effectively defined, by the Jamuna (Brahmaputra) to the east and the Ganges to the south (Figure 3.1). These two rivers, into which the entire area drains, meet up at the south east corner of the region and play a dominant role in constraining its drainage. Before the construction of the confining embankments the Ganges and Jamuna rivers were major contributors to flooding in the region, and in more recent times they have also been so at times of breaches of the embankments. The major internal rivers are also shown in Figure 3.1.

Three large tributaries of the Jamuna, the Teesta, Dharla and Dudhkumar, pass through the north east corner of the region, and the Mohananda, a tributary of the Ganges, passes through the south west

corner. All other rivers in the region are connected to the Atrai-Karatoya-Bangali system which drains to the Jamuna through the Hurasagar at the south east corner of the region.

The Teesta, Dharla and Dudhkumar rivers originate in the Himalayas and Himalayan Piedmont Plains. Though they are large rivers they are relatively steep on entry from India into Bangladesh, and their floods can be flashy. On a number of occasions the Teesta has changed its course in the vicinity of its outwash fan.

The Mohananda river has a large catchment area in India to the west of the Barind Tract, but it is also fed by outflows from the north western corner of Bangladesh via the Tangon and Punarbhaba which pass through India before joining the Mohananda in the south west of the region.

The river Atrai rises in West Bengal to the north of Panchagarh. Its catchment area in India is fairly small, but it appears that it is subject to occasional spillage from the upper Teesta at times of exceptional flood flows. Together with the Tangon the Atrai drains the north west corner of the region. After passing southwards through Khansama, it bifurcates into the western Punarbhaba branch and the eastern Atrai branch, both of which pass through the Indian Barind enclave and return to Bangladesh further south. Subsequently the Atrai turns south eastward at Jotebazar and picks up various tributaries including the Little Jamuna, Nagor and Barnai before joining with the Bangali to become the Hurasagar which is the major outflow channel for the internal drainage of the region to the Jamuna.

The Karatoya rises as the Jamuneswari, which has only a very small contributing catchment in India. It also appears to be subject to occasional flood spillage from the Teesta. After flowing in a generally south or southeast direction the Jamuneswari becomes the Karatoya, and, having bifurcated at Chakrahimpur, its eastern main branch joins up south of Gaibandha with the Alai, part of the Ghagot system, a tributary flowing roughly parallel to the east. At times of low flow in the Jamuna, some of the Ghagot flow is discharged direct to the Jamuna via the Manos regulator. Further southwards, the Karatoya becomes the Bangali; channels bifurcate and rejoin at several places before joining the Atrai to form the Hurasagar.

In the south of the region the Baral joins the Ganges to the lower Atrai. Natural flows are from the Ganges inland, but these are now regulated by a structure at Charghat.

Within the region, the rivers in the north east corner have relatively steep gradients of 1 in 2000 or more, but in nearly all the remainder of the area river courses have very flat gradients of 1 in 5000 or less. The rivers are heavily meandering and have limited capacity for passing flood discharges. The system is exacerbated in the lower areas by the tendency of some channels to overflow towards others during flood periods. An additional factor of fundamental importance to the flooding problems in the southern part of the region is the fact that flood levels in the Ganges and the Jamuna are often equal to or higher than internal river levels for long periods. This means that drainage from the region can freely outfall to the main rivers for only relatively short periods at the beginning and end of the flood season. The great bulk of the internal drainage therefore ponds in the lower Atrai/Hurasagar/Bangali against the backwater effects from the Jamuna. Even in a relatively dry year such as 1992 extensive areas are flooded for long periods. Past attempts to reclaim land in this area by constructing polders has in some cases seriously confined flood drainage courses, with a consequent increase in typical flood levels in other places.

3.5 The Flooding Regime

Flooding and drainage problems in the region may be separated into a number of categories depending on their cause and location. The Master Plan Organisation (MPO) distinguishes between "areas normally flooded by major river spills" and "areas normally flooded by minor rivers"; the former naturally lie along the main river embankments and the latter cover most of the rest of the region. This correctly identifies the general locations of flooding, but in the North West Region it is appropriate to distinguish more precisely between different causes of flooding in the region because different modes of analysis and provision are likely to be required.

The first type of flooding in the region is due to breaches in the embankments of the major rivers - primarily the Jamuna, but also the Teesta and to a lesser extent the Ganges, Dharla and Dudhkumar. Flood damage is only partially related to the severity of the flood event because accidental or intentional breaches can occur with "normal" as well as extreme floods.

The second type of flooding is due to outfall constraints, primarily from the Hurasagar to the Jamuna. This comprises flooding in the lower Atrai and Karatoya-Bangali systems, and is predominantly caused by high stages in the Jamuna causing backing up of levels in the river system. The severity of flooding is also related to rainfall conditions within the region (and to a small extent cross-border flows on the minor rivers from India) because the total flow volume from the internal rivers must be stored until the levels in the Jamuna permit natural drainage via the Hurasagar. The severity of the flooding is therefore directly linked to the severity (i.e. return period) of the conditions both in the main rivers and in the region itself.

It is appropriate to make a distinction between a backwater effect and backflow; the latter refers to reverse flow, while the former is the backing up of water levels caused by high downstream water levels inhibiting drainage. It is not possible to precisely define the importance of high river flows from upstream and of backing up from high downstream levels because the two are closely interlinked, but the problems in the Atrai system are substantially due to backwater effects caused by high Jamuna levels, the effects of which may extend to Atrai Railway Bridge or beyond (i.e. well in excess of 100 km) in a high Jamuna flood. Actual reverse flow in the Hurasagar is very rare, and would only affect a short distance near to the outfall. The problems of drainage from the Hurasagar are considered in more detail in Chapter 7.

Similar problems occur on the Mohananda and associated river systems when localised storm runoff coincides with high stages in the Ganges which constrain outflow.

The third type of flooding is that caused by storm runoff in the upper catchments of the region. These problems are often very localised in nature and may best be alleviated by specific localised measures.

Although flooding problems have been separated into different categories there is obviously considerable overlap between them. Flooding in the lower Karatoya-Bangali basin, for example, may be predominantly caused by the lack of drainage to the Hurasagar, but it is also likely to be exacerbated by spills from the Jamuna further upstream.

The severity of flood problems can be critically influenced by the timing of the flood peaks on the two main rivers. In 1988, which was by far the most severe year on record for flooding in Bangladesh as a whole, the peaks of the Ganges and Jamuna were both very high and were almost coincident. Recession from flood levels was further restricted by the peaking a few days later of the Meghna, which combines with the other rivers before they outfall to the sea. Figure 3.2 gives an

indication of the flooded areas in Bangladesh in that year; note that this shows the areas still flooded two weeks or more after the peak of the flood. The extent of backing up of flood waters on the Atrai and Karatoya-Bangali systems is clearly shown. Parts of the centre and north of the region which escaped relatively unscathed in 1988 suffered greater flooding problems from more localised causes in 1991.

3.6 River Flows

Observed discharges

There are 57 river gauging stations in the region at which flows have been recorded; more than 30 of these are still active. The station locations are marked on Figure 3.3, with different symbols from stations at which only water level is measured. Monthly mean flows for selected gauging stations are shown in Table 3.1.

Discharge data at various gauging stations include some spillage from other rivers, including spillage from India. Discharge values are daily mean discharges which have been obtained by applying the rating curve to observed water levels at gauging stations. Observed water levels are subject to the occurrence of spillage in upstream reaches due to insufficient conveyance capacity of the rivers during large floods. In some years water levels were not observed or a rating curve was not prepared. This means that discharge data are lacking in some years at some stations.

Regional discharge assessment

In the North West Region, rainfall-runoff calculations were conducted for the period from 1965 to 1991 on a daily basis by the NAM hydrological model. The use and calibration of the NAM model is described in the Hydrology Annexe.

Design discharges at key points in the region were estimated using the runoff results from the NAM model. The details of this analysis together with the results are given in the Hydrology Annexe.

The standard flood level for engineering design considerations is the 20-year return period flood and obtain estimates of these flood discharges frequency analyses have been undertaken using the Gumbel Distribution on the annual peak flows calculated by the NAM model because the NAM series is generally longer and/or more complete than observed flows. This has been preceded by cross checks between the model results and observed data.

Table 3.1

Mean Monthly River Flows
(cumecs)

No	Station	River	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Year	Data Period
10	Simulbari	Bangali	9	39	150	356	371	363	279	67	41	29	19	14	145	1974–88
17.1	Baral R B	Baral	8	24	45	98	174	184	164	89	35	14	6	4	70	1964–87
62–1	Baratia	Deonai	2	6	38	127	89	85	50	9	5	4	3	2	35	1964–87
66	Ullapara	Karatoa	17	45	175	493	706	633	408	132	67	50	39	21	232	1964–89
76	Taluksimulbari	Dharla	81	177	455	926	646	686	463	189	125	99	80	66	333	1968–80
77	Kurigram	Dharla	92	194	741	1440	1340	1170	585	223	155	121	90	81	519	1973–88
81	Pateswari	Dudhkumar	115	246	656	1380	1390	1100	651	243	166	131	105	91	523	1968–89
83.1	Naldanga R B	Barnai	3	7	34	76	98	100	97	65	27	9	5	4	44	1965–88
96a	Jafarganj	Ghahgot	0	2	11	33	26	23	16	2	1	1	1	0	10	1964–80
133	Naogaon	L Jamuna	1	10	74	179	182	180	122	24	9	4	2	1	66	1973–89
140	Panchagarh	Karatoa	5	7	30	137	134	102	41	15	10	8	7	5	42	1964–89
145	Mohadevpur	Atrai	9	27	122	431	359	353	165	39	25	20	16	13	132	1973–89
147	Atrai R B	Atrai	9	25	102	312	401	381	297	126	51	29	17	11	147	1964–89
211.	Ch. Nawabganj	Mohananda	31	49	289	1027	1687	1793	1365	436	134	80	55	43	582	1981–88
238	Rohanpur	Punarbhaba	6	11	41	186	385	416	266	55	23	17	13	7	119	1966–89
261	Nowhata	Sib	0	2	12	43	65	60	58	34	12	2	1	1	24	1973–89
285	Thakurgaon	Tangon	2	3	14	57	52	43	18	5	4	3	3	2	17	1964–88
294	Kaunia	Teesta	261	561	1360	2430	2240	1920	938	380	237	175	150	166	902	1972–89
90	Hardinge Bridge	Ganges	1280	1590	3500	20500	40800	37400	15600	5060	2830	1660	1370	1100	11100	1975–82
46.9L	Bahadurabad	Jamuna	7520	14700	30700	46300	42700	36000	22600	10300	6590	4790	4130	4730	19300	1965–82

Notes: Ganges/Jamuna data from National Water Plan, MPO, 1986 (post–Farakka Barrage for Ganges)

Remaining data collected from Directorate of Surface Water Hydrology II, BWDB, or MPO.
(for most stations some raw data was collected from both BWDB and MPO, and analysis carried out by FAP–2)

Values over *1000 cumecs rounded to 3 significant figures.*

There are missing years or part–years in the data records at some stations.

Figure 3.1
The River System

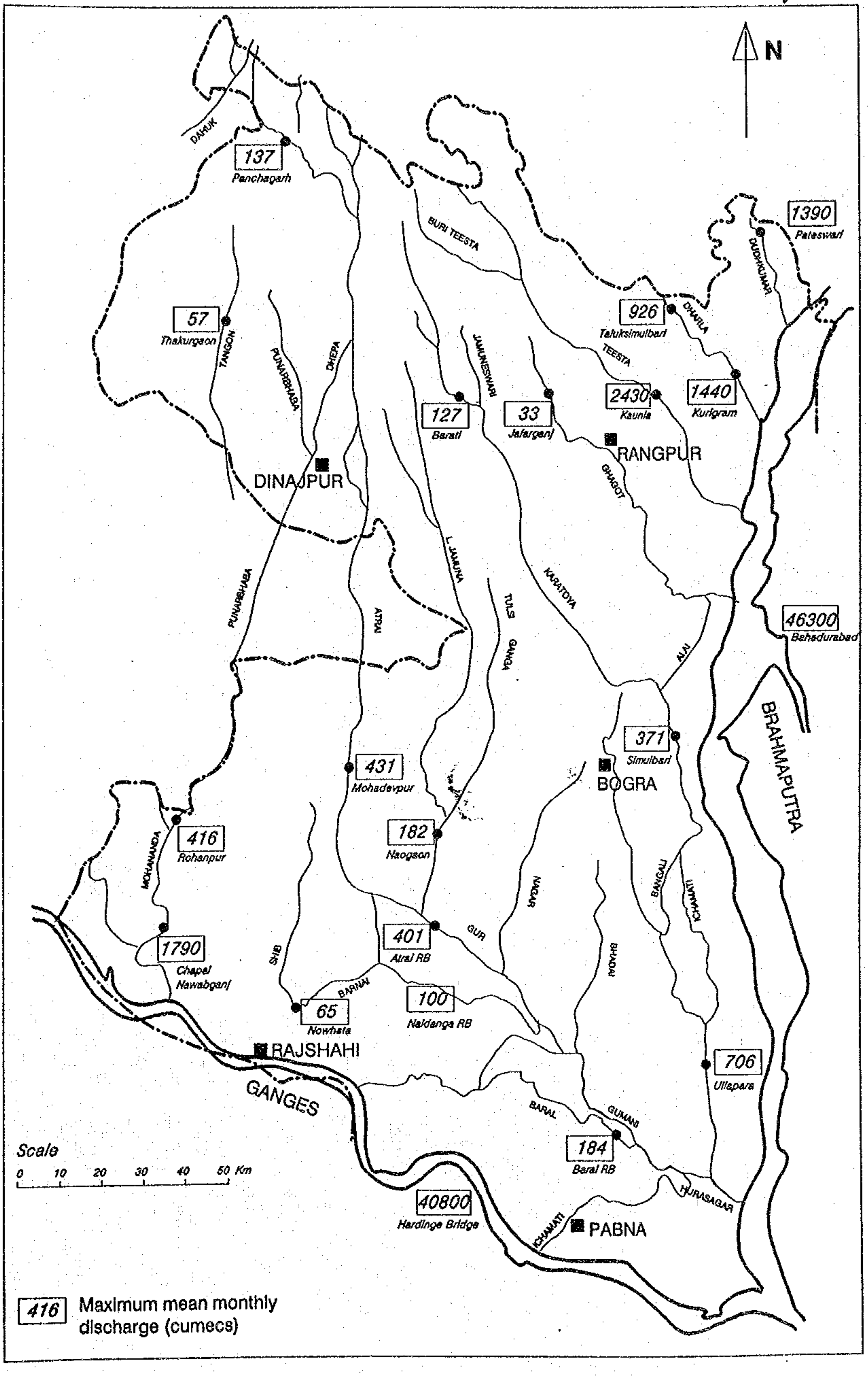


Figure 3.2
Areas Flooded in 1988

1988 FLOOD EXTENT

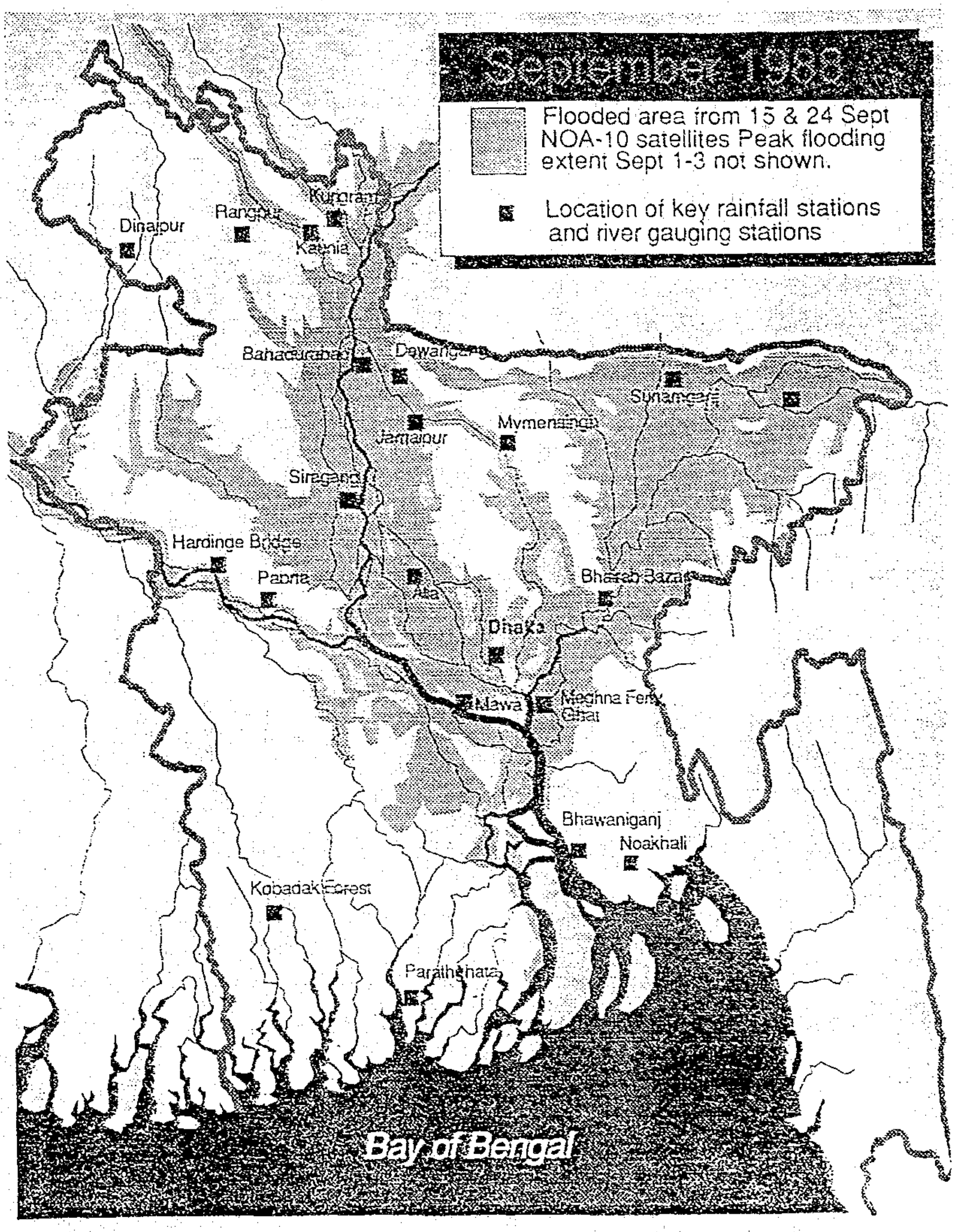
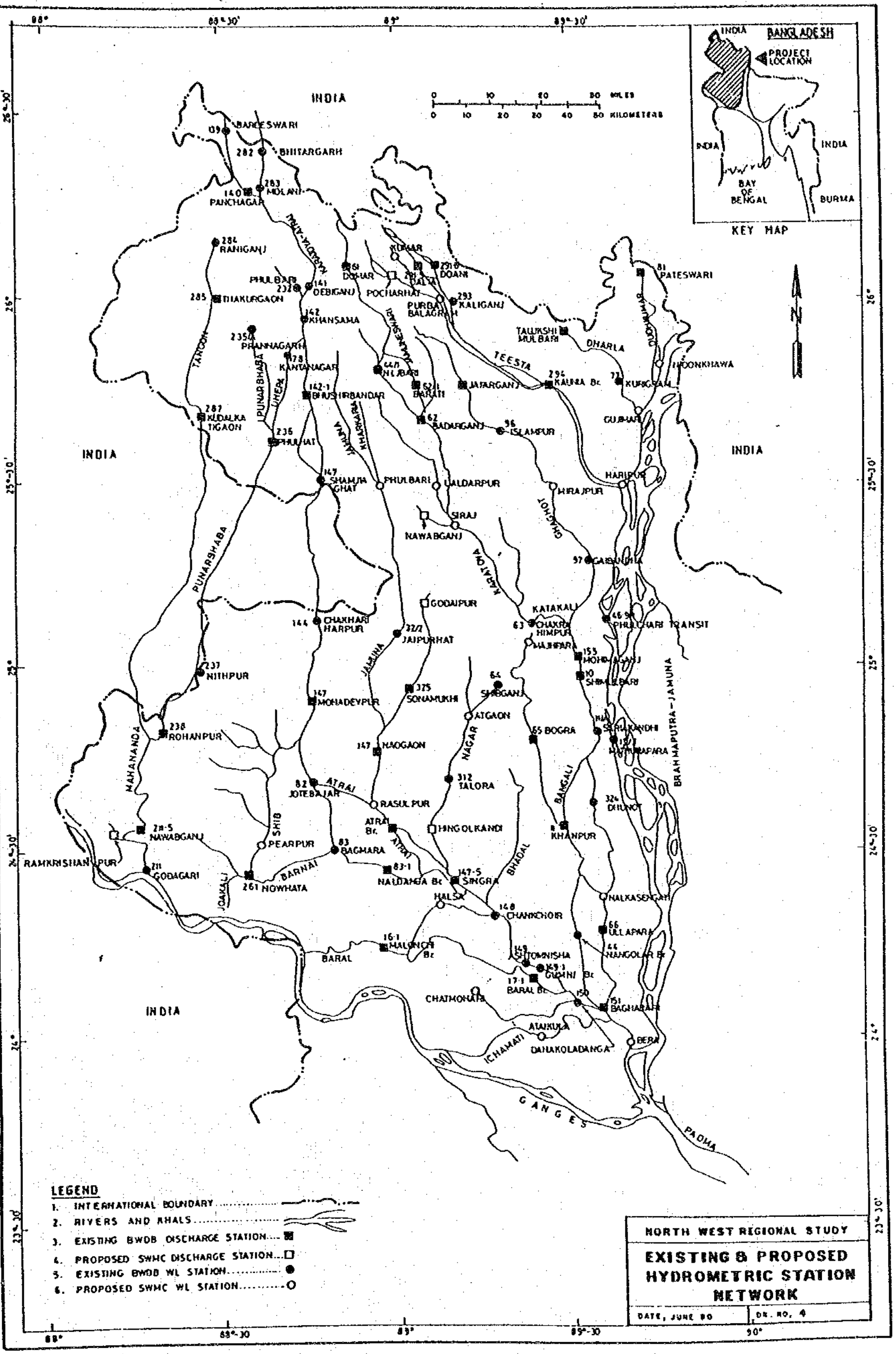


Figure 3.3 Hydrometric Stations



CHAPTER 4

MORPHOLOGICAL ASSESSMENT

4.1 Introduction

The purpose of the morphological studies was to determine the long-term sustainability of the proposed flood control and drainage measures by considering channel stability and the morphological response of the system. This chapter discusses the morphology of the region and types of morphological problems that may arise. This is also relevant to some aspects of the environmental impact analysis. Any morphological problems which may be associated with the proposed developments in the planning units which are not included in the hydraulic models are also addressed.

4.2 Morphology of rivers in the North West region

The greater part of the region is drained by rivers which rise within its borders. The notable exceptions are the Teesta and the rivers further north-east, the Dharla and the Dudhkumar, together with the Mohananda, which rises in India and drains the area around Thakurgaon, and the area to the west of the Barind Tract in the south.

Of the rivers in the North West region the Teesta is notable in being both the largest river and also being predominantly braided in plan form.

In the monsoon season the head waters of the Atrai, Karatoya and Ghagot appear to be fed by spills from the Teesta.

The rivers in the North West region are, in general, single thread channels with a tortuously meandering plan form. Such rivers frequently demonstrate significant changes in channel pattern as meanders develop and also migrate downstream. Evidence from satellite imagery demonstrates that the rivers in the North West region are subject to change except where extensive river training works have been carried out in an attempt to stabilise their course.

The Brahmaputra and Teesta rivers act as two external major sources of sediment to the region. This input of sediment to the internal rivers occurs when flows from these rivers spill into adjoining rivers. The remaining sediment has its origins within the catchments of the rivers within the region.

The river sediments consist of sands and silts and are predominantly fine sands with sediment diameters in the size range 0.1 to 0.4 mm. The river banks normally consist of sands and clays. While suspended sediment concentrations as high as 700 mg/l have been observed in the Little Jamuna (Ref. 4.1), the normal range of measured concentrations for suspended sediment is 100 to 200 mg/l. The dominant agricultural activity in the area is paddy cultivation. This may help to reduce sediment yields from these catchments and so reduce suspended sediment concentrations.

Previous studies have indicated that during floods significant quantities of sand are transported. This can lead to changes to the mean bed level, cross-section shape and channel plan form. The rivers in the region tend to be morphologically active in that changes in river course are common. The weakness of the bank material, the large bed shear stresses generated during flood flows and changes in bed topography directing flow towards the river banks all contribute to frequent changes in the plan form of the rivers.

Sediment transport in rivers is a non-linear function of the discharge, with the transport rate increasing rapidly with discharge. Thus for the rivers in Bangladesh a high proportion of the sediment movement occurs during the flood season. The amount transported during the dry season is extremely small by comparison. In any morphological analysis, therefore, it is the magnitude and duration of the flood flows that need to be considered. The large seasonal variation in flows can result in annual variations in bed topography from the dry to the wet season. It is important not to confuse such changes with long-term trends in bed levels.

4.3 Factors affecting river morphology and the impact of flood control works

The major influence on river size, shape and plan form is the discharge in the river. Any alteration in the discharge, either by increasing the discharge, by diverting flow from another river system or reduction in discharge, for example, by diversion, will change the morphology of the river. In general an increase in discharge will increase the width and depth of the channel and will increase any tendency to meander or braid while a reduction in discharge will reduce channel size and reduce any tendency to meander or braid.

Even if the discharge is not altered, any works to confine a river by, for example, constructing flood embankments may have a morphological impact. The action of flood embankments is, in general, to increase flow velocities and depths. This affects the sediment transporting capacity of the channel. If the input of sediment and water upstream is not changed then erosion or, more commonly, deposition may take place.

4.3.1 Prevention of spills from major rivers

If the spills from the Teesta or the Brahmaputra are prevented then there will be a reduction in both the flow and sediment input to the rivers within the region. The change in both flow and sediment transport is likely to lead to significant changes in the morphology of the rivers affected. These aspects are discussed in more detail in the relevant Chapters.

4.3.2 CFD works

If partial or complete CFD is carried out on the internal rivers then this will have a two-fold impact. The CFD will remove flood storage from the system and hence impact on discharges and secondly, by restricting flow widths, it will change the sediment transporting capacity of the river sections.

4.3.3 Desilting rivers/khals

An option that has been discussed is the desilting of various rivers in the North-west region. The purpose of desilting is to increase the conveyance of the channel by increasing the flow area.

Desilting has been carried out on the lower reaches of the Alai Kumari. Sediment has been excavated from the channel during the dry season but it has been deposited either within the main channel or along the bank of the channel. The sediment has thus been placed in an area where significant flow takes place. As a result the increase in flow area in one part of the channel is off-set by a reduction in another part of the channel. The overall effect on the conveyance of the channel is therefore negligible. Thus the desilting that has been carried out would be ineffective in reducing flood levels. If desilting is to be used as a technique to reduce flood levels then the way that the excavated sediment is disposed of must be carefully considered and closely defined and controlled.

While desilting may give an immediate increase in conveyance it cannot be regarded as a permanent solution. If bed levels have risen in the past then the desilted bed levels will continue to rise at the

same, or in some cases at an enhanced rate. In general if a short length of channel is desilted then the hydraulic benefits will be small and the sedimentation rate will be increased so that the channel will rapidly return to its original state. If a significant length of the channel is desilted then along the major length of the desilted reach the sedimentation rate will be little affected, that is, if the original channel was aggrading then it will continue to aggrade at the same rate. The sedimentation rate will be increased, however towards the lower limit of the desilted reach. Thus desilting will only provide temporary relief before the channel returns to its original form.

4.3.4 Meander loop cutting

Another option that has been discussed has been cutting off meander bends. In a meandering river cut-offs occur from time to time while in other reaches new meanders develop. Attempts to reduce the length of a stable river by carrying out cut-offs are normally unsuccessful as new meander bends usually develop and the river gradually reverts to its former sinuosity. This can be prevented by carrying out bank protection works to prevent further changes in plan form at the same time as carrying out the cut-offs. An exception to this however is when a river is not stable and is evolving in time. If the sinuosity of the river is reducing naturally then artificially induced meander cut-offs may accelerate the process and help to stabilise the river. Cut-offs are not only relevant to the river morphology but may also impact on the environment of the area.

Effecting a cut-off will have a number of impacts both short-term and long-term. The immediate impact of a cut-off is usually to reduce water levels both through the cut-off and also for a distance upstream. In channels with erodible beds, however, erosion and sedimentation are likely to take place. Erosion usually occurs upstream of the cutoff and deposition downstream. This deposition will have the effect of raising water at the lower end of the cut-off and immediately downstream.

4.4 Timescale of morphological change

The timescale of morphological change is difficult to predict with the tools available during the study. If the long term morphological module of MIKE11 had been available for this study then aggradation and/or degradation could have been investigated in greater detail. In the absence of this module, a simple attempt was made to estimate the order of magnitude of the timescales involved.

River morphology is a developing science which seeks to understand how natural channels behave. This includes a knowledge of the dimensions, slopes and patterns of channels which are in equilibrium and an understanding of the way natural channels react to perturbations away from their equilibrium condition.

Most rivers in Bangladesh are natural in the sense that they run through an alluvial plain which places few restrictions on channel size or channel movement. Furthermore Bangladesh comprises a developing deltaic formation where three of the major rivers of the world deposit their sediment load. Flows in these rivers depend on climatic conditions and, to some extent, man-made influences such as land use practices and water demand, mainly external to Bangladesh, all of which change with time. For all these reasons there are few rivers in Bangladesh which are truly in equilibrium. Most rivers are changing their dimensions and courses and the rate of change is determined by the extent to which individual rivers differ from their equilibrium dimensions and slopes.

Projects developed under FAP may affect river morphology by introducing works which effectively move individual rivers further away from their natural or equilibrium condition. Changes in flows, sediment supply, channel dimensions and flood plain widths all produce perturbations away from equilibrium. For this reason it is important to look at the morphological implications of projects and to assess future changes which will occur as a result of the works.