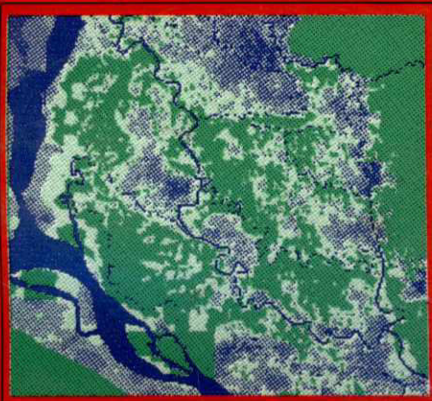
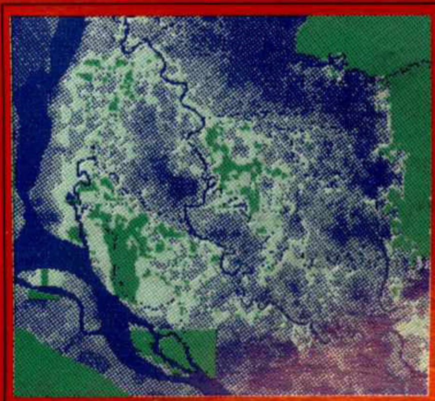


Government of the
People's Republic of Bangladesh
Flood Plan Coordination Organisation

FAP25

Flood Modelling and Management

Flood Management Model

Final Report - Volume II
Applications and Demonstrations

Danish Hydraulic Institute

in association with
Euroconsult
BCEOM

Donors
Denmark, France, the Netherlands

FAP 25: Flood Modelling and Management

Flood Management Model

Final Report

Volume II: Applications and Demonstrations

October 1994

FMM DOCUMENTS

FAP25-FMM has produced the following documents

Reports

- Inception Report
- Interim Report - I
- Interim Report - II
- Final Report
  Vol I: Main Report
  Vol II: Applications and Demonstrations

Technical and Training Documents

- MIKE11-GIS Reference and User's Guide
- MIKE11-GIS Training Manual
- MIKE11-GIS Menus
- MIKE11-NAM Dynamic Interface - Reference and User's Guide
- Training Materials for the FPCO Training Course

Proposals

- Transfer and Establishment of FMM at SWMC

Papers

- *Bangladesh Flood Management Model - Toward a Spatial Decision Support System* 2nd International Conference on River Flood Hydraulics, HR Wallingford, UK, 1994.
- *Flood Management Model an Integrated Numerical Flood Modelling-GIS Approach* 9th Congress of APD/IAHR, Singapore, 1994
- *Flood Maps and Improved Flood Management* Paper presented at the Bangladesh Institution of Engineers, Dhaka, 1994.
- *Profiling a Flood Management System for Bangladesh: The strategy of the generic model - GIS connection* Journal of Hydraulic Research, Issue on Hydroinformatics, 1994.
- *GIS in Flood Mapping for Improved Flood Management* Hydroinformatics Conference, IHE Delft 1994.

PREFACE TO VOLUME II

To illustrate the concept and use of FMM, its application is demonstrated in this Volume. These demonstrations are presented in three parts: Part A - National Level; Part B - Regional Level and Part C - Compartment Level.

With the exception of the Compartment Level demonstration, the applications are based on purely hypothetical scenarios and should not be interpreted as representing any development policy or construction programme.

The maps presented in the Volume are highly dependent on the accuracy and suitability of the MIKE11 models and the DEMs from which they are derived. In view of the limitations of the General Model and the preliminary nature of the North Central Regional Model, the impacts shown on the maps should not be considered as definitive.

The use of both technical terms and technical details are minimised to permit a clearer understanding of FMM by a wide range of readers. Those wishing to pursue the more detailed technical aspects of FMM should familiarise themselves with the contents of the manuals which accompany the Final Report: *MIKE11-GIS Reference and User's Guide*, *MIKE11-GIS Training Manual* and *MIKE11-GIS Menus*.

ACRONYMS AND ABBREVIATIONS

BRS	Branch Route System
BWDB	Bangladesh Water Development Board
CBL	Channel Boundary Line
CPP	Compartmentalisation Pilot Project
DEM	Digital Elevation Model. Three-dimensional (X,Y,Z coordinate) description of the ground surface topography.
FAP	Flood Action Plan
FAP10	Flood Forecasting Component of FAP
FAP19	Geographic Information System Component of FAP
FAP20	Compartmentalization Pilot Project (CPP) Component of FAP
FAP25	Flood Modelling and Management Component of FAP
FCD	Flood Control and Drainage
FINNMAP	Finnish Mapping Agency
FF&WC	Flood Forecasting & Warning Centre
FPCO	Flood Plan Coordination Organization
FMM	Flood Management Model
GIS	Geographic Information System
GM-FF	General Model Used for Flood Forecasting
GPS	Global Positioning System
MIKE11	River Modelling System developed by DHI
MIKE11-GIS	FMM software interfacing MIKE11 and ARC/INFO GIS
MPO	Master Plan Organisation
NAM	Rainfall runoff software developed by DHI (Danish Abbreviation)
NCR-FMM	North Central Region Flood Management Model
NCRM	North Central Regional Model
O&M	Operation and Maintenance
SCC	Storage Cell Coverage
SWMC	Surface Water Modelling Centre
SWSMP	Surface Water Simulation Modelling Program
TC-FMM	Tangail Compartment Flood Management Model
TCM	Tangail Compartment MIKE11 Model
TIN	Triangular Irregular Network used for 3-D surface modelling
TOF	Time of Forecast
TOR	Terms of Reference for FAP25-FMM
WLC	Water Level Cell
WLL	Water Level Line
XSC	Cross Section Coverage

This page intentionally left blank.

9

CONTENTS

PART A

PART B

PART C

PART A
NATIONAL LEVEL

CONTENTS: PART A

LIST OF TABLES

LIST OF PLATES

A.1 INTRODUCTION

A.1.1 Background

The development of a coarse National FMM was envisaged as the first step towards an on-line flood management system for Bangladesh. The system would be closely linked to flood forecasting activities, and would output, on-line, areas and depths of inundation, and potential impacts on crops, communities and infrastructure.

Such a system is a highly ambitious, but foreseeable in the longer term. A coarse National FMM would more clearly define the feasibility and practicalities of the system, and form a base for further development and application.

The TOR stipulates the output of the National FMM to be a:

> 'coarse FMM using the existing (SWMC) General Model for off-line prediction of floodplain inundation for various scenarios of river floods, rainfall, and embankment and structure configurations. Linked to FAP 10's flood forecasting model, it may be used for inundation forecasting (but at a coarse level). This would be the first pilot step in on-line management.'

A.1.2 Collaboration with FAP10

The TOR also states to:

> 'establish a close linkage to FAP10 and the Flood Forecasting and Warning Centre of BWDB to ensure that the proposed development of FMM are fully compatible with the GM-FF (the modified (SWMC) General Model being used for Flood Forecasting) and any regional flood forecasting models being applied, especially the real-time procedures applied in the FF&WC'

and to:

> 'make the DEM for the General Model, including interfacing to MIKE 11 output and graphic modules available for FAP10 and test, in cooperation with FAP10, the possibilities of deriving, off-line, relationships between river water levels and floodplain inundations, also considering effects of direct rainfall, to be used in conjunction with real-time river level forecasting in the major rivers'

The next phase of FAP10 was planned to start during the course of this study, but is now expected to start after its completion. Therefore, any close collaboration with FAP10 was impossible, although close relations with BWDB's Flood Forecasting and Warning Centre were pursued.

The objective of deriving off-line relationships between river water level and floodplain inundations was formulated with the assumption that the time lag between the forecast and the production of the accompanying flood map would be impractical. It has been found that this is not the case and that flood maps can be prepared within an acceptable period after the time of forecast. As a result of this, no further investigations were made to establish such relationships.

A.1.3 Objectives

The objectives indicated in the TOR can only be addressed in a restricted way, because of the delay to FAP10. Also, the capacity of the SWMC General Model to be used for flood mapping is regarded as limited, diminishing the usefulness, at this stage, of a National FMM.

The realistic objectives sought by FAP25 have therefore been centred on the preparations of the foundations for the National FMM, the demonstration of its potential for use as a planning tool and to document the benefits and limitations of the National FMM in its present form.

Incorporating BWDB Flood Forecasting and Warning staff in training programmes and workshops was also an important objective as documented in Main Report (Volume I).

A.2 NATIONAL FMM

A.2.1 Inputs

A.2.1.1 MIKE11 Model

The SWMC General Model was used, unchanged, for the National FMM. It covers the whole of Bangladesh except for the Greater Chittagong and Chittagong Hilltracts Districts. The major rivers, Jamuna (Brahmaputra), Ganges, Padma and Upper and Lower Meghna, dominate the model, draining a catchment area in excess of ten times that contained within the Bangladesh national border. These rivers drain into the Bay of Bengal which forms the model's southern boundary.

A detailed description is given in *Surface Water Simulation Modelling Programme Phase II - Final Report*.

Suitability for FMM
The SWMC General Model was primarily developed to provide boundary conditions to the regional models, and as a planning tool for studies on the major rivers. The emphasis was therefore directed to modelling the major national and regional rivers. Of the 495 cross-sections in the model, 20% are located on the Jamuna, Ganges, Padma and Meghna, 57% on major regional rivers (Teesta, Atrai, Dhaleswari, Surma, etc.) and 18% on other rivers/estuaries. Only 5% are used for links and floodplains. These are located on the Jamuna left bank floodplain (the western floodplains of the North Central Region).

The floodplains have generally been lumped with the river cross-sections or ignored. Therefore, because estimates of floodplain water levels would be based on river levels, flood mapping using the results from the General Model could be highly misleading, particularly for low and medium floods. Flooding from localised rainfall and differences between river and floodplain levels cannot be mapped.

This is not to say that no useful output can be obtained. In the case of the 1988 flood *peak*, when river and floodplain levels are probably very similar it should be possible to produce a flood map indicative of the real situation.

The usefulness of the General Model for flood mapping can only be expected to be limited. This is not a criticism, but recognition that the model was designed and developed for other purposes, such as the provision of boundary conditions for regional models To upgrade the model to a higher level of detail in the regions and on the floodplain is a task outside the scope of this project and one demanding considerably more computer hardware resources than presently available.

The model, like any other model, can be used for flood mapping, but interpretation of flood maps must be treated with caution and an understanding of the limitations of its output.

A.2.1.2 GIS Coverages

Two GIS coverages were obtained from FAP19 as input to the National Level FMM:

1. Administrative thana and district boundaries.

2. Rivers (national and regional).

Plate A.1 illustrates coverages of the greater district administration areas and major national and regional rivers.

The administrative boundaries were used to calculate statistics from flood maps. The rivers coverage was widely used for display on the computer screen and to build them into the DEM.

A.2.1.3 National DEM

A national DEM with a 1 km cell size was created from spot elevations and the rivers coverage using the method described in the *MIKE11-GIS Reference Manual and User's Guide* for building a DEM.

The spot elevations, obtained from FAP19, are based on the MPO 1 km grid elevations. A TIN was created, giving a three-dimensional model of the ground surface of Bangladesh. In some areas no elevations exist, either because of no surveys or areas covered by water. Large areas of no elevation data which are flooded were the rivers and Sundarbans.

Major rivers were built into the DEM using the rivers coverage by lowering DEM elevations to -10 m. There is no basis to the -10 m other than it is well below dry season river levels. With the rivers represented as such, the flood maps will now show deep water along their courses. Without lowering the DEM along the rivers, the rivers would not be distinguishable on a flood map.

Plate A.2 illustrates the National DEM.

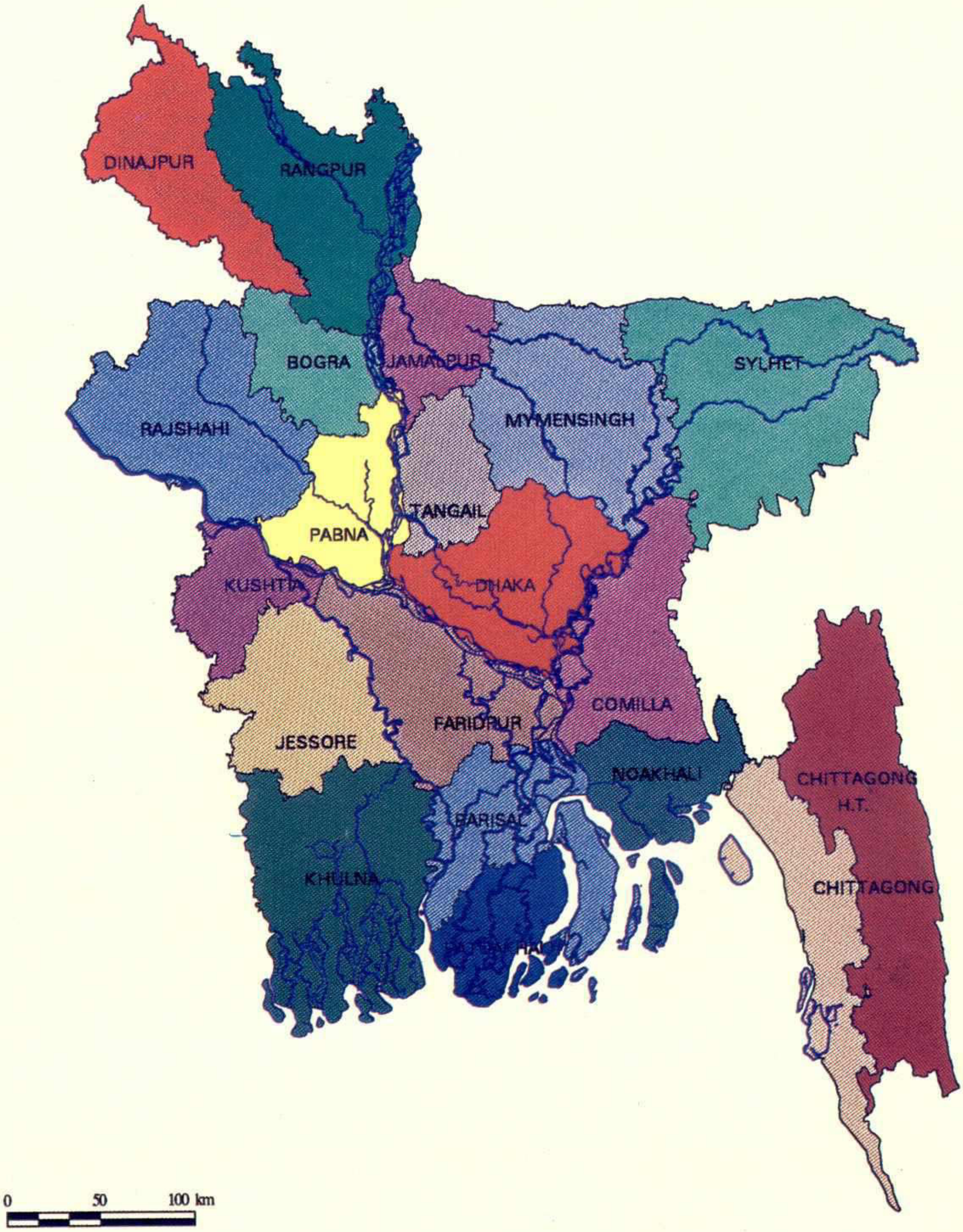
A.2.2 Flood Mapping

A.2.2.1 Preparation

Branch Route System (BRS)
A BRS was digitised using the rivers coverage as a guide. The GM network details were imported to assign branch names and chainages to the routes in the BRS.

Plate A.3 illustrates the BRS and shows some of the branch names. Also shown are the locations of cross-sections in the GM.

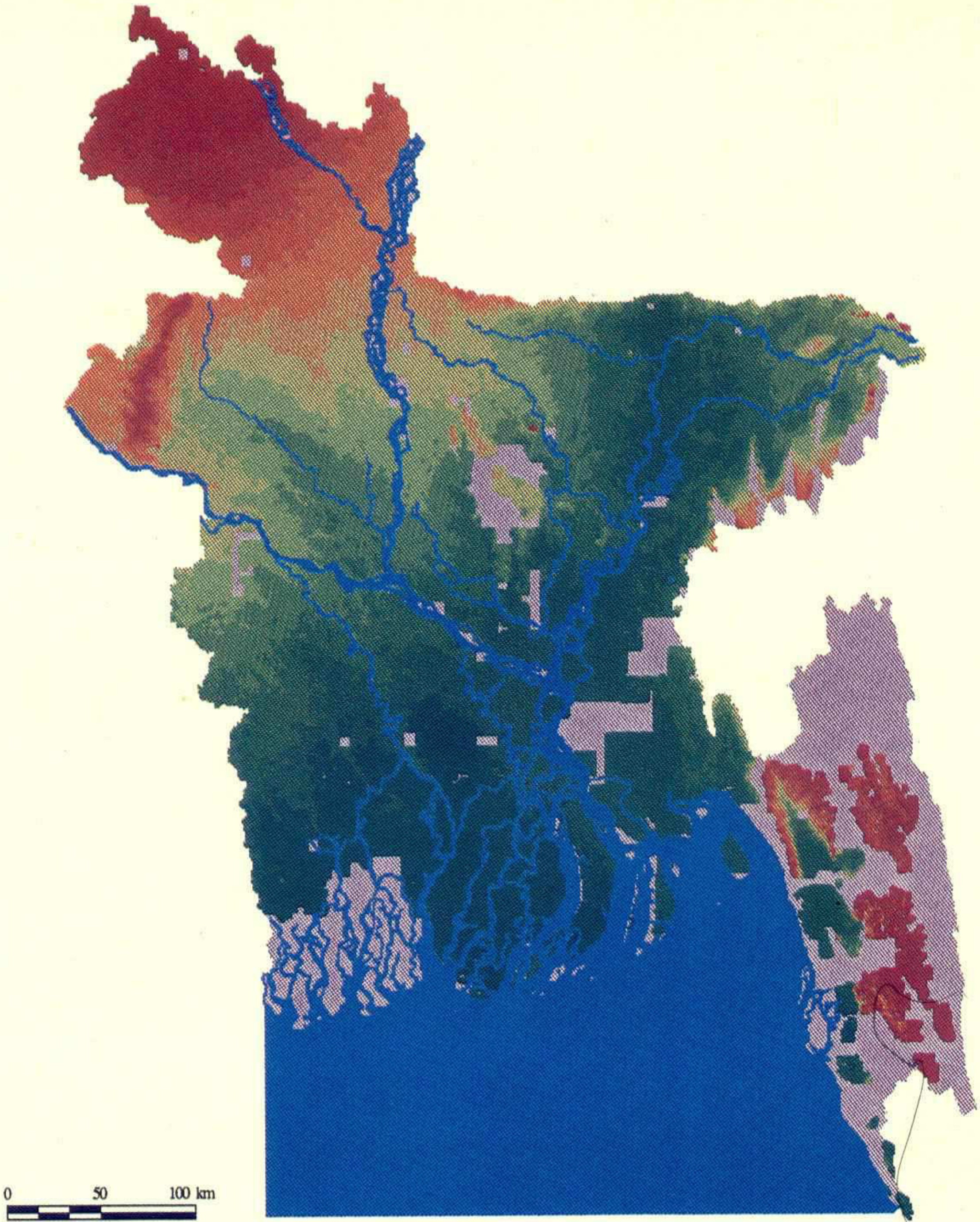
Coverages of Major Rivers and Greater Districts

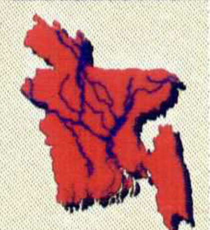


River

Greater District

National DEM

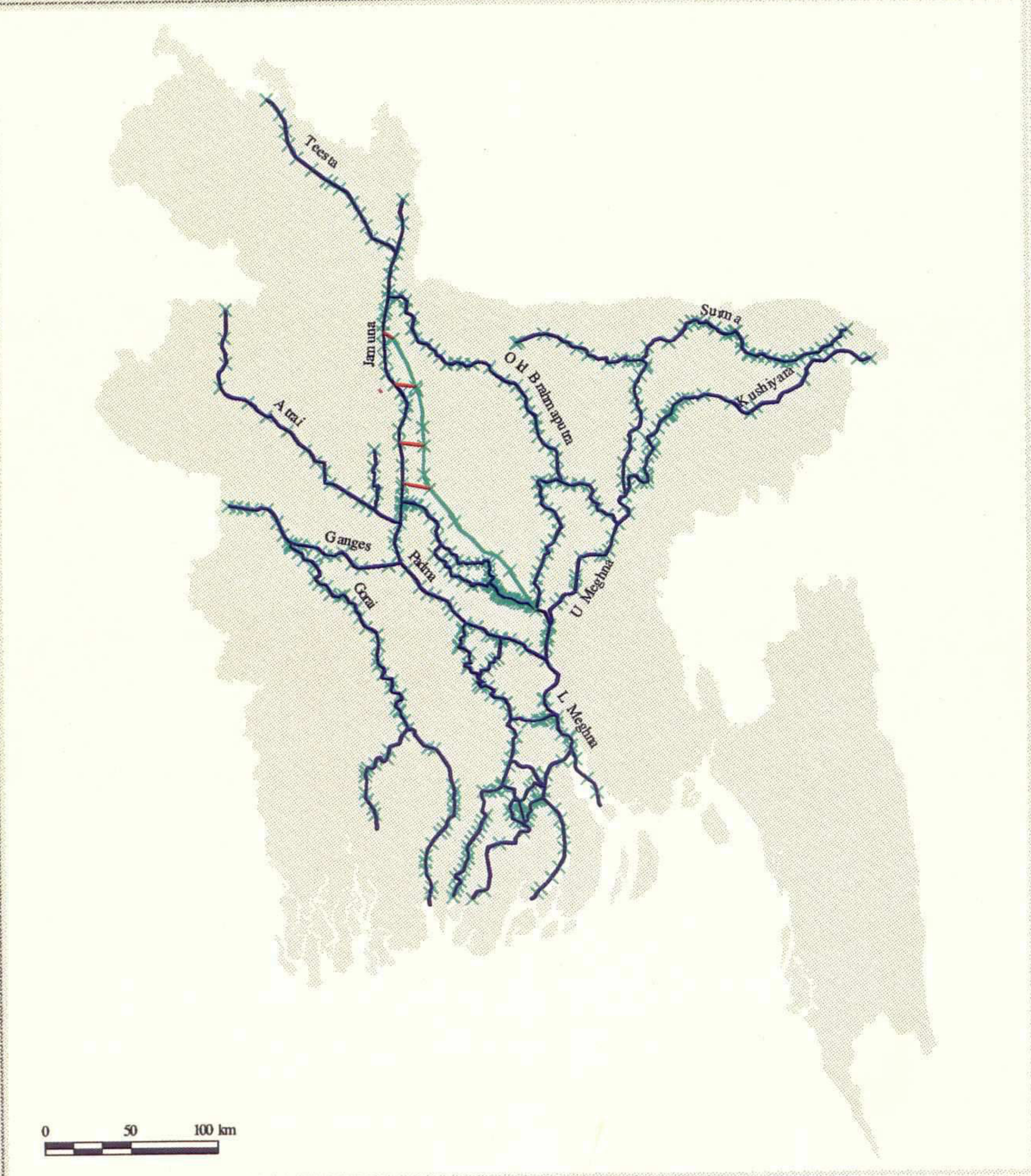


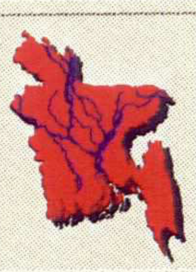


Elevation (m) – PWD Datum

0.0 – 2.0	11.0 – 14.0	25.0 – 30.0	Rivers/Ocean
2.0 – 5.0	11.0 – 17.0	30.0 – 35.0	No Data
5.0 – 8.0	17.0 – 20.0	35.0 – 45.0	
8.0 – 11.0	20.0 – 25.0	Above 45.0	

National Branch Route System





River
Artificial River
Spill Channel
Cross-Section
(Based on SWMC General Model)

Water Surface Coverage (WSC)

A WSC was prepared for producing flood maps and is illustrated in Plate A.4. The *MIKE11-GIS Reference and User's Guide* should be consulted for further explanation of terms and methods.

Over the floodplains difficulties arise because floodplain flood levels have to be based on an interpolation from the river levels. On the floodplain, a decision has to be made whether the flood level is best represented by that of a nearby river, or, if the point lies between two rivers, an interpolation of the two rivers' levels.

For example in the central north east floodplains flood levels are interpolated between the major rivers, such as the Surma and Kushiyara Rivers as noted on Plate A.4. However, around the perimeter of the north east region the floodplain levels are set equal to those of the nearest river by extending the river's WLLs (Water Level Lines) across the floodplain and into the hills.

Therefore, creating the WSC was largely based on good judgement by observing the floodplain terrain (using the DEM) and estimates of the likely flooding patterns. However, the only sections of the WSC which can be truly representative are along the GM rivers. Along the minor regional rivers and on the floodplains, no guarantee of accuracy can be given.

From the WSC a WSC TIN (see Plate A.4) was generated for producing three-dimensional flood surfaces from which flood maps were created.

A Water Surface Mask (WSM) was created to mask out areas of the TIN where flood level interpolation would be incorrect (for example the area between the Teesta and Atrai Rivers as shown on Plate A.4).

A.2.2.2 Flood Maps

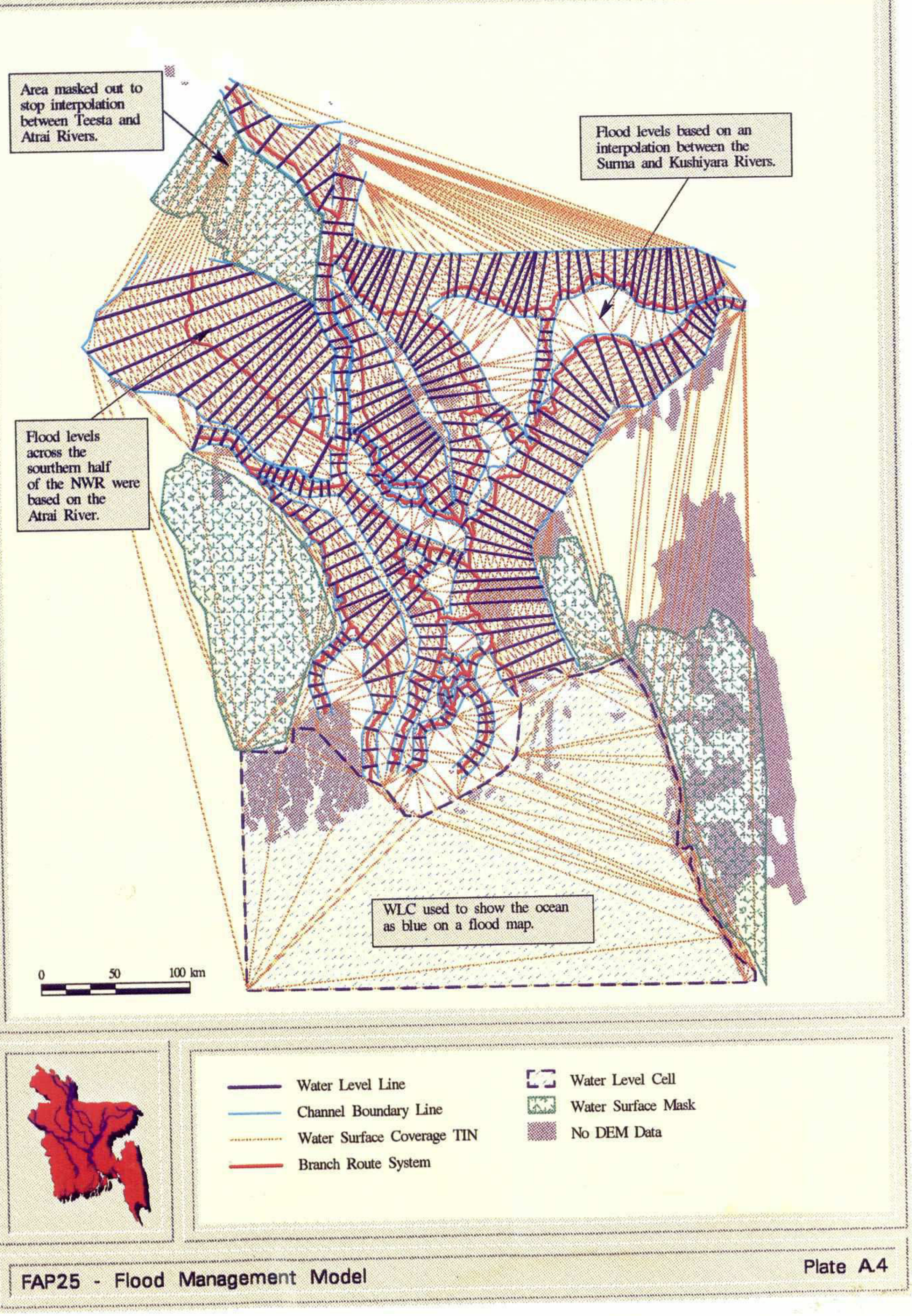
Several flood depth maps were produced at different stages of the 1988 flood. Plate A.5 shows the maximum flood depths which occurred during the course of the flood.

Deep flooding can be observed in the North East, North West, South West and South East Regions. The maximum flood depth statistics for greater districts which are covered by the flood map are presented in Table A.1 and compared with BWDB Flood Forecasting and Warning Centre observations (not published). A good agreement can be observed, especially for the Bogra, Faridpur, Rajshahi, Sylhet and Tangail districts which were all within 7%.

Table A.1 Flooded Area Statistics - Comparison of BWDB Observed and Simulated

Greater District	Total Area	BWDB Observed	Simulated	BWDB Observed	Simulated	Difference
	km^2	km^2	km^2	%	%	%
Bogra	3875	2149	1849	55	48	7
Comilla	6734	4909	4202	73	62	11
Dhaka	7446	7107	5999	95	81	14
Faridpur	7091	6766	6949	95	98	-3
Jamalpur & Mymensingh	12988	10215	11773	79	91	-12
Pabna	4840	3781	4776	78	99	-21
Rajshahi	9427	5878	5182	62	55	7
Sylhet	12375	9024	9191	73	74	-1
Tangail	3450	2748	2576	80	75	5

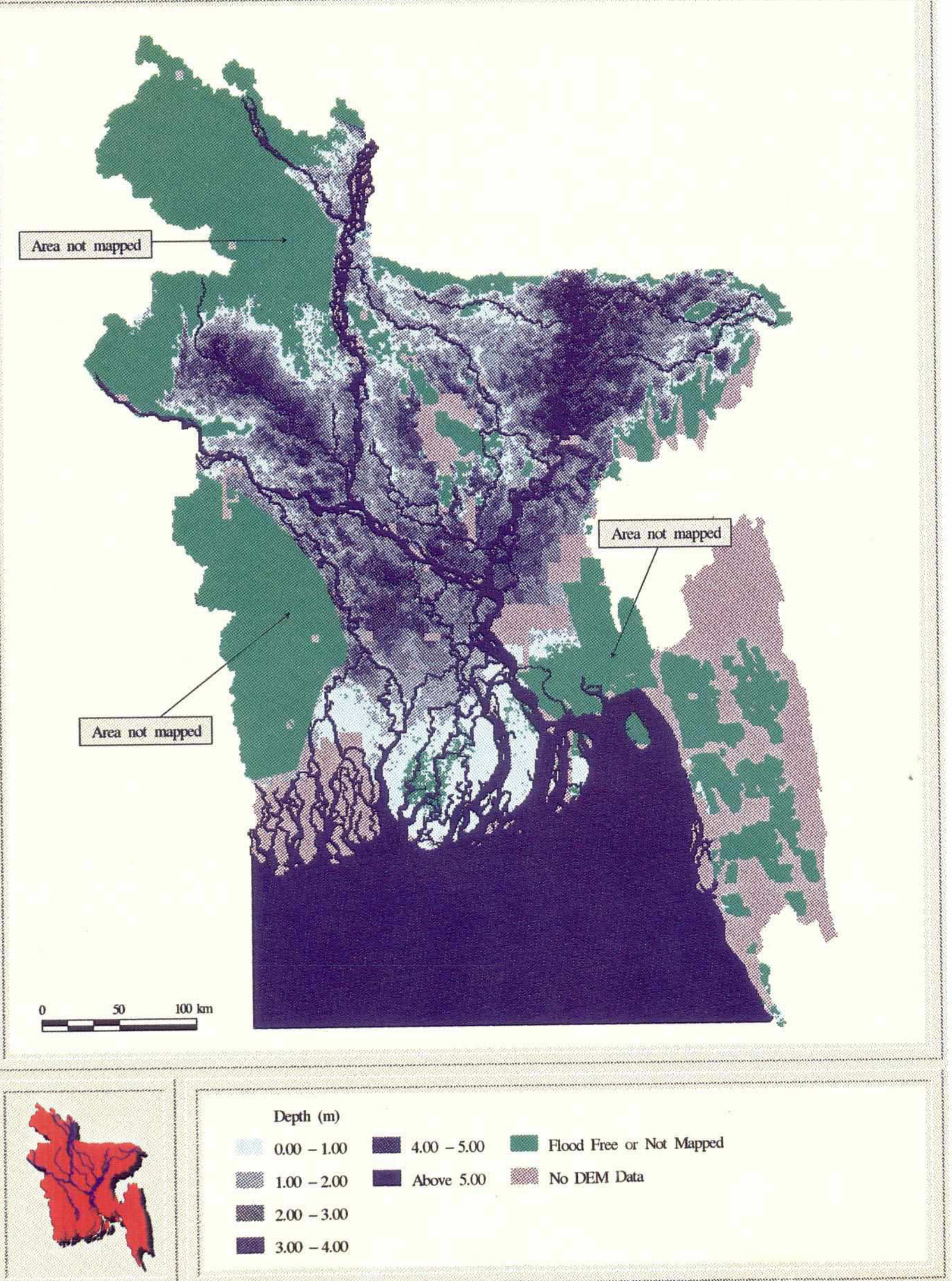
Water Surface Coverage for National Flood Mapping



FAP25 - Flood Management Model

Plate A.4

Simulated Maximum Flood Depths - 1988



A.2.3 Usefulness for Planning

A demonstration of the potential usefulness of the National FMM for planning was performed by modelling the impact of building an embankment along the left bank of the Jamuna River.

The Jamuna left embankment (JLE) was modelled according to Scenario 3 in the *FAP25: Flood Modelling and Management, Flood Hydrology Study, Final Report and Annex 1.*

The four links connecting the Jamuna River with the artificial river branch on the left bank were closed off. The Dhaleswari River branch was left unchanged.

Further observation of the Jamuna left bank artificial river branch showed that its cross-sections were an unrealistic representation and there was no rainfall/runoff from surrounding catchments. The model was corrected to direct rainfall/runoff to the artificial river branch. Also of concern, was the absence of any links with the Dhaleswari River. In effect, the model detail over the Jamuna left bank floodplain is very rough.

The impact on flood levels and depths can be visualised by comparing maximum flood depth maps for the without and with embankment cases. Based on the 1988 flood, Plate A.6 shows the two flood depth maps at the top, and a flood depth comparison map underneath showing the change in maximum flood level (or depth) due to the embankment.

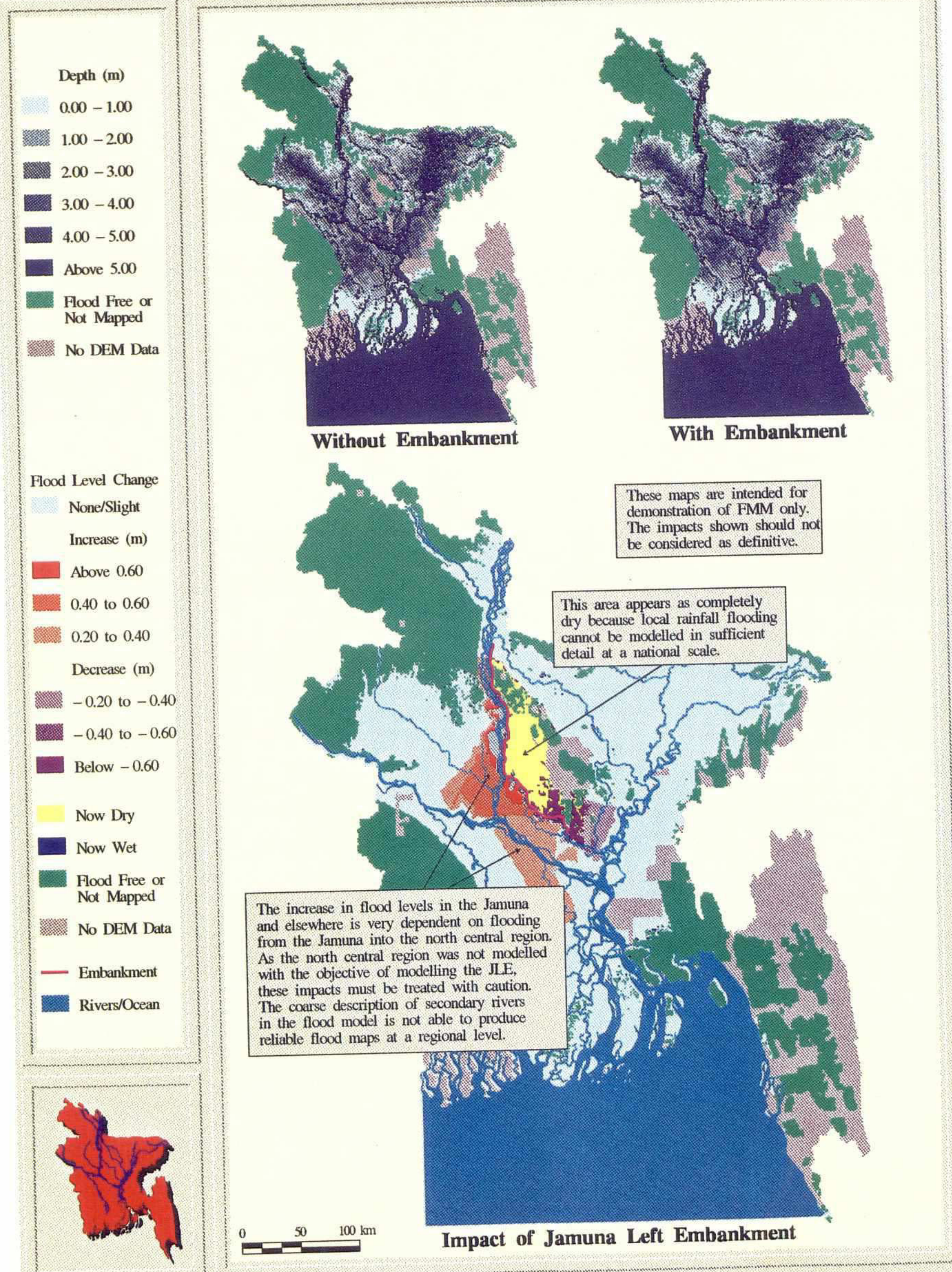
A rise in flood level can be seen to occur in the Jamuna adjacent to the embankment and to dissipate upstream. A rise also occurs in the Atrai River and adjacent floodplains, and parts of the Padma and Arial Khan Rivers.

A large portion of the western North Central Region is shown as "now dry" indicating there would be no flooding with the embankment in place. A slight decrease in flood levels occurs in areas north west of Dhaka.

At best, the comparison map gives a *very rough indication* of the embankment's impact, and *to use the results for impact assessments or design purposes could be erroneous*. The map is presented as a warning, illustrating the possibility of incorrect interpretation. It is likely the rise in levels would be more dominant in the rivers and less on the floodplains, however, to show this a much more detailed MIKE11 model would need to be developed. Also, the large "now dry" area is questionable, as there would be floodplain flooding from local rainfall which the GM does not model.

This page intentionally left blank.

Simulated JLE Impact on Maximum Flood Levels - 1988



A.3 CONCLUSIONS AND RECOMMENDATIONS

A coarse National FMM was developed and tested based on the SWMC General Model (GM) and GIS data supplied by FAP19. It is capable of producing flood maps for the majority of the country and statistical information for local government administrations and regions.

However, the National FMM is, at best, limited in its usefulness for flood mapping, with the possible exception at flood peaks when river and floodplain levels are similar. The GM's representation of the floodplains is rough, and therefore any flood map produced using GM output will also be rough. The model was designed to provide boundary conditions for regional models and for river based studies, not for flood mapping.

The National FMM cannot be used with confidence as a general planning tool for floodplain mapping. The GM is too coarse on the floodplains to model adequately changes in floodplain flood levels because of an intervention. This does not imply the model cannot be used for other planning purposes. Studies which are primarily concentrated in the major rivers, such as morphological studies, can make good use of the GM as a planning and design tool.

The delay to the commencement of FAP10's next phase has prevented the possibility of collaboration for developing the National FMM for flood forecasting. It is expected FAP10 will work closely with SWMC, the likely future custodian of FMM, in this regard. BWDB Flood Forecasting and Warning staff have been included in training courses and workshops on FMM.

In conclusion:

- The National FMM is functional and usable, but limited in its accuracy.
- The National FMM should not be used for floodplain planning purposes.

The recommendation is:

- No further development should be carried out at the national level in the immediate term. However, with the advent of more powerful computers which are affordable, a GM of Bangladesh with much more detail on the regional rivers and floodplains will be viable in the future. A National FMM requires a GM of this complexity if it is to be useful as a flood management tool.

PART B
REGIONAL LEVEL

29

CONTENTS: PART B

28

LIST OF TABLES

LIST OF FIGURES

60

LIST OF PLATES

B.1 INTRODUCTION

B.1.1 Background

Under the Flood Action Plan, a total of five Regional Studies were begun in 1990/91. These were FAP2, the North West Region, FAP3, North Central Region, FAP4, South West Region, FAP5, the South East Region and FAP6, the North East Region. As an integral part of these planning studies, the hydraulic behaviour of the rivers and floodplains of the region was investigated using simulation models based on MIKE11 software.

Each regional study constructed a model specific to its region. In some cases, the model had already undergone significant development at the Surface Water Modelling Centre, and in others, model development commenced with the inception of the regional study. With the exception of small, localised areas, each model reflects a 1-dimensional view of the river system; that is, floodplains are not considered as separate entities, except for their storage capacities.

The main thrust of the regional studies was directed towards the assessment of flood control and drainage options to reduce or manage flooding such that sustained development of the region might take place. Therefore, much of the attention of the planners, agriculturalists, fisheries experts, environmentalists and other specialists was directed towards the flooding characteristics of the floodplains.

Models were used to simulate effects of interventions, but the output from these models could only be directly obtained for the river channels. Information related to floodplain inundation had to be derived by the modellers by development of individual post-processing programs. Each regional study used different programs, usually written in-house, the applicability of each being largely dictated by the amount of topographic data available. In all cases, however, the output from these post-processing programs differed due to differing methodology, differences in the detail of data and the resolution of the data used.

These shortcomings of the regional models used in the Flood Action Plan to date have highlighted a pressing need for a tool which provides more detailed information of floodplain inundations for analysis by sectoral specialists. This tool should take account of the water level on the floodplain differing from that in the river, give better discrimination of the areal extent of flooding and to provide a better representation of the hydraulic behaviour during the pre- and post-monsoon periods.

The requirements of the Terms of Reference for the second stage of the project related to the regional applications are as follows:

- build a regional FMM for the North Central Region and carry out FMM demonstration runs showing the effects of different structural arrangements and operations under different flooding conditions and produce flood hazard maps for various historic floods and return periods;
- initiate, on this basis, the establishment of a database of simulated historic events, (e.g. 1987 and 1988), which can assist, (in the long term), to identify optimal

operation strategies in real-time situations, but in the short term and within the present study, may serve the purpose of demonstration of the possible benefits of FMM without having to run the hydrodynamic part;

- demonstrate the effects of flood retention in a series of successive compartments on the flood conditions around Dhaka;
- make the DEM for the NCRM, including interfacing to MIKE11 output and graphic modules available for FAP10 and test, in cooperation with FAP10, the possibilities of deriving off-line relationships between river water levels and floodplain inundations, also considering effects of direct rainfall, to be used in conjunction with real-time river level forecasting on regional level

B.1.2 Objectives

The objective of the project with respect to regional modelling is to build a pilot FMM for the North Central Region and to demonstrate that FMM can be used to show the effect of different structural arrangements under different flooding conditions.

The possibility of cooperating with FAP10 to derive off-line relationships between river water level and floodplain inundations was also to be investigated. However, the late start of the next phase of FAP10 has meant that close cooperation has not been possible. Nevertheless, some attempt has been made to demonstrate that the off-line production of flood maps, based on real-time forecasts, is possible and that the time taken to produce these maps from the forecast eliminates the need for river/floodplain water level relationships, (see TORs above).

The content of the application demonstrations for the North Central Region was agreed among FPCO, donors and FAP25 at a meeting held in March, 1994. These runs were to be based around the central theme of compartmentalisation.

Demonstration runs were envisaged which would show the impact of the construction of a series of compartments on the flood conditions around Dhaka.

B.1.3 Approach

Owing to the pilot nature of FMM, and the descriptions of floodplain inundation, the MIKE11 model component of FMM requires further definition and calibration, (particularly on the floodplains), before fully representative mapping can be done. However, the emphasis has been placed on the methodology involved in FMM, amplified by demonstration of the types of output available. Therefore, any mapping output should be viewed qualitatively, rather than quantitatively, at this stage of FMM development.

B.2 DEVELOPMENT OF REGIONAL FMM

B.2.1 Introduction

This section of the Report highlights the development processes involved in the NCR-FMM. While the details given are specific to the NCR, the general requirements for data, methodology for model schematisation and production of flood maps could apply to any other model of this scale. The extent of the FAP25 NCRM is limited to that part of the North Central Region which lies to the west of the Madhupur Tract. This is mainly because a suitable DEM does not yet extend into the eastern part of the region but also because the western part was considered more suitable for the demonstration purposes of this project.

Figure B.1 Development Path of NCR-FMM

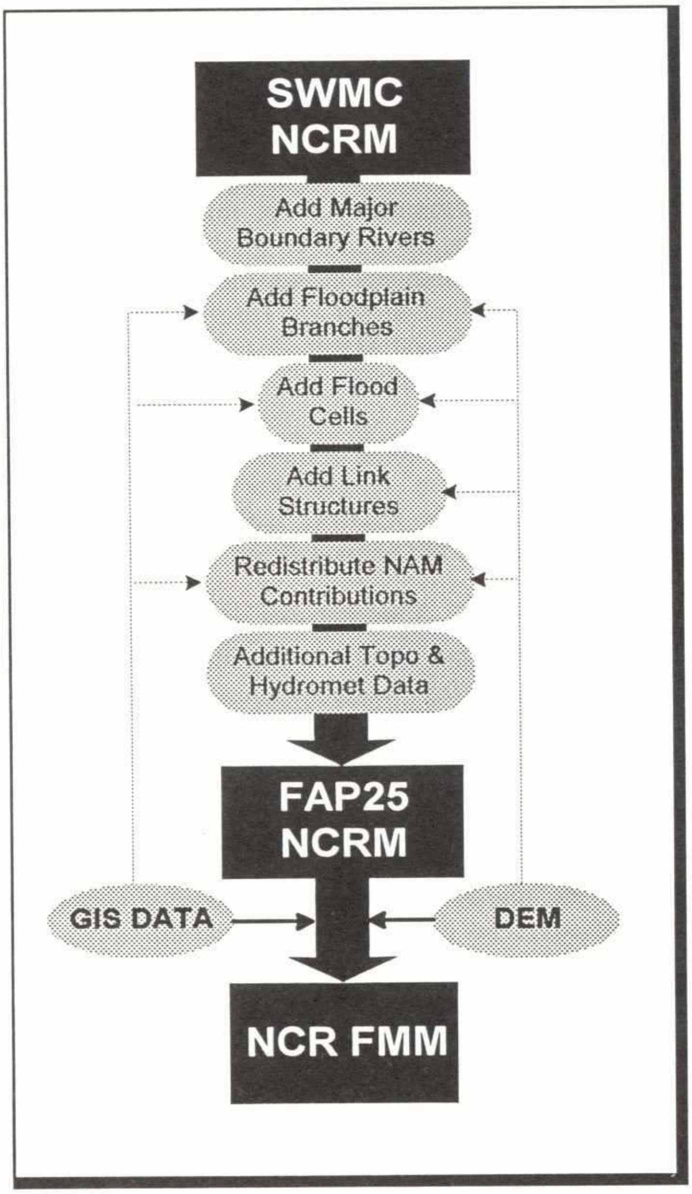


Figure B.1 shows the development path of NCR-FMM, highlighting the inputs and/or modifications needed at each stage. Clearly, some components are related only to MIKE11, (such as the addition of the major boundary rivers), but others utilise the MIKE11-GIS tools which draw on the DEM and GIS data and must be assembled prior to model modification. By virtue of its additional GIS data requirements, FAP25 NCRM should not be considered as being simply another version of the SWMC NCRM.

In order to demonstrate the particular needs of a regional FMM, the reasons why the existing SWMC NCRM was not appropriate are explained. There then follows a brief overview of the NCR-FMM data requirements and the problems associated with the acquisition of such data.

The methodology for the use of the above data in the schematisation and subsequent calibration of the FAP25 NCRM is explained. Finally, the use of the NCR-FMM for the production of flood maps and their derivatives is shown, providing guidelines resulting from the experience of the FAP25 team in working on the NCR-FMM.

B.2.2 SWMC NCRM

B.2.2.1 Description

The SWMC NCRM covers a total area of approximately 14,000 km^2, which is divided into 19 subcatchments for the rainfall-runoff model. The channels selected for the river schematisation are based on the 1989/90 SPOT imagery, taken in the dry season. Major rivers in the model include the Old Brahmaputra, (which forms the northern boundary of the region), the Bangshi and Turag in the central part, the Jhenai and Futikjani in the north, the Dhaleswari and Makar along the left bank of the Jamuna and the Kaliganga/Dhaleswari in the south. Eastern rivers include the Lakhya, Banar and Arial Khan.

The rainfall-runoff component of the model, (NAM), uses 19 catchments varying in size from 300 km^2 to 1500 km^2. Catchment boundaries are generally based on the original definitions by WARPO, with minor subsequent revisions to account for the construction of new roads and embankments.

In 1992 a new formulation was introduced into the NAM with an improved description of the soil infiltration in the flat terrain characteristic of Bangladesh. Using the new Irrigation/Infiltration module, the full NAM was recalibrated for the period 1986 to 1991 and verified in 1993 with 1992 data. The NAM component was calibrated against observed groundwater levels as discharge records are only available for four well-defined catchments.

A total of 57 rivers with an accumulated length of some 2,000 kilometres is included in the model, schematized with 60 nodal points, (junctions or boundaries). The model also incorporates off-stream storage areas near Kawaljani, Mirzapur and Rupganj, where flow exchanges between the river and the storage areas take place over broad-crested weirs.

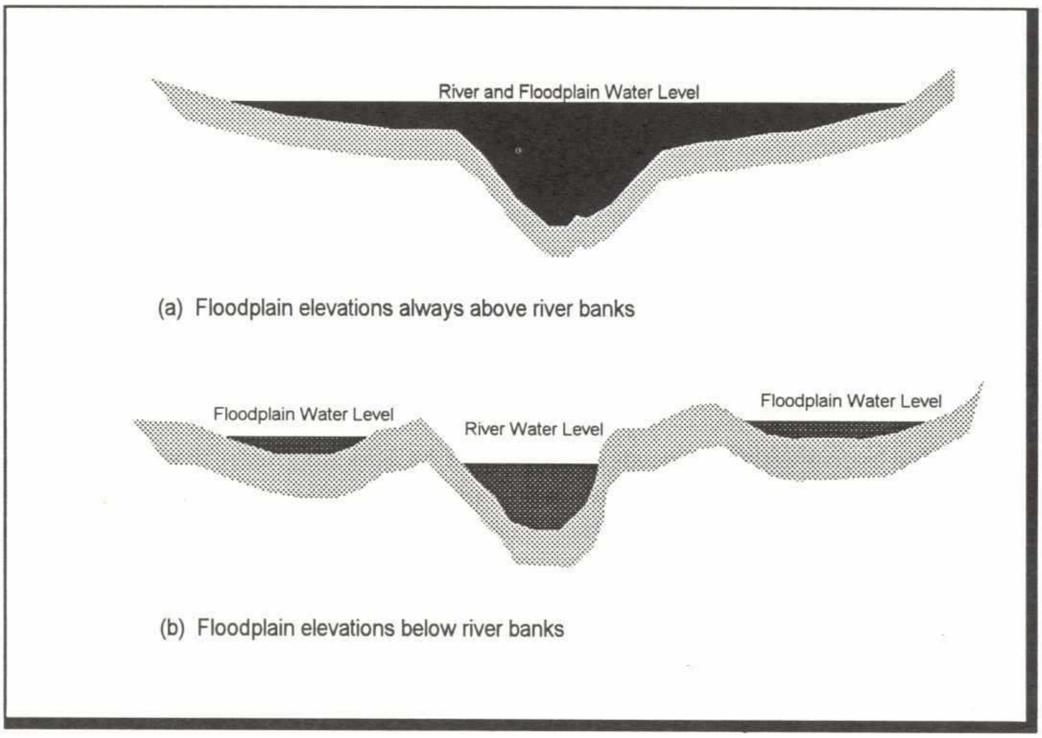
Sources of river cross sections include BWDB Morphology, FAP-3 surveys, FAP-3.1 surveys, Jamuna Multipurpose Bridge Authority, (JMBA), and SWMC. A limited number of cross sections was made available through the FAP25 embankment survey programme. The majority of the cross sections date from 1990-91, but approximately half of the BWDB surveys date from 1989 or earlier. Floodplain data were taken from the 1 kilometre grid of levels from MPO.

B.2.2.2 Need for Upgrading

It is emphasised that the SWMC NCRM satisfactorily performs the functions for which it was intended. It is simply that the functional requirements of FMM are different from those upon which the SWMC NCRM is based. The principal reason for upgrading the SWMC NCRM lies in the FMM requirement for enhanced representation of floodplain behaviour in the greater part of the North Central Region.

Characteristic of the river system in the NCR are the embankments and natural levees that separate the river from the floodplain. In most places, the banks of the river are at a higher elevation than the adjacent floodplain. Also, the local rainfall on the floodplain can accumulate in depressions without immediately finding its way into the river system. This situation is not necessarily applicable to all regional scale models. Figure B.2 (a) & (b) illustrates the two main different river/floodplain configurations. The majority of the western part of the NCR assumes the configuration shown in (b), whereas other regions, (or

Figure B.2 River/floodplain Configurations



parts of regions), may assume the configuration of (a) and would be adequately represented by the type of schematisation used in the SWMC NCRM.

Floodplains are incorporated in the model by considering them as area elevation curves attached to the appropriate cross section. In this schematisation, floodplain flow is always considered to be taking place at the same elevation as that in the river. Conveyance differences between the river and the floodplain are accounted for by increasing the relative roughness of the floodplain. This reduces the conveyance of the floodplain while still retaining the full flood width storage capacity.

Local excess rainfall in the SWMC NCRM is assumed to enter the river system directly, since the NAM catchment runoff is uniformly distributed along the river length. No retention of water on the floodplain is possible with this schematisation, (type (a)), and hence it is not possible to discriminate between flooding from local excess rainfall and flooding from rivers.

The SWMC NCRM has been developed without the inclusion of the Jamuna, Padma and Meghna, the major boundary rivers of the region. The Old Brahmaputra, which forms the northern boundary is, however, included. Without the other major boundary rivers, it is not possible to model the interchange of flow between these boundary rivers and the adjacent floodplain.

B.2.3 Data

B.2.3.1 Hydrometric Data

In common with the SWMC NCRM, the FAP25 NCRM utilises river water level and discharge data at selected locations throughout the region. Such data are needed for two main purposes: either as boundary data for the hydrodynamic model, or as comparison data in the calibration process.

The inclusion of the Jamuna, Padma, part of the Ganges and Lower Meghna in the model required the supply of boundary conditions for these rivers. There are no permanent monitoring stations at suitable locations on these rivers and therefore the General Model was used to provide water level and discharges at such locations. Runs of the General Model were made for the years 1988 and 1993, with output of water level and discharge at appropriate chainages for transfer to the FAP25 NCRM.

The hydrometric data needs of the FAP25 NCRM are greater than those of the basic SWMC NCRM due to the difference in floodplain descriptions. In addition to the existing river water level and discharge data, collected by BWDB Hydrology and SWMC, there is a need for water level data on the floodplain. This data is needed to assist in the calibration process and to provide a better understanding of the mechanism of flooding.

Table B.1 Hydrometric Data Used in FAP25 NCRM

Type	No of Stations	Source	Year
Rainfall	25	BWDB, SWMC	1988,1993
Evaporation	3	BWDB, SWMC	1988,1993
Water Level	36	BWDB, SWMC	1988,1993
	40	FAP25	1993
Discharge	9	BWDB, SWMC	1988,1993
	24	FAP25	1993

Little or no information was available to quantify the depth of flooding on any of the floodplains, nor was it certain that reliable information of such could be practically obtained. The area covered by the FAP25 NCRM is too large to contemplate installing a network of floodplain gauges throughout the region. In addition, it would be difficult to determine the extent to which the recorded water level fluctuations of a gauge applied, given the complex system of secondary embankments and khals. The resource limits of the project permitted twelve additional gauges to be installed at selected locations in the floodplain. These gauges were primarily installed on an experimental basis, to give some insight into the difficulties described above. Readings were taken on a daily basis.

In the restructured model, with flow interchange between the rivers and the floodplains, additional water level and discharge measurements were required at locations where flow behaviour was particularly uncertain in the SWMC NCRM. Measurements were also carried out on smaller rivers which were considered to exert significant influence over the flow patterns. Prior to the 1993 monsoon season, 40 water level gauges were installed throughout the region and a discharge monitoring programme commenced at 24 locations. Full details of this monitoring programme may be found in the report *Hydrologic and Topographic Measurements - 1993*, issued in February, 1994

Table B.1 summarises the hydrometric data used in the FAP25 NCRM.

B.2.3.2 Coverages

To assist in the construction of the FAP25 NCRM, GIS coverages of rivers and major roads were included. These coverages were obtained from FAP19, the rivers coverage derived from SPOT satellite imagery and the roads coverage from existing topographic maps.

The rivers coverage, superimposed over the DEM, assisted the construction of the basic Branch Route System, (BRS), while the roads coverage guided the delineation of floodplains and their boundaries.

Plate B.1 shows the rivers and roads coverages for the North Central Region.

B.2.3.3 DEM

The DEM for the western part of the NCR was supplied by FAP19 and was based on the BWDB 1953-67 4" and 8" to the mile contour maps. The raw data spot elevations were at approximately 300m x 300m grid spacing.

Some areas within the western part of the NCRM, notably that between the Turag, Bangshi and Buriganga, were not covered by this grid and these areas were infilled with data from the National 1 km. MPO grid. There remain areas for which data are not available, and these areas were identified in map displays as having no data.

The DEM was modified along the alignment of river channels, (obtained from the rivers coverage), by reducing the value of the elevations to -10m. This level is well below dry season flow level and ensured that the river channels could be easily identified in the DEM at all stages of flow and would always show as deep water on flood maps.

Plate B.2 shows the full NCR DEM with rivers added for clarity. The north west to south east drainage pattern can be clearly seen on this representation.

B.2.3.3 Supplementary Surveys

With the emphasis on output placed on the floodplain behaviour, it is important to realistically model the water exchange between the river and floodplain. This exchange takes place through the network of intersecting khals and over river embankments or natural levees.

It was already clear from inspection of the DEM, that many of the rivers included in the FAP25 NCRM were located along ridges of higher ground, these ridges gently sloping into the floodplain. A more detailed description of the elevations of these natural levees was needed in order to set up the river/floodplain linkages.

Surveys of the longitudinal profile of river embankments were commissioned. For practical reasons, not all rivers could be included in these surveys, and therefore only those rivers judged to exert major influence on regional flood behaviour were selected. Those rivers surveyed are identified in Table B.2, (chainages refer to those used in the MIKE11 models).

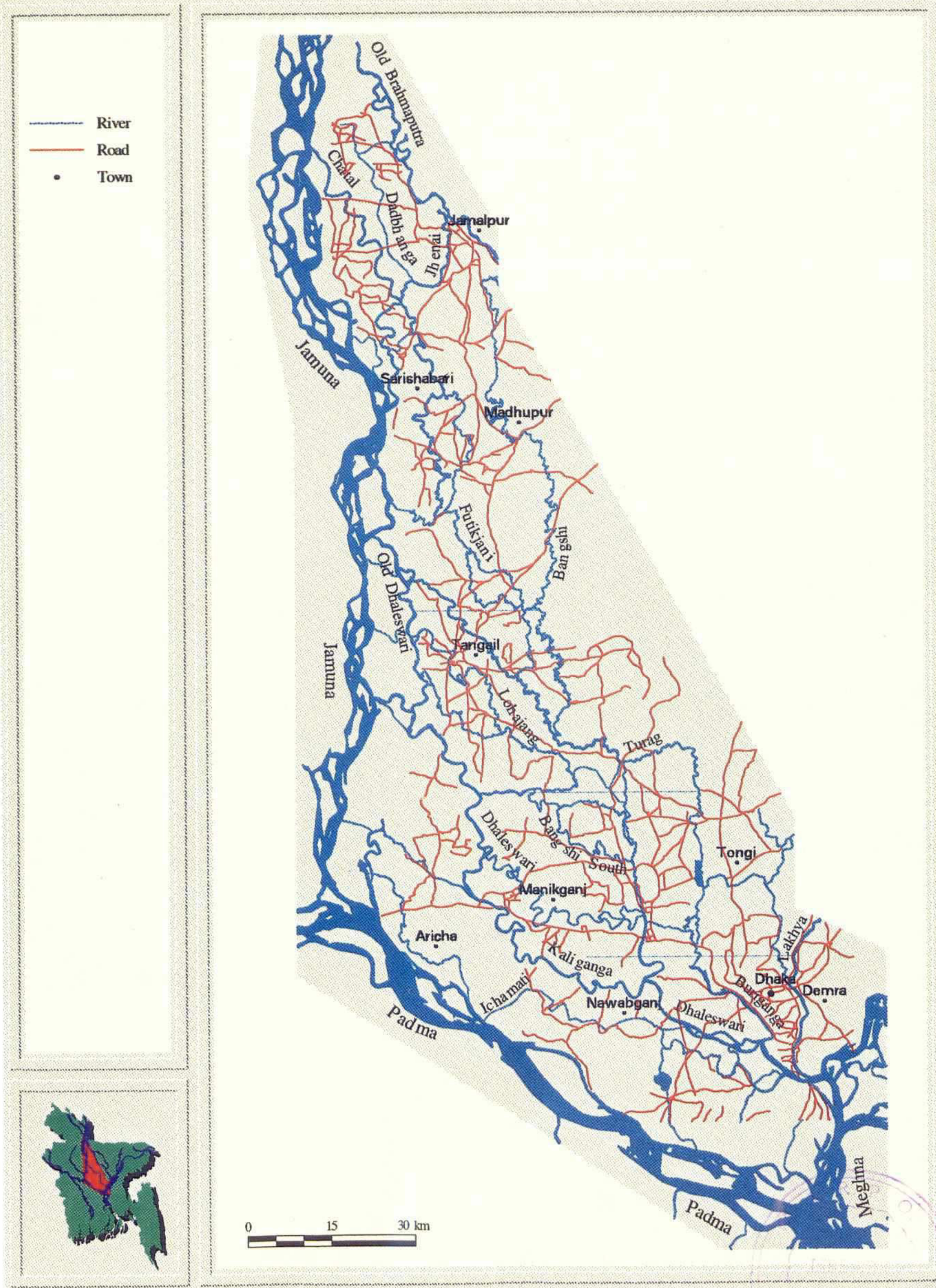
Table B.2 River Embankments Surveyed

	Chainage (km)	
River Name	**From**	**To**
Futikjani	30.0	43.0
Bangshi	0.0	202
Dhaleswari	52.0	120.0
Turag	0.0	75.0
Buriganga	23.0	40.0
Barinda	0.0	30.7
Dhantara Khal	1.0	14.25
Bangshi South	31.0	70.6
Kaliganga	0.0	73.0

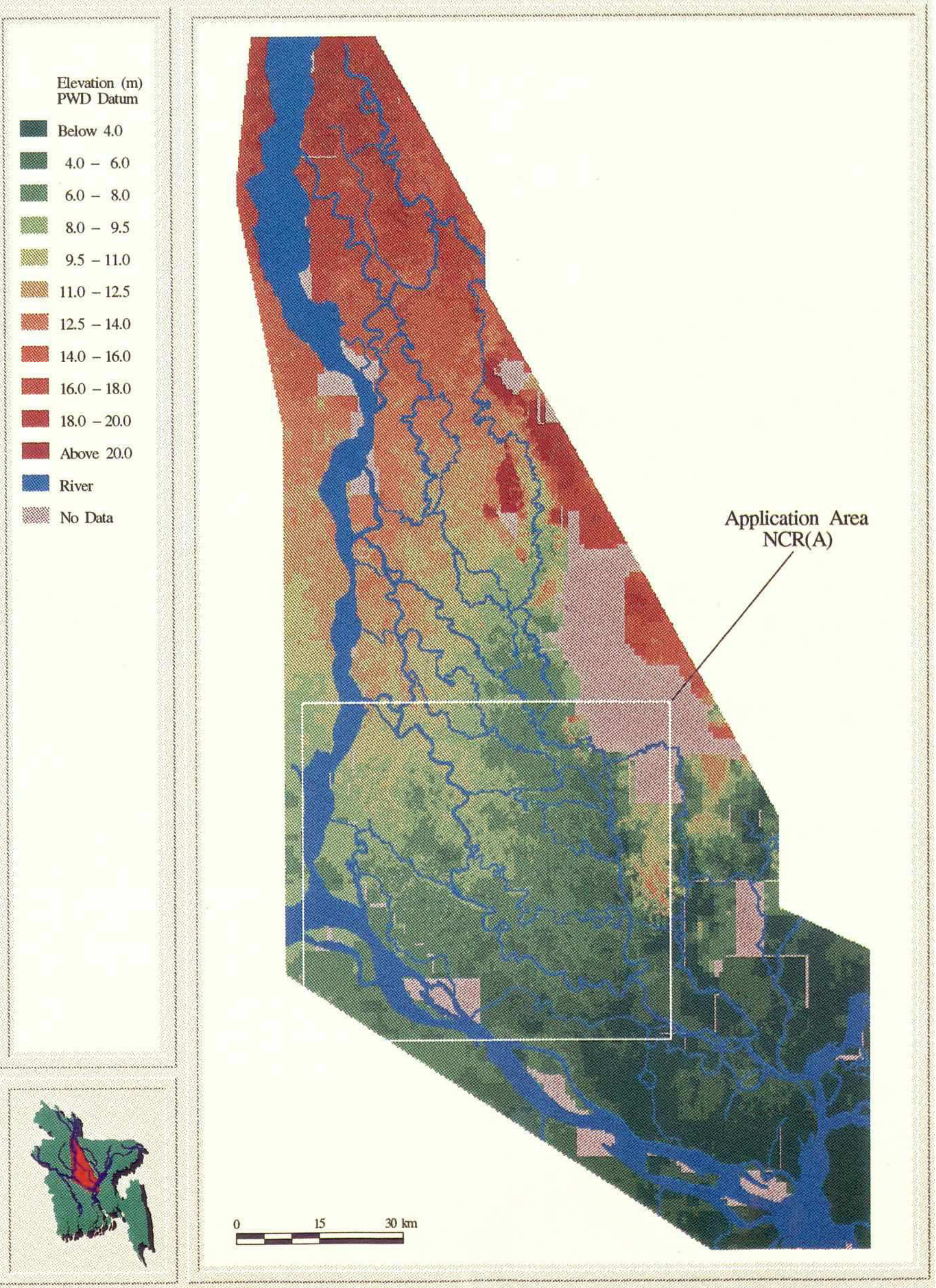
Spot levels were obtained at 100 metre intervals along the top of the embankment, (or highest natural levee elevation, as appropriate). When the line of survey was intersected by a khal, the width and bottom elevation of the khal were recorded. In addition, every 1000 metres, transects of 200 metre length were taken into the adjacent floodplain. This latter exercise served to confirm the relative elevations of floodplain and embankment. The Report *Hydrologic and Topographic Measurements - 1993, Volumes 1 and 2*, describe these surveys in detail.

It cannot be expected that all embankment level variations be included in the regional model, nor can each and every khal be represented. Such features are "lumped" together such that they are represented in overall effect, if not in precise detail. Sub-regional, or compartment models would probably fully describe these features.

NCR River and Road Coverages



NCR DEM



Elevation (m)
PWD Datum
Below 4.0
4.0 – 6.0
6.0 – 8.0
8.0 – 9.5
9.5 – 11.0
11.0 – 12.5
12.5 – 14.0
14.0 – 16.0
16.0 – 18.0
18.0 – 20.0
Above 20.0
River
No Data
Application Area
NCR(A)
0
15
30 km

B.2.4 Construction of FAP25 NCRM

B.2.4.1 General

In revising the structure of the SWMC NCRM, the amount of detail to represent for flood mapping purposes becomes a major issue. The flooding patterns in the North Central Region are very complex because of the very extensive network of secondary embankments that have been constructed throughout the region which modify the natural topography. It is not feasible to include details of all such embankments due to the amount of additional survey needed to collect information and the size and complexity of the model that would be needed to include the details. Regional modelling therefore becomes a trade-off between the time and resources available for surveys and data collection and the "accuracy" of the subsequent modelling results. This is particularly relevant when modelling floodplains in areas with topographic characteristics found in the North Central Region.

The basic schematisation of the river network in the FAP25 NCRM closely follows that of the western part of the SWMC NCRM, upon which it is based. The major difference is the inclusion of parts of the Jamuna, Ganges, Padma, Lower Meghna and Arial Khan in the setup. In addition, lateral discharge inflows were introduced to represent the contribution of the Teesta and Atrai. Table B.3 shows the chainages of each major boundary river now included in the FAP25 NCRM. The Arial Khan and Upper Arial Khan are included as they are major offtakes from the Padma and their exclusion might result in incorrect description of the flow conditions at the Padma/Meghna confluence.

Table B.3 Boundary River Details

River	Upper Chainage (km)	Lower Chainage (km)
Jamuna	37.1	235
Ganges	54.0	119
Padma	0	104
U. Meghna	88.57	125.2
L. Meghna	0	21.75
U. Arial Khan	0	34.1
Arial Khan	0	56.35

The external boundaries on the major rivers were chosen at suitable corresponding chainages in the General Model, at which discharge or water level values were simulated with runs of the GM.

Plate B.3 shows the Branch Route System and the boundaries of the FAP25 NCRM related to the regional BRS. Floodplain branches and links, added during restructuring, are shown in red and green, respectively.

Flows into the region from the Jamuna are ungauged. The magnitude of these discharges are controlled by the morphological conditions at the offtakes, which changes from year to year. In order to match the water levels internally, structures are sited at the offtakes, their geometry determining the flow conditions.

The physical characteristics of the western part of the NCR were reviewed to enable a more appropriate description of floodplains to be incorporated in the FAP25 NCRM for flood mapping purposes.

Topographic data provided by the DEM was used to appreciate the physical characteristics of the floodplain, supplemented by a coverage in the GIS of the major roads of the region. Using this information, it was possible to judge whether a floodplain should be considered as simple off-stream storage, interconnected flood cells or be treated as a major flood pathway, (floodplain types FP2, FP3 or FP4, as described in *Reference Manual and User's Guide*, Chapter 4).

By displaying both the DEM and rivers coverage, shown in Plate B.2, a visual impression of the topographic variations in the floodplain was obtained. One-by-one, the floodplains were inspected, this visual, 2-dimensional information being enhanced by selection of profile lines in any direction along the floodplain. The displayed profiles showed the general trend of the floodplain topography. Supplementing this information with the main road coverage showed the probable location of constrictions to the floodplain flow. It was assumed that major roads were constructed on higher ground or embankments; an assumption that was clearly verified when the roads coverage was superimposed on the DEM.

In general, smaller floodplains were treated as flood cells, (FP2). In such cases, floodwater was assumed to move into storage onto the floodplain through links from the surrounding rivers.

In areas where the floodplain topography showed few constrictions to flow, the floodplains were treated as separate branches, behaving in a similar way to the river channels, (FP4).

The model represents floodplains in FP2, FP3 and FP4 types, according to the conditions prevailing along each reach.

B.2.4.2 Floodplain Cross Sections

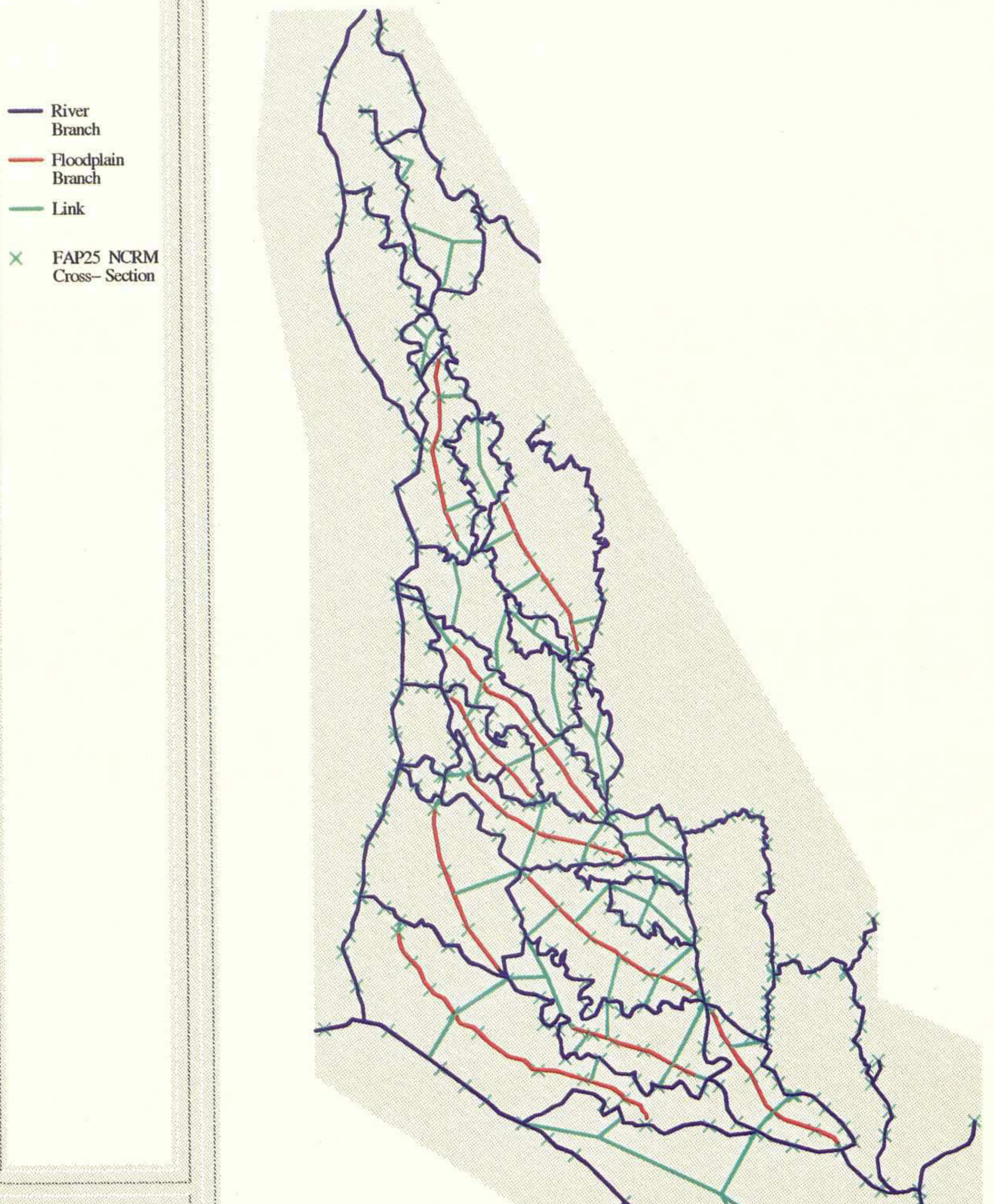
It is important for modellers to appreciate the importance of selecting suitable locations for cross sections and the implications on hydraulic simulations of their choice. The limitations of the DEM to supply all data needed for the selection of cross sections should also be noted.

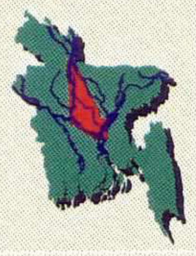
If the floodplains are represented as branches, their modelling should be approached in the same way as river channels. As in river channels, flow conditions are influenced by the size of the cross section and the slope of the channel. Cross sections should therefore be chosen at representative locations.

All floodplains should be schematised such that they have the ability to drain. In the case of a floodplain schematised as a branch, this drainage can either take place at the "downstream" end or through lateral links, or a combination of both.

Floodplains in the North Central Region are relatively flat and some cross sections show little variation across their width. Thus the actual depth of the section used is often quite small compared to the possible depth of floodwater. When floodplain cross sections are

NCR Branch Route System





imported into MIKE11, they should be processed so that their "banks" extend above the peak flood levels.

The DEM provides much of the data needs for floodplain modelling. However, it is equally important to verify certain features which may not be included in detail, such as embankments, roads, culverts and other smaller watercourses not included in the MIKE11 model. The alignment of the linear features could be represented in the DEM, but often with no knowledge of their elevations. It is therefore necessary to supplement the DEM data by further surveys to provide this information.

It is not always necessary to carry out a detailed topographic survey of secondary embankments. A sensible estimate of their elevation relative to the adjacent floodplain is often sufficient. Evidence of the existence of secondary embankments can be obtained by a study of the secondary road network, (as a GIS coverage), since it is reasonable to assume that such roads will be sited on some form of embankment. Other embankment locations may be found from FCD project documents.

Location and alignment of minor watercourses can be obtained from aerial photography or satellite imagery. These minor watercourses will often give valuable insight into the movement of water on the floodplain and can help in determining their appropriate schematisation. It is generally not appropriate for regional scale modelling to include such watercourses in the model.

B.2.4.3 Floodplain Storage

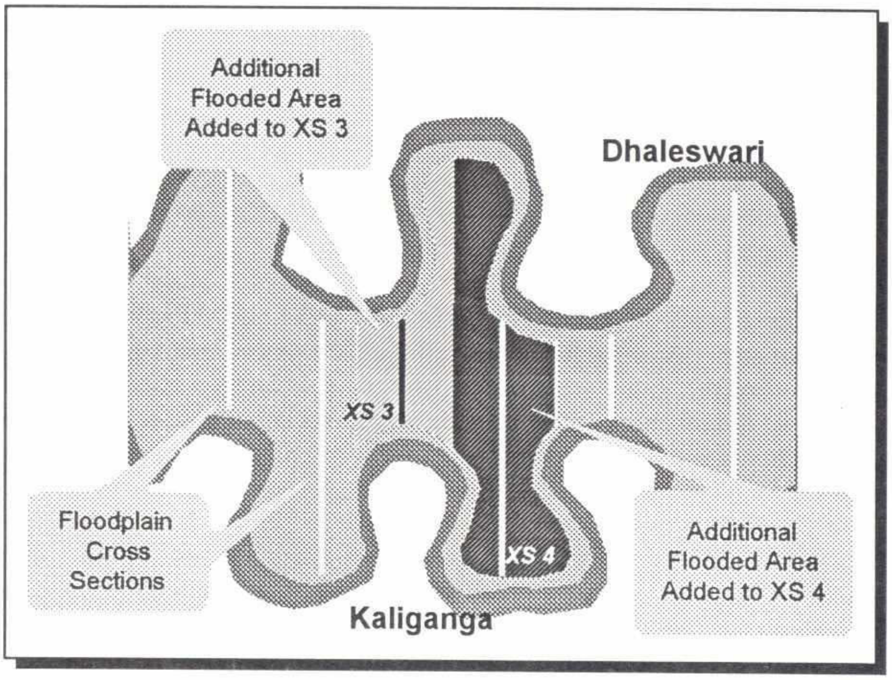
Floodplain storage is represented in the FAP25 NCRM by schematisation of flood cells.

Visual display of the DEM is an important tool in the determination of flood cell delineation. By careful selection of the appropriate contour interval and display colours, identification of areas with typical flood cell configurations becomes simpler, although some judgement is still required. Choosing an appropriate contour interval is a matter of experience and depends on the general topographical variation of the floodplain. In the NCR a contour interval of approximately 1.0 metre was found to give satisfactory definition.

Floodplain storage between two significantly meandering rivers, such as the Dhaleswari and Kaliganga where the size of adjacent cross sections can vary greatly, is best treated as additional flooded area attached to floodplain conveyance cross sections, as shown in Figure B.3. In these cases, the cross section storage width is set to zero, (see Reference and User's Guide . Delineation of these Additional Flooded Area Cells is done in the same way as that for Flood Cells, the storage volume calculated using area-elevation curves.

Plate B.4 shows the location of floodplain cross sections in the application area, with the areas considered as flood cells marked in light blue.

Figure B.3 Allocation of Storage to Floodplain Cross Sections



B.2.4.4 Link Structures

The movement of water to and from the river and floodplain takes place through short branches in the MIKE11 model called Link Structures. They are probably the most crucial element in quasi 2-dimensional modelling of the North Central Region. Their shape, size, elevation and location determine the magnitude and timing of the river/floodplain water interchange.

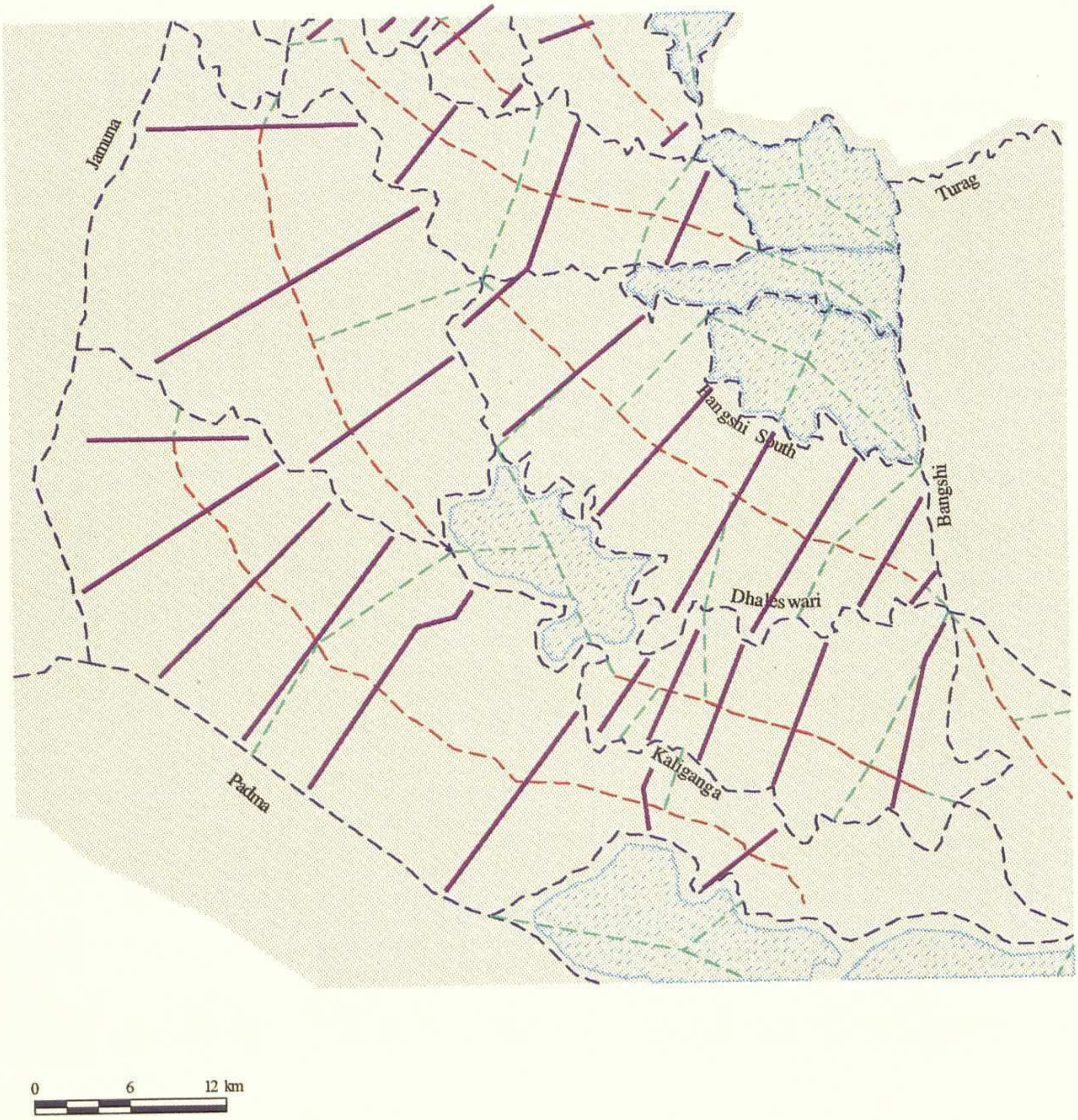
Link structures have been developed which include provision for the sloping nature of levees and which incorporate their frictional resistance properties. Their location, size and shape were based on the supplementary surveys of the river embankments and natural levees, carried out as part of the project. In situations where no data was available, the DEM was used to provide the required information.

The surveyed profiles of the embankments were treated as cross sectional data and were entered into the MIKE11 database as such. The processed data gave composite widths at certain elevations for each section of the embankment.

When entering survey data of the embankment, it is important to identify elevations which represent khals or other low breaks in the embankment. The detail required for links relate to the general overspill level and not to any low level inlets. These low level inlets are incorporated into the links, but considered as independent structures, although their size and shape is determined using the same methodology as that for the overspill links, (see *Reference Manual and User's Guide*, p.4-15).

83

NCR(A) Storage Cell and Cross Section Coverages



- XSC Cross- Section Line
- SCC Storage Cell
- River Branch
- Floodplain Branch
- Link

With the level of detail incorporated in the regional scale model, it is not possible to locate links precisely, since they represent a "lumped" description of the overspill characteristics of a length of embankment. The modeller must use both the information available from surveys and DEM, together with his judgement in defining the most suitable locations.

Khals are treated as open long culverts for regional modelling, but for sub-regional modelling they would probably be included explicitly in the river network by cross sections. Using the concept of open long culverts permits the simple simulation of the khal length and conveyance properties.

It is good practice to add a simple open culvert structure to a link, any adjustment is then only made to the culvert, the link geometry remaining the same. In addition, multiple culverts may be inserted in any link, making calibration adjustments easier.

A link is a structure, and the more structures incorporated, the longer the model computation times. Therefore, every effort should be made to try to reduce the number of links in the regional model to the minimum consistent with satisfactory calibration and performance. The FAP25 NCRM contains 100 links and 15 culverts, operating in combination.

B.2.5 Calibration of FAP25 NCRM

B.2.5.1 Introduction

The overall calibration of the FAP25 NCRM may be regarded as being adequate for the purposes of this project. It may be applicable for the "Planning Cycle" but not for the "Design Cycle", (Volume 1 pp. 1-8, 1-9). The main function of the FAP25 NCRM was to provide a platform for the demonstration of FMM on a regional basis. This required a suitably structured model which could give a realistic, (but not necessarily specifically accurate), representation of regional flooding.

Calibration of the FAP25 NCRM commenced with the data of 1992. As further data for 1993 became available, calibration switched to this year because additional monitoring stations were installed for the 1993 monsoon.

B.2.5.2 Rivers

It was noted that using the initial setup, based on 1992, but using 1993 data, water levels and discharges within the region were generally far too high. It was reasoned that the offtakes from the Jamuna had become more constricted as a result of the dry monsoon season in 1992. Since the model was constructed using pre-1993 cross sections, (which showed a larger offtake section), any given water level in the Jamuna would result in more water being passed into the region.

To overcome this, and for the purposes of this project only, the offtake geometry was slightly constricted to improve the representation of the 1993 flood conditions.

The additional hydrometric survey in 1993 provided valuable comparison data for this year. Anomalies in the original SWMC model could be resolved in some locations, but the area around the Bangshi-Futikjani confluence remains inconclusive. Simulated water levels in this area are still too high. Cross sections of the Hai River and Mirzapur Khal look somewhat suspect when viewed in long section. It appears that there could be a datum error in the original survey. Such possible errors had to be overlooked in the calibration exercise because no resources were available to rectify the datum error. Figures B.4 to B.6 are included as examples of the FAP25 NCRM calibration in the area defined for applications.

Simulation of the water levels in the Dhaleswari/Kaliganga area is quite acceptable. 1993 water levels show divergence after mid-August and this may be due to the offtakes opening up after initial high Jamuna water levels. Discharge simulation is quite good, given the uncertainty in the inflows from the Jamuna. Likewise, the Pungli water level and discharge simulation is excellent. Some uncertainties remain in the vicinity of the Lohajang/Bangshi confluence which still cause higher water levels and discharges than recorded.

B.2.5.3 Floodplains

Calibration of floodplain flooding is particularly difficult, given the scarcity of any reliable comparison data. Installation of a number of floodplain gauges in the region during the 1993 monsoon presented the only quantitative evidence. Unfortunately, as discussed in the section on hydrometric data, the choice of location and number of these gauges is questionable when modelling on a regional scale.

It is inherent in regional modelling that given local variations in floodplain flooding details become lost. The modeller then has to use his subjective judgement as to whether or not the model representation is satisfactory. Flood maps created with FMM can themselves be used to assist in the calibration process. A particular setup can be applied, the model run and the resulting flood map examined. Flood extents mapped can then be compared with local knowledge and possibly radar imagery, if available. The latter method, while still in its early stages, promises to be the most useful tool for floodplain calibration in the future.

The incorporation of floodplains and links into the model adds another dimension to calibration. This also provides the modeller with additional flexibility when calibrating. Link channel geometry can be adjusted to increase or reduce the volume of flood water leaving the river and therefore calibration of discharge in rivers is generally enhanced. This also applies to the drainage behaviour of the floodplains, where appropriate settings for the low level culverts can model the drainage back into the river more realistically.

B.2.5.4 Present Model Status

The present FAP25 NCRM now presents the modeller with the ability to simulate the different flood characteristics resulting from construction of embankments of different heights, which was not possible with earlier 1-dimensional models.

Joining the General Model cross sections of the Jamuna with the North Central Regional Model presented problems with suitable simulations of the Jamuna river levels. The use of an upstream discharge boundary on the Jamuna resulted in water levels approximately 1m higher than observed. Changing this upstream discharge boundary to a water level boundary reduced the increase, but a discrepancy of up to 75 cm still remains. It is possible that the General Model oversimulates the spill into the region through the artificial channel and the resulting roughness assumed for the Jamuna cross sections is therefore too high. Further investigation of this is needed in the General Model to determine the full implications on the existing calibration.

Since the area chosen for demonstration of the application of FMM was located in the south west of the region, little emphasis was placed on the calibration in the Jamalpur area. In addition, new topographic information for Jamalpur has now been made available which should be incorporated into the regional model for better simulation of this area. The incorporation of this new topographic information may result in the need for a revision of the location and geometry of the links between river and floodplain.

The Bangshi has been simulated with an upstream observed water level boundary. Every effort should be made to obtain a discharge boundary for this river by means of field measurements and subsequent derivation of a stage/discharge relationship or an improved NAM output.

Simulated water levels are too high in the Bangshi/Futikjani confluence. Checks should be made on the surveyed cross section data for the Hai River, which appears to have a very high bed level relative to the other rivers in the area.

Discharge simulation in the Barinda and Dhantara Khal can probably be improved. The geometry of the cross sections at the bifurcation of the Bangshi South and Barinda should be checked to ensure proper discharge distribution at this point.

Despite the remaining discrepancies in the FAP25 NCRM, it represents a major improvement over past 1-dimensional models for use in regional planning, where an overview of flood characteristics is required. For more specific feasibility and design tasks, however, more detailed sub-regional models will be needed. The regional model may then be used to give an overview of possible regional implications of any individual or group of sub-regional schemes and provide boundary conditions for such schemes.

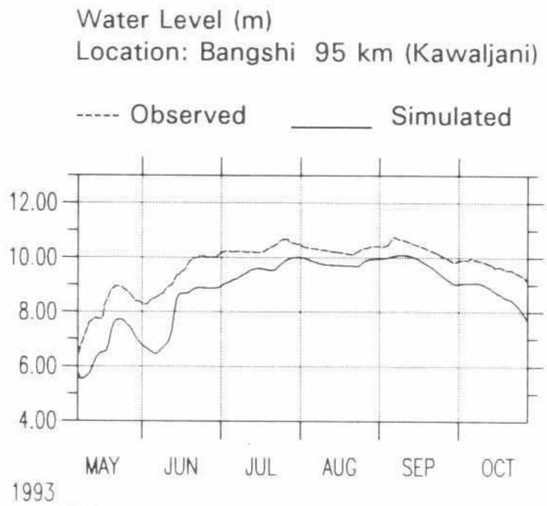
B.2.6 Flood Maps

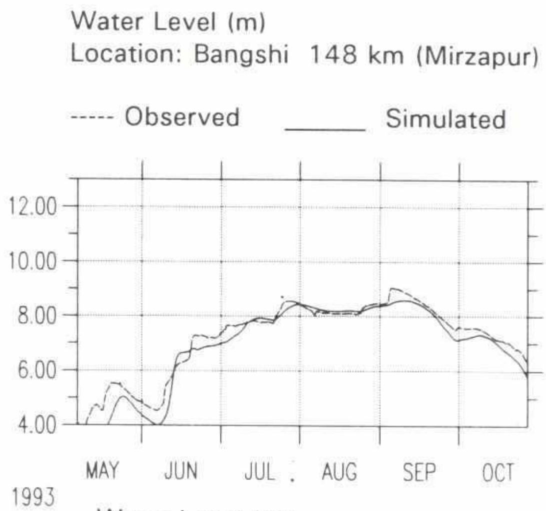
B.2.6.1 Water Surface Coverage

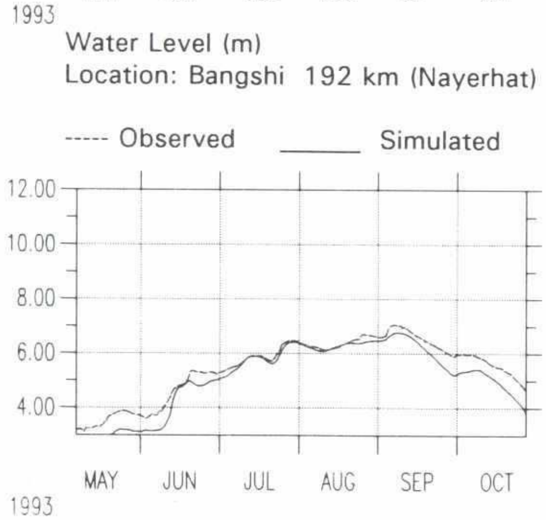
The final interactive stage prior to the production of flood maps is the construction of the WSC. This activity involves the delineation of river channel boundary lines, flood cell boundaries and water level lines. The precise methodology for this is described in the *MIKE11-GIS Reference and User's Guide*.

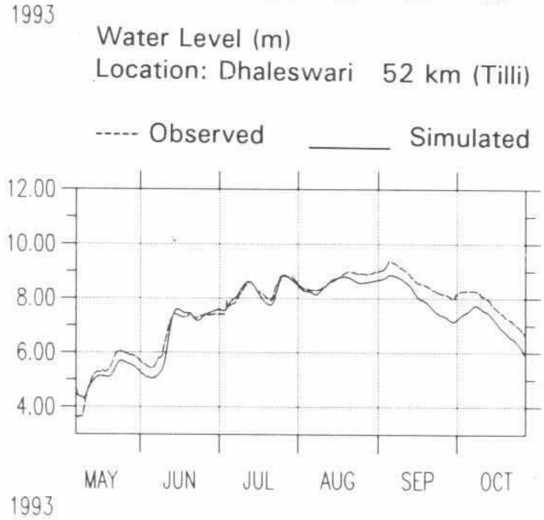
Applying the techniques to regional modelling is quite straightforward, provided the basic procedures are followed and the user has sufficient experience to appreciate the way the water levels are interpolated in MIKE11-GIS.

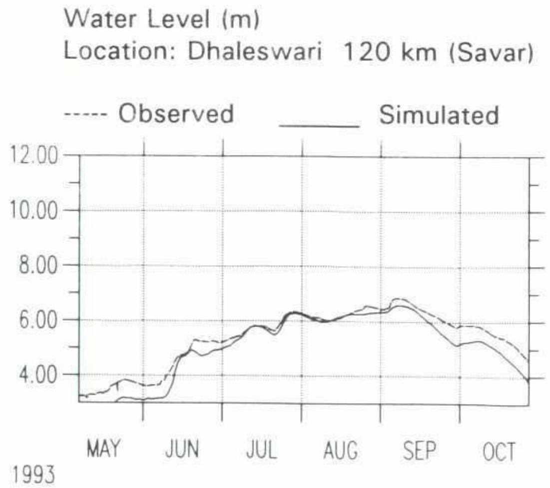
Figure B.4 Sample FAP25 NCRM Water Level Calibration 1993











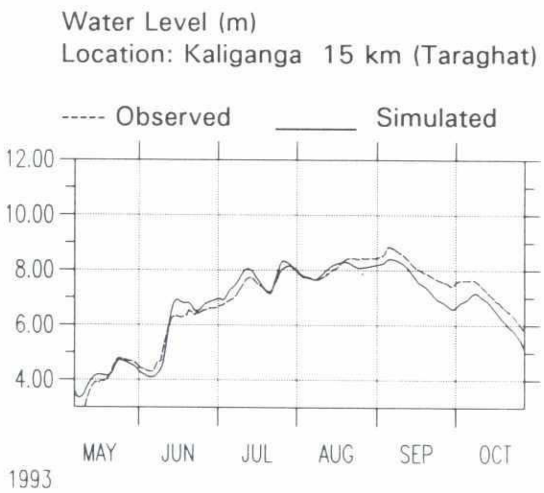
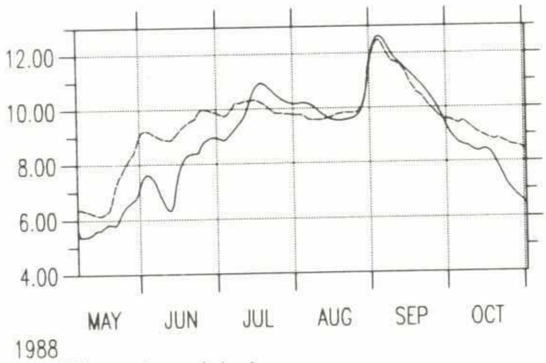


Figure B.5 Sample FAP25 NCRM Water Level Calibration 1988

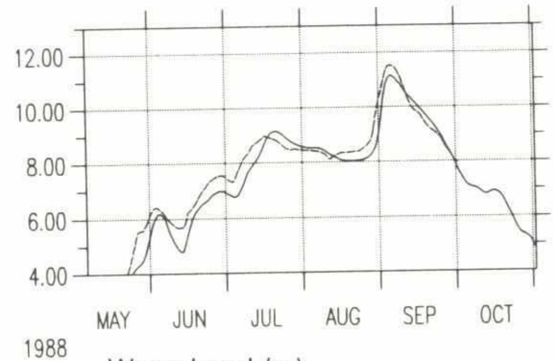
Water Level (m)
Location: Bangshi 95 km (Kawaljani)

----- Observed ______ Simulated



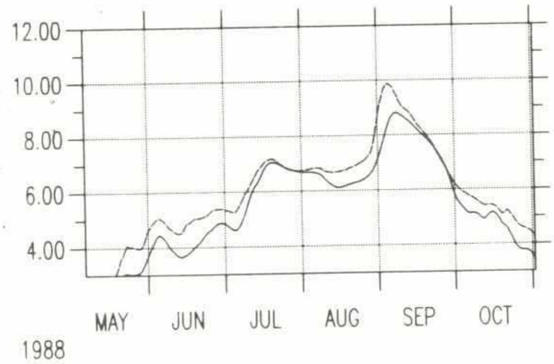
Water Level (m)
Location: Bangshi 148 km (Mirzapur)

----- Observed ______ Simulated



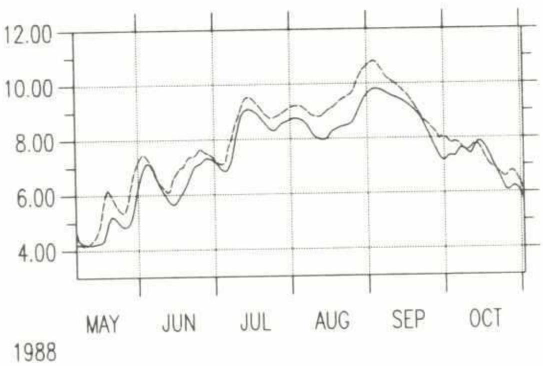
Water Level (m)
Location: Bangshi 192 km (Nayerhat)

----- Observed ______ Simulated



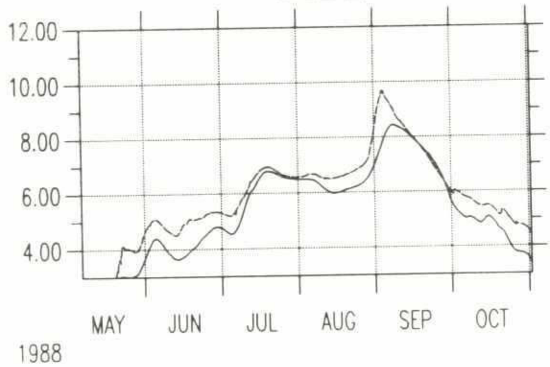
Water Level (m)
Location: Dhaleswari 52 km (Tilli)

----- Observed ______ Simulated



Water Level (m)
Location: Dhaleswari 120 km (Savar)

----- Observed ______ Simulated



Water Level (m)
Location: Kaliganga 15 km (Taraghat)

----- Observed ______ Simulated

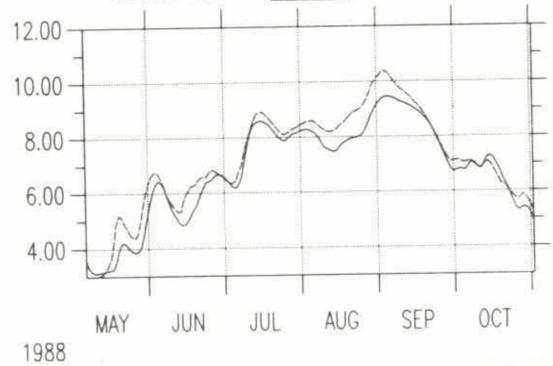
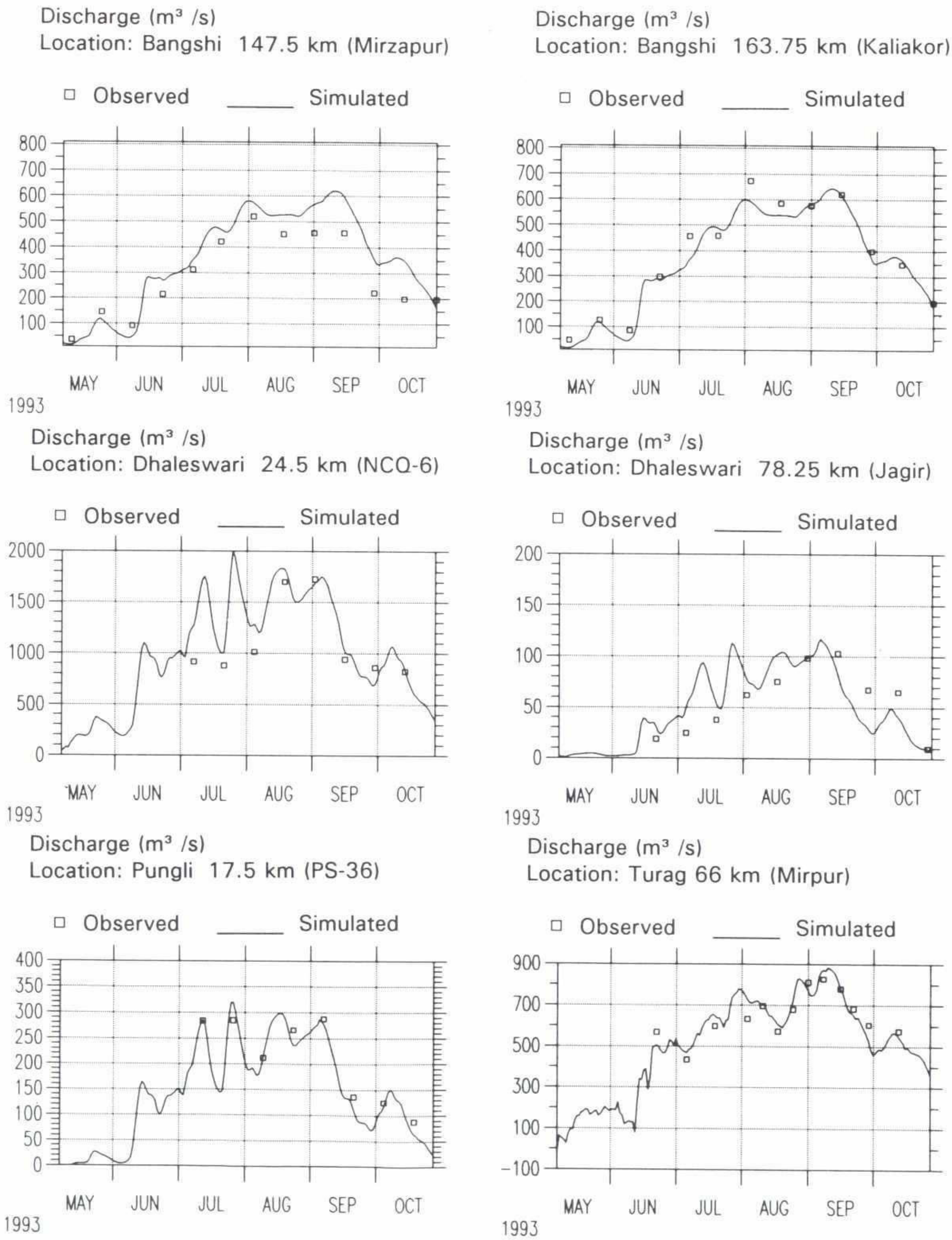


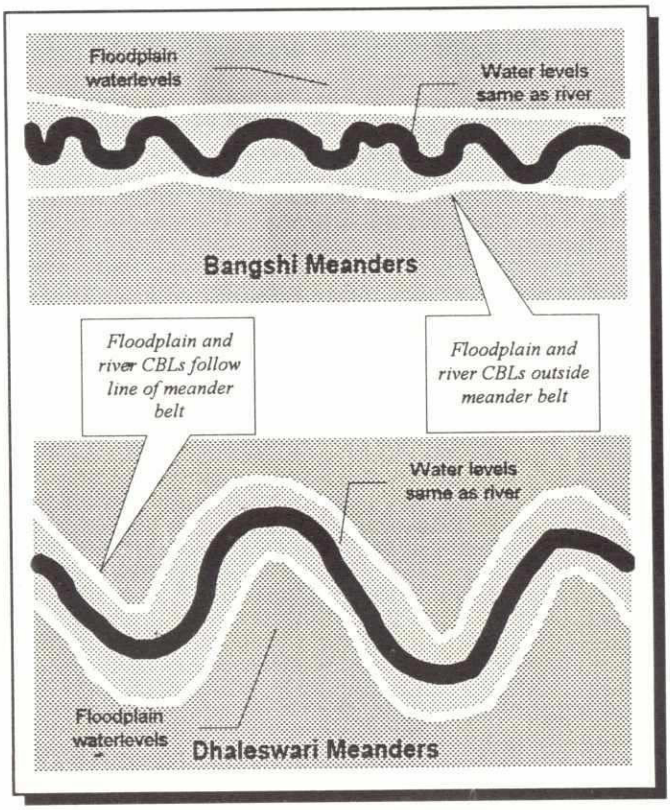
Figure B.6 Sample FAP25 NCRM Discharge Calibration 1993



Water levels in flood cells are always horizontal and these do not generally pose problems. Floodplain branches, conveying water with a surface slope, are slightly more complex. In defining the extent of the Channel Boundary Line, (CBL), for the floodplain, consideration should be given to whether a particular area is influenced by river levels or floodplain water levels. If the former is the case, the area should be included within the river CBL, whereas for the latter case, the floodplain CBL should include the area.

Dealing with the meander loops of the Dhaleswari and Kaliganga provides a good illustration of the above alternatives. The floodplain CBL and river CBL are virtually interchangeable and it depends on the alignment of the levee or embankment as to which one includes the land within the meander loop. When the river has "shallow" meanders, it is usually quite appropriate at regional level modelling to define the river CBL as the outer limit of the meander width, as was done on the Bangshi, for example, (upper diagram Figure B.7). With significant meander width rivers, such as the Dhaleswari and Kaliganga, it is more appropriate to follow the alignment of the river for the river CBL, as shown in Figure B.7, lower diagram.

Figure B.7 Alternative CBL Alignments



Insertion of Water Level Lines, (WLLs) for river and floodplain branches for the regional model follows the normal procedure. Spacing of WLLs at this scale is appropriate at approximately 1 km. Any closer spacing, unless locally justified, is not worthwhile and simply increases the computation time.

Plate B.5 shows the water surface and storage cell coverage for the part of the region selected for demonstration of applications.

B.2.6.2 Flood Depth Maps

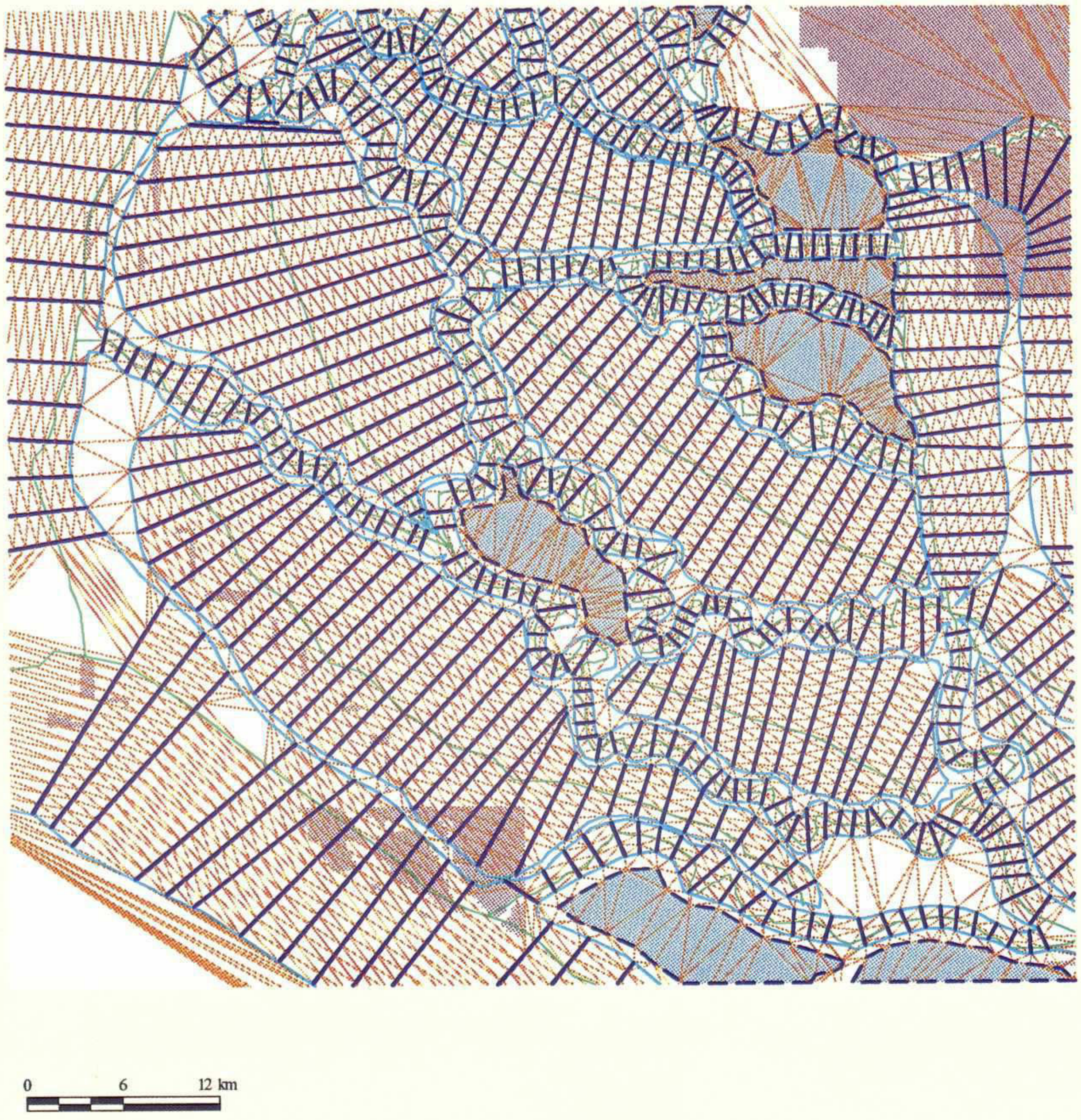
The restructured MIKE11 model, (FAP25 NCRM), was run for 1988 and 1993, producing 2 sets of basic simulation data in the respective models. Using the NCR-FMM, flood depth maps were produced for the western part of the North Central Region.

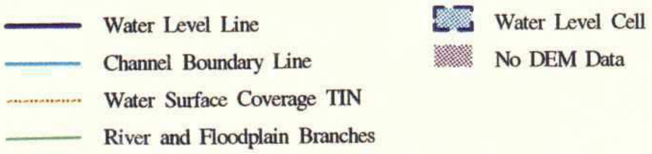
Plate B.6 shows the inundated area at the peak of the flood for each year, which occurred in September in both years. The accumulation of floodwater in the lower south east of the region can be clearly seen on each map. The high levels prevailing in the Meghna and Padma prevent free drainage from the region.

Plate B.7 shows the extent of flooding in September for both 1988 and 1993 expressed in terms of the MPO flood phase categories.

TCII

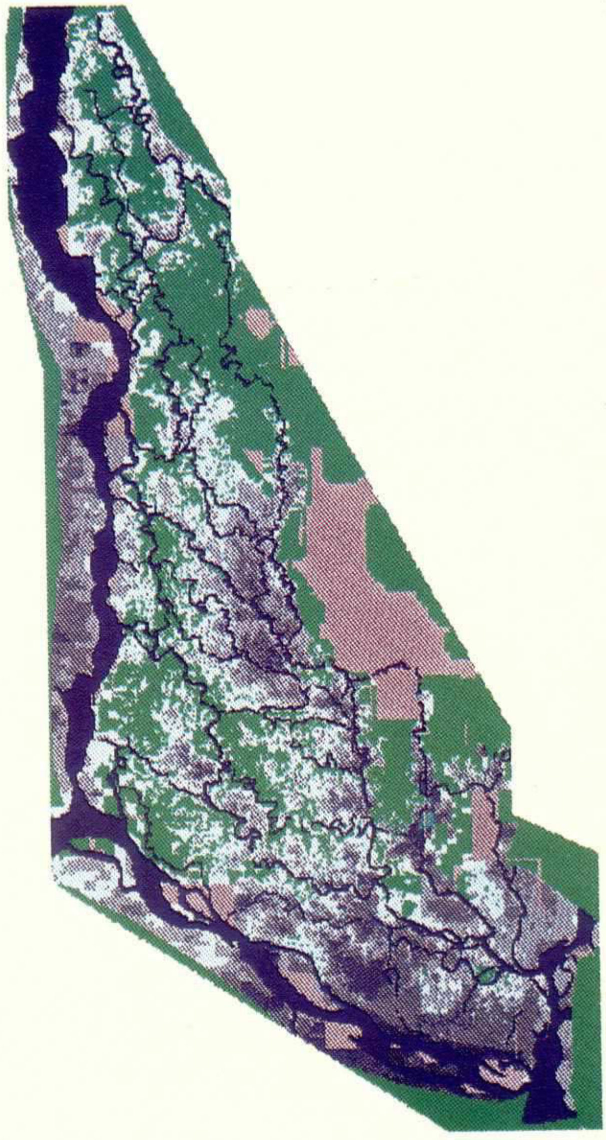
NCR(A) Water Surface Coverage



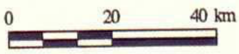


Simulated 1988 and 1993 Flood Depths

September 3, 1988



September 7, 1993

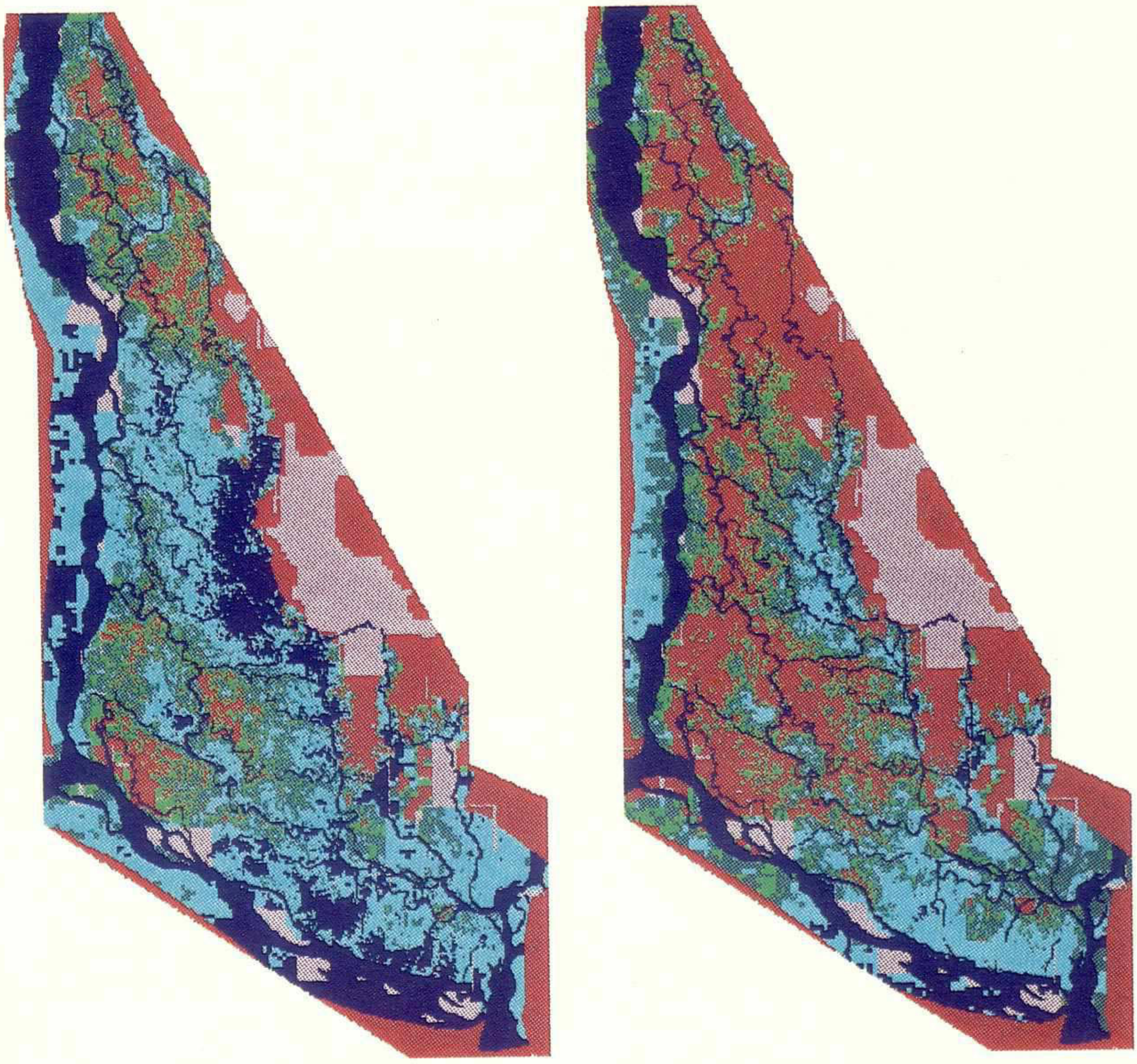


Depth (m)

- 0.00 – 1.00
- 1.00 – 2.00
- 2.00 – 3.00
- 3.00 – 4.00
- 4.00 – 5.00
- Above 5.00
- Flood Free
- No DEM Data

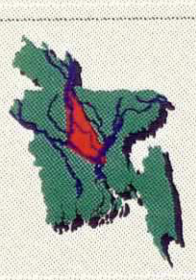
89

1988 and 1993 Flood Phase Classes



September 3, 1988

September 7, 1993



Flood Phase

- F0 (< 0.3 m)
- F1 (0.3 – 0.9 m)
- F2 (0.9 – 1.8 m)
- F3 (1.8 – 3.6 m)
- F4 (> 3.6 m)
- No DEM Data

85

B.3 APPLICATION OF REGIONAL FMM

B.3.1 Introduction

The objective was the demonstration of the uses of FMM on a regional scale, by showing how it might be applied within the context of the type of FCD schemes considered under the Flood Action Plan.

It is most important that the results and maps produced in the following application demonstrations are not misinterpreted. With little calibration data presently available for the simulation of floodplain water levels, the accuracy of the maps, graphs and tables produced in the following application demonstrations reflect the present uncertainty in these areas and they should be considered as appropriate for planning purposes only. They do, however, highlight the very powerful tool that FMM provides in the appreciation and analysis of floodplain inundations. Future users of FMM, if they seek greater accuracy, will need to devote adequate resources to further improve the basic calibration of the FAP25 NCRM. However, improving the inputs is all that is required: the analysis and presentation tools of FMM are already developed and are demonstrated in this section.

The demonstration of the NCR-FMM application has been based on an area in the south western corner, as shown on the location map, Figure B.8. The scope of the applications has been kept limited, concentrating on the flexibility of the output from FMM. They have been deliberately chosen to incorporate most of the elements that are likely to be encountered in FCD scheme modelling; that is, embankments, gates, culverts, weirs, drainage improvements. In addition, the use of FMM to show the possible effects of an embankment breach in a compartment is illustrated in the form of a time series of flood maps.

B.3.2 Base Model

Before the effects of interventions in the demonstration area can be shown, base flood maps were made for 1988 and 1993 for the monsoon peak in each year, (Plate B.6), based on the "existing" conditions.

Plate B.7 shows the same floods but expressed in terms of the MPO flood phase categories. In each case, flood maps of the application area were based on a 100m display grid in the DEM. This improved the quality of the output when producing maps to this scale.

These initial flood maps proved of great value in assisting in the basic calibration exercise. Inspection of the flood maps can reveal areas which exhibit unrealistic response, (flood free when it is known to be flooded, and vice versa). The MIKE11 model could then be adjusted to improve the representation of these areas.

B.3.3 Compartmentalisation

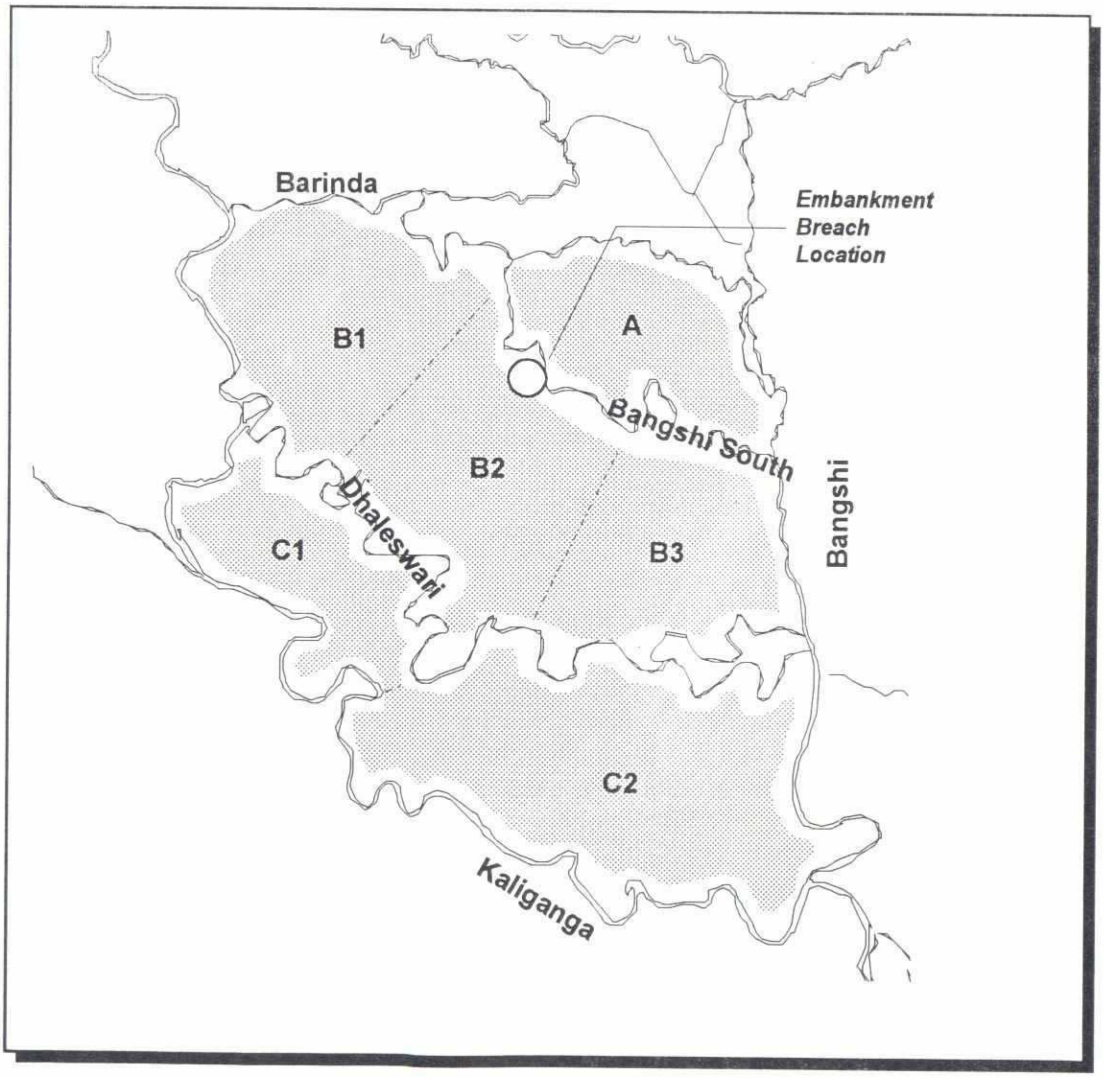
B.3.3.1 Concept

Compartmentalisation forms a central theme of the Flood Action Plan structural interventions. They contain almost all the possible construction elements that are required to be demonstrated; that is, embankments, gates, weirs, and drainage improvements. The demonstration application has not considered the operation of the compartments themselves, only the control of the external gates. This is in keeping with the purpose of FMM at a regional level.

B.3.3.2 Setup

It has been assumed that the compartments, (labelled A, B1, B2, B3, C1 and C2 on Figure B.8), are constructed on the floodplains between the area bounded by the Bangshi South, Dhantara Khal and Bangshi River, the Dhaleswari and Bangshi South and the Kaliganga and Dhaleswari. The surrounding embankments are of a sufficient height that they are never overtopped, but flood waters are permitted to enter and drain through a system of overshot gates, located on one or more links.

Figure B.8 Application Area - Location Plan



The gates are given an operational sequence such that they remain fully open until the second week in July to enable fish movement onto the floodplain. After this time they are closed and remain fully closed for the duration of the monsoon. All gates, however, are designed to drain water from the floodplain whenever the river level falls below that in the floodplain.

The compartment between the Dhaleswari and Bangshi South has been sub-divided into 3, (B1, B2 and B3 in Figure B.8), and that between the Kaliganga and Dhaleswari into 2, (C1 and C2 in Figure B.8). Flow between adjacent sub-compartments takes place through links and structures inserted between floodplain branches, but no specific override control has been imposed. It has been assumed that no improvement has been made in the hydraulic efficiency of the drainage channels into and out of the compartments.

Figure B.9 Model Setup for Compartmentalisation

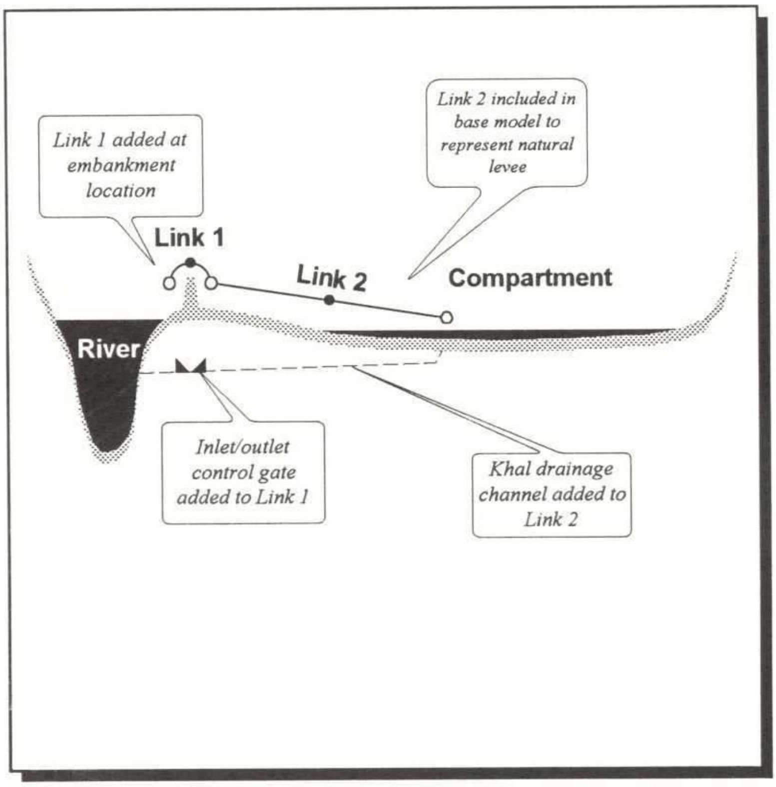


Figure B.9 shows the way the compartments have been linked to the rivers in the model, using multiple structures.

B.3.3.3 Output

MIKE11 computations were performed for 1988 and 1993 using the above model setup to represent the construction of the compartments. For each of the years, a flood depth map was produced, (Plates B.8 and B.9), based on the maximum level reached at each location. These Plates clearly illustrate the effect of a reduction in the volume of river flood water allowed into the compartments during the peak of the monsoon. The upper left map shows the flooding situation without compartments, while the upper right shows the "with project" situation. Most of compartments A, B1, B2 and C2 are now flood free, while the remaining compartments are flooded to a lesser depth.

A more emphatic illustration of these changes is shown as the lower map on Plates B.8 and B.9 which quantify the flood depth changes as a result of this intervention. Note should be made of the increase in flood level within the middle sub-compartment of the Bangshi South compartment, (B2). This is indicative of the presence of a low bund across the compartment which is restricting the flow. In the 1988 simulation, this is shown as a smaller reduction in levels, whereas the 1993 simulation shows a clear increase. This is because the flood levels were much higher in 1988. Flood depths are seen to rise slightly upstream of the compartments and in the adjacent river channels with no effect on river levels downstream.

Plate B.10 shows the 1993 case, with flooding expressed in terms of Flood Phase.

Table B.4 shows the 1993 flood depth statistics for each of the areas to be compartmentalised, (see Figure B.8). In this case, they are expressed as areas flooded for each selected depth range, assuming that no compartments have been constructed, (the "Without Project" case).

Table B.4 Flood Depth Statistics as Areas (1993 No Compartments)

Zone	Area sq.km	No Data sq.km	Dry sq.km	0-1m sq.km	1-2m sq.km	2-3m sq.km	3-4m sq.km	4-5m sq.km	> 5m sq.km
A	56.2	0	15.1	25.3	12.6	3.1	0.1	0	0.0
B1	66.4	0	48.6	15.0	2.72	0.0	0	0	0
B2	98.2	0	47.7	43.3	6.7	0.4	0	0	0
B3	121.1	0	20.8	51.3	34.1	14.2	0.7	0	0
C1	54.5	0	8.4	19.6	21.9	4.6	0.0	0	0
C2	157.8	0	34.9	73.0	39.6	9.5	0.6	0	0.2

Table B.5 shows statistics for the same situation but flood depths are expressed in terms of a percentage of the total area. Table B.6 shows the areal extent of the MPO Flood Phases for the "Without Project" situation.

From the Tables it can be seen that sub-compartment B3 has the highest amount of deeply flooded area, the extent of F3 land being approximately 21 km^2, or 17.5% of the total area of the sub-compartment.

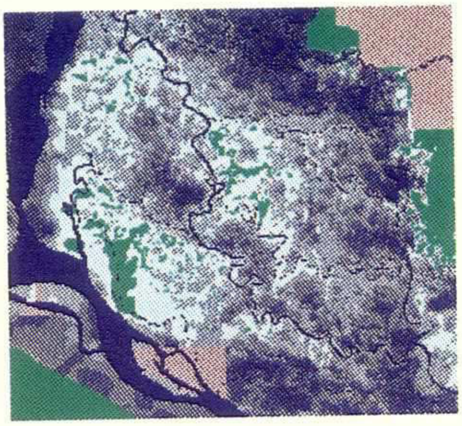
Compartmentalisation Impact on Flood Levels - 1988

Depth (m)
- 0.00 – 1.00
- 1.00 – 2.00
- 2.00 – 3.00
- 3.00 – 4.00
- 4.00 – 5.00
- Above 5.00
- Flood Free
- No DEM Data

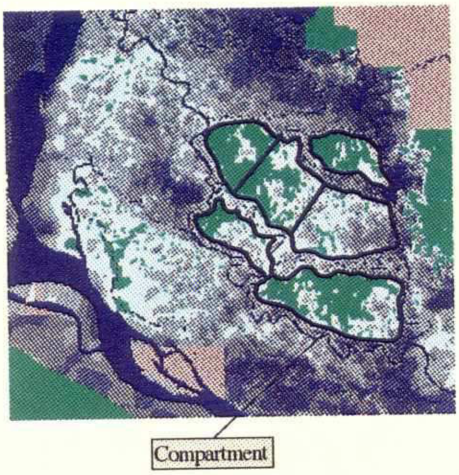
Flood Level Change
- None/Slight

Increase (m)
- Above 0.50
- 0.40 to 0.50
- 0.30 to 0.40
- 0.20 to 0.30
- 0.10 to 0.20

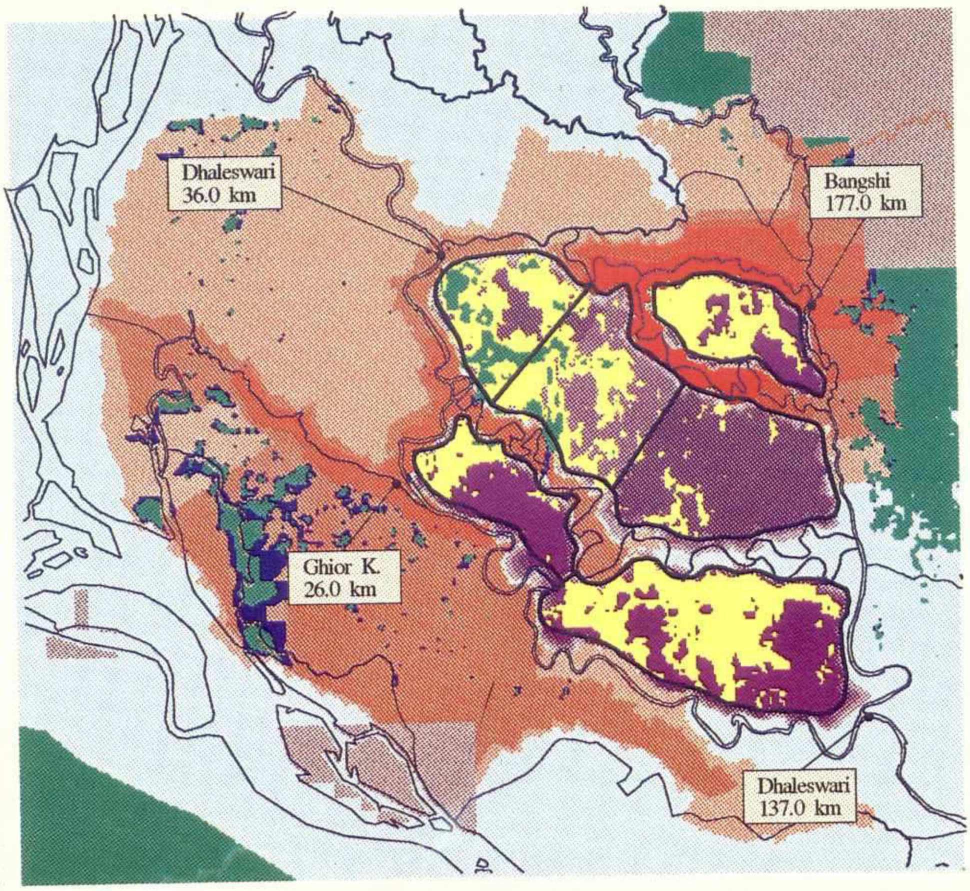
Decrease (m)
- – 0.10 to – 0.60
- – 0.60 to – 1.10
- – 1.10 to – 1.60
- Below – 1.60
- Now Dry
- Now Wet
- Flood Free
- No DEM Data
- River
- Compartment



Without Compartments
Maximum Flood Depths



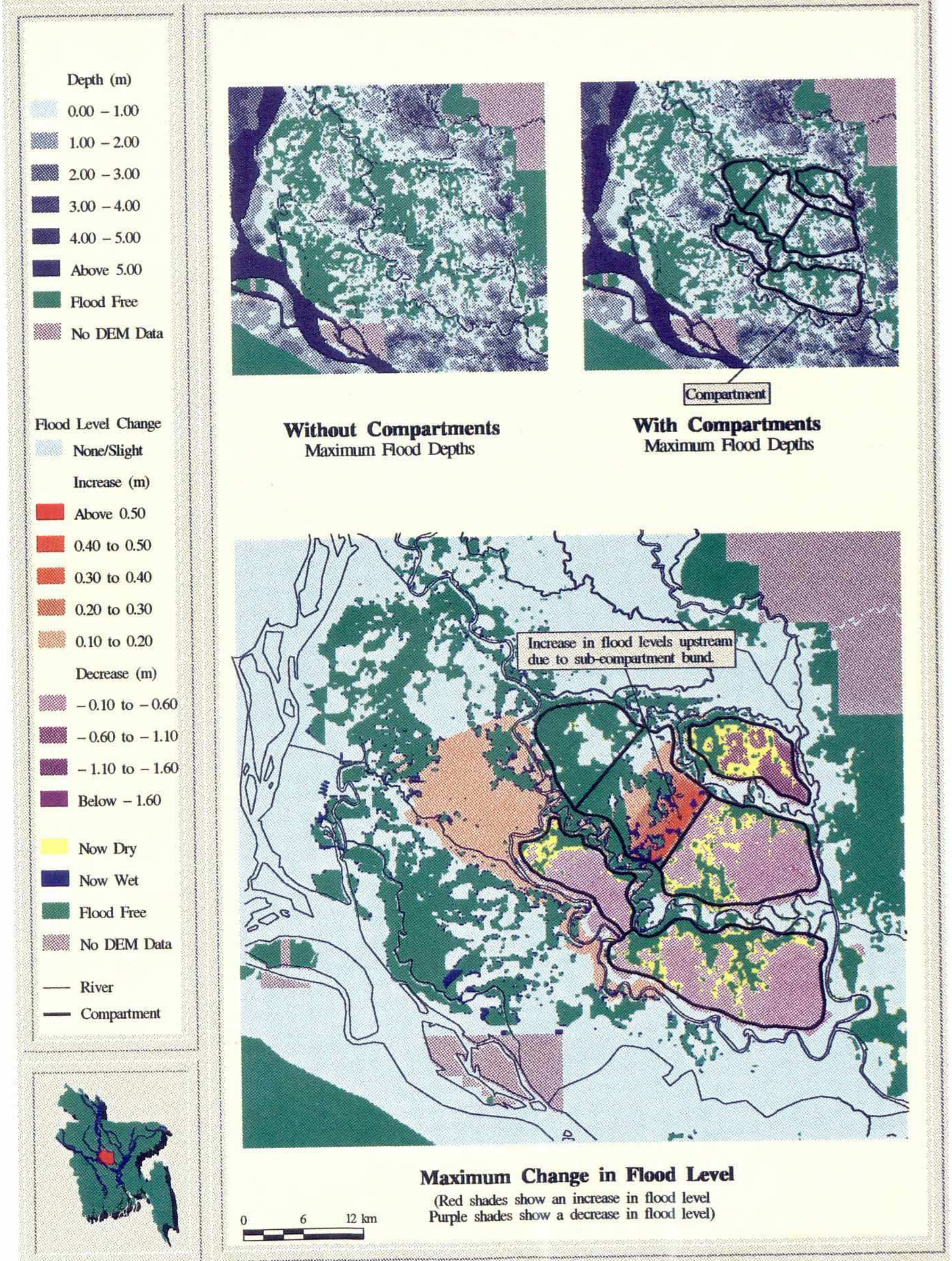
With Compartments
Maximum Flood Depths



0 6 12 km

Maximum Change in Flood Level
(Red shades show an increase in flood level
Purple shades show a decrease in flood level)

Compartmentalisation Impact on Flood Levels - 1993



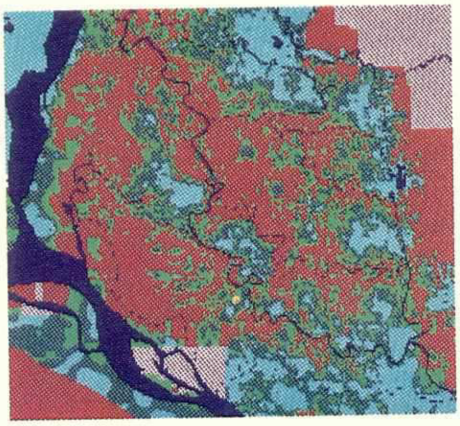
Without Compartments
Maximum Flood Depths

With Compartments
Maximum Flood Depths

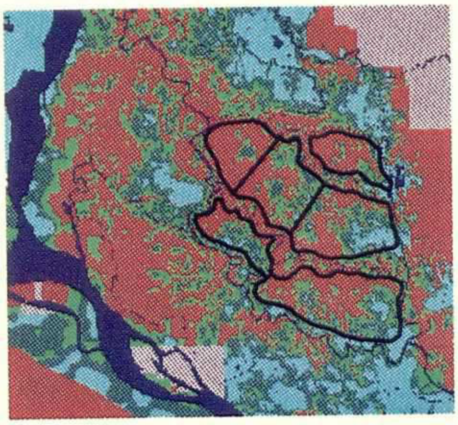
Maximum Change in Flood Level
(Red shades show an increase in flood level
Purple shades show a decrease in flood level)

Compartmentalisation Impact on Flood Phases - 1993

Flood Phase
- F0 (<0.3m)
- F1 (0.3 – 0.9m)
- F2 (0.9 – 1.8m)
- F3 (1.8 – 3.6m)
- F4 (> 3.6m)
- No DEM Data



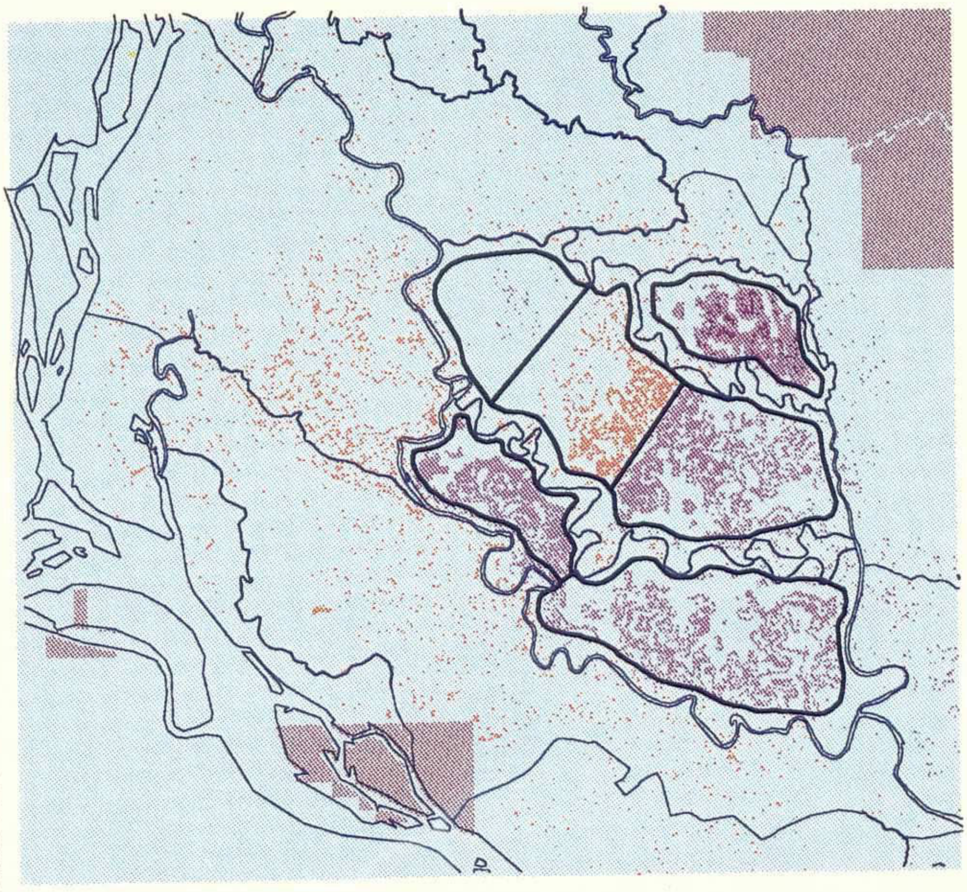
Without Compartments



With Compartments

Phase Change
- Up 2 Phases
- Up 1 Phase
- No Change
- Down 1 Phase
- Down 2 Phases
- No DEM Data
- River
- Compartment

Note:
Flood phases based on maximum flood depth.



0 6 12 km

Maximum Change in Flood Phase

(Red shades show an increase in flood phase
Purple shades show a decrease in flood phase)

Table B.5 Flood Depth Statistics as Percentages (1993 No Compartments)

Zone	Area sq.km	No Data %	Dry %	0-1m %	1-2m %	2-3m %	3-4m %	4-5m %	> 5m %
A	56.2	0	26.8	45.1	22.5	5.4	0.2	0	0.1
B1	66.4	0	73.2	22.7	4.1	0.0	0	0	0
B2	98.2	0	48.6	44.1	6.9	0.4	0	0	0
B3	121.1	0	17.2	42.4	28.1	11.7	0.5	0	0
C1	54.5	0	15.4	36.0	40.1	8.4	0.0	0	0
C2	157.8	0	22.1	46.3	25.1	6.0	0.4	0	0.1

Table B.6 Flood Phase Statistics (1993 No Compartments)

Zone	Area sq.km	No data sq.km	F0 sq.km	F1 sq.km	F2 sq.km	F3 sq.km	F4 sq.km
A	56.2	0	23.3	15.2	13.7	4.0	0.0
B1	66.4	0	56.3	6.8	3.2	0.1	0
B2	98.2	0	64.3	24.8	8.4	0.8	0
B3	121.1	0	36.5	31.4	32.0	21.2	0
C1	54.5	0	13.0	12.6	21.7	7.2	0
C2	157.8	0	57.2	44.4	40.8	15.2	0.2

After compartmentalisation of the areas, the flood characteristics change quite dramatically, as can be seen from Plates B.8 and B.9. Tables B.7 to B.9 express these changes in numerical form and should be compared with the appropriate Tables for the "Without Project" case.

Considering sub-compartment B3, compartmentalisation reduces the area of F3 land from about 21 km², (Table B.6), to slightly below 12 km², (Table B.9), and the area of flood-free land is increased form 17%, (Table B.5), to 33%, (Table B.8). All values refer to those at peak flood conditions.

Table B.7 Flood Depth Statistics as Areas (1993 With Compartments)

Zone	Area sq.km	No Data sq.km	Dry sq.km	0-1m sq.km	1-2m sq.km	2-3m sq.km	3-4m sq.km	4-5m sq.km	> 5m sq.km
A	56.2	0	36.4	15.3	3.8	0.7	0.1	0	0.0
B1	66.4	0	52.3	12.0	2.1	0	0	0	0
B2	98.2	0	39.9	47.6	10.1	0.7	0.0	0	0
B3	121.1	0	40.6	44.9	28.5	7.1	0.0	0	0
C1	54.5	0	16.8	25.4	11.3	1.0	0	0	0
C2	157.8	0	56.8	67.0	28.2	5.5	0.1	0	0.2

Table B.8 Flood Depth Statistics as Percentages (1993 With Compartments)

Zone	Area sq.km	No Data %	Dry %	0-1m %	1-2m %	2-3m %	3-4m %	4-5m %	> 5m %
A	56.2	0	64.7	27.3	6.7	1.2	0.1	0	0.1
B1	66.4	0	78.8	18.0	3.2	0	0	0	0
B2	98.2	0	40.6	48.5	10.2	0.7	0.0	0	0
B3	121.1	0	33.5	37.1	23.6	5.8	0.0	0	0
C1	54.5	0	30.8	46.7	20.8	1.8	0	0	0
C2	157.8	0	36.0	42.5	17.9	3.5	0.1	0	0.1

Table B.9 Flood Phase Statistics (1993 With Compartments)

Zone	Area sq.km	No data sq.km	F0 sq.km	F1 sq.km	F2 sq.km	F3 sq.km	F4 sq.km
A	56.2	0	42.0	8.9	3.8	1.5	0.0
B1	66.4	0	59.0	4.9	2.6	0.0	0
B2	98.2	0	55.7	29.1	12.1	1.3	0
B3	121.1	0	57.0	25.2	27.1	11.8	0
C1	54.5	0	23.2	16.6	12.7	1.9	0
C2	157.8	0	79.3	39.4	30.6	8.2	0.2

Table B.10 gives an example of the direct abstraction of "difference" data in tabular form between two situations. In this case, the differences relate to the change in Flood Phase inside and outside the compartments. An increase or decrease of 2, for example, means that the indicated area had changed by 2 phases, (F3 to F1, for example). It does not indicate the absolute change in each flood phase.

Table B.10 Change in Flood Phase Due to Compartments

Zone	Area	No Data	Increase or Decrease in Flood Phase						
			-3/4	-2	-1	0	+1	+2	+3/4
	sq.km	sq.km	sq.km	sq.km	sq.km	sq.km	sq.km	sq.km	sq.km
OUT	3203	144.3	0	0.0	18.4	2970	70.3	0	0
A	56.2	0	0	2.9	29.3	24.0	0	0	0
B1	66.3	0	0	0	1.1	65.2	0.0	0	0
B2	98.2	0	0	0	0.0	76.9	21.3	0	0
B3	121.1	0	0	0	44.1	77.0	0	0	0
C1	54.5	0	0	0	29.1	25.3	0.0	0	0
C2	157.8	0	0	0	46.8	111.0	0.0	0	0

Figure B.10 shows the time series graphs for water level at selected points on the Dhaleswari upstream and downstream of the compartments for the 1988 simulation. These points are located on Plate B.8. The graphs show the variation in water levels at each location before and after compartmentalisation.

Compartmentalisation appears to have little effect on the river levels downstream of the compartments, as shown by the water level comparison on the Dhaleswari at Chainage 137.00. The peak level occurs 2 days earlier with compartments, but the level is unchanged. Upstream of the compartments, at Ch. 36 on the Dhaleswari, the peak river level increases by approximately 25 cms. The Ghior Khal experiences a rise of about 40 cms.

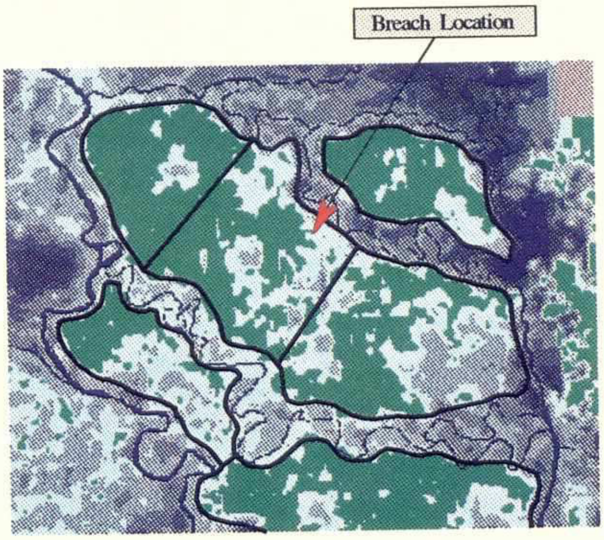
B.3.4 Embankment Failure

To illustrate that FMM may be used to help evaluate the impacts of embankment breaches, a simulation of a progressively eroding breach using the MIKE11 Dambreak Module was set up to occur in a compartment boundary embankment. Failure was assumed to occur due to initial piping failure, resulting in an erosive breach in the embankment.

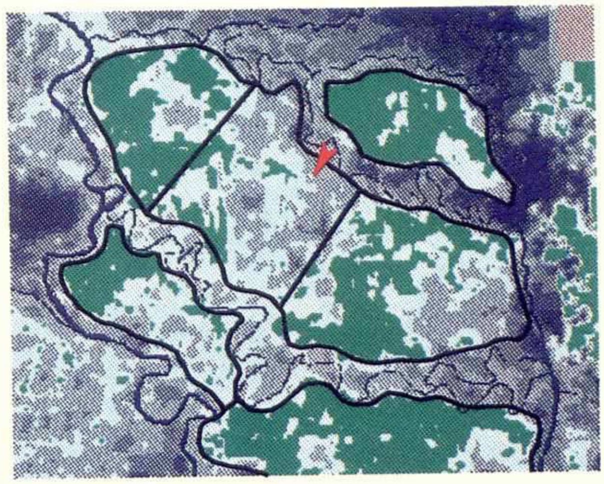
FMM permits the visual appreciation of the implications of a breach and, with the enhanced model structure and statistical routines, enables the user to quantify the effects of flooding within the compartment. Plates B.11 and B.12 show a sequence of flood maps which illustrate the inundation area and flood wave progression. The breach was assumed to occur on the right bank of the Bangshi South at chainage 40 km., located on the maps as a red/yellow arrow.

The flood depth comparison map clearly shows a slight lowering of river level just upstream of the breach, with a significant water level rise within the compartment. Using the graphical output from FMM, shown as Figure B.11, the changes in water level and discharge resulting from the breach can be seen. As the water moves into the compartment, large areas of sub-compartment B1 experience additional flooding.

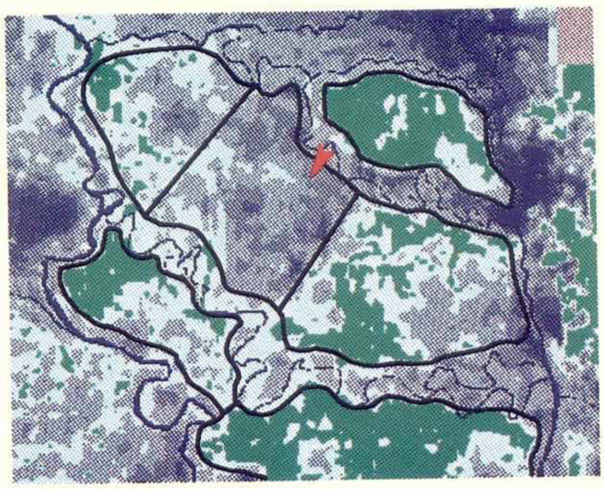
Embankment Breach Flood Depths



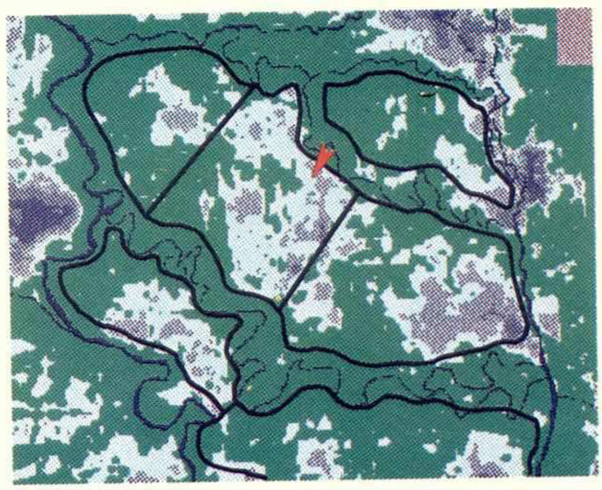
September 3, 1988
(Before Breach)



September 5, 1988
(1 day after breach)



September 10, 1988
(6 days after breach)



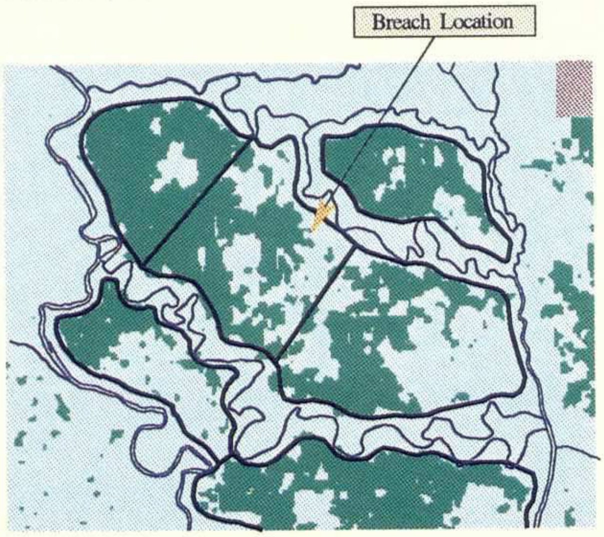
September 30, 1988
(26 days after breach)

0 6 12 km

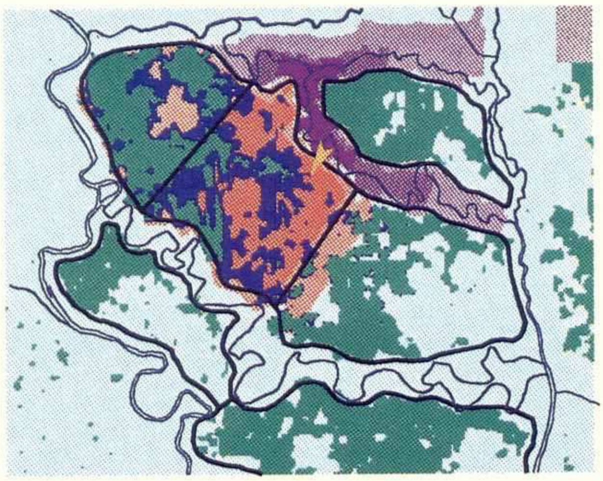
Depth (m)

- 0.00 – 1.00
- 1.00 – 2.00
- 2.00 – 3.00
- 3.00 – 4.00
- 4.00 – 5.00
- Above 5.00
- Flood Free
- No DEM Data
- Breach Location
- Compartment

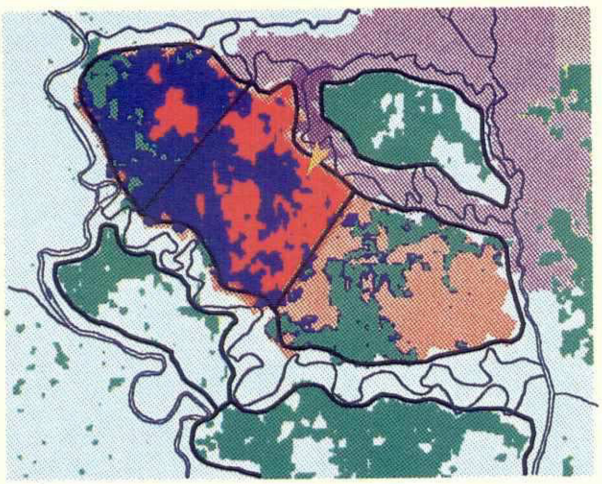
Embankment Breach Impact on Flood Levels



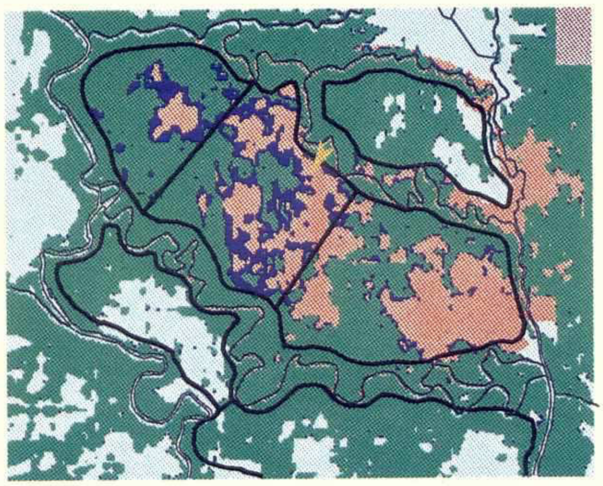
September 3, 1988
(Before Breach)



September 5, 1988
(1 day after breach)



September 10, 1988
(6 days after breach)



September 30, 1988
(26 days after breach)

0 6 12 km

Flood Level Change

- None/Slight Increase (m)
- Above 1.50
- 0.80 to 1.50
- 0.10 to 0.80

Decrease (m)

- −0.10 to −0.20
- −0.20 to −0.30
- Below −0.30

- Now Dry
- Now Wet
- Flood Free
- No DEM Data

- Breach Location
- Compartment
- River

Figure B.10 Effect of Compartments on River Levels

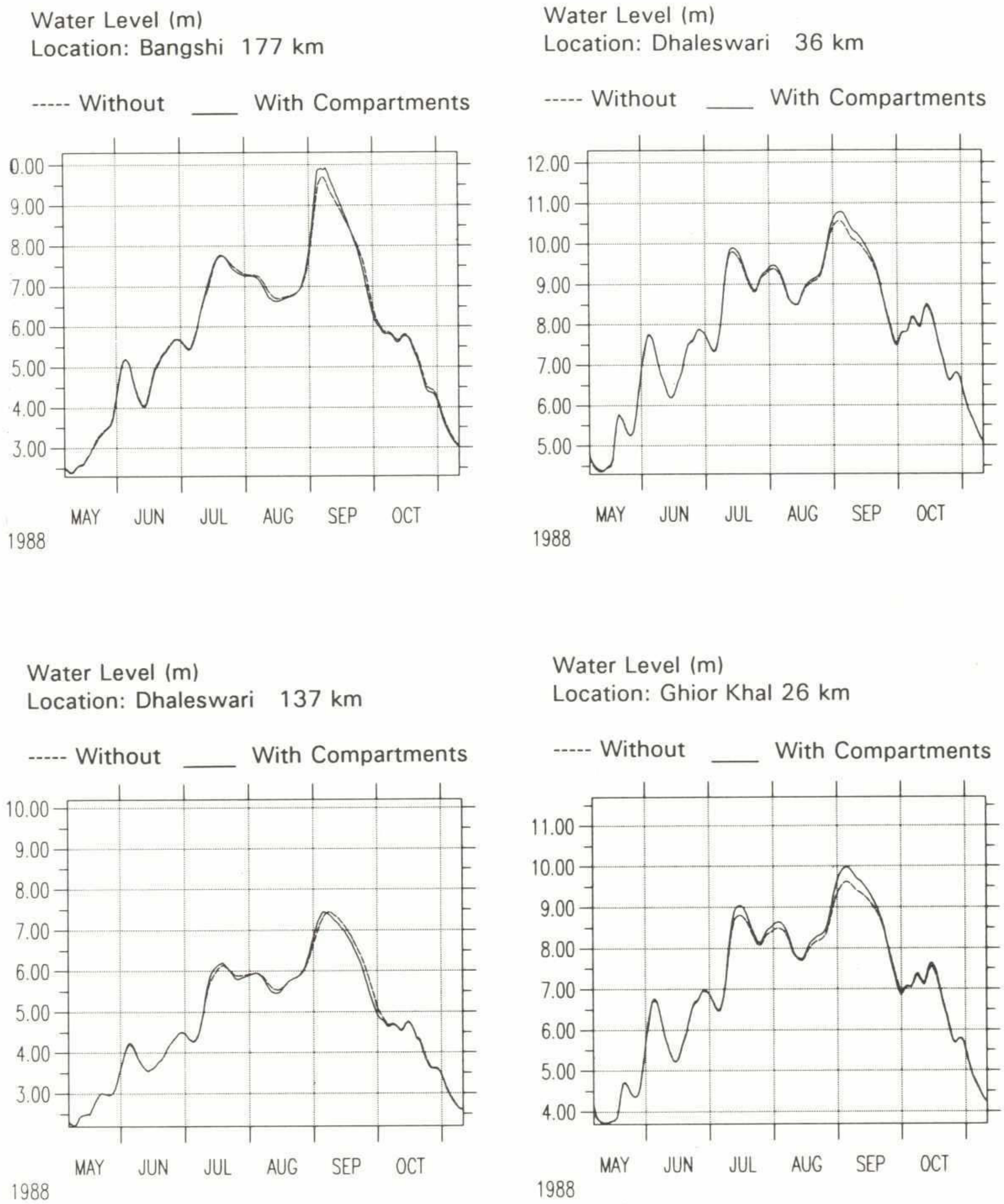
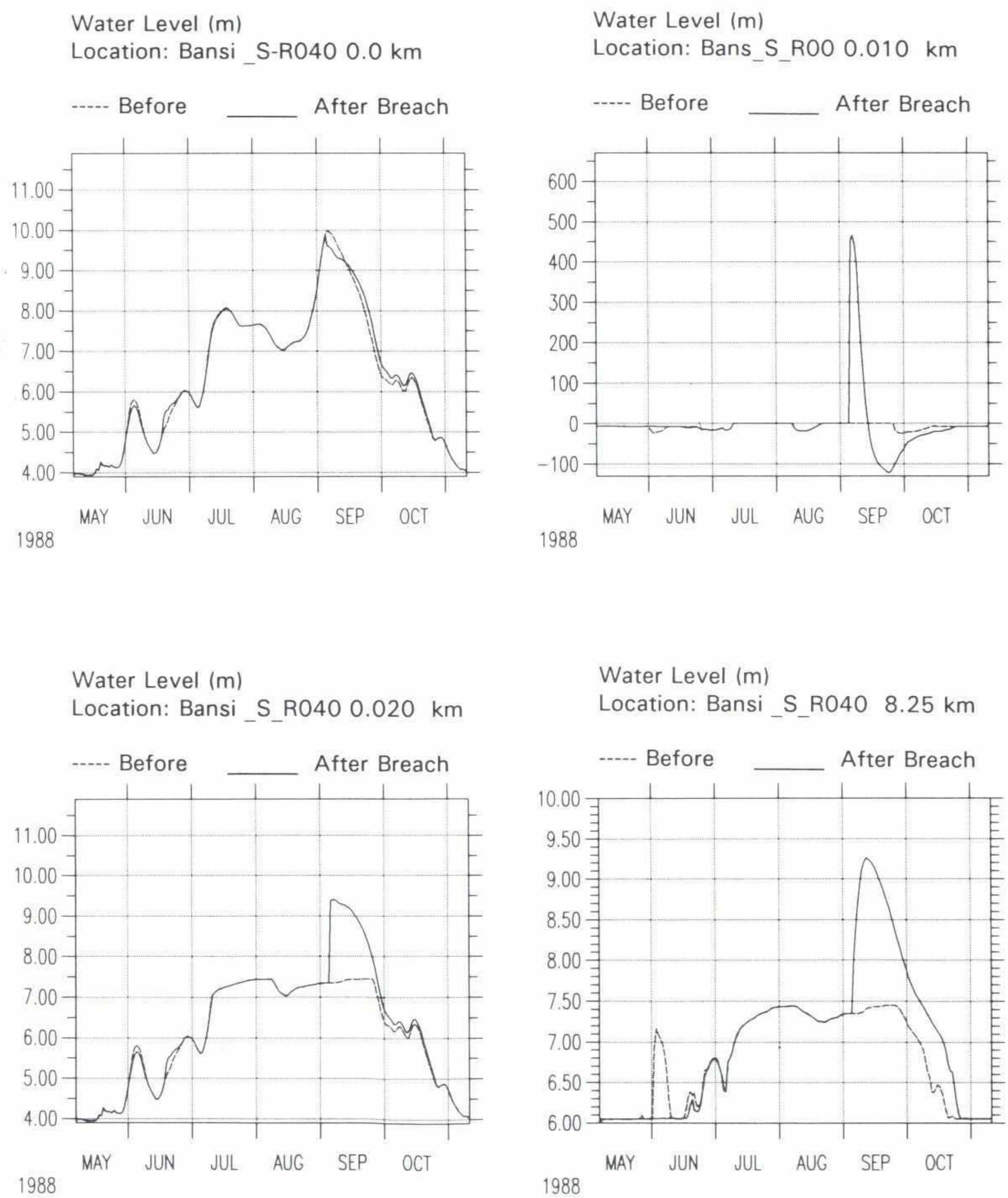


Figure B.11 Water Levels and Discharges Near Embankment Breach



The upper left graph on Figure B.11 shows the water level in the river adjacent to the breach. Comparison with the "no breach" case shows a lowering of the river level over the peak, followed by a slight increase in river levels as the peak recedes. This increase is the result of floodwater flowing out of the compartment through the breach. The upper right graph shows this discharge as negative from about mid-September to late October. The small negative flows occurring before the breach represent accumulated rainfall excess flowing out of the compartment.

The two lower graphs show the variation in water level within the compartment. The lower left graph shows the variation just below the breach and the lower right that further within the compartment.

A high flood condition, (1988), was assumed for the simulation, as this would illustrate a "worst case" scenario.

Table B.11 Flood Depth Changes due to Embankment Breach

Zone	Area sq.km	No Data sq.km	Dry sq.km	Now Dry sq.km	< -0.3 sq.km	-0.2 to -0.3 sq.km	-0.1 to -0.2 sq.km	No Change sq.km	0.1 to 0.8 sq.km	0.8 to 1.5 sq.km	> 1.5 sq.km	Now Wet sq.km
A	56.2	0	36.5	0.1	0	0.01	0.8	18.9	0	0	0	0
B1	66.4	0	8.0	0	0	0	0	0.0	0.9	1.5	7.6	48.4
B2	98.2	0	0.3	0	0	0	0.0	0.2	1.7	5.9	40.3	50.0
B3	121.1	0	36.6	0	0	0	0.1	8.2	62.2	1.2	0	12.8
C1	54.5	0	18.2	0.1	0	0	0	36.2	0	0	0	0
C2	157.8	0	85.3	0.4	0	0	0	72.1	0	0	0	0

Table B.11 shows the changes in flood depth resulting from the embankment breach between September 3rd and September 10th. Within sub-compartment B1, for example, an additional 48km^2 land is now flooded and the area of land originally flooded in excess of 1.5m. has increased by just over 7km^2.

B.3.5 Flood Map Interpretation

It is important that any interpretation of flood depth maps or flood impact maps be carried out with a full understanding of the hydraulic and hydrologic processes taking place within the area. Unless such expertise is used, it is possible that erroneous conclusions may be drawn from initial examination of the maps produced by FMM.

To illustrate the above points, an example scenario has been run and an interpretation of the resulting flood maps, (Plates B.13 and B.14), is given.

The offtakes from the Jamuna into the North Central Region from the Chatal in the north to the Dhaleswari in the south west were assumed to be cut off by the construction of an embankment. The Dhaleswari remains open and the embankment is then assumed to follow the north bank alignment of this river, cutting off the Barinda river and terminating near the confluence of the Dhaleswari and Bangshi. Plate B.13 shows the alignment of this embankment.

The right hand map on Plate B.13 shows the resulting flood depth map and a general reduction in flooding within the region may be observed.

It is not until the map showing the impact of the embankment of flood levels is studied, (Plate B.14), that the complete extent of the changes can be appreciated. This map shows that flood levels within the region, north of the Dhaleswari, are generally reduced by over 50 cm, and that some areas are now flood free.

Increases in flooding, (red shading on Plate B.14), are shown for the Jamalpur area. At first glance, it might seem unreasonable for the Jamalpur area to suffer increased flooding from the embankment, but an understanding of the hydraulic processes involved can explain this phenomenon.

The Jamalpur area normally drains through two locations: Baushi Bridge, on the Jhenai, and through the Chatal South into the Jamuna, (see Plate B.14 for locations). Cutting off the Chatal South from the Jamuna prevents the drainage of the region at this point, while water still enters through the Jhenai offtake from the Old Brahmaputra. Consequently, water accumulates, resulting in deeper flooding.

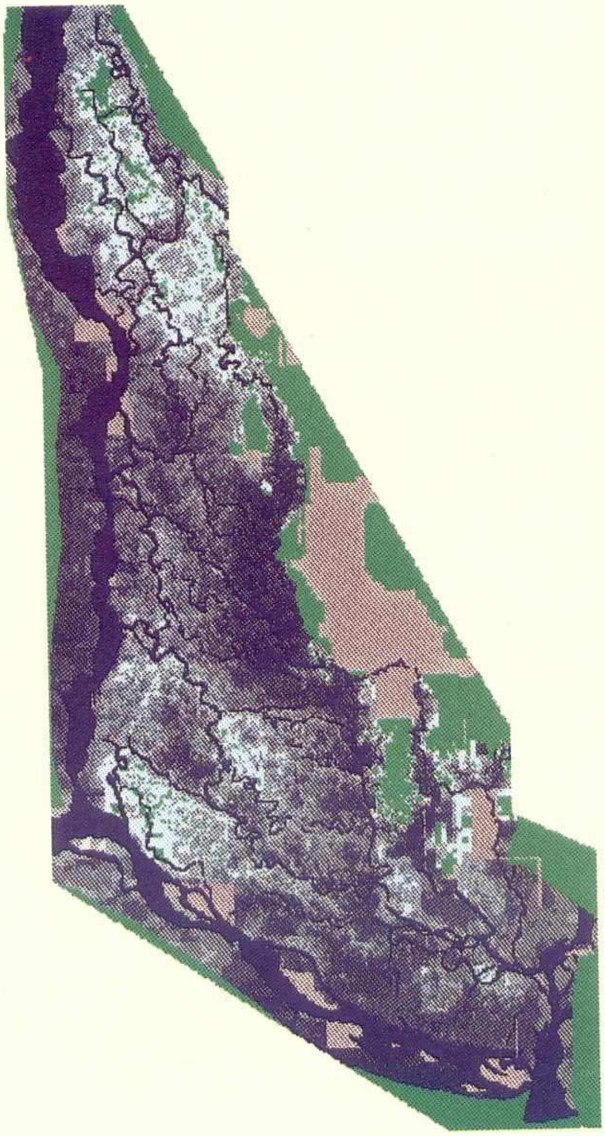
The reduction in flood levels on the floodplain south of the Dhaleswari offtake is due to the lower discharge carried by the adjacent Dhaleswari, (the Old Dhaleswari no longer contributes to the flow of the Dhaleswari). The lower river levels result in less spillage onto the floodplain.

Floodplain levels to the south of the Dhaleswari near its confluence with the Bangshi are controlled by river levels in rivers to the north and east. Since these levels are now reduced, correspondingly less floodwater enters the floodplain.

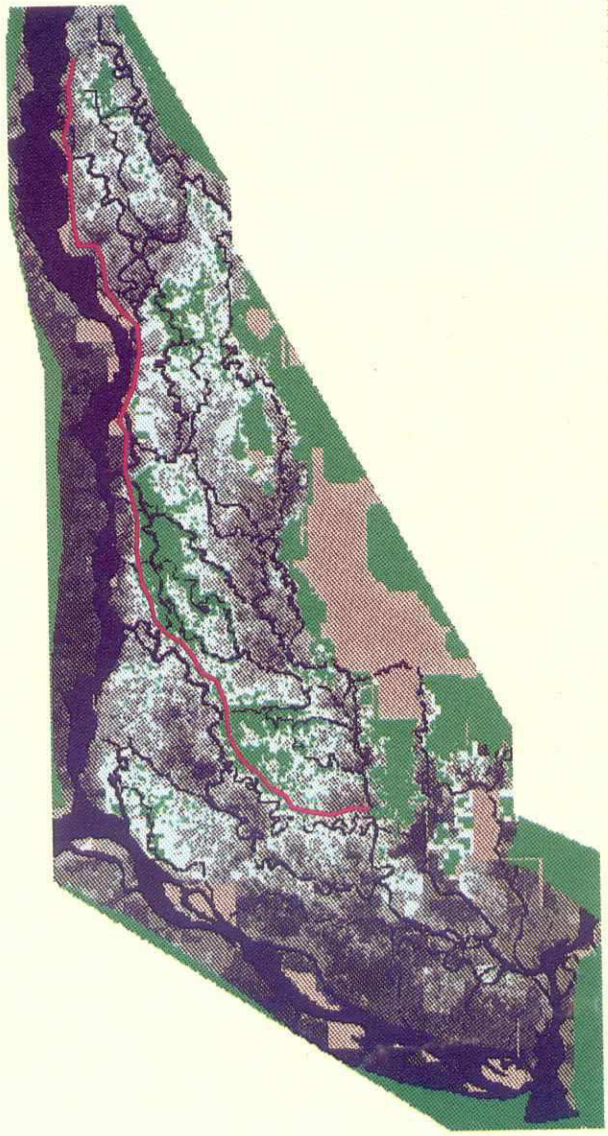
This example points to the need for careful interpretation of the maps produced by FMM. It shows that the regional FMM may be used to highlight areas which, as a result of intervention, require further investigation.

If such investigations are considered necessary, it is likely that the information would be provided through a more detailed sub-regional model.

Regional Embankment Application



Maximum Flood Depths 1988
Without Embankment

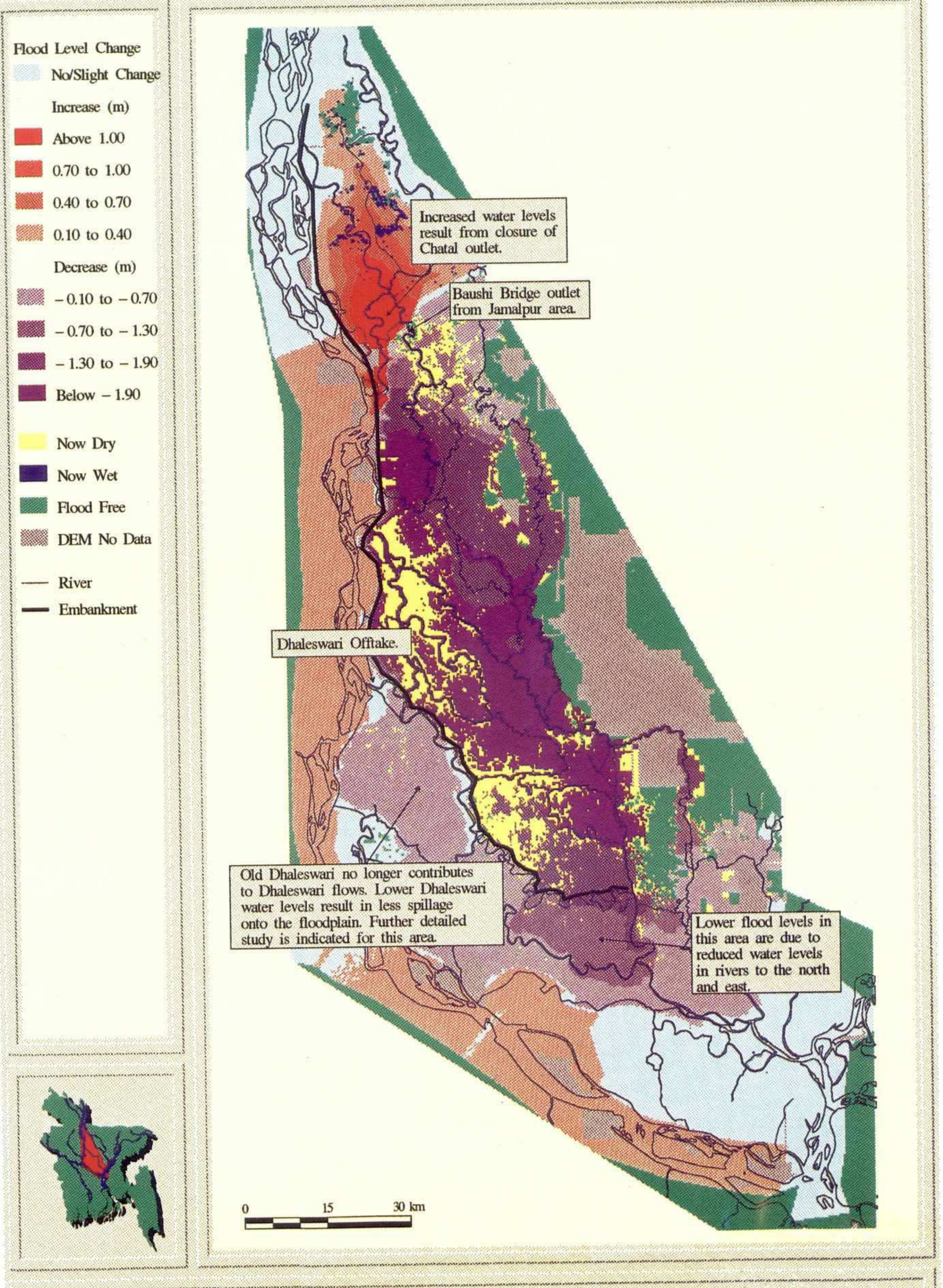


Maximum Flood Depths 1988
With Embankment

Depth (m)

- 0.00 – 1.00
- 1.00 – 2.00
- 2.00 – 3.00
- 3.00 – 4.00
- 4.00 – 5.00
- Above 5.00
- Flood Free
- No DEM Data
- Embankment

Regional Embankment Impact on Flood Levels



FAP25 - Flood Management Model

Plate B.14

99

B.3.6 Real-Time Flood Forecasting

B.3.6.1 Introduction

This section presents a model concept for real-time flood forecasting in the North Central Region. A test run based on real-time data is performed and the depth-area inundation mapping with the NCR-FMM is presented. Applicability of the model concept and data requirements are discussed at the end of the section.

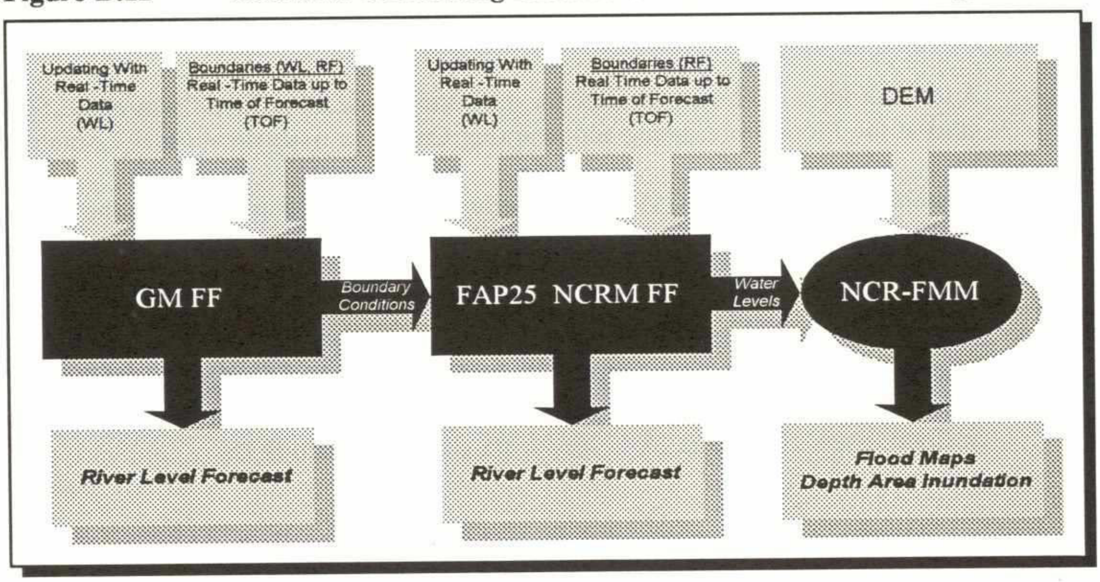
B.3.6.2 Model setup

The interrelationship between models for real-time flood forecasting in the North Central region is illustrated in Figure B.12. This diagram shows that flood forecasting is performed as a 3 step procedure.

1) Forecasting, including updating of water levels on the major rivers, is carried out with the General Model Flood Forecasting version, (GM FF).

2) Water level and discharge boundaries required for the North Central Regional model are retrieved from GM FF. Forecasting in the North Central river system is carried out with the FAP25 NCRM FF.

Figure B.12 Real-time Forecasting Procedure in the North Central Region



3) Using the NCR-FMM, forecast water levels are mapped as depth-area inundation.

GM FF uses real-time data from 29 water level stations and 31 rainfall stations throughout the country. Quantitative rainfall and water level boundary forecasts are given in the forecast period. Further details of the GM FF may be found in *Application of SWSMP*

models for real-time forecasting. Report to WMO, project BGD/88/013. Danish Hydraulic Institute, October 1992.

FAP25 NCRM FF uses quantitative rainfall forecast in the forecast period. To function properly, the updating procedure requires a number of real-time water level stations inside the region.

B.3.6.3 Real-time Forecasting Demonstration

Experimental flood forecasting of river water level applying the SWMC NCRM was carried out in 1991 and 1992 at the Flood Forecasting and Warning Centre. Water levels from GM FF, used as boundaries, were automatically transferred to the NCRM and simulation, updating and forecasting performed.

To test the real-time data linkage and to make recommendations for FAP10, application with real-time data was performed. Simulation results from GM FF were collected at the Flood Forecasting and Warning Centre and applied as input to the FAP25 NCRM. The simulation was carried out without using the updating procedure as no real-time data was available within the region.

Experience from earlier experimental flood forecasting with the NCRM indicates that extension of the real-time network in the North Central Region is highly desirable. The accuracy of the forecasts depends on the number of real-time stations included in the setup. Particularly in the Northern part of the region and on the floodplains some real-time stations will improve the accuracy of the forecasts.

A test run for a 72 hours forecast for the period June 28 to July 1 was made. GM FF was used at the Flood Forecasting and Warning Centre to issue the normal 72-hours forecast.

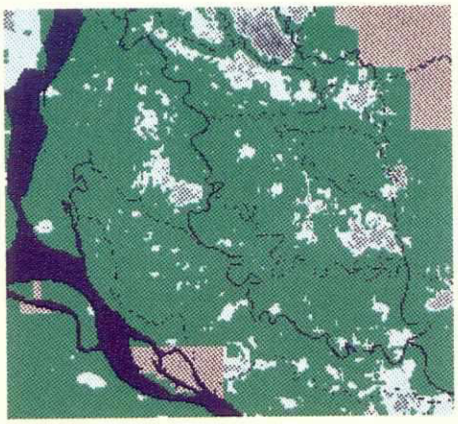
Boundary data from the GM FF simulation were retrieved and input to the FAP25 NCRM which then provided a forecast of river water levels in the North Central Region. This forecast was carried out without updating.

Applying the NCR-FMM, forecasting of depth area inundation was carried out on the Manikganj area in the south western part of the North Central Region. The flood extent on June 28 at the time of forecast, the 72 hour forecast flood extent on July 1 and the change in flood extent from June 28 to July 1 are shown in Plate B.15.

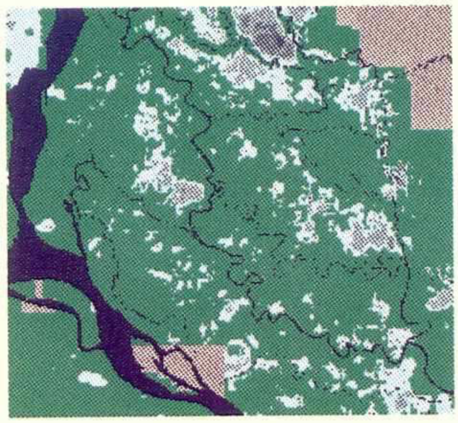
72 hour Flood Forecast Maps

Depth (m)

- 0.00 – 1.00
- 1.00 – 2.00
- 2.00 – 3.00
- 3.00 – 4.00
- 4.00 – 5.00
- Above 5.00
- Flood Free
- No DEM Data



Time of Forecast
(June 28, 1994)



72 hr Forecast
(July 1, 1994)

Flood Level Change

- No Change

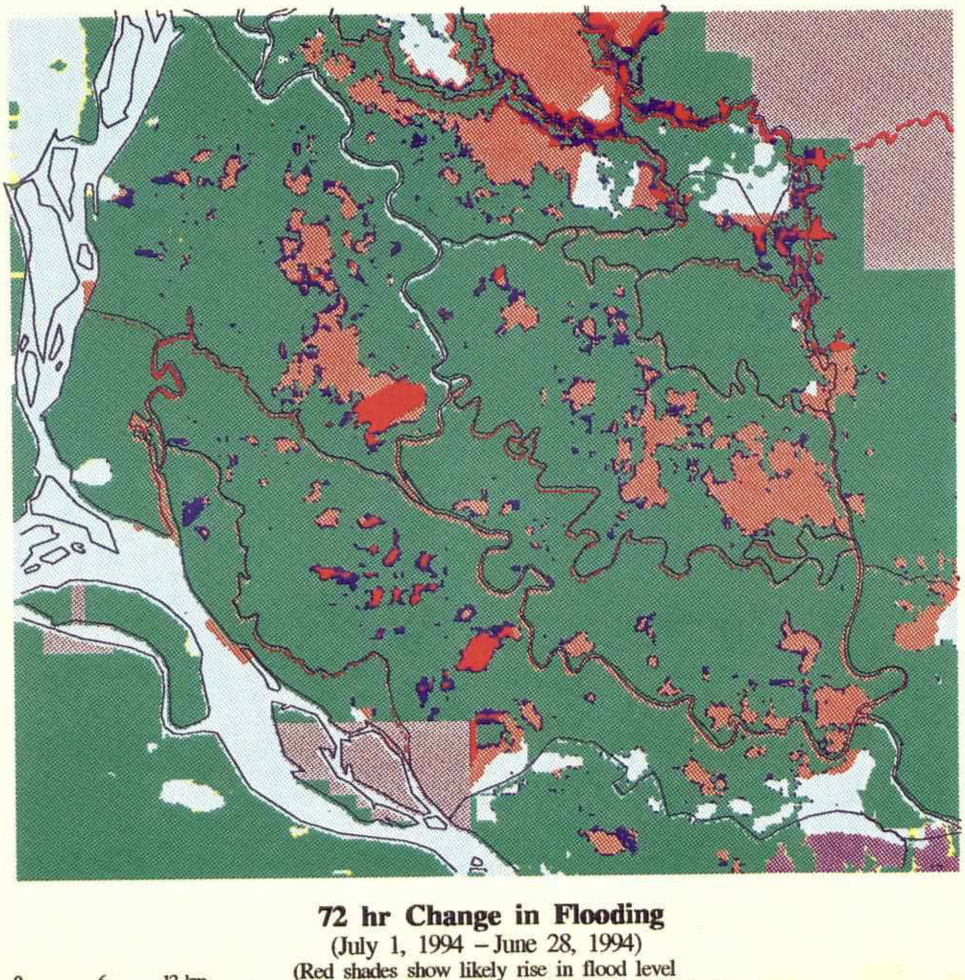
Increase (m)

- Above 0.30
- 0.10 to 0.30

Decrease (m)

- – 0.10 to – 0.30
- Below – 0.30

- Now Dry
- Now Wet
- Flood Free
- No DEM Data
- River



72 hr Change in Flooding
(July 1, 1994 – June 28, 1994)
(Red shades show likely rise in flood level
Blue shade shows areas which might become flooded)

0 6 12 km

B.3.7 Historical Database

The Terms of Reference require that a historical database of simulated events be initiated which, within the present study, could serve the purpose of demonstration of the benefits of FMM without having to run the hydrodynamic model.

In practise, the historical database is provided by the MIKE11 simulation results files. FMM provides the means for presentation of these results in mapping form. However, visual presentation , combined with statistical tables, provide ready access to historical information.

It is possible to present historical information in many forms, depending on the user needs. Whatever that need, these data which are from the MIKE11 simulation results. It is this data which is manipulated to provide inputs into FMM for display. For example: maximum monthly water levels for each year, for each location in the region; maximum 10-day duration water levels for selected periods for each year, etc..

The FAP25 NCRM was run for a 25 year period from 1967 to 1993, (1971 and 1992 were omitted due to lack of data). The results from these runs highlighted the need to investigate differences between the General Model and the regional model in the simulation of the Jamuna water levels. These levels are affected by the simulation of the spill into the region in both models.

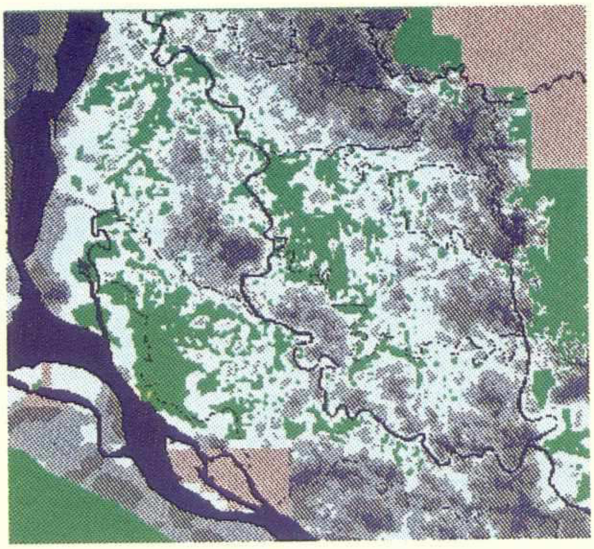
As an initiation of a historical database, Plate B.16 shows a series of output maps based on the twenty-five year period, 1967 to 1993, (excluding 1971 and 1992). Each water level output is statistically analyzed to provide the 1 in 2 year, 1 in 5 year, 1 in 20 year and 1 in 50 year return period depth and the resulting envelopes of flood inundation are mapped.

Plate B.16 shows the flood depth envelope maps associated with this analysis.

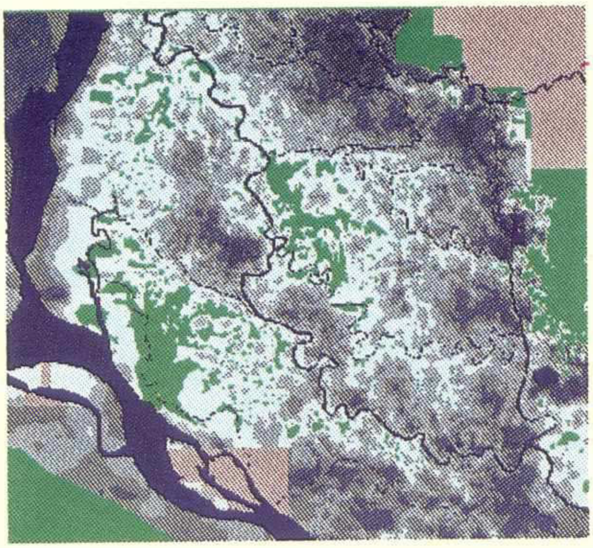
These maps may be used as flood hazard maps, giving the selected return period depth of flooding for any location. This concept can be extended to the production of maps defining development zones, which may be based on depth of flooding, duration of flooding, frequency of flooding or a combination of these. The regional model level of detail would be insufficient to produce detailed flood zoning maps for limited areal extents, particularly urban areas, but more general zones could be established over larger areas, based on simple categories, e.g. agricultural zones or urban zones. For more complex zoning, detailed sub-regional models would be required.

This page intentionally left blank.

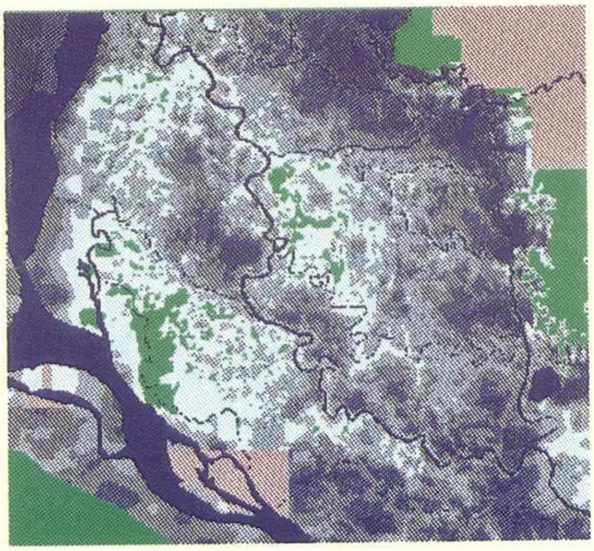
Annual Maximum Flood Depths



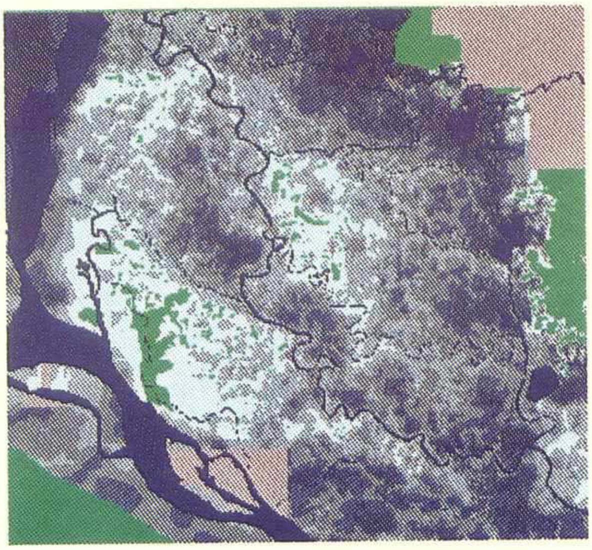
Return Period 2 years



Return Period 5 years



Return Period 20 years



Return Period 50 years

0 10 20 km

Depth (m)

- 0.00 – 1.00
- 1.00 – 2.00
- 2.00 – 3.00
- 3.00 – 4.00
- 4.00 – 5.00
- Above 5.00
- Flood Free
- No DEM Data

B.4 CONCLUSIONS AND RECOMMENDATIONS

B.4.1 General

The application demonstrations have clearly shown that FMM can be a powerful tool to aid both model development and to present MIKE11 model results in a form that is easily appreciated and understood.

For the model developer, MIKE11-GIS tools have greatly enhanced the speed and potential accuracy of floodplain representation within the MIKE11 models. However, of paramount importance to output accuracy is the accuracy of the input data. FMM can only be as accurate and representative in its output as that of the basic input data.

Regional applications have shown that its use at this level is worthwhile at planning level. Necessary reductions in detail mean that some specific areas may not reflect the precise characteristics found in the field. Within the present-day limits of computational hardware, FMMs at this regional level of detail are a practical proposition. Sufficient detail can be represented to provide planners with the information needed for pre-feasibility level studies and to provide model boundary conditions for sub-regional models, which are to be used for feasibility studies and design. The user must appreciate the limitations in detail that must be present in a regional level model and should interpret the results accordingly.

B.4.2 MIKE11 Model

The restructured MIKE11 model, incorporating separate floodplains, provides a significantly better description of the flooding conditions in the North Central Region. Unfortunately, while much effort has been made in the past in gathering hydrometric data on the river system, little attention has been paid to the floodplains. Calibration of the floodplains in this model, therefore, needs improvement. Nevertheless, the existing calibration is sufficiently representative to provide a suitable means for the demonstration of FMM on a regional scale. The following specific items should be addressed by future users of the model:

- Simulation around the Bangshi-Futikjani confluence should be improved. Check the cross sections included for the Hai River and Mirzapur Khal.
- Investigate the reasons for the discrepancies in simulation of Jamuna water levels between the GM and the regional model. Adjustments to the high level spill channels from the Jamuna in the FAP25 NCRM may be required
- Extend the embankment surveys to include the remaining rivers and use a Global Positioning System to locate the embankment lines
- Install water level gauge posts within the floodplains on the khal inlets from the main rivers.
- Check the setup in the Jamalpur area and make any necessary revisions, based on the new FINNMAP survey data

- Compile an inventory of major culverts and embankment openings which will assist in the understanding of movement of water on the floodplain

The present FMM for the North Central Region is pilot only. Undertaking further development to improve accuracy is a large task, for which the necessary resources should be made available. The extension of the model to represent floodplains has added another dimension to the data requirements, which must be satisfied if improvements are to be made.

SWMC is currently investigating cross sections and datums of the Hai River and Mirzapur Khal; will possibly be making a revision of the Jamalpur area; and has started investigating the discrepancy in the Jamuna between the GM and NCRM.

The use of radar imagery for verification of floodplain inundation appears to be encouraging, but this can only be regarded as a qualitative comparison at this early stage in its development. For regional level modelling, it may even be too precise, (i.e. showing too much detail), for sensible comparison, considering the level of detail possible in the model.

B.4.3 DEM

Output from the FMM has highlighted the necessity for good quality input. This extends to the MIKE11 hydrodynamic model structure and simulation accuracy, which itself depends on accurate raw data, both hydrometric and topographic. However, if the ground representation within the DEM is unrepresentative, no amount of accurate water level simulations will produce reliable flood maps.

At a regional scale, the resolution of the DEM should be consistent with the degree of topographic variation over the floodplain. The spot level grid of 300 metres used in the DEM for the NCR-FMM appears to be adequate at regional level to describe the floodplain variation in sufficient detail.

The resolution used for display purposes, however, can be more detailed although any image with a resolution greater than that of the raw data will be the result of interpolation. It is best to display the DEM with the highest resolution that overcomes excessive "blockiness" of the output. Using a grid size of 100 metres for display was found to be satisfactory and produced an acceptably smooth image.

The following recommendations are made for the enhancement of the NCR DEM:

- Incorporate new topographic survey data for Tangail and Jamalpur
- Initiate a long term project for a complete update of the topographic mapping in the NCR and revise the DEM accordingly

B.4.4 Coverages

Present coverages in the GIS include the rivers and major and some minor roads. These prove very useful in the definition of the extent of floodplains, but firm information is lacking on the existing openings in the embankments on which these roads are constructed. A better knowledge of this will improve the representation of floodplain flow in the regional model.

B.4.5 Flood Maps

The mapping output of FMM can be a very useful verification tool for the MIKE11 simulations. By examining both the flood depth maps and the flood depth comparison maps, anomalies may be detected which are not immediately apparent from the standard MIKE11 outputs.

Care must be exercised in the presentation of maps. They must be carefully scrutinised and any phenomena for which satisfactory physical explanations cannot be given should be identified. The relevant output from the MIKE11 model should then be examined to check, for example, that no model instabilities exist which result in a sudden water level rise.

B.4.6 Flood Forecasting

Applying the real-time flood forecasting model concept it has been demonstrated that forecasting including depth-area inundation mapping can be carried out real-time. The output using FMM is a significant improvement over the existing time series graphs which are only available for selected locations in the river system.

The test run was carried out without updating in the FAP25 NCRM, however the updating procedure has already been tested with good results under FAP10, (*Application of SWSMP models for real-time forecasting. Report to WMO, project BGD/88/013. Danish Hydraulic Institute, October 1992.*)

The inundation mapping technique applied under FAP25 is capable, with a reasonable resolution, to be applied for real-time forecasting at Upazilla level. The quality of the inundation mapping depends on the Digital Elevation Model and the calibration of the model. A good Digital Elevation Model must be developed before a new area can be used for real-time forecasting. A resolution on surveyed spot heights of 0.2 to 0.5 m, with 0.15 to 0.30 m preferred, in a 100 m grid system would be acceptable for real-time forecasting.

More real-time stations should be considered to update the water levels, particularly on the floodplains. Applying satellite images and radar data for model calibration and updating during real-time application should also be considered.

63

PART C
COMPARTMENT LEVEL

69

CONTENTS: PART C

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ND

C.1 INTRODUCTION

C.1.1 Background

During the early stages of the Flood Action Plan, the concept of compartmentalisation was introduced. This was seen as a means by which the flood characteristics of defined areas of land could be controlled in a beneficial way. To investigate the implications of this concept, two pilot projects were implemented, one of which was in the Tangail area.

The controlled flooding proposed in the CPP will be achieved through operation of inlet regulators and internal waterways while controlled drainage will be achieved by the internal drainage system and outlet regulators.

To operate these regulators a high degree of water control and management will be required. Within flood protection compartments, inlet regulators and drainage outlets will be managed to control the timing, depth and duration of flooding during the rainy season within limits that ensure growing conditions for the major crops.

The Compartmentalization Pilot Project FAP20 has developed a mathematical flow model for the Tangail Compartment, (FAP20 TCM), to model the behaviour of the river system and associated structures.

The original FAP20 TCM was not suitable to be used as a tool for flood management. The representation of flood control structures is insufficient, while for determination of flood management strategies a comprehensive user-interface and dedicated post-processing facilities are required.

C.1.2 Objectives

The main objective of this part of the study is the demonstration of FMM concepts on a compartment level. This is to be achieved through the development of a FMM for a compartment (micro) level, based on a modified FAP20 TCM. The accuracy of prediction of inundation depths and durations for various management strategies should be improved through a better representation of floodplain behaviour and enhanced structure descriptions.

It can test the effects of operation of hydraulic structures and, as a pilot for a more comprehensive management model, will allow direct determination of the impacts in terms of potential crop and fisheries damage, infrastructure disruption, etc. including graphical displays, through a coupling with GIS.

This page intentionally left blank.

C.2 DEVELOPMENT OF THE COMPARTMENT FMM

C.2.1 Introduction

The Compartmentalization Pilot Project FAP20 developed a mathematical flow model for the Tangail Compartment (FAP20 TCM) for use as a tool for planning and design *(Ref. FAP20, 1992/1)*. For FMM use at compartment level, this model needs refinement, as the representation of the floodplain characteristics are not sufficiently accurate.

Figure C.1 Development Path of TC-FMM

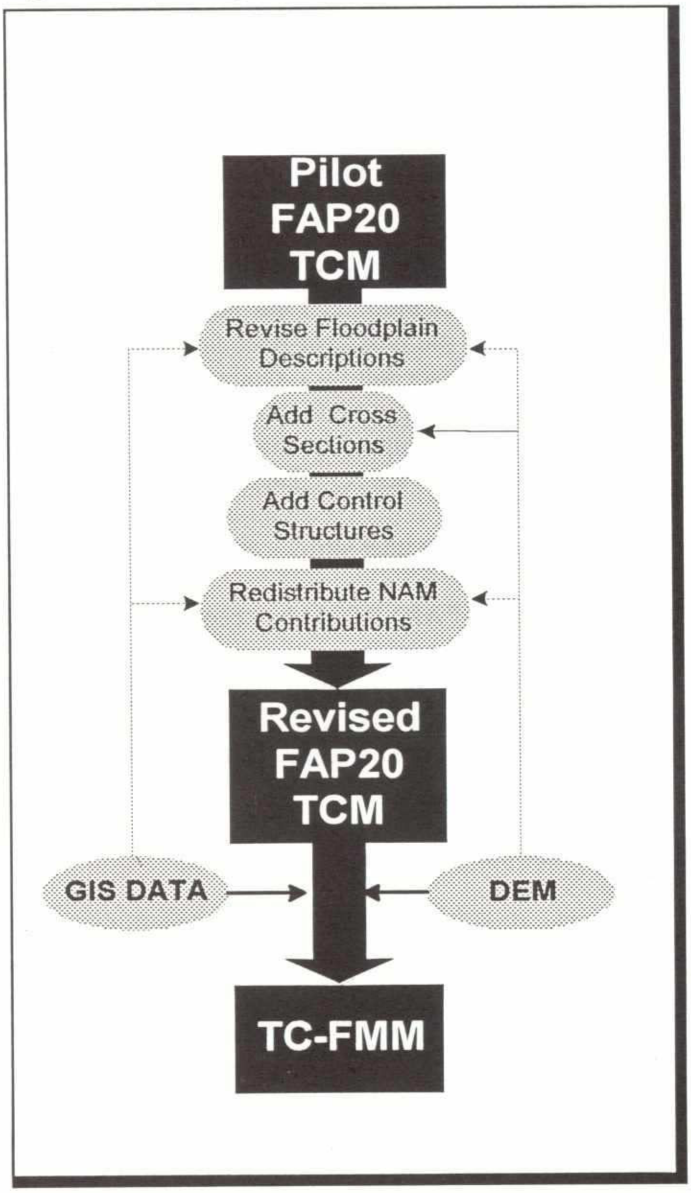


Figure C.1 shows the development path of the TC-FMM. From the original FAP20 TCM, using DEM and GIS data, together with MIKE11-GIS tools, the revised FAP20 TCM is produced, which forms the basis of the TC-FMM. To test structure operation, the north-eastern part of the revised FAP20 TCM has been detailed up to chawk level.

C.2.2 Pilot FAP20 TCM

C.2.2.1 Description

The Tangail Compartment is situated in the North-Central Region of Bangladesh in the Young Brahmaputra floodplain (see Figure C.2). The Dhaleswari river, originating from the Jamuna river is the main source of flooding in this area. The river Lohajang, a tributary of the Dhaleswari river, bisects the area, running through Tangail town. The area is bounded by a horse-shoe embankment along the Dhaleswari and Elanjani rivers in the West, the Lohajang river and Gala khal in the North and the Pungli river in the East. The southern boundary follows the Silimpur-Karatia-Nathkola road.

The Compartment area comprises 13,000 ha. The average elevation of the land is +10.0m (PWD) with a variation of +/- 2 to 3m. The regional drainage pattern has a south-eastern slope, the drainage pattern within the compartment is directed towards the Lohajang river. Large depressions/beels are found throughout the Compartment. The Compartment has been divided into 16 sub-compartments based on the existing infra-structure of roads, embankments and villages.

All rivers and the major khal system, important for flooding and drainage of the area, have been included in the model.

The location and layout of the pilot FAP20 TCM is shown in Figure C.2.

The locations of the boundaries for the hydrodynamic model have been selected such that their hydraulic conditions will not be affected by future project conditions. The upstream boundary of the model has been extended up to the Dhaleswari offtake from the Jamuna. Although the upstream boundary of a model should preferably be a discharge boundary, discharge data were not available and time dependent water level data were used. The same type of boundary condition has been used for the downstream boundaries in the Lohajang River at Mirzapur, in the Pungli River at Nathkola and in the Dhaleswari river at the junction with the New Dhaleswari River.

Four existing inlet structures (in the western embankment) have been included in the model.

The pilot FAP20 TCM has been calibrated against the 1991 situation.

The model has primarily been used to test possible future developments. Because boundary conditions were not available to run a statistical range of years, the years 1987, 1989 and 1991 have been selected as the most relevant years to simulate the various implementation alternatives.

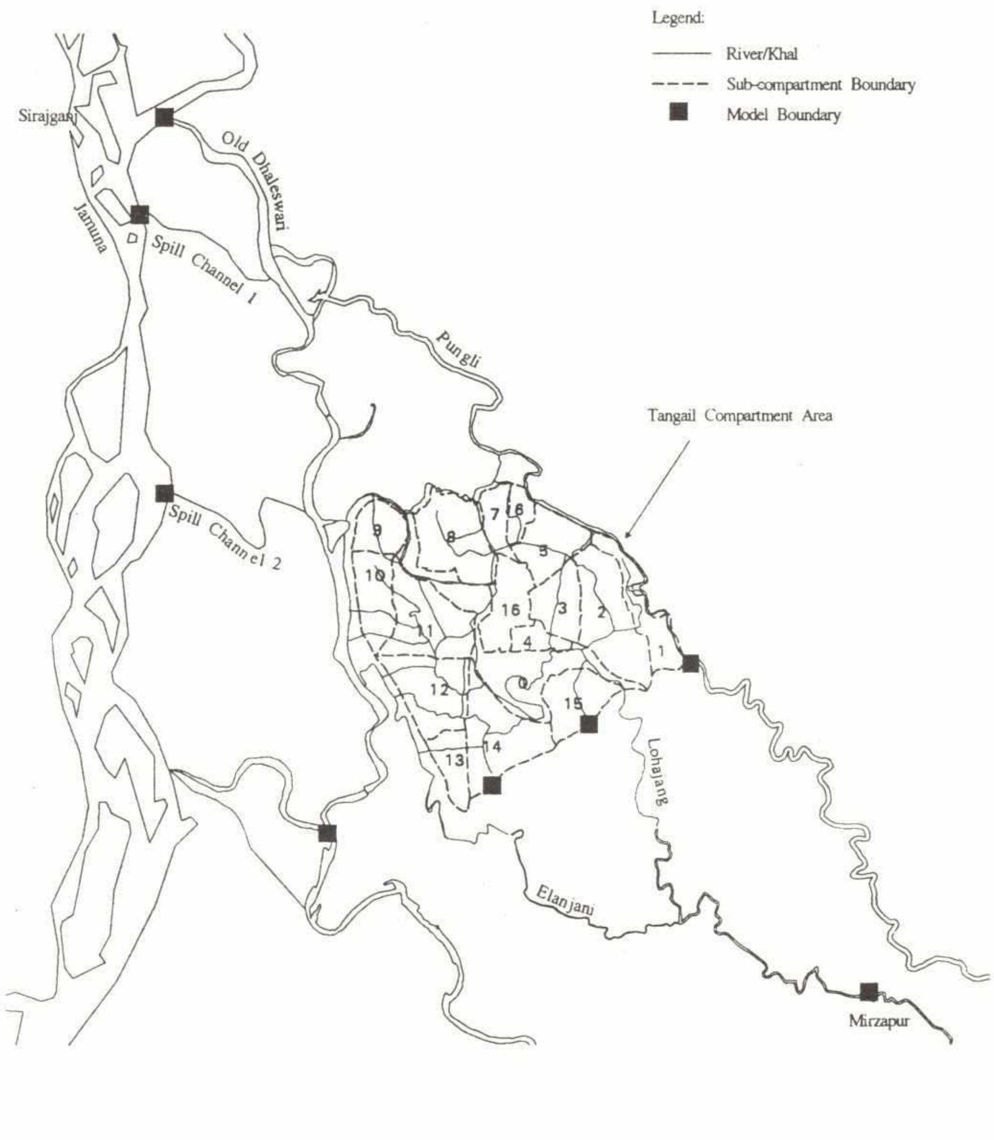
C.2.2.2 Need for Detailing

The final design of the proposed Main Inlet in the Lohajang and outlets along the Lohajang require structures consisting of one or more gates independently controlled or combined with a weir with a fixed sill level. This type of controlled structure was not available in earlier versions of MIKE11 on which the pilot FAP20 TCM was based.

To simulate structure operation on a more detailed scale (on chawk level), the smaller khals and artificial khals simulating overland flow should be included along with internal structures of the above mentioned type. With a model of such detail, together with an accurate DEM, it would be possible to produce flood maps showing water depths at chawk-level for different situations.

In the pilot FAP20 TCM the floodplains were schematised as a part of the channel cross-section profile but represented as area elevation curves. Although this model computes water levels fairly well for wet years, this is not the case for less wet and dry years. In the revised FAP20 TCM, area elevation curves were extracted from the new FINNMAP DEM and the use of these curves based on these data improved the accuracy of the water level simulations.

Figure C.2 Location and Layout of FAP20 TCM



The cross-section profiles of the khals used in the model should be checked with the latest available survey data and adjusted where necessary. This is particularly necessary where re-excavation of khals has taken place.

C.2.3 Data

C.2.3.1 Hydrometric Data

For the calibration of the model against the 1993 situation water level data have been collected from 32 water level gauge stations in the Tangail Compartment and the adjacent areas. Of these stations, 6 are located in the floodplains of the Compartment. Water level data have been collected at 4 locations outside the Compartment, which serve as boundary data.

The rainfall-runoff (NAM) model has been calibrated using observed rainfall data of station Atia (R02) and ground water level data collected from 4 locations in the model area.

In 1993 the discharge was measured at 4 locations in the study area to assist in model calibration, but the results obtained could not be used with confidence and they were discarded.

C.2.3.2 GIS Coverages

GIS data on compartment embankments, roads, sub-compartment boundaries, khals, rivers and beels were obtained from FAP19. These original coverages were based on old data and were refined using more detailed and up-to-date information from FAP20 and FINNMAP topographic photo maps. From these maps, additional coverages such as settlements were also digitised.

Plate C.1 shows coverages of the sub-compartments, roads, settlements (Tangail Township and villages), river and beels used for the Tangail Compartment FMM (TC-FMM).

C.2.3.3 DEM

Initially a DEM of the Tangail area was obtained from FAP19. This DEM was based on BWDB 4":1 mile maps of 1964 and a 40 m grid was extracted from 300 m by 300 m spot elevations.

Later this DEM was replaced by one based on 100m by 200m spot elevations, digitised from the 1:10,000 photomaps produced by FINNMAP in December 1990 for FAP20. The elevations were adjusted to PWD datum (+0.46m). Grid cell sizes of 20 and 10 m were used for the TC-FMM and the FMM of sub-compartments 9-11 respectively.

Floodplain features such as rivers, khals and embankments were incorporated in the DEM using the coverages described in the previous section.

Compartment, sub-compartment boundaries and roads were included by raising the DEM elevations along their alignments. Areas in the DEM corresponding to Tangail Township

Tangail Compartment Coverages

- Sub- Compartment Boundary (Sub- Compartments shown in different shades)
- Road
- Settlement
- River
- Beel

and villages were raised two metres (based on an average estimate of settlement height above the floodplain). The exact height of the settlements was not included in the original DEM surveys and is presently not known. The bed levels of the rivers, khals and beels were also unknown and their elevations in the DEM were lowered to below dry season levels. The rivers and khals were lowered more than the beels to distinguish between them.

Plate C.2 shows the revised DEM of the Tangail Compartment. The lower floodplain areas can be seen in the green shades, with higher areas in the red-brown. Settlements, roads and compartment boundaries are shown in the darkest red-brown shade. Beels fall into the darkest green shade (areas below 7.0 m) and river and khals are shown in blue.

The original DEM, based on BWDB data and obtained from FAP19, and the revised DEM were compared to establish their differences. The comparison map shown on Plate C.3 indicates there are significant areas differing by ±1.0 m. These differences, which represent changes in field levels since 1964, are probably due to a complexity of reasons, too difficult to assess within this project. However, more reliance should be placed on the FINNMAP data than the BWDB data because they are more recent.

C.2.3.4 Supplementary Surveys

More detailed data were obtained from supplementary surveys carried out by FAP20 in sub-compartments 9, 10 and 11. These comprised cross-section profiles of smaller khals and water level observations from a further 10 locations. The additional cross-section profiles have been used to detail the model for SC9-11 MIKE11 model while a number of the additional water level observations was used for the calibration of the revised FAP20 TCM.

C.2.4 Development of the Revised FAP20 TCM

C.2.4.1 Model Schematisation

The pilot FAP20 TCM has been used as a basis for the development of the revised FAP20 TCM for the 1993 situation. The network layout of the pilot FAP20 TCM has been checked and refined where appropriate. In a number of areas channels have been added to the network to give a better representation of the current situation.

The network layout of the revised FAP20 TCM is illustrated in Plate C.4 using the TC-FMM Branch Route System (BRS). Also shown are the river and khal cross-sections, and the project's FCD structures. Future reference to the FAP20 TCM within this report means the revised FAP20 TCM.

The cross-section profiles of all channels have been checked and the floodplains have been disconnected. Re-excavations, carried out in 1992-1993 dry season, have been represented in the revised cross-sections. The floodplain which was removed from the cross sections has been schematised as additional storage using MIKE11-GIS (see C.2.4.2).

Rainfall-runoff catchments have been checked and revised to accord with the modifications in the network layout. Due to greater detail in the model, some catchments have been sub-divided and adjusted for embankment locations.

Although a discharge boundary upstream of the model would be preferable, reliable discharge data are not available and, apart from some internal channels having a boundary condition of 'zero' discharge, water level boundaries have been applied all around the model.

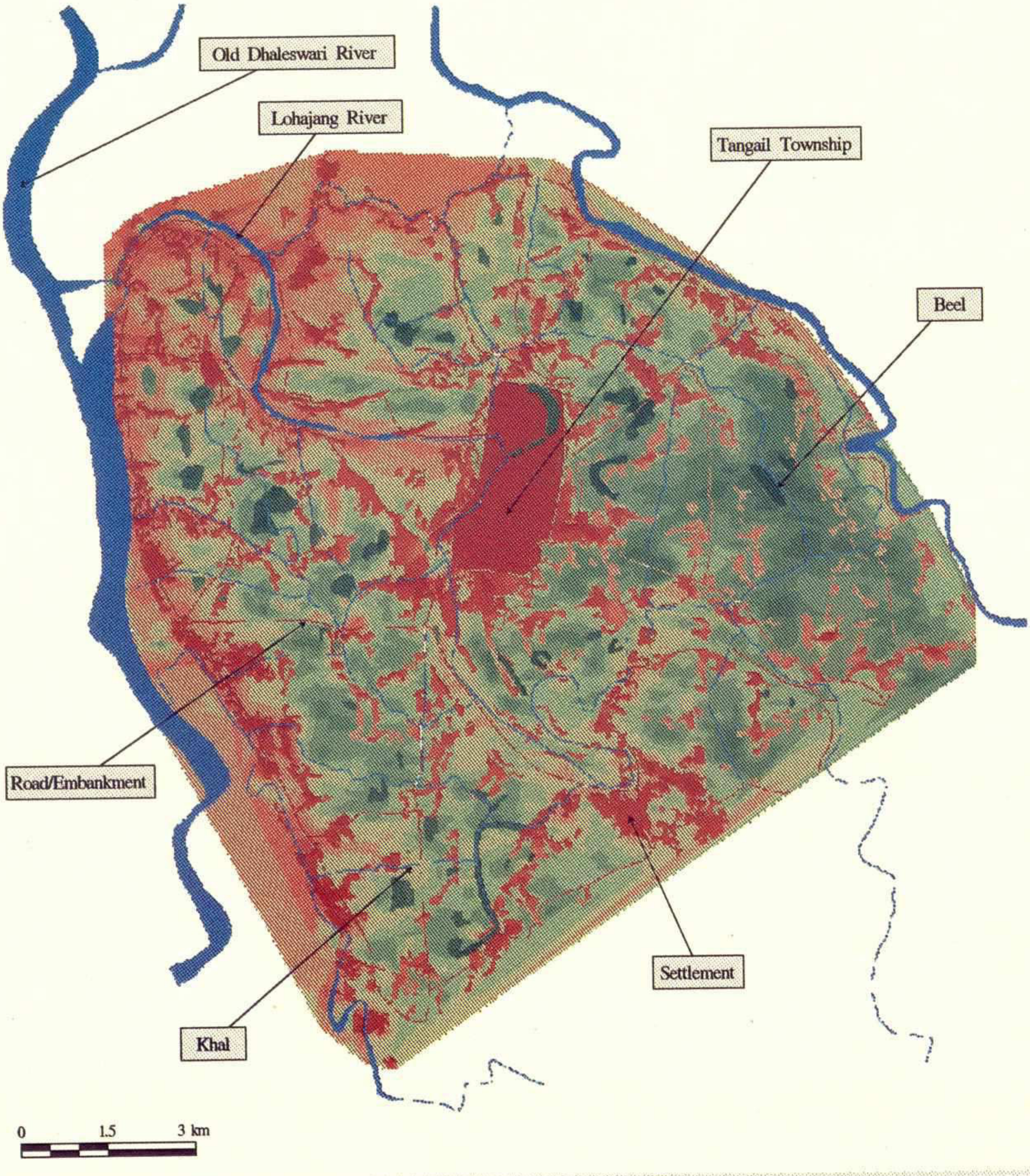
C.2.4.2 Floodplain Storage

In the FAP20 TCM, the floodplain has been schematised as additional storage. In most of the Tangail Compartment the khals have direct connection with the floodplain. The floodplain has been modelled as khal cross-section profiles plus additional flooded area, (AE curve), which means that the water level in the floodplain is always equal to the water level in the khal to which it is connected.

The additional flooded area data were extracted from the DEM for each of the SCC cells shown on Plate C.4. The resulting AE curves were assigned to a cross-section and exported to the MIKE11 cross-section database.

When data become available, those beels which are not part of khals should be modelled as separate flood cells, connected by links to the appropriate khal cross section. In most cases, the beel is part of a khal and is not modelled as additional storage.

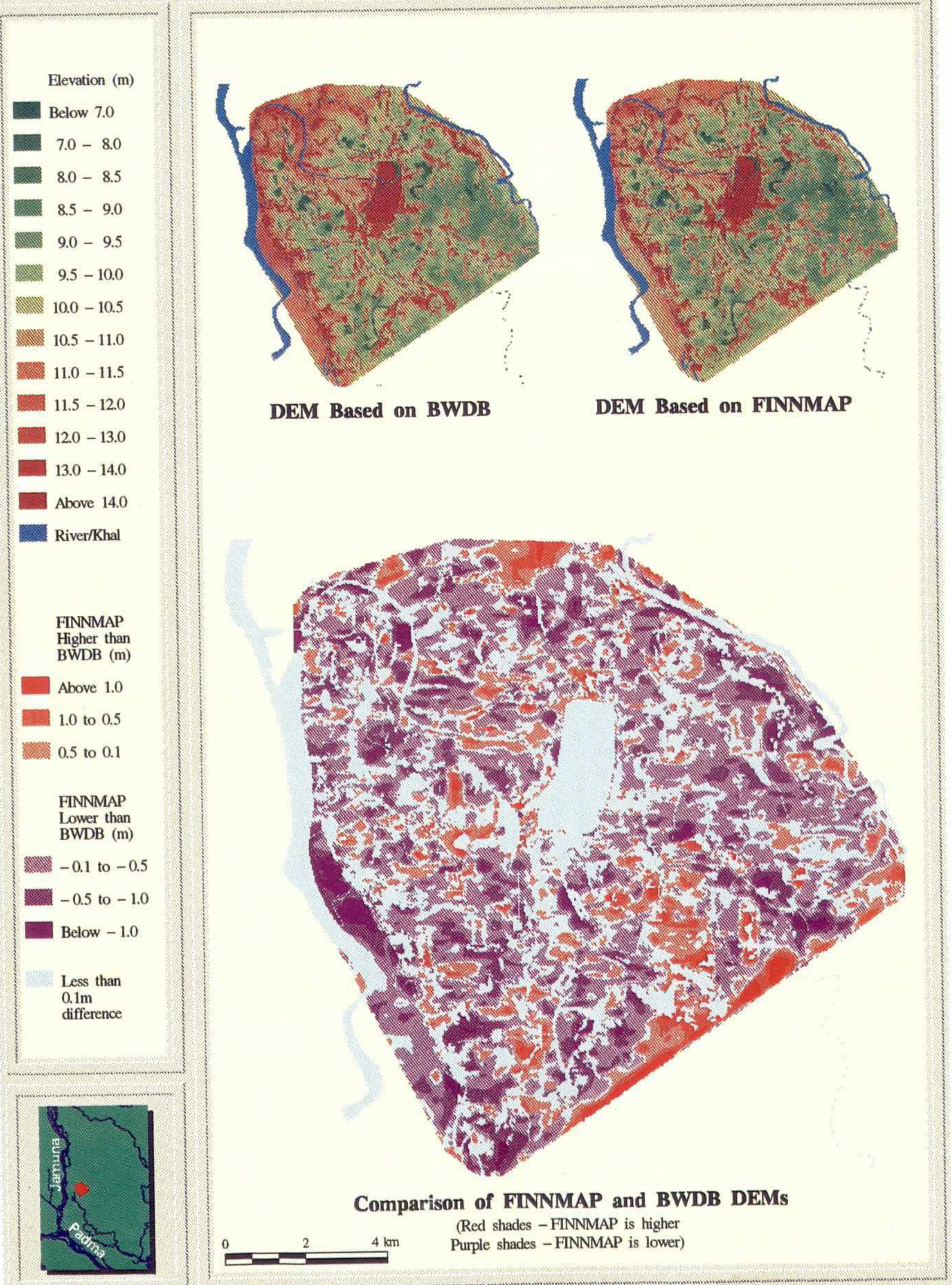
Tangail Compartment DEM (FINNMAP)



Elevation (m)

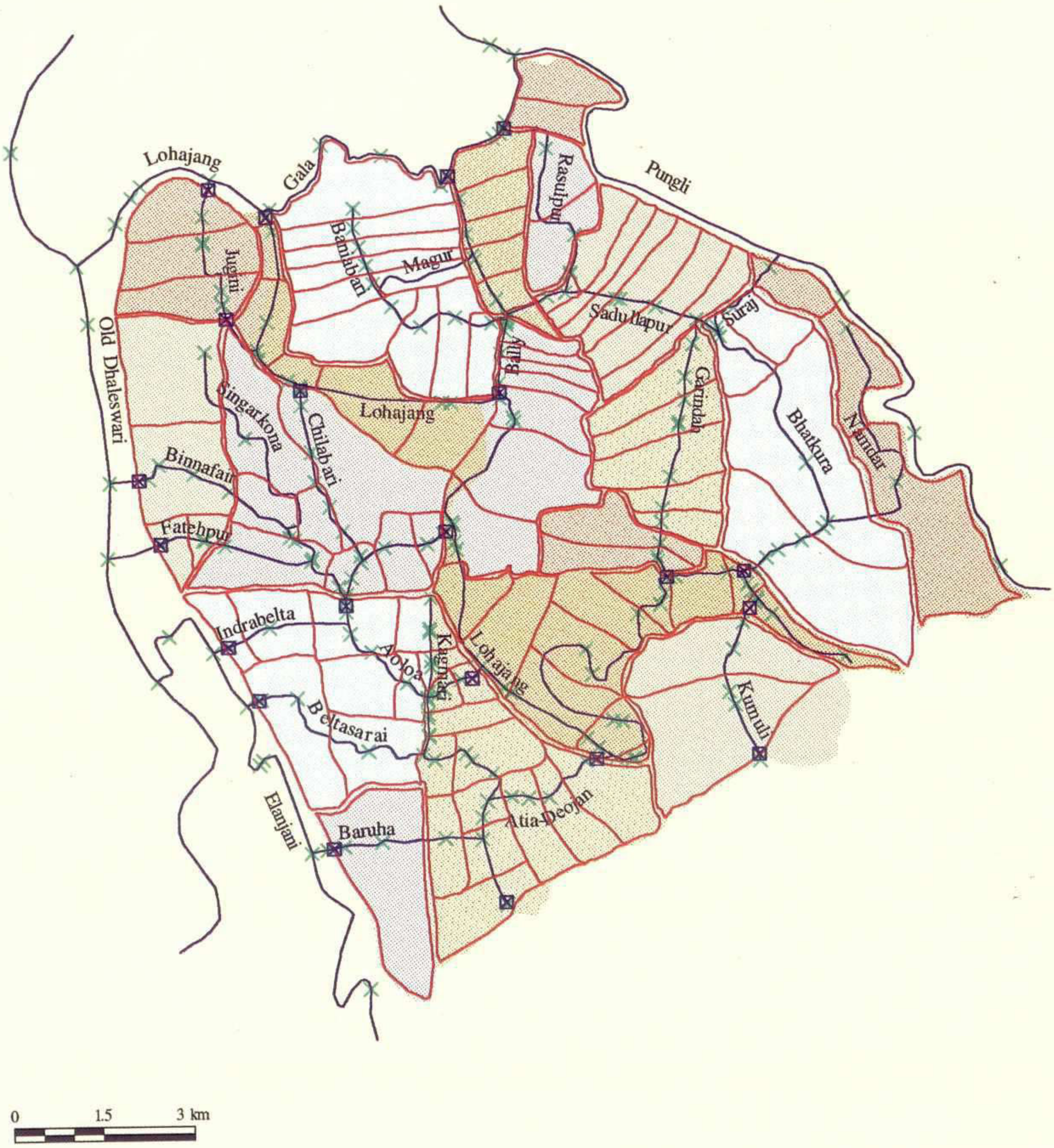
Below 7.0	9.0 – 9.5	11.0 – 11.5	Above 14.0
7.0 – 8.0	9.5 – 10.0	11.5 – 12.0	River/Khal
8.0 – 8.5	10.0 – 10.5	12.0 – 13.0	
8.5 – 9.0	10.5 – 11.0	13.0 – 14.0	

Comparison of FINNMAP and BWDB DEMs



Comparison of FINNMAP and BWDB DEMs
(Red shades – FINNMAP is higher
Purple shades – FINNMAP is lower)

TC Branch Route System and Storage Cell Coverage



Branch Route System

SCC Storage Cell

Cross- Section

Structure

(Sub-Compartments shown in different shades)

C.2.5 FAP20 TCM Calibration

The FAP20 TCM was calibrated for 1993. Although the calibration year of the FAP20 TCM was 1991, calibration of the FAP20 TCM was performed with 1993 data because reliable observed water level data is available at many locations for this year, especially in floodplain areas. For 1991 observed water level data is available at only a few locations, mainly in the Lohajang and major khals, and is not very reliable.

All water level comparison locations in the Lohajang river show good agreement, (see Lohajang in Figure C.1). At the locations in western areas the observed and computed water levels match quite well (see Binnafair khal in Figure C.3). The results in the eastern part are less accurate (see Garinda khal in Figure C.3) , but still satisfactory.

C.2.6 Flood Mapping

C.2.6.1 Water Surface Coverage

Plate C.5 illustrates the Water Surface Coverage (WSC) used for producing flood maps. For further explanation of terms and methods refer to the *MIKE11-GIS Reference and User's Guide*.

A sub-compartment's floodplain flood level was assumed in the MIKE11 model to be essentially the same as the sub-compartment's main river or khal. Therefore, for each sub-compartment, Channel Boundary Lines (CBLs) were located along the adjacent side of the embankments, roads and/or settlements, and the Water Level Lines (WLLs) were extended across the sub-compartment (from CBL to CBL), intersecting with the river or khal.

In a few areas, floodplain levels have been based on an interpolation between neighbouring khals (as seen by the "whiter" areas on Plate C.5). These areas had no clear demarcations, such as an embankment, road or settlement, between the khals.

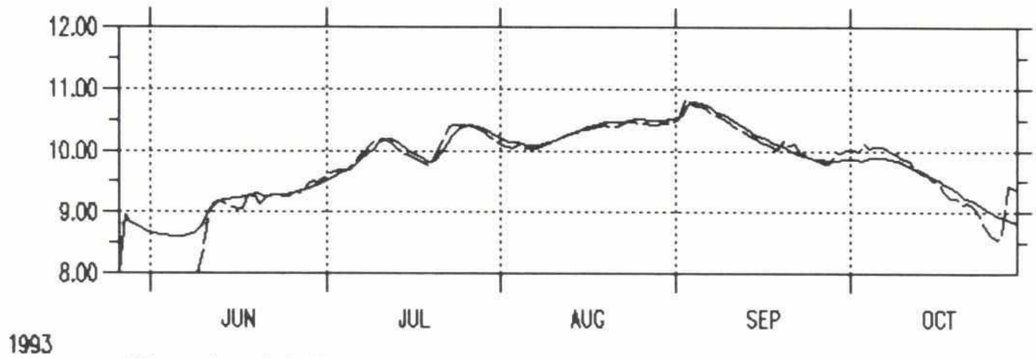
Water Level Cells (WLCs) were either used at the upstream ends of a khal to extend the sub-compartment's flood levels up to the neighbouring sub-compartments' embankments, or where there was only a single h-point (flood level computation point) on which to create the flood level surface. The WLCs are shown as the pale blue areas on the plate.

The WSC TIN was created from the WLLs and WLCs as also illustrated on Plate C.5.

Figure C.3 Calibration Results of FAP20 TCM (1993)

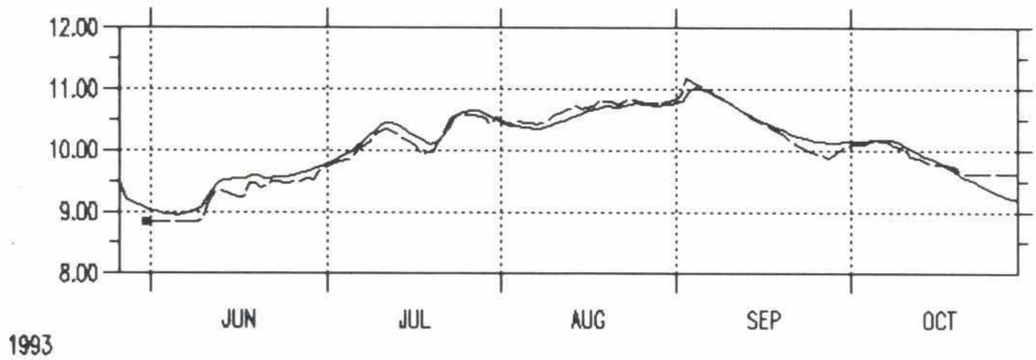
Water Level (m)
Location: Lohajang 18.13 km (G05)

----- Observed ______ Simulated



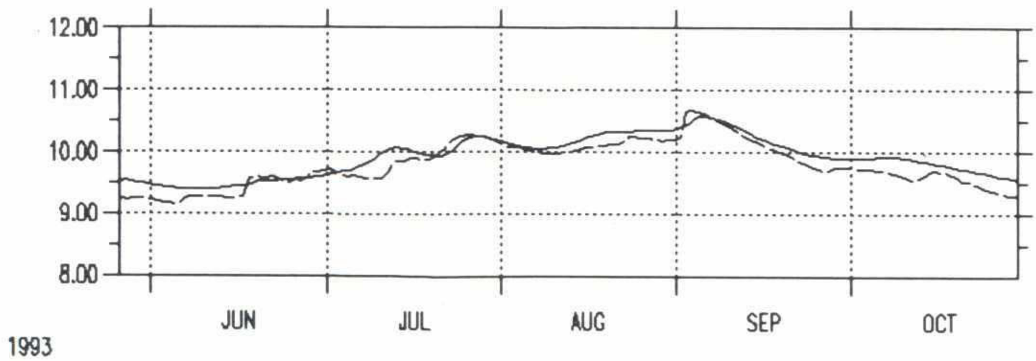
Water Level (m)
Location: Binnafair 5.30 km (G22)

----- Observed ______ Simulated



Water Level (m)
Location: Garinda 0.00 km (G31)

----- Observed ______ Simulated



TC Water Surface Coverage

Water Level Line
Channel Boundary Line
Water Surface Coverage TIN
Branch Route System
Water Level Cell
No DEM Data

C.2.6.2 Flood Depth Maps

Examples of flood depth maps are shown in Plate C.6, which were derived from the Water Surface Coverage shown in Plate C.5 and described in the previous section. The plate shows the variation in flood depth over the Tangail Compartment on June 14 (pre-monsoon) and September 4 (monsoon peak), 1993, based on the FAP20 TCM flood simulation results. The maps give a clear picture of the depth and extent of the flood inundation.

Colour shading is provided at increments in water depth of 30 cm. The darker the shade of blue, the deeper the water. The dry areas are shown in green and include the settlements. Rivers, khals and beels appear as deep water (dark blue) because the bed elevations of corresponding areas in the DEM were lowered to below dry season water levels.

C.2.6.3 Radar Image Flood Extent Verification

Plate C.7 shows a comparison of the TC-FMM flood extent map and a radar image supplied by FAP19 on July 24, 1993. The flood extent map and the radar image show good agreement with approximately 75% of the area matching.

There is a geo-referencing problem between the two as some pronounced beels, for example the beel in the northern part of Tangail Township (see note on plate), appear in different locations. By inspection, it is estimated that as much as 5-10% of the non-matching areas is due to geo-referencing inaccuracies. The geo-referencing inconsistency is suspected to be due to the river and beel coverage being incorrectly located, and will be further investigated by FAP20.

Other reasons for discrepancies would be inaccuracies in the computed flood levels and in the radar image. Of particular importance is the effect of crops, hyacinth and other vegetation distorting the radar signal, therefore, causing problems in delineating water from land.

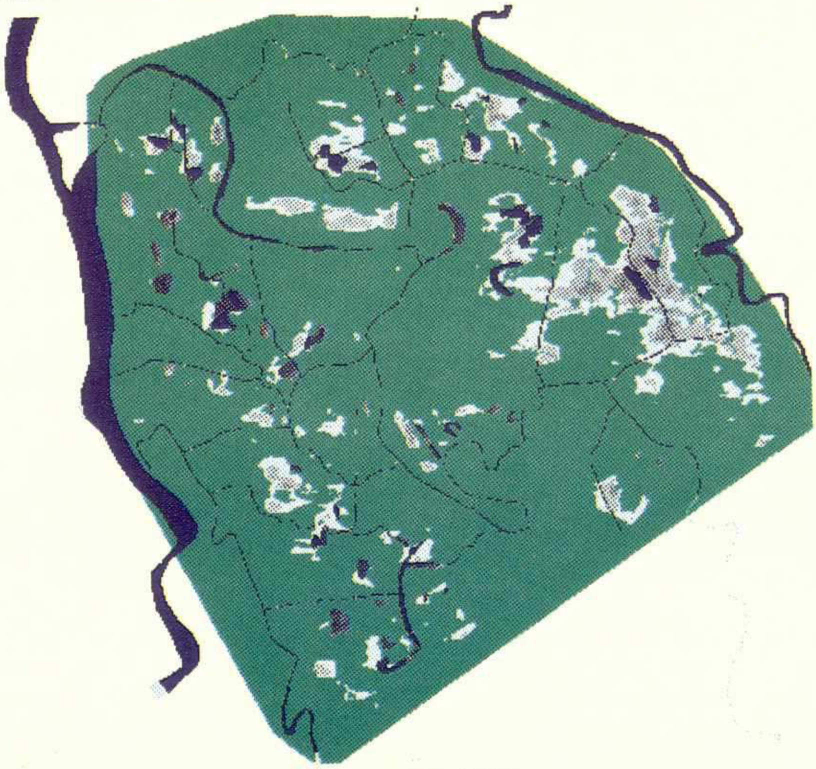
Nevertheless, the usefulness of radar imagery for flood extent verification is very apparent based on this exercise. Of particular importance is the use of the radar image for further calibration of the MIKE11 model. Close observation of Plate C.7 clearly shows some sub-compartments where the FAP20 TCM flood levels are either predominantly too low (more green than blue) or too high (more blue than green) - examples are annotated on the plate. This type of information will further help MIKE11 model development.

This page intentionally left blank.

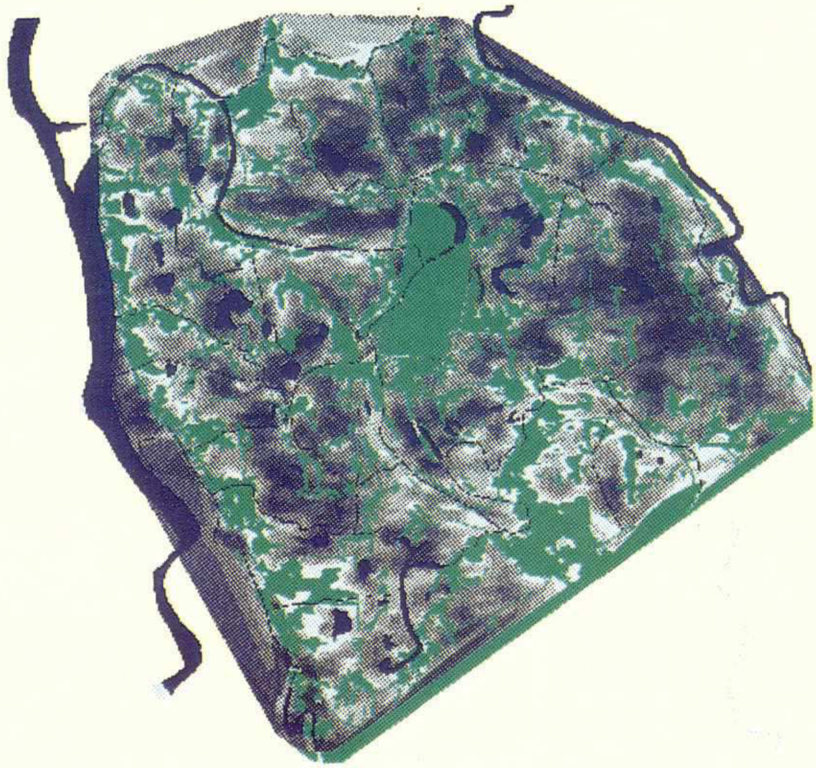
Simulated Flood Depths (Without Project) - 1991

Depth (m)

- 0.00 – 0.30
- 0.30 – 0.60
- 0.60 – 0.90
- 0.90 – 1.20
- 1.20 – 1.50
- 1.50 – 1.80
- 1.80 – 2.10
- Above 2.10
- Flood Free



June 14, 1991



September 13, 1991

0 2 4 km

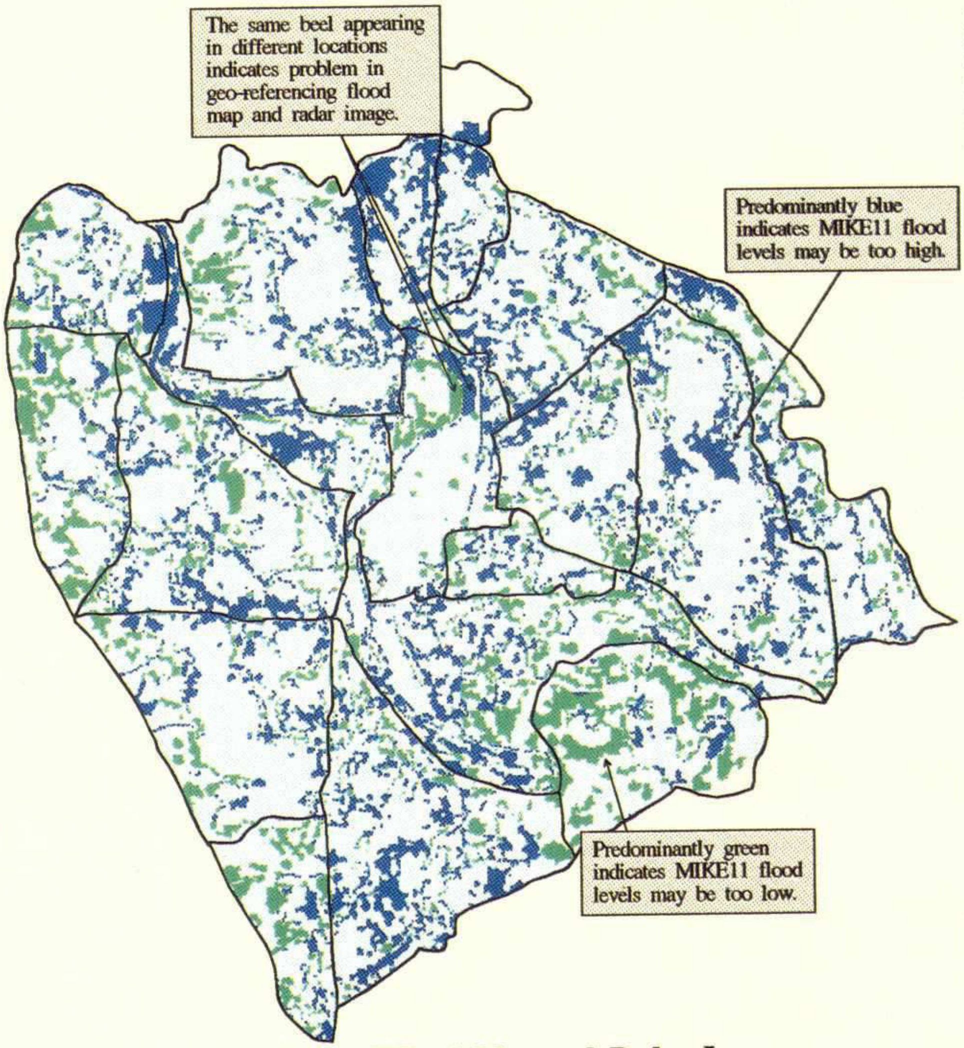
Radar Image Flood Extent Verification - July 24, 1993

Flood Free
Flooded
Sub–Comparment

Simulated Flood Extent Map

Radar Image

Flooded on radar image, but flood free on flood map
Same on both flood map and radar image
Flooded on flood map, but flood free on radar image
Sub–Comparment



Comparison of Flood Map and Radar Image
(Blue: Flooded on flood map, flood free on radar image
Green: Flood free on flood map, flooded on radar image)

0 1.5 3 km

C.3 APPLICATION OF THE COMPARTMENT FMM

C.3.1 Introduction

Using the FAP20 TCM, structure operation options were tested for different flooding situations.

To test structure operation on a more detailed scale a sub-compartment TCM has been developed with a detailed schematisation of sub-compartments 9, 10 and 11 (SC9-11). This detailed model includes water level control up to chawk level in SC9-11.

From results of different simulations flood depth maps, flood difference maps, duration depth maps and depth classification maps were produced, using the TC-FMM.

C.3.2 Compartment FCD Structures

C.3.2.1 Inclusion of FCD Structures

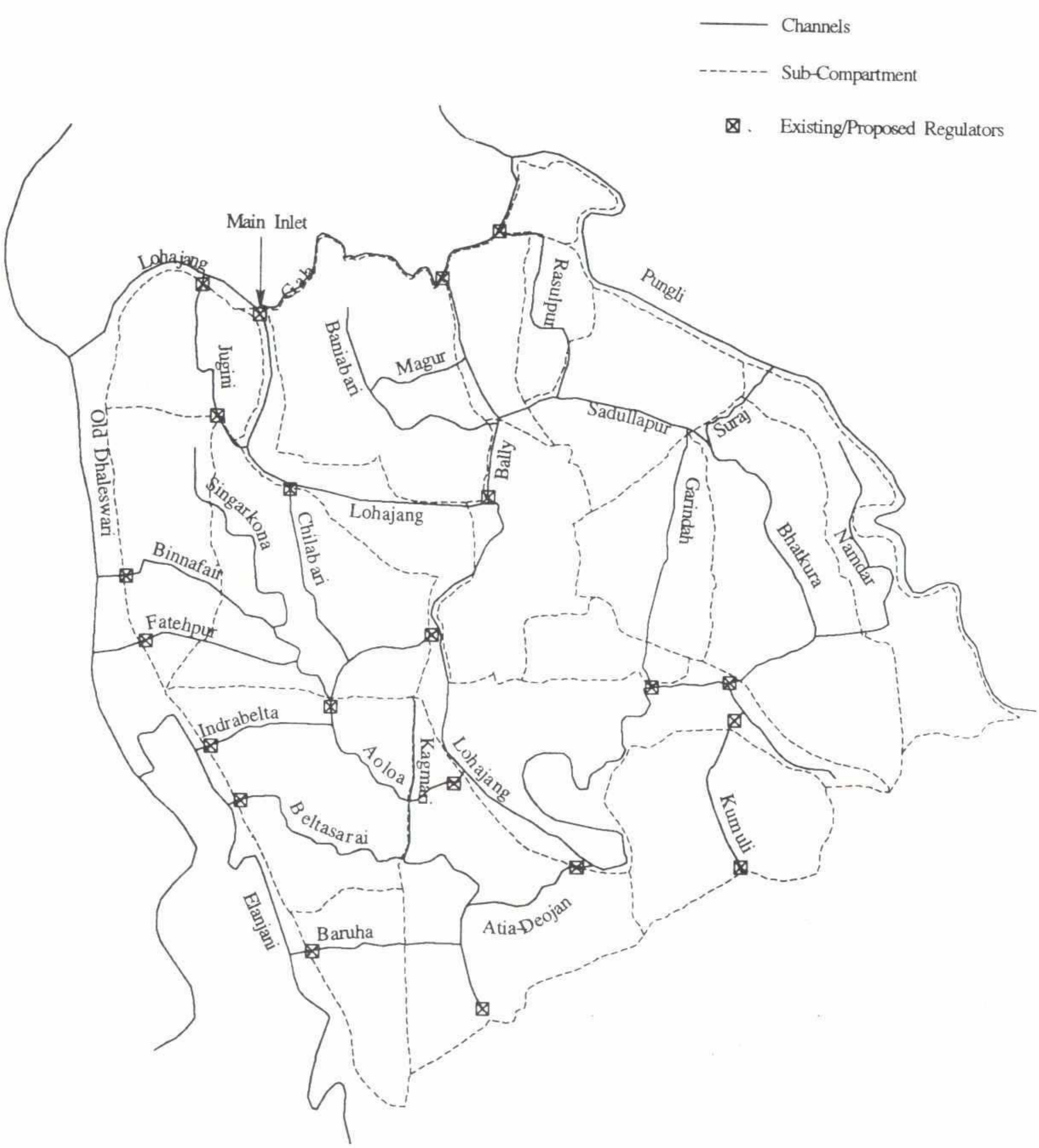
The main-inlet to the Tangail Compartment is located in the Lohajang river, downstream of the Gala khal offtake, in the northern embankment and controls the downstream water level. To allow drainage to the Lohajang downstream of the Main Inlet, the water level just downstream of the structure will be maintained at approximately +11m PWD using the 3 inner gates (underflow). The two outer gates have sill levels at +11m PWD and act as weirs (overflow) to allow fish passing the structure. All peripheral inlet structures are located in the horse-shoe embankment.

The combination of gates/control was modelled using the multiple structure facility in MIKE11.

For the sub-compartments average required water levels (target water levels) have been computed by and obtained from FAP20 *(FAP20/1)*.

The network layout of the FAP20 TCM is represented in Figure C.4, also showing the location of structures.

Figure C.4 FAP20 TCM Setup with Peripheral and Internal Structures



0202

C.3.2.2 FCD Structure Operation Guidelines

FCD structure operation guidelines are based on agriculture and fisheries requirements of obtaining an average water level within an acceptable tolerance for each sub-compartment.

The general operation guidelines rules for different structures are as follows: (*FAP20/2*):

Type	Operation
Main Inlet	Fully open until mid-July, then, when the water level downstream exceeds +11m PWD, the first gate of the three inner vents will be lowered to the sill. To control the water level downstream, the second gate must be used together with the two outer vents which stay open, (sill level +11m PWD); the two outer vents will be closed depending on the flow velocity and water level difference.
Peripheral Inlet	fully open until mid-July and after monsoon, during monsoon to be operated depending on the downstream water level and target water level of the sub-compartment.
Controlled inlet/outlet between Lohajang and SC's	Functioning as inlet or outlet structure, depending on water levels in the sub-compartment and the Lohajang river during monsoon open when drainage is possible and depending on target water level of the sub-compartment, else closed and open after monsoon
Controlled structure between chawks and SC's	Low section with regulator, (based on pre-monsoon discharge requirements), closed during monsoon, the weir section has a fixed weir level based on the required water level in the upstream part during monsoon

Based on the FCD structure operation guidelines the peripheral inlets are operated as follows:

> when the water level in the control point of the downstream area is 20 cm below target water level the inlets will be opened. They will be closed when the water level reaches the target water level. When the upstream water level is less than the inside level the gate(s) will be closed.

Structures are placed within the compartment at the junction of all draining khals with the Lohajang. These structures permit drainage flow from the sub-compartment into the Lohajang, but do not permit flow in the reverse direction. The operation rules applied for these outlets are as follows:

> when the water level in the control point of the upstream area is greater than target water level + 20 cm, the gate(s) will be opened and drainage will take place when the inside level is higher than the Lohajang level, which is

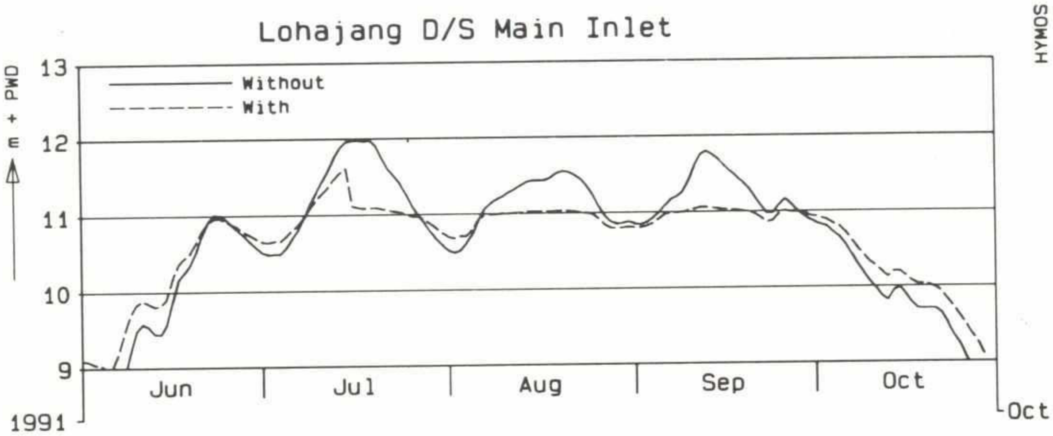
controlled by the Main Inlet, (see above). The gate(s) will be closed again when the inside water level has dropped to the target water level.

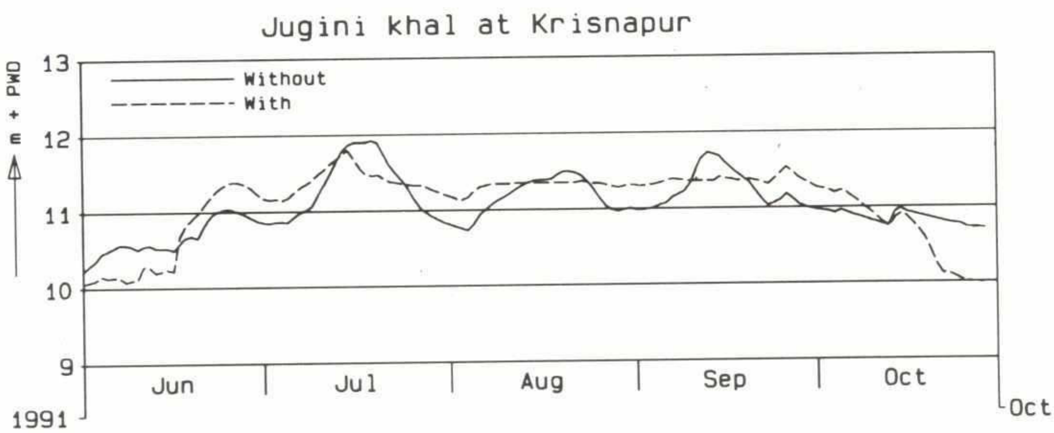
As an overall override inlet control, all structures will be fully open until July 15 (to permit fish-hatchlings entering the Compartment) and at the start of the post-monsoon (to permit drainage as fast as possible).

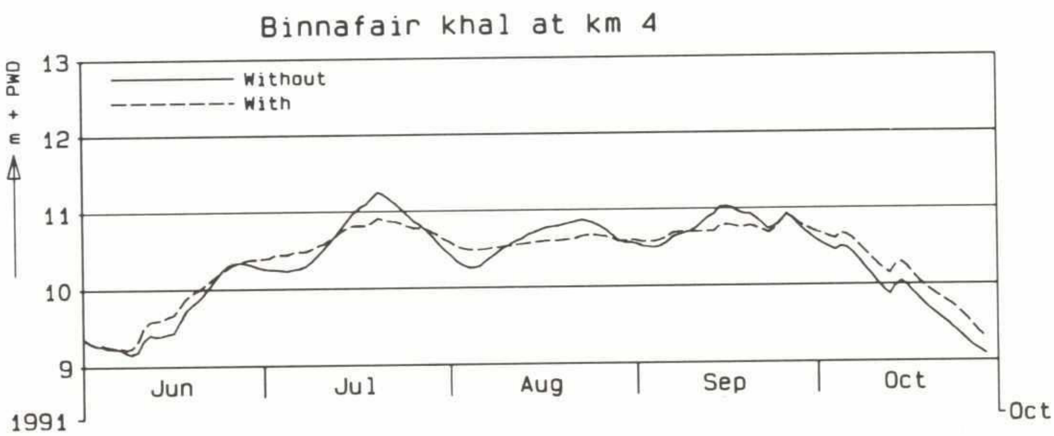
Figure C.5 shows the effect of structure operation by comparing water levels of the Without and With Project cases in the Lohajang downstream of the Main Inlet, a location in sub-compartment 9 (SC9, Jugini khal) and a location in SC11 (Binnafair khal) for the 1991 situation. The average target water level in SC-9 is set to +11.4m PWD and that of SC-11 to +10.4m PWD.

The results show that water retention will occur when structure operation is applied as above. This means that water levels may be higher in the With Project case but will nevertheless match the required water level.

Figure C.5 Comparison Graphs Without and With Project Cases 1991



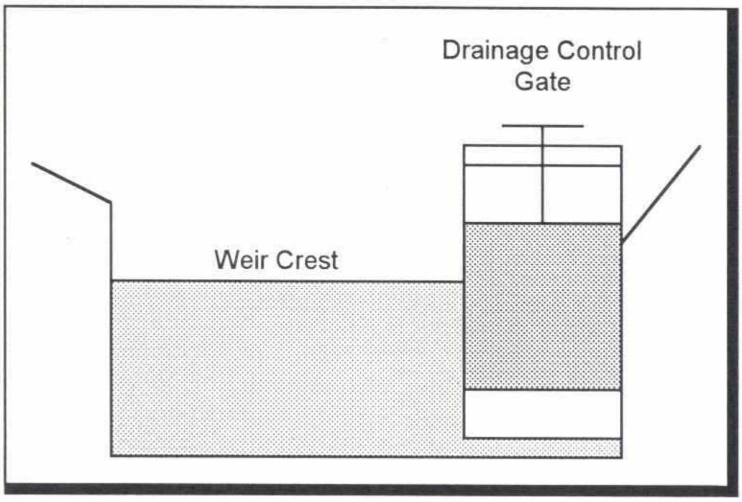




C.3.2.4 Detailing of Sub-Compartments 9 - 11 (SC9-11)

The north-western part (SC9-11) of the FAP20 TCM was detailed to include internal structures to control water levels on chawk level. Most of these structures consist of a gate and a weir section, modelled in MIKE11 using the composite structure module. The weir controls the upstream water level under normal conditions, while under extreme conditions and during post-monsoon the gate is used to drain water, (see sketch below)

Sketch of Typical Chawk Control Structure



Target water levels for all chawks, detailed information on average field level and total and cultivable area were provided by FAP-20.

The NAM contributions were redistributed by totalling the area of the chawks and assuming the resulting runoff to be laterally distributed along the length of the khals.

The chawks have been schematised as additional storage, using the average field level and the given net cultivable area.

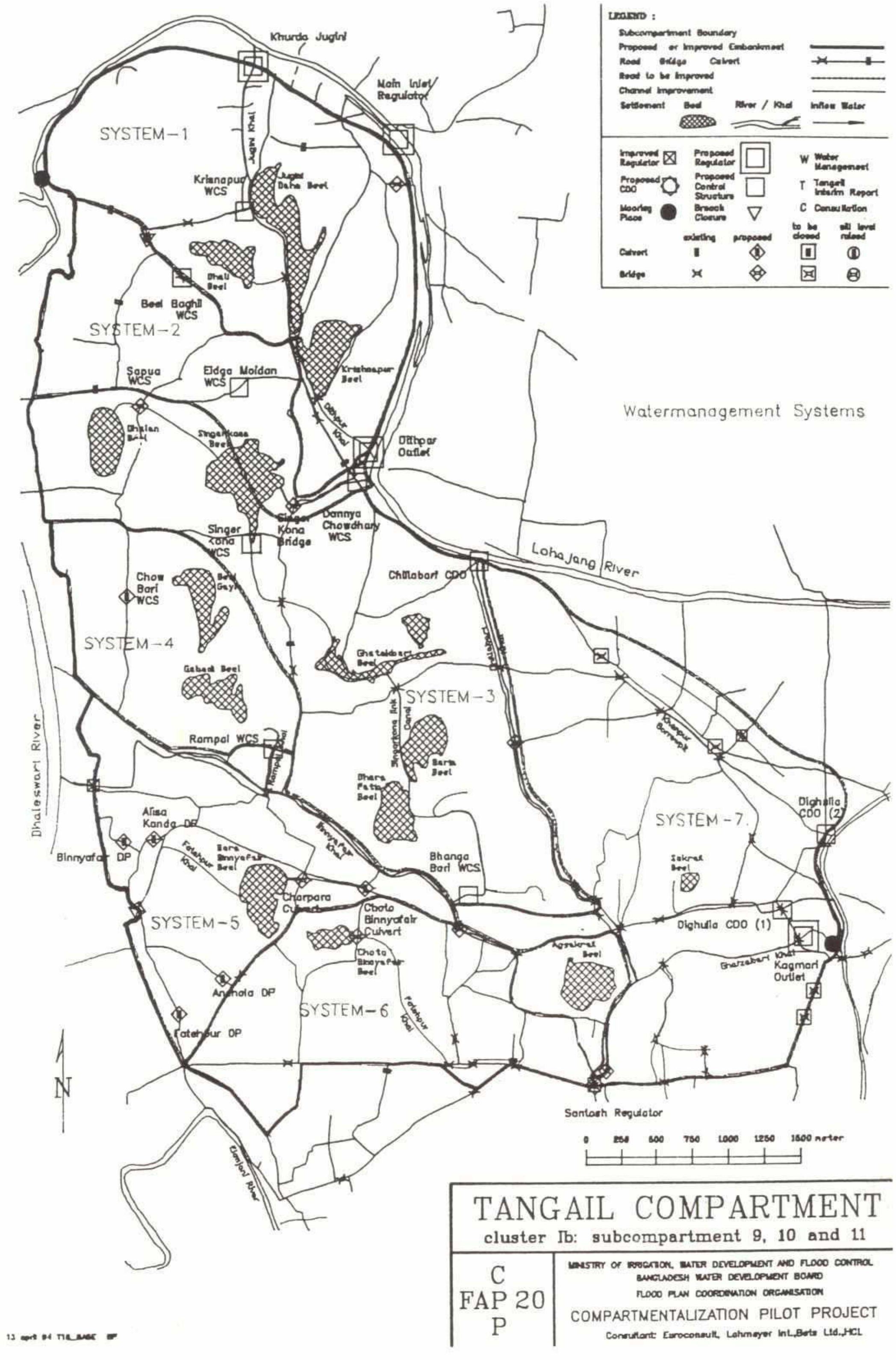
Proposed re-excavation of minor khals has been included and where no khals are present, artificial khals have been modelled to simulate water level variation in a proper way.

For the internal outlet structures and the peripheral inlet structures the same general operation rules have been applied as for Compartmental structure operation. However, these structures now are operated on target water levels of the chawks or average target water levels of groups of chawks downstream of the inlets or upstream of the outlets. The gates of the internal minor water control structures are open during pre-monsoon and post-monsoon and during monsoon they act as weirs maintaining the upstream water level at target level.

With the detailed TC-FMM the results of structure operation scenarios can be visualised on a detailed scale. After completion of the construction works and calibration of the structures, on-line testing can be done.

The detailed schematisation of SC9-11 of the FAP20 TCM is represented in Figure C.6

Figure C.6 Schematisation of Sub-Compartments 9 - 11



C.3.3 Flood and Crop Damage Mapping

Plate C.8 shows the flood depth maps of the Without and With Project cases on August 20, 1987, which is considered as a peak flood situation. The water levels in the sub-compartments are maintained at the required water level within acceptable limits. The lower map on Plate C.8 shows the change in flood levels resulting from the project. The comparison map shows the large decrease of depths over the area for this extreme event due to structure operation. An increase may be noted in water level in the northern adjacent area of about 45 cm.

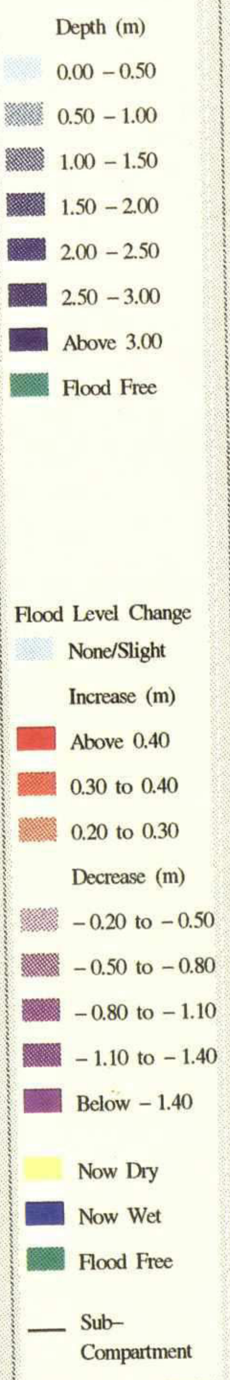
Plate C.9 shows the flood depth and comparison maps of the Without and With Project cases on September 13, 1991. The eastern part of the area experiences little difference as a result of the project. This is caused by water levels in these areas being approximately 40 cm higher than target in the With Project case. The comparison map shows an increase in water level in the northern adjacent area of about 50 cm.

Plate C.10 shows flood phase maps of the Without and With Project cases together with the change in flood phase between the two situations for 1991. In this case, the depths are grouped in flood phase depth range according to the Bangladesh Flood Phase Classification.

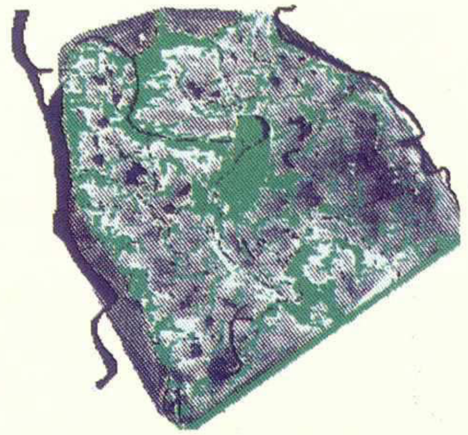
Plate C.11 shows an example of the type of crop damage mapping that is possible. These maps take account of the duration for which a crop can tolerate inundation and also the crop's growth stages.

To produce the crop damage maps in Plate C.11, a critical depth criterion for each period, (the depth of water which will damage the crop), has been assumed for all crop types. A period of analysis of 15 days, (half month), has been chosen, within which, the maximum depth which is equalled or exceeded for 3 consecutive days is determined. If the critical depth is exceeded by this maximum, the crop is assumed to be damaged. The FAP20 TCM (without sub-compartment detailing), was used for this demonstration. Statistics generated from the damage maps are shown in Table C.1

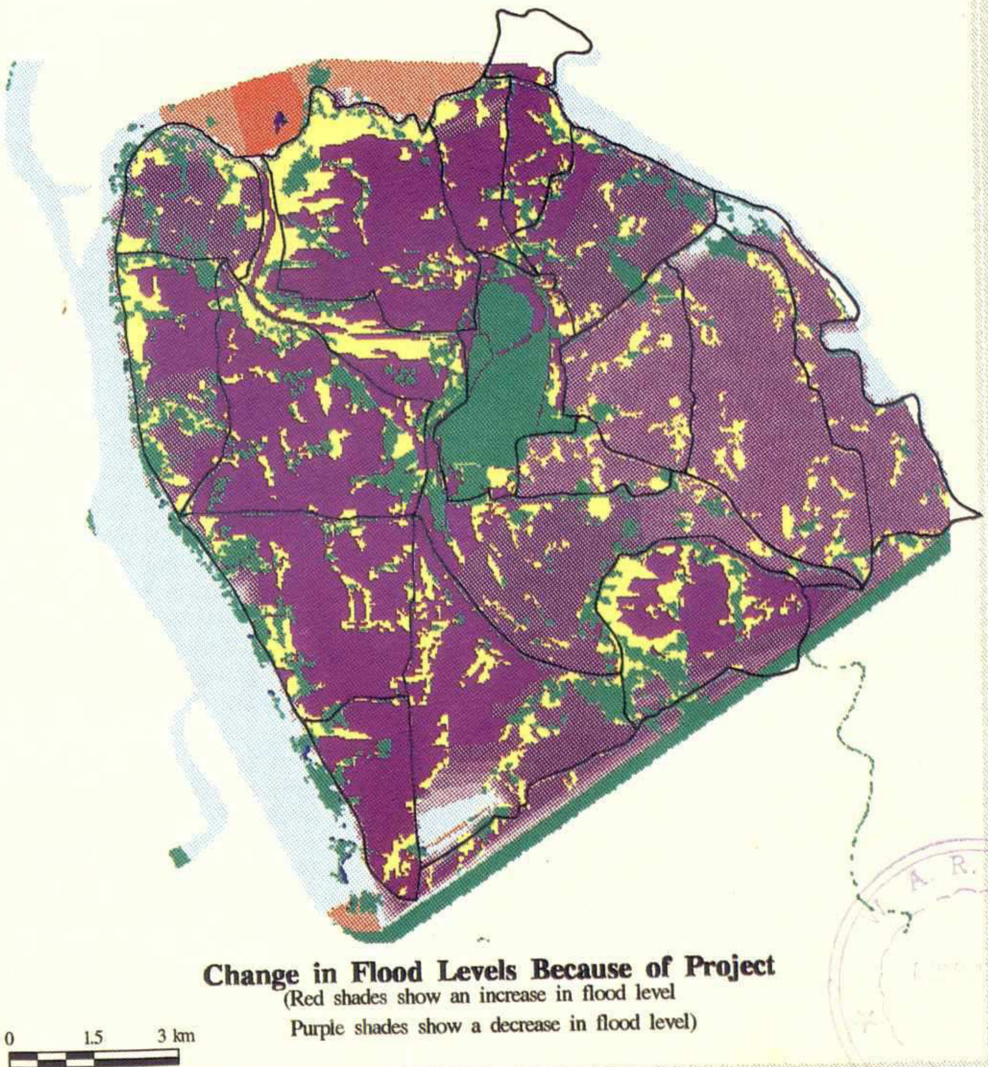
Simulated Impact on Flood Levels - 1987



August 20, 1987 (Without Project)



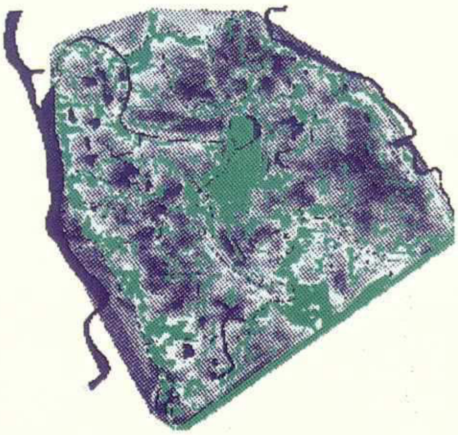
August 20, 1987 (With Project)



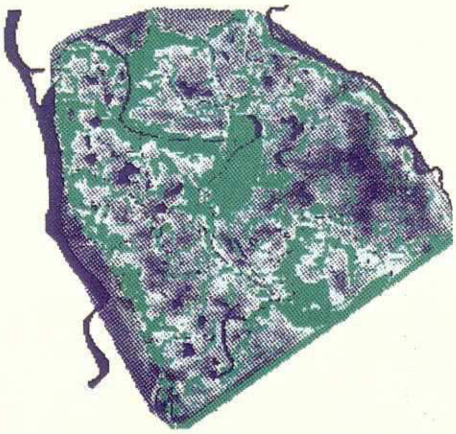
Change in Flood Levels Because of Project
(Red shades show an increase in flood level
Purple shades show a decrease in flood level)

Simulated Impact on Flood Levels - 1991

Depth (m)
- 0.00 – 0.30
- 0.30 – 0.60
- 0.60 – 0.90
- 0.90 – 1.20
- 1.20 – 1.50
- 1.50 – 1.80
- 1.80 – 2.10
- Above 2.10
- Flood Free



September 13, 1991
Without Project



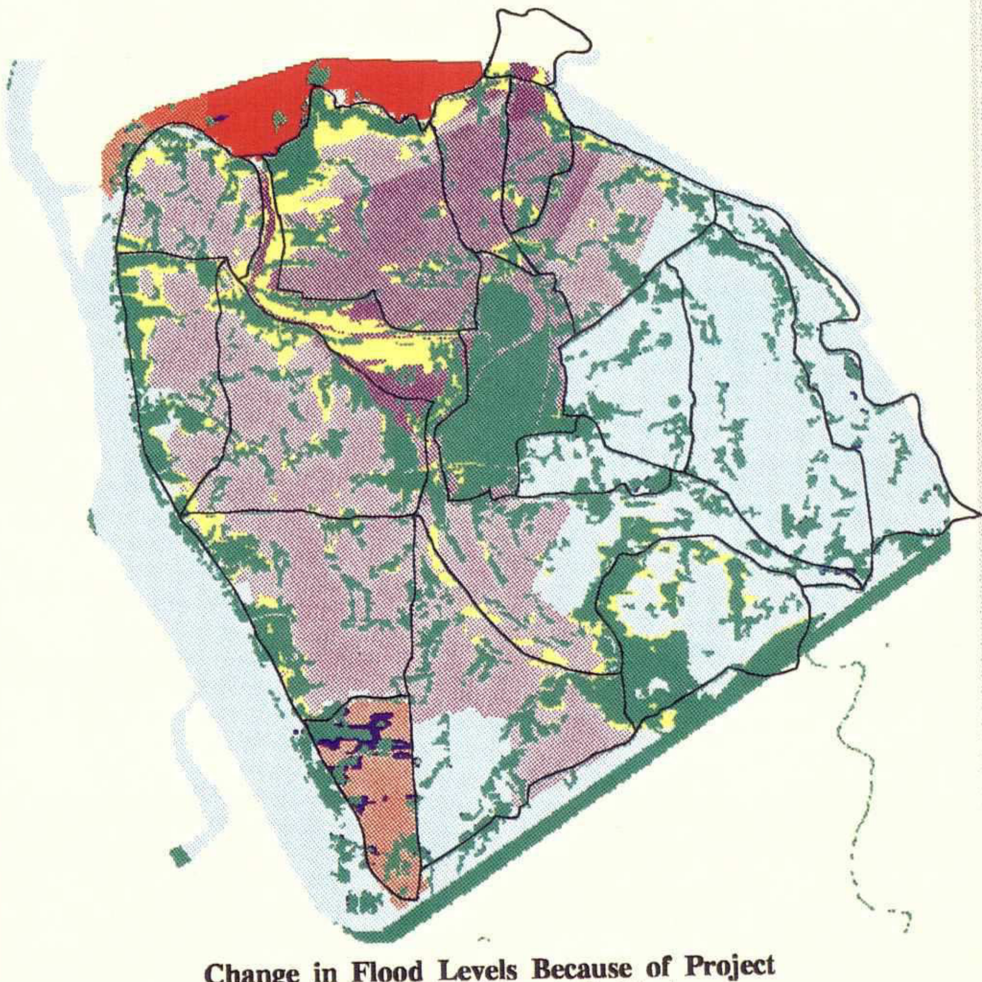
September 13, 1991
With Project

Flood Level Change
- None/Slight

Increase (m)
- Above 0.40
- 0.30 to 0.40
- 0.20 to 0.30

Decrease (m)
- –0.20 to –0.50
- –0.50 to –0.80
- –0.80 to –1.10
- –1.10 to –1.40
- Below –1.40

- Now Dry
- Now Wet
- Flood Free
- Sub-Compartment



0 1.5 3 km

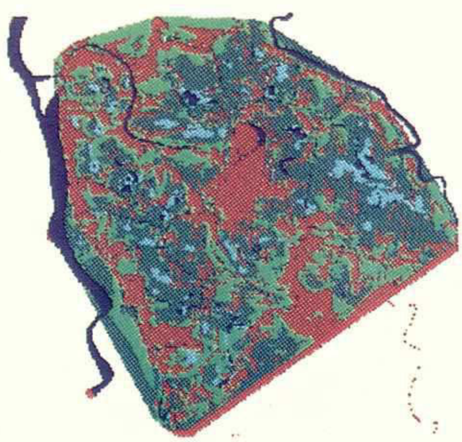
Change in Flood Levels Because of Project
(Red shades show an increase in flood level
Purple shades show a decrease in flood level)

Simulated Impact on Flood Phase - 1991

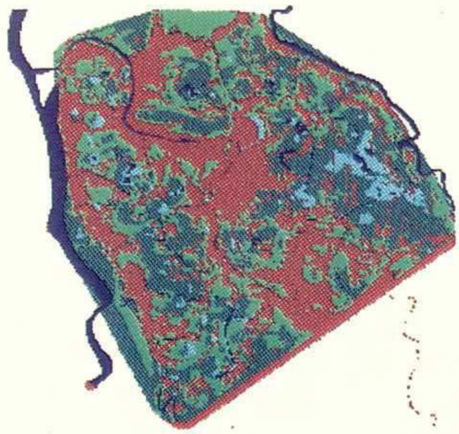
Flood phase maps are based on 3 day critical duration depths calculated for the period September 16 – 30.

Phase

- F0 (< 0.3m)
- F1 (0.3 – 0.9m)
- F2 (0.9 – 1.8m)
- F3 (1.8 – 3.6m)
- F4 (> 3.6m)



Without Project

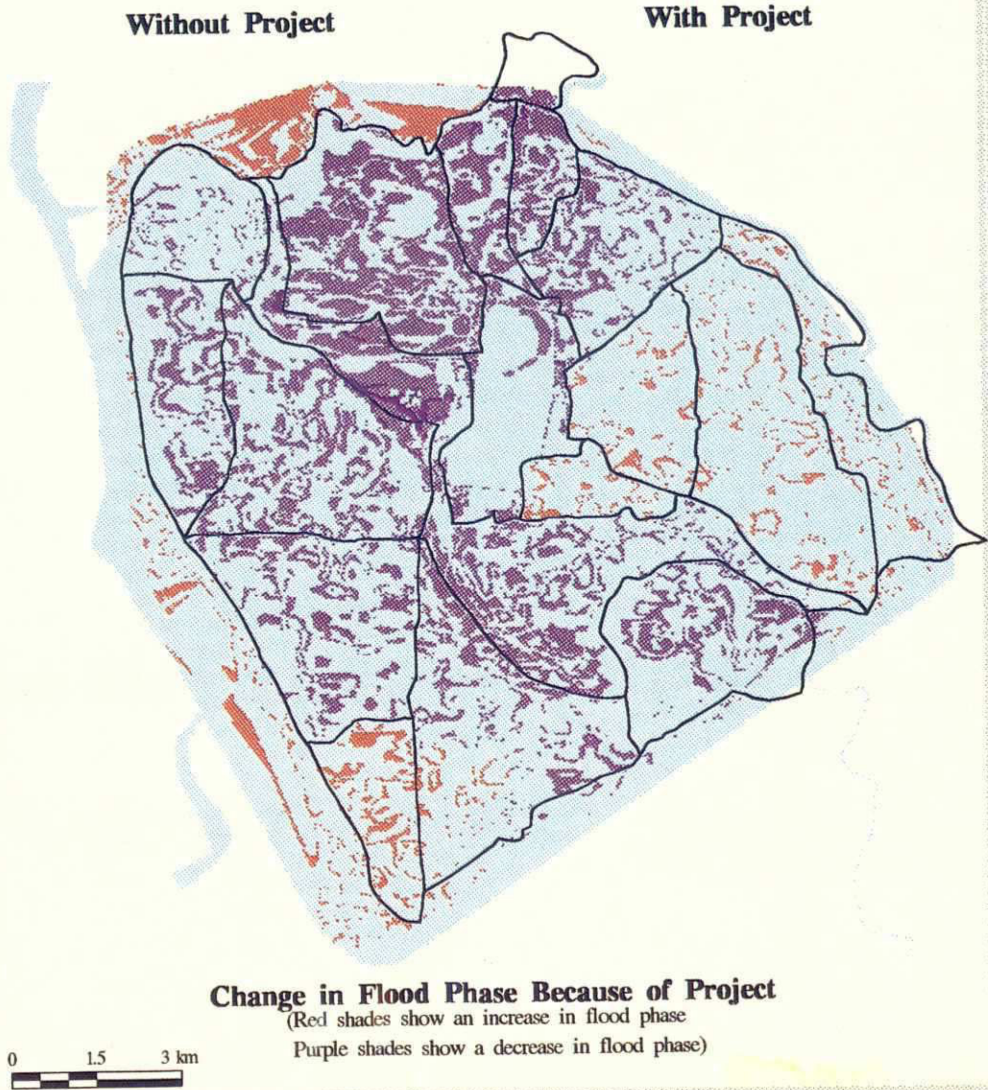


With Project

Phase Change

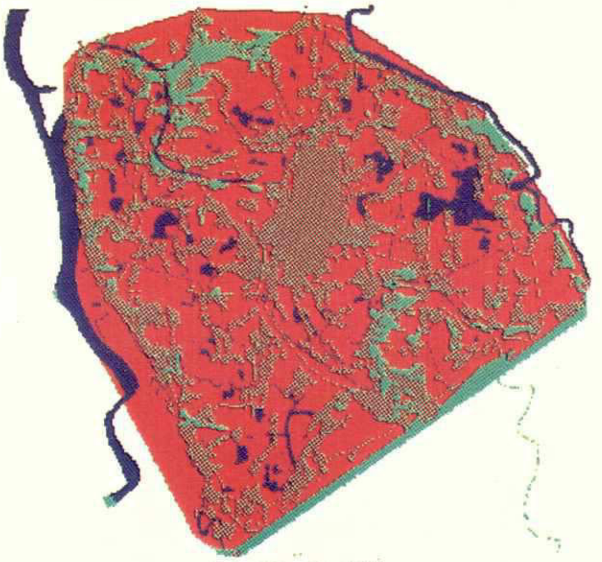
- Up 2 Phases
- Up 1 Phase
- No Change
- Down 1 Phase
- Down 2 Phases

— Sub-Compartment



Change in Flood Phase Because of Project
(Red shades show an increase in flood phase
Purple shades show a decrease in flood phase)

Tangail Compartment - Crop Damage - 1987

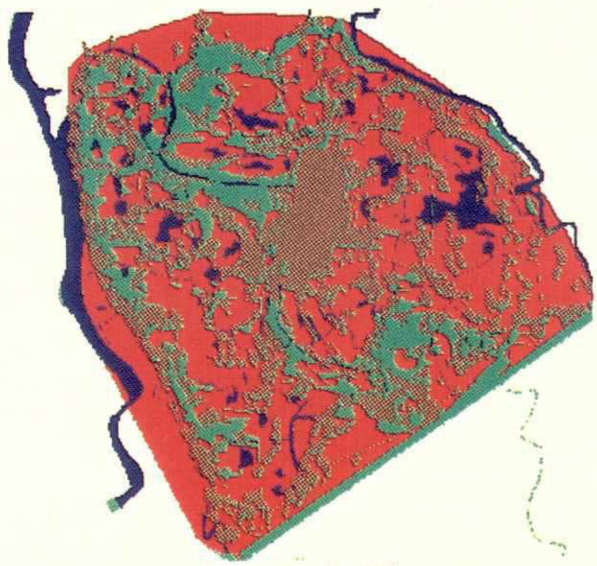


July 16 – 31, 1987

August 16 – 31, 1987

Without Project

July 16 – 31, 1987



August 16 – 31, 1987

With Project

0 3 6 km

- No Damage
- Crop Damaged
- Crop not Planted
- Settlement/Township

Note: A crop is defined as damaged if it is inundated for more than 3 consecutive days at a depth greater than its critical depth. The critical depth is defined for half-monthly periods based on the crop's growth rate and resistance to flooding.

The crops are based on a HYV T.Aus rice crop planted throughout the compartment. Critical depths and other criteria are from TANGAIL CPP INTERIM REPORT (Annex 2: Agriculture).

722

Table C.1 Crop Damage Statistics

Sub-Compartment No	Total Area	Cropped Area	Uncropped Area	Crop Damaged Area			
				From 16-31 July, 1987		From 16-31 Aug,1987	
				Without Project	With Project	Without Project	With Project
	km²	%	%	%	%	%	%
1	6.52	86	14	70	42	98	90
2	12.62	68	32	95	78	98	97
3	5.82	70	30	96	67	98	96
4	2.44	71	29	87	61	98	91
5	6.88	70	30	87	32	98	88
6	2.42	76	24	91	39	96	70
7	3.41	81	19	95	64	97	72
8	11.08	81	19	74	37	98	45
9	5.02	74	26	76	39	98	42
10	6.43	70	30	77	26	97	41
11	11.25	69	31	92	51	97	66
12	10.19	76	24	94	67	98	80
13	4.26	78	22	92	46	98	67
14	11.70	71	29	97	65	99	85
15	8.15	78	22	65	22	95	35
16	6.76	16	84	91	28	93	54

C.3.4 FCD Structure Operation Rules

C.3.4.1 Introduction

The TC-FMM model has been applied for the years 1991 (basic situation used by FAP-20 for planning and design) and 1987 (extreme wet). Preliminary simple operation rules have been derived based on interaction with the local people and model simulation results. FAP20 is in the process of finalising the operation rules using a dedicated version of MIKE11 customised to suit the situation in Tangail Compartment.

C.3.4.2 Main Inlet

The water level downstream of the Main Inlet in the Lohajang river has to be maintained at the proposed +11m PWD during monsoon. In the model this is achieved by operating the three inner gates on the water level downstream of the structure (the three gates are operated as one gate). During the whole period the two outer vents of the structure act as weirs with a sill level of +11m PWD.

Figures C.7 and C.8 show the gate operation of the Main Inlet, together with the upstream and downstream water level and the structure discharge, for the years 1991 and 1987 respectively.

According to the general operation rules above, the figures show that the gates are fully open until July 15. During monsoon the gate level varies to keep the downstream level at approximately +11m PWD. The gates are fully opened when the upstream level falls below the downstream target water level.

As the downstream water level is more or less constant and only influenced by the gate level (the upstream level is greater than the sill level of the outer vents) a relation can be made between the upstream water level and the gate level. The relation has been made for the 1987 results, showing a wide range of upstream water levels (see Figure C.9). This curve is an example only and needs to be enhanced with the inclusion of data from other floods.

The lower symbols represent the initial closing of the gate in the second half of July and the beginning of August. The relation curve has been computed from all available data between fully open and fully closed gates. In practice, the operator would observe the upstream water level, read the curve and note the corresponding gate opening to set.

C.3.4.3 Peripheral Inlets and Internal Outlets

Figure C.10 shows the gate operation of a peripheral inlet (Jugini inlet), together with the upstream and downstream water level and the structure discharge, for the year 1991. As can been seen from the second graph, the gate level operation is not only determined by the upstream water level.

Structure operation rules, in particular at sub-compartment level, need to be simple and easy to adopt by structure operators. Operators would generally change the gate setting only once per day and the setting would preferably be based only on the observed water levels upstream and/or downstream of the structure. Communication with other upstream and downstream operators would not be on a regular basis.

At present, structures in MIKE11 are operated as automatic, constant level regulators. An optimum operation strategy is simulated with gate settings being adjusted each time step in the computations, which is an ideal situation but not practical for field implementation.

FAP20 should utilise FMM to devise and test easy to apply guidelines which could be based on volumes of water to be let in or out and on the water level dependent discharge capacities of structures.

Figure C.7 Structure Operations Main Inlet 1991

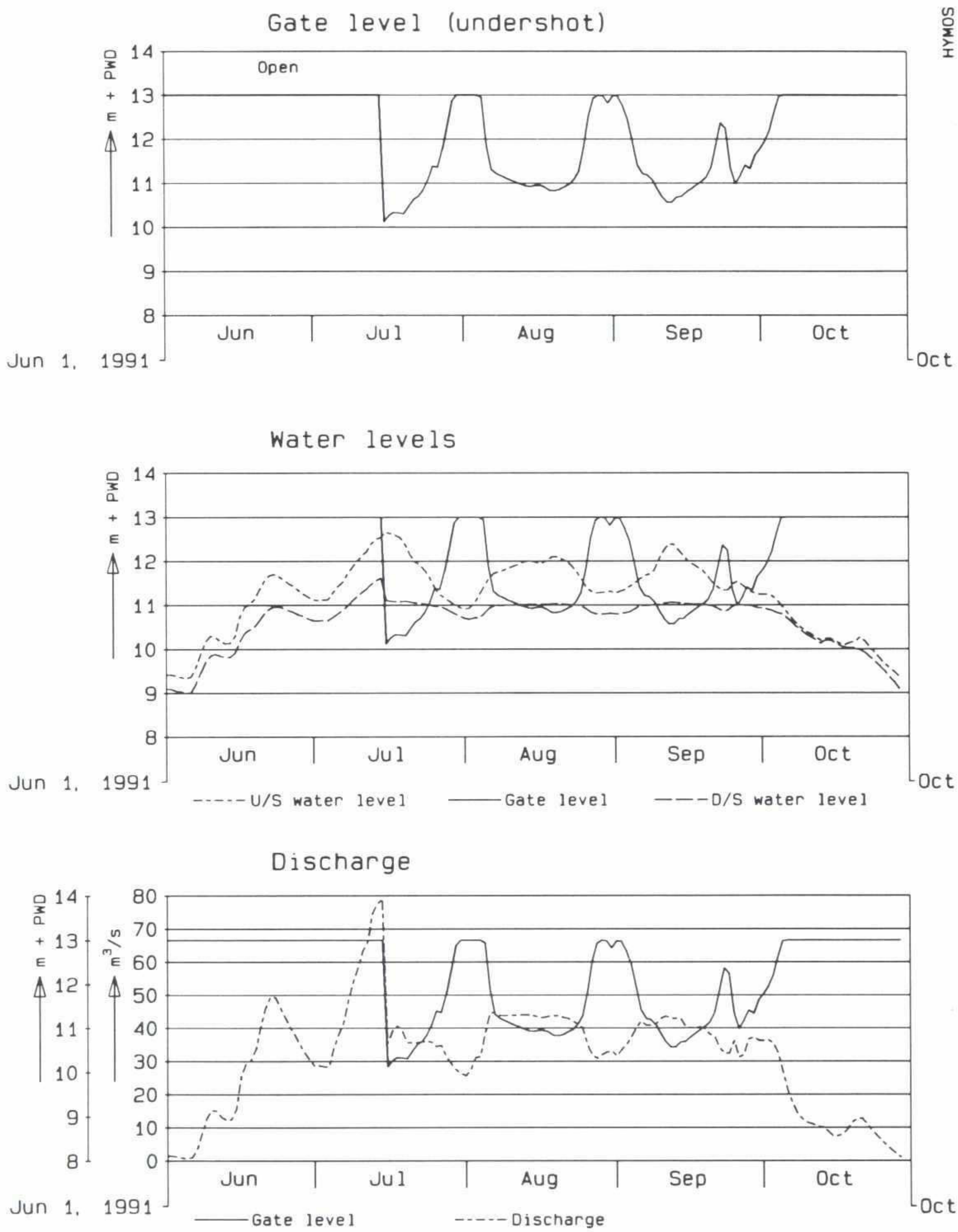


Figure C.8 Structure Operations Main Inlet 1987

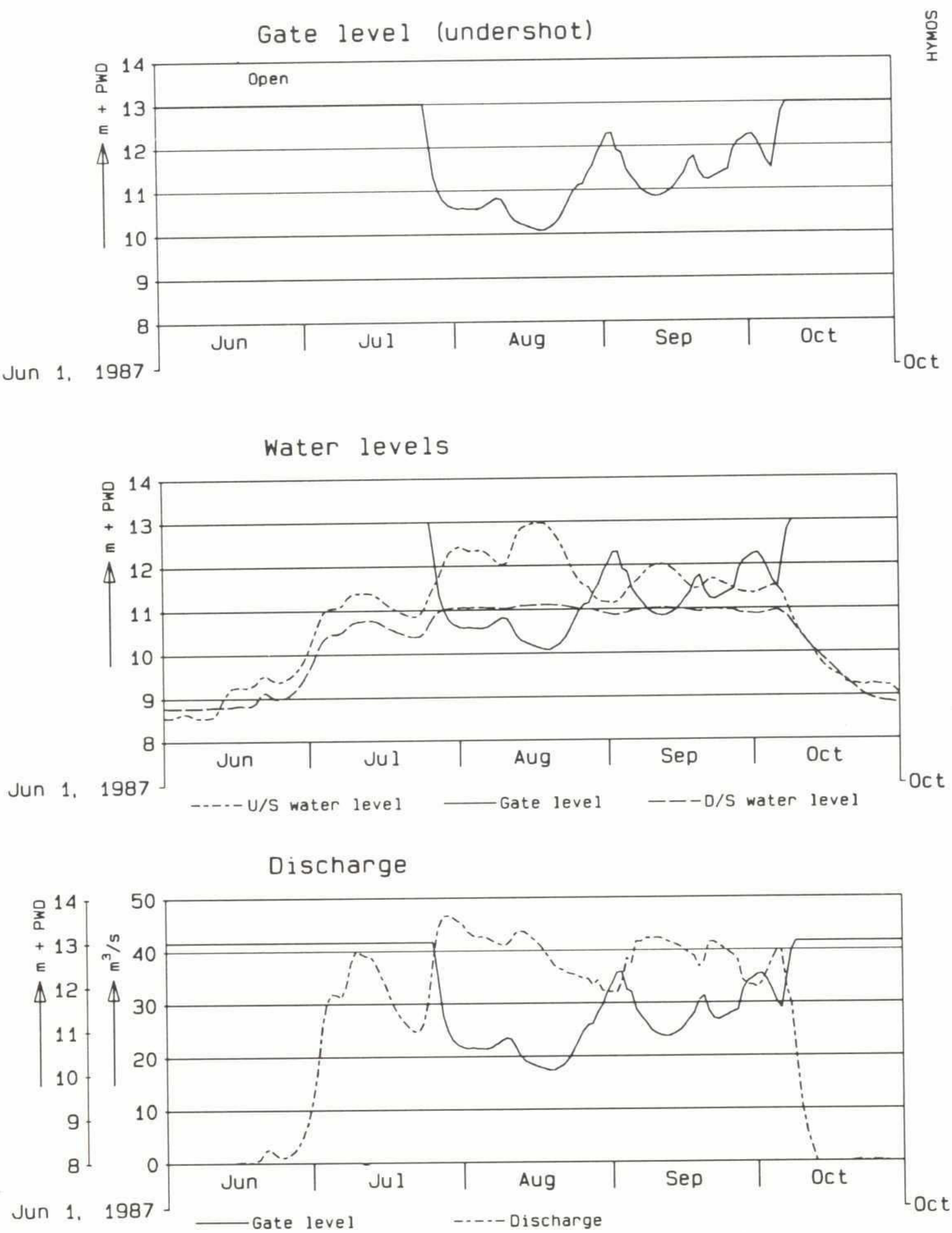


Figure C.9 Main Inlet: U/S Water Level vs Gate Level

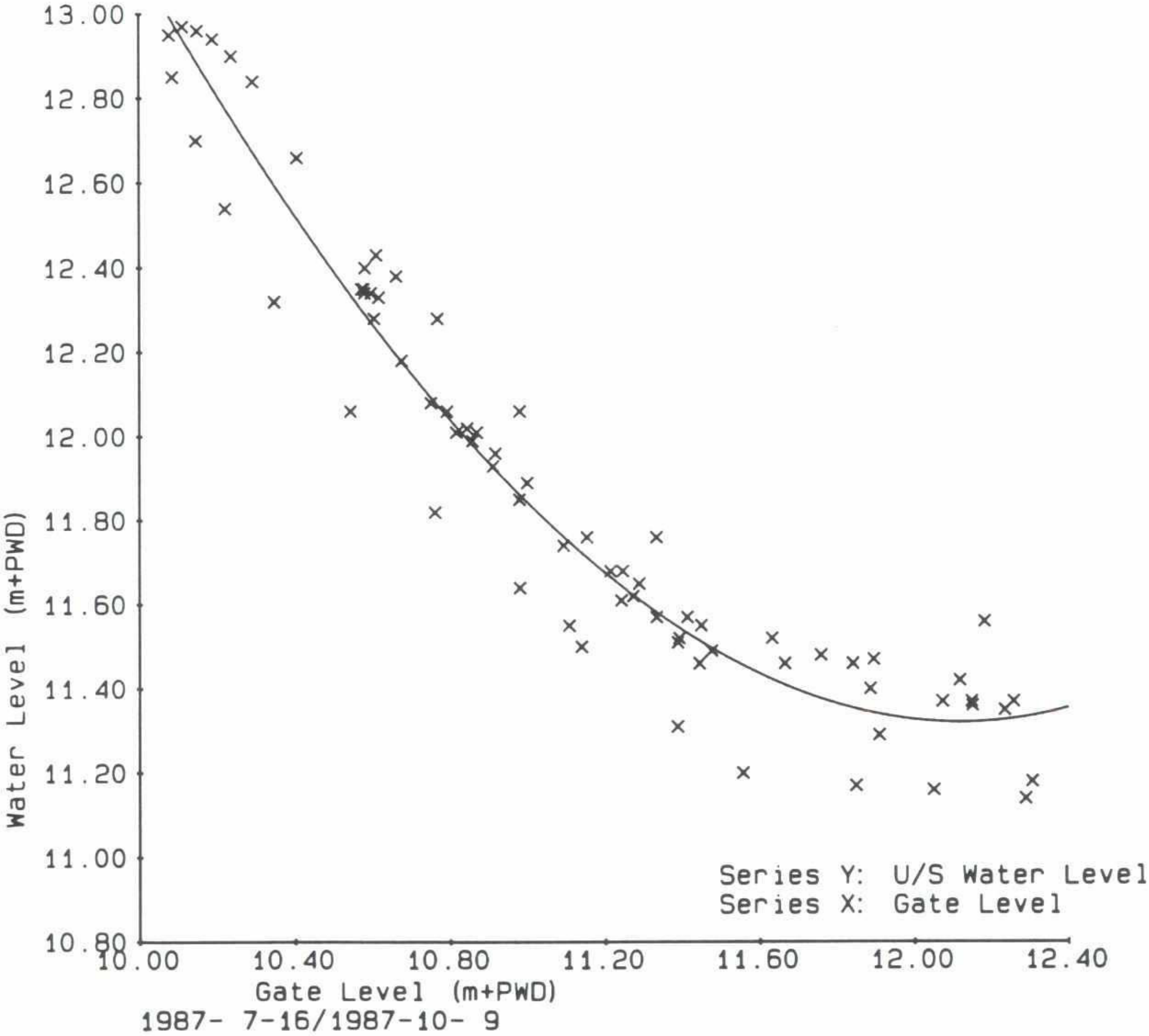


Figure C.10 Structure Operations: Jugini Peripheral Inlet

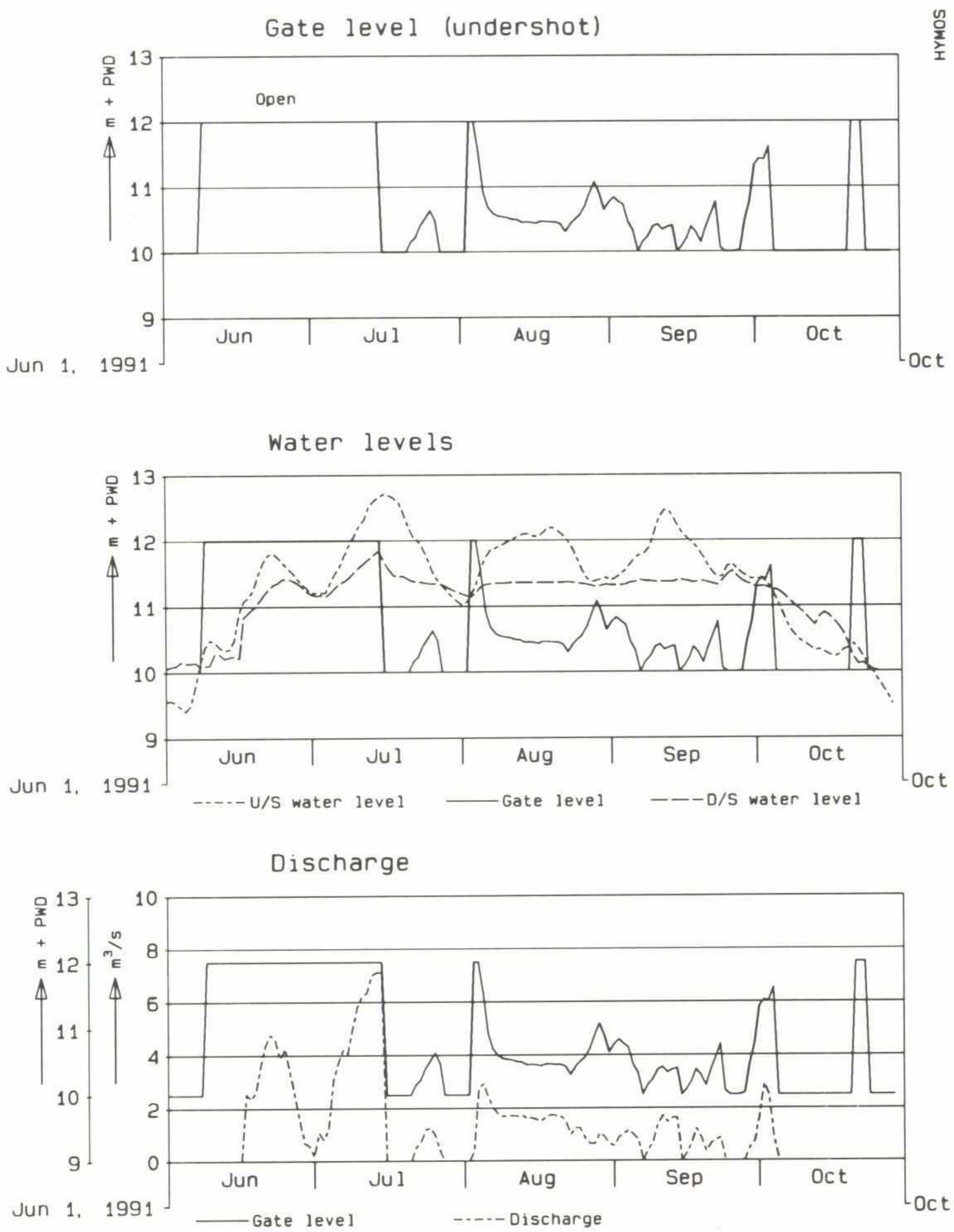
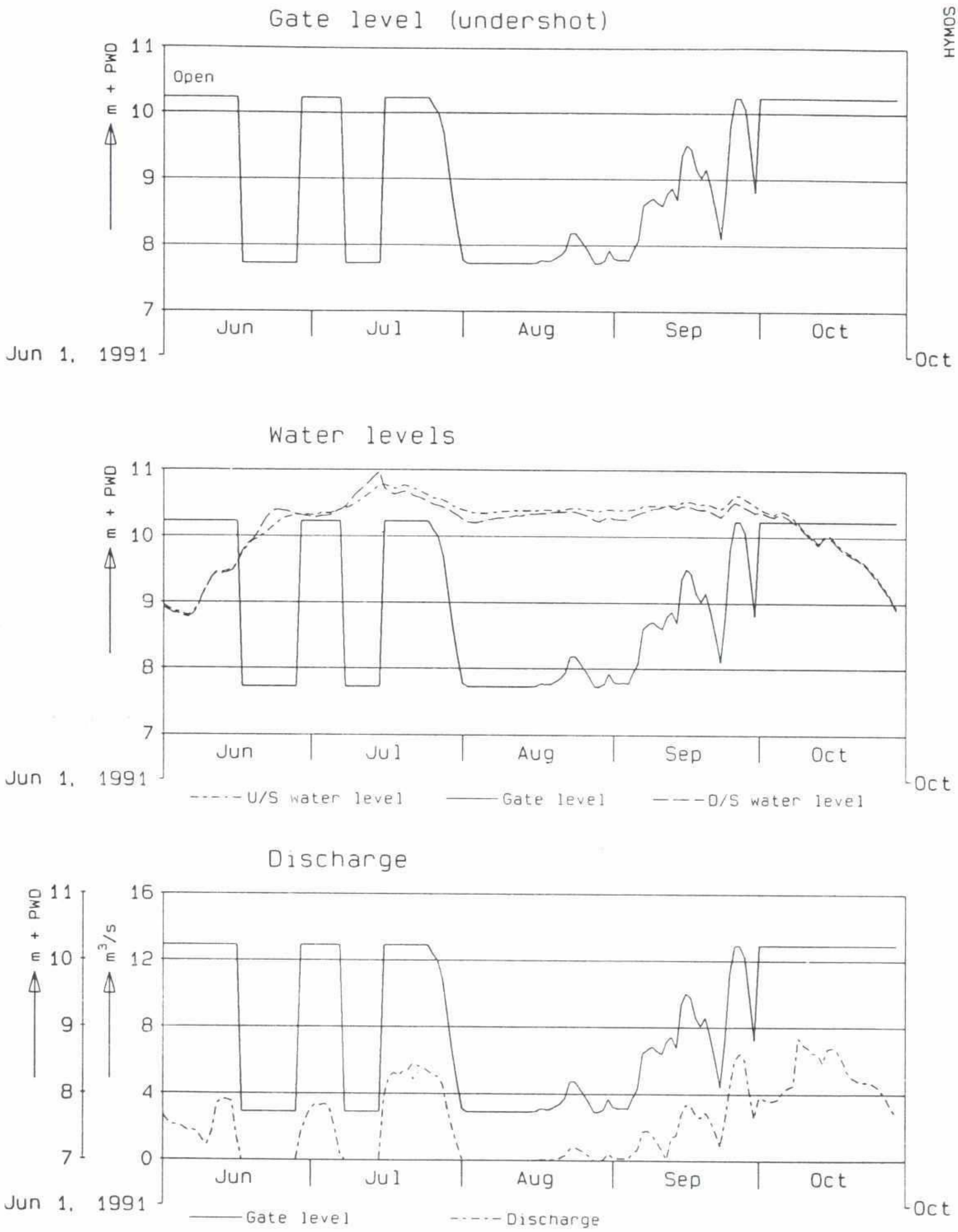


Figure C.11 Structure Operation: Santosh Internal Outlet



C.3.4.4 Mapping Performance of Operation Rules

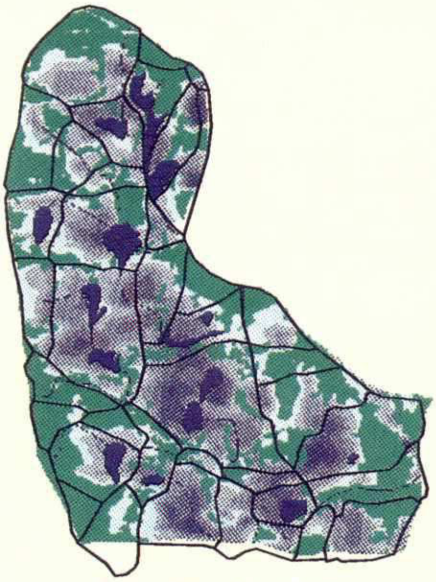
To illustrate the performance of the FCD structures operation rules, the target chawk water levels were compared with the simulated duration depths shown in Plate C.12. Duration depths were used because this eliminates minor water level fluctuations that might occur on a day-to-day basis without damaging crops. In practice, it would be quite normal for such fluctuations to occur as a result of gate operation without having detrimental effects.

Plate C.13 shows the areas which are maintained within the optimum target range as blue, those that are above in red, and those below in yellow. From the middle of June to the end of August, much of the western part of the area is successfully maintained within the target range.

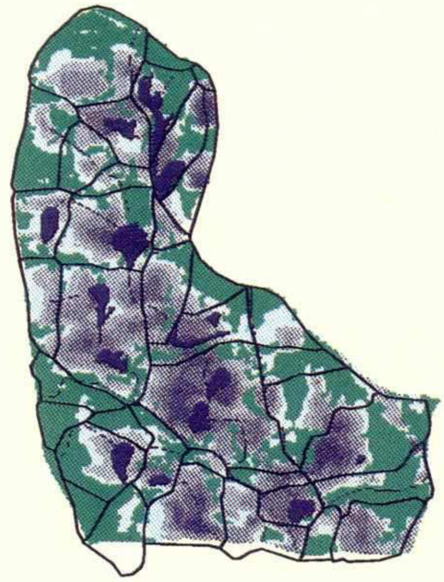
The areas shown in red, (water level exceeds target), are confirmed by field observations as being difficult to operate successfully. The mapping illustrates that the structure operation rules for these areas may require revision. FAP20 is still in the process of establishing the final operation rules.

This page intentionally left blank.

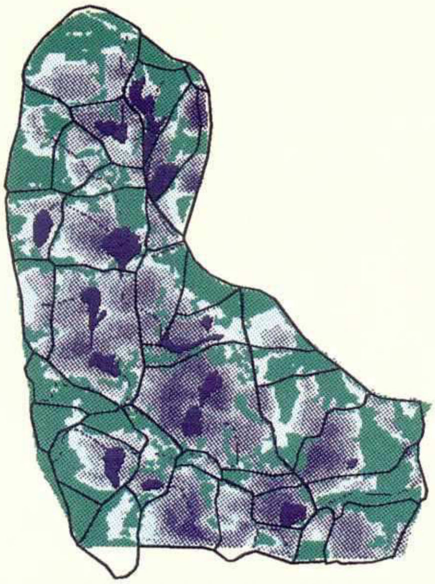
Simulated Duration Depths - Chawk Level - 1993



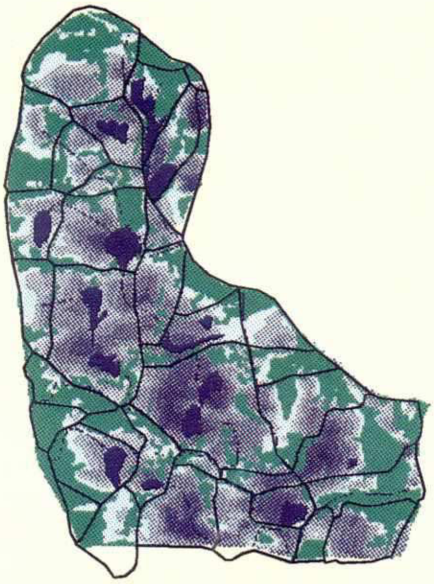
July 16 - 31, 1993



August 01 - 15, 1993

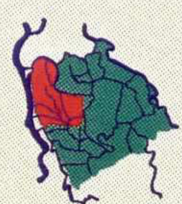


August 16 - 31, 1993



September 01 - 15, 1993

0 1.5 3 km



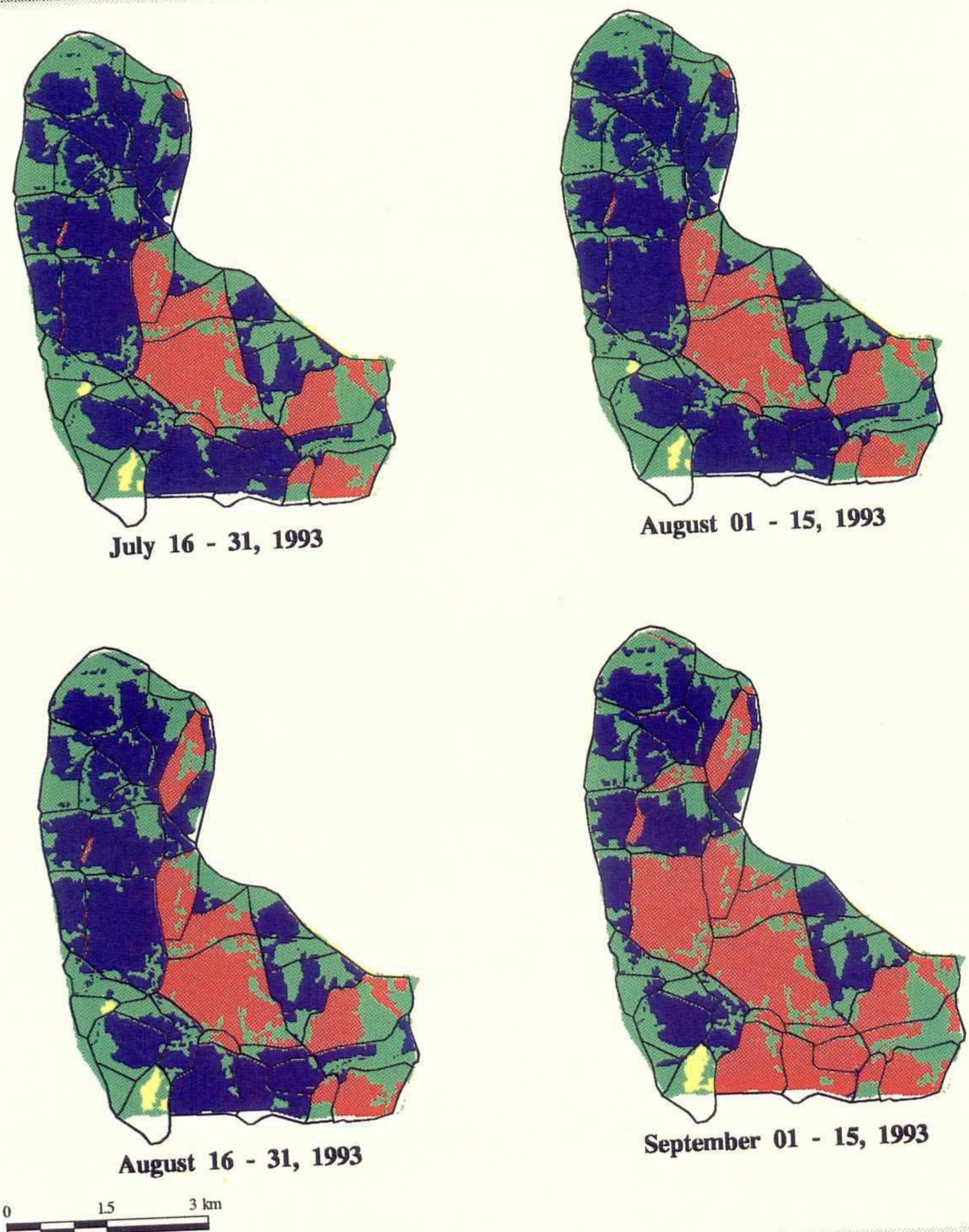
Duration Depth (m)

- 0.00 – 0.30
- 0.30 – 0.60
- 0.60 – 0.90
- 0.90 – 1.20
- 1.20 – 1.50
- 1.50 – 1.80
- 1.80 – 2.10
- Above 2.10

- Flood Free
- Chawk Boundary

262

Structure Operation Performance - Chawk Level - 1993

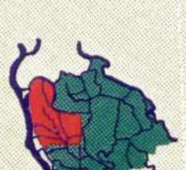


July 16 - 31, 1993

August 01 - 15, 1993

August 16 - 31, 1993

September 01 - 15, 1993



Tangail Compartment

- Flood Free
- Water level below target range
- Water level maintained within target range
- Water level exceeds target range
- Chawk Boundary

C.4 Conclusions and Recommendations

C.4.1 General

A dedicated FMM for the Tangail Compartment has been developed and its applications demonstrated. It is clear that FMM at this level of detail provides for significant enhancement in the understanding and visualisation of flood characteristics. It will be of particular help in public participation exercises which seek to convey complex processes in the simplest and most easily understood way.

Sub-compartment scale modelling allows much detail to be represented, since data collection is generally over a limited area and may be done in detail without the commitment of the large resources that would be needed at, say, regional level.

The revised FAP20 TCM is detailed to a level which incorporates all required structures and can simulate their operation with sufficient accuracy to permit simple operation rules to be tested. The TC-FMM presents the impacts of these structure operations in a form that is readily appreciated by both technical and non-technical users.

C.4.2 MIKE11 Model

Structure operation is a MIKE11 modelling exercise, but the visualisation of the impacts is done using FMM. Therefore, as with all levels of FMM, the output mapping accuracy will reflect the accuracy of the MIKE11 model and the topographic data inputs to that model.

The following recommendations are made for further enhancement of FAP20 TCM:

- Hydrological data collection programmes should continue with more emphasis placed on quality control.
- The lack of reliable discharge data must be addressed by closer field supervision of gauging teams.
- As construction of FCD structures proceeds, FAP20 should be continue to work on calibration of the structures and detailed development and calibration of sub-compartment model(s). With the main part of the structures being in place during 1995 monsoon and data available for the 1994 and 1995 monsoons, the Compartment FMM could be fully applied.
- For on-line structure operation testing, gate operation should reflect the normal field practise, that is, the actions and decision-making by the operators. This includes model operation of gates at a fixed level for a certain period and the interaction between the operation of several structures. FAP20 should use FMM extensively for derivation of easy-to-use operation rules.

208

C.4.3 DEM

As is common in GIS applications, much effort is required for supplying basic data such as the DEM of the area, various coverages, etc. Cross checking of survey datums should be carried out carefully.

The following recommendations are made for the enhancement of the TCM DEM:

- The level of detail of compartment models is such that it is important that settlement boundaries are identified and the DEM adjusted within these boundaries.
- For the development of a Compartment FMM, the accuracy of the basic data is of great importance and therefore a reliable DEM should be available based on a grid no larger than 20 m.

C.4.4 Flood Mapping

The outputs of the FMM have been mainly centred around the production of basic flood extent, depth and duration depth maps. In this project it was not the intention to produce detailed flood impact maps. More detailed impact of changes in these phenomena on other sectoral interests, such as fisheries, agriculture, environment, etc., requiring specialist inputs, could be considered and it is suggested that more work be undertaken by FAP20 in 1995 to elaborate on these basic maps. This project could act as a pilot project for the use of MIKE11-GIS for flood damage assessment.

202

REFERENCES

Danida/1 *Expansion of Flood Forecasting and Warning Services (FAP10) Appraisal Report* Ministry of Foreign Affairs, DANIDA, February 1994.

DHI/1 *NAM Documentation and User's Guide* Danish Hydraulic Institute, 1990.

DHI/2 *Application of SWSMP Models for Real-Time Forecasting* Danish Hydraulic Institute report to WMO, Project BGD/88/013, October 1992.

DHI/3 *MIKE11-NAM Dynamic Interface Draft User's Guide and Documentation* Danish Hydraulic Institute, October 1993.

DHI/4 *MIKE11 Reference Manual* Danish Hydraulic Institute, 1993.

DHI/5 *MIKE11 User's Guide* Danish Hydraulic Institute, 1993.

FAP5/1 *Interim Report Volume II - Hydrology and Water Modelling* FAP5: South East Regional Water Resources Development Program, November 1991.

FAP10/1 *Expansion of Flood Forecasting and Warning Services - Draft Terms of Reference* FAP10, March 1993.

FAP11/1 *Evaluation Report - Draft Final Report* FAP11: Flood Response Study, December 1992.

FAP19/1 *Draft Interim Report* FAP19: Geographic Information System, December 1992.

FAP19/2 *Draft Technical Report - Classification of Flood Depth and Extent using GIS and MIKE11* FAP19: Geographic Information System, February 1992.

FAP20/1 *Tangail CPP Interim Report* FAP20: Compartmentalization Pilot Project, September 1992.

FAP20/2 *Water Management Sub-Compartment 9,10 and 11; Tangail Compartment - First Draft* FAP20: Compartmentalization Pilot Project, May 1994.

FAP25/1 *Terms of Reference for Flood Management Model (FMM)* FAP25: Flood Modelling and Management, May 1992.

FAP25/2 *Flood Hydrology Study Final Report and Annex 1* FAP25: Flood Modelling and Management, June 1992.

FAP25/3 *Coordination Advisory Team - Fourth Mission Report* FAP25: Flood Modelling and Management, February 1993.

FAP25/4 *Flood Management Model Inception Report* FAP25: Flood Modelling and Management, April 1993.

FAP25/5 *Flood Hydrology Study Annex 2* FAP25: Flood Modelling and Management, April 1993.

FAP25/6 *Hydrologic and Topographic Measurements - 1993 - Completion Report* FAP25: Flood Modelling and Management, 1993.

FAP25/7 *Coordination Advisory Team - Fifth Mission Report* FAP25: Flood Modelling and Management, January 1994.

FAP25/8 *Flood Management Model Interim Report I* FAP25: Flood Modelling and Management, April 1994.

FAP25/9 *Coordination Advisory Team - FMM Review Mission Report* FAP25: Flood Modelling and Management, May 1994.

FAP25/10 *Flood Management Model Interim Report II* FAP25: Flood Modelling and Management, July 1994.

FAP25/11 *MIKE11-GIS Reference Manual and User's Guide* FAP25: Flood Modelling and Management, August 1994.

FAP25/12 *MIKE11-GIS Training Manual* FAP25: Flood Modelling and Management, August 1994.

FAP25/13 *MIKE11-GIS Menus* FAP25: Flood Modelling and Management, August 1994.

SWMC/1 *SWSMP Phase II General Model Update Draft Report* Surface Water Modelling Centre, September 1993.

SWMC/2 *SWSMP Phase II Final Report* Surface Water Modelling Centre, November 1993.

SWMC/3 *SWSMP Phase II North Central Regional Model Verification* Surface Water Modelling Centre, December 1993.