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

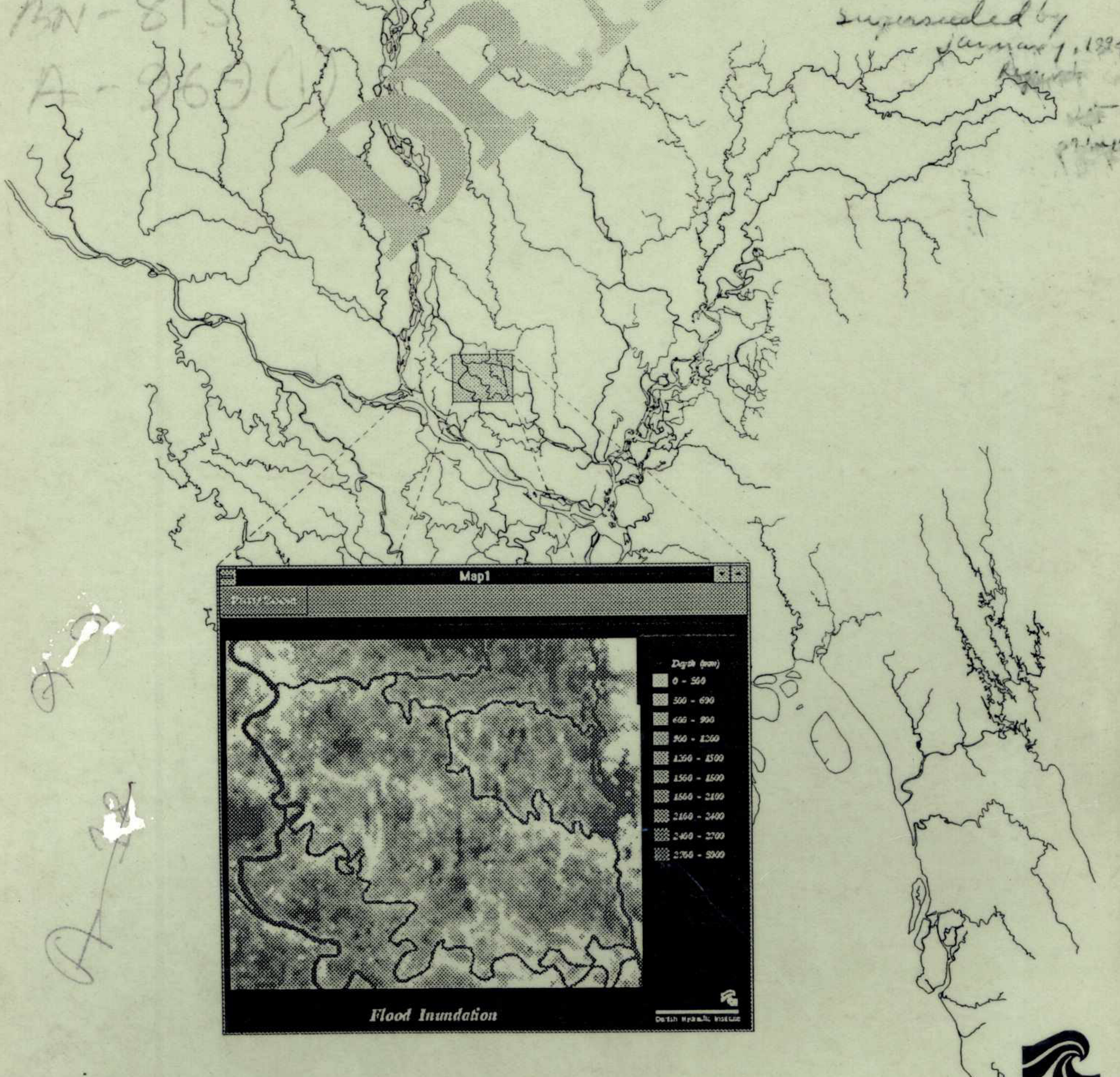
FAP25: Flood Modelling & Management

Flood Management Model

Interim Report - I

October 1993

DRAFT



Consultants: **Danish Hydraulic Institute**
in association with
EUROCONSULT
BCEOM

Donors: Denmark France The Netherlands

FAP 25: Flood Modelling and Management

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ACRONYMS / ABBREVIATIONS

AML	ARC/INFO Macro Language
ARC/INFO	Geographic Information System Package
BADC	Bangladesh Agricultural Development Corporation
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BIWTA	Bangladesh Inland Water Transport Authority
BRDB	Bangladesh Rural development Board
BRRI	Bangladesh Rice Research Institute
BWDB	Bangladesh Water Development Board
CAT	Coordination Advisory Team.
CFD	Caisse Francaise Developpement
CHE	Computational Hydraulic Engineer
CIDA	Canadian International Development Agency
CPP	Compartmentalization Pilot Project.
DAE	Department of Agricultural Extension
DANIDA	Danish International Development Assistance
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
DOE	Department of Environment
DOF	Directorate of Fisheries
EIP	Early Implementation Project (Dutch-assisted FCD Project)
FAP	Flood Action Plan
FCD	Flood Control and Drainage
FCDI	Flood Control, Drainage, and Irrigation
FF&WC	Flood Forecasting & Warning Centre
FFW	Food-For-Work
FHS	Flood Hydrology Study
FMM	Flood Management Model
FPCO	Flood Plan Coordination Organization (under MIWDFC)
GIS	Geographic Information System
GM	General Model
GOB	Government of Bangladesh
GPS	Geopositional Satellite
HD	Hydrodynamic
HYV	High Yielding Variety
HP	Hewlett Packard
ISPAN	Irrigation Support Project for Asia and the Near East
JPPS	Jamalpur Priority Pilot Study
LGEB	Local Government Engineering Bureau
LGED	Local Government Engineering Directorate
MIKE11-GIS	River Modelling - Geographic Information System Interface
MIWDFC	Ministry of Irrigation, Water Development and Flood Control
MOA	Ministry of Agriculture

MPO	Master Plan Organisation (under MIWDFC) now WARPO
NAM	Rainfall Runoff Model (Danish Abbreviation)
NCRM	North Central Regional Model
NCRS	North Central Regional Study
NGO	Non-Governmental Organization
O&M	Operation and Maintenance
POE	Panel of Experts
R&H	Roads and Highways
RRI	River Research Institute
SPARRSO	Space Research and Remote Sensing Organization
SSWCSIII	Small Scale Water Control Structures III Project
SRP	Systems Rehabilitation Project
SWH	Surface Water Hydrology
SWMC	Surface Water Modelling Centre
SWSMP	Surface Water Simulation Modelling Program
TCM	Tangail Compartment Model
TL	Team Leader
TIN	Triangular Irregular Network
TOR	Terms of Reference
UNDP	United Nations Development Program
USAID	United States Agency for International Development
UX	UNIX
WARPO	Water Resources Planing Organization
WBS	Work Breakdown Structure
WMO	World Meteorological Organisation
WS	Work Station

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1. INTRODUCTION

1.1 Background

In the past, floods in Bangladesh have hampered the national economic progress by causing widespread damage to physical infrastructure. The resulting international concern led to the formulation of the Flood Action Plan (FAP). Donors from Denmark, France, the Netherlands and the United Kingdom responded positively by participating in the execution of the FAP Component No 25: Flood Modelling and Management. The Danish International Development Assistance (DANIDA) has supported FAP 25 as the lead donor.

The FAP 25 - Flood Modelling and Management Project commenced in October 1990 and has three components. The Flood Hydrology Study (FHS) is designed to establish the hydrological basis for engineering design criteria along the major rivers and to develop common modelling standards and techniques for the FAP studies. A Coordination Advisory Team (CAT) has been set up to ensure consistency and compatibility in modelling, and to coordinate development of models for FAP at the Surface Water Modelling Center (SWMC). The third component is the development of a Flood Management Model (FMM) and demonstration of its applicability.

The Flood Plan Coordination Organization (FPCO) under the Ministry of Irrigation, Water Development and Flood Control (MIWDFC) is the implementing agency of the FMM component. DANIDA is the coordinating donor agency on behalf of the contributing donors, Denmark, France and the Netherlands. The Dutch support to the project is being provided through FAP 20 - the Compartmentalization Pilot Project (CPP). The Danish Hydraulic Institute (DHI) in association with EUROCONSULT and BCEOM, French Engineering Consultants, are undertaking the FMM study.

1.2 Introduction to FMM

The FMM is conceived as a spatial decision support tool which integrates the MIKE 11 based flood modelling system with advanced graphical displays and analysis using Digital Elevation Models (DEM) and a Geographic Information System (GIS). FMM will assist in flood management including planning and operation of flood control and drainage systems and in flood forecasting.

MIKE11 based hydraulic simulation models have been developed at the Surface Water Modelling Centre (SWMC) and many of them have been used for some time in the FAP studies in Bangladesh. Geographic Information System (GIS) technology has been shown by FAP 19 to be a viable tool for flood mapping. Using GIS technology as an underlying platform for hydraulic models provides an effective mechanism for performing complex, multi-basin, large-area flood management studies. So far, no fully featured GIS designed to support hydraulic modelling exists. To address this deficiency, the MIKE11 model developed by the Danish Hydraulic Institute for modelling flows in rivers and floodplain has been linked to the ARC/INFO package developed by the Environmental Systems Research Institute through custom programming based on the Arc Macro Language (AML) in order to perform the required hydraulic analysis and flood mapping.

The FMM study is being carried out in two stages. The main activity of Stage 1, the Development Phase, is to develop the MIKE11-GIS interface. This will permit improved river and floodplain modelling leading to the generation of flood depth maps by directly integrating MIKE11 models with the DEMs. Stage 2, the Application Phase, concentrates on the development of the bespoke Flood Management Models for the General Model, North Central Regional Model and the Tangail Compartmental Model and their illustrative applications.

1.3 Objectives

The overall objective of the FMM is to provide a tool which, through prediction and analysis of the behaviour of floods, assists in the management of mitigation measures to reduce the resulting potential loss of life and infrastructural damage.

The MIKE11 based simulation models developed at SWMC provide the basis for such tools, although additional features are required to make them operational for flood management purposes. The objectives of the present study should be seen in conjunction with other on-going modelling activities in Bangladesh, in particular those under the FAP. The specific objectives of the present study are laid out as follows.

- To develop an integrated MIKE11-GIS software as the main FMM tool to assist in flood modelling and management in Bangladesh.
- To integrate the developed technology with other activities, and apply it on a test basis at National, Regional and Compartment levels.
- To present the developed technology to GOB authorities and other potential users, and identify and implement required modifications.

The overall long term objective is to achieve an on-line mathematical model linked the flood forecasting model of FAP 10, which would provide information to assist in the management and control of floods in real-time with parallel simulation of arrange of possible scenarios. The model would indicate river water levels, areas and depths of inundation and ideally the impacts in terms of potential crop losses, displacees, infrastructural disruption etc., all in clear graphical or tabular form which could be easily and rapidly assimilated. The information would be used for disaster preparedness / management as well as for the

FMM TOR (Ref. 2)

1.4 Documentation

The general concepts and methodology of FMM and a detailed work plan for the study were presented in the Inception Report (Ref. 1). This First Interim Report presents the status of project progress and presents the FMM features developed to date by the study team. The Report is presented in five Chapters, with supporting Appendices.

Chapter 2 describes the data collection activities of the project. Limited data collection has been carried out during Stage 1 mainly to improve the topographic database for the North Central Region and to obtain additional hydrological data.

The various components of FMM and the development of the MIKE11 - GIS software are described briefly in Chapter 3. A separate document - FMM Reference Manual has been prepared where the full details of the various modules of FMM are presented and all the features described. Chapter 3 also presents a brief description of the MIKE11-NAM dynamic interface developed to simulate the effect of local rainfall on floodplain flooding. Another separate document - MIKE11-NAM Dynamic Interface Documentation and User Guide has been prepared where the details of the interface are presented with an example application from the NC region. .

Chapter 4 presents the status of the activities related to the development of the bespoke models and their application to national, regional and the compartment levels.

Chapter 5 presents the activities of training and workshops.

Appendices A-C provide additional information on work progress including schedule of staff input, survey data and an update on the Flood Hydrology Study, respectively.

2. DATA COLLECTION

2.1 Introduction

The challenge in developing the FMM is largely a problem of data integration. Flooding is a "complex" problem typically addressed by a variety of experts who tend to specialize in some aspect of the problem, e.g. hydraulics, hydrology, modelling, fisheries, agriculture, socio-economics. Usually these experts have their own special models that use data created by another expert. The effort spent on acquiring and loading this data must be minimized. Hence it has been the intention to take full advantage of the existing data with various organizations and studies being carried out under the auspices of FAP. Table 2.1 presents a summary of various data uses and collection. As can be seen from this table existing data with the various organizations plays a key role in the successful application of FMM. In order to establish a smooth data exchange both the technical and institutional aspects must be considered.

Different modelling systems typically use "proprietary" data structures that are unreadable by other modelling systems. By defining exchange formats for different types of data it becomes easier to exchange data. Standardized exchange formats decrease the complexity of moving data from one modelling system to another.

Another aspect of data integration is addressed by relational database technology. Relational databases store all information in tables that consist of rows and columns, where each row has the same number and type of columns. ARC/INFO uses files with fixed length records for tables; MIKE11 uses variable length records, which are very difficult to manage using relational database techniques. Through a process called normalization it is possible to design a relational database so that information from variable length files may be exported to relational tables. FAP25 has normalized the information in the MIKE11 files so that ARC/INFO, or any other relational database system, can more easily use the information.

2.2 Data Sources

The Surface Water Modelling Center is seen as a key data source for the Mike11 models which form the basis of FMM. Several models developed by the SWMC have been transferred to FAP25. The data consists of model topography, topology and the hydrometeorological time series.

Topographic data related to the DEMs have been obtained from FAP19. Recently, spot elevations from the 1:10000 orthomaps produced by FINNMAP for FAP20 were digitized and a DEM grid produced.

The Local Government Engineering Department (LGED) is another potential source of map based data. LGED has embarked upon a project to digitize the thana maps used in planning local engineering projects. These data collection and mapping activities are also based on Arc/Info. The information being collected by the LGED will eventually be useful to the FMM, while the results of the FMM would be also be of use to LGED in developing minor structural design specifications (culvert requirements, roadway heights, etc).

Table 2.1 Summary of Data Use and Collection

Objective/ Output/ Activity	Data Needed	Data Source	Data Collection by FAP25-FMM	Data Quality/ Remarks
FMM_GM	River X-S Hydrometric Data	SWMC FAP25	-	Quality Checked by SWMC, FAP25 (FHS)
DEM for GM	Digitized Elevation Data	FAP 19	-	Data based on old topo maps (MPO 1km Grid)
FMM_NCRM	River X-S Hydrometric Floodplain topo	SWMC FAP 3	- Extract from DEM	Checked by SWMC & FAP 3. Field survey (pilot check only)
DEM for NCRM	Digitized Elevation Data	FAP 19	Embankment Survey	Old topo maps, quality check by FAP 19
FMM_TCM	All data for Mike11 model	FAP 20	-	FAP 20 responsible for quality control
DEM for TCM	Digitized Elevation Data	FAP 19	-	FAP 19 responsible for quality control
Flood Forecasting	Realtime Hydrometric Data	FAP 10/ FF&WC	-	BWDB Hydrology responsible for quality
FMM enhanced Floodplain modelling	Floodplain topography, Water level data on floodplains	BWDB topo maps -	From DEM. Collecting flood plain WL Data during 93 monsoon in a pilot area in the NCR	Pilot field survey check FAP 25 responsibility
Impact Assessment	GIS Data on Agric., Landuse, Infrastructure, etc.	FAP 19, LGED, other FAPs	Secondary data to be collected from others	Sources responsible for quality

Other sources of GIS data for future applications of FMM, particularly for agricultural and fisheries impact assessment studies, are the Crop Diversification Project (CDP), and FAP17: Riverine Floodplain Fisheries Study and Pilot Project.

The first Earth Resources Satellite (ERS-1) launched by ESA last year is able to collect RADAR images of potential use to the FMM. There are two types of RADAR imagery of interest, each collected with a special detector. The first type, Side Aperture Radar (SAR), might allow areas of inundation to be determined. The second type, radar altimetry, might allow very precise measurement of water surface elevation. RADAR can penetrate the clouds that block conventional satellite operational bandwidths. The possible acquisition of RADAR imagery for the flood season in Bangladesh is being coordinated by FAP 19.

FAP25 has participated in a RADAR ground truthing exercise coordinated by FAP19. The purpose of this exercise is to collect data on ground conditions at the time the satellite passes over so that later the image may be analyzed to see if "signatures" for different types of land/water cover can be determined. Once a signature is found, an entire image may be classified. It is hoped that the classification will distinguish flood extent, but this technology is in its infancy and some caution must be exercised if anticipating definitive results in the short term.

Application of FMM to realtime inundation forecasting will be based on the realtime data from the BWDB's Flood Forecasting and Warning Centre. SPARRSO is the source of satellite imageries.

2.3 Field Data Collection

2.3.1 Additional Survey in the North Central Region

The North Central Regional Model needs considerable restructuring in certain areas so as to realistically represent the hydraulic connection between the river channel and flood plain to meet the requirements of Flood Management Model. Representation of hydraulic connection of the conveyance channel and the flood plain storage cell is a key element in modelling flood flows in certain areas of the north central region. Quasi 2-dimensional modelling was considered appropriate and a limited programme of embankment survey was undertaken to those rivers having significant influence on the regional hydraulic behaviour. The survey work concentrated on establishing the locations of water interchange between river and flood cell.

To further improve understanding of the river/floodplain interaction, additional water level gauges were set up in selected flood plains of the region. The purpose of this was to study fluctuations of flood plain water level with respect to adjacent river level variations and to establish the degree of connectivity between them.

Topographic Survey

Embankment survey was carried out by contract with SWMC and Hydroland Surveys Ltd. The specifications called for the establishment of levels of embankment or natural levee, together with the location of intersecting rivers and khals. In addition, the surveyors were required to make 200 metre long transects into the adjacent flood plain at approximately 1 km. intervals.

The SWMC surveyors attempted to make a survey of the location and size of hydraulic structures encountered, but were only partially successful owing to the prevailing high water levels.

Both banks of the following rivers were included in the overall survey programme:-

River	**Contractor**
Futikjani	SWMC
Bangshi	SWMC, Hydroland
Dhaleswari	SWMC, Hydroland
Turag	SWMC
Tongi Khal	SWMC
Buriganga	SWMC
Barinda	Hydroland
Dhantara Khal	Hydroland
Bangshi South	Hydroland
Kaliganga	Hydroland

Figure 2.1 shows the location of the embankment surveys , further details are given in Appendix B1.

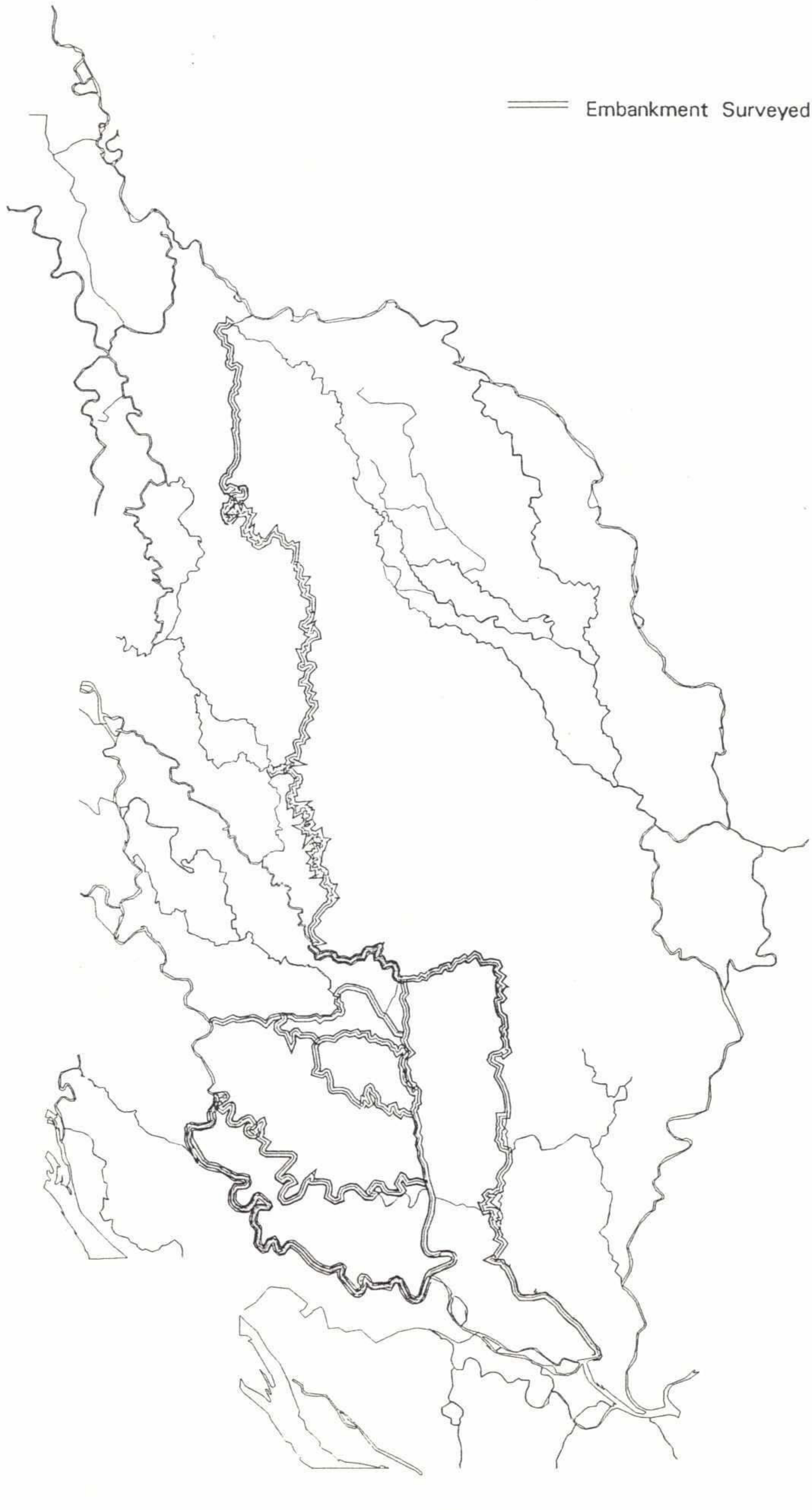
2.3.2 *Floodplain Water Level Data*

A total of 12 water level gauges were installed, 5 along the Dhaka-Aricha road, 4 along the Dhaka-Tangail road, 1 on Savar-Kaliakair road and 2 along the Dhaka-Mawa road. The location of the gauges are shown in Figures 2.2 to 2.8. Local people, mainly school/college students living near the gauge stations were engaged on contract basis for the monsoon period (1st June to 31st October, 1993) to record water level data twice a day (0900 and 1800 hours) on a format supplied by FAP 25. They also record qualitative intensity (in terms of High, Low or Medium) and duration of local rainfall on the same format. Preliminary training was offered to the gauge readers by the project staff on how to read and record data on the format.

Further details are given in Appendix B2.

Hydrometric Survey

In support of the proposed feasibility level studies in the Bhuapur region and final design stage of the Jamalpur Priority Area, the Caisse Française de Developpement, (CFD), have funded a preparatory data collection programme. Since all the hydrometric stations established in this programme, (40 in all), are located within the NCR, the regional FMM may derive benefit from the monitoring of these stations.



Location of Additional Embankment Survey

Figure 2.1 **NORTH CENTRAL REGION**

A number of the stations are re-installations, since the previous gauge was missing or damaged, but the majority are new locations which were chosen to best assist in the simulation of fluvial behaviour in critical areas. This particularly refers to the Bangshi River, which serves as the main drainage "spine" for the region, but which, up to now, has not been fully understood in the middle and upper reaches.

Monitoring commenced during the month of June, 1993 on all 40 stations and is due to continue until the end of October, 1993. Water levels are recorder every 3 hours on a routine basis, but with provision for additional monitoring during periods of high flows. BWDB Hydrology Division are also carrying out a programme of fortnightly discharge measurements at 20 of the above 40 stations with a further 4 additional locations at existing BWDB water level stations.

Figures 2.2 to 2.8 show the location of all these gauges and have been consolidated to include the locations of other major gauging stations in the North Central Region. Refer to Appendix B1 for details of the water level and discharge gauging stations

2.3.3 *Data Collection by CPP, Tangail*

Topographic Data

All the cross-section profiles of khals surveyed in 1991 and after have been checked and included in the 1993 MIKE11 model.

Prior to the wet season of 1993, excavation was carried out of 3.575 km of the Binyafair Khal, starting at Santosh, of the Gaizabari Khal (2.402 km) and the Chilabari Khal (3.322 km). The changes resulting from these excavations have been included in the cross-section profiles of the 1993-model.

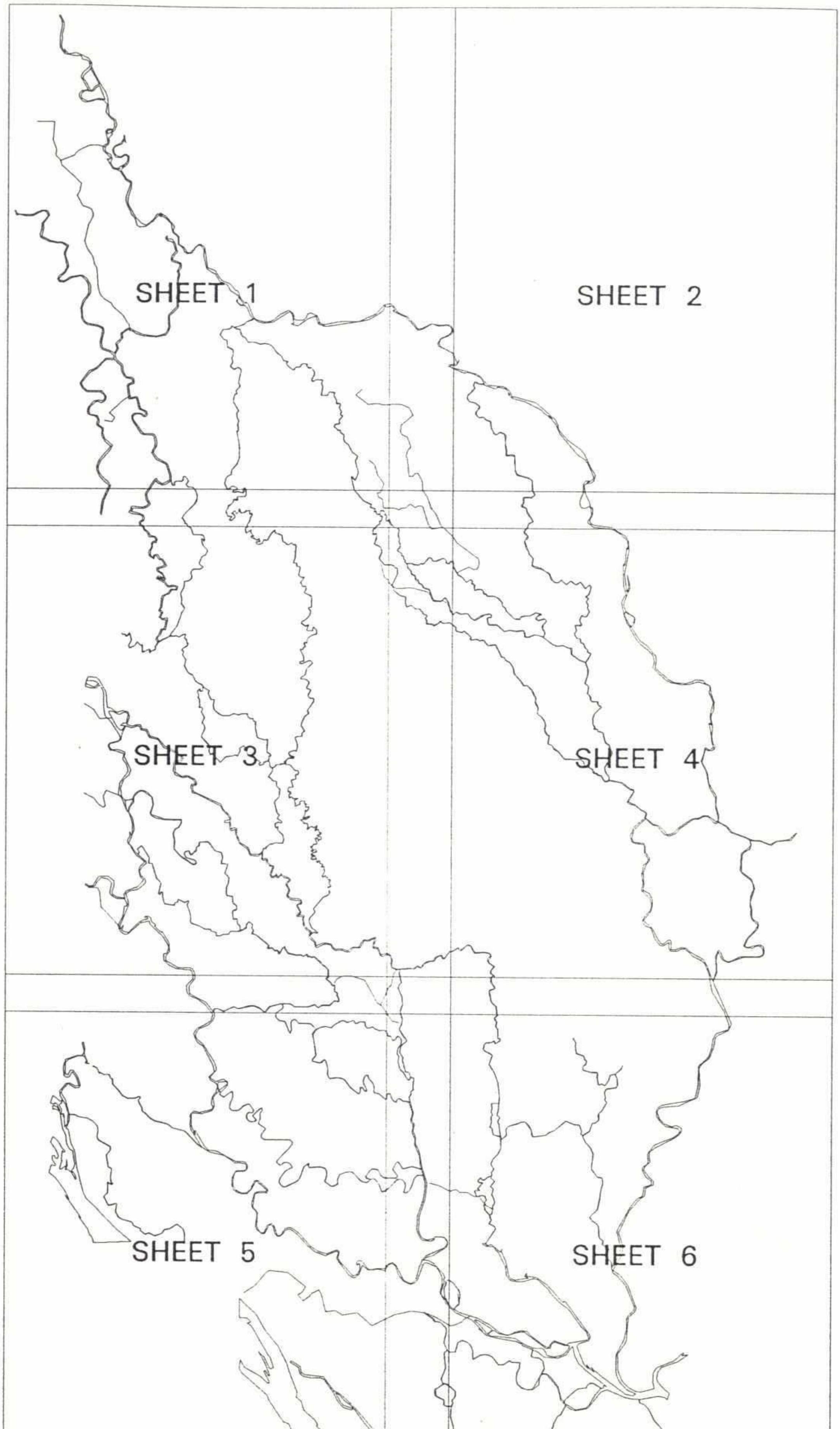
In accordance with the FMM methodology, the flood plain cross-section profiles will be derived from a DEM. A test has already been performed using the FAP 19 DEM which was derived from BWDB mapping. In July, 1993, owing to the availability of 1991 FINNMAP 1:10,000 scale photomaps, a new DEM was digitised and has subsequently replaced the previous version. It is now possible to extract up-to-date flood plain cross-section profiles.

The main embankment elevation data (except SC-E1) are available.

For the SC 9, 10 and 11 road locations and beel location, depth and extent data are available. Additional measurements will be carried out in these and other sub-compartments by FAP 20 commencing in the 1993 wet season.

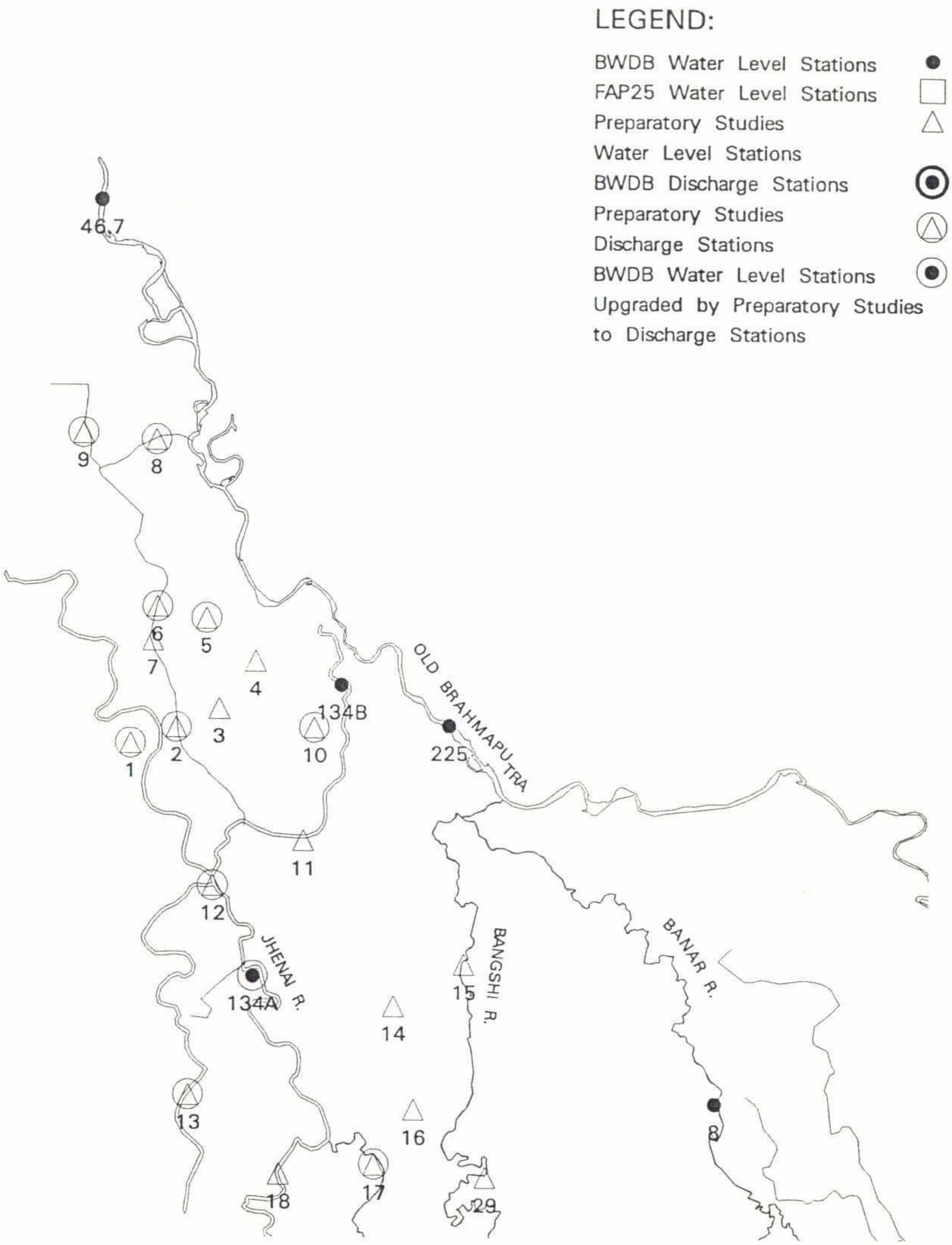
Hydrometric Data

The predominant source of data for the FMM of Tangail area is FAP 20 and available water level, rainfall and groundwater level data of 1992 have been collected. Details are given in Appendix B3.



NORTH CENTRAL REGION

Figure 2.2 MAP SHEET INDEX



MAP SHEET 1

Figure 2.3 **NORTH CENTRAL REGION**

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MAP SHEET 2

Figure 2.4 **NORTH CENTRAL REGION**

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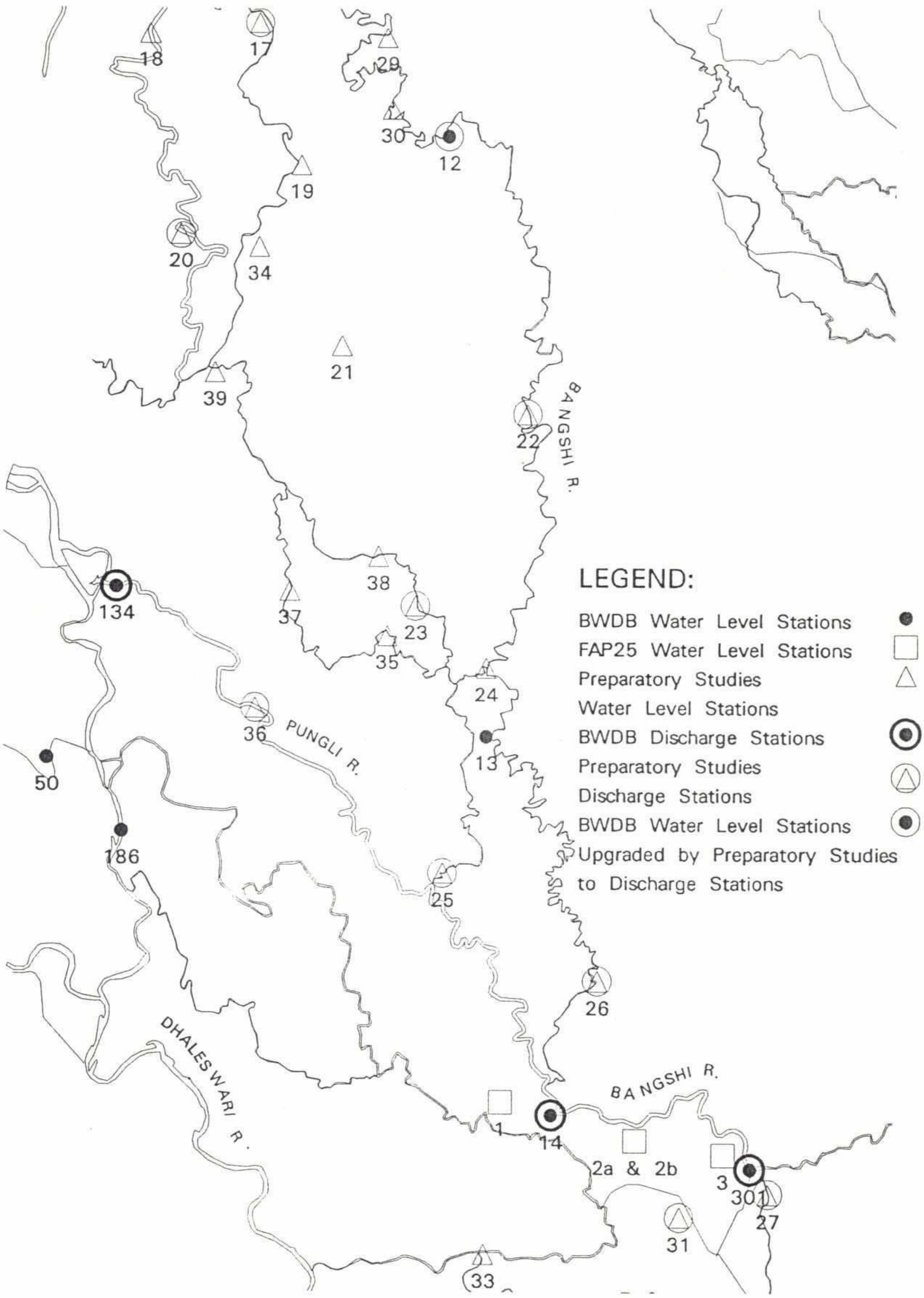

MAP SHEET 3

Figure 2.5 **NORTH CENTRAL REGION**

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MAP SHEET 4

Figure 2.6 **NORTH CENTRAL REGION**

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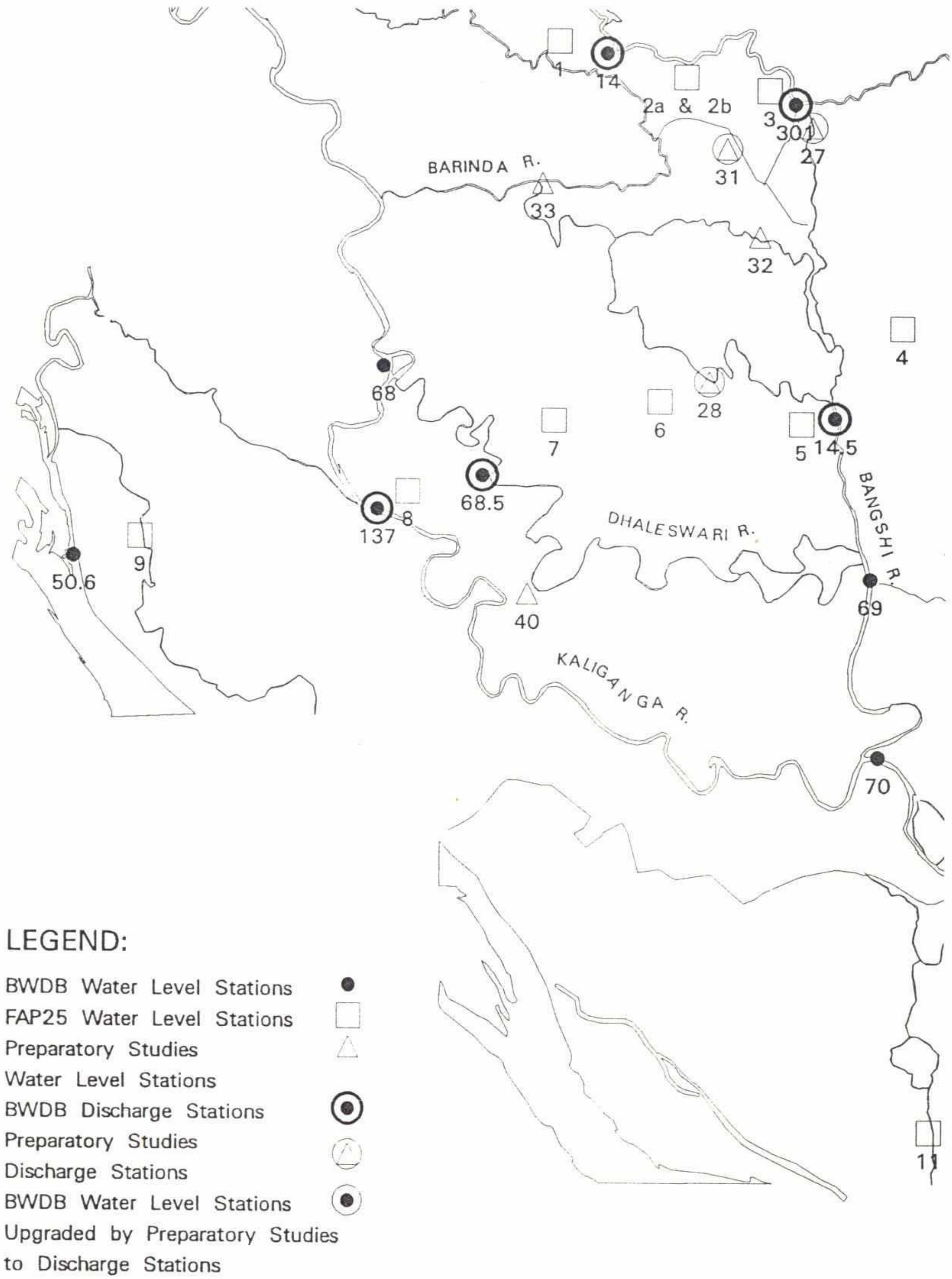

MAP SHEET 5

Figure 2.7 **NORTH CENTRAL REGION**

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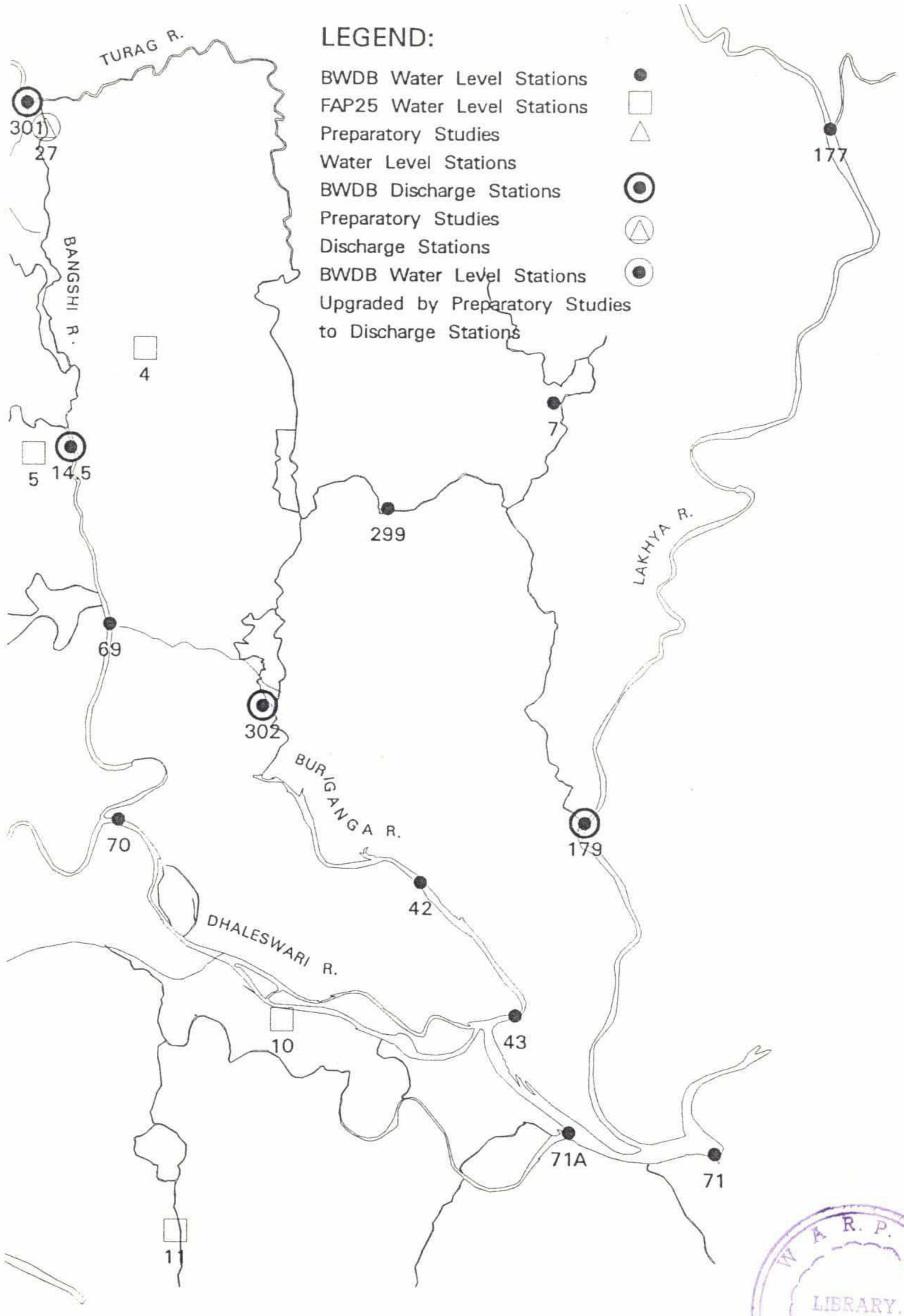

MAP SHEET 6

Figure 2.8 **NORTH CENTRAL REGION**

During the wet season of 1993 the water level has been observed at 32 locations in- and outside the Tangail Compartment (Table 2.2 and Figure 2.9). Presslogs have been installed at G35, G36, G3 and G8. The water level data of the months May (partly), June, July and August of these locations and the rainfall data of station R2, Atia, already have been made available and have been checked. The monthly availability and checking of the data improves the quality significantly.

During the months July, August and September of 1993 discharge measurements have been carried out every week at 5 locations.

Groundwater levels are measured at 5 locations in the Tangail Compartment.

2.3.4 *Ground Survey for Radar Images*

FAP 25 has participated in the field campaigns for ground truthing of satellite radar imagery coordinated by FAP 19. FAP 25 were responsible for the field campaigns in two areas in the North Central Region, (Figure 2.10), on 31 July and 28 August, 1993 to coincide with the passage of ERS - 1 over the region.

Two survey teams were constituted from FAP 25 to record the information relevant for ground truthing. One of the teams moved along the Dhaka - Aricha highway and the other team worked along the Dhaka - Tangail road. The sites were selected on the basis of diversity of land use, covering such variations as paddy fields, jute plants and sugarcane, bridges, major buildings, forest coverage etc.

After selection of a site, coordinates were recorded from a GPS and the site was marked on SPOT images. Photographs were taken of the area and information on canopy coverage, percentage of area under cultivation, length of crops above water and depth of water with colour of water, (if sediment-laden), were recorded in a specified format. Details of weather conditions, height of trees, road width, side slope, roofing of the houses etc. were noted. This information, together with photographs were handed over to FAP 19 for use in the "calibration" process.

Table 2.2 CPP Water Level Gauge Stations in the Tangail Area

Gauge 92/3	91	River/kahl/beel	Place	Zero value (m+PWD)	Years
G1		Lohajang River	Pichuria	8.36	91/2/3
G2		Lohajang River	Tangail Town	7.69	92/3
G3	G2	Lohajang River	Kagmeri bridge	7.24	91/2/3
G4		Lohajang River			92
G5		Lohajang River	Deojan	7.86	92/3
G6		Lohajang River	Nagar Jalfai	6.81	92/3
G7	G3	Lohajang River			91/2
G8	G4	Lohajang River	Karatia	5.78	91/2/3
G9		Elanjani River	Charabari		92
G10		Barabelta Canal	Barabelta	9.48	91/2/3
G11		Elanjani River	Barabelta		92
G12	G8	Elanjani River	Goziabari	5.74	91/2/3
G13	G10	Pungli River	Pauli	7.11	91/2/3
G14	G11	Pungli River	Nothkola	6.41	91/2/3
G15		Chowdury Maloncho Khal	Chowdury Maloncho	10.11	92/3
G16		Dhaleswari River	Shubarnotholi	7.32	92/3
G17		Beel Ghaghorjan	Ghaghorjan	8.69	92/3
G18		Floodplain	Bara Basalia	9.82	92/3
G19		Beel E1	Salina	8.96	92/3
G20		Old Dhaleswari River	Fatehpur		91/2
G21		Binyafair Khal	Fatehpur	10.24	92/3
G22	G5	Binyafair Khal	Santosh	9.00	91/2/3
G23		Beel Baghil	Baghil	9.28	92/3
G24		Panch(Ghatakbari) Beel	Dinya Shibram	8.49	92/3
G25	G7	Beel Atia	Chala Atia	7.65	91/2/3
G26	G8	Birkushia Canal	Birkushia	7.43	91/2/3
G27		Beel Rupshi	Sheoratoil, Rupshi	8.28	92/3
G28	G14	Gala Khal	Rasulpur	8.62	91/2/3
G29		Sadullapur Khal	Sadullapur	8.21	92/3
G30		Sadullapur Khal	Enayetpur	8.02	92/3
G31	G9	Gharinda Khal	Gharinda	7.87	91/2/3
G32		Beel Garasin	Namdar Pungli	9.62	92/3
G33		Floodplain	Rakhitbelta	9.79	92/3
G34		Enayetpur Beel	Magur Ata	9.31	92/3
G35		Lohajang River	Shibpur (Ramdebpur)	8.55	93
G36		Lohajang River	Dithpur	9.12	93
G37		Baruha Khal	Bhurbhuria	9.09	93

LEGEND:-

PROJECT BOUNDARY

HIGHWAYS

LOCAL ROAD

RIVER & KHAL

GAUGE LOCATION (G21)

DISCHARGE MEASUREMENT LOCATION

NEW MEASURING STAFFGAUGE – G35 (G36) G37

1993 PROGRAMME

JUGINI ★

NEW PRESSLOG POSITION □

GAUGE LOCATION DISCONTINUED AFTER 1992 ⊗

MINISTRY OF IRRIGATION, WATER DEVELOPMENT AND FLOOD CONTROL
BANGLADESH WATER DEVELOPMENT BOARD
FLOOD PLAN COORDINATION ORGANIZATION

COMPARTMENTALIZATION PILOT PROJECT
FAP 20

LOCATION OF WATER LEVEL MEASURING STATIONS, DISCHARGE MEASUREMENTS AND PRESSLOGS, 1993

Consultants: Euroconsult, Lahmeyer Int, Bets Ltd, HCL.

Drawn by: K. Rahman	Checked by:	Fig./Drg No. 2.9
Date:	Date: Feb. 1993	

89° 55'

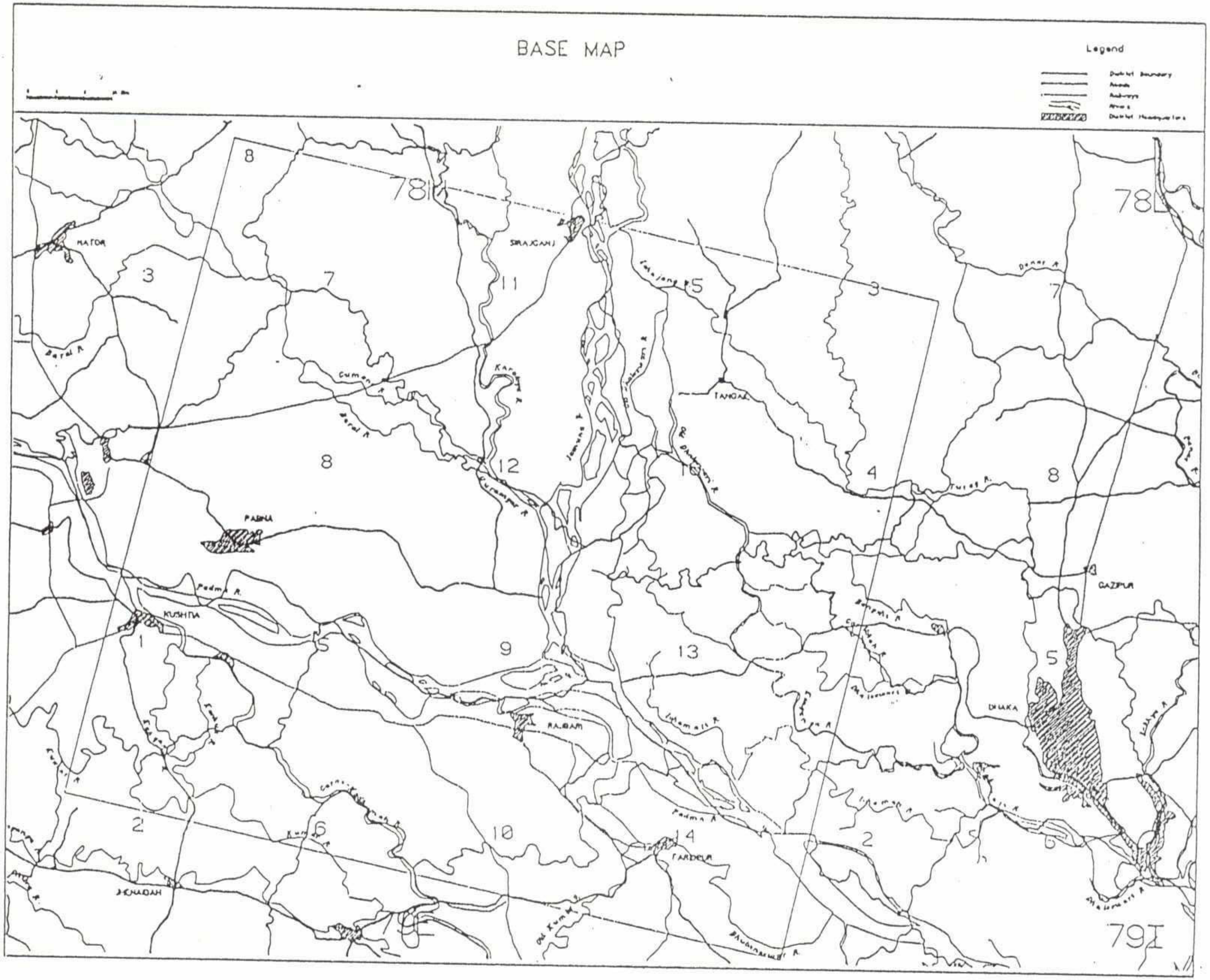

Figure 2.10 Ground Coverage for Radar Satellite

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3. FMM DEVELOPMENT

3.1 Introduction

This Chapter briefly describes the basic features of the Flood Management Model (FMM) developed by the project team. As mentioned earlier FMM is conceived as a decision support tool in the management of Bangladesh's rivers and floodplains.

The main purpose of FMM is to integrate the Mike 11 modelling system with the GIS to produce detailed maps of flood extent and flood impact in order to make flood management decisions more sound, easier and more readily accepted. The Mike 11 based hydrodynamic models form the basis of FMM development and the DEMs of specific areas and other GIS data are used in flood mapping and further applications. Table 3.1 presents a summary of various models and their relationship to the overall FMM activities.

In addition to the new FMM development, improvements being carried out to flood modelling and incorporation of a suite of composite FCD structures are described.

Table 3.1 Summary of Models Use and Development

Model/Output	Description	Software	Source/ Developer
FMM	The basic integrated Mike11-GIS model to be used in flood management in Bangladesh	ARC/INFO Mike11	being developed at FAP 25
FMM_GM	The bespoke General FMM for application on a national level flood management and flood forecasting	FMM (ARC/INFO Mike11 GM)	The General Model developed at SWMC with the latest update is being used. For Flood forecasting, FAP10 will use FMM_GM with GM-FF
FMM_NCRM	The bespoke Regional FMM for application on a regional level	FMM (ARC/INFO Mike11 NCRM)	The NCRM developed by SWMC is used, the model is being upgraded (restructured) to incorporate floodplain modelling.
FMM_TCM	The bespoke Compartmental FMM for application to Tangail Compartmental. Pilot Project.	FMM (ARC/INFO Mike11 TCM)	The TCM developed by FAP20 is used. Advanced structural operation module is being developed at FAP25.

3.2 The MIKE11 Modelling System

Mike11 is a software package for the simulation of flows, sediment transport and water quality in rivers, channels, irrigation systems and other water bodies dominated by one dimensional flows.

It is a user-friendly modelling tool for use in the design, management and operation of both simple and complex river and channel systems, and has been designed for applications on relatively low-cost microcomputers under MS-DOS and work stations operated under UNIX.

The Mike11 design is based on an integrated modular structure offering basic modules for:

- hydrology
- hydrodynamics
- advection-dispersion and water quality
- cohesive and non-cohesive sediment transport

More add-on modules are available to extend further this basic software, and the modular structure ensure a smooth data transfer between all modules, basic as well as add-on.

Organisation and manipulation of the hydrometric and hydrological data used as input to Mike11 are carried out with the help of advanced database techniques ensuring efficient storage and smooth transfer of data between all media.

The modular structure and interaction between Mike11 models is illustrated in Figure 3.1. Details of the MIKE11 system are found in MIKE11 Users Guide (Ref. 2) and MIKE11 Reference Manual (Ref. 3).

NAM-Hydrological Modelling

The NAM model is a rain-fall runoff simulation model which is integrated in the Mike11 software Modelling System as the hydrological part of the modelling system. The NAM simulates the rainfall-runoff process in rural catchments. The model is a so-called deterministic, conceptual, lumped type of model with moderate input data requirements. Being a lumped model, NAM treats each catchment as one unit. The input data to the model are precipitation and potential evapotranspiration. It operates by continuously accounting for the water content in the surface storage, the root zone and the groundwater storage. The three storages are mutually interrelated and represent physical elements of the catchment. As its main output the NAM model simulates the runoff from the catchment, which then forms the input to the hydrodynamic model.

River Modelling System

The core of the MIKE11 system consists of the Hydrodynamic (HD) module which is capable of simulating unsteady flows in a network of channels. The results of an HD simulation consists of time series of water levels and discharges at the computational nodes of a schematized channel network. Flows over floodplains can be modelled in a variety of ways depending on field conditions (see MIKE11-GIS Reference Manual, Ref. 5).

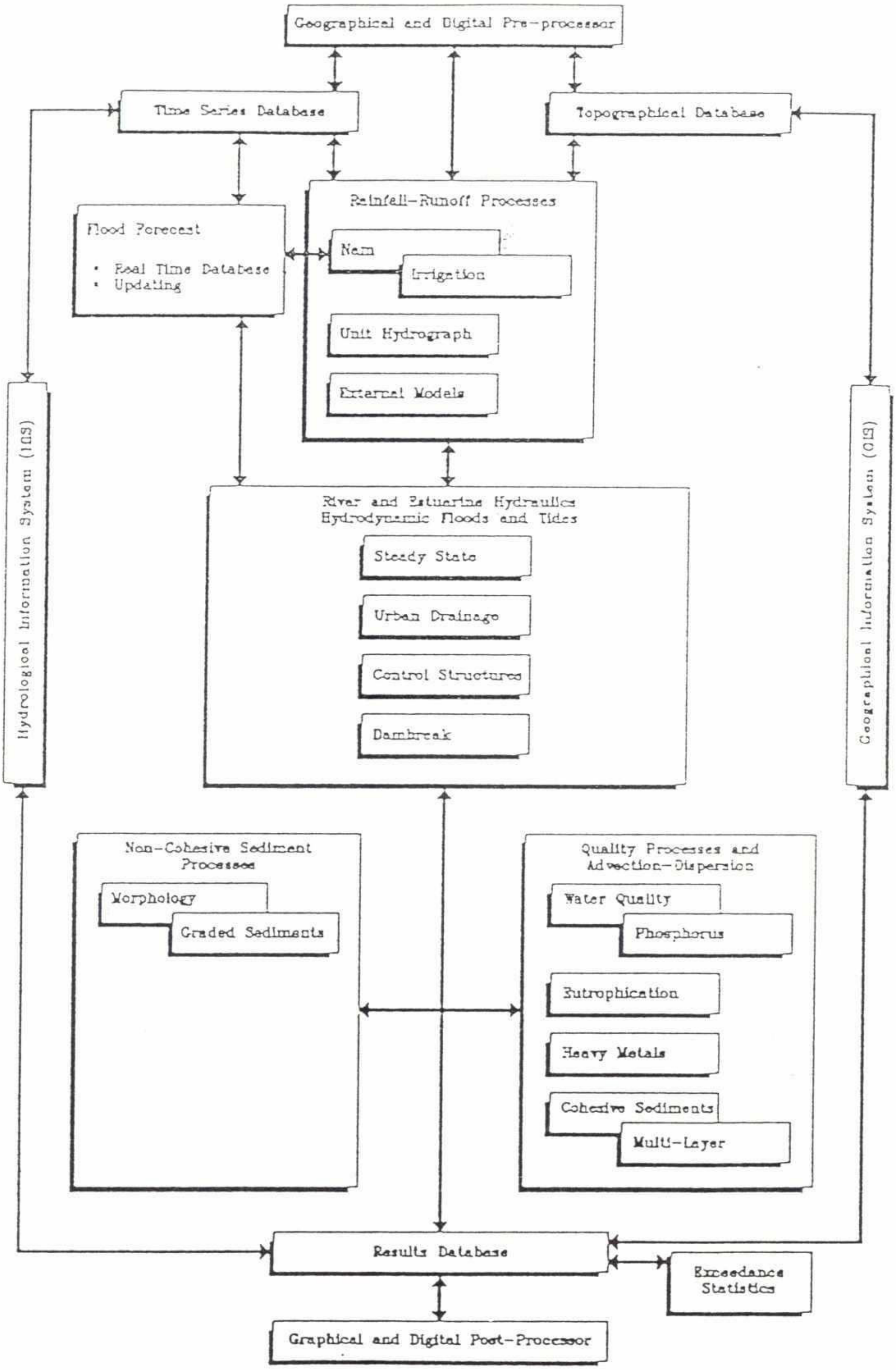

Figure 3.1 Modular Structure of the Mike11 Modelling System

O2

3.3 The Geographic Information System (GIS)

GIS has widely been recognized as a valuable tool in analysing and graphically displaying spatial data. It forms the basis for developing spatial decision support tools. Of the various GIS software commercially available, ARC/INFO has been used for the present demonstration of FMM. ARC/INFO has been found suitable to be integration with the Mike11 system in data exchange and for subsequently undertaking flood mapping impact analysis and subsequently to flood mapping and impact analysis.

ARC/INFO is a toolbox; the tools it contains manipulate geographic data sets. The following types of geographic data sets are used within the FMM: coverages, TINs (Triangulated Irregular Network) and GRIDs.

The type of geographic data set used to represent a particular geographic phenomenon must be determined by the application designer. There is no single "best" way to represent a geographic feature, it is dependent upon the type of analysis required. For example, flood plain topography may be more precisely modelled as a TIN, but by representing it as a grid many types of analyses are simplified.

The FMM application was reviewed to determine the types of analysis required. Coverages, TINs and GRIDs were designed to represent the various data objects needed by the FMM; graphical user interfaces (GUIs) were designed to carry out the necessary operations on each object were identified and a user interface was designed for their administration.

The flood phenomenon exists in time and space as a four dimensional object and cannot be modelled using solely one data type; the FMM combines several simple data types, each representing particular dimensions of flooding. MIKE11 models flooding in three dimensions: water elevation, time, and chainage. ARC/INFO uses several types of geographic data structures to extend these multi-temporal water elevations into the xy dimension: a route system provides a means of interpolating objects referenced by river chainage space along a route having xy dimension; a TIN extrapolates elevations along a route into a three dimensional surface. A grid is created from the water surface TIN and overlaid with the DEM to produce a flood depth map.

An important property of a TIN, is that the topology of a TIN is independent of its Z values. This means that the Z values of the nodes in the TIN may be updated without requiring the TIN topology to be re-built. Table 3.2 presents a summary of ARC/INFO data types in relation to various themes utilized in the FMM.

Table 3.2 Themes and ARC/INFO Data used in FMM

Theme	ARC/INFO Data Type
Rivers	route system
Structures	point event, point coverage
Q-points	point event, point coverage
H-points	point event, point coverage
Water Surface	line coverage, TIN, GRID
DEM	line coverage, point coverage, TIN GRID
Simulation	table

3.4 Digital Elevation Models (DEM)

Elevation in the FMM is represented digitally as a smooth surface generated from elevation surveyed at discrete points. The surface depends upon the regularity of the spacing of the survey data.

The DEMs used by FMM are in a "grid" format, sometimes referred to as raster. A DEM grid consists of square cells where each cell has been assigned an elevation. Smaller cell sizes provide greater resolution at the expense of slower performance and greater disk space requirement. Different methods may be used to assign elevations to cells within the same grid.

It is often easier to use a TIN as an intermediate step between elevation survey data and a DEM grid. As survey data becomes more irregularly spaced, the differences between the measured elevation and the elevation predicted by the DEM grid increases. In much of the flood plain this is inconsequential; yet for some geographic features such as roads and canals, it is more critical. When such features are excluded from the DEM, the applications that use the FMM results to analyze connectivity most affected. For example, when roads flood, villages become inaccessible; when canals become dry, fish can no longer migrate.

The elevations of roads and embankments are collected on a chainage based system. While it is possible to create three dimensional arcs that could be incorporated into a TIN, the FMM uses a grid based data structure for DEMs. This methodology requires the grid cells through which the roads and embankments pass to be forced to the appropriate elevation.

3.5 MIKE11 - NAM Dynamic Interface

3.5.1 Introduction

The effect of rainfall is represented in flood modelling by incorporating the NAM simulated catchment runoff into the hydrodynamic model for the purposes of flood prediction in the river channel. However, for accurately simulating floodplain flooding the effect of local most rainfall be considered in a different way than is being done by the existing Mike11 model. At present, the NAM model is run first to simulate runoff from a catchment for a given rainfall time series. The runoff is then input to the hydrodynamic model as lateral inflow to specified reaches or to points in the river channel. NAM being a lumped conceptual model, simulates the aggregate runoff from a catchment. There is a routing of the various flow components (baseflow, interflow and overland flow) within a catchment, which is landed by the calibrated time constants .

One of the main objectives of FMM is to simulate floodplain flooding more accurately. Also, from a flood management point of view it is desirable to simulate the flooding due to local rainfall separately from that due to spills from river channels. This necessities a major restructuring of the modelling approach, for example, using floods cells in a quasi 2-dimensional approach. In addition, the NAM and hydrodynamic components should be run in parallel so that at every computational step there is an interaction between the two modules. Water exchange between a flood cell and a river channel depends upon both the river stage and the water level in the flood plain.

A dynamic interface to couple the NAM and MIKE11 computations has been developed. The dynamic interface between the NAM and the Hydrodynamic (HD) modules of Mike11 is able to address such cases, where calculations in the catchments and the rivers are required simultaneously. This approach will give a better description of the following situations:

- Setup with overlap between the river network and the catchment with interaction between rivers and catchment.
- Areas with flooding where the catchment is inundated for a longer period.
- Areas with spilling from the rivers to the catchment.

The new dynamic interface is based on the existing NAM irrigation/infiltration approach with a coupling procedure between NAM and HD. The calculation and coupling is performed for each NAM time-step.

The details of the interface with an example application to the North Central Region is presented in separate documentation called "Mike11-NAM Dynamic Interface Documentation and Users Guide" (Ref. 6). The basic principles of this coupling are presented in this section.

3.5.2 Structure of the Interface Model

The dynamic interface allows the user to define areas (for example flood cells or floodplains), where calculation in NAM catchments and the river system takes place simultaneously.

Figure 3.2 schematically shows an example of a catchment with 3 flood cells, where the simultaneous calculation and coupling between NAM and the HD model can take place. It should be noticed that the flood cells/floodplains need not be located within one catchment; The flood cells/floodplains are allowed to cover several catchments and also cover areas between catchments in the setup. In the part of the catchment outside the flood cells, the NAM calculation is carried out as usual without coupling.

A modified version of the NAM irrigation/infiltration approach is used as the basic tool for the hydrological calculations in the coupled approach (see the NAM Documentation and User's Guide, Appendix A (Ref. 6) for a more detailed description).

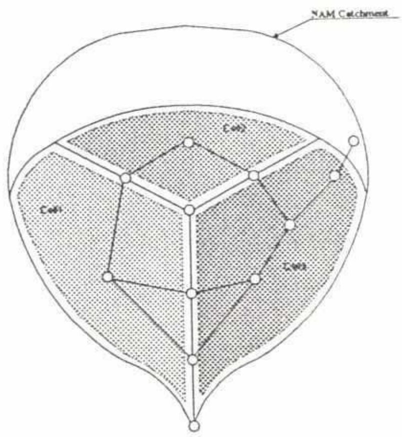

Figure 3.2 A NAM Catchment with 3 Flood Cells

Figure 3..3 shows the modified version of the model, which includes the coupling procedure between the NAM and the HD modules. The coupling takes place between the NAM surface storage and the HD flood cells/floodplains. A part of the surface water storage represents flooded water in NAM while the same water is stored in the flood cells or floodplains in the HD.

The calculation and the coupling procedure is performed for each NAM time-step. Firstly, calculation on a NAM time-step takes place, typically one day, and then the HD calculation is carried out with the lateral inflow from the NAM time-step used as input to the HD-calculation. For the next NAM timestep lateral inflow from the HD in the previous timestep(s) is used as input to the NAM calculation.

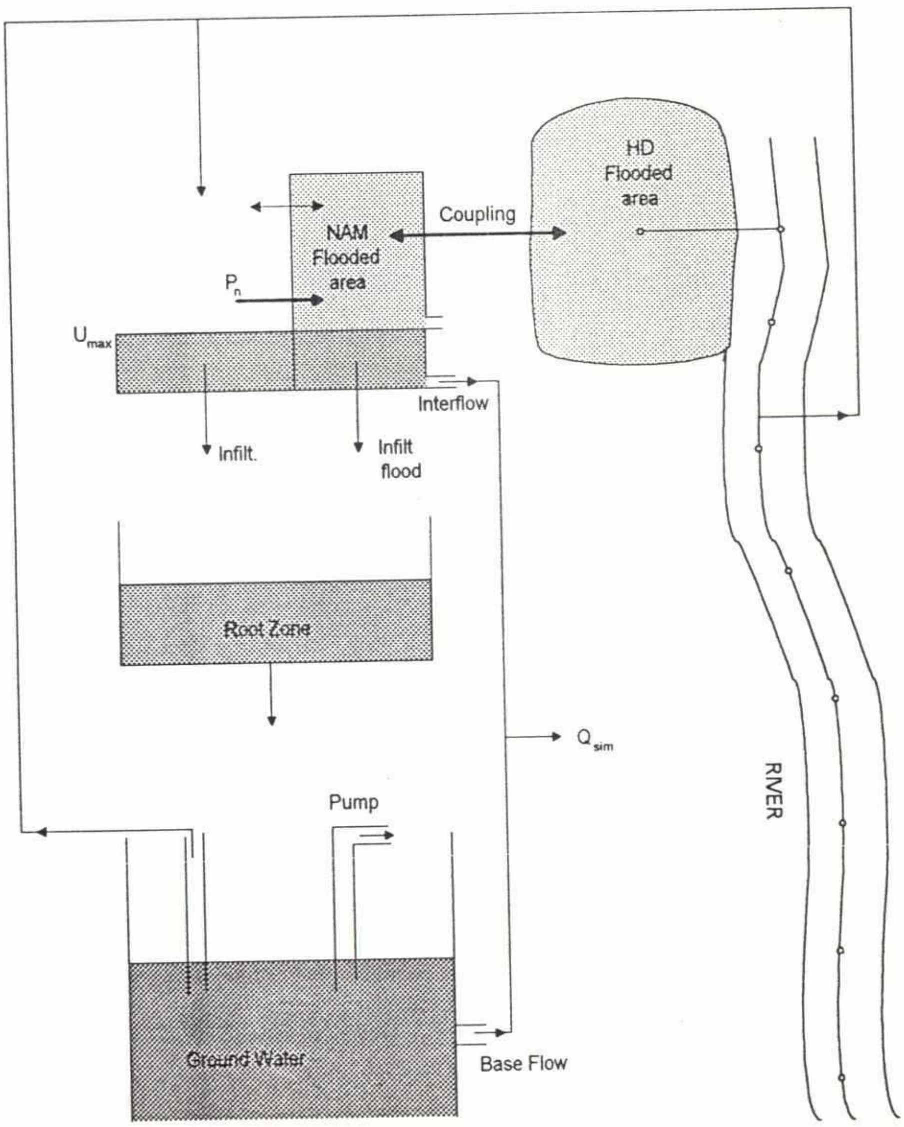

Figure 3.3 Structure of the NAM Model with direct coupling between the NAM surface storage and the HD flooded area.

3.6 MIKE11-GIS

3.6.1 Introduction

The major FMM development objective aims to integrate mathematical flood modelling and GIS. The result: MIKE11-GIS - a prototype flood management spatial decision support tool, which interfaces MIKE11 and ARC/INFO within a graphical user interface.

MIKE11-GIS was developed following a clearly defined work schedule and software development guidelines. Generally, most development task objectives were met and often exceed the TOR requirements. Some tasks are additional to the TOR, but were included because they were deemed necessary for Stage 2: FMM Application.

The TOR required the interface to:

1. process topographical floodplain and rainfall-runoff catchment data,
2. calculate intersection between MIKE11 output (three-dimensional water surface) and three-dimensional ground surface,

and have:

3. graphic modules, including zoom and pan facilities, to display:
   (a) time series of rainfall, water level and discharges
   (b) two- and three-dimensional images of land and water surfaces
   (c) tables showing inundation depths
   (d) line drawings showing position of gate controls and pumps, and their mode of operations
4. a statistical package for analysis of model performance and output.

Points 1, 2, 3a and 3b, have been met, except for rainfall time-series which has been deferred at this time, pending discussion as its is more adequately handled in MIKE11.

Point 3c will be included but needs to be more clearly clarified - it is impractical to tabulate the vast quantity of calculated inundation depths, but it would be very useful to tabulate depth statistics for defined areas (eg. thanas, irrigation compartments). This will be raised as a discussion point in the Second Workshop.

For Point 3d, MIKE11-GIS displays MIKE11 structure positions and type. Graphical displays of the gate position of an individual structure will be developed in MIKE11.

Point 4 is difficult to apply to MIKE11-GIS because it is essentially a data processor, not a computational model. The purpose of Point 4 needs to be more clearly defined, particularly during the application stage.

Additional tasks were incorporated into MIKE11-GIS's development to create a useful and functional system. Without these tasks, it would not be practical to apply MIKE11-GIS or train and educate potential users. Additional major tasks carried out were:

5. User-friendly graphic interface.

6. A relational database to handle large quantities of imported MIKE11 and generated three-dimensional surface data.
7. Graphical editors to create and edit coverages for geo-referencing MIKE11 networks, processing floodplain topographic data and generating flood surfaces.
8. Composing graphic displays of flood maps, graphs and other GIS data for rapid assimilation by others and report presentation.

Tasks 5, 6 and 7 required the most professional resources of all development tasks.

3.6.2 *Inputs and Outputs*

MIKE11-GIS requires input from developed MIKE11 models, a DEM and optionally GIS data coverages of rivers, roads, land use, satellite images, etc.

MIKE11-GIS outputs floodplain topographic data, flood maps, comparative flood maps, graphs and other graphic displays (Figures 3.4 and 3.5)..

Figure 3.4 Inputs and Outputs of MIKE11-GIS

Floodplain topographic data (cross-section profiles and flooded area-elevation curves) are extracted from a DEM and exported to MIKE11. The streamlined process greatly reduces the time taken for these tasks compared with traditional methods.

Flood maps and comparative flood maps are potentially useful for flood impact and damage assessments on infrastructure, agriculture, fisheries. Comparative flood maps illustrate the impact on flood depths and inundation from proposed works, structure failure, embankment breaching.

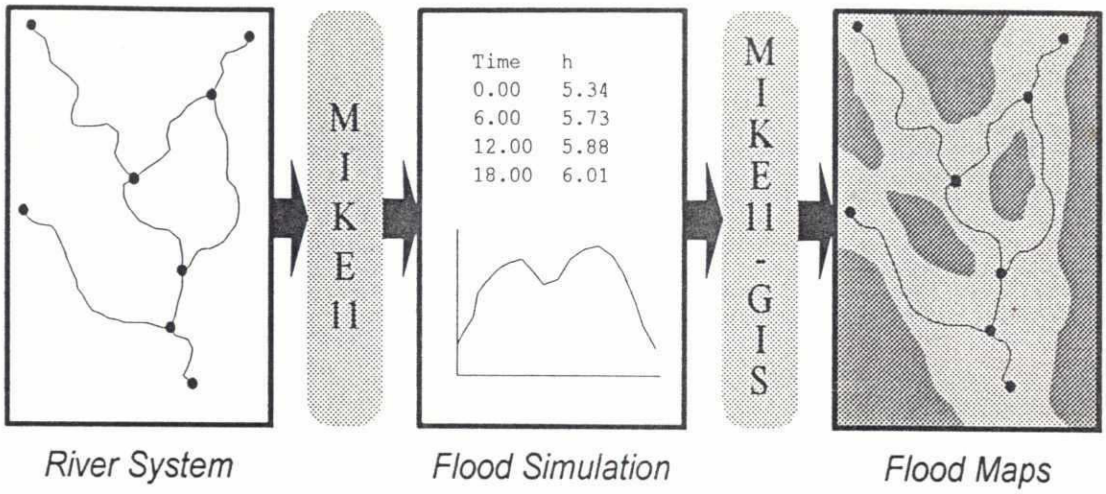

Figure 3.5 Processes of Flood Mapping

3.6.3 Modules

MIKE11-GIS uses a modular structure, partly because of ARC/INFO's separate ARCEDIT and ARCPLOT programs, but also to logically separate processes (Figure 3.6).

The modules are:

SYSM System Module. The parent module from which all other modules are started.

DBM Database Module. A database manager for importing MIKE11 model data and simulation output. The relational database structure facilitates fast data retrieval and easy comparison of different models and simulations.

EDM Edit Module. A customised graphical editor operating under ARCEDIT for creating and editing MIKE11-GIS coverages.

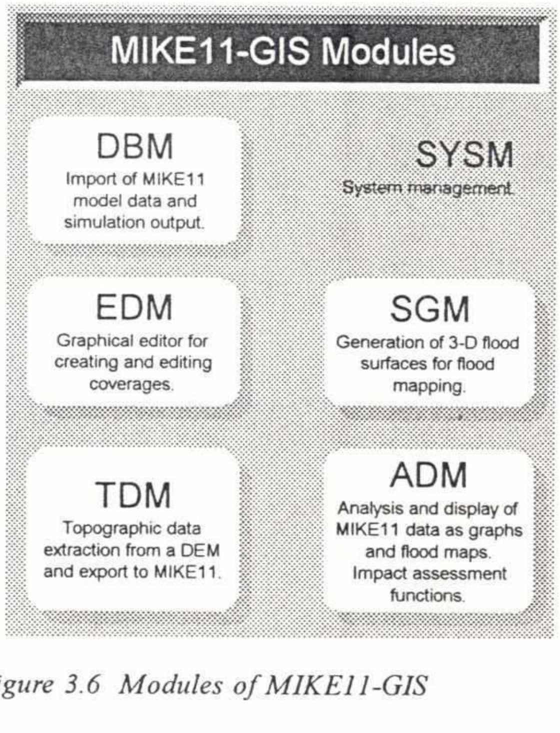

Figure 3.6 Modules of MIKE11-GIS

TDM Topographic Data Module. Extracts and exports cross-section (XS) profiles and flooded area versus elevation (AE) curves from a DEM to a MIKE11 cross-section database.

SGM Surface Generation Module. Generates 3-D flood surfaces from MIKE11 simulations. The flood surfaces are related with a DEM to give flood depth surfaces, and are further related with time to give flood duration surfaces.

ADM Analysis and Display Module. A graphical viewing environment for displaying MIKE11 output as time-series and profile graphs, and as flood inundation, flood depth and flood duration maps. Analysis functions compare simulations and can help analyze impacts on agriculture, fisheries, etc.

3.6.4 User Interface

MIKE11-GIS operates under ARC/INFO in the X-Window environment. It uses dialogue, menu, graphic and text windows to communicate with the user. The user opens and closes menu windows to access other menus, enter geographical information and start processes. MIKE11-GIS automatically opens and closes the main graphic windows, but the user may open additional ones for panning and zooming.

Much effort has been directed towards developing a user interface which is user-friendly and functional. Without such an interface the techniques developed for flood mapping and DEM data extraction would be awkward, if not impractical, to apply. The user interface will be refined during Stage 2 (FMM Application) based on feedback from users.

3.6.5 Documentation

The TOR states that an Interim Scientific Documentation will accompany the First Interim Report and an Interim FMM User's Guide will accompany the Second Interim Report. A different approach was taken, namely: to replace these documents with a Reference Manual and a Workbook.

why? did we agree this during Inception Report?

Simply a Scientific Documentation at this stage considered to be insufficient. With Stage 2 (FMM Application) starting, both methodologies and step by step guidelines for applying MIKE11-GIS needed to be documented for training and use by the application engineers. Hence, the Reference Manual, a technical reference and user's guide combined, was written and accompanies this First Interim Report. It introduces the concepts of MIKE11-GIS, and discusses methodologies and step by step procedures for application.

The future of FMM is dependent on training MIKE11-GIS users and making other FAP and non-FAP projects aware of its capabilities. The Workbook, in conjunction with the Reference Manual, will aim to assist this process by presenting a series of tutorials and real-world applications. A draft version of the Workbook will accompany the Second Interim Report.

The Reference Manual chapters are:

Introduction	Introduces flood management and MIKE11-GIS concepts and basic MIKE11-GIS components and functions.
Preparatory Activities	Guidelines for preparing DEMs and MIKE11 flood models.

	Presents requirements, procedures and outputs for applying MIKE11-GIS.
MIKE11-GIS	Overview of modules. Introduces the MIKE11-GIS work area. User interface structure and details. How to get started.
Data Exchange	Methods for exchanging data between MIKE11 and MIKE11-GIS.
Coverage Editing	Real-world coordinate registration. MIKE11-GIS graphic edit environment. General editing procedures and tools. Creating and editing coverages.
Branch Route System	Introduces the branch route concept for geo-referencing MIKE11 networks. Creating and editing a branch route system.
Cross-Section Profiles	Methodology and procedure for extracting, displaying and exporting DEM cross-section profiles.
Area Elevation Curves	Methodology and procedure for computing, displaying and exporting flooded area versus elevation curves from a DEM.
Hydrologic Data	Methodology and procedure for extracting catchment areas. Compiling rain gauge information.
Flood Maps	Methodology and procedure for generating a flood surface. Flood mapping viewing environment. Displaying flood extent, flood depth and comparison maps.
Graphs	Graphing viewing environment. Displaying flood level and discharge graphs.
Display Compositions	Display composer viewing environment. Creating a composition of flood maps, graphs and other GIS data to display and print/plot.
Appendix A	Installation guidelines.
Appendix B	Common problems and solutions - to be documented.
Appendix C	MIKE11-GIS symbol set - to be documented.
Appendix D	Data exchange formats.
Appendix E	Menu Descriptions; details the functionality of each menu.

4. APPLICATION OF THE FMM

4.1 Introduction

The application of the FMM technology centres on the development of a system of bespoke models on various scales (national, regional and compartment). These will be based on the General Model, (GM), North Central Regional Model (NCRM) and the Tangail Compartmental Model (TCM). The system of models will be operated at different levels - central, regional and compartmental and applied to different purposes, such as:

off-line flood management, i.e. planning, design and training, purposes;

on-line flood management, i.e. real-time flood forecasting and management.

Table 4.1 summarises the model basis, the level of operation, the main drainage features which may be accommodated at the various model scales and the main application areas. The bespoke FMM developments will be carried out in stages,the first stage involving a coarse model to test the concepts and logic for demonstration and training and identifying additional data collection and the second stage developing full integration with the DEM and the GIS.

As clearly indicated in the TOR (Ref. 2), the present study aims to demonstrate the uses of FMM and will develop a sound foundation for achieving the long-term objectives. To this end, the applications will be carried out on a pilot scale at different levels. The following outputs are envisaged:

- **National Level:** A course FMM using the updated General Model for off-line prediction of flood plain inundation for various scenarios of river floods, rainfall and embankment and structure configurations. Linked to BWDB-FFWC's (FAP 10) flood forecasting model, it may be used for inundation forecasting (but at a coarse level).

- **Regional Level:** A detailed pilot FMM for the North Central Region using the verified NCRM of SWMC, (eventually allowing for some additional details in selected areas), for prediction of flood plain inundations as for the General Model above. However, as described in Section 5.3, the difference would be in detail; extent and depths of inundation would be less coarse, ideally giving more accurate forecasts at Upazila level; and simulating different configurations and operational

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models for compartments and polders.

- **Compartment Level:** A detailed FMM at compartment level using the existing model for Tangail Compartmentalization Pilot Project (CPP) developed by FAP 20 for predicting inundation depths and durations for various management strategies, but with greater accuracy. It would test out the effects of operation of hydraulic structures and, as a pilot for a more comprehensive management model, would introduce flood impact assessment on agriculture, fisheries etc by coupling with GIS. Status of the development of the application models are provided in the following sections.

Table 4.1 Flood Management Model - Basic Characteristics and Applications

		FMM Basis	
Characteristic Applications	General Model	Regional/sub-regional model	Compartmental Model
Possible Model Operation Level	Central level	Central or Regional level	Central,Regional or District Level
Potential Model Users	BWDB, WARPO, RRI DoE, BIWTA,BUET, consultants	BWDB, WARPO,RRI, DoE, RHD, MoA, BIWTA, BUET, consultants	BWDB, FPCO, LGEB, MoA, Project Committees, BUET. consultants, NGO's
Typical Drainage Features in the Model	*Major river drainage network	*Regional river drainage network *Compartments as controlled hydrological units *Subcompartments (1,000-2,500 ha) as uncontrolled hydrological units	*Compartment with major drainage network *Subcompartments (1,000-2,500 ha) as controlled hydrological units *Subcompartment units (100-250ha) as uncontrolled hydrological units
Main Types of Model Application	Off-line: Development of flood management strategies. Planning, design, training and demonstration. On-line: Real-time flood forecasting and management.	Off-line: As for GM On-line: Real-time flood forecasting and management, but only on central level	Off-line: As for the GM On-line: Flood management, structure operation.

Source: FMM TOR (Ref. 2)

4.2 General Model

4.2.1 Background

The General Model of Bangladesh has been developed at SWMC mainly for the study of macrolevel planning issues. The GM is also used to generate boundary conditions for the regional models. A special version of GM (GM-FF) has been used for real time flood forecasting by FAP 10 at the Flood Forecasting and Warning Center of BWDB. Another version of GM has been used by the FHS component of FAP 25 to carry out long term historical simulations. SWMC updates the GM on a regular basis and verifies it with the latest available hydrological data. SWMC has carried out a major update of the GM recently and the updated version has been available from August 1993.

In order to present a full background, the following sections give a detailed description of the new up-dated General Model

4.2.2 Description of the Model

The latest updated General Model of SWMC would be used in the FMM study. The present version of GM is briefly described below . details of the model are available in SWMC publications (see Ref. 10).

River System

The three major rivers, i.e. the Jamuna, Ganges-Padma and Meghna, with their major tributaries and distributaries (Table 4.2) make up the hydrodynamic component of the GM. The scheme plan of GM is presented in Figure 4.1

Table 4.2 River Systems in the General Model.

MAJOR RIVER	MAIN TRIBUTARIES	MAIN DISTRIBUTARIES
Jamuna	Dharla Teesta Atrai	Old-Brahmaputra Dhaleswari
Ganges	none	Gorai- Rupsa- Madhumati system
Padma	none	Arial Khan- Biskhali system
Upper Meghna	Surma-Kushiyara- Kangsa-Boulai- Kalni system Old-Brahmaputra Dhaleswari	none
Lower Meghna	none	Tentulia-Lohalia system

Flood Plains

Flood plains are represented in the General Model in many different ways. In the original set up, the flood plain boundary of the GM was delineated from the 1 in 20 year return period

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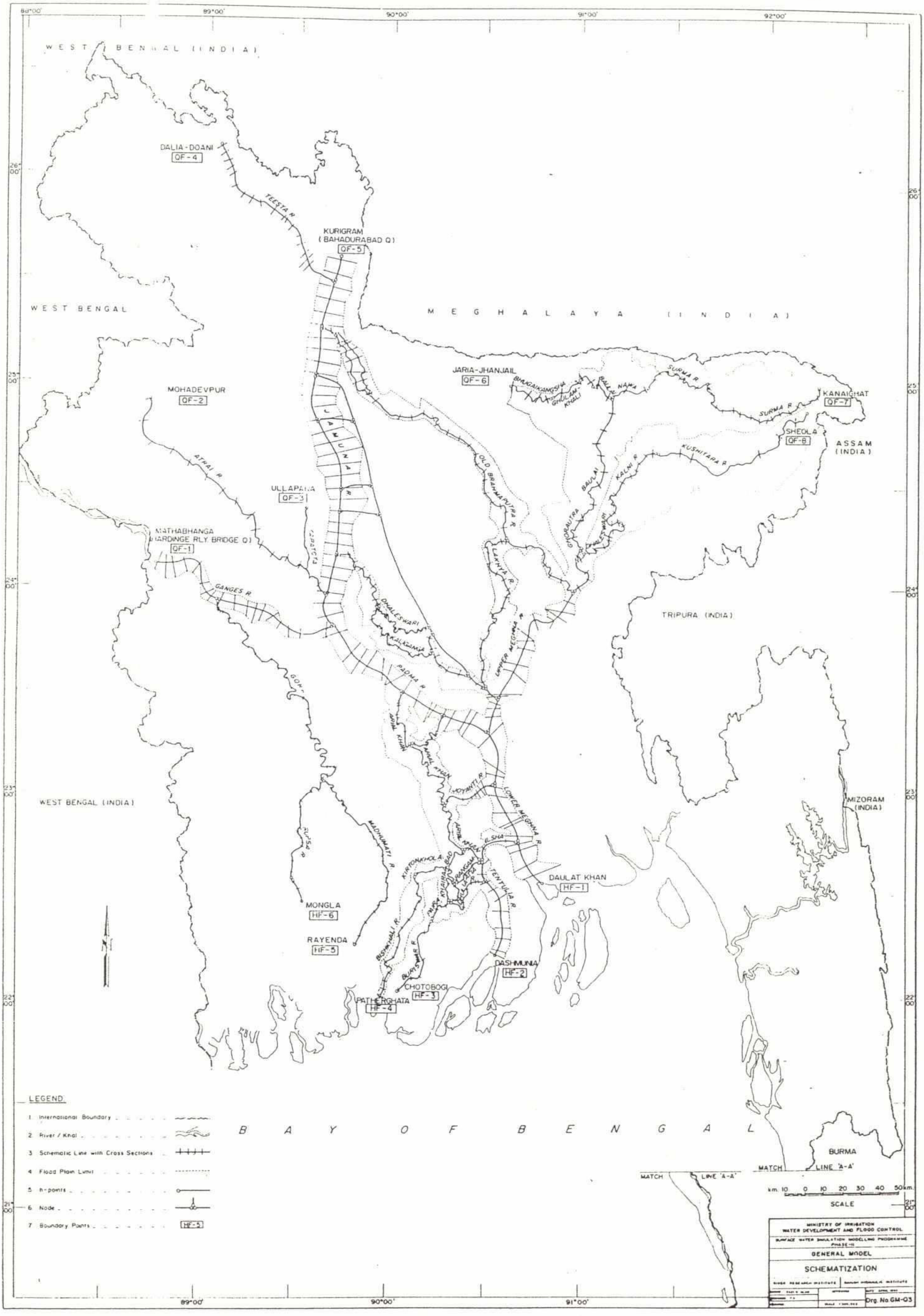


Figure 4.1 General Model Schematisation

flood depth map by the National Water Plan of MPO (now WARPO). This boundary data and spot level data from the square kilometre grid were used to generate an area-elevation function. This area elevation function is transformed into a width-elevation function by dividing the representative channel length (the portion contained within the flood plain). The width elevation function is then combined with the cross sections of the rivers using a higher relative roughness on the flood plains to represent vegetation and other obstacles on the flood plain. During the recent update, flood plains along the rivers Old Brahmaputra, Lakhya, Dhaleswari and Kaliganga are shown separately on the respective banks to provide the realistic representation of the model setup.

A quasi 2-dimensional approach is adopted to model the flood plain flow in the left bank of Jamuna by schematizing a series of spill channels and cross-connections. During the recent update, flood plain definitions have been revised in the rivers falling in the North Central and North Eastern Rivers.

Cross-Sections

Table 4.3 shows the number of river cross-sections used in the General Model, together with their source (surveyed by) and the year.

Table 4.3 River Cross-sections used in the Updated General Model.

River	Length in km	No. of X-sections	Surveyed Year	Surveyed by
Jamuna	210	32	1990-91	BWDB
Ganges	119	18	1990-91	BWDB
Padma	104	15	1988-89	BWDB
Lower Meghna	92	14	1992-93	BWDB,MRBPS
Upper Meghna	125	21	1989-90-91	BWDB
Dhaleswari	148	30	88-89 & 91-92	BWDB, JBA
Old Brahmaputra	241	38	88-89 & 91-92	BWDB, SWMC
Lakhya	115	20	1989-90	BWDB
Kaliganga	62	10	1986-87	BWDB
Gorai	197	32	1988-89	BWDB
Upper A. Khan	34	8	1987-88	BWDB
Surma	172	29	1990-91	BWDB
Kushiyara	132	9	1991-92	SWMC
Kalni	72	17	1989-90	SWMC
Bhogakangsha	40	5	1991-92	SWMC

River	Length in km	No. of X-sections	Surveyed Year	Surveyed by
Someswari	17	3	1991-92	SWMC
Nawa	28	3	1991-92	SWMC
Baulai	114	14	1991-92	SWMC
Ghorautra	34	5	1991-92	SWMC
Ghulamkhal	26	3	1991-92	SWMC
Atrai	150	16	1978-79	BWDB
Bishkhali	96	17	1980-81	BWDB
Tentulia	60	10	1986-87	BWDB
Lohalia	60	6	1986-87	BWDB
Karatoya	20	5	1978-89	BWDB
Makar	8	3	1991-92	JBA
Madhumati	128	17	1991-92	SWMC
Arial Khan	149	18	1987-88	SWMC
SPChannel3	8.5	3	1992	JBA
Joyanti	30	7	1992	SWMC
Ilsha	27	2	1992	FAP 4
Kirtonkhola	40	5	1992	FAP 4
Khairabad	58	9	1992	FAP 4
Rangamatia	28	4	1992	FAP 4
Pandab	20	4	1992	FAP 4
Dhulia	35	8	1992	FAP 4
Paira	23	4	1992	FAP 4
Buriswar	47	5	1982-83	BIWTA
Teesta	84	15	1990-91	BWDB
Rupsa	85	11	1991-92	SWMC

Source: SWMC (Ref. 10)

NAM Connection

The rainfall runoff model (NAM) computes the runoff to the rivers due to rainfall. For this purpose the whole area covered by the GM has been divided into several NAM catchments.

Rivers which pass through each catchment are defined and also the total catchment area. The runoff is transformed into discharge and distributed along the river reaches. The catchment delineation and parameters of the NAM model are based on the calibrated regional NAM models. As the GM covers only selected regional rivers, the regional NAM catchments are lumped. As a result, 48 catchments (including 7 river catchments covering the surface area of the three major rivers) are now incorporated in the GM.

Boundary Conditions

There are 8 upstream discharge boundaries in the General Model. These are at Mathabhanga (Ganges - discharge at Hardinge Bridge applied with a time lag), Mahadevpur (Atrai), Ullapara (Karatoya), Dalia-Doani (Teesta), Kurigram (Jamuna - discharge at Bahadurabad with a time lag), Jariajanjail (Bhogakangsa), Kanairghat (Surma) and Sheola (Kushiyara).

There are 6 downstream water level boundaries - at Daulatkhan (Lower Meghna), Dasmonia (Tentulia), Galachipa (Lohalia), Chotobogi (Buriswar), Patherghata (Bishkhali), Rayenda (Madhumati) and Mongla (Rupsa). The mean daily water levels computed from low and high tide levels are used as model boundaries.

4.2.3 *DEM for GM*

A coarse DEM of Bangladesh covering the entire country except the Sundarbans and some area of the Chittagong Hill Tracts has been developed by FAP 19. This is based on the MPO 1 km grid elevations. This is being used by FAP 25 for a course national level flood mapping, i.e. for planning and flood forecasting applications. The planning applications will allow modellers to edit the DEM to reflect proposed embankments. The location and height of the embankments will be determined by the modeller. The application will not determine optimal embankment locations, but will allow comparison among proposed embankment configurations.

4.2.4 *GM-FMM*

The basic purpose of the national FMM (GM-FMM) is to assist in general flood control planning and management (including real time flood forecasting) in Bangladesh. Specifically, the tool will be used for:

(i) off-line prediction of flood plain inundation for various hydrological scenarios as well as large scale structural flood control (embankments) scenarios; and

(ii) linked with the forecasting model of BWDB (FF&WC) for inundation forecasting at coarse level.

Thus, in addition to adopting the GM developed at SWMC, the two other versions described above, GM-FAP 25 and GM-FF will be used. The central focus of this application is "flood mapping" both for off-line as well as on-line information. However, owing to the coarse resolution of the GM and its inability to represent flood plain to the details required for inundation forecasting and the coarseness of the national DEM (1 Km grid) the model output will be coarse and should be used as indicative only. Attempts are being made to improve the quality of flood mapping in selected areas. The area between the Dhaleswari-Kaliganga system and the Padma has been selected for this purpose.

The basic approach of flood mapping for both the off line and on-line (forecasting) applications is to superimpose the MIKE 11 generated water surface on the DEM. Using the flood maps, off-line relationships between river water levels and flood plain inundations will be developed for various scenarios based on pre-run simulations. These relations can then be used for long term flood management and real time inundation forecasting.

4.3 Updating of FHS

Flood Hydrology Study (FHS) under FAP 25 has provided the hydrological basis for engineering design criteria and to assess the effects of alternative flood protection scenarios on water levels and flow distribution along the major rivers (Ref. 11). It has been achieved by 25 years simulation (1965-89) of the General Model developed by SWMC. This basis is not unique and is subject to change with the improvement of the model performance. Therefore, a concept of safety margin was introduced to take into account the effects of random morphological processes, model errors and shortness of records. The margin would therefore be reduced on improvement of model errors. As such it is stated in FHS Annex -2 (Ref. 12) "It is proposed that the next updating of hydrological design criteria along the major rivers be undertaken in early 1993 following the SWMC update of the GM"

A full report of the Flood Hydrology Study Update is given in Appendix C, which accompanies this Report.

4.4 North Central Regional Model

4.4.1 Background

It has been made clear from the onset of this project that major structural revision to the existing NCRM would be needed if meaningful representation of flooding patterns within the region were to be reproduced. To this end, emphasis has been initially placed on obtaining better detail of floodplain delineation and river/floodplain interaction through additional surveys and study of existing aerial photographs and Digital Elevation Models.

The programme of activities outlined in the project Inception Report, (April 1993), proposed that work on the model restructuring precede any application of the FMM. Such application runs of the regional FMM would be scheduled to take place in early 1994.

4.4.2 *Hydraulic Model Development*

One requirement of the FMM activities necessitates the development of computerised routines for the interactive identification and construction of flood cells or pathways, to be included in the hydraulic model. The hydraulic model development is being phased in conjunction with the development of these computer tools in order that maximum benefit may be derived for both activities. In this way, the hydraulic model development would be simplified and software routines could be tested and refined in a realistic environment. Consequently, model development has been conditional on the development programme of the software.

To simplify the development and testing of both the MIKE11-GIS interface and the NCRM restructuring, a limited sub-model was constructed, (called the Manikganj Model), where an initial quasi 2-dimensional topology was employed in certain areas. Coarse delineations of flood cells and flood pathways were made, considering available topographic information from surveys, DEM and aerial photographs. MIKE11-GIS tools were used to define area/elevation curves of flood cells, floodplain cross-sections and fundamental branch route systems. No major calibration effort was made at this stage.

Concurrent with the sub-model development, a programme of field survey and data collection was initiated. Information from these surveys will be incorporated in the sub-model, as appropriate, and will be used to assist in the extension of the limits of the sub-model to the region. The data will be of particular use in the refinement of the layout of the flood cells and in the calibration of the critical levels and locations of the interaction between the rivers and the flood plains, which have not yet been rigorously addressed in the Manikganj sub-model.

The Manikganj sub-model gives an initial impression of the number and typical area of flood cells expected in a regional level model. It is important here to emphasise that the Manikganj model is not a sub-regional model, but a sub-model of a region, having the same resolution and detail definition as expected from a full regional model.

Figure 4.2 shows the extent and layout of the Manikanj sub-model, from which it can be seen that there are fifty-one flood cells within the total 4600 sq. km., having an average area of 20 km. With some recently acquired topographic survey of embankments, floodplains and khals still requiring evaluation, it is likely that this initial layout will be modified in the future.

It is of interest to note that not all the area covered by the sub-model has been represented by flood cells. Some areas north of the Dhaleswari have been considered as flood plain branches in themselves and, accordingly, have been attributed as major flood flow pathways. The MIKE11-GIS tools developed make the adjustment of flood cells or flood pathways very simple and they can be refined during the calibration process which will follow the initial restructuring exercise.

4.4.3 *FMM Development*

Following on from the restructuring of the North Central Region Model, which is anticipated to be completed by January, 1993, at the latest, development will commence of the bespoke Regional Flood Management Model. At this stage of the project, however, little direct work has been done on the production of the integrated MIKE11-GIS based North Central Model, as this is contingent on the finalisation of the MIKE11 based hydrodynamic model. This approach accords with the programme of activities defined in the Inception Report.

Work on the Manikganj sub-model has provided valuable insight into the problems likely to be encountered during development of the regional model and thus it is felt that the cautious approach adopted has been vindicated.

4.5 Tangail Compartment Model

4.5.1 Hydraulic modelling

Model Transfer and Simulation.

The final 'with-project' and calibration models of the Tangail Compartment have been transferred from the Tangail PC to the FAP 25 office. MIKE11 Version 2.0 has been used to run the model in Tangail, whereas Version 3.0 is being used in the FAP 25 office. This gave rise to some model incompatibility problems. These problems have now been resolved and it was possible to run the 1991 calibration model, using Version 3.01.

The transfer of the models to the UNIX system gave rise to yet further incompatibility problems but which have now been resolved. All models now yield identical results, irrespective of the operational platform.

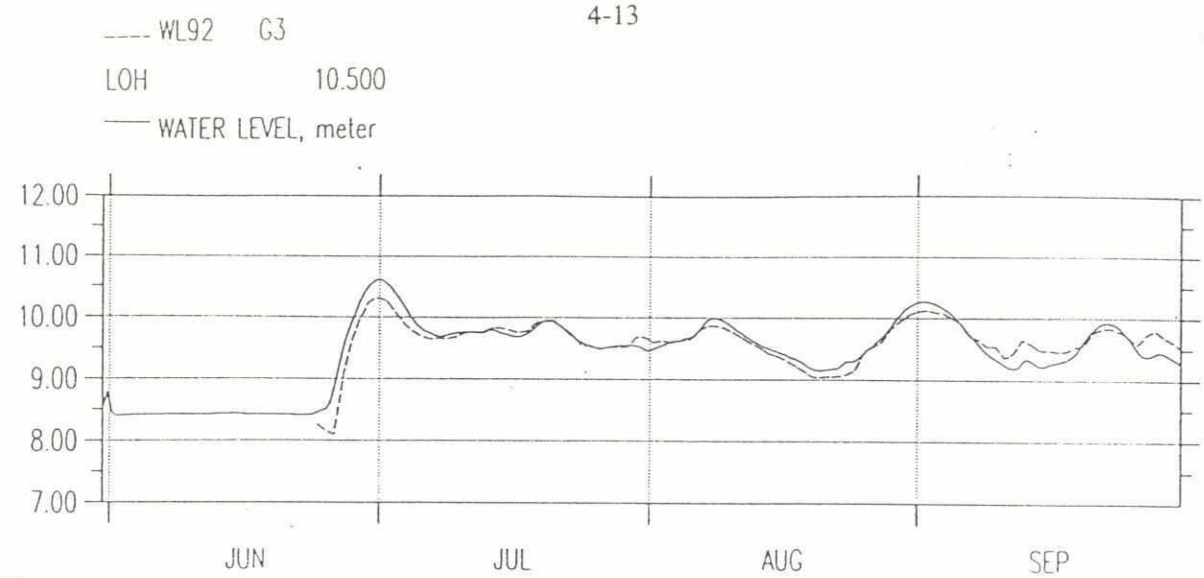
The 'with-project' model has been run under the UNIX operating system, which has removed the constraint on the number of structures permitted.

The model has been verified for the period May - September 1992, although the wet season of 1992 was very dry and significantly different from that of 1991. It was found that the model does not cope well with a "dry" wet season because the floodplain is presently included in the cross-section profiles. This had little effect on the calibration results of 1991 because of the high water levels experienced in that year. Part of the floodplain has to be schematized as flood cells while that part of the floodplain included in the cross-section profiles should be assigned a higher relative bed resistance. The best results which could be achieved without adapting the schematization are shown in Figure 4.3.

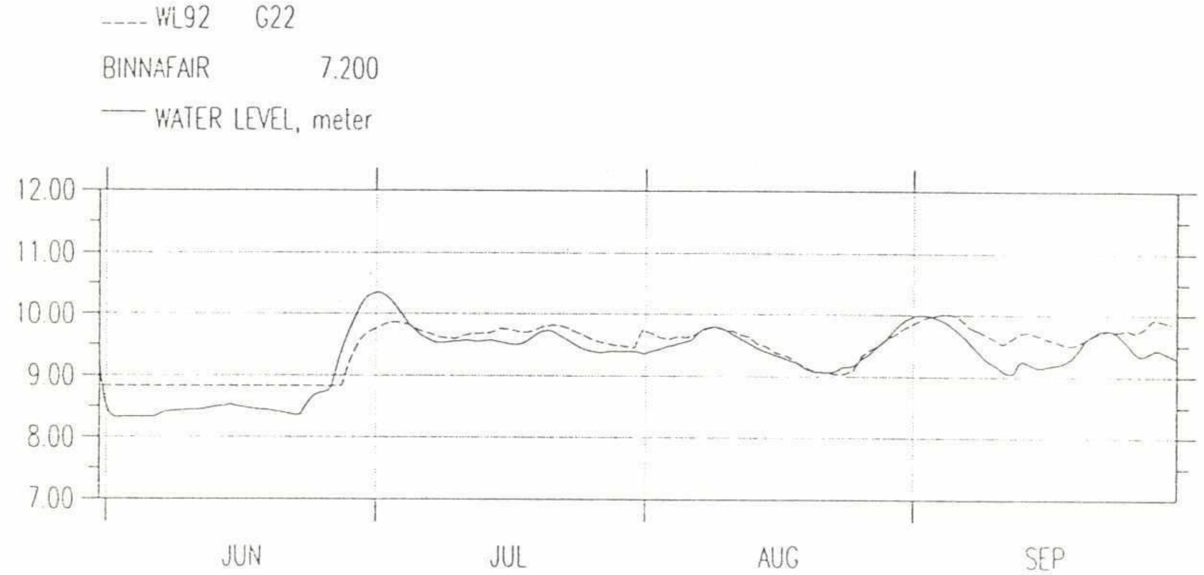
Better results for the NAM model have been achieved by re-calibrating with ground water levels and using the irrigation module.

It was decided to postpone the verification run for 1992 until the model has been refined, as indicated, and re-calibrated for 1991.

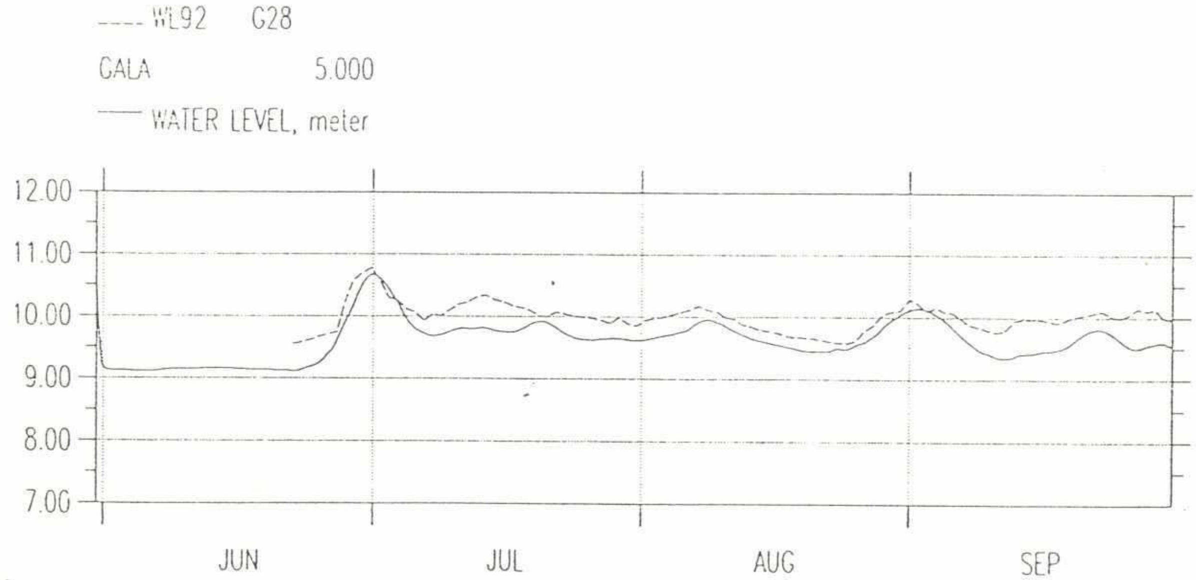
Figure 4.2 Manikganj Model with Storage Cells and Link Channels



1992



1992



1992

Tangail Compartment Model

Comparison between measured & computed Water Level for 1992

MIKE 11

DATA FILE : CPP92C.RDF
RESULT FILE : CPPOP.RRF

BOUNDARY FILE : CPP92C.BSF
CALCULATED : 4-JUL-1993, 15:38

Dwg no.:

Fig. No.: 4.3

Model refinement.

The network layout for the current situation has been checked and the connections between Korda Jugini structure and the Binnafair / Gaizabari Khal, the connections between Garinda and the Lohajang through Garinda Khal, (called Jalfai in the model), to Jalfai and Bathkura Khal to Bathkura will be re-schematized.

The flood plain representation in the model has been checked. Major beels which cannot be included in the cross-section because they are not directly connected to the khals, will be schematized as flood-cells while the remainder of the floodplain will be included in the cross-sections but assigned a high relative resistance, (a start has been made with the area East of the road Tangail - Karatia).

The rainfall-runoff catchments (NAM catchments) have been checked but will be adjusted to accord with the modifications in the network layout. Due to greater detail in the model, some catchments will require sub-division and adjusting for embankment locations.

It is not anticipated that any changes will be required in the number and location of boundary conditions.

4.5.2 *DEM Transfer and Refinement*

The main refinement of the DEM followed from the replacement of the current elevations based on the 1964 BWDB map, by the FINNMAP elevations. It appears that no digital data on this will be made available by FINNMAP. FINNMAP have supplied 1:10,000 photo maps from which elevations have been digitized and a new DEM has been created. The elevations of the main-embankment, (with respect to FINNMAP BM), have been included (except SC-E1). Surveys will be carried out to verify the locations of roads, khals and beels, (as far as possible, these locations have been derived from the FINNMAP photo maps), and to obtain the elevation of the roads and the depth and extent of the beels.

4.5.3 *FMM Development*

The Branch Route System has been incorporated in the DEM in addition to the water level points for the link with those defined in the MIKE 11 network.

Tests have been carried out to extract floodplain cross-section profiles from the DEM and to export them to MIKE 11, using the Topographic Data Module of the newly developed MIKE 11-GIS Interface software. The resulting MIKE 11 input files have also been used to plot cross-section profiles at various locations to show the shape of the floodplain.

An additional feature may be developed to combine channel cross-section profiles, obtained by surveys, and floodplain cross-section profiles. Moreover, the calculation of flooded area versus elevation curves from the DEM and their export to MIKE 11 has been tested, results being used to define flood cells, storage areas, etc. in the MIKE 11 model.

Presentation of MIKE 11 output.

The MIKE 11-GIS interface software has been used to produce flood maps and flood-difference maps of available MIKE 11 results of the Tangail Compartment Model (see Figure 4.4). The Surface Generation and Analysis & Display Modules, together with flood maps, also produced discharge and water level hydrographs.

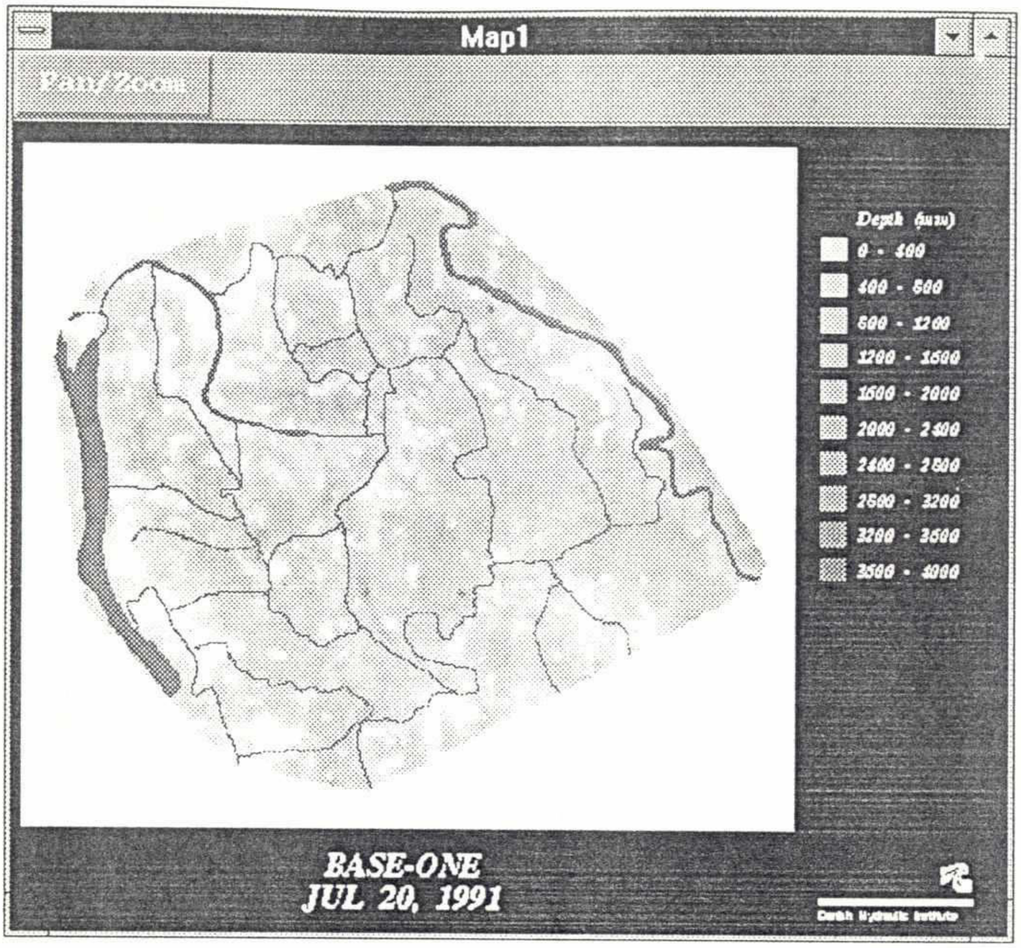
4.6 Impact Assessment

The main objective of a flood control project is to reduce flood damages. It is almost inevitable that such projects will have consequences on agriculture, fisheries, environment, social values and infrastructure, among many others. An important task of the Flood Management Model is to provide both qualitative and quantitative information on the impacts that any planned flood mitigation measure might have on these factors.

The assets in the flood prone area must be investigated for each aspect mentioned above. This investigation should be carried out for a unit area delineated on the basis of some unique feature such as for each contour area (topographical based) or for each administrative area (administrative based).

The development of the impact assessment module of FMM and the methodology to calculate the amount of impact, (damage), on the assets identified above will be based on flood maps for different structural and non-structural options. Economic assessment of the impacts would be limited to the calculation of a damage index on assets due to floods rather than the total damages in monetary terms.

The damages on the assets depend not only on the depth of inundation but also on the duration of inundation, particularly for the agricultural crops. The damage analysis due to a flood is a much discussed subject and relevant literature (Ref. 8; Ref. 9) reveals that the normal practice is to establish a damage ratio based on the previous floods and on survey of the damages incurred due to those floods of the study area. This can be achieved based on the data available with governmental organizations and the statistical survey of flood disasters. The damage indices so collected could be superimposed on flood maps to prepare flood damage maps.



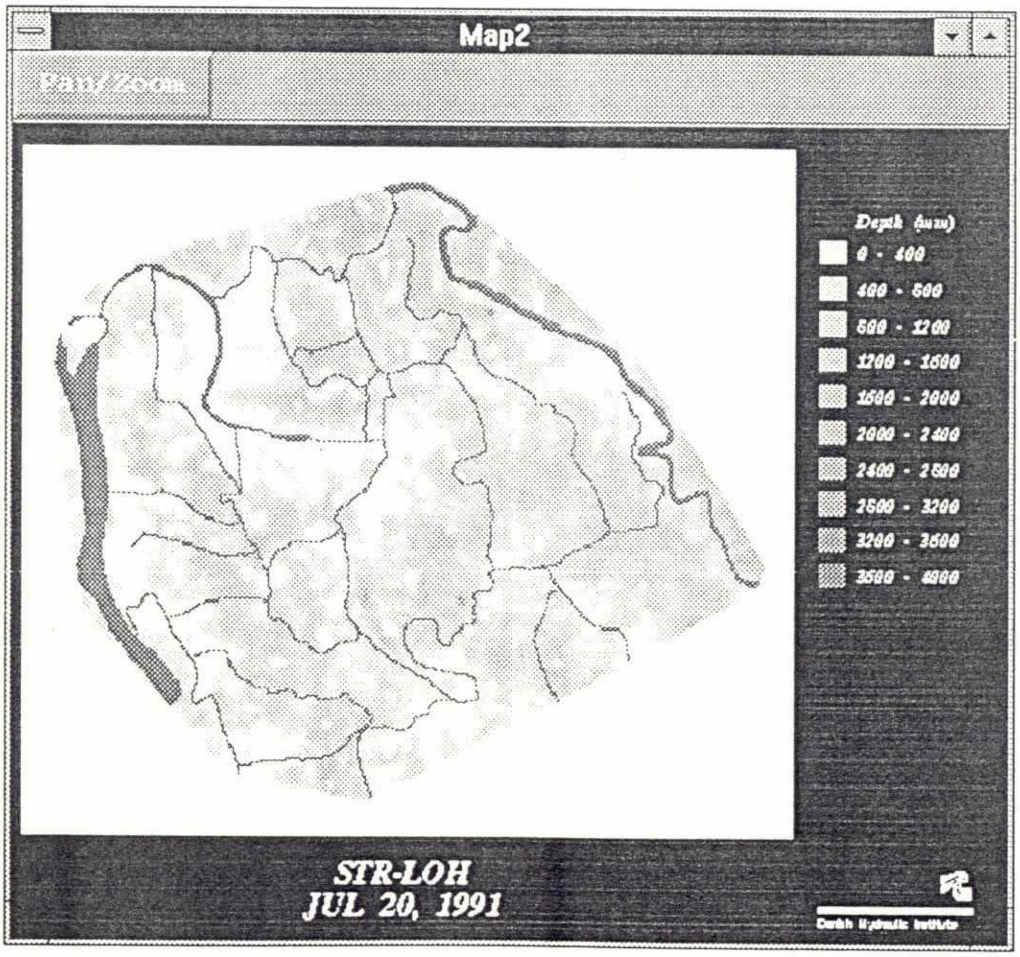


Figure 4.4 Sample Flood Mapping in The CPP

5. TRAINING AND WORKSHOP

5.1 Training Courses

5.1.1 Background

In accordance with the Terms of Reference, the first workshop was held from 9-11 February, 1993, at which the concepts of FMM were outlined, user needs and targets discussed and the Draft Inception Report was presented.

One of the major observations of the workshop was the identification of the need for training of personnel during the development stages of FMM. This training was to be targeted at those staff of GOB who would be in a position of either running the models in the future or who would require a full understanding of model capabilities in order to make management decisions.

In response to requests from FPCO and BWDB, DANIDA agreed to support a suitable training programme to be administered by FAP 25. FPCO and BWDB would be responsible for nominating suitable trainees.

FPCO Training Course on Flood Modelling & Management

Module I: Flood Modelling (19 July - 4 August 1993)

Module II: Geographic Information Systems (GIS) (2 - 14 October 1993)

Module III: Flood Management Model (FMM) (16 - 30 November 1993)

Module IV: FMM Applications (2 weeks in 1994)

5.1.2 Course Modules

A training course on Flood Modelling and Management consisting of 4 modules has been designed and is presently on-going. The course consists of 4 modules and is being conducted by the expatriate experts of FAP25 assisted by the local professional staff.

The course outline is presented below:

Module I: Flood Modelling (2 weeks):

1. Overview of Mathematical Modelling
2. Mike 11 Modelling system
3. Hands on training on various modules of Mike11 NAM, HD, AD, ST, Structure Operation
4. Flood Forecasting
5. Data Management
6. Hydrological Analysis

Module II: Geographic Information System (GIS) (2 weeks):

1. Concepts of GIS and applications in Flood Modelling and Management
2. Points, Lines, Polygons, Raster data concepts....
3. Representating surfaces with GIS, Digital Elevation Models (DEM's), water levels, non-geographic surfaces, preparation of contour map of DEMs.
4. Various GIS software, capability and limitations
5. Hands-on practice with Arc/Info
6. ArcView concepts and applications
7. Digitizing, GPS.
8. Radar satellite data, processing requirements

Module III: Flood Management Model (FMM) (2 weeks):

1. Introduction to FMM and Mike11 - GIS
2. Databases, Topographic and hydrological data, Import and Export
3. FMM Relational Database
4. Editors for FMM
5. Branch route systems, storage cells
6. Analysis and Display, Flood Mapping, factor surfaces
7. Impact Assessment, overlaying flood extents with land use.
8. Hands-on-practice on various FMM modules and exercises.

Module IV: Applications of FMM

1. Advanced features of FMM
2. Applications at national, regional and compartmental levels.
3. Impacts of alternative embankment design and FCD structures.
4. Further practices on modelling and use of FMM

To make the training more effective, individual and group exercises are given to the participants who are required to submit their work as and when required. The participants will also be required to submit a final training report.

5.1.3 Participants

A total of 11 participants (6 from FPCO, 2 from BWDB's FF&WC and 3 from SWMC) are participating in the training course. Most of the participants are senior officers (Superintending Engineers, Executive Engineers and Sub-Divisional Engineers.

The officials nominated for the training are either using the models or are aware of the model results in their present profession. The trainees have shown a keen interest in the course and their performances have been very satisfactory.

5.2 On-the-Job Training

All local staff of the project are being trained in-house through on-the-job training. While the local staff, (Software Specialist and GIS Engineer), are directly involved in developing the Mike11 - GIS software, others are regularly exposed to the FMM development process. It is expected that during the application phase of the project all the local engineers will become expert users of FMM. They will also learn the details of the Mike11-GIS interface and data exchange mechanism between Mike11 and Arc/Info.

In addition to the in-house training, hands-on demonstrations are presented from time to time to interested GOB officials and consultants from SWMC and other FAP studies. It is also planned to organize special presentations in the future.

5.3 Future Training

It is expected that short training courses on FMM will be conducted during the application Phase in 1994. Course programs and training materials will be prepared for future training courses. Such training courses will be necessary not only for transfer of technology but also for assisting potential users in applying FMM technologies, (particularly the MIKE11-GIS software), in all aspects of flood management in Bangladesh.

5.4 Workshops

5.4.1 First Workshop

The First Workshop was carried out during 9-10 February at the end of the Inception Phase of the FMM study.

The objectives of the First Workshop were to:

- Develop an understanding of the present modelling capabilities and identify the needs and targets of FMM in relation to flood management decisions in Bangladesh.
- Present the FMM concepts and logic developed by FAP 25 project team, review the draft inception report and obtain feedback.
- Provide an opportunity for dialogue between the modellers, model users, decision makers and individuals affiliated to governmental, non-govermental and research institutions.

Participants

A total of 61 participants from various organisations such as MIWD&FC, SPARRSO, BMD, LGED, RHD, DOE, BARC, DAE, IFCDR, RRI, WARPO, SWMC, BWDB, FPCO, POE/FPCO, CAT members, FAP consultants, NGO Representatives and FAP 25 officials participated the First Workshop.

Programme

The programme on the first day introduced existing planning process of BWDB and FAPs and various model used with the data availability.

The features of FMM as developed up to the time of the workshop were demonstrated on the second day.

On the concluding day, the Inception Report of FMM was presented and discussions were held under four working groups on River Modelling, Planning and Design, FCD Structure Operation and Flood Forecasting. Notes from the discussion were placed in the closing session and the Team leader responded to various issues.

Summary of the Group Recommendations

Important observations and recommendations from the meeting are summarised below:

Why Model?

Planners and designers should be educated about how, when and if the FMM can be used in their jobs. This led to discussion of planning and planning organizations in Bangladesh.

User Needs

This was seen as the fundamental purpose of the working group. The challenge was seen as identifying who would use the FMM so that it could be designed to assist them in their activities. The interests of the public was assumed to be the basis for planning. It was felt the FMM should provide mechanisms so that the interests of the public are incorporated into the planning process.

Scenario Management

Different levels of modelling were defined: General, Regional and Sub-regional. The scenarios at these different levels would be managed and used by different user groups. No "local" level planning & design models will be addressed by the FMM. The connections between the different levels of models will require institutional coordination, for example between BWDB and LGED. Flood maps should differentiate between agriculture and non agriculture lands through proper structure operation. Better understanding of rain induced flood is necessary. Forecast with respect to a local reference at sub compartment level (100 sq km) would be required.

Planning Hierarchy

There are differing views on the structure of the planning activities in Bangladesh. Maybe it is more like a network than a hierarchy? Some felt that plans were proposed at the local level, while others felt centralized planners dictated.

Training

The type of training necessary depends on the type of user. Different levels of training would be needed according to the level and purpose of the user. The analogy was drawn to the concept of mechanic, driver and passenger of a vehicle:a mechanic needed to know how a car worked;a driver needed to know what the car could do and the passenger determined where the car was to go.

Sustainability

What happens to the FMM when FAP25 ends? The demand for the FMM must be driven by the user. Regular contacts will be maintained with potential users from the working group to clarify some of the issues and concerns identified during the meeting.

Software and Hardware

Simplified GIS software on PC to manage the likely scenario at site would be needed.

Institution

There are a few institutions as BWDB(FF&WC), SWMC with the potential to take over and develop FMM on completion of FAP 25. These may be reviewed during the development of FMM and based upon the outcome of FAP 26(if any), the final recommendation can be made.

5.4.2 *Second Workshop*

Objectives

The second Workshop is planned to be conducted during 13-14 November 1993. The objectives of the second Workshop are to:

- Present the FMM Interim Report -I and obtain feedback;
- Present the FMM Development for flood mapping from river and flood plain modelling;
- Provide an opportunity for dialogue between the modellers, model users, decision makers and individuals affiliated to governmental, non-govermental and research institutions on the sustainability and institutional aspects of FMM.

Programme for the Second workshop

13 November 1993 :(Saturday)

08:30	- Registration
09:00 - 09:55	- Opening Ceremony
09:55 - 10:25	- Coffee break
10:25 - 11:30	- **Session I:** Presentation of FMM - Introduction to the Project - The Overall Approach - Concepts and Modules of FMM - Editors and Branch Route System - Topographic Data Module
11:30 - 13:00	- Discussion, Coffee and Computer Demonstration
13:00 - 14:00	- Lunch
14:00 - 15:00	- **Session II:** Presentation of FMM: **Flood Mapping** - Surface Generation - Analysis and Display
15:00 - 16:00	- Discussion and Computer Demonstration

14 November 1993 (Sunday)

09:00 - 09:20	- Land Classification & Flood Mapping in Atrai Basin
09:20 - 09:40	- MIKE11-NAM Dynamic Interface
09:40 - 10:00	- Briefing on Interim Report, - Formation of Working Groups
10:00 - 13:00	- Working Group Meetings Computer Demonstration Review of FMM Interim Report
13:00 - 14:30	- Lunch
14:00 - 14:30	- Institutional Issues of FMM
14:30 - 16:00	- **Final Session** Panel Discussion and Recommendations. Closing.

Participants

As for the First Workshop, participants from various organisations such as MIWD&FC, SPARRSO, BMD, LGED, RHD, DOE, BARC, DAE, IFCDR, RRI, WARPO, SWMC, BWDB, FPCO, POE/FPCO, CAT members, FAP consultants, NGO Representatives and FAP 25 officials are expected to join the Second Workshop. This will help to develop a future FMM user group for further development and maintenance of FMM.

6. CONCLUDING REMARKS

6.1 Observations

The MIKE11-GIS software developed as an integral part of FMM has a potential application in Flood Management in Bangladesh. Not only will FMM facilitate examination of a wider range of alternative structural and non-structural flood management options than would be possible using standard methods, but it also will form a basis for real time inundation forecasting and warning at various levels.

Stage 1 of the project is largely complete. The development tools have been successfully formulated and are now ready for rigorous testing in the application environment. It is expected that there will be significant feed-back from the application developers which will necessitate some changes to the work done in Stage 1. However, these changes should be limited to improving the user interface, rather than major code revisions.

During the Development Stage it became even more clear that the project was developing a basic product that would have significant impact on a wide spectrum of sectoral interests. Ad-hoc, informal discussions with other sectoral specialists taking part in studies related to all aspects of water management, watershed management or environmental aspects, have illustrated the potential of FMM. It is of utmost importance that the benefits of FMM be realised by as wide a range of potential users as possible, either in the form which will result from this project, or in sectoral-specific variants to be developed later.

6.2 Future Activities

Future efforts of the project will be focussed on fulfilling the TOR requirements during the Stage 2 - Application and Demonstration Phase. The activities include development of three bespoke flood management models to be applied to the national, regional and compartmental levels. The activities related to knowledge transfer through demonstrations, and on-the-job trainings will continue. Recommendations for future training requirements and training materials will be prepared.

As mentioned in Section 3.1, further development of the MIKE11-GIS will continue based upon user feedback and on the outcome of the Second Workshop.

In addition to the above, the future activities for the remainder of the project will include the following:-

- **Development of guidelines for the on-line operation of FCD structures.** This will be based on compilation of historical simulation results to generate a long-term operational policy with a provision for "switching" to a short-term operation rule using a real-time forecast of flooding and its impacts.

- **Application of MIKE11-GIS flood mapping in impact assessment.** This activity will demonstrate the use of FMM as a spacial decision support tool, (SDSS), which will integrate the spacial outputs, (flood mapping), from MIKE11-GIS into a multiple criteria-oriented DSS. Recommendations will be made on data and modelling requirements for quantitative impact assessments needed for project appraisal.

u 8

- **Institutionalisation of FMM.** Recommendations will be drawn up on the possible future institutional responsibilities associated with the operation, maintenance and further development of FMM.

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APPENDICES

Work Progress & Activity Schedule

DATE ==> 30/ 09/ 93

EXPATRIATE STAFF INPUT

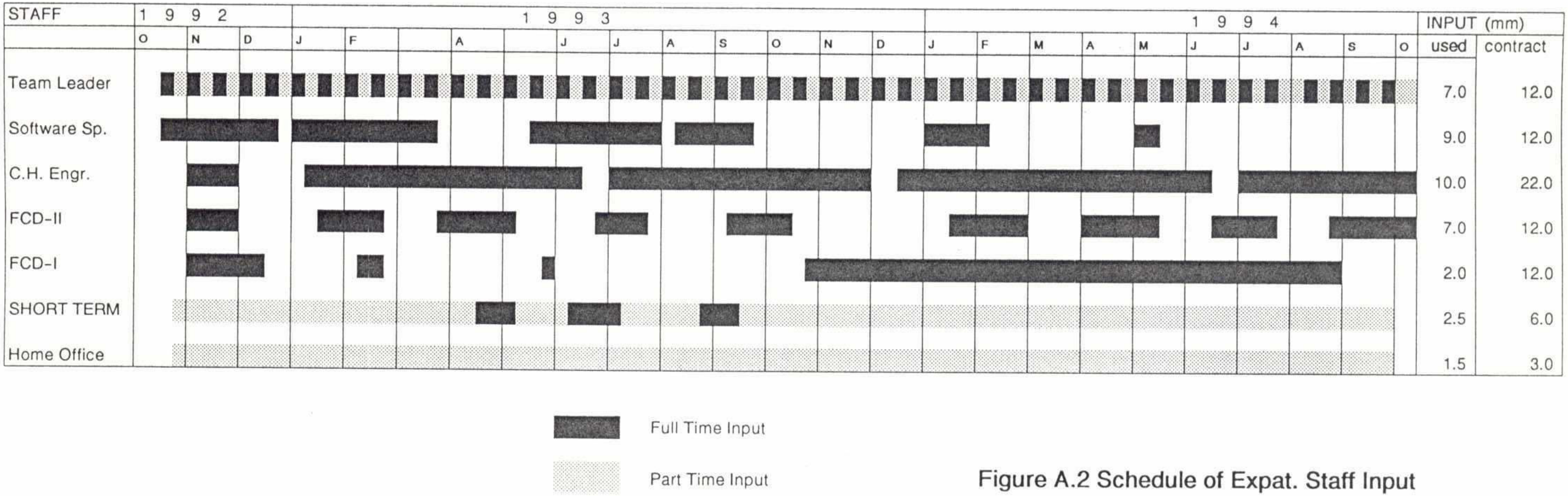

Figure A.2 Schedule of Expat. Staff Input

DATE ==> 30/ 09/ 93

LOCAL STAFF INPUT

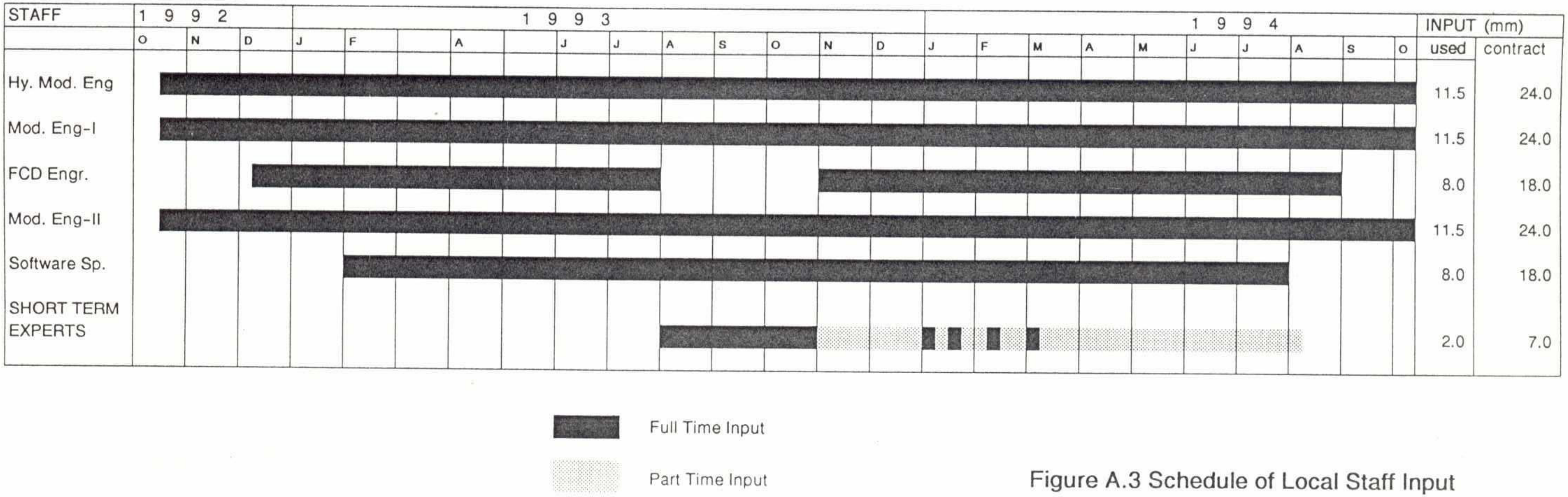

Figure A.3 Schedule of Local Staff Input

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Appendix B Survey Data

B1 Topographic Survey in the North Central Region

B1.1 Work Description

Background

The North Central Regional Model needs considerable restructuring in certain areas so as to realistically represent the hydraulic connection between the river channel and flood plain to meet the requirements of Flood Management Model. Representation of hydraulic connection of the conveyance channel and the flood plain storage cell is a key element in modelling flood flows in certain areas of the north central region. Quasi 2 dimensional modelling was considered appropriate and a limited programme of embankment survey was undertaken to those rivers having significant influence on the regional hydraulic behaviour. The survey work concentrated on establishing the locations of water interchange between river and flood cell.

The embankment survey programme was accomplished by SWMC as per request of FAP 25. SWMC carried out the survey work by its survey personnel and the responsibility was given to NCRM group to organise and supervise the survey work. The assignment was performed by two survey groups having one surveyor and one assistant surveyor each. Joint field monitoring of embankment survey work was done as per schedule. Following are the brief of survey activities.

Survey Programme - I

Area Surveyed: Embankment survey along both banks of the rivers Futikjani (partly), Bangshi and Dhaleswari (partly).

Duration: March 14 to June 19, 1993 (84 working days)

Distance: Total distance covered 277 km.

The survey work started on 14th March, 1993, with carrying of BM from FINNMAP BM No. 5803 in front of Chamraria Free Primary School at Kalihati. A total of 277 km were covered on both the banks of Futikjani, Bangshi and Dhaleswari river from Charan, Kalihati to Dhalikandi (Kalatia) Keraniganj. The work was suffered several times due to heavy rainfall. Representative ground levels on the embankment or on natural levee along both banks of the river were taken at around 200 m interval. Three representative spot levels at 30 m interval were taken laterally to the country side flood plain at an interval of around 1 km along the bank survey. The survey party took cross-sections of a number intersecting channels across the survey route. The work has been completed in June 19, 1993.

Hydraulic Structures

The party noted down information on hydraulic structures during the survey work. However, they could not collect information on many structures as they were under water during the survey. The information are listed in Table B.1.1

Table B.1.1 Information on Hydraulic Structures.

Sl.No	Location	Size of vent	Sill level	No. of vent	Connecting River
1.	Charan R/B	1.56x1.22m	6.376 m	1	Futikjani
2.	Salim Nagar L/B	...	...	2	Bangshi
3.	Bullah's Khal L/B	Fully upset	..		Bangshi

Cross-sections on Bangshi River

The party surveyed three river cross-section on Bangshi river. The cross-sections would be used in NCR FMM. The location of cross-sections surveyed are given in Table B.1.2.

Table B.1.2 Location of the Cross-sections Surveyed on Bangshi River.

Sl.No.	River/Canal	Location	Remarks
1.	Bangshi	Boalia, P.S.Kaliakoir, BH1 # 22R.	200 m d/s from Kalimajang & Bangshi confluence.
2.	Bangshi	Gohalbari,P.S.Savar BH1 # 23R	
2.	Bangshi	Nalam, P.S. Savar Cross-section No.BH1 # 24R	

Cross-sections of intersecting channels across the Survey Route

The party also surveyed cross-sections of canals and rivers that falls into the river surveyed. The party found 23 nos. of intersecting channels on the left bank of the river Bangshi from Ratanganj to Dhalikandi, P.S. Keraniganj. The width and the bottom level of the channels are given in Table B.1.3. The party surveyed 3 intersecting channels on the right bank of the river Futikjani from Charan, P.S. Kalihati to Ratanganj Bazar and 25 intersecting channels on the right bank of the river Bangshi from Ratanganj bazar to Dhalikandi, P.S. Keraniganj. The width and the bottom level of the channels are given in Table 4.4 and 4.5 respectively.

Table B.1.3 Width and Bottom Level of Channels on Left Bank of Bangshi

Sl.No.	Name of Intersecting Channels	Width (Metre)	RL.of deepest point(mPWD)	Chainage from Charan (km)
1.	Bangshi river	90	3.44	7.285
2.	Toonkigang	60	4.566	11.331
3.	Khal	56	6.25	17.623
4.	Khal	40	6.25	20.803
5(a).	Khal	40	6.06	32.784
5(b)	Khal	80	6.14	40.092
6.	Khal	160	5.03	43.302
7.	Khal	20	6.18	49.943
8.	Khal	20	5.65	50.716
9.	Kamailarjore at Patharghata	47	0.81	55.716
10.	Pathakhaligang	110	(-)2.392	63.853
11(a).	Bhullah's khal	73	2.85	73.945
11(b)	Khal	30	3.09	80.687
11(c)	Khal	33	2.95	82.509
12.	Turag river	112	(-)1.127	85.007
13.	Khal	17	2.101	93.459
14.	Gang	190	2.101	97.024
15.	Dallai Bill	195	3.698	103.375
16.	Khal	30	1.09	105.991
17.	Khal	35	0.58	118.142
18.	Khal	85	1.65	123.752
19.	Karnatali khal	137	(-)1.11	124.164
20.	Santirbazar to Boilapur river.	290	(-)0.91	135.107

Table B.1.4 Width and Bottom Level of Channels on Right Bank of Futikjani

Sl.No	Name of Intersecting Channels	Width (Meter)	Rl. of Bottom point (m PWD)	Chainage from Charan (km)
1.	Charan Khal(East para)	30	9.72	0.174
2.	Langulia Gang at Ballah	48	6.30	2.704
3.	Maragangy (Haora river) at Gonabari, Kalihati	42	7.10	4.435

Table B.1.5 Width and Bottom Level of Channels on Right Bank of Bangshi

Sl.No	Name of Intersecting Channels	Width (Meter)	Rl. of Bottom point (m PWD)	Chainage from Charan (km)
1.	Dafadarbari Khal at Jorebari,Kalihati	20	7.37	7.545
2.	Darbarshi Khal at Dulshimul,Kalihati	20	5.88	9.312
3.	Johang river	80	8.32	11.038
4.	Langlai south	196	4.44	12.953
5.	Bangrar Khal south site of Sunnah Bazar.	50	4.97	25.056
6.	Khal	18	5.92	38.496
7.	Mirikpur Khal	66	-0.12	39.144
8.	Khal	25	5.49	42.300
9.	Khal	61	3.95	46.925
10.	Old Bangshi	117	2.17	57.213
11.	Pungli river at Chak Laskar, Mirzapur	95	2.92	62.735
12.	Khal at Mirzapur	120	5.78	65.143
13.	Talipara Khal, P.S.Mirzapur	56	3.06	68.519
14.	Kodalia Khal, Mirzapur	95	3.14	71.017
15.	Khal	58	2.53	78.791
16.	Khal	45	2.41	80.412

17.	X-section BH1 # 21 R at Kaliakoir	72	2.88	82.714
18.	Khal	185	2.25	91.104
19.	Dhantara Khal(Low land area)	120	0.98	95.079
20.	Khal (Low land area)	160	1.99	96.404
21.	Khal (Low land area)	117	1.85	99.953
22.	Kaklajani River	182	0.11	105.520
23.	Gazikhali River	195	-0.89	115.976
24.	Dhaleswari River (1)	203	0.73	116.599
25.	Dhaleswari River (2)	82	1.02	117.691

BM/TBM Connection for Checking

The survey party cross checked five BWDB gauge TBM and seven FINNMAP BM values during their embankment survey to verify the accuracy of the survey. The findings are given in Table B.1.6.

Table B.1.6 BWDB TBM, FINNMAP BM & the Survey Values

Location	Type of TBM/BM	TBM/BM values in m PWD	Survey values in m PWD	Difference in m
Kawaljani	BWDB Gauge TBM FINNMAP BM 6105	11.390 11.836	10.947 11.820	+ 0.443 + 0.016
Mirzapur	BWDB Gauge TBM FINNMAP BM 6112	10.690 11.065	10.895 11.101	- 0.205 - 0.036
Kaliakoir	BWDB Gauge TBM FINNMAP BM 7912	8.990 9.901	8.954 9.926	+ 0.036 - 0.025
Nayerhat	BWDB Gauge TBM	9.543	9.214	+ 0.329
Savar	BWDB Gauge TBM FINNMAP BM 6313 FINNMAP BM 6312	8.358 7.981 7.699	8.037 8.041 7.749	+ 0.321 - 0.060 - 0.050
Keraniganj	FINNMAP BM 6309 FINNMAP BM 6308	6.923 6.985	6.915 6.883	+ 0.008 + 0.102

Survey Programme - II

Area Surveyed: Embankment survey along both bank of the rivers Turag, Tongi khal (partly), and Buriganga.

Duration: April 10 to May 28, 1993 (42 Working days).

Distance : Total distance covered 129 km.

The survey started on 10th April, 1993, with carrying of BM from FINNMAP BM No. 7912 at Kaliakoir. It covered 48 kilometers on both the banks of Turag river from Kaliakoir to Asulia. The survey party could not proceed with the work on the right bank of the river Turag after Asulia as the area was submerged and need to abandon 3 kms from chainage 48 to 51 km. The survey party continued work on the Greater Dhaka City Flood Protection Embankment from Tongi Highway Bridge to Keller More in Dhaka.

The survey work disrupted frequently due to heavy rainfall and early monsoon flooding. The field condition did not allow always to follow strictly the work guidelines. Finally, the work was completed on 28th May, 1993.

Hydraulic structures

The party found some hydraulic structures during the survey work and noted down the ventage of regulator, but could not take the size of vents and sill levels since they were partly under water. The informations are listed in Table B.1.7.

Table B.1.7 Informations on Hydraulic Structures.

Sl.No.	Location	No. of Vents	Connecting River
1.	Tyebpur R/B	3	Turag
2.	Rustampur R/B	2	Tongi Khal
3.	Tongi R/B	2	Tongi Khal
4.	Near Botanical Garden L/B	8	Turag
5.	Diabari L/B	1	Turag
6.	Kallyanpur L/B	4	Turag
7.	Rayer bazar L/B	2	Turag
8.	Nawabgonj L/B	1	Turag
9.	Nawabgonj L/B	2	Turag

Cross-sections on Tongi Khal & Turag River

The party took two cross-sections on Turag river and one on Tongi khal. These cross-sections would be used in NCR FMM. Locations of the cross sections are shown in Table B.1.8.

Table B.1.8 Cross-sections Surveyed on Tongi Khal and Turag River

Sl.No.	River	Location	Remarks
1.	Tongi Khal	Nayanchala (ATT4)	
2.	Turag	Rustampur	100 m d/s to Turag-Tongi Khal confluence
3.	Turag	Gabtali	100 m d/s to Mirpur Bridge.

Cross-sections on Intersecting Channels along the Survey Route

The party surveyed some cross-sections on different rivres and channels those fall into the river surveyed. On the way of their survey route the party found eight intersecting channels on left bank of the river Turag from Kaliakoir to Asulia bazar. Informations on those cross-section are listed in Table B.1.9

Table B.1.9 Width and bottom level of channels on left bank of Turag

Sl.No.	Name of Intersecting Channels	Width (meter)	RL of Deepest point (m PWD)	Chainage from Kaliakoir (km)
1.	Niknakhali Khal	22	2.486	6.200
2.	Narakhali Khal	30	2.083	11.170
3.	Goallar Khal	25	1.918	11.770
4.	Saldah Nadi(1)	25	1.098	15.000
5.	Saldah Nadi(2)	26	1.201	15.500
6.	Nynni Khal	30	2.678	16.950
7.	Kata Khal	38	1.543	18.410
8.	Kata Khal	18	1.087	25.900

Table B.1.10 Additional Hydrometric Stations in NCR

Station Number	Station Name	River	Station Number	Station Name	River
1 (Q)	Belamari	Kalu Mondal Daha	21	Baniapara	Dahitoka
2 (Q)	Char Atiapara	Datbhanga	22 (Q)	Ganjana	Bangshi
3	Dhaluabari	Lohajong	23 (Q)	Pach charan	Jhenai
4	Hat Gobindah	Nangla Khal	24	Ratangonj	Jhenai
5 (Q)	Gobindapur	Nangla Khal	25 (Q)	Nakasim	Nangila
6 (Q)	Poyla Bridge	Madar Daha	26 (Q)	Patharghata	Bangshi
7	Khashimara	Madar Daha	27 (Q)	Latifpur	Bangshi
8 (Q)	Islampur	Old Brahmaputra	28 (Q)	Kalampur	Bangshi
9 (Q)	Delirpar	Dali	29	Mallabari	Bangshi
10 (Q)	Madhyachar	Bhabki Khal	30	Kaitkai	Bangshi
11	Hazipur	Jhenai	31 (Q)	Teki chandpur	Barinda
12 (Q)	Benjail Rampur	Chatal/Jhenai	32	Dhantara	Dhantara
13 (Q)	Jhalopara	Branch of Jamuna	33	Saforta	Warshi
14	Digpaith	Bangshi	34	Gopalpur	Bairan
15	Rashidpur	Kairar Khal	35	Kuturia	Sapa
16	Rubshanti	Kuchiamara	36 (Q)	Pungli Bridge	Pungli
17 (Q)	Koyra	Jhenai	37	Bill palima	Borni
18	Bhengula	Jhenai	38	Kalihati	Jhenai
19	Dhopa Kandi	Katakhali Khal	39	Nolsafa	Jhenai/Lohajang
20 (Q)	Belua	Jhenai	40 (Q)	Mitara Bridge	Mitara Khal

Note: (Q) indicates location of discharge measurement

Source: North Central Region Feasibility Studies - Preparatory Studies

B2 Flood Plain water Level Data

Work Description and Area Coverage.

Hydrological data are collected by BWDB on the important water courses and MIKE 11 models of SWMC are based on this data and represent the flood plain equally to the nearest h point of the river in the model. This representation, though approximate, is considered suitable for planning since the hydrodynamic modelling of the flood plain is complicated, time consuming and simulation would be difficult for want of observed data. FMM has the mandate to look more closely in the modelling of flood plain and with that understanding capturing of water level data in a sample area of North Central region got priority. The Inception Report of Flood Management Model therefore proposed for monsoon data collection (water level) in the flood plain on a priority area under the North Central region (Ref. 1). The purpose of this data collection would be to verify the FMM output with the observed data for subsequent improvement of FMM.

A total of 12 water level gauges were installed, 5 along the Dhaka-Aricha road, 4 along the Dhaka-Tangail road, 1 on Savar-Kaliakair road and 2 along the Dhaka-Mawa road. The location of the gauges are shown in Figures 2.2 to 2.8. Local people, mainly school/college students living near the gauge stations were engaged on contract basis for the monsoon period (1st June to 31st October, 1993) to record water level data twice a day (0900 and 1800 hours) on a format supplied by FAP 25. They also record qualitative intensity (in terms of High, Low or Medium) and duration of local rainfall on the same format. A preliminary training was offfered to the gauge readers by the project staff on how to read and record data on a prescribed format.

Bench Mark Connection and Monitoring of Data Collection.

Bench Mark connection to the gauge was made from the nearby FINNMAP B.M. except for 2 gauges along the Dhaka-Mawa road. These were connected from the BWDB B.M. at Mawa. Adjustment to elevation of the FINNMAP is made according to

PWD datum = GTS (FINNMAP) + 0.46 m

Therefore, the zero value of the gauges connected from FINNMAP B.M. were increased by 0.46 m. List of water level gauges and the reference B.M. is given in Table 2.3.10. In case of shifting of gauges, reading from both the gauges were recorded simultaneously for a few days. In addition survey was carried out to recheck the B.M. connection after gauge shifting and very little differences were observed from the earlier value. However, results from the second survey (recheck) were finally adopted.

In order to obtain reliable and quality data, emphasis was given to proper and frequent monitoring of data collection. The gauge locations were selected along the main highway so that regular monitoring of data collection could be done. Project staffs make a routine visit to the gauges to monitor the data collection and to solve problem, if any, on the spot.

Table B2.1 Information on Flood Plain Water Level Gauges

Area Coverage	ID No. of Gauges	Name of Place	FINNMAP B.M. No.	Elevation
Dhaka-Tangail road	FMM-01	Kurni	FM-7907	9.8251
	FMM-02A	Sohagpur	FM-7909	9.6103
	FMM-02B	Sohagpur	FM-7909	9.6103
	FMM-03	Sutrapur	FM-7911	10.8706
Savar-Kaliakoir road	FMM-04	Sripur	FM-8139	9.2095
Dhaka-Aricha road	FMM-05	Dhulivita	FM-8136	7.0476
	FMM-06	Srirampur	FM-8133	7.6607
	FMM-07	Krishnapara	FM-8131	7.8534
	FMM-08	Bhatbaur	FM-8128	7.5359
	FMM-09	Uthali	FM-6230	9.1212
Dhaka-Mawa road	FMM-10	Kuchiamora	BWDB-Mawa	
	FMM-11	Srinagar	BWDB-Mawa	

Data Plots and Analysis

Sample plots of water level hydrograph on the flood plain data captured in the FMM gauges are shown in Figures B2.a-d. In general, the hydrographs are similar in shape in the flood period i.e. they maintain similar trend. However, in the early monsoon (in this case up to about the third week of June) the features of hydrographs are not uniform. These may be explained as follows:

- In the monsoon, links among the channels, major rivers and flood plains are established. The channel slopes in the flood plain being very gentle, most of the links are established simultaneously. One can therefore conclude that the gauges are all installed in a single basin though at different locations;

- The rise and fall of the flood plain hydrographs match very nicely with that of major rivers/channels;

- Before the establishment of any connection with the channels, the water level gauges are independent and depend on the local rainfall or independent sources;

- The fluctuations in the hydrograph are sharp in the flood plain over the major rivers due to the influence of local rainfall;

- Gauge 2A and 2B are located on two sides of the same road at one site. The hydrographs have separation and rejoining (see Figure B2.b). A clear explanation could not be developed as yet except 2A is located at the downstream and 2B is near the river;

- The rate of rise and fall of water ranges from 0.02 - 0.05 m/day with the highest in one day by about 0.36 m. As such, gauging twice a day in the flood plain appears sufficient to represent the flooding.

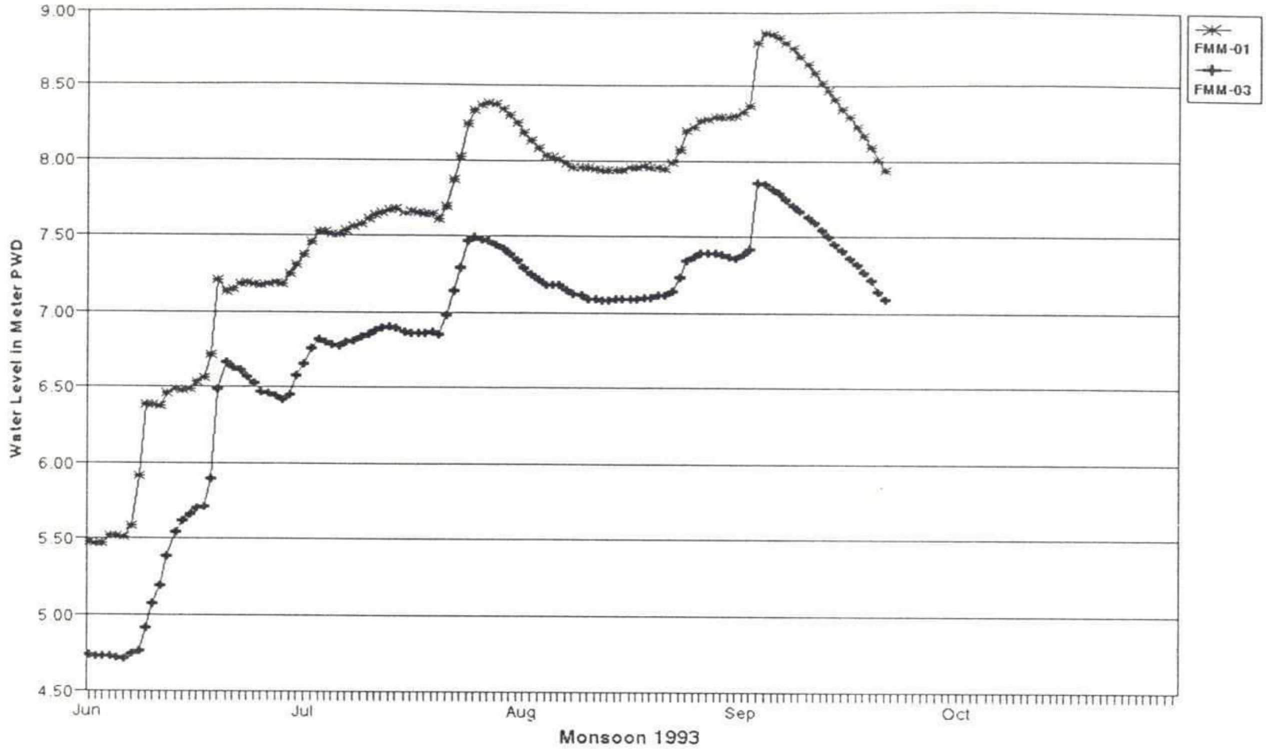

Figure B.2a : Water Level Hydrographs for the Gauges on Tangail Road

Which side of the road?

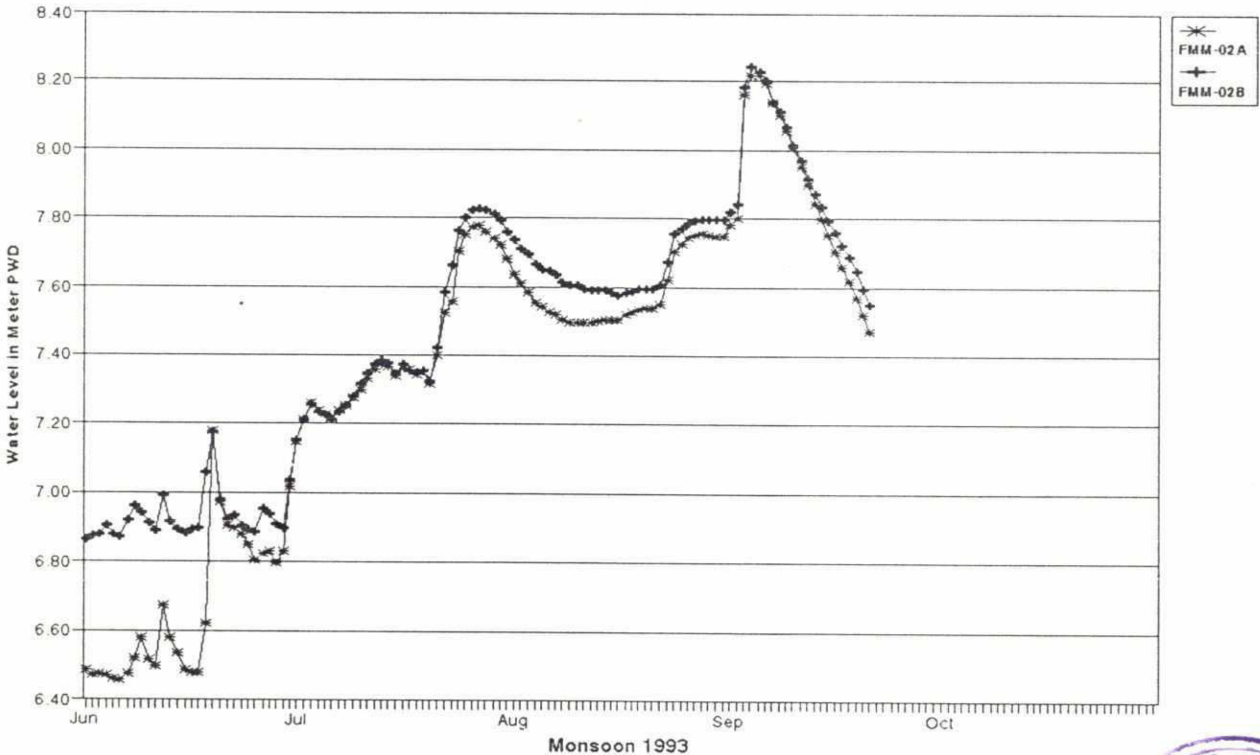

Figure B.2b : Water Level Hydrographs for the Gauges on Tangail Road

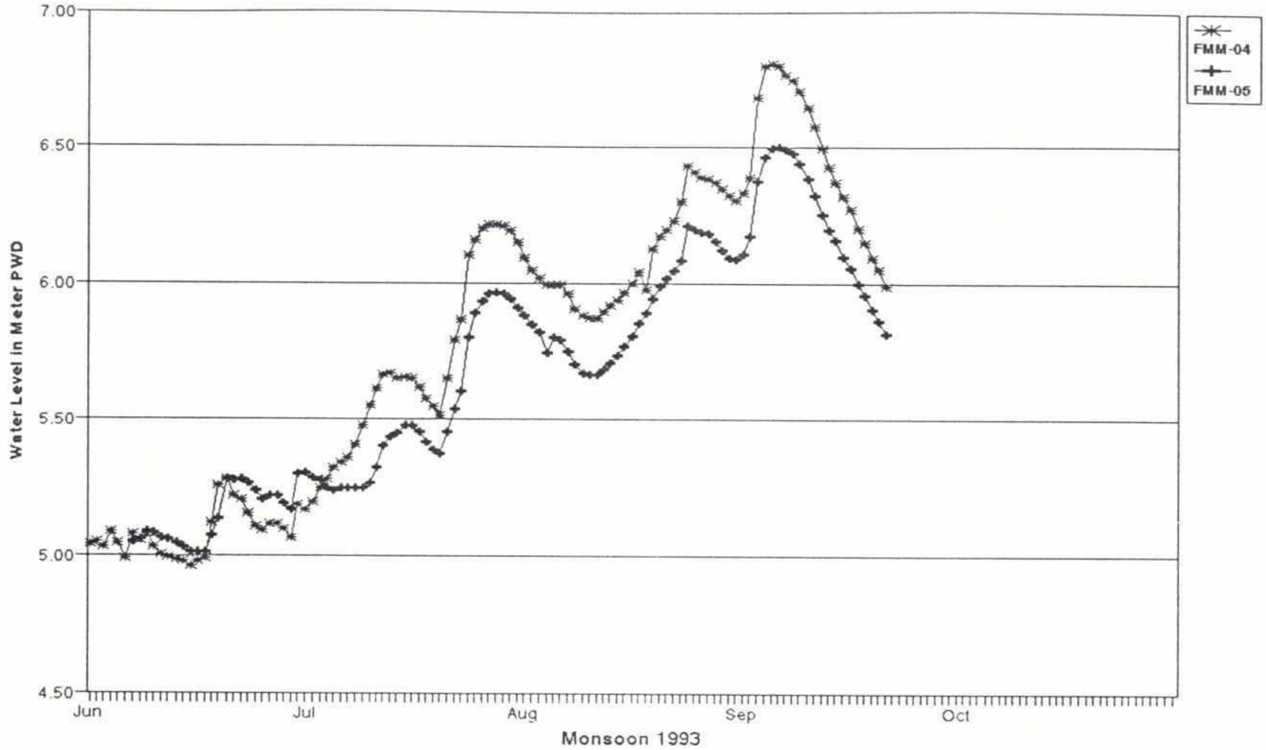

Figure B.2c : Water Level Hydrographs for the Gauges on Savar-Kaliakoir Road

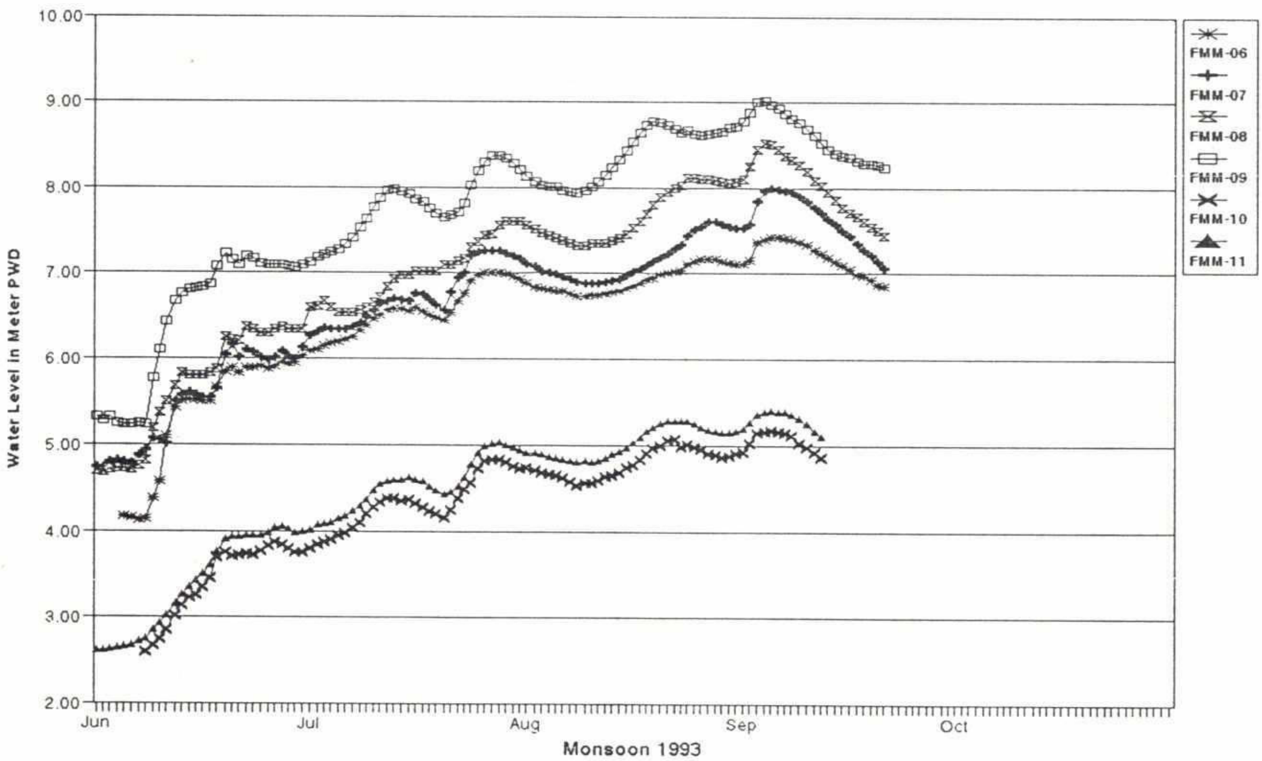

Figure B.2d : Water Level Hydrographs for the Gauges on Aricha and Mawa Road b6

B3 Data on CPP

Table B3.1 CPP Discharge measurement locations 1993

No.	River/Khal	Location
1	Gala Khal	N. of Rasulpur (gauge station G28)
2	Lohajang River	Dithpur (gauge station G36)
3	Lohajang River	Deojan (gauge station G5)
4	Lohajang River	Karatia (gauge station G8)
5	Gaziabari Khal	Santosh (gauge station G22)

Table B3.2 CPP Groundwater level stations

No.	Name	Data Collected
TA03	Fatehpur	1987-92
TA08	Panchelachine	1987-92
TA09	Aditangail	1987-92
TA35	Akurtakur	1987-92
TA39	Suruj	1987-92

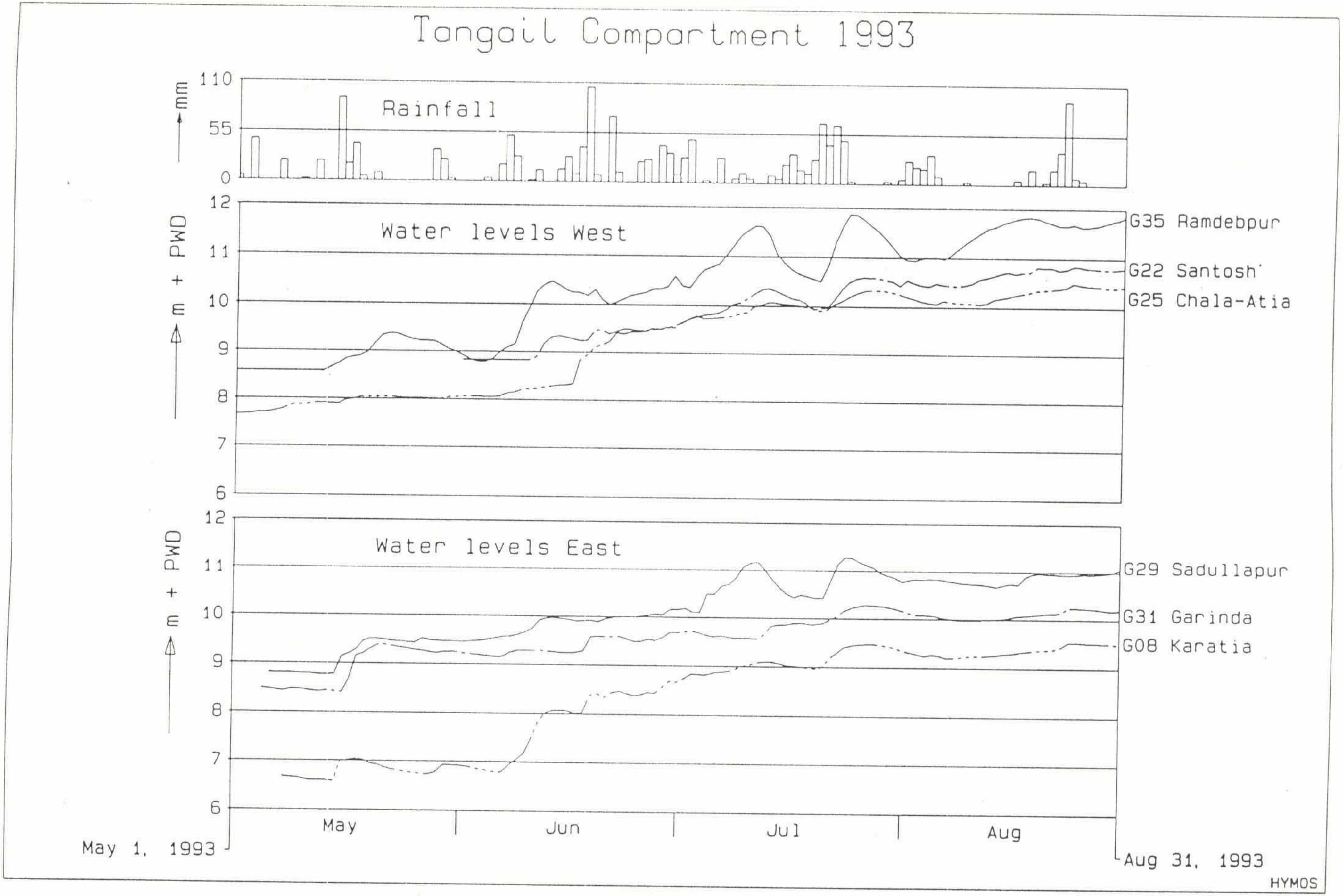

Figure B.3 CPP Rainfall and WL Data (1993)

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Appendix C Flood Hydrology Study Update

C1 Background

Flood Hydrology Study (FHS) under FAP 25 has provided the hydrological basis for engineering design criteria and to assess the effects of alternative flood protection scenarios on water levels and flow distribution along the major rivers (Ref. FHS Report). It has been achieved by 25 years simulation (1965-89) of the General Model developed by SWMC. This basis is not unique and is subject to change with the improvement of the model performance. Therefore, a concept of safety margin was introduced to take into account the effects of random morphological processes, model errors and shortness of records. The margin would therefore be reduced on improvement of model errors. As such it is stated in FHS Annex -2 "It is proposed that the next updating of hydrological design criteria along the major rivers be undertaken in early 1993 following the SWMC update of the GM"

C2 Updating of GM at SWMC

SWMC updates the General Model on a regular basis and verifies with the latest available hydrological data. The FHS was based upon the verified model of SWMC in 1992. The GM of SWMC has carried out a major updating recently and the model has been made available to FAP 25 in August 1993. The updated GM has taken into consideration the improvements made in the regional models such as incorporation of recent cross sections, GPS verified gauge locations etc.

The following modifications are also made in the latest update;

- datum at Daulatkhan i,e.+0.116m correction has been applied to the observed mean daily water levels;
- new cross sections at Lower Meghna;
- GPS of the gauge stations;
- improved boundary discharge from FAP 24 (Discharges are different from BWDB at higher stages in 1988 and onwards).

1993 survey shows no major ?? difference which needs to look back into the previous FAP-24 & BWDB data.

The model has been verified for the period of 1986-92.

C3 Review of the updated GM of SWMC

The updated GM has been re-run in the Unix workstation of FAP 25 for the flood period (May to October) during 1986-1992. The results were compared and no errors were observed during model transferring process.

An effort was made to compare the performance of the previous model (Run 6) and the updated GM results for the peak water levels during the period of 1986-89. The results are shown in the Table C.1 and Figures C.1 to C.4. The general performance was viewed upto 1992.

From the review it is seen that the updated GM has shown improvement in peak water levels for most of the stations for the year 1986 and 1987. The results of 1988 has significantly deteriorated and shown a poor match between the observed and simulated water levels (Figures C.1 to C.4). In 1989, no significant improvement has been noticed rather poor performance is observed in Chilmari and Porabari in the Jamuna, Sengram in the Ganges, Gorai Railway Bridge in the Gorai, Taraghat in the Kaliganga and Demra in the Lakhya. The overall performance from 1989 onwards are discouraging.

In most of the stations, overall performance of the updated GM is not much improved compared to Run 6. Few stations have recorded clearly a biased result.

C4 *Discussion*

While looking for improvement achieved under the updated General Model, search was made with SWMC's ongoing reports. Nothing could be unearthed except comments on the general improvement. SWMC prefers to present the result on time series plots without any statistical analysis or any comparison with the previous GM. The comparison made by FAP 25 with the previous model does not seem to provide a positive justification on the improvement it has made. One important feature of the present model is that it has provided poor performance in most of the locations after 1988. Therefore, the following comments can be made:

- the updated GM has incorporated much changes over the previous model in adding lot of new cross sections, using new GPS location and changing roughness parameter and thus need a recalibration of the model;

- due to the major changes, the basis of comparison with the previous model has been lost;

- due to marginal changes in the simulation results of the updated GM it is recommended not to carry out another 25 years run. Hence, the hydrological analysis presented by FAP 25 based on the Run 6 should be maintained for the time being.

Table C.1 : Comparison Between FHS Run6 & Updated GM Results

Rivers	Stations	1986					1987					1988					1989				
		Obs	Run6	Up	R6	Up	Obs	Run6	Up	R6	Up	Obs	Run6	Up	R6	Up	Obs	Run6	Up	R6	Up
Jamuna	Chilmari	23.44	22.97	23.37	-0.47	-0.07	24.69	24.13	24.45	-0.56	-0.24	25.04	25.03	25.04	-0.01	0.00	23.58	23.86	24.22	0.28	0.64
	Bahadurabad	19.15	18.75	18.87	-0.40	-0.28	19.68	20.08	20.06	0.40	0.38	20.61	20.84	20.70	0.23	0.09	19.57	19.84	19.77	0.27	0.20
	Kazipur	15.39	14.86	15.08	-0.53	-0.31	16.18	15.98	16.06	-0.20	-0.12	16.76	16.77	16.68	0.01	-0.08	15.54	15.70	15.74	0.16	0.20
	Serajganj	13.66	13.39	13.39	-0.27	-0.27	14.57	14.56	14.44	-0.01	-0.13	15.11	15.30	15.03	0.19	-0.08	13.65	14.26	14.12	0.61	0.47
	Porabari	11.90	11.35	11.57	-0.55	-0.33	12.88	12.42	12.68	-0.46	-0.20	13.14	13.16	13.23	0.02	0.09	11.53	12.06	12.19	0.53	0.66
	Mathura	9.70	9.30	9.58	-0.40	-0.12	10.88	10.24	11.02	-0.64	0.14	11.35	10.91	11.52	-0.44	0.17	9.71	9.54	9.84	-0.17	0.13
Ganges	Hardinge Br.	14.11	14.17	14.55	0.06	0.44	14.79	15.00	14.98	0.21	0.19	14.87	15.08	15.10	0.21	0.23	13.26	13.18	13.23	-0.08	-0.03
	Sengram	11.71	12.00	12.03	0.29	0.32	12.50	12.77	12.66	0.27	0.16	12.70	12.89	12.67	0.19	-0.03	10.79	11.16	10.74	0.37	-0.05
	Mahendrapur	10.23	10.72	10.74	0.49	0.51	11.29	11.33	11.35	0.04	0.06	11.59	11.53	11.39	-0.06	-0.20	10.09	10.03	9.68	-0.06	-0.41
Padma	Baruria	7.88	8.14	8.19	0.26	0.31	9.04	8.91	8.79	-0.13	-0.25	9.35	9.37	9.34	0.02	-0.01	7.74	7.97	7.93	0.23	0.19
	Mawa	5.76	5.72	5.95	-0.04	0.19			6.97			7.06	6.89	6.92	-0.17	-0.14	5.69	5.69	5.90	0.00	0.21
Meghna	Bhirab Bazar	5.67	6.04	5.82	0.37	0.15	6.90	6.85	6.82	-0.05	-0.08	7.65	7.50	7.78	-0.15	0.13	6.41	6.50	6.54	0.09	0.13
	Meghna FG	4.97	4.89	5.17	-0.08	0.20	5.98	5.71	6.27	-0.27	0.29	6.53	6.20	6.97	-0.33	0.44	5.14	5.21	5.54	0.07	0.40
	Chandpur	3.82	4.07	4.04	0.25	0.22	4.5	4.82	4.99	0.32	0.49	4.99	5.2	5.63	0.21	0.64	4.29	4.41	4.35	0.12	0.06
Gorai	Gorai RB	12.71	12.93	12.96	0.22	0.25	13.43	13.64	13.61	0.21	0.18	13.65	13.71	13.61	0.06	-0.04	11.86	11.89	11.35	0.03	-0.51
	Kamarkhali	8.82	9.16	9.30	0.34	0.48	9.26	9.90	9.81	0.64	0.55	9.47	10.00	9.79	0.53	0.32			8.10		
Arial Khan	Madaripur	4.04	4.52	4.44	0.48	0.40	5.17	5.39	5.55	0.22	0.38	5.59	5.83	6.04	0.24	0.45	4.20	4.62	4.44	0.42	0.24
Old Brah.	Jamalpur	15.96	15.78	15.56	-0.18	-0.40	17.20	16.93	17.00	-0.27	-0.20	17.81	17.64	17.37	-0.17	-0.44	16.28	16.68	16.62	0.40	0.34
	Nilukhirchar	11.36	11.49	10.57	0.13	-0.79	12.72	12.33	12.95	-0.39	0.23	13.70	13.17	13.95	-0.53	0.25	11.84	11.95	12.18	0.11	0.34
	Toke	7.38	8.53	7.05	1.15	-0.33	8.92	9.48	9.15	0.56	0.23	9.81	10.01	9.87	0.20	0.06			8.27		
Kaliganga	Taraghat	8.38	7.94	8.67	-0.44	0.29	9.70	9.23	9.71	-0.47	0.01	10.37	9.92	9.90	-0.45	-0.47	7.87	8.59	9.01	0.72	1.14
Lakhya	Demra	5.12	4.90	5.23	-0.22	0.11	6.38	5.95	6.50	-0.43	0.12	6.92	6.47	7.20	-0.45	0.28	5.32	5.38	5.73	0.06	0.41

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Figure C.1 : RUN6 VS UP-GM (1993)
YEAR : 1986

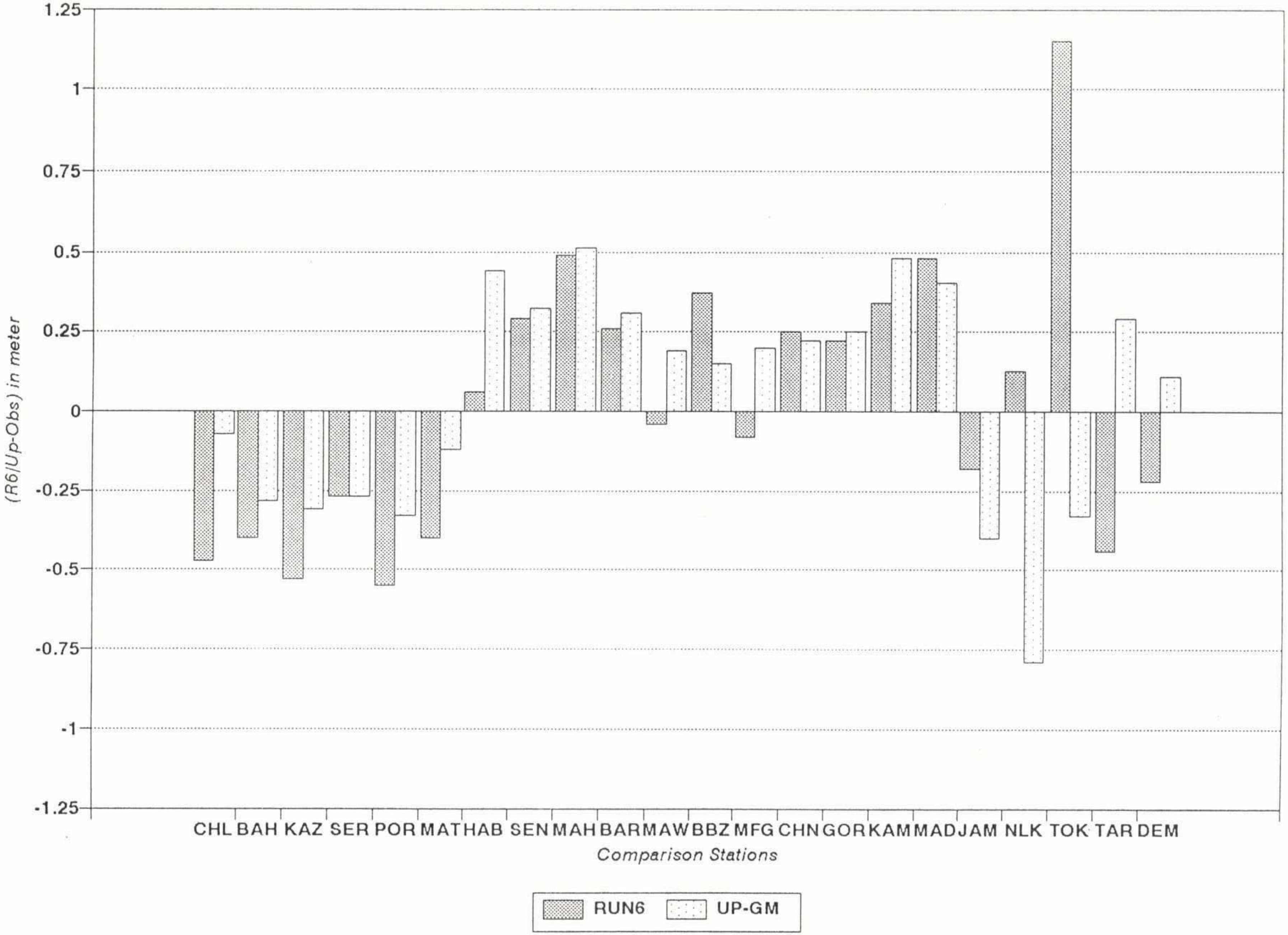

Figure C.2 : RUN6 VS UP-GM (1993)
YEAR : 1987

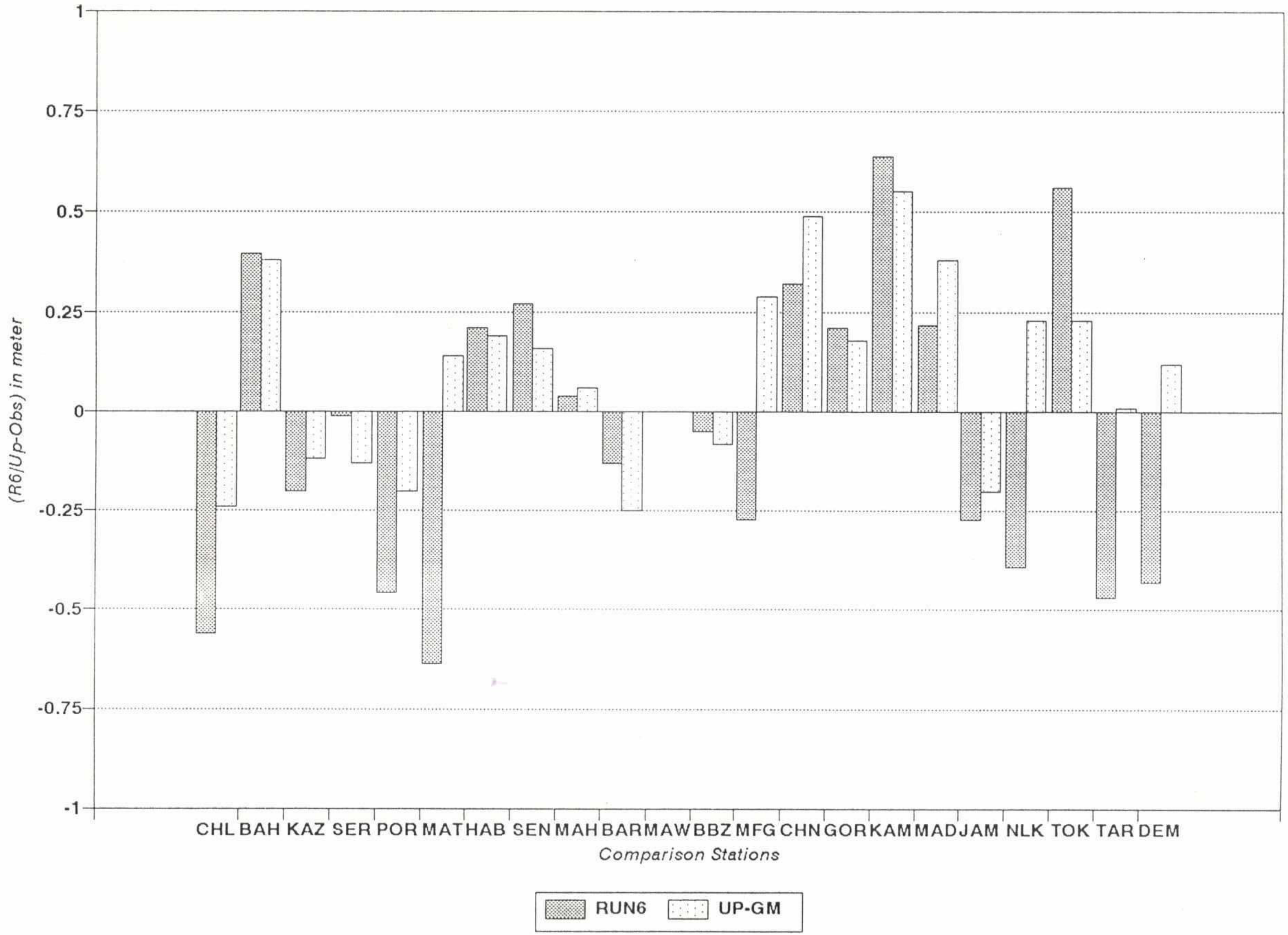

Figure C.3 : RUN6 VS UP-GM (1993)
YEAR : 1988

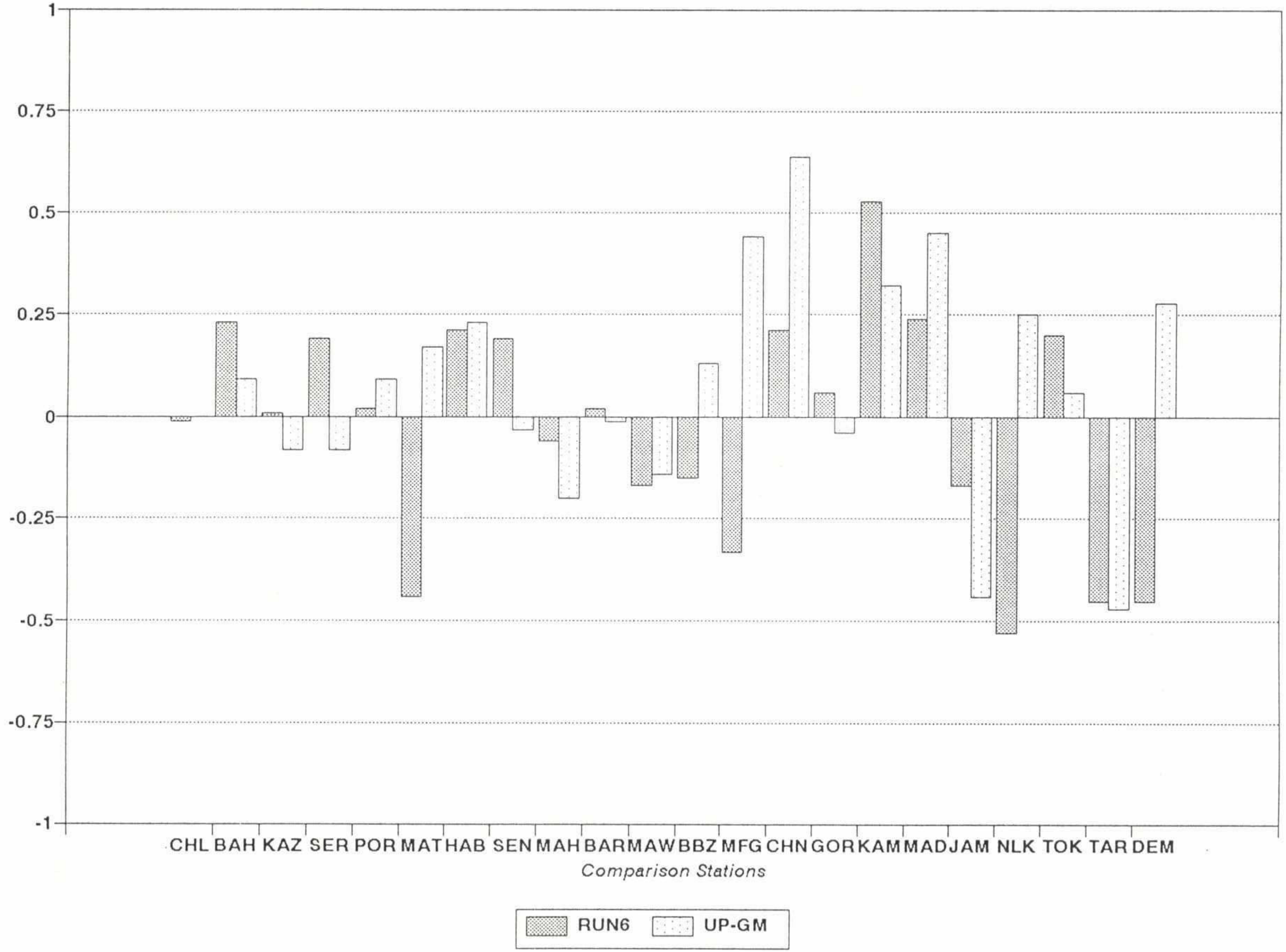

Figure C.4 : RUN6 VS UP-GM (1993)
YEAR : 1989