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

FLOOD ACTION PLAN

NORTHEAST REGIONAL WATER MANAGEMENT PROJECT (FAP 6)

NORTHEAST REGIONAL MODEL

FINAL REPORT
March 1995

SNC • LAVALIN International
Northwest Hydraulic Consultants

in association with

Engineering and Planning Consultants Ltd.
Bangladesh Engineering and Technological Services
Institute For Development Education and Action
Nature Conservation Movement

Canadian International Development Agency

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COVER PHOTO: A typical village in the deeply flooded area of the Northeast Region. The earthen village platform is constructed to keep the houses above water during the flood season which lasts for five to seven months of the year. The platform is threatened by erosion from wave action; bamboo fencing is used as bank protection but often proves ineffective. The single *hijal* tree in front of the village is a remnant of the past lowland forest that used to cover much of the region. The houses on the platform are squeezed together leaving no space for courtyards, gardens or livestock. Water surrounding the platform is used as a source of drinking water and for waste disposal from the hanging latrines. Life in these crowded villages can become very stressful especially for the women, because of the isolation during the flood season. The only form of transport from the village is by small country boats seen in the picture. The Northeast Regional Water Management Plan aims to improve the quality of life for these people.

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ACRONYMS AND ABBREVIATIONS

BARC	Bangladesh Agricultural Research Council
BWDB	Bangladesh Water Development Board
CIDA	Canadian International Development Agency
EIA	Environmental Impact Assessment
EVI, EVII, EVIII	Extreme Value Type I Distribution, Type II, Type III (subsets of the GEV)
FAP	Flood Action Plan
FNI	Future No Intervention (model scenario assuming Tipaimukh Dam is implemented unless suffixed with "NTD")
FPCO	Flood Plan Coordination Organization
GEV	General Extreme Value Distribution
HD	Hydro-dynamic
IEE	Initial Environmental Examination
JRC	Joint Rivers Commission
MPO	Master Planning Organization
NERP	Northeast Regional Water Management Planning Organization
NERP6.4, NERP7.7	model versions used for calibration and simulation of existing conditions
NHC	Northwest Hydraulic Consultants
NTD	No Tipaimukh Dam (model scenario assuming Tipaimukh project is not implemented)
PWD	Public Works Department (also refers to a levelling datum widely adopted throughout Bangladesh including this report) (add 0.460 m SOB datum to convert to PWD datum)
RDP	Regional Development Plan (model scenario assuming Tipaimukh Dam is implemented unless suffixed with "NTD")
SOB	Survey of Bangladesh
SLI	SNC-Lavalin International
SWMC	Surface Water Modelling Centre
TBM	temporary bench mark

MPO Land Classification Terminology

Class F0	Land inundated to a depth of less than 0.3 m
Class F1	Land inundated to a depth of between 0.3 m - 0.9 m
Class F2	Land inundated to a depth of between 0.9 m - 1.8 m
Class F3	Land inundated to a depth of more than 1.8 m
Class F4	Land inundated to a depth of more than 1.8 m and on which deepwater aman cannot be grown

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EXECUTIVE SUMMARY

This report describes a program of modelling to support the Northeast Regional Water Management Plan, conducted under the Northeast Regional Water Management Project (NERP) which is component 6 of the Flood Action Plan for Bangladesh (FAP-6). The regional model was used to simulate the discharges and water levels throughout the rivers and floodplains of the region over a nine-year period and to simulate the changes due to flood control/drainage/irrigation projects and morphological changes.

An extensive data base of water levels, discharges, rainfall, and evaporation data from 1964 to 1993 was compiled for model input and for other project uses. Approximately 400 cross-sections were surveyed for the model through joint programs with the Surface Water Modelling Centre (SWMC). A precise levelling program was also undertaken with Survey of Bangladesh to check the elevations of the water level gauges and to establish a network of accurate benchmarks for future uses in the region. The second-order levelling program determined that there were errors as large as 1.6 m in gauge elevations although most gauges were within 0.5 m of their actual elevations. The most hydraulically-significant gauge corrections were found in the deeply-flooded central basin where the hydraulic gradient is flat and is sensitive to even small errors in water levels.

Model development from 1991 to 1993 was conducted by the SWMC with support and assistance from NERP. Further development at NERP included extending the model to upstream areas, solution of low-flow problems, and revisions to cross-sections and water level data as indicated by the results of the second-order levelling survey. A number of other changes were made to the model to improve its simulation of water levels and discharges at various places.

The rainfall-runoff model, NAM, was calibrated for the 1985-to-1993 period in sufficient accuracy to permit simulation of the runoff from the internal catchments, those areas lying within Bangladesh. However, the calibration of boundary catchments was not adequate due to the variability of rainfall over short distances, the lack of recent rainfall data within the Indian portion of the catchment, and overbank spills which affect the reliability of available discharge measurements during flood conditions. Ultimately it was found that the boundary inflows could be better estimated from the available discharge data, even if it required extrapolation from a neighbouring catchment. Flow estimates which were made in this way were adjusted for differences in watershed size, physiography, and rainfall by means of inter-basin correlations derived from the available discharge data.

The river model (MIKE-11) was calibrated against recorded discharge and water level data at 66 water level gauges and 21 discharge gauges. Initially the calibration was made for the 1991 water year which was generally a year of high runoff. The calibration was subsequently extended to three years from 1991 to 1993. Calibration results were very good.

A statistical analysis of historic rainfall, water levels, and discharge data demonstrated that the simulation period was slightly conservative compared with the past 30-year period.

The model was then used to conduct nine years of simulation from 1985 to 1993 for existing conditions. Results were compared with recorded levels to verify the model and to see if it could be used to detect the changes that have occurred recently. Results of the simulation confirmed that the model accuracy was adequate for regional planning purposes. Accuracy of the model in simulating flood statistics was judged to be better than 0.3 m in water level and 25% of discharge in the main stem rivers and 1.0 m in water level and 50% of discharge in the boundary rivers. Model results were rejected from the final analysis at a few locations where this accuracy could not be provided. Effects of embankment breaches, cross-damming, local dry-flow conditions, and morphological changes could be detected in the simulated levels.

The calibrated model was then used to simulate the effects of on-going and predicted morphological changes, implementation of the Tipaimukh Dam/Cachar Plains project in India, and the projects which are proposed in the regional water management plan. Initially these simulations were made for a one-year period (1991) during the preparation of the regional plan report. The simulations were subsequently extended to nine years (1985 to 1993) and the final results were analyzed on a statistical basis. The simulation had been originally planned to include the earlier period from 1964 to 1984 but this proved to be impractical due to limitations of the available data which are required for model input.

Results of the simulations demonstrated that the proposed Tipaimukh project could have the greatest impact on the region. Monsoon flood levels will be lowered by as much as 1.5 m which would have benefits to flood control in the upper Kushiyara and Surma Rivers. Dry-season water levels will be raised by as much as 1.5 m which will aggravate the problems of post-monsoon drainage and pre-monsoon flooding in the lower Kalni River. These dry-season problems will be further aggravated by on-going deposition within the Kalni River. These results were based on preliminary information regarding the Tipaimukh Dam's design and operation and further data is needed before definitive conclusions can be drawn.

The predicted rise in flood levels due to the regional plan projects is less than 0.5 m in most locations. Monsoon flood levels may rise by as much as 0.6 m in the Kushiyara River between Fenchuganj and Sherpur if the Tipaimukh Dam is implemented and 1.2 m if it is not implemented. Flood levels may rise by as much as 1 m in the Mogra River if drainage is directed from the Kangsha basin as was proposed in the Kangsha basin pre-feasibility study to improve flooding and drainage conditions in the Kangsha basin. These changes will need to be taken into account during the feasibility studies and design of these projects.

Outflows from the region will be essentially unchanged. Therefore there is little possibility of downstream impacts.

Flooding and drainage problems will continue unabated and in some cases will increase if no intervention is taken. Continuing avulsion and siltation of the Shibganjdhala channel will cause more flooding on the east side of the Someswari alluvial fan. Flooding and drainage problems will persist at the present level in the upper Kangsha basin and along the Surma and Kushiyara Rivers. The Jadukata River will continue to shift about its fan and likely will direct more flow and sediment westward into Tangua Haor, a regionally important mother fishery. The Khowai and Manu Rivers will continue to spill overbank during high flows and will flood adjacent areas. Deposition in the Khowai River will cause a 1 m rise in water levels near Habiganj and will increase the risk of overtopping and breaching of the embankments in this reach.

1. INTRODUCTION

1.1 Objectives and Scope

This report describes the computer modelling program in the Northeast Regional Water Management Project (FAP-6).

The Northeast Regional Water Management Project (NERP) is the sixth component of the Flood Action Plan (FAP). Its objective is to provide a plan for water resources management, especially flood control, in the Northeast region of Bangladesh. Generally the region includes that part of Bangladesh lying to the northeast of Dhaka and east of the Old Brahamaputra River and consists of the basin of the upper Meghna River and its tributaries.

The computer modelling component of NERP has the objective of modelling the flows and water levels in the region. Specific objectives are to estimate the changes that will occur when the regional plan is implemented and to determine the resulting water levels and discharges with the Regional Development Plan in place.

This report describes the program of computer modelling to meet these objectives. The following topics are addressed:

- an overview of the principle hydrologic characteristics of the region and the manner in which they are modelled;
- model development and calibration at SWMC;
- further model development and calibration at NERP;
- model applications in the Regional Development Plan and pre-feasibility studies at NERP; and
- experience gained with the computer model as a guide to further modelling in the region.

Salient findings of the modelling program have been included in the Regional Water Management Plan report and other reports. The present report reviews the analysis which was conducted in support of the regional plan. The analysis was subsequently extended to include a nine-year simulation which is also described herein. A description of the model development and calibration is also provided.

Much of the model development work has been carried out by the Surface Water Modelling Centre (SWMC), who were given the responsibility for development and calibration of a country-wide model and regional models in the Flood Action Plan. The program and results of the SWMC activities are reported elsewhere in reports by SWMC and will only be summarized to provide the background for the present report.

1.2 Methodology

The general approach included the following principal activities:

- compilation of a computer data base of historic water levels, discharges, rainfall, evaporation, and evapotranspiration data;

- field surveys and hydrometric monitoring to collect additional data required for calibrating the model;

- development and calibration of the model;

- simulation of the proposed Regional Development Plan projects to determine their impact on discharges and water levels in the region, based on simulation of the 1991 water year;

- longer-term simulations to provide the basis for statistical analysis of the results.

This approach generally followed the original plan but the scheduling of some tasks had to be changed to meet the schedule of the planning process. In particular the regional plan simulations were made with an enhanced version of the "full" model provided by SWMC, rather than the "pilot" model which had been originally planned. The long-term simulations had to be postponed until after the Regional Plan simulations and the pre-feasibility studies were completed.

1.3 Data Base

The modelling program used a variety of primary and secondary data including:

- approximately 200 cross-sections of the Kalni, Dhaleswari, Meghna, and Surma Rivers which were surveyed by BWDB in 1989 and 1990, and 100 cross-sections of the Khowai River which were surveyed by BWDB in 1988;

- approximately 400 cross-sections which were surveyed by SWMC, NERP, and SWMC/NERP joint programs from 1990 to 1993;

- water level and discharge monitoring data from 1991 to 1993 gathered by BWDB and compiled by SWMC;

- daily water levels, observed discharges, and daily discharge data compiled from BWDB records from 1964 to date, and at some locations from 1938 to date;

- daily rainfall data from 1960 to date within Bangladesh and 1896 to 1947 within the Indian portions of the catchment;

- evaporation data from BWDB from 1964 to date;

- estimates of potential evapotranspiration generated by BARC from temperature, wind, and solar radiation from 1964 to 1991;

- topographic maps in scales of 1:15,840 (4" = 1 mile), 1:40,000, 1:50,000, 1:250,000, and 1:1,000,000, mostly dating from the 1950's and 1960's;

- SPOT satellite images in a scale of 1:50,000;

- land elevation data provided by MPO in a 1 km grid, derived from topographic maps which were prepared by BWDB in the early 1960's.

1.4 Report Layout

The report is organized as follows:

- Chapter 1, the present chapter, provides an introduction to the report and its scope;

- Chapter 2, *The Northeast Region*, provides an overview of the region and its principal hydrologic characteristics which form the context for the regional model;

- Chapter 3, *Potential Hydrologic Impacts of FCDI Projects*, provides a qualitative description of the types of impact that can occur, along with some examples from the region;

- Chapter 4, *The Computer Model*, provides an overview of the model and how it represents the region;

- Chapter 5, *Data Collection*, describes several programs which were conducted in support of the modelling activities and other study components;

- Chapter 6, *NAM Model Development and Calibration*, describes the program of calibrating the rainfall-runoff model (NAM), which is used to generate inflows into the HD model;

- Chapter 7, *HD Model Development and Calibration*, reviews the program of developing and calibrating the hydrodynamic (HD) river model;

- Chapter 8, *Tipaimukh Dam/Cachar Plains Project*, describes the simulation of the proposed Tipaimukh Dam in India, upstream of the Northeast Region, and simulation of the potential consequences of a dambreak;

- Chapter 9, *Preliminary Simulations of the Regional Development Plan*, summarizes the modelling work that was done during the preparation of the Regional Plan Report;

- Chapter 10, *Extended Simulations of the Regional Development Plan*, reports on the extension of the modelling of the Regional Plan projects to include nine years of simulation and a statistical analysis of the results;

- Chapter 11, ***Conclusions***, summarizes the principal findings of the study;
- ***Annexes A through C*** contain more details of various aspects of the modelling program;
- ***Annex D*** contains the report Figures.

2. THE NORTHEAST REGION

2.1 Overview of The Region

Figure 1 provides a three-dimensional view of the Northeast Region and the main river channels. Generally the region has the topography of a basin or saucer which collects runoff from the region and from the tributary areas of India. The central basin is drained by the Baulai and Kalni Rivers into the Meghna River, which forms the outlet from the region. The Old Brahamaputra River forms the west boundary of the region.

Figure 2 provides a plan view of the Northeast Region showing the major rivers, the locations of discharge gauges and water level gauges, and a schematic outline of the model. Generally the model includes all of the larger rivers which are shown except the Old Brahamaputra River, as well as the primary floodplains. Floodplain links are shown as dashed lines in Figure 2. A simplified view of the model schematic is provided in Figure 3.

2.2 Drainage Basin

The outline of the drainage basin is shown in Figure 4. Catchments of the primary tributaries are also shown. They include the Meghalaya tributaries on the north, the Tripura tributaries on the southeast, and the Barak River catchment on the east.

The distribution of drainage area summarized in Table 2.1. The total area of the catchment is approximately 65,000 km^2 of which two-thirds lies outside Bangladesh. The Barak River, the single largest tributary, drains an area of 25,600 km^2 (40 percent of the total area). The Meghalaya and Tripura regions each represent approximately 15 percent of the total area.

2.3 Rainfall

Figure 5 shows the distribution of rainfall in the basin. The mean annual rainfall varies from 2,000 mm in the south of the basin to over 10,000 mm in the Meghalaya region. This region has some of the highest rainfall that has been measured in the world.

2.4 Topography

Figure 6 shows the ground elevations in the region. Ground elevations range from approximately 3 m in the central basin to 30 m in the fringes and in isolated hills in the eastern part of the region. The low area in the centre of the region (the central basin) is flooded annually to a depth of 4 m or more.

Table 2.1: Drainage Areas

Region	Drainage Area km^2	Percent of total
Meghalaya	10,200	15.8
Tripura	8,100	12.5
Barak	25,600	39.7
Northeast Region	20,600	31.9
Total	64,500	100

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2.5 Flood Conditions

The extent of flooding in the region can be appreciated in Figure 7 which is a satellite image taken shortly after the flood peak in 1988, one of the most severe flood years on record. The dark areas in this image show the areas that were under water. Over half of the region was flooded including the central basin north of Bhairab Bazar, low-lying areas in the Sylhet region, and low areas north of Mymensingh.

The depth of flooding in the 1:2 year pre-monsoon flood is shown in Figure 8. Flooded areas include the deeper central basin as well as the major haors in the Sylhet region. Flood depths generally are in the range of 0 to 2 m except in the deeper haors and deeper areas of the central basin. Flood depths in a 1:2 year monsoon flood are shown in Figure 9. The central basin is flooded to depths exceeding 4 metres in places.

The indicated flood depths and extent were derived from gauge records and are only approximate.

2.6 River Systems

The Northeast Region contains a variety of hydrologic conditions. The principal rivers of the Northeast Region are the Kushiyara, the Surma, and the Kangsha. These will be described briefly below.

Barak River
The Barak River is the largest tributary to the Northeast Region and generates between 15 and 20 percent of the total runoff in the basin. It is located in the Assam region of India and enters Bangladesh at Amalshid where it splits into the Kushiyara and Surma Rivers. Peaks as high as 5,000 m^3/s have occurred at Amalshid.

Kushiyara River
The Kushiyara River is the larger branch of the Barak River and carries approximately 70% of the total flow during summer periods. During the dry season the Kushiyara River carries most of the flow.

The Kushiyara River spills over its banks during the monsoon season. Embankments have been constructed in the upstream reaches to reduce the overbank spills and to protect the floodplain. However these embankments continue to breach during floods.

Some appreciation of the magnitude of these overbank spills can be gained from discharge measurements which were taken during the

Table 2.2: July 1993 Flood Discharges in the Kushiyara River and its Floodplain

Location	River Flow m^3/s	Floodplain Flow m^3/s
Amalshid (Barak)	5,100	not measured
Amalshid (Kushiyara)	3,500	not measured
Sheola	3,000	800
Fenchuganj	2,300	2,000
Sherpur	3,900	1,600
Markuli	2,000	not measured

July 1993 flood as summarized in Table 2.2. These measurements were taken at seven locations in the Kushiyara River and at three locations in the floodplain where the floodplain flow is confined to discrete channels (Sheola, Fenchuganj, and Sherpur)[1/]. The proportion of total flow which was carried by the floodplain is estimated below:

- Sheola 20%
- Fenchuganj 50%
- Sherpur 30%
- Markuli 65%.

The reach between Sherpur and Markuli has undergone substantial changes in the past few decades. The earlier course of the river (the Bibiyana channel) has been abandoned and the new course has been straightened by means of several loop cuts.

Sedimentation has been occurring in the lower reaches of the Kushiyara River (called the Kalni downstream of Markuli). This has resulted in higher water levels during the winter and pre-monsoon periods and in earlier pre-monsoon flooding. Various measures have been taken to control the flooding and to improve navigation including closure of the old Kalni River north of Markuli, closure of the Old Surma channel at Ajmiriganj, and cutoff of several loop cuts. Water levels and channel bed elevations appear to be continuing to rise in this reach.

Surma River

The Surma River typically carries 30% of the Barak River flow during the monsoon season but carries little flow during the dry season due to shallow channel depths at its inlet.

The river spills over its banks during the monsoon season upstream of Kanairghat. High embankments have been constructed on the left bank and have closed off most of these spills except for a few khals which connect the river to the Surma-Kushiyara floodplain. Embankments have also been constructed along the right bank of the Surma and Lubha Rivers from Kanairghat to high ground at the border. The right embankments have not been successful at cutting off the spills in this direction due to frequent breaching and public cuts.

Some of floodplain spill continues overland into the Sarigowain basin before returning to the Surma River near Chatak. Discharge measurements taken during the flood peak in 1993 indicate that as much as 1,000 m^3/s may have spilled in this direction. The remainder returns to the Surma River near Sylhet.

The Surma River also collects runoff from Meghalaya tributaries upstream of Chatak. The floodplains of the Sarigowain and Surma Rivers absorb this runoff and attenuate the flood peaks. These tributaries and floodplains converge near Chatak, where the Surma River continues westward as the main outlet. Several smaller distributary channels, of which the Bhattadahuka is the largest, also carry flow from the Surma River into the central basin upstream of Chatak.

Embankments between Chatak and Sunamganj have mostly eliminated spills over the left bank. The right bank is not similarly protected and continues to spill.

1/ It is difficult to measure discharges where the flow spreads out over the floodplain. These measurements were taken at locations where the floodplain flow is confined by topography into discrete channels, typically at bridge openings.

Downstream of Sunamganj the Surma River abandoned its original channel several decades ago. The present main channel, which is called the Nawa River, continues westward into the central basin where it joins the Kangsha and Baulai Rivers, the major tributaries from the west. Downstream of this location the river flows through the central basin as the Baulai River. The former main channel branches southward; it is still open but its flow has reduced due to siltation of its inlet.

Meghalaya Tributaries
The Meghalaya tributaries include the Lubha, Sarigowain, Jaflong, Dhalagang, Chela, and Jhalukali in the eastern portion, and the Jadukata, Someswari, Nitai, and Kangsha tributaries (Bhogai, Chellakhali, Malijhi, and Darong) in the west. Basin elevations are as high as 2,000 m and slopes are steep. Rainfall is very high as is shown in Figure 5. As a result these streams have very flashy peaks and large flows.

Where these border rivers join the floodplain of Bangladesh they spill over their banks. The overbank spills are absorbed into storage between the Surma and Someswari Rivers, in the floodplain of the upper Kangsha, and in other low-lying areas and haors adjacent to the international border. This floodplain storage substantially attenuates the flood peaks. Ultimately these areas drain into the central basin.

These rivers also carry a high sediment load which is deposited on the piedmont plains and in the lower floodplain areas. High sediment loads, overbank and in-channel deposition, and flashy peaks contribute to lateral shifting of these rivers and to periodic avulsions (large-scale shifts in channel location). Such avulsions have occurred recently in the upper Someswari, Jadukata, Chela, and Dhalai Rivers. These border tributaries have formed extensive alluvial fans where their sediment load is deposited.

Tripura Tributaries
These are piedmont streams; steep, flashy, having high sediment loads, but are not as extreme as the Meghalaya tributaries. Rainfall in this area is also less than in the Meghalaya region. These rivers frequently overtop their banks and have raised their banks by deposition of the transported sediment. River levels are often "perched", or higher than the adjacent floodplain.

The primary rivers of the Tripura region are the Khowai, Dhalai, Manu, Juri, and Sonai Bardal. The Sutang, Karangi, and Lungla Rivers are smaller streams that are located mostly in Bangladesh but extend across the border to drain a small part of the Tripura region.

Embankments have been constructed on the larger rivers to try to contain the overbank spills and to prevent flooding of the adjacent areas. Embankments have been constructed in the Manu Project to protect the project area from flooding in the Manu River but are periodically cut by people who live on the unprotected river side. The Khowai River has been confined by embankments from Chunarghat to downstream of Habiganj but continues to spill upstream of the embanked reach. Breaches or public cuts also continue to occur during high floods. Most other rivers have smaller embankments from place to place.

The Juri and Lungla Rivers spill into large haors (Hakaluki and Hail Haors) a short distance downstream of the location where they enter Bangladesh. These haors absorb the flood peaks and most of the sediment loads.

Kangsha Basin
The Kangsha River collects runoff from a number of flashy border tributaries (the Malijhi, Chelaklahi, Bhogai, Nitai, and Someswari Rivers) upstream of Jaria Janjail. Further downstream the river splits into three channels, the Ghulamkhali, Donaikhlai, and the original Kangsha Rivers. The original channel has mostly silted in and Ghulamkhali has grown to become the main channel.

The flashy border tributaries spill into low-lying areas of the floodplain. Floodplain storage helps to attenuate these flood peaks and helps to trap sediment which is carried from India. Floodplain storage is especially significant in the low-lying area along the Malijhi River (upstream of Sarchapur), along the Shibganjdhala River, and in the Kangsha north floodplain.

The Kangsha River is relatively stable in its upper reaches where it appears to be a relic branch of the Brahamaputra River. The river receives large volumes of runoff and sediment inflow from the Someswari River near Jaria Janjail where it becomes considerably more active. High sediment loads and recent changes in the Someswari flow distribution have resulted in the lower Kangsha channel silting in and becoming almost a dead channel.

Central Basin
The central basin is a backwater zone that is deeply flooded in the monsoon months. This flooding absorbs and attenuates the peaks from the tributary rivers. Most of the flow passes via the floodplain during monsoon months. This area is slow to drain after the monsoon season has ended when water levels are controlled by backwater from the Meghna River.

Haors
Significant haors occur in the lower areas between raised river banks. The haors are flooded for most of the monsoon season and may retain water over winter in beels and other depressions.

Submersible embankments have been constructed in many places during recent years to protect these haor areas from early-season "flash" flooding. These embankments prevent inflows during the winter and pre-monsoon periods but are designed to be overtopped during the monsoon period. These embankments are often damaged by river erosion and by overtopping during the monsoon season.

2.7 Flood Profiles

Longitudinal profiles of the Kushiyara, Surma, and Kangsha Rivers are shown in Figures 10 to 12. The Kangsha profile includes the Ghulamkhali River and Someswari River which form the main branch in the lower basin. These profiles show the water surface for typical monsoon floods, pre-monsoon floods, and low winter conditions.[2/] The bottom of the river channel and the approximate floodplain elevations are also shown.

Generally the monsoon water levels are near the top of bank and the floodplain level in the upstream reaches. Further downstream the monsoon levels rise above the top of bank

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[2/] The flood profiles represent approximately the 1:2 year flood condition. Winter water levels are for February 1992.

(downstream of Sherpur on the Kushiyara, Sukdebpur on the Surma/Baulai, and Madhyanagar on the Kangsha/Ghulamkhali).

Pre-monsoon levels are below the top-of-bank in most places except in the Kushiyara River near Markuli. A shallow reach of the Kushiyara River exists between Markuli and Madna. This reach has had considerable deposition in the past few years which has resulted in higher water levels and earlier pre-monsoon flooding. This constriction increases the water surface gradient near Markuli.

During the monsoon periods the downstream reaches are affected by backwater conditions. The longitudinal gradient becomes very flat because the floodplain is deeply flooded and has substantial conveyance capacity.

Late winter water levels are well below the top-of-bank in all reaches. Backwater extends upstream in the Surma/Baulai system as far upstream as Sylhet during the winter season when discharges are low.

3. POTENTIAL HYDROLOGIC IMPACTS OF FCDI PROJECTS

Following is a general review of the general responses of rivers to flood control works. These comments are not intended to address case-specific impacts, but rather to provide a general framework for the later discussions.

FCDI projects can change water levels and discharges through:

- confinement;
- reduction of floodplain storage; and
- improved drainage due to loop cutting and channel re-excavation.

Morphological changes in the river system are briefly described as well, although they are generally not modelled.

3.1 Confinement Effects

Rivers of the Northeast region are mostly "perched", their river banks having been raised above the general floodplain level by overbank deposition. The rivers spill water overbank during floods and because the rivers are perched the overbank spills may not return to the river but can be carried for some distance in the floodplain or into an adjacent river.

Constructing embankments to eliminate the overbank spill causes the flow to be confined within the river channel, and thus results in higher in-channel discharges and water levels. The amount of this increase depends on the location and the magnitude of floodplain spills.

Confinement effects are evident at several locations in the Northeast region, but most dramatically in the Khowai River. Embankments were constructed along the Khowai in the 1980's to prevent flooding of adjacent overbank areas in the Karangi and Sutang River basins. By cutting off the overbank spills the discharges and water levels in the embanked reach have increased substantially. Figure 13 shows the discharges and water levels which have been recorded at Shaistaganj. Water levels have risen by 2 m or more. Further increases are possible if the embankments are strengthened to prevent the breaches and overbank spills which continue to occur.

Similar but less dramatic changes have occurred in the Kushiyara River upstream of Sheola. These changes can be seen in Figure 14, which shows the discharges in the floodplain and in the river channel over the period of record (there is a gap in this plot from 1978 to 1991 when no measurements were taken). Floodplain discharges have decreased and river discharges have increased, apparently as a result of embankments and khal closures which were constructed along the Surma and Kushiyara Rivers to reduce the flooding of the interior floodplain. River flood levels have risen by approximately 1 m since 1949 as shown in Figure 15. The channel also appears to have eroded slightly in response to the increased discharges[3/]. Winter levels fell by approximately 0.5 m between 1949 and 1985, apparently due to the increased channel capacity.

3/ "River Sedimentation and Morphology', Northeast Regional Water Management Project, Specialist Study, December 1994.

3.2 Reduction of Floodplain Storage

Embankments also have the effect of reducing the amount of storage of water on the floodplain. This results in increased discharges. The effect is greatest with high or "full" embankment projects but also occurs with submersible embankments.

Floodplain storage acts to reduce peak discharges in the river by buffering or attenuating the overbank spills. Regional inflows are compared with the outflow at Bhairab Bazar for the 1991 water year in Figure 16, where it can be seen that the peak inflow is approximately 50% higher than the peak outflow. The difference goes into temporary and seasonal storage. It follows that the peak discharges from the region would be increased by approximately 50% if all of the flooding were to be eliminated.

Inflows in Figure 16 include all the (gauged) discharges in the border streams plus the runoff from the internal catchments within Bangladesh (generated with the NAM model). Losses to evaporation and groundwater are deducted through the NAM model simulation.

The volume of floodplain storage in the Northeast region is quite substantial. It is estimated that as much as 25 km^3 of water was stored on the floodplain during the 1991 water year, which corresponds to an average depth of approximately 2.5 m over the flooded area.

3.3 Loop Cuts and Drainage Improvements

Loop cuts have been used to improve navigation (in the Baulai and Kalni Rivers), to reduce the length of embankment (in the Khowai River), and to improve drainage conditions and reduce flood levels (proposed for the Kangsha River). Drainage improvements include widening and/or deepening of drainage channels so as to enable the area to drain more efficiently. They also provide a deeper channel for navigation.

Loop cuts tend to lower the upstream water levels and increase the velocities by reducing the effective length of the river. Effects of individual loop cuts tend to be small, but a number of loop cuts in series can create a significant change. Flow velocities and channel erosion may also increase and need to be considered.

Loop cuts can increase the discharges downstream of the modified reach by decreasing the upstream storage (water level) but this effect tends to be small.

Channel re-excavation and deepening provides faster post-monsoon drainage so as to permit earlier access to the land for agricultural production. Drainage works are often fitted with regulators to prevent water levels from falling too low. Flood benefits and impacts are generally of a secondary nature but this depends on the nature of the drainage constriction and the magnitude of the channel changes.

3.5 Morphologic Response to Flood Control Works

Changes to the channel discharges can lead to morphological changes. Increased velocities due to flow confinement or loop cuts can cause erosion of the channel and deposition of the eroded material in downstream reaches. The long term response may include changes in planform and increased tendency to meander or to shift location. Such changes have been observed in the Khowai River and in the upper Kushiyara River in response to earlier FCDI projects.

The HD model is a fixed-bed model and as such it does not replicate these changes directly. They can be simulated by making suitable changes in the river cross-sections in the model.

Morphological changes are considered in NERP's specialist study on river morphology[4/].

4/ "River Sedimentation and Morphology', Northeast Regional Water Management Project, Specialist Study, December 1994.

4. THE COMPUTER MODEL

The following is an overview of the computer model and how it describes the rivers of the Northeast region, and introduces some of the model concepts and terminology.

4.1 Overview of the Model

Figure 2 shows the major rivers of the Northeast region and an outline of the model. Figure 3 shows the model layout in a schematic form.

The model contains essentially all of the major rivers of the region as well as the primary floodplains. The major rivers form the skeleton to which the floodplains are connected through overbank spills. Lateral weirs are used to control the rate of overbank flow in the model.

The Old Brahamaputra River and Lakhya Rivers are not included in the regional model although they are shown in Figure 2 for completeness. They are mostly separated from the other rivers of the Northeast Region, being an offtake of the Brahamaputra River, and have been modelled by SWMC in the General Model and the North Central Regional model. The Meghna River (downstream of Bhairab Bazar) has been modelled by NERP in a sub-model, separately from the main model.

Excluding the Meghna sub-model the Northeast Regional Model consists of 147 reaches, 533 cross-sections, 33 flood cells, 84 weirs, 33 boundary points (including 8 internal boundaries that are required for special modelling purposes), and 59 sub-catchments. The Mid-Meghna sub-model contains one additional reach and 14 cross-sections.

The Northeast Regional model provides a fairly coarse spatial resolution which is required for a regional model. The larger rivers and the most significant floodplain spills are modelled. Cross-sections are typically spaced at intervals of 10 to 20 km in the major rivers and 5 to 10 km in the steeper, smaller tributaries. The floodplains are modelled in a lumped fashion without much detail of the internal flow processes.

The model is quite large and requires between 8 and 15 hours to run for one year of simulation on an IBM-compatible computer equipped with an 80486DX2/66 mHz processor and 16 mB of memory running under the UNIX operating system. The simulation time step is generally 30 minutes although the results are usually stored at time intervals of 6 hours. The 6-hour output step minimizes the size of the output files while providing reasonable temporal resolution which is consistent with that of the input data. One year of simulation generates an output data file of 18 megabytes.

Outputs from the model consist of simulated water levels at each cross-section and discharges between each cross-section, for each output time step. The results can be displayed in the form of time graphs, profiles, and maximum/minimum summaries for the simulation period. Other processing is done outside the model to produce presentation graphics and flood depth maps.

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4.2 Model Concepts and Terminology

The model consists of two parts, a **rainfall-runoff** model (the NAM model) and a **hydrodynamic** model (the HD model). The NAM model is used to calculate the runoff into the river system from rainfall which occurs within the region. Inflows which occur from outside the region (the Meghalaya, Tripura, and Assam states of India), are generally derived from recorded discharge data. The HD model accumulates these inflows and simulates their passage through the rivers and floodplains, and calculates the water levels and discharges throughout the river system.

The hydrodynamic model represents the region as an interconnected network of river **reaches**. River reaches connect to each other at **junctions** and to the outside world at **boundaries**. Physically the junctions correspond to confluences or bifurcations of the river channels or to locations where water spills onto the floodplain. Each reach is described by two or more **cross-sections** which are usually taken from channel surveys. The hydraulic **roughness** is the resistance of the cross-section to flow; together with the cross-sectional geometry the roughness determines what water levels occur for a given flow condition.

The locations of the cross-sections and the junctions are specified by river **chainage** which is measured along the river channel from a specified point (typically the upstream junction of a reach, a gauge location, or some other significant point). The **coordinates** of a cross-section describe its location on the surface of the earth in degrees of latitude and longitude; these are not used in the calculation but are used to locate the cross-section in space and to map the model output.

Floodplains are represented in the model in one of three ways depending on the prevailing conditions:

- They are **attached** directly to the river if the floodplain is predominately above the level of the river bank and/or the water levels in the floodplain are essentially the same as those in the river (that is to say, there is free exchange of water between the river and floodplain);

- They are represented as a flood cell if the floodplain takes the form of a depressed storage basin or **haor**, separated from the river by the river banks. They can receive large overbank spills from the adjacent rivers during floods. Water levels may be significantly different from those in the adjacent river, especially during low flows, but are assumed to be the same throughout the flood cell. Storage volume is assigned to the flood cell by means of an **area-elevation curve**, which specifies the water surface area as a function of elevation.

- They are described as **routing channels** if they have higher velocities such that the water surface falls significantly along the length of the floodplain, but are separated from the main channel except during overbank spills. Hydraulically, floodplain routing channels are similar to river reaches except that they generally have a shallower depth of flow and relatively greater resistance. Generally the cross-section of a routing channel is derived from topographic maps or the MPO 1 km grid elevation data.

Flood cells and routing channels are connected to other flood cells or to the rivers by means of **weirs**. These weirs simulate the spill from the river channel above the top-of-bank and are assigned elevations that approximate the actual bank elevation. The weir length can be estimated from the actual length of overbank spill but can be adjusted during calibration. Weirs can also be used for other purposes, for example to simulate regulators or other structures.

Inputs into the river system consist of **boundary inflows** and runoff from **internal catchments**. Boundary inflows represent the inflow from an upstream or external catchment (say the Barak River in India which contributes runoff to the Northeast Region at Amalshid). Internal catchments contribute runoff from within the region, downstream of the boundary locations.

The model uses a **water level boundary** to describe the water levels at the downstream end. The main model ends at Bhairab Bazar which is simulated as a water level boundary using the recorded water level data. The Meghna sub-model is extended downstream to Satnal as the downstream boundary.

The boundaries should be located outside the area that is under study and should not be affected by projects or morphological changes within the region. This is not always strictly possible, for example where overbank spills occur upstream of the border gauges; however the existing model provides a reasonable and practical definition of the regional boundaries. Discharges and water levels at Bhairab Bazar are not materially affected by the proposed projects, as will be discussed later; therefore this location provides a suitable downstream boundary for the model.

Schematization is the process of constructing the model and compiling the input data. **Calibration** is the process of modifying the model parameters after comparing the simulated discharges and water levels within the river system with those which are actually recorded. Generally the primary calibration parameters are the roughness coefficients, but calibration can also involve changes to model schematization (adding, subtracting, or re-arranging reaches or control weirs), and adding or otherwise modifying channel cross-sections.

Modelling a river system requires various compromises in the level of detail and the extent of the model. Greater **spatial resolution** (closer spacing of cross-sections and inclusion of smaller channels) results is smaller time steps in order to satisfy the governing flow equations, and in longer execution times and a larger amount of input data. The purpose and ultimate application of the model must be considered in the design model. More details can be added in later stages to portions of the model if they are required for more detailed analysis of specific projects.

The computer program which is used to conduct the modelling is called **Mike 11**, a commercial software package developed and distributed by DHI (Danish Hydraulics Institute). It contains an integrated data management system as well as the modelling software itself. The modelling software contains a full solution of the dynamic wave equations (the **St. Venant Equations)** which describe the dynamic behaviour of gradually varied flow.

5. DATA COLLECTION

5.1 Cross-section Survey Programs in 1992, 1993, and 1994

A large number of cross-sections were surveyed in 1991, 1992, and 1993 through joint programs with SWMC. An additional 19 cross-sections which were surveyed by NERP in 1993 during morphological investigations were added to the NERP6 and NERP7 versions of the model. During the winter of 1993 and 1994 some 93 additional cross-sections were surveyed in the Kangsha, Mogra, Baulai, and Jadukata Rivers. Some of these have been included in the regional model while others are intended for use during feasibility studies.

A data base of surveyed cross-sections (CRS4) is being maintained separately from the model cross-sections[5/]. Table 5.1 summarizes the present status of the CRS4 data base.

Table 5.1: Summary of Surveyed Cross-Section Data Base CRS4

Source	Date of Survey	Number of Cross-sections
SWMC	1991	45
SWMC/NERP	1992	154
	1993	18
NERP	1993	19
	1994	93
BWDB: Morphological surveys	1989-91	103
Discharge sections	varies	8
Khowai R. survey	1988	112
Pre/post monsoon surveys	1991-93	122

5.2 Hydrometric Data Base

A comprehensive hydrometric data base (HYDAT) has been compiled for the Northeast Region, from 1964 to date. These data include:

- daily water levels
- daily discharges
- observed discharges
- evaporation (re-converted to pan data[6/])
- potential evapotranspiration (derived by BARC using the Penman method).

In addition historical rainfall data for the 50-year period prior to 1947 were compiled from records available in Britain. The historic data

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5/ It is common in the model to extend the cross-section across the floodplain using other data or to estimate intermediate cross-sections where none are surveyed. CRS4 preserves a record of the original surveyed section.

6/ BWDB adjusts the measured evaporation data by applying a pan coefficient which is assumed to equal 0.7. The actual pan coefficient varies according to the type of evaporation pan and local climatic conditions. Therefore the reported evaporation data have been converted back to pan evaporation data in NERP's data base.

were available for rain gauges in India as well as in Bangladesh. This historic data were used in the hydrology studies to help determine the long-term average rainfall at different locations.

A summary of the hydrometric data base is provided in Annex B.

Digital data bases are being maintained in both HYMOS and LOTUS spreadsheet formats, and are converted to MIKE11 format when required for modelling purposes. The HYMOS software package has been installed and is used for many data management and analysis tasks. However the spreadsheet format has also proven to be more useful to most team members.

Hydrographs were plotted and were scanned for obvious errors. A standard suite of hydrograph plots, summaries, and flood statistics were generated for use by other members of the project team.

The rainfall data have been retained in a text file format. A computer program has been written to process the data and generate summaries for hydrological analyses.

5.3 Second Order Levelling Program

A second-order levelling program was conducted to accurately check the elevation of water level gauges in the region and to provide accurate benchmarks for future projects and feasibility studies. The program involved high-precision level surveys to second-order accuracy[7/]. SOB (Survey of Bangladesh) conducted the surveys, CIDA provided the funding, and NERP provided a field monitor and administered the program.

A location map of the survey routes and benchmark locations is provided in Figure 17. All survey lines were tied to existing first-order benchmarks. All lines were surveyed in both directions to form a closed loop and were closed to within second-order tolerance as specified in the terms of reference.

Ten sets of precision levelling instruments and staves were provided by NERP to SOB. Five additional sets of survey instruments were provided by FPCO, three by BWDB, and two by SOB. Twenty survey crews were mobilized in 1993 and eight were mobilized in 1994.

Field surveys were carried out from February to June 1993 and from January to May 1994. Sixty-five water level gauges and 374 SOB pillars were connected in the first year's program. The 1994 program included additional ties in the central area, ties to the North Central and Southeast Region networks which had been surveyed by FINMAP, and connection of twelve

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7/ The permissible tolerance for second-order levelling surveys is $8.4\sqrt{\text{length}}$, where length is the distance to form a complete loop (in units of kilometres) and tolerance is in units of millimetres.

remaining gauges. The scope of the survey is summarized in Table 5.2.

Table 5.2: Summary of Second-Order Survey Program

Item	1992 to 1993	1993 to 1994	Total
Survey lines (km)	2283	458	2741
Monuments connected	374	23	397
BWDB gauges connected	65	12	77

A final report on the 1993 survey was submitted by SOB in May 1994. A final report on the 1994 program was submitted by SOB in January 1995.

Original and revised elevations of the gauge benchmarks and TBMs, as well as the resulting gauge corrections, are provided in Annex A. A summary of the gauge datum corrections to date is provided in Annex A.

At half of the surveyed gauges the datum error is less than 0.1 m and can be ignored. At 29 gauges (38% of the total number) the datum error is minor, between 0.1 and 0.3 m. At 13 gauges the datum correction is significant (greater than 0.3 m); three of these have corrections greater than 0.5 m (Chamarghat, Chelasonapur, and Jagannathpur). The largest correction is 1.6 m at Jagannathpur. The most significant datum errors occur in the deeply-flooded central part of the region where the hydraulic gradients are sensitive to even small datum errors.

NERP also conducted level surveys at 20 gauge locations to connect TBMs (temporary benchmarks) to the permanent gauge benchmarks. In most cases SOB had connected the TBM only if a permanent benchmark was not available. The TBMs are generally used for day-to-day operation of the gauges and were used as source benchmarks for some of the cross-section surveys.

Results of the TBM surveys are included in Annex A. In general the TBM's are consistent with the gauge benchmarks except for two locations (Bijoypur and Ghosgaon) where discrepancies of the order of 0.3 m occurred. Similar errors had been encountered during the model calibration at these two locations and may be related to the TBM datum errors.

Table 5.3: Summary of Gauge Benchmark Corrections

Range of corrections	Number of Gauges	Percent of Gauges
less than 0.1 m	35	45%
0.1 to 0.3 m	29	38%
0.3 to 0.5 m	10	13%
greater than 0.5 m	3	4%
Total	77	100%

Preliminary elevations in the critical deeply-flooded central portion of the region were incorporated into the Regional Plan simulations. Final results of the survey program were incorporated into the extended simulations which are reported later in this report.

Presently all new surveys by NERP are being tied to the new datum. The additional new benchmarks provide for more efficient and more accurate surveys.

5.4 Hydrometric Monitoring Programs

A large amount of hydrometric data has been collected through joint programs with SWMC. Water level and discharge data were compiled at all locations within the region.

A priority of the program has been to measure the incoming discharges at the border as accurately as possible. In some cases the gauges were moved upstream of known overbank spills. Discharges were also measured in the Kushiyara floodplain[8] at Sheola, Fenchuganj, and Sherpur and in the Kushiyara River at Markuli during 1993 to help quantify the floodplain discharges. This program has provided excellent data for the calibration of the model and for estimation of the floodplain discharges, in part measure due to the occurrence of a large flood during 1993.

Discharges and water levels were also monitored during 1994 in the Kangsha basin and in the Kalni floodplain in support of the feasibility studies in those areas. These programs are continuing into 1995.

5.5 Field Observation of Flood Conditions

A number of field visits were made during 1991, 1992, and 1993 to verify the model and to observe flood conditions at various locations. Flood conditions were also observed in the Khowai and Kushiyara Rivers in 1993.

5.6 Floodplain Mapping and Flood Depth Mapping

Contour maps of the region were prepared to help understanding the floodplain topography and floodplain flow pattern. Previously no topographic maps were available in a suitable scale and suitable resolution. Contour maps of ground elevation were prepared at a scale of 1:100,000 and 1:250,000 and maps of flood depth and elevation were prepared at a scale of 1:250,000.

These maps were prepared from ground elevation data in a 1 km grid. The grid data had been digitized by MPO from four-inch-to-one-mile map sheets published by SOB in 1962. The location of the map origin was adjusted after comparing a sample of the data points with the original map sheets. Actual locations of the data points could not be verified in all cases and thus there remains some uncertainty in the accuracy of the digitized data. The positions of the corrected data were then transformed to the Transverse Mercator projection system which is used for AutoCad mapping at NERP.

The SURFER software package was used for contouring and for flood depth mapping. Features such as channels, haors, roads, and railways were added using the AUTOCAD software; these

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[8] It is difficult to measure discharges where the flow spreads out over the floodplain. These measurements were taken at locations where the floodplain flow is confined by topography into discrete channels, typically at bridge openings.

features have been digitized from satellite images and other maps as part of NERP's mapping program. Finished maps were plotted in a scale of 1:100,000 with 0.5 m contour intervals (a reduced copy of one map sheet is shown in Figure 18). Similar maps have been produced in a scale of 1:250,000 with 1 m contours for a more general depiction of the regional topography (Figure 6 is a reduced copy).

Maps of flood elevation were prepared using from water level records and model output. Flood depth maps were then prepared from the difference between the water surface elevation and the ground surface elevation.

A computer software named FLD was also developed to produce raster images of the flood depth maps. The software reads the flood depth grid file which is produced in SURFER and it maps different flood classes (MPO's F0, F1, F2, and F3 classes) in different colours on the computer screen. It also calculates the areas of the various flood depth classes for engineering analysis. The result is then converted to AUTOCAD format to produce the final maps and to incorporate the additional information available in NERP's map data base.

A related program is used to compute the area-elevation curve for a project area, flood cell, or haor. The area-elevation curve shows the amount of flooded area that lies below a certain elevation and is widely used by planners, designers, and others. Flood areas and volumes for various water surface elevations are output in hard copy and digital format.

6. NAM MODEL DEVELOPMENT AND CALIBRATION

NAM is a rainfall-runoff model developed by Danish Hydraulic Institute (DHI). The model takes rainfall and evaporation data as input and it generates a time series of runoff based on the physical characteristics of the catchment.

The main purpose of using the NAM model is to generate runoff from the internal catchments of the region. The NAM model can also be used to generate boundary inflows for periods when they are not gauged. In either case the model must be calibrated, preferably using discharge data at the outlet from each catchment.

A map of the catchments in the drainage basin is provided in Figure 19. The map also shows the outline of the Barak catchment which was not modelled with the NAM model. External or boundary catchments are located in the Tripura and Meghalaya regions of India and the Sutang, Karangi, and Lungla catchments which are located within Bangladesh. Internal catchments are the remainder.

6.1 Pilot Calibration

The NAM model was given initial calibration during the pilot model stage. The development and calibration were conducted by SWMC. NERP contributed a portion of the funding and assistance with the data analysis.

Details of the pilot calibration are contained in SWMC's pilot calibration report which was submitted in July 1992. The results will be reviewed briefly below.

6.1.1 Internal Catchments

Internal catchments were modelled with NAM to estimate the local runoff from within the region.

Modelling of the internal catchments was done with a recently-developed "irrigation" version of the NAM model. Functionally this model differs from the "standard" NAM model in three respects:

- It uses a more physically correct description of groundwater infiltration than does the standard model. The revised approach is generally more suitable for regions that have a significant amount of surface storage such as the Northeast region.
- It allows the catchment to be divided into two or more sub-catchments, each having different properties (this feature is useful for modelling the border catchments as will be described later).
- It can be used to simulate irrigation of the catchment and the effect that this has on infiltration and runoff.

Internal catchment boundaries were generally adopted from MPO's delineation. Initial values of model parameters were estimated from experience elsewhere in Bangladesh, subject to later refinement by calibration. Catchment rainfall estimates were generated from point rainfall data

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using a Theisson Polygon approach, which averages near-by rain gauges according to their distance from the catchment.

The model was calibrated by comparing simulated groundwater levels with those which were recorded in sample wells in each catchment. Overall the simulation of groundwater levels was good, and differences appeared to be as much due to measurement errors as to model errors. These results confirm the overall water balance but not the hydrograph time pattern and the magnitude of flood peaks.

Discharge data were available for calibration in only one catchment, the Mogra River upstream of Netrokona (Catchment 59B). The discharge hydrographs, especially flood flows, are required to calibrate the time coefficients which control the shape and magnitude of the peak flows in the model. The calibration results in the Mogra River were good and provided a reasonable basis for estimating the parameters for other internal catchments.

6.1.2 Boundary Catchments

In general the recorded discharges have been used in the boundary catchments in preference to NAM-generated discharges wherever possible. Most of the boundary catchments have been gauged over the past three years. However, the NAM model was required in the Juri River and Karangi River catchments, which are affected by backwater conditions and overbank spills respectively, and to supplement the available discharge data in other catchments.

In addition it was hoped that the NAM model could be used to generate the historic inflows for the period before discharge measurements were made. The NAM-generated inflows would represent the present state of development once the model is adequately calibrated for present conditions. Therefore the model had to be calibrated using recent discharge data.

The following problems exist with modelling of the boundary catchments:

- no rainfall data is available in the catchment areas outside Bangladesh other than historic data prior to 1947;
- catchment runoff is very flashy, rising and falling over a few hours, whereas the rainfall data is measured only daily at most rain gauges;
- overbank spills occur upstream of some of the discharge gauges, which results in part of the flood peaks not being gauged.

Therefore the initial calibration was conducted at an exploratory level in order to better define the nature of these problems and the prospects for a successful calibration. The standard NAM model was used for the initial simulations of the cross-border catchments because it is somewhat simpler to calibrate than the irrigation model.

Methodology

Catchment areas were discretized from 1:250,000 scale maps upstream of the boundary discharge gauges. Other model parameters were estimated from experience elsewhere.

Catchment rainfall over India was estimated from the closest rain gauges within Bangladesh, adjusted to allow for the normal variation in rainfall which is shown in Figure 5. Rainfall adjustment factors were computed from the long-term average rainfall in each Indian catchment divided by the long-term average rainfall at the applicable Bangladesh rain gauges. This provides a simple method for estimating the catchment rainfall and accounts for the long-term patterns but cannot account accurately for variations in individual storms.

Results

Results of the calibration were somewhat inconsistent. The calibration ranged from fair to good, depending on the catchment and local conditions. The over-riding problem was the lack of rainfall data within India, resulting in rather variable calibration of individual storm events. Other problems which affected the calibration included:

- Ururgaon was modelled as a separate catchment but was later discovered to receive overbank spills from the Chela. Notwithstanding this discrepancy the calibration was surprisingly good;

- In the Juri River catchment, discharge records are affected by a split in the channel upstream of the Continala gauge and by backwater effects from Hakaluki Haor and the Kushiyara River. The discharge measurement location was later moved to Silghat, upstream of the channel split, which gives much better calibration. However, the backwater problem still remains;

- The Sutang gauge is also affected by backwater conditions which makes the development of an accurate rating curve impossible;

- The Karangi River discharges are affected by overbank spills from the Khowai River during floods and therefore the peak flows cannot be used for calibration;

- Most locations are affected by ungauged overbank spills to one extent or another, which results in peak flows being underestimated. The Karangi and Sutang Rivers receive overbank spills from the Khowai River and the flood measurements are therefore not representative of the catchment runoff

- Most locations have rating curves that are extrapolated from relatively low discharge measurements, which leads to uncertainty in the actual flood flows to be used for calibration.

A somewhat more detailed study was done in the Sarigowain catchment. This catchment was selected because:

- It has good quality discharge data and continuous records of water level (not daily or 3-hourly data as at other locations);

- It is located near an hourly recording rain gauge.

Hourly and daily rainfall data and hourly, three-hourly, and daily discharge data were used in the analysis. Discharge rating curves were reviewed and the gauge location was confirmed in the field. The reach upstream of the gauge was also inspected to determine the nature and magnitude of overbank spills upstream of the gauge.

The ungauged overbank spills were estimated to represent 25% or more of the peak flow. Allowing for this overbank spill, the calibration results for this catchment were good. It was observed that daily resolution of discharge was adequate to define flood peaks for this catchment (this is not the case in all boundary catchments). These results were encouraging.

6.2 Full Model Schematization

The NAM model was re-schematized to correspond to the HD model discretization. Boundaries of the internal catchments were modified and the model was re-calibrated. No changes were made to the cross-border catchments except for Catchment 3A and the Lubha River (Catchment 3), which were re-simulated using the NAM irrigation model.

6.3 Re-calibration of the Cross-Border Catchments

A more detailed study was made by NERP of selected boundary catchments using the NAM model. The irrigation model was used instead of the standard model since it provides a more sound description of the infiltration process. The objective was to improve the accuracy of the model in simulating boundary inflows.

Generally the program involved five components:

- sensitivity tests of model parameters;
- re-calibration of the Sarigowain catchment;
- trial calibrations in three other catchments representing a range of conditions (Bhogai, Jadukata, and Sonai Bardal catchments);
- detailed calibration of the Manu catchment;
- re-delineation of catchment areas.

6.3.1 Sensitivity Analysis

The sensitivity analysis has been an important guide in estimating model parameters in the calibration process. The purpose was to identify which key parameters affect the simulation of peak discharges and runoff volumes the most. Generally this involved systematically varying one parameter at a time while holding the other parameters constant.

A model was set up for the Sarigowain catchment using the irrigation model. Starting values for the various parameters were taken from the SWMC calibration of the Lubha catchment which is located adjacent to the Sarigowain. The model was run for a number of combinations of parameters and the results were compared to determine their variation.

Peak flows in both the NAM irrigation model and the NAM standard model were found to depend primarily on the parameters which represent the time response and surface storage in the catchment (CK1, CK2, and CKIF). Runoff volumes were found to be quite insensitive to all model parameters, including the soil moisture storage parameter L_{max}.

6.3.2 Re-calibration of the Sarigowain Catchment

Recorded discharges at Sarighat were revised when it was observed that the rating curve did not fit the low-to-intermediate discharges very well. Both the NAM irrigation model and the NAM standard model were then re-calibrated against the revised discharges. The results in both cases were better than those of the previous pilot calibration. However, both showed significant deviations in individual events which were attributed to:

- the lack of rainfall measurements within the catchment;
- the presence of overbank spill upstream of the gauge location which could not be adequately quantified.

A comparison of the pilot model calibration with the revised calibration is provided in Figure 20. The irrigation model was found to yield results that were more-or-less comparable with those of the corresponding standard model if the models were similarly calibrated. However, peak flows were higher with the irrigation model which seems to be justified in view of the ungauged overbank spill upstream of the gauge.

6.3.3 Calibration of Bhogai, Jadukata, and Sonai Bardal Catchments

The potential for improving the calibration was further investigated in three catchments which represent a range of hydrologic conditions. These are the Bhogai, the Jadukata, and the Sonaibardal catchments.

The Bhogai is a small catchment on the west side of the Meghalaya (Catchment 19A in Figure 19), and is generally representative of the smaller catchments in the vicinity. The Jadukata (Catchment 48 in Figure 19) is one of the largest border catchments and is located centrally in the Meghalaya region where the rainfall is greatest. The Sonaibardal (Catchment 26 - Figure 19) is located in the Tripura region and is somewhat unique in that it has a more gradual response than other border catchments. This unusual response appears to be due to its elongated shape and considerable floodplain storage.

These catchments were modelled using the NAM irrigation model and the NAM standard model. Results of the revised calibration were compared with those of the pilot calibration. Generally it was concluded that some improvement in NAM model calibration is possible but that the model calibration is too limited by the lack of rainfall data to accurately represent individual runoff events. Other observations were:

- the standard model and the irrigation model produce much the same total flows when they are suitably calibrated, but yield substantially different flow components (surface runoff, interflow, and groundwater flow);

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- considerable improvement in simulation of peak flows is possible by making judicious selection of the time coefficients (CK1 and CK2), while the other parameters can be used to fine-tune the calibration.

6.3.4 Detailed Calibration of the Manu Catchment

A more detailed calibration was made of the Manu catchment using the NAM irrigation model. The Manu catchment was selected for several reasons:

- it contains an important project, the Manu Project, that is sensitive to the magnitude of incoming flood discharges;

- discharges appear to be increasing, possibly due to watershed changes and projects upstream of the gauge location;

- it is generally representative of other Tripura catchments, especially the Khowai, Dhalai, and Juri catchments, in topographic and hydrologic conditions;

- it has extensive discharge data for calibration.

The irrigation model was used in the analysis because of its better description of the infiltration process, and because it could be sub-divided into a number of sub-catchments, each having different properties. This latter feature is important in the Manu catchment which is non-homogeneous and is not described well with a lumped, single catchment model. It has a ridge-and-swale topography aligned parallel to the river. The catchment contains a band of high ridges which drain to a lower band of piedmont plains and then to a low flat floodplain along the Manu River.

Initially the catchment was modelled with a single-catchment model. Hydrograph shape parameters (CK1, CK2, and CKBF) were estimated by hydrograph analysis of several peak events. Initial values of other model parameters were estimated and were adjusted in the subsequent calibration.

Initial calibration results using the single catchment model were disappointing. Model parameters were systematically varied in an attempt to improve the calibration. Rainfall weighting parameters were reviewed and point rainfall data from individual rain gauges were tried. Crop coefficients were applied to improve the seasonal estimates of potential evapotranspiration. BARC potential evapotranspiration estimates, which were computed using the Penman method, was substituted for pan evaporation. None of these changes made a significant improvement in the simulation of peak flows nor in the overall water balance.

Significant improvement was obtained when the catchment was divided into three sub-catchments, each representing the three different zones of the catchment. In the final analysis the best results were obtained with 30% of the catchment modelled as highland, 20% as piedmont plain, and 50% as lowland floodplain, which roughly corresponds to the distribution of topography in the catchment. Peak flows were, however, considerably higher than were indicated by the recorded discharges.

On the assumption that the discrepancy in peak discharge rates was due to under-estimation of floodplain storage, two methods were tried to increase the surface storage effect. These included:

- increasing the time parameters in different sub-catchments which has the effect of increasing the surface storage;

- representing the floodplain storage explicitly by routing the NAM discharges through an HD model of the floodplain storage.

The second approach was found to be the more successful. The NAM model was linked to an HD model that consisted of one link and attached floodplain, and the floodplain storage was varied incrementally until the flood peaks were better represented. This approach was able to improve on the estimation of peak discharges but it distorted the overall shape of the hydrograph such that the flood runoff volumes appeared to be too high.

Finally an overbank spill was added upstream of the discharge gauge on the assumption that some portion of the flow is being lost from the channel during flood peaks. A single reach of river was modelled with the HD model, using cross-sections that were surveyed in 1992, and a weir was added at bankfull stage to represent the overbank spill. The width and elevation of this weir were adjusted until the downstream channel discharges best matched the recorded flows at Manu Railway bridge. This change made a significant improvement in the modelling of the Manu catchment.

The hydrograph of simulated discharge at Manu Railway Bridge is compared with the recorded discharges and with the pilot calibration in Figure 21. Generally the simulated peak flows agree well with the recorded discharges although there are several events such as in 1988 when the modelled discharges are still too low. The larger flood peaks are well represented.

The river has been recently confined by embankments upstream of the Manu Railway Bridge and these embankments have recently been re-sectioned. However further investigation revealed that the embankments have breached during high floods. Field investigation and BWDB reports indicate that several breaches occurred in 1993 and totalled approximately 700 m in length.

Good calibration was achieved in the model by assuming weir widths of 500 to 1,000 m, which coincides with the field reports. For this condition the overbank spill was of the order of 1,000m^3/s. This is approximately the same magnitude as the in-channel peak discharge which was recorded at Manu Railway Bridge and implies that as much as one-half of the peak flow may have bypassed the gauge.

Much of the flood spill collects in the floodplain and returns to the Manu River further downstream, where it spills into the Manu Project through breaches and public cuts. There have been similar reports of overbank spills from the Dhalai River which drains into the Manu River. These overbank spills also collect in the floodplain and then return to the river downstream of the gauge location.

The implications for the Manu River are that the flood peaks may be significantly under-estimated in the existing discharge data. This observation is consistent with earlier experience in the HD model. These conclusions are not definitive, however, due to the variability which is introduced by the lack of rainfall data within the catchment. Therefore discharge measurements are required upstream of the spilling reach to confirm these indications.

6.3.5 Re-delineation of Catchment Areas

The watershed boundaries of several catchments were reviewed and revised. These included the Chela, Bhogai, Lungla, Karangi, Sutang, Manu, and the abutting catchment 37B. Catchment 33A was divided into three sub-catchments (16B Malijhi, 16C Darong, and 33A - the remainder which is located within Bangladesh). The boundaries and drainage area of catchment 33 were also revised, as were those of the abutting catchment 59B. Revised catchment boundaries are included in Figure 19.

6.4 Discussion of Results

Calibration of the boundary catchments indicated that the irrigation model simulates the rainfall runoff process better than the standard NAM model. The experience suggested that the model can be made to simulate runoff volumes well if there is enough data for simulation and calibration. However the model could not be made to consistently reproduce flood peaks due to the variability of rainfall and the lack of rainfall data within the Indian portion of the catchments. Overbank spills upstream of the calibration points also affects the reliability of the calibration. In most cases it was found that the boundary inflows in ungauged basins could be better estimated from data for adjacent basins as will be discussed later in this report.

The model also suffers from being a lumped catchment model. Some improvement can be made by dividing the catchment into sub-catchments having different parameters as was done in the Manu calibrations.

In the final analysis the NAM model was used mostly for simulating runoff from the internal catchments, that is to say those which are located within Bangladesh. These flows are damped by floodplain storage in the HD model such that the accuracy of peak flow rates is less critical. However there is little data with which to verify the simulated discharges other than groundwater data and measured discharges in one catchment, the Mogra River at Netrokona, which provide only a qualitative calibration.

It appears that overbank spills may represent a significant proportion of the peak flows in the boundary rivers. This is a significant consideration in planning and designing projects in boundary rivers such as the Manu River. Further efforts are needed to measure the boundary discharges upstream of these overbank spills. Their impact on downstream rivers is attenuation by storage on the floodplain.

7. HD MODEL DEVELOPMENT AND CALIBRATION

7.1 "Pilot" Model January 1991 to June 1992

SWMC began work on a pilot model in early 1991, before the start of the Northeast Regional Project. The pilot model was intended to provide a basic representation of the region which would form the basis for a full model in the subsequent stage.

At the start of the program river cross-section data existed for some of the larger rivers; the Surma River from Amalshid to Sunamganj, the Old Surma River from Sunamganj to Markuli, and the Kalni, Baida, Dhaleswari, and Meghna Rivers from Markuli to Chandpur. These cross-sections had been surveyed by BWDB Morphology Directorate in 1989 and 1990. Detailed cross-section surveys had also been conducted of the Khowai River in 1988 by BWDB.

Forty-five new cross-sections were surveyed by SWMC between April and June 1991. During the winter of 1991-92, 154 additional cross-sections were surveyed; 99 of these were included in the pilot model and the remainder were added later after they were tied to BWDB datum.

A hydrometric data collection program was also initiated to collect additional data on water levels and discharges for the model calibration. Eleven new discharge monitoring locations were added in the 1991/92 water year and ten were added in 1992/93, bringing the total number of gauges available for model calibration to 45. The major priority was to measure discharges in the boundary rivers, as far upstream as possible, to provide data on inflows to the model which was generally lacking.

In addition, 12 water level gauges were added to the network in 1991 and 8 were added in 1992, bringing the total number of water level gauges to 73. Most of these stations were operated on a twelve-hourly basis (five readings taken every three hours from 6:00 A.M. to 6:00 P.M), but a selected few in the downstream tidal area were operated for 17 or 24 hours each day.

The pilot model was set up in two sub-models, east and west, divided roughly on each side of the central depression. Calibration of the pilot model was completed in June 1992 using hydrometric data up to the end of October 1991.

Financial assistance and a field monitor in the survey program were provided by NERP. Part of the cost of the hydrometric program was also paid by NERP. To achieve closer coordination between the two projects and to help in the field programs, part of the NERP modelling team worked at the Modelling Centre for approximately six months during this period.

7.2 "Full" Model July 1992 to June 1993

SWMC worked from July 1992 until June 1993 on developing the "full" model. Essentially the model is a combination of the east and west sub-models, expanded to include better definition of the floodplains and extended to include upstream reaches of several boundary rivers. Other improvements were made in the Surma-Kushiyara floodplain and in the extension of the Surma and Kushiyara Rivers upstream to Amalshid, which permitted better representation of the flow split between the two rivers and their floodplain.

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Eighteen additional cross-sections were surveyed during the winter of 1992/93 and were incorporated into the model, as were several of the remaining cross-sections which had been surveyed in 1992 and were tied to BWDB datum in 1993. At the same time the NAM model was re-discretized to better match the HD model setup, and its calibration was reviewed.

The model was calibrated for the 1991 and 1992 water years. Calibration was completed at the end of May 1993 and the model was installed at NERP in June 1993.

Much effort was spent at NERP in consolidating and checking the model data base. The locations of several of the cross-sections were checked and revised or verified. A separate data base was compiled which contained the original cross-sections, prior to modelling revisions. Discrepancies between the original survey data and the cross-sections as entered into the model were checked and resolved. Locations of the surveyed cross-sections were checked and verified.

A utility program was developed at NERP to help in this process. Its primary function is to develop a map of the model in AutoCad format, directly from the MIKE-11 model setup file and cross-section data base. It also checks for configuration errors, discrepancies in cross-section locations, missing cross-sections at junctions, and other potential error conditions. It also checks the survey data base to identify the cross-section. It locates cross-sections which have been extended using map data. This program has proven to be extremely valuable in diagnosing and resolving model errors.

Further work continued at NERP during this time period in completing the hydrometric data base and in developing a methodology for mapping the flood depth and extent as was described in Chapter 5.

The "full" model was installed at NERP in June 1993. This model, after further refinement at NERP, became the basis for the simulation of the Regional Plan.

7.3 NERP6 Model

After installation of the full model at NERP a number of revisions were made prior to modelling the Regional Development Plan. These included changes to the Manu, Juri, Kushiyara, Khowai, and Meghna Rivers, Shanir Haor, and adjacent channels near Sunamganj. Preliminary results of the second-order survey program were included in the central portion of the region, where datum errors are particularly significant.

These changes were verified by re-calibration using the 1991 water year. The resulting model (version NERP6.3) was used as the basis for the initial Regional Plan simulations and pre-feasibility studies. These changes are summarized below.

Manu and Juri Rivers
A sub-model was constructed to facilitate changes in the Manu River and Hakaluki Haor and to model the proposed Manu River diversion into Hakaluki Haor. The locations of several cross-sections were corrected. The model was extended upstream of Manu Railway Bridge using an additional cross-section which was surveyed in 1992. Several additional cross-sections were

surveyed by NERP and were added to the model between Maulvi Bazar and the mouth of the Manu River to improve the representation of this reach and the calibration at Maulvi Bazar.

The schematization of Hakaluki Haor and the Juri River was also revised to include additional cross-sections which were surveyed by NERP in 1993. Cross-section locations were reviewed and revised. A weir was added in the model to cure instability problems at the inlet to Hakaluki Haor.

The revised sub-model was recalibrated for the 1991 water year and was used in modelling the Manu Diversion project. These changes were then incorporated into the full model.

Upper Kushiyara River

The model was extended to permit the boundary location to be moved upstream of Amalshid. The calibrated model was used to estimate the inflows from the Barak River for the 1991 water year. These changes enabled the Surma/Kushiyara flow distribution to vary according to downstream conditions rather than being fixed in the model.

Subsequent to the Regional Plan simulations the Barak inflows have been revised in the NERP7 version of the model using rating curves for the Kushiyara and Surma Rivers. These were derived to include the results of the 1993 monitoring program.

Upper Khowai River

The Khowai River was extended upstream from Shaistaganj to the Indian border at Ballah in order to permit simulation of overbank spills. During high flows a significant portion of the Khowai flow spills overbank into the Karangi River, and options were being considered for extending the Khowai embankments upstream.

Field observation in 1991 and 1993 indicated that the Khowai spills into the Karangi in at least two locations upstream of Chunarghat. The largest of these spills occurs a short distance upstream of the start of the embankment. Other spills occur nearer to Ballah but appear to be confined mostly to the floodplain. These overbank spills have a significant effect on discharges and water levels in the Khowai and in the Karangi.

The Khowai River was extended in a sub-model which was initially calibrated for the 1991 water year (later extended to include 1992 and 1993). The sub-model included several cross-sections which were surveyed by BWDB in 1988. The overbank spills upstream of Chunarghat were modelled using a broad-crested weir at the top-of-bank elevation.

The model was run with Ballah as a water level boundary. The dimensions of the Chunarghat spill weir and the roughness of the channel were adjusted until the water levels at Chunarghat, Shaistaganj, and Habiganj, and the discharges at Shaistaganj, best reproduced the recorded levels. Model results were used along with observed discharge data to help develop the rating curve at Ballah which was later used to generate boundary inflows for subsequent model runs.

The sub-model revisions were later brought into the main model.

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Meghna River downstream of Bhairab Bazar

A sub-model was constructed of the Meghna River from Bhairab Bazar to Satnal using a number of cross-sections which were provided by the General Model group of SWMC. The cross-sections were reviewed and a number of revisions were made to chainages, locations, and coordinates.

The sub-model was calibrated using water level data for 1991 at several locations between Bhairab Bazar and Satnal. Recorded discharges were input at Bhairab Bazar (the upstream boundary), and recorded water levels were used at Satnal (the downstream boundary).

This sub-model was used during the Regional Plan simulations to evaluate the feasibility of a proposed bypass around Bhairab Bazar. Modelling of this proposal indicated that it would reduce the upstream flood levels by at most 0.2 m; furthermore there were serious concerns regarding the impact of sedimentation on the long-term sustainability of this proposal and it was dropped from further consideration.

The sub-model can be easily added to the main model if there is a need to do so. However for most applications Bhairab Bazar is a suitable water level boundary. Therefore the main model has not been extended in order to minimize execution times.

Haors near Sunamganj

The Rakti River was added to the model schematization and Shanir Haor, Matian Haor, and Halir Haor were modelled as separate flood cells. Several cross-sections which were surveyed by NERP in the surrounding channels (Rakti, Patnaigang, Nandiagang, and Jadukata) were added to the model in order to improve the resolution in this area for project purposes. The floodplain links to the adjacent rivers were also modified to reflect the revised schematization.

Preliminary SOB datum adjustments

Preliminary results of the second-order benchmark levelling program were applied in the central deeply-flooded area. These included adjustments of approximately of 0.5 m at Khaliajuri and Itna, 0.3 m at Dilalpur, and 0.8 m at Chamarghat. Hydraulic gradients are small in this part of the Northeast Region due to the extensive flow on the floodplain and they affect a large part of the region. The datum adjustments reduced the overall hydraulic gradient in this critical area by as much as 50%.

The elevations of the Baulai and Ghorautra River cross-sections were adjusted according to the indicated datum corrections. The model was then re-calibrated by changing the dimensions of the control weirs that define the overbank spills and by adjusting the roughness of the floodplain so as to match water levels at Sukdebpur.

At other locations the effects of datum errors are more localized and are less critical to the overall model performance. Other datum changes were therefore deferred until the survey results could be finalized.

Instability Problems

A number of other changes were made to the model to solve instability problems which occur in the steep border tributaries and cause the model to crash unpredictably from time to time.

These problems have mostly been solved by adding a vertical slot to the bottom of the channel. This artificial slot allows the water levels to fall below the bottom of the real channel and helps to prevent the abrupt transitions that lead to instability in the model. Dry-season water levels are not modelled correctly as a result but this is of little practical significance in the border tributaries. In some places an artificial weir was added to help prevent the channel from drying out completely.

At two locations in floodplain routing channels, similar conditions resulted in continuity errors and in an artificial increase in simulated winter discharges. These problems were solved by adding small artificial slots to the bottom of the cross-section.

7.4 Verified Full Model July 1993 to November 1993

Further changes to the model were made by SWMC between June and November 1993. Mostly these changes resulted from consolidation and clean-up of the model data bases and review of cross-section locations. The model was verified using monitoring data from 1993, which included a severe flood in the region and provided excellent data for calibration. A report on the "full" model calibration was submitted by SWMC in December 1993.

These changes and other revisions have been incorporated into the latest version of the model (NERP7).

7.5 NERP7 model

7.5.1 Model Revisions

A number of additional changes were made to the model by NERP subsequent to the preparation of the Regional Plan. These changes arose from the experience in the Regional Plan modelling and the pre-feasibility studies. The final results of the second-order survey program were also included. The principal changes are discussed below.

Surma River water levels
A junction was added at km 99.8 of the Surma River, near Rampur, to better approximate the energy transfer from floodplain flows and its effect on water levels at this location.

Surma/Kushiyara floodplain
The Kushiyara floodplain north of Markuli was re-schematized to include the Mahasing River and additional links to the Old Surma and Kushiyara Rivers. Water levels in the floodplain north of Markuli were previously too high. Several changes were made in the Old Surma River, and the floodplain conveyance was adjusted in order to provide better simulation of water levels. Water levels were monitored in the floodplain by NERP in 1993 at Dhal Bazar, north of Markuli, and these data were used in the calibration.

It was observed that discharges in the connecting channels (the Surma and Bhattadahuka Rivers) are very sensitive to small changes in water levels in the floodplain. This sensitivity has provided a demanding test of the model calibration in this area. The calibrated model reproduces these discharges well.

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Low Flow Conditions
Winter discharges and water levels were found to be generally too high in the lower Surma and Baulai River during the winter season, which affected the ability of the model to predict changes with the channel improvements which are proposed in this area. The problem was traced to continuity errors in a dry channel and was corrected by replacing the problem link. Winter discharges were found to be too high in several border tributaries and were adjusted to match the observed discharge data.

These changes made a significant improvement to the calibration.

In addition it was observed that the available cross-sections do not provide sufficient resolution of the Nawa and Baulai River channel between Sunamganj and Sukdebpur. This reach forms the transition between the upstream transport reach and the downstream backwater reach during the monsoon season. Reconnaissance surveys during the winter of 1993/94 indicated that this reach is quite irregular, having unusually deep scour holes and shallow sections. Consequently several additional cross-sections were surveyed and were added to the model.

SOB datum adjustments
Cross-sections were adjusted for the datum corrections which were found in the second-order levelling program.

Preliminary adjustments had been made earlier, prior to the original Regional Plan simulations, in the central basin where the gradients are small and the datum errors were significant. These were extended to include other reaches of the model. Water levels and cross-section data were adjusted for the datum corrections. Generally datum corrections of less than 0.1 m were not considered to be significant and were ignored.

These changes improved the reliability of model calibration. It did not materially affect the central basin where the datum corrections had been made earlier.

Khowai River
The Khowai sub-model was revised to include the cross-sections which were surveyed in 1991 and 1992 as well as BWDB's 1988 cross-sections.

The floodplain conveyance was increased in the upstream reach to better represent the overbank spills. All cross-sections were corrected for gauge datum errors. The revised model was recalibrated to include the 1993 flood. A rating curve was developed from the model results to estimate discharges at Ballah for other years and to provide boundary data for the model. An intensive discharge monitoring program was also been undertaken (by SWMC) during the 1994 monsoon to confirm the rating curve and boundary discharges at Ballah.

Outlets from flood cells and haors
Flood cells in the model were provided with deeper outlets to permit them to drain during the post-monsoon and winter seasons. Previously the flood cells had retained water during the winter season. The weirs which represent the outlets were modified to add a narrow slot to permit the flood cells to drain.

Cross-section locations
The latitude and longitude of the model cross-sections were reviewed and were revised to correspond to their actual locations. Junction locations were also checked and the attached cross-sections were moved as required.

7.5.2 Revised Calibration

The revised NERP7 model was re-calibrated for the 1991, 1992, and 1993 water years[9]. Particular emphasis was placed on simulation of the 1993 conditions since flood levels were among the highest ever experienced in the region. Calibration involves comparing the simulated water levels and discharges with those that have been measured within the region, and adjusting model components as required. Results will be reviewed below.

Representative hydrographs at key locations are provided in Figures 22 through 27. In general the calibration was considered to be adequate for a regional model. The calibration results were generally best in those areas that were given specific attention, such as the Kushiyara, the Manu, and the Khowai Rivers. This implies that given enough time, effort, and field data, equally good results are possible at other locations as well. Calibration also tended to be best near boundary locations. Sometimes the differences appear to be due to errors in the water level records. Thus the model may be used as a tool to help check and correct the field data.

As a general rule the water levels agree better with recorded levels than do the discharges. This is because the water levels are less sensitive to modelling approximations and local conditions, for example the exact location of an overbank spill.

It should be noted that a rigorous or perfect calibration is not possible and should not be expected owing to:

- the complexity of the hydraulic and hydrologic processes;
- limitations in the quality of the input data, including the data that are being used for comparison;
- the fairly coarse resolution which is required in a regional model.

Surma and Kushiyara Rivers
Calibration results in the Kushiyara River are very good (see Figure 22 at Sheola and Figure 23 at Markuli). Simulated water levels are within 0.5 m of the recorded levels most of the time and the peak water levels are almost identical. Figure 23 shows that good calibration results were achieved at Markuli.

The calibration is also good in the Surma River. Water levels are generally within 0.5 m of the recorded levels. As in the Kushiyara River, the calibration is generally best in the upstream reaches.

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[9] The water year starts on April 1 of the calendar year and extends until March 31 of the following calendar year.

Surma/Kushiyara Floodplain
Monitoring data in 1993 provided an excellent opportunity to confirm the modelling of floodplain discharges at Sherpur, Fenchuganj, and Sheola. Floodplain discharges are simulated well.

Kangsha River
Calibration results are good in the Kangsha basin as shown in Figure 24 for Sarchapur. The simulated water levels are generally within 0.5 m of the recorded levels and the discharges show good agreement. Water levels and discharges are reproduced well in the upper Someswari River (the Shibganjdhala). Peak discharges are slightly underestimated at Jaria Janjail and peak water levels are also slightly too low.

Discharges are poorly simulated at Mohanganj and at Kalmakanda, apparently due to significant floodplain spills. A recently formed avulsion is the likely cause of the discrepancy at Mohanganj. There are large floodplain spills near Kalmakanda and the exact location of these spills may not be represented properly. However, water levels are simulated well.

More cross-sections have been recently surveyed in the Kangsha basin, and these will be used to refine the model during feasibility studies.

Eastern Meghalaya Tributaries
Simulation of the Meghalaya tributaries is generally good except for two locations (Ururgaon and Muslimpur) where the results are only fair. A high degree of accuracy is not required in these rivers and indeed is not possible in the regional model because of their steep slope and overbank flows. More cross-sections and shorter time steps could be provided in reach-specific sub-models, if it is required for more detailed study.

Winter water levels are modelled poorly in several rivers. This occurs where artificial slots have been added to cure the instability problems which were mentioned earlier. Aside from the aesthetic problem, the winter water levels in these border rivers are of little practical significance to the Regional Plan.

Tripura Tributaries
The main tributaries (Manu, Dhalai, and Khowai) are simulated well. Figure 25 shows the calibration results in the Khowai River at Shaistaganj. Water levels and discharges are both simulated well, and the peak water levels are generally within 0.3 m of the recorded peak. Similar results were achieved in the Manu and Dhalai Rivers. The calibration included provision of overbank spills upstream of Chunarghat and, in 1993, near Shaistaganj.

The Karangi and Sutang River levels are not simulated well. More field surveys are required to represent these rivers properly, and the Sutang gauge needs to be moved upstream outside the influence of backwater from the deeply flooded central basin.

Central Basin and Meghna River
Excellent calibration has been achieved in the central basin (see Figure 26 for Sukdebpur). The available discharge data, which unfortunately is quite limited, confirms the modelled discharges in the Baulai river. This is an important part of the regional model and, therefore, the calibration results are encouraging.

Figure 27 shows the simulated and observed discharges at Bhairab Bazar, the outlet from the region. As has been the case in previous simulations the discharges appear to have a phase lag, which may be due to two possible causes:

- underestimation of flood discharges in border tributaries due to overbank spills;
- overestimation of surface storage in the NAM model.

This phase lag error is too small to be of much practical significance. Recent improvements in the NAM model which include a linkage between surface storage in the NAM model and floodplain storage in the HD model, may help reduce the residual error. Continued efforts should be made to improve the measurement of flood peaks in the tributary rivers.

7.6 Assessment of Results

A large number of improvements have been made in the HD model and its calibration both at SWMC and at NERP. As a result the model and its calibration are considerably improved over that which was possible in the pilot stage of the program. Generally the results are judged to be adequate for regional planning purposes and perhaps as good as can be expected from a regional model. There is still room for further improvement which will be made during feasibility studies when specific attention can be focused on individual areas of the model.

Boundary tributaries are not represented as well and should be regarded as being only generally correct until more detailed modelling of these tributaries is done. A significant improvement has been made, especially in the central basin, by including the datum corrections of the second-order levelling program.

Further review of the accuracy of the model is made in Chapter 10 based on the results of the nine-year simulation of existing conditions.

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8. TIPAIMUKH DAM AND CACHAR PLAIN PROJECT

8.1 Simulation of Project Operation

A simulation was made to estimate discharges in the Barak River at Amalshid after the Tipaimukh Dam is constructed. These data are required for simulation of the future conditions with implementation of the project.

The Tipaimukh Dam is proposed to be constructed on the Barak River in India approximately 200km upstream of Amalshid. It will significantly affect the discharges in the Kushiyara and Surma Rivers as will be shown below. The dam is planned primarily for power generation but will also be operated to control flooding in the Barak floodplain within India downstream of the dam. Such operation would also reduce flooding in the Northeast Region. Water will be withdrawn from the river downstream of the dam in order to irrigate the Cachar Plains project.

Little is known about the proposed design and operation of the project. Salient characteristics of the Tipaimukh Dam and reservoir which were provided by the Joint Rivers Commission (JRC) and are documented in NERP's hydrology study[10] are summarized in Table 8.1.

8.1.1 Methodology

The simulation was made with a custom water balance program which simulates the operation of the reservoir. Inputs are the recorded discharges in the Barak River at Amalshid. The program computes the inflow to the reservoir, the outflow under various operating conditions, and the resulting discharge at Amalshid. The proposed irrigation withdrawal for the Cachar Plains irrigation project in India is subtracted from the regulated Barak River discharge. The assumed operation of the reservoir and other assumptions in the calculation are described below.

Model inputs (existing flows at Amalshid) were derived by applying the rating curves for the Surma River at Amalshid and the Kushiyara River at Amalshid in order to compute the discharges in the two channels. These were added together to derive the total discharge in the Barak river for the existing, unregulated case.

Table 8.1: Salient Characteristics of Tipaimukh Dam and Reservoir

Type of dam	Rockfill structure
Height	160 m
Crest length	390 m
Full supply level	175 m
Highest flood level	178 m
River bed elevation at the damsite	22 m
Reservoir gross storage	16 km^3
Reservoir live storage	12 km^3
Surface area	219 km^2

10/ "Flood Hydrology Study", FAP-25 Flood Modelling and Management, Krüger Consult in association with BCEOM, June 1992.

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Initially the simulation was made for the 1991 water year during the Regional Plan simulations. More recently they were extended to include the period from 1985 to 1993 as part of the extended simulations of the Regional Development Plan.

8.1.2 Assumptions

The reservoir operation was simulated according to the following assumptions:

1. The inflows to the reservoir were estimated to be 40% of the recorded discharges at Amalshid on the basis that 40% of the Barak River drainage basin is located upstream of Tipaimukh. The remaining 60% is located downstream of Tipaimukh and will therefore be unregulated.

2. The withdrawal for irrigation in the Cachar Plains project was assumed to be 100 m^3/s from November 1 to April 30 as per estimates made in NERP's hydrology study.

3. The turbine flow (for power generation) was assumed to be 405 m^3/s, the turbine capacity, throughout the year in accordance with the data supplied by the JRC. The proposed power release is sufficient to supply the irrigation demand of 100 m^3/s and therefore no additional winter releases will be required.

4. Approximately two-thirds of the available live storage was assumed to be reserved for power supply and the remaining 4,000 million cubic metres was assumed to be available for flood control based on preliminary estimates of flood storage requirements. The actual distribution will depend on operational studies which would be done during the design of such a project but are not available to NERP.

   It is noted on the basis of the above assumptions that the average inflow to the reservoir would be 440 m^3/s in an average year which is just barely sufficient to supply the average power generation demand (405 m^3/s). There would be a 50% shortfall in dry years which would need to be met from carry-over storage from previous years. Therefore the reservoir would be operated to conserve water and the river discharges would be highly regulated.

5. The dam and reservoir were assumed to be operated according to the following rules:

   - during normal operation the dam would retain water for power generation; releases would be only as required for the turbines (405 m^3/s as described above);

   - when the reservoir rises to Full Supply Level (8,000 million cubic metres as assumed above) the excess inflow would be spilled in order to save storage capacity for flood control;

   - during flood conditions the spillway gates would be closed in order to reduce flooding along the Barak River. Releases would be limited to 405

m^3/s as required for power generation which would still be lower than the natural flow during these conditions.

6. The spillway was assumed to discharge at a rate of 800 m^3/s, which was estimated as the capacity required to empty 4,000 million cubic metres of flood storage in four months (the actual design discharge is not known).

7. The reservoir was assumed to be one-half full at the start of the simulation.

8. Flood stage in the Barak River valley was assumed to correspond to a discharge of 3,000 m^3/s, the approximate bankfull stage at Amalshid.

8.1.3 Results

Simulated hydrographs of reservoir inflow, outflow (minus irrigation demand), and storage volume for the 1991 to 1993 period are shown in Figure 28. In general the flood discharges in the Barak River would be reduced and the winter discharges would be increased. During the peak of the 1991 flood the outflow would be reduced by 1,800 m^3/s since there would be no releases other than for power generation during this period. The peak outflow would be 1,200 m^3/s which would occur after the flood had passed.

During a dry year such as 1992 the reservoir outflows would be constant at 400 m^3/s throughout the year and there would be no flood spill. Thus the peak flows would be reduced by 1,100 m^3/s (from 1500 m^3/s to 400 m^3/s). During 1993 the reservoir levels would exceed Full Supply Level. Initially there would be no flood releases, but these would occur later in the year when the flood peak had passed (the simulation ended in July 1993 and will be further extended when more data is available).

Thus there would be considerable reduction of flood peaks in the Barak River. These flood benefits extend downstream to Amalshid, even allowing for the intervening inflow. Resulting discharges at Amalshid are shown in Figure 29. Flood peaks would be reduced by one-third in a wet year such as occurred in 1991 and 1993[11/].

Dry season releases would be held constant at 405 m^3/s. Approximately 100 m^3/s would be withdrawn from the river further downstream to supply the Cachar Plains irrigation project, with the result that the winter flows would be increased by as much as 300 m^3/s.

8.2 Dambreak Simulations

8.2.1 Purpose and Scope

A dambreak is a sudden catastrophic failure of a dam which drains the reservoir and causes a severe flood wave downstream. While such failures are rare they have happened to large dams from time to time.

11/ Flood storage reservoirs can actually cause higher discharges in an extreme flood, particularly if they are not operated wisely. Such extreme conditions are not considered in this analysis.

The Tipaimukh Dam will be located approximately 200 km upstream of Amalshid as shown in Figure 30. It would be located in a narrow steep-sided valley in the Tripura Hills. From the damsite the Barak flows northward in a narrow valley some 80 km, then turns westward and crosses the Cachar Plain, a low wide floodplain, before entering Bangladesh at Amalshid.

The purpose of the dambreak analysis was to define the potential impact of a sudden failure of the Tipaimukh Dam. Such a failure might occur due to overtopping, operational error, or earthquake damage. The analysis is not exhaustive but is only indicative of the order of magnitude impacts since only sketchy information is presently available about the project.

8.2.2 Case studies of Dambreak Failures

The technical literature contains reports of a number of dam failures around the world. Worldwide the failure rate of dams has been approximately one dam in 10,000 per year. This translates into a risk in the order of one percent that any one dam might fail within a 100 year period, which might reasonably be assumed as the life expectancy of such a project. Thus the probability of a failure is relatively low but finite.

The most common cause of failure has been seepage or piping in the fill or foundations. Spillway capacity (overtopping) is the cause in one-quarter of the cases. By comparison the incidence of failure due to earthquakes is relatively low, representing about one percent of the cases reported.

The Tipaimukh Dam is located in a sensitive earthquake zone. Earth/rockfill dams such as proposed for the Tipaimukh Dam appear to be relatively immune to direct earthquake damage owing to their large mass and flexibility of the fill. Failure could occur, however, due to large flood waves being generated by earthquake-induced landslides. Once a dam is overtopped and a breech is formed it grows rapidly due to spillage of water from the reservoir.

The critical variables are the rate at which the dam is breached and the size of the opening. The failure typically starts as a point breech at the crest of the dam and grows into a trapezoidal shape. Breech widths of 2 to 3 times the dam height have been reported, and failures have occurred over a few minutes to several hours. However there are too few occurrences and too much variability in site conditions for general conclusions to be reached.

Although the resulting flood wave can be quite impressive near the dam, past experience demonstrates that substantial attenuation can occur within a relatively short distance. However, this depends on the rate of failure and the volume of the reservoir. The Tipaimukh reservoir volume would be at least one order of magnitude larger than the largest dam that has failed and therefore the attenuation would likely be less significant than has been reported elsewhere.

Generally the flood wave travels downstream at a rate in the order of 10 km/hour although velocities as high as 30 km/hr have been reported near the failure site. With these velocities the initial flood wave would travel the 200 km from the damsite to the eastern limit of Bangladesh within about 24 hours.

Two examples illustrate the types of failures that have occurred. The Huaccoto Dam in Peru was 170 m high, similar to the Tipaimukh Dam; it failed over 48 hours due to a natural landslide in the reservoir. The Teton Dam in the United States was a 90 m high earthfill dam which failed in 1.25 hours. The flood wave had a peak discharge of 65,000 m^3/s at the dam and a height of 20 m in the downstream canyon.

Implications for the Tipaimukh Dam are as follows:

- the probability of dambreak failure is low based on the history of observed failures and the type of fill material, but some allowance must be made for earthquakes and the possibility of operational errors;

- the Tipaimukh reservoir is larger than any that have failed. The Teton Dam, for instance, which is about the largest reported, released a volume of 300 million m^3, which is only 2% of Tipaimukh's storage capacity. Thus the flood waves that could occur might well be larger than have been previously experienced;

- the ultimate size of the breech opening is the most important parameter with respect to the peak discharge rate, and the most difficult to predict. However, given the large volume of water that would be drained, a large portion of the embankment would be destroyed.

8.2.3 Modelling Methodology and Assumptions

The DAMBREAK module of the MIKE-11 computer model was used in the analysis. It simulates the dynamic behaviour of a flood wave, given the dimensions of the reservoir and of the valley downstream of the dam. The rate of failure and the dimensions of the breech must also be specified. Given the uncertainty as to the exact rate and mode of failure a range of possible conditions was tested.

The geometry of the reservoir and the downstream valley were approximated from available topographic maps. These maps were in a scale of 1:1,000,000 and 1:250,000 and show contours of 500 feet (150 m) and 200 feet (60 m). The valley sections are considered to be conceptual rather than an accurate representation. Assumed valley sections downstream of the dam are shown in Figure 31.

The breech was assumed to originate as a point failure at the crest of the dam and to become deeper at a constant rate. The width of the breech was assumed to grow at two times its depth and the side slopes were taken as 1:1 as has been reported in the literature. The limiting case was assumed to be one in which the breech would erode to a depth of 100 m (50 m above the base of the dam). However, several runs were made with shallower and deeper breeches to test the sensitivity of the resulting flows to the assumed breech geometry.

A failure time of 4 hours was initially assumed but this was varied from 0 to 24 hours. Peak flows at Amalshid were not sensitive to this parameter due to the extensive reservoir storage. Virtually identical results were obtained at Amalshid with an instantaneous failure as with a 24-hour failure.

The reservoir was assumed to be full at the onset of failure. Inflow hydrographs preceding and during the failure were modelled after the 1991 water year, which was approximately a 25-year return period event. Runoff was also included from the unregulated area between the dam and Amalshid. Amalshid was modelled as a stage-discharge boundary, with stage-discharge characteristics estimated by extrapolating the historic rating curve at this location.

Several problems were encountered with the computer model code for both the dambreak model and the control structure model which serves as its alternative. In the final analysis the dambreak had to be approximated as an instantaneous rather than time-variable failure. Sensitivity tests demonstrated that this is a reasonable approximation for the Tipaimukh Dam.

8.2.4 Simulation Results

Peak flows and water levels at Amalshid were found to depend mostly on the breech geometry. A variety of breech geometries were tested to determine the sensitivity of this parameter. These are summarized in Table 8.2 along with the peak discharge and water level which were computed in each case. It can be seen that the peak discharges at Amalshid could range from 12,000 to 100,000 m^3/s depending on the size of the breech. These flows would as much as 10 times higher than have ever been experienced.

Table 8.2: Flood Wave Characteristics for Various Breech Dimensions

Breech depth (m)	Breech width at bottom (m)	Peak discharge at Amalshid (m^3/s)	Peak water level at Amalshid (m)
50	0	12,000	20.0
50	100	27,000	23.0
50	200	32,000	23.5
100	0	40,000	24.0
100	100	62,000	27.0
100	200	75,000	27.5
200	0	75,000	27.5
200	100	100,000	30.0

Modelled flood waves are illustrated in Figure 32 for the case of a 50 m wide instantaneous failure 50 m above the base of the dam. Hydrographs are presented for three locations; at the exit from the mountain valley (km 80), at Silchar (in the middle of the Cachar plain, at km 140) and at Amalshid (km 200). It can be seen that substantial attenuation of the flood wave would occur. The flood peak at Amalshid would occur approximately 2 to 3 days after the dam had failed and flooding would continue for ten days or more. The flood wave would require approximately 24 hours to reach Amalshid.

Most of the released volume would be ponded over the Northeast Region. Assuming a flooded area of 100 km by

100 km and a released volume of 10 km^3, the average depth of flooding is estimated to be 1.0 m above the ambient flood level. The critical conditions would occur when the reservoir is full, at the height of the monsoon season, when the Northeast Region is already in a flood condition. High flows would persist for ten days or longer and the flooded area would likely take several weeks to drain.

9. PRELIMINARY SIMULATIONS OF THE REGIONAL DEVELOPMENT PLAN

9.1 Regional Development Plan Report

A preliminary simulation of the proposed projects was made during the preparation of the Regional Water Management Report in 1993. The initial simulation was made with a preliminary version of the model (version NERP6.3) and covered only the 1991 water year. Scenarios modelled included existing conditions, future without intervention, and Regional Plan projects.

Two scenarios were simulated; the future without intervention, and the future with the proposed regional plan in place. Separate simulations were made with and without the Tipaimukh Dam.

The initial simulations were made for the 1991 water year which was the basis for calibration at the time. The 1991 pre-monsoon flood ranged in severity from 1:2 years to more than 1:25 years, depending on location in the region (see Figure 33). The monsoon or annual flood had a return period ranging from less than 2 years in the central basin to more than 25 years in the Kushiyara River (Figure 34).

Results were included in the Regional Plan report[12/].

These simulations were subsequently extended in 1994 to include the period from April 1991 to the end of July 1993. This period included the severe flood of July 1993 which caused some of the highest levels ever recorded in the region. These simulations used a revised version of the model (NERP 7.0), which was similar to the earlier version except in the following respects:

- cross-section elevations were revised in accordance with the final results of the 1993 second order survey program (only cross-sections in the critical central basin had been adjusted earlier);
- the model was calibrated for three years from 1991 to 1993 as described earlier in this report, whereas only one year (1991) was simulated earlier;
- development concepts were refined in accordance with the project pre-feasibility studies which were prepared in late 1993 and early 1994, notably in the Kangsha Basin where the development plan has evolved considerably as will be described in the following section.

Results of the revised simulations were reported in the July 1994 draft of the present report.

The modelling has been subsequently extended to include nine years of simulation as will be described in Chapter 10. The methodology and results are similar to those which were presented earlier except that they cover a longer time period. Since the earlier simulations were superseded only the results of the final simulations will be reported herein.

12/ "Northeast Regional Water Management Plan", Northeast Regional Water Management Project, September 1993.

9.2 Kangsha Basin Pre-Feasibility Study

The Upper Kangsha basin consists of the Kangsha River and its tributaries from the Meghalaya state of India (the Malijhi, Chelakhali, Bhogai, Nitai, and Shibganjdhala Rivers). Flashy runoff occurs in the Meghalaya tributaries and spills over the low-lying, flatter topography of the Kangsha floodplain. This results in extensive flooding during the monsoon season. The ponded water is slow to drain because of the somewhat restrictive capacity of the Kangsha River channel.

A number of development options had been considered earlier, including one to confine the upper Kangsha within embankments so as to prevent it from spilling onto the Malijhi floodplain. The Chelakhali and Malijhi Rivers would be diverted into the Mogra basin in order to provide better drainage. Modelling of this scheme indicated that it would raise the flood levels within the confined reach and the Mogra River to an unacceptable degree. A number of alternatives were simulated with the computer model to test their effectiveness and their impacts. The simulations were made with a sub-model in order to reduce the simulation time. The sub-model extended from the upstream end of the Kangsha basin to the Baulai River. The sub-model also included the Mogra River and its downstream branches, the Dhanu and the Baruni Rivers.

Fourteen different alternatives and variations were modelled to compare their effectiveness and possible impacts. Out of this analysis the following scheme was recommended:

- extension of the existing Konapara Embankment all the way upstream to the Bhogai/Malijhi River confluence where it would connect with existing embankments along the Bhogai River;

- improvement of the Malijhi River and Bhogai River channels for 20 km upstream and 40 km downstream of Sarchapur in order to reduce flood levels and provide better drainage in this area;

- diversion of part of the peak plows at a rate of approximately 100 m^3/s from the Kangsha River into the Mogra River through re-excavation of an old channel which had silted in, combined with channel improvements in the Mogra River which would avoid increasing flood problems;

- embankment of the right bank of the Kangsha River between Sarchapur and Jaria Janjail, to connect with the existing Kangsha River Improvement Project embankment at Jaria, and draining the protected area into the Mogra River upstream of Netrakona;

- closure of the Atraikhali avulsion channel in order to arrest further shifting toward the east side of the Someswari fan.

Further information on the simulation of alternatives is contained in the Upper Kangsha Basin Development Report.

The revised scheme has been included in the Regional Plan model which was used in the present analysis.

The Kangsha basin is undergoing more detailed study in the Upper Kangsha Basin Plan which is under preparation. As part of this study the Kangsha sub-model is being revised to include updated and more detailed channel cross-section surveys. Additional water level and discharge data are being collected at key locations in the Kangsha basin to help calibrate the model.

10. EXTENDED SIMULATIONS OF THE REGIONAL DEVELOPMENT PLAN

10.1 Purpose and Scope

The model simulations were extended to include nine years of simulation, from April 1, 1985 to July 31, 1993. Objectives were as follows:

- to verify the model operation over a longer period of time;
- to confirm the changes in the region that had been identified or suspected through other sources of information;
- to simulate a broader range of hydrologic conditions than the 1991 water year which was used for the initial calibration;
- to provide a statistical basis for analysis of project impacts;
- to include the final results of the second-order levelling program and other improvements to the model.

The underlying objective was to determine the flood levels for conditions with and without the proposed projects in place.

Initially the simulations were extended to three years, from 1991 to 1993. This period includes two relatively wet years (1991 and 1993) that produced some of the highest water levels recorded in the region, as well as a dry year (1992) that had some of the lowest levels reported. Subsequently the simulations were extended to include the nine years from 1985 to 1993. This period include the 1988 water year which caused widespread flooding throughout Bangladesh.

The long-term simulations were originally planned to extend for 25 years, from 1964 to 1991, using a combination of recorded discharges and NAM-generated discharges as boundary inflows. This approach does not appear to be feasible due to the limitations of the available data and the lack of recent rainfall data within the tributary Indian catchments for the NAM model. The revised methodology is considered to be a more practical approach than the original proposal and is more consistent with the limitations of the available data.

10.2 Methodology

The model was first updated to include the final benchmark corrections. These datum corrections were established from the results of the second-order levelling program which was completed in 1994. Cross-sections which had been surveyed earlier were adjusted to the revised datum. Water level records were also revised.

Boundary inflows were estimated using several methods - by analysis of recorded water levels and discharges, by inter-basin correlations, and by application of the rainfall-runoff model (NAM) as will be discussed further below. Runoff from the internal catchments was generated using the y y

NAM model. Rainfall and evaporation data for this simulation were taken from NERP's HYDAT data base.

The model was first run for existing conditions. Simulated water levels and discharges were then compared with recorded data for the same period to verify the operation of the model and to determine if recent changes could be detected. Results in the form of hydrographs and flood statistics will be presented below.

Four development scenarios were also modelled; two without intervention and two with the Regional Development Plan in place. Each case was modelled with and without the proposed Tipaimukh Dam in order to isolate the potential impacts of the dam from those of the Regional Development Plan. The most recent planning information was used in defining the projects in the model including the results of the pre-feasibility studies.

The models were run for each year individually in the nine-year period. Result files were then processed to prepare annual summaries for key locations (primarily gauge sites) and to compress the hydrograph files into one continuous record. Hydrograph files were compressed from 6-hour time steps to 24-hour averages to reduce their size, but six-hourly maxima were retained for annual summary statistics.

The annual summaries were analyzed to compute flood levels for the 2-year and 10-year return period. Hydrographs and flood statistics were compared with recorded (historic) levels for the same return period to verify the model operation. Simulations of the various scenarios were compared to quantify the changes in discharges and water levels and to identify their causes.

An analysis was also made of historic water levels, discharges, and storm rainfalls to determine whether the simulation period is representative of long-term conditions. In this analysis the recent conditions were compared with those experienced in the longer term (1964 to date). The analysis and results will be described further below.

10.3 Limitations

The following limitations of the model should be kept in mind in interpreting the results:

- Planning-level information was used in defining the project concepts and scope. This data is preliminary and is subject to refinement as the plans and feasibility studies evolve.

- The model is regional in scope and large in extent; thus a number of simplifications of the river system and hydrologic processes are required. It cannot be expected to simulate all details well at all locations.

- Regulated discharges in the Barak River and hence the Surma and Kushiyara Rivers will depend on the design and operation of the Tipaimukh Dam and reservoir, of which little is known at present. More information is needed before the scope and design of the projects in the upper Surma and Kushiyara Rivers can be finalized.

- The model operates with a fixed bed which has been adjusted to replicate only the largest morphological changes that are expected. Experience and fundamental principles dictate that the rivers will adjust to changes in the hydrologic regime, generally by eroding if the discharges are increased or the channel is straightened, and in-filling if the discharges are reduced or the channel is deepened. These adjustments will tend to mitigate the changes in water levels over time.

10.4 Boundary Conditions

A summary of the boundary conditions which were used in the regional model is provided in Table 10.1.

Boundary inflows to the model were established from rating curves and three-hourly water level data wherever possible. A rating curve is the relationship between discharge and water level which is established by analysis of the available discharge measurements. SWMC and BWDB rating curves were reviewed and were revised as necessary. Water level records were also reviewed for evidence of gauge shifting or channel instability, and adjustments were made in the rating curves as necessary. The adopted rating curves were then applied to the available water level data to generate boundary discharges.

This method of calculating river discharges is so widely used and accepted that the estimated values are generally thought of as "measured" discharges. It is accurate if the channel is stable and the actual measurements cover the full range of water levels such that no extrapolation is needed. These conditions are rarely met in the boundary rivers, where peak-flow data are scarce, but this is the best method available.

In some cases (the Someswari, Barak, and Khowai Rivers) only recent discharge measurements are available although water level records have been kept for a longer period. In these cases the rating curves were applied to the longer period after reviewing the water level record for evidence of gauge relocation or channel shifting. Where possible the estimated discharges were compared with data for downstream locations to confirm their validity.

At many of the boundary locations, primarily in the central Meghalaya region, there are no water level or discharge data prior to 1991. In this case the discharges were estimated by inter-basin correlations. This approach involved using the 1991-to-1993 data to establish a relationship between the target location and another gauge (the base station) that has a longer period of record. Available daily discharges were correlated with those measured at the base station. Once the correlation was established it was applied to earlier records at the base station to estimate discharges in the target station. These correlations account in a fashion for differences in watershed size, topography, and rainfall, and are successful if the two catchments are reasonably close together in the same physiographic zone.

Base stations which were used in the analysis were Bijoypur on the Someswari River and Sarighat on the Sarigowain River. These gauges are located on the west and east side of the Meghalaya region, respectively, and have a long period of record. Motiganj on the Lungla River was used as a base station for estimating discharges in the adjacent Karangi and Sutang catchments in the Tripura region.

At many locations the discharge records are affected by overbank spills and bypass flows on the floodplain. One such location is the Manu River which spills out of the river upstream of the Manu Railway Bridge and drains back to the river further downstream There is no effective way to quantify these spills except to move the discharge gauge as far upstream as possible. Thus the potential flood peaks may be underestimated in some cases.

At one instance, the Juri River, the available discharge data are too limited to support these approaches. Water levels at this location are affected by backwater from Hakaluki Haor such that there is no meaningful relationship between discharge and water level. At this location boundary flows were estimated using the NAM model. In all other cases the estimates made by rating curves and inter-basin correlations were found to be better.

The Meghna River at Bhairab Bazar was selected as the downstream (water level) boundary.

10.5 Relative Severity of the Simulation Period

Historic data on rainfall, water levels, and discharges were analyzed to compare the simulation period (1985 to 1993) with the longer term. The purpose was to determine whether the simulation period is representative of long-term conditions or whether it has been unusually wet or dry.

Rainfall

Rainfall data are available since 1954 at some stations but the data prior to 1964 is sparse. Therefore the analysis was based on data for the thirty-year period from 1964 to 1993. This period is consistent with that of the hydrometric data base.

The annual one-day maximum rainfall and the annual five-day maximum rainfall were used as indicators of flood potential. The annual one-day maximum is the largest amount of rainfall to occur over a one-day period during the year. It is an indicator of flood potential in small catchments and in the flashy tributary rivers. The five-day rainfall is the total amount of rainfall that occurs over five consecutive days; its maximum during the year is the "annual five-day maximum rainfall". The 5-day maximum rainfall is an indicator of flood potential in larger or damped catchments and is commonly used in Bangladesh for design of regulators.

Daily rainfall data were used in the analysis. The period of record was analyzed for each rain gauge to extract the 1-day maximum and 5-day maximum for each year. A statistical analysis was then conducted for each gauge[13/]. Data for thirty-nine rain gauges were analyzed in this way.

The 1-day and 5-day rainfalls were computed in this manner for return periods of 2 years and 10 years. Statistics for individual gauges were averaged over the region to determine the general trends. The analysis was first conducted for the entire 30-year period (1964 to 1993) and was

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13/ The Gumbel (EVI) distribution was used in the analysis as is common for short-duration rainfall analysis. Missing or incomplete periods were rejected in order to avoid biasing the results. Only data from April 1 to October 31 were considered in order to minimize the number of partial periods that would have to be rejected.

then repeated for the nine years (1985 to 1993) which were used for modelling to detect what difference existed.

Results of the analysis are presented in Table 10.2 (Annual 1-day Maximum Rainfall Statistics) and Table 10.3 (Annual 5-day Maximum Rainfall Statistics). Each table provides the estimates for return periods of 2 years and 10 years, based on analysis periods of 30 years and 9 years. These data indicate that the storm rainfall in the recent nine-year period has been slightly more severe than the longer term, on average. The 1-day maximum rainfall was about 5% higher in the nine years than in the longer term for both 2-year and 10-year return periods. The 5-day maximum rainfalls were about 3% higher than normal.

Figure 35 shows the general trend in storm rainfall over the 30-year period. Regional averages of 1-day and 5-day storm rainfall are plotted against time and show a slight increase. The year-to-year variability also appears to be greater in recent years especially in the 5-day rainfalls. High rainfall years in this graph (1976, 1994, 1988, 1991, and 1993) were years of severe flooding in the region, which supports the use of these rainfall indicators for estimating flood potential.

During the analysis it was observed that daily rainfall amounts of up to 600 mm have been reported. Daily rainfall amounts greater than 350 mm are fairly common. There were five instances of daily rainfall reported to be greater than 500 mm.

Nineteen of the largest reported events were reviewed to search for evidence of data errors (a decimal out of place which can easily occur and causes a ten-fold error). The reported rainfall was compared with data for other gauges to determine whether the reported maximum was consistent with the general pattern of rainfall for each event. Point rainfall was found to be extremely variable over short distances, with individual gauges often reporting twice the rainfall, or more, of other gauges located only 20 to 30 km apart. Because of this variability there is little basis to reject the reported data. It was concluded that daily rainfalls of more than 400 mm are possible and in the final analysis none of the reported data were rejected[14/].

Flood Water Levels and Discharges

An independent analysis was made of historic flooding conditions in the region using the historic water level and discharge data. These data are generally available since the 1960's and have been compiled into NERP's data base for the period 1964 to date. Short-term and discontinued gauges were excluded. Sixty-eight locations were analyzed for water levels and 20 for discharges.

Analysis of these data was accomplished by fitting a frequency distribution model to the annual and pre-monsoon peaks. The analysis was made for the 30-year period and for the recent 9-year

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14/ The possibility of data errors can be significant in the analysis of an individual gauge as it has a direct effect on rainfall amounts of low probability and it should be considered in any critical application. The present analysis is concerned more about the overall pattern for the region rather than about the characteristics of individual locations. Therefore single extreme measurements are of less concern and their influence was reduced by fitting a frequency distribution to the data for each gauge, by averaging the rainfall statistics over the region to determine the general trends, and by restricting the analysis to relatively modest return periods (1:2 year and 1:10 year).

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period. Results were then compared for return periods of 2 years and 10 years and were averaged throughout the region to define the regional pattern.

There is considerable scope for judgement regarding the choice of frequency distribution models. FAP-25 has recommended the 3-parameter log-Normal distribution for analysis of annual maximum water levels and the EVI and EVII distributions (sub-sets of the GEV family) for analysis of annual maximum discharge data[15]. This recommendation was based on a sampling of five of the largest main-stem rivers. Chowdhury[16] analyzed 31 discharge gauges and 48 water level gauges throughout the country and recommended the log-Normal distribution for analysis of annual maximum water levels. GEV was the second choice of the five distributions considered. The GEV distribution was recommended for annual maximum discharges. The GEV was also recommended if a single distribution is to be applied to both water level and discharges.

As a practical matter there is little difference between the various distributions provided that the period of record is adequate, the data has no statistical anomalies, and the distribution is not extrapolated beyond the range (time period) of the data. If these conditions are not met, no theoretical distribution will give reliable results. In the present analysis the General Extreme Value distribution (GEV) was used as the probability model and the analysis has been restricted to return periods of 2 years and 10 years, which are consistent with the time period of the simulation. A sample sub-set were checked using the log-Normal distribution to ensure that there were no inconsistencies.

Gauges having fewer than five years of record were rejected in order to reduce the statistical problems and to ensure that the results are not unduly biased by unusual events. Mean daily data were used[17]. Water levels were corrected for gauge datum adjustments as indicated by the results of NERP's second-order levelling program.

The purpose of this analysis was to provide a basis for comparing the recent period with the long-term period and for evaluating the model calibration. It was not intended to provide design levels which would normally be based on more detailed analysis and would also consider other sources of data.

Results are presented in the following Tables:

Table 10.4 Annual Maximum Water Level Statistics (Historic)
Table 10.5 Pre-Monsoon Maximum Water Level Statistics (Historic)

15/ "Flood Hydrology Study", FAP-25 Flood Modelling and Management, Krüger Consult in association with BCEOM, June 1992.

16/ "Selection of Probability Distribution Function for Flood Frequency Analysis in Bangladesh", Jahir Uddin Chowdhury and Md. Abdul Karim, Final Report to Institute of Flood Control and Drainage Research, BUET, June 1993.

17/ "Mean daily" values are reported by BWDB as the average of five readings taken every three hours from 6:00 AM to 6:00 PM. Thus the reported value represents the daytime average, which is lower than the peak. The distinction is generally not significant in the larger main-stem rivers but can be significant in the border rivers that can rise and fall 2 m or more during the day. However, peak values are not consistently available prior to 1985 and are not observed during the night-time.

Table 10.6 Annual Maximum Discharge Statistics (Historic)
Table 10.7 Pre-Monsoon Maximum Discharge Statistics (Historic)

Review of these data indicate that flood conditions have been generally more severe in the recent nine years than in the longer term. Peak water levels were, on average, about 0.1 to 0.2 m higher than in the longer term, for both pre-monsoon and annual (monsoon) floods. Individual gauges show larger differences on account of project changes or morphological changes. Notable examples include the following:

Khowai River at Shaistaganj: Monsoon floods are 1.6 m higher at the 2-year level and 0.6 m higher at 10-year level due to sediment deposition and confinement of flow.

Peak flows are almost doubled due to confinement of overbank spills.

Khowai River at Habiganj: Monsoon floods are 1.7 m higher at the 2-year level and 0.7 m higher at the 10-year level, due to deposition and confinement of flow.

Upper Kushiyara River: Monsoon levels are 0.2 to 0.3 m higher probably due to confinement of overbank spills by embankments.

Kalni River at Markuli: Pre-monsoon floods are about 0.4 m higher due to deposition.

Upper Surma River: Pre-monsoon peaks are 0.7 to 0.8 m higher and pre-monsoon peak discharges about 10% higher, possibly due to closure of floodplain spills.

Manu River at Maulvi Bazar: Monsoon peaks are about 0.3 to 0.7 m higher than recorded due to confinement.

Monsoon-season flood discharges were higher at most locations, by an average of 10 to 15%. However pre-monsoon peak discharges have been lower at most locations, at least for the relatively common 2-year return period floods. At the 10-year return period the pre-monsoon peak discharges are more-or-less the same as the long-term, with an increase of about 10% in the upper Surma River.

For the most part these differences are not great. They are, however, greater than can be explained by differences in rainfall alone and are partly the result of projects and morphological changes.

It is concluded that the recent nine-year period from 1985 to 1993 which serves as the basis for modelling is reasonably representative of long-term hydrologic and meteorological conditions and may be slightly conservative. It is also concluded that the existing projects have substantially affected the flood discharges and water levels in some locations.

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10.6 Simulation of Existing Conditions (NERP7)

The model was run for existing conditions to serve as a basis for evaluating the effects of future scenarios. This simulation was run with the NERP7 version of the model. The results are reviewed below and are compared with the recorded water levels and discharges. Results are presented in two forms; hydrographs which compare the simulated water levels and flows with those which were recorded, and tables which summarize the flood statistics at gauge locations.

It should be noted that the simulated levels represent the present conditions (with the river network as it is today) while the recorded levels represent historic conditions which have been affected by changing river morphology and flood-control embankments over time. These changes have been relatively small during the nine-year simulation period.

Differences between recorded and simulated flood levels can also be caused by factors other than model calibration/simulation errors:

- differences in temporal resolution (model output is stored at 6-hour intervals whereas the recorded data is computed as the average of five readings taken between 6 AM and 6 PM. This difference mostly affects the flashy boundary rivers such as the Someswari and Sarigowain);
- effects of morphological changes as in the Khowai River;
- embankment breaching or cutting which is highly variable and affects the recorded levels in the Upper Kushiyara, Manu, and Khowai Rivers;
- data errors.

Water Level and Discharge Hydrographs

Hydrographs of the simulated and recorded water levels at 36 locations are presented in Figures 36 to 53. Hydrographs of simulated and recorded discharges are presented in Figures 54 to 58.

Comparison of simulated and recorded water levels indicates that the model simulates discharges and water levels remarkably well in most locations, considering the extensive regional coverage and the relatively coarse resolution required of a regional model. The general pattern of flood peaks is reproduced well. Peak levels are generally similar to those which have been recorded.

Generally the model simulates water levels better during high stages than during the dry season. Low stages are more sensitive to local conditions, small errors in discharges, and model approximations such as the artificial slots that are required in the steep boundary reaches to ensure dry-season model stability. Main-stem locations are simulated better than the steep, flashy boundary rivers which are more sensitive to the relatively coarse temporal and spatial resolution.

In many cases the differences between simulated and recorded water levels are likely due to embankment breaches, changes in channel morphology, or data errors. These include the following:

Ajmiriganj: Dry-season levels have risen since 1992 due to deposition in the channel after the cross-sections were surveyed.

Sunamganj: Simulated peak levels in 1988 are about 1 m higher than were recorded, indicating that embankments may have been overtopped or breached.

Motiganj: Shift in 1988 indicates that changes may have occurred in gauge datum or location or in the downstream channel. Winter cross-damming is evident in 1988 and 1989.

Shaistaganj: Historic peaks are about 1 m lower than the simulated peaks in some years due to breaching of embankments (the model was initially calibrated with embankment breaches that occurred near Shaistaganj in 1993 and these were closed for the simulations).

Habiganj: Same as Shaistaganj.

Sofiabad: Recorded discharges do not include flood spills to the east upstream of the gauge and are therefore lower than the simulated discharges.

Ratnerbhanga: The effects of substantial channel shifting is evident.

Differences are judged to be due to model calibration/simulation errors at the following locations:

Continala: Flood peaks are too "spiky" due to uncertainties in the NAM runoff estimates and simplification of distributary channels (this is not a critical location and has been excluded from the statistical analysis). Winter levels are affected by cross-damming (no attempt has been made to reproduce winter cross-damming which is of minor interest).

Bathkuchi: Peak levels are too low due to uncertainties in the rating curve used to generate boundary discharges. This is not a critical location and was rejected from the statistical analysis.

Sarchapur: Peak water levels are underestimated by up to 1 m in some years. This appears to indicate that the boundary inflow or internal runoff is being underestimated (possibly at Bathkuchi).

Nakuagaon: Dry-season levels are too low but peaks are simulated well.

Nalitabari: Same as Nakuagaon.

Ratnerbhanga: Dry-season levels are too low because of the artificial slot required for model stability during low flows. Peak levels are not affected.

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Discharge hydrographs (Figure 54 to 58) generally show good agreement. Differences are mostly due to embankment breaches or morphological changes:

Sheola: Peak river flows may be reduced by embankment breaches which were not simulated.

Shaistaganj: Discharge records are affected by embankment breaches and uncertainties in the recorded data (discharges have not been measured at high stages and have therefore been estimated by extrapolation of the rating curve).

Sofiabad: Substantial overbank spills are not measured and therefore the recorded discharges are lower than the simulated discharges.

Durgapur: Simulated discharges are lower than were recorded at Durgapur prior to 1988. The Atrakhali spill channel opened in 1988 and has the effect of reducing the main channel flow. The model was run with Atrakhali open in order to simulate existing conditions.

Floodplain discharges were found to be quite substantial at some locations. Floodplain flows and main-channel flows are compared in Figure 59 at two locations: Sherpur on the Kushiyara River and Sukdebpur on the Baulai River. At Sherpur the floodplain peaks were typically 40 to 50% of the total. At Sukdebpur the floodplain carries as much as 90% of the peak flow. As much as 15,000 m3/s passed on the Surma/Baulai floodplain during the 1988 flood.

Simulated discharges are compared with recorded discharges at Bhairab Bazar in Figure 58. This location is important as the outlet from the region. As can be seen in this graph the recorded discharges are reproduced well in all years. The comparison confirms the ability of the model to simulate the regional water balance and floodplain storage.

The simulation of discharges was not adequate at Mohanganj and Kalmakanda. These locations are affected by overbank spills which need to be revised in the model. Simulated discharges have been excluded from the statistical analysis as these are not critical locations.

Flood Statistics

The 1:2 year and 1:10 year flood statistics which were derived from the model results are compared with recorded levels in the following tables[18/]:

Table 10.8	Annual Maximum Water Levels
Table 10.9	Pre-Monsoon Maximum Water Levels
Table 10.10	Annual Maximum Discharges

18/ The GEV distribution was used in the analysis The simulated conditions have a six-hour resolution, the length of the model output time step, while the recorded levels have 24-hour resolution since they are derived from "mean daily" data. The 6-hour peaks should be higher than the corresponding 24-hour levels.

Results are organized by sub-region within these tables to make the comparison easier. These sub-regions are:

Kushiyara:	main stem Kushiyara, Kalni, Dhaleswari, and Meghna Rivers from Amalshid to Bhairab Bazar (including floodplain discharges at Sherpur)
Surma:	main stem Surma, Nawa, Baulai, and Ghorautra Rivers from Amalshid to the confluence with the Meghna River at Dilalpur
East Meghalaya:	cross-border tributaries of the Surma River including the Lubha, Sarigowain, Jaflong, Dhalagang, Chela, and Jhalukali Rivers and their various branches
Tripura:	cross-border tributaries of the Kushiyara River from the southeast including the Sonai-Bardal, Juri, Manu, Dhalai, Lungla, Karangi, Khowai, and Sutang Rivers
Kangsha/Mogra basin:	the Kangsha and Mogra Rivers and their various tributaries from the northwest Meghalaya region, including the Chillakhali, the Bhogai, Nitai, Someswari/Shibganjdhala, and Jadukata Rivers and their various branches.

On average the simulated annual peak water levels are within 0.3 m of the recorded levels at the 2-year return period and 0.4 m at the 10-year level. The greatest discrepancy, 2.5 m, occurs in the Khowai River and is attributed to embankment breaches and differences in temporal resolution.

In some cases the reasons for these differences are clear. In the Khowai River, for example, the embankment breaches and differences in temporal resolution are involved. Embankment breaches are also a factor in the upper Kushiyara and Surma Rivers. Differences in temporal resolution are an important factor in the boundary rivers. In the upper Kangsha basin the calibration errors are a significant factor and are in the order of 0.5 to 0.7 m in annual flood levels.

The differences which can be attributed to model calibration have an average value of ± 0.15 m at the 2-year return period and ± 0.1 m at the 10-year return period. At the 10-year return period 95% of the locations have calibration errors of less than 0.2 m, excluding the special cases which are noted above.

Simulated peak discharges are generally higher than were recorded due to the finer temporal resolution in the model. Simulated flood peaks are substantially higher in the Karangi River because they include overbank spills which are not included in the recorded discharges. Overall the simulated peak flows are within 25% of the recorded levels for the 2-year return period and 12% for the 10-year return period. If the Karangi is excluded the average difference between the recorded and simulated peak discharge is approximately 15%, much of which is attributable to the difference in temporal resolution.

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10.7 Model Accuracy

The question of model accuracy is highly subjective, as it varies from time to time and from place to place. It depends on the use that the model is put to and what conditions are significant. Furthermore the data with which to evaluate the model accuracy is limited to specific locations and is affected by measurement errors, project changes, embankment breaches, and morphological changes. It is also important to consider that the model will be applied to conditions that are somewhat different from those which were used in the calibration and therefore cannot be tested due to the lack of actual measurements under these conditions.

The accuracy of the model in simulating flood frequency statistics is probably greater and more important than its ability to faithfully simulate individual events. The relative accuracy (the ability to simulate changes) is probably better than its accuracy in absolute levels.

Considering these qualifications, and at the risk of over-simplifying the matter, the following judgements are offered:

- In the main stem rivers and the lower reaches of the tributary rivers the model can be expected to give flood levels that are within 0.3 m of actual conditions and flood discharges that are within 25% of actual conditions.

- In the floodplains, discharges are dispersed and vary considerably from place to place in a complex fashion that is difficult to quantify. The overall accuracy is probably similar to that achieved in the main-stem rivers.

- In the steep boundary reaches the model can probably be expected to give flood levels that are within 1 m of actual conditions and peak discharges that are within 50% of actual conditions. There is, however, insufficient data with which to make a reliable assessment.

At several locations which are not critical to the regional analysis the model does not reproduce actual conditions with acceptable accuracy. These locations have been rejected from the statistical analysis:

Continala	- flood water levels
Bathkuchi	- flood water levels
Mohanganj	- flood discharges
Kalmakanda	- flood discharges.

In the upper Kangsha River the regional model does not simulate flood levels with sufficient accuracy but the model results have been retained for evaluation of project changes at a regional scale. The model problems are known and understood and revisions are being made in the basin plan and project feasibility studies.

10.8 Future Scenarios Modelled

Future without Intervention (Scenarios FNI and FNI-NTD)

These scenarios included the changes which are on-going or are expected to occur in the region over the next 20 years without implementation of the Regional Development Plan. These changes include the following:

Kalni River Siltation:
Siltation is occurring in the Kalni River between Markuli and Madna and is resulting in higher water levels throughout this reach. It is assumed that this trend will continue and will result in higher water levels, particularly during the pre-monsoon season, between Markuli and Ajmiriganj. These changes were replicated by raising the bed of the channel in the model.

Baulai River Siltation:
Siltation has also been occurring in the Baulai River although at a lower rate than in the Kalni. It was assumed that this trend would continue. The channel bed was raised in the model to replicate the anticipated changes.

Jadukata Avulsion:
Recent changes in the Jadukata River have caused a shift in discharge toward the west into the Patnaigang River. It was assumed that this trend would continue in the near future and that the Jadukata River would become shallower due to deposition. These changes were replicated in the model by raising the Jadukata River cross-sections near the bifurcation.

Lower Khowai River Deposition:
Deposition of bed material is occurring in the Khowai River downstream of Habiganj due to embankments and channel cutoffs further upstream. The future changes in channel cross-section were estimated and were applied to the model in this reach.

Someswari/Shibganjdhala River Avulsion:
An avulsion has been recently forming into the Atrakhali channel which will tend to grow if it is not checked. It will have the effect of reducing the discharges in the Shibganjdhala River which will begin to silt in near the flow split. These changes were replicated by raising the Someswari River cross-sections.

The morphological changes were inferred from regime calculations, sediment transport modelling, and geomorphic methods in NERP's specialist report on river morphology[19/]. Given the uncertainties in geomorphic predictions these simulations are only approximate. However they provide a means for assessing the sensitivity of hydraulic conditions to future channel changes.

Two scenarios were simulated - one with the Tipaimukh Dam in place (FNI, or Future with No Intervention) and one without the Tipaimukh Dan (FNI-NTD) - in order to separate the impacts

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19/ "River Sedimentation and Morphology', Northeast Regional Water Management Project, Specialist Study, December 1994.

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of the dam from those related to morphological changes. The Tipaimukh Dam was simulated separately to generate the regulated Barak inflows as was described in Chapter 8.

Regional Development Plan (Scenarios RDP and RDP-NTD)

Simulations of the Regional Development Plan included the anticipated morphological changes. One simulation (RDP) was made with the Tipaimukh Dam in place and one without (RDP-NTD).

The following projects were modelled:

full flood control embankments:

- Upper Surma/Kushiyara Project
- Surma Right Bank
- Khowai-Habiganj Flood Control Project
- Kushiyara-Bijna Interbasin Project
- Upper Kangsha River Basin Development - Konapara Embankment
- Upper Kangsha River Basin Development - Greater Dampara Project
- Someswari Project - Atrakhali closure

submersible embankments:

- Surma/Kushiyara/Baulai Basin Project
- Dharamapasha Rui Beel
- Updakhali Project
- Jadukata-Rakti River Improvement (Patnaigang weir)

diversions:

- Khowai-Habiganj Flood Control Project
- Upper Kangsha River Basin Development - diversion to Mogra River
- Manu River Project

channel dredging or deepening:

- Kalni River Improvement
- Baulai River Improvement
- Jadukata-Rakti River Improvement

channel straightening:

- Upper Kangsha River Basin Development - Malijhi, Bhogai, Kangsha, and Mogra Rivers

The projects and modelling assumptions are described in Annex C. Generally the river cross-sections were modified to represent channel improvements and floodplain spills were raised or otherwise modified to represent changes in overbank spills due to embankments. The Tipaimukh Dam and the Manu Diversion were simulated outside of the main model and were applied as boundary inflows.

10.9 Impact Analysis

The impacts of the Regional Plan projects, Tipaimukh Dam/Cachar Plains project, and predicted morphological changes were assessed by comparing the model results for the various scenarios. The model results were first processed to generate 1:2 year and 1:10 year flood statistics at key locations for each of the five scenarios (NERP7, FNI, FNI-NTD, RDP, RDP-NTD). The flood statistics were then compared as follows to isolate the impacts of different components:

Morphological changes:	FNI-NTD (Future without intervention and without Tipaimukh dam) minus NERP7 (existing)
Proposed Regional Plan projects:	RDP (Regional Development Plan) minus FNI (Future without intervention)
Tipaimukh Dam project:	RDP (Regional Development Plan) minus RDP-NTD (Regional Development Plan without Tipaimukh)
Aggregate or net change:	RDP (Regional Development Plan) minus NERP7 (existing).

The data and results of the analysis are presented in the following Tables and will be discussed below[20]:

Table 10.11	Impact Analysis - 1:2 Year Annual Flood Water Levels
Table 10.12	Impact Analysis - 1:10 Year Annual Flood Water Levels
Table 10.13	Impact Analysis - 1:2 Year Pre-Monsoon Flood Water Levels
Table 10.14	Impact Analysis - 1:10 Year Pre-Monsoon Flood Water Levels
Table 10.15	Impact Analysis - 1:2 Year Annual Flood Discharges
Table 10.16	Impact Analysis - 1:10 Year Annual Flood Discharges

Hydrographs of water levels and discharges at significant locations are presented in Figures 60 to 69. These show the aggregate effect of the Regional Plan, the Tipaimukh project, and the predicted morphological changes by comparison with existing conditions.

10.9.1 Impacts of Morphological Changes without Intervention

Morphological changes include siltation in the Shibganjdhala, Jadukata, Khowai, and lower Kalni and Surma Rivers. Simulated changes in flood levels are as follows:

Markuli:	0.3 m rise in monsoon peaks, 25% reduction in peak discharges, and 0.2 m rise in pre-monsoon peaks due to channel siltation in the lower Kalni River

[20] The impact assessment assumes that other factors are held constant. Consequently the aggregate impact which is computed as the change from existing conditions to conditions of full development is not the exact sum of the individual components due to various interactions. Only external impacts are considered; the internal benefits resulting from project implementation are not considered.

Habiganj: 1.0 m rise in flood levels due to channel siltation in the lower Khowai River

Durgapur: 0.4 m drop in pre-monsoon peak levels and 20% reduction in peak discharges in the Shibganjdhala channel due to increased spill into Atrakhali channel and continuing siltation of the Shibganjdhala channel. Monsoon peak water levels will not be changed.

JariaJanjail: 0.3 to 0.5 m reduction in flood levels and 12% reduction in peak discharge due to reduced flood peaks in the Shibganjdhala channel.

Peak flows will be reduced in the lower Kangsha and Ghulamkhali branch by about 10 to 15%.

Loureghar: 8% increase in Patnaigang branch discharges and 8% reduction in Jaflong branch discharges due to on-going avulsion toward the Patnaigang branch.

10.9.2 Proposed Regional Plan Projects

Impacts of the proposed Regional Development Plan will be as follows:

Upper Kushiyara River: Monsoon peak flood levels will be raised by confinement from proposed embankments - by about 0.2 m at Amalshid to 1.2 m at Fenchuganj. Peak discharges will be increased by as much as 45% at Fenchuganj due to confinement of floodplain spills.

Peak discharges will be reduced in the floodplain by as much as 40% at Sadipur (near Sherpur).

Markuli: Monsoon peak flows will be increased by about 20% but the proposed dredging of the Kalni River prevents peak water levels from rising.

Upper Surma River: Monsoon flood levels will be raised by about 0.5 to 0.7 m upstream of Sylhet due to proposed embankments. Pre-monsoon peaks will be also raised for the 10-year return period. Flood discharges will be raised by about 10%.

Surma-Kushiyara Floodplain: Monsoon levels at Akter Bazar will be lowered by about 0.1 to 0.2 m and pre-monsoon levels will be lowered by 0.2 to 0.4 m due to reduced inflows from the Surma and Kushiyara Rivers and due to downstream channel improvements.

Sukdebpur: Pre-monsoon and annual flood levels will be raised by about 0.2 m.

Manu River: Monsoon flood levels will be reduced by 1.3 to 1.5 m at Maulvi Bazar due to diversion of flood peaks to Hakaluki Haor for flood control.

Lower Khowai River: Monsoon flood levels will be raised by 0.5 m at the 2-year return period and 1.5 m at the 10-year return period from Chunarghat to downstream of Habiganj due to confinement of overbank spills. Peak discharges will be increased by 20 to 50%. These changes need to be taken into account in design of the embankments.

Monsoon flood levels in the Karangi River at Sofiabad will be lowered by 1.4 to 1.8 m by reduction of overbank spills from the Khowai. Peak discharges will be reduced by 60 to 80%.

Flood levels will be raised in the Sutang River by about 0.9 m due to diversion of a portion of the upper Khowai River catchment to reduce flood peaks in the Khowai River. Peak discharges will be increased by 50 to 75%.

Durgapur: Monsoon peaks will be about 0.2 to 0.4 m higher due to closure of the Atrakhali branch channel. Pre-monsoon peaks will be raised by 0.7 to 0.8 m. Flood discharges increase in the Shibganjdhala channel by 20 to 25%.

Sarchapur: Flood levels in the river and the floodplain will be lowered by 0.3 to 0.5 m due to proposed channel improvements in the upper Kangsha for drainage and flood control. Monsoon peak discharges increase by 8% due to reduced floodplain storage.

Jaria Janjail: Monsoon flood levels will be raised by about 0.3 to 0.5 m and peak discharges will be increased by 10% due to closure of Shibganjdhala spill channels. This change will have to be taken into account in the height of the embankments along the Kangsha River.

Netrokona: Monsoon flood levels will be raised by 1.2 to 1.4 m and peak discharges will be doubled by drainage of water from the Kangsha basin.

Meghna River: Discharges at Bhairab Bazar will be essentially unchanged by the project work. Thus there will be no downstream impacts.

10.9.3 Tipaimukh Dam/Cachar Plains Project

It is understood that the Tipaimukh project will be operated for flood control in India, which will decrease monsoon-season peaks, and for power generation which will increase the dry-season flows. Thus summer flood levels in the Surma and Kushiyara Rivers will be lowered and winter and pre-monsoon levels will be raised. The changes will be greatest in the upstream reaches and will be reduced further downstream by tributary inflows, floodplain storage, and routing effects.

Specific impacts are as follows:

Upper Kushiyara River:	Peak discharges will be reduced upstream of Sherpur, by as much as 30% at Amalshid. Peak water levels will be lowered by as much as 1.5 m at Amalshid. There is no change downstream of Sherpur. Floodplain discharges will also be reduced substantially (by about 25%) near Sherpur.
Lower Kushiyara River:	Pre-monsoon flood peak water levels will be reduced slightly (by 0.1 m).
Upper Surma River:	Similar changes occur as in the Kushiyara River. Pre-monsoon and monsoon flood levels will be reduced by about 0.5 m at Sylhet and 1.5 m at Amalshid. Peak discharges in the river will be reduced by about 20 to 30%.
Lower Surma River:	There is little change in flood levels downstream of Sunamganj. Peak discharges in the river will be reduced by about 5 to 10%. The floodplain discharge is reduced by about 8% at Sukdebpur.
Upper Meghna River:	Peak discharges will be decreased by 5%. Winter discharges increase slightly.

Discharges in the upper Kushiyara and Surma Rivers will be substantially altered by the Tipaimukh Dam/Cachar Plains project. These changes have implication for the entire length of the Kushiyara and Surma Rivers and a portion of their tributaries. Generally the flood levels are expected to be lowered in the upper reaches of these rivers. Dry-season discharges and water levels will be significantly higher and will impede drainage of low-lying areas adjacent to the river channels. The increased drainage problems will be especially significant along the Kalni River where deposition of bed material has been occurring. Post-monsoon and winter drainage will be impeded and pre-monsoon flood levels will be higher than without the Tipaimukh Dam.

10.9.4 Aggregate or Net Change

The aggregate or net change is the cumulative effect of the proposed projects, morphological changes, and implementation of the Tipaimukh Dam in India. These factors interact and sometimes offset each other. Specific changes are summarized below:

Kushiyara River: Peak discharges will be reduced by the Tipaimukh dam and winter discharges will be increased. These changes are partly offset by proposed embankments and regulators which will raise monsoon levels, and by the proposed dredging of the Kalni River which will lower the winter and pre-monsoon peaks. The net effect is a lowering of peak water levels by 1.3 m at Amalshid, a rise of 0.6 m at Fenchuganj, and a rise of 0.1 to 0.2 m at Markuli. Pre-monsoon floods will be similarly affected but to a slightly lesser degree.

Operation of the Tipaimukh Dam for flood storage will reduce peak discharges throughout the main-stem Kushiyara/Kalni/Meghna Rivers. The reduction varies from 30% at Amalshid to 4% at Bhairab Bazar. Floodplain spills will be reduced by the proposed projects and by the operation of the Tipaimukh Dam (by as much as 50% near Sherpur).

Dry-season water levels will be higher in the lower Kushiyara/Kalni River because of increased winter flows and channel siltation. Winter water levels will be raised by 1.5 m at Markuli (see Figure 61). Pre-monsoon peak levels may rise by 0.2 to 0.3 m, depending on the amount of channel deposition that takes place and how much dredging is undertaken to counteract the effects of siltation.

Upper Surma River: Peak discharges at Amalshid will be reduced by about 20 to 30% at Amalshid due to the Tipaimukh Dam. Monsoon flood levels will be reduced by 1.3 m. The benefits will be restricted to a short reach. Proposed embankments will cause a small net rise in flood levels further downstream, generally of the order of 0 to 0.4 m in the 10-year monsoon flood.

Lower Surma/Baulai River:
Peak water levels will be 0.2 to 0.3 m higher in the reach from Sunamganj to Sukdebpur as a result of siltation and project changes. Proposed projects will increase the peak channel discharges by about 15 to 20% and the floodplain discharge will be reduced slightly.

Upper Meghna River: Peak discharges will be decreased by 5%. Thus the peak monsoon water levels at Bhairab Bazar and downstream will be lowered slightly.

Manu, Khowai, and Kangsha basin:
Morphological changes are not affected by the Tipaimukh Dam. Impacts will be mostly due to project changes as summarized above for the ***Proposed Regional Plan Projects.***

Pre-monsoon and post-monsoon water levels will be significantly higher in the Kalni River due to channel siltation and due to increased flows from the Tipaimukh Dam. At Markuli the dry-season water levels will be increased by about 1.5 to 2 m. Implications include:

- retarded drainage during the post-monsoon season;
- earlier and more severe pre-monsoon flooding in unprotected areas adjacent to the river.

11. CONCLUSIONS

Reliability of the Model:

The computer model does a realistic simulation of the water levels and discharges in the Region and provides a reasonable basis for estimating the future changes. Where the model does not provide the required accuracy its results have been rejected from the analysis. Model results may be slightly conservative (in the order of 5% of peak discharge) since the simulation period has had slightly more rainfall and more severe storms than normal.

Potential Impacts of Flood Control, Drainage, and Irrigation Projects:

Floodplain discharges in the Northeast Region are substantial and must be considered in planning and design of FCDI projects. Attempting to fully contain the Surma/Baulai River would increase the river discharges five-fold which would be impossible. Completely confining the Kushiyara River would double the river discharge in places which would be very difficult. Such problems have already been experienced in the Khowai River. The impact of the proposed Regional Plan projects will be described below.

Impacts of the Tipaimukh Dam/Cachar Plain Project:

By regulating the peak and dry-season flows the proposed Tipaimukh Dam has the potential to cause the greatest impact on the Northeast Region as it affects a large part of the region. It is estimated that monsoon flood levels will be lowered by as much as 1.5 m and winter levels will be raised by as much as 1.5 m. The actual impacts will depend on details of the project's design and operation of which little is known at present.

The changes will have benefits for flood control but will adversely affect drainage of low-lying areas along the Kalni River.

The scope and scale of the upper Surma and upper Kushiyara projects will be considerably altered by construction of the Tipaimukh Dam. Pre-feasibility studies in the Upper Surma-Kushiyara Project and the Surma Right Bank Project, which both involve high embankments, assumed that the Tipaimukh Dam would not be constructed which is the worst case scenario. Flood levels are expected to be reduced by the dam and thus the scope of both projects could be reduced if they are delayed until after the dam is completed. The Regional Development Plan assumed that this would be the case.

The assessment of impacts is preliminary as it is based on sketchy information regarding the design and operation of the project.

Impacts of the Regional Development Plan:

By protecting portions of the floodplain from flooding, the Regional Plan projects will generally cause the water levels in the adjacent rivers to rise slightly. The rise in river levels will be less than 0.5 m in most locations. These changes will need to be taken into account during the feasibility studies and design of these projects.

In the Kushiyara River between Fenchuganj and Sherpur monsoon flood levels may rise by as much as 0.6 m if the Tipaimukh Dam is implemented and 1.2 m if it is not implemented. This change results primarily from closing off the floodplain in the Damrir Haor Project. This change will affect Hakaluki Haor, the Kushiyara embankments, and other areas adjacent to the river in this reach. The impact of this change needs to be considered during the feasibility study for this project.

Flood levels will rise in the Mogra River if drainage is directed from the Kangsha basin as is proposed in the Kangsha basin pre-feasibility study report. The regional model has limited detail in this part of the Region and does not give an accurate estimate of the amount of this impact. Potential impacts and remedial works are being more fully investigated in greater detail in the Kangsha basin water management plan and feasibility studies.

The proposed channel improvements in the Kalni and Baulai Rivers will cause post-monsoon drainage to be improved and advanced by up to two weeks. Winter water levels will be lowered by 0.5 to 1 m as a result of these drainage improvements. Pre-monsoon water levels will generally be lower.

Future without Intervention (Consequences of Doing Nothing):

Flooding and drainage problems will continue and in some cases will increase if no intervention is taken. Continuing avulsion and siltation of the Shibganjdhala channel will cause more flooding on the east side of the Someswari alluvial fan. Flooding and drainage problems will persist at the present level in the upper Kangsha basin and along the Surma and Kushiyara Rivers. The Jadukata River will continue to shift about its fan and likely will direct more flow and sediment westward into Tangua Haor, a regionally important mother fishery. The Khowai and Manu Rivers will continue to spill overbank during high flows and will flood adjacent areas.

Without intervention the increased winter discharges and the expected siltation of the Kalni and Baulai Rivers will raise the pre- and post- monsoon water levels by as much as 1.5 m. This change will have significant impacts on post-monsoon drainage and pre-monsoon flooding. Drainage problems and pre-monsoon flooding will be aggravated along the lower Kushiyara/Kalni River. Drainage in the central basin and the Baulai River system will be further retarded.

The predicted deposition in the Khowai River will cause a 1 m rise in water levels near Habiganj. Higher flood levels will increase the risk of overtopping and breaching of the embankments in this reach. The change would be only minor at Shaistaganj. There will be no increase in the present spillage upstream of Chunarghat unless the channel deposition extends upstream of Shaistaganj.

Downstream Impacts

Outflows from the region will be essentially unchanged. Therefore there is little possibility of downstream impacts.

TABLES

Table 10.1
Boundary Conditions for the Regional Model

River	Location	Period	Method	Notes
Chillakhali	Bathkuchi	1988-1993	SWMC rating curve	no high-flow measurements;
		1985-1987	adjusted rating cuve	poor fit - much scatter due to channel shifting; shift of 0.3 m in 1987; no high flow measurements
Bhogai	Nakuagaon	1985 to 1993	SWMC rating curve	some shifting in the river; no measured data at high stages
Nitai	Ghosegaon	1985 to 1993	SWMC rating curve interpolation during cross-damming	two recent discharge measurement above the bankfull stage
Someswari	Bijoypur	1985 to 1993	SWMC rating curve	gauge or datum shifts occur from time to time
Jadukata	Lourergarh	1992 to 1993	SWMC rating curve	considerable extrapolation and overbank spills
	Muslimpur	1991	SWMC family of rating curves	variable backwater effects from Surma River
	Lourergarh	1985 to 1990	correlation with Muslimpur	Muslimpur estimated by simplified rating curve and correlation with Someswari
Jhalukhali	Dulura	1992 to 1993	SWMC rating curve	good gauging site but limited data available
		1988 to 1990	correlation with Muslimpur	overbank spills between the two locations
		1985 to 1987	correlation withSomeswari	
Chela	Chelsonapur	1989 to 1993	SWMC rating curve	affected by substantial instability; part spills to Piyain River
		winter discharges	inter-basin correlation with Sarigowain	
		1985 to 1988	inter-basin correlation with Sarigowain	divided between Chela and Nawagang branches
Nawagang	Urargaon	1988 to 1993	SWMC rating equation	branch of the Chela River; variable backwater conditions from the Surma River
		1985 to 1987 plus winter discharges	inter-basin correlation with Sarigowain	divided between Chela and Nawagang branches
Dhalagang	Islampur	1989 to 1993	SWMC rating curve	considerable shifting
		1988	shifted rating curve	0.4 m shift in 1988
		1985 to 1987	inter-basin correlation with Sarigowain	reliability is low
Jaflong	Jafflong	1991 to 1993	SWMC rating curve	main branch of Jafflong River; variability over a range of 1 m or more
		1985 to 1990	interbasin correlation with Sarigowain	flow split developed from available data
Piyan	Ratnerbhanga	1989 to 1993	SWMC rating curve	branch of Jafflong River; substantial channel shifting and avulsion - gauge should be moved upstream
		1985 to 1988	interbasin correlation with Sarigowain	flow split developed from available data
Sarigowain	Sharighat	1991 to 1993	SWMC rating curve	overbank spills upstream of the gauge are not included
		1985 to 1990	revised rating curve	included previous data
Lubha	Borogram	1985 to 1993	estimated from Sarigowain	backwater from Surma River makes rating curve impossible
Barak	Amalshid	1985 to 1993	sum of Surma and Kushiraya established using SWMC rating curves	main tributary to the Northeast Region; upstream spills may bypass gauge; stable location, good quality data; embankment effects appear to be negligible
Sonaibardal	Jaldhup	1985 to 1993	SWMC rating curve	less flashy that other Tripura catchments; used daily data for 1988; limited measurements of high discharges
Juri	Silghat	1985 to 1993	NAM model	backwater effects from Hakaluki Haor; NAM discharges are not reliable due to lack of dsta (not a critical location)
Manu	Manu Railway Bridge	1985 to 1993	SWMC rating curve	substantial bypass flows affect peak estimates; some data at high stages; variability due to channel activity and embankments
Dhalai	Kamalganj	1985 to 1993	SWMC rating curve	reports of significant bypass flowa; some variability due to channel activity some measurements at high flows; used daily data for 1987 (3-hr not available)
Lungla	Motiganj	1988 to 1993	SWMC rating curve	shift of 0.5 m since 1970's and in 1988; backwater from Hail Haor; cross-damming during winter
		1985 to 1987	shifted rating curve	shifted in 1988
Karangi	Sofiabad	1991 to 1993	NAM model	
		1985 to 1990	proportion of Lungla by drainage area	boundary is upstream of Khowai spills
Khowai	Ballah	1985 to 1993	rating curve, verified using sub-model	substantial overbank spills downstream of gauge; Shaistaganj is unreliable
	Tributary inflow	1985 to 1993	proportion of Ballah discharge	modelled as tributary inflow at km 14.0; diverted to Sutang in Regional Plan
Sutang	Sutang RR Bridge	1985 to 1993	estimate from Lungla	rating curve is not useful (affected by backwater from Kalni River)
Meghna	Bhairab Bazar	1991 to 1993	recorded hourly water levels	
		1985 to 1990	mean daily water levels	average of daily minimum and maximum (hourly data not available)

Table 10.2

Annual 1 – Day Maximum Rainfall Statistics

Gauge	Location	1:2 Year Return Period			1:10 Year Return Period		
		30–Year Estimate (mm)	9–Year Estimate (mm)	Ratio 9yr/30yr	30–Year Estimate (mm)	9–Year Estimate (mm)	Ratio 9yr/30yr
R–061	Bajitpur	150	142	0.95	232	233	1.00
R–062	Dewanganj	166	217	1.31	275	391	1.42
R–063	Durgapur	197	206	1.05	293	308	1.05
R–065	Gouripur	150	155	1.03	218	224	1.03
R–068	Jaria–Jhanjail	186	178	0.96	276	247	0.89
R–071	Kishoreganj	139	129	0.93	224	184	0.82
R–072	Muktagacha	158	140	0.89	253	224	0.89
R–073	Mymensingh	159	179	1.13	233	286	1.23
R–074	Nalitabari (Taraganj)	167	184	1.10	267	318	1.19
R–077	Phulpur	149	198	1.33	257	275	1.07
R–078	Sherpur (Town)	159	173	1.09	261	293	1.12
R–101	Bhairab Bazar	138	126	0.91	213	168	0.79
R–102	Bholaganj	213	208	0.98	294	298	1.01
R–103	Brahmanbaria	151	134	0.89	221	225	1.02
R–104	Chandbagh	156	184	1.18	215	217	1.01
R–105	Chandpur Bagan	136	128	0.94	219	237	1.08
R–107	Chhatak	220	227	1.03	321	296	0.92
R–108	Dakshinbagh (Samanbagh)	154	138	0.90	223	202	0.91
R–109	Gobindaganj	194	182	0.94	273	226	0.83
R–110	Habiganj	151	179	1.19	215	281	1.31
R–111	Itakhola (Baikunthapur)	155	156	1.01	244	258	1.06
R–112	Itna	143	135	0.94	206	202	0.98
R–113	Khaliajuri	195	190	0.97	310	292	0.94
R–114	Kamalganj	140	148	1.06	208	218	1.05
R–116	Lallakhal	216	199	0.92	296	236	0.80
R–117	Langla	151	192	1.27	240	298	1.24
R–118	Latu	165	189	1.15	240	271	1.13
R–120	Markuli	132	168	1.27	197	282	1.43
R–121	Mohanganj	162	169	1.04	261	289	1.11
R–122	Moulvibazar	146	165	1.13	216	256	1.19
R–123	Netrokona	161	192	1.19	232	253	1.09
R–125	Sheola	204	228	1.12	284	356	1.25
R–126	Srimangal	148	141	0.95	241	210	0.87
R–127	Sunamganj	252	264	1.05	340	347	1.02
R–128	Sylhet	212	216	1.02	312	307	0.98
R–129	Tajpur	202	195	0.97	297	306	1.03
R–130	Zakiganj	179	204	1.14	264	287	1.09
R–131	Sarail	140	137	0.98	211	198	0.94
R–132	Nasirnagar	129	136	1.05	176	179	1.02
Regional average		167.3	175.2	1.05	250.2	261.0	1.05

Table 10.3

Annual 5 – Day Maximum Rainfall Statistics

Gauge	Location	1:2 Year Return Period			1:10 Year Return Period		
		30 – Year Estimate (mm)	9 – Year Estimate (mm)	Ratio 9yr/30yr	30 – Year Estimate (mm)	9 – Year Estimate (mm)	Ratio 9yr/30yr
R – 061	Bajitpur	294	289	0.98	445	458	1.03
R – 062	Dewanganj	316	396	1.25	473	613	1.30
R – 063	Durgapur	414	402	0.97	561	531	0.95
R – 065	Gouripur	331	344	1.04	458	442	0.97
R – 068	Jaria – Jhanjail	422	426	1.01	597	650	1.09
R – 071	Kishoreganj	276	268	0.97	404	390	0.97
R – 072	Muktagacha	309	281	0.91	457	390	0.85
R – 073	Mymensingh	327	346	1.06	481	523	1.09
R – 074	Nalitabari (Taraganj)	332	367	1.11	499	555	1.11
R – 077	Phulpur	334	380	1.14	582	588	1.01
R – 078	Sherpur (Town)	282	318	1.13	415	456	1.10
R – 101	Bhairab Bazar	283	259	0.92	408	350	0.86
R – 102	Bholaganj	582	553	0.95	917	733	0.80
R – 103	Brahmanbaria	296	236	0.80	464	403	0.87
R – 104	Chandbagh	344	394	1.15	531	687	1.29
R – 105	Chandpur Bagan	288	263	0.91	452	424	0.94
R – 107	Chhatak	561	557	0.99	845	827	0.98
R – 108	Dakshinbagh (Samanbagh)	366	349	0.95	563	549	0.98
R – 109	Gobindaganj	472	416	0.88	737	735	1.00
R – 110	Habiganj	310	308	0.99	455	489	1.07
R – 111	Itakhola (Baikunthapur)	299	273	0.91	449	456	1.02
R – 112	Itna	356	355	1.00	499	448	0.90
R – 113	Khaliajuri	414	437	1.06	635	633	1.00
R – 114	Kamalganj	289	305	1.06	460	460	1.00
R – 116	Lallakhal	577	540	0.94	818	720	0.88
R – 117	Langla	309	394	1.28	511	634	1.24
R – 118	Latu	394	429	1.09	590	543	0.92
R – 120	Markuli	402	453	1.13	607	885	1.46
R – 121	Mohanganj	362	393	1.09	559	694	1.24
R – 122	Moulvibazar	291	314	1.08	462	526	1.14
R – 123	Netrokona	373	411	1.10	561	550	0.98
R – 125	Sheola	445	477	1.07	685	725	1.06
R – 126	Srimangal	280	274	0.98	422	403	0.95
R – 127	Sunamganj	610	678	1.11	869	908	1.04
R – 128	Sylhet	473	508	1.07	713	761	1.07
R – 129	Tajpur	417	429	1.03	650	774	1.19
R – 130	Zakiganj	404	437	1.08	588	617	1.05
R – 131	Sarail	273	246	0.90	406	369	0.91
R – 132	Nasirnagar	280	278	0.99	401	433	1.08
Regional average		368.9	379.1	1.03	554.6	572.6	1.03

Table 10.4
Annual Maximum Water Level Statistics

BWDB Gauge No.	River	Location	Datum	1:2 Year Return Period (m,PWD) 30-Year Estimate	9-Year Estimate	Difference 9yr-30yr	1:10 Year Return Period (m,PWD) 30-Year Estimate	9-Year Estimate	Difference 9yr-30yr
3A	Anderson khal	Brahamabaria		6.53	6.35	-0.18	7.23	7.46	0.23
9.5	Banar	Trimohini		8.05	7.65	-0.40	8.76	8.82	0.07
34	Bhohai	Nakuagaon		24.61	24.79	0.18	25.01	25.24	0.23
35	Bhohai	Nalitabari		18.18	18.22	0.04	18.33	18.30	-0.03
35.5	Kangsha	Sarchapur		13.38	13.46	0.08	13.98	14.19	0.22
36	Kangsha	Jaria Janjail		10.90	11.12	0.22	11.25	11.35	0.10
36.1	Kangsha	Mohanganj		7.61	7.55	-0.07	8.15	8.17	0.03
45.5	Brahmaputra	Chilmari	*	23.96	23.95	-0.01	24.50	24.92	0.42
46	Brahmaputra	Kamarjani	*	22.34	22.06	-0.28	23.34	23.47	0.13
46.7	Brahmaputra	Kholabarichar	*	20.72	20.65	-0.06	21.29	21.39	0.10
46.9	Brahmaputra	Bahadurabad	*	19.76	19.52	-0.24	20.21	20.30	0.09
53	Chilla Khali	Bathkuchi	*	25.92	26.55	0.63	26.93	27.63	0.70
67	Dhalai	Kamalganj		20.60	20.76	0.16	20.90	20.92	0.01
71	Dhaleswari	Kalagachia	*	5.32	5.17	-0.14	5.90	6.03	0.13
71 A	Dhaleswari	Rekabi Bazar	*	5.52	5.29	-0.23	6.10	6.26	0.16
72	Baulai	Kaliajuri		7.27	7.21	-0.07	7.96	8.06	0.10
72 B	Baulai	Sukdevpur		7.28	7.15	-0.13	7.93	7.98	0.05
73	Baulai	Itna		7.12	6.93	-0.19	7.76	7.76	0.00
74	Ghorautra	Dilalpur		6.77	6.53	-0.24	7.49	7.53	0.04
115	Gumti	Daudkandi	*	5.44	5.32	-0.12	6.03	6.29	0.26
123	Hawrah	Gangasagar RR Brd	*	6.14	6.21	0.07	6.75	7.01	0.26
131	Jadukata	Saktiarkhola	*	9.26	9.16	-0.10	9.61	9.65	0.04
135A	Juri - Contina	Continala		10.85	11.18	0.33	11.41	11.62	0.21
138	Korangi	Sofiabad		11.90	11.75	-0.16	12.18	12.18	0.01
157	Khowai	Ballah		24.25	23.77	-0.48	25.62	25.48	-0.14
158	Khowai	Chunarghat		17.47	17.74	0.27	18.18	18.34	0.16
158.1	Khowai	Shaistaganj		12.24	13.79	1.55	13.74	14.37	0.63
159	Khowai	Habigonj		8.51	10.19	1.68	10.11	10.82	0.71
172	Kushiyara	Amalshid		17.33	17.63	0.31	17.81	17.91	0.10
173	Kushiyara	Sheola		13.89	14.09	0.20	14.15	14.18	0.03
174	Kushiyara	Fenchuganj		10.59	10.81	0.22	11.03	11.30	0.28
175.5	Kushiyara	Sherpur		9.01	9.06	0.06	9.35	9.40	0.05
177	Lakhya	Lakhpur		6.86	6.65	-0.21	7.48	7.90	0.42
179	Lakhya	Demra	*	5.73	5.36	-0.37	6.30	6.12	-0.17
192	Langla	Motiganj		8.71	8.85	0.15	9.01	9.06	0.05
201	Monu	Monu R.R. bridge		18.68	18.89	0.21	19.02	19.10	0.07
202	Monu	Moulavi bazar		11.96	12.66	0.70	12.87	13.15	0.29
223	Old Brahmaputra	Goal Khanda	*	22.70	22.61	-0.09	23.28	23.47	0.19
225	Old Brahmaputra	Jamalpur	*	17.05	16.92	-0.13	17.52	17.86	0.34
227	Old Brahmaputra	Sutia Offtake		13.40	13.19	-0.22	14.17	14.66	0.49
228.5	Old Brahmaputra	Mymenshing		12.34	12.26	-0.08	13.10	13.49	0.39
229	Old Brahmaputra	Toke	*	8.50	8.21	-0.29	9.32	9.91	0.59
230.1	Old Brahmaputra	Bhairab Bazar R.R.		6.47	6.29	-0.18	7.17	7.46	0.30
233	Piyan	Ratnerbhanga		13.82	13.53	-0.30	14.73	14.57	-0.16
234	Piyan	Companyganj		10.66	10.92	0.26	11.36	11.57	0.21
251	Sarigowain	Sharighat		13.93	13.88	-0.05	14.35	14.27	-0.08
252	Sarigowain	Gowainghat		11.74	11.80	0.06	12.17	12.32	0.15
252.1	Sarigowain	Salutikar		10.66	10.86	0.19	11.12	11.18	0.07
262	Someswari	Bagmara		16.91	17.10	0.19	17.67	17.66	-0.01
263	Someswari	Durgapur		14.11	14.34	0.23	14.72	14.83	0.12
263.1	Someswari	Kalmakanda		7.93	8.14	0.21	8.76	9.12	0.36
265	Sonai-Bardal	Jaldhup		12.02	12.39	0.37	12.58	12.87	0.29
266	Surma	Kanairghat		14.86	14.96	0.10	15.15	15.22	0.07
267	Surma	Sylhet		11.25	11.35	0.11	11.68	11.80	0.12
268	Surma	Chatak		10.04	10.20	0.16	10.70	11.03	0.33
269	Surma-Meghna	Sunamganj		8.65	8.81	0.17	9.10	9.21	0.12
270	Kusiyara	Markuli		7.43	7.39	-0.03	7.90	7.77	-0.13
271	Kalni	Ajmiriganj		7.12	6.93	-0.19	7.78	7.84	0.06
272	Kalni	Madna		6.95	6.83	-0.12	7.63	7.77	0.14
272.1	Dhaleswari	Austagram		6.77	6.64	-0.13	7.52	7.73	0.21
273	Meghna	Bhairab bazar		6.50	6.30	-0.20	7.18	7.30	0.12
274	Meghna	Narsingdi		5.89	5.84	-0.05	6.67	7.30	0.63
275	Meghna	Badyar Bazar	*	5.49	5.60	0.11	6.07	6.36	0.29
275.5	Meghna	Meghna Ferry Ghat	*	5.45	5.39	-0.07	5.93	5.97	0.04
276	Meghna	Satnal	*	5.18	5.05	-0.13	5.68	5.80	0.12
280	Sutang	Sutang rly.br.		7.54	7.48	-0.06	8.03	8.04	0.01
295	Titas	Ajabpur		6.66	6.45	-0.22	7.37	7.50	0.13
296	Titas	Akhaura		6.43	6.25	-0.18	7.13	7.35	0.22
297	Titas	Gokarnaghat		6.35	6.20	-0.15	7.03	7.32	0.28
298	Titas	Nabinagar	*	6.25	6.09	-0.16	6.91	7.10	0.19
310	Mogra	Netrokona		8.97	8.99	0.02	9.58	9.52	-0.06
311	Mogra	Atpara		7.77	7.72	-0.05	8.23	8.26	0.03
314	Nitai	Ghosegaon		16.69	17.16	0.47	17.26	17.30	0.05
326	Lubachara	Outfall	*	15.29	15.29	0.00	15.50	15.40	-0.10
327		Boalmari	*	24.32	24.57	0.25	26.44	26.84	0.41
Regional average						0.04			0.17

* = not connected

Table 10.5
Pre–Monsoon Maximum Water Level Statistics

BWDB Gauge No.	River	Location	Datum	1:2 Year Return Period (m,PWD) 30–Year Estimate	9–Year Estimate	Difference 9yr–30yr	1:10 Year Return Period (m,PWD) 30–Year Estimate	9–Year Estimate	Difference 9yr–30yr
3A	Anderson khal	Brahamabaria		3.08	2.94	−0.14	3.89	3.11	−0.78
9.5	Banar	Trimohini		3.18	2.89	−0.28	4.13	3.58	−0.55
34	Bhohai	Nakuagaon		21.10	21.57	0.48	22.24	22.48	0.24
35	Bhohai	Nalitabari		15.59	15.91	0.32	16.37	16.64	0.27
35.5	Kangsha	Sarchapur		9.31	9.81	0.50	10.74	10.53	−0.21
36	Kangsha	JariaJanjail		6.63	7.31	0.68	8.38	8.61	0.23
36.1	Kangsha	Mohanganj		5.25	5.53	0.28	6.12	6.21	0.09
45.5	Brahmaputra	Chilmari	*	19.95	20.21	0.25	21.12	21.24	0.12
46	Brahmaputra	Kamarjani	*	18.36	18.19	−0.17	19.54	19.11	−0.43
46.7	Brahmaputra	Kholabarichar	*	16.93	16.97	0.04	17.96	18.20	0.24
46.9	Brahmaputra	Bahadurabad	*	15.97	16.15	0.19	16.99	16.54	−0.45
53	Chilla Khali	Bathkuchi	*	24.39	24.59	0.20	24.98	25.11	0.13
67	Dhalai	Kamalganj		19.75	19.50	−0.25	20.63	20.38	−0.25
71	Dhaleswari	Kalagachia	*	2.67	2.66	−0.01	3.31	2.80	−0.51
71 A	Dhaleswari	Rekabi Bazar	*	2.85	2.90	0.04	3.20	3.12	−0.08
72	Baulai	Kaliajuri		3.87	4.25	0.39	5.16	5.73	0.57
72 B	Baulai	Sukdevpur		5.00	5.07	0.08	5.65	5.79	0.14
73	Baulai	Itna		3.50	3.79	0.30	4.56	4.92	0.36
74	Ghorautra	Dilalpur		2.99	2.99	0.00	3.61	3.55	−0.06
115	Gumti	Daudkandi	*	2.87	2.87	0.00	3.30	3.32	0.02
123	Hawrah	Gangasagar RR Brd	*	5.04	5.17	0.13	5.56	5.76	0.20
131	Jadukata	Saktiarkhola	*	6.28	6.32	0.04	7.22	6.92	−0.30
135A	Juri – Contina	Continala		9.86	10.07	0.21	10.73	11.07	0.34
138	Korangi	Sofiabad		10.14	9.47	−0.67	11.73	11.13	−0.60
157	Khowai	Ballah		21.70	21.71	0.02	23.24	23.14	−0.09
158	Khowai	Chunarghat		15.49	15.23	−0.26	17.17	16.75	−0.42
158.1	Khowai	Shaistaganj		10.75	10.74	−0.01	12.61	13.31	0.70
159	Khowai	Habigonj		7.91	8.43	0.52	9.32	10.24	0.92
172	Kushiyara	Amalshid		13.33	14.18	0.85	16.27	17.42	1.16
173	Kushiyara	Sheola		11.19	12.04	0.84	13.44	14.16	0.72
174	Kushiyara	Fenchuganj		8.13	8.62	0.48	10.07	10.86	0.79
175.5	Kushiyara	Sherpur		7.41	7.23	−0.18	8.87	9.00	0.13
177	Lakhya	Lakhpur		2.98	2.75	−0.22	3.61	3.20	−0.41
179	Lakhya	Demra	*	2.87	2.79	−0.08	3.40	3.18	−0.22
192	Langla	Motiganj		8.30	8.33	0.03	8.78	8.81	0.03
201	Monu	Monu R.R. bridge		17.33	16.68	−0.65	18.68	18.39	−0.29
202	Monu	Moulavi bazar		10.21	9.70	−0.51	11.95	12.10	0.15
223	Old Brahmaputra	Goal Khanda	*	18.81	19.11	0.30	19.83	20.00	0.17
225	Old Brahmaputra	Jamalpur	*	12.99	12.50	−0.48	14.04	13.56	−0.48
227	Old Brahmaputra	Sutia Offtake		8.48	8.17	−0.31	9.70	9.23	−0.47
228.5	Old Brahmaputra	Mymenshing		7.90	7.55	−0.35	8.95	8.62	−0.34
229	Old Brahmaputra	Toke	*	3.18	2.78	−0.40	4.20	3.30	−0.90
230.1	Old Brahmaputra	Bhairab Bazar R.R.		2.88	2.93	0.05	3.42	3.08	−0.33
233	Piyan	Ratnerbhanga		11.19	11.45	0.26	12.71	12.46	−0.25
234	Piyan	Companyganj		8.09	8.27	0.18	9.21	9.49	0.28
251	Sarigowain	Sharighat		11.87	12.12	0.25	13.64	13.67	0.03
252	Sarigowain	Gowainghat		9.19	10.08	0.89	10.96	11.33	0.36
252.1	Sarigowain	Salutikar		7.86	8.44	0.58	9.41	9.93	0.52
262	Someswari	Bagmara		13.82	14.05	0.23	14.72	14.98	0.26
263	Someswari	Durgapur		11.29	11.27	−0.02	12.17	12.40	0.23
263.1	Someswari	Kalmakanda		5.16	5.85	0.69	6.18	6.48	0.31
265	Sonai–Bardal	Jaldhup		9.93	10.35	0.42	11.44	12.28	0.84
266	Surma	Kanairghat		11.74	12.59	0.85	14.03	14.80	0.78
267	Surma	Sylhet		8.85	9.53	0.67	10.46	11.17	0.71
268	Surma	Chatak		7.07	7.46	0.39	8.42	9.13	0.71
269	Surma–Meghna	Sunamganj		6.69	7.07	0.38	7.62	8.02	0.40
270	Kusiyara	Markuli		5.69	6.02	0.32	6.83	7.24	0.41
271	Kalni	Ajmiriganj		4.01	4.56	0.56	5.12	5.46	0.34
272	Kalni	Madna		3.14	3.11	−0.02	3.91	4.07	0.16
272.1	Dhaleswari	Austagram		3.01	3.04	0.03	3.61	3.78	0.17
273	Meghna	Bhairab bazar		2.94	2.95	0.01	3.53	3.52	−0.01
274	Meghna	Narsingdi		2.86	2.86	−0.00	3.30	3.21	−0.09
275	Meghna	Badyar Bazar	*	2.73	3.13	0.40	3.37	3.79	0.42
275.5	Meghna	Meghna Ferry Ghat	*	2.86	3.09	0.23	3.37	3.38	0.01
276	Meghna	Satnal	*	2.81	2.95	0.14	3.40	3.21	−0.19
280	Sutang	Sutang rly.br.		5.31	4.92	−0.39	6.88	6.97	0.09
295	Titas	Ajabpur		2.99	2.97	−0.02	3.59	3.56	−0.03
296	Titas	Akhaura		3.02	2.78	−0.25	3.88	3.07	−0.81
297	Titas	Gokarnaghat		2.94	2.99	0.05	3.48	3.13	−0.35
298	Titas	Nabinagar	*	2.88	2.92	0.05	3.40	3.42	0.01
310	Mogra	Netrokona		5.17	5.29	0.11	6.12	6.18	0.06
311	Mogra	Atpara		5.40	5.49	0.08	6.22	6.28	0.06
314	Nitai	Ghosegaon		13.52	15.02	1.50	15.97	17.31	1.34
326	Lubachara	Outfall	*	12.32	12.71	0.39	14.94	15.17	0.23
327		Boalmari	*	21.17	21.39	0.22	21.77	21.81	0.04
Regional average						0.15			0.09

* = not connected

Table 10.6

Annual Maximum Discharge Statistics

BWDB Gauge No.	River	Location	1:2 Year Return Period (m3/s)			1:10 Year Return Period (m3/s)		
			30−Year Estimate	9−Year Estimate	Ratio 9yr/30yr	30−Year Estimate	9−Year Estimate	Ratio 9yr/30yr
34	Bhugai	Nakuagaon	506	564	1.11	906	745	0.82
36	Kangsha	Jariajanjail	1047	1330	1.27	1386	1441	1.04
46−9	Brahmaputra	Bahadurabad	64643	71333	1.10	84712	110187	1.30
67	Dhalai	Kamalganj	243	314	1.29	346	374	1.08
123	Hawrah	Gangasagar RR Bridg	33	35	1.06	57	64	1.12
138	Karangi	Sofiabad	87	97	1.11	193	240	1.24
158−1	Khowai	Shaistaganj	237	490	2.07	554	894	1.61
173	Kushiyara	Sheola	2234	2610	1.17	2842	3112	1.10
175−5	Kushiyara	Sherpur	2632	2726	1.04	3493	3668	1.05
179	Lakhya	Demra	2094	2011	0.96	2441	2566	1.05
192	Lungla	Motiganj	74	115	1.55	171	222	1.30
201	Manu	Manu RR Bridge	616	748	1.21	778	817	1.05
228−5	Old Bramahputra	Mymensingh	2945	2468	0.84	4003	4262	1.06
230−1	Old Bramahputra	Bhairab Bazar	546	350	0.64	915	606	0.66
251	Sarigowain	Sarighat	1067	1159	1.09	1384	1328	0.96
263A	Shibganjdhala	Durgapur	1316	1449	1.10	2001	2119	1.06
265	Sonai Bardal	Jaldhup	441	495	1.12	556	578	1.04
266	Surma	Kanairghat	2218	2466	1.11	2577	2693	1.05
267	Surma	Sylhet	2064	2064	1.00	2326	2270	0.98
314	Nitai	Ghosegaon	356	486	1.37	602	770	1.28
Regional average					1.16			1.09

Table 10.7

Pre–monsoon Maximum Discharge Statistics

BWDB Gauge No.	River	Location	1:2 Year Return Period (m3/s)			1:10 Year Return Period (m3/s)		
			30–Year Estimate	9–Year Estimate	Ratio 9yr/30yr	30–Year Estimate	9–Year Estimate	Ratio 9yr/30yr
34	Bhugai	Nakuagaon	36	33	0.92	123	135	1.10
36	Kangsha	Jariajanjail	145	149	1.03	388	480	1.24
46–9	Brahmaputra	Bahadurabad	15418	16678	1.08	23721	27864	1.17
67	Dhalai	Kamalganj	130	101	0.78	229	210	0.92
123	Hawrah	Gangasagar RR Bridge	15	17	1.13	34	42	1.24
138	Karangi	Sofiabad	24	9	0.38	54	29	0.54
158–1	Khowai	Shaistaganj	101	72	0.71	189	188	0.99
173	Kushiyara	Sheola	722	595	0.82	1513	1483	0.98
175–5	Kushiyara	Sherpur	1375	1071	0.78	2325	2239	0.96
192	Lungla	Motiganj	28	10	0.36	76	43	0.57
201	Manu	Manu RR Bridge	301	235	0.78	558	402	0.72
228–5	Old Bramahputra	Mymensingh	277	140	0.51	630	423	0.67
251	Sarigowain	Sarighat	268	176	0.66	733	369	0.50
263A	Shibganjdhala	Durgapur	100	78	0.78	264	250	0.95
265	Sonai Bardal	Jaldhup	177	172	0.97	313	342	1.09
266	Surma	Kanairghat	878	733	0.83	1565	1715	1.10
267	Surma	Sylhet	768	737	0.96	1343	1374	1.02
314	Nitai	Ghosegaon	25	19	0.76	76	90	1.18
Regional average					0.79			0.94

Table 10.8
Comparison of Historic and Simulated Annual Maximum Water Levels

Location	Reach	1:2 year (m)			1:10 year (m)		
		Historic	Simulated (Existing)	Difference	Historic	Simulated (Existing)	Difference
Amalshid	UPPER KUSHIYARA	17.63	17.99	0.36	17.81	18.31	0.50
Sheola	KUSHIYARA	14.09	14.46	0.38	14.15	14.70	0.55
Fenchuganj	KUSHIYARA	10.81	10.78	−0.03	11.03	11.16	0.14
Sherpur	KUSHIYARA	9.06	9.01	−0.05	9.35	9.21	−0.14
Markuli	KUSHIYARA	7.39	7.39	−0.00	7.90	7.81	−0.09
Ajmiriganj	KALNI	6.93	6.70	−0.23	7.78	7.61	−0.17
Madna	DHALESWARI	6.83	6.55	−0.27	7.63	7.52	−0.11
Austagram	DHALESWARI	6.64	6.48	−0.16	7.52	7.47	−0.05
Ajabpur	UPPER MEGHNA	6.45	6.41	−0.04	7.37	7.41	0.04
Amalshid	UPPER SURMA	17.63	17.99	0.36	17.81	18.31	0.50
Kanairghat	SURMA	14.96	14.60	−0.36	15.15	14.96	−0.19
Sylhet	SURMA	11.35	11.49	0.14	11.68	12.03	0.35
Chattak	SURMA	10.20	9.77	−0.43	10.70	10.72	0.02
Sunamganj	SURMA	8.81	8.87	0.06	9.10	9.99	0.89
Sukdebpur	BAULAI	7.15	7.15	0.00	7.93	7.98	0.05
Kaliajuri	BAULAI	7.21	6.91	−0.30	7.96	7.80	−0.16
Itna	BAULAI	6.93	6.87	−0.06	7.76	7.77	0.01
Dilalpur	GHORAUTRA	6.53	6.49	−0.04	7.49	7.47	−0.02
Sarighat	SARIGOWAIN	13.88	15.09	1.21	14.35	15.85	1.50
Gowainghat	SARIGOWAIN	11.80	11.72	−0.08	12.17	12.30	0.13
Salutikar	SARIGOWAIN	10.86	10.32	−0.53	11.12	11.16	0.04
Ratnerbhanga	ACTIVE PIYAN	13.53	13.24	−0.29	14.73	13.93	−0.80
Jaldhup	SONAIBARDAL	12.39	12.01	−0.38	12.58	12.32	−0.26
Manu RR Bridge	MANU	18.89	19.07	0.18	19.02	19.29	0.27
Moulavi bazar	MANU	12.66	12.84	0.18	12.87	12.95	0.08
Kamalganj	DHALAI	20.76	21.12	0.36	20.90	21.28	0.38
Motiganj	LUNGLABIJNA	8.85	9.02	0.17	9.01	9.23	0.22
Sofiabad	KARANGI	11.75	12.15	0.40	12.18	13.26	1.09
Ballah	UPPER KHOWAI	23.77	24.39	0.62	25.62	25.76	0.14
Chunarghat	UPPER KHOWAI	17.74	17.60	−0.14	18.18	18.99	0.81
Shaistaganj	KHOWAI	13.79	14.35	0.56	13.74	15.78	2.04
Habigonj	KHOWAI	10.19	11.28	1.09	10.11	12.58	2.47
Sutang RR Bridge	SUTANG	7.48	7.64	0.16	8.03	8.12	0.09
Nakuagaon	BHUGAI	24.79	25.27	0.48	25.01	25.66	0.65
Nalitabari	BHUGAI	18.22	18.94	0.72	18.33	19.33	1.00
Ghosegaon	NITAI	17.16	17.18	0.02	17.26	17.30	0.04
Bagmara	SHIBGANJDHAL	17.10	18.18	1.08	17.67	18.54	0.87
Durgapur	SHIBGANJDHAL	14.34	14.22	−0.12	14.72	14.48	−0.24
Kalmakanda	SOMESWARI	5.85	5.6	−0.24	6.18	6.3	0.11
Sarchapur	KANGSHA	13.46	12.76	−0.70	13.98	13.24	−0.74
JariaJanjail	KANGSHA	11.12	10.64	−0.48	11.25	11.16	−0.09
Mohanganj	LOWER KANGSHA	7.55	7.47	−0.08	8.15	8.29	0.14
Netrokona	MOGRA	8.99	8.88	−0.10	9.58	9.56	−0.02
Atpara	MOGRA	7.72	7.58	−0.14	8.23	8.29	0.06

Table 10.9
Comparison of Historic and Simulated Pre–Monsoon Peak Water Levels

Location	Reach	1:2 year (m)			1:10 year (m)		
		Historic	Simulated (Existing)	Difference	Historic	Simulated (Existing)	Difference
Amalshid	UPPER KUSHIYARA	14.18	13.8	−0.34	16.27	17.6	1.29
Sheola	KUSHIYARA	12.04	11.5	−0.50	13.44	14.3	0.83
Fenchuganj	KUSHIYARA	8.62	8.5	−0.11	10.07	10.4	0.36
Sherpur	KUSHIYARA	7.23	7.4	0.13	8.87	8.7	−0.13
Markuli	KUSHIYARA	6.02	6.6	0.58	6.83	7.2	0.38
Ajmiriganj	KALNI	4.56	4.7	0.17	5.12	5.3	0.22
Madna	DHALESWARI	3.11	3.2	0.07	3.91	4.1	0.21
Austagram	DHALESWARI	3.04	2.9	−0.13	3.61	3.6	0.01
Ajabpur	UPPER MEGHNA	2.97	2.9	−0.10	3.59	3.5	−0.05
Amalshid	UPPER SURMA	14.18	13.8	−0.34	16.27	17.6	1.29
Kanairghat	SURMA	12.59	11.8	−0.80	14.03	14.5	0.46
Sylhet	SURMA	9.53	8.8	−0.70	10.46	11.2	0.70
Chattak	SURMA	7.46	7.0	−0.45	8.42	8.8	0.36
Sunamganj	SURMA	7.07	6.2	−0.85	7.62	7.8	0.15
Sukdebpur	BAULAI	5.07	5.1	0.00	5.65	6.0	0.36
Kaliajuri	BAULAI	4.25	4.3	0.03	5.16	5.2	0.04
Itna	BAULAI	3.79	4.1	0.30	4.56	5.1	0.53
Dilalpur	GHORAUTRA	2.99	3.0	0.04	3.61	3.8	0.23
Sarighat	SARIGOWAIN	12.12	12.3	0.15	13.64	14.9	1.25
Gowainghat	SARIGOWAIN	10.08	9.7	−0.37	10.96	11.4	0.43
Salutikar	SARIGOWAIN	8.44	8.1	−0.32	9.41	9.6	0.23
Ratnerbhanga	ACTIVE PIYAN	11.45	10.4	−1.04	12.71	12.5	−0.25
Jaldhup	SONAIBARDAL	10.35	9.9	−0.45	11.44	11.7	0.23
Manu RR Bridge	MANU	16.68	17.0	0.29	18.68	18.7	−0.01
Moulavi bazar	MANU	9.70	9.7	−0.02	11.95	12.1	0.10
Kamalganj	DHALAI	19.50	19.9	0.44	20.63	21.0	0.36
Motiganj	LUNGLABIJNA	8.33	8.6	0.27	8.78	9.0	0.25
Sofiabad	KARANGI	9.47	10.2	0.75	11.73	11.4	−0.31
Ballah	UPPER KHOWAI	21.71	22.2	0.46	23.24	24.0	0.79
Chunarghat	UPPER KHOWAI	15.23	14.8	−0.44	17.17	17.0	−0.18
Shaistaganj	KHOWAI	10.74	10.9	0.20	12.61	13.3	0.71
Habigonj	KHOWAI	8.43	8.1	−0.37	9.32	10.2	0.91
Sutang RR Bridge	SUTANG	4.92	6.3	1.34	6.88	7.3	0.39
Nakuagaon	BHUGAI	21.57	21.7	0.10	22.24	22.9	0.69
Nalitabari	BHUGAI	15.91	15.6	−0.28	16.37	16.7	0.37
Ghosegaon	NITAI	15.02	14.1	−0.90	15.97	15.3	−0.70
Bagmara	SHIBGANJDHAL	14.05	14.1	0.06	14.72	15.3	0.62
Durgapur	SHIBGANJDHAL	11.27	11.3	0.03	12.17	12.3	0.17
Kalmakanda	SOMESWARI	5.85	5.6	−0.24	6.18	6.3	0.11
Sarchapur	KANGSHA	9.81	10.2	0.41	10.74	10.9	0.12
JariaJanjail	KANGSHA	7.31	7.7	0.36	8.38	8.6	0.19
Mohanganj	LOWER KANGSHA	5.53	5.4	−0.12	6.12	6.1	−0.03
Netrokona	MOGRA	5.29	4.9	−0.43	6.12	6.0	−0.16
Atpara	MOGRA	5.49	4.9	−0.54	6.22	5.7	−0.48

Table 10.10

Comparison of Historic and Simulated Annual Maximum Flood Discharges

Location	Reach	1:2 year (m3/s)			1:10 year (m3/s)		
		Historic	Simulated (Existing)	Ratio Sim/hist	Historic	Simulated (Existing)	Ratio Sim/hist
Sheola	KUSHIYARA	2610	3036	1.16	3112	3285	1.06
Sherpur	KUSHIYARA	2726	2745	1.01	3668	3039	0.83
Kanairghat	SURMA	2466	2472	1.00	2693	2684	1.00
Sylhet	SURMA	2064	2025	0.98	2270	2154	0.95
Sarighat	SARIGOWAIN	1159	1547	1.33	1328	1936	1.46
Jaldhup	SONAIBARDAL	495	546	1.10	578	646	1.12
Manu RR Bridge	UPPER MANU	748	837	1.12	817	897	1.10
Kamalganj	DHALAI	314	357	1.14	374	387	1.03
Motiganj	LUNGLABIJNA	115	117	1.02	222	149	0.67
Sofiabad	KARANGI	97	286	2.95	240	774	3.22
Shaistaganj	KHOWAI	490	604	1.23	894	939	1.05
Nakuagaon	BHUGAI	564	658	1.17	745	760	1.02
Ghosegaon	NITAI	486	398	0.82	770	429	0.56
Durgapur	SHIBGANJDHALA	1449	1570	1.08	2119	1834	0.87
Jariajanjail	KANGSHA	1330	1201	0.90	1441	1467	1.02

Table 10.11
Impact Analysis – 1:2 Year Annual Flood Water Levels

Location	Reach	Model Chainage (km)	1:2 Year Flood Level (m,PWD) Existing (NERP7)	With Tipaimukh FNI	With Tipaimukh RDP	Without Tipaimuk FNI	Without Tipaimuk RDP	Impacts Change in water level (metres) Morph.	Projects	Dam	Net
AMALSHID	UPPER KUSHIYARA	0.0	18.0	16.4	16.7	18.0	18.3	0.0	0.3	−1.6	−1.3
SHEOLA	KUSHIYARA	0.0	14.5	13.5	14.3	14.5	15.7	0.0	0.8	−1.4	−0.2
FENCHUGANJ	KUSHIYARA	51.0	10.8	10.3	11.4	10.8	12.1	0.0	1.1	−0.7	0.6
SHERPUR	KUSHIYARA	91.0	9.0	8.8	8.7	8.9	8.9	−0.1	0.0	−0.1	−0.3
MARKULI	KUSHIYARA	132.5	7.4	7.6	7.6	7.7	7.6	0.3	0.0	0.0	0.2
AJMIRIGANJ	KALNI	24.0	6.7	6.7	6.7	6.7	6.7	0.0	0.0	0.0	0.0
MADNA	DHALESWARI	4.8	6.6	6.5	6.5	6.5	6.6	0.0	0.0	0.0	0.0
AUSTAGRAM	DHALESWARI	27.0	6.5	6.5	6.5	6.5	6.5	0.0	0.0	0.0	0.0
AJABPUR	UPPER MEGHNA	16.0	6.4	6.4	6.4	6.4	6.4	0.0	0.0	0.0	0.0
AMALSHID (SURMA)	UPPER SURMA	0.0	18.0	16.4	16.7	18.0	18.3	0.0	0.3	−1.6	−1.3
KANAIRGHAT	SURMA	2.0	14.6	14.2	14.6	14.6	15.4	0.0	0.5	−0.7	0.0
BARAIGRAM	SURMA	27.1	13.1	12.6	13.1	13.1	13.9	0.0	0.5	−0.7	0.1
SYLHET	SURMA	62.5	11.5	11.0	11.3	11.5	11.9	0.0	0.3	−0.6	−0.2
RAMPUR	BHATTA-DAHUKA	0.0	10.2	10.1	10.3	10.2	10.5	0.0	0.2	−0.2	0.1
CHATTAK	SURMA	117.0	9.8	9.7	9.8	9.8	9.9	0.0	0.1	−0.1	0.0
SUNAMGANJ	SURMA	162.0	8.9	8.8	9.0	8.9	9.1	0.0	0.2	−0.1	0.1
DURLABPUR	NAWA	13.0	7.6	7.5	7.7	7.6	7.8	0.0	0.2	0.0	0.2
SUKDEBPUR	BAULAI	26.0	7.2	7.2	7.3	7.2	7.4	0.0	0.2	0.0	0.2
KHALIAJURI	BAULAI	58.5	6.9	6.9	6.9	6.9	6.9	0.0	0.0	0.0	0.0
ITNA	BAULAI	77.0	6.9	6.9	6.8	6.9	6.9	0.0	0.0	0.0	0.0
DILALPUR	GHORAUTRA	29.0	6.5	6.5	6.5	6.5	6.5	0.0	0.0	0.0	0.0
NILPUR	SURMA	177.0	7.6	7.5	7.4	7.6	7.5	0.0	−0.1	−0.1	−0.2
AKHTER BAZAR	MAHASING	20.0	7.4	7.3	7.1	7.4	7.2	0.0	−0.2	−0.1	−0.2
BOROGRAM	LUBHACHARA	0.0	15.6	15.3	15.6	15.6	16.2	0.0	0.3	−0.6	−0.1
SARIGHAT	SARIGOWAIN	0.0	15.1	15.1	15.1	15.1	15.1	0.0	0.0	0.0	0.0
GOWAINGHAT	SARIGOWAIN	24.0	11.7	11.7	11.7	11.7	11.7	0.0	0.0	0.0	0.0
SALUTIKAR	SARIGOWAIN	48.0	10.3	10.3	10.3	10.3	10.4	0.0	0.1	−0.1	0.0
JAFFLONG	JAFFLONG	5.0	12.9	12.8	12.8	12.8	12.9	0.0	0.0	0.0	0.0
RATNERBHANGA	ACTIVE PIYAN	0.0	13.2	13.2	13.3	13.2	13.3	0.0	0.1	0.0	0.0
AMBARI	ACTIVE PIYAN	45.0	9.9	9.8	9.9	9.9	10.0	0.0	0.1	−0.1	0.0
ISLAMPUR	DHALAGANG	0.0	13.0	13.0	13.0	13.0	13.0	0.0	0.0	0.0	0.0
CHELASONAPUR	ACTIVE CHELA	0.0	12.1	12.1	12.1	12.1	12.1	0.0	0.0	0.0	0.0
URURGAON	NAWAGANG	0.0	10.6	10.4	10.4	10.6	10.6	−0.1	0.0	−0.2	−0.2
DULURA	JHALUKHALI	0.0	12.6	12.6	12.6	12.6	12.6	0.0	0.0	0.0	0.0
MUSLIMPUR	JHALUKHALI	5.5	9.8	9.8	9.8	9.8	9.8	0.0	0.0	0.0	0.0
JALDHUP	SONAIBARDAL	0.0	12.0	11.9	12.2	12.0	12.5	0.0	0.2	−0.4	0.2
MANU RR BRIDGE	MANU	0.0	19.1	19.1	17.5	19.1	17.5	0.0	−1.6	0.0	−1.5
MAULVIBAZAR	MANU	37.1	12.8	12.8	11.5	12.8	11.6	0.0	−1.3	0.0	−1.3
KAMALGANJ	DHALAI	0.0	21.1	21.1	21.1	21.1	21.1	0.0	0.0	0.0	0.0
MOTIGANJ	LUNGLABIJNA	0.0	9.0	9.0	9.0	9.0	9.0	0.0	0.0	0.0	0.0
TERAPASHA	LUNGLABIJNA	39.0	7.1	7.0	7.0	7.0	7.0	−0.1	0.0	0.0	−0.1
SOFIABAD	KARANGI	0.0	12.2	12.2	10.8	12.2	10.8	0.0	−1.4	0.0	−1.4
BALLAH	UPPER KHOWAI	0.0	24.4	24.4	24.4	24.4	24.4	0.0	0.0	0.0	0.0
CHUNARUGHAT	UPPER KHOWAI	24.4	17.6	17.6	18.2	17.6	18.2	0.0	0.6	0.0	0.6
SHAISTAGANJ	KHOWAI	0.0	14.4	14.5	15.1	14.5	15.1	0.2	0.5	0.0	0.7
HABIGANJ	KHOWAI	13.5	11.3	12.3	12.8	12.3	12.8	1.0	0.5	0.0	1.5
SUTANG RR BRIDGE	SUTANG	0.0	7.6	7.6	8.5	7.6	8.5	0.0	0.9	0.0	0.9
NAKUAGAON	BHUGAI	0.0	25.3	25.3	25.3	25.3	25.3	0.0	0.0	0.0	0.0
NALITABARI	BHUGAI	19.0	18.9	18.9	18.9	18.9	18.9	0.0	−0.1	0.0	−0.1
GHOSEGAON	NITAI	0.0	17.2	17.2	17.2	17.2	17.2	0.0	0.0	0.0	0.0
BIJOYPUR	SHIBGANJDHAL	0.0	18.2	18.2	18.3	18.2	18.3	0.0	0.0	0.0	0.1
DURGAPUR	SHIBGANJDHAL	6.5	14.2	14.2	14.5	14.2	14.5	0.0	0.2	0.0	0.3
KALMAKANDA	SOMESWARI	0.0	8.0	8.0	8.0	8.0	8.1	0.1	0.0	0.0	0.1
MADHYANAGAR	SOMESWARI	15.0	7.5	7.5	7.8	7.5	7.9	0.0	0.3	0.0	0.3
LOURERGARH	JADUKATA	0.0	12.5	12.6	12.7	12.6	12.7	0.1	0.1	0.0	0.2
SARCHAPUR	KANGSHA	0.0	12.8	12.7	12.3	12.7	12.3	0.0	−0.4	0.0	−0.5
JARIAJANJAIL	KANGSHA	62.0	10.6	10.3	10.6	10.3	10.6	−0.3	0.2	0.0	−0.1
TAKURAKONA	DHONAIKHALI	0.0	8.2	8.0	8.3	8.1	8.3	−0.1	0.3	0.0	0.1
MOHANGANJ	LOWER KANGSHA	128.0	7.5	7.4	7.6	7.4	7.6	−0.1	0.2	0.0	0.1
NETROKONA	MOGRA	0.0	8.9	8.9	10.1	8.9	10.1	0.0	1.2	0.0	1.2
ATPARA	MOGRA	31.5	7.6	7.5	7.9	7.5	7.9	−0.1	0.4	0.0	0.3
GOG BAZAR	SAIDULI/BARUNI	34.1	6.9	6.9	7.1	6.9	7.1	0.0	0.2	0.0	0.2
DAKSIN HASANPUR	DHANU	42.0	6.9	6.8	6.9	6.9	6.9	0.0	0.1	0.0	0.0
CHAMRAGHAT	DHANU	75.0	6.8	6.7	6.7	6.7	6.8	0.0	0.0	0.0	0.0

Table 10.12
Impact Analysis – 1:10 Year Annual Flood Water Levels

Location	Reach	Model Chainage (km)	1:10 Year Flood Level (m,PWD) Existing (NERP7)	With Tipaimukh FNI	With Tipaimukh RDP	Without Tipaimuk FNI	Without Tipaimuk RDP	Impacts Change in water level (metres) Morph.	Projects	Dam	Net
AMALSHID	UPPER KUSHIYARA	0.0	18.3	16.8	17.1	18.3	18.6	0.0	0.3	−1.5	−1.2
SHEOLA	KUSHIYARA	0.0	14.7	13.7	14.6	14.7	16.0	0.0	0.9	−1.4	−0.1
FENCHUGANJ	KUSHIYARA	51.0	11.2	10.6	11.9	11.1	12.7	0.0	1.2	−0.8	0.7
SHERPUR	KUSHIYARA	91.0	9.2	8.9	8.9	9.1	9.0	−0.1	−0.1	−0.2	−0.4
MARKULI	KUSHIYARA	132.5	7.8	7.9	7.9	8.0	7.9	0.2	0.0	−0.1	0.1
AJMIRIGANJ	KALNI	24.0	7.6	7.6	7.6	7.6	7.6	0.0	0.0	0.0	0.0
MADNA	DHALESWARI	4.8	7.5	7.5	7.5	7.5	7.5	0.0	0.0	0.0	0.0
AUSTAGRAM	DHALESWARI	27.0	7.5	7.5	7.5	7.5	7.5	0.0	0.0	0.0	0.0
AJABPUR	UPPER MEGHNA	16.0	7.4	7.4	7.4	7.4	7.4	0.0	0.0	0.0	0.0
AMALSHID(SURMA)	UPPER SURMA	0.0	18.3	16.8	17.1	18.3	18.6	0.0	0.3	−1.5	−1.2
KANAIRGHAT	SURMA	2.0	15.0	14.6	15.2	15.0	16.0	0.0	0.6	−0.8	0.2
BARAIGRAM	SURMA	27.1	13.4	13.1	13.7	13.4	14.4	0.0	0.7	−0.7	0.4
SYLHET	SURMA	62.5	12.0	11.6	11.9	12.0	12.5	0.0	0.3	−0.5	−0.1
RAMPUR	BHATTA−DAHUKA	0.0	11.0	10.9	11.1	11.0	11.3	0.0	0.3	−0.2	0.2
CHATTAK	SURMA	117.0	10.7	10.6	10.8	10.7	11.0	0.0	0.2	−0.1	0.1
SUNAMGANJ	SURMA	162.0	10.0	9.9	10.1	10.0	10.3	0.0	0.2	−0.1	0.1
DURLABPUR	NAWA	13.0	8.3	8.3	8.5	8.3	8.5	0.0	0.2	−0.1	0.2
SUKDEBPUR	BAULAI	26.0	8.0	8.0	8.1	8.0	8.2	0.0	0.1	−0.1	0.1
KHALIAJURI	BAULAI	58.5	7.8	7.8	7.8	7.8	7.8	0.0	0.0	0.0	0.0
ITNA	BAULAI	77.0	7.8	7.8	7.7	7.8	7.8	0.0	0.0	0.0	0.0
DILALPUR	GHORAUTRA	29.0	7.5	7.5	7.5	7.5	7.5	0.0	0.0	0.0	0.0
NILPUR	SURMA	177.0	8.3	8.2	8.2	8.3	8.3	0.0	0.0	−0.1	−0.1
AKHTER BAZAR	MAHASING	20.0	8.2	8.1	8.0	8.2	8.1	0.0	−0.1	−0.1	−0.2
BOROGRAM	LUBHACHARA	0.0	16.1	15.8	16.1	16.1	16.8	0.0	0.4	−0.7	0.1
SARIGHAT	SARIGOWAIN	0.0	15.9	15.9	15.9	15.9	15.9	0.0	0.0	0.0	0.0
GOWAINGHAT	SARIGOWAIN	24.0	12.3	12.3	12.3	12.3	12.3	0.0	0.0	0.0	0.0
SALUTIKAR	SARIGOWAIN	48.0	11.2	11.1	11.2	11.2	11.4	0.0	0.2	−0.1	0.1
JAFFLONG	JAFFLONG	5.0	13.1	13.1	13.1	13.1	13.2	0.0	0.0	0.0	0.0
RATNERBHANGA	ACTIVE PIYAN	0.0	13.9	13.9	14.0	13.9	14.0	0.0	0.0	0.0	0.0
AMBARI	ACTIVE PIYAN	45.0	10.9	10.8	11.0	10.9	11.1	0.0	0.2	−0.1	0.1
ISLAMPUR	DHALAGANG	0.0	14.8	14.8	14.8	14.8	14.8	0.0	0.0	0.0	0.0
CHELASONAPUR	ACTIVE CHELA	0.0	12.5	12.5	12.5	12.5	12.6	0.0	0.0	0.0	0.0
URURGAON	NAWAGANG	0.0	11.1	11.1	11.1	11.1	11.2	0.0	0.0	−0.1	0.0
DULURA	JHALUKHALI	0.0	13.7	13.7	13.7	13.7	13.7	0.0	0.0	0.0	0.0
MUSLIMPUR	JHALUKHALI	5.5	10.6	10.6	10.6	10.6	10.7	0.0	0.1	0.0	0.0
JALDHUP	SONAIBARDAL	0.0	12.3	12.2	12.6	12.3	13.0	0.0	0.3	−0.5	0.2
MANU RR BRIDGE	MANU	0.0	19.3	19.3	17.5	19.3	17.5	0.0	−1.8	0.0	−1.8
MAULVIBAZAR	MANU	37.1	13.0	12.9	11.8	12.9	11.8	0.0	−1.1	0.0	−1.1
KAMALGANJ	DHALAI	0.0	21.3	21.3	21.3	21.3	21.3	0.0	0.0	0.0	0.0
MOTIGANJ	LUNGLABIJNA	0.0	9.2	9.2	9.2	9.2	9.2	0.0	0.0	0.0	0.0
TERAPASHA	LUNGLABIJNA	39.0	7.8	7.8	7.7	7.8	7.8	0.0	0.0	0.0	−0.1
SOFIABAD	KARANGI	0.0	13.3	13.3	11.4	13.3	11.4	0.0	−1.8	0.0	−1.8
BALLAH	UPPER KHOWAI	0.0	25.8	25.8	25.7	25.8	25.7	0.0	0.0	0.0	0.0
CHUNARUGHAT	UPPER KHOWAI	24.4	19.0	19.0	20.6	19.0	20.6	0.0	1.6	0.0	1.6
SHAISTAGANJ	KHOWAI	0.0	15.8	16.0	17.4	16.0	17.4	0.2	1.5	0.0	1.7
HABIGANJ	KHOWAI	13.5	12.6	13.7	15.0	13.7	15.0	1.1	1.4	0.0	2.4
SUTANG RR BRIDGE	SUTANG	0.0	8.1	8.1	8.9	8.1	8.9	0.0	0.8	0.0	0.8
NAKUAGAON	BHUGAI	0.0	25.7	25.7	25.7	25.7	25.7	0.0	0.0	0.0	0.0
NALITABARI	BHUGAI	19.0	19.3	19.3	19.2	19.3	19.2	0.0	−0.1	0.0	−0.1
GHOSEGAON	NITAI	0.0	17.3	17.3	17.3	17.3	17.3	0.0	0.0	0.0	0.0
BIJOYPUR	SHIBGANJDHAL	0.0	18.5	18.6	18.6	18.6	18.6	0.0	0.1	0.0	0.1
DURGAPUR	SHIBGANJDHAL	6.5	14.5	14.4	14.8	14.4	14.8	0.0	0.4	0.0	0.3
KALMAKANDA	SOMESWARI	0.0	8.9	8.9	9.0	9.0	9.0	0.1	0.0	0.0	0.1
MADHYANAGAR	SOMESWARI	15.0	8.4	8.4	8.7	8.4	8.7	0.0	0.3	0.0	0.3
LOURERGARH	JADUKATA	0.0	13.3	13.3	13.6	13.3	13.6	0.1	0.3	0.0	0.4
SARCHAPUR	KANGSHA	0.0	13.2	13.2	12.9	13.2	12.9	0.0	−0.3	0.0	−0.4
JARIAJANJAIL	KANGSHA	62.0	11.2	10.9	11.1	10.9	11.1	−0.3	0.2	0.0	−0.1
TAKURAKONA	DHONAIKHALI	0.0	8.8	8.7	9.0	8.7	9.0	−0.1	0.2	0.0	0.1
MOHANGANJ	LOWER KANGSHA	128.0	8.3	8.2	8.4	8.2	8.4	−0.1	0.2	0.0	0.1
NETROKONA	MOGRA	0.0	9.6	9.6	10.9	9.6	10.9	0.0	1.4	0.0	1.4
ATPARA	MOGRA	31.5	8.3	8.2	8.5	8.2	8.5	−0.1	0.3	0.0	0.2
GOG BAZAR	SAIDULI/BARUNI	34.1	7.7	7.7	7.9	7.7	7.9	0.0	0.1	0.0	0.1
DAKSIN HASANPUR	DHANU	42.0	7.8	7.7	7.8	7.7	7.8	0.0	0.0	0.0	0.0
CHAMRAGHAT	DHANU	75.0	7.7	7.6	7.7	7.7	7.7	0.0	0.0	0.0	0.0

Table 10.13
Impact Analysis – 1:2 Year Pre–Monsoon Flood Water Levels

Location	Reach	Model Chainage (km)	1:2 Year Flood Level (m,PWD) Existing (nerp7)	With Tipaimukh FNI	With Tipaimukh RDP	Without Tipaimuk FNI	Without Tipaimuk RDP	Impacts Change in water level (metres) Morph.	Projects	Dam	Net
AMALSHID	UPPER KUSHIYARA	0.0	13.8	12.9	12.9	13.8	13.9	0.0	0.0	−1.0	−0.9
SHEOLA	KUSHIYARA	0.0	11.5	10.8	10.8	11.6	11.6	0.0	0.0	−0.8	−0.7
FENCHUGANJ	KUSHIYARA	51.0	8.5	8.5	8.4	8.6	8.6	0.1	−0.1	−0.2	−0.1
SHERPUR	KUSHIYARA	91.0	7.4	7.5	7.3	7.6	7.4	0.3	−0.2	−0.1	−0.1
MARKULI	KUSHIYARA	132.5	6.6	7.1	6.8	7.2	6.9	0.6	−0.3	−0.1	0.2
AJMIRIGANJ	KALNI	24.0	4.7	4.8	4.8	4.8	4.9	0.0	0.1	0.0	0.1
MADNA	DHALESWARI	4.8	3.2	3.2	3.3	3.2	3.3	0.0	0.1	0.0	0.1
AUSTAGRAM	DHALESWARI	27.0	2.9	2.9	2.9	2.9	2.9	0.0	0.0	0.0	0.0
AJABPUR	UPPER MEGHNA	16.0	2.9	2.9	2.9	2.9	2.9	0.0	0.0	0.0	0.0
AMALSHID (SURMA)	UPPER SURMA	0.0	13.8	12.9	12.9	13.8	13.9	0.0	0.0	−1.0	−0.9
KANAIRGHAT	SURMA	2.0	11.8	11.1	11.1	11.8	11.8	0.0	0.0	−0.7	−0.7
BARAIGRAM	SURMA	27.1	10.4	9.8	9.8	10.4	10.4	0.0	0.0	−0.6	−0.6
SYLHET	SURMA	62.5	8.8	8.5	8.5	8.8	8.8	0.0	0.0	−0.4	−0.3
RAMPUR	BHATTA–DAHUKA	0.0	7.9	7.7	7.7	8.0	8.0	0.0	0.0	−0.2	−0.2
CHATTAK	SURMA	117.0	7.0	7.0	7.0	7.1	7.1	0.1	0.0	−0.1	0.0
SUNAMGANJ	SURMA	162.0	6.2	6.3	6.3	6.3	6.4	0.1	0.0	−0.1	0.1
DURLABPUR	NAWA	13.0	5.7	5.8	5.8	5.8	5.8	0.1	0.0	0.0	0.2
SUKDEBPUR	BAULAI	26.0	5.1	5.2	5.2	5.2	5.3	0.2	0.0	0.0	0.2
KHALIAJURI	BAULAI	58.5	4.3	4.4	4.2	4.4	4.2	0.1	−0.1	0.0	0.0
ITNA	BAULAI	77.0	4.1	4.2	4.0	4.2	4.0	0.1	−0.2	0.0	−0.1
DILALPUR	GHORAUTRA	29.0	3.0	3.0	3.0	3.0	3.0	0.0	0.0	0.0	0.0
NILPUR	SURMA	177.0	5.5	5.6	5.2	5.6	5.3	0.1	−0.4	−0.1	−0.3
AKHTER BAZAR	MAHASING	20.0	5.1	5.2	5.0	5.2	5.0	0.1	−0.2	0.0	−0.1
BOROGRAM	LUBHACHARA	0.0	12.3	11.8	11.8	12.3	12.3	0.0	0.0	−0.5	−0.5
SARIGHAT	SARIGOWAIN	0.0	12.3	12.3	12.3	12.3	12.3	0.0	0.0	0.0	0.0
GOWAINGHAT	SARIGOWAIN	24.0	9.7	9.7	9.7	9.7	9.7	0.0	0.0	0.0	0.0
SALUTIKAR	SARIGOWAIN	48.0	8.1	8.1	8.1	8.2	8.2	0.0	0.0	0.0	0.0
JAFFLONG	JAFFLONG	5.0	11.2	11.2	11.2	11.2	11.2	0.0	0.0	0.0	0.0
RATNERBHANGA	ACTIVE PIYAN	0.0	10.4	10.4	10.4	10.4	10.4	0.0	0.0	0.0	0.0
AMBARI	ACTIVE PIYAN	45.0	7.0	7.0	7.0	7.1	7.1	0.1	0.0	−0.1	0.0
ISLAMPUR	DHALAGANG	0.0	9.9	9.8	9.7	9.8	9.8	−0.1	0.0	−0.1	−0.1
CHELASONAPUR	ACTIVE CHELA	0.0	10.7	10.7	10.7	10.7	10.7	0.0	0.0	0.0	0.0
URURGAON	NAWAGANG	0.0	9.5	9.2	9.2	9.3	9.5	−0.1	0.0	−0.3	−0.3
DULURA	JHALUKHALI	0.0	10.2	10.2	10.2	10.2	10.2	0.0	0.0	0.0	0.0
MUSLIMPUR	JHALUKHALI	5.5	7.1	7.2	7.2	7.2	7.3	0.0	0.0	−0.2	0.0
JALDHUP	SONAIBARDAL	0.0	9.9	9.9	9.9	9.9	9.9	0.0	0.0	−0.1	0.0
MANU RR BRIDGE	MANU	0.0	17.0	17.0	17.0	17.0	17.0	0.0	0.0	0.0	0.0
MAULVIBAZAR	MANU	37.1	9.7	9.7	9.7	9.7	9.7	0.0	0.0	0.0	0.0
KAMALGANJ	DHALAI	0.0	19.9	19.9	19.9	19.9	19.9	0.0	0.0	0.0	0.0
MOTIGANJ	LUNGLABIJNA	0.0	8.6	8.6	8.6	8.6	8.6	0.0	0.0	0.0	0.0
TERAPASHA	LUNGLABIJNA	39.0	4.8	4.8	4.9	4.9	4.9	0.0	0.0	0.0	0.0
SOFIABAD	KARANGI	0.0	10.2	10.2	10.1	10.2	10.1	0.0	−0.1	0.0	−0.1
BALLAH	UPPER KHOWAI	0.0	22.2	22.2	22.2	22.2	22.2	0.0	0.0	0.0	0.0
CHUNARUGHAT	UPPER KHOWAI	24.4	14.8	14.8	14.7	14.8	14.7	0.0	−0.1	0.0	−0.1
SHAISTAGANJ	KHOWAI	0.0	10.9	11.0	10.8	11.0	10.8	0.0	−0.2	0.0	−0.1
HABIGANJ	KHOWAI	13.5	8.1	9.0	8.9	9.0	8.9	0.9	−0.1	0.0	0.8
SUTANG RR BRIDGE	SUTANG	0.0	6.3	6.3	6.5	6.3	6.5	0.0	0.2	0.0	0.2
NAKUAGAON	BHUGAI	0.0	21.7	21.7	21.7	21.7	21.7	0.0	0.0	0.0	0.0
NALITABARI	BHUGAI	19.0	15.6	15.6	15.6	15.6	15.6	0.0	0.0	0.0	0.0
GHOSEGAON	NITAI	0.0	14.1	14.1	14.1	14.1	14.1	0.0	0.0	0.0	0.0
BIJOYPUR	SHIBGANJDHAL	0.0	14.1	14.1	14.1	14.1	14.1	0.0	0.0	0.0	0.0
DURGAPUR	SHIBGANJDHAL	6.5	11.3	10.9	11.7	10.9	11.7	−0.4	0.7	0.0	0.4
KALMAKANDA	SOMESWARI	0.0	5.6	5.8	5.8	5.8	5.8	0.2	0.0	0.0	0.2
MADHYANAGAR	SOMESWARI	15.0	5.6	5.6	5.8	5.6	5.8	0.1	0.2	0.0	0.2
LOURERGARH	JADUKATA	0.0	7.9	8.3	8.4	8.3	8.4	0.4	0.1	0.0	0.5
SARCHAPUR	KANGSHA	0.0	10.2	10.2	9.8	10.2	9.8	0.0	−0.3	0.0	−0.4
JARIAJANJAIL	KANGSHA	62.0	7.7	7.2	7.7	7.2	7.7	−0.5	0.5	0.0	0.0
TAKURAKONA	DHONAIKHALI	0.0	6.2	6.0	6.4	6.0	6.4	−0.2	0.4	0.0	0.2
MOHANGANJ	LOWER KANGSHA	128.0	5.4	5.4	5.6	5.4	5.6	0.0	0.2	0.0	0.2
NETROKONA	MOGRA	0.0	4.9	4.8	5.8	4.8	5.8	−0.1	1.0	0.0	0.9
ATPARA	MOGRA	31.5	4.9	4.9	5.3	4.8	5.3	−0.1	0.5	0.0	0.4
GOG BAZAR	SAIDULI/BARUNI	34.1	4.1	4.1	4.4	4.1	4.4	0.0	0.4	0.0	0.3
DAKSIN HASANPUR	DHANU	42.0	3.8	3.7	3.8	3.7	3.8	0.0	0.1	0.0	0.0
CHAMRAGHAT	DHANU	75.0	3.5	3.5	3.4	3.5	3.4	0.0	−0.1	0.0	−0.1

Table 10.14

Impact Analysis – 1:10 Year Pre–Monsoon Flood Water Levels

Location	Reach	Model Chainage (km)	1:10 Year Flood Level (m,PWD) Existing (nerp7)	With Tipaimukh FNI	With Tipaimukh RDP	Without Tipaimuk FNI	Without Tipaimuk RDP	Impacts Change in water level (metres) Morph.	Projects	Dam	Net
AMALSHID	UPPER KUSHIYARA	0.0	17.6	16.0	16.2	17.6	17.8	0.0	0.2	−1.7	−1.4
SHEOLA	KUSHIYARA	0.0	14.3	13.2	13.7	14.3	15.1	0.0	0.5	−1.4	−0.5
FENCHUGANJ	KUSHIYARA	51.0	10.4	10.0	10.7	10.4	11.3	0.0	0.7	−0.6	0.2
SHERPUR	KUSHIYARA	91.0	8.7	8.5	8.5	8.7	8.7	0.0	0.0	−0.2	−0.2
MARKULI	KUSHIYARA	132.5	7.2	7.5	7.5	7.6	7.5	0.3	0.0	0.0	0.3
AJMIRIGANJ	KALNI	24.0	5.3	5.3	5.4	5.4	5.4	0.1	0.0	−0.1	0.0
MADNA	DHALESWARI	4.8	4.1	4.1	4.2	4.2	4.3	0.1	0.1	−0.1	0.1
AUSTAGRAM	DHALESWARI	27.0	3.6	3.6	3.6	3.7	3.7	0.0	0.0	0.0	0.0
AJABPUR	UPPER MEGHNA	16.0	3.5	3.6	3.5	3.6	3.6	0.0	0.0	0.0	0.0
AMALSHID(SURMA)	UPPER SURMA	0.0	17.6	16.0	16.2	17.6	17.8	0.0	0.2	−1.7	−1.4
KANAIRGHAT	SURMA	2.0	14.5	14.0	14.3	14.5	15.2	0.0	0.3	−0.9	−0.2
BARAIGRAM	SURMA	27.1	12.9	12.4	12.8	12.9	13.6	0.0	0.4	−0.9	−0.1
SYLHET	SURMA	62.5	11.2	10.6	10.8	11.2	11.4	0.0	0.2	−0.6	−0.4
RAMPUR	BHATTA–DAHUKA	0.0	9.7	9.5	9.6	9.7	9.9	0.0	0.1	−0.3	−0.1
CHATTAK	SURMA	117.0	8.8	8.7	8.8	8.8	9.0	0.0	0.1	−0.2	0.0
SUNAMGANJ	SURMA	162.0	7.8	7.7	8.0	7.8	8.1	0.1	0.3	−0.1	0.2
DURLABPUR	NAWA	13.0	6.7	6.8	7.0	6.8	7.1	0.1	0.2	−0.1	0.3
SUKDEBPUR	BAULAI	26.0	6.0	6.1	6.3	6.1	6.3	0.1	0.2	0.0	0.3
KHALIAJURI	BAULAI	58.5	5.2	5.3	5.1	5.3	5.2	0.1	−0.1	−0.1	−0.1
ITNA	BAULAI	77.0	5.1	5.1	5.0	5.2	5.1	0.2	−0.1	−0.1	−0.1
DILALPUR	GHORAUTRA	29.0	3.8	3.8	3.8	3.9	3.8	0.0	−0.1	0.0	−0.1
NILPUR	SURMA	177.0	6.7	6.7	6.2	6.8	6.2	0.1	−0.5	0.0	−0.5
AKHTER BAZAR	MAHASING	20.0	6.2	6.2	5.8	6.3	5.9	0.1	−0.4	−0.1	−0.4
BOROGRAM	LUBHACHARA	0.0	15.4	15.0	15.2	15.5	16.0	0.0	0.3	−0.8	−0.2
SARIGHAT	SARIGOWAIN	0.0	14.9	14.9	14.9	14.9	14.9	0.0	0.0	0.0	0.0
GOWAINGHAT	SARIGOWAIN	24.0	11.4	11.4	11.4	11.4	11.4	0.0	0.0	0.0	0.0
SALUTIKAR	SARIGOWAIN	48.0	9.6	9.6	9.6	9.7	9.7	0.0	0.0	−0.1	0.0
JAFFLONG	JAFFLONG	5.0	12.7	12.7	12.7	12.7	12.7	0.0	0.0	0.0	0.0
RATNERBHANGA	ACTIVE PIYAN	0.0	12.5	12.5	12.5	12.5	12.5	0.0	0.0	0.0	0.0
AMBARI	ACTIVE PIYAN	45.0	8.8	8.7	8.8	8.8	9.0	0.0	0.1	−0.2	0.0
ISLAMPUR	DHALAGANG	0.0	11.7	11.9	11.8	11.9	11.8	0.2	−0.1	0.0	0.1
CHELASONAPUR	ACTIVE CHELA	0.0	11.6	11.6	11.6	11.6	11.6	0.0	0.0	0.0	0.0
URURGAON	NAWAGANG	0.0	10.4	10.1	10.3	10.0	10.4	−0.4	0.1	−0.1	−0.2
DULURA	JHALUKHALI	0.0	11.2	11.2	11.1	11.1	11.1	0.0	0.0	0.0	0.0
MUSLIMPUR	JHALUKHALI	5.5	8.9	8.9	9.0	8.9	9.0	0.0	0.1	0.0	0.1
JALDHUP	SONAIBARDAL	0.0	11.7	11.6	11.7	11.7	12.0	0.0	0.2	−0.2	0.1
MANU RR BRIDGE	MANU	0.0	18.7	18.7	17.5	18.7	17.5	0.0	−1.2	0.0	−1.2
MAULVIBAZAR	MANU	37.1	12.1	12.1	11.3	12.1	11.3	0.1	−0.8	0.0	−0.8
KAMALGANJ	DHALAI	0.0	21.0	21.0	21.0	21.0	21.0	0.0	0.0	0.0	0.0
MOTIGANJ	LUNGLABIJNA	0.0	9.0	9.0	9.0	9.0	9.0	0.0	0.0	0.0	0.0
TERAPASHA	LUNGLABIJNA	39.0	6.0	5.9	5.8	5.8	5.8	−0.2	−0.1	0.0	−0.2
SOFIABAD	KARANGI	0.0	11.4	11.4	10.6	11.4	10.7	0.0	−0.8	−0.2	−0.8
BALLAH	UPPER KHOWAI	0.0	24.0	24.0	24.0	24.0	24.0	0.0	0.0	0.0	0.0
CHUNARUGHAT	UPPER KHOWAI	24.4	17.0	17.0	17.1	17.0	17.1	0.0	0.1	0.0	0.1
SHAISTAGANJ	KHOWAI	0.0	13.3	13.4	13.5	13.4	13.5	0.1	0.0	0.0	0.1
HABIGANJ	KHOWAI	13.5	10.2	11.3	11.4	11.3	11.4	1.1	0.1	0.0	1.2
SUTANG RR BRIDGE	SUTANG	0.0	7.3	7.3	7.9	7.3	7.9	0.0	0.6	0.0	0.6
NAKUAGAON	BHUGAI	0.0	22.9	22.9	22.9	22.9	22.9	0.0	0.0	0.0	0.0
NALITABARI	BHUGAI	19.0	16.7	16.7	16.7	16.7	16.7	0.0	0.0	0.0	0.0
GHOSEGAON	NITAI	0.0	15.3	15.3	15.3	15.3	15.3	0.0	0.0	0.0	0.0
BIJOYPUR	SHIBGANJDHAL	0.0	15.3	15.4	15.4	15.4	15.4	0.0	0.0	0.0	0.1
DURGAPUR	SHIBGANJDHAL	6.5	12.3	11.9	12.7	11.9	12.7	−0.4	0.8	0.0	0.4
KALMAKANDA	SOMESWARI	0.0	6.3	6.5	6.6	6.5	6.6	0.2	0.1	0.0	0.3
MADHYANAGAR	SOMESWARI	15.0	6.2	6.2	6.6	6.3	6.6	0.1	0.3	0.0	0.4
LOURERGARH	JADUKATA	0.0	9.5	9.9	10.0	9.9	10.0	0.4	0.1	0.0	0.5
SARCHAPUR	KANGSHA	0.0	10.9	10.8	10.3	10.8	10.3	0.0	−0.5	0.0	−0.5
JARIAJANJAIL	KANGSHA	62.0	8.6	8.0	8.7	8.0	8.7	−0.5	0.6	0.0	0.1
TAKURAKONA	DHONAIKHALI	0.0	6.8	6.6	7.1	6.6	7.1	−0.2	0.4	0.0	0.2
MOHANGANJ	LOWER KANGSHA	128.0	6.1	6.1	6.3	6.1	6.3	0.0	0.3	0.0	0.2
NETROKONA	MOGRA	0.0	6.0	5.9	7.2	5.9	7.2	−0.1	1.3	0.0	1.2
ATPARA	MOGRA	31.5	5.7	5.6	6.1	5.6	6.1	−0.1	0.5	0.0	0.3
GOG BAZAR	SAIDULI/BARUNI	34.1	5.0	5.0	5.4	5.0	5.4	0.0	0.4	0.0	0.4
DAKSIN HASANPUR	DHANU	42.0	4.7	4.7	4.7	4.7	4.7	0.0	0.0	0.0	0.0
CHAMRAGHAT	DHANU	75.0	4.6	4.6	4.5	4.7	4.5	0.1	−0.1	0.0	−0.1

Table 10.15
Impact Analysis – 1:2 Year Annual Flood Discharges

Location	Reach	Model Chainage (km)	1:2 Year Discharge (m3/s) Existing (NERP7)	With Tipaimukh FNI	With Tipaimukh RDP	Without Tipaimuk FNI	Without Tipaimuk RDP	Impacts Change in Peak Discharge (%) Morph.	Projects	Dam	Net
AMALSHID(K)	UPPER KUSHIYARA	1.4	3278	2271	2236	3278	3239	0	−2	−31	−32
SHEOLA	KUSHIYARA	2.1	3036	2154	2216	3036	3222	0	3	−31	−27
FENCHUGANJ	KUSHIYARA	53.0	2377	2128	2925	2389	3531	0	37	−17	23
SHERPUR	KUSHIYARA	88.5	2745	2617	2711	2827	2900	3	4	−7	−1
MARKULI	KUSHIYARA	130.0	1729	1281	1622	1303	1636	−25	27	−1	−6
SADIPUR	DKB floodplain	2.8	1832	1398	823	1771	1113	−3	−41	−26	−55
AMALSHID(S)	UPPER SURMA	1.5	1855	1229	1277	1855	1896	0	4	−33	−31
KANAIRGHAT	SURMA	4.2	2472	2211	2337	2472	2774	0	6	−16	−5
SYLHET	SURMA	65.4	2025	1688	1813	2024	2230	0	7	−19	−10
SUNAMGANJ	SURMA	163.0	4084	3944	4018	4094	4233	0	2	−5	−2
SUKDEBPUR	BAULAI	30.5	2232	1936	2637	1931	2632	−13	36	0	18
RAMPUR	BHATTA–DAHUKA	2.6	633	573	320	627	353	−1	−44	−9	−49
NILPUR	SURMA	174.6	349	350	289	353	295	1	−17	−2	−17
Baulai floodplain	FPSBREV floodplain	21.6	7317	7532	6565	7661	7171	5	−13	−8	−10
BHAIRAB BAZAR	UPPER MEGHNA	25.3	14041	13505	13447	14127	14024	1	0	−4	−4
BOROGRAM	LUBHACHARA	1.5	1516	1515	1514	1516	1515	0	0	0	0
SARIGHAT	SARIGOWAIN	4.2	1547	1547	1547	1547	1547	0	0	0	0
JAFFLONG	JAFFLONG	2.5	1079	1079	1079	1079	1079	0	0	0	0
RATNERBHANGA	ACTIVE PIYAN	0.5	848	850	848	850	848	0	0	0	0
Madhyadala branch	MADHYADHALA	2.0	339	333	340	336	340	−1	2	0	0
ISLAMPUR	DHALAGANG	1.1	1969	1969	1971	1969	1971	0	0	0	0
CHELASONAPUR	ACTIVE CHELA	1.8	710	711	710	710	710	0	0	0	0
URURGAON	NAWAGANG	3.0	209	210	208	209	209	0	−1	0	0
DULURA	JHALUKHALI	2.8	1668	1668	1668	1668	1668	0	0	0	0
JALDHUP	SONAIBARDAL	2.3	546	546	546	546	546	0	0	0	0
CONTINALA	JURI	0.7	399	399	401	399	401	0	1	0	1
MANU RR BRIDGE	UPPER MANU	2.5	837	837	838	837	838	0	0	0	0
KAMALGANJ	DHALAI	4.8	357	357	357	357	357	0	0	0	0
MOTIGANJ	LUNGLABIJNA	0.5	117	117	117	117	117	0	0	0	0
SOFIABAD	KARANGI	7.0	286	287	101	287	101	0	−65	0	−65
BALLAH	UPPER KHOWAI	2.1	803	802	803	802	803	0	0	0	0
SHAISTAGANJ	KHOWAI	1.2	604	599	721	599	721	−1	20	0	19
SUTANG RR BRIDGE	SUTANG	1.5	122	122	207	122	207	0	70	0	69
BATHKUCHI	CHILLAKHALI	1.5	198	198	198	198	198	0	0	0	0
NAKUAGAON	BHUGAI	2.4	658	658	658	658	658	0	0	0	0
GHOSEGAON	NITAI	1.5	398	398	397	398	397	0	0	0	0
BIJOYPUR	SHIBGANJDHALA	0.4	3912	3912	3912	3912	3912	0	0	0	0
DURGAPUR	SHIBGANJDHALA	7.0	1570	1235	1473	1235	1473	−21	19	0	−6
KALMAKANDA	SOMESWARI	1.5	492	519	450	515	447	5	−13	1	−9
Patnaigang	PATNAIGANG	2.5	3324	3580	2951	3580	2951	8	−18	0	−11
Jadukata main	JADUKATA	2.8	3137	2871	3545	2872	3545	−8	23	0	13
SARCHAPUR	KANGSHA	3.5	267	268	289	268	289	0	8	0	8
JARIAJANJAIL	KANGSHA	61.0	1201	1051	1157	1052	1156	−12	10	0	−4
Ghulamkhali branch	GHULAMKHALI	4.8	342	297	300	295	300	−14	1	0	−12
TAKURAKONA	DHONAIKHALI	1.5	443	402	446	404	447	−9	11	0	1
NETROKONA	MOGRA	2.0	201	201	407	201	407	0	102	0	102

Table 10.16
Impact Analysis – 1:10 Year Annual Flood Discharges

Location	Reach	Model Chainage (km)	1:10 Year Discharge (m3/s) Existing (NERP7)	With Tipaimukh FNI	With Tipaimukh RDP	Without Tipaimuk FNI	Without Tipaimuk RDP	Impacts Change in Peak Discharge (%) Morph.	Projects	Dam	Net
AMALSHID(K)	UPPER KUSHIYARA	1.4	3572	2479	2463	3572	3561	0	−1	−31	−31
SHEOLA	KUSHIYARA	2.1	3285	2339	2431	3285	3542	0	4	−31	−26
FENCHUGANJ	KUSHIYARA	53.0	2592	2288	3322	2605	4058	0	45	−18	28
SHERPUR	KUSHIYARA	88.5	3039	2807	2924	3136	3225	3	4	−9	−4
MARKULI	KUSHIYARA	130.0	1873	1373	1674	1408	1712	−25	22	−2	−11
SADIPUR	DKB (floodplain)	2.8	2211	1703	1087	2135	1447	−3	−36	−25	−51
AMALSHID(S)	UPPER SURMA	1.5	2029	1352	1403	2029	2086	0	4	−33	−31
KANAIRGHAT	SURMA	4.2	2684	2416	2667	2683	3276	0	10	−19	0
SYLHET	SURMA	65.4	2154	1800	1960	2153	2380	0	9	−18	0
SUNAMGANJ	SURMA	163.0	5477	5303	5584	5485	5846	0	5	−4	0
SUKDEBPUR	BAULAI	30.5	2833	2460	3364	2463	3381	−13	37	0	19
RAMPUR	BHATTA−DAHUKA	2.6	973	901	453	969	490	0	−50	−8	−53
NILPUR	SURMA	174.6	476	483	403	486	416	2	−17	−3	−15
Baulai floodplain	FPSBREV (floodplain)	21.6	11436	11575	10515	11741	11024	3	−9	−5	0
BHAIRAB BAZAR	UPPER MEGHNA	25.3	19440	18369	18471	19478	19455	0	0	−5	0
BOROGRAM	LUBHACHARA	1.5	1912	1910	1909	1912	1910	0	0	0	0
SARIGHAT	SARIGOWAIN	4.2	1936	1936	1936	1936	1936	0	0	0	0
JAFFLONG	JAFFLONG	2.5	1322	1322	1322	1322	1322	0	0	0	0
RATNERBHANGA	ACTIVE PIYAN	0.5	957	957	957	957	957	0	0	0	0
Madhyadala branch	MADHYADHALA	2.0	581	582	583	581	585	0	0	0	0
ISLAMPUR	DHALAGANG	1.1	3333	3333	3333	3333	3334	0	0	0	0
CHELASONAPUR	ACTIVE CHELA	1.8	947	947	947	947	947	0	0	0	0
URURGAON	NAWAGANG	3.0	278	280	280	278	278	0	0	0	0
DULURA	JHALUKHALI	2.8	2886	2886	2886	2886	2886	0	0	0	0
JALDHUP	SONAIBARDAL	2.3	646	646	646	646	646	0	0	0	0
CONTINALA	JURI	0.7	696	696	719	696	719	0	3	0	0
MANU RR BRIDGE	UPPER MANU	2.5	897	897	898	897	898	0	0	0	0
KAMALGANJ	DHALAI	4.8	387	387	387	387	387	0	0	0	0
MOTIGANJ	LUNGLABIJNA	0.5	149	149	149	149	149	0	0	0	0
SOFIABAD	KARANGI	7.0	774	778	181	778	181	0	−77	0	−77
BALLAH	UPPER KHOWAI	2.1	1520	1520	1520	1520	1520	0	0	0	0
SHAISTAGANJ	KHOWAI	1.2	939	933	1434	933	1434	0	54	0	53
SUTANG RR BRIDGE	SUTANG	1.5	158	158	244	158	244	0	54	0	54
BATHKUCHI	CHILLAKHALI	1.5	301	301	301	301	301	0	0	0	0
NAKUAGAON	BHUGAI	2.4	760	760	760	760	760	0	0	0	0
GHOSEGAON	NITAI	1.5	429	429	429	429	429	0	0	0	0
BIJOYPUR	SHIBGANJDHALA	0.4	4559	4559	4559	4559	4559	0	0	0	0
DURGAPUR	SHIBGANJDHALA	7.0	1834	1469	1837	1469	1837	−20	25	0	0
KALMAKANDA	SOMESWARI	1.5	582	595	517	593	515	2	−13	0	−11
Patnaigang	PATNAIGANG	2.5	4948	5195	4067	5196	4067	5	−22	0	−18
Jadukata main	JADUKATA	2.8	4251	3992	5164	3992	5164	−6	29	0	21
SARCHAPUR	KANGSHA	3.5	318	319	373	319	373	0	17	0	17
JARIAJANJAIL	KANGSHA	61.0	1467	1309	1429	1309	1429	−11	9	0	0
Ghulamkhali branch	GHULAMKHALI	4.8	379	327	345	326	343	−14	6	0	0
TAKURAKONA	DHONAIKHALI	1.5	610	573	634	580	638	−5	11	0	0
NETROKONA	MOGRA	2.0	280	280	572	280	572	0	104	0	104

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ANNEX A

SECOND ORDER SURVEY DATUM CORRECTIONS

Table A1: Summary of Gauge Benchmark Corrections

STA. NO.	NAME OF RIVER	NAME OF GAUGE	BENCHMARK			TBM			Datum Correction	Remarks
			BWDB	SOB	DIFF.	BWDB	SOB	DIFF.		
			(m,PWD)	(m,PWD)	(m)	(m,PWD)	(m,PWD)	(m)	(m)	
3A	Anderson khal	Brahamanbaria	9.09	9.04	−0.05	NO TBM			−0.05	
9.5	Banar−Lakhya	Trimohini	8.85	9.00	0.15				0.15	connected in 1994
34	Bhogai−kangsha	Nakuagaon	24.31	24.33	0.02	NO TBM			0.02	
35	Bhogai−kangsha	Nalitabari	17.69	17.99	0.30	NO TBM			0.30	
35.5	Bhogai−kangsha	Sarchapur	13.67	13.69	0.02	14.31	14.34	0.02	0.02	
36	Bhogai−kangsha	Jaria Jhanjail	NO BM			11.09	10.94	−0.15	−0.15	Only TBM exists
36.1	Bhogai−kangsha	Mohanganj	8.39	8.38	−0.01				−0.01	TBM was destroyed in Feb 1994
53	Chilla Khali	Bathkuchi							**	Connected by Finmap
67	Dhalai	Kamalganj	19.41	19.50	0.09	NO TBM			0.09	
71	Dhaleswari	Kalagachia							NA	Not connected
71 A	Dhaleswari	Rekabi Bazar							NA	Not connected
72	Baulai	Kaliajuri	8.39	7.90	−0.49	NA			−0.49	TBM has been destroyed and cannot be checked
72 B	Baulai	Sukdevpur	9.10	9.15	0.05	NO TBM			0.05	
73	Baulai	Itna	8.47	8.00	−0.46	NA	9.12		−0.46	
74	Ghorautra−Balulai	Dilalpur	8.13	7.81	−0.32	NO TBM			−0.32	
115	Gumti	Daudkandi							NA	Not connected
123	Hawrah	Gangasagar RR Brdg							NA	Not connected
135	Juri	Juri(Continala)	11.06	11.15	0.09	NO TBM			0.09	
138	Korangi	Sofiabad	10.91	10.92	0.01	NO TBM			0.01	
157	Khowai	Ballah	24.18	24.51	0.33	NO TBM			0.33	
158	Khowai	Chunarghat	16.38	16.50	0.12				0.12	Connected to BM (TBM was installed in 1993)
158.1	Khowai	Shaistaganj	NO BM			16.55	16.07	−0.48	−0.48	No BM exists
159	Khowai/Barak	Habigonj	NO BM			10.14	9.79	−0.35	−0.35	No BM exists
172	Kushiyara	Amalshid	17.59	17.59	−0.00	16.49	16.48	−0.01	−0.00	
173	Kushiyara	Sheola	13.67	13.73	0.06	14.23	14.29	0.06	0.06	
174	Kushiyara	Fenchuganj	15.07	15.12	0.05	11.66	11.69	0.04	0.05	Connected to BM and new TBM installed in 1993
175.5	Kushiyara	Sherpur	9.52	9.48	−0.04	9.27	9.27	0.00	−0.04	
177	Lakhya	Lakhpur	7.71	7.73	0.01				0.01	connected in 1994
179	Lakhya	Demra							NA	Not connected
180	Lakhya	Narayanganj							NA	Not connected
192	Langla	Motiganj	8.85	8.81	−0.04	NO TBM			−0.04	
201	Monu	Monu R.R. bridge	17.00	17.18	0.18	NO TBM			0.18	
202	Monu	Moulavi bazar	12.14	12.15	0.01	NO TBM			0.01	
225	Old Brahmaputra	Jamalpur							NA	Not connected
227	Old Brahmaputra	Sutia Offtake	15.04	15.01	−0.03				−0.03	Connected in 1994
228.5	Old Brahmaputra	Mymenshing	NO BM			14.34	14.31	−0.02	−0.02	No BM exists
229	Old Brahmaputra	Toke	**	11.44					NA	BM was destroyed (new BM was connected in 1994)
230.1	Old Brahmaputra	Bhairab Bazar R.R. bridge	9.86	9.79	−0.07	NO TBM			−0.07	
233	Piyan	Ratner bhanga	14.18	14.05	−0.13				−0.13	
233A	Piyan/Dauki	Jaflong	14.03	14.26	0.23	13.56	13.78	0.22	0.23	
234	Piyan	Companyganj	10.95	10.68	−0.27	NO TBM			−0.27	
251	Sari−gowain	Sharighat	14.73	15.19	0.46	NO TBM			0.46	
252	Sari−gowain	Gowainghat	12.60	12.60	0.00	NO TBM			0.00	

Table A1: Summary of Gauge Benchmark Corrections

STA. NO.	NAME OF RIVER	NAME OF GAUGE	BENCHMARK BWDB (m,PWD)	BENCHMARK SOB (m,PWD)	BENCHMARK DIFF. (m)	TBM BWDB (m,PWD)	TBM SOB (m,PWD)	TBM DIFF. (m)	Datum Correction (m)	Remarks
252.1	Sari–gowain	Salutikar	13.99	13.99	–0.00	NO TBM			–0.00	
262	Someswari	Bijoypur	21.92	21.92	0.01	19.00	18.72	–0.29	0.01	BM (not consistent with TBM)
									–0.29	Based on TBM installed in 1988
263	Someswari	Durgapur	13.84	14.08	0.24	14.69	14.89	0.20	0.24	
263.1	Someswari	Kalmakanda	8.12	8.27	0.15				0.15	New TBM; disturbed and resurveyed
263.2	Someswari	Madhyanagar	**	8.01		7.39	7.77	0.38	0.38	Connected in 1994 (TBM and BM to be confirmed)
264–A	Sonai	Madhabpur(Mantala)	NO BM				8.70		NA	Gauge relocated – connected to new TBM
265	Sonai–Bardal	Jaldhup	13.96	14.01	0.05	NO TBM			0.05	
266	Surma	Kanairghat	14.31	14.50	0.19	14.06	14.25	0.18	0.19	
267	Surma	Sylhet	12.09	12.06	–0.03	12.49	12.45	–0.03	–0.03	
268	Surma	Chatak	10.30	10.31	0.01	10.63	10.60	–0.02	0.01	New BM has been installed (connected to old BM)
269	Surma–Meghna	Sunamganj	8.45	8.44	–0.01	NO TBM			–0.01	Connected to BM installed in 1991
270	Kusiyara	Markuli	8.16	8.05	–0.11	8.15	8.04	–0.11	–0.11	BM was destroyed in 1993 after survey
271	Kalni–Kushiyara	Ajmiriganj	8.09	7.95	–0.14	NO TBM			–0.14	
272	Kalni–Kushiyara	Madna	7.70	7.57	–0.12	NO TBM			–0.12	
272.1	Dhaleswari–Kushiyara	Austagram	8.84	8.87	0.04				0.04	Connected in 1994
273	Meghna	Bhairab bazar	7.37	7.30	–0.07	NO TBM			–0.07	
274	Meghna	Narsingdi – old BM	6.81	6.84	0.03	NO TBM			0.03	BM has been replaced – connected both
274		Narsingdi – new BM	NA	7.13		NA				
275	Meghna	Badyar Bazar							NA	Not connected
275.5	Meghna	Meghna Ferry Ghat							NA	Not connected
276	Meghna	Satnal							NA	Not connected
280	Sutang	Sutang rly.br.	8.17	8.21	0.03	NO TBM			0.03	
295	Titas	Ajabpur	6.92	6.83	–0.10	5.94			–0.10	
296	Titas	Akhaura	11.12	10.92	–0.19	NO TBM			–0.19	
297	Titas	Gokarnaghat	6.89	6.83	–0.06	4.92	4.84	–0.08	–0.06	
298	Titas	Nabinagar							NA	Not connected
310	Mogra	Netrokona	9.36	9.19	–0.16	9.97			–0.16	Connected to BM (TMB was installed in 1992)
311	Mogra	Atpara	8.55	8.33	–0.23	NO TBM			–0.23	
314	Nitai	Ghosegaon	16.67	16.88	0.21	17.34	17.21	–0.13	0.21	BM (not consistent with TBM)
									–0.13	Based on TBM (installed 1991??)
326	Lubachara	Luba Outfall							NA	
332	Dhalagang	Islampur	13.01	12.85	–0.16	13.52			–0.16	
333	Jhalukati	Muslimpur	9.92	10.02	0.10	NO TBM			0.10	
337	Nawagang	Ururgaon	11.83	11.91	0.08	NO TBM			0.08	
341	Umium	Chelasonapur	12.00	12.60	0.60	11.79			0.60	
SWMC	Mahasingh	Akther Bazar	6.93	7.11	0.18	8.23	8.42	0.19	0.18	SWMC use TBM
SWMC	Active Piyan	Ambari	10.97	10.95	–0.01	NO TBM			–0.01	
SWMC	Surma	Baraigram	12.80	12.91	0.11				0.11	Connected in 1994
SWMC	Matian Haor	Barakhal							NA	Not connected
SWMC	Itakhola	Biswanath (Kaliganj)	9.11	9.27	0.17				0.17	Connected in 1994
SWMC	Dhanu	Chamraghat	8.93	8.13	–0.80	NA			–0.80	
SWMC	Dhanu	Daksin Hasanpur							NA	Not connected

Table A1: Summary of Gauge Benchmark Corrections

STA. NO.	NAME OF RIVER	NAME OF GAUGE	BENCHMARK			TBM			Datum Correction	Remarks
			BWDB	SOB	DIFF.	BWDB	SOB	DIFF.		
			(m,PWD)	(m,PWD)	(m)	(m,PWD)	(m,PWD)	(m)	(m)	
SWMC	Jhalukhali	Dulura	14.99	15.15	0.16		8.42		0.16	Connected in 1994
SWMC	Rukti	Durlabpur	7.71	8.11	0.40				0.40	Connected in 1994
SWMC	Saiduli	Gogbazar	8.87	8.87	−0.01				−0.01	Connected by NERP
SWMC	Najur	Jaganathpur	7.25	8.84	1.60				1.60	Connected in 1994
SWMC	Zurdia Regulator	Joysree	6.90	7.02	0.12	7.68			0.12	BM used in dry season & TBM used in monsoon
SWMC	Old Kushiyara	Khagapasha(Najibpur)	7.45	7.59	0.15				0.15	SWMC use BM
SWMC	Gowain	Lallakhal (u/s of Sarighat)							NA	Not connected
SWMC	Jadukata	Lourerghar	12.99	13.32	0.33				0.33	Connected in 1994
SWMC	Lubha	Lubhachara							NA	Not connected
SWMC	Surma	Nilpur	7.90	8.16	0.26	NO TBM			0.26	
SWMC	Dahuka/Bhatta	Rampur	10.08	10.10	0.02	NO TBM			0.02	
SWMC	Bijna River	Terapasha	7.93	7.79	−0.15				−0.15	Connected in 1994
SWMC	Dhona Khali	Thakurakona	12.84	13.03	0.19	NO TBM			0.19	

NOTE:
PWD=SOB+1.509 ft
Gauge 3A, 274,295, 296 C.I. cap broken; so some adjustment may be needed
NA = not available

ANNEX B

HYDROMETRIC DATA BASE (HYDAT)

DAILY WATER LEVEL

STATION NO.	TYPE	NAME OF RIVER	NAME OF STATION	LATITUDE (N)		LONGITUDE (E)		CONFIRM	DATE INSTALLED	DATE REMOVED	WATER YEAR																													
				DEG	MIN	DEG	MIN				64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93
3	T	Anderson khal	Brahamabaria R.R. bridge	23	57.0000	91	7.0000		1957	1981	H	H	H	H	H	H	H	H	H	H	H																			
3A	TQ	Anderson khal	Brahamabaria	23	57.3845	91	7.3746	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C			
6	Q	Bahia	Surma Offtake	24	54.0000	91	49.0000		1959		H	H	H	H	H	H	H	H	H	H	H	H	H																	
9.5	T	Banar-Lakhya	Trimohini	24	15.5000	90	33.5000		1962		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H				C	C	C	C	C	C	C		
33	Q	Bhattakhal	Gobindaganga	24	56.2000	91	41.5000		1958		H	H	H	H	H	H	H		H	H	H	H	H	H	H	H	H	H												
34	Q	Bhogai-kangsha	Nakuagaon	25	11.3807	90	13.1257	GPS	1957		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
35		Bhogai-kangsha	Nalitabari	25	5.0569	90	11.9557	GPS	1957		H	H	H	H		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	S	S	S
35.5	Q	Bhogai-kangsha	Sarchapur	24	59.7503	90	21.6908	GPS	1964		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	S	S	S
36	Q	Bhogai-kangsha	Jaria Jhanjail	25	0.5591	90	39.3106	GPS	1949		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
36.1	Q	Bhogai-kangsha	Mohanganj	24	52.3357	90	58.5817	GPS	1963		H	H	H	H		H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	S	S	S
45.5		Brahmaputra	Chilmari	25	32.5000	89	43.5000		1957			C	C	C	C	C	C	C	C	C	C	C	C	C	C	H	C	H	C	C	C	C	C	C	C	C	C	C		
46		Brahmaputra	Kamarjani	25	23.2000	89	38.6000		1957		C	C	C	C	C	C	C	H	C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C		
46.7 L		Brahmaputra	Kholabarichar	25	13.8000	89	42.0000		1963		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C		
46.9 L	Q	Brahmaputra	Bahadurabad	25	8.5000	89	41.0000		1963		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C			
53	Q	Chilla Khali	Bathkuchi	25	11.6235	90	10.7062	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	S	S	S
67	Q	Dhalai	Kamalganj	24	21.3579	91	51.0793	GPS	1957		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	H	C	C	C	C	C	C	C	C	C	S	S	S
71	T	Dhaleswari	Kalagachia	23	34.7684	90	32.5516	GPS	1945			H	H	H	H	H	H	H	H	H	H	H	H	C	C		C			C	C	C	C	C	C	C	C			
71 A	T	Dhaleswari	Rekabi Bazar	23	34.1856	90	30.2902	GPS	1965			H	H	H	H	H	H	H	H	H	H			H			H			C	C	C	C	C	C	C	C			
72	T	Baulai	Kaliajuri	24	41.3052	91	7.3302	GPS	1945		H	H	H	H	H	H	H	H	H	H	H		H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
72 B	Q	Baulai	Sukdevpur	24	52.7637	91	9.9385	GPS																					C	C	C	C	C	C	C	C	C	S	S	S
73	T	Baulai	Itna	24	31.8347	91	5.6318	GPS	1945		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
74	T	Ghorautra-Balulai	Dilalpur	24	11.2258	90	58.5953	GPS	1945		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
115	T	Gumti	Daudkandi	23	32.3719	90	43.0712	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H			H		C	C	C	C	C	C	C	C			
123	Q	Hawrah	Gangasagar RR Brdg	23	49.9887	91	12.0678	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C			
131	Q	Jadukata	Saktiarkhola	25	11.4795	91	15.2472	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	S		
131.5	Q	Jadukata	Lourerghar						1991																													S	S	S
135	Q	Juri	Juri	24	36.4800	92	8.2200	GPS	1957		C	C	C	H	H	H	H	H	H	H	H	H	H	C	H										H					
135A	Q	Juri – Continala Branch	Juri(continala)	24	35.5983	92	6.7331	GPS	1967					H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	S	S	S
138	Q	Korangi	Sofiabad	24	17.5477	91	32.9787	GPS			H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	S	S	S
155.5		Khajanchi Khal	Khajanchigaon	24	52.5000	91	45.5000	NHCL			H																													
157		Khowai	Ballah	24	5.0070	91	36.0154	GPS	1958		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	S	S	S
158		Khowai	Chunarghat	24	12.1010	91	31.8220	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
158.1	Q	Khowai	Shaistaganj	24	16.3825	91	28.5790	GPS	1964		C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
159		Khowai/Barak	Habiganj	24	22.1080	91	25.6750	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
172	Q	Kushiyara	Amalshid	24	52.1300	92	28.5400	GPS	1951		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
173	Q	Kushiyara	Sheola	24	53.3950	92	11.4460	GPS	1949		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
173A	Q	Sada Khal	Sheola	24	53.8055	92	10.7268	GPS	1947		H		H	H	H	H	H	H	H	H	H	H	H	H															S	S
174	Q	Kushiyara	Fenchuganj	24	42.1250	91	56.4800	GPS	1947		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	S	S	S
175	Q	Kushiyara	Monumukh	24	35.7000	91	43.5000	NERP	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	C	H				C											
175.5	Q	Kushiyara	Sherpur	24	37.6564	91	40.9657	GPS																					C	C	C	C	C	C	C	C	C	S	S	S
177	T	Lakhya	Lakhpur	24	3.9359	90	38.4169	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C			C	C	C	C	C	C	C				
178	T	Lakhya	Ghorasal	23	56.8300	90	37.5000		1957		H	H	H	H	H	H	H	H	H	H	H	H	H	H			H													
179	TQ	Lakhya	Demra	23	43.6029	90	30.5306	GPS	1952		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	H	C	C	C	C	C	C	C		C	C			
180	T	Lakhya	Narayanganj	23	37.8185	90	31.0363	GPS	1947			H	H	H	H	H	H	H	H	H	H	H	H	H	H		H	H	H											
192	Q	Langla	Motiganj	24	18.2950	91	40.8870	GPS	1958		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	S	S	S
199	Q	Mahasingh	Mahasingh Ferryghat	24	55.5000	91	28.5000		1958		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H															
201	Q	Monu	Monu R.R. bridge	24	25.7133	91	56.5840	GPS	1958		H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
202		Monu	Moulavi bazar	24	29.6476	91	46.4358	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	S	S	S
223		Old Brahmaputra	Goal Khanda	25	19.5000	89	49.3000		1944		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C		
224		Old Brahmaputra	Bangshi offtake	25	0.0000	89	53.3000	NHCL	1958		H	H																												
225		Old Brahmaputra	Jamalpur	24	55.3728	89	57.9079	GPS	1945		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	H	C		
226		Old Brahmaputra	Sirkhali offtake	24	52.5000	90	12.0000		1958		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C									
227	Q	Old Brahmaputra	Sutia Offtake	24	47.8486	90	19.2707	GPS	1958		H	H	H	H		H	H		H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C		
228		Old Brahmaputra	Mymensingh	24	45.0000	90	25.5000		1944		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H		C	C	C	C								
228.5	Q	Old Brahmaputra	Mymenshing	24	43.5058	90	26.6017	GPS	1964				C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		
229	T	Old Brahmaputra	Toke	24	15.5000	90	39.0000		1948		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C			
230	T	Old Brahmaputra	Motkhola	24	14.0000	90	41.0000		1957		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H			H										
230.1	TQ	Old Brahmaputra	Bhairab Bazar R.R. bridge	24	2.2875	90	57.8883	GPS	1964		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	H	C	C	C	C	C	C	C	C	C	C			
233	Q	Piyan	Ratner bhanga	25	9.7168	91	58.2311	GPS	1956		H	H										H	H	H	H	H	H		C	C	C	C	C	C	C	C	C	S	S	S
233A	Q	Piyan/Dauki	Jaflong	25	9.3000	92	1.3880	GPS	1991												H	H																		
234	Q	Piyan	Companyganj	25	5.4598	91	45.7364	GPS	1950		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	H	H	H	C	C	C	C	C	C	C	C		S	S	S
251	Q	Sari-gowain	Sharighat	25	5.7650	92	6.7760	GPS	1950		H	H	C	C	C	C	C	H	C	C	C	C	C	C	C	C	C	H	C	C	C	C	C	C	C	C	C	S	S	S
252	Q	Sari-gowain	Gowainghat	25	5.4936	91	59.1089	GPS	1950		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	S	S	S
252.1	Q	Sari-gowain	Salutikar	24	59.4890	91	51.1250	GPS	1964		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
262	Q	Someswari	Bagmara/Bijoypur	25	10.2212	90	39.7547	GPS	1945		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	S	S	S
263	Q	Someswari	Durgapur	25	6.5765	90	40.2972	GPS	1958		C	C	C	C	C	C	C	C	C	C	C	H	C	C	C	C	C	C	C	H	C	C	C	C	C	C	C	S	S	S

DAILY WATER LEVEL

STATION NO.	TYPE	NAME OF RIVER	NAME OF STATION	LATITUDE (N)		LONGITUDE (E)		CONFIRM	DATE INSTALLED	DATE REMOVED	WATER YEAR																													
				DEG	MIN	DEG	MIN				64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93
263.1	Q	Someswari	Kalmakanda	25	4.5854	90	53.8631	GPS	1963		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	S	S	S
263.2		Someswari	Madhyanagar	25	2.7294	90	59.6071	GPS																						C								S	S	
264		Sonai	Madhabpur	24	5.3000	91	17.6000		1958		H	H	H	H		H	H	H	H	H	H	H																		
265	Q	Sonai-Bardal	Jaldhup	24	46.4370	92	10.3620	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C		C	C	S	S	S
266	Q	Surma	Kanairghat	25	0.0000	92	15.5520	GPS	1951		H	H	H	H	H	C	C	H	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	S	S	S
267	Q	Surma	Sylhet	24	53.2413	91	52.2655	GPS	1938		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	S	S	S
268	Q	Surma	Chatak	25	2.1561	91	39.9331	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	H	H	C	C	C	C	C	C	C	C	C	S	S	S
269	Q	Surma-Meghna	Sunamganj	25	4.5307	91	24.8461	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	S	S	S
270	T	Kusiyara	Markuli	24	41.6220	91	22.8710	GPS	1947		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C		C		S	S	S
271	T	Kalni-Kushiyara	Ajmiriganj	24	33.2220	91	13.7290	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
272	T	Kalni-Kushiyara	Madna	24	20.1410	91	14.2620	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H		C	C	C	H		C	C	C	C	C	C	C	C		S	S	S
272.1	T	Dhaleswari-Kushiyara	Austagram	24	16.3000	91	6.0000		1962			H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C		C	S	S	S
273	TQ	Meghna	Bhairab bazar	24	2.6911	90	59.6681	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	S	S	S
274	T	Meghna	Narsingdi	23	55.0915	90	43.7660	GPS	1949		H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	H	H	C	C	C	C	C	C	C	C	C	C		
275	T	Meghna	Badyar Bazar	23	38.8833	90	37.5825	GPS	1958			H	H	H	H	H	H	H	H	H	H	H	H	C	H	H	H	C	C	C	C	C	C		C	C	C	C		
275.5	T	Meghna	Meghna Ferry Ghat	23	36.0757	90	37.3871	GPS	1965			H	H	H	H	H	H	H	H	H	H	H	H	C	H	H	H	C	C	C	C	C	C	C			C	C		
276	T	Meghna	Satnal	23	28.6911	90	35.7416	GPS	1951			H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C		
280	Q	Sutang	Sutang rly.br.	24	16.9890	91	24.1560	GPS	1957		H	H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	H	H	C	C	C	C	C	C	C	C	C	S	S	S
295	T	Titas	Ajabpur	24	7.2362	91	3.5001	GPS	1959		H	H	H	H	H	H	H	H	H	H	H	H		C		H	H	H	C	C	C	C	C	C	C	C	C	S	S	S
296	T	Titas	Akhaura	23	52.7330	91	12.2282	GPS	1947		H	H	H	H	H	H	H	H	H	H	H	H	C	C	H	H	H	H	C	C	C	C	C	C	C	C	C			
297	T	Titas	Gokarnaghat	23	57.2592	91	5.2856	GPS	1959			H	H	H	H	H	H	H	H	H	H	H	H	C	H	H	H	C	C	C	C	C	C	C	C	C	C			
298	T	Titas	Nabinagar	23	54.2545	90	58.5626	GPS	1947			H	H	H	H	H	H	H	H	H	H	H	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		
308	Q	Khajanchi Nadi	Khajanchigaon RR Brdg.	24	52.5000	91	45.5000		1964		H	H	H	H	H	H	H	H	H	H	H	H	H	H																
310	Q	Mogra	Netrokona	24	52.8989	90	43.6416	GPS																H	H	H			C	C	C	C	C	C	C	C	C	S	S	S
311		Mogra	Atpara	24	48.5167	90	52.1404	GPS																					C	C		C	C	C	C	C	C	S	S	S
314	Q	Nitai	Ghosegaon	25	8.5000	90	30.5000		1964			C	C	C	C	C	C	H	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	S	S	S
315	Q	Madhabpur khal	Chhatak	25	0.5000	91	39.8000		1965				H	H		H	H	H	H	H	H																			
326	Q	Lubachara	Luba Outfall	25	2.2000	92	18.1000																						C	C	C	C	C	C	C	C			S	S
327			Boalmari	25	19.6000	89	46.7000																						C	C	C	C	C	C	C	C	C	C		
332	Q	Dhalagang	Islampur	25	7.9680	91	45.2750	GPS																													S	S	S
333	Q	Jhalukati	Muslimpur	25	6.6640	91	23.4850	GPS																													S	S	S
337	Q	Nawagang	Ururgaon	25	7.2500	91	35.6400	GPS																													S	S	S
341	Q	Umium	Chelasonapur	25	7.6900	91	40.3200	GPS																													S	S	S
BWDB		Rukti	Durlabpur	24	59.8068	91	15.8226	GPS																														S	
BWDB		Monu river	Manu Pumping Station	24	36.3735	91	45.4563	GPS																														
BWDB		Monu river	Manu Barrage	24	29.5406	91	48.1379	GPS																													S		
SWMC	Q	Surma	Nilpur	24	59.7166	91	23.2457	GPS																													S	S	
SWMC	Q	Dhona Khali	Thakurakona	24	54.5052	90	49.8149	GPS																													S	S	S
SWMC	Q	Dahuka/Bhatta	Rampur	24	55.6101	91	41.4085	GPS																													S	S	
SWMC		Bijna River	Terapasha	24	33.1202	91	36.5193	GPS																													S	S	S
SWMC		Mahasingh	Akther Bazar	24	53.5895	91	28.7161	GPS																													S	S	
SWMC		Saiduli	Gogbazar	24	41.2783	90	51.9817	GPS																														S	S
SWMC		Dhanu	Chamraghat	24	27.5470	90	57.7330	GPS																													S	S	S
SWMC		Old Kushiyara	Khagapasha(Najibpur)	24	33.0590	91	26.2750	GPS																														S	
SWMC	Q	Jhalukhali	Dulura(u/s of Muslimpur)	25	9.7510	91	23.5200	GPS																														S	S
SWMC		Surma	Baraigram	24	54.4700	92	8.6450	GPS																													S	S	S
SWMC		Itakhola	Biswanath (Kaliganj)	24	47.4290	91	44.3240	GPS																														S	S
SWMC	Q	Gowain	Lallakhal (u/s of Sarighat)	25	6.9900	92	10.9400	GPS																														S	S
SWMC	Q	Lubha	Lubhachara	25	2.7440	92	20.0770	GPS	1992																													S	
SWMC		Zurdia Regulator	Joysree (River side)	24	57.7746	91	6.5605	GPS																													S	S	
SWMC		Zurdia Regulator	Joysree (Haor side)	24	57.4618	91	5.5192	GPS																													S	S	
SWMC	Q	Active Piyan	Ambari	25	3.1000	91	41.4300	GPS																														S	
SWMC		Naluar	Jaganathpur																																		S	S	
SWMC	Q	Surma	Amalshid																																			S	S
SWMC	Q	Jaflong	Jaflong	25	9.3	92	1.388	GPS																													S	S	S
SWMC	Q	Telekhal	Telekhal																																			S	
SWMC		Dhanu	Daksin Hasanpur	24	35	90	58.6	GPS																														S	S
SWMC		Matian Haor	Barakhal																																		S	S	
SWMC	Q		Kotwalpur																																				S
SWMC	Q	Sadipur khal	Sadipur																																				S

OBSERVED DISCHARGE

STATION NO.	TYPE	NAME OF RIVER	NAME OF STATION	LATITUDE DEG	LATITUDE MIN	LONGITUDE DEG	LONGITUDE MIN	CONFIRM	DATE INSTALLED	DATE REMOVED	YEARS OF RECORD
3A	TQ	Anderson Khal	Brahmanbaria RR Bridge	23	57.3845	91	7.3746	GPS	1957		
6	Q	Bahia	Surma Offtake	24	54.0000	91	49.0000		1959	1977	1960–62
33	Q	Bhattakhali	Gobindaganj	24	56.2000	91	41.5000		1958	1977	1961–63
34	Q	Bhugai–kangsha	Nakuagaon	25	11.3807	90	13.1257	GPS	1957		
35.5	Q	Bhugai–kangsha	Sarchapur	24	59.7503	90	21.6906	GPS	1991		
35.5FP		Kangsha FP	Sarchapur								
36	Q	Kangsha	Jariajanjail	25	0.5591	90	39.3106	GPS	1949		
36.1	Q	Kangsha	Mohanganj	24	52.3357	90	56.5617	GPS	1991		
46.9L	Q	Brahmaputra	Bahadurabad	25	9.3000	89	40.5000		1953		
53	Q	Chilla Khali	Bathkuchi	25	11.6235	90	10.7062	GPS	1957		
67	Q	Dhalai	Kamalganj	24	21.3579	91	51.0793	GPS	1957		1960–63
72B	Q	Baulai	Sukdebpur	24	52.7637	91	9.9385	GPS	1990		
123	Q	Hawrah	Gangasagar RR Bridge	23	49.9887	91	12.0678	GPS	1957		
131	Q	Jadukata	Saktiarkhola	25	11.4795	91	15.2472	GPS	1957		
131.5	Q	Jadukata	Lourerghar						1991		
135	Q	Juri	Continala	24	36.4800	92	8.2200	GPS	1957	1977	
135A	Q	Continala	Continala	24	35.5983	92	6.7331	GPS	1964	1980	
138	Q	Karangi	Sofiabad	24	17.5477	91	32.9787	GPS	1958		
158.1	Q	Khowai	Shaistaganj	24	16.3825	91	26.5790	GPS	1964		
172	Q	Kushiyara	Amalshid	24	52.1300	92	28.5400	GPS	1951		
173	Q	Kushiyara	Sheola	24	53.3950	92	11.4460	GPS	1949		1958–63
173A	Q	Sada Khal	Sheola	24	53.8055	92	10.7268	GPS	1947	1977	
174	Q	Kushiyara	Fenchuganj	24	42.1250	91	56.4800	GPS	1947		1951–63
175	Q	Kushiyara	Monumukh	24	35.7000	91	43.5000	NERP	1949		1956–63
175.5	Q	Kushiyara	Sherpur	24	37.6564	91	40.9657	GPS	1982		
179	TQ	Lakhya	Demra	23	43.6029	90	30.5306	GPS	1952		
192	Q	Lungla	Motiganj	24	18.2950	91	40.8870	GPS	1958	1980	
199	Q	Mahasingh	Mahasing Ferryghat	24	55.5000	91	28.5000		1958		1962–63
201	Q	Monu	Monu rly. br.	24	25.7133	91	56.5840	GPS	1958		
227	Q	Old Bramahputra	Sutia Offtake	24	47.8486	90	19.2707	GPS	1958		
228.5	Q	Old Bramahputra	Mymensingh	24	43.5058	90	26.6017	GPS	1964		
230.1	TQ	Old Bramahputra	Bhairab Bazar	24	2.2875	90	57.8883	GPS	1964		
233	Q	Piyagang	Ratnerbhanga	25	9.7168	91	58.2311	GPS	1956	1980	1961–64
233A	Q	Piyan/Dauki	Jaflong	25	9.3000	92	1.3880	GPS	1965	1977	
234	Q	Piyan	Companyganj	25	5.4596	91	45.7364	GPS	1950		1960–63
251	Q	Sarigowain	Sarighat	25	5.7650	92	6.7760	GPS	1950		1960–63
252	Q	Sarigowain	Gowainghat	25	5.4936	91	59.1089	GPS	1950		1960–63
252.1	Q	Sarigowain	Salutikar	24	59.4890	91	51.1250	GPS	1964	1977	
262	Q	Someswari	Bijoypur/Bagmara	25	10.2212	90	39.7547	GPS	1945		
263	Q	Someswari Com.	Durgapur								
263.1	Q	Someswari	Kalmakanda	25	4.5854	90	53.8631	GPS	1968		
263A	Q	Someswari Main	Durgapur	25	6.5765	90	40.2972	GPS	1958		
263B	Q	Someswari Old	Durgapur	25	6.8124	90	40.5226	GPS	1958		1958–61
263C	Q	Someswari Atraikhal	Durgapur								
265	Q	Sonai bardal	Jaldhup	24	46.4370	92	10.3620	GPS	1957		1960–63
266	Q	Surma	Kanairghat	25	0.0000	92	15.5520	GPS	1951		1960–63
267	Q	Surma	Sylhet	24	53.2413	91	52.2655	GPS	1938		50–58,60–63
268	Q	Surma	Chhatak	25	2.1561	91	39.9331	GPS	1949	1977	49–56,58–63
269	Q	Surma	Sunamganj	25	4.5307	91	24.8461	GPS	1949		
270	TQ	Kushiyara	Markuli	24	41.6220	91	22.8710	GPS			
273	TQ	Meghna	Bhairab bazar	24	2.6911	90	59.6681	GPS	1949		
280	Q	Sutang	Sutang rly b	24	16.9890	91	24.1560	GPS	1957		
308	Q	Khajanchi Nadi	Khajanchigaon RR Bridge	24	52.5000	91	45.5000		1964	1977	
310	Q	Mogra	Netrokona	24	52.8989	90	43.6416	GPS	1991		
314	Q	Nitai	Ghosegaon	25	8.5000	90	30.5000		1964		
315	Q	Madhabpur Khal	Chhatak	25	0.5000	91	39.8000		1965	1977	
326	Q	Lubachara	Luba Outfall	25	2.2000	92	18.1000			1980	
332	Q	Dhaligang	Islampur	25	7.9680	91	45.2750	GPS	1990		
333	Q	Jhalukhali	Muslimpur	25	6.6640	91	23.4850	GPS	1988		
337	Q	Jawagang	Urargaon	25	7.2500	91	35.6400	GPS	1988		
341	Q	Umium	Chelasonapur	25	7.6900	91	40.3200	GPS	1988		
BWDB	Q	Juri	Silghat (Auto)	24	35.3326	92	7.3977	GPS			
NERP	Q	Khowai	Remabagan	24	6.5414	91	35.9903	GPS			
NERP1		Malijee	Barakanda								
NERP18		Nagla	Nagla								
NERP35		B.Kangsha	Nalitabari								
NERP6		Mogra N.B	Jalalpur								
SWMC	Q	Surma	Amalshid								
SWMC	Q	Active Piyan	Ambari	25	3.1000	91	41.4300	GPS			
SWMC	Q	Jalukhali	Dulura (u/s of Muslimpur)	25	9.7510	91	23.5200	GPS			
SWMC	Q	Ilaspur Khal	Ilaspur								
SWMC	Q	Jaflong	Jaflong	25	9.3	92	1.388	GPS			
SWMC	Q	Ratna Khal	Kotwalpur								
SWMC	Q	Sarigowain	Lallakhal (u/s of Sarighat)	25	6.9900	92	10.9400	GPS			
SWMC	Q	Lubha	Lubachara	25	2.7440	92	20.0770	GPS			
SWMC	Q	Surma	Nilpur	24	59.7166	91	23.2457	GPS	1991		
SWMC	Q	Dahuka/bhatta	Rampur	24	55.6101	91	41.4085	GPS	1991		
SWMC	Q	Sadipur Khal	Sadipur								
SWMC	Q	Napith Khal	Sheola (Spill from Kushiyara)								
SWMC	Q	Telekhal	Telekhal								
SWMC	Q	Dhonai khali	Thakurakona	24	54.5052	90	49.8149	GPS	1991		

MEAN DAILY DISCHARGE

STATION NO.	TYPE	NAME OF RIVER	NAME OF STATION	LATITUDE (N)		LONGITUDE (E)		CONFIRM	DATE INSTALLED	DATE REMOVED	WATER YEAR																													
				DEG	MIN	DEG	MIN				64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93
3A	Q	Anderson Khal	Brahmanbaria RR Bridge	23	57.3845	91	7.3746	GPS	1957		H		H							H	H	H	H																	
6	Q	Bahia	Surma Offtake	24	54.0000	91	49.0000		1959	1977	C	C	C	C	C	C	C		C	C	C	C	C	C																
33	Q	Bhattakhal	Gobindaganj	24	56.2000	91	41.5000		1958	1977	C	C	C	C	C	C	C		C	C	C	C	C	C																
34	Q	Bhugai-kangsha	Nakuagaon	25	11.3807	90	13.1257	GPS	1957		C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C			C	C	C	C	C	C	C	C	S	S	S
35.5	Q	Bhugai-kangsha	Sarchapur	24	59.7503	90	21.6908	GPS	1991																													S	S	S
36	Q	Kangsha	Jarıajanjail	25	0.5591	90	39.3106	GPS	1949		C	C	C	C	C		C		C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	S	S	S
36.1	Q	Kangsha	Mohanganj	24	52.3357	90	58.5817	GPS	1991																													S	S	S
46.9 L	Q	Brahmaputra	Bahadurabad	25	9.3000	89	40.5000		1953		C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C		
53	Q	Chilla Khali	Bathkuchi	25	11.6235	90	10.7062	GPS	1957																										C	C	C	S	S	S
67	Q	Dhalai	Kamalganj	24	21.3579	91	51.0793	GPS	1957		C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	S	S	S
123	Q	Hawrah	Gangasagar RR Bridge	23	49.9887	91	12.0678	GPS	1957			C										C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		
131	Q	Jadukata	Saktiarkhola	25	11.4795	91	15.2472	GPS	1957																										C			C		
131.5	Q	Jadukata	Lourerghar						1991																													S	S	S
135	Q	Juri	Continala	24	36.4800	92	8.2200	GPS	1957	1977	C	C					C		C	C		C	C	C																
135A	Q	Continala	Continala	24	35.5983	92	6.7331	GPS	1964	1980	C									C	C	C	C	C	C	C	C												S	
138	Q	Karangi	Sofiabad	24	17.5477	91	32.9787	GPS	1958		C	C	C			C	C		C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	S	S	S
157	Q	Khowai	Ballah	24	5.007	91	36.0154	GPS	1958																							N	N	N	N	N	N	N	N	N
158.1	Q	Khowai	Shaistaganj	24	16.3825	91	28.5790	GPS	1964		C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
172	Q	Kushiyara	Amalshid	24	52.1300	92	28.5400	GPS	1951																													S	S	S
173	Q	Kushiyara	Sheola	24	53.3950	92	11.4460	GPS	1949		C	C	C	C	C	H	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
173A	Q	Sada Khal	Sheola	24	53.8055	92	10.7268	GPS	1947	1977	H	H				H	H		H	H	H	H	H																S	S
174	Q	Kushiyara	Fenchuganj	24	42.1250	91	56.4800	GPS	1947																													S	S	S
175.5	Q	Kushiyara	Sherpur	24	37.6564	91	40.9657	GPS	1982																				C	C	C	C	C	C	C	C	C	S	S	S
179	Q	Lakhya	Demra	23	43.6029	90	30.5306	GPS	1952			C	C	C	C							C	C	C		C	C	C	C	C	C	C	C	C	C	C				
192	Q	Lungla	Motiganj	24	18.2950	91	40.8870	GPS	1958	1980	C						C			C	C	C	C	C	C	C	C								C	C	C	S	S	S
201	Q	Monu	Monu rly. br.	24	25.7133	91	56.5840	GPS	1958		C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
227	Q	Old Bramahputra	Sutia Offtake	24	47.8486	90	19.2707	GPS	1958		H	H	H			H	H					H	H	H	H	H	H	H	H											
228.5	Q	Old Bramahputra	Mymensingh	24	43.5058	90	26.6017	GPS	1964		C	C	C	C	C	C	C				C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		
230.1	Q	Old Bramahputra	Bhairab Bazar	24	2.2875	90	57.8883	GPS	1964							H	H		C	C	C	C		C	C	C	C		C					C	C	C	C	C		
233	Q	Piyagang	Ratnerbhanga	25	9.7168	91	58.2311	GPS	1956	1980	H																								C	C	C	S	S	S
233A	Q	Piyan/Dauki	Jaflong	25	9.3000	92	1.3880	GPS	1965	1977																														
251	Q	Sarigowain	Sarighat	25	5.7650	92	6.7760	GPS	1950		H	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
252.1	Q	Sarigowain	Salutikar	24	59.4890	91	51.1250	GPS	1964	1977	H	H	H			H	H		H	H	H	H	H	H																
262	Q	Someswari	Bijoypur/Bagmara	25	10.2212	90	39.7547	GPS	1945																										N	N	N	N	N	N
263	Q	Someswari	Durgapur (total flow)																																N	N	N	N	N	N
263A	Q	Shibganjdhala	Durgapur	25	6.5765	90	40.2972	GPS	1958		C		C	C	C	C	C		C	C	C	C	C	C	C				C	C	C	N	N	N	N	N	N	N	N	N
263B	Q	Someswari	Durgapur	25	6.8124	90	40.5226	GPS	1958			C	C	C		C	C		C	C												N	N	N	N	N	N	N	N	N
263C	Q	Atrakhali	Durgapur																																N	N	N	N	N	N
263.1	Q	Someswari	Kalmakanda	25	4.5854	90	53.8631	GPS	1988																													S	S	S
265	Q	Sonai bardal	Jaldhup	24	46.4370	92	10.3620	GPS	1957		C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C				C	C	C	C	C	C	C	S	S	S
266	Q	Surma	Kanairghat	25	0.0000	92	15.5520	GPS	1951							C	C		C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	S	S	S
267	Q	Surma	Sylhet	24	53.2413	91	52.2655	GPS	1938		C	C	C			C	C		C	C	C	C	C	C				C	C	C	C	C	C	C	C	C	C	S	S	S
268	Q	Surma	Chhatak	25	2.1561	91	39.9331	GPS	1949	1977		H	H	H		H	H			H																				
269	Q	Surma	Sunamganj	25	4.5307	91	24.8461	GPS	1949																													S	S	S
273	Q	Meghna	Bhairab bazar	24	2.6911	90	59.6681	GPS	1949		C	C	C	C	C	C	C		C	C	C	C	C					C	C	C	C	C	C	C	C	C	C	C		
280	Q	Sutang	Sutang rly.b	24	16.9890	91	24.1560	GPS	1957		C	C								C	C	C	C	C		C									C	C	C	S	S	S
308	Q	Khajanchi Nad	Khajanchigaon RR Bridge	24	52.5000	91	45.5000		1964	1977		H	H			H	H		H		H																			
310	Q	Mogra	Netrokona	24	52.8989	90	43.6416	GPS	1991																													S	S	S
314	Q	Nitai	Ghosegaon	25	8.5000	90	30.5000		1964		C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C			C	C	C	C	C	C	C	C	S	S	S
315	Q	Madhabpur Khal	Chhatak	25	0.5000	91	39.8000		1965	1977		H	H			H	H		H	H	H																			
332	Q	Dhaligang	Islampur	25	7.9680	91	45.2750	GPS	1990																										C	C	C	S	S	S
333	Q	Jhalukhali	Muslimpur	25	6.6640	91	23.4850	GPS	1988																										C			S		
337	Q	Jawagang	Urırgaon	25	7.2500	91	35.6400	GPS	1988																													S	S	S
341	Q	Umium	Chelasonapur	25	7.6900	91	40.3200	GPS	1988																													S	S	S
SWMC	Q	Surma	Nilpur	24	59.7166	91	23.2457	GPS	1991																													S	S	
SWMC	Q	Dhonai khali	Thakurakona	24	54.5052	90	49.8149	GPS	1991																													S	S	S
SWMC	Q	Dahuka/bhatta	Rampur	24	55.6101	91	41.4085	GPS	1991																													S	S	
SWMC	Q	Gowain	Lallakhal (u/s of Sarighat)	25	6.9900	92	10.9400	GPS																															S	S
SWMC	Q	Jalukhali	Dulura (u/s of Muslimpur)	25	9.7510	91	23.5200	GPS																															S	S
SWMC	Q	Active Piyan	Ambari	25	3.1000	91	41.4300	GPS																																
SWMC	Q	Surma	Amalshid																																			S	S	S
SWMC	Q	Jaflong	Jaflong	25	9.3	92	1.388	GPS																														S	S	S
SWMC	Q	Sadipur Khal	Sadipur																																					S
SWMC	TQ	Kushiyara	Markuli																																			S	S	S
SWMC	Q		Kotwalpur																																					S

BWDB Rain Gauges in and around Northeast Reginal Project Compiled by NERP (FAP-6)

SL No	STN. NO.	STATION NAME	TYPE	Latitude (N) Deg	Latitude (N) Min	Longitude (E) Deg	Longitude (E) Min	CONFIRM	PLATFORM ELEVATION (m PWD)	DATE INSTALLED OR RE-INSTALLED	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93
1	R017	Joydevpur	NR	24	0.0000	90	25.0000		8.93	1961-03-11																																	
2	R032	Sarishabari	NR	24	44.3000	89	49.5000		15.87	1961-02-24																																	
3	R061	Bajitpur	NR	24	12.6619	90	57.5170	GPS	7.91	1961-09-11																																	
4	R062	Dewanganj	NR	25	8.5000	89	45.7000		22.86	1961-03-09																																	
5	R063	Durgapur	NR	25	7.1512	90	40.7995	GPS	14.76	1961-02-26																																	
6	R064	Gaffargaon	NR	24	26.0000	90	33.5000		11.78	1961-09-22																																	
7	R065	Gouripur	NR	24	43.3000	90	34.5000		11.21	1961-09-16																																	
8	R067	Jamalpur	NR	24	56.0000	89	55.5000		18.82	1961-02-25																																	
9	R068	Jaria-Jhanjail	NR	25	0.5000	90	39.3000		10.59	1961-09-10																																	
10	R071	Kishoreganj	NR	24	26.0000	90	47.5000		10.51	1961-01-22																																	
11	R072	Muktagacha	NR	24	45.0000	90	16.0000		14.74	1961-09-21																																	
12	R073	Mymensingh	R	24	45.9073	90	23.8345	GPS	14.30	1960-12-18																																	
13	R074	Nalitabari (Taraganj)	NR	25	5.0410	90	11.8812	GPS	17.23	1961-02-28																																	
14	R075	Nandail	NR	24	33.8000	90	42.0000		8.38	1962-06-11																																	
15	R076	Narsingdi	NR	23	55.0053	90	42.7025	GPS	6.49	1961-03-06																																	
16	R077	Phulpur	NR	24	58.0000	90	22.0000		14.88	1962-06-11																																	
17	R078	Sherpur (Town)	NR	25	0.0000	90	0.8000		18.94	1961-04-14																																	
18	R079	Shibpur	NR	24	1.5000	90	46.0000		6.95	1961-11-16																																	
19	R-101	Bhairab Bazar	NR	24	2.7335	90	59.6548	GPS	6.86	1961-09-11																																	
20	R-102	Bholaganj	NR	25	9.9000	91	45.1000			1961-09-09																																	
21	R-103	Brahmanbaria	NR	23	58.7000	91	7.0000		8.93	1961-02-05																																	
22	R-104	Chandbagh	NR	24	36.5103	91	55.6928	GPS	21.59	1961-03-04																																	
23	R-105	Chandpur Bagan	NR	24	9.3000	91	29.0000		47.47	1960-11-01																																	
24	R-107	Chhatak	NR	25	2.1000	91	40.2000		10.79	1961-09-08																																	
25	R-108	Dakshinbagh (Samanbagh)	NR	24	38.0000	92	9.7000		12.79	1961-08-06																																	
26	R-109	Gobindaganj	NR	24	55.7000	91	41.7000		10.24	1961-09-06																																	
27	R-110	Habiganj	NR	24	22.0000	91	25.5000		8.08	1961-02-13																																	
28	R-111	Itakhola (Baikunthapur)	NR	24	9.0000	91	22.0000		7.25	1961-06-14																																	
29	R-112	Itna	NR	24	31.5000	91	5.5000		8.38	1962-03-29																																	
30	R-113	Khaliajuri	NR	24	41.5000	91	8.5000		8.81	1962-03-31																																	
31	R-114	Kamalganj	NR	24	21.0000	91	51.5000		21.01	1961-03-06																																	
32	R-115	Kendua	NR	24	39.6000	90	50.5000		7.96	1962-06-26																																	
33	R-116	Lallakhal	NR	25	6.0000	92	11.0000		29.61	1961-04-05																																	
34	R-117	Langla	NR	24	28.4304	91	57.3989	GPS	26.01	1961-02-01																																	
35	R-118	Latu	NR	24	35.0000	92	15.5000		13.49	1961-10-26																																	
36	R-119	Manumukh	NR	24	35.6306	91	43.5419	GPS		1961-02-18																																	
37	R-120	Markuli	NR	24	41.0000	91	23.0000		8.29	1961-09-11																																	
38	R-121	Mohanganj	NR	24	52.5000	90	58.8000		8.26	1962-04-04																																	
39	R-122	Moulvibazar	NR	24	28.5521	91	46.3526	GPS	10.12	1961-02-20																																	
40	R-123	Netrokona	NR	24	53.0350	90	43.6910	GPS	10.51	1961-01-29																																	
41	R-125	Sheola	R	24	53.1000	92	11.3000		13.49	1962-09-27																																	
42	R-126	Srimangal	NR	24	18.2000	91	44.0000		22.12	1961-01-31																																	
43	R-127	Sunamganj	R	25	4.6280	91	24.7527	GPS	9.23	1961-01-31																																	
44	R-128	Sylhet	R	24	53.4000	91	55.5000		14.21	1961-01-31																																	
45	R-129	Tajpur	NR	24	42.5000	91	44.8000		9.92	1961-10-25																																	
46	R-130	Zakiganj	NR	24	52.5000	92	22.0000		15.79	1962-03-01																																	
47	R-131	Sarail	NR	24	4.3000	91	7.0000			1961-02-15																																	
48	R-132	Nasirnagar	NR	24	11.8000	91	12.0000		6.28	1961-10-26																																	
49	R-227	Nakuagaon																																									
50	R-228	Kanairghat																																									
51	R-229	Manu Rly.Br.																																									
52	R-351	Bancharampur	NR	23	44.5000	90	47.5000		4.89	1961-03-02																																	
53	R-365	Munshiganj	NR	23	33.1000	90	32.2000		5.51	1960-11-25																																	
54	R-367	Nabinagar	NR	23	53.3000	90	58.5000		7.12	1961-04-18																																	
55	R-501	Ghosegaon																																									
56	R-502	Maheshkhola																																									
57	R-503	Laouergorh																																									
58	R-504	Jafflong																																									

DAILY EVAPORATION

STATION NO.	NAME OF STATION	LATITUDE (N)		LONGITUDE (E)		CONFIRM	DATE INSTALLED	DATE REMOVED	WATER YEAR																													
		DEG.	MIN.	DEG.	MIN.				64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93
6	Brahmanbaria	23	58.7	91	7		1961																															
24	Mymensingh	24	46	90	24		1961																															
26	Netrokona	24	53	90	43		1961																															
36	Srimangal	24	18.2	91	44		1961																															
37	Sunamganj	24	4.5	91	25		1961																															
38	Sylhet	24	53.4	91	55.5		1961																															

ANNEX C

SUMMARY OF REGIONAL WATER MANAGEMENT PROJECTS

DD 4

ANNEX C
SUMMARY OF REGIONAL WATER MANAGEMENT PROJECTS

The following is a brief summary of the projects which are proposed in the Regional Development Plan, a qualitative description of the likely impacts of these projects, and a summary of the changes which were made in the model to represent these projects.

E.1 Upper Surma-Kushiyara Project

Project Concept

The concept is to provide flood protection with high embankments which will prevent entry of flood waters into the project along the entire Surma border and along the Kushiyara from Amalshid to Manikkona (upstream of Fenchuganj). Improved gravity drainage will be provided through an open channel discharging into the Kushiyara at Manikkona. Once the project is completed the drainage requirements will be less since the present flood spills from the Surma and Kushiyara River will be greatly reduced.

The pre-feasibility study assumed that the Tipaimukh dam is not constructed. If it is constructed, the project concept and design may be substantially modified. In particular the need for raising the embankment and constructing new embankments may be reduced, and this reduction could be substantial. However, regulation of spills through major channels such as Kakura Khal would still be required.

Impacts

Flood spills from the Surma and Kushiyara Rivers into the floodplain will be reduced and the in-channel discharges will increase commensurately. Higher in-channel flood discharges and water levels will occur on the Surma River downstream of Kakura Khal. There should be minor changes in flood flows on the Upper Kushiyara from Amalshid to Zakiganj, and larger increases from Zakiganj to Sheola, due to the cutting off of overbank spills. There will be a tendency for channel widening, increased channel shifting, and possibly some degradation (erosion) of the bed.

Modelling Approach

The effect of the embankments was replicated in the model by closing off the overbank spills from the Surma and Kushiyara Rivers. This was accomplished by raising the model weirs USD1SK1, UKD1SK1, D1SUR2, and D1KUS3 (Kakura Khal) to a high elevation such that they would not spill in any flood events.

Weir S12AD1 (on the floodplain downstream of Fenchuganj) was raised to represent an embankment to close the floodplain channel, and weir D1KUS5 was lowered to facilitate drainage to the Kushiyara River.

E.2 Surma Right Bank

Project Concept

The project plan calls for a high embankment to provide full flood control over a short length of the Surma River and the Lubha River from Lubha Tea Garden to 5 km downstream of Kanairghat to close off spills into Bara Haor. The existing embankment would be re-sectioned and existing breeches would be closed.

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Further downstream there are two spill channels in the right bank (Rustampur Khal and Bagha Khal) which would be closed up to the pre-monsoon level (they presently have culverts at their inlets) although they would continue to spill overbank during monsoon peaks. The concept described in the pre-feasibility report is without the Tipaimukh dam; if the dam is constructed, the scope of this project could be somewhat reduced.

Impacts
Channel discharges and water levels will increase downstream of Kanairghat due to the reduction in overbank spills. Higher flood levels will increase the tendency for spills over the left bank, which will have to be countered, as well as higher greater main channel velocities, channel widening, and bank erosion along the river, depending on the magnitude of the increased floods.

Modelling Approach
Weir S34USUR42.2, which describes the existing breeches and overbank spills upstream of Kanairghat, was closed by raising it to a high level in the model. Weir S34USUR14.4 (formerly D3SUR1) and S34USUR33.1 (formerly D3SUR2), which represent the overbank spills downstream of Kanairghat, were raised to above the 1:10 pre-monsoon flood level.

E.3 Surma-Kushiyara-Baulai Basin Project

Project Concept
This project covers a large area, the central floodplain lying between Chatak and Sunamganj on the north, Sherpur and Markuli on the south, and Sukdebpur and Khaliajuri on the west. Flood embankments would be completed on three sides of basin to prevent entry of pre-monsoon floods; the left bank of the Surma and Nawa/Baulai Rivers (202 km total of which 145 km is already embanked) and the right bank of Kushiyara/Kalni River (115 km of which 72 km is already embanked). The south and south west sides would be left open for monsoon and post-monsoon drainage.

The inflow from the Kushiyara floodplain near Fenchuganj would be closed and the floodplain would be drained to the Kushiyara river as described above under Upper Surma-Kushiyara Project.

Regulators are proposed to check flood inflows into the project area through open khals; five on the Surma spill channels, four on the Kushiyara channels, and one on the Piyain spill channel. The regulators on the Surma offtakes would normally be left partly open to provide a nominal flow (approximately one-third of the design capacity), but would be opened to discharge at capacity during severe pre-monsoon events and during the monsoon season in order to minimize the potential impacts on the Surma River water levels. The Kushiyara regulators would also be opened during the monsoon season and during unusual pre-monsoon events and the inlet from the Nawa River (via the Old Surma) would be closed to pre-monsoon flows.

A number of internal drainage improvements would also be made in Sadipur Khal and the Bhattadhuka, Ratna, Old Surma, and Mahasing Rivers to improve post-monsoon conditions.

The purpose of the project is to provide increased protection of boro rice in pre-monsoon floods as well as to reduce flood damage to aus and deep water aman.

The proposed initiative outlined in the pre-feasibility study assumes no Tipaimukh dam. If the dam were constructed, the height and extent of submersible embankments might need to be modified from that which is described in the pre-feasibility study. In particular, the requirements for submersible embankments would likely be increased. The scope of drainage improvements is less dependent on the effects of the Tipaimukh dam.

Impacts
Due to the reduction in floodplain discharges the flows and water levels will increase slightly in the bounding rivers. The potential impact is mitigated considerably by maintaining some flow in the regulators and by opening them completely during monsoon floods and unusually-severe pre-monsoon floods.

Closure of spill channels will increase pre-monsoon flood levels in the Nawa and Baulai Rivers. The increased velocities may increase the Baulai's capacity to flush sediments deposited during the monsoon season when the area is deeply flooded and they may promote channel enlargement. There may be an increased tendency to channel shifting on the Baulai River.

Reduction of Surma spills will reduce flash flood erosion on Madhabpur Khal, Bhattadhuka Khal, and Bahia Nadi. This will reduce sediment loads contributed by spills from Surma and by erosion of the channel banks. less siltation will occur along distributary channels in the basin.

Re-excavation of drainage channels (Old Surma, Darain River, Ratna River, and Sadipur Khal) will channelize pre-monsoon flows and will result in lower pre-monsoon water levels, reduced pre-monsoon flood spills, and reduced overbank sediment deposition. As a result, the pre-monsoon flows in the Surma-Kushiyara interbasin will be confined to a few well defined channels. A more efficient drainage system will lead to faster drainage during the post-monsoon season and to lower water levels.

The effect of the submersible embankments on the Kushiyara-Kalni River is expected to be quite small. Increased confinement of pre-monsoon floods will improve the river's capacity to flush sediments deposited during the monsoon. Therefore, the embankments will marginally reduce the rate of channel aggradation in the lower Kalni River.

Modelling Approach
The proposed regulators were modelled with compound broad-crested weirs to provide the required hydraulic capacities. They were sized to release one-third of their design flow up to a 1:2 flood condition, to provide their design flow in a 10-year pre-monsoon flood, and to be overtopped in floods higher than the 1:10 pre-monsoon flood (submersible embankment design case). The modified weirs are purely conceptual in that they are intended to represent the desired hydraulic characteristics and not the actual design of the physical structures.

Weirs were added to represent the proposed control structures on the Bhattadahuka River near Rampur and the and Surma River near Nilpur. A weir was also added to represent closure of the right bank spill from the Kalni River at Ajmiriganj, which was constructed in 1993.

Weirs which are located on overbank spills and which represent submersible embankments were raised to the 1:10 pre-monsoon level and were assigned their original width.

The modified weirs include:

D2SKREV2
BHATTA-DAHUK km 0.5
S4REVSUR5
SURMA km 175.0
NF1
BF1
BF2
S12AKUS1
S12CKUS1
KUS122.5
SURMA km 281.0
S12AD1 (closed)

Internal drainage works could not be modelled with the level of floodplain discretization that is presently available. These generate mainly internal project benefits and only limited regional impacts and therefore need not be modelled in the regional model. Additional surveys and modelling of the drainage improvements may be undertaken during the forthcoming Kalni feasibility study.

E.4 Jadukata-Rakti River Improvement

Project Concept
There are two components to this project:

- partial control of an avulsion on the Jadukata alluvial fan into the upper Baulai River by constructing a weir on the Patnaigang (also called Maharam) channel where it splits off from the Jadukata;

- improvement of drainage from the area adjacent to Shanir Haor, Matian Haor, and Angurali Haor by re-excavating the lower Jadukata/Rakti River to its junction with the Surma River. This work will also improve navigation along the river.

Impacts
Reducing spills from the Jadukata during the pre-monsoon season will reduce flash floods and channel erosion along the Patnaigang River system and will counter-act the recent trend for this river to capture more of the Jadukata River discharge. It will also reduce sediment deposition in Matian and Tangua Haors, which are important fish sanctuaries. However, flows will tend to increase downstream on the lower Jadukata River and Rakti River.

Re-excavating the Rakti River will confine pre-monsoon and winter inflows from the Jadukata River and will reduce spills to Shanir Haor, Matian Haor, and Halir Haor. This will tend to cause the channels to become more incised which will reduce overbank flow and sediment spills to the floodplain, haors, and fans. A greater proportion of the sediment from the Jadukata/Jhalukhali Rivers will be flushed through the Rakti River into the Surma River.

Modelling Approach
The proposed weir at the entrance to the Patnaigang River (PATNAIGANG 0.5) was modelled with a 300 m wide broadcrested weir at the 1:10 pre-monsoon flood level; ie all flows up to the

1:10 pre-monsoon flood condition are directed into the Jadukata River. The Jadukata channel, which has silted in, was deepened in the model to provide a depth of 3 to 3.5 m.

E.5 Baulai River Improvement

Project Concept
Objectives are:

- To lower pre-monsoon and post monsoon water levels on a portion of the Baulai River by selective dredging;
- To increase pre-monsoon channel capacity and post-monsoon drainage from tributary channels flowing into the Baulai River (Piyain R., Someswari, Kangsha, and Upper Baulai River) by re-excavation of the tributary channels.

The project concept is not affected by the implementation of the Tipaimukh dam.

Impacts
Water levels on the Baulai/Nawa River (principally between Kaliajuri and Sunamganj) will be lowered by a few tenths of a metre during the pre-monsoon and post-monsoon seasons. There will be virtually no impacts during the monsoon season when the area is deeply flooded and the channel capacity is relatively small when compared with the floodplain conveyance.

Rectification, widening, and deepening of tributaries channels will channelize flows into the main stem drains during the pre-monsoon and post-monsoon seasons, which will reduce the spill over the floodplain and into haors. Expect a more stable channel system with less shifting and avulsion. Headcutting and erosion along smaller khals that flow into the re-excavated drains may occur as the streams become more incised. Spoil from excavation may produce impacts if used for embankments without prior planning; it could confine and deflect flows which could initiate other channel instability problems.

Modelling Approach
The channel cross-sections of the Baulai River from Sukdebpur to the junction with the Ghorautra River (km 26.0 to 114) were deepened by as much as 0.75 m to replicate the proposed deepening of the Baulai River. The tributary rivers were not changed on the assumption that the winter water levels would be largely controlled by backwater from the Baulai; furthermore the existing level of detail is not adequate to represent the proposed changes on the smaller tributaries.

E.6 Kalni River Improvement

Project Concept
To stabilize and rehabilitate the lower Kalni River by conducting local channel dredging and river training, and thereby:

- to arrest ongoing deposition which is affecting pre-monsoon flooding and post monsoon drainage in the Central Basin; and
- to improve navigation on the Kalni River between Madna and Markuli.

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The project concept is not strongly dependant on the implementation of Tipaimukh dam although the pre- and post-monsoon drainage benefits become greater with the increased winter discharges that the dam will produce.

Impacts
There will be virtually no impact during the monsoon season when most of the project area is deeply inundated. Pre-monsoon water levels will be reduced between Madna and Sherpur by a few tenths of a metre. Spills from the Kalni towards the Baulai River system will be reduced and the tendency for channel shifting in this direction will also be reduced.

Modelling Approach
The river cross-sections were deepened in the model by as much as 1.5 m to represent the dredging that is planned, in the reach from KALNI km 16.501 to km 72.5. This is a somewhat simplifying assumption which is consistent with the level of cross-section data that is available; the actual dredging will be more specifically targeted to specific shoals and problem areas which will be better defined when the detailed surveys are completed during the on-going feasibility study and the effects can be modelled with more precision at that time.

E.7 Kushiyara-Bijna Interbasin Project

Project Concept
Protection against flooding along the left bank of the Kushiyara/Kalni River is proposed by full flood embankments between Sherpur and Markuli and by submersible embankments from Markuli to Ajmiriganj. Spills from the Kushiyara River into Shaka Barak River will be prevented by a control structure.

The pre-feasibility report for this project assumed no Tipaimukh Dam and no other upstream flow control. If the dam is constructed, the scope of the project could be substantially modified - for example the need for the flood control embankment might be significantly reduced or eliminated, and the potential impacts on Kushiyara River flood levels would be reduced.

Impacts
The flood embankments proposed in this project would impact on flows and water levels during the pre-monsoon and monsoon flood seasons. Left bank spills from the Kushiyara River would be eliminated, causing increased in-channel flows in the Kushiyara/Kalni River and higher water levels between the Manu River confluence and Markuli. The impact on river discharges and on spills over the right bank of the Kushiyara River could be large during the monsoon season. The impact on water levels depends on a number of factors, including the backwater conditions and the increased spill over the right bank, and can best be estimated from the model results. Pre-monsoon impacts will be less, since the spill is at a relatively high level.

The confinement of pre-monsoon flows might, in the long-term, initiate channel enlargement and minor degradation downstream of Markuli; however this change is complicated by the confinement of monsoon floods whose impact of channel stability cannot be assessed at this time.

Modelling Approach
This project was not modelled in the original simulations because it was expected to involve

submersible embankments at the time, which would have little potential for impacts. However the project now proposed full embankments to cut off the overbank spill which could cause greater impacts.

The project was modelled in the revised simulations by raising weir S11REVKUS1 which represents the overbank spill downstream of Sherpur to a level above the highest flood. Weir S11REVKUS2 which represents the Shaka Barak spill was modified to represent a control structure at this location.

The submersible embankments downstream of Markuli are expected to have only minor impact on water levels in the Kalni River. Floodplain flooding is mainly due to backwater from the Kalni River such that the rate of overbank spill in this reach is thought to be small. This has been assumed in the model setup and has been confirmed in the calibration. Therefore the submersible embankment has not been modelled, but these assumptions will be reviewed in greater detail during the Kalni River improvement feasibility study when more detailed surveys will be available and the magnitude of the overbank spills can be confirmed.

E.8 Dharmapasha Rui Beel

Project Concept
This project involves construction of submersible embankments at strategic locations along the Kangsha, Someswari, Gunai, and Updakhali Rivers to protect boro crops from pre-monsoon flash flooding.

Impacts
This project is situated in a morphologically unstable reach that is being affected by upstream channel changes on the Ghulamkhali/Someswari Rivers and by downstream siltation in the backwater of the Baulai River. Future impacts of the project will depend on how these channel changes develop. For example, it is conceivable that future channel shifts could cause the project to be completely by-passed.

Impacts will be minor during the monsoon season when the entire area will be deeply flooded, unless the embankments are so high as to encroach on monsoon flows. However, completion of the new embankments will effectively channelize portions of the Gunai, Someswari, and Kangsha Rivers during pre-monsoon conditions and their design must accommodate the discharges that will occur. These rivers are already partly confined on their left banks by submersible embankments which were constructed as part of Gurmar Haor Project, Sonamoral Haor Project, Chandra Sonar Thal Project and Haijda Embankment Project. Consequently, pre-monsoon flows will probably be increased by the project. Additional channel instability, bank erosion, and sediment deposition can be anticipated downstream of the project.

Modelling Approach
The weirs which represent the overbank spills into the project area (FC8KAN1, FC8SOM1, and FC8SOM2) were raised to the 1:10 pre-monsoon level. These revisions prevent overbank spills from occurring up to the 1:10 design case.

E.9 Updakhali Project

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Project Concept
The project is planned to protect boro crop and enhance boro rice cultivation by constructing submersible embankments and regulators to prevent pre-monsoon overbank spills. A recently formed avulsion channel (Jatrabari Dhala) will be closed by a regulator and the river will be re-routed back down the Gunai River by diverting it through an excavated pilot channel.

Impacts
This project is situated in a morphologically unstable area that is being affected by upstream changes along the Ghulamkhali/Someswari Rivers and by siltation downstream in the backwater zone from the Baulai River. Future changes in the channel location and form cannot be reliably forecast at this time. It is conceivable that future channel shifts could cause the project to be completely by-passed.

The project is not expected to produce significant impacts during the monsoon flood season when it will be completely inundated. The channel diversion at Jatrabari Dhala will reduce channel instability and erosion in the short-term within the newly forming active channel zone on the north side of the project. However, this diversion will direct pre-monsoon flows back towards Singar Beel so the emerging channel instability and sedimentation problems may be simply transferred to the south.

Modelling Approach
The model weirs which define the overbank spills into the project area (FC17SOM1 and FC17GHUL1) were raised to the 1:10 pre-monsoon level to replicate construction of submersible embankments.

E.10 Upper Kangsha River Basin Development

Project Concept
This initiative involves three components on the Upper Kangsha/Bhogai River (Malijhi River Improvement Project, Extension of the Konapara Embankment, Greater Dampara Project) and as well as river training on the Someswari alluvial fan (Someswari River Project).

Malijhi River Improvement Project
To improve drainage from land adjacent to the Malijhi River, it is proposed to increase the discharge capacity of the outlet by making a series of loop cuts on the Kangsha and Bhogai Rivers. In addition, a 35 km long diversion channel will be constructed, to divert approximately 100 m^3/s into the Mogra River basin.

Konapara Embankment Extension
To protect crops and homesteads on the left bank of the Bhogai River, the existing Konapara embankment will be extended 20 km upstream to the Malijhi confluence. The proposed extension will tie to existing embankments to provide a continuous, full flood control embankment along the Bhogai/Kangsha River from the International border to Phutkai, a length of approximately 100 km.

Greater Dampara Project
A 35 km long full flood embankment is proposed along the right bank of the Kangsha

River upstream from Jaria almost to Sarchapur to control right bank spills and to reduce damage further downstream in the existing Kangsha River Improvement Project.

Someswari River Project
The Someswari alluvial fan is subject to avulsion hazards, flash flooding, high-velocity spills, bank erosion, and sediment deposition. Given the nature of these hazards, a substantial portion of the fan surface must be retained as a floodway for conveying flash floods and as a natural sediment basin for storing sediment. It is proposed to increase the security on the remaining, presently-inactive portion of the fan by upgrading, extending, and protecting the existing roadway between Jaria and Durgapur so it will act as an embankment. Furthermore, a recently developing new avulsion path, down the Atraikhali River will be closed.

Impacts of the Kangsha River Projects
The upper Kangsha, Bhogai, and Malijhi Rivers will be shortened considerably in order to improve drainage and reduce upstream flood levels.

These changes, in conjunction with confinement effects from the full flood embankments, could initiate changes to the river's longitudinal profile, channel pattern, and morphology. In particular the flow velocities will be increased which will increase the ability of the river to transport sediments. The magnitude and time scale of these impacts will depend on the nature of the bed and bank materials along the channel, as well as on the hydrologic conditions and the incoming sediment loads that are experienced after the work is completed.

At the present time the river appears to be relatively stable and there are few signs of significant channel activity upstream of Jariajanjail. A more detailed analysis of the potential morphological impacts needs to be made during the feasibility study, when more detailed field surveys and modelling will be available.

A partial diversion from the Malijhi River could increase discharges and sediment inflows to the lower Mogra River. These impacts can be reduced by bypassing Netrokona via the upper Saiduli River and by making the proposed channel improvements in the Mogra River.

Impacts from the Someswari Project
Preventing a future avulsion down the Atrikhali channel will reduce spills of water and sediment into the low-lying poorly drained land lying between the Someswari and Lungla Rivers and will prevent the Shibganjdhala River discharges from further decreasing. Reduction of the roadway spills will also increase the flood discharges in the Shibganjdhala River and a portion of the Kangsha River, although the reach of river is somewhat limited by the flows return to the floodplain downstream of Jaria Janjail.

This action would also reduce future channel instability, erosion, and disruption of drainage patterns along the lower Someswari River. However, reducing eastward spills will force more water and sediment southwards, down the Shibganjdhala channel and into the Kangsha River. The Shibganjdhala channel will continue to widen and to develop a shallow, more braided pattern. Large volumes of sediment will continue to be deposited in low-lying beels adjacent to the river as well as along the lower Kangsha River.

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Modelling Approach

The project options were modelled extensively in a sub-model and the recommenced alternative was incorporated into the main regional model. Modelling of the proposed work required a number of interventions:

- extension of the Konapara embankment - weir BK3 was raised to close off the left bank spill into the Gangina khal channel upstream of Sarchapur

- Kangsha River channel improvements - the channel roughness (N value) was reduced in the reach KANGSHA km 0.0 to 24.0 to estimate the effects of reducing the effective channel length in the Kangsha River channel improvements. This change approximates the increased water surface slope due to channel straightening and the effect it has on increasing the discharge (other factors being equal the discharge is inversely proportional to the roughness factor and directly proportional to the square root of energy slope). Similar changes were made in the channels upstream of Sarchapur (BHOGAI km 28.5 to 56.0 and BHOGAI_N (Malijhi branch) km 0.0 to 20.0.

- diversion to Mogra - a diversion channel having a capacity of approximately 100 m3/s was added from KANGSHA km 0.0 to MOGRA km 0.0 to represent the proposed diversion. Mogra River discharges at Netrokona were attached as a later inflow at MOGRA km 0.001.

- Mogra channel improvements - the channel roughness (N value) was adjusted in MOGRA km 0.0 to 31.5 to estimate the effect of channel straightening downstream of Netrokona

- right embankments (Greater Dampara Project) - no provision exists in the model for simulating the effect of this project. Investigation in the field indicates that the spill over the right bank is likely small in magnitude and thus the effects on Kangsha water levels is not likely to be significant. Therefore no changes were required to simulate this project, but these assumptions are to be reviewed once the detailed bank survey which is proposed during the feasibility study is completed.

- drainage of south floodplain (Greater Dampara Project) - the drainage areas from the NAM model were reassigned to connect this area (136 km2 of catchment 33) to the Mogra River at Netrokona. A more detailed discretization will be made in the feasibility study.

- closure of Atraikhali channel - the model weir (FPSK km 4.0) that defines the overbank spill (including Old Someswari River) was modified to reflect the closure of the Atraikhlai channel. This weir is conceptual only and will be replaced in the re-schematization which is in progress during feasibility study

- closure of roadway spills in the Durgapur Road - the model weir (BK7) that defines the roadway spills was modified to reflect the closure of five small bridge openings and raising of the roadway.

The modelling results were judged to be adequate for the regional plan scale of investigation. However a number of the changes are conceptual in nature and the existing model does not provide an adequate level of precision for more detailed studies, and as a result a more detailed channel survey has been conducted. The basin sub-model is being upgraded and re-schematized to include the new surveys. Monitoring of discharges and water levels is under way to provide additional data for calibration of the revised model.

E.11 Mrigi River Drainage Improvement Project

Project Concept
It is proposed to re-excavate 28.2 km of the lower Mrigi River from Boysha Beel to Char Betmari to reduce crop damage from drainage congestion and upstream flooding. Excavation along 28 km of the Upper Mrigi (Karnajhora) River was scheduled for completion in 1993 under the Canal Digging Programme. The proposed project, along with the completed upstream excavation work, will channelize flows into a single drain that conveys runoff from the Piedmont Hills on the Indian border to the Old Brahmaputra River.

Impacts
Channelization will substantially increase the in-channel discharges carried by the Mrigi River and reduce the flows spilling across the floodplain and in distributary channels. Higher discharges and channel velocities could promote bank erosion and increased channel shifting of the Mrigi River. Furthermore, sediment deposition and channel aggradation could be expected downstream of the excavated reach, particularly if the gradient decreases as it approaches the Old Brahmaputra River. This deposition could initiate long-term adjustments to the bed profile, causing infilling of the channel (starting at the downstream end and progressing upstream).

Modelling Approach
Since the work is local in nature and its impacts are localized it was not included in the regional model.

E.13 Khowai-Habiganj Flood Control Project

Project Concept
The main aim of the work is to upgrade and complete the existing Khowai River Project embankments so that they can function properly. The proposed work includes raising, re-sectioning, and re-aligning the existing full flood control embankment between Chunarghat and Habiganj and extending it upstream to the Indian border in order to prevent overbank spills from occurring into the neighbouring Karangi and Sutang River basins. Tributaries entering near the upstream end of the river will be diverted into the Karangi River and Sutang River in order to reduce flood discharges on the Khowai. The largest of these, the Isa Chara, drains approximately ten percent of the Khowai drainage basin.

Drainage improvement by channel re-excavation and re-alignment are proposed for the lower Khowai River (Barak River) in order to reduce agricultural damage from pre-monsoon floods.

Impacts

By preventing overbank spills and breaches from occurring, the works will increase the magnitude of in-channel flood discharges along the Khowai River downstream of Chunarghat while decreasing the magnitude of spills into the adjacent rivers, particularly the Karangi.

Further channel enlargement by bank erosion can be expected along the river, particularly upstream of Chunarghat. Additional sediment deposition and aggradation can be expected along the lower reach, particularly below Habiganj where the river gradient decreases due to backwater from the Upper Meghna River. Much of this aggradation will occur in the form of overbank sand deposition.

During flood conditions, the diversion of tributary channels into the Karangi River will be more than offset by the elimination of spills from the Khowai River. Therefore, it is expected that flood discharges on the Karangi River will be decreased and the channel will become more stable over time with less tendency for channel erosion, shifting, or sediment deposition.

It is believed that spills into the Sutang River have been less frequent and lower in magnitude. Therefore, the net effect of diverting Isa Chara channel into the Sutang River will be to increase flood magnitudes on this river. Additional bank erosion may be expected along the upper reaches of this stream and increased sand deposition can be expected at its lower end where the gradient decreases abruptly.

Modelling Approach

The effects of the embankments were modelled by raising the model weir which represents the overbank flow (CHUNDIV) to a high level above flood conditions. The diverted drainage area was represented as a lateral inflow of $0.1*Q_{Ballah}$, attached as a lateral inflow to SUTANG 0.1 km.

It was noted earlier that the Sutang and Karangi channels are not represented very well in the existing model due to the lack of cross-section data and uncertainties in the boundary discharges. Khowai River levels are represented very well in the calibration results and can be used with more confidence, but further work is required to confirm the boundary inflows and to provide additional cross-section data. Once the boundary inflows are confirmed the magnitude of the overbank spills can be refined and the design levels for the embankments can be determined more accurately. These aspects should be investigated in more detail in feasibility studies for the project.

Work is ongoing to measure discharges at Ballah in order to better define the boundary inflows, and additional cross-sections have been surveyed from Shaistaganj to Madna. These results as well as the proposed excavation of the downstream channel will be included in future revisions to the model.

E.12 Manu River Project

Project Concept

Flood damages will be reduced along the Manu River and in the Manu Project by diverting a portion of the flood flows through a control structure down a prepared floodway channel into Hakaluki Haor.

Impacts

Flood discharges on the Manu River downstream of the diversion structure will be greatly reduced, particularly between the structure and the Dhalai River confluence. Flood levels will only seldom exceed bankfull conditions.

The reduced flows will probably induce sediment deposition in the Manu River at the mouth of the Dhalai River and possibly further downstream along the Manu River. Overall, the river will have a more stable channel, with less capacity to erode its banks and form breaches. However, deposition zones such as point bars will tend to expand, which will promote the development of a more sinuous pattern. This could initiate further local erosion along the river.

The diversion structure will pass flood flows and sediment through an excavated floodway into Hakaluki Haor. Impacts to water levels in Hakaluki Haor will be very minor since the entire area is deeply flooded by monsoon-season backwater from the Kushiyara River.

It is expected that in the order of half of the Manu River's sediment load will be deposited near the downstream end of the diversion route. This will cause a shallow delta to develop at the end of the floodway, which will be accompanied by considerable channel switching, local sedimentation, and erosion and infilling of beels and other lowlands. Sediment loads being carried by the Manu river into the Kushiyara River will be reduced, which will help to restore stability to the Kushiyara River, although this is a secondary effect.

Modelling Approach

The diversion was modelled by means of a lateral outflow from the Manu River at Manu Railway Bridge (UPPER MANU km 9.9) and by adding a corresponding lateral inflow into Hakaluki Haor (JURI km 22.89). The diversion flow was calculated by means of a rule curve which relates the diversion flow to the incoming Manu River discharge at Manu Railway Bridge.

The rule curve represents objective of maintain discharges at Maulvi Bazar to less than 800 m3/s, the flood stage at that location. It allows for inflows between Manu Railway Bridge and Maulvi Bazar, which occur from the Lungla River and local runoff.

Mathematically the rule curve can be expressed as follows:

$$Q_{diversion} = 1.75*(Q_{Manu}-470)$$

subject to the following constraints:

$$Q_{diversion} = 0.0 \text{ for } Q_{Manu} < 470$$

and $$Q_{diversion} <= Q_{Manu}$$

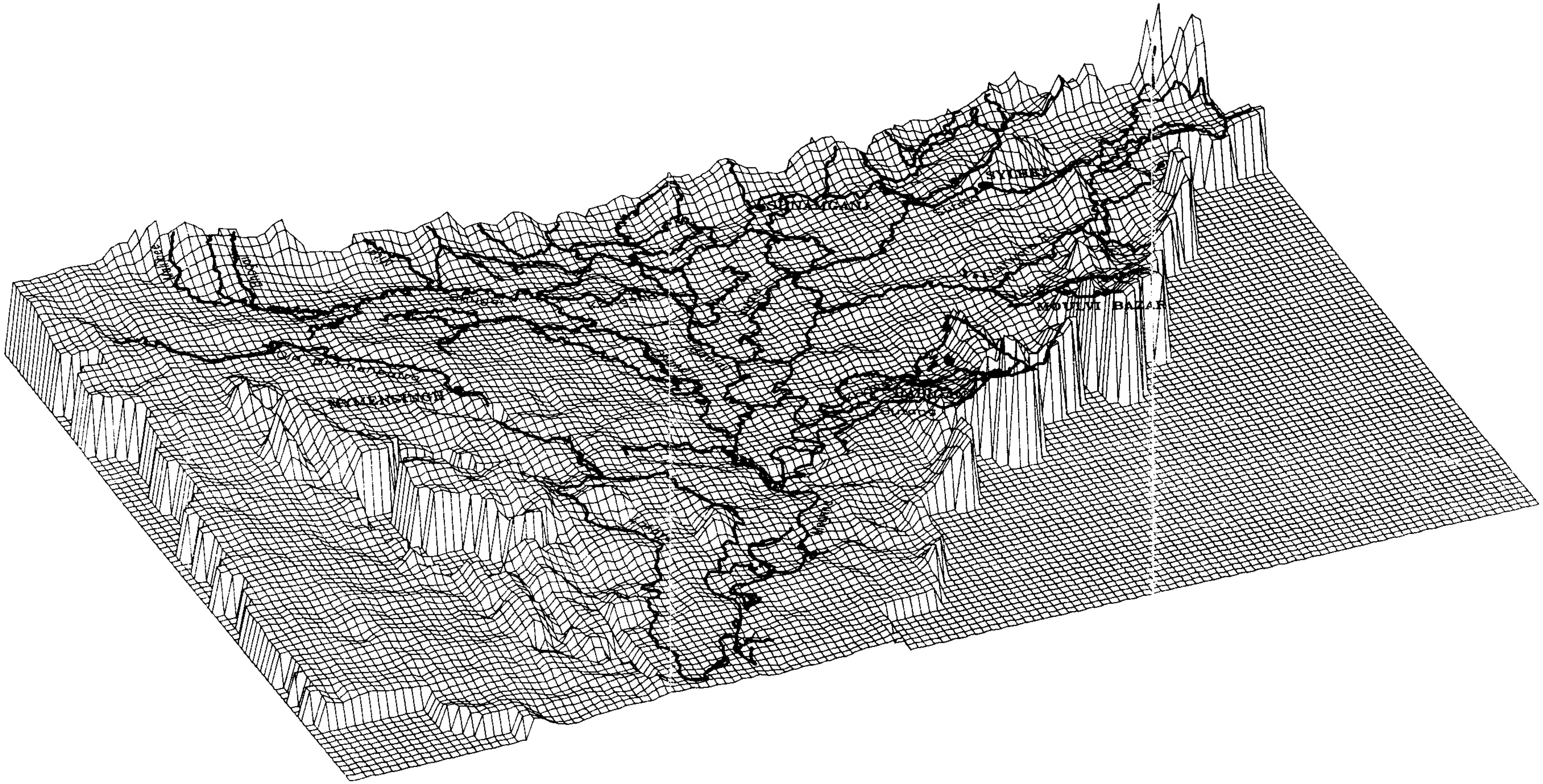
Thus there would be no diversion for Manu River discharges of less than 470 m3/s at Manu Railway Bridge (800 m3/s at Maulvi Bazar when downstream inflows are added) and the diversion would increase successively with increasing river discharge. Also, the diversion flow cannot be greater than the incoming river discharges.

Coefficients for the above relationship were developed from actual discharge data in 1991.

ANNEX D

FIGURES

Figure 1

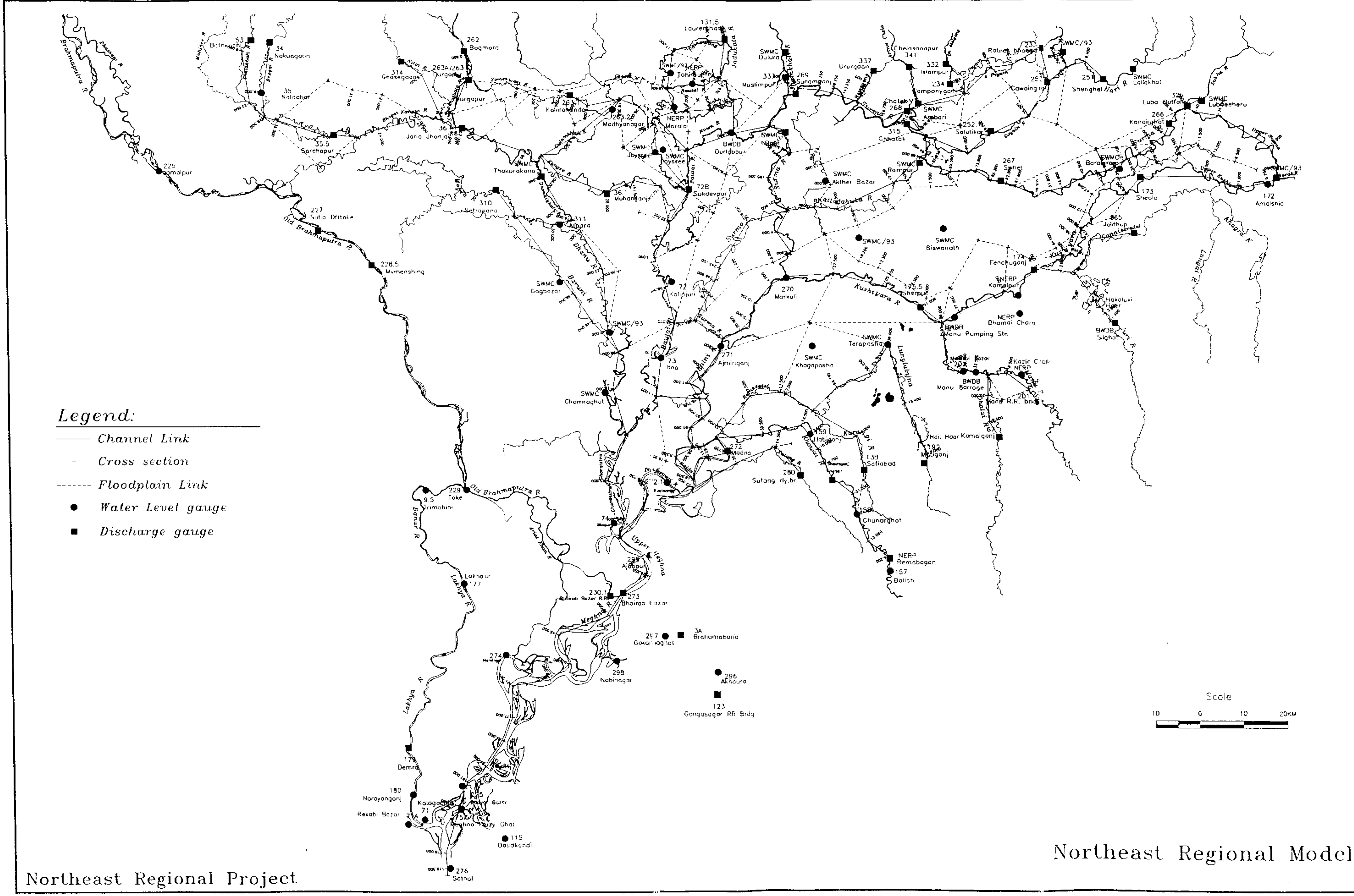


The Northeast Region

Northeast Regional Project

MODL-126.DWG

Figure 2



Northeast Regional Model

Northeast Regional Project

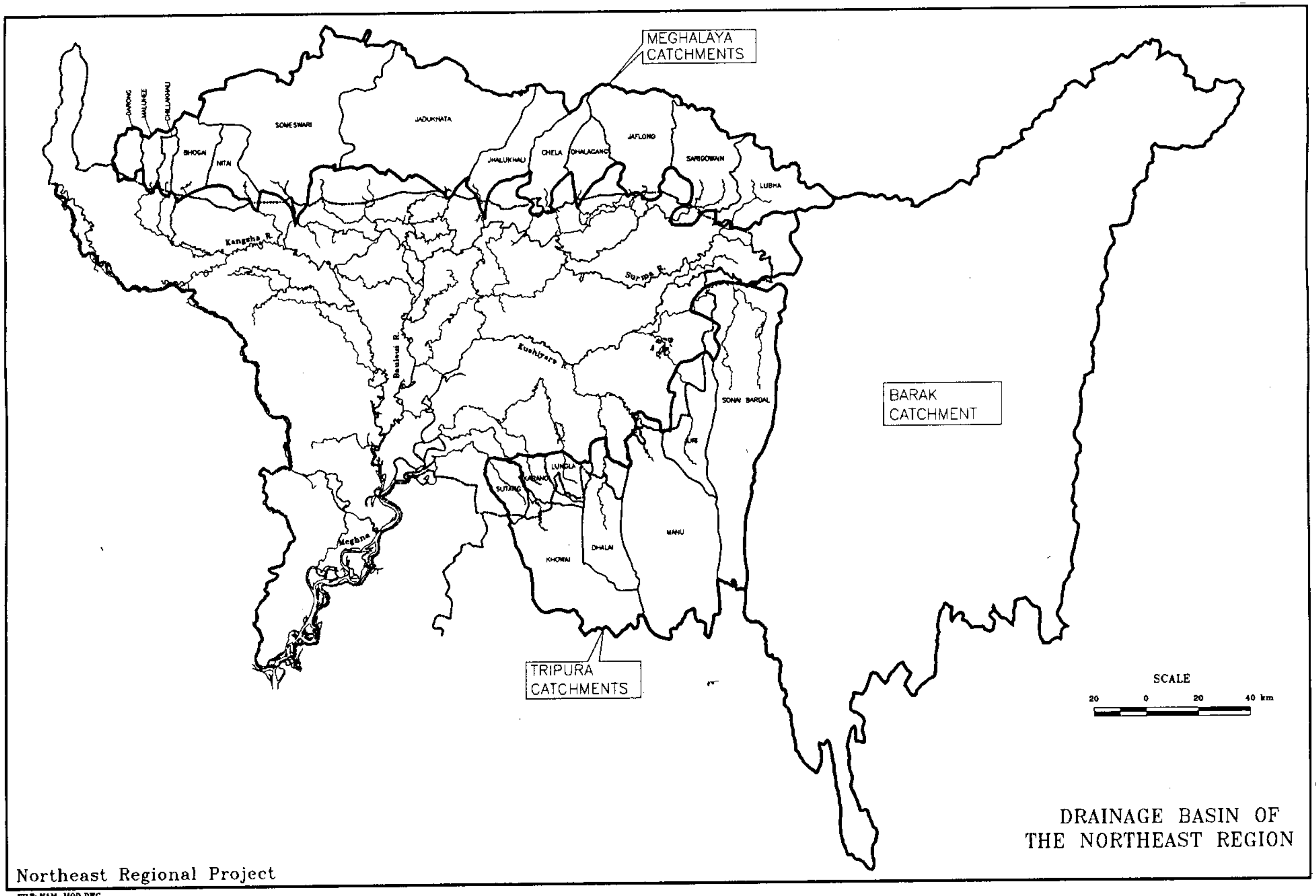
FILE: NERP7.DWG

Figure 3

Model Schematic

Northeast Regional Project

FILE: NERP7-1.DWG

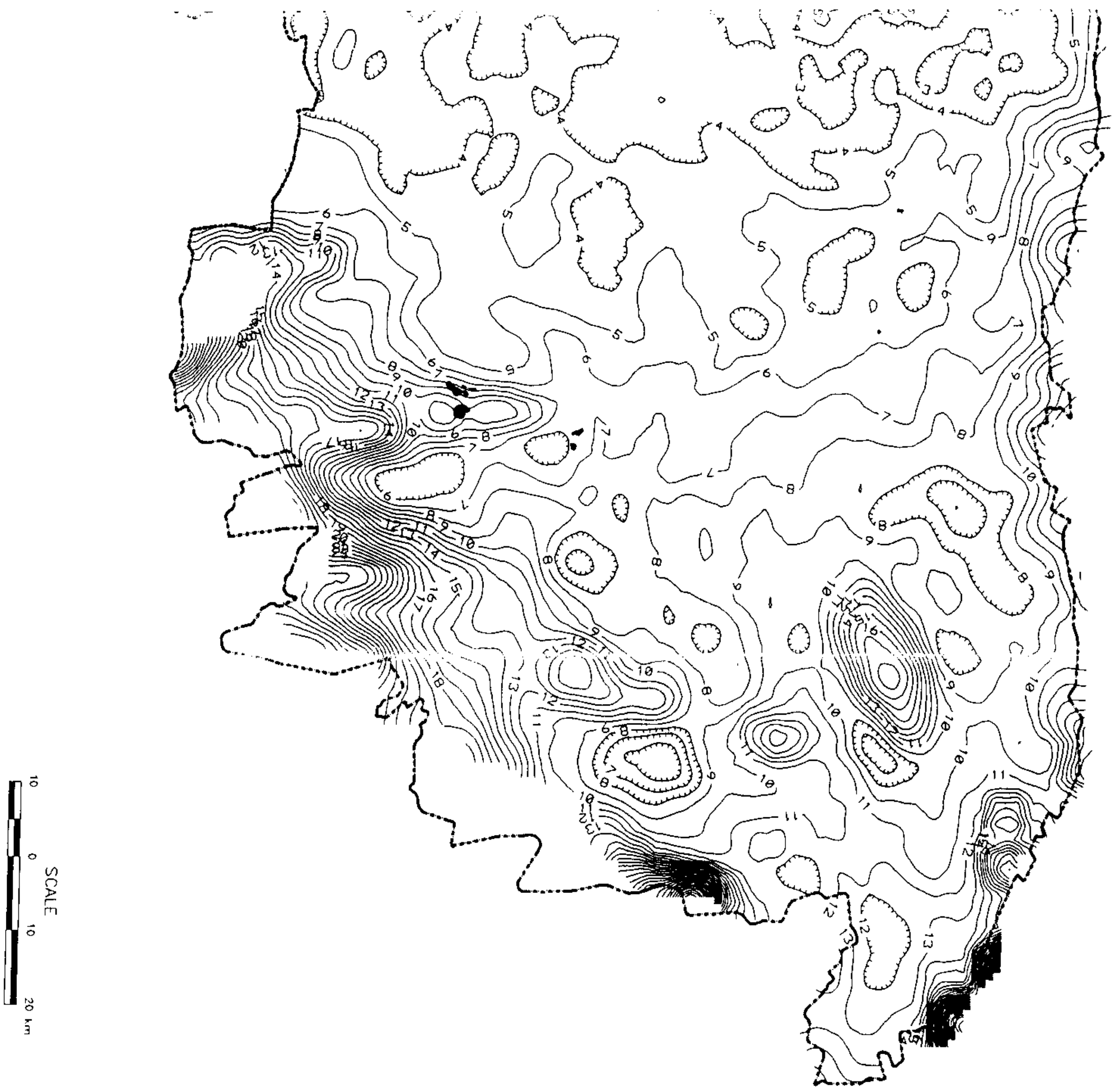


DRAINAGE BASIN OF
THE NORTHEAST REGION

Figure 4

Northeast Regional Project

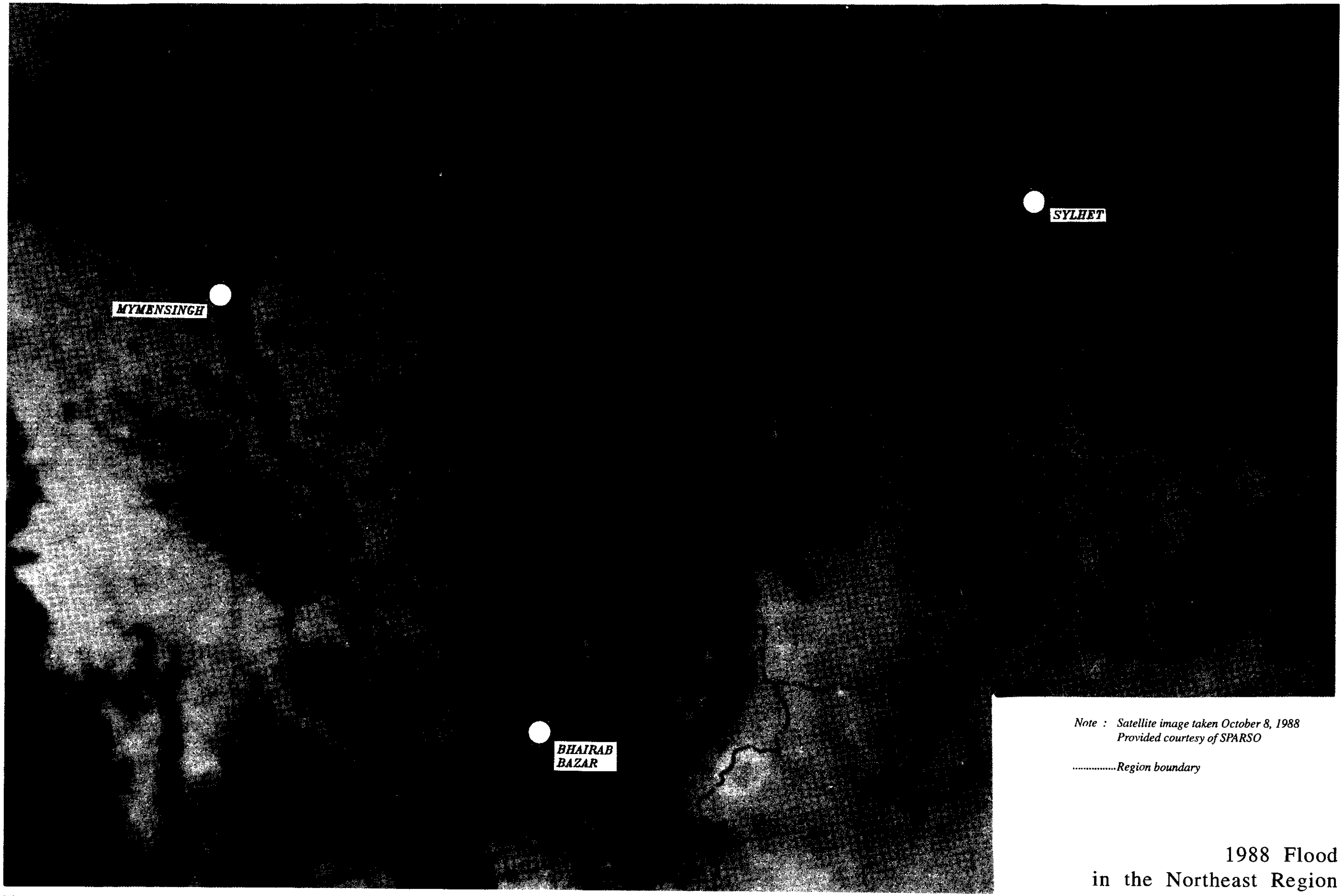
FILE: NAM-MOD.DWG



Ground Elevations

Figure 6

Figure 7



Note : Satellite image taken October 8, 1988
Provided courtesy of SPARSO

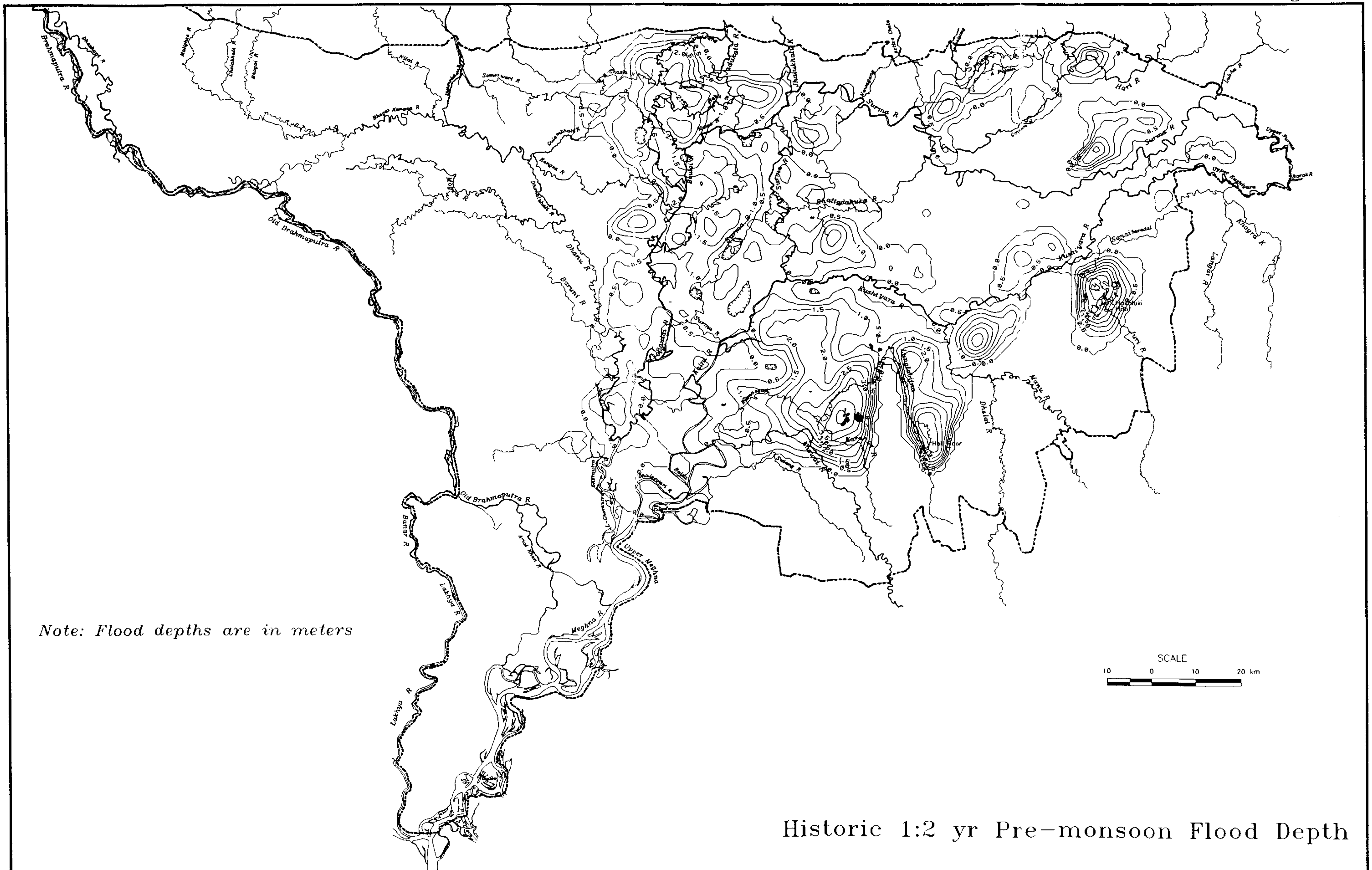
..............Region boundary

1988 Flood
in the Northeast Region

Northeast Regional Project

FILE : MODL - 137

Figure 8



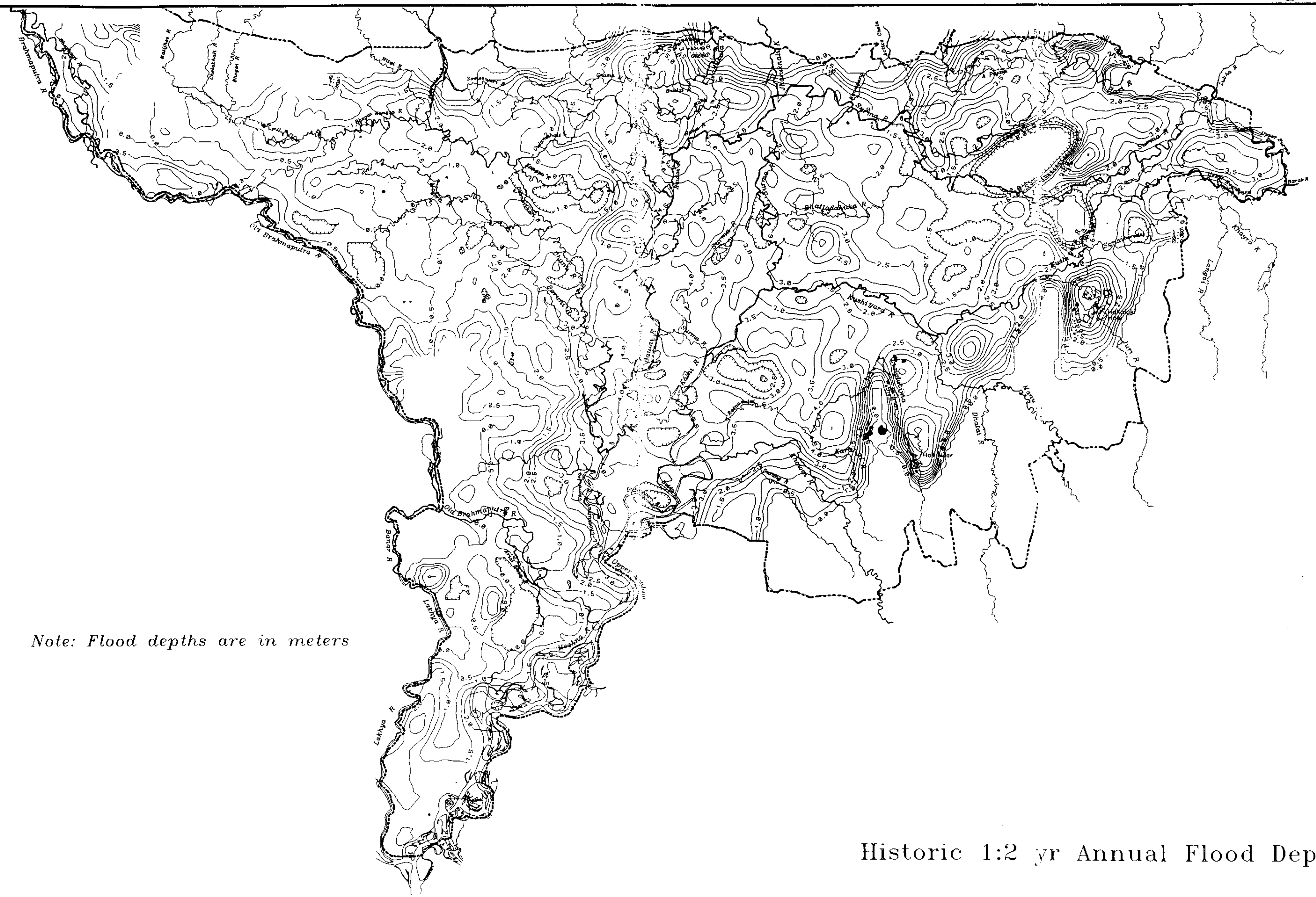
Note: Flood depths are in meters

Historic 1:2 yr Pre-monsoon Flood Depth

Northeast Regional Project

FILE : MODL-129.DWG

Figure 9



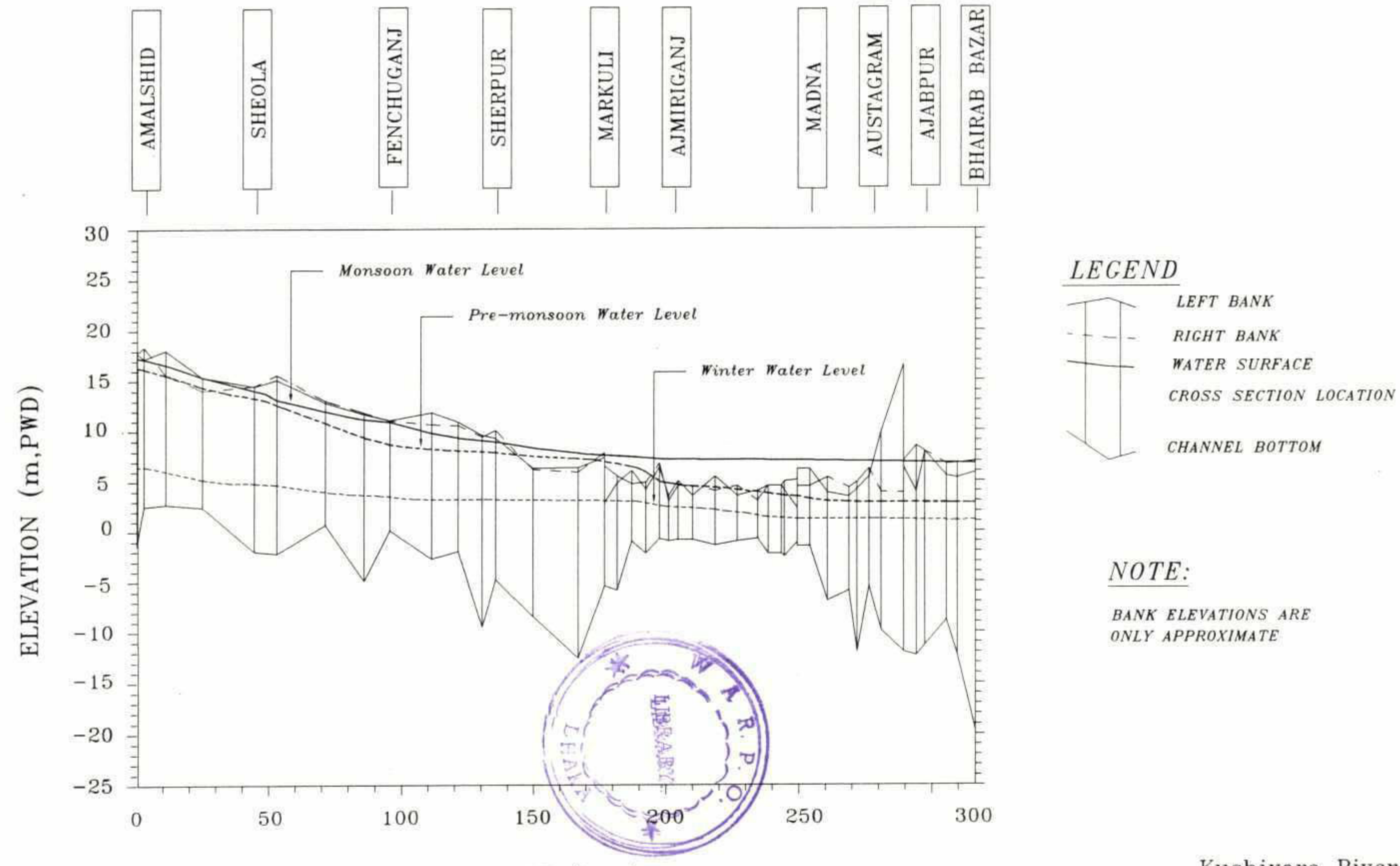
Note: *Flood depths are in meters*

Historic 1:2 yr Annual Flood Depth

Northeast Regional Project

FILE : MODL-127.DWG

Figure 10

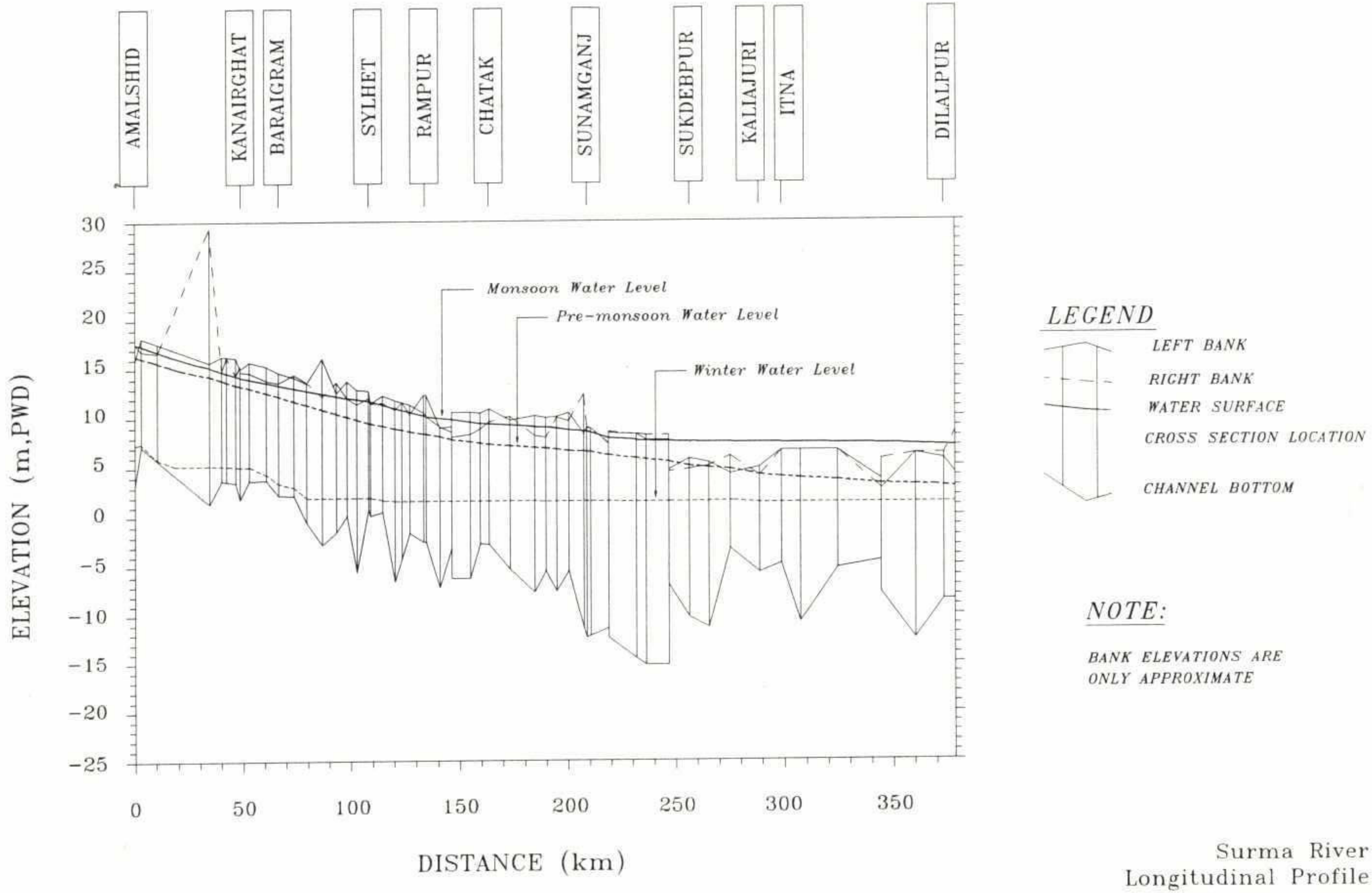


Kushiyara River
Longitudinal Profile

Northeast Regional Project

FILE: KUSH-PRO.DWG

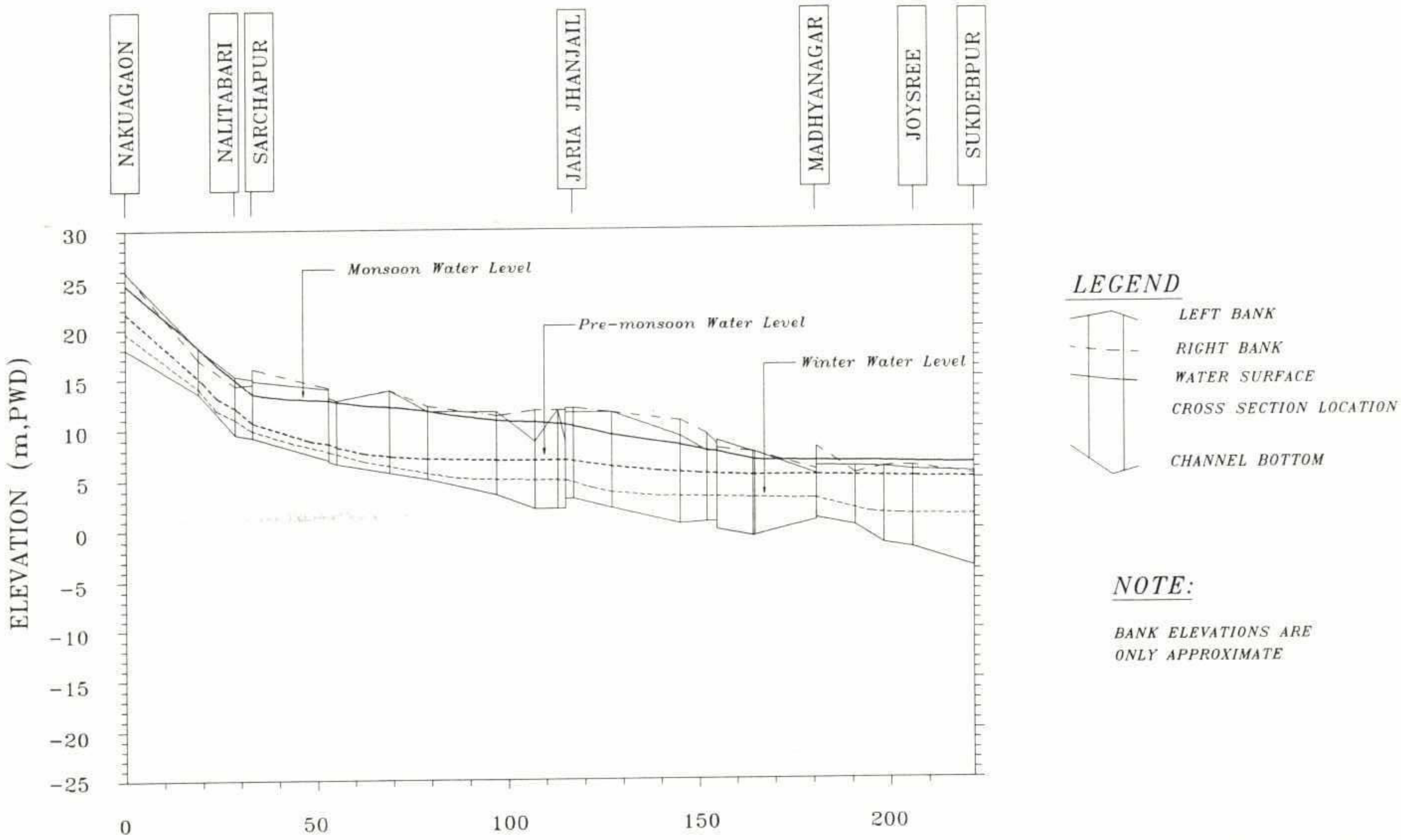
Figure 11



Surma River
Longitudinal Profile

Northeast Regional Project

FILE: SUR-PRO.DWG



Kangsha River
Longitudinal Profile

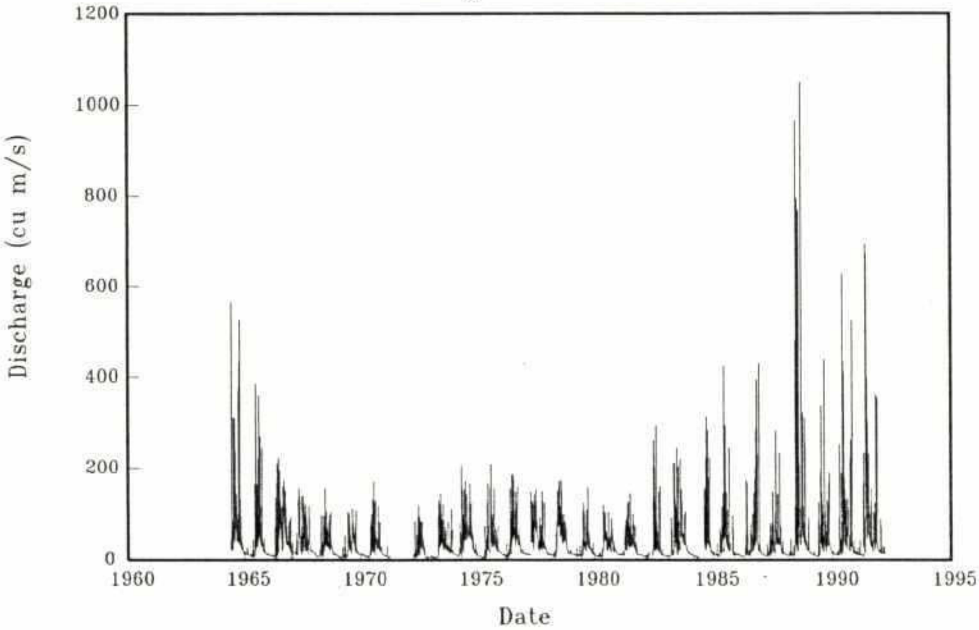
Northeast Regional Project

FILE: KANG-PRO.DWG

Figure 13

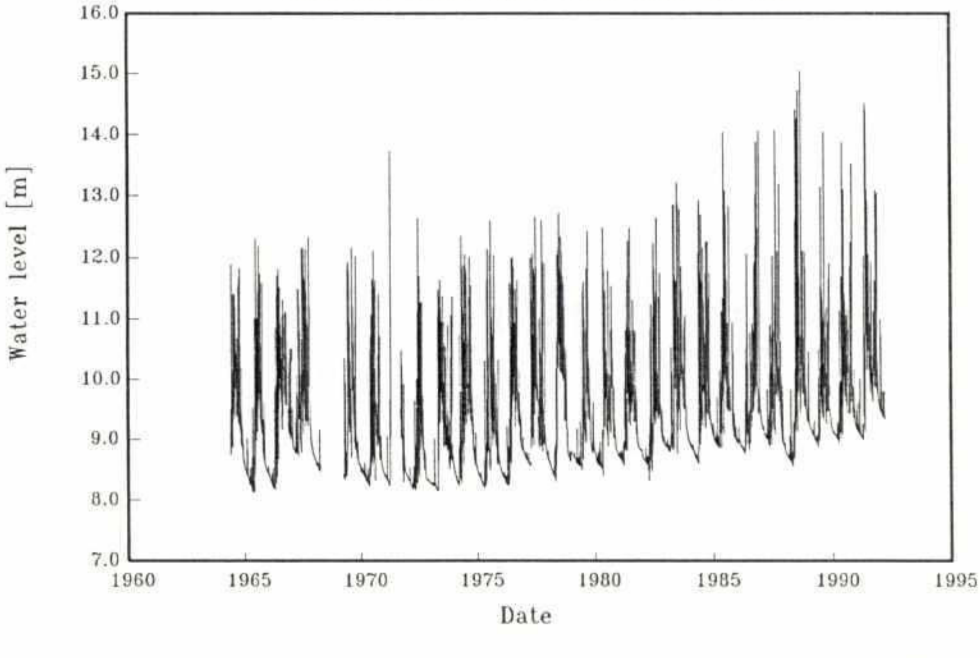
Gauge 158.1 KHOWAI R. at SHAISTAGANJ

Recorded Discharges from 1964 to 1992



Gauge 158-1 KHOWAI R. at SHAISTAGANJ

Recorded Water level from 1964 to 1992

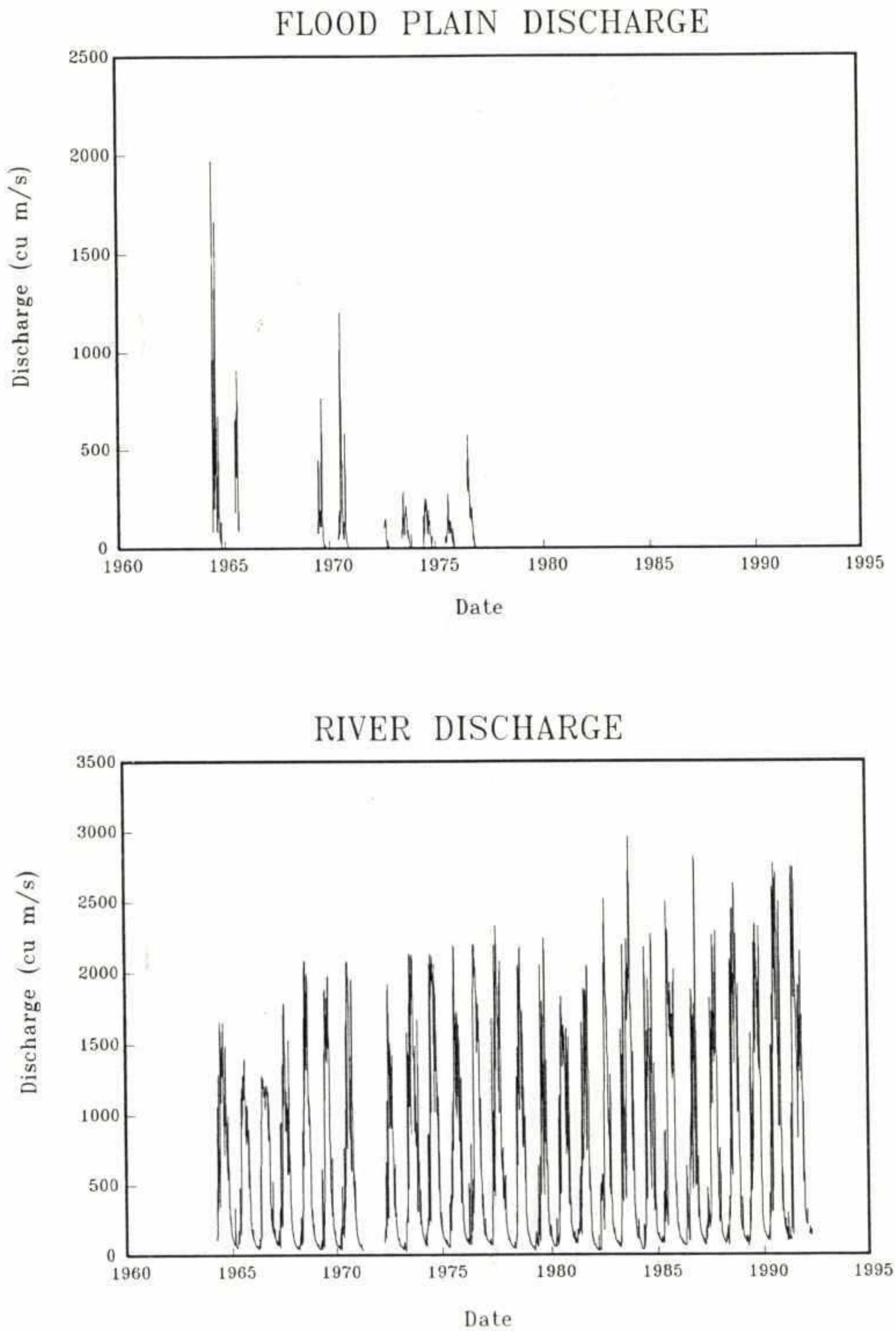


Discharges and Water Levels in the Khowai River at Shaistaganj

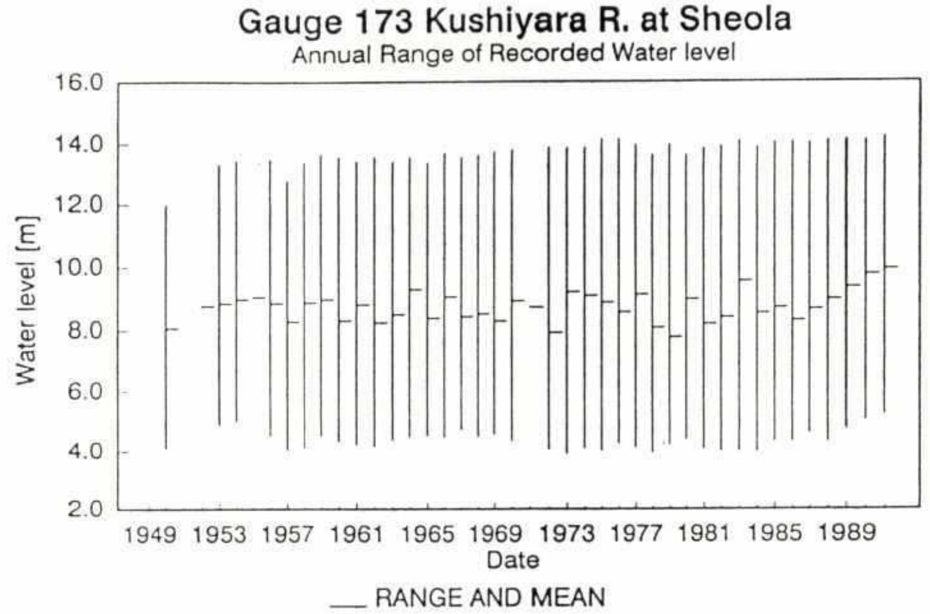
Northeast Regional Project

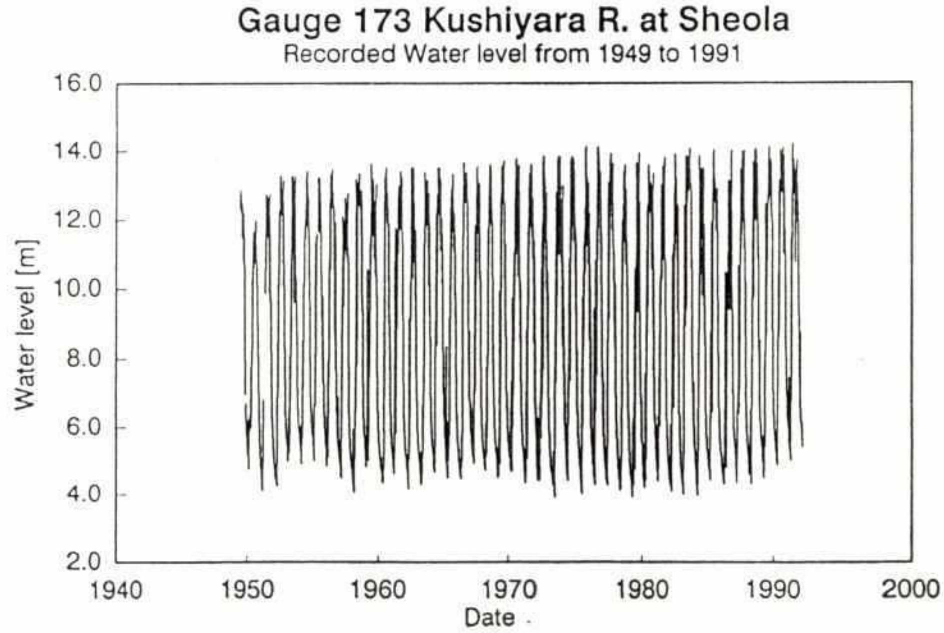
FILE:MODL-301.DWG

Figure 14

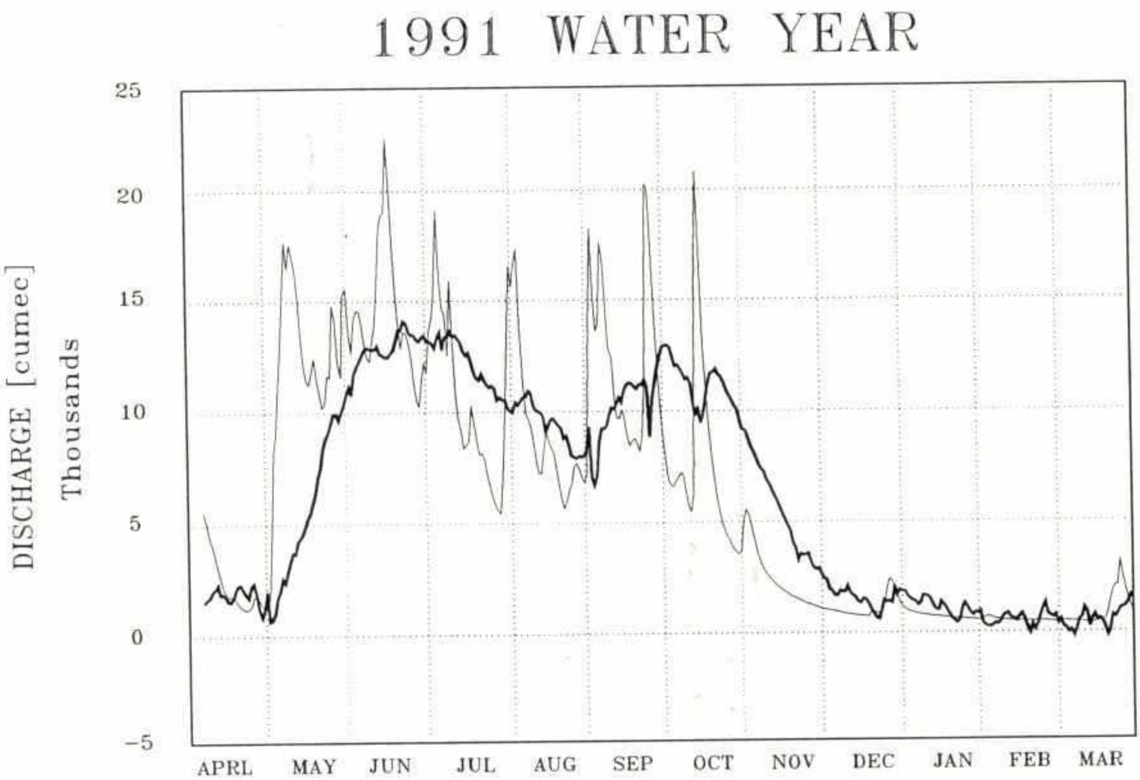


Changing Flood plain and Channel Flows
Kushiyara River at Sheola





Water Levels at Sheola Since 1949



NOTE: HYDROGRAPHS SHOW 24- HOUR AVERAGED DISCHARGE

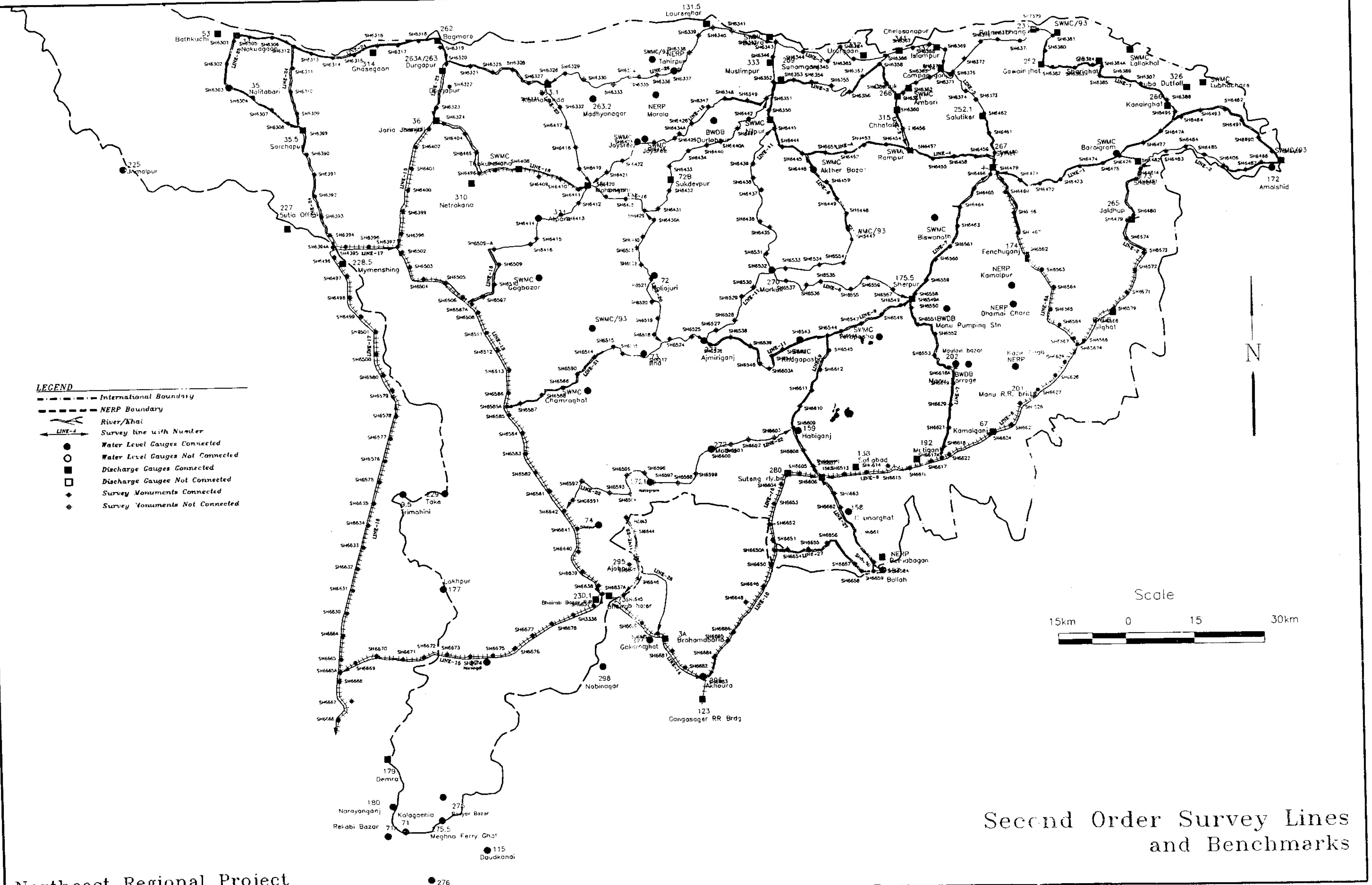
LEGEND

INFLOW (INCLUDING LOCAL RUN-OFF)

OUTFLOW AT BHAIRAB BAZAR

Effect of flood storage on Outflows from the region

Figure 17



Second Order Survey Lines
and Benchmarks

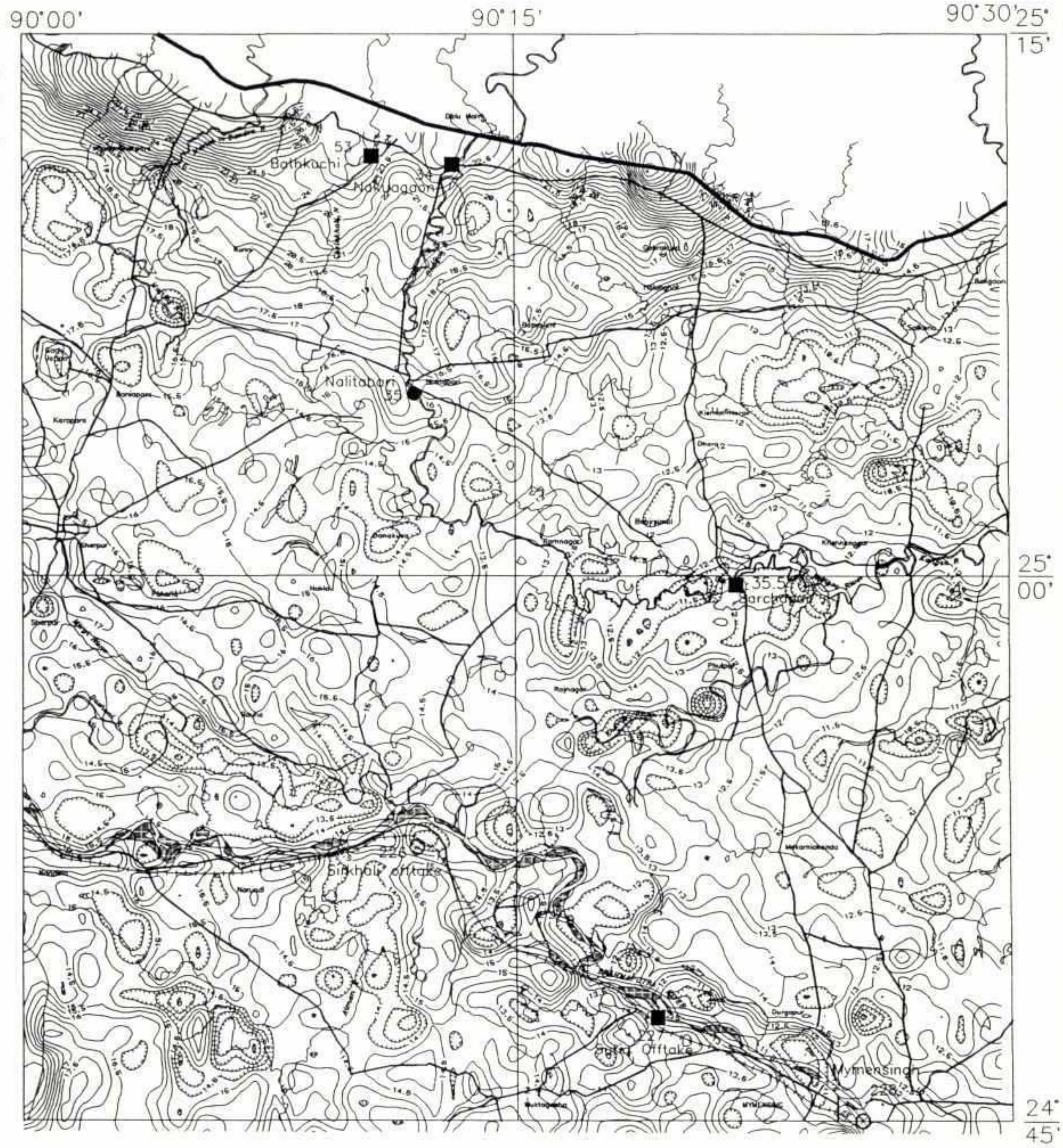
Northeast Regional Project

FILE : MODL-134.DWG

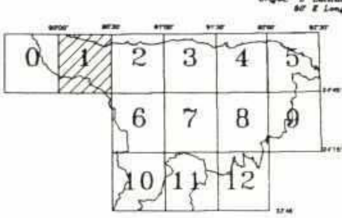
Figure 18

Northeast Regional Project

FILE: MODL-130.DWG



NOTES:
1. 0.5m contour interval
2. Derived from MPO 1 km land level data
3. Transverse Mercator Projection:
Everest spheroid
Scale factor at central meridian 0.9996
Origin: 0 Latitude
90 E Longitude



Northeast Regional Project

TOPOGRAPHIC MAP
BLOCK 1

Prepared by: AWLAD/NASIM | December 92

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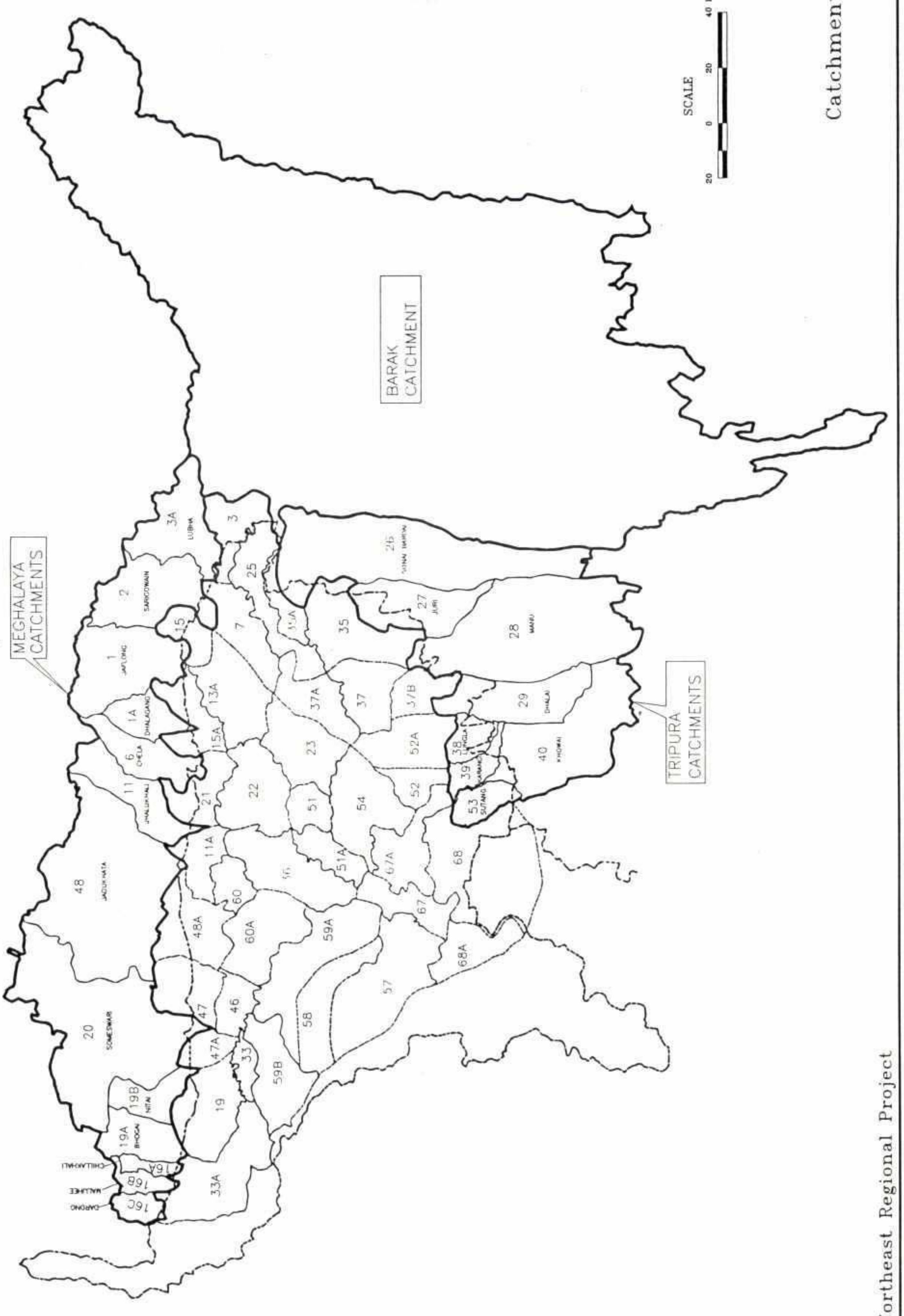
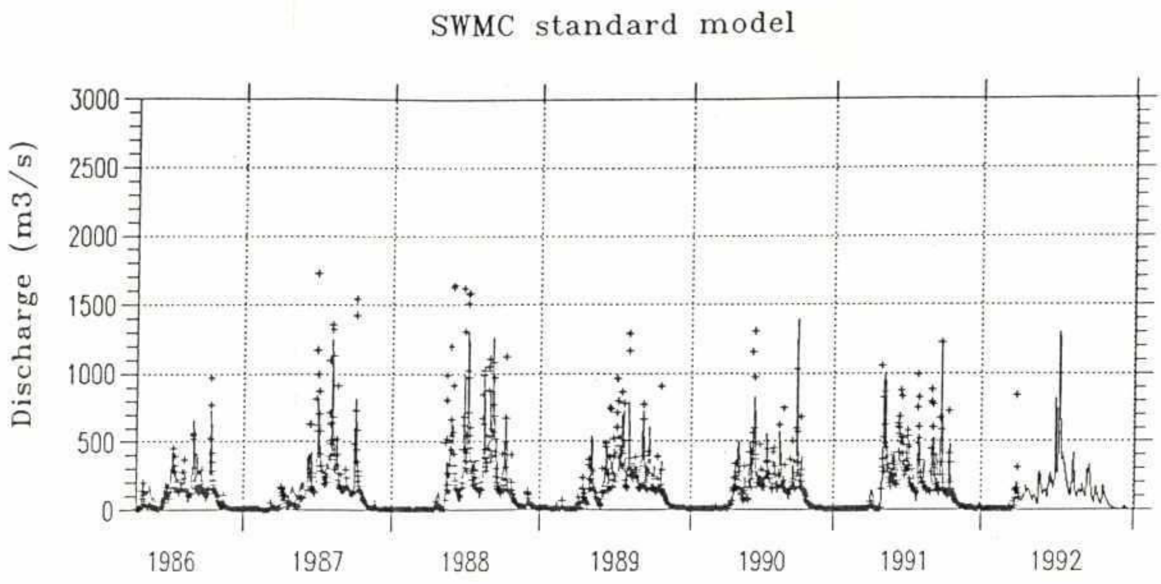
Figure 19

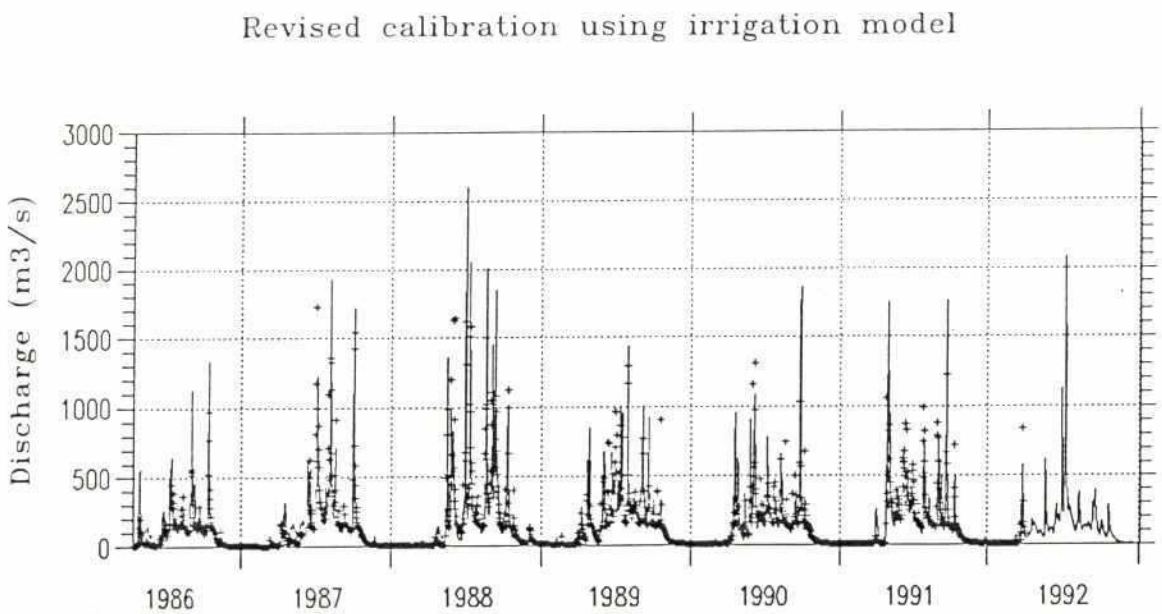


Catchments

Northeast Regional Project

FILE: NAM-MOD1.DWG





LEGEND

++ +++ *Observed*

——— *Calibrated*

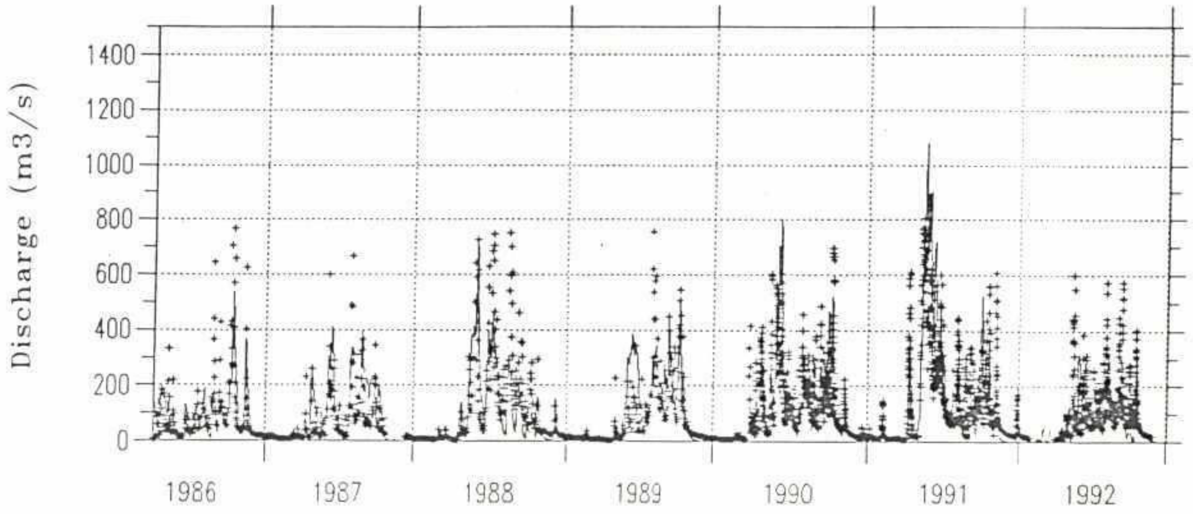
NAM calibration in the Sarigowain catchment

Northeast Regional Project

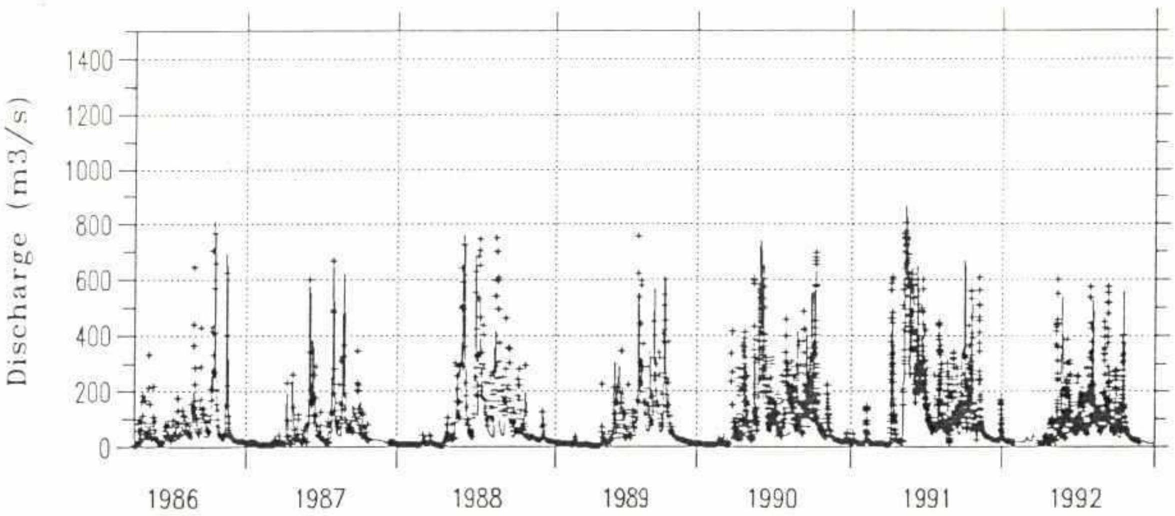
FILE:MODL-310.DWG

Figure 21

SWMC standard model



Revised calibration using irrigation model and flood plain model



LEGEND

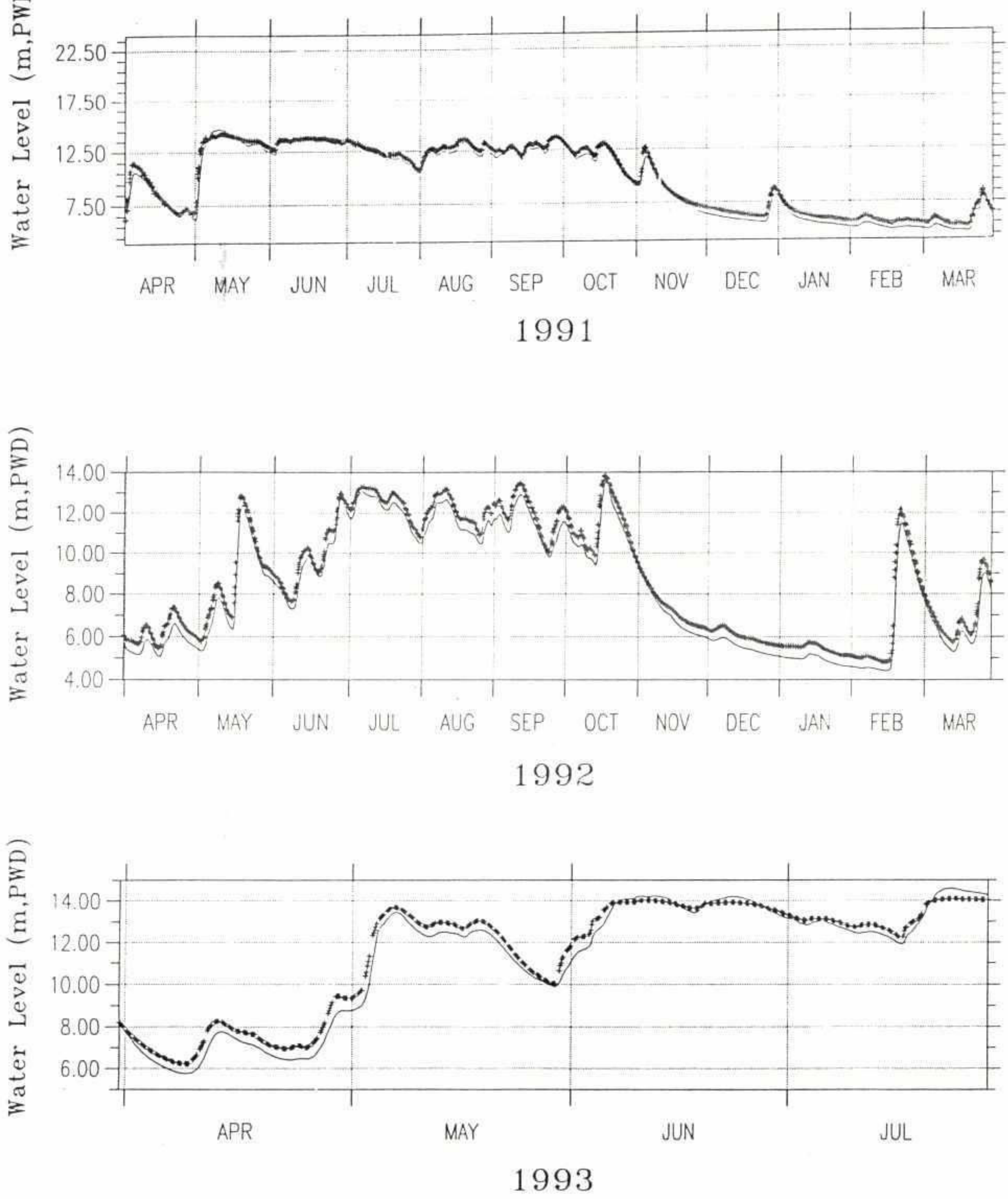
+ + +++ *Observed*

——— *Calibrated*

NAM calibration in the Manu catchment

Northeast Regional Project

FILE: MODL-311.DWG



LEGEND

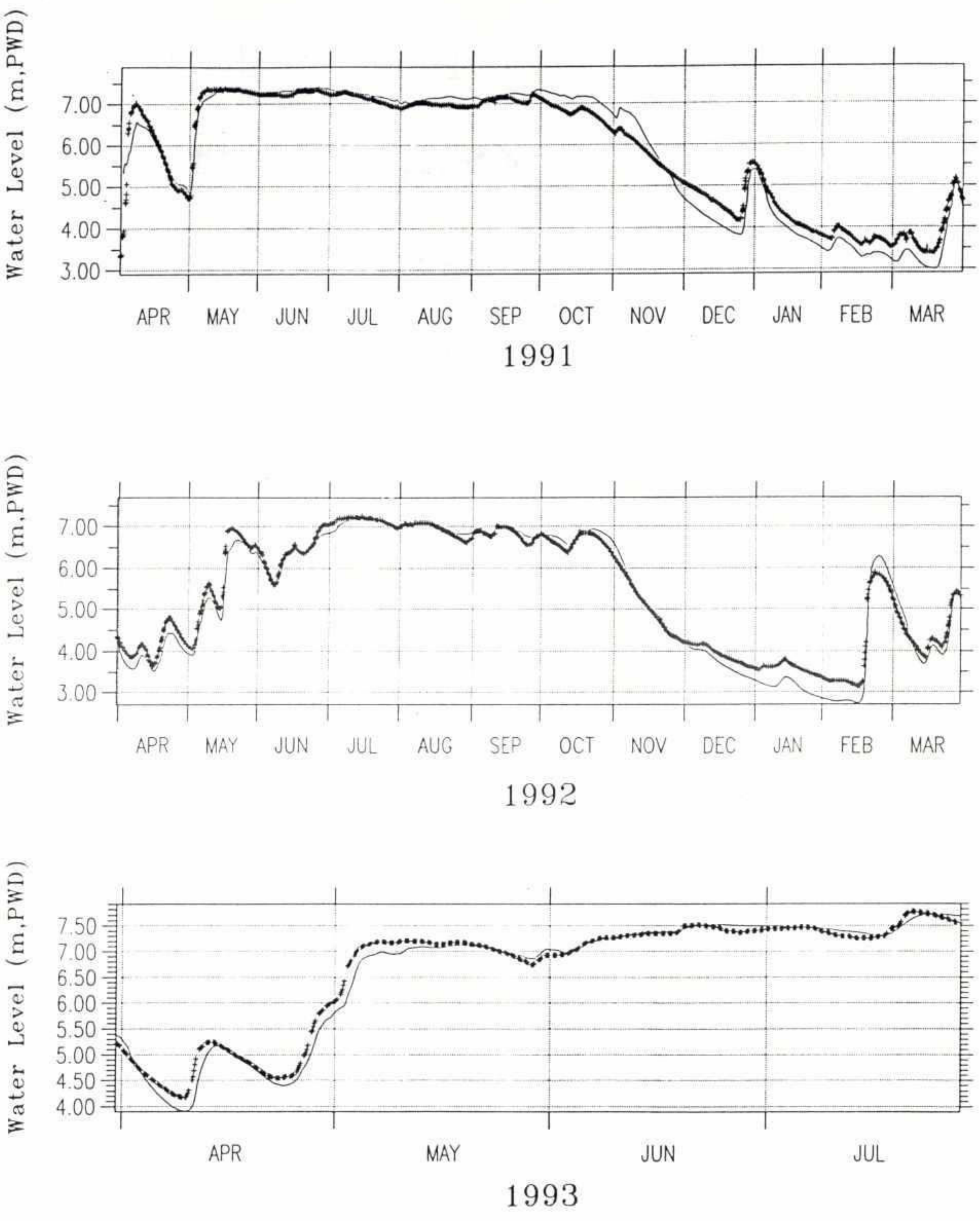
+ + +++ *Observed*

———— *Simulated*

NERP7 Model Calibration
Kushiyara River at Sheola

Northeast Regional Project

FILE:MODL-304.DWG



LEGEND

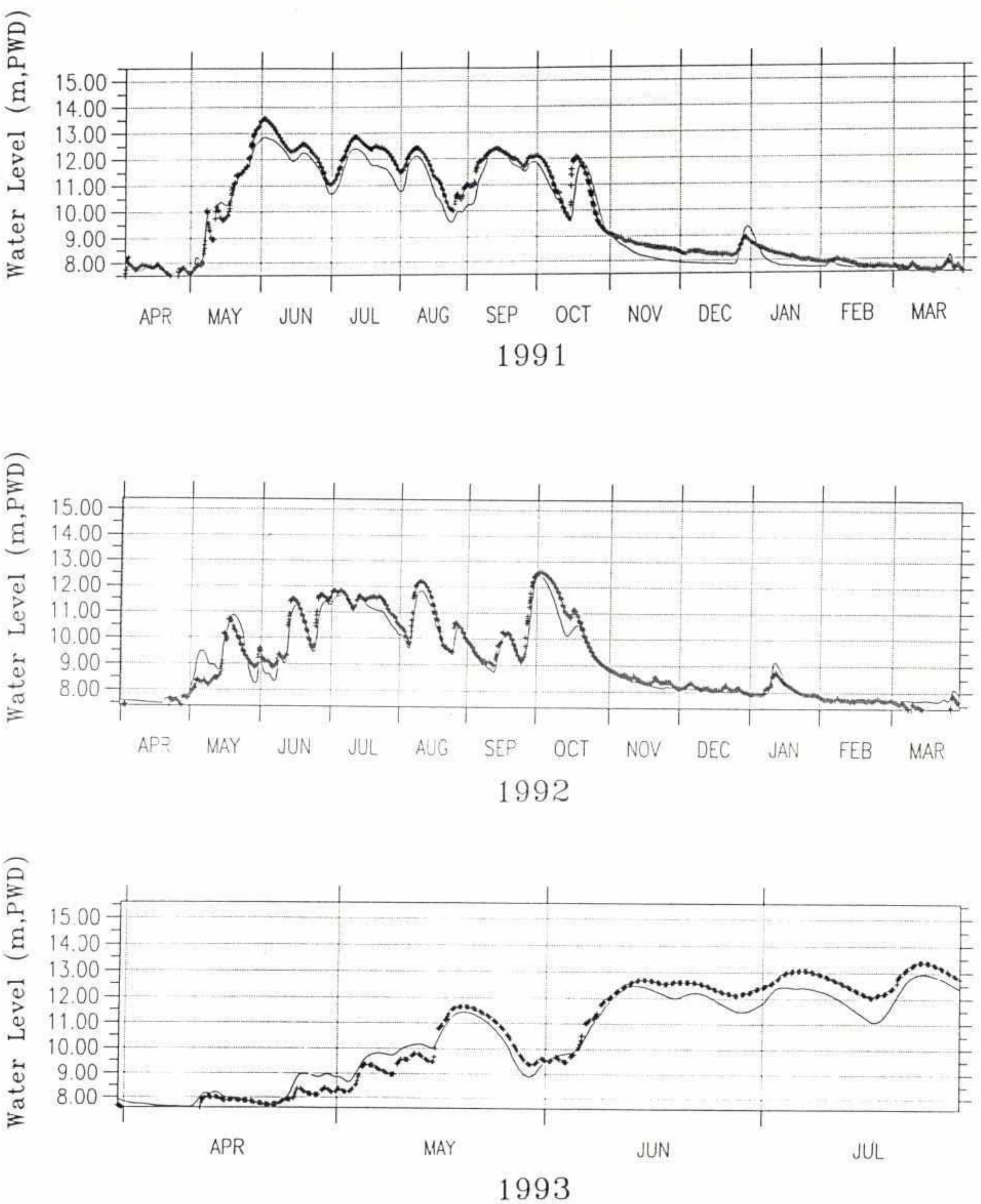
++ +++ *Observed*

——— *Simulated*

NERP7 Model Calibration
Kushiyara River at Markuli

Northeast Regional Project

FILE: MODL-305.DWG



LEGEND

\+ + + + + *Observed*

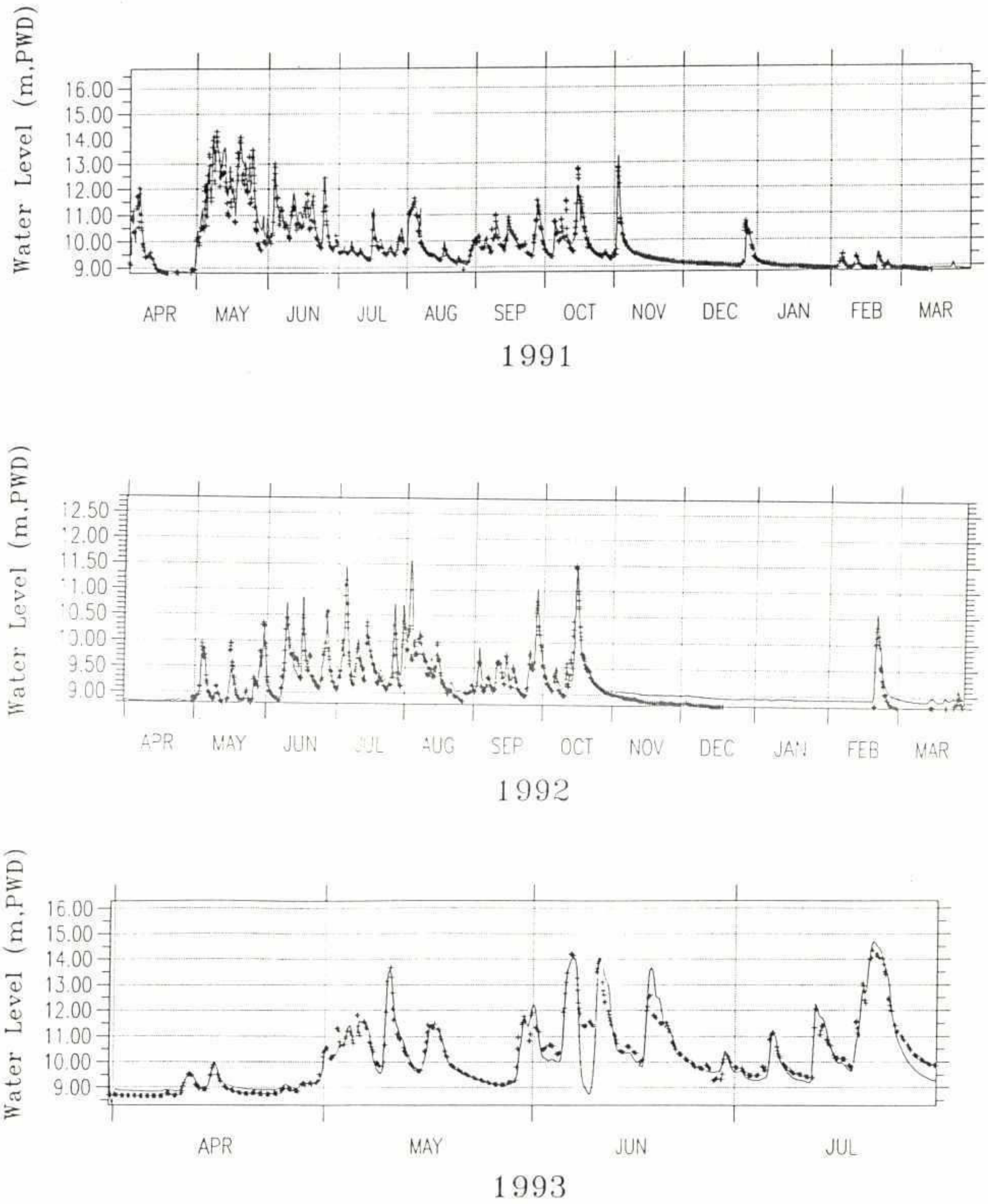
——— *Simulated*

NERP7 Model Calibration
Kangsha River at Sarchapur

Northeast Regional Project

FILE: MODL-307.DWG

Figure 25



LEGEND

+ + +++ *Observed*

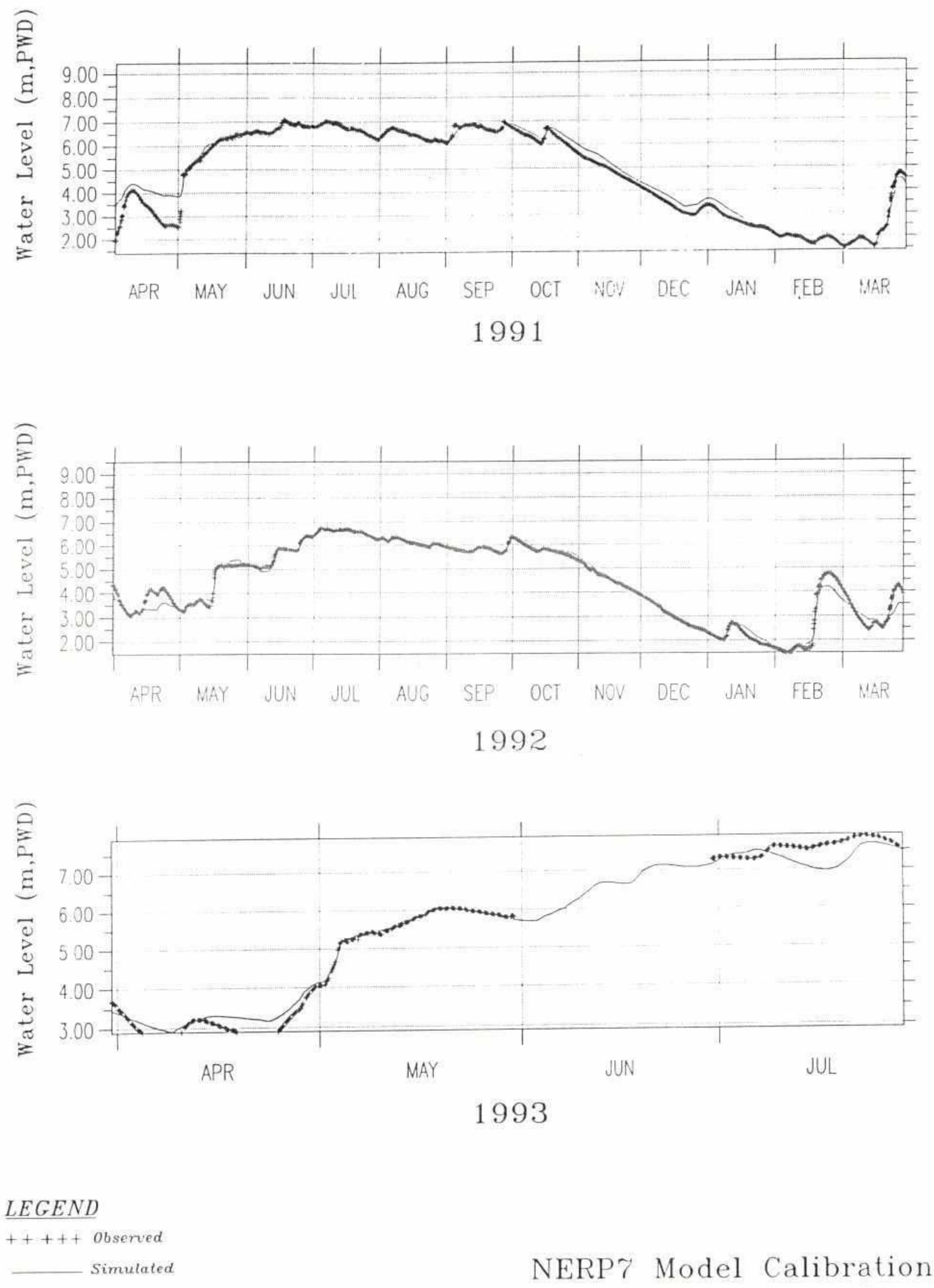
——— *Simulated*

NERP7 Model Calibration
Khowai River at Shaistaganj

Northeast Regional Project

FILE:MODL-308.DWG

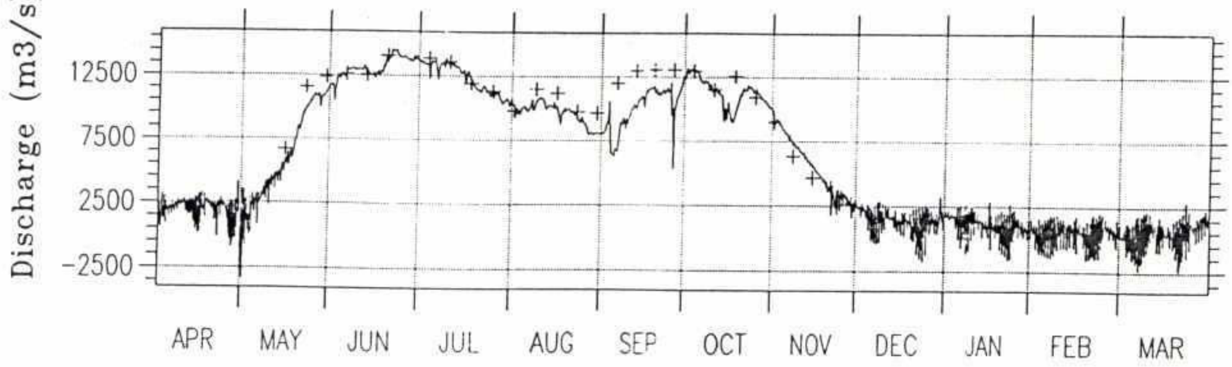
Figure 26



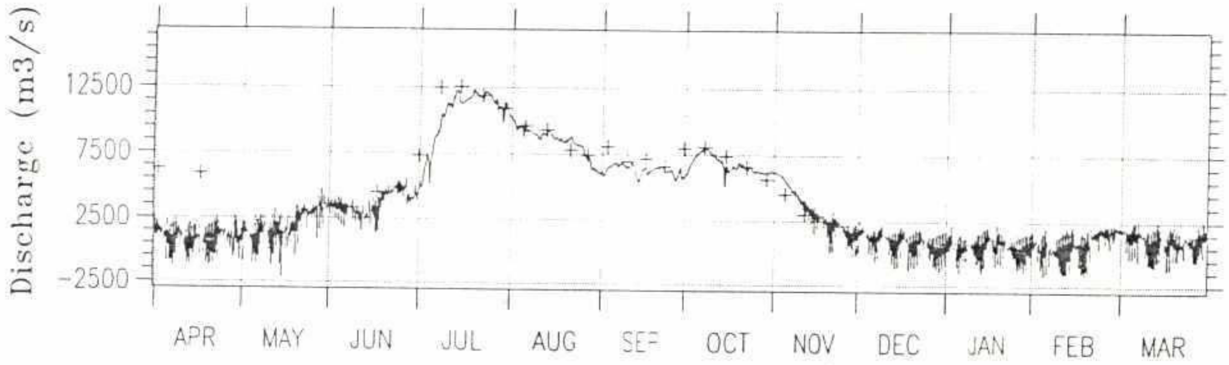
NERP7 Model Calibration
Baulai River at Sukdebpur

Northeast Regional Project

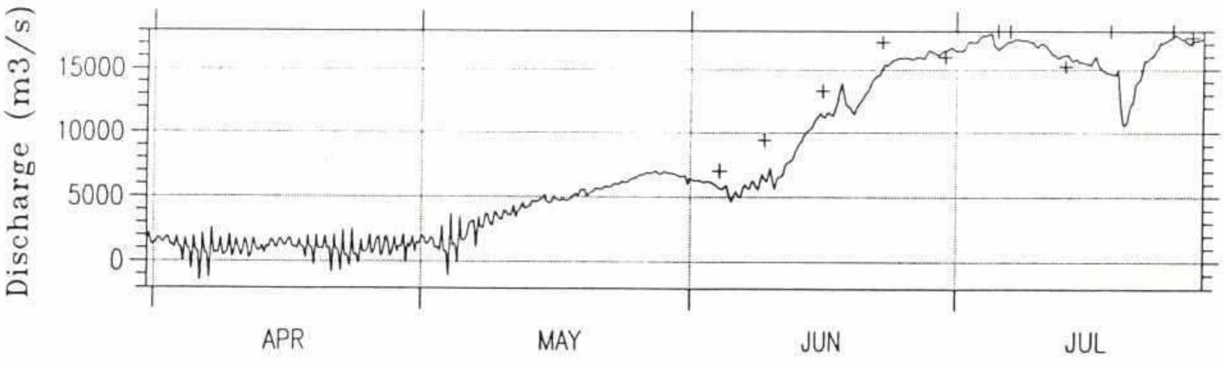
FILE: MODL-306.DWG



1991



1992



1993

LEGEND

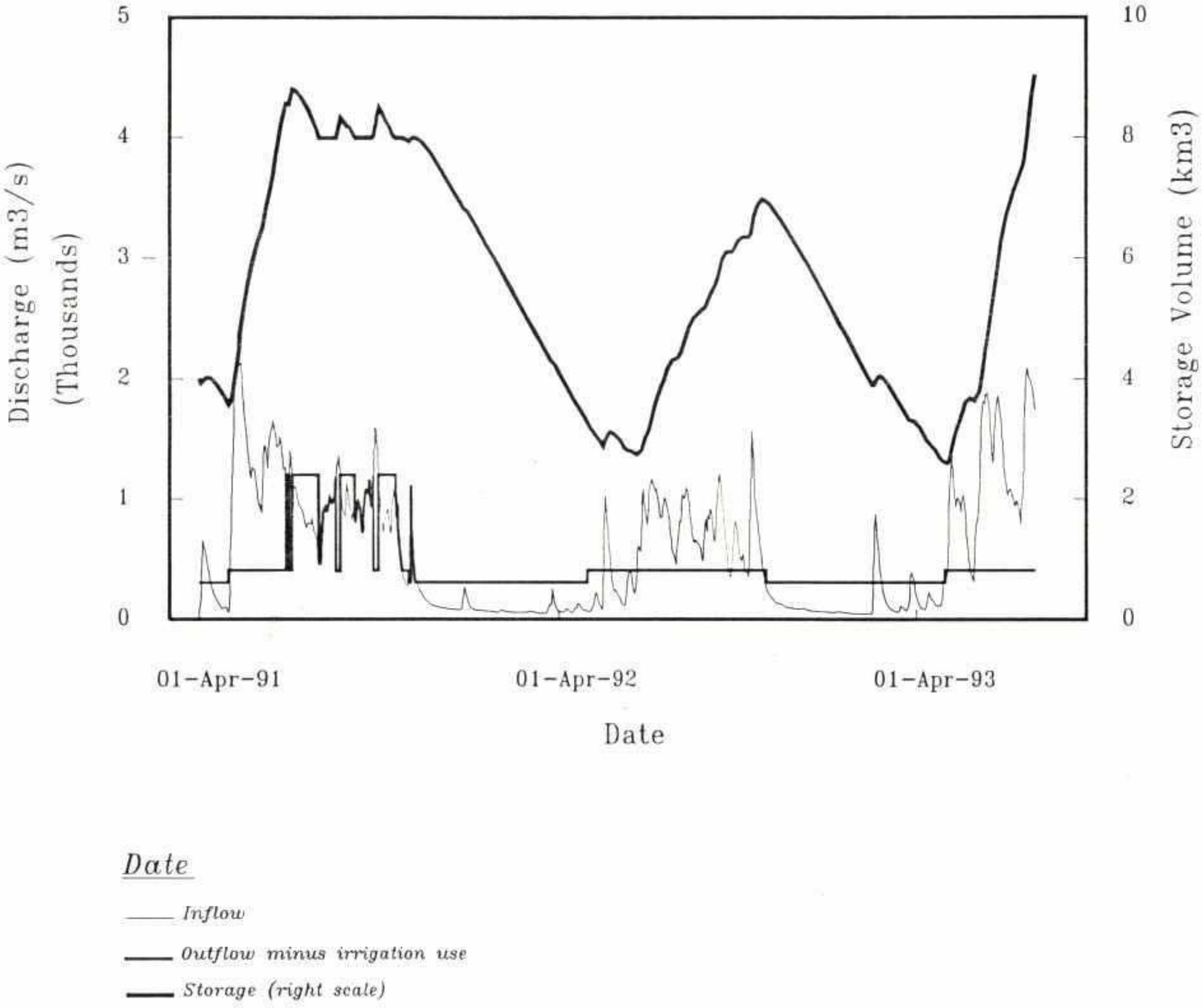
+ + +++ *Observed*

——— *Simulated*

NERP7 Model Calibration
Meghna R. at Bhairab Bazar

Northeast Regional Project

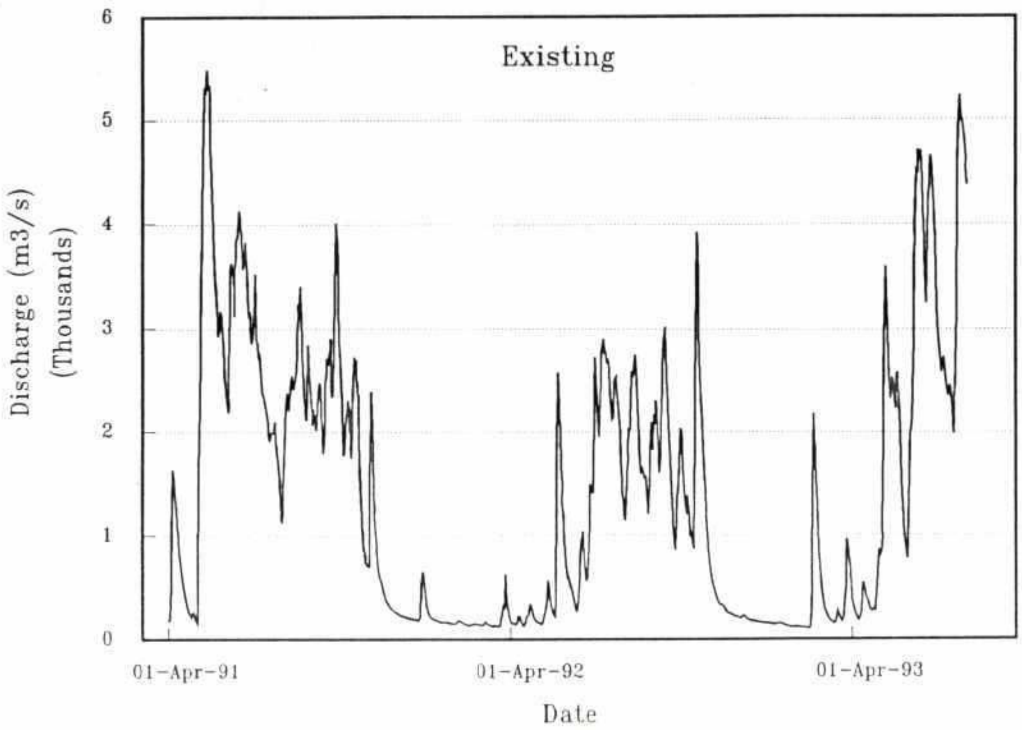
FILE: MODL-309.DWG

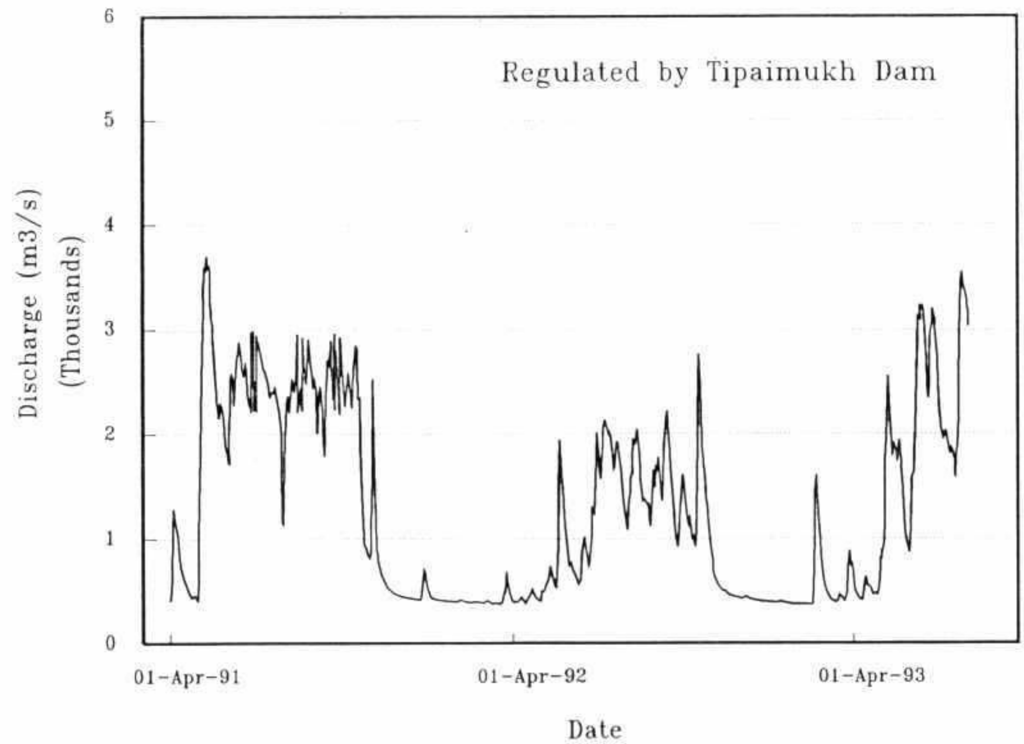


Simulation of Tipaimukh Reservoir operation

Northeast Regional Project

FILE: BARRESOP.DWG



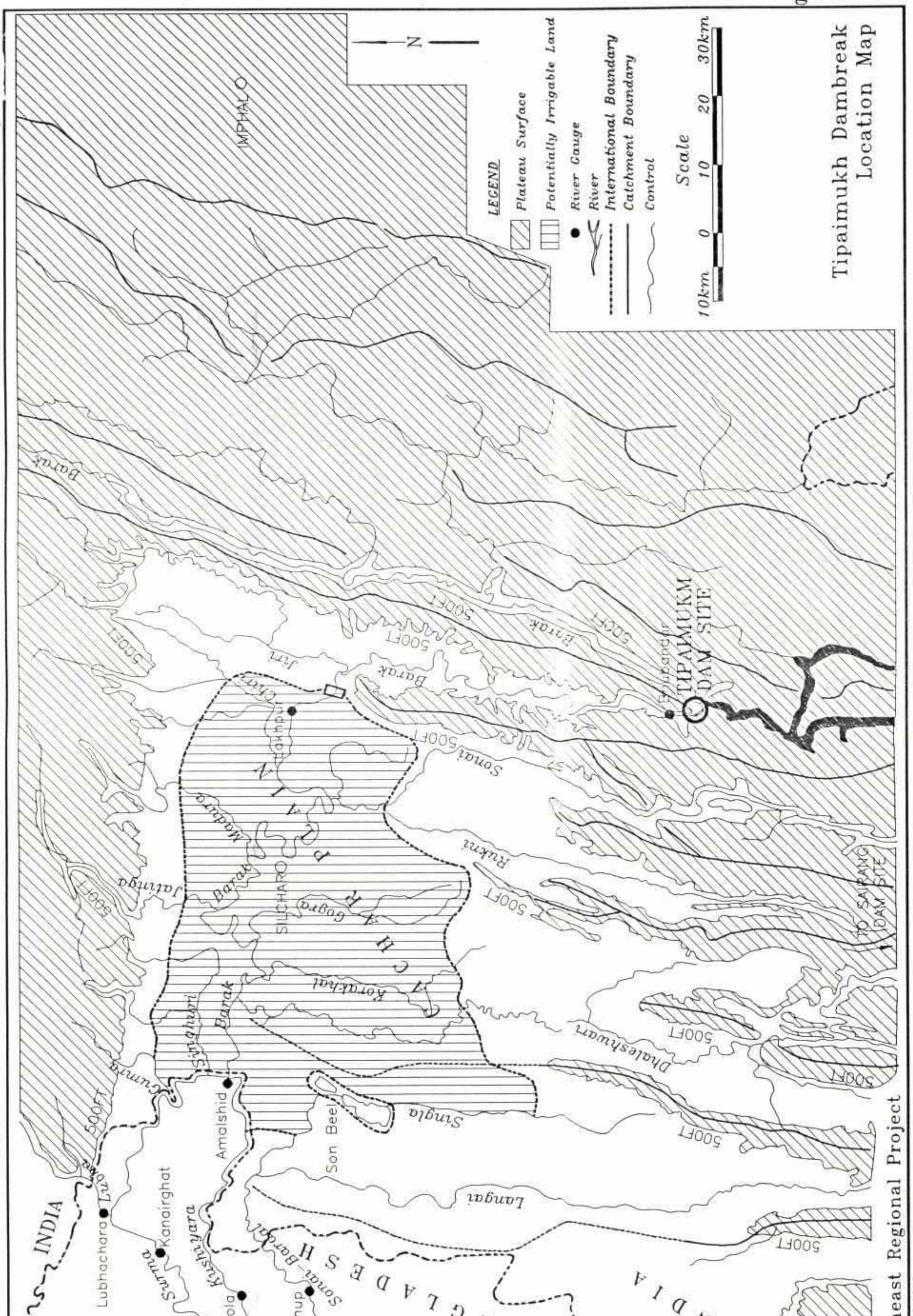


Simulated Discharges in the Barak River at Amalshid

Northeast Regional Project

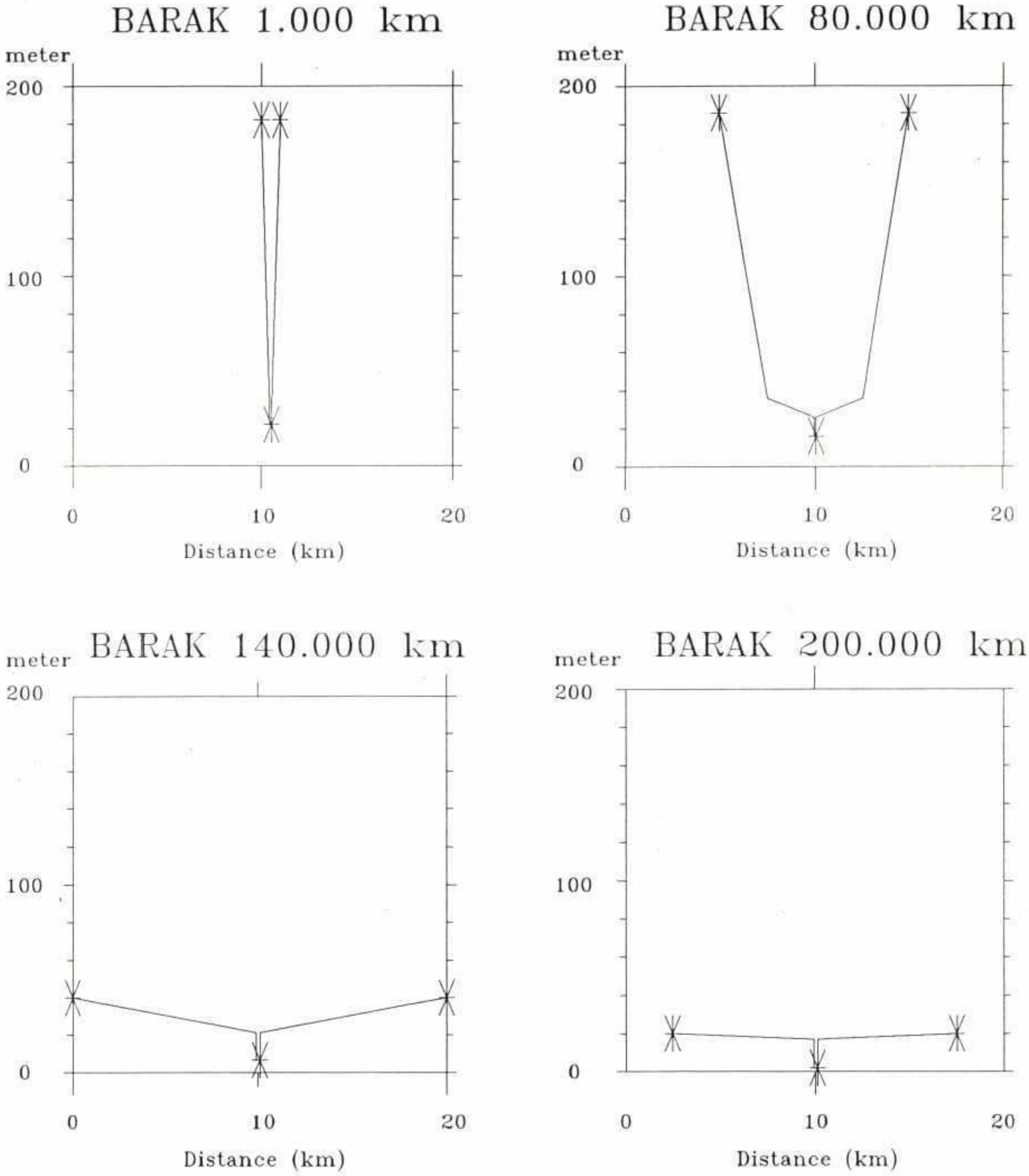
FILE: BARKSIMQ.DWG

Figure 30



Tipaimukh Dambreak Location Map

Figure 31

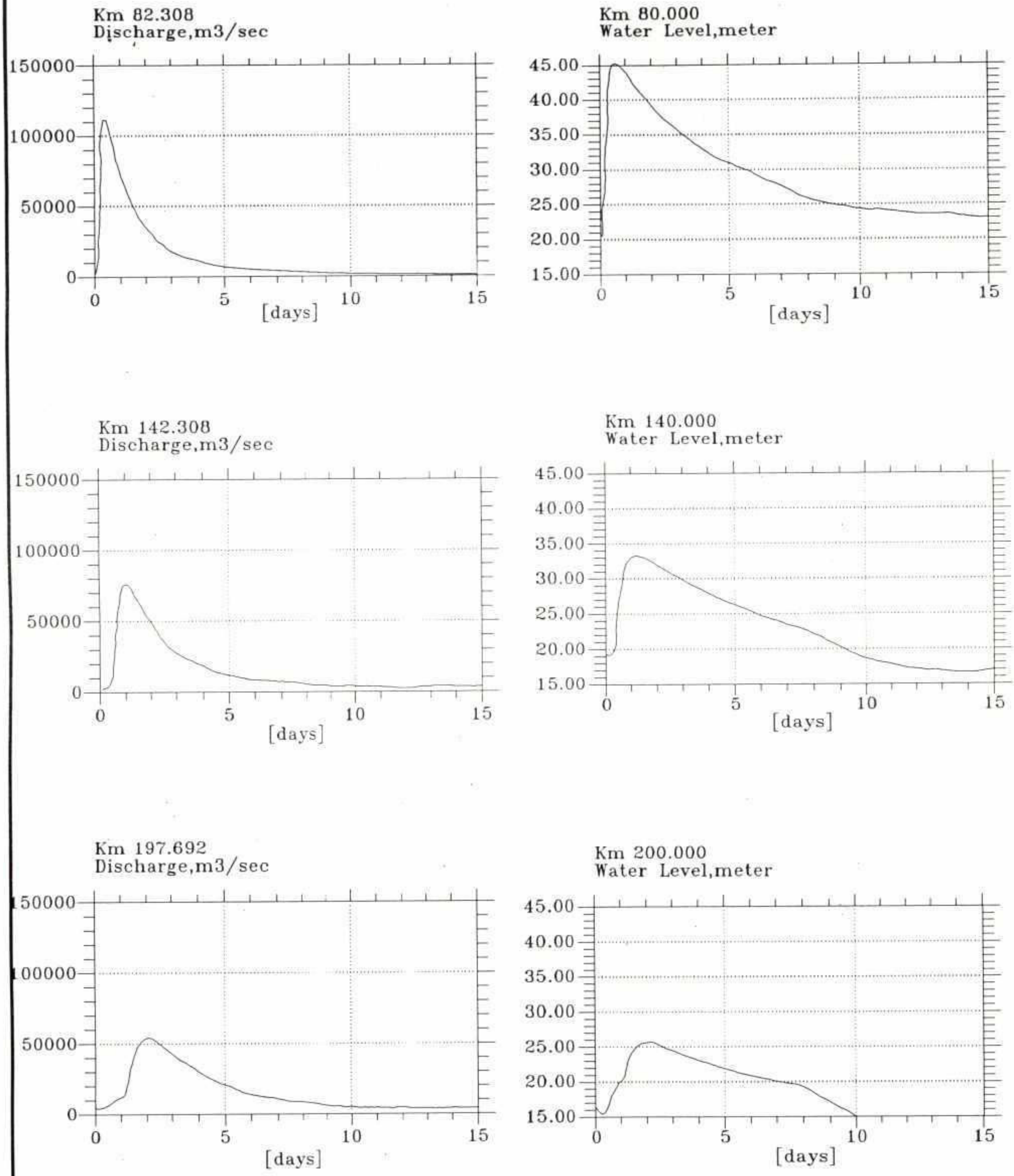


Tipaimukh Dambreak Model
Conceptual Valley Cross-sections

Northeast Regional Project

FILE:MODL-320.DWG

Figure 32



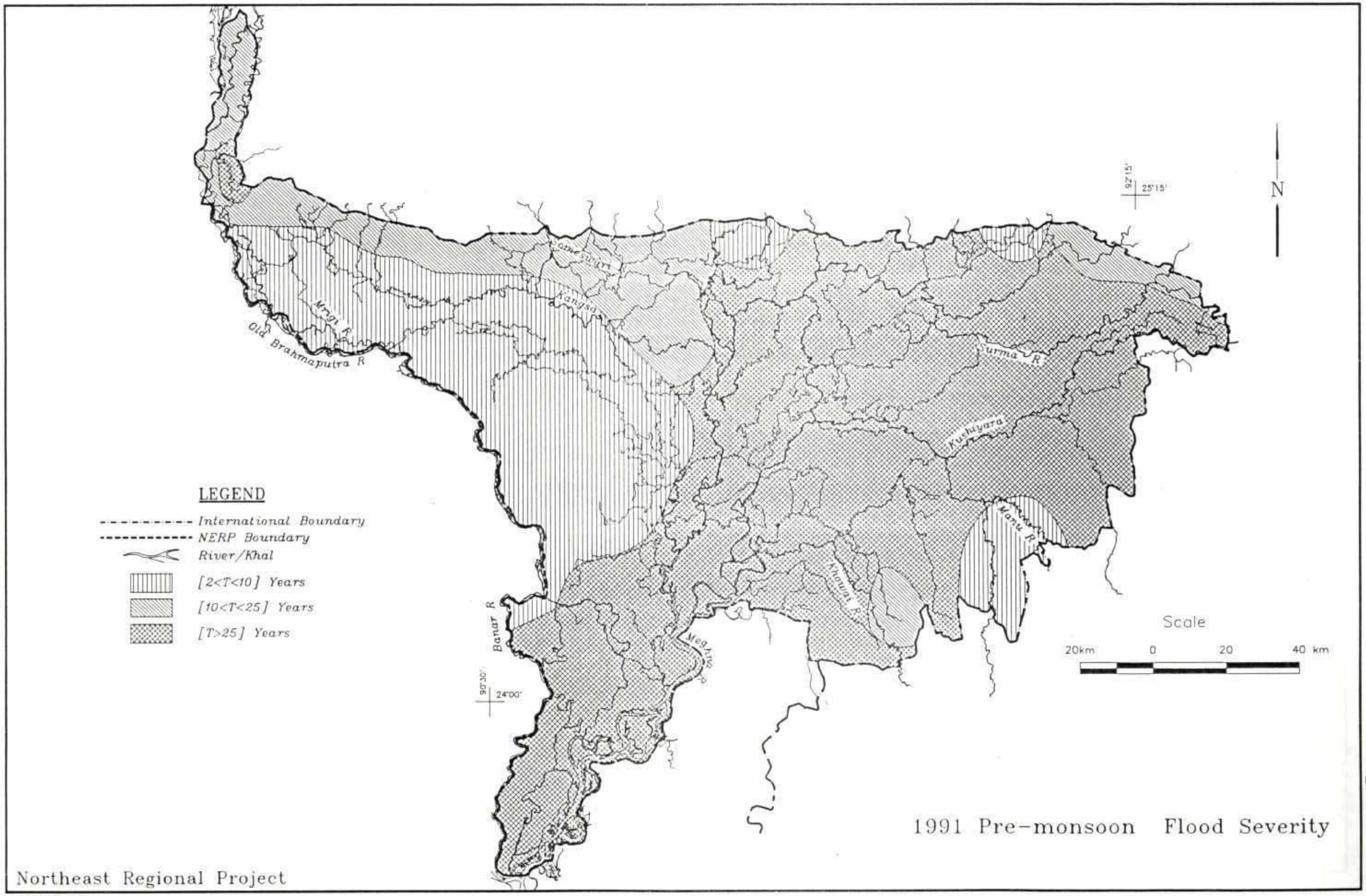
Note: Start date of Simulation is June 15,1991

Dambreak Flood Wave
Upstream of Amalshid

Northeast Regional Project

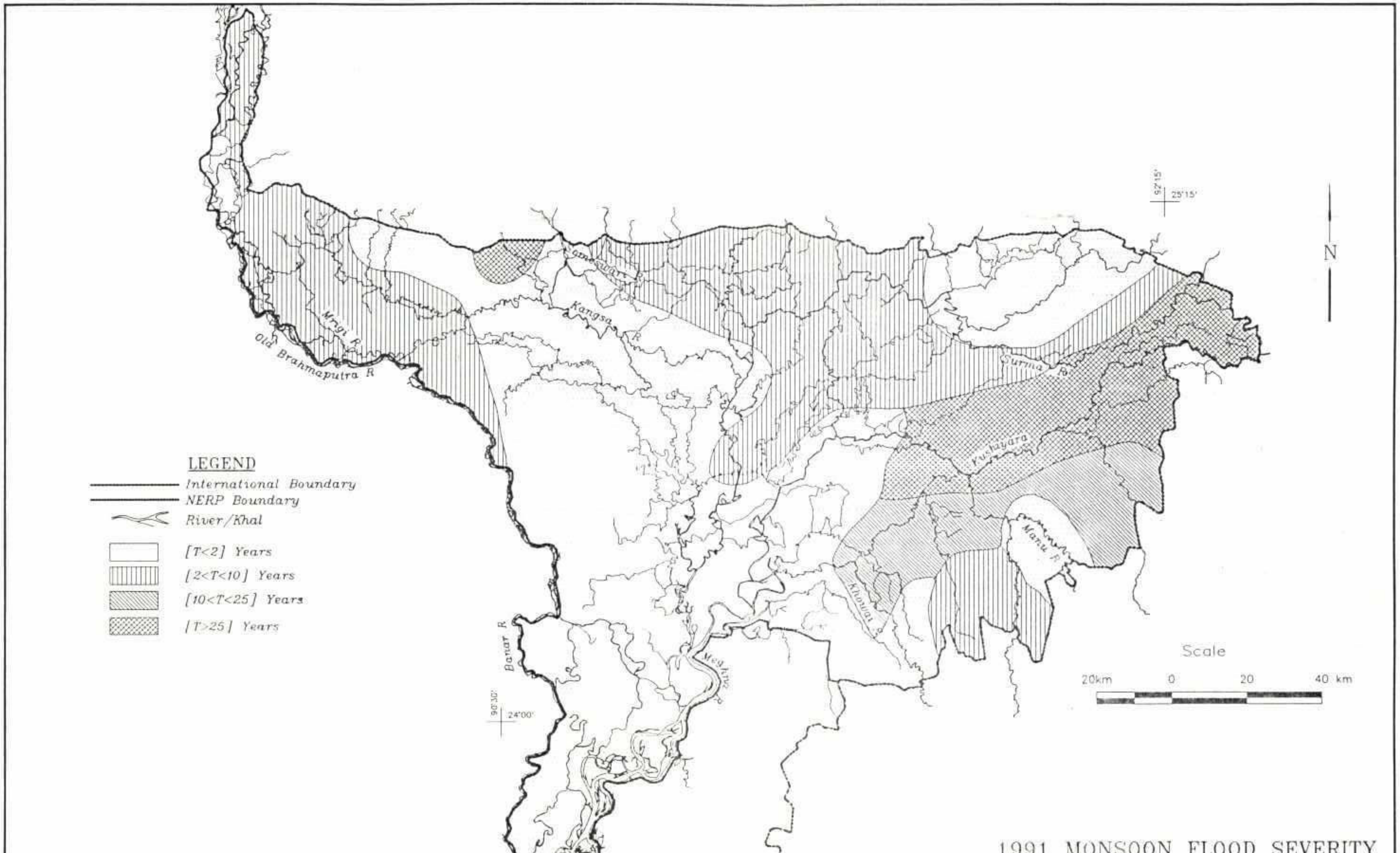
FILE: MODL-321.DWG

Figure 33



1991 Pre-monsoon Flood Severity

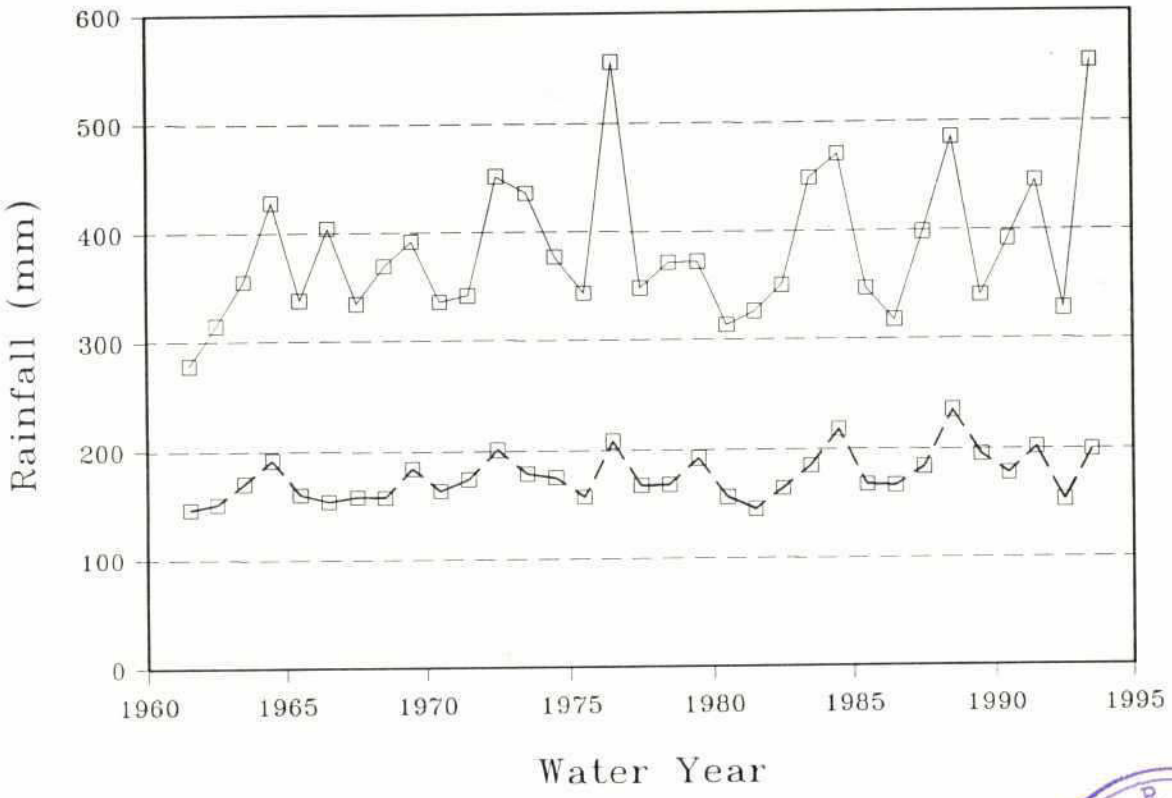
Northeast Regional Project



1991 MONSOON FLOOD SEVERITY

Northeast Regional Project

FILE: MODL-313



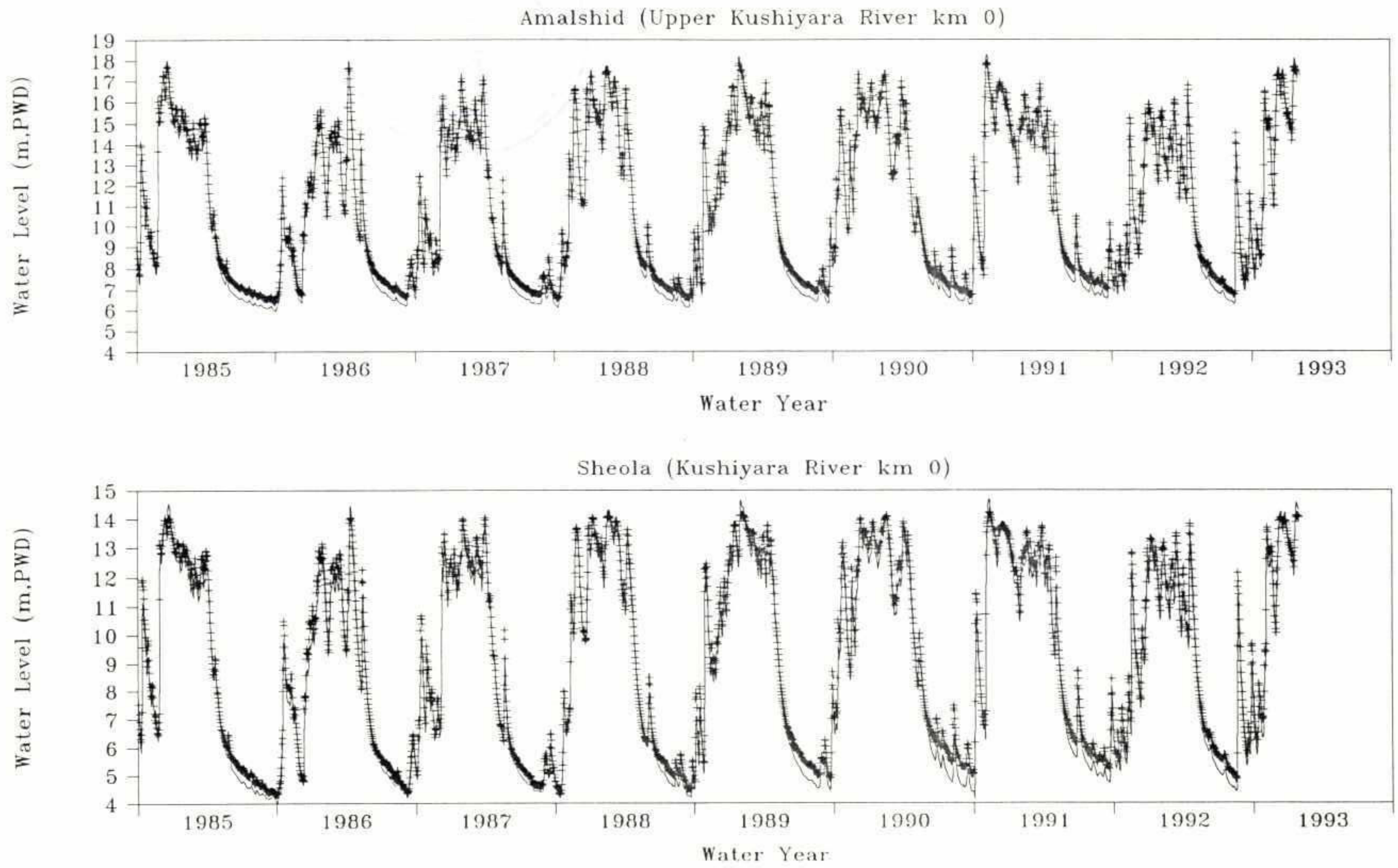
Legend :

Regional Average 5 -day Maximum Rainfall
Regional Average 1 -day Maximum Rainfall

Trends in Short-Duration Rainfall

Northeast Regional Project

FILE: RAIN.DWG



Legend

——— *Simulated (existing conditions)*

++++++ *Recorded (historic conditions)*

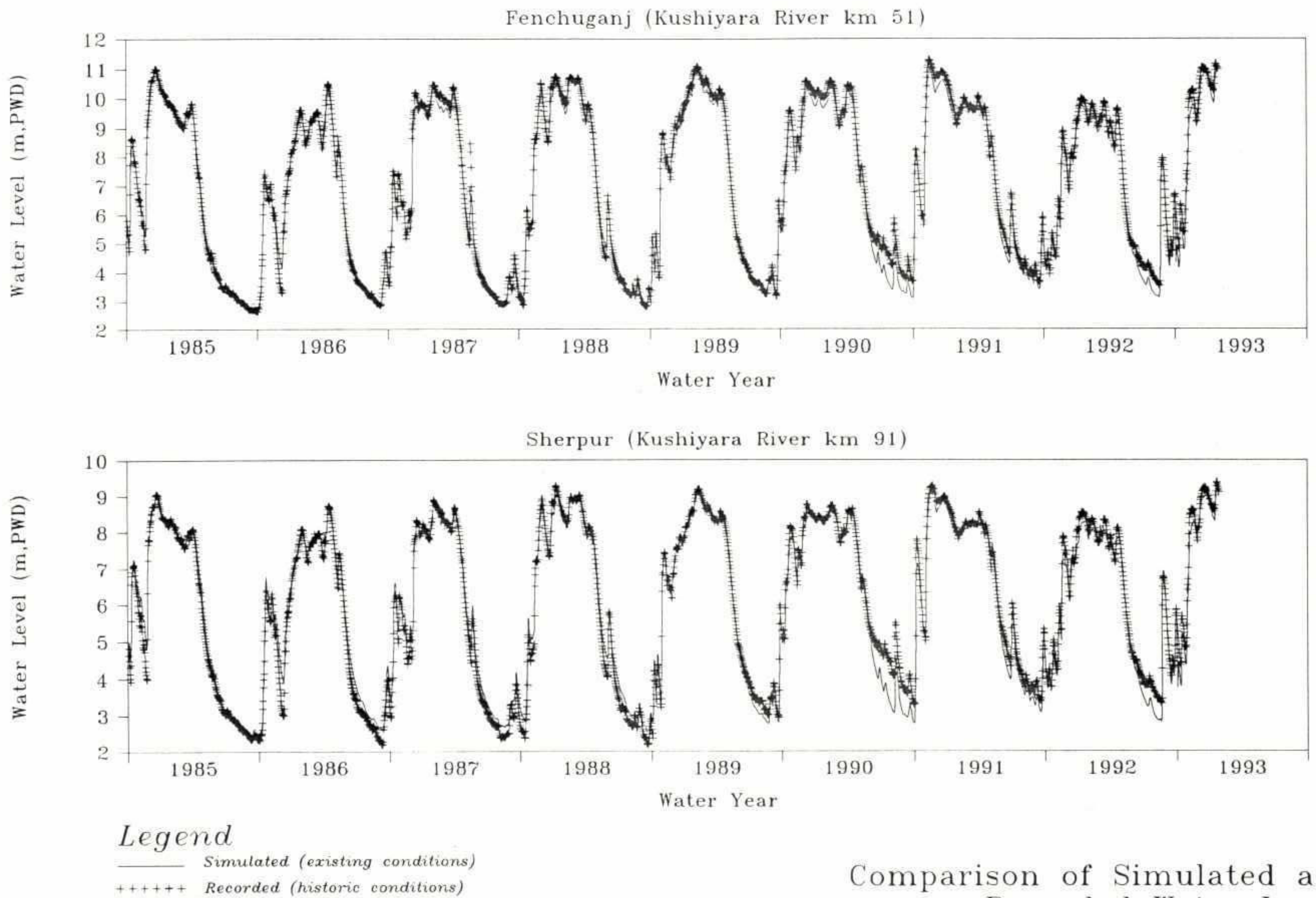
Comparison of Simulated and Recorded Water Levels

Figure 36

Northeast Regional Project

FILE:MODL-701.DWG

Figure 37

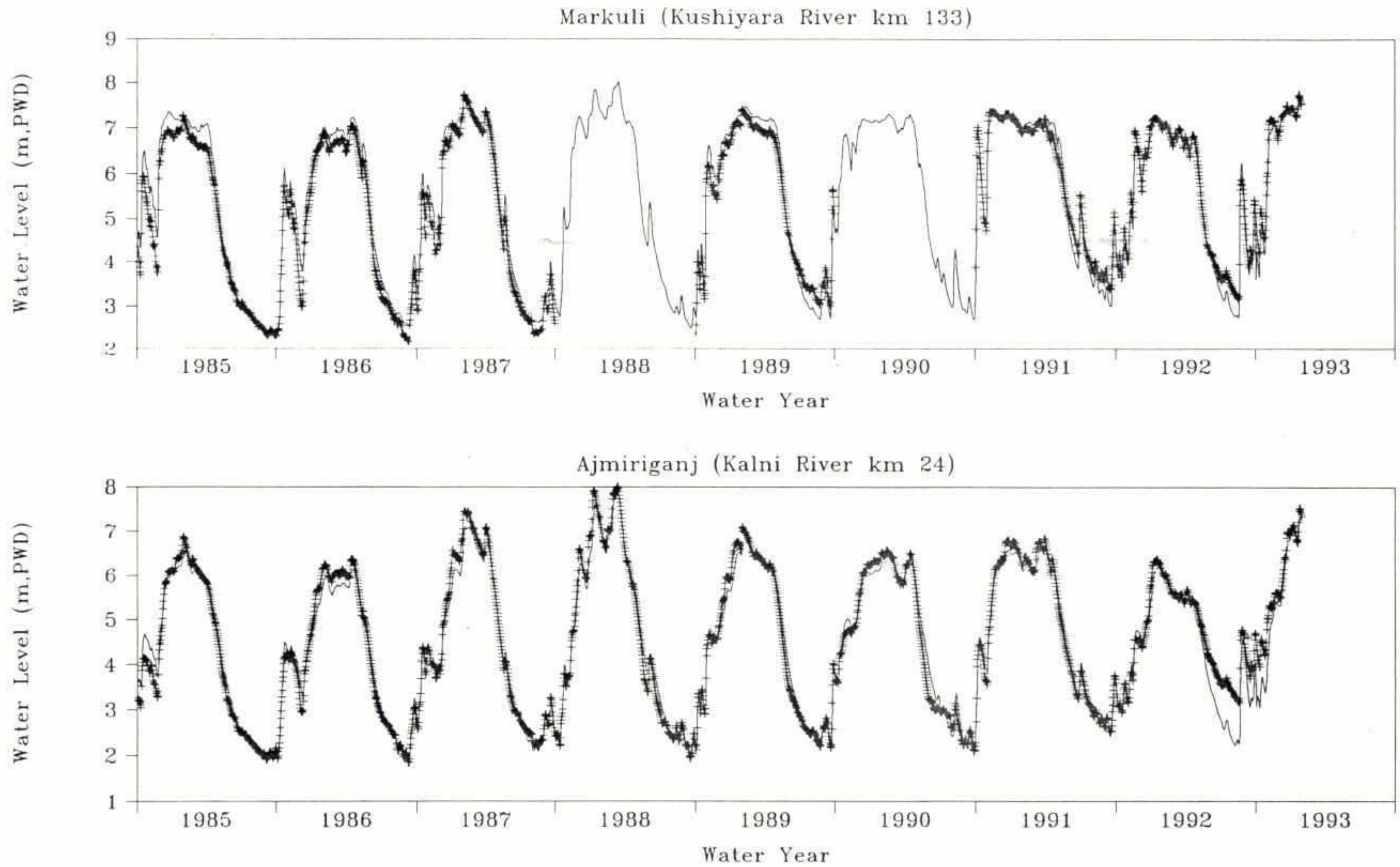


Comparison of Simulated and Recorded Water Levels

Northeast Regional Project

FILE:MODL-702.DWG

Figure 38



Legend

——— *Simulated (existing conditions)*

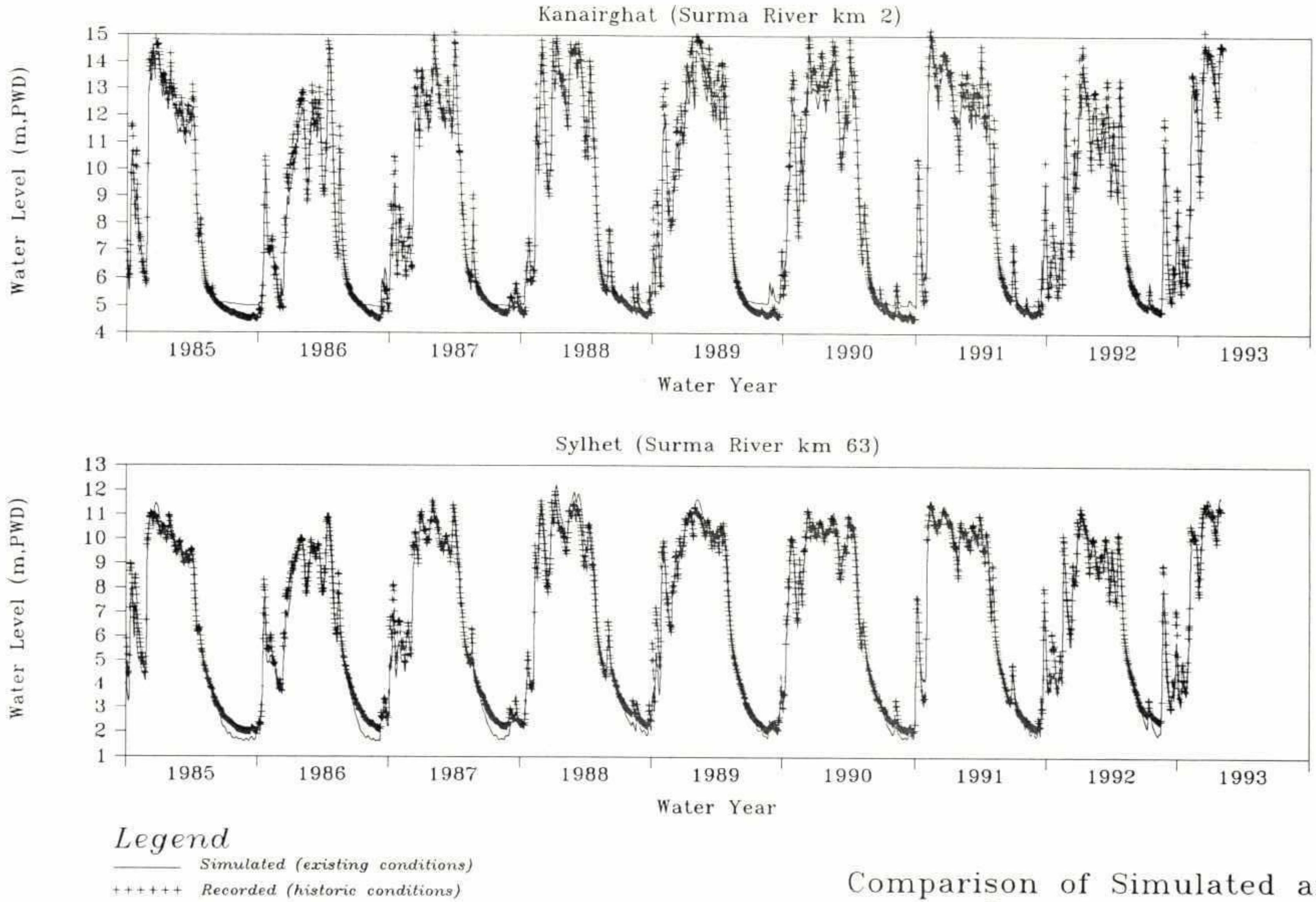
++++++ *Recorded (historic conditions)*

Comparison of Simulated and Recorded Water Levels

Northeast Regional Project

FILE:MODL-703.DWG

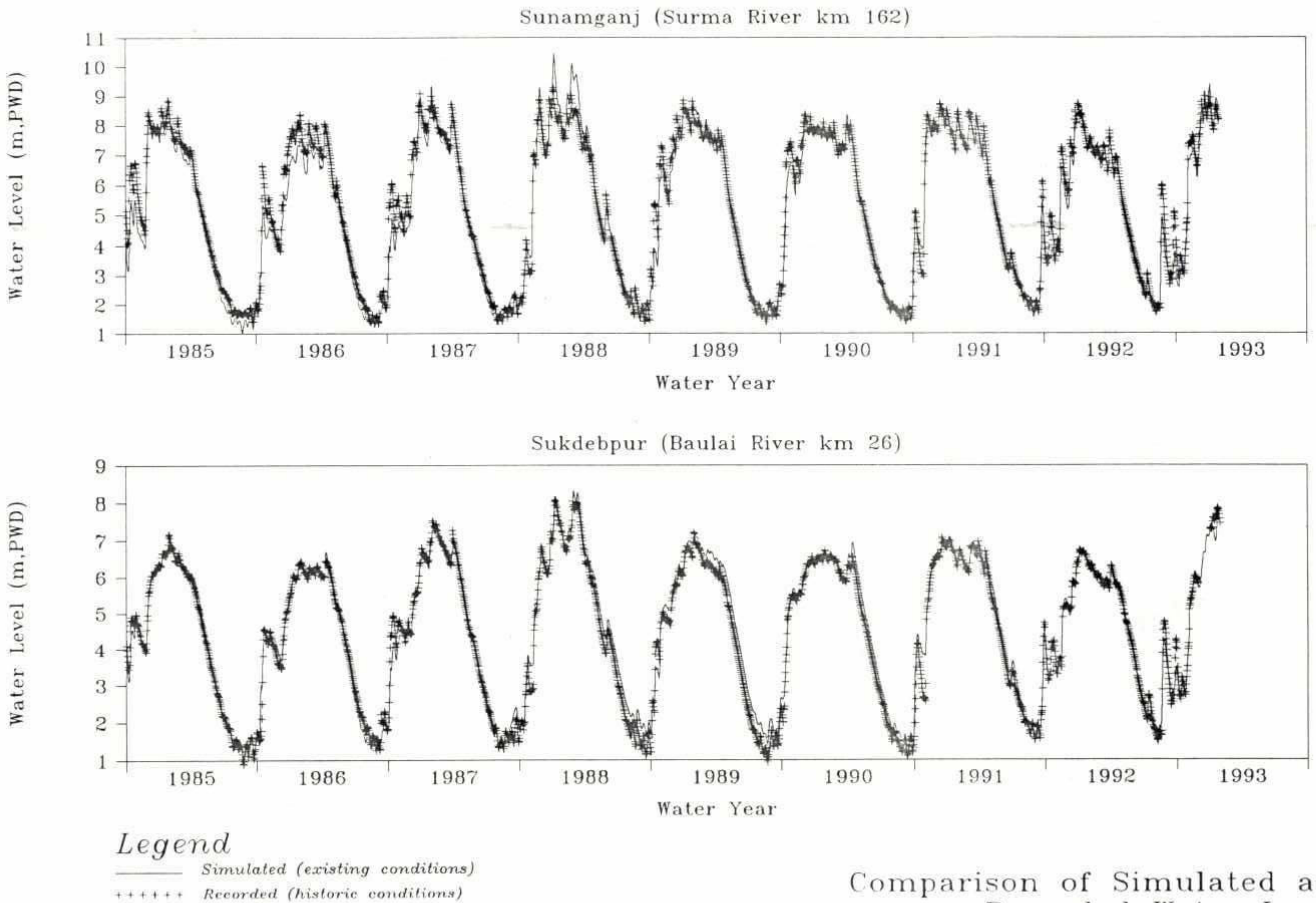
Figure 39



Comparison of Simulated and Recorded Water Levels

Northeast Regional Project

FILE:MODL-704.DWG

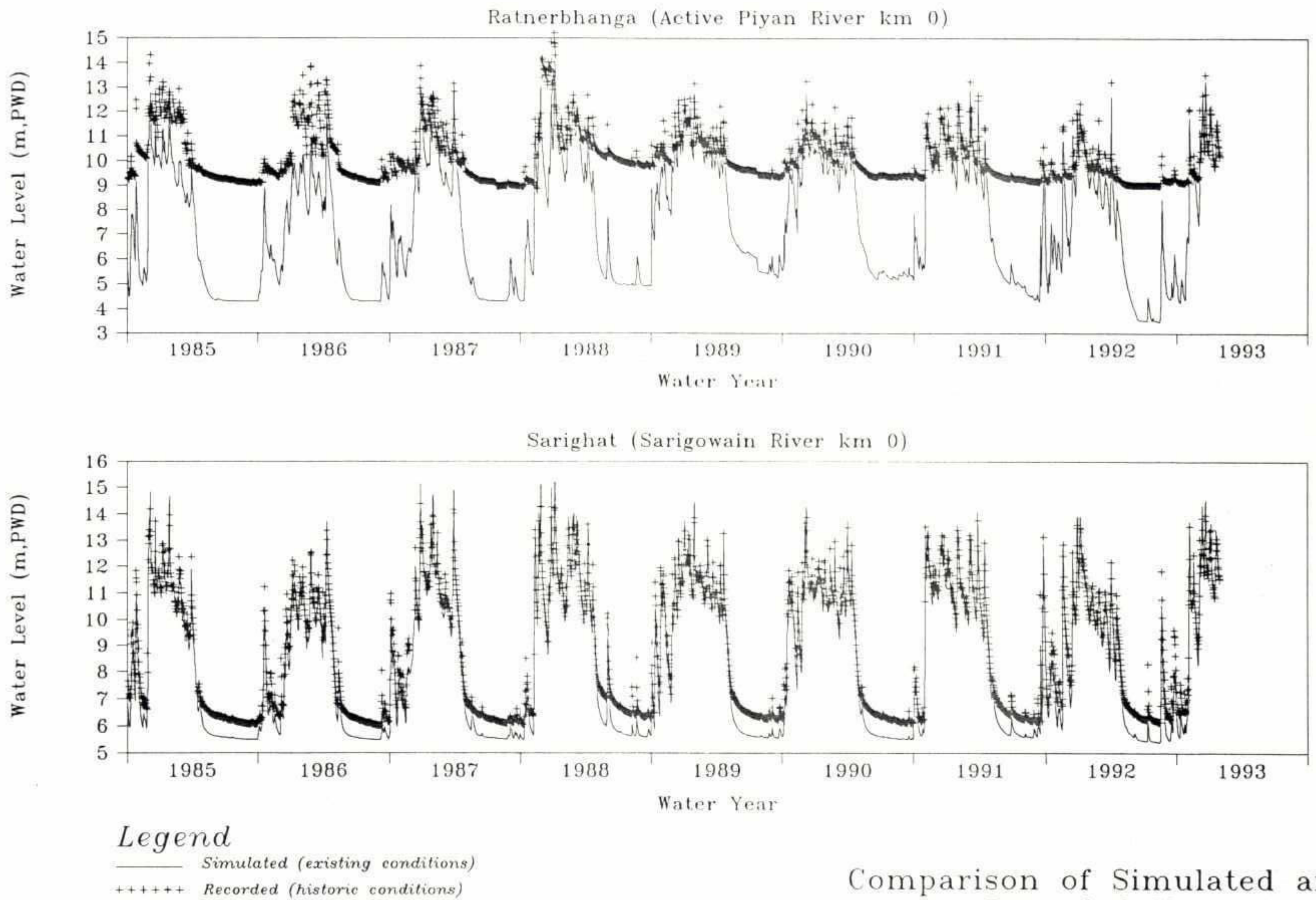


Comparison of Simulated and Recorded Water Levels

Northeast Regional Project

FILE:MODL-705.DWG

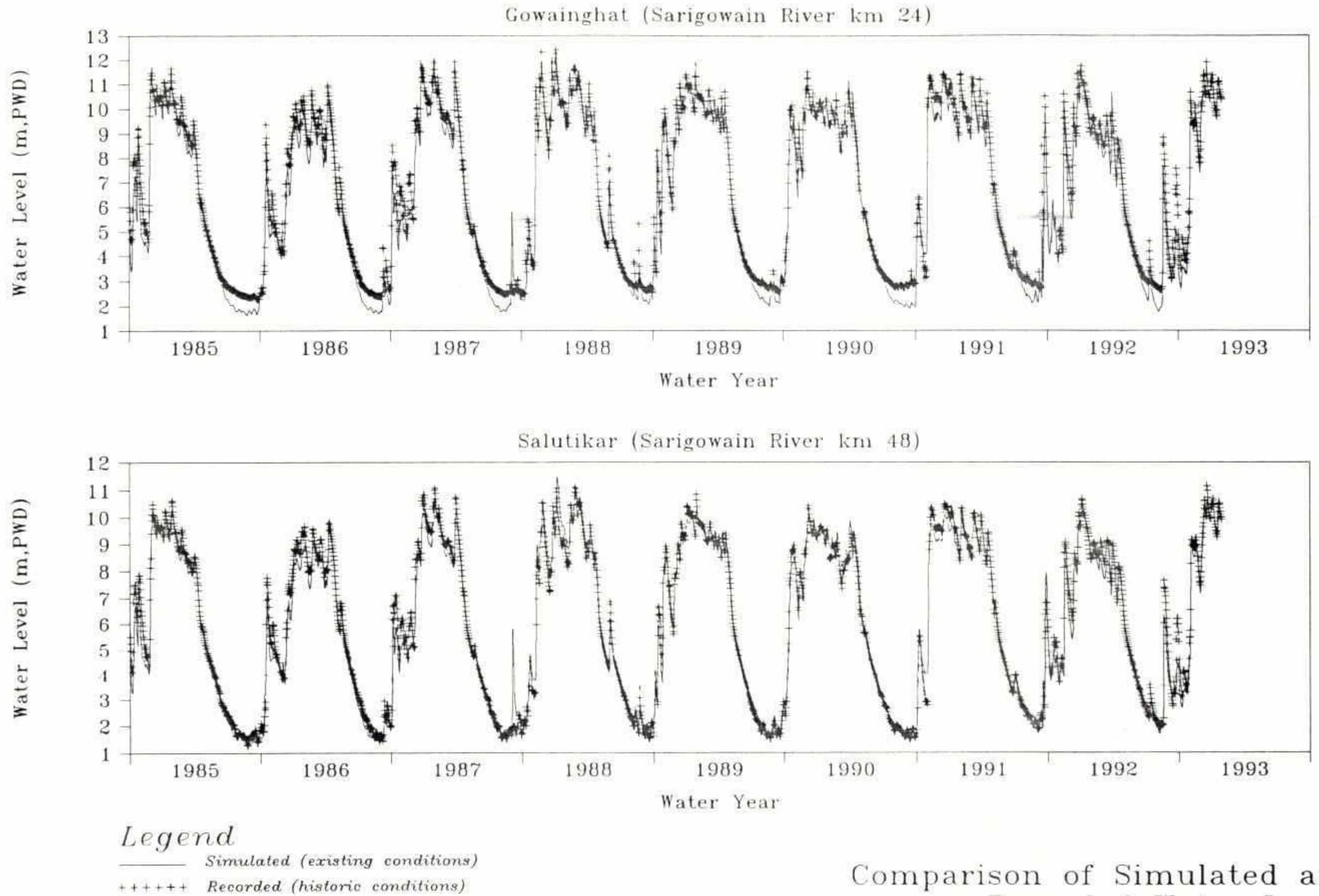
Figure 41



Comparison of Simulated and Recorded Water Levels

Northeast Regional Project

FILE:MODL-712.DWG

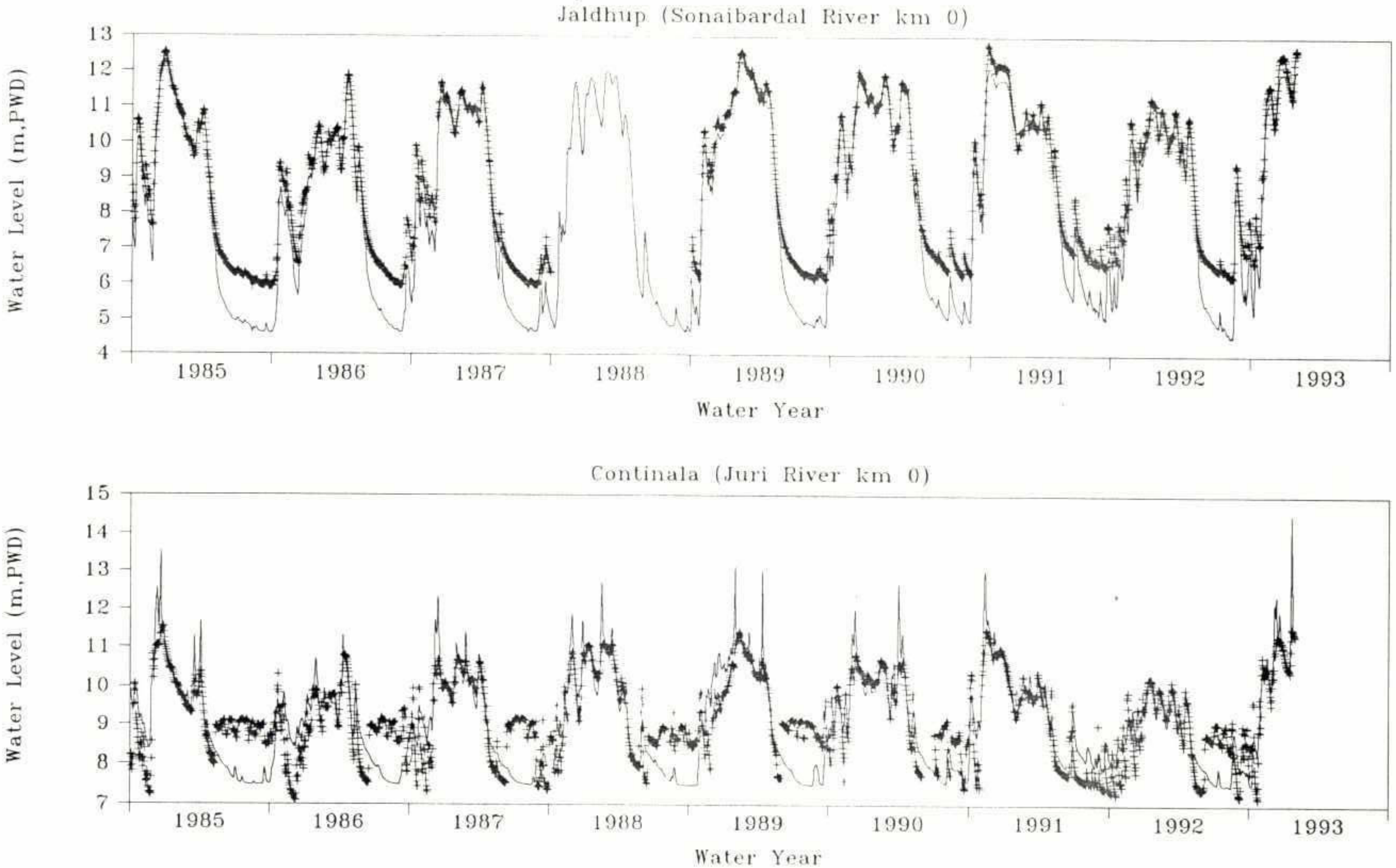


Comparison of Simulated and Recorded Water Levels

Figure 42

Northeast Regional Project

FILE:MODL-713.DWG



Legend

——— *Simulated (existing conditions)*

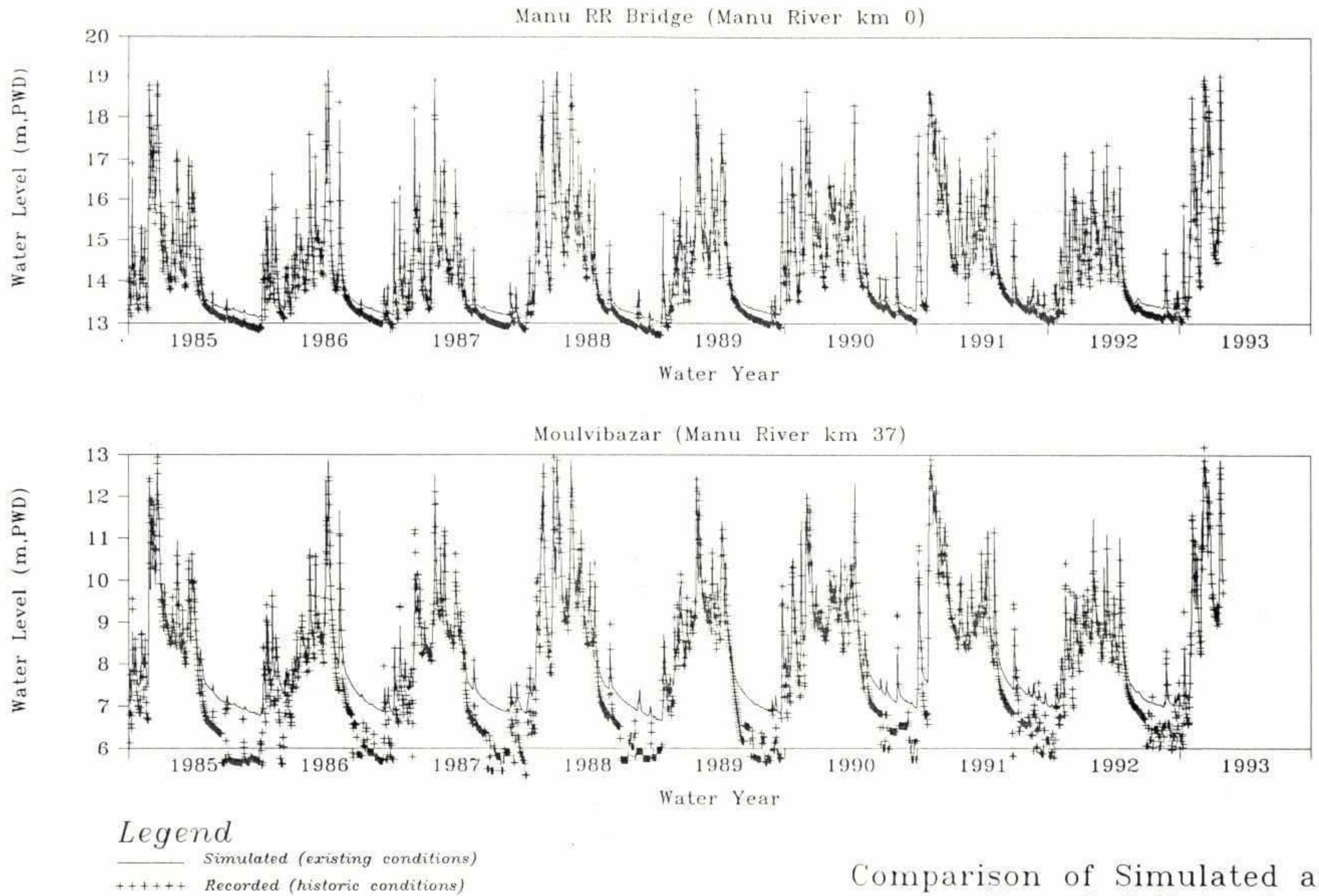
++++++ *Recorded (historic conditions)*

Comparison of Simulated and Recorded Water Levels

Northeast Regional Project

FILE:MODL-706.DWG

Figure 44

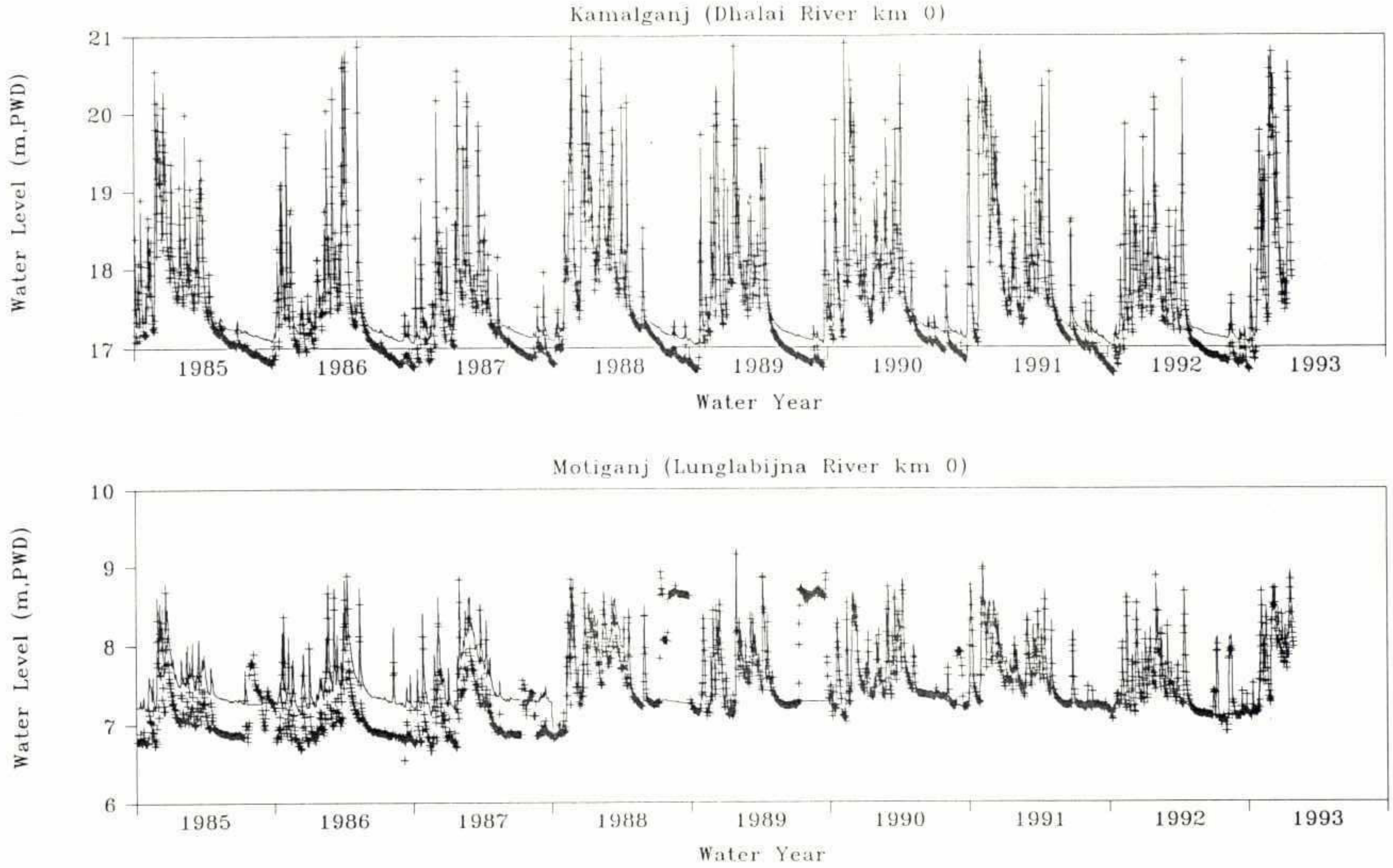


Comparison of Simulated and Recorded Water Levels

Northeast Regional Project

FILE:MODL-707

Figure 45



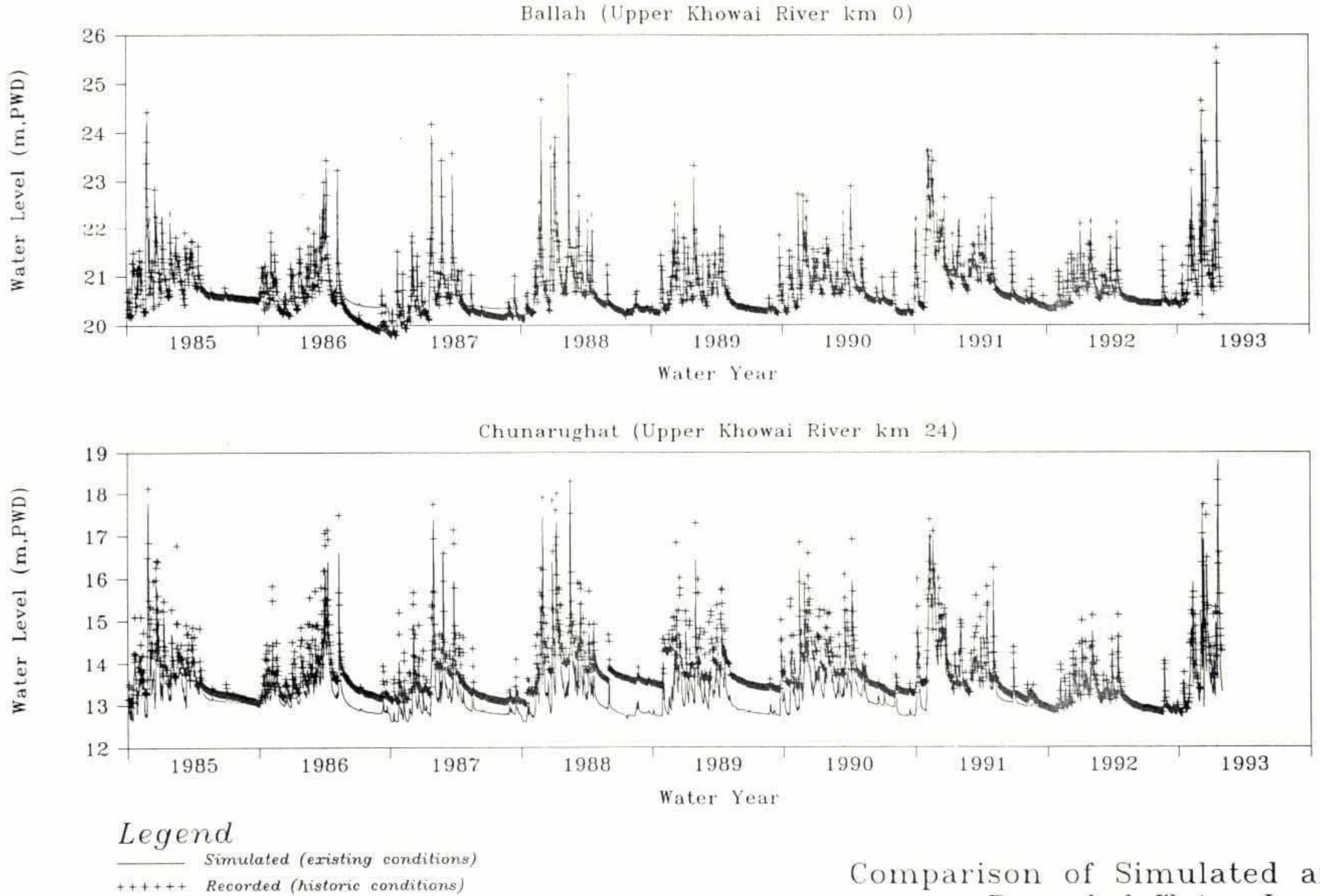
Legend
——— *Simulated (existing conditions)*
++++++ *Recorded (historic conditions)*

Comparison of Simulated and Recorded Water Levels

Northeast Regional Project

FILE:MODL-708.DWG

Figure 46

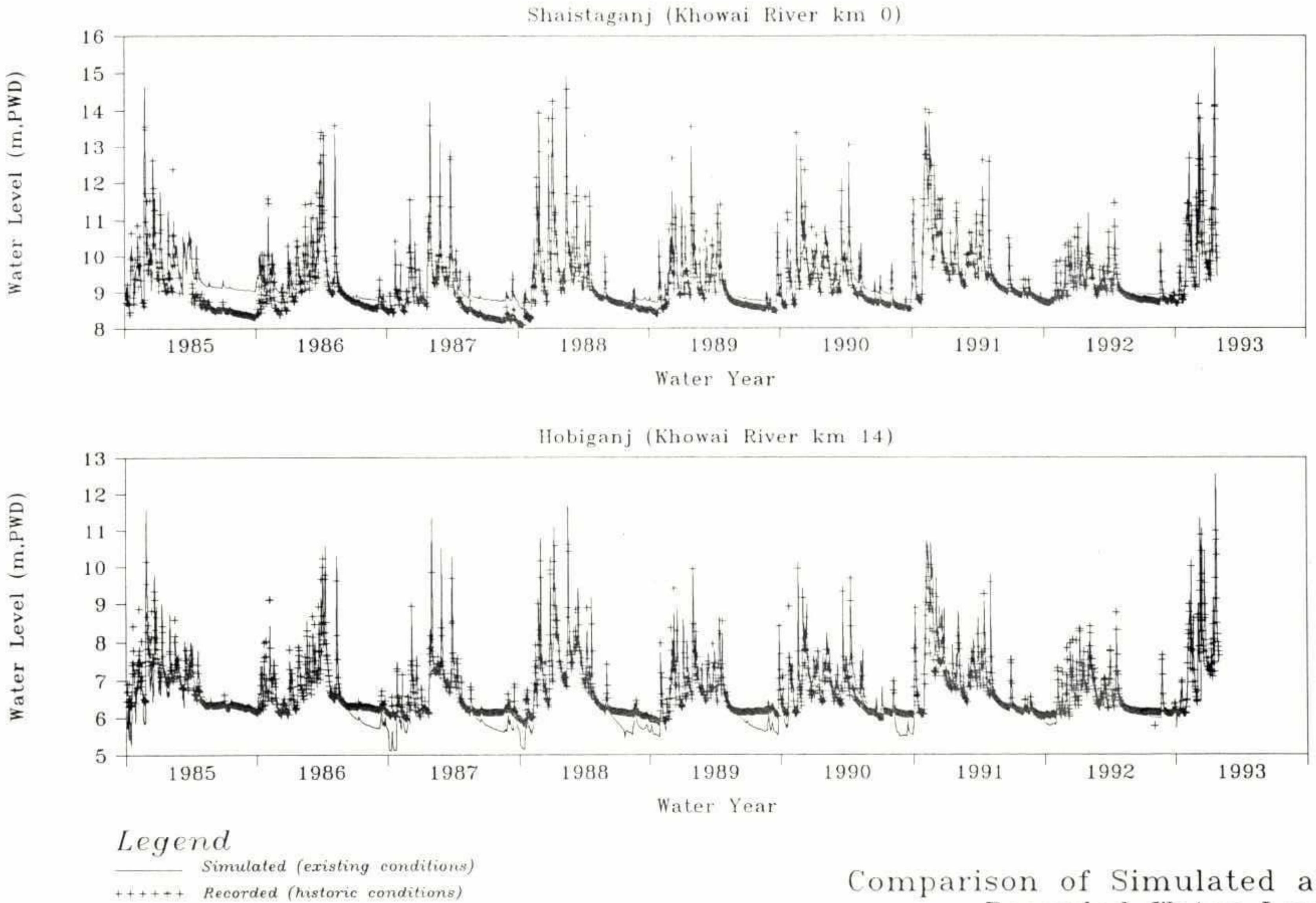


Comparison of Simulated and Recorded Water Levels

Northeast Regional Project

FILE:MODL-709.DWG

Figure 47

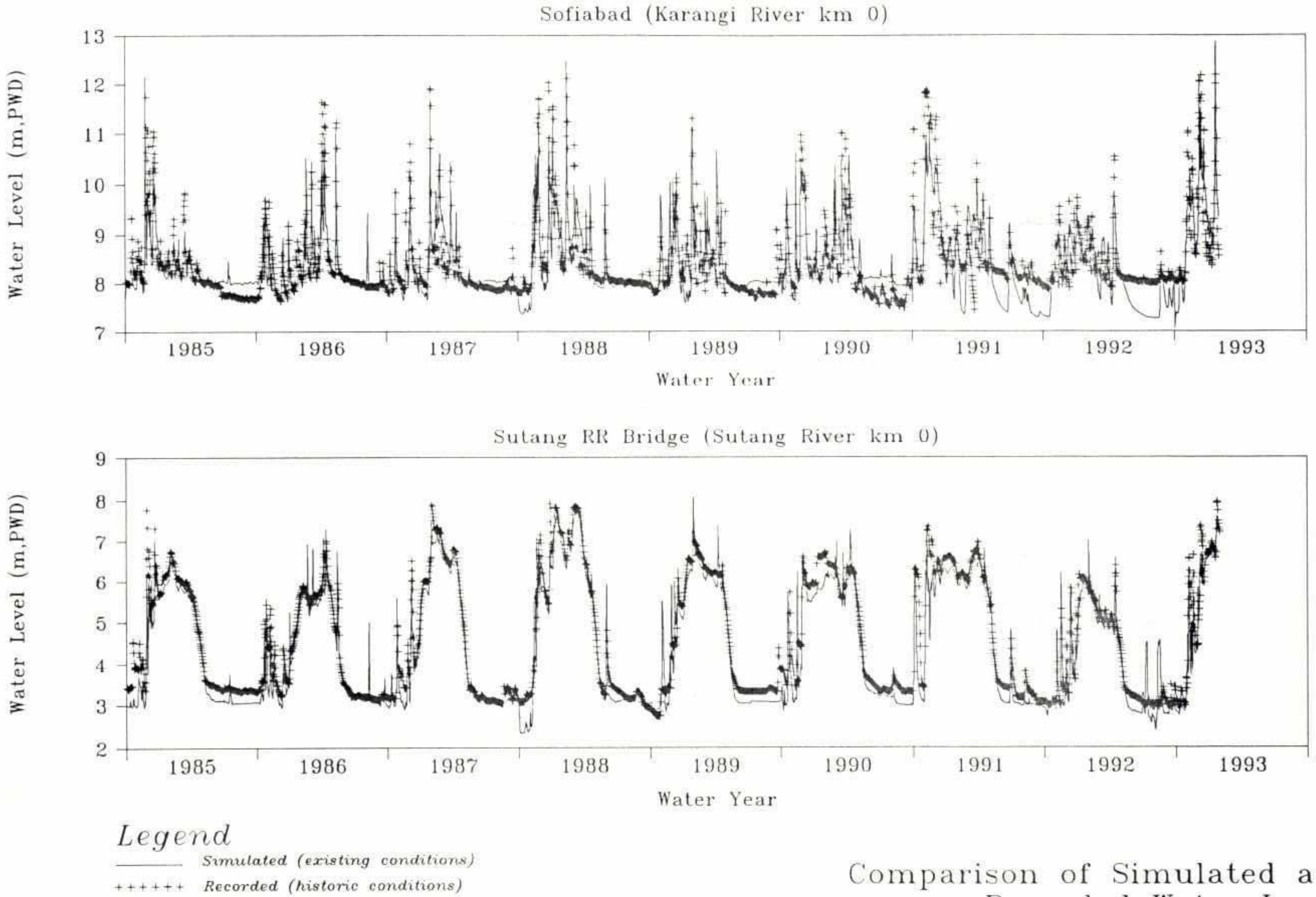


Comparison of Simulated and Recorded Water Levels

Northeast Regional Project

FILE:MODL-710.DWG

Figure 48

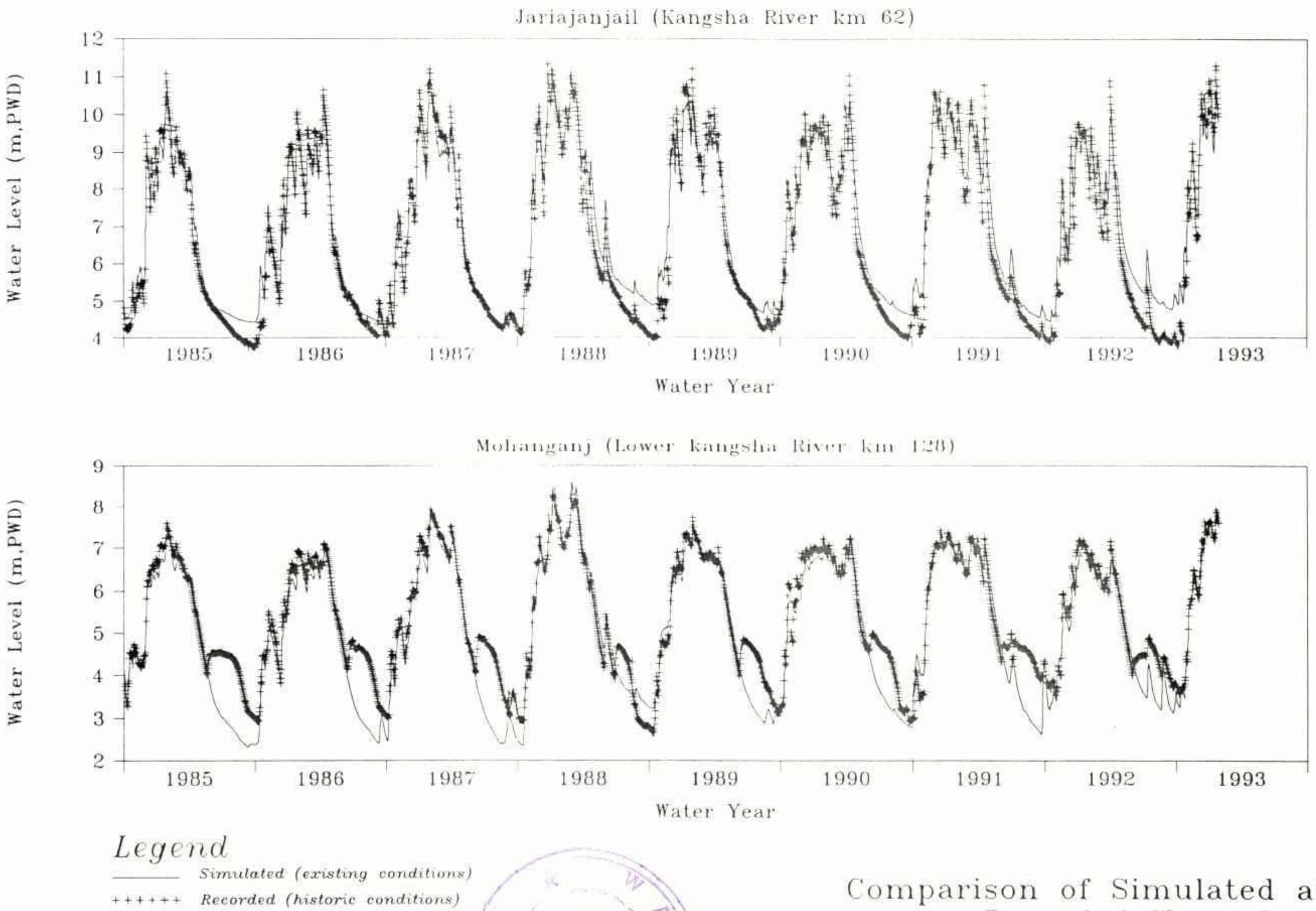


Comparison of Simulated and Recorded Water Levels

Northeast Regional Project

FILE:MODL-711.DWG

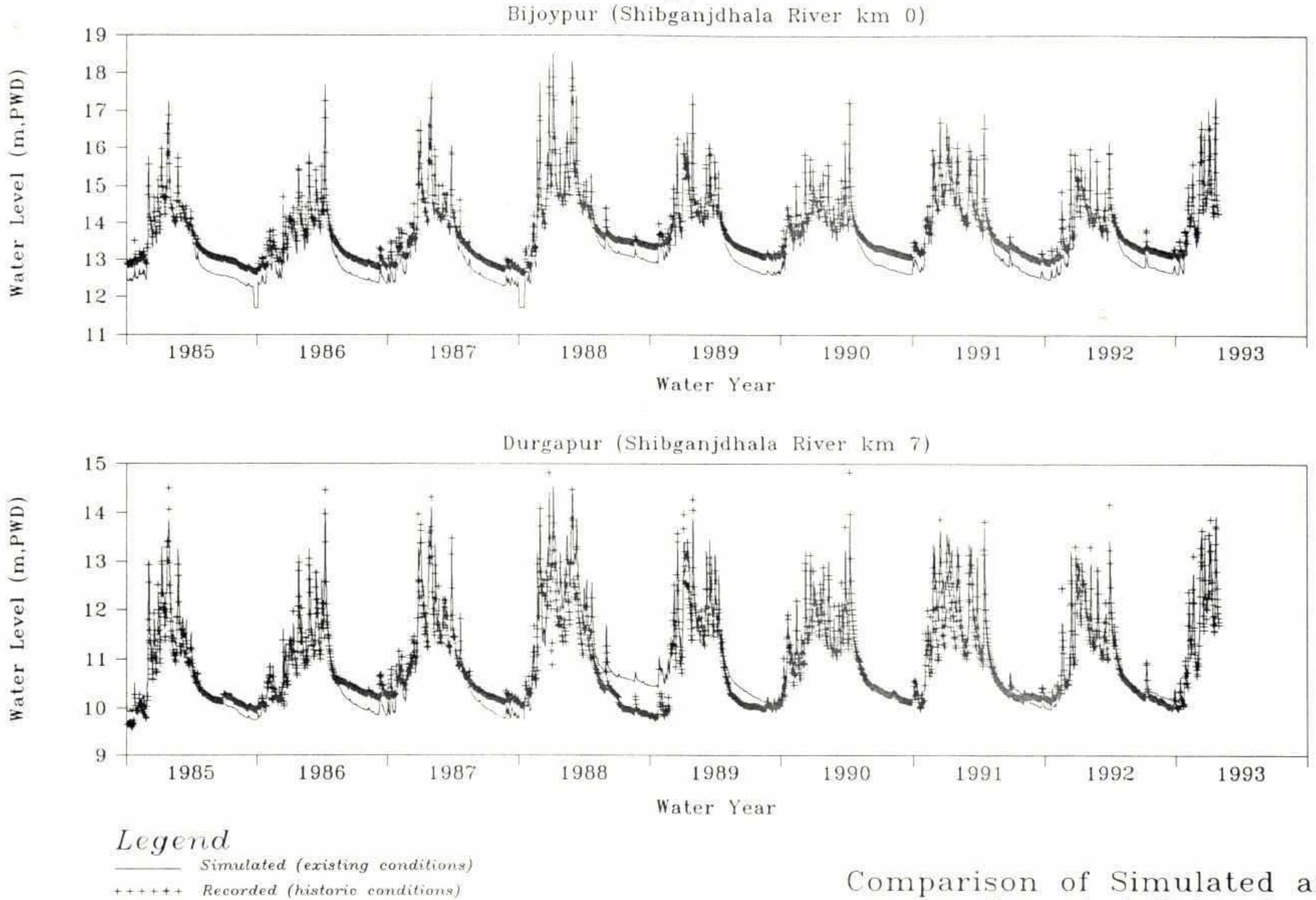
Figure 51



Comparison of Simulated and Recorded Water Levels

Northeast Regional Project

FILE:MODL-716.DWG



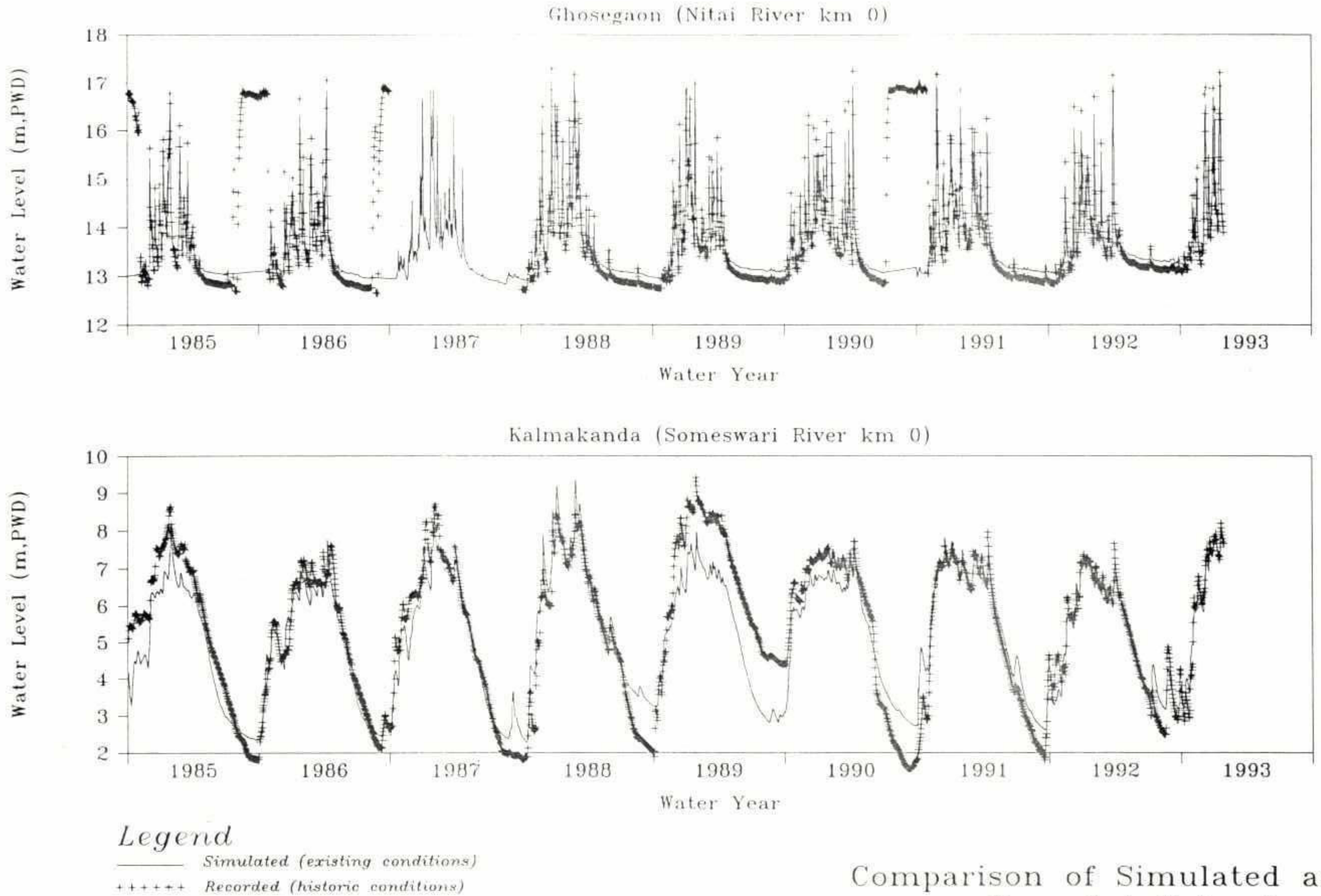
Comparison of Simulated and Recorded Water Levels

Figure 52

Northeast Regional Project

FILE:MODL-717.DWG

Figure 53

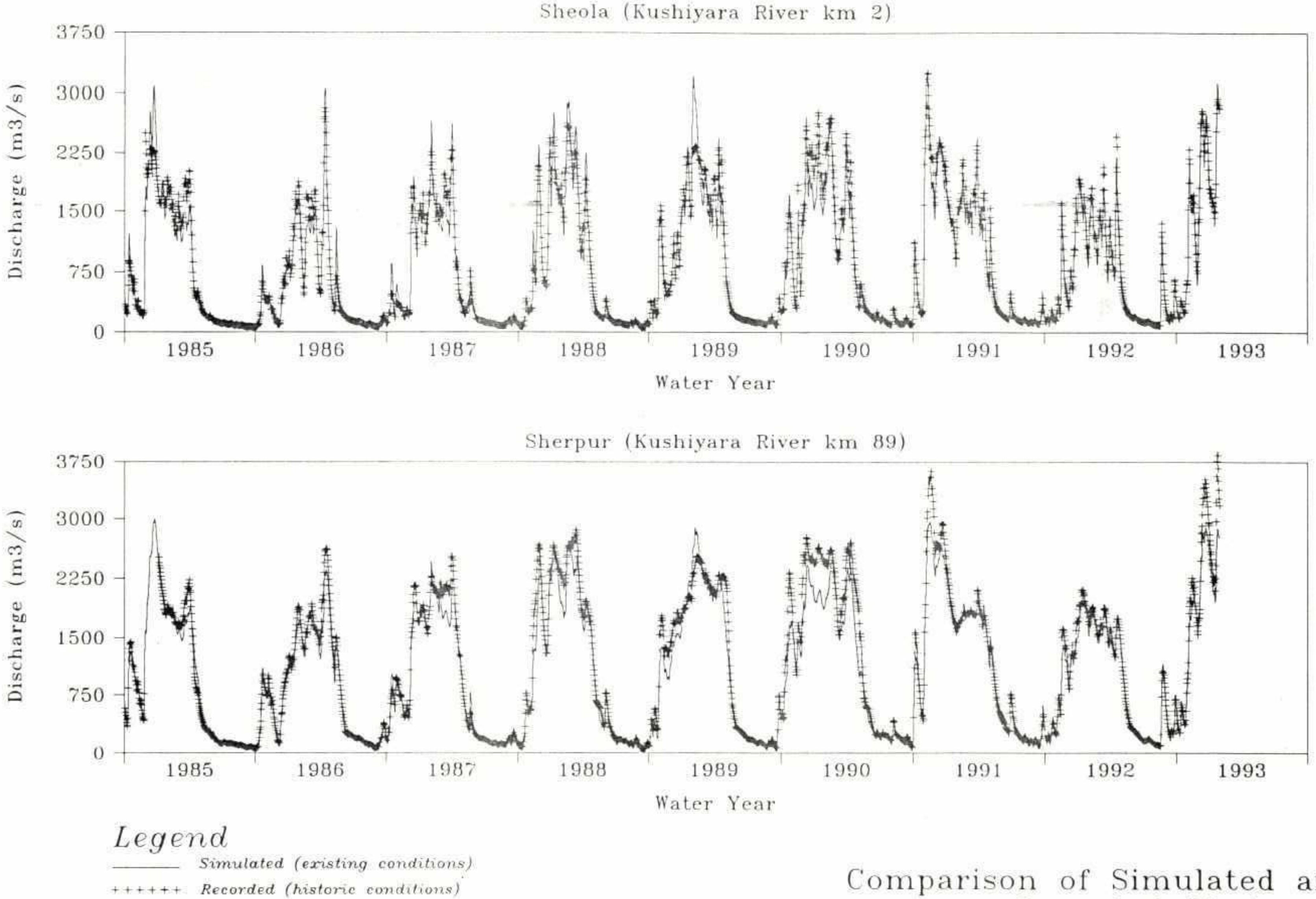


Comparison of Simulated and Recorded Water Levels

Northeast Regional Project

FILE:MODL-718.DWG

Figure 54

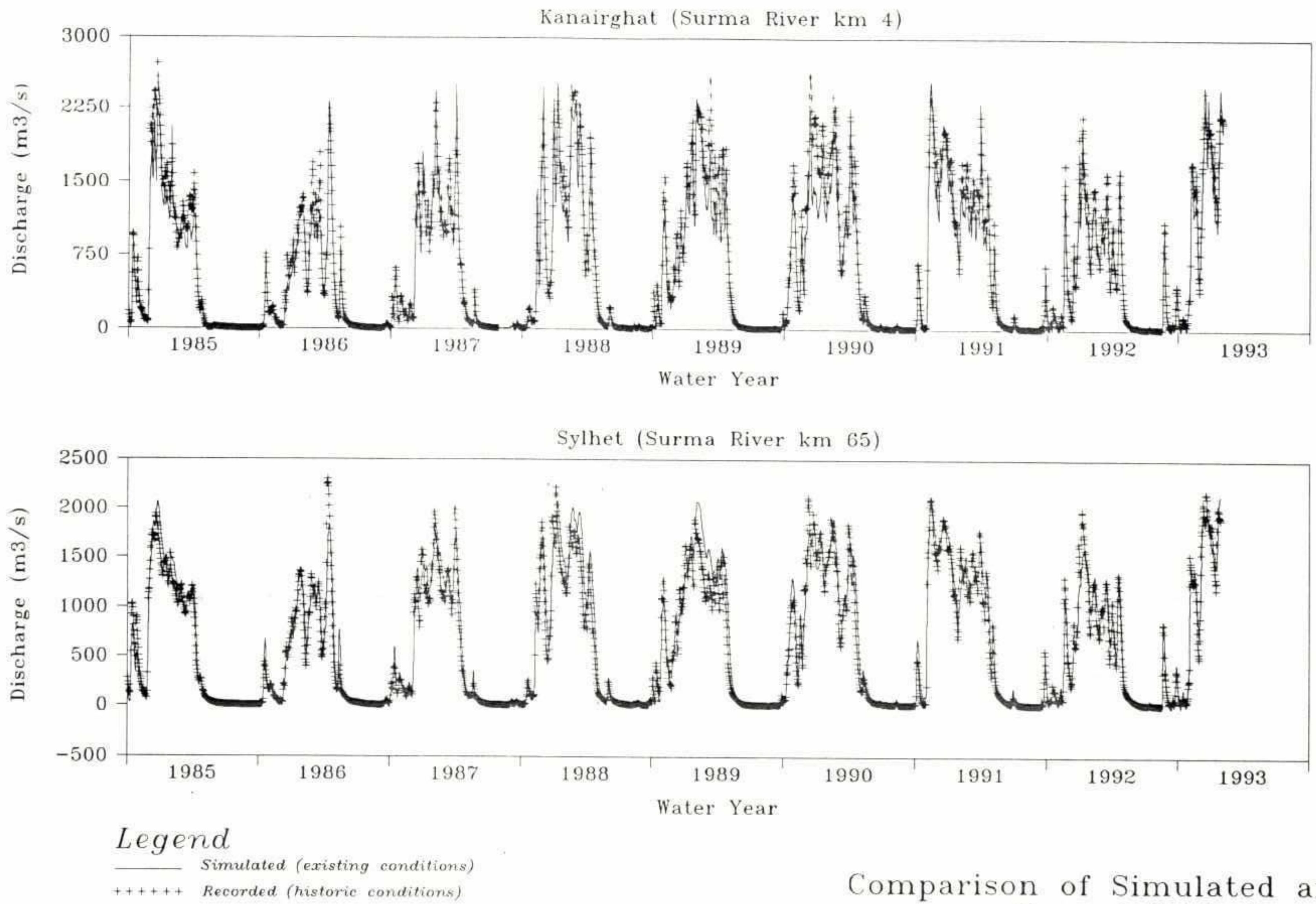


Comparison of Simulated and Recorded Discharges

Northeast Regional Project

FILE:MODL-719.DWG

Figure 55

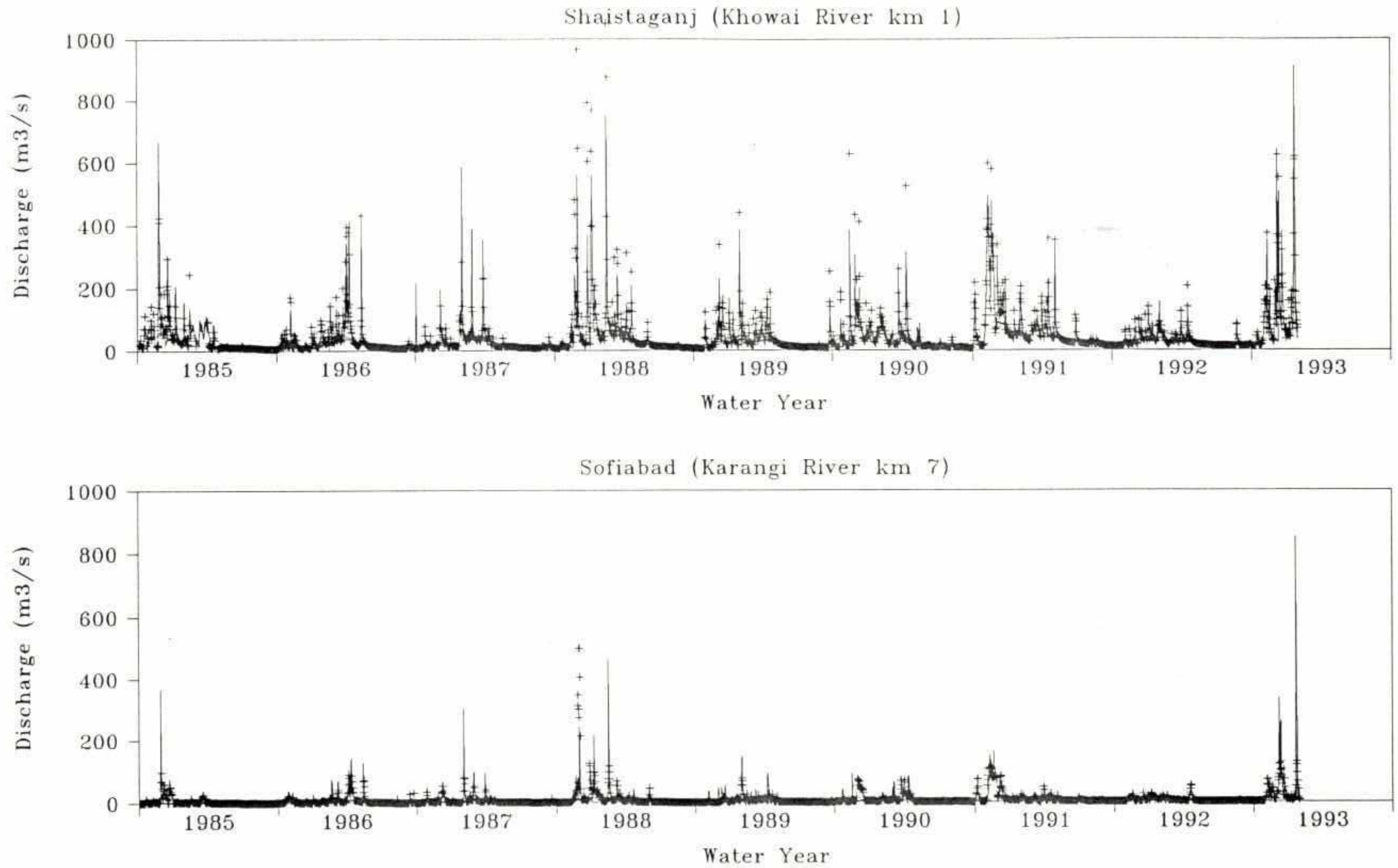


Comparison of Simulated and Recorded Discharges

Northeast Regional Project

FILE:MODL-720.DWG

Figure 56



Legend

——— *Simulated (existing conditions)*

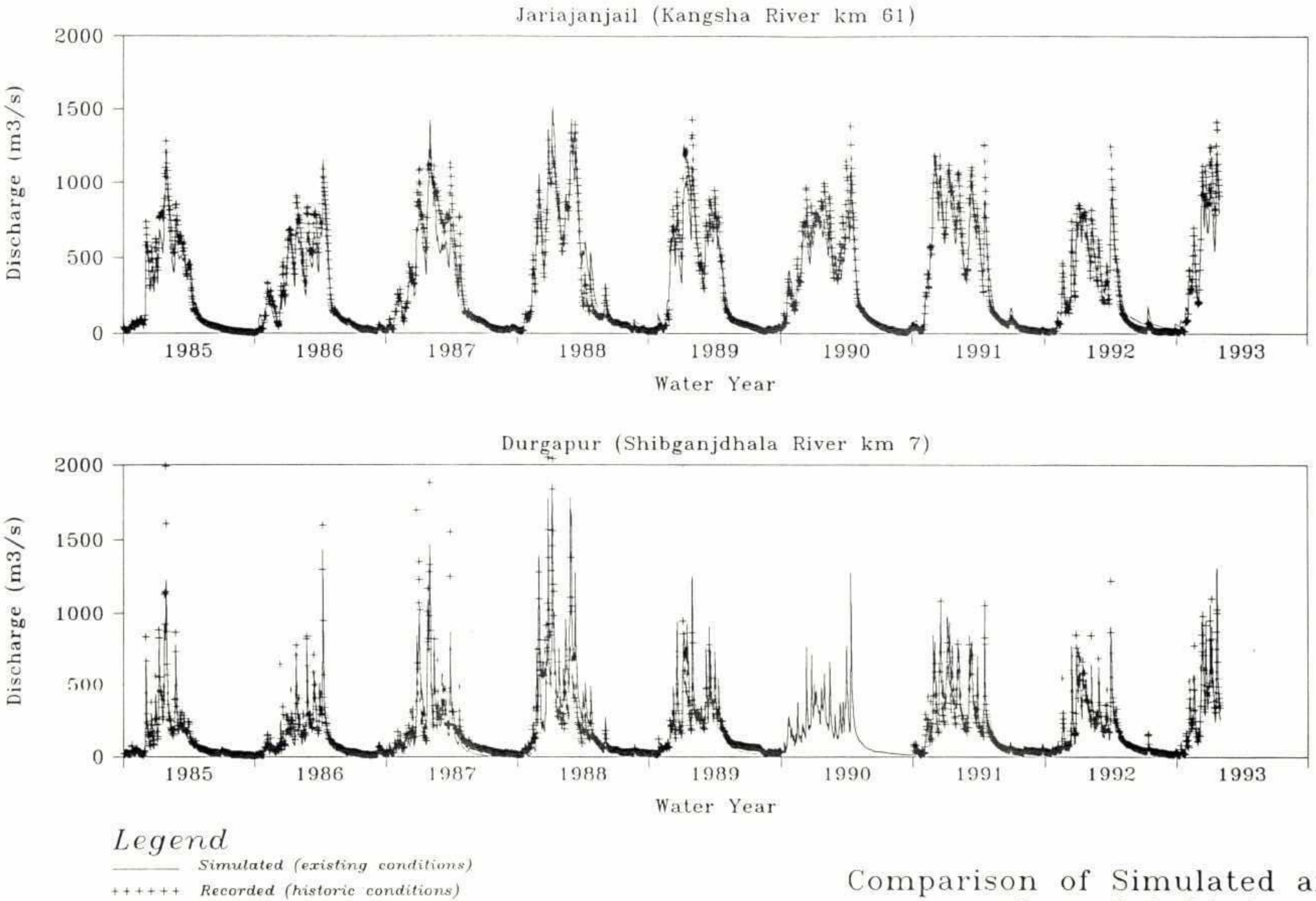
++++++ *Recorded (historic conditions)*

Comparison of Simulated and Recorded Discharges

Northeast Regional Project

FILE:MODL-721.DWG

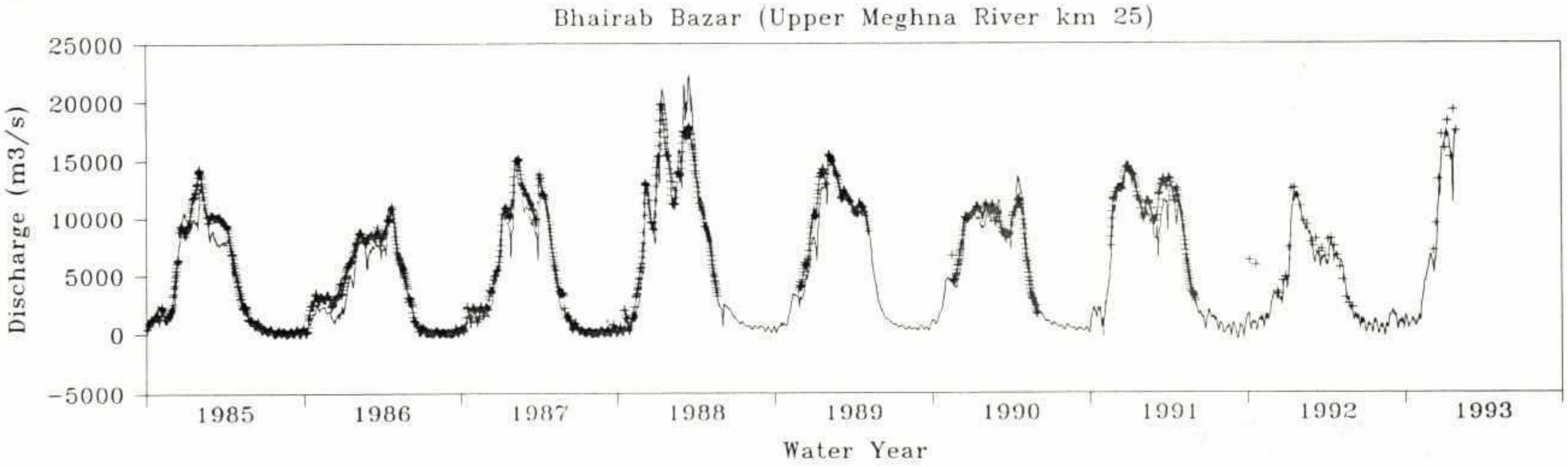
Figure 57



Comparison of Simulated and Recorded Discharges

Northeast Regional Project

FILE:MODL-722.DWG



Legend

——— *Simulated (existing conditions)*

++++++ *Recorded (historic conditions)*

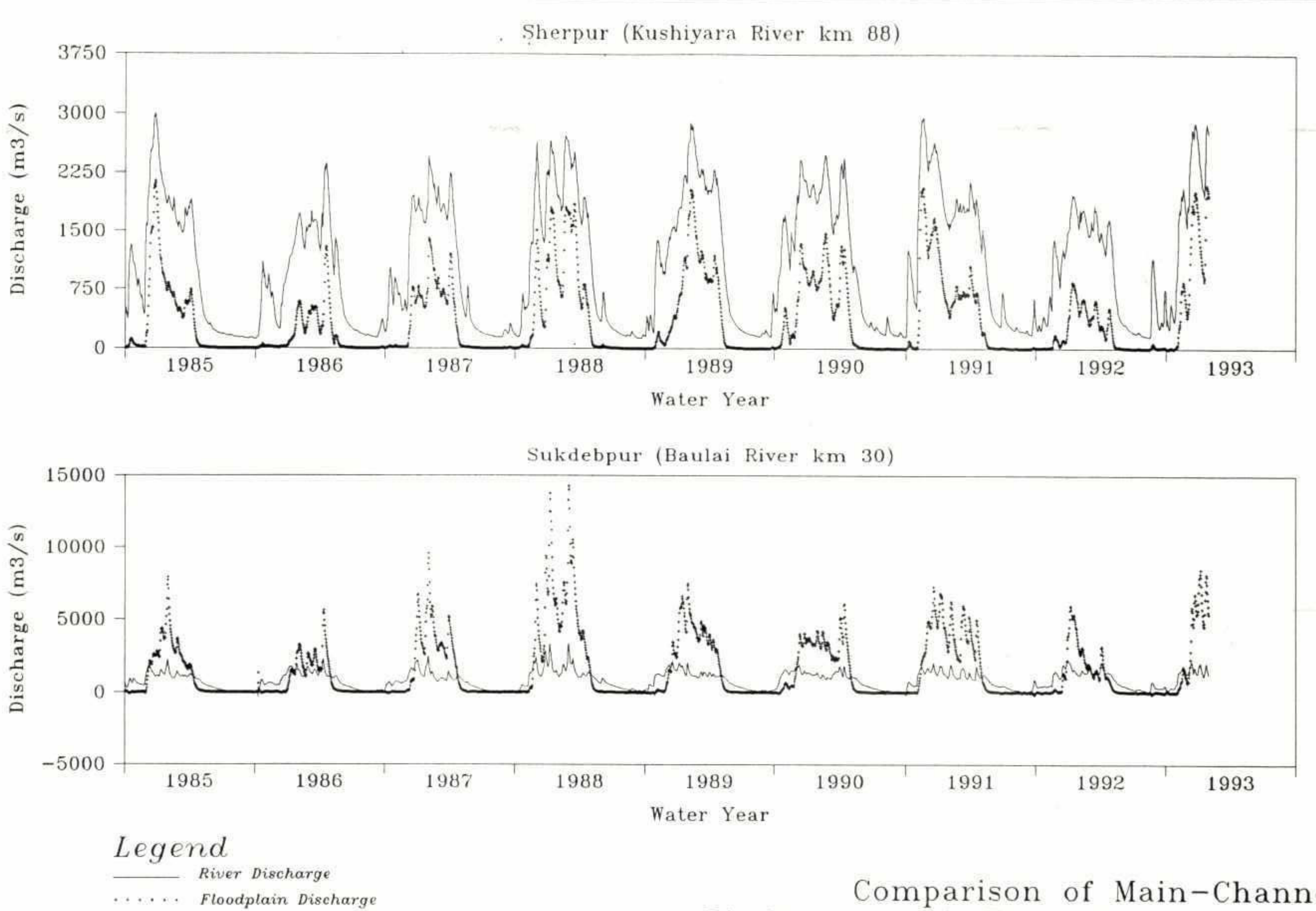
Comparison of Simulated and Recorded Discharges

Figure 58

Northeast Regional Project

FILE:MODL-723.DWG

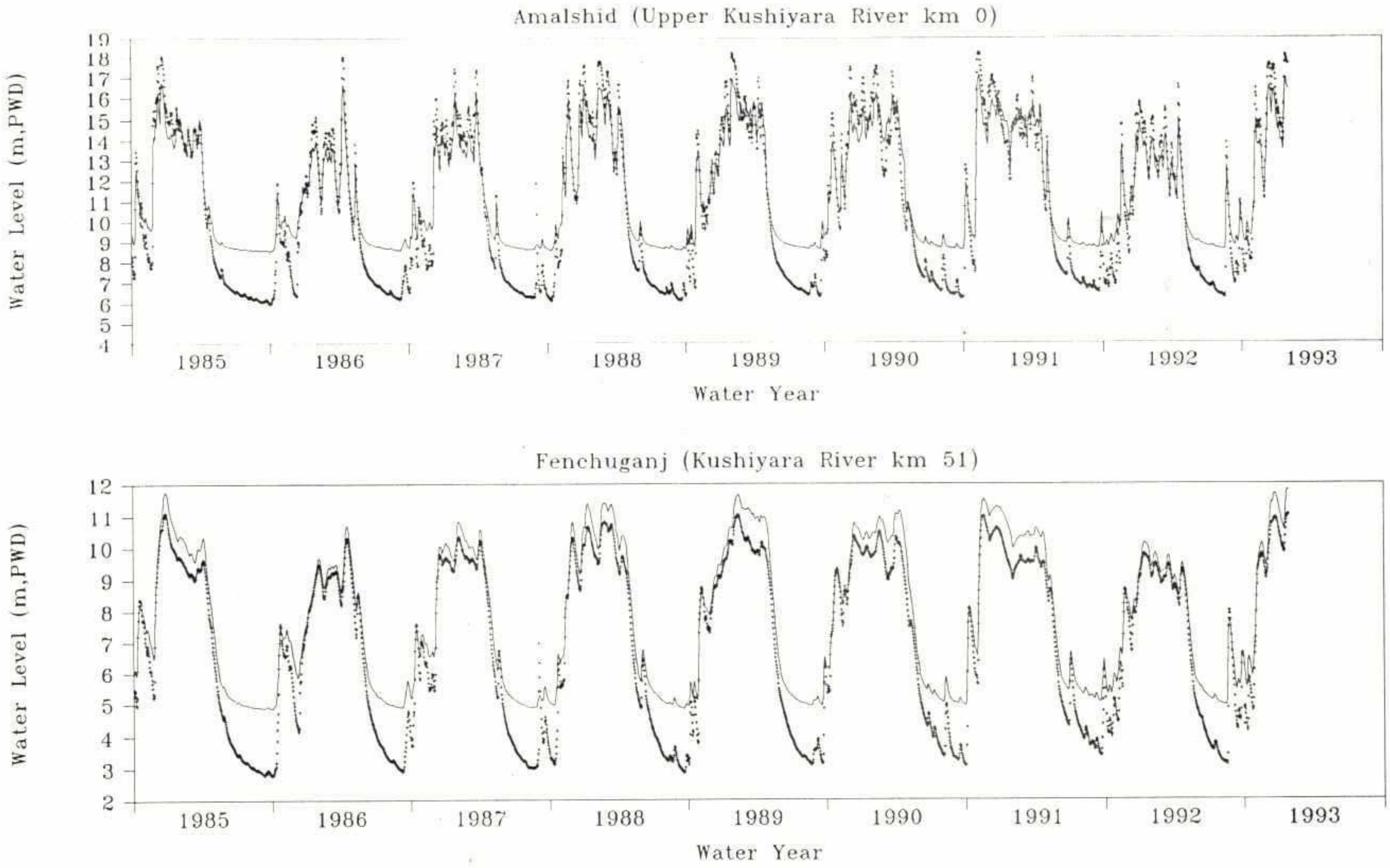
Figure 59



Comparison of Main-Channel Discharges with Floodplain Discharges

Northeast Regional Project

FILE:MODL-724.DWG



Legend

——— *Modified Condition (RDP)*

...... *Existing Condition (NERP7)*

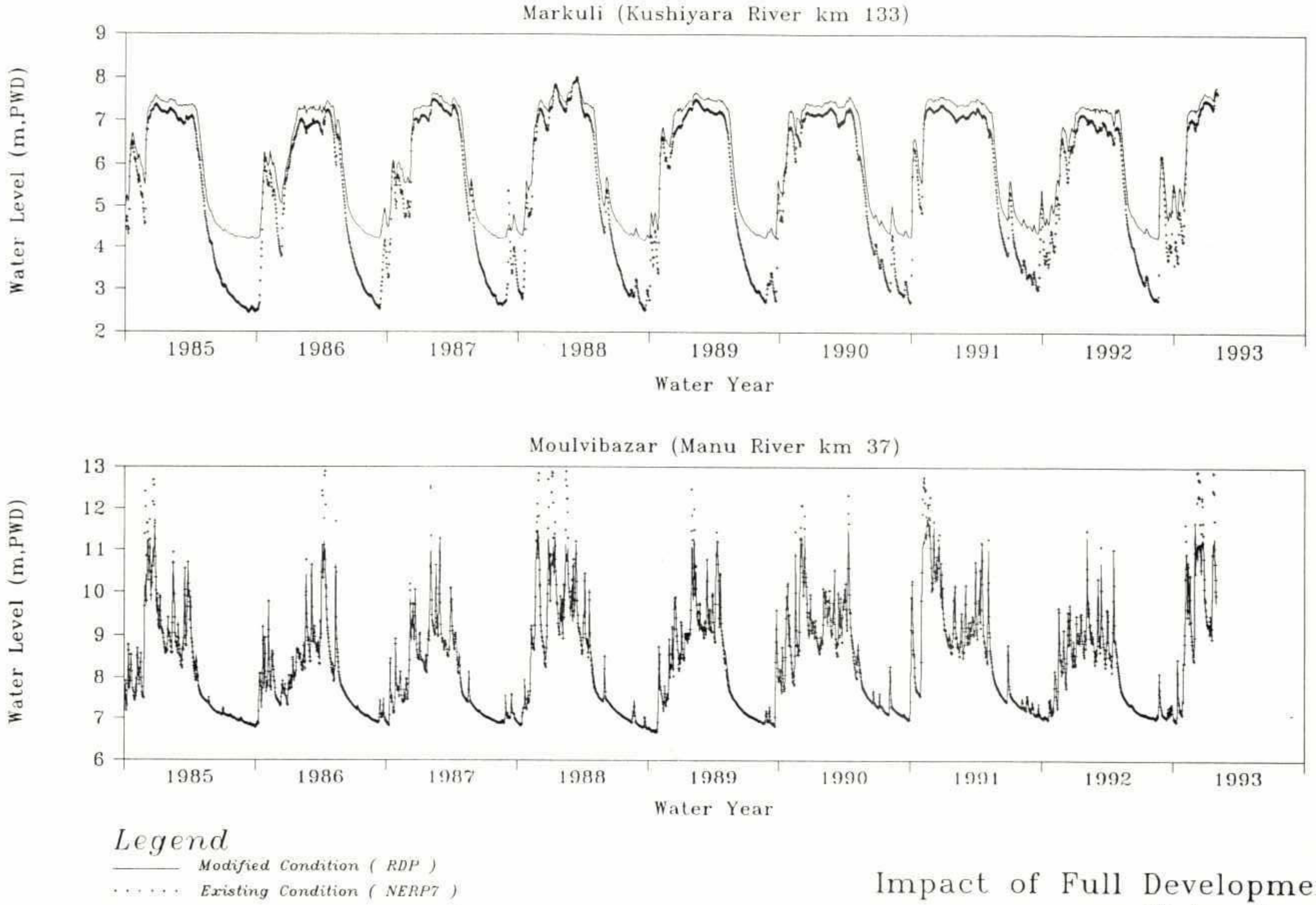
Impact of Full Development on Water Levels

Figure 60

Northeast Regional Project

FILE:MODL-740.DWG

Figure 61

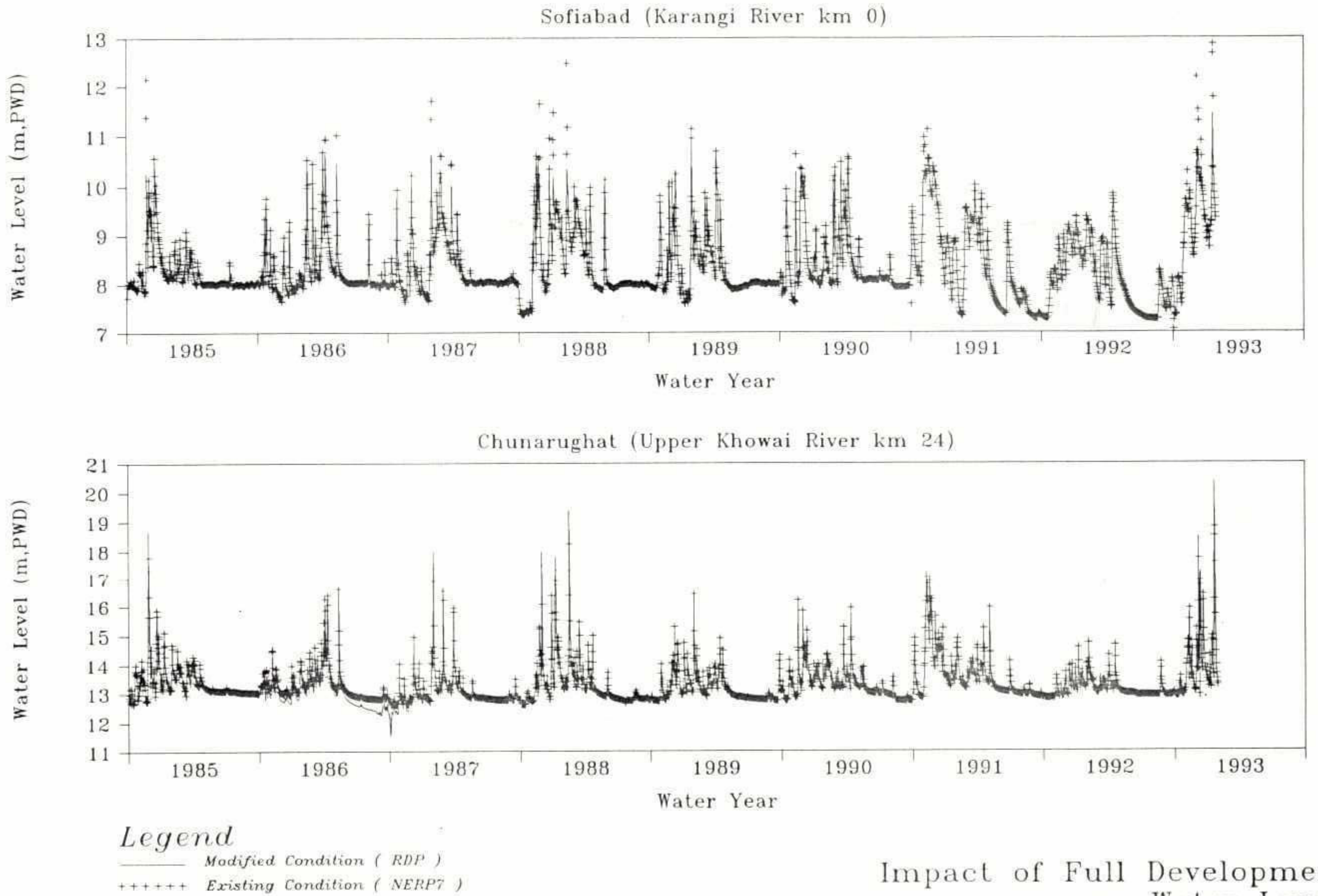


Impact of Full Development
on Water Levels

Northeast Regional Project

FILE:MODL-741.DWG

Figure 62

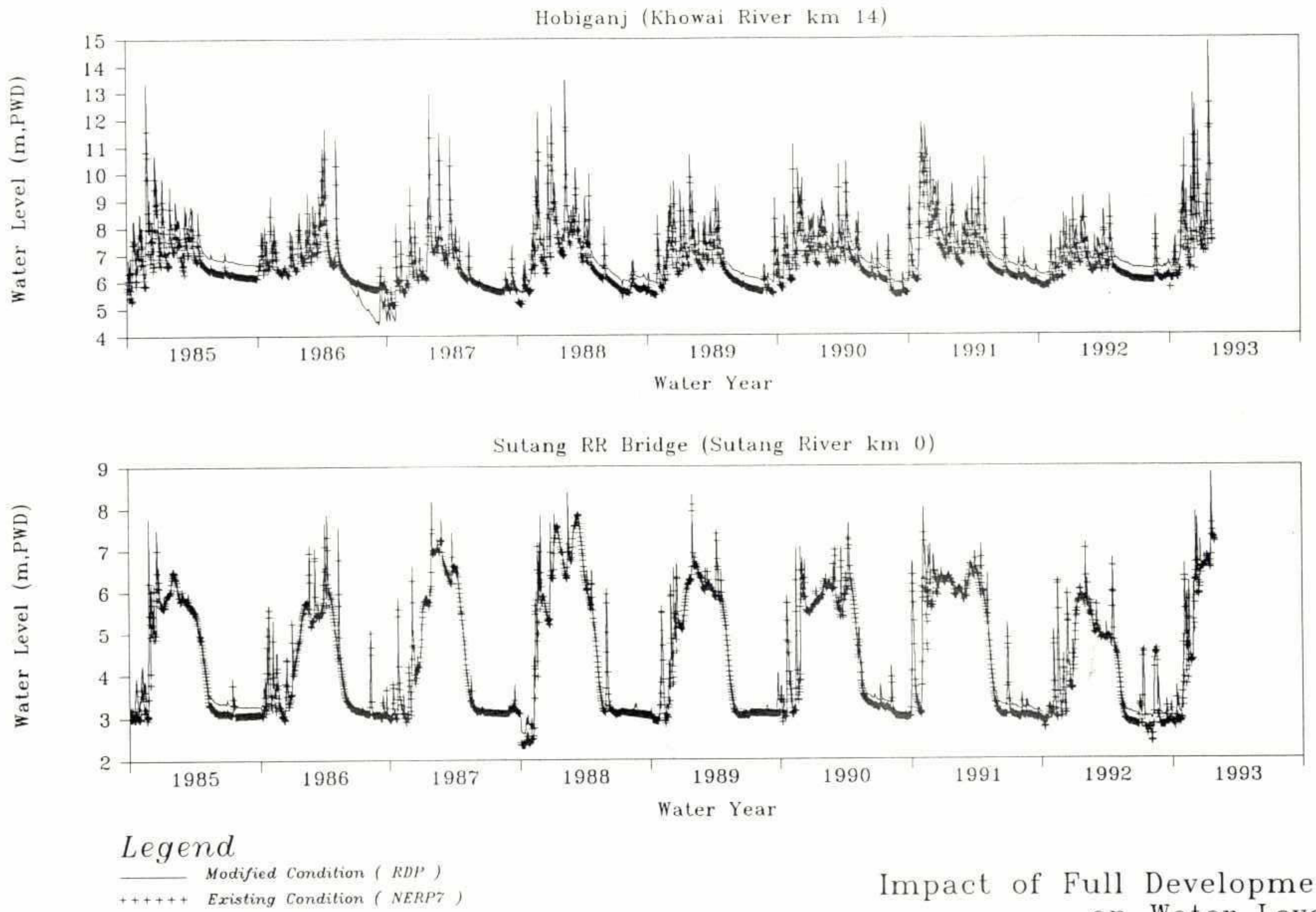


Impact of Full Development on Water Levels

Northeast Regional Project

FILE:MODL-742.DWG

Figure 63

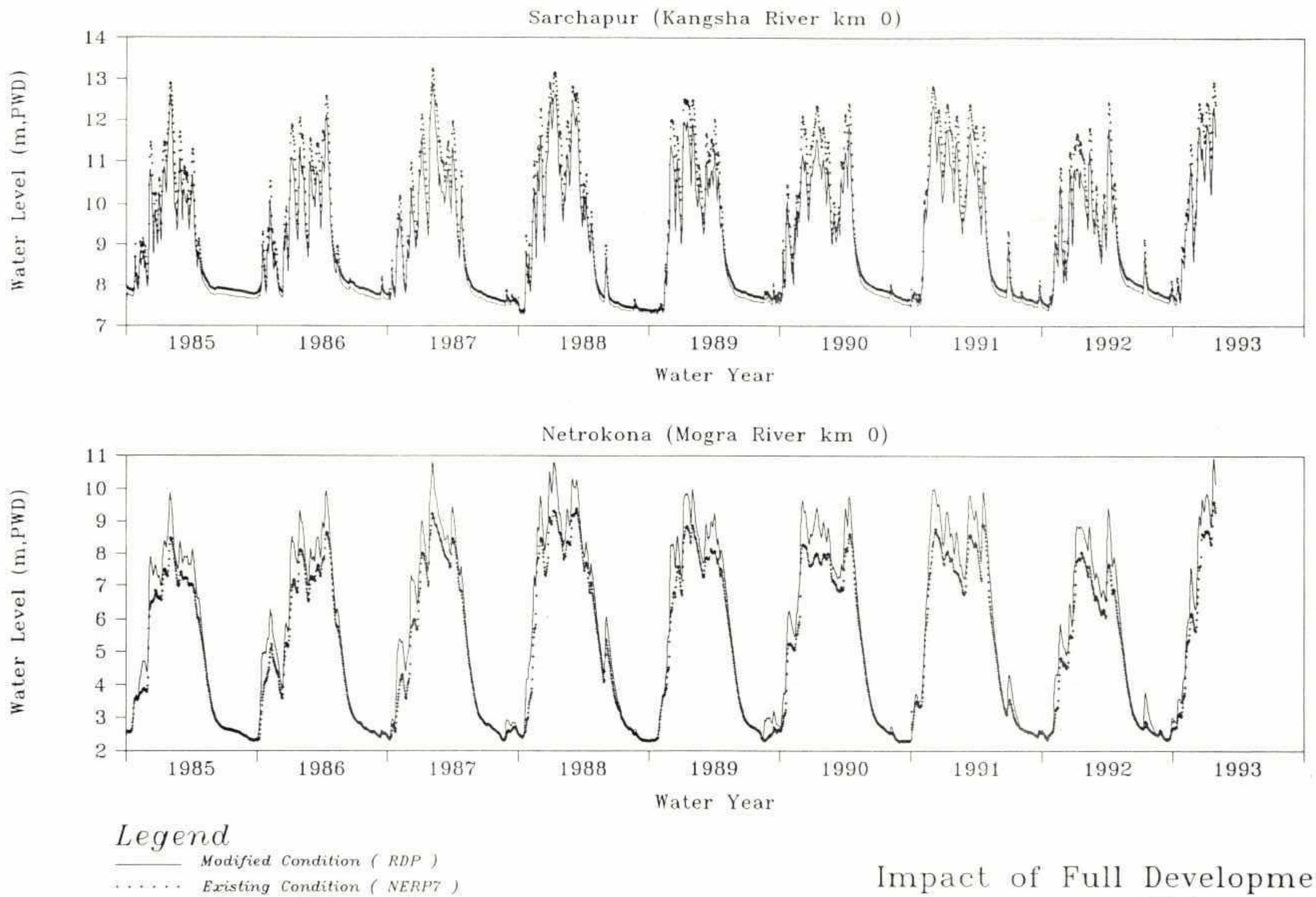


Impact of Full Development on Water Levels

Northeast Regional Project

FILE:MODL-743.DWG

Figure 64

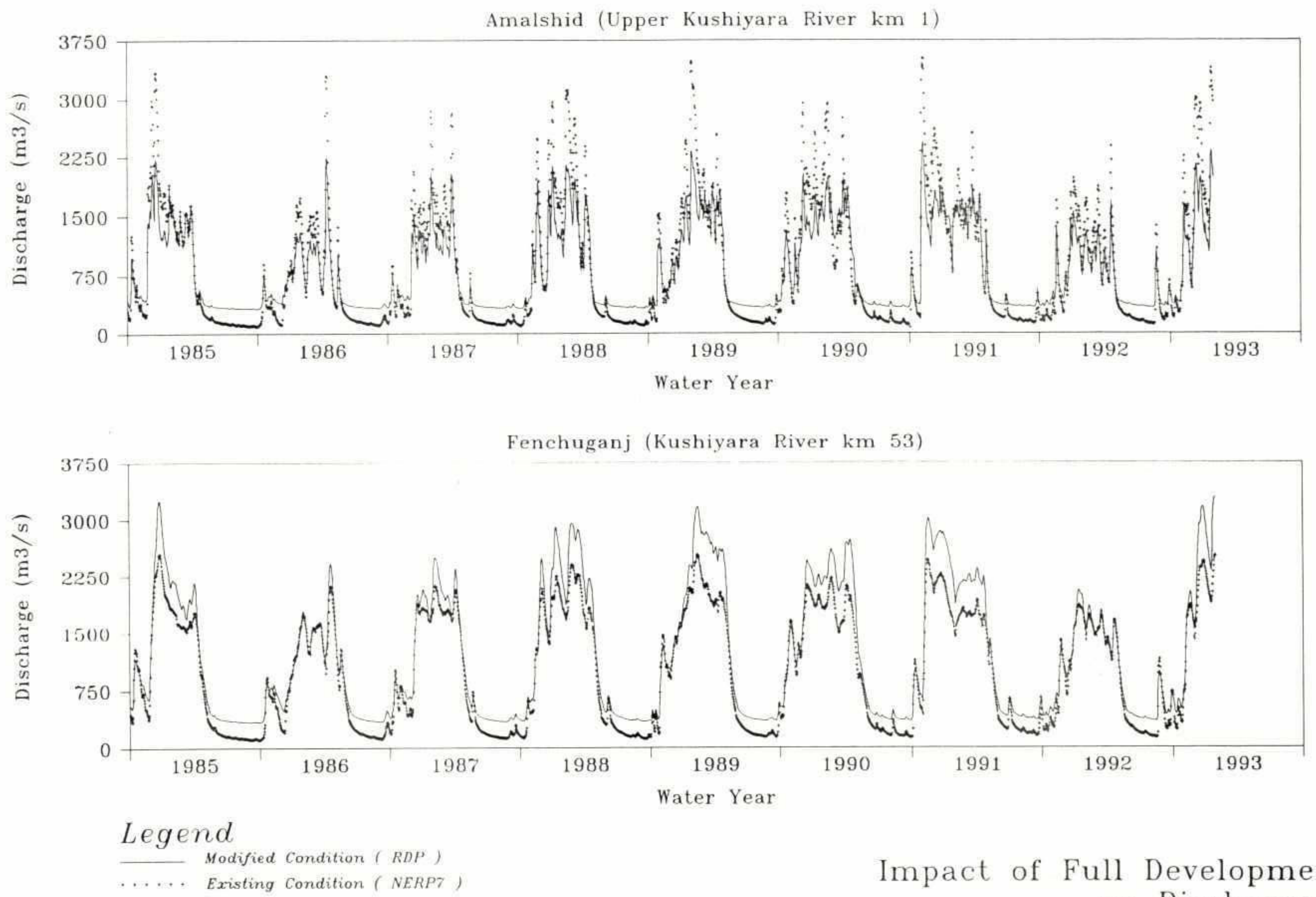


Impact of Full Development on Water Levels

Northeast Regional Project

FILE:MODL-744.DWG

Figure 65

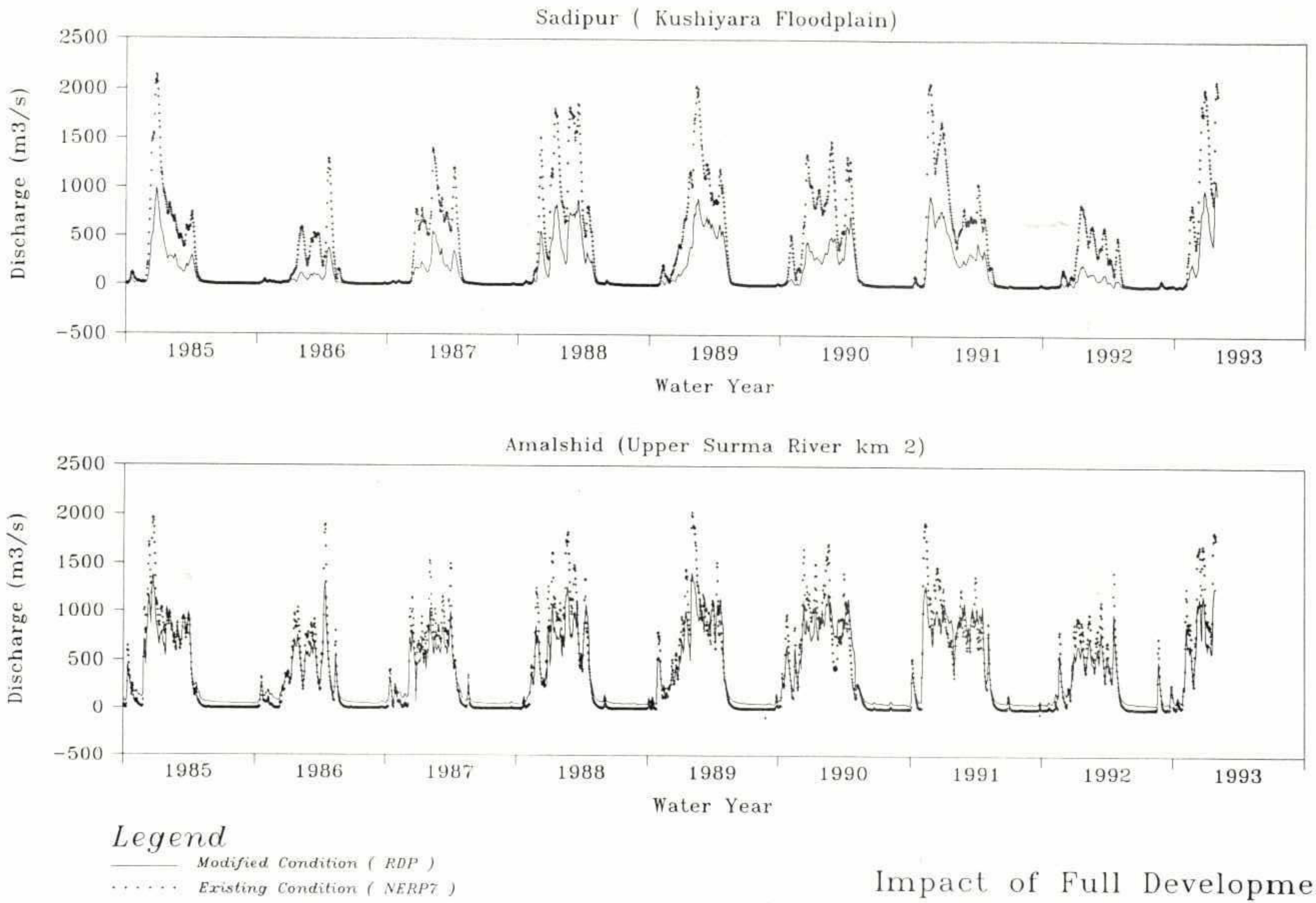


Impact of Full Development on Discharges

Northeast Regional Project

FILE:MODL-745.DWG

Figure 66

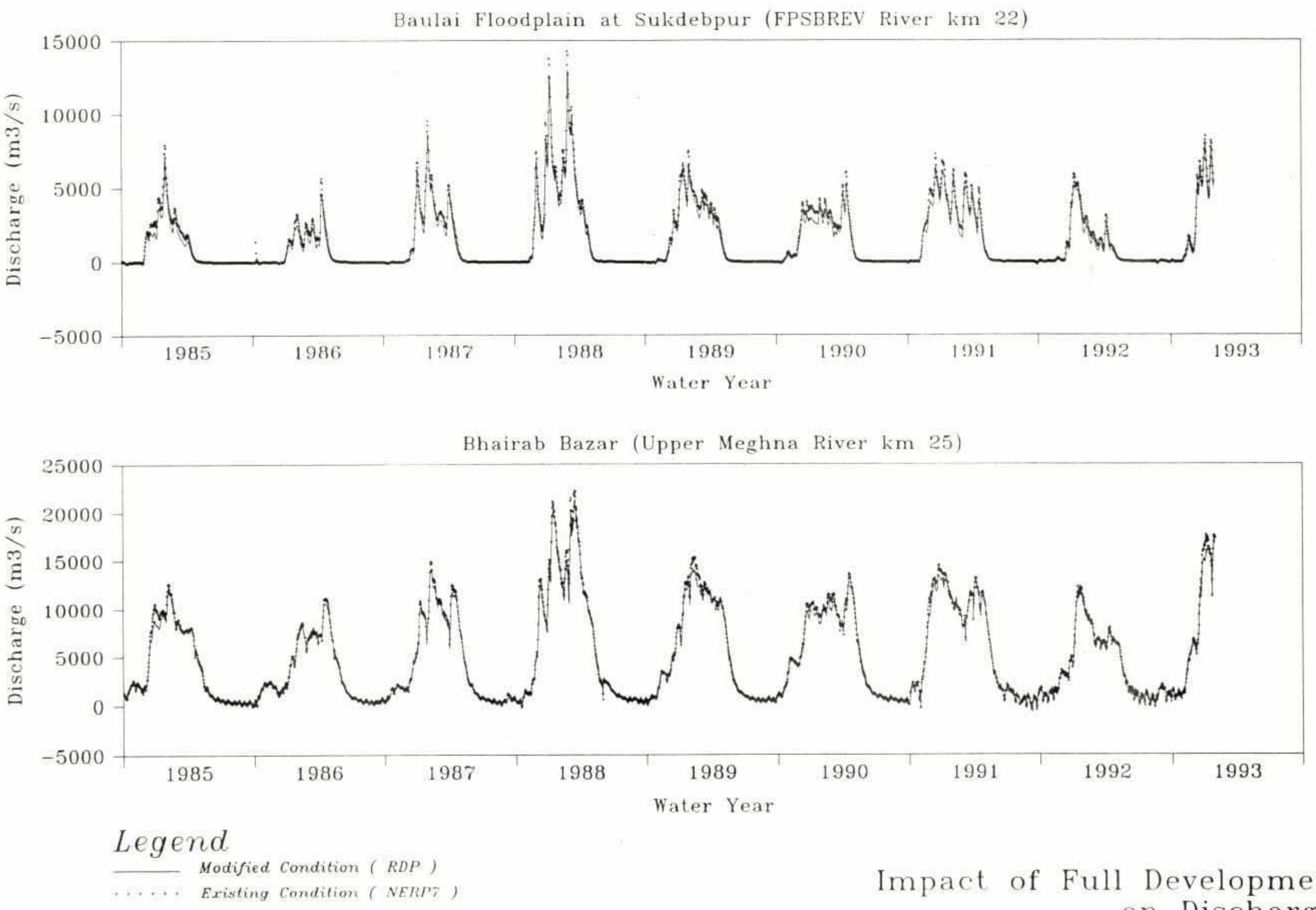


Impact of Full Development on Discharges

Northeast Regional Project

FILE:MODL-746.DWG

Figure 67

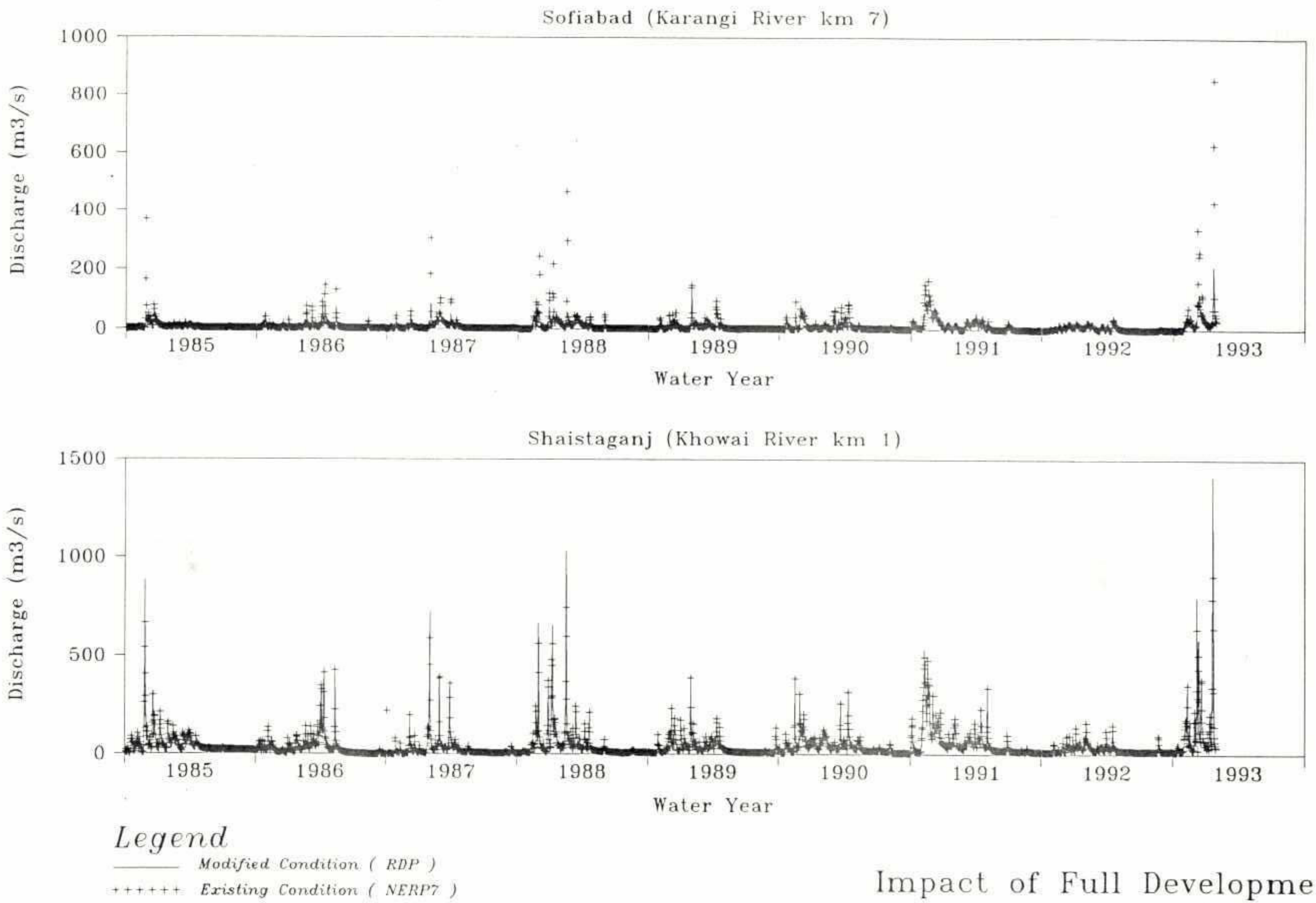


Impact of Full Development on Discharges

Northeast Regional Project

FILE:MODL-747.DWG

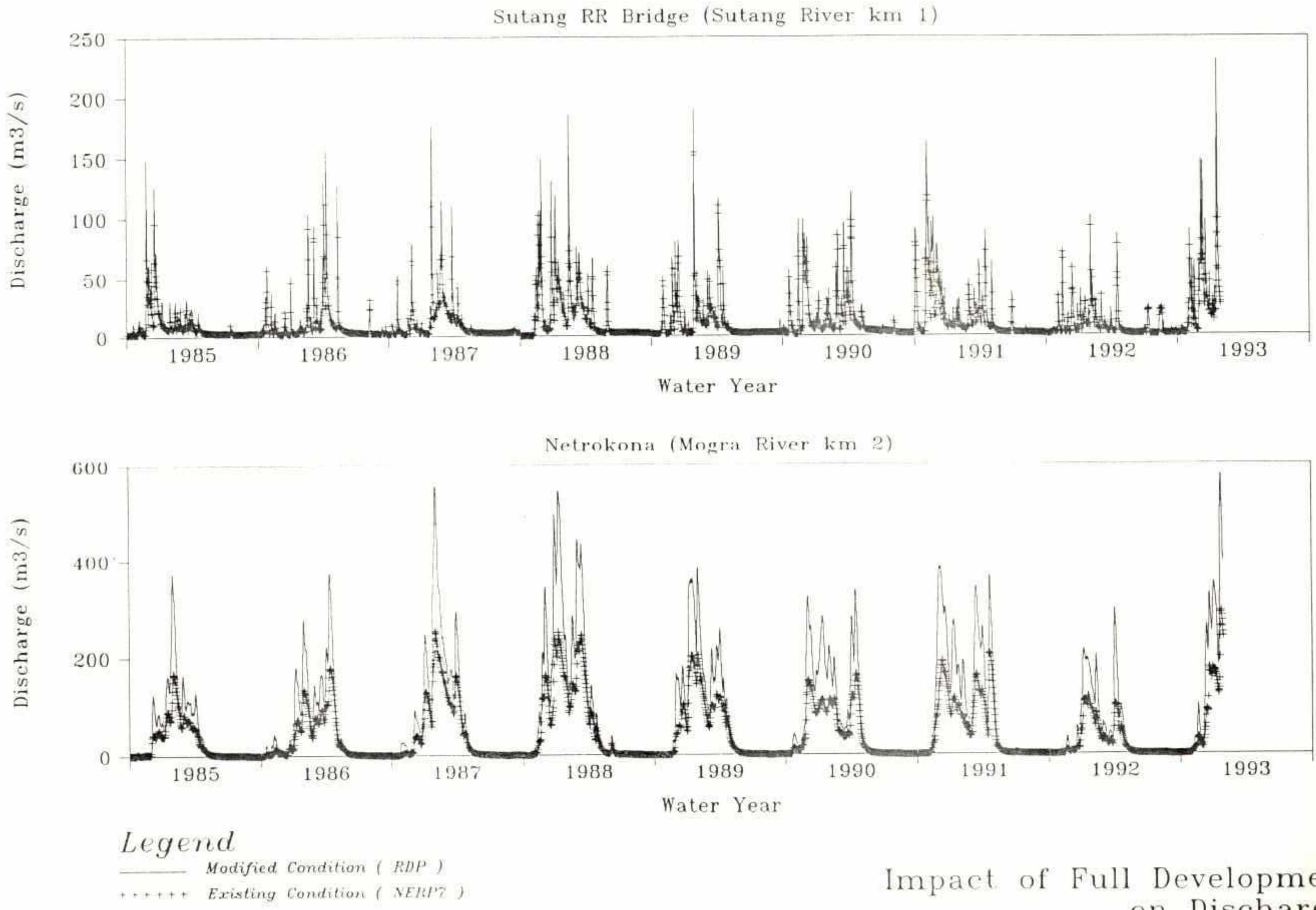
Figure 68



Impact of Full Development on Discharges

Northeast Regional Project

FILE:MODL-748.DWG



Impact of Full Development on Discharges

Figure 69

Northeast Regional Project

FILE:MODL-749.DWG