Government of the People's Republic of Bangladesh
Bangladesh Water Development Board
Water Resources Planning Organization

FLOOD ACTION PLAN

NORTHEAST REGIONAL WATER MANAGEMENT PROJECT (FAP 6)

KALNI-KUSHIYARA RIVER MANAGEMENT PROJECT FEASIBILITY STUDY

ANNEX B MIKE 11-HYDRODYNAMIC MODEL

Final Report
March 1998

SNC ♦ Lavalin International
Northwest Hydraulic Consultants

in association with

Engineering and Planning Consultants Ltd.
Bangladesh Engineering and Technological Services

Canadian International Development Agency

COVER PHOTO: A typical village in the deeply flooded area of the Northeast Region. The earthen village platform is created 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 all that remains of the past lowland forest. 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 by 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

BMD	Bangladesh Meteorological Department
BWDB	Bangladesh Water Development Board
CIDA	Canadian International Development Agency
cm	centimetre
FCDI	Flood Control Drainage and Irrigation
FW	Future With Project
FWO	Future Without Project
GEV	General Extreme Value
GPS	Global Positioning System
ha	hectare
kg	kilogram
km	kilometre
KKRMP	Kalni-Kushiyara River Management Project
m	metre
MPO	Master Plan Organization
mt	metric tonne
NERP	Northeast Regional Water Management Project
PWD	Public Works Department
SOB	Survey of Bangladesh
SWMC	Surface Water Modelling Centre
TBM	Temporary benchmark
USGS	United states Geological Survey
WARPO	Water Resources Planning Organization

GLOSSARY

beel	floodplain lake that may hold water perennially or dry up during the winter season
haor	depression on floodplain located between two or more rivers
khal	channel

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1. INTRODUCTION

1.1 Objectives

This annex describes the hydrodynamic modelling component of the Kalni-Kushiyara River Management Project (KKRMP) feasibility study. The objective of the modelling work was to develop a calibrated hydrodynamic model capable of simulating various project scenarios and to determine project impacts on water levels, discharges and the extent of inundation in the region. The model results provide the foundation for estimating the benefits of the proposed alternative developments.

1.2 Scope

Figure B.1 shows the 335,600 ha project area. Figure B.2 shows the area that was modelled. The focus of the hydraulic investigations was on the 130 km reach of the Kushiyara-Kalni-Dhaleswari River system between Sherpur and Astagram. However, for accurate representation of the hydraulics of this system, the model had to include portions of the Upper Meghna, Baulai-Surma, Old Surma and Ratna river systems and their distributary channels. The total modelled region, covered an area of 500,000 ha and included 800 km of river channels.

1.3 Project Requirements

In order to assess the impact of the project, it was necessary to simulate the effect of a number of proposed interventions including loop cutting, spill channel closures and channel re-excavation. Since the pre-monsoon floods have been responsible for most of the agricultural damage in the region, accurate representation of pre-monsoon flood conditions was considered critical. These floods are difficult to model accurately because the flood damage tends to occur as a result of spill, through bank breaching, from the main river into the adjacent floodplain and minor distributary channels. The magnitude and location of these spills are governed by local variations in bank levels and resistance to erosion. Year to year variations in conditions such as closure and re-opening of connecting *khals* due to man-made works and natural erosion or deposition processes also determine size and location of spills. Furthermore, pre-monsoon floods generally occur in flashes causing the distribution of runoff in the project area to be more variable than during the monsoon season.

These requirements impose the need for the ability to simulate a complex branching network of channels subject to overbank spills and floodplain storage. There is also a need for high resolution surveys of the channel and floodplain topography in order to accurately represent the interaction between the main channel and floodplain flow.

1.4 The Computer Model

MIKE-11, developed by the Danish Hydraulics Institute, was used for the hydraulic modelling. This program has been chosen by Water Resources Planning Organization (WARPO), as a standard in Bangladesh, and has been applied by the Surface Water Modelling Centre (SWMC) on many projects throughout the country (SWMC, 1997). The program contains two main components:

- a lumped parameter rainfall-runoff model (NAM) that simulates local runoff generated from catchments within the project area, and
- a one-dimensional, single layer hydrodynamic model that simulates the passage of a flood wave through a network of river channels and floodplains by solving the Saint Venant equations of unsteady, gradually varied flow.

The inputs to the MIKE-11 model are :

- time dependent discharges at upstream boundaries;
- time dependent runoff generated from local catchments inside the project area by means of a separate rainfall-runoff model (NAM), and
- time dependent water levels at downstream boundaries.

The outputs from MIKE-11 are time series of water levels, cross-sectional mean velocities and flows at desired points along the rivers and floodplain.

The Kalni-Kushiyara Project model was constructed from the Northeast Regional Model (NERP, 1995), but with improved representation of the main channels and floodplain in the project area. The Northeast Regional Model was developed in cooperation with SWMC between 1991 - 1995 for predicting hydrodynamic conditions in the entire northeast region (SWMC, 1993). The regional model was used for establishing some of the boundary conditions to the project model. This "nested approach" provides an efficient means for simulating a large complex system, since the project model can be constructed with high resolution in the areas of interest, while a relatively coarse grid of computations can be used in the out-lying areas that will not be affected by project impacts.

2. OVERVIEW OF THE PROJECT AREA

2.1 Setting and Topography

The project area lies within the Sylhet Basin, a large bowl-shaped depression bounded by the Surma River on the north, the Surma/Kushiyara floodplain on the east, the Old Brahmaputra River floodplain on the west and the Meghna floodplain on the south (Figure B.1). The land in this area is dissected by a maze of active and abandoned distributary channels and ox-bow lakes. The main river channels are bordered by natural levees that extend up to 3 m above the surrounding back basins. There are many saucer-shaped depressions or *haors* in these lowlands, the most prominent include Dekker Haor, Baram Haor, Chaptir Haor, Naluar Haor, Tangua Haor, Mokar Haor, Puber Haor and Kakailseo Haor.

Elevations typically range between 3 to 8 m PWD, with the highest land on the east where it merges with the Surma-Kushiyara floodplain and the lowest land in the south-west near the Upper Meghna River. As a result, the dominant drainage is from the northeast to the south-west. Approximately 25% of the land lies below 4 m PWD and 50% is below 5 m PWD.

2.2 River Systems

The Kushiyara River originates at the international boundary near Amalshid where the Barak River forks into the northward flowing Surma River and the south flowing Kushiyara River. The reach of the Kushiyara River downstream of Markuli to its junction with the Dhaleswari River is called the Kalni River. The Dhaleswari River joins the Baulai River to form the Upper Meghna River near Bhairab Bazar. Tributaries to the Kushiyara-Kalni River system include the Juri, Manu, Khowai, Karangi and Sonai-Bardal rivers which drain the Tripura Hills of India to the south and the Ratna River, which drains the low floodplain land south of Nabiganj and Ajmiriganj, and joins the Dhaleswari River near Madna.

The project area is dissected by a maze of distributary channels, some of which are actively flowing, others representing former channels that have been abandoned as a result of channel shifting or man-made closures. The north side of the Kalni-Kushiyara River consists of low-lying floodplain and flood basins. This inter-basin land contains major distributary channels including the Old Surma River, Darain River, Sadipur Khal, Itakhola Nadi, Kamarkhali Khal and Cherapur Khal. The connection between the Kalni-Kushiyara River and the inter-basin has gradually been reduced over the last 20 years as a result of closures at Markuli in 1978 and Bheramohona in 1993. These structures have reduced spills from the Kalni River into the low-lying *haor* areas to the north and have also re-directed drainage during the post-monsoon season into the Baulai River system. Major distributary channels on the south side of the Kushiyara River include Sakra-Singli river, Ratna river and Gangajuri rivers.

2.3 Hydrology

Discharges on the Kalni-Kushiyara River are governed by inflows from the Barak River at Amalshid and from tributary streams (Juri, Manu, Khowai, Sonai-Bardal, Karangi), by inflows or losses that occur through distributaries and breaches and by locally generated runoff from rainfall over the project area. In addition, backwater from the Meghna River controls river stages which affects the distribution of flow carried in the main river channels and on the floodplain. Figure B.3 shows the range in daily water levels and discharges that have been recorded by Bangladesh Water Development Board (BWDB) on the Kushiyara River at the Sherpur station.

Three types of floods occur in the project area:

- winter floods
- pre-monsoon floods
- monsoon floods

Winter floods, which occur between December and February, are caused by storms in the outlying hills and by local rainfall. They occur suddenly and are of a relatively short duration. They rarely overtop the river banks but water readily enters the *haors* because at this time of the year there are numerous openings in the river banks including hydraulic structures with open gates. Pre-monsoon floods occur between March and mid-May for the purpose of agricultural water management projects. Low magnitude pre-monsoon floods are usually confined within the channel but may enter the adjacent low-land through open *khals* and bank breaches. Larger floods overtop the river banks and flood the adjacent basins and floodplain by overland flow as well as through spills and breaches. The flood volumes are sufficient to fill the *haor* depressions and they are the cause of major crop damage in the project area. Historically, the most damaging spills have occurred at the Koyer Dhala, Paharpur, near Markuli, Bharda Beel and near the Bibiyana River off-take.

Monsoon season floods normally last from July to October and can inundate virtually all of the project area. Flooding is due to a combination of high inflows from external rivers, seasonal rainfall over the project area and from backwater effects from the Lower Meghna River.

The BWDB has measured discharges on the Kushiyara River at Sherpur since 1982. Although the record length is relatively short, this station provides a good reference for describing flood conditions since the flows at Sherpur represent the main inflows into the project area. Also, the cross section is relatively stable compared to sites at other stations on the river due to its partial confinement by the Sherpur highway bridge.

The frequency and magnitude of pre-monsoon and annual maximum flood discharges was estimated by fitting a General Extreme Value (GEV) distribution using the 14 years of records at Sherpur between 1982 - 1995. This frequency distribution was adopted by NERP in 1995 after a regional assessment of flood frequency predictions in the northeast region (NERP, 1995). Figure B.4 shows plots of the estimated pre-monsoon and annual maximum frequency distributions at Sherpur. Table B.1 summarizes key statistics from the analysis.

It should be noted that historic water level data at many hydrometric stations in the project area are not suitable for flood frequency analysis since the data are clearly non-homogeneous and nonstationary - that is, the data do not reflect consistent physical conditions of flood generation. In such cases, flood frequency estimates derived from the whole record represent an average of historic conditions and are not necessarily applicable to present or future conditions. In particular, pre-monsoon water levels at key stations such as Ajmiriganj and Markuli show systematic trends over the last 30 years as a result of ongoing sedimentation and other man-made channel changes. The occurrence of such trends also suggests that having a longer period of record for analysis at Sherpur would not necessarily improve the reliability of the flood frequency estimates. This is because discharges in 1960's and 1970's are probably not representative of present hydrological conditions.

**Table B.1: Flood Frequency Analysis of Discharges-
Kushiyara River at Sherpur**

Type	Discharge (m^3/s)				
	Return Period				
	1:2 Year	1:5 Year	1:10 Year	1:20 Year	1:50 Year
Pre-monsoon	1,694	2,398	2,834	3,228	3,709
Annual Maximum	2,579	2,977	3,225	3,451	3,729

3. SCHEMATIZATION OF THE MODEL

3.1 Kalni-Kushiyara Model

Figure B.5 shows a schematic representation of the Kalni-Kushiyara model. The model was constructed to provide detailed spatial resolution of the Kalni, Kushiyara, Dhaleswari, Darain, Cherapur and Lamakhara rivers and also of the Kushiyara-Kalni south and north floodplains between Sherpur and Madna. Shaka Barak, Sakra-Singli, Koyer Dhala, Old Kushiyara, Jhingari, Sutki and Puran Barak channels were schematised earlier in the regional model as conceptual storage cells with spill weirs. These storage cells were replaced by individual channels.

Surveys were carried out in 1995 and 1996 along the Kushiyara from Manumukh to Markuli, Kalni River, Dhaleswari River, Baida River, Ratna-Satai River and Cherapur Khal to account for recent channel changes and to provide more detailed resolution of the channel geometry along the river.

The exchange of flow between the rivers and the adjacent floodplain and *haors* was simulated by inserting longitudinal broad-crested weirs at specified locations. The impact of opening or closing these spill channels could be simulated by lowering or raising the weir crests in the model.

3.2 Local Rainfall and Runoff

As described under Section 1.4, one of the two components of the MIKE-11 model is a lumped parameter rainfall-runoff model (NAM) that simulates local runoff generated from catchments within the project area. The NAM is a lumped conceptual model whose input consists of rainfall, evaporation, catchment parameters and water abstraction data. The rainfall is distributed spatially by a Thiessen Polygon which considers the rainfall stations located within and in the immediate vicinity of the project area.

3.3 Boundary Conditions

The conditions imposed at the model extremities or boundaries determine to a large extent the water movement inside the model area. Two principal types of boundary conditions were specified:

- discharges at the upstream model boundaries, and
- water levels at the downstream boundaries

The boundaries were located sufficiently far upstream and downstream from the proposed channel improvement works so that any potential impacts would not affect the hydraulic conditions near the model boundaries. If the influence of the project interventions extend to the boundaries. the model could underestimate the project impacts.

Table B.2 lists the boundary conditions that were specified in the model. Discharge time series were obtained from the BWDB's regular hydrometric measurement programme or in some cases by applying stage-discharge rating curves to published water level data. Upstream discharge boundaries for the Baulai, Lower Kangsha, Dhanu, and Saiduli-Baruni rivers were taken from the regional model. The NAM rainfall-runoff model was used to generate local runoff from catchments inside the project area.

Two water level boundaries were established at the downstream extremities of the model. These included BWDB's water level gauge at Bhairab Bazar on the Upper Meghna River, and a section on the Nawa River which was taken from the regional model.

Table B.2: Boundary Conditions

Type	Location	Source of Data
discharge	Barak River at Amalshid	BWDB station
discharge	Saiduli-Baruni River	NERP Regional Model
discharge	Dhanu River near Atapara	NERP Regional Model
discharge	Kangsha River at Mohanganj	NERP Regional Model
discharge	Baulai River at Sukdevpur	NERP Regional Model
discharge	Jhalukhali river at Dulura	SWMC station
discharge	Nawagang (Umium) River at Ururgaon	BWDB station
discharge	Chela River at Chelsonapur	BWDB station
discharge	Dhalagang River at Islampur	BWDB station
discharge	Jaflong River at Jaflong	BWDB station
discharge	Piyan River at Ratnerbhanga	BWDB station
discharge	Sarigowain River at Sharighat	BWDB station
discharge	Lubha River at Borogram	BWDB station
discharge	Sonairbardhal at Jaldhup	BWDB station
discharge	Juri River at Silghat	BWDB station
discharge	Manu River at railway bridge	BWDB station
discharge	Dhalai River at Kamalganj	BWDB station
discharge	Lungla River at Motiganj	BWDB station
discharge	Khowai River at Ballah	BWDB station
discharge	Sutang River at RR Bridge	BWDB station
water level	Meghna River at Bhairab	BWDB station
water level	Nawa River	NERP Regional model

3.4 Discretisation

The number of computational grid points and the time step of the computations depends on the flood wave period. Distance steps ranged from 3 to 5 km in the steeper tributary rivers and about 5 to 10 km in the main lowland rivers. A time step of 20 minutes was used. This relatively small time interval was necessitated by the flashy aspect of some rivers in the study area. Tests with a shorter time step (15 minutes), produced comparable results and confirmed that the selected time step was adequate.

3.5 Modelling Limitations

The following limitations need to be considered when interpreting the model results:

- The region is large in extent and spatially very complex, so it is impossible to reproduce the river system exactly. Thus a number of simplifications of the river system and hydrologic processes are required. It cannot be expected to simulate all details exactly at all locations.

- The channel geometry was assumed to be fixed during a simulation, whilst in reality cross-sections may change due to erosion and deposition. Particularly, the initiation of spills is often governed by bank erosion and bank breaching, and the occurrence of these spills may vary from year to year due to changes in local conditions. Other morphologic modelling was carried out to assess long-term channel changes on the Kalni-Kushiyara River system. Results of these mobile bed simulations are described in Annex A - Sedimentation and Morphology.

- The rainfall-runoff model component (NAM) is not coupled directly with the hydrodynamic model. The NAM component calculates net volume of runoff and groundwater recharge in the area under study. This runoff is in turn fed as an input in the MIKE-11 component. Given the availability and quality of data in Bangladesh, a more sophisticated process-based runoff model is unlikely to give additional benefit.

4. DATA COLLECTION

4.1 Cross-section Surveys

Accurate river cross-sections are a fundamental requirement for adequately representing the conveyance of the river channels and floodplains in the model. The cross-section database in the regional model was up-dated to account for recent channel changes and to provide a more detailed description of the channel characteristics. Cross-sections were surveyed, during the winter of 1995 and the 1996 pre-monsoon season, along the Kushiyara River downstream of Manumukh to Markuli, Kalni River, Dhaleswari River, Baida River and Cherapur Khal. These cross-sections extended from low water level to at least 500 m over the bank into the floodplains. The underwater portions of the channel were surveyed using a digital depth sounder and differential Global Positioning System (GPS). Overbank portions of the sections were surveyed manually. Additional cross-sections were also surveyed on important distributary channels including Darain River, Old Kushiyara River, Lamakhara, Koyer Dhala, Jhingari, Sutki, Ratna-Satai, Sakra-Singli, Shakha Barak and Puran Barak Rivers. To ensure an accurate datum, all surveys were referenced to benchmarks established from the CIDA funded SOB Second Order Levelling Programme.

4.2 Bankline Surveys

A field inspection was carried out on April 6, 1996 when the river was experiencing a 1:5 year pre-monsoon flood to document bankfull flow conditions and to observe locations of potential spills. Additionally both banks of the Kalni-Kushiyara River were surveyed in the 50 km reach between Shantipur and Raniganj. The surveys were made by levelling between NERP benchmarks and surveying short floodplain cross-sections at intervals of approximately 100 m.

4.3 Hydrometeorological Data

Hydrometeorological data required by the model consists of local rainfall, evaporation, ground water levels and hydrometric data, ie. discharges and water levels, to provide model calibration for local runoff. Discharges and water level data are also required to provide model boundary conditions.

Rainfall
A number of rainfall gauges operated by Bangladesh Meteorological Department (BMD) are located within and the immediate vicinity of the project area. The locations of these gauges are shown on Figure B.1 and their period of record is summarized in Table B.3.

Evaporation
Observations on evaporation are only available from Sylhet meteorological station operated by BMD.

Ground Water Levels
Ground water levels were obtained from the Master Plan Organization (MPO) database.

Table B.3: Summary of Rainfall Data

Gauge	Location	Latitude (degrees)	Longitude (degrees)	Period of Record
R-107	Chhatak	25.035	91.670	1962-1993
R-110	Habiganj	24.367	91.425	1961-1993
R-112	Itna	24.525	91.092	1962-1993
R-113	Khaliajuri	24.692	91.142	1962-1993
R-120	Markuli	24.683	91.383	1962-1993
R-122	Moulvibazar	24.476	91.773	1961-1993
R-125	Sheola	24.885	92.188	1962-1993
R-127	Sunamganj	25.077	91.413	1961-1993
R-128	Sylhet	24.890	91.925	1961-1993
R-129	Tajpur	24.708	91.474	1962-1993

Hydrometric Data
Water level and discharge data were collected from regular hydrometric stations operated by the BWDB. Table B.4 summarizes the period of records. The locations of these gauges are shown on Figure B.2.

NERP installed and operated a number of water level and discharge stations in the project area throughout 1995 and 1996 to provide additional data for calibrating and verifying the model. Table B.5 lists the type of information recorded and the period of record for each gauge. Water level measurements were made by establishing a permanent staff gauge on the river bank, referenced to PWD datum. The levels were read manually by a trained observer four times during the day. The discharge measurements were used to establish stage-discharge rating curves for the pre-monsoon season at a number of key locations on the Kalni-Kushiyara River, including Sherpur, Markuli, Ajmiriganj, Shantipur and Kadamchal. Additional discharge measurements were also made to assess the flow splits at Cherapur Khal and at the Baida/Kalni bifurcation near Issapur. The discharge measurements were made two or three times per week during the dry season and pre-monsoon seasons at established metering lines. The measurements were made using a standard USGS Price current meter and reel mounted on a country boat. Horizontal positioning was accomplished using a tag line. The velocity measurements were made at 5 m intervals across the channel, which resulted in 20 to 30 segments for each complete discharge measurement. The corresponding water level was determined by levelling from a NERP bench mark. In total, 157 discharge measurements were made during 1995 and 1996. The complete set of data has been tabulated in Annex A - Sedimentation.

4.4 Second Order Levelling Survey

A second-order levelling program was conducted in 1992-94 to accurately check the elevation of water level gauges within and in the vicinity of the project area and to provide accurate benchmarks for future projects and feasibility studies. The program involved high precision level surveys to second-order accuracy[1/].

1/ The permissible tolerance (mm) for second-order levelling surveys is $8.4\sqrt{\text{Length}}$, where length is the distance in km to form a complete loop.

Table B.4: Summary of BWDB Hydrometric Measurements

Station No.	Type	River	Station	Latitude (N) Deg	Latitude (N) Min	Longitude (E) Deg	Longitude (E) Min	Confirm	Date Installed	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
33	Q	Bhattakhal	Gobindaganga	24	56.20	91	41.50		1958	H	H	H	H	H	H	H		H	H	H	H	H	H	H	H	H	H												
67	Q	Dhalai	Kamalganj	24	21.36	91	51.08	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	34.77	90	32.55	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	34.19	90	30.29	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	41.31	91	7.33	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	52.76	91	9.94	GPS																				C	C	C	C	C	C	C	C	C	S	S	S
73	T	Baulai	Itna	24	31.83	91	5.63	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	11.23	90	58.60	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
135	Q	Juri	Juri	24	36.48	92	8.22	GPS	1957	C	C	C	H	H	H	H	H	H	H	H	H	C	H											H					
135A	Q	Juri - Continala Branch	Juri(continala)	24	35.60	92	6.73	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	17.55	91	32.98	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
157		Khowai	Ballah	24	5.01	91	36.02	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	12.10	91	31.82	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	16.38	91	28.58	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	22.11	91	25.68	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	52.13	92	28.54	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	53.40	92	11.45	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	53.81	92	10.73	GPS	1947	H		H	H	H	H	H	H	H	H	H	H	H	H															S	S
174	Q	Kushiyara	Fenchuganj	24	42.13	91	56.48	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	35.70	91	43.50	NERP	1949	H	H	H	H	H	H	H	H	H	H	H	H	H	C	H				C											
175.5	Q	Kushiyara	Sherpur	24	37.66	91	40.97	GPS																				C	C	C	C	C	C	C	C	C	S	S	S
192	Q	Langla	Motiganj	24	18.30	91	40.89	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
201	Q	Monu	Monu R.R. bridge	24	25.71	91	56.58	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	Moulvi bazar	24	29.65	91	46.44	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
265	Q	Sonai-Bardal	Jaldhup	24	46.44	92	10.36	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	0.00	92	15.55	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	53.24	91	52.27	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	2.16	91	39.93	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	4.53	91	24.85	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	Kushiyara	Markuli	24	41.62	91	22.87	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	33.22	91	13.73	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	20.14	91	14.26	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	Astagram	24	16.30	91	6.00		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	2.69	90	59.67	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	55.09	90	43.77	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	38.88	90	37.38	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	36.08	90	37.39	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	28.69	90	35.74	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	16.99	91	24.16	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

Type: Q= Discharge, T= Water level (Tidal), TQ= Discharge (Tidal)
Observations: H= Hard copy, C= Computer copy, S= SWMC

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Table B.5: Summary of NERP Hydrometric Measurements

Stn No	Station Name	River	Latitude		Longitude		1995									1996							
			Deg	Min	Deg	Min	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
B175-5	Sherpur	Kushiyara	24	27.43	91	40.98	S	S	S	S	S	S	S										
B270	Markuli	Kalni	24	41.68	91	22.92		S	S	S	S	S	S										
B271	Ajmiriganj	Kalni	24	32.52	91	13.67	S	S	S	S	S	S	S		S	S	S	S	S	S			
1	Ajmiriganj (closure)	Bheramohona	24	34.45	91	14.40	W	W	W	W	W	W	W	W	W	W	W	W	W	W			
2	Aktar Bazar	Mahasingh	24	53.59	91	28.72	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W		
7	Durgapur	Bashira						W	W	W	W	W	W	W	W	W	W	W	W	W			
8	Ilaspur	F.P							W	W	W	W	W	W	W	W	W	W	W	W			
9	Jagannathpur	Naljur						W	W	W	W	W	W	W	W	W	W	W	W	W			
10	Khagapasha	Old Kushiyara	24	33.06	91	26.28	W	W	W	W	W	W	W	W	W	W	W	W	W	W			
13	Madhabpur	Singli	24	37.53	91	32.54	W	W	W	W	W	W	W	W	W	W	W	W	W	W			
15	Nilpur	Old Surma	24	59.70	90	23.27	W	W	W	W	W	W	W	W	W	W	W	W	W	W			
18	Ratna	Ratna Shatal						W	W	W	W	W	W	W	W	W	W	W	W	W			
19	Shadipur	Shadipur Khal						W	W	W	W	W	W	W	W	W	W	W	W	W			
20	Terapasha	Bijna	24	33.09	91	36.53		W	W	W	W	W	W	W	W	W	W	W	W	W			
21	Katakhali	Kalni	24	37.27	91	18.20	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	
22	Shantipur	Kalni	24	28.86	91	11.17	W	W	W	W	W	W	W	W	S	S	S	S	S	W	W		
23	Kadamchal	Kalni	24	25.70	91	12.21	W	W	W	W	W	W	W	W	S	S	S	S	S	S	W	W	
24	Dhanpur	Gachiduar											W	W	W	W	W	W	W	W			
25	Gazaria	Kalni	24	32.10	91	13.25												S	S	S	S	S	S
26	Kakailseo	Kalni	24	30.55	91	12.20										S	S	S	S				
27	Kaisar	Cherapul khal	24	27.17	91	9.47								Q	Q	Q	Q	Q	Q	Q			

Legend :
B = Station corresponding to BWDB
S= Suspended sediment station (including discharge and water level)
Q = Discharge and water level
W = Water level only
Note : Discharge at Sherpur estimated from published rating curves.

The Survey of Bangladesh (SOB) conducted the surveys, CIDA provided the funding, and NERP provided a field monitor and administered the program. The program is summarized in Table B.6.

Table B.6: 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

Table B.7 presents the results of the survey. At about 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 (Chamraghat, Chelasonapur, and Jagannathpur). The largest correction is 1.6 m at Jagannathpur. The most significant datum errors occurred 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.

Final results of the survey program were incorporated into the simulations of the MIKE 11 model.

Table B.7: 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	14%
Total	77	**100%**

During the feasibility study all new surveys by NERP (1994-96) have been tied to the new datum. The additional new benchmarks provided for more efficient and more accurate surveys.

4.5 Floodplain Topography

No particular surveys were carried out to update the topography of the floodplain. The floodplain topography was based on the Survey of Bangladesh 4"=1 mile topographic maps. These 1:15,840 scale maps were produced from air photos taken in 1962/63 and field verification in 1964. Ground topography is represented with 0.3 m interval contours and spot levels. The maps were digitized to provide a base map. It should be noticed that sediment deposition may have changed some local elevations between the time the air photos were taken and the KKRMP feasibility study was carried out.

5. MODEL CALIBRATION AND VERIFICATION

Calibration is the process of adjusting certain model parameters (essentially channel and floodplain roughness) so it can reproduce observed conditions within acceptable limits. Once the initial calibration was completed, a set of independent verification runs were made to ensure the calibration was stable and to assess the model's overall accuracy. Finally, a sensitivity analysis was made to assess how floodplain water levels were affected when water levels on the main channel of the Kalni River were lowered.

5.1 Comparisons with Northeast Regional Model

A number of preliminary test comparisons were made with the full Northeast Regional Model to ensure that the model was formulated accurately and was able to reproduce the results of the full model. This is the most fundamental test of a sub-model when it is first built out of a larger model. After this test, the schematisation, discretisation and the roughness values can be changed within physically meaningful limits to improve the sub-model's accuracy.

5.2 Calibration using 1991-1993 Data

Once it was verified that the basic model schematization and channel geometry were correctly represented, an iterative calibration procedure was conducted to adjust the roughness of the channel and floodplain and parameters that controlled overbank spills. In most locations, calibration results were judged by comparing simulated water levels and discharges with recorded values at the same locations. These calibration runs were made using hydrometric data and cross-section survey data from 1991, 1992 and 1993. Although the goodness of fit was based on comparison of annual hydrographs, particular attention was given towards the fit during the pre-monsoon season. This was because the most critical modelling tasks involved predicting project impacts during the pre-monsoon flood season.

The simulated peak water levels during the pre-monsoon season were within 0.3 m of the observed values in virtually all locations. Comparisons between observed and recorded water levels and discharges at key locations in the pre-monsoon season are summarised in Figures B.6 to B.8 and are described briefly below.

Sherpur on Kushiyara River (Figures B.6 and B.7): Good agreement with peak water levels and hydrograph shape in all years. Peak discharges were underestimated by around 10% in 1991, while excellent agreement was achieved in 1992 and 1993;

Markuli on Kalni River (Figure B.6): Good agreement with peak water levels (no discharge data available);

Ajmiriganj on Kalni River (Figure B.6): Good agreement with peak water levels (no discharge data available);

Madna on Dhaleswari River (Figure B.6): Excellent agreement in water levels (no discharge data available);

Sukdevpur and Itna on Baulai River (Figure B.8): Excellent agreement with water levels (no discharge data available);

On the basis of these runs, the following Manning's roughness values were adopted for the Kalni-Kushiyara River:

- main channel roughness = 0.033
- floodplain roughness = 0.05

5.3 Verification with 1995-1996 Flow Data

Verification involves testing the stability of the model calibration by comparing the observed and predicted water levels and discharges using data that were not included in the original calibration. These comparisons provided the ultimate test of the model's ability to realistically simulate the current flow conditions and the hydraulic effects induced by changes in channel topography. In this investigation, verification runs were made by using the model calibration parameters developed from the 1991 to 1993 data to predict hydraulic conditions in 1995 and 1996. It was realized that substantial changes have occurred to the channel topography along portions of the river since 1991. Therefore, the channel geometry along the Kalni-Kushiyara River reach was updated to include the new survey information from 1995-1996. All other parameters in the model were kept the same as in the previous calibration runs. Measured discharges and rainfall for 1995-1996 were not available at all model boundary inflow points at the time of these investigations. As a result, it was not possible to simulate the 1995-1996 flows and directly compare the observed and predicted hydrographs. Therefore, an alternative approach was adopted by re-running the 1991 and 1993 inflow hydrographs using the 1995 channel topography. The predicted stage-discharge relations at selected cross-sections were then compared with observed stage-discharge rating curves that were established from NERP's hydrometric measurements in 1995-1996.

Figure B.9 compares the predicted and observed stage-discharge relations at all hydrometric stations that were operated by NERP in 1995-1996. The observed rating curves were developed by making "best-fit" regression equations using the measured discharges and water levels from the 1995 and 1996 pre-monsoon seasons. The predicted stage-discharge rating curves were derived from the MIKE-11 model output for the pre-monsoon. The agreement between the observed and predicted relation was judged to be good, particularly at Sherpur, Markuli, Ajmiriganj and Kadamchal.

Another verification was made by comparing the observed and predicted flow splits at key bifurcation points along the river. Table B.8 summarizes the predicted and measured flow splits during the pre-monsoon season at Cherapur Khal and the Baida/Kalni bifurcation. The agreement was judged to be reasonably good, particularly when it is recognized that the accuracy of the measured discharges is probably within ± 10%. Exact coincidence of the simulated and observed values can not be expected under all conditions due to the practical limitations of model schematization, data accuracy and channel adjustments during the simulation period.

Table B.8: Predicted and Measured Flow Splits on Kalni River

Location	Predicted Split Ratio		Measured Split Ratio		Discharge (m^3/s)
	Kalni	Distributary	Kalni	Distributary	
Cherapur Khal	0.76	0.24	0.75	0.25	1,350
Baida Bifurcation	0.40	0.60	0.47	0.53	1,000

On the basis of these results it was judged that the model is able to represent the hydraulic effects of the proposed project alternatives on the water levels and discharges on the main channel, particularly since the magnitude of the change is generally more important than the absolute value of the predicted water levels. Verification of the floodplain water levels and the extent of flooding remains problematic, since there is relatively little quantitative information available in some parts of the project area. Therefore, information from field investigations, interviews with local inhabitants and the experience and judgement of the water resource planners all were utilized to judge the reasonableness of the estimates in these areas.

5.4 Sensitivity Analysis

Preliminary test runs were made to estimate the likely range of water level variations and the areal extent of project impacts out on the floodplain from project interventions on the river downstream of Ajmiriganj. First a "baseline condition" was run for the 1991 pre-monsoon flood flows. To replicate the effects of channel improvements a run was conducted with the water levels in the Kalni River at Ajmiriganj lowered by about a metre below the base condition. This reduction was accomplished by artificially reducing the Manning's roughness coefficient in the reach between Ajmiriganj and Madna. Predicted floodplain water levels were extracted from the two model runs and compared. It was found that the resulting water level changes out on the floodplain ranged from 0.3 m directly north and south of Ajmiriganj and were less than 0.1 m upstream of Markuli at the time of the flood peak. These results demonstrate that during an extreme pre-monsoon flood (approximately a 1:10 year return period at Sherpur), changes in water levels in the main channel induce relatively small changes out on the floodplain. However, the impacts extend over a large area.

6. SIMULATION OF PROJECT SCENARIOS

6.1 Method of Approach

6.1.1 Project Scenarios

The calibrated model was used to assess the impacts of various project concepts and scenarios. An initial baseline run was made to represent the present (1996) conditions. Studies were carried out to assess the trends in sedimentation and morphology that have been occurring along the river. On the basis of these studies, a "future without project" scenario was developed to represent conditions 30 years in the future, in 2026. The channel topography in the model was then modified to reflect these changes and a run was made to predict the new conditions.

Following this, a number of test runs were made to assess the incremental effects of various project interventions, including loop cuts, channel closures and channel re-excavation. After assessing these findings, final runs were made for two project Alternatives:

Alternative 1: two loop cuts at Issapur and Katkhal, closure of spill channels upstream of Ajmiriganj and channel re-excavation along portions of the Kalni River;

Alternative 2: one loop cut only at Katkhal, channel re-excavation along the Kalni-Dhaleswari River and closure of spill channels upstream of Ajmiriganj.

The project was designed to effectively confine the 1:5 year pre-monsoon flood within bankfull conditions while eliminating major upstream spills. Additional studies were made to assess whether further channel re-excavation could confine the 1:10 year pre-monsoon flood. Based on these considerations, the following scenarios are described in this annex:

- Present conditions;
- Future without project scenario;
- Loop cuts at Issapur and Katkhal;
- Closure of spill channels upstream of Ajmiriganj;
- Alternative 1 - 1:5 year design criteria;
- Alternative 1 - 1:10 year design criteria, and
- Alternative 2 - 1:5 year design criteria.

The impacts of the scenarios were all assessed for three pre-monsoon flood conditions, the 1:2 year, 1-5 year and 1:10 year floods. In addition, impacts during the monsoon season and post-monsoon season were also reviewed.

6.1.2 Adopted Hydrological Conditions

The adopted pre-monsoon flood conditions for the project were based on a frequency analysis of discharges at Sherpur hydrometric station. Results of the flood frequency analysis were presented in Section 2.3 of this report. Table B.1 lists the discharges at Sherpur for various flood frequencies. Figure B.4 shows the pre-monsoon and annual maximum daily flood frequency plots.

Continuous simulations were made using inflow conditions from 1991 and 1993. These years were chosen because they included a good representation of pre-monsoon floods, with up to a 1:10 year flood occurring in 1991 and a 1:2 year flood occurring in 1993 at Sherpur. In fact, the 1991 flood is the last major pre-monsoon flood on the Kalni-Kushiyara River. Table B.9 lists the dates corresponding to the adopted 2-year, 5-year and 10-year pre-monsoon flood discharges at Sherpur. Figure B.10 shows the inflow hydrographs at Sherpur. The dates corresponding to the adopted 2-year, 5-year and 10-year pre-monsoon floods have also been marked on the plots. The predicted water levels were output from the model on these dates at various locations in the project area in order to assess the extent of inundation under the adopted design flood conditions.

Table B.9: Dates of Adopted Pre-monsoon Floods at Sherpur

Return Period (Year)	Date of Occurrence	
	1991	1993
2	May 4	May 5
5	May 7	-
10	May 10	-

During the simulations it was found that the exact time of occurrence of the adopted flood discharges varied slightly (typically by one day or less), depending on the channel modifications represented in the model. This indicates that the proposed interventions had a negligible impact on the shape and time base of the inflow hydrograph at Sherpur. In order to provide a consistent set of results for comparing project impacts, the predicted water levels in the project area were output when the discharges at Sherpur matched the adopted 2-year, 5-year and 10-year flood conditions.

6.1.3 Assessment of Impacts on the Floodplain

The extent and depth of inundation in the surrounding project area was quantified for each project scenario. This was accomplished by generating a digital terrain model of the project area, interpolating the computed water levels on the floodplain over the same grid and then determining the depth of inundation at each grid point. The land elevations were established by digitising the 4 inch to 1 mile SOB topographic maps (surveyed in 1962). A grid interval of 200 m was used for the terrain modelling. The analysis was carried out using the program "SURFER". Other in-house computer programs were developed by NERP for extracting information from MIKE-11 output and for estimating the area of inundation for various flood depth intervals. The following flood depth classes were used in this analysis:

- < 0.3 m (considered to represent flood-free land);
- 0.3 m - 0.9 m (considered to represent shallow flooding);
- 0.9 m - 1.8 m (considered to represent moderate flooding), and
- > 1.8 m (considered to represent deep flooding).

A measure of the project's potential benefits to agriculture were expressed in terms of the increase in flood-free land (< 0.3 m of inundation) and the increase in shallowly flooded land (<0.9 m inundation) by comparing the "future-with-project" and "future-without-project" scenarios.

The presence of the existing submersible embankment projects in the modelled area complicated the estimation of flooding extent. Water levels inside these polder projects depends on (1) the outside water levels; (2) embankment elevation; (3) accumulated rainfall inside the polders; (4) the occurrence of spills or embankment breaches, and (5) the operating characteristics of the regulating structures. After carrying out several trial runs it was decided that the best approach was to use the model to predict flood levels outside these polders, and to estimate the levels inside by manual calculation. This required making some assumptions about the initiation of flooding inside the embankments. The following steps illustrate the procedure that was followed for the case of a 1:2 year pre-monsoon flood under present conditions:

Step 1: the depth and extent of inundation over the entire gross project area was estimated from the MIKE-11 output;

Step 2: the inundated area determined by the model, inside each submersible embankment project was then computed separately and excluded from the gross estimates;

Step 3: The depth of inundation inside the existing projects were re-estimated based on the outside water level and the accumulated rainfall inside it, and

Step 4: The inundated areas from Step 3 were then added back into the estimates from Step 2 to produce the adjusted total inundated area.

The initial (unadjusted) inundated areas are summarised in Table B.10 while the final adjusted areas are summarised in Table B.11. A test calculation was made to assess whether these adjustments to the flooding extent inside the embankments would have any effect on the predicted water levels outside of the structures on the floodplain. This could arise because the flow confinement effect predicted from the initial model runs is slightly less than the results predicted from the manual calculations. It was found that the results of the manual adjustment could affect the outside floodplain water levels by up to 3 cm in a 1:2 year pre-monsoon flood. This error is considerably lower than the accuracy of the calibration results and is well within the precision of the overall predictions. Therefore, it was concluded that this procedure will not significantly affect the predicted water levels outside of the existing embankment projects.

6.2 Present Conditions

Bankfull conditions are reached near a 1:2 year pre-monsoon flood along most of the Kalni River and portions of the Kushiyara River up to about Raniganj. Under these conditions, the bankfull pre-monsoon discharge will be around 1,750 - 2,000 m^3/s between Markuli and Ajmiriganj and around 1,350 m^3/s below Cherapur Khal. Spills may occur at local weak points in the banks or at poorly constructed temporary closures. Figures B.11 to B.13, adjusted for existing FCDI projects, show the estimated extent of inundation caused by 1:2 year, 1:5 year and 1:10 year pre-monsoon floods. The simulations include local rainfall in the project area.

During a 1:2 year pre-monsoon flood, 21% of the project area was inundated to a depth greater than 0.3 m, with flooding occurring primarily in the following areas:

- south of Koyer Dhala;
- north of Markuli;
- north and west of Ajmiriganj;
- west of Katkhal along Cherapur Khal, and
- along the Barak - Ratna floodplain north of Madna.

Table B.10: Pre-monsoon Flood Extent (not adjusted for submersible embankments)

Run	ID number	Flood Depth Range (m)	Area in Flood Depth Range (ha) Return Period 1:2 Year	1:5 Year	1:10 Year
Present Condition	B-100	< 0.3	228,809	92,610	45,527
		0.3 - 0.9	68,992	89,677	48,358
		0.9 - 1.8	30,683	106,562	131,710
		> 1.8	7,116	46,751	110,005
		< 0.9	297,801	182,287	93,885
		Inundation	31.8%	72.4%	86.4%
Future Without	FWO-101	< 0.3	211,005	83,785	40,886
		0.3 - 0.9	75,419	80,826	44,430
		0.9 - 1.8	40,044	115,258	121,482
		> 1.8	9,131	55,730	128,802
		< 0.9	286,425	164,611	85,316
		Inundation	37.1%	75.0%	87.8%
Alternative 1	FW-109	< 0.3	262,604	113,729	59,326
		0.3 - 0.9	47,134	95,849	55,347
		0.9 - 1.8	20,277	84,550	123,854
		> 1.8	5,586	41,472	97,074
		< 0.9	309,738	209,578	114,673
		Inundation	21.8%	66.1%	82.3%
Alternative 2	FW-119	< 0.3	254,493	106,051	54,862
		0.3 - 0.9	53,255	95,798	49,685
		0.9 - 1.8	22,164	91,131	124,135
		> 1.8	5,688	42,620	106,919
		< 0.9	307,748	201,850	104,547
		Inundation	24.2%	68.4%	83.7%

Notes: 1. Inundated areas are gross values unadjusted for the presence of submersible embankment projects
2. Per cent inundation = (Land area flooded by >0.3 m / Total Area)*100

Table B.11: Estimated Pre-monsoon Flood Extent (adjusted for submersible embankments)

Run	ID number	Flood Depth Range (m)	Area in Flood Depth Range (ha)		
			Return Period		
			1:2 Year	1:5 Year	1:10 Year
Present Condition	B-100	< 0.3	266,100	117,471	45,527
		0.3 - 0.9	35,890	67,609	48,358
		0.9 - 1.8	26,494	103,770	131,710
		> 1.8	7,116	46,751	110,005
		< 0.9	301,990	185,080	93,885
		Inundation	20.7%	65.0%	86.4%
Future Without	FWO-101	< 0.3	235,867	96,215	40,886
		0.3 - 0.9	53,352	69,793	44,430
		0.9 - 1.8	37,252	113,863	121,482
		> 1.8	9,131	55,729	128,802
		< 0.9	289,219	166,008	85,316
		Inundation	29.7%	71.3%	87.8%
Alternative 1	FW-109	< 0.3	299,971	151,428	85,333
		0.3 - 0.9	13,981	62,594	32,743
		0.9 - 1.8	16,062	80,132	120,527
		> 1.8	5,586	41,446	96,997
		< 0.9	313,952	214,022	118,076
		Inundation	11.0%	54.8%	74.6%
Alternative 2	FW-119	< 0.3	291,784	143,342	79,722
		0.3 - 0.9	20,153	62,696	27,617
		0.9 - 1.8	17,975	86,942	121,343
		> 1.8	5,688	42,620	106,919
		< 0.9	311,937	206,038	107,339
		Inundation	13.1%	57.3%	76.2%

Notes:
1. Inundated areas have been adjusted to account for presence of existing submersible embankments
2. Per cent inundation = (Land area flooded by >0.3 m / Total Area)*100

Under more extreme pre-monsoon floods, bankfull conditions were exceeded over most of the river downstream of Markuli. Furthermore, the magnitude of spills into the adjacent floodplain increased substantially between Sherpur and Ajmiriganj. For example, at a 1:5 year pre-monsoon flood it was estimated that 26% of the flow will be lost between Sherpur and Ajmiriganj. Consequently, the extent of inundation in the project area increased to 65% at a 1:5 year flood and up to 86% at a 1:10 pre-monsoon flood (Table B.11).

During monsoon flood conditions, backwater from the Lower Meghna River drowns out most of the floodplain west of Ajmiriganj. During an extreme monsoon flood (1:10 year) the top of bank will be exceeded by up to 2 m along the lower Kalni River and Dhaleswari River.

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6.3 Future Without Project Scenario

The "future without project" (FWO) scenarios were estimated for a time period of 30 years, ending in the year 2026. Figure B.14 shows the future without project scenario. It was assumed that the main spill channels upstream of Ajmiriganj would remain open during major floods. It was also assumed that Cherapur Khal would continue to grow and would develop into an important branch of the Kalni River. Consequently, sediment deposition would occur along the Kalni-Dhaleswari River downstream of the bifurcation in response to the reduced flows. This trend has already been documented by NERP's river survey monitoring programme. For the purposes of this investigation it was assumed that the average bed levels would rise by 1.5 m on the lower Kalni River and 1.0 m on the Dhaleswari River. The channel width remained unchanged. It was assumed that Cherapur Khal would enlarge until its cross-section was similar to the Kalni River near Katkhal.

With these assumptions, the model showed the flow split into the Baulai River through Cherapur Khal would increase from around 20 - 30% at present to between 45 - 65% in the future. Peak pre-monsoon flood levels in the lower Kalni River increased by 0.2 - 0.35 m (Figures B.15 to B.18).

Table B.11 and Figures B.19 to B.21 show the extent of inundation during 1:2 year, 1:5 year and 1:10 year pre-monsoon floods for the future without project scenario. The greatest impacts from the channel changes occurred at the 2-year pre-monsoon flood condition, with the extent of inundation increasing by 30,233 ha. Most of this additional inundation occurred along the Cherapur channel west of Katkhal and along the Barak-Ratna floodplain northeast of Madna.

6.4 Impact of Loop Cuts

The proposed loop cuts at Issapur and Katkhal are intended to improve the river's stability and reduce sediment deposition in these reaches. They shorten the length of the main channel by 16.5 km and 5.5 km respectively, which will steepen the water surface gradient and lower the water levels upstream of the cuts.

Test runs were made to assess the magnitude and extent of impacts from loop cutting. Initial hydraulic computations were made to develop preliminary designs of the fully excavated channels. The new channels were then schematised in the model to correctly represent the modified alignment. The portion of the existing channel near Katkhal was assumed to be closed. Initial calculations at the Issapur loop cut showed the Baida River channel should be left open, since it carries most of the flow during high flows. However, it was assumed that the Kalni branch would be closed just downstream of Issapur in order to prevent sediment from being deposited in the branch of the channel near Madna.

The effect of the loop cuts on water levels was found to be greatest during the pre-monsoon and dry seasons, when the river slopes are steepest. It is negligible during the monsoon and post-monsoon season when the gradients are backwater controlled. The Issapur loop cut lowered the pre-monsoon flood levels by 0.5 - 0.7 m immediately upstream of the cut (Figure B.22). Pre-monsoon flood levels at Madna and on the adjacent Ratna - Barak floodplain were lowered by approximately 0.4 m. However, the upstream extent of the improvements was relatively limited.

By Kadamchal, 15 km upstream of Issapur, the peak pre-monsoon flood levels were lowered by about 0.2 m. The Katkhal loop cut lowered peak pre-monsoon flood levels by approximately 0.5 m near Rahala and by 0.25 m 10 km upstream near Ajmiriganj.

Channel degradation upstream of the loop-cuts will eventually lower water levels further. Consequently, over a period of several years, flood levels at Kadamchal should be reduced by approximately the same amount as at Issapur (0.5 - 0.7 m). Water levels at Ajmiriganj will be reduced by the cumulative effects of degradation from both loop cuts, so the ultimate long-term water level lowering should be around 1 m during conditions when the flows remain confined within the channel and are not backwater controlled.

The simulations demonstrated that loop-cuts alone will reduce pre-monsoon flood levels upstream of the cuts, but are not adequate to eliminate flooding altogether.

6.5 Impacts of Spill Closures

Bank protection will be constructed at locations where persistent pre-monsoon spills and bank breaching has occurred in the past. These structures are designed to overtop during extreme floods and will be submerged throughout most of the monsoon season. The effect of closing all right and left bank spills between Ajmiriganj and Sherpur was investigated in the model to determine the effect on discharges and water levels in the adjacent floodplain and in the main river channel. The spills were represented in the model by a series of overflow weirs and the magnitude of the spills was controlled by adjusting the height of the weir crest. The location of the spill channels are shown schematically in Figure B.14.

The model was very effective in demonstrating the impact of closing the spill channels in the FW conditions and confining the flows in the reach upstream of Ajmiriganj. Table B.12 summarises the estimated discharges carried by the main channel at various locations downstream of Sherpur. When the spills were eliminated under FW conditions, discharges into the floodplain were reduced, which decreased the extent of inundation north and south of the Kushiyara River. However, pre-monsoon discharges were increased above existing conditions by between 15 - 25% at Ajmiriganj, which increased the magnitude of spills through Cherapur Khal. The increased discharges also raised water levels along the Kalni River, which will tend to offset the effect of other downstream channel improvements.

Water levels on the Kushiyara River upstream of the closures were increased as a result of backwater effects. This increased the magnitude of spill into Damrir Haor, north of Fenchuganj.

Therefore, the benefits of closing the spill channels need to be considered very carefully against the potential increase in flooding upstream and downstream.

6.6 Alternative 1

1:5 year Design Criteria
Alternative 1 includes loop cuts at Issapur and Katkhal, channel re-excavation along the Kalni River and closure of major spill channels on the Kushiyara River between Ajmiriganj and the old Bibiyana River channel (Figure B.23). Due to the variability in bank heights in some reaches, it was assumed that low levees might have to be provided in some localised reaches to contain the overflows. The overall goal of the Alternative was to effectively confine the 1:5 year pre-

monsoon flood within bankfull conditions, while eliminating the main spills upstream of Ajmiriganj.

Table B.12: Discharges along Kalni-Kushiyara River - Alternative 1

Location	Present Conditions (m^3/s)	Future Without Project (m^3/s)	Project-Alternative 1 (m^3/s)
1:2 year pre-monsoon flood discharge			
Sherpur	1,704	1,691	1,705
Markuli	1,556	1,287	1,661
Below Koyer Dhala	1,417	1,153	1,625
Ajmiriganj	1,378	1,143	1,609
Below Cherapur Khal	976	330	1,311
Baida River channel	565	323	300
1:5 year pre-monsoon flood discharge			
Sherpur	2,410	2,401	2,400
Markuli	1,929	1,559	2,310
Below Koyer Dhala	1,798	1,433	2,283
Ajmiriganj	1,789	1,430	2,270
Below Cherapur Khal	1,429	521	1,998
Baida River channel	966	517	685

Requirements for channel re-excavation had to be determined through a series of iterative calculations which involved modifying the channel geometry, executing the model run, and evaluating the project impacts. This process was repeated until the flow was judged to be confined in the channel.

Table B.12 summarises the discharges at various points along the river with this Alternative and for the "future without" (FWO) and present condition. Due to the confinement of the flow, the peak discharge at Ajmiriganj will be increased above existing conditions by 17% at the 2-year pre-monsoon flood and by 27% at the 5-year pre-monsoon flood condition.

Given that the discharge at Cherapur Khal is equal to the discharge at Ajmiriganj minus the discharge below Cherapur Khal, for the 1:2 year pre-monsoon flood, the flow at Cherapur Khal is 402 m^3/s under present condition, 813 m^3/s under "future without project" condition and 298 m^3/s under "future with project" condition. Therefore, under Alternative 1, the flow through Cherapur Khal will be approximately 75% of the present values and 38% of the future without scenario. Flows in the Baida River channel below Issapur will remain close to those in the "future without" scenario. These flows are substantially lower than the present condition, since most of the discharge will be carried by the new channel.

The net result of Alternative 1 was to lower pre-monsoon flood levels by 0.35 - 0.45 m between Madna and Ajmiriganj in spite of the increased discharge carried by the main channel (Figures B.16 to B.18). Upstream of Markuli the lowering was negligible during peak pre-monsoon flood conditions. Peak pre-monsoon flood levels were lowered out on the floodplain by around 0.4 m northeast of Madna and by 0.3 - 0.4 m west of Ajmiriganj and near Cherapur Khal (Figure B.18).

Figure B.24 shows a longitudinal profile of the 1:5 year pre-monsoon flood levels and the bank levels. This profile shows the Alternative was able to maintain the water levels below the top of the bank except in localised areas just upstream of Katkhal and near Kadamchal. Consequently all major upstream spills were eliminated.

Figures B.25 to B.27 and Table B.11 summarize the extent of inundation in the project area. When compared to the "future without project" condition, Alternative 1 will increase the area of flood-free land by 64,104 ha during a 1:2 year pre-monsoon flood, by 55,213 ha during a 1:5 year pre-monsoon flood and by 44,447 ha during a 1:10 pre-monsoon flood. The extent of shallowly flooded land (areas subject to <0.9 m of inundation) will increase by 48,014 ha during a 1:5 year pre-monsoon flood and by 32,760 ha during a 1:10 year pre-monsoon flood.

These results show the project will continue to improve the flooding situation even during extreme events that exceed the adopted design criteria. This is primarily because the overall channel conveyance is increased by the channel improvements for all flow conditions. Secondly, preventing breaches at the upstream spill channels will reduce overflows even during extreme floods when the water levels exceed the top of the bank.

Figure B.15 shows project impacts on water levels over the entire year. As expected, monsoon flood levels were virtually unchanged by the channel improvements. The project had a major impact on post-monsoon and dry-season water levels on the Kalni - Kushiyara River. During December and January water levels were lowered by up to 1.5 m near Ajmiriganj and 1 m at Fenchuganj. Impacts to post-monsoon levels on the Ratna floodplain were estimated to be around 0.5 m in mid-December.

The primary effect of the project is the lowering of water levels. This is graphically illustrated in Figures B.28 to B.30 which show the profiles along the Kalni-Kushiyara River for the present, FWO and FW conditions for the three flood frequencies considered in the study. Figures B.31 to B.33 illustrate the effect of lowering the water levels in the floodplain between the FWO and FW scenarios for these same three flood frequencies.

1:10 Year Design Criteria

The 1:10 year pre-monsoon flood at Sherpur was estimated to be 2,834 m^3/s, which is about 20% higher than the 1:5 pre-monsoon flood condition and exceeds the value of the 1:2 year annual monsoon flood. Test runs were made to assess whether the 1:10 year pre-monsoon flood could be confined if further dredging was carried out. It was found that lowering bed levels downstream of Ajmiriganj had very little influence on water levels upstream of Ajmiriganj during this flood condition. Furthermore, it is not practical to significantly increase the channel cross-section upstream of Ajmiriganj since, with the exception of some local shoals, most of the channel is already very deep. Over-dredging downstream of Ajmiriganj could conceivably draw-down the upstream water levels, however, it was judged that this would not be sustainable, since the deep excavation in the dredged reach would simply fill-in quickly with sediment. On the basis of these findings, it was concluded that the proposed channel improvements will not be able to confine the 1:10 pre-monsoon flood over the length of the project. In order to meet a 1:10 year flood criteria, other measures such as submersible embankments would be required.

6.7 Alternative 2

Alternative 2 is similar to Alternative 1, except that the loop cut at Issapur was eliminated and instead an additional channel re-excavation was carried out on the lower Kalni River near Madna (Figure B.34). Alternative 2 will have a lower capital cost than Alternative 1 but will require greater channel maintenance dredging and will have reduced benefits to navigation over the life time of the project. Re-excavation upstream of Abdullahpur was kept identical to Alternative 1, as were the spill closures upstream of Ajmiriganj. Based on the results of the previous investigations, the works were planned on the basis of a 1:5 year design flood.

With Alternative 2, it was found virtually impossible to achieve the same water level reductions in the lower Kalni-Dhaleswari River as with Alternative 1. This was because additional dredging downstream of the Baida-Kalni bifurcation caused more flow to be diverted from the Baida channel into the Kalni channel, which reduced the effectiveness of the work. However, except for this lower reach, the pre-monsoon flood levels along the remaining upstream portions of the river were very close to the results from Alternative 1.

Figures B.35 to B.37 and Table B.11 summarize the extent of inundation in the project area. When compared to the "Future Without Project" scenario, this scheme will increase the flood free land by 55,917 ha during a 1:2 year pre-monsoon flood, by 47,127 ha during a 1:5 year pre-monsoon flood and by 38,836 ha during a 1:10 year pre-monsoon flood. These values are roughly 6,000-8,000 ha lower than for Alternative 1.

With Alternative 2, impacts to post-monsoon and dry-season water levels are generally similar to Alternative 1, except for the localised conditions on the Ratna floodplain near Madna. In this area, post-monsoon water levels with Alternative 2 are approximately the same as existing conditions.

7. CONCLUSIONS

The model has been successfully calibrated and verified using data from 1991-1993 and 1995-1996. The model was found to have reasonable accuracy at all locations. The reliability of the predicted water levels is lower out on the floodplain than in the main river channels. This is due to a lack of available data for calibration and verification. Variations in bank topography and year to year variations in bank conditions contribute to uncertainties in predicting the magnitude and location of spills during extreme floods.

The model was judged to be adequate for demonstrating the hydraulic effects of the proposed interventions, particularly since the magnitude of the predicted rise or drop is more important than the absolute accuracy of the water levels. More long-term field measurements of floodplain water levels and floodplain discharges are required to significantly improve the model simulation of these areas.

The model was very effective in demonstrating the effect of closing spill channels upstream of Ajmiriganj. Although the extent of inundation was reduced upstream of Ajmiriganj, the peak discharges on the Kalni River were increased, raising water levels and increasing downstream spills through Cherapur Khal. These results show that construction of any new closures should be phased after other downstream channel improvements, so that downstream flooding will not be made worse.

Alternative 1, which included loop cuts at Issapur and Katkhal, channel re-excavation at selected reaches along the Kalni River and Dhaleswari River and closure of spill channels upstream of Ajmiriganj, was able to confine the 1:5 year pre-monsoon flood within the banks with only minimal need for local levees. The extent of inundation in the surrounding project area was estimated to be reduced by 55,213 ha during a 1:5 year pre-monsoon flood.

Alternative 2, with the Issapur loop-cut replaced by additional channel re-excavation below the Baida bifurcation, was less effective in lowering pre-monsoon flood levels near Madna. Consequently, the increase in flood-free land, with Alternative 2, was approximately 8,000 ha less than in Alternative 1.

The impacts of project interventions during the monsoon season will be negligible. Dry season water levels near Ajmiriganj may be lowered by as much as 1.5 m. Impacts on post-monsoon drainage will be relatively small, because most major channels that formerly connected the river with the surrounding floodplain and *haor* areas have already been closed. Improvements to post-monsoon drainage are restricted primarily to the lower reach of the river around Cherapur Khal and Madna. Post-monsoon drainage improvements could be increased further if former connecting *khals* and channels were re-opened and provided with regulators to prevent pre-monsoon flooding. The effects of the Alternatives on water levels and flows downstream of the project area will be negligible.

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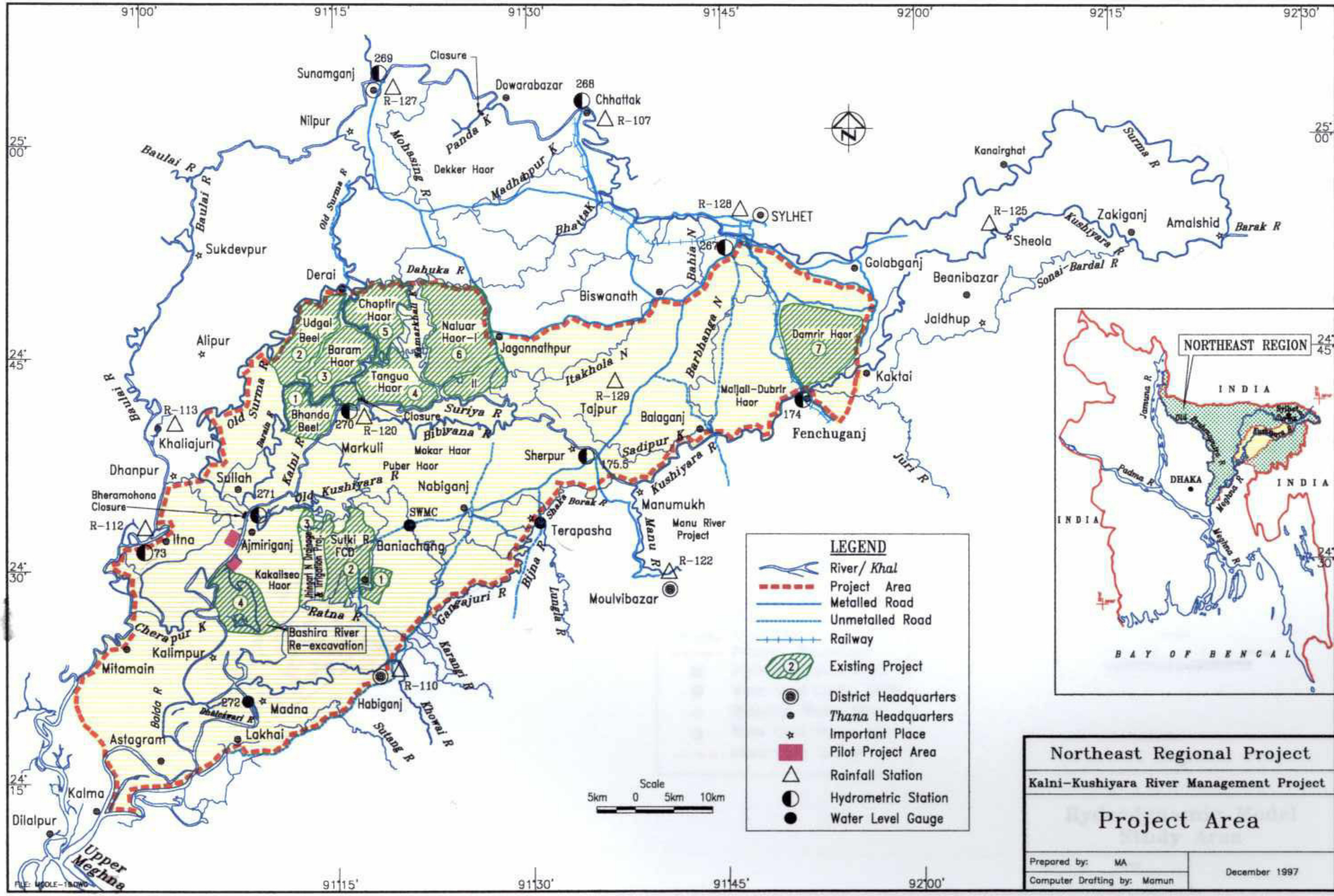
SWMC, 1997: "Mike 11 Model Development Manual", Surface Water Modelling Centre, March 1997.

SWMC, 1993: "Northeast Regional Model-Full Calibration Verification", Report, Surface Water Modelling Centre, December 1993.

FIGURES



Northeast Regional Project
Kalni-Kushiyara River Management Project
Project Area
Prepared by: MA
Computer Drafting by: Mamun
December 1997
LEGEND
River/ Khal
Project Area
Metalled Road
Unmetalled Road
Railway
Existing Project
District Headquarters
Thana Headquarters
Important Place
Pilot Project Area
Rainfall Station
Hydrometric Station
Water Level Gauge
Scale
5km 0 5km 10km
NORTHEAST REGION
INDIA
DHAKA
BAY OF BENGAL
Sunamganj
Nilpur
Dowarabazar
Chhattak
Closure
Dekker Haor
SYLHET
Kanairghat
Zakiganj
Amalshid
Barak R
Surma R
Kushiyara R
Sonai-Bardal R
Sheola
Golabganj
Beanibazar
Jaldhup
Kaktai
Fenchuganj
Juri R
Biswanath
Jagannathpur
Tajpur
Balaganj
Sherpur
Manumukh
Manu River Project
Moulvibazar
Terapasha
Nabiganj
Baniachang
SWMC
Habiganj
Madna
Lakhai
Astagram
Mitamain
Kalimpur
Ajmiriganj
Itna
Sullah
Dhanpur
Khaliajuri
Alipur
Sukdevpur
Derai
Markuli
Kalma
Dilalpur
Upper Meghna
Damrir Haor
Mallali-Dubrir Haor
Naluar Haor-I
Chaptir Haor
Udgal Beel
Baram Haor
Tangua Haor
Bhanda Beel
Kakailseo Haor
Sutki R FCD
Bashira River Re-excavation
Mokar Haor
Puber Haor
Bheramohona Closure
R-127
R-107
R-128
R-125
R-129
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175.5
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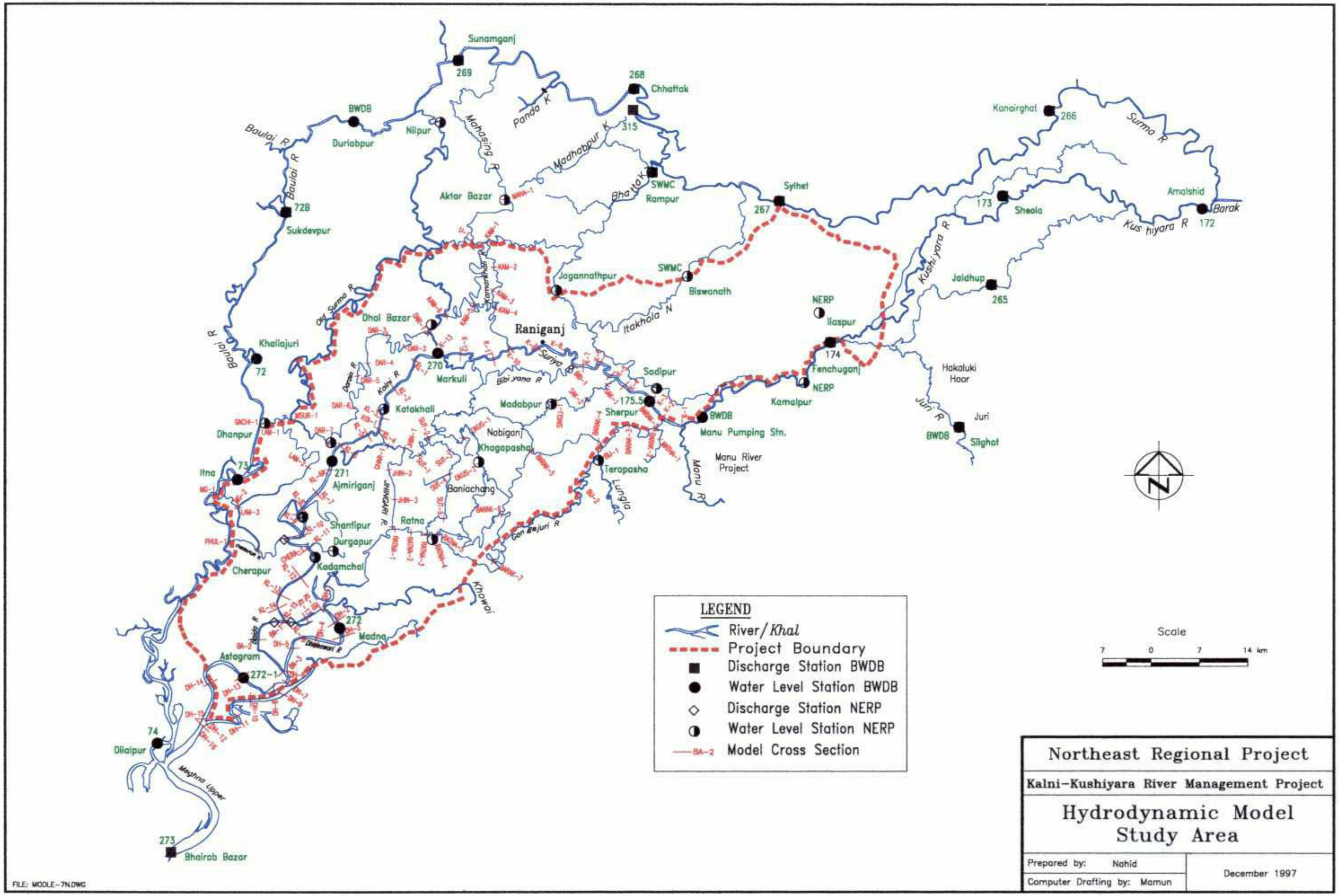
271
272

Figure B.1

Figure B.2


Northeast Regional Project
Kalni-Kushiyara River Management Project
Hydrodynamic Model
Study Area
Prepared by: Nahid
Computer Drafting by: Mamun
December 1997
LEGEND
River/Khal
Project Boundary
Discharge Station BWDB
Water Level Station BWDB
Discharge Station NERP
Water Level Station NERP
Model Cross Section
Scale
7 0 7 14 km
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Sunamganj
269
268
Chhattak
315
Kanairghat
266
Surma R
Amalshid
Barak
172
Kus hiyara R
173
Sheola
Sylhet
267
Kushiyara R
Jaldhup
265
BWDB
Durlabpur
Nilpur
Baulai R
728
Sukdevpur
Panda K
Mahasing R
Madhabpur K
Bhata K
SWMC
Rampur
Aktar Bazar
Jagannathpur
Biswanath
Itakhola N
NERP
Ilaspur
174
Fenchuganj
Kamalpur
Hakaluki Haor
Juri R
Juri
Silghat
Raniganj
Old Surma R
Dhal Bazar
Khaliajuri
72
270
Markuli
Bibiyana R
Sadipur
175.5
Sherpur
Manu Pumping Stn.
Manu River Project
Manu R
Madabpur
Katakhali
Kalni R
Darain R
Dhanpur
73
Itna
271
Ajmiriganj
Nobiganj
Khagapasha
Baniachang
JHINGARI R.
Ratna
Teropasha
Lungla
Gon Bejuri R
Shantipur
Durgapur
Kadamchal
Cherapur
Khowai
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Madna
Astagram
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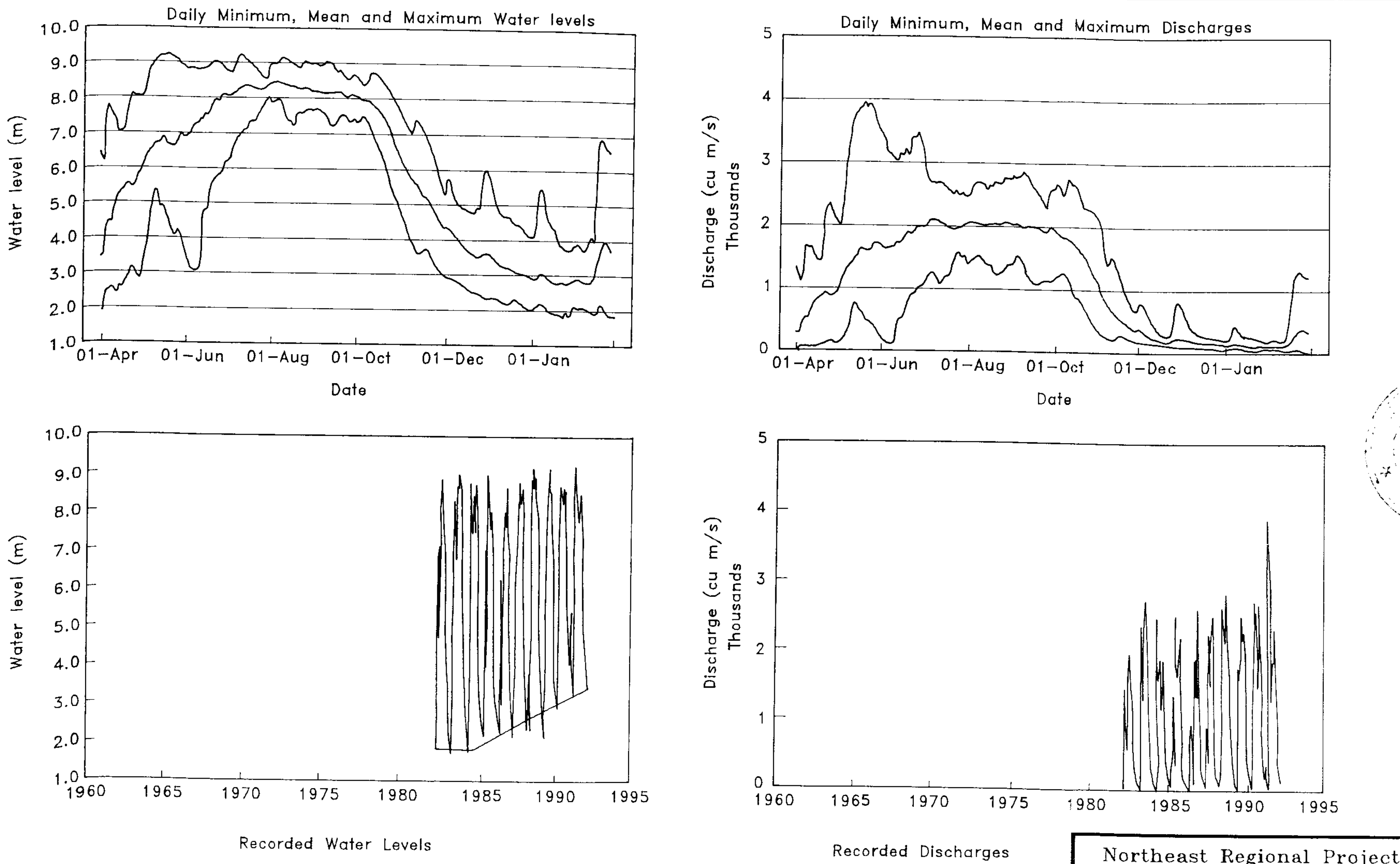
Meghna Upper
273
Bhairab Bazar

Figure B.3



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Kalni-Kushiyara River Management Project	
Kushiyara River Range of Discharges at Sherpur	
Prepared by: DGM/Tarek Computer Drafting by: Mamun	December 1997

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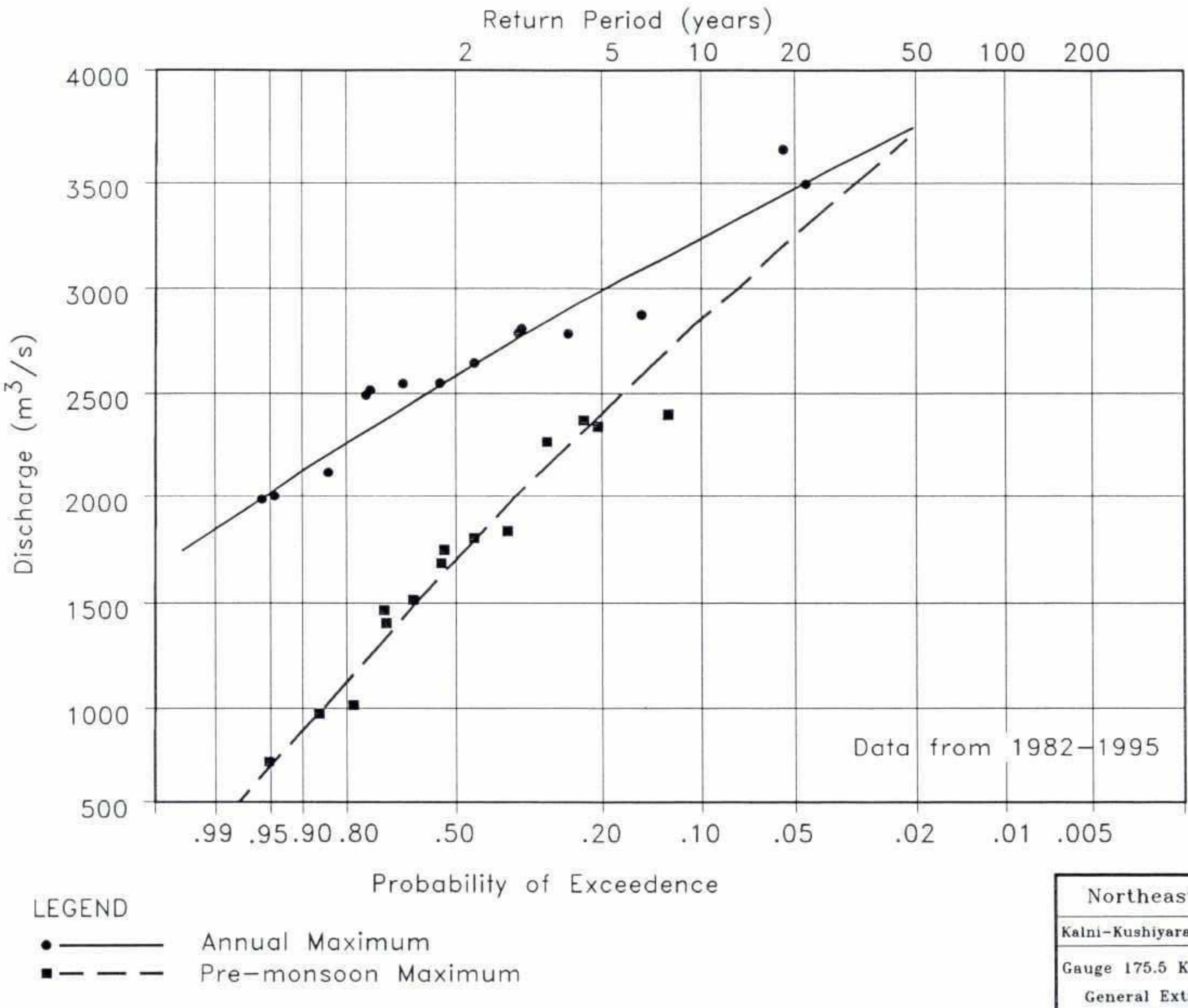
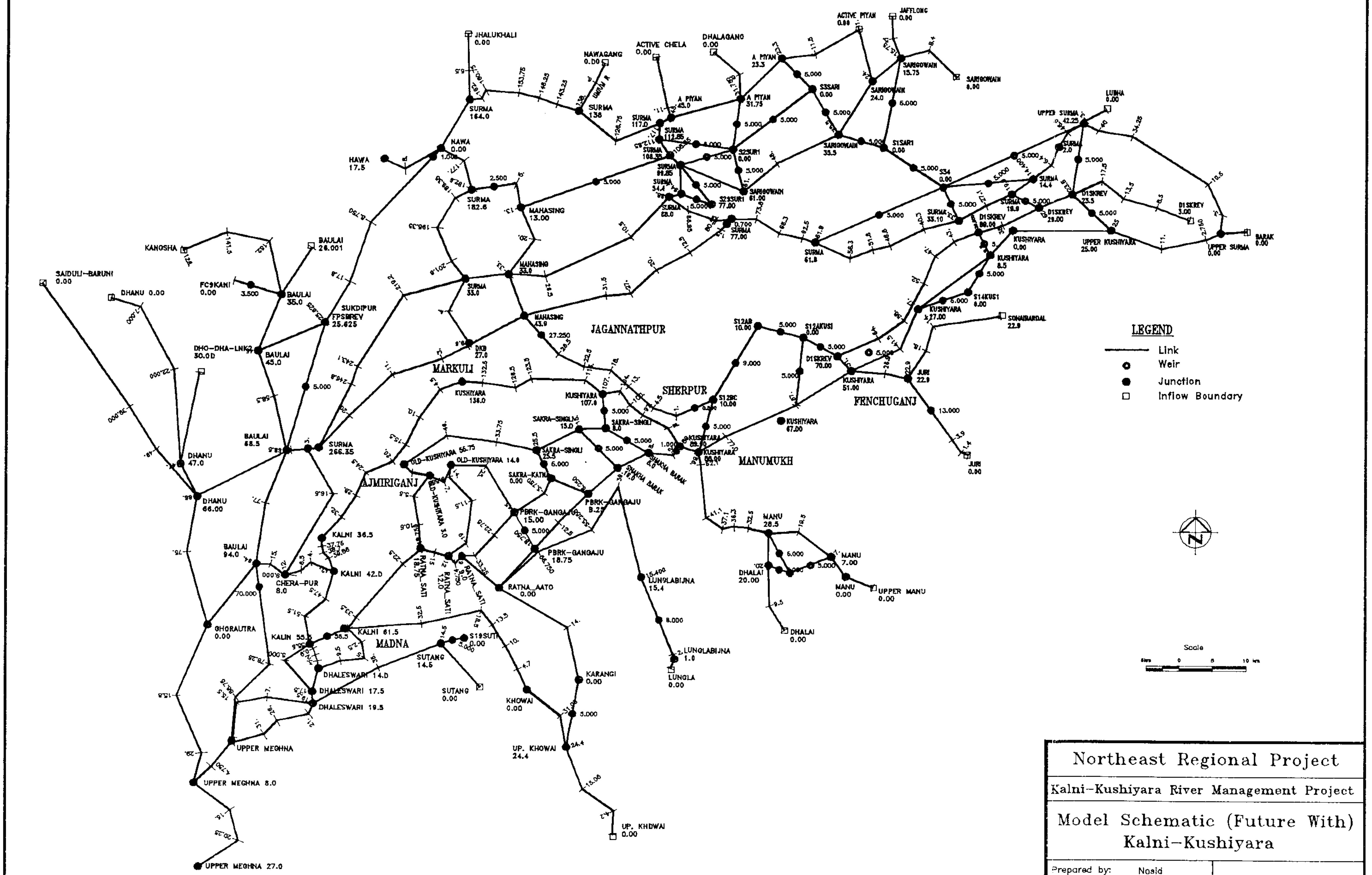


Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Gauge 175.5 Kushiyara River at Sherpur General Extreme Value Distribution	
Prepared by: Tarek	December 1997
Computer Drafting by: Mamun	

Figure B.5



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Northeast Regional Project

Kalni-Kushiyara River Management Project

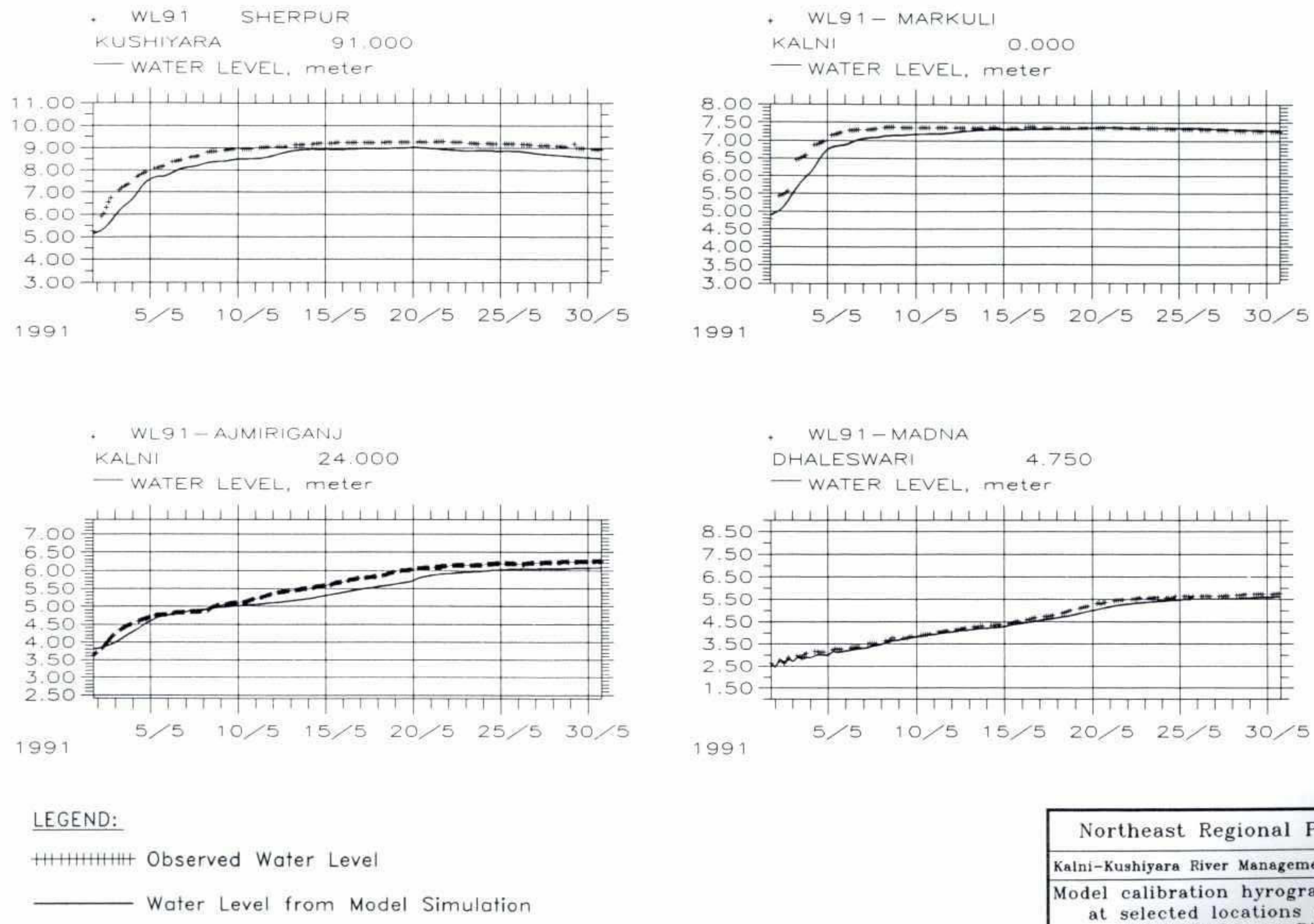
Model Schematic (Future With) Kalni-Kushiyara

Prepared by: Nasid

Computer Drafting by: Mamun

December 1997

Figure B.6



Northeast Regional Project	
Kalni-Kushiyara River Management Project	
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Prepared by: Nahid	December 1997
Computer Drafting by: Mamun	

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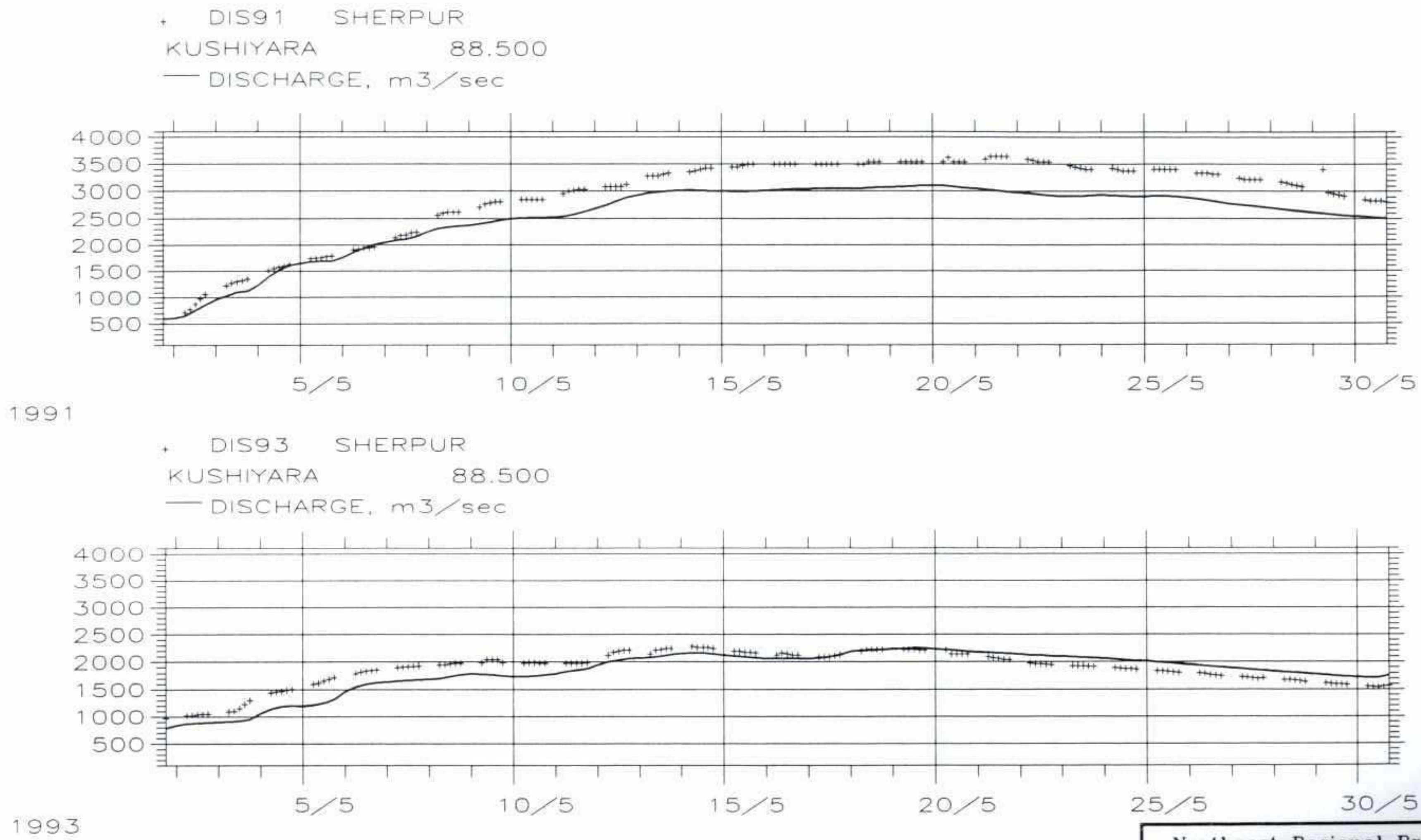


LEGEND:

++++++++++++ Observed Discharge

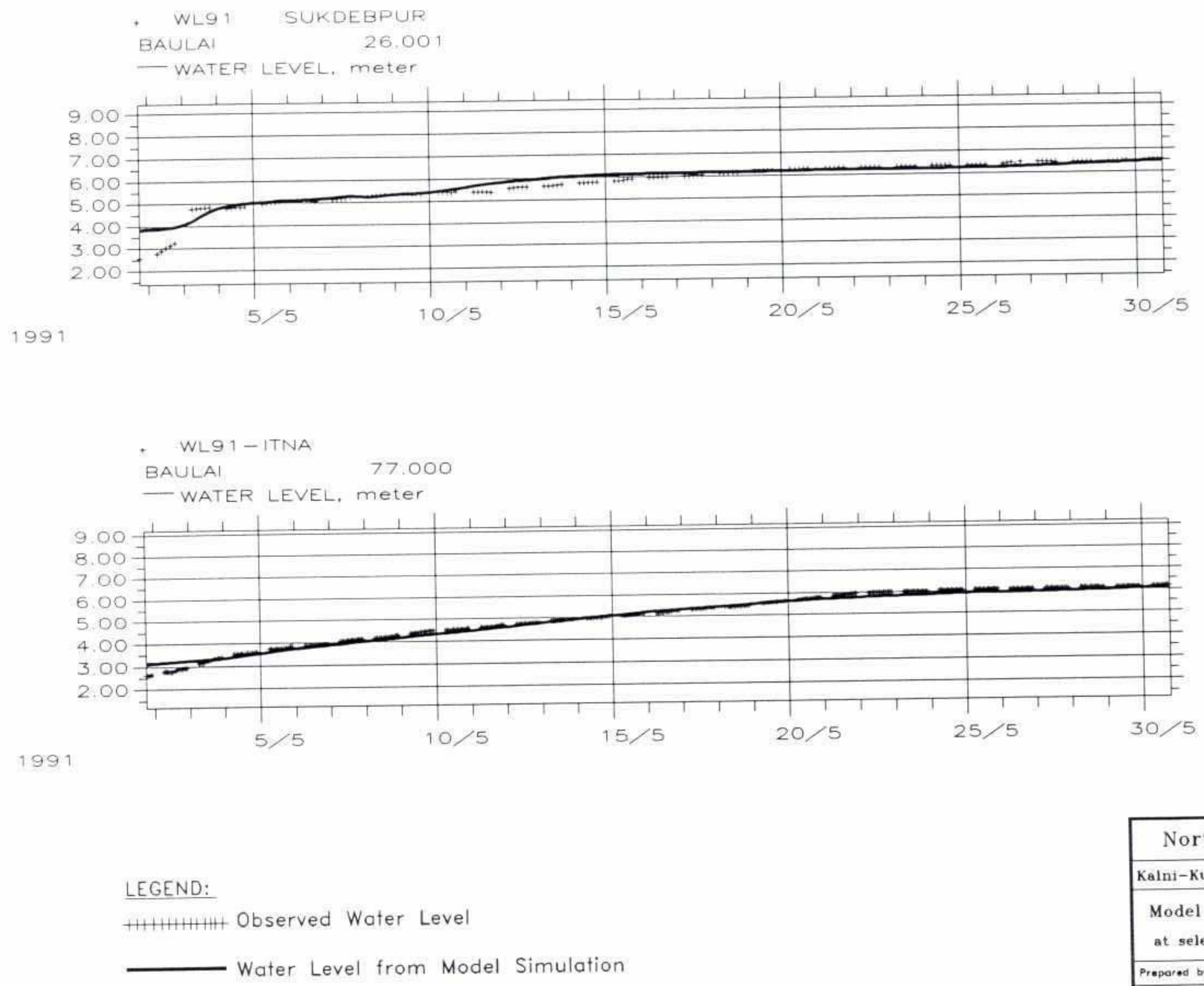
———— Discharge from Model Simulation

FILE: MODLE-08.DWG

Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Model calibration hydrographs 1991, 1993 at Sherpur on the Kushiyara R.	
Prepared by: Nahid	December 1997
Computer Drafting by Mamun	

Figure B.7

40



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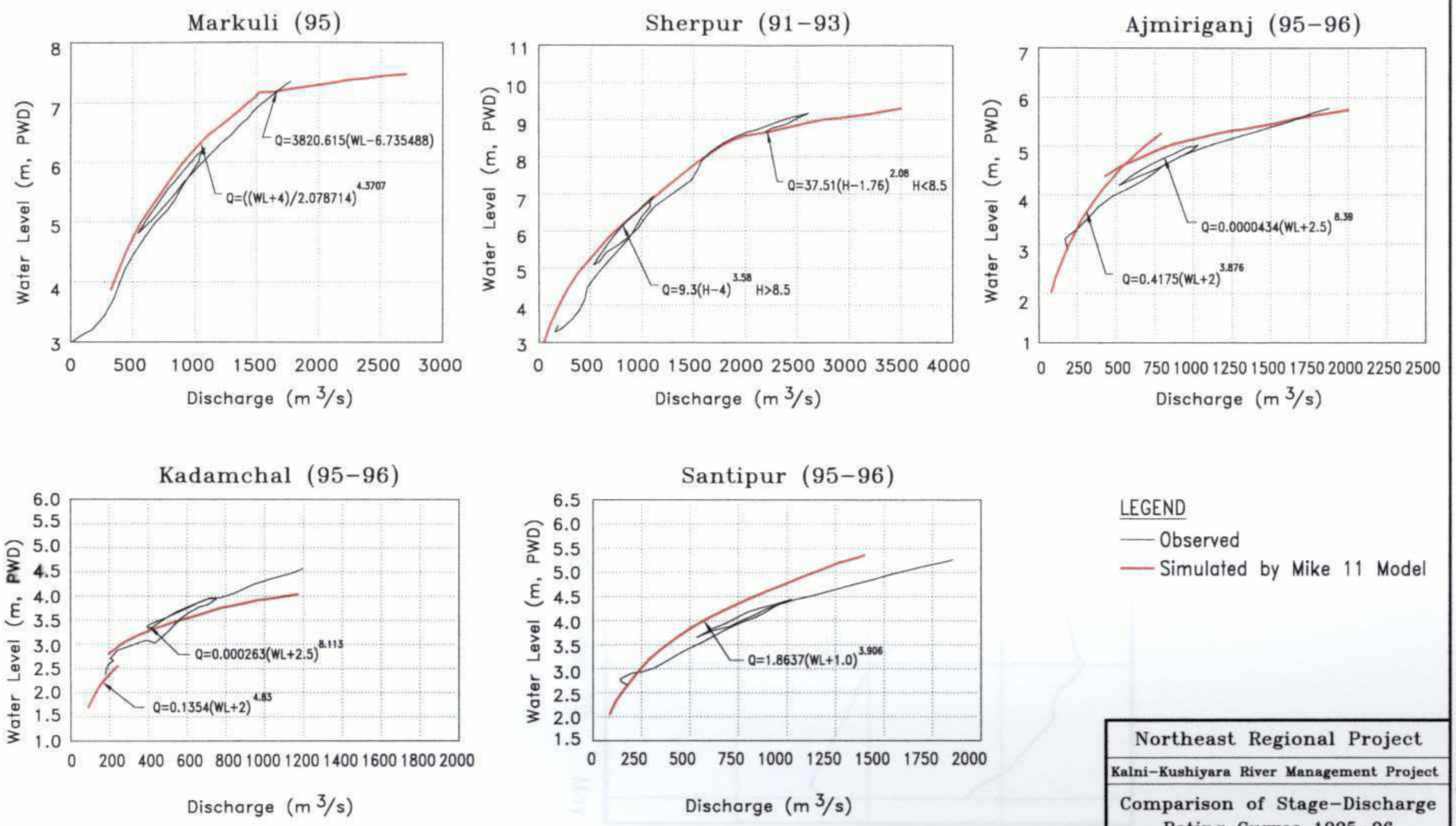
Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Model calibration hydrographs 1991 at selected locations on the Baulai River	
Prepared by: Nahid Computer Drafting by: Mamun	December 1997

Figure B.8

Figure B.9



Northeast Regional Project

Kalni-Kushiyara River Management Project

Comparison of Stage-Discharge Rating Curves 1995-96

Prepared by: Nahid	December 1997
Computer Drafting by: Mamun	

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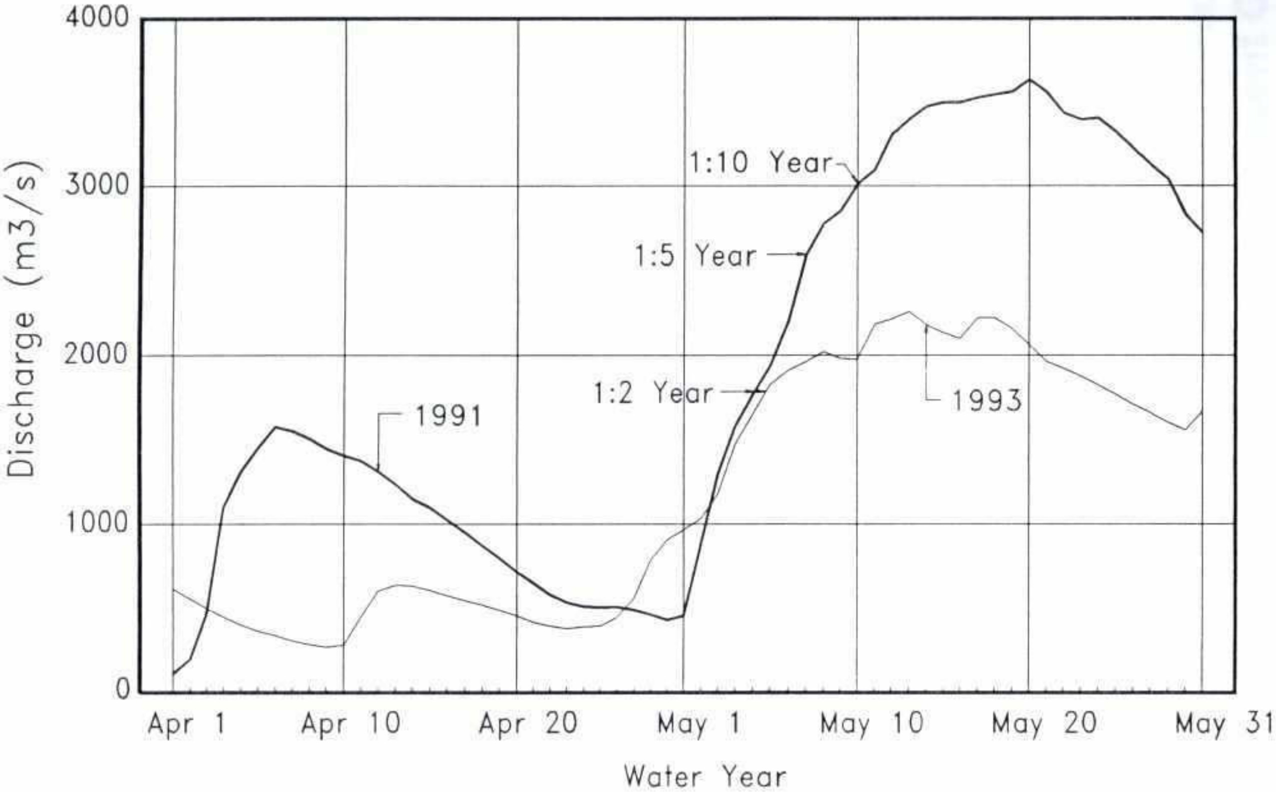
Figure B.10



Northeast Regional Project	
Kalni–Kushiyara River Management Project	
Pre–Monsoon Floods	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

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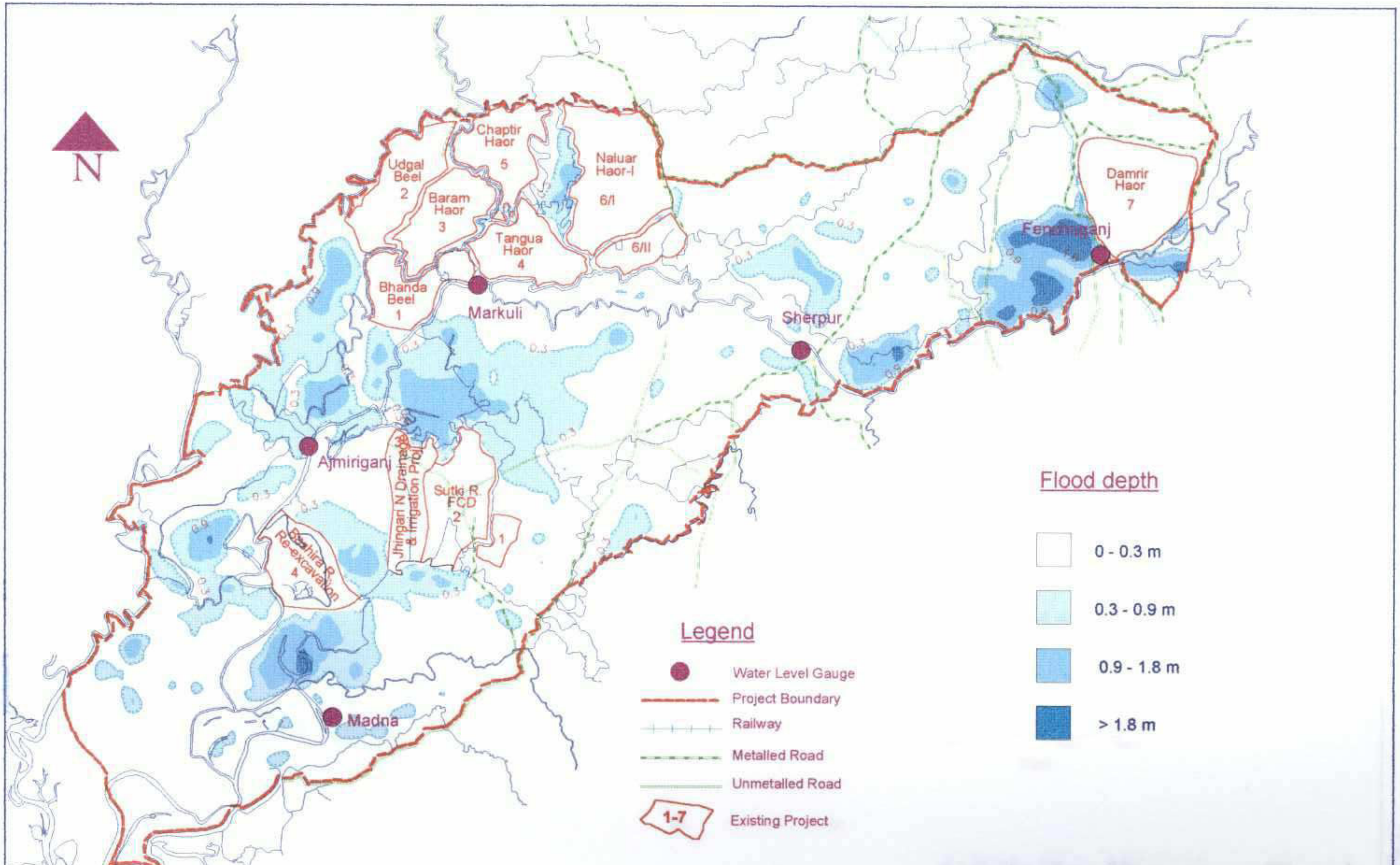
Figure B.11

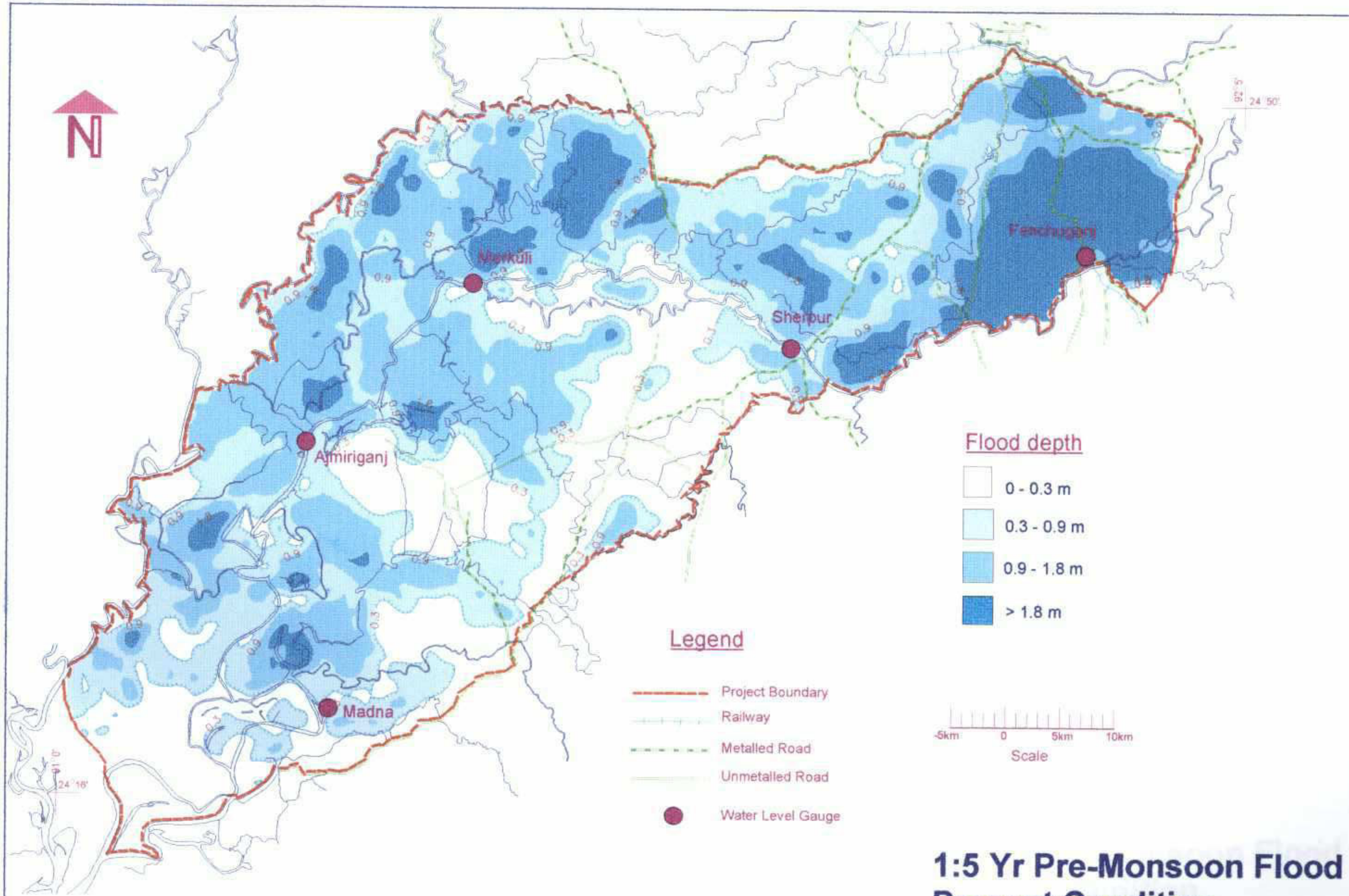


1:2 Yr Pre-Monsoon Flood Present Condition

Kalni-Kushiyara River Management Project

FILE DB0200.SRF Prepared by TAREK, Nov 97

Figure B.12



1:5 Yr Pre-Monsoon Flood
Present Condition

Kalni-Kushiyara River Management Project

FILE: DB0500.SRF Prepared by: TAREK, Nov 97

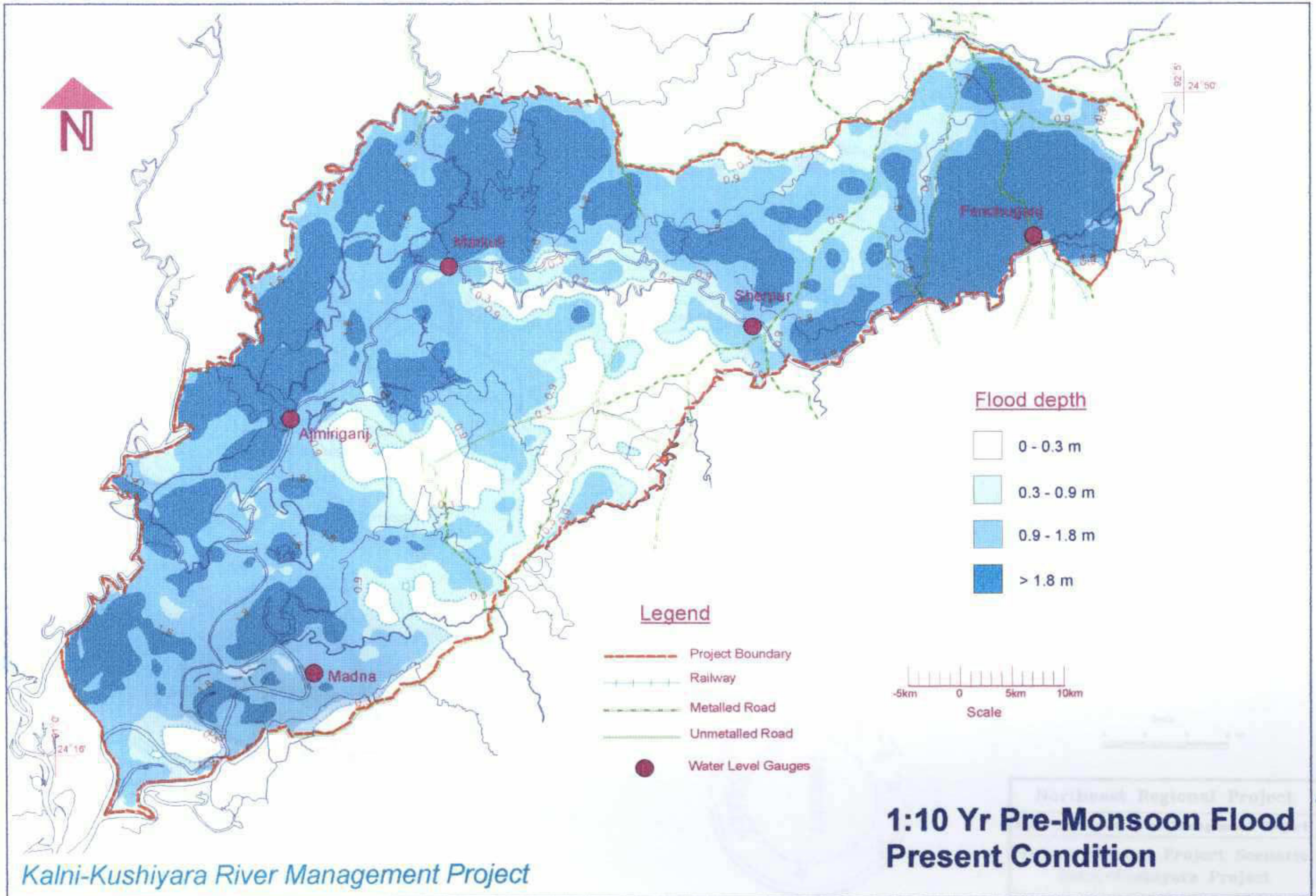
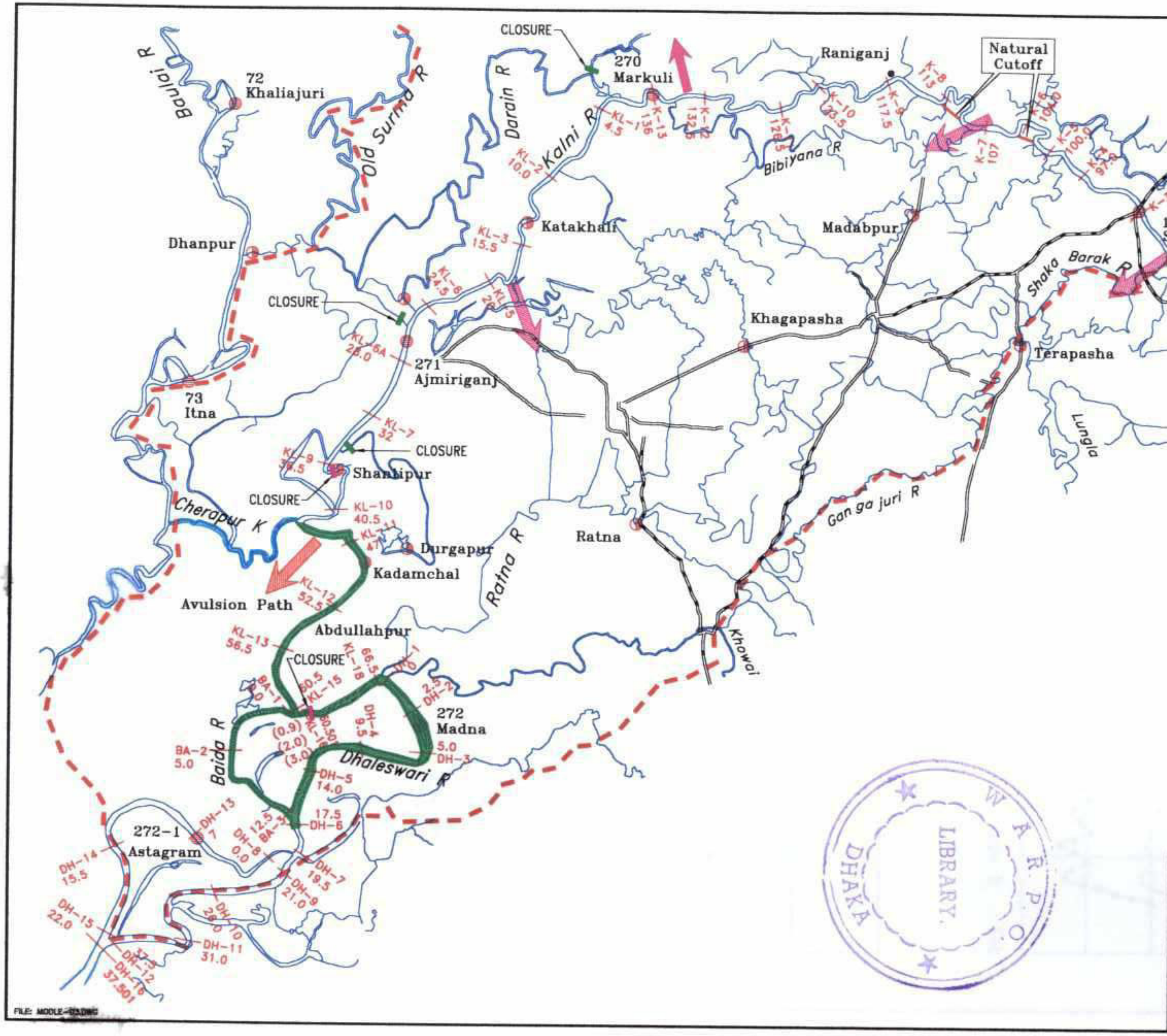


Figure B.13

1:10 Yr Pre-Monsoon Flood Present Condition

a9

Figure B.14



Northeast Regional Project

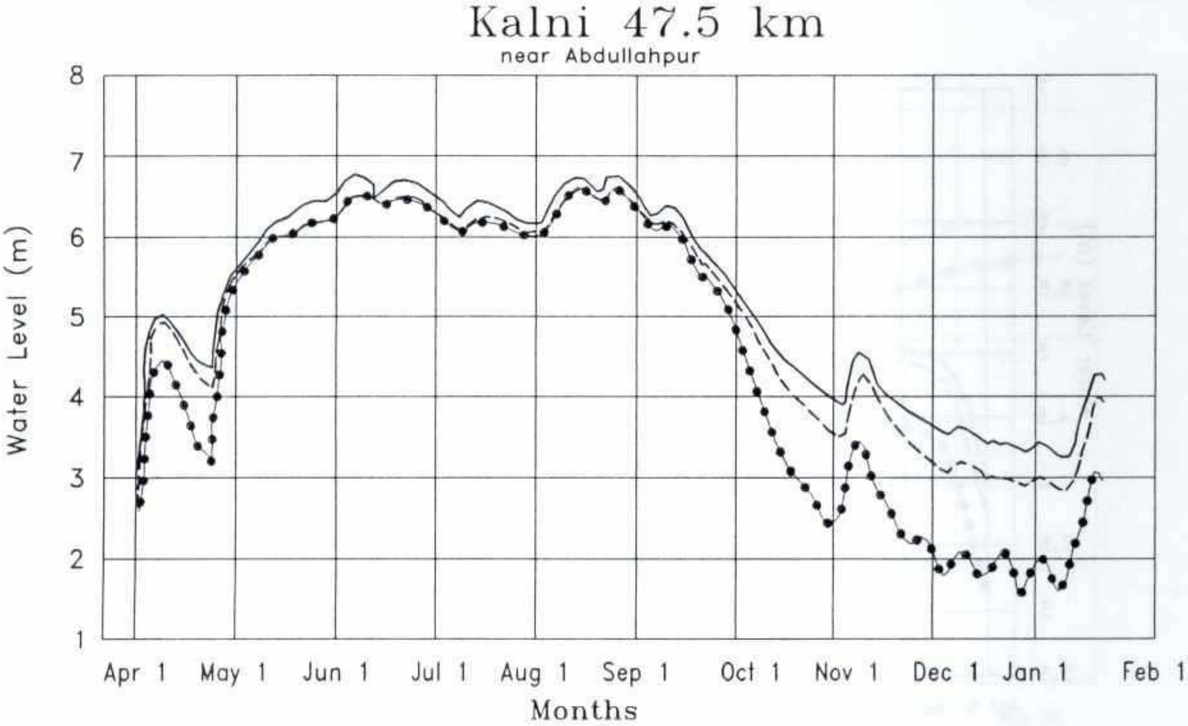
Kalni-Kushiyara River Management Project

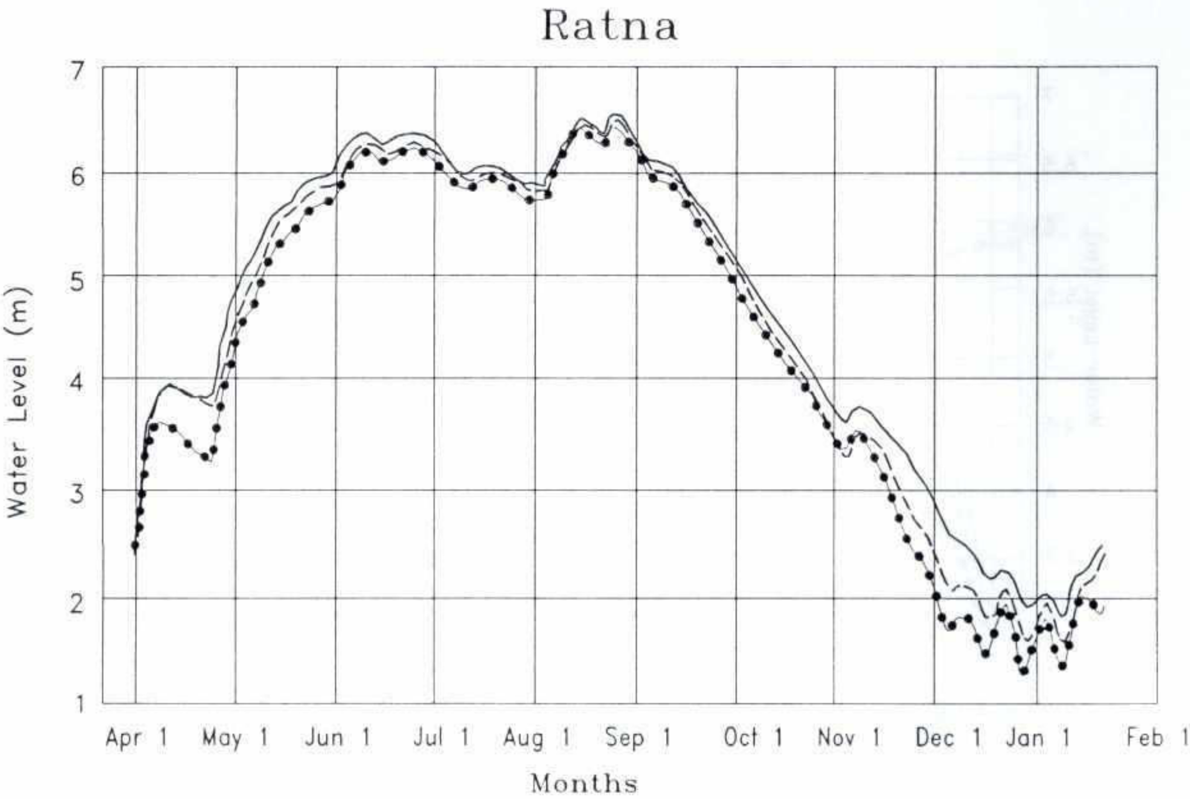
Future Without Project Scenario
Kalni-Kushiyara Project

Prepared by: Nahid
Computer Drafting by: Mamun

December 1997

Figure B.15





LEGEND:

----PRESENT

——FWO

•••••FW (Alternative 1)

Northeast Regional Project

Kalni-Kushiyara River Management Project

Annual Time Series of Water Levels

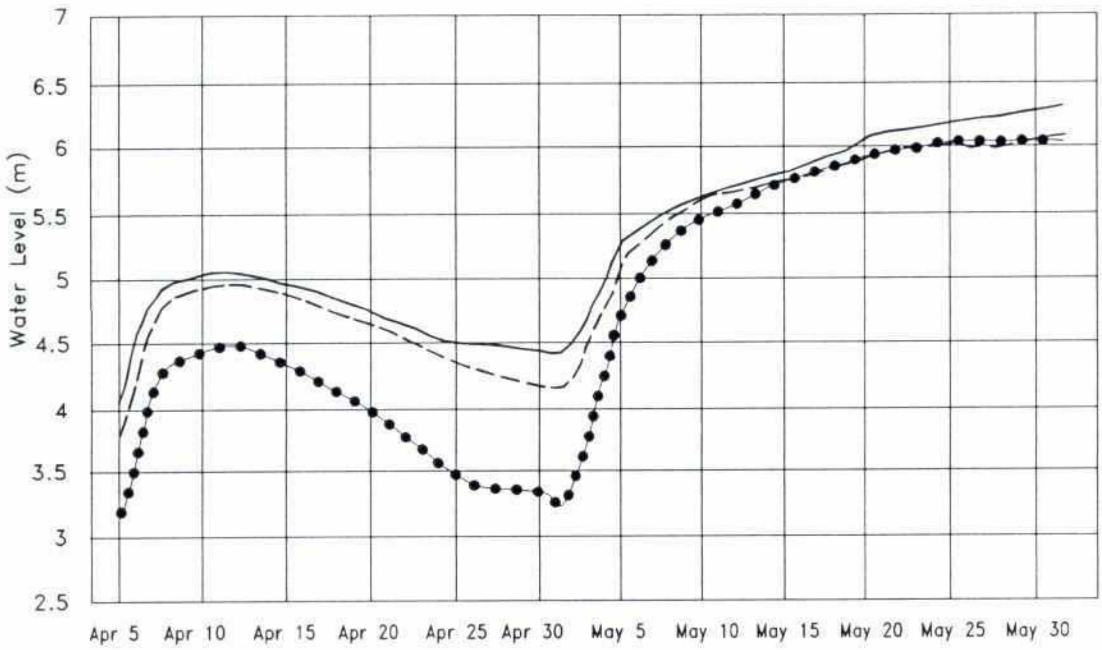
Prepared by: Nahid

Computer Drafting by: Mamun

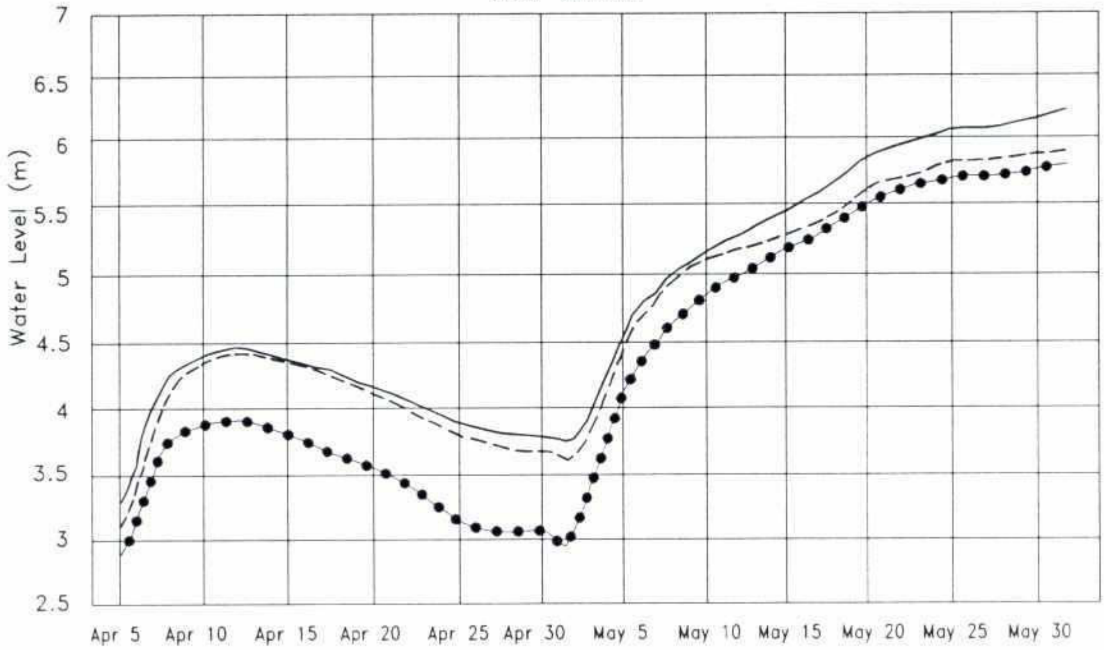
December 1997

FILE: MODLE-09.DWG

KALNI 24.0 Km
upstream of Ajmiriganj



KALNI 36.5 Km
near Rahala



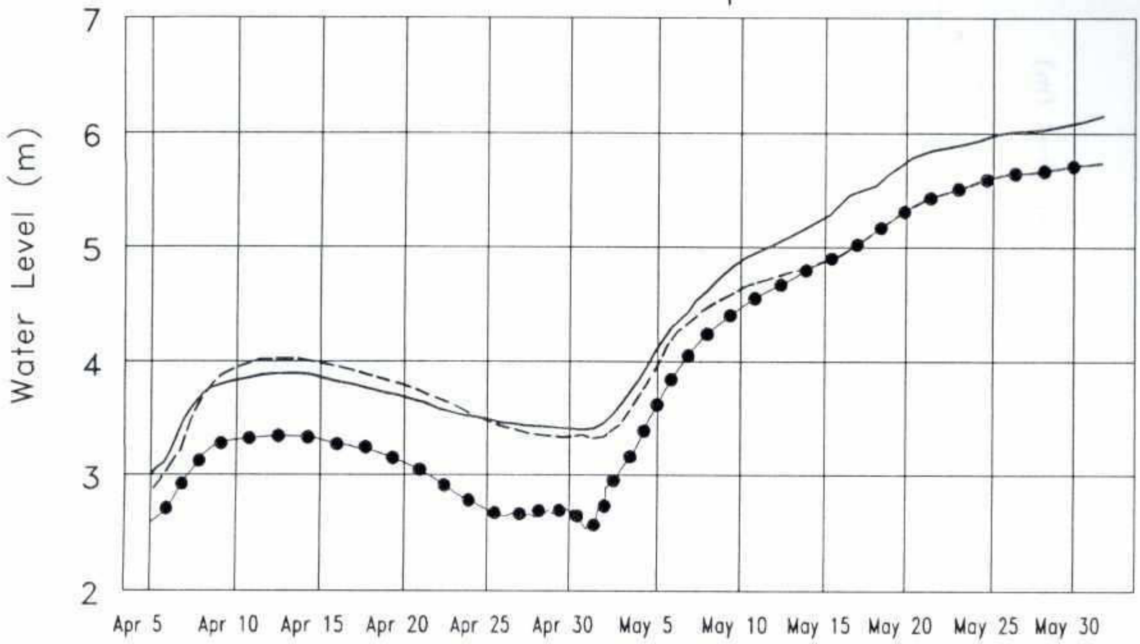
LEGEND:
- - - - - PRESENT
——— FWO
• • • • • FW (Alternative 1)

FILE: MODLE-10.DWG

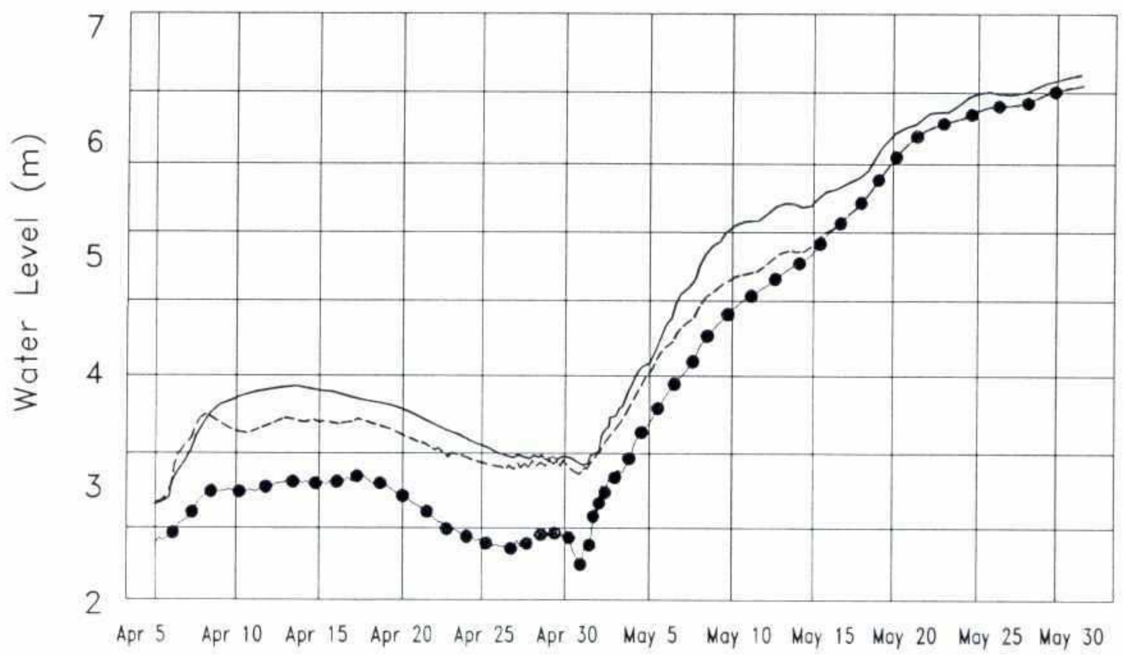
Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Pre-Monsoon Water Levels near Ajmiriganj	
Prepared by: Nahid	December 1997
Computer Drafting by: Mamun	

Figure B.17

Kalni 47.5 Km
near Abdhullhapur



Kalni 55.5 Km
at Baida Bifurcation



LEGEND:

- ---- PRESENT
- —— FWO
- ●●●● FW (Alternative 1)

FILE: MODLE-12.DWG

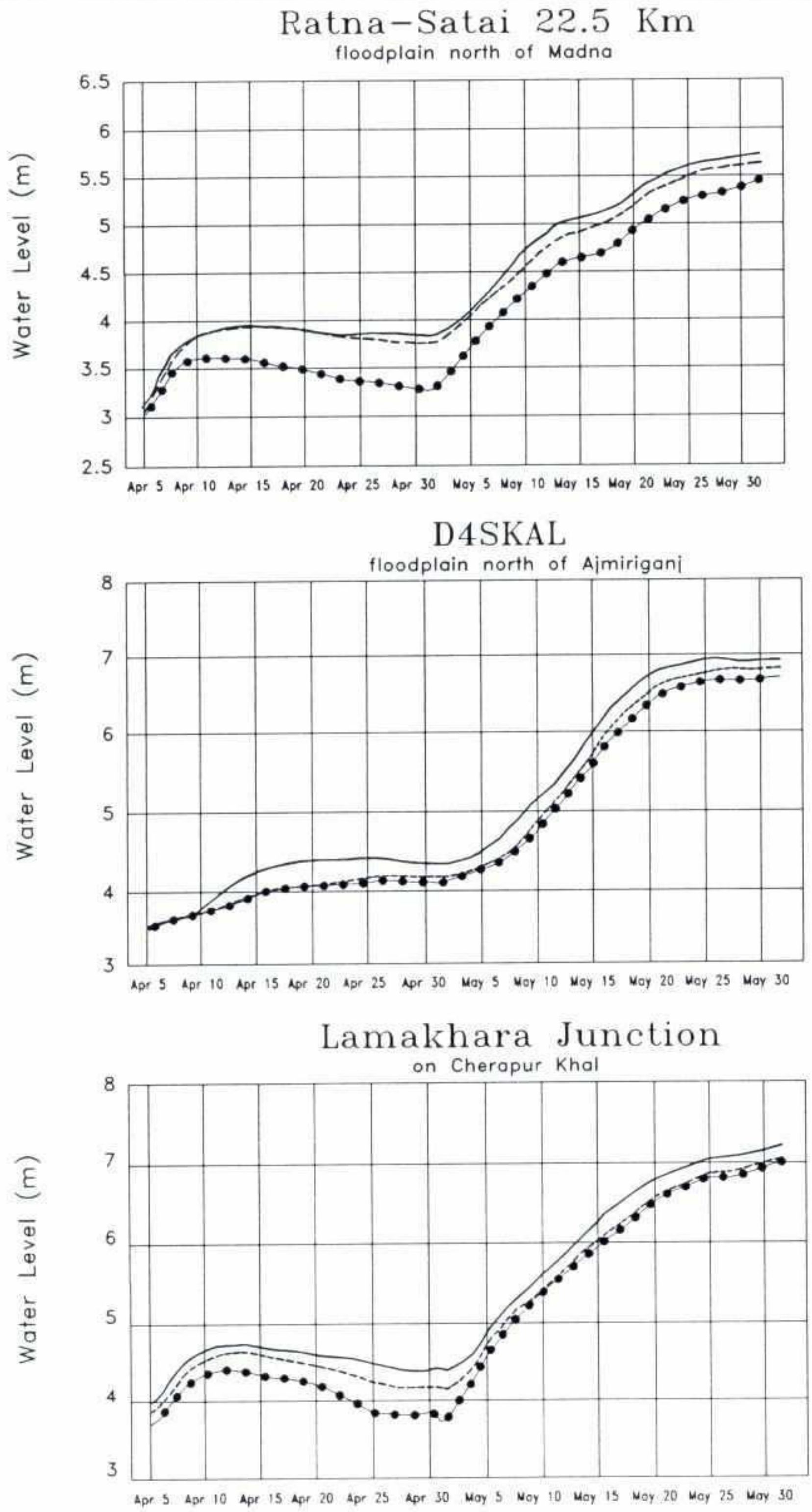
Northeast Regional Project

Kalni-Kushiyara River Management Project

Pre-monsoon Water Levels on Lower Kalni River

Prepared by: Nahid	December 1997
Computer Drafting by: Mamun	

Figure B.18



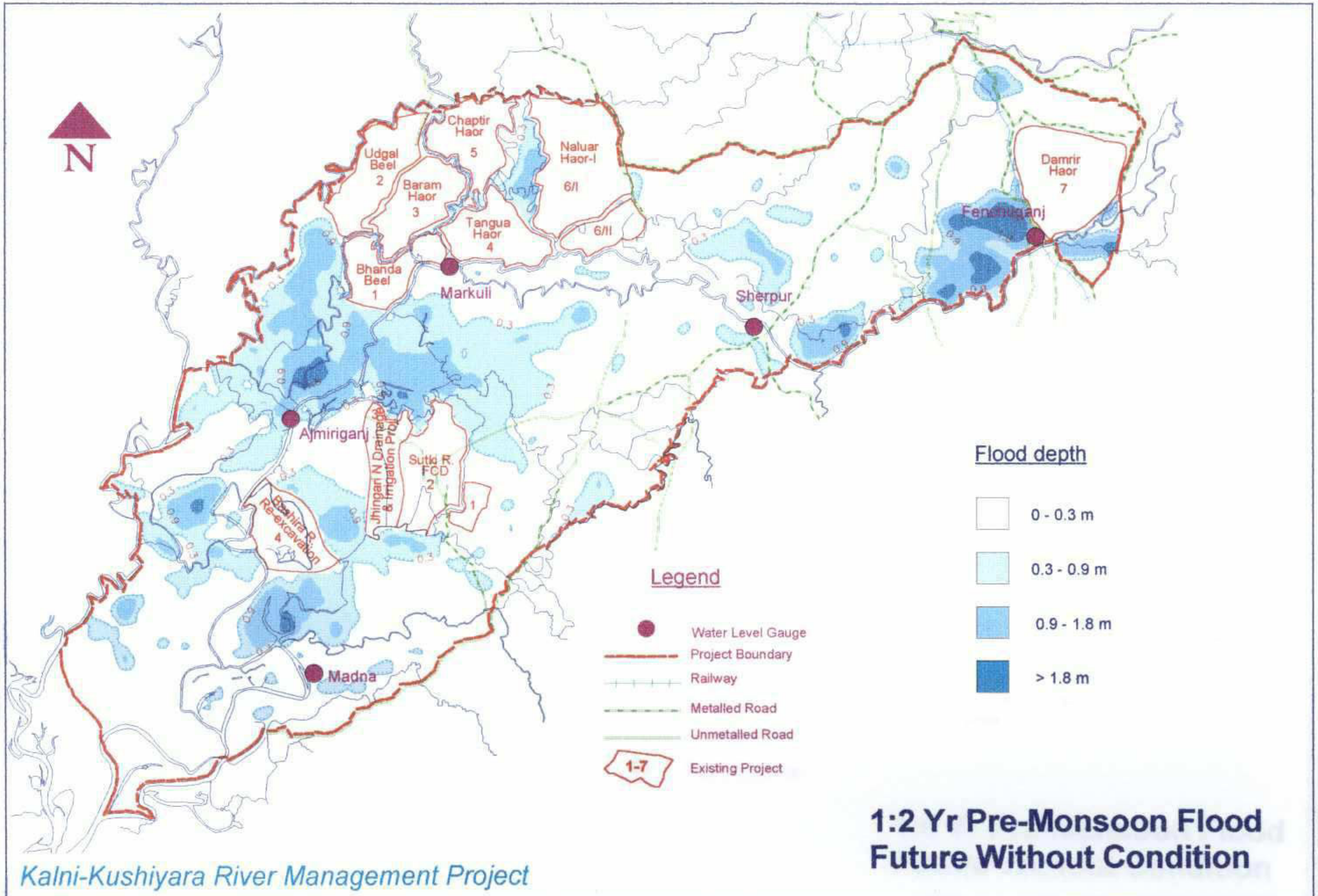
LEGEND:

- ----- PRESENT
- ——— FWO
- •••••• FW (Alternative 1)

FILE: MODLE-11.DWG

Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Pre-monsoon Water Levels in Floodplain Areas	
Prepared by: Nahid	December 1997
Computer Drafting by: Mamun	

Figure B.19



FILE DFW0200.SRF Prepared by TAREK, Nov 97

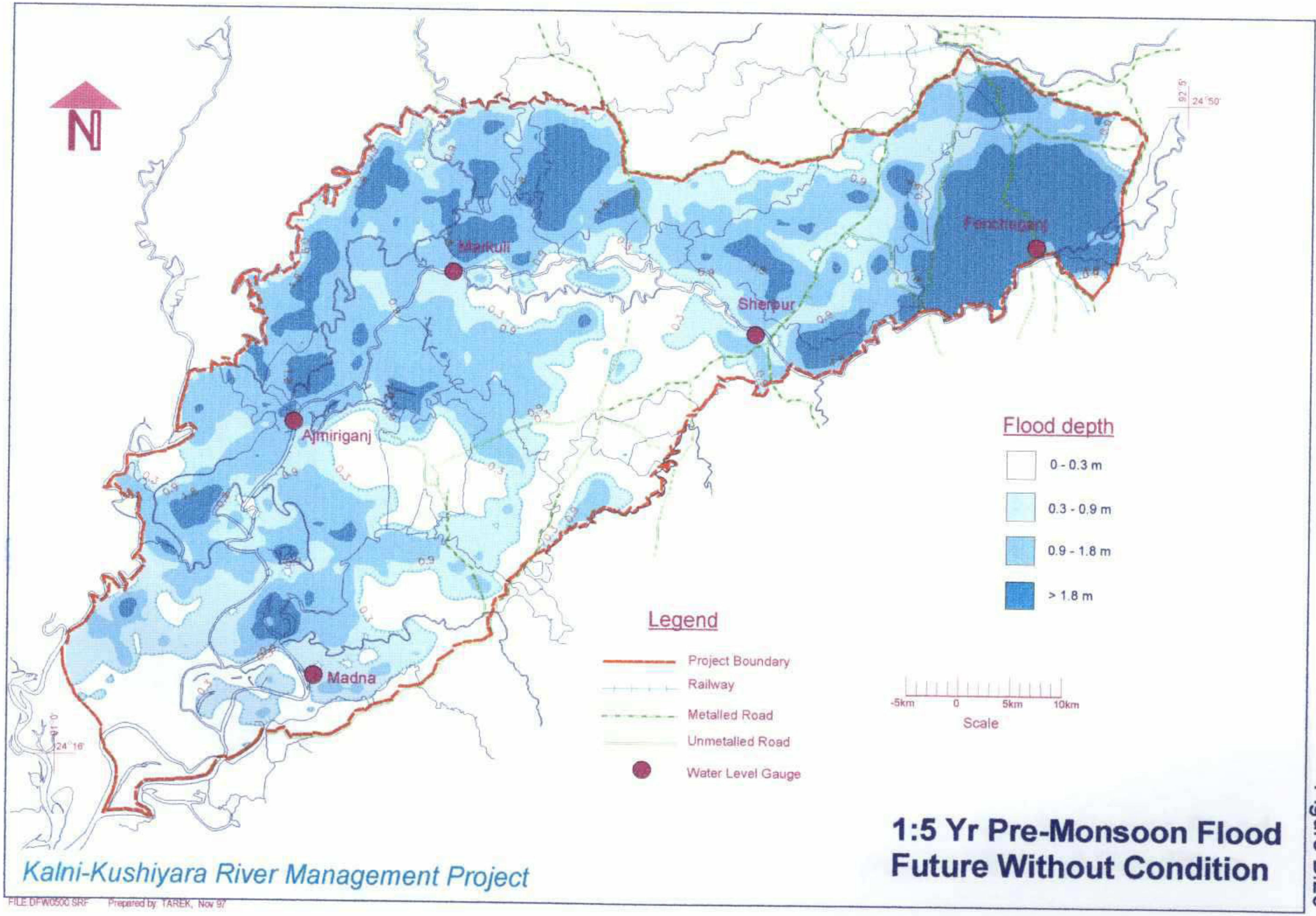
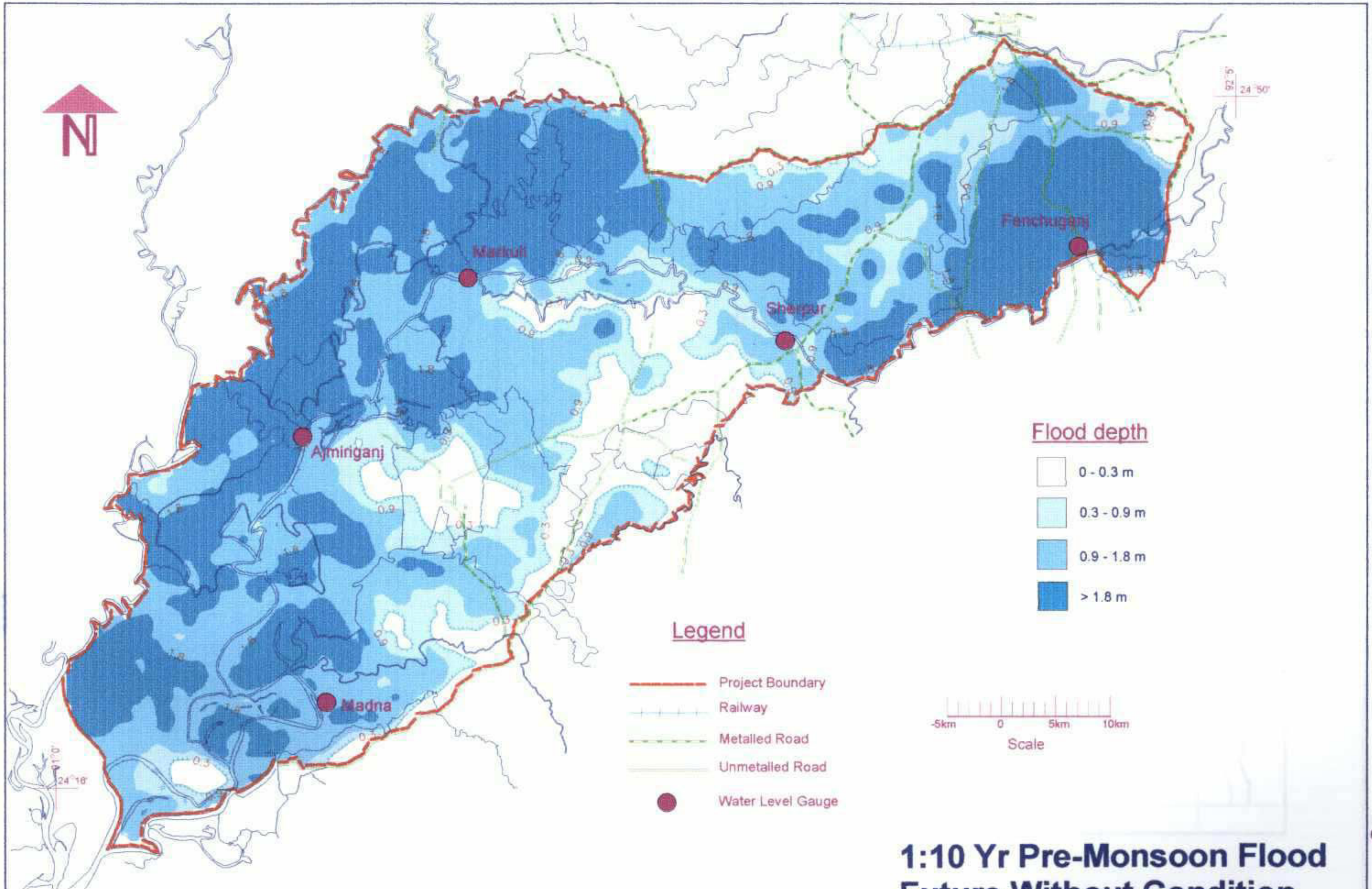


Figure B.20

1:5 Yr Pre-Monsoon Flood Future Without Condition

Figure B.21

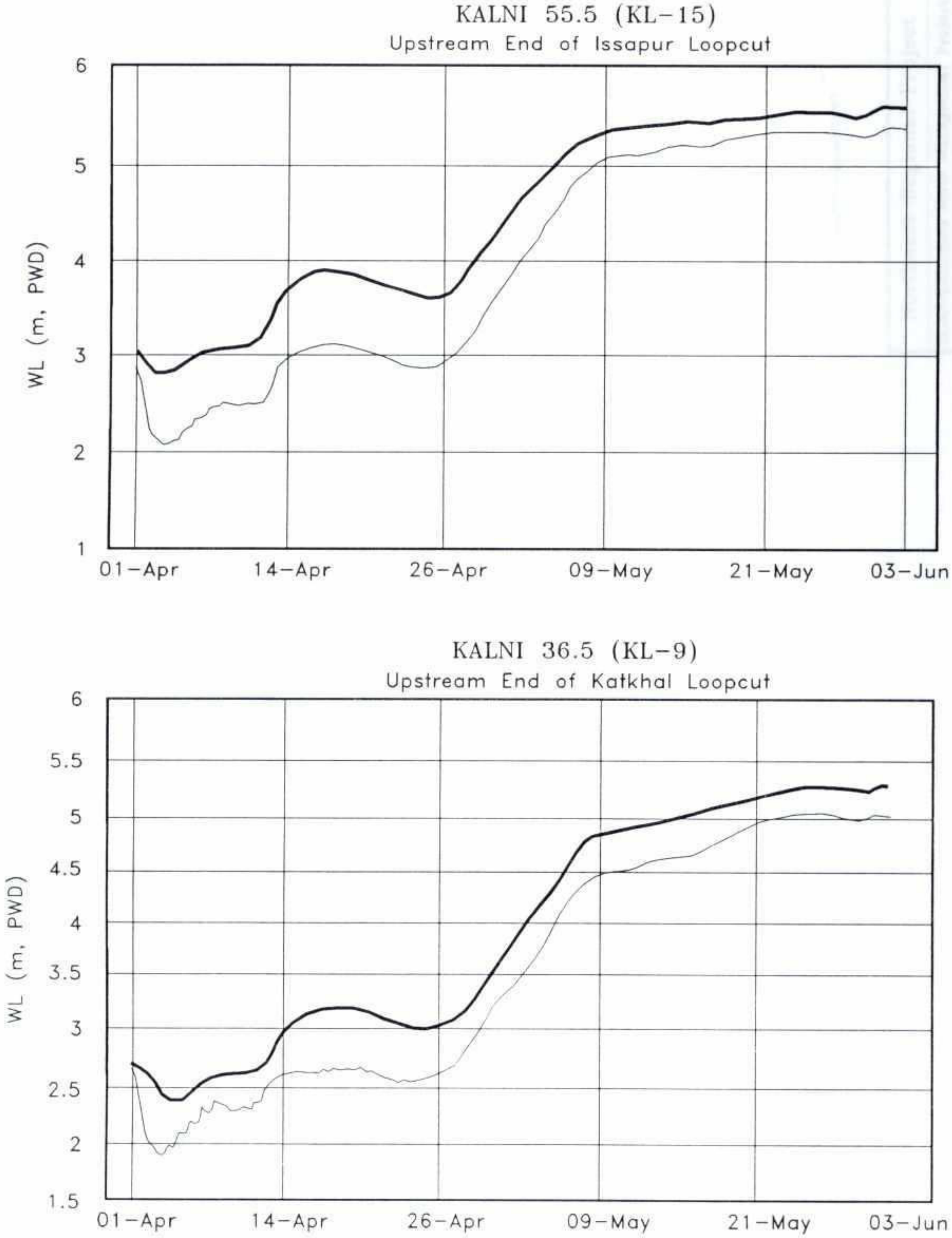


1:10 Yr Pre-Monsoon Flood Future Without Condition

Kalni-Kushiyara River Management Project

FILE DFW1000.SRF   Prepared by: TAREK, Nov 97

Figure B.22



LEGEND:

- **———** Water Levels without Loop Cut
- ——— Water Levels with Loop Cut

Note : Refer to Figure B.23 for Location of Cross Sections

Northeast Regional Project	
Kalni-Kushiyara River Management Project	
Impact of Loop cuts on Water Levels	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

FILE: MODLE-01.DWG

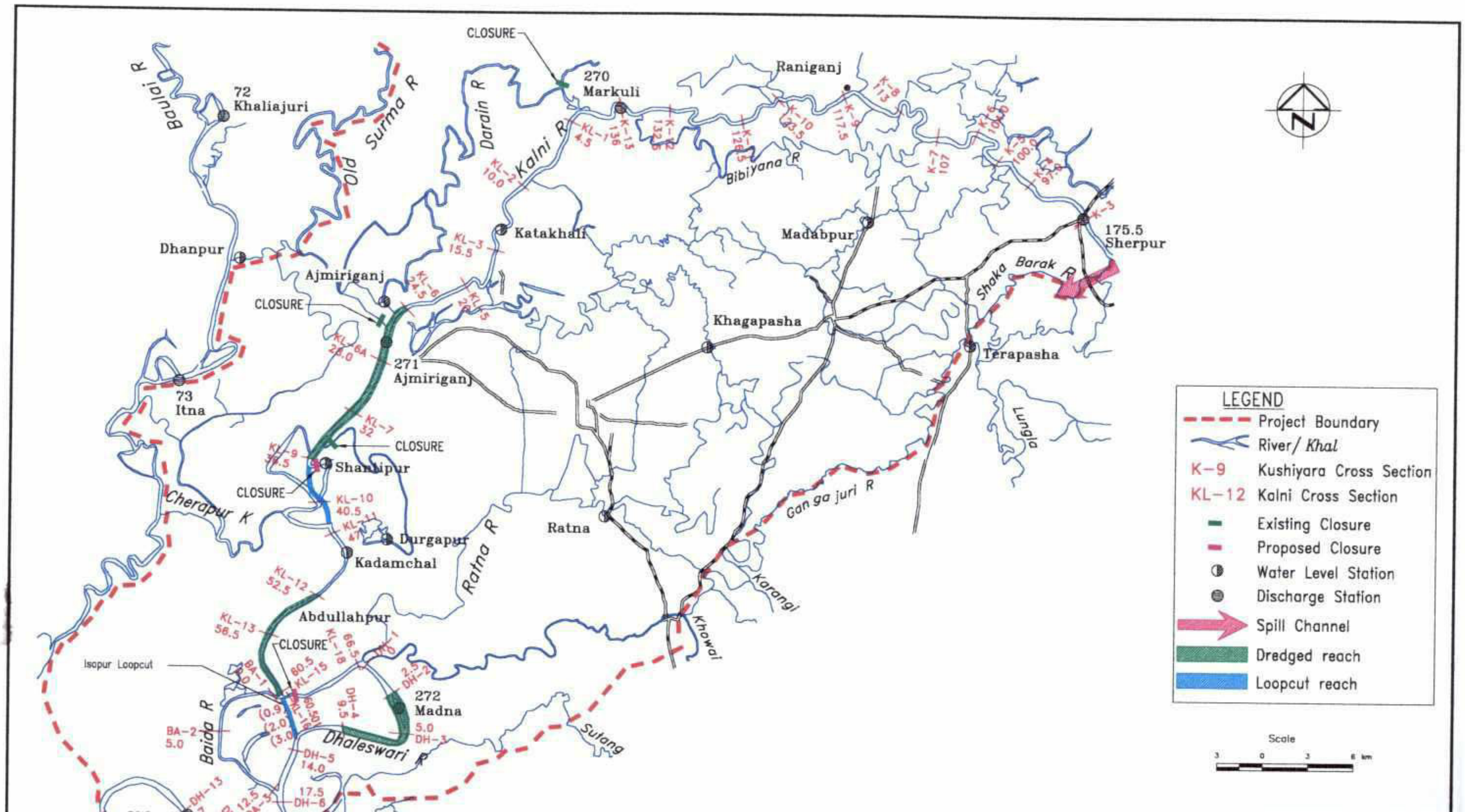


Figure B.23

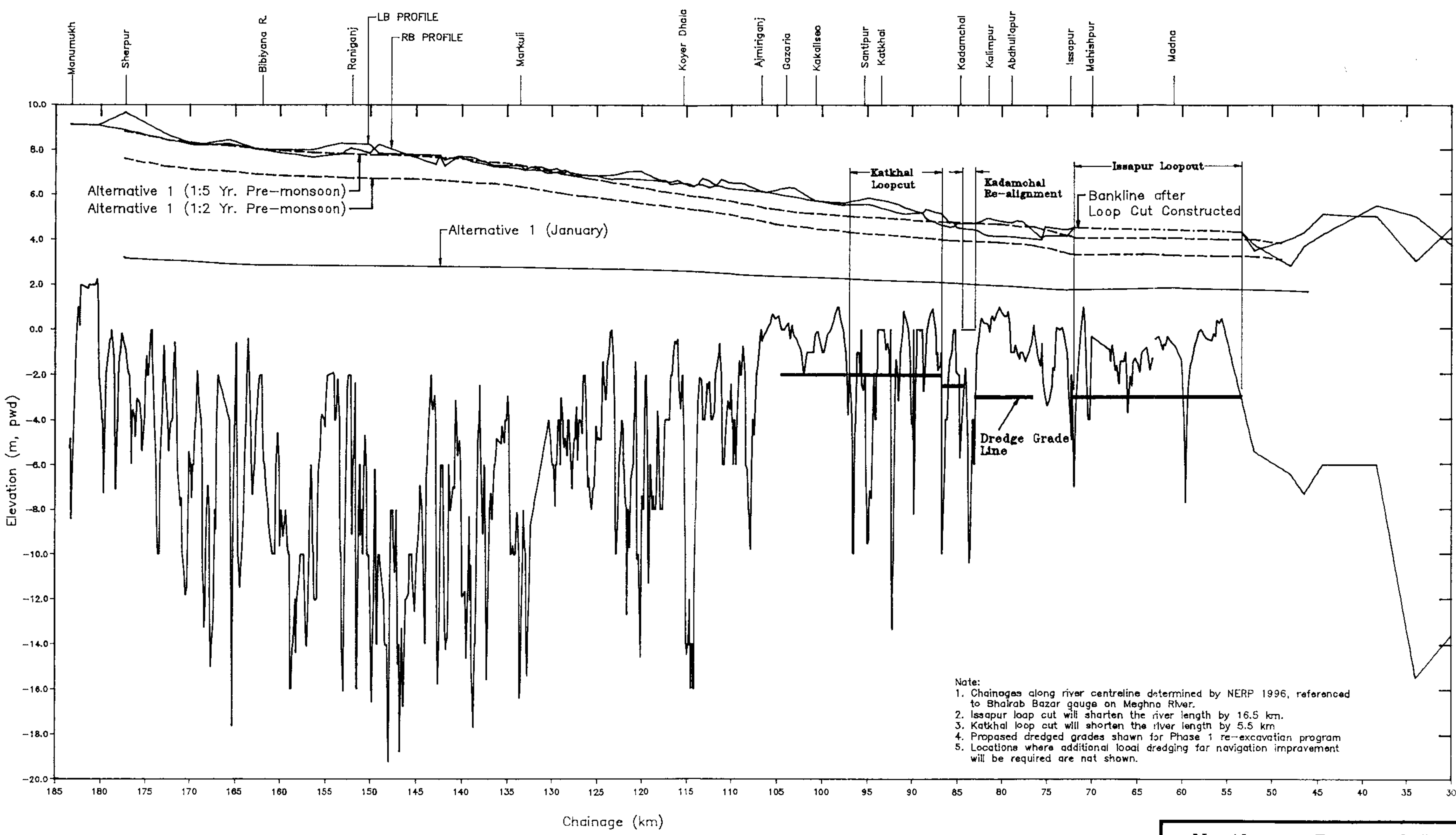
Northeast Regional Project

Kalni-Kushiyara River Management Project

Proposed Project Interventions (Alternative-1)

Prepared by: Nahid
Computer Drafting by: Mamun
December 1997

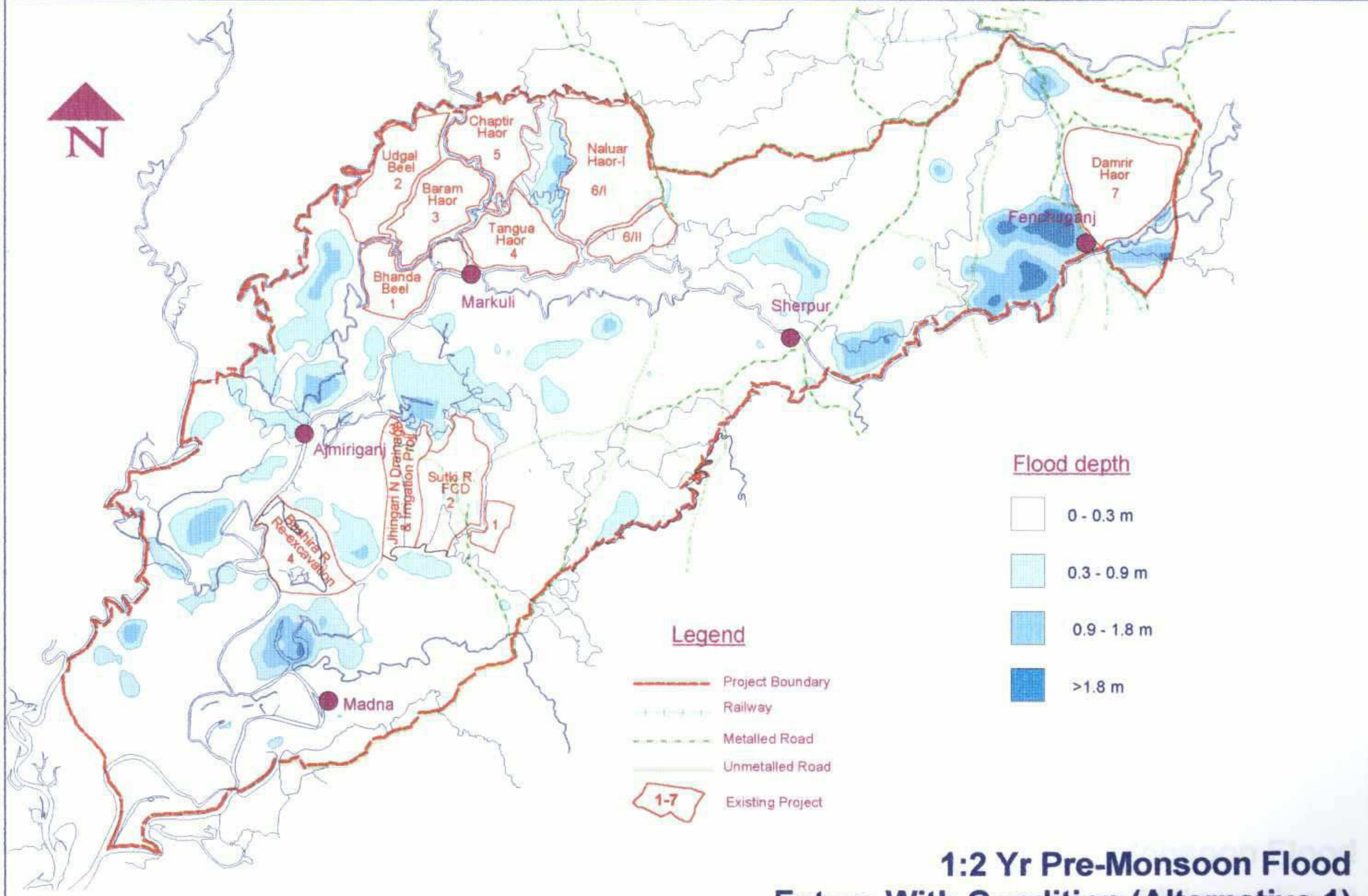
Figure B.24



Northeast Regional Project	
Kalni–Kushiyara River Management Project	
Water Surface Profile (1:5yr. Flood) (Alternative 1)	
Prepared by: D.G.M.	December 1997
Computer Drafting by: Mamun	

FILE: NODLE–18.DWG

Figure B.25

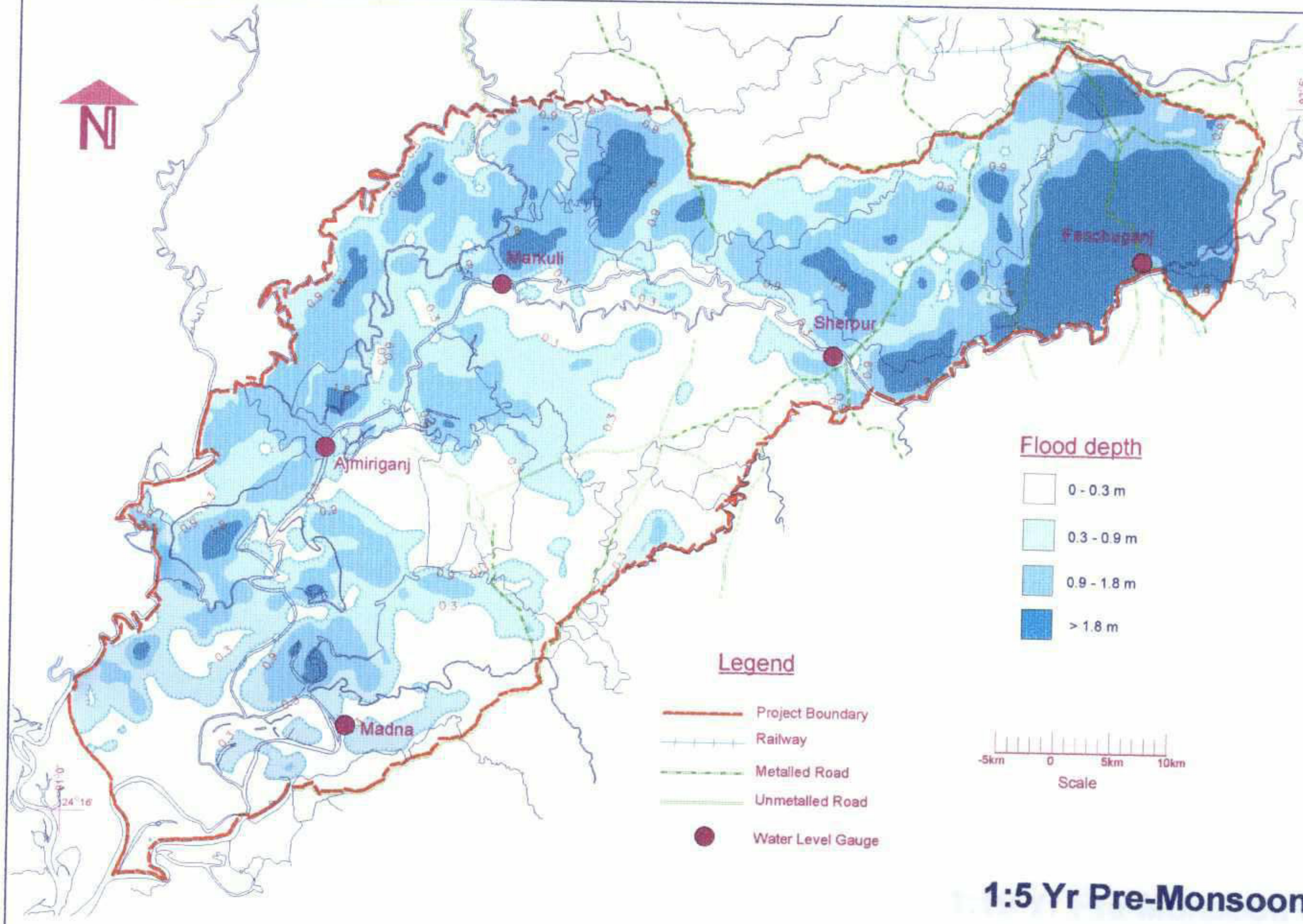


1:2 Yr Pre-Monsoon Flood
Future With Condition (Alternative 1)

Kalni-Kushiyara River Management Project

FILE:DFW0209.SRF Prepared by Tarek, Nov 97

Figure B.26

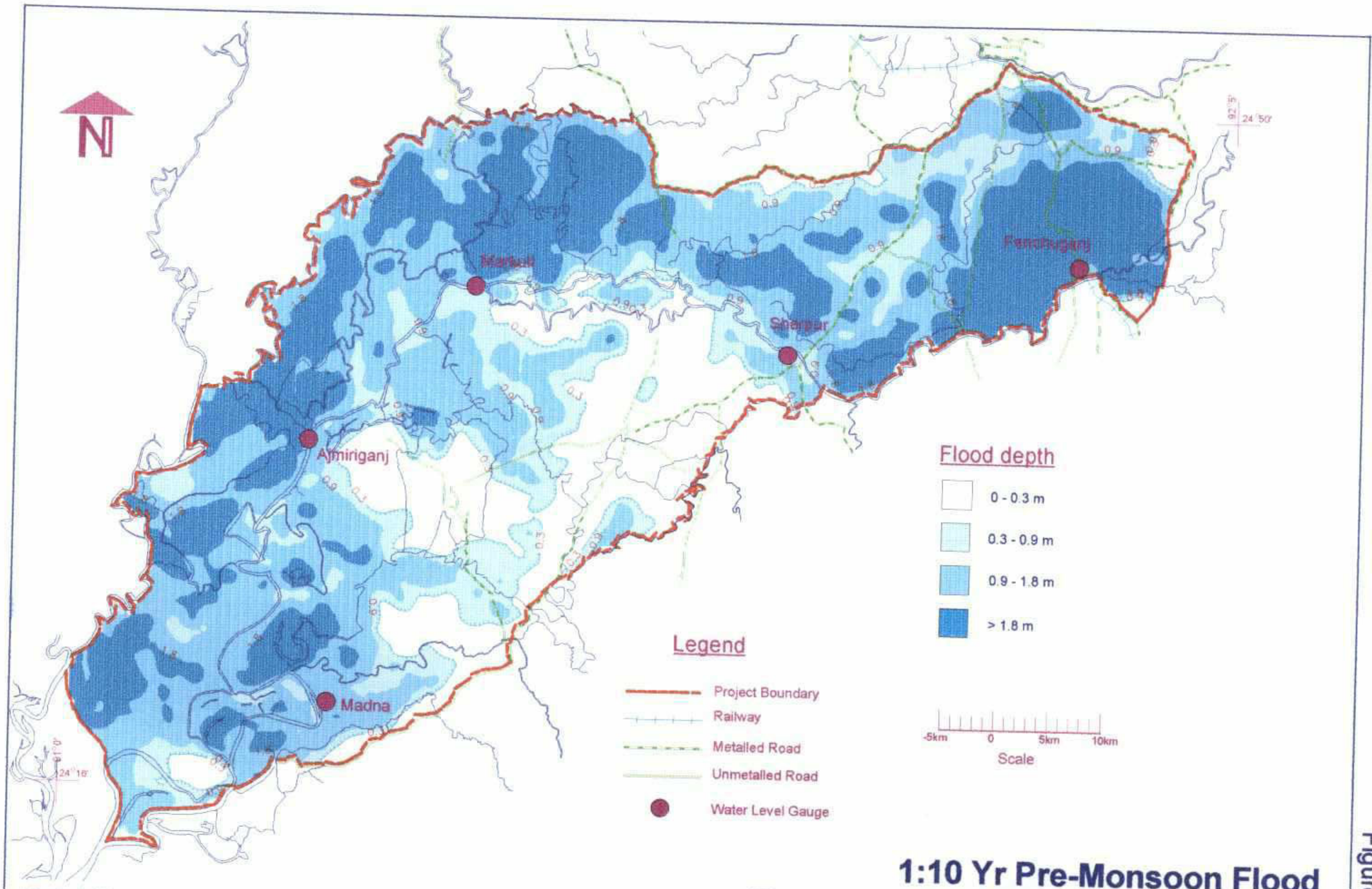


1:5 Yr Pre-Monsoon Flood
Future With Condition (Alternative 1)

Kalni-Kushiyara River Management Project

FILE DFW0509.SRF Prepared by: TAREK, Nov 96

Figure B.27

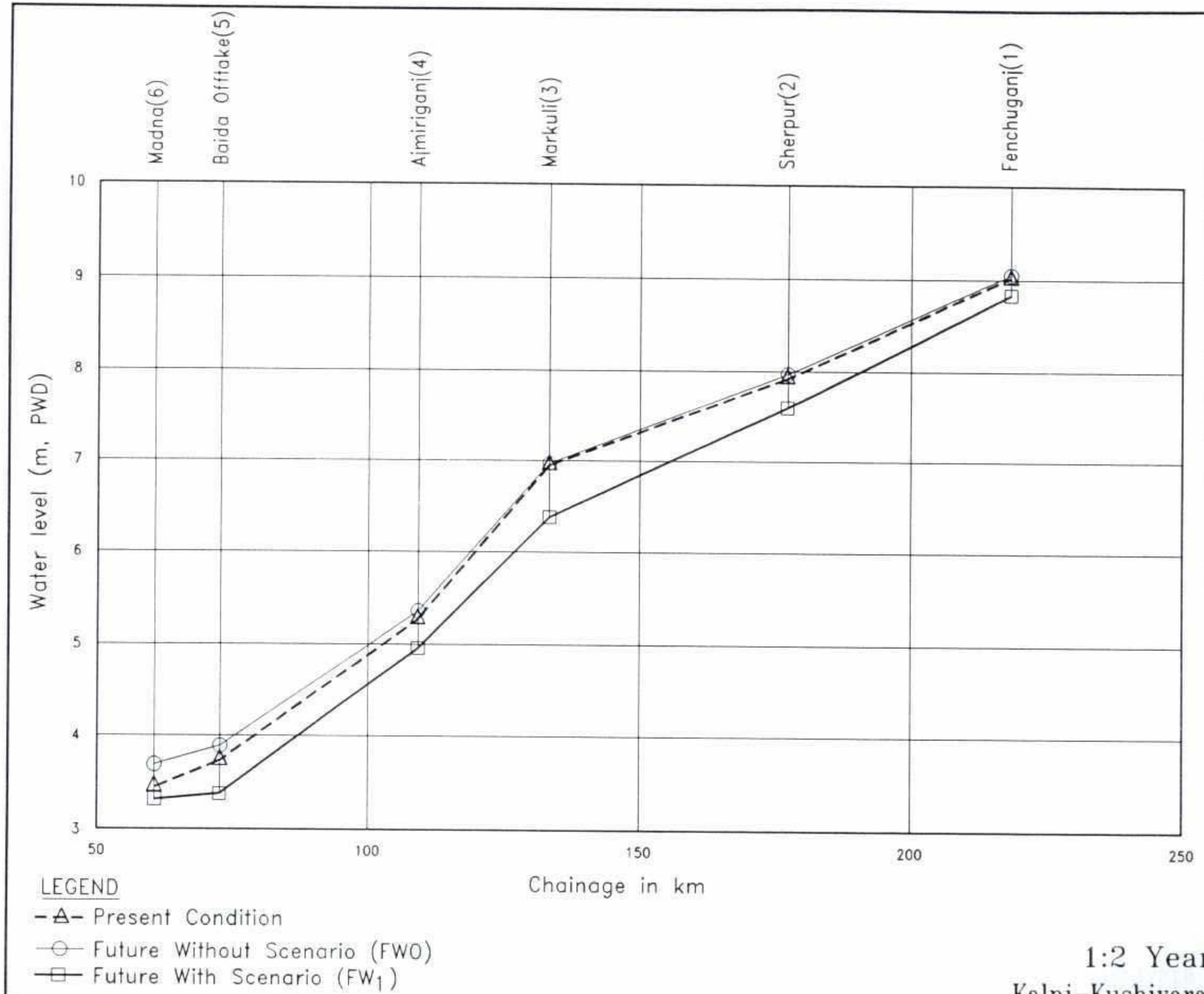


1:10 Yr Pre-Monsoon Flood Future With Condition (Alternative-1)

Kalni-Kushiyara River Management Project

FILE:DFW1009.SRF Prepared by: TAREK, Nov 97

Figure B.28



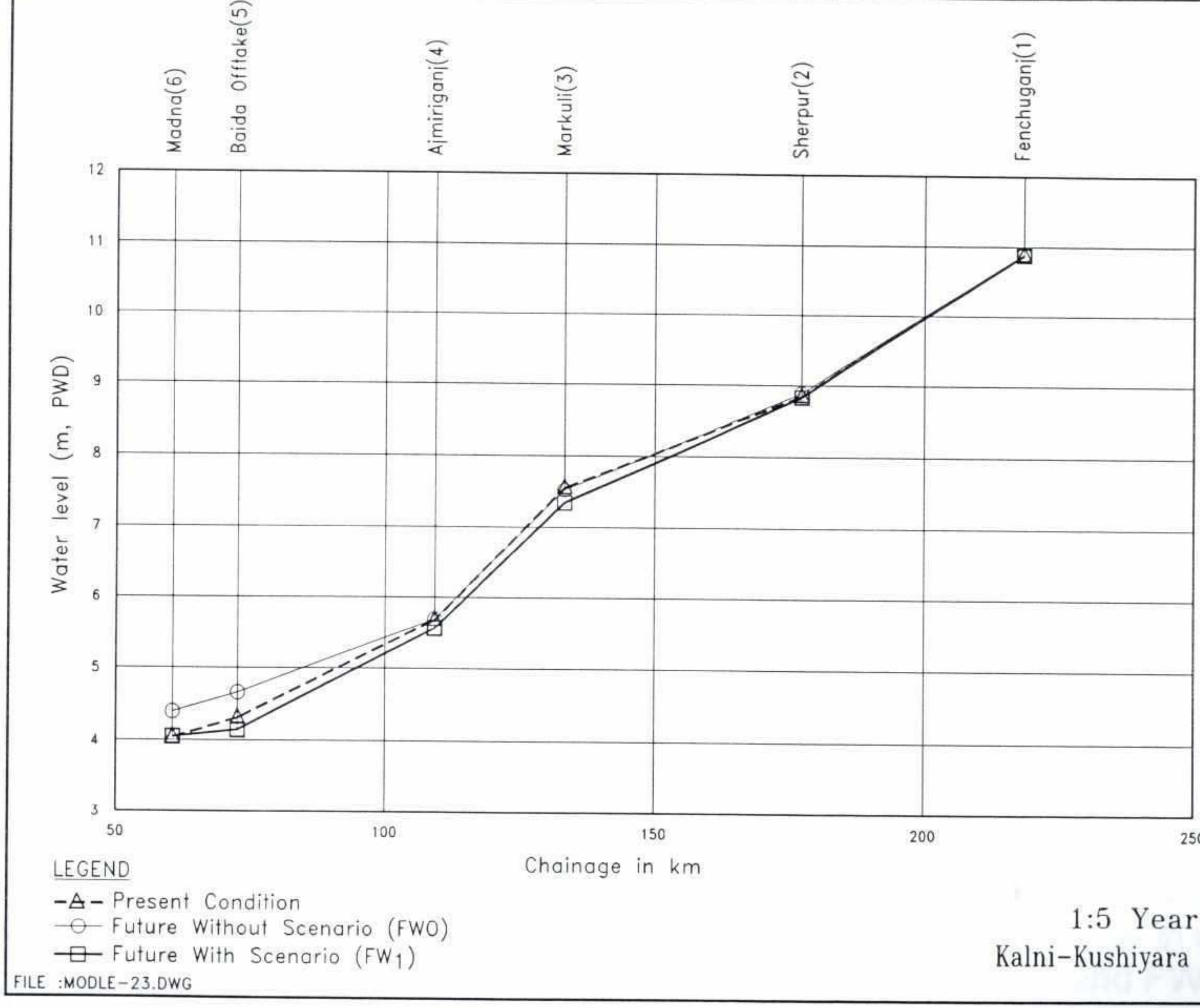
Station	Peak Water Level (m) Present	FWO	FW_1
1	9.02	9.05	8.83
2	7.92	7.97	7.60
3	6.95	6.97	6.38
4	5.27	5.36	4.96
5	3.73	3.89	3.38
6	3.45	3.69	3.32

Note : FW is Alternative-1 under 1:5 Year Design

FILE : MODLE-22.DWG

1:2 Year Water Level Profiles
Kalni-Kushiyara River Management Project

Figure B.29



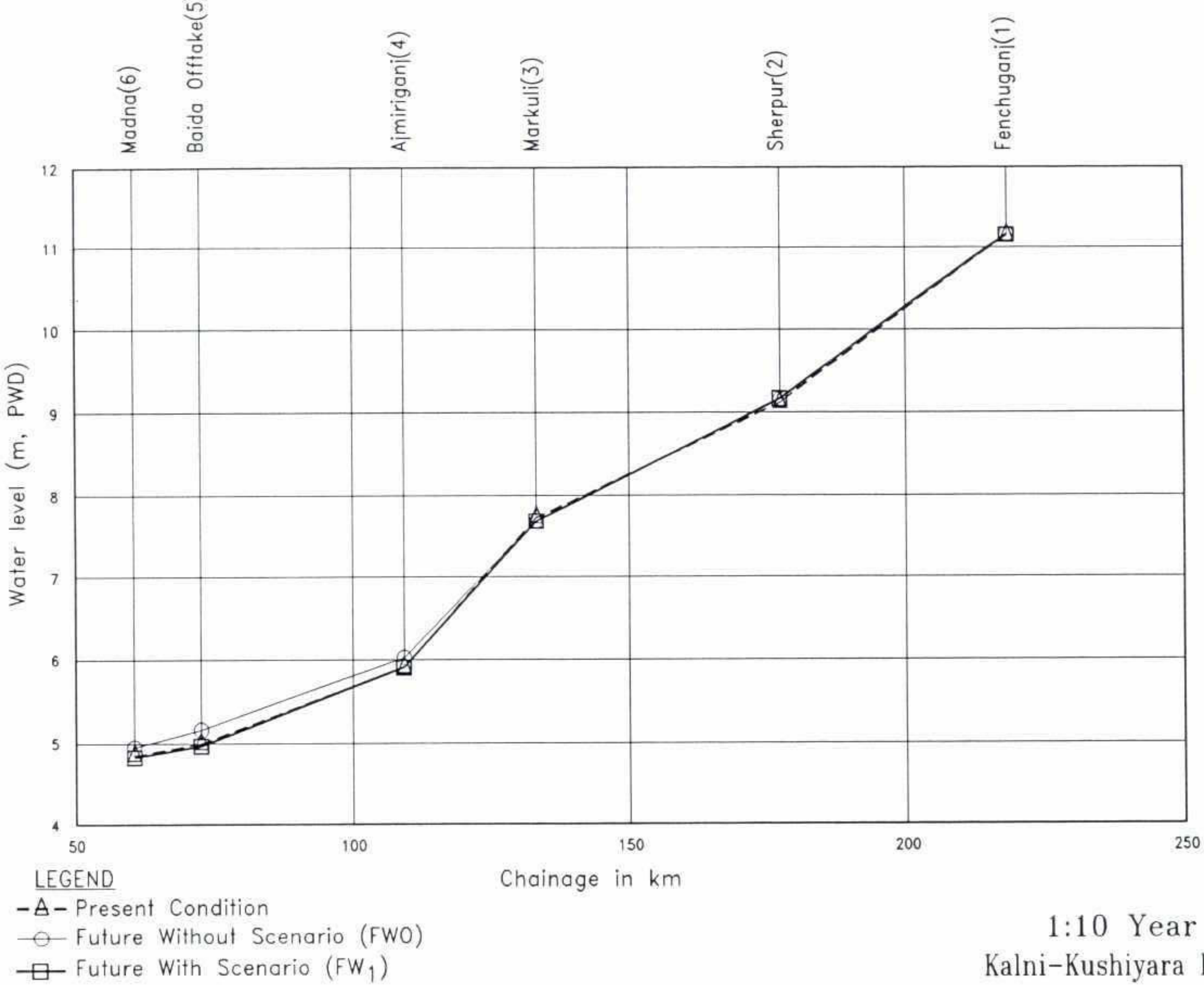
Station	Peak Water Level (m)		
	Present	FWO	FW_1
1	10.88	10.89	10.86
2	8.85	8.89	8.83
3	7.55	7.52	7.34
4	5.66	5.70	5.57
5	4.31	4.66	4.15
6	4.04	4.40	4.05

Note : FW is Alternative-1 under 1:5 Year Design

1:5 Year Water Level Profiles

Kalni-Kushiyara River Management Project

Figure B.30



Station	Peak Water Level (m)		
	Present	FWO	FW_1
1	11.15	11.16	11.16
2	9.12	9.16	9.17
3	7.73	7.69	7.69
4	5.91	6.03	5.91
5	5.00	5.16	4.97
6	4.85	4.95	4.83

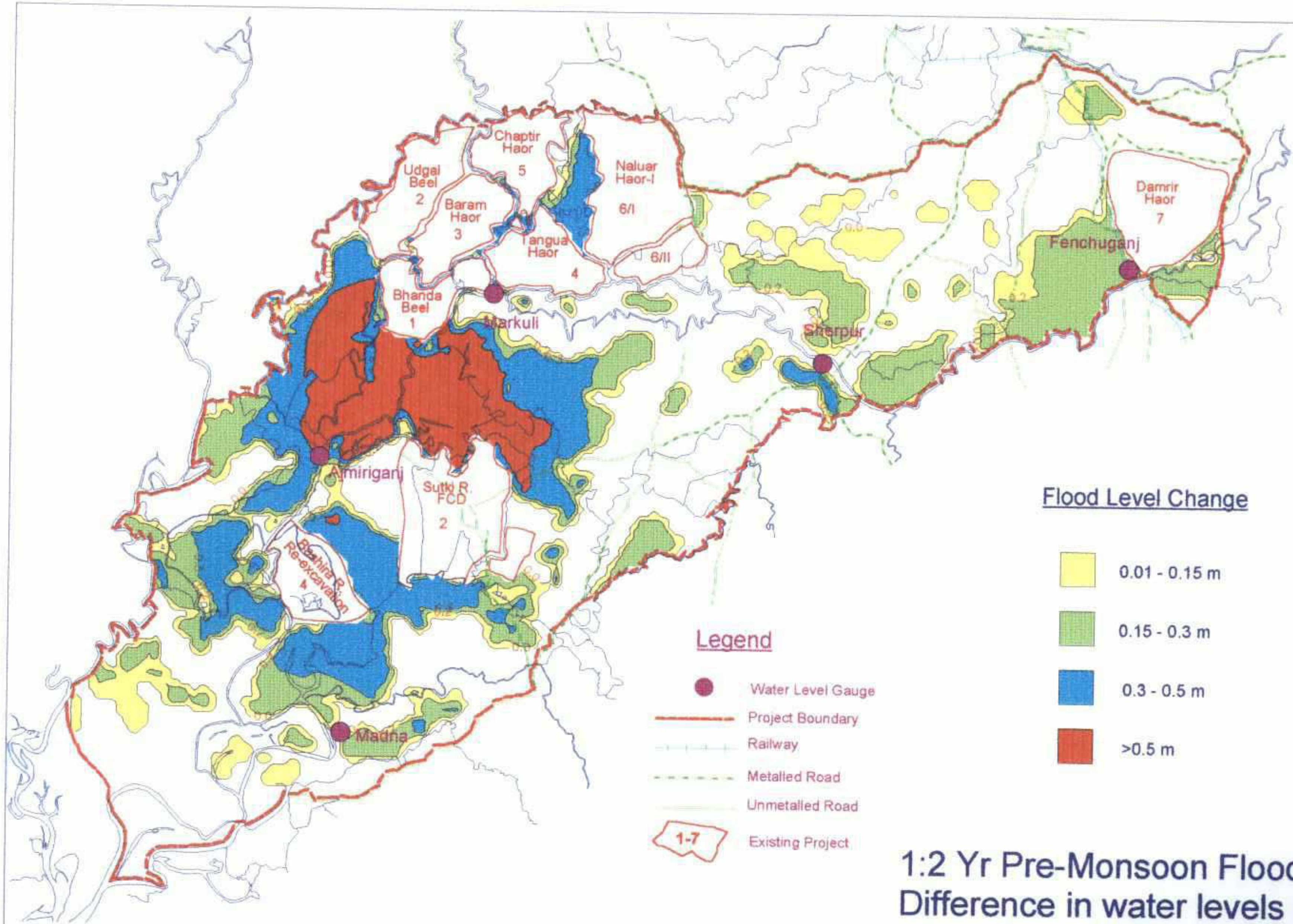
Note : FW is Alternative-1 under 1:5 Year Design

1:10 Year Water Level Profiles

Kalni-Kushiyara River Management Project

FILE :MODLE-24.DWG

Figure B.31



1:2 Yr Pre-Monsoon Flood Difference in water levels under FWO and FW Project Condition

Kalni-Kushiyara River Management Project

FILE:FWO-FW02.SRF Prepared by: Tarek, Nov 97

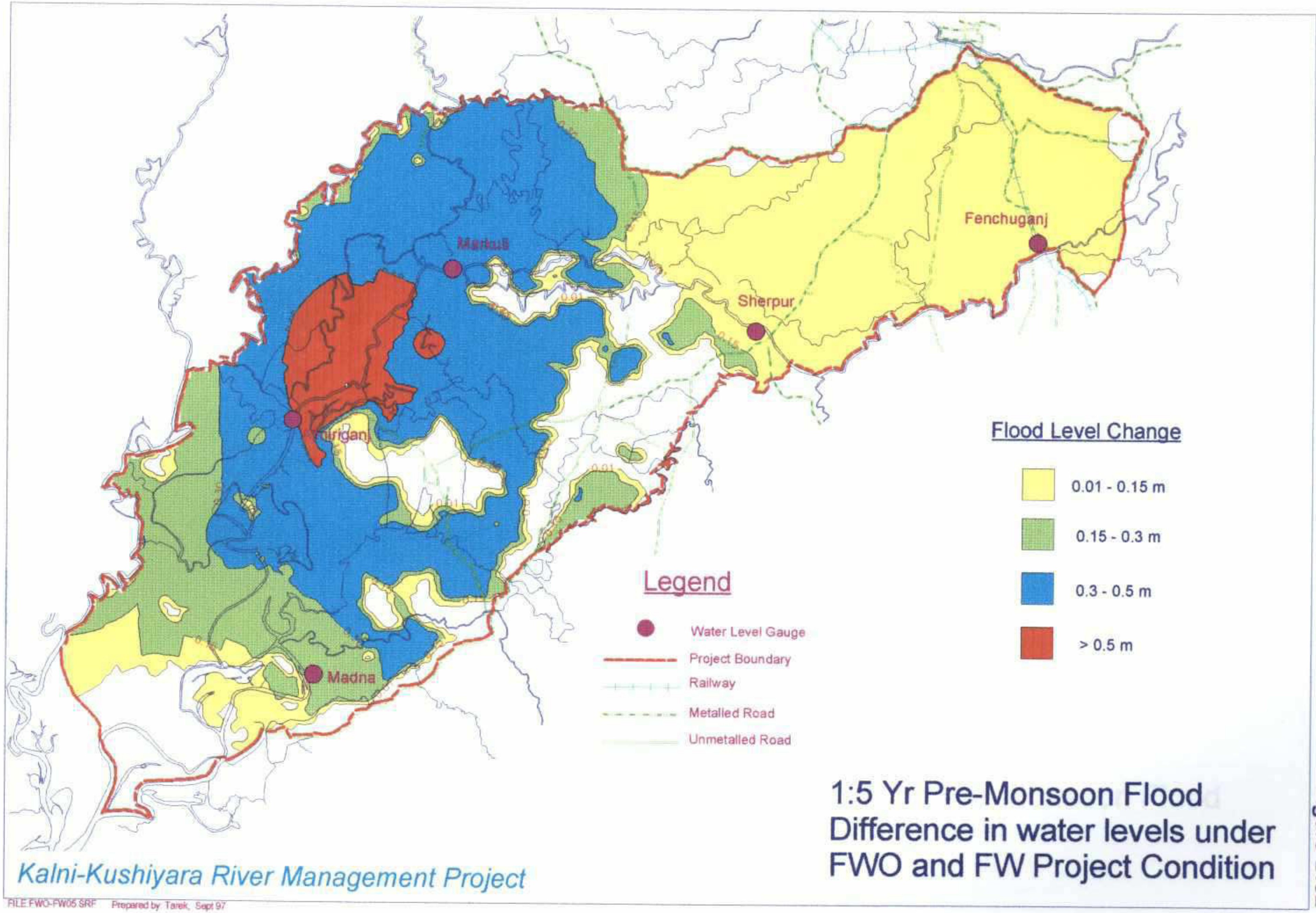
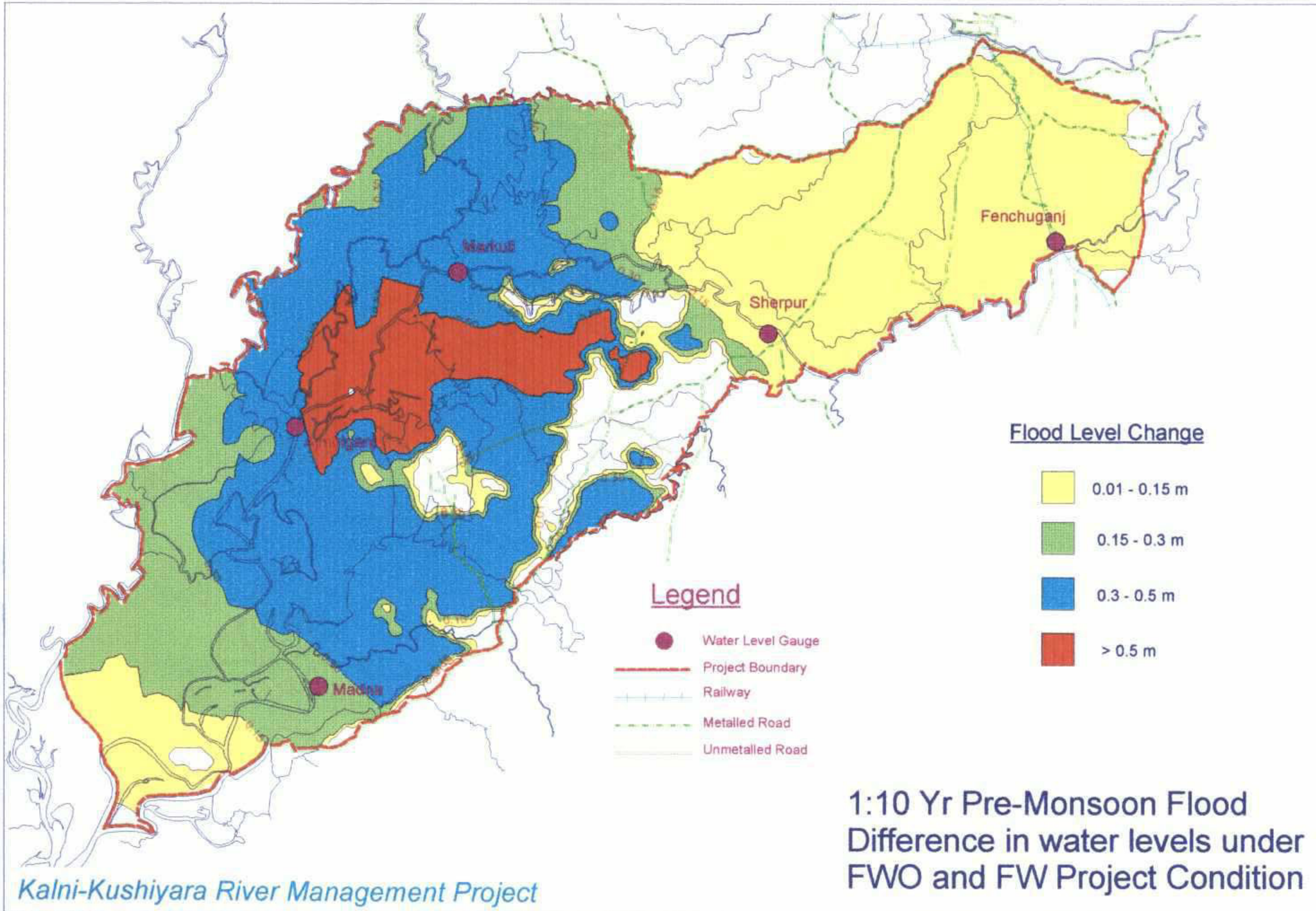


Figure B.32

1:5 Yr Pre-Monsoon Flood
Difference in water levels under FWO and FW Project Condition

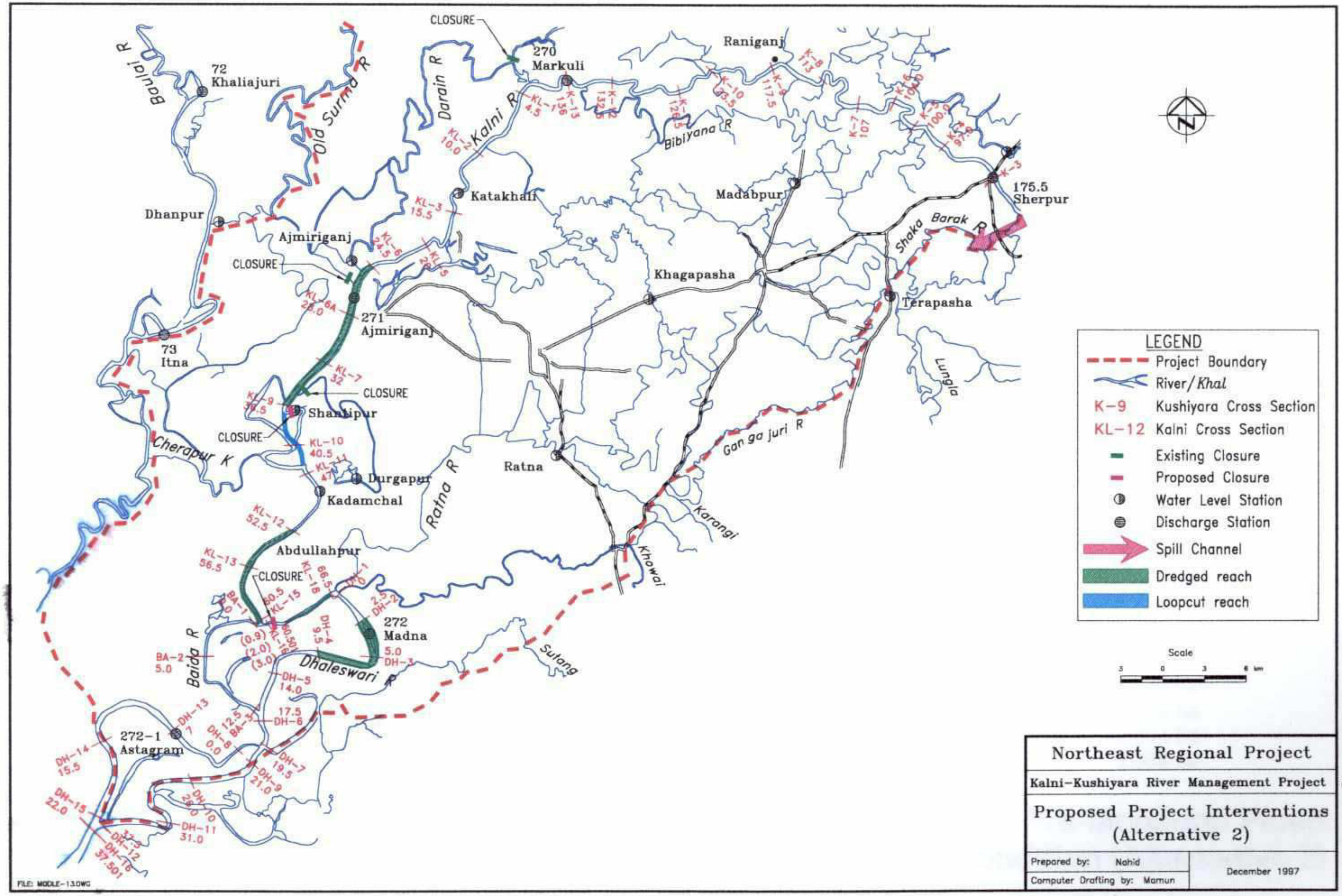
Figure B.33



1:10 Yr Pre-Monsoon Flood
Difference in water levels under
FWO and FW Project Condition

Kalni-Kushiyara River Management Project

FILE FWO-FW10.SRF Prepared by: Tarek, Sept 97



Northeast Regional Project

Kalni-Kushiyara River Management Project

Proposed Project Interventions (Alternative 2)

Prepared by: Nahid

Computer Drafting by: Mamun

December 1997

Figure B.34

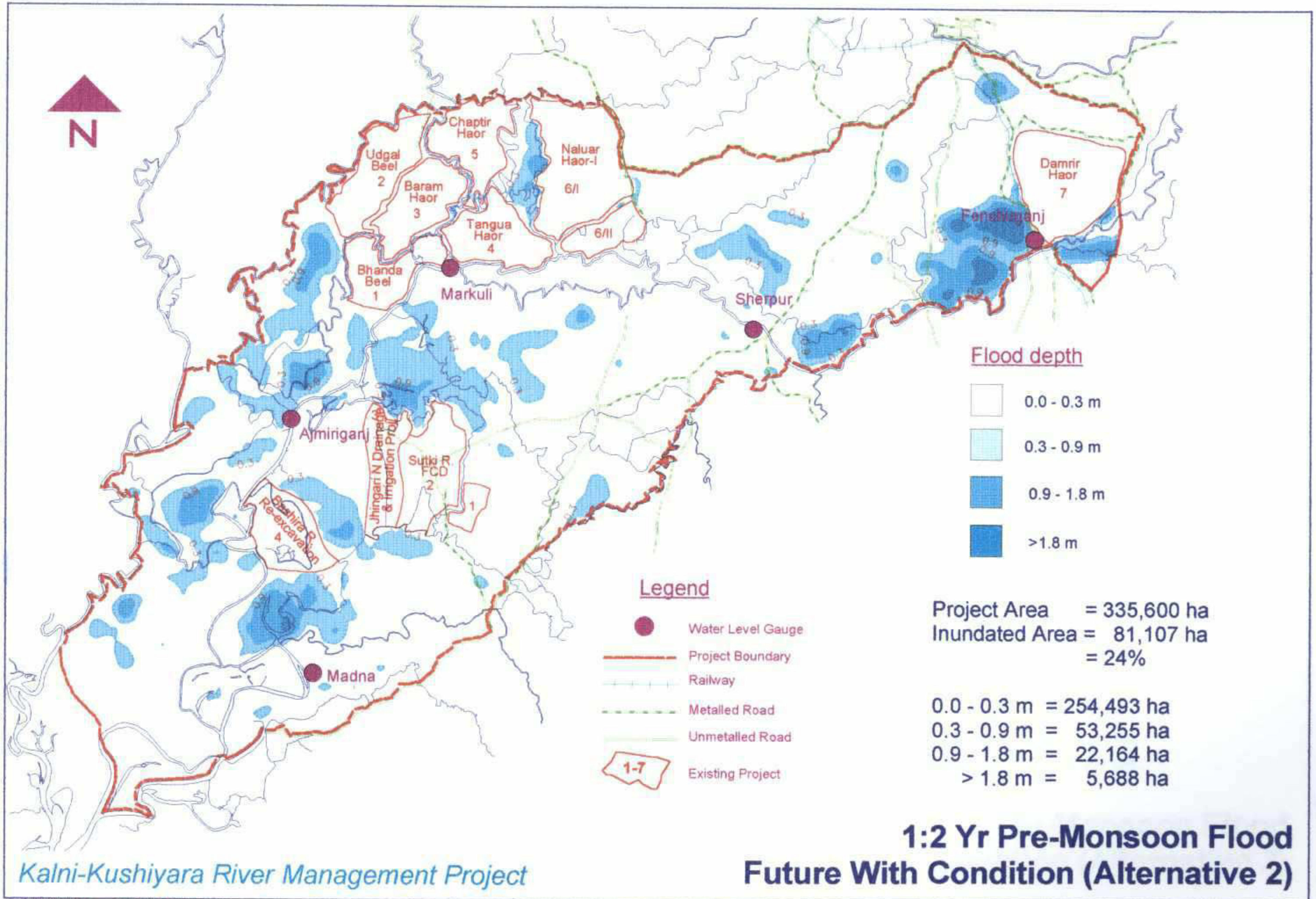
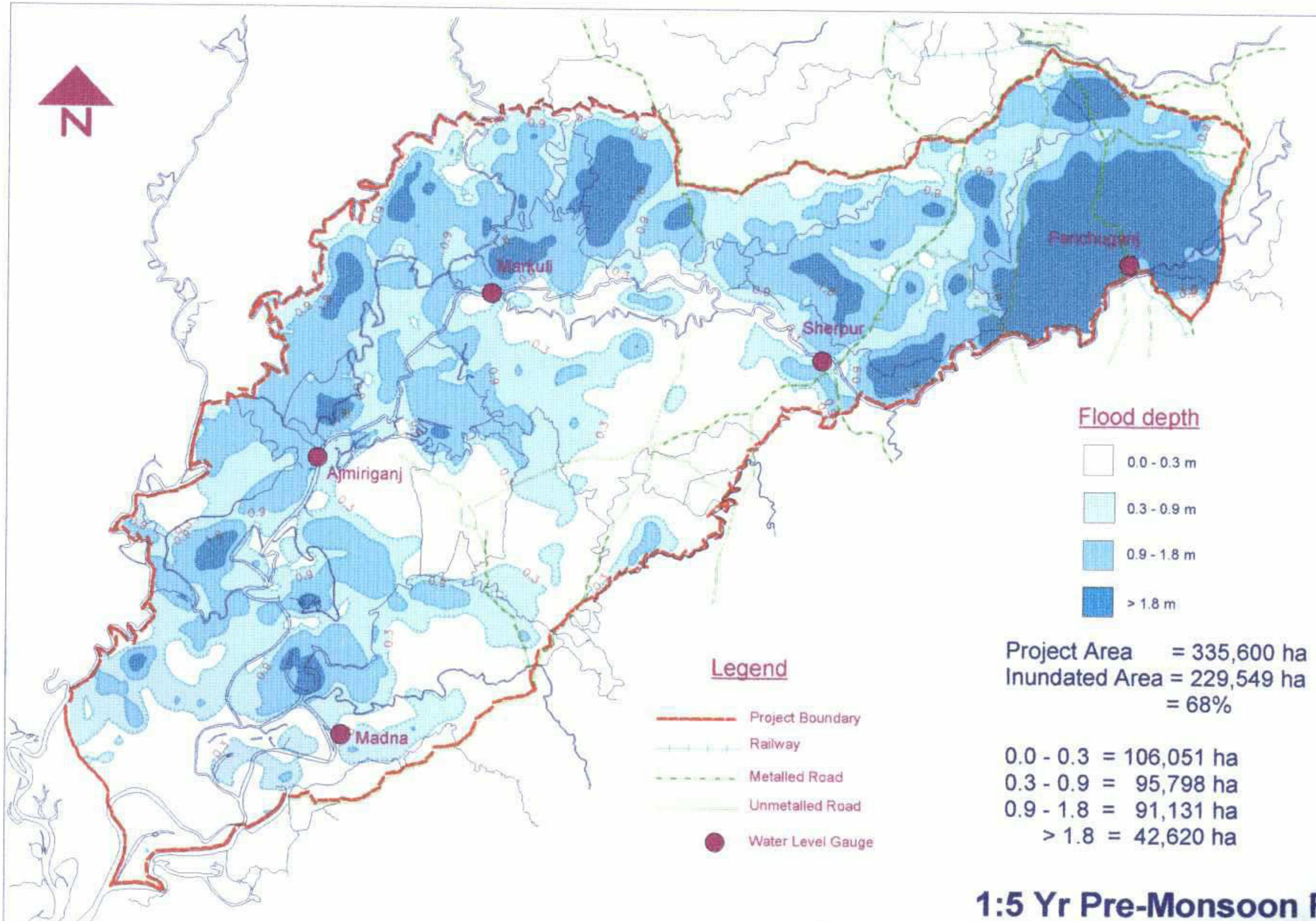


Figure B.35

1:2 Yr Pre-Monsoon Flood
Future With Condition (Alternative 2)

Figure B.36



1:5 Yr Pre-Monsoon Flood
Future With Condition (Alternative 2)

Kalni-Kushiyara River Management Project

FILE FD0519A.SRF Prepared by Tarek, Nov 97

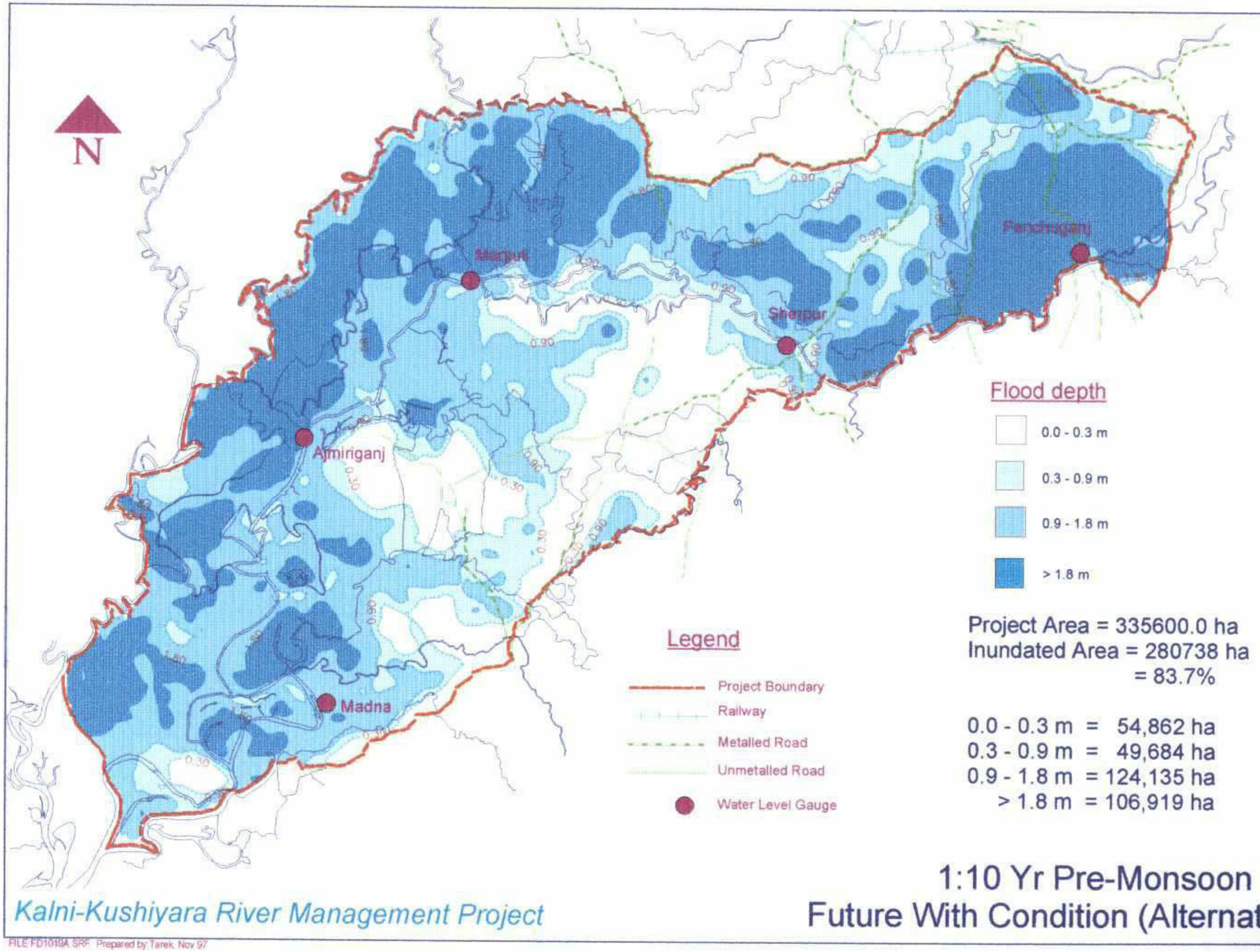


Figure B.37

1:10 Yr Pre-Monsoon Flood
Future With Condition (Alternative 2)