People's Republic of Bangladesh
Ministry of Irrigation, Water Development and Flood Control

Flood Plan Coordination Organisation

Southwest Area Water Resources Management Project

United Nations Development Programme
(BGD/88/038)

Asian Development Bank
(TA No 1498-BAN)

FAP 4

FINAL REPORT

Volume 12

Pre - Feasibility Study
Gorai Augmentation Project

August 1993

Sir William Halcrow & Partners Ltd.

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SOUTHWEST AREA WATER RESOURCES MANAGEMENT PROJECT (FAP-4)

GORAI AUGMENTATION PROJECT

PRE-FEASIBILITY STUDY

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ACRONYMS AND ABBREVIATIONS

ADB	Asian Development Bank
AEZ	Agro-Ecological Zones
Aman	Main Monsoon Paddy
AST	Agricultural Sector Team
Aus	Late dry season/early monsoon Paddy
BADC	Bangladesh Agriculture Development Corporation
B.Aman	Broadcast Aman
Baor	Ox-bow lake
BARC	Bangladesh Agricultural Research Council
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BBS	Bangladesh Bureau of Statistics
BFDC	Bangladesh Fisheries Development Corporation
BFRI	Bangladesh Forest Research Institute
BIWTA	Bangladesh Inland Water Transport Authority
BIWTC	Bangladesh Inland Water Transport Corporation
BIWTMAS	Bangladesh Inland Water Transport Master Plan
BKB	Bangladesh Krishi Bank
BLRI	Bangladesh Livestock Research Institute
BMD	Bangladesh Meteorological Department
Boro	Winter (dry) season Paddy
BRAC	Bangladesh Rural Advancement Committee (NGO)
BRDB	Bangladesh Rural Development Board
BRRI	Bangladesh Rice Research Institute
BSS	Bhumiheen Samabay Samity (Landless Cooperative Society)
BWDB	Bangladesh Water Development Board
CARE	Cooperative for American Relief Everywhere (NGO)
CEP	Coastal Embankment Project
CERP II	Second Coastal Embankment Rehabilitation Project
CH	Chainage (1 Chain = 100 feet)
CIDA	Canadian International Development Agency
DAE	Department of Agricultural Extension
DANIDA	Danish International Development Agency
DHI	Danish Hydraulic Institute
DOF	Department of Fisheries
DPHE	Directorate of Public Health Engineering
DSSTW	Deep Set Shallow Tube Well
DTW	Deep Tube Well
EIRR	Economic Internal Rate of Return
FAO	Food and Agriculture Organisation of the United Nations
FAP	Flood Action Plan
FCD	Flood Control and Drainage
FCD/I	Flood Control, Drainage and Irrigation
FFYP	Fourth Five Year Plan
FPCO	Flood Plan Coordination Organisation
GB	Grameen Bank
GIS	Geographical Information System
G-K	Ganges - Kobadak
GOB	Government of Bangladesh
HYV	High Yielding Variety
IDA	International Development Agency (World Bank)

IECO	International Engineering Company Inc
IFAD	International Fund for Agricultural Development
Khariff	Summer, monsoon cropping season
KSS	Krishi Samabya Samity (Farmers' Cooperative Society)
LAD	Least Available Depth
LLP	Low Lift Pump
LGEB	Local Government Engineering Bureau (now LGED)
MBR	Madaripur Beel Route
MLGRDC	Ministry of Local Government, Rural Development and Cooperatives
MP	Muriate of Potash
MPO	Master Plan Organisation
MS	Ministry of Shipping
MSY	Maximum Sustainable Yield
NAM	Rainfall Runoff Model
NFC	National Flood Council
NFMP	New Fisheries Management Policy
NGO	Non - Government Organisation
NWC	National Water Council
O & M	Operation and Maintenance
ODA	Overseas Development Administration (U.K)
PDB	Power Development Board
PDEU	Population Development and Evaluation Unit
PEP	Production Employment Programme
PET	Potential Evapotranspiration
PU	Planning Unit
PWD	Public Works Department
Rabi	Winter (dry) season crop
RAOM	Resource Allocation and Optimisation Model
RB	Right Bank
R & H	Roads and Highways
SC	South Central
SCR	South Central Region
SCRM	South Central Regional Model
STW	Shallow Tube Well
SW	South West
SWA	South West Area
SWAM	South West Area Model
SWMC	Surface Water Modelling Centre
SWR	South West Region
SWRM	South West Regional Model
T. Aman	Transplanted Aman
TOR	Terms of Reference
TSP	Triple Super Phosphate
UCCA	Upazila Central Cooperative Association
UNDP	United Nations Development Programme
UNO	Upazila Nirbahi Officer
Upazila (Now Thana)	Administrative Unit above Union and below Zila
WARPO	Water Resources Planning Organisation
WFP	World Food Programme
WSS	Women's Cooperative Society

GORAI AUGMENTATION PROJECT

PRE - FEASIBILITY REPORT

SUMMARY

S1 Introduction

Southwest Area Water Resources Management Project (FAP 4), identified the augmentation of the dry season flow to the Southwest Area (SWA) as one of the key issues. It also concluded that for achieving food security in the long term large scale expansion in irrigated agriculture is required, which is also inconsistent with the Government's Policy and the National Water Plan. Expansion of agriculture exploiting groundwater was studied under FAP 4 and the study concluded that there is only a limited potential for groundwater exploitation in the Area, mainly in the north and northeast, and given the progressive movement of the saline front northwards and therefore the need for maintaining a buffer zone, it would be prudent to exploit this resource in a cautious manner. Even if the groundwater potential is fully exploited, the predicted widening gap of food grains deficiency cannot be narrowed, the study concluded. The augmentation from surface water resources has thus become paramount.

This pre-feasibility study was carried out as part of the Southwest Area Water Resources Management Project (FAP 4).

S2 Choices for Augmentation

To meet the current dry season water requirements in the SWA, flows from the boundary rivers must be effectively transferred to the SW region. A wide variety of options of how to do this have been considered including possibilities of extractions from the Ganges, the Padma and the Lower Meghna. The dry season water levels in the Padma and Lower Meghna are low and extensive pumping against the gradient of the land would be required to command much of the Area. The Ganges water levels are relatively higher and therefore provides the most suitable source of water for augmentation of flows to the SWA.

Various options have been considered for the augmentation from the Ganges and the Gorai river comes out as the most suitable conveyor of flow into the SWA.

S3 Deterioration of the Gorai River

The dominant discharge in the Gorai River is about 4250 m^3/s which maintains a large channel (400 - 600 m wide) at the head of the Pussur - Sibsa esturial system upon which the city of Khulna and the second largest sea port of Mongla are located. Dry season flows have declined from minima of about 150 m^3/s twenty years of ago to zero for the last five years. The flow rate in the Gorai depends on water levels in the Ganges. The post-monsoon water level on the Ganges has been lowered by approximately 1 m since the construction of the Farakka Barrage in India. Reduction in the dry season flows in the Ganges has also caused the bed level of the Gorai to rise sufficiently (by deposition of sediments) at the mouth to block all dry season flows.

Historic mapping dating back to 1779 (Renell) and satellite images from 1973 to 1992 show that the alignment of the Ganges undergoes a un-favourable path to the Gorai offtake every 40 - 50 years causing the Gorai to go into a cycle of deterioration and recovery at about the same frequency. This coupled with the low flows in the Ganges during dry season due to the operation of the Farakka Barrage has steepened the falling limb of Ganges flow hydrograph to cause severe bar formation at the mouth. The funnel shaped wide mouth, tortuous planform of the Gorai all point to a 'dying' river and all indications are that the Gorai will in the near future will become detached from the Ganges and become an inland river just as the Chandana, the Bhairab and the Mathabanga did in the past. The timing of this cannot be predicted accurately, but it may be sooner rather than later. If this happens the monsoon season flows to the SWA will be lost.

Whilst loss of the dry season flows in the Gorai would have relatively small impacts, as it will not be worse than the present situation, the loss of wet season discharges could have major impacts on the hydrology, environment and ecology of the Region with catastrophic consequences to the Area. The environmental degradation itself will be of gigantic proportions.

The losing of wet season flows to the SWR will have, apart from the obvious impact on agriculture (almost the entire SWR depends on the Gorai during the wet season and the loss to agriculture sector alone due to the Gorai 'dying' would be in the order of Tk 700 M annually) impacts on fisheries, navigation, forestry, groundwater, salinity and siltation. The saline front, which is now kept south by the flows from the Gorai during the wet season, will move northwards even during the wet season and probably stay there permanently making the water supply to the areas south of Jessore unsuitable for agriculture and drinking purposes.

The damage to the fisheries although cannot be quantified at this stage, will lead to substantial reductions in the inland open water capture fishery and the salinity ingression will affect the sweet water species.

The impacts on the forestry sector will be less than obvious but the lack of upland flow and consequent depletion of soil moisture and the increase of salinity will have severe consequences on Sundarbans which is the principal supplier of commercial timber. Natural regeneration of mangrove forests will remarkably retard while 'top-dying' of the commercially attractive Sundri trees might become more pronounced and widespread.

Inland navigation will be another hard hit sector where communication will suffer severely if the upland flows are reduced. As most of the SWA depends entirely on the river transport this will have social, economic and ecological consequences resulting in hardship and eventual migration of the population from these areas.

Therefore the need to intervene at the mouth to keep it open is of paramount importance. This will also gives an opportunity to augment dry season flows for increased agriculture production.

S4 Needs and Benefits

The overwhelming need for intervening in the Gorai is to keep the mouth open throughout the year thus securing the wet season flows and augment flows in the dry season. The justification of the project lies on the disbenefit of the project not proceeding and the resultant catastrophic effects, both hydro-morphological and environmental.

The strongly perceived need for augmentation comes from a variety of sectors. Those requirements have been studied and the potential benefits and alternative means of achieving the desired objectives have been considered. The perceived needs are summarised below:

Sector	Requirement	Desirable Flow rate in Dry Season (m^3/s) (Not cumulative)
Agriculture	Irrigation	1000
Domestic Water Supply	Khulna (2 m^3/s)	150 - 200 (for salinity control) 2 m^3/s for direct supply
Industry	Industrial users at Khulna	150 - 200 for salinity control
Forestry	Commercial Production of Sundri in Sundarbans	> 250
Transportation	Mongla Port	1000

The actual requirements must be considered in light of what is practically attainable and is summarised below:

Condition	Flow Rate (m^3/s Monthly Average) Driest Month		
	Post Agreement 1989-1992	During 1976-1988*	Pre-Farakka 1934 - 1975
Minimum	517	664	1260
Mean	576	1063	2031

* 1978 to 1982 - Agreement with India
1983 to 1984 and 1986-1988 - Memorandum of Understanding

The amount that may reasonably be extracted without control on the Ganges is therefore estimated as 350 m^3/s if there is 576 m^3/s in the river. The amount extracted with control in the Ganges can be much higher. However in recent years the minimum flow in the Ganges has fallen further with the all-time low of 261 cumec recorded on 30 March 1993.

The current requirements for the G-K Project is about 100 m^3/s (max) leaving a maximum of about 250 m^3/s that could be abstracted elsewhere, assuming that about 500 m^3/s is available.

The benefits of augmentation could be summarised as :

(a) Irrigated agriculture : further 165 - 175,000 ha could be brought under irrigated agriculture increasing the cropping intensity from the present 156% to 191%.

(b) Control of salinity : salinity in the rivers around Khulna during the dry season could be controlled if at least 150 m^3/s could be made available at Khulna. This will not only serve the potable water supply to the Khulna town but also benefit the industries notably the paper pulp mills around Khulna which at present import water from further upstream by barges.

(c) Navigation : navigation, particularly the country boats would benefit and some of the old navigation routes which disappeared in recent years could be resurrected.

(d) Pollution : pollution in rivers, including agro-chemicals could be flushed down the river system, thus improving the environment and public health.

(e) Sundarbans : additional freshwater to Sundarbans will almost certainly be beneficial to the commercially attractive "Sundri" trees which are growing stunted at present due to increase in salinity.

With the controlled structure at the mouth the wet season flows can be controlled thereby reducing the drainage problems downstream. This improved drainage in the area will benefit during the critical period of cropping.

S5 Intervention Options

Several options were considered to intervene at the Gorai mouth, some with control structure and some without. The favoured option is with a structure at the mouth together with dredging the mouth and about 30 km of the river downstream (Option A2). Guide banks and groynes would be required to sustain the dredged low flow channel and also to improve the flow conditions.

In addition a barrage is required downstream of the Kamarkhali bend to raise the water level to command areas for irrigation.

S6 Dredging Requirements

All options considered require substantial capital dredging. For the preferred option (option A2) it is estimated that about 13 Mm^3 of excavation is required to enable a flow of about 170 m^3/s to pass during the dry season.

The disposal arrangements for this large quantity of dredged material have been studied and the recommended proposal can be summarised as :

(a) material in the first 8.0 km of the Gorai could be used in the construction of the embankments associated with the water control structure and this amounts to about 6 Mm^3

(b) material from km 8.0 to km 20.0 could be discharged into the Ganges (5.5 Mm^3)

(c) from km 20.0 to km 29.0 (about 1.5 Mm^3) could be used to refill existing unused borrow pits along the banks and also strengthening the associated flood control embankments from km 15.0 to km 34.0.

One of the features of the option is the recurrent maintenance dredging required annually to keep the channel open. The maintenance dredging requirements have been calculated using a computer program (BENDFLOW), which was also used recently in another FAP programme (FAP 1). It is estimated that it would require about 0.5 Mm^3 of dredging annually to keep a channel open to carry about 170 m^3/s in the dry season. Although this amount appears to be large it is comparable with the maintenance dredging requirements of 0.4 Mm^3 in the G K Project to keep the inlet channel to the pump stations open. During the early days of the G-K Project (in the 1970's) it was reported that the maintenance dredging requirement was nearly 1.0 Mm^3. It can therefore be concluded that although the maintenance dredging requirement is substantial, it is well within the capability of the BWDB, who will eventually be responsible for the operation and maintenance of the project including the control structure at the Gorai mouth.

S7 Sustainability

Gorai Augmentation Project proposed as a 'stand alone' project offers a worthwhile investment and a necessity which addresses the immediate risks associated with the closure of the Gorai mouth. With the assumed rate of flow in the Ganges the Project is technically and economically feasible (S12) and offers the opportunity to develop a significant area for irrigated agriculture in the SW Region. This will also enable to secure the dry season fresh water supplies for Khulna by transferring about 10 m^3/s through the Chitra. However, the project's success depends on the commitment to annual maintenance dredging, which is a significant amount (about Tk 59.0 m/year), at the mouth and to about 15 km downstream. Dredging requirements in the initial years will be much less as the project is developed in phases and the channel required to carry about 60 m^3/s will be smaller and therefore requires less dredging. However, the project is sensitive to low flows in the Ganges.

The Project alone cannot meet the Area's food requirement and further development is required to maximise opportunity and narrow the widening gap. This is therefore dependent on further abstractions from the Ganges, which in turn is dependent on releases from the Farakka barrage. An agreement on the sharing of the Ganges water with India therefore becomes paramount. With an Agreement and assuming a level of flow similar to that agreed in the 1984 M of A, over 1 Mha of land could be brought under irrigated agriculture. However this needs political will on both sides to achieve. In the absence of any Agreement and with the current flows, water levels in the Ganges need to be controlled for long term sustainability. This would give opportunities for development of additional areas in addition to securing water supplies to existing schemes, notably to the G-K Project, where the storage levels in the Ganges will ensure higher levels at the pumping station.

S8 Development Programme

A phased development for the Gorai Augmentation Project is proposed which is summarised as follows:

1 - 3 yrs	-	Construction of the Gorai mouth works to allow about 60 cumecs to pass; construction of the Kamarkhali Barrage.
4 - 6 yrs	-	Area Development of about 60,000 ha.
7 - 10 yrs	-	Further dredging of the Gorai to increase flow to 170 cumecs. Development of additional area of about 105,000 ha.
11 yrs +	-	Development of additional areas is contingent upon a Ganges Barrage and/or Agreement with India on sharing of the Ganges water.

S9 Impacts

As part of the study a preliminary assessment of the socio-economic and environmental impacts were made. The preliminary conclusions can be summarised as:

(a) The project will benefit agriculture and therefore farmers. Improved agriculture should improve the diet of local communities and therefore the nutrition of the people.

(b) With the development, new internal road network will be developed which will benefit in the transport of produce and goods.

(c) The project will be able to create employment opportunities both during and after construction of the project. As this is targetted to the people in the lower rung of the society it is hoped that this will also ensure equitable distribution of income.

(d) River transport may be marginally disadvantaged due to structures in area but this could be mitigated

(e) large dredging requirement poses negative impacts on fisheries and generally on river environment. Mitigation measures needed in the final design.

(f) Water related diseases may increase and pollution from agrochemical likely to rise.

During feasibility study, detailed studies need to be undertaken to examine the impacts and mitigation measures suggested.

S10 Impact on G-K Project

The effect of abstracting about 170 m^3/s during the dry season on the performance of the pumping at G K Project was studied and it was concluded that it will have minimal effect. The effect of abstracting of about 170 m^3/s will effectively lower levels at Bheramara by 0.1 m, with a flow of 400 m^3/s in the Ganges. The impact will be smaller for larger flows in the Ganges. It is therefore concluded that although augmentation of flow through the Gorai would have a minor effect on water levels at the G-K pump house, the effect is much smaller than the natural variation in levels for the same flow rate. The G K pump house will be most affected by the total flow in the Ganges, as controlled by releases from Farakka Barrage.

S11 Operation, Maintenance and Institutional Issues

O&M and Institutional requirements were studied as part of the pre-feasibility studies and several measures proposed. The need for cost recovery is recognised and is reflected in the recommendations. The institutional arrangement for a selected area is given in the report which takes account of the need to form Water Users Associations and beneficiary participation from the initial planning and implementation stages through to O&M stage.

This needs further detailed study during the feasibility studies.

S12 Costs and Economic Analysis

Detail cost estimate of the project components have been worked out using the 1991 BWDB unit rates(as required by the FPCO Guidelines for Project Assessment).

A summary of the development cost is given in the table below :

Component	Total Cost (M Tk)
Gorai Intake/Control Structure	3236
Gorai Capital Dredging	1850
Gorai Guide Banks/Groynes	290
Kamarkhali Barrage	1860
River Links	660
River Control Structures	835
Irrigation/Drainage canals	
Earthwork	768
Structures	2258
LLP	551
Land Acquisition (20 km^2)	730
Total	13038

= US$ 325M

A detailed economic analysis was carried out and the proposed development will have an EIRR of 15.6% with a net present value (NPV) of Tk 1800 M.

A series of sensitivity analyses were carried out and the project is found to be sensitive to both increases in costs and reduction in benefits. However if costs increase by about 20% the EIRR will still be slightly above the 12% discount rate.

S13 Conclusions and Recommendations

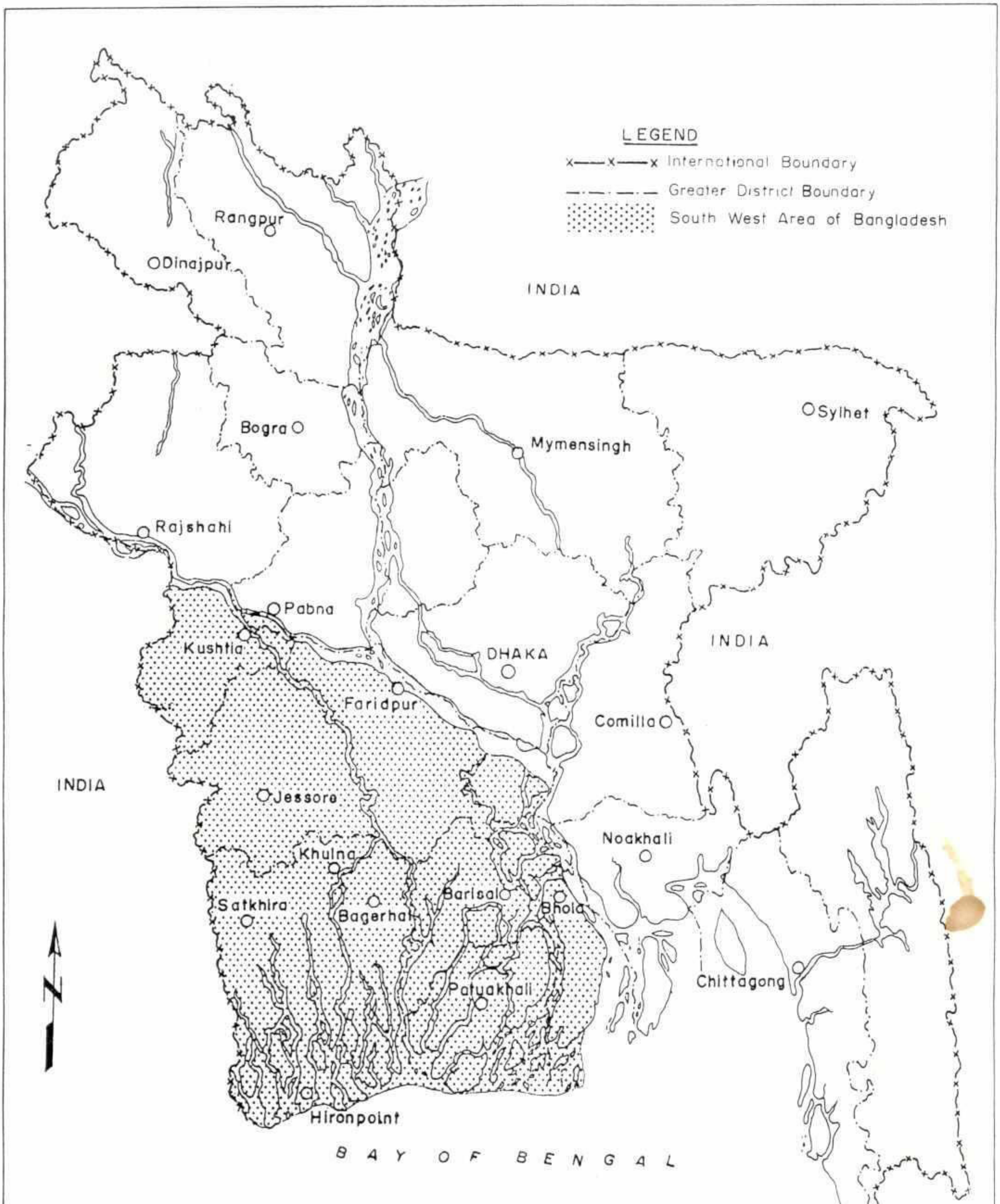
The Gorai is vital to the natural ecosystem, water resources and navigation of the SWA. Its decline and predicted demise would have catastrophic impacts on the Area and rejuvenating the river is therefore a priority. The alternative of not doing anything could have irreparable hydro-morphological and environmental changes to the region which will have social and political implications resulting in eventual migration of the population from the SWA to other regions of Bangladesh causing additional pressures on these regions.

Augmentation of dry season flows is necessary for the sustainability of the river itself and developing further irrigated agriculture with the ultimate aim of achieving self-sufficiency in food. The project as proposed is technically feasible and economically viable as a 'stand alone' project. A phased development is proposed for the project to suit the institutional and financial capability of the Government. The annual maintenance dredging requirements are substantial but is within the capability of the present BWDB organisation. For long term sustainability of dry season flows an assured level of flows in the Ganges would be necessary.

The social, environmental and other impacts identified need to be studied further and mitigation measures to be incorporated in the final design. Cost recovery methods, O & M and institutional arrangements should also be studied in detail.

It is recommended that a Feasibility Study of the Project should be carried out as soon as possible. The risks and impacts of low flows in the Ganges on the Project will be studied in detail during the feasibility study stage. Draft Terms of Reference for the feasibility study together with a work programme are given in this Report.

Figure 1.1



South West Area Location Map

1 PROJECT SETTING

1.1 Introduction

The Gorai River is the main distributary of the Ganges River that flows through the Southwest Area. The dominant discharge in the Gorai is 4250 m^3/s. The dry season flows in the Gorai which until the late 1980s had supported some irrigated agriculture, have declined dramatically from minima of about 150m^3/s twenty years ago to zero for the last five years. The Pussur-Sibsa estuarial system on which the city of Khulna and the port of Mongla are located, is sustained mainly by the Gorai flows.

Though a slow decline of distributary rivers of the Ganges is part of the delta development process as has been the case for rivers such as the Bhagirathi (in India), the Mathabhanga and the Bhairab and Kobadak, the decline of the Gorai has been accelerated by upstream abstractions and control of the Ganges at Farakka (in India). Furthermore, according to available historical information the Ganges appears to follow a cyclical trend of dry season planform movement with a periodicity of 40-50 years, which causes a similar cycle of improvement and deterioration of the Gorai river to occur. The trough of the deterioration limb of the curve, which has in the past had a duration of 2-3 years, corresponds to a period when total cessation of flow occurs during the intervening dry seasons. However, the current trough has already continued for five years. The Gorai also now exhibits many of the features generally observed when rivers are in terminal decline, giving rise to concern that the above dry season closure may become a permanent feature, as already seen in the Mathabhanga and the Bhairab.

Such a decline would not only affect the agricultural, fisheries and groundwater potentials of the Southwest Area, but also would have catastrophic impacts on the salinity and siltation in the river network further north of Khulna, particularly affecting the water resources of Khulna (the township and the major industrial area) and the viability of Mongla Port.

There is, therefore, a strongly perceived need for augmenting dry season flows from the Ganges and other boundary rivers (Padma and Lower Meghna). Different options for transferring water to the Southwest Area from the boundary rivers have been examined under the Southwest Area Water Resources Management Study. The augmentation of the dry season flows through the Gorai has been identified as the best option.

This prefeasibility study report carried out as part of the Southwest Area Water Resources Management Project (FAP-4), examines the technical feasibility of the Gorai Augmentation Project and its sociological and environmental impacts and identifies the scope for the necessary institutional strengthening in order to attain project sustainability through beneficiary participation at the initial planning and implementation stages and during the subsequent operation/maintenance of the project. Cost recovery is considered an important aspect for project sustainability and measures to achieve it are also discussed.

Figure 1.1 shows the Southwest Area and Figure 1.2 shows the location of the project area.

1.2 Related Studies of the Study Area

The Consultants referred to a number of previous reports relating to possible developments in the project area and to other relevant sectoral studies. The reports pertaining to the area are:

- Southwest Regional Plan; IECO et al, 1980
- Soil Association Maps for National Water Plan Phase-II; MPO, 1990 : Sheets No. 20, 24, 25, 26 and 27
- Land Resources Appraisal for Bangladesh for Agricultural Development; FAO, 1988:

    Report 2 - Agroecological Regions of Bangladesh

    Report 5 - Land Resources Map and Legend; Volumes II 8 & II 9

- Reconnaissance Soil Survey; Soil Resources Development Institute, Faridpur District (1969) and Jessore District (1970).

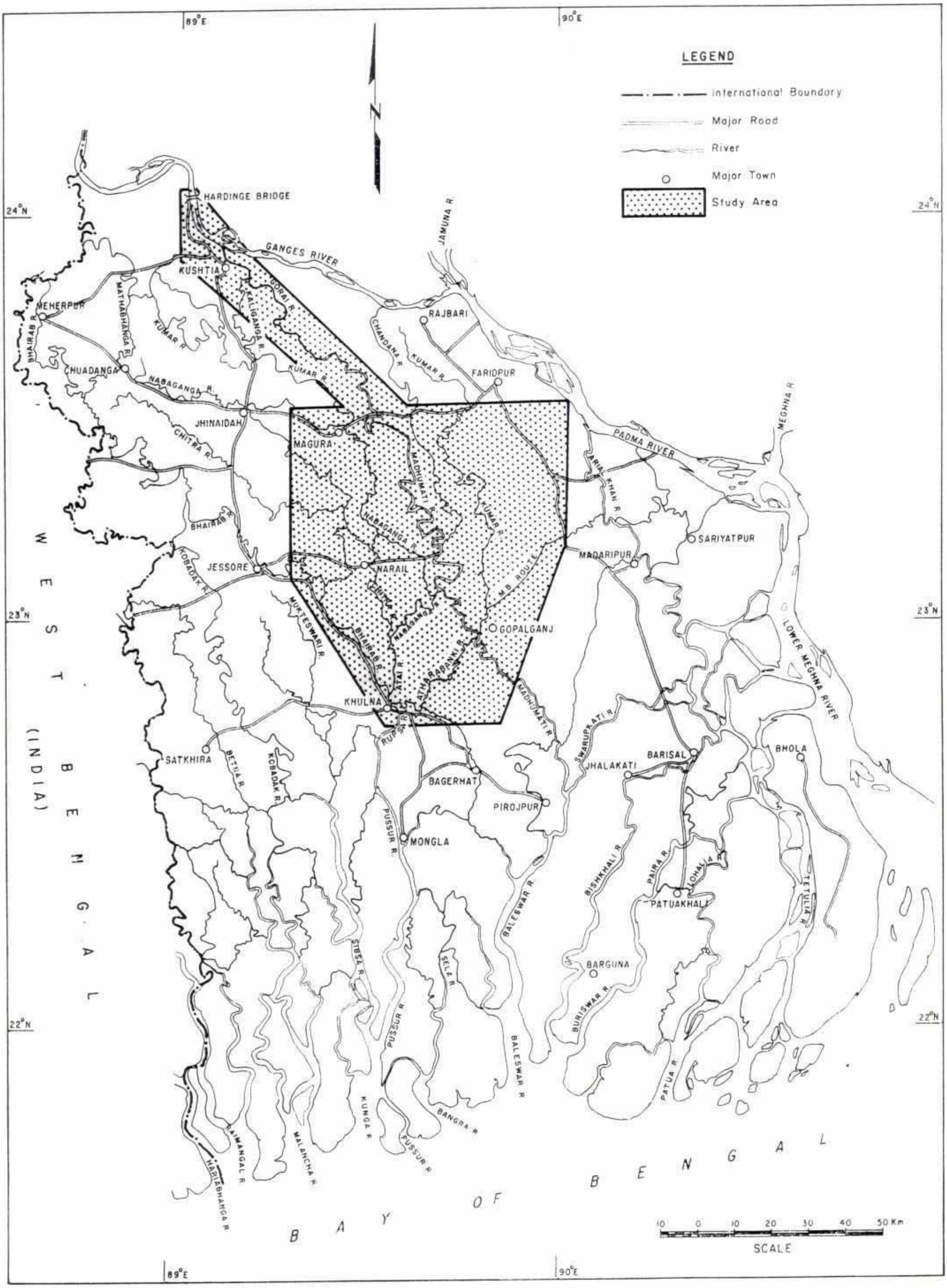
Reports of other relevant FAPs are:

- Compartmentalisation Pilot Project (FAP-20); Euroconsult et al, 1992
- FCD/I Agricultural Study (FAP-12); Hunting Technical Services Ltd et al, 1992
- Operation and Maintenance Study (FAP-13); Hunting Technical Services Ltd et al, 1992
- River Training Studies of the Brahmaputra River; Halcrow et al, 1993
- Environmental Study (FAP-16); ISPAN et al, 1993.

In addition, the following reports have been referred to:

- Engineering Appraisal of the Ganges Barrage Project; Halcrow et al, 1984
- Ganges Barrage Project; Associated Consulting Engineers Ltd, 1969.

Figure 1.2



Study Area

2 DETERIORATION OF THE GORAI RIVER

2.1 Importance of the Gorai

The Gorai river is the main channel for conveying flow into the Southwest Region. The dominant flow in the river is 4250 m^3/s which maintains a large (400-600m wide) channel at the head of the Pussur Sibsa estuarial system upon which the city of Khulna and the sea port of Mongla are located. Dry season flows have declined from minima of about 150m^3/s twenty years ago to zero for the last five years. At the end of the monsoon, the level in the Ganges drops rapidly by over 7m causing the water level at the mouth of the Gorai to drop by a similar amount. Because the Gorai has a relatively wide flat sand bed the water depth in the Gorai at typical dry season flows is only of the order of 1-2m. A small change in the bed of the Gorai, therefore, causes large changes in the dry season flows. At present the bed level of the Gorai has risen sufficiently at the mouth to block all dry season flow. The post monsoon water level in the Ganges has been lowered by approximately 1m since the construction of the Farakka barrage in India.

2.2 Planform Changes in the Ganges and Silting of the Gorai Mouth

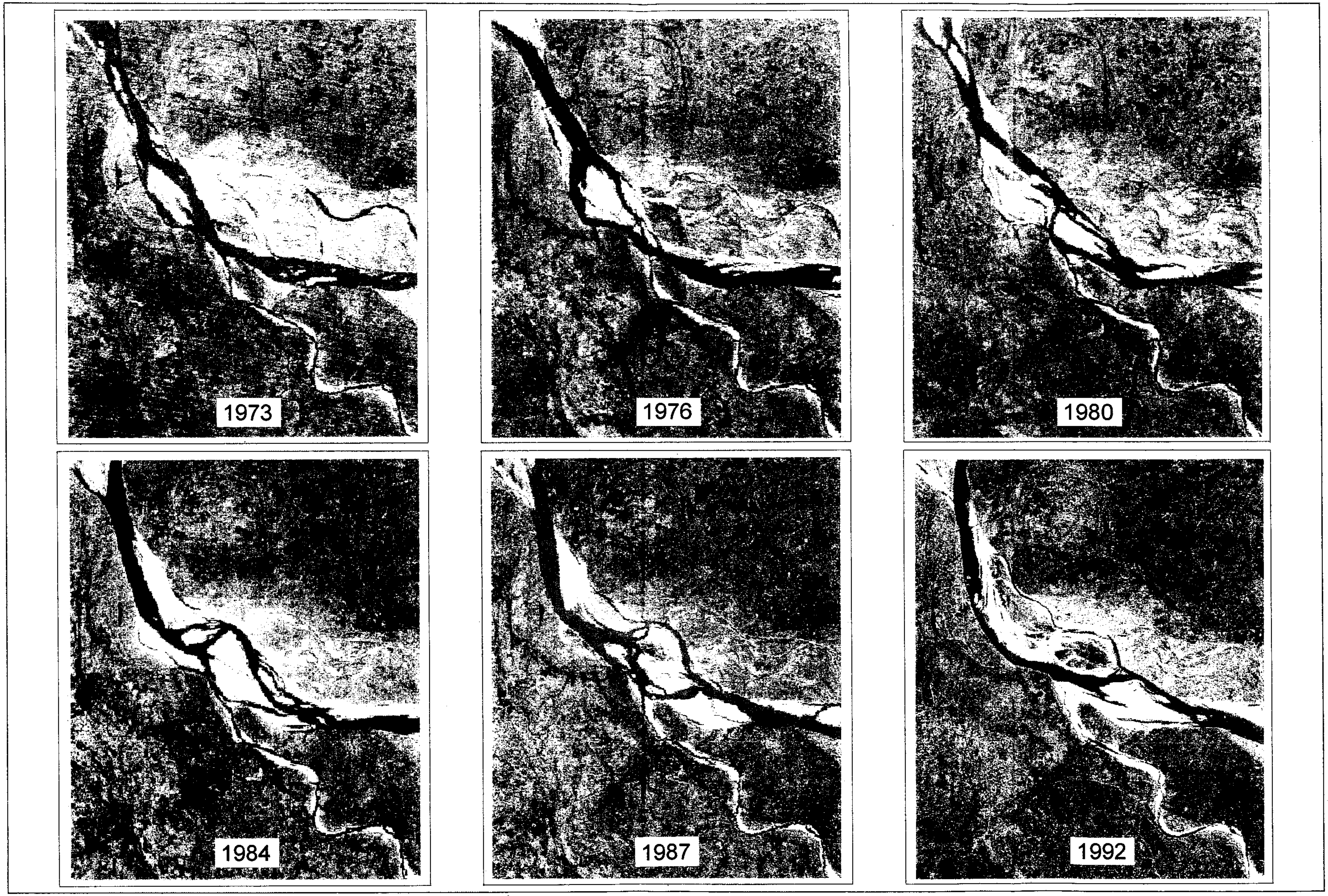
Historic mapping dating back to 1779 (Rennell) and satellite imagery from 1973 to 1992 have been used to analyse the changes that have taken place at the Gorai mouth. The recent changes as recorded by satellite in the dry period is shown in Figure 2.1. It can be seen in Figure 2.1 that the Ganges thalweg is subject to wide movement and that presently the river alignment is orthogonal to the Gorai offtake, leaving a very wide channel at the mouth of the Gorai. Such a wide channel is likely to have low velocities and hence siltation would be expected. This alignment of the Ganges occurs periodically every 40 to 50 years, the limit of the previous right bank embayment can be seen clearly on the satellite images. It is no coincidence that the Gorai also became disconnected from the Ganges in the early 1950's when the Ganges alignment was similar to the present.

The changes in the Gorai since 1950 are quite marked however. Examining survey results of the bathymetry of the area (Figure 2.2) it may be seen that the level of the bed has minima of around +6m PWD which is approximately 1m above the Ganges water level. A long section profile of the lowest section (Figure 2.3) shows how much the bed levels have risen for a considerable distance into the Gorai, whilst at the same time the Ganges levels during the dry period have fallen. The flow channel below a level of +5m (approximately the Ganges low water level) for different years is shown in Figure 2.4 indicating that there is a significant change in the bed levels and not just the lowest point.

2.3 Specific Gauge Analysis

There are two flow gauging sites on the Gorai, one at the Gorai railway bridge which is just outside Kushtia approximately 11 Km from the mouth, the other gauge at Kamarkhali is about 88 Km from the mouth and is just upstream of the major looping bed near the tidal limit. The record for the railway bridge gauging site goes back to 1947, while data was available for Kamarkhali back to 1966.

There is a strong upward trend in stages for low discharges that is not so apparent in the high flow stages. At the railway bridge the lowest line, for 200 cumecs, rises by over 1.2 metres over the 45 year period. Increases diminish progressively as discharge increases, and the 2,000 cumecs stage is barely affected. The stages associated with dominant discharge (about 4,250 cumecs) show no clear trend over the period. The Kamarkhali site shows a similar trend although there seems to be a stronger downward shift for high flows in the sixties that has reversed in the eighties.



(Source : Landsat Satellite Imagery, Supplied by FAP-19. Approx Scale : 1 : 300000)

Changes in Rivers Ganges and Gorai at Gorai Mouth, 1973 - 1992

The rising stages at low flows are consistent with the theory that falling stage flows in the Gorai are not dissecting the high flow bars sufficiently to maintain a low flow channel. The impact is to pond water behind bar crests and raise flow lines and stages for low discharges. Higher flows are able to remould the bed as required by their hydraulics, and so are relatively less affected by bar topography.

There are serious implications for dry season flows into the Gorai, because the raising on the water levels at the railway bridge during low discharges reduces the head difference and, therefore, the energy slope between the mouth of the Gorai and the railway bridge. This could critically reduce the sediment transport capacity of the flow, leading to sedimentation and bar building in the mouth during high/intermediate stages.

Perhaps more critically, a reduction of energy slope (and sediment transport capacity) during falling stages (say at around 1,000-2,000 cumecs in the post-monsoon period, when the Ganges is at about 10,000-20,000 cumecs but is falling rapidly) would mean that flows entering the Gorai and flowing downstream via the railway bridge would be unable to scour a recession flow channel through the high flow bed and bars. The Gorai would be disconnected from the Ganges early in the autumn as a result. The effect of such scouring is illustrated by the change in rating curve at Talbaria on rising stage and the difference between the model results with a fixed bed and the measured flows and levels as shown in Figure 2.5. Talbaria is not a flow gauging station, so to construct a rating curve the flows measured at the railway bridge are assumed equal to the flow into the mouth.

The findings of the specific gauge analysis of the railway bridge are disturbing from the point of view of water resources developments in the SW Region. They suggest that siltation problems are not confined only to the mouth of the Gorai but extend downstream at least as far as the railway bridge, a distance of about 15 kms, and similar trends even seem apparent more than 90 km from the mouth.

2.4 Planform Development of the Gorai

Examination of recent satellite images and maps indicate that (as shown in Figure 2.1) :

(1) The upper course of the Gorai has been remarkably stable in the last twenty years.

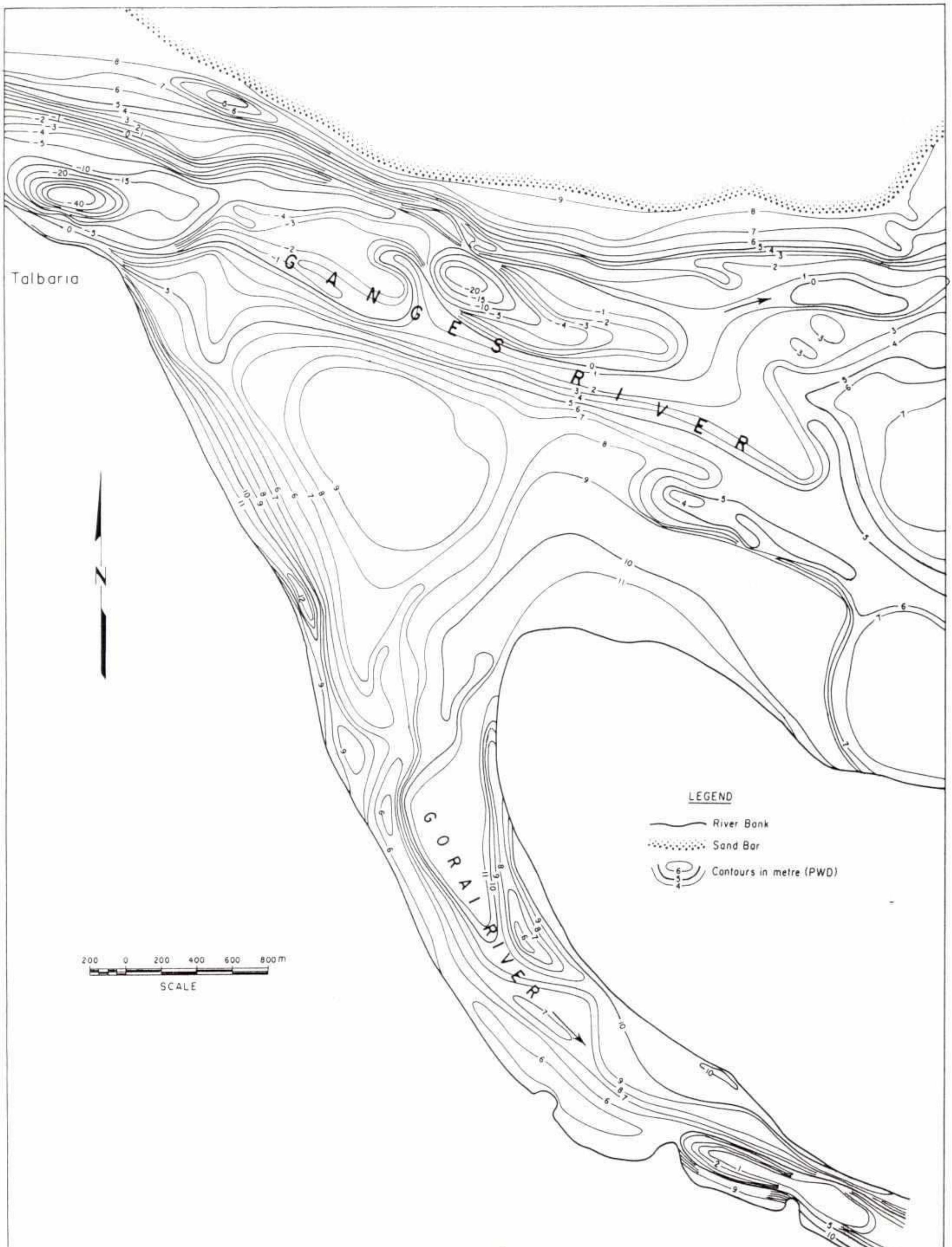
(2) The bends at Kamarkhali are a prominent feature throughout this period. A neck cut-off of the downstream bend occurred in the 1970s, but after some years of using both the bend and cut-off channels, the river resumed flow in the bend channel. This behaviour is not consistent with the usual sequence of events in alluvial bends and it strongly suggests that these bends are constrained in some way.

(3) The straight reaches downstream of Kamarkhali have been very persistent and there must be some reason for this. The planform appearance of the reaches is unusual for an alluvial stream and hints at exterior control by geology or topography.

(4) The lower Gorai-Madhumati has increased in sinuosity very markedly in recent years.

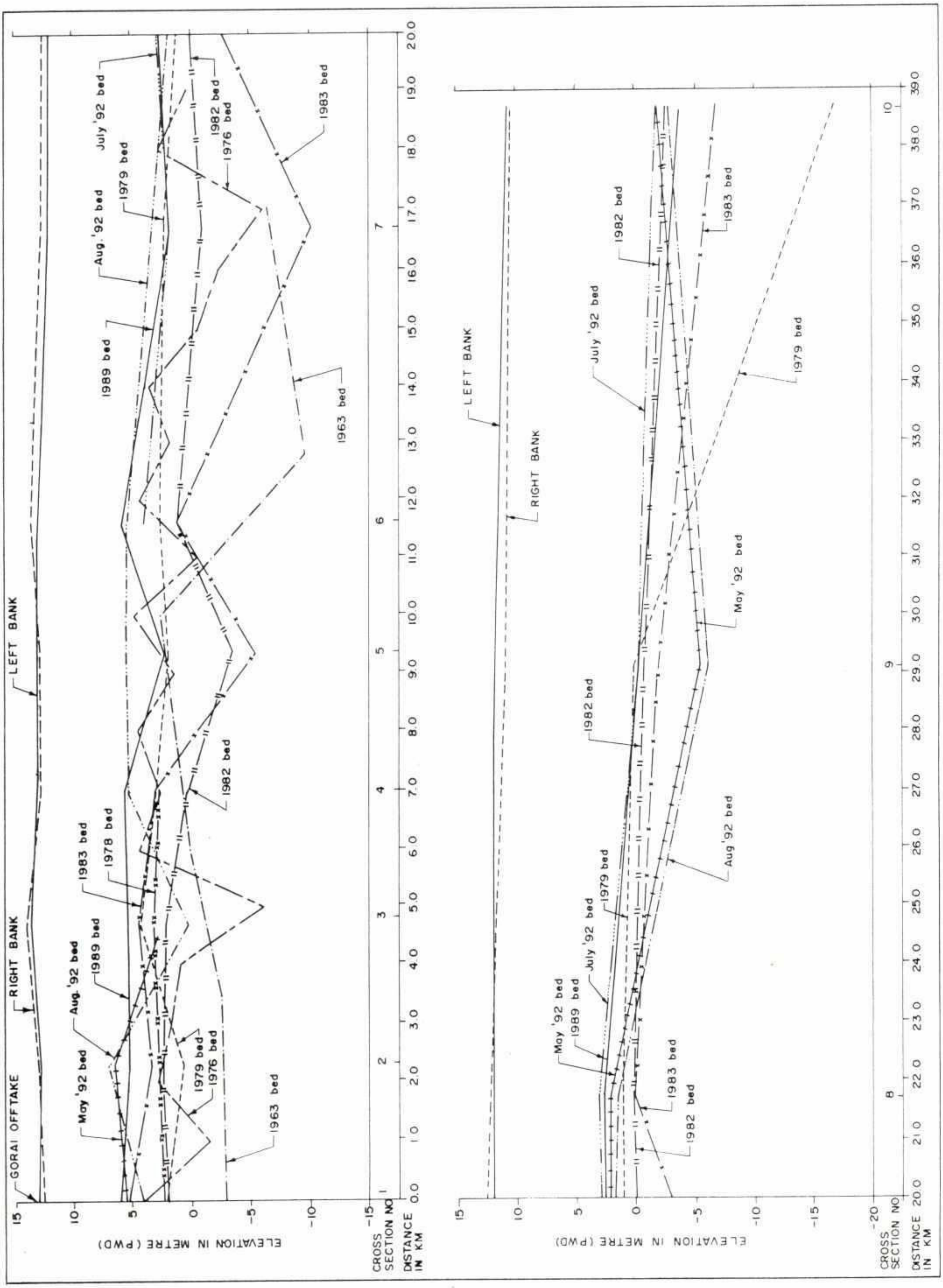
Important observations of the behavoir of the rivers of the Ganges delta were made by Fergusson (1863) and Adams-Williams (1918). From extensive work in the region they conclude that the deterioration in conveyance and velocity of an offtake channel due to the growth of tortuous meanders was a significant factor in its declining importance as a distributary.

Figure 2.2



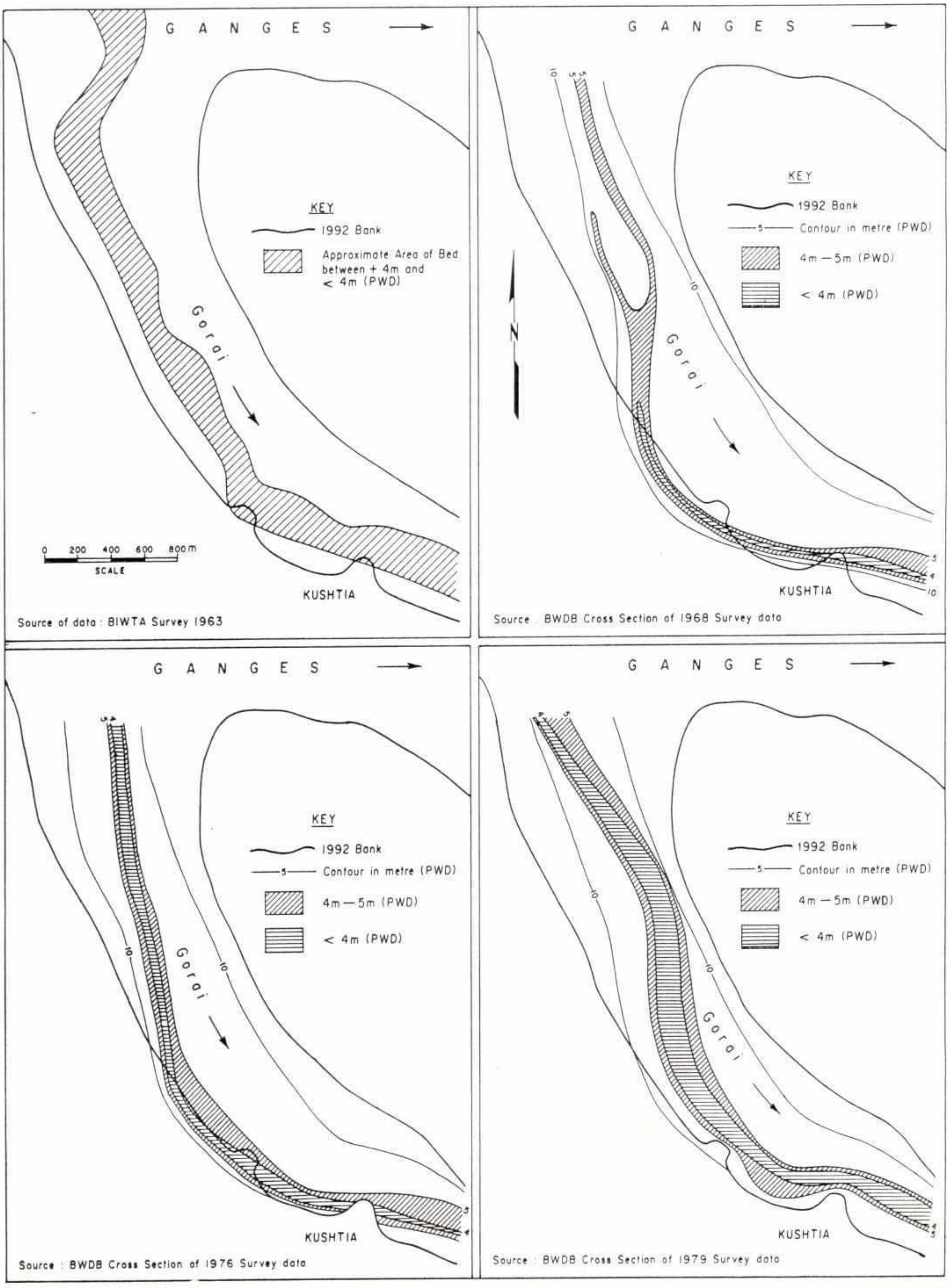
Bathymetry Survey, July 1992

Figure 2.3



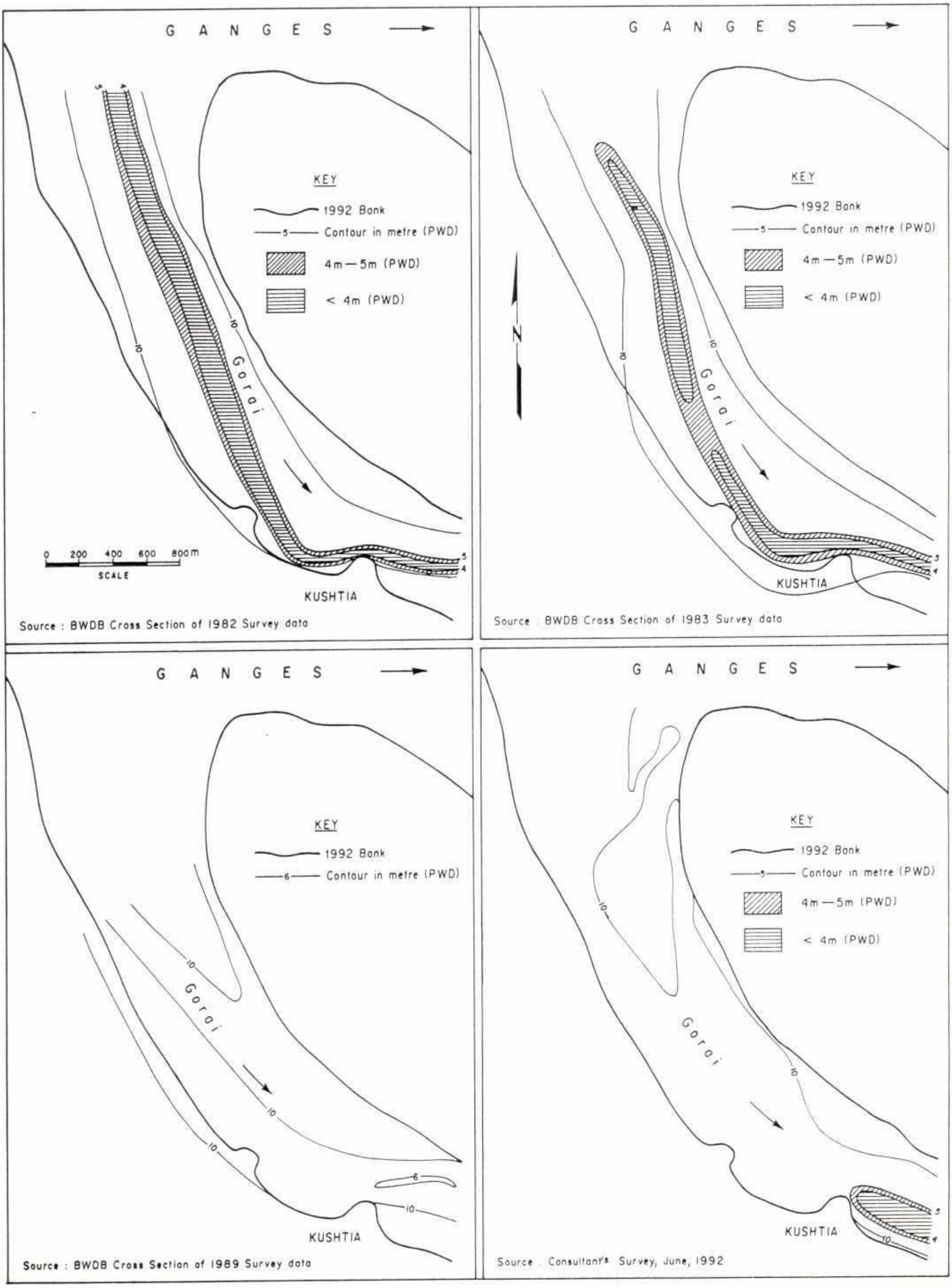
Gorai River : Long Profile of Low Section

Figure 2.4a



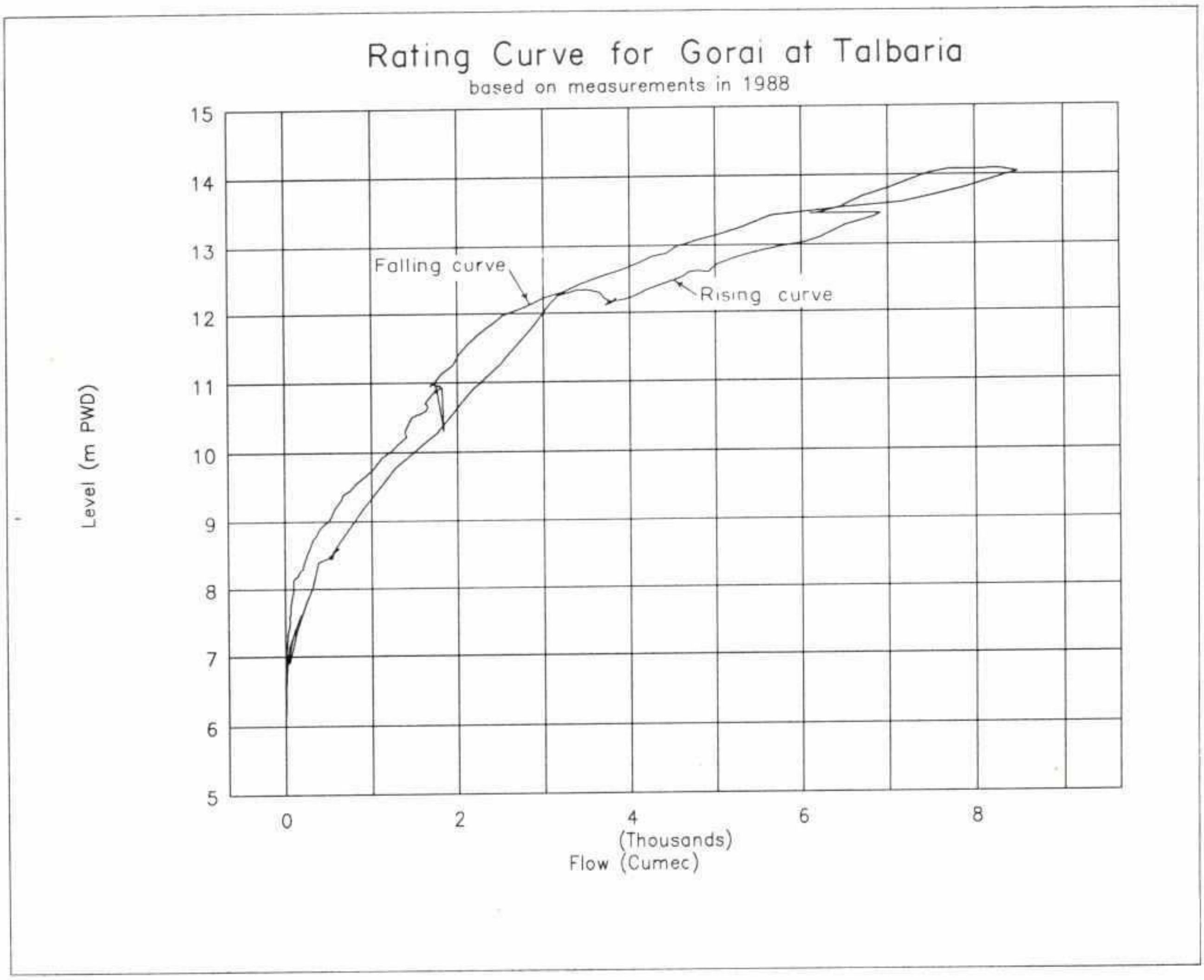
Gorai River: Changes to Low Flow Channel (below 5.0m PWD) According to Surveys in 1963, 1968, 1976 & 1979

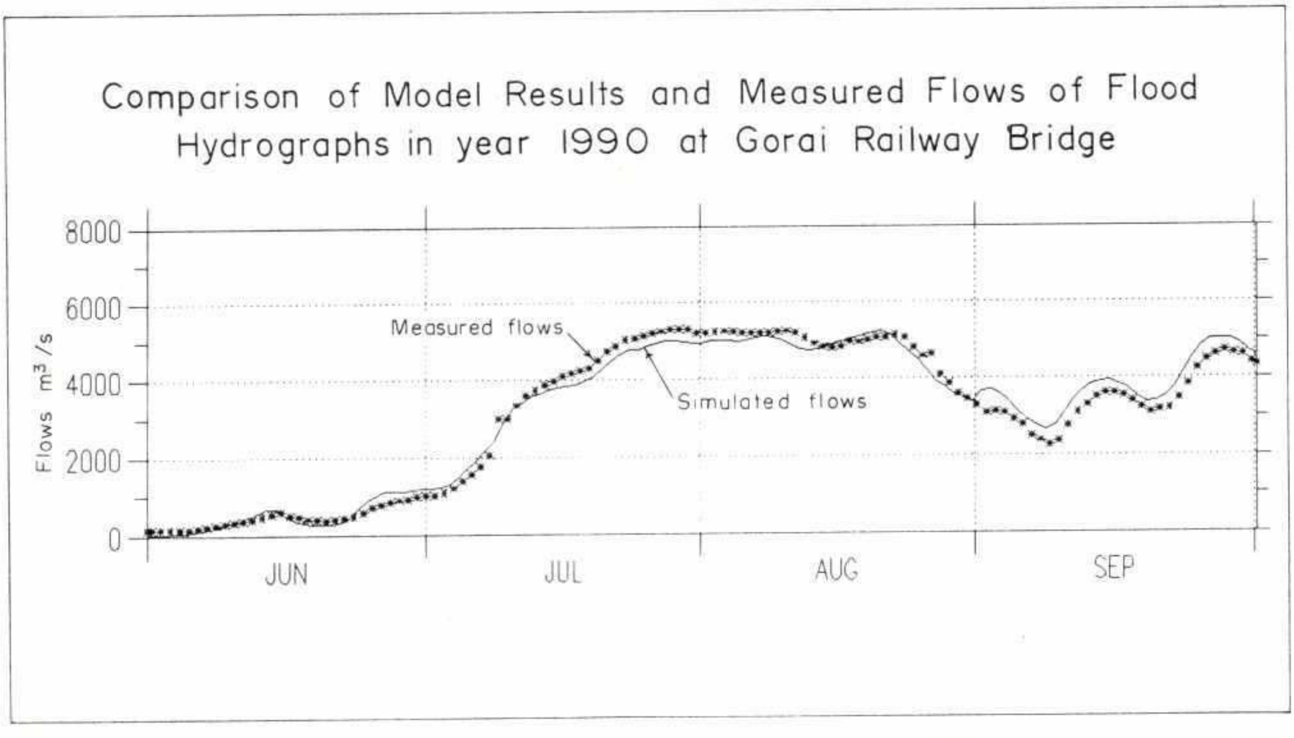
Figure 2.4b



Gorai River: Changes to Low Flow Channel (below 5.0m PWD) According to Surveys in 1982, 1983, 1989 & 1992

Figure 2.5





Gorai Rating Curve at Talbaria and
Gorai Hydrographs at Railway Bridge

2.5 Siltation and Sinuosity

Since the first survey in 1780, the planform of the Gorai has changed little, especially in the upper part, where it has simply tended to develop more tortuous meander bends. Examples of this are the bend at Kamarkhali and the two bends immediately upstream and a further two bends downstream of Kushtia railway bridge (Figure 2.6). There was also a realignment of the channel between kilometers 29.2 and 46.1 downstream from the mouth, with the old channel becoming a present day flood channel. These bends illustrate meander development patterns, but it is surprising (especially in view of the changes seen on other rivers) that features such as the Kamarkhali bend should be so relatively stable. In 1780 the planform of the river downstream of Kamarkhali was similar to that upstream but since that time it has become considerably more sinuous (Table 2.1).

TABLE 2.1

Meander Geometry of the Gorai-Madhumati

YEAR	AVERAGE SINUOSITY	AVERAGE WAVELENGTH (km)
1780	1.5	
1849-60	1.5	
1904-24	1.7 ((upper section 1.4 lower section 2.2)	9.2
1952-58	1.7	9.6
1989	1.8 (upper section 1.5 lower section 2.3)	8.9
With all proposed cutoffs	1.5	

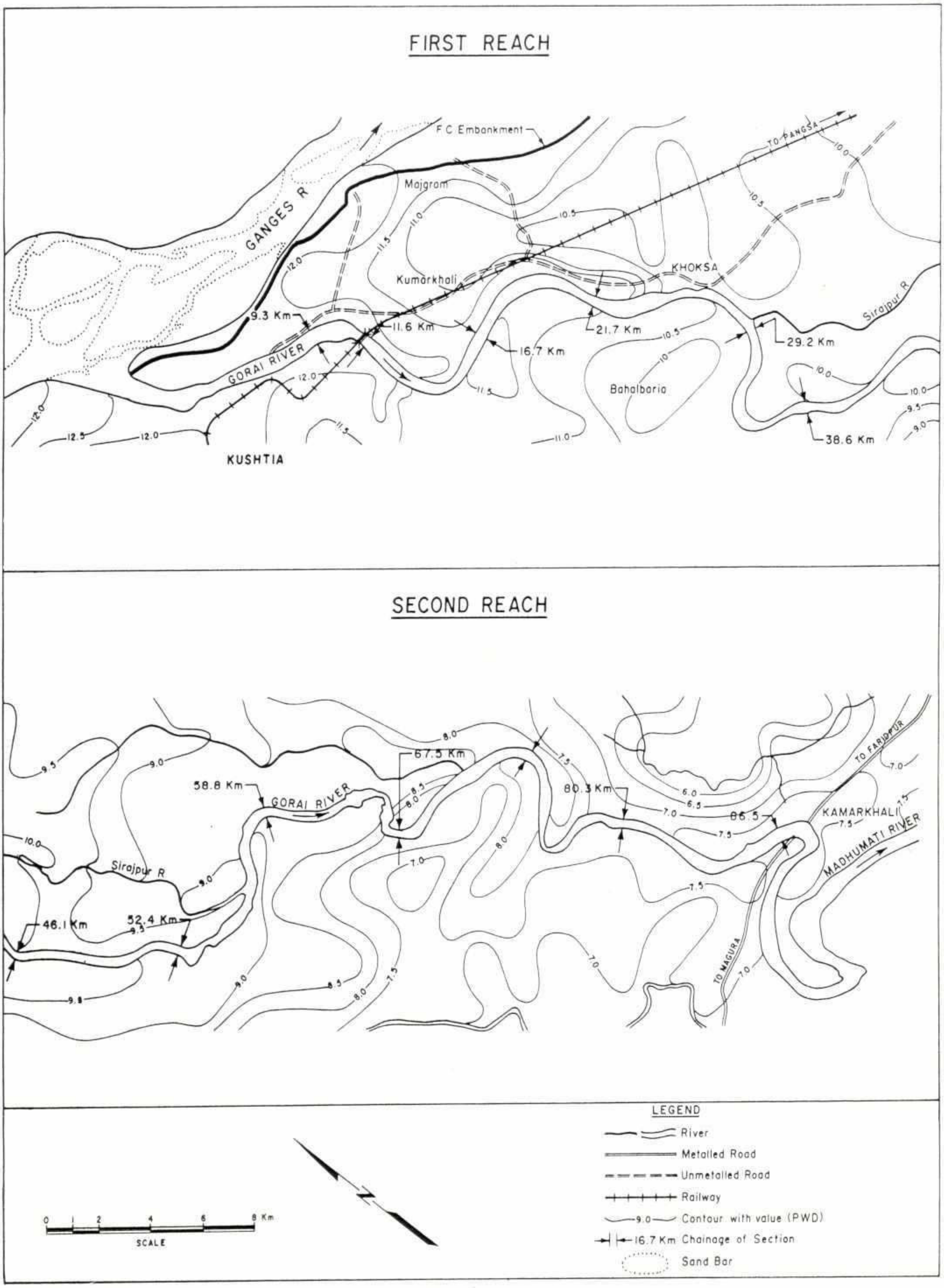
As can be seen from Table 2.1 the average sinuosity of the Gorai-Madhumati has increased from 1.5 in the 18th and 19th centuries to about 1.85 presently while since about 1904 the sinuosities of both areas above and below Kamarkhali have increased slightly. The average wavelength about 9.23 km during this period has possibly decreased slightly. Changes in sinuosity and possibly wavelength would have meant the Gorai's ability to transport water and sediment in its lower reaches would be impaired as energy losses increased and the channel slope decreased, which could eventually affect the sections upstream.

Upstream, the natural choking of the mouth of the Gorai due to deterioration of its shape and changes in the position of the Ganges can be expected to take place at regular intervals, clearing itself when a new offtake mouth is occupied and as the flow in the Ganges and the distribution of its chars changes. It is likely that, with no human interference if left the Gorai would continue to become gradually moribund, with a consequent flow reductions in the dry season and eventually during the monsoon. However, the current situation is exacerbated by a number of factors including the reduction of low Ganges flows caused by upstream abstractions during the dry season.

The main reasons for the Gorai becoming permanently moribund at an accelerating rate, are as follows :

(i) The present position of a main Ganges accretion zone lies adjacent to the entrance.

Figure 2.6



Gorai River

Mouth to Kamarkhali (Ch 0.0 Km to Ch. 86.50 Km)

(ii) The entrance is funnel shaped thus flow entering slows, depositing sediment, raising bed levels. As the flow entering the mouth is strongly curved, leading to energy loss, flow separation and sediment deposition.

(iii) The Farakka barrage, while enhancing flood flows has reduced the occurrence of lower flows.

(iv) The Farakka has, therefore, steepened the falling limb of the Ganges' and Gorai's flow hydrographs.

(v) The bars formed by the high flows, both in the mouth and channel (Figure 2.7), cannot be removed by the subsequent and now less frequent falling stage flows, leaving the elevation of the bed high (tops of the bars), further reducing the occurrence of the lower flows.

(vi) The Gorai railway bridge appears to be a flood flow restriction and the net effect of the above appears to enhance its adverse impact.

(vii) Due to its age the channel of the Gorai-Madhumati has become evenly tortuous, leading to on increase in flow resistance and a decrease in its flow and sediment transport capacity.

(viii) Possible morphological controls along the Gorai-Madhumati produce long straight sections separated by abrupt bends. The straight sections lack a continuous thalweg and are subject to severe and erratic bar siltation which impeded the flow, especially at low discharges.

While points (i) and (ii) above are natural and might be expected to produce (v) and (vi), as was seen in the 1950's the river appears to have recovered quite rapidly. When flow conditions in the Ganges adjacent to the offtake improved. However, the impact of the Farakka (completed in 1975) indicates that a similar recovery in the 1990's cannot be expected without a significant human intervention.

A further indication of the changes to both the Ganges and Gorai can be seen in the rating curves, measured at Hardinge Bridge and Gorai railway bridge (Figure 2.8). Both rivers have been aggrading since 1975 (Figures 2.3 and 2.9) and, since the Water Treaty with India ran out in 1987, the change to the Gorai rating curve has been very rapid, raising the lower flow stage level by almost 1 m. Also, while prior to about 1980 the annual mean and peak discharges of the Gorai appear to have been related, since that time despite some very high flows, the mean flow of the Gorai continue to fall.

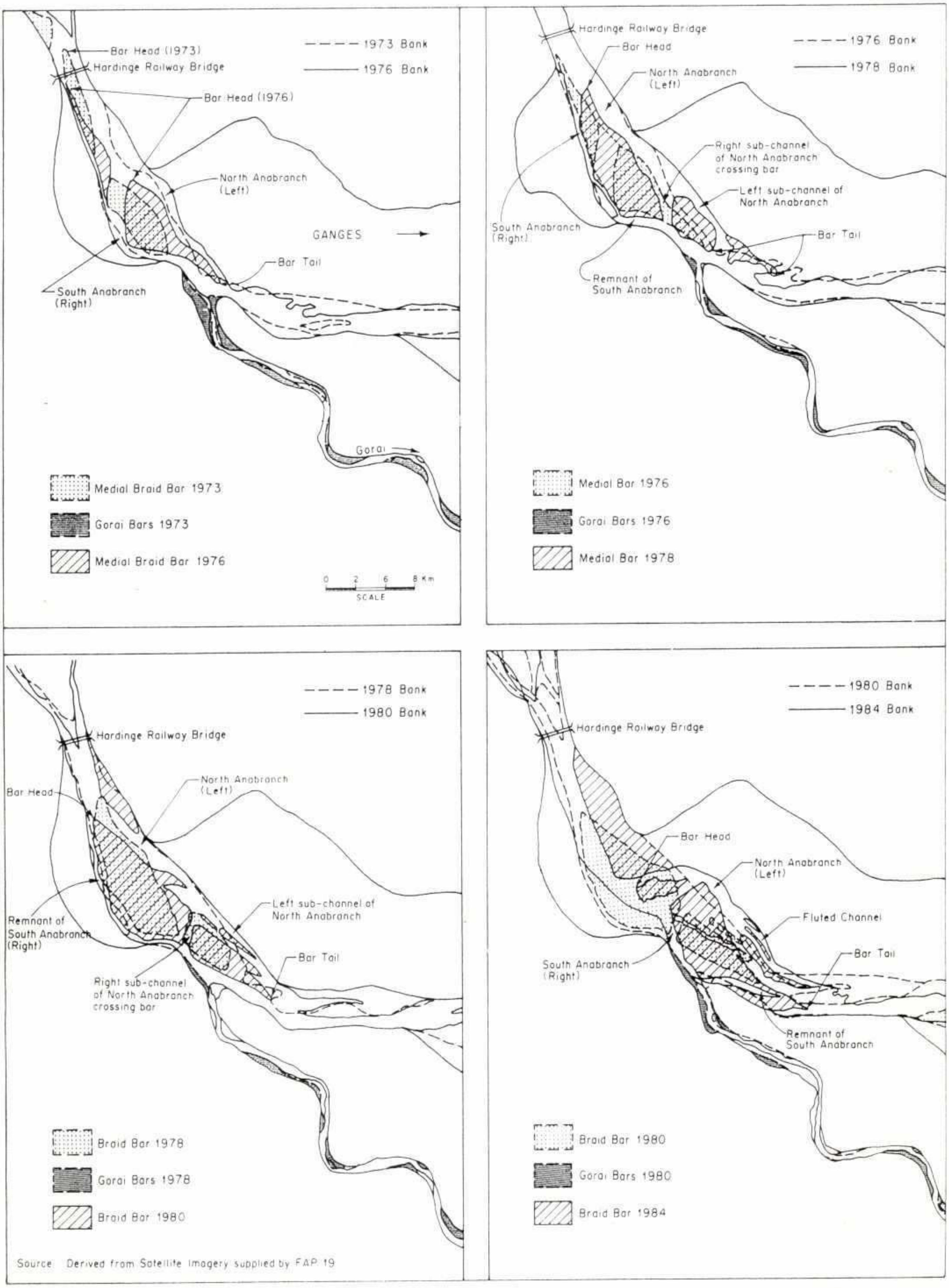
2.6 Changes in Flow Rate

The variation of flow in the Gorai above a threshold is on average remarkably linear over a wide range. Considering the proportion of Gorai to Ganges flow, therefore, removes the influence of climatic variables and upstream extractions. The variation in the proportion of Gorai flow to Ganges flows is shown in Figure 2.10. This demonstrates that both high and low flows have declined although the high flows are not at an unprecidentedly low proportion of the Ganges flowrate.

2.7 Future of the Gorai River

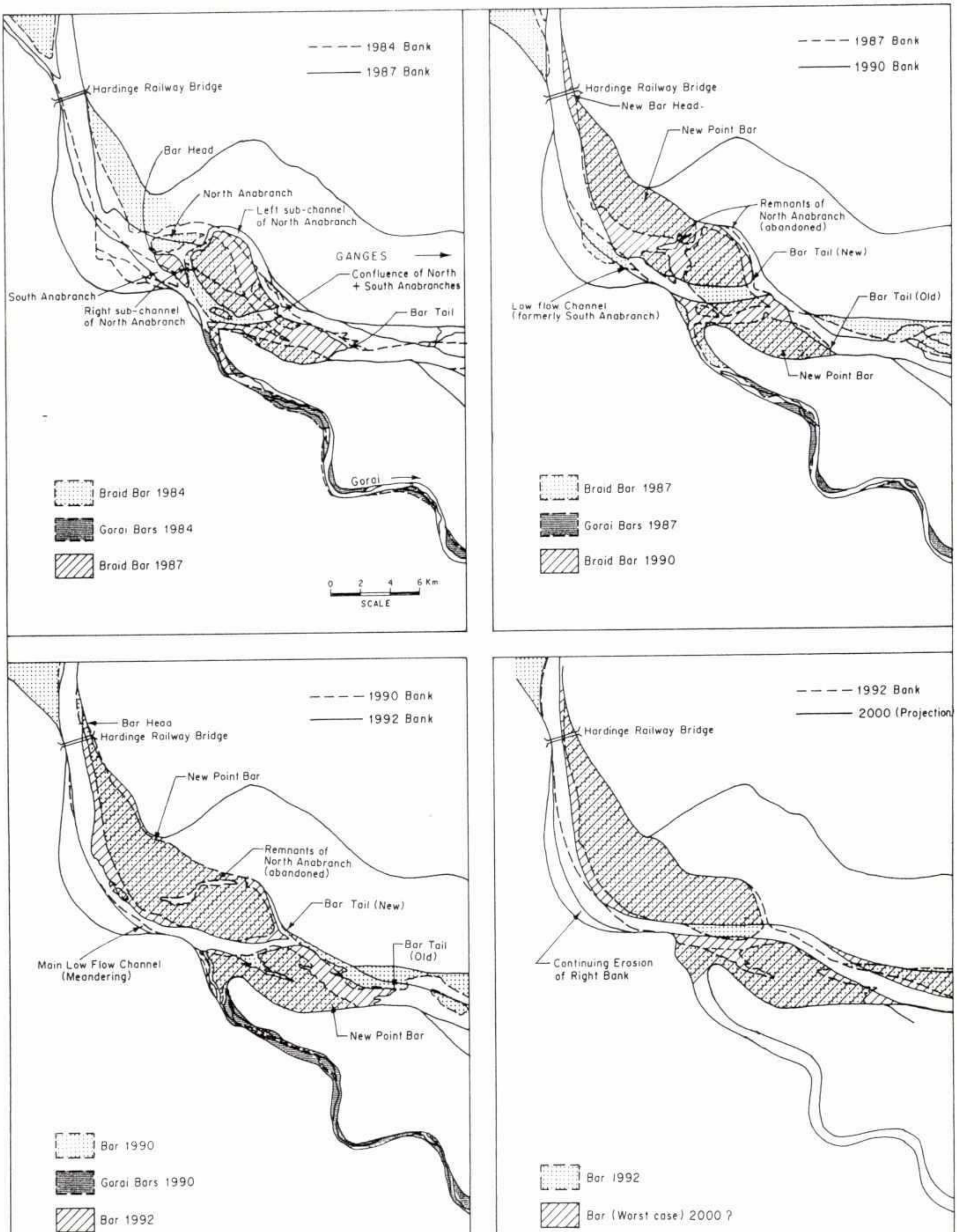
The Gorai is still a major conveyor of water into the Southwest Region in the monsoon season and though there are too many indications of a declining river to ignore, it can be expected that the declining monsoon flows will take some time to reach critically low values. However the deterioration is likely to accelerate and the opportunity to reverse the decline and reattach the river to the Ganges without control of level will be gone. The decline of the river is likely to be accompanied by morphological instability in the planform due to increased erosion to accommodate the decreasing meander wavelength.

Figure 2.7a



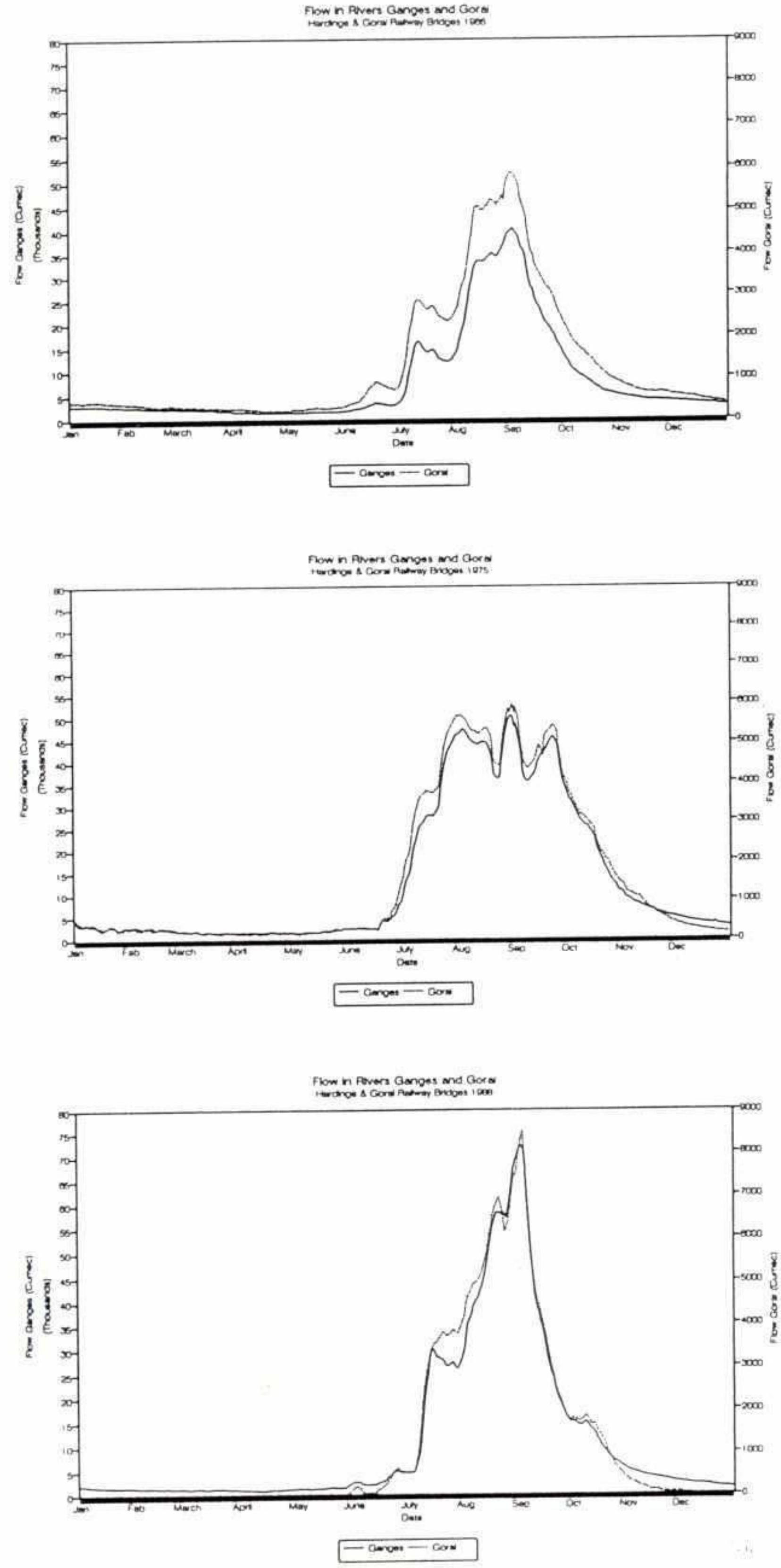
Movement of Sand Bars in Ganges at Gorai Mouth 1973–1984

Figure 2.7b



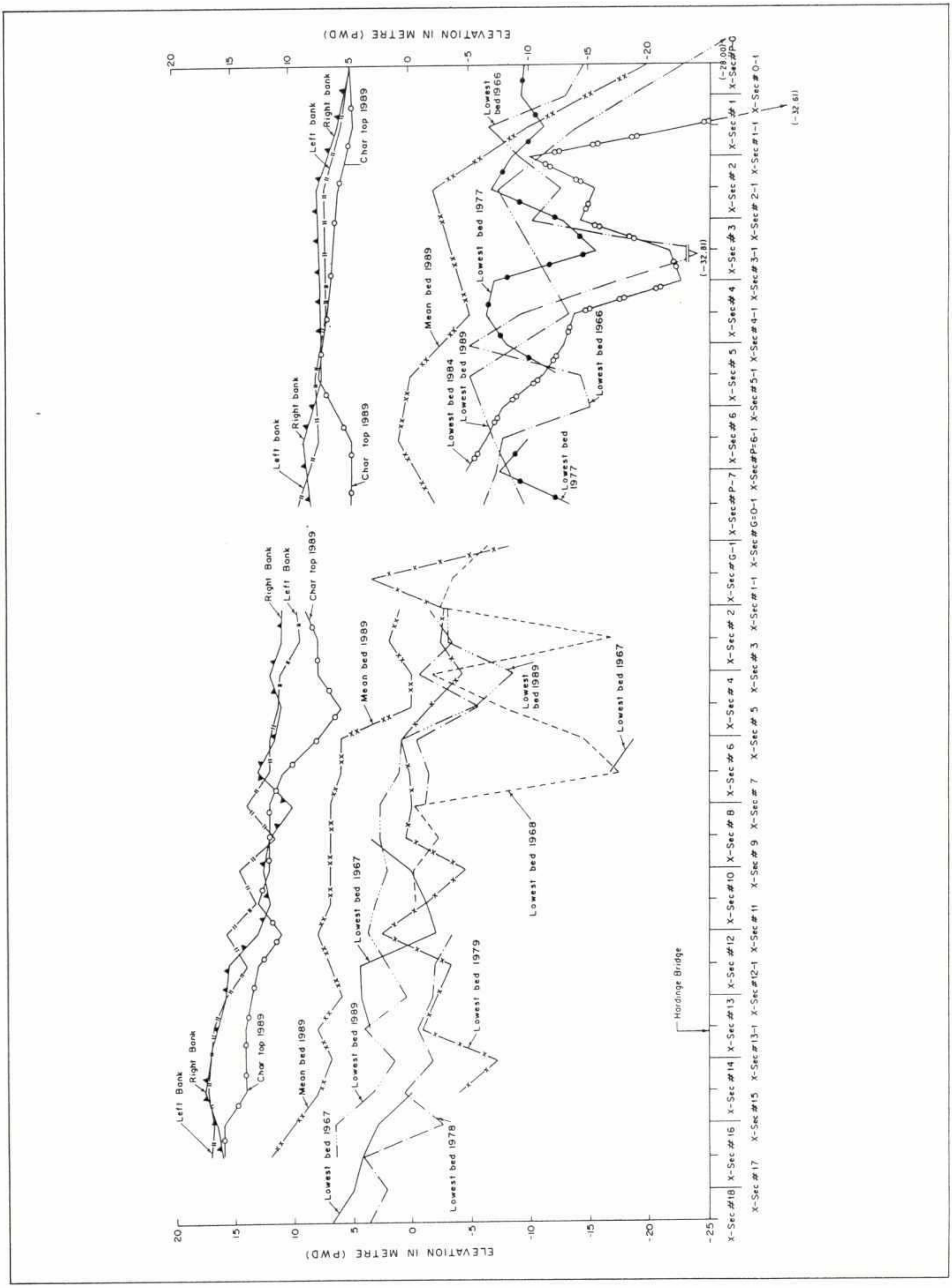
Movement of Sand Bars in Ganges at Gorai Mouth 1984–1992

Figure 2.8



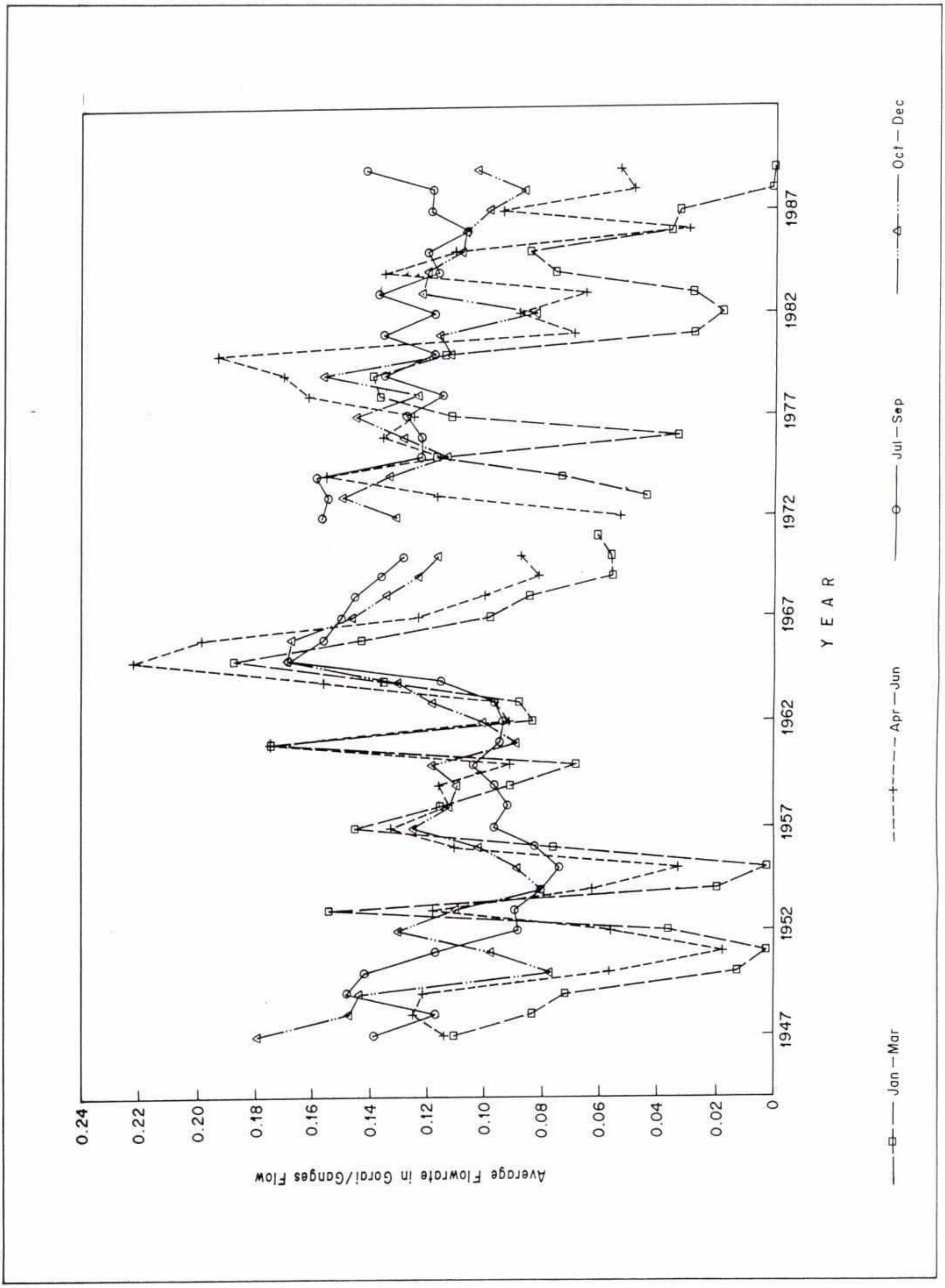
Flows in the Rivers Ganges and Gorai 1965, 1975 and 1988

Figure 2.9



Profile of Ganges-Padma

Figure 2.10



Proportion of Gorai to Ganges Flows
at Hardinge & Gorai Railway Bridges 1947–1990

3 CLIMATE AND HYDROLOGY

3.1 Ganges Flows

3.1.1 General

The Ganges River forms the northern boundary of the study area. The flow regime in the river Ganges entering Bangladesh has been subject to a water sharing agreement with the Indian government primarily as a consequence of the building of the Farakka Barrage in Indian teritory. The agreement was based on varying proportions for the Indian and Bangladeshi share of the 75% probable decadal flow between January and May arriving at Farakka which was derived from data for the period 1948 to 1973 i.e. prior to the building of the barrage. The agreement was first made in 1977 and later re-negotiated in 1982 and again in 1985 with slight modifications and was valid until 1988.

Flows in the Ganges have a significant impact on the study area, primarily as a source of irrigation water to the Ganges Kobadak Irrigation Project and as a major source of fresh water into the region via the Gorai-Madhumati river system.

3.1.2 Data Availability and Analysis

Discharge Data

Flow data for the Ganges at Hardinge Bridge was available from FAP-25 for the period 1934 to 1992 with few gaps and mean monthly flows are shown in Table 3.1. The data was grouped into the so called 'pre-Farakka period' (1934-1974), 'post-Farakka period' (1975-1988) and the 'post-agreement period' (1989-1993). Basic statistical analysis was carried out and the results are shown in Table 3.2. Box plots for monthly data for the three periods are shown in Figure 3.1. Mean monthly flows for the various periods of interest have been plotted in Figure 3.2.

A few observations can be made from Figure 3.2 as outlined below:

- The mean monthly flows during the dry season from October to June during the 'post-Farakka period' are less than during the 'pre-Farakka period'.

- The mean monthly flows during the wet season from July to September are however larger during the 'post-Farakka' period.

- The flows during the 'post-agreement period' are the lowest in all months except during June and July. Of particular significance are the lowest ever recorded monthly flows for January, February and March (1934-1992) which were observed during the 'post-agreement period'.

Table 3.3 shows a comparison of the shortfall in mean monthly flows during January and May between observed flows since 1975 and the Bangladeshi share of the 75% availability at Farakka on which the the agreement was based. The comparison does not take into account periods of exceptional low flows. It can be seen that during the 'post-Farakka period', the mean monthly flow surpluses were atleast 8% of the agreed share of the 75% availability flow at Farakka. On the other hand, during the 'post-agreement period', the mean monthly flows showed a shortfall ranging from -3.23% in January to -45.79% in March. The data on which this is based, however, is short and any inferences made from this should be qualified.

TABLE 3.1

Mean Monthly Flow in River Ganges at Hardinge Bridge (cumecs)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1934				2138	1987	3646	19776	36277	40160	18625	6202	3432	
1935	2778	2461	2228	1889	1654	2911	13086	38239	27707	13908	4535	3356	9563
1936	2389	2062	1625	1433	1778	5172	22873	39497	37980	16688	6672	3830	11833
1937	2858	2317	2442	1806	1877	3443	11893	33913	30137	18748	6391	3495	9943
1938	2630	2495	2392	2215	2053	8630	28319	43681	33527	10132	4884	3254	12018
1939	2550	2176	2013	1749	1790	3104	13052	28607	26507	12759	5281	3132	8560
1940	2291	2163	2097	1911	1838	2920	12997	30807	25113	8468	4374	3203	8182
1941	2749	2298	1930	1565	1947	4247	10760	23584	26750	10306	4671	2997	7817
1942	2389	2248	2271	1822	1889	2600	17709	39713	36447	14615	7006	3379	11007
1943	2641	2534	2062	1812	2022	4768	14023	33952	35000	15699	6572	3496	10382
1944	2585	2354	2396	2470	2423	3435	13056	31000	29173	14299	5945	3456	9383
1945	2744	2517	1998	1943	2008	2899	17212	26284	36067	20571	9510	4886	10720
1946	3206	2515	2183	2039	2629	7197	26590	45484	39203	16071	7927	3643	13224
1947	3197	2503	1987	1738	1653	3333	13665	34990	40827	18252	6630	3917	11058
1948	2827	2447	2069	1939	2151	3954	19882	45581	56000	24387	7524	6094	14571
1949	3834	3440	2669	2306	3080	5352	15599	41797	35260	16868	10119	5255	12132
1950	3770	3243	2721	2200	2069	6227	20284	45745	33823	11779	5102	3459	11702
1951	2714	2616	2121	1994	1969	3713	16116	25836	28297	9945	4929	3407	8638
1952	2444	2104	1891	1834	2090	4201	21813	41671	37473	13612	4811	2869	11401
1953	2055	1897	1615	1260	1400	2344	21741	43174	35257	15678	5529	3158	11259
1954	2353	1922	1893	1492	1516	4484	16401	48026	38190	20508	7462	4436	12390
1955	3296	2931	2694	2168	2079	4097	29482	53019	48367	30807	11741	6319	16417
1956	4182	3523	2789	2334	3136	9677	25297	47984	46373	31390	16537	6726	16662
1957	5099	4743	3592	2714	2493	3475	16722	35036	34163	12178	6716	4859	10982
1958	3643	3016	2405	2314	2430	2979	14158	49216	35260	26055	9135	5507	13010
1959	4388	4419	3592	2973	2886	5382	16017	43232	33017	22365	8742	5438	12704
1960	3898	2934	2462	2234	2014	3764	19166	39423	38990	24455	6518	3266	12427
1961	2439	2325	2170	1898	1934	5106	17233	46032	55570	42300	12362	6116	16291
1962	4271	3744	3338	2685	2886	6794	19887	46119	43077	23309	7227	4546	13990
1963	3670	3045	2503	2391	2727	5976	22016	40623	47677	21077	9145	4984	13819
1964	3621	2840	2409	2228	2417	3309	21411	40274	40927	21506	7235	4285	12705
1965				2219	2161	3209	9704	24442	25510	9160	5272	3565	
1966	2853	2316	1958	1408	1460	2637	12374	31315	25508	7714	4145	3275	8080
1967	2493	2138	1764	1647	1744	3093	16337	30971	43439	12010	5294	3686	10385
1968	2909	2550	2039	2084	2045	4684	22720	36485	20907	17644	5556	3605	10269
1969	2604	2003	1576	1868	2066	5062	17516	44407	35309	18685	6934	4527	11880
1970	3015	2504	2294	1870	2435	4903	19784	32663	32941	15656	6061	4143	10689
1971	2981	2434											
1972				2472	2813	4714	13382	23877	28969	12700	6070	4156	
1973	3007	2615	2059	1962	2776	7596	18692	42251	41906	29219	9848	5764	13974
1974	4049	2989	2391	2224	2807	4518	18047	48678	35733	14665	7046	4262	12284
1975	2855	2273	1722	1585	1827	3797	30092	44132	40326	20908	6931	3654	13342
1976	2032	1525	843	263	706	3732	14198	34425	44329	13352	4682	2601	10224
1977	1456	1060	834	1501	1813	4056	21814	41942	33789	17251	6099	3339	11246
1978	2242	1741	1535	1502	2179	6025	26032	51086	43889	20149	6862	3561	13900
1979	2050	1907	1520	1293	1517	1512	14390	29896	15360	7813	2864	1951	6839
1980	1249	884	742	725	1221	3235	25071	48032	44484	14008	5064	2770	12290
1981	1844	1567	1256	1320	1695	2394	22799	40970	33577	15795	3846	2186	10771
1982	1302	1162	1011	1206	1520	4786	11725	38336	47952	10556	4934	2888	10615
1983	1484	1223	806	664	1485	2409	12481	26574	44454	23903	7021	3334	10486
1984	2245	1666	1304	982	1435	7958	24959	33919	44922	11068	4214	2377	11421
1985	1599	1187	854	832	945	2422	17752	37898	37528	35058	11949	4598	12718
1986	2610	1724	1538	1191	1541	2365	25324	39269	30533	17868	6066	3395	11119
1987	2433	1515	1060	889	1070	2102	13553	45215	51760	15042	5941	2621	11933
1988	1653	1310	1147	929	1349	3169	21361	50861	36363	10820	3752	1930	11220
1989	1453	862	523	741	1187	5377	18914	26650	27035	15329	4090	2064	8685
1990	1204	551	638	733	1508	4547	30256	42931	31344	20466	4790	2266	11769
1991	1472	852	625	663	1232	5125	11636	28209	38348	8599	3519	2125	8534
1992	1616	889	517										
1993			319	399									
Avg 34–74	3090	2668	2287	2031	2178	4489	17920	38348	36063	17870	7091	4180	11685
Avg 75–88	1932	1482	1155	1063	1450	3569	20111	40183	39233	16685	5730	2943	11295
Avg 89–93	1436	788	524	634	1309	5016	20269	32596	32243	14798	4133	2151	9663
Min 34–74	2055	1897	1576	1260	1400	2344	9704	23584	20907	7714	4145	2869	7817
Min 75–88	1249	884	742	263	706	1512	11725	26574	15360	7813	2864	1930	6839
Min 89–93	1204	551	319	399	1187	4547	11636	26650	27035	8599	3519	2064	8534
Max 34–74	5099	4743	3592	2973	3136	9677	29482	53019	56000	42300	16537	6726	16662
Max 75–88	2855	2273	1722	1585	2179	7958	30092	51086	51760	35058	11949	4598	13900
Max 89–93	1616	889	638	741	1508	5377	30256	42931	38348	20466	4790	2266	11769

TABLE 3.2a

Basic Statistics of Monthly Flow in River Ganges at Hardinge Bridge (cumecs)

Parameter	January			February			March			April		
	Pre - Farakka	Post - Farakka	Post - Agreement	Pre - Farakka	Post - Farakka	Post - Agreement	Pre - Farakka	Post - Farakka	Post - Agreement	Pre - Farakka	Post - Farakka	Post - Agreement
	1934-74	1975-88	1989-92	1934-74	1975-88	1989-92	1934-74	1975-88	1989-92	1934-74	1975-88	1989-92
Years of Data	38	14	4	38	14	4	37	14	4	40	14	3
Mean	3090	1932	1436	2668	1482	788	2287	1155	576	2031	1063	712
Std Dev	702	501	171	634	372	159	477	327	65	367	376	43
Skew	0.89	0.26	-0.33	1.52	0.34	-0.73	1.12	0.28	0.01	0.22	-0.39	-0.37
Kurtosis	0.01	-1.3	-1.85	2.17	-0.7	-1.7	1.17	-1.52	-2.42	-0.09	-0.82	-2.33
Minimum	2055	1249	1204	1897	884	551	1576	742	517	1260	263	663
Maximum	5099	2855	1616	4743	2273	889	3592	1722	638	2973	1585	741
Lower cutoff	1031	346	1128	1348	468	468	1344	152	439	1204	140	557
Lower fourth	2585	1484	1329	2298	1187	701	1993	843	520	1817	832	663
Median	2855	1938	1463	2503	1520	857	2183	1103	574	1978	1086	733
Upper fourth	3621	2242	1463	2931	1666	857	2425	1304	574	2226	1293	733
Upper cutoff	5175	3379	1664	3881	2385	1091	3074	1994	655	2839	1985	839
Outliers				4419			3338			2973		
Outliers				4743			3592					
Outliers							3592					

TABLE 3.2b

Basic Statistics of Monthly Flow in River Ganges at Hardinge Bridge (cumecs)

Parameter	May			June			July			August		
	Pre - Farakka	Post - Farakka	Post - Agreement	Pre - Farakka	Post - Farakka	Post - Agreement	Pre - Farakka	Post - Farakka	Post - Agreement	Pre - Farakka	Post - Farakka	Post - Agreement
	1934-74	1975-88	1989-92	1934-74	1975-88	1989-92	1934-74	1975-88	1989-92	1934-74	1975-88	1989-92
Years of Data	40	14	3	40	14	3	40	14	3	40	14	3
Mean	2178	1450	1309	4489	3569	5016	17920	20111	20269	38348	40183	32596
Std Dev	453	382	174	1679	1737	425	4719	5990	9383	7847	7401	8984
Skew	0.43	-0.13	0.36	1.21	1.13	-0.24	0.51	-0.04	0.14	-0.28	-0.15	0.37
Kurtosis	-0.79	-0.6	-2.33	1.09	0.45	-2.33	-0.32	-1.58	-2.33	-0.99	-1.1	-2.33
Minimum	1400	705	1186	2344	1511	4547	9704	11725	11636	23584	26574	26650
Maximum	3136	2179	1508	9677	7958	5377	29482	30092	30256	53019	51086	42931
Lower cutoff	1059	740	1118	521	289	3680	4482	0	718	13907	19865	24311
Lower fourth	1883	1221	1186	3259	2394	4547	13844	14198	11636	31989	34425	26650
Median	2060	1501	1232	4149	3202	5125	17374	21587	18914	39605	40120	28209
Upper fourth	2432	1541	1232	5084	3797	5125	20085	24959	18914	44044	44132	28209
Upper cutoff	3257	2022	1300	7822	5902	5992	29447	41101	29832	62126	58692	30547
Outliers		705	1508	8630	6025		29482		30256			42931
Outliers		2179		9677	7958							
Outliers												

[vp\gorai\tab3-2ab]

TABLE 3.2C

Basic Statistics of Monthly Flow in River Ganges at Hardinge Bridge (cumecs)

Parameter	September			October			November			December			Annual		
	Pre - Farraka	Post - Farraka	Post - Agreement	Pre - Farraka	Post - Farraka	Post - Agreement	Pre - Farraka	Post - Farraka	Post - Agreement	Pre - Farraka	Post - Farraka	Post - Agreement	Pre - Farraka	Post - Farraka	Post - Agreement
	1934-74	1975-88	1989-92	1934-74	1975-88	1989-92	1934-74	1975-88	1989-92	1934-74	1975-88	1989-92	1934-74	1975-88	1989-92
Years of Data	40	14	3	40	14	3	40	14	3	40	14	3	37	14	3
Mean	36063	39233	32243	17870	16685	14798	7091	5730	4133	4180	2943	2151	11685	11295	9663
Std Dev	7928	9146	5710	7179	6935	5951	2486	2210	637	1038	749	103	2241	1684	1826
Skew	0.52	-1.06	0.15	1.15	1.14	-0.09	1.67	1.34	0.07	0.85	0.45	0.24	0.36	-0.9	0.38
Kurtosis	0.07	0.74	-2.33	1.57	0.92	-2.33	3.39	1.8	-2.33	-0.47	-0.63	-2.33	-0.3	1.13	-2.33
Minimum	20907	15360	27035	7714	7813	8599	4145	2864	3519	2869	1930	2064	7817	6839	8534
Maximum	56000	51760	38348	42300	35058	20466	16537	11949	4790	6726	4598	2266	16662	13900	11769
Lower cutoff	14615	17791	20572	587	866	-1497	1979	1387	2662	1428	933	1972	6756	8637	8306
Lower fourth	29655	33789	27035	12729	11068	8599	5288	4214	3519	3393	2377	2064	10325	10615	8534
Median	35285	42108	31344	16379	15419	15329	6601	5502	4090	3758	2829	2125	11702	11233	8685
Upper fourth	39682	44454	31344	20824	17868	15329	7493	6099	4090	4702	3339	2125	12705	11933	8685
Upper cutoff	54722	60452	37807	32966	28070	25424	10801	8926	4946	6667	4782	2217	16274	13911	8913
Outliers	55570	15360	38348	42300	35058		11741	11949		6726		2266	16290	6839	11769
Outliers	56000						12362						16417		
Outliers							16537						16662		

[vp\gorai\tab3-2c]

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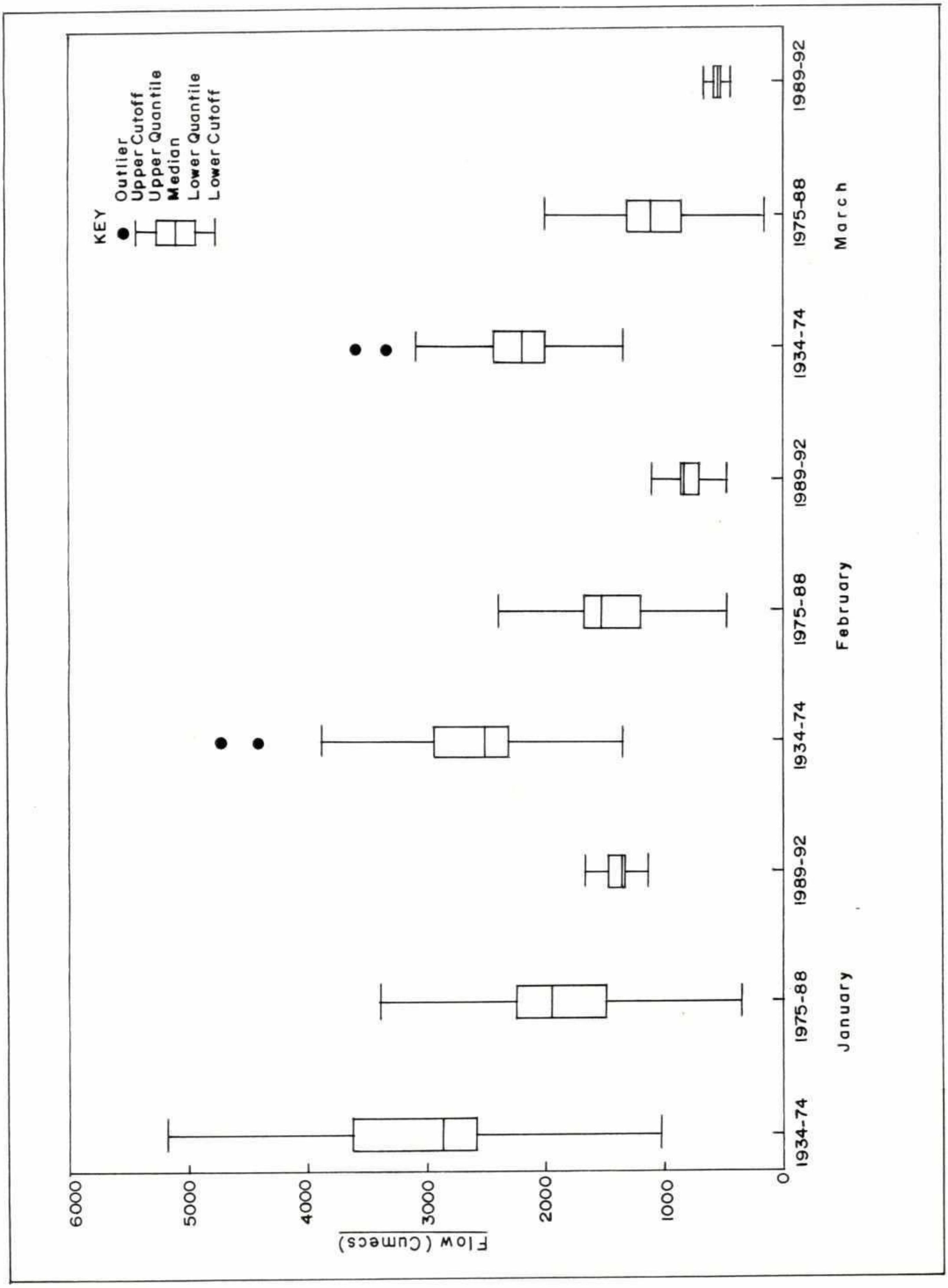
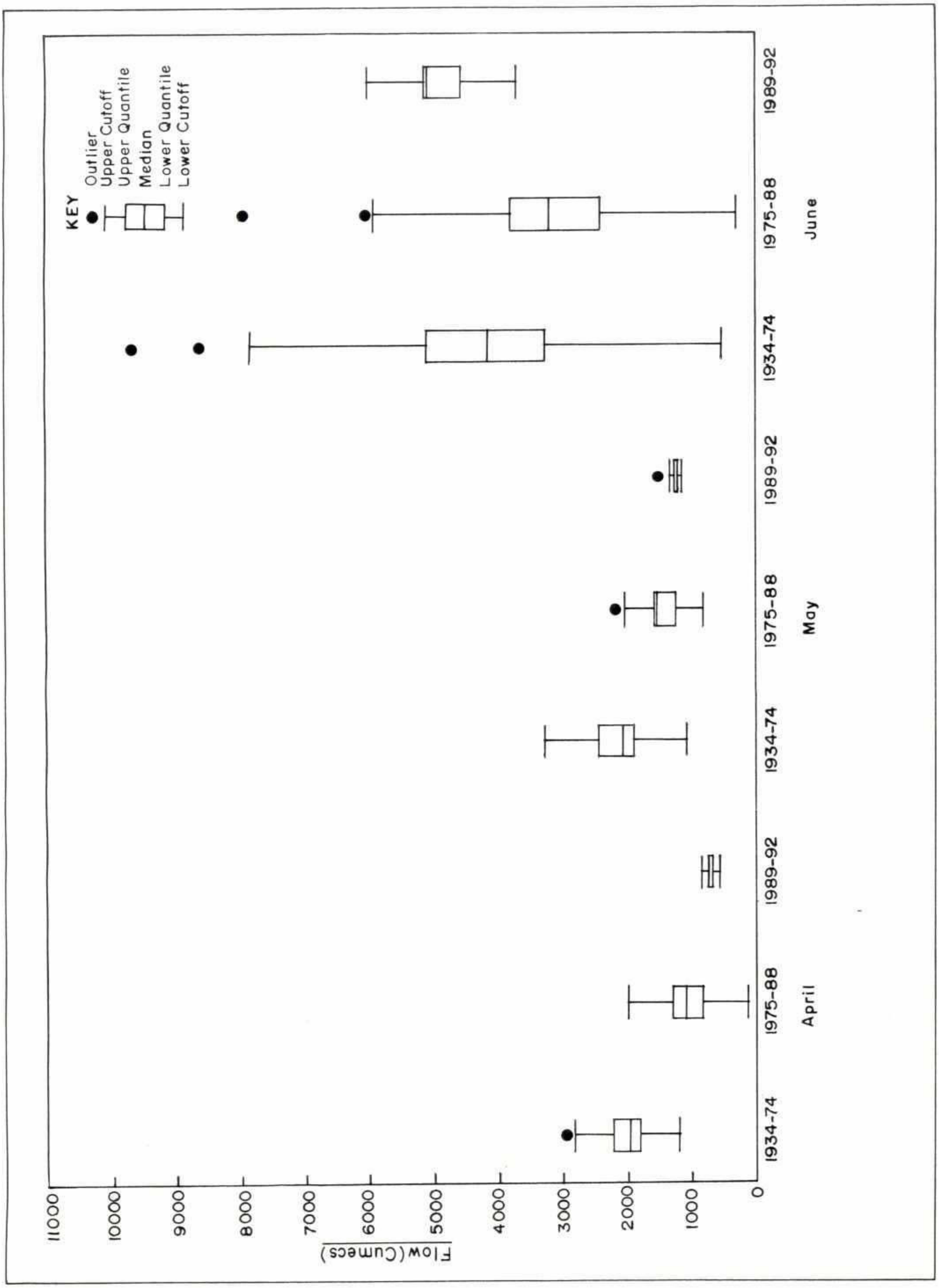
Figure 3.1a



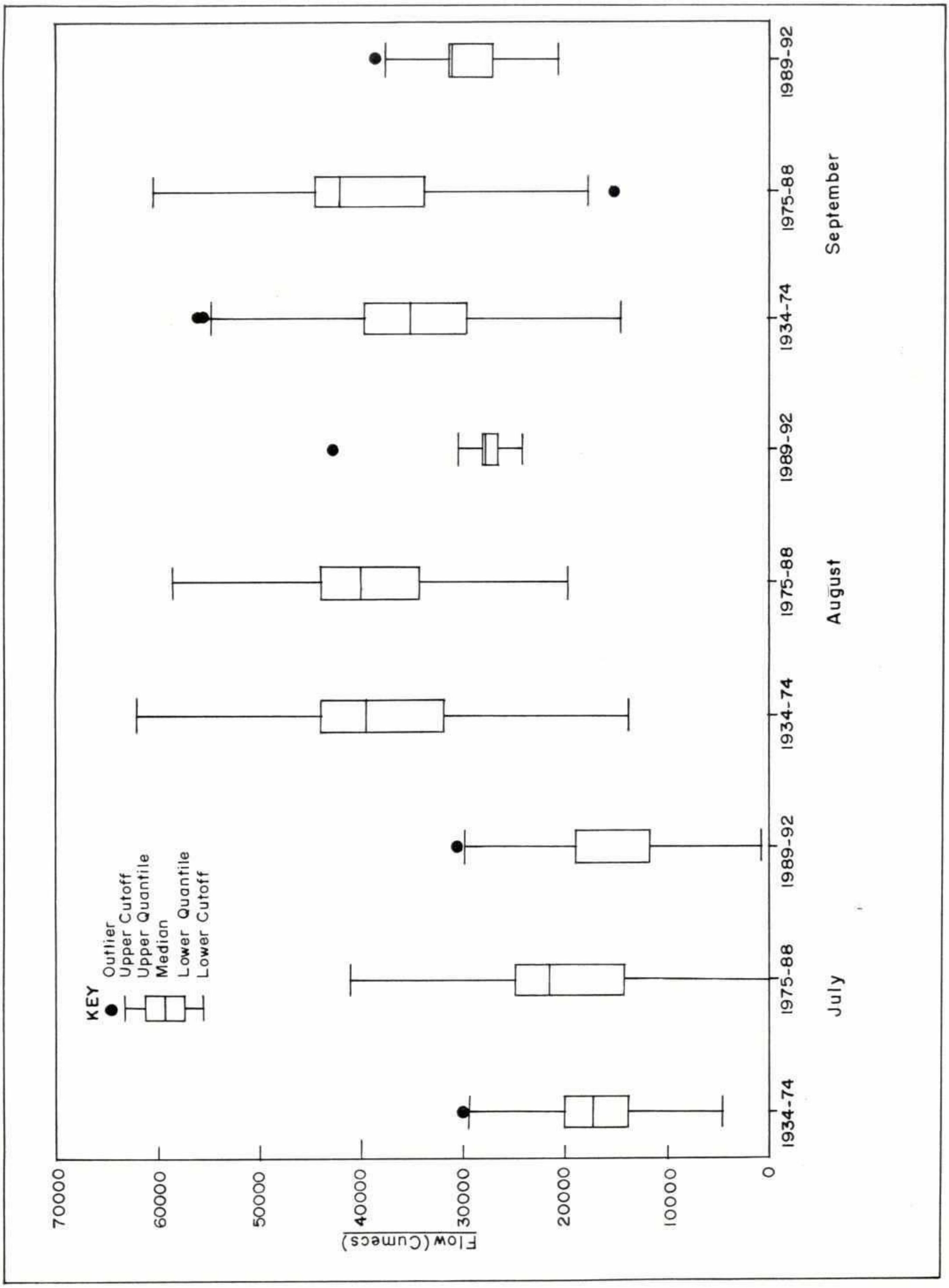
Box Plot of Monthly Flows in River Ganges at Hardinge Bridge

Figure 3.1b



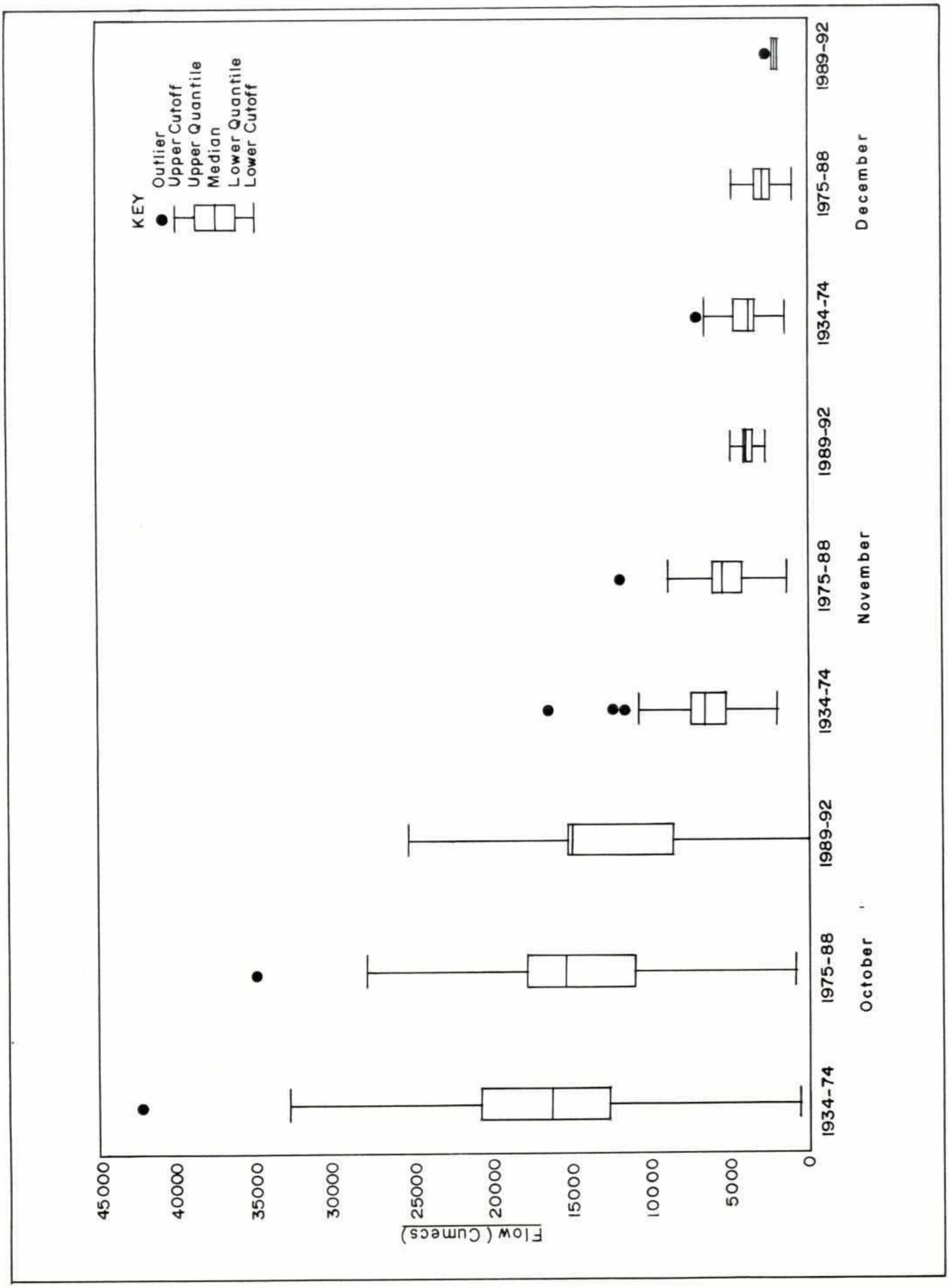
Box Plot of Monthly Flows in River Ganges at Hardinge Bridge

Figure 3.1c



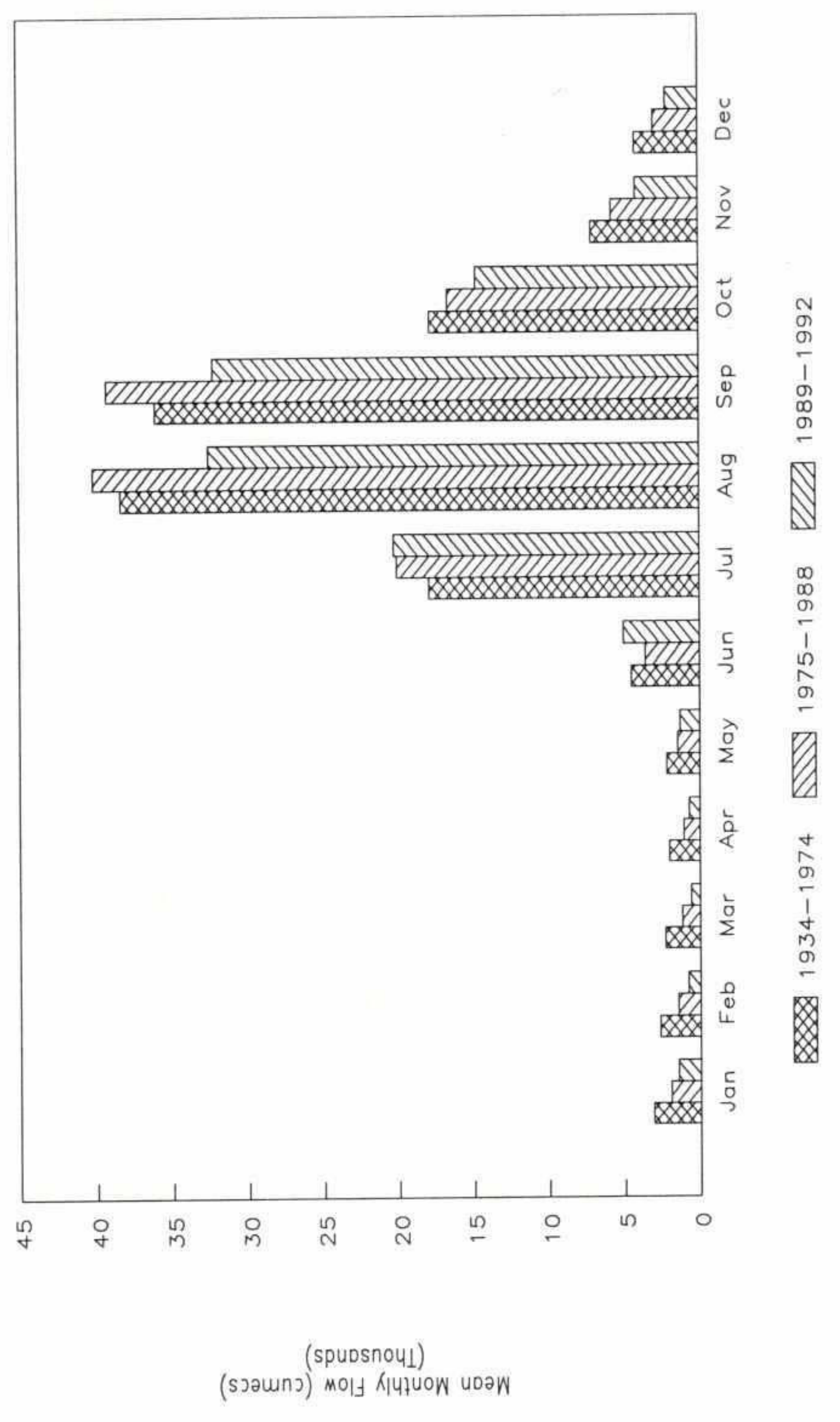
Box Plot of Monthly Flows in River Ganges at Hardinge Bridge

Figure 3.1d



Box Plot of Monthly Flows in River Ganges at Hardinge Bridge

Figure 3.2



Mean Monthly Flow in River Ganges
at Hardinge Bridge

TABLE 3.3

Comparison of Dry Season Flows in River Ganges at Hardinge Bridge (cumecs)

	Jan	Feb	Mar	Apr	May
Bangladesh Share *	1484	1208	1062	984	1029
Average Flow 1975-88	1932	1482	1155	1063	1450
Average Flow 1989-92	1436	788	576	712	1309
Percent Shortfall	Jan	Feb	Mar	Apr	May
1975-88	30.18	22.62	8.78	8.03	40.96
1989-92	-3.23	-34.74	-45.79	-27.64	27.22

* Bangladesh share of the Ganges flow based on 75% availibility at Farakka Barrage computed from 1948-1973 data.

Probability distributions were fitted to the monthly flow series for the 'post-Farakka period' to assess the 80% probable flow during January and May for any intervention works requiring diversion of flow from the Ganges into the study area. The results are shown in Table 3.4. The minimum 80% probable flow of 695 m^3/s occurs in the month of April.

TABLE 3.4a

Monthly Flows for Ganges at Hardinge Bridge (Cumecs)
(post-Farakka 1975 - 1988)

Month	Distribution	Model Parameters		Observed Mean	1 in 1.25 year 80% probable
		U1	U2		
Jan	Weibull	4.39	2122.11	1932	1538
Feb	Weibull	4.42	1622.92	1482	1119
Mar	Weibull	4.04	1276.09	1155	931
Apr	Extreme Type I	875.25	379.05	1063	695
May	Weibull	4.45	1590.14	1450	1102

TABLE 3.4b

Monthly Flows for Ganges at Hardinge Bridge (Cumecs)
(post-Farakka and post-agreement 1975 - 1992)

Month	Distribution	Model Parameters		Observed Mean	1 in 1.25 year 80% probable
		U1	U2		
Jan	Extreme Type I	1599.70	368.63	1822	1424
Feb	Weibull	3.37	1480.48	1328	909
Mar	Extreme Type I	849.81	303.71	1026	705
Apr	Extreme Type I	823.93	341.05	1001	662
May	Weibull	4.56	1558.44	1425	1089

The mean monthly flow data was also analysed to check for trends using the Armsen test which is equivalent to a rank correlation test of Kendall. The test checks for stationarity at the 95% significance level. The results are shown in Table 3.5. There was evidence of a decreasing trend in the mean monthly flows during the wet season from February to May. The flows during December also showed a trend, but this was not significant at the 95% level.

TABLE 3.5

Trend Analysis of Monthly Flows in River Ganges at Hardinge Bridge (1975-1992)

Month	Standard Normal Deviate	Probability = P(z)
Jan	1.0606	0.856
Feb	2.3484	0.991 *
Mar	2.2727	0.988 *
Apr	2.4304	0.992 *
May	1.7713	0.962 *
Jun	1.0949	0.863
Jul	0.7003	0.758
Aug	0.7003	0.758
Sep	0.4531	0.675
Oct	0.3707	0.645
Nov	1.2770	0.899
Dec	1.6065	0.946

Note : * This test for stationarity is based upon that ARMSEN (J Nat Inst Per Res : 1956; Vol 6.p 177-9). If P(z) exceeds 0.95 there is a significant trend in the data : i.e. the time series is not stationary.

Frequency analysis of the annual maximum mean daily discharge was also done for the Ganges at Hardinge Bridge. The observed maximum mean daily discharge is shown in Table 3.6 and the results of the extreme value analysis are shown in Table 3.7. It can be seen from Table 3.7 that analysis of flows for the 'post-Farakka period' gives higher flood estimates than the 'pre-Farakka period'. The 1 in 200 year mean daily flow is 836.5 m^3/s for the 'pre-Farakka period' and rises to 937.6 m^3/s during the 'post-Farakka period'. If data for the 'post-agreement period' is also included in the analysis, the 1 in 200 year mean daily discharge increases to 949.5 m^3/s. Growth factors for the flood frequencies have also been computed by taking the 1 in 2 year flood as the mean annual flood and the growth factors for the various periods are shown in Table 3.8. The growth factors for the 1 in 100 year event range between 1.6 and 1.7 depending on the period of record chosen for the analysis.

Water Levels

Water level data was available from 1964 to 1992 from FAP-25. Mean monthly water levels in the Ganges at Hardinge Bridge are shown in Table 3.9. Figure 3.3 shows the mean monthly water levels for various periods. It can be seen from Figure 3.3 that the dry season levels from November to May in the Ganges at Hardinge Bridge during the 'post-agreement period' are consistently lower than during the 'post-Farakka period' as would be expected from the flow analysis. The levels in June and July are however higher during the 'post-agreement period'. This observation is important in the context of any schemes involving pumping of water from the Ganges and any planned storage or diversion schemes on the Ganges. The stage fluctuations also have an impact on the fluvial processes in the river and may need to be studied further.

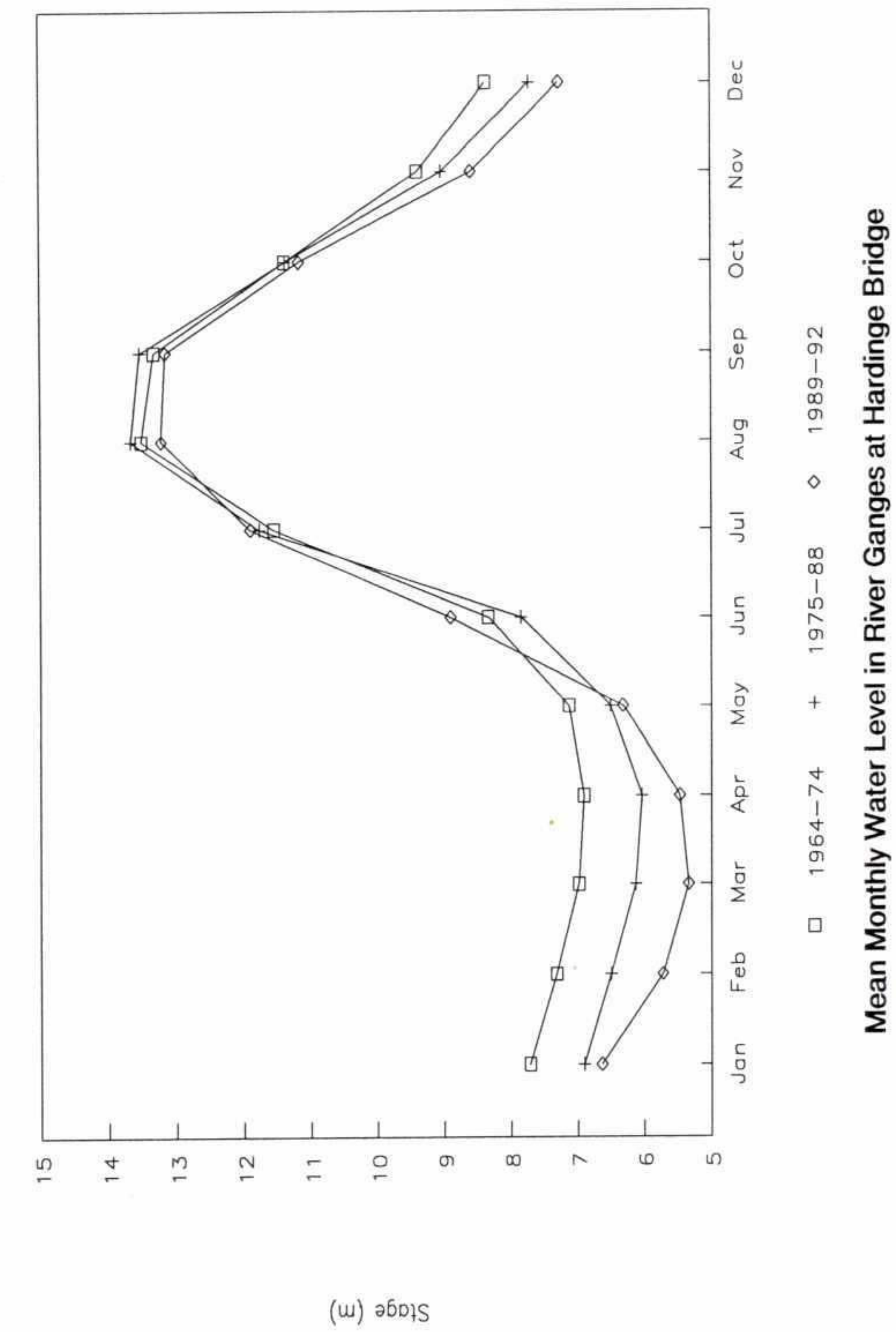
Table : 3.6

Maximum Mean Daily Flow in River Ganges at Hardinge Bridge (cumecs)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1934	-1	-1	-1	2200	2110	7330	29300	45300	46600	35400	8770	3930	-1
1935	2970	2570	2390	2130	1900	3540	28200	44000	36300	31500	6030	3590	44000
1936	2710	2140	1900	1490	2450	8030	32300	45300	42800	27600	8930	5020	45300
1937	3250	2430	2510	2180	2200	4270	17800	37800	39400	25800	9840	4320	39400
1938	2820	2540	2460	2280	2750	18800	39600	47800	40000	16600	6570	3790	47800
1939	2820	2280	2110	1870	2460	6280	27000	34900	35900	20900	7260	3840	35900
1940	2520	2220	2220	2110	2110	4310	27300	37700	39100	15000	5160	3780	39100
1941	2890	2590	2100	1720	2590	6830	15200	38300	38300	15400	6280	3540	38300
1942	2690	2540	2430	2030	2230	5310	31100	44700	42200	26100	47000	4100	47000
1943	2760	2740	2340	1910	2190	8720	23400	40800	43300	33200	8600	4610	43300
1944	2720	2440	2670	2760	2600	4810	30000	43300	42400	25000	7920	4410	43300
1945	2930	2720	2200	2000	2240	4680	25400	34800	42200	27600	14600	6340	42200
1946	3850	2790	2300	2260	3650	80900	41000	49100	49100	22400	11900	6200	80900
1947	3650	2790	2220	1950	1760	4810	28800	39300	51200	27200	8500	4870	51200
1948	3310	2580	2340	2070	2940	6710	37600	55000	61100	39600	11500	6710	61100
1949	5150	4020	3170	2660	3850	7700	28400	52600	47800	28000	12800	6620	52600
1950	4300	3310	3080	2420	2260	15000	28000	52600	46700	25000	6000	4240	52600
1951	2910	2700	2420	2070	2470	6060	23300	42200	40500	16100	6570	4300	42200
1952	2790	2300	1950	1910	2620	9960	30600	47400	52600	25900	6370	3580	52600
1953	2410	2000	1800	1390	1740	3840	39900	50900	48100	25500	7640	4050	50900
1954	2530	2220	1970	1680	1870	9760	36500	58600	56000	31500	10300	5890	58600
1955	3620	3100	3010	2430	2310	9340	50800	60300	58100	40000	17400	8240	60300
1956	4680	3740	3170	2460	4330	20300	40400	57500	60100	46700	26500	11200	60100
1957	5910	5040	4080	3030	2570	6000	37900	37500	46200	19200	8240	5660	46200
1958	4190	3280	2510	2400	2680	5090	32700	56300	42900	38400	13900	6170	56300
1959	5040	4700	3990	3260	3000	8040	29600	52700	41300	31000	12500	6740	52700
1960	4440	3330	2640	2360	2440	6030	35100	47700	48000	32400	11200	4190	48000
1961	2670	2670	2630	1940	2060	11300	27600	72000	73200	57800	20700	7780	73200
1962	5180	4440	3540	3170	3140	12900	31800	58700	57800	47600	9140	5770	58700
1963	4050	3310	2730	2430	3060	10900	34700	52700	56100	32100	12900	6200	56100
1964	4080	3060	2600	2290	2580	5740	33300	47800	49000	40600	10700	5180	49000
1965	-1	-1	-1	2290	2210	5010	12400	28900	36800	17000	6270	4210	-1
1966	3010	2560	2160	1571	1624	3481	16247	40286	40525	12580	4924	3663	40525
1967	2868	2239	2137	1815	1915	5728	25368	42621	49083	25783	6524	4408	49083
1968	3127	2785	2187	2305	2251	9391	40036	43315	40503	29473	7391	4354	43315
1969	3028	2210	1759	1961	2833	7086	31870	56083	51038	36215	8085	5875	56083
1970	3536	2742	2481	2003	3023	10437	32932	37088	39460	25900	7779	4922	39460
1971	3398	2680	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
1972	-1	-1	-1	2585	3594	7561	24329	28559	35565	22424	7136	4814	-1
1973	3359	2808	2192	2118	3500	17058	40970	48089	47537	36679	13400	7199	48089
1974	4784	3450	2634	2606	3229	8089	42114	53303	53908	24783	9762	5200	53908
1975	4114	2671	1998	1799	2396	10013	46269	50248	48737	31533	10136	4710	50248
1976	2738	1715	1191	295	974	6620	19015	48571	60993	27633	6432	3354	60993
1977	1838	1247	951	1617	2122	5553	33595	48034	41847	26654	8367	4233	48034
1978	2655	2185	2128	1624	3348	12231	35557	62587	57334	36551	9655	4430	62587
1979	2751	2073	1781	1438	2054	2491	35650	37309	23014	10245	4249	2339	37309
1980	1568	995	802	787	1440	5376	43017	57602	57000	26294	7712	3450	57602
1981	2220	1719	1396	1779	2241	3241	40217	47768	43907	28386	5491	2791	47768
1982	1583	1289	1097	1422	1696	8863	21236	50564	61430	23253	6226	4179	61430
1983	1718	1306	998	790	2105	3741	19545	34747	57958	37968	10705	4489	57958
1984	2605	2108	1534	1048	2124	18028	41246	49622	55757	22473	5899	3000	55757
1985	1899	1366	977	877	1070	3630	36625	47507	44877	46489	21108	6721	47507
1986	3270	1931	2029	1394	1666	7388	42981	52270	40685	27441	8532	4399	52270
1987	3246	1785	1252	987	1172	3971	32587	67959	70806	30019	11673	3506	70806
1988	1997	1406	1189	1120	2401	4919	30015	70687	72385	15190	5291	2646	72385
1989	1598	1196	632	854	3902	8553	31163	31874	30742	27033	5987	2857	31874
1990	1503	709	738	913	2622	8282	44906	48508	42025	38004	7381	2779	48508
1991	1674	1420	700	806	1839	9596	17001	35777	56418	15276	4537	2787	56418
1992	2776	1063	671	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Max	5910	5040	4080	3260	4330	80900	50800	72000	73200	57800	47000	11200	80900

[vp\gorai\tab3-6]

Figure 3.3



Mean Monthly Water Level in River Ganges at Hardinge Bridge

TABLE 3.7

Frequency Analysis of Maximum Mean Daily Flow in River Ganges at Hardinge Bridge (Cumecs)

Period of Analysis		Model.	F(x)= T=	0.5 2	0.2 5	0.1 10	0.05 20	0.02 50	0.01 100	0.005 200
Full Record	(1934-92)	EV1		497.8	588.1	647.9	705.2	779.4	835.1	890.5
Pre-Farakka	(1934-74)	GEV3		488	570.4	624.2	675.3	740.5	788.8	836.5
Post-Farakka to date	(1975-92)	EV1		522.6	620.8	685.8	748.1	828.8	889.3	949.5
Post-Farakka	(1975-88)	EV1		542.1	633.1	693.3	751	825.8	881.8	937.6

TABLE 3.8

Growth Factors for Maximum Mean Daily Flow in River Ganges at Hardinge Bridge

Period of Analysis		Model.	F(x)= T=	0.5 2	0.2 5	0.1 10	0.05 20	0.02 50	0.01 100	0.005 200
Full Record	(1934-92)	EV1		1.000	1.181	1.302	1.417	1.566	1.678	1.789
Pre-Farakka	(1934-74)	GEV3		1.000	1.169	1.279	1.384	1.517	1.616	1.714
Post-Farakka to date	(1975-92)	EV1		1.000	1.188	1.312	1.431	1.586	1.702	1.817
Post-Farakka	(1975-88)	EV1		1.000	1.168	1.279	1.385	1.523	1.627	1.730

[vp\gorai\tab3-7]

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Table : 3.9
Mean Monthly Water Level in River Ganges at Hardinge Bridge (meter)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1964				7.46	7.63	8.13	12.16	13.93	14.04	12.29	10.08	8.90	
1965	8.24	7.81	7.48	7.47	7.43	8.19	10.96	13.03	13.08	10.65	9.19	8.20	9.31
1966	7.71	7.31	7.01	6.66	6.73	7.86	11.35	13.56	13.04	10.36	8.97	8.38	9.08
1967	7.77	7.45	7.07	7.03	7.13	8.07	11.63	13.35	14.14	11.17	9.31	8.51	9.39
1968	8.04	7.79	7.39	7.09	7.06	8.61	12.28	13.59	12.18	11.75	9.23	8.20	9.44
1969	7.52	7.02	6.61	6.53	6.70	8.54	11.32	13.97	13.38	11.51	9.44	8.32	9.24
1970	7.43	7.06	6.90	6.60	7.11	8.54	11.94	13.41	13.44	11.47	9.38	8.34	9.30
1971	7.56	7.12											
1972				6.86	7.10	8.19	10.62	12.38	12.86	10.60	8.86	7.93	
1973	7.24	6.97	6.53	6.51	7.11	9.08	11.78	13.83	13.81	12.87	10.22	8.74	9.56
1974	7.91	7.28	6.86	6.82	7.23	8.11	11.38	14.11	13.28	11.12	9.21	8.05	9.28
1975	7.25	6.86	6.40	6.28	6.50	7.75	12.71	13.90	13.63	11.81	9.35	7.83	9.19
1976	6.68	6.22	5.37	5.13	6.07	8.25	11.19	13.14	13.79	10.95	8.89	7.90	8.63
1977	7.01	6.59	6.30	6.42	6.71	8.16	11.85	13.80	13.31	11.61	9.10	7.79	9.05
1978	7.06	6.65	6.44	6.51	7.06	8.93	12.60	14.19	13.83	11.90	9.34	7.96	9.37
1979	6.98	6.88	6.53	6.33	6.56	6.53	10.84	13.14	11.46	9.82	7.62	6.96	8.30
1980	6.28	5.82	5.61	5.54	6.30	7.90	12.19	14.33	14.08	11.09	9.08	7.83	8.84
1981	7.01	6.72	6.35	6.42	6.86	7.52	12.09	13.77	13.25	11.26	8.55	7.33	8.93
1982	6.40	6.22	6.01	6.20	6.53	8.26	10.67	13.54	14.01	10.28	8.63	7.54	8.69
1983	6.49	6.22	5.68	5.54	6.60	7.41	11.00	13.12	14.18	12.73	9.72	8.04	8.90
1984	7.31	6.80	6.42	6.08	6.59	9.53	12.75	13.46	14.05	10.67	8.49	7.41	9.13
1985	6.77	6.33	5.90	5.73	5.88	7.20	11.24	13.54	13.52	13.29	10.59	8.43	9.04
1986	7.37	6.71	6.52	6.10	6.46	6.93	12.33	13.36	12.84	11.51	8.94	7.75	8.90
1987	7.15	6.43	5.95	5.97	6.23	7.20	10.98	13.94	14.21	11.36	9.43	7.74	8.88
1988	6.91	6.54	6.34	6.32	6.83	8.20	12.15	14.16	13.31	10.86	8.58	7.38	8.96
1989	6.95	6.21	5.63	5.57	6.15	9.12	11.88	12.86	12.89	11.35	8.51	7.11	8.69
1990	6.22	5.22	5.39	5.45	6.52	8.73	12.63	13.66	12.90	11.79	8.89	7.36	8.73
1991	6.57	5.65	5.23	5.39	6.30	8.85	11.16	13.14	13.68	10.32	8.35	7.34	8.50
1992	6.80	5.81	5.13										
Avg 64-74	7.71	7.31	6.98	6.91	7.12	8.33	11.54	13.52	13.32	11.38	9.39	8.36	9.32
Avg 75-88	6.90	6.50	6.13	6.04	6.51	7.84	11.76	13.67	13.53	11.37	9.02	7.71	8.92
Avg 89-92	6.64	5.72	5.34	5.47	6.32	8.90	11.89	13.22	13.16	11.15	8.58	7.27	8.64

Source : FAP-25

[vp\gorai\tab3-9]

The annual peak water level data was checked for trends and no significant trend was observed in the data. Frequency analysis of peak water level data was also carried out and the results were compared with the FAP-25 results and are shown in Table 3.10. The differences in the 1 in 100 year event based on data from 1965 to 1989 was found to be of the order of 0.05 m. We have adopted the results of the FAP-25 analysis to be consistent with their recommendations for main rivers in Bangladesh.

TABLE 3.10

Comparison of Water Level Frequency Results in River Ganges at Hardinge Bridge

River	Ganges		
Station Name	Hardinge Bridge		
Station No.	90		
Fitted Distribution Return Period	GEV3	EV1 (FAP-25)	Diff
2	14.34	*	-
5	14.67	*	-
10	14.80	*	-
50	14.94	14.97	-0.03
100	14.97	15.02	-0.05

*FAP 25 analysis was done using left censoring and hence comparison of peak levels at lower return periods would be misleading.

EV1 Gumbel
GEV3 General Extreme Value Type III

3.2 Gorai Flows

3.2.1 General

The river Gorai is one of the major fresh water carriers into the Southwest Region. It supports irrigation in the region and is instrumental in controlling the movement of the saline front. It also performs a secondary role of slowing down the siltation rate in some channels in the tidal area in the southern part of the study area. The flows in the Gorai-Madhumati are linked to the flows in the Ganges from which it derives its water.

3.2.2 Data Availability and Analysis

Flow data for the Gorai is available at Gorai railway bridge from 1965 to 1989 and at Kamarkhali from 1965 to 1982 with few gaps. Mean, median and 80% dependable monthly flows are shown in Table 3.11. The flow at Kamarkhali was found to be less than the flow at Gorai railway bridge even though Kamarkhali is located further downstream. Sample hydrographs comparing the flow pattern are shown in Figure 3.4. This may be due to overbank spilling in the intermediate region with the result that part of the flood flows are bypassing the gauging station at Kamarkhali and therefore not being measured. The discharge data at Kamarkhali should be treated with caution and may not represent the resource available at that point in the catchment. It is understood that BWDB are currently investigating the source of the discrepancy in the flood discharge records.

A comparison of the mean monthly flows in the Gorai at Gorai railway bridge has been done with the mean monthly flows in the Ganges at Hardinge Bridge and is shown in Table 3.12. The average flow in the Gorai is of the order of 12% of the flow in the Ganges.

TABLE 3.11
Gorai Flows

Mean Monthly Flow (cumecs)

Sl.No.	Station Name	Station No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann *	Ann #
1	Gorai Rly. Bdg. (1)	99	190	137	98	113	175	576	2715	4936	4645	2175	731	340	1403	1395
	Gorai Rly. Bdg. (2)	99	116	80	56	62	123	491	2670	4737	4598	2041	609	240	1319	1302
2	Kamarkhali (1)	101.5	303	175	124	136	192	554	2466	4421	3955	2023	913	526	1316	1359
	Kamarkhali (2)	101.5	343	164	107	117	181	525	2684	4415	3944	2007	1024	621	1344	1327

Median Monthly Flow (cumecs)

Sl.No.	Station Name	Station No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann *	Ann #
1	Gorai Rly. Bdg. (1)	99	174	112	71	57	122	584	2612	4828	4764	1965	698	356	1362	1355
	Gorai Rly. Bdg. (2)	99	104	48	18	28	81	395	2612	4762	4790	1931	596	244	1301	1339
2	Kamarkhali (1)	101.5	212	151	127	129	183	505	2425	4548	4383	2129	767	400	1330	1303
	Kamarkhali (2)	101.5	163	102	81	132	208	499	2909	5182	4558	2183	667	321	1417	1302

80% Dependable Monthly Flow (cumecs)

Sl.No.	Station Name	Station No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann *	Ann #
1	Gorai Rly. Bdg. (1)	99	55	29	11	14	67	284	2129	3904	3804	1445	417	158	1026	1151
	Gorai Rly. Bdg. (2)	99	4	3	2	1	38	259	2071	3857	3874	1301	400	39	987	1078
2	Kamarkhali (1)	101.5	97	64	36	43	76	426	1781	3396	2587	1257	454	208	869	1151
	Kamarkhali (2)	101.5	60	33	15	4	38	239	1439	50	194	1128	409	187	316	977

* Average of monthly values

\# Average of 80% dependable annual flow for complete years

(1) Based on series 1964 to 1989 (includes pre-Farakka period)

(2) Based on series 1975 to 1989 (excludes pre-Farakka period)

vp\gorai\tab3-11

TABLE 3.12

Comparison of Annual Flows in River Ganges and River Gorai

Year	Mean Annual Flow (cumecs)		Gorai flow as a % of Ganges flow
	Ganges	Gorai	
1965		1355	
1966	8080	1293	16
1967	10385	1518	15
1968	10269	1404	14
1969	11880	1510	13
1970	10689	1276	12
1971			
1972			
1973	13974	2042	15
1974	12284	1834	15
1975	13342	1611	12
1976	10224	1238	12
1977	11246	1475	13
1978	13900	1668	12
1979	6839	967	14
1980	12290	1474	12
1981	10771	1359	13
1982	10615	1151	11
1983	10486	1345	13
1984	11421	1335	12
1985	12718	1471	12
1986	11119	1114	10
1987	11933	1343	11
1988	11220	1216	11
1989	8685	1078	12
1990	11769		
1991	8534		
Avg 75-88	11294.5	1340.5	11.8

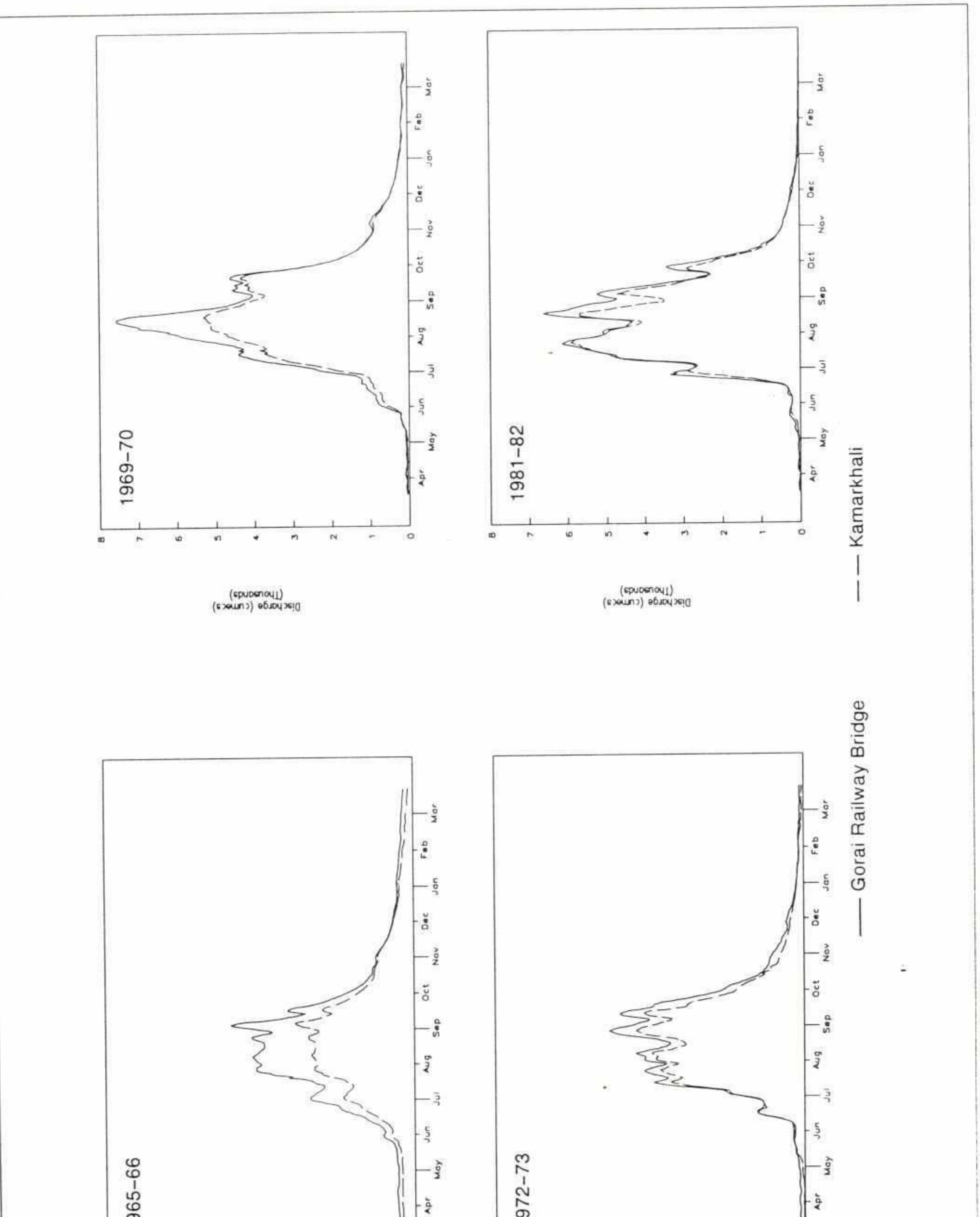
Trend analysis of the monthly Gorai flows was done using the Armsen test and significant downward trends for the months of December to May were found as shown in Table 3.13.

TABLE 3.13

Trend Analysis of Monthly Flows in River Gorai at Gorai Railway Bridge (1965-1989)

Month	Standard Normal Deviate	Probability = P(z)
Jan	2.9265	0.998 *
Feb	2.9265	0.998 *
Mar	2.0785	0.981 *
Apr	1.7518	0.960 *
May	2.6723	0.996 *
Jun	1.3856	0.917
Jul	1.1877	0.883
Aug	0.4949	0.690
Sep	0.4949	0.690
Oct	0.6928	0.756
Nov	1.3856	0.917
Dec	2.2764	0.989 *

Figure 3.4



Comparison of Flows on River Gorai

Note: * This test for stationarity is based upon that ARMSEN (J Nat Inst Per Res : 1965; Vol 6. p 177-9). If P(z)exceeds 0.95 there is a significant trend in the data : i.e. the time series is not stationary.

Frequency analysis of the annual maximum mean daily flow for the Gorai was done for the period of record from 1965 to 1989 and is shown in Table 3.14. Growth factors for the flood frequencies have also been computed by taking the 1 in 2 year flood as the mean annual flood and the growth factors for the various periods are shown in Table 3.15.

TABLE 3.14

Frequency Analysis of Historical Maximum Mean Daily Flows (cumecs) (1965-1989)

Station No.	Station Name	River	Return Perion (years)							Fitted Distribution
			2	5	10	20	50	100	200	
99	Gorai Rly Bridge	Gorai-Madhumati	6127	7198	7907	8587	9467	10126	10784	EV1

TABLE 3.15

Growth Factors for Historical Maximum Mean Daily Flows (cumecs) (1965-1989)

Station No.	Station Name	River	Return Perion (years)							Fitted Distribution
			2	5	10	20	50	100	200	
99	Gorai Rly Bridge	Gorai-Madhumati	1.00	1.17	1.29	1.40	1.55	1.65	1.76	EV1

Water level data was available for the Gorai at Gorai railway bridge for the period from 1965 to 1989. Frequency analysis was carried out for the annual peak levels and the results are shown in Table 3.16. A comparison with FAP-25 results is also shown in Table 3.16. Adopting the FAP-25 criteria of fitting a 3-Parameter Log-Normal distribution to the annual maximum water level data, the 1 in 100 year flood level is 14.01 m.

TABLE 3.16

Comparison of Water Level Frequency Results

River	Gorai-Madhumati		
Station Name	Gorai Railway Bridge		
Station No.	99		
Fitted Distribution	EV1	LN3	Diff
Return Period			
2	12.76	12.91	-0.15
5	13.15	13.30	-0.15
10	13.41	13.51	-0.10
50	13.97	13.88	0.09
100	14.21	14.01	0.20

EV1 Gumbel
LN3 3 Parameter Log Normal Distribution fitted by FAP-25.

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3.3 Hydrology of the Irrigation Area

3.3.1 Rainfall

There are 15 rainfall stations in the vicinity of project area. Rainfall records at all these stations were available for the period 1965 to 1989 with a few gaps in the record at some stations. Of these, the stations at Faridpur and Jessore are climatic stations. The location of the rainfall stations are shown in Figure 3.5.

The annual rainfall data of all stations was checked for trends using the Armsen test which is equivalent to a rank correlation test of Kendall. The test checks for stationarity at the 95% significance level. The results are shown in Table 3.17. Evidence of trend was found in the records at Jessore (R-456), Shibchar (R-414) and Kaliganj (R-458). Long term rainfall records available at Jessore from 1902 to 1991 were also checked for trends and no evidence of trend was found. The data at Jessore was, therefore, retained. Data at Kaliganj and Shibchar was not used.

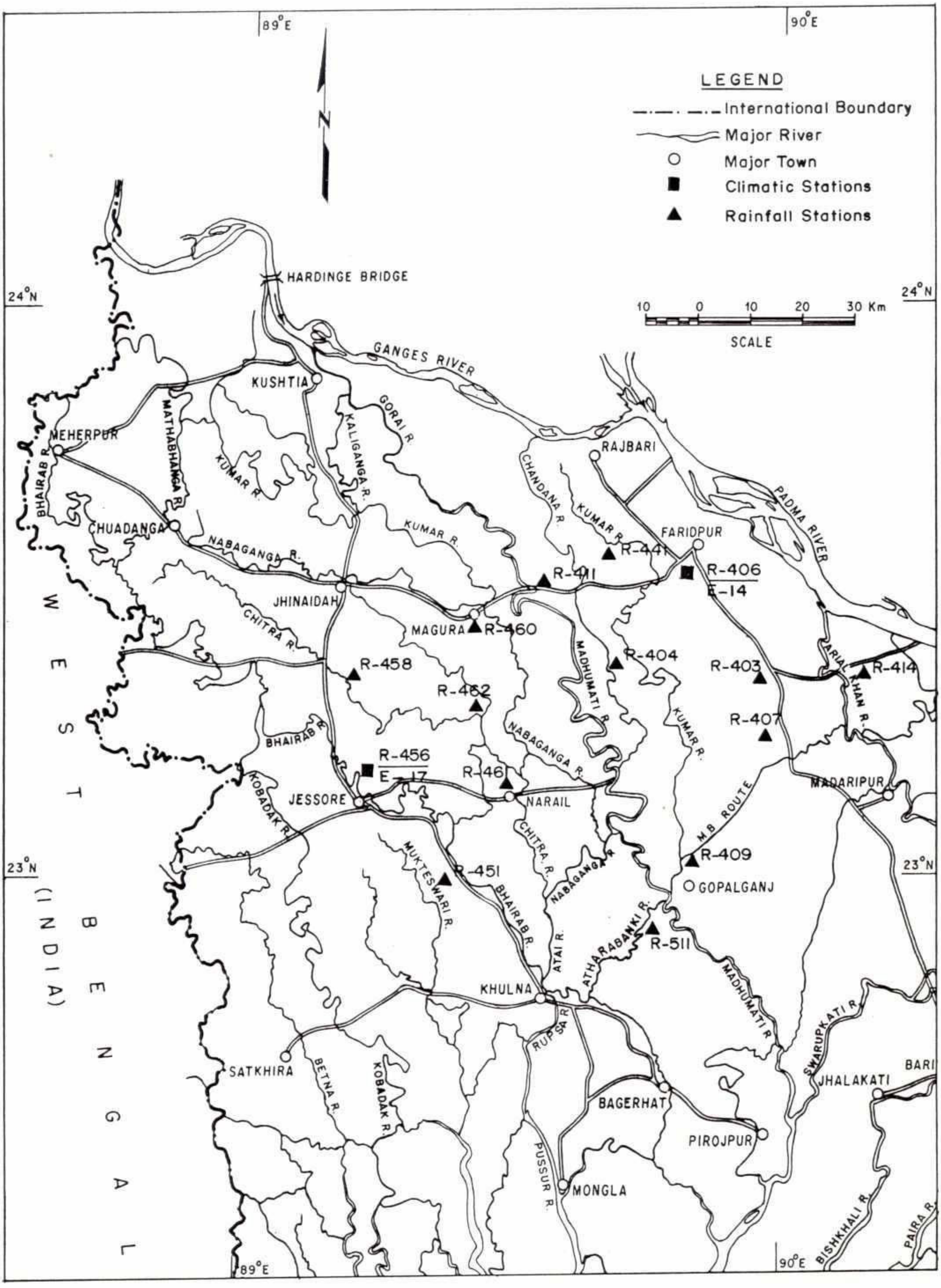
TABLE 3.17

Trend Analysis of Annual Rainfall (1965-1991)

Station No.	Station Name	Standard Normal Deviate	Probability = P(z)
R 403	Bhanga	0.8111	0.791
R 404	Bhusna (Boalmari)	0.8682	0.807
R 406	Faridpur	0.6164	0.731
R 407	Fatehpur	0.4905	0.688
R 409	Haridaspur	0.2641	0.604
R 411	Madhukhali	0.0000	0.500
R 414	Shibchar	2.0836	0.981 *
R 451	Abhoynagar	0.1056	0.542
R 456	Jessore	2.2482	0.988 *
R 458	Kaliganj (Jessore)	3.0636	0.999 *
R 460	Magura	0.4713	0.681
R 461	Narail	0.4226	0.664
R 462	Salikha	0.4530	0.675
R 511	Mollahat	0.0324	0.513

Note: * This test for stationarity is based upon that of Armsen. If P(z) exceeds 0.95, there is a significant trend in the data i.e. the time series is not stationary.

Figure 3.5



Location of Hydroclimatic Stations

TABLE 3.18
Mean Monthly Rainfall (mm)

Station No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann*	Ann#
R - 403	Bhanga	7.3	15.9	43.2	154.9	214.1	348.1	371.0	285.9	210.1	135.2	35.1	10.0	1830.8	1847.5
R - 404	Bhusna (Boalmari)	6.5	18.4	39.9	123.0	211.6	290.8	323.2	271.8	259.9	144.0	36.5	6.9	1732.5	1761.3
R - 406	Faridpur	6.9	22.5	47.8	140.3	252.0	355.1	331.4	287.7	248.7	139.6	34.3	10.8	1877.1	1930.2
R - 407	Fatehpur	10.0	18.6	43.6	141.3	224.9	372.9	344.6	271.7	226.7	139.8	37.3	8.8	1840.2	1722.5
R - 409	Haridaspur	8.4	21.1	47.9	115.3	189.1	354.2	345.9	299.3	254.8	124.8	31.7	8.2	1800.7	1784.4
R - 411	Madhukhali	1.9	17.6	65.8	142.9	258.4	314.1	330.9	227.5	270.9	140.7	39.3	2.9	1812.9	1844.4
R - 414	Shibchar	11.5	18.3	44.2	198.7	236.6	409.6	414.4	319.3	280.0	135.4	35.7	7.5	2111.2	2202.5
R - 451	Abhoynagar	8.2	22.1	33.1	84.2	181.3	336.6	399.1	407.0	290.1	142.6	23.5	9.2	1937.0	1898.2
R - 456	Jessore	11.8	21.8	36.4	83.0	179.5	307.4	341.5	311.8	246.3	126.8	28.9	10.3	1705.5	1738.2
R - 458	Kaliganj (Jessore)	7.0	16.7	43.4	84.0	187.6	292.9	345.6	296.5	241.6	126.5	27.5	11.8	1681.1	1695.7
R - 460	Magura	6.2	20.9	46.1	104.0	213.8	309.6	330.9	292.5	252.0	129.7	30.6	8.7	1745.0	1743.1
R - 461	Narail	7.7	20.3	43.4	82.4	180.9	308.1	339.3	336.8	241.6	130.2	27.6	9.1	1727.4	1718.3
R - 462	Salikha	10.1	15.4	42.8	98.5	189.6	333.4	341.5	332.4	258.3	115.5	45.3	8.7	1791.5	1779.6
R - 511	Mollahat	14.1	25.6	39.7	90.1	200.4	402.0	420.5	383.1	313.1	137.6	24.7	8.9	2059.8	2166.2

* Sum of monthly means.
# Mean of annual rainfall values for complete years.

TABLE 3.19
Median Monthly Rainfall (mm)

Station No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann*	Ann#
R - 403	Bhanga	0.0	11.4	41.9	135.7	189.6	326.4	333.3	272.4	195.8	100.7	24.6	0.0	1631.8	1876.8
R - 404	Bhusna (Boalmari)	0.0	14.9	16.6	88.9	182.9	281.5	273.4	228.8	257.2	119.5	12.7	0.0	1476.4	1782.8
R - 406	Faridpur	1.5	12.6	31.5	127.4	240.4	342.3	312.2	264.2	232.4	127.1	16.9	0.0	1708.5	1994.6
R - 407	Fatehpur	3.5	7.9	38.0	122.7	218.9	316.7	347.7	238.1	215.0	131.7	23.4	0.0	1663.6	1717.2
R - 409	Haridaspur	0.0	10.9	20.3	100.0	203.7	329.1	283.0	269.2	212.1	103.6	14.4	0.0	1546.3	1720.9
R - 411	Madhukhali	0.0	11.7	7.9	139.9	236.5	299.6	358.3	177.7	239.6	98.3	10.2	0.1	1579.8	1811.7
R - 414	Shibchar	0.0	2.8	18.3	180.5	238.3	350.3	385.4	269.7	212.9	134.6	10.1	0.0	1802.9	2021.6
R - 451	Abhoynagar	0.0	3.2	13.5	74.3	140.0	324.0	373.0	310.3	240.6	107.9	10.5	0.0	1597.3	1813.0
R - 456	Jessore	4.2	5.5	18.8	76.1	164.4	300.4	316.7	283.9	204.6	105.5	12.1	0.0	1492.2	1809.8
R - 458	Kaliganj (Jessore)	0.0	7.6	27.6	77.4	176.3	282.7	319.5	251.0	225.0	91.9	11.4	0.0	1470.4	1697.0
R - 460	Magura	0.6	12.9	40.3	105.5	195.8	267.4	316.3	271.9	225.1	129.1	14.5	0.0	1579.4	1752.4
R - 461	Narail	0.0	13.7	30.5	73.2	164.0	274.3	335.9	330.6	200.4	111.6	2.5	0.0	1536.7	1721.4
R - 462	Salikha	3.8	4.6	10.1	74.8	185.3	269.9	303.9	249.3	219.0	115.3	1.5	0.0	1437.5	1784.8
R - 511	Mollahat	0.0	15.3	26.6	80.0	180.5	338.5	404.9	355.2	280.7	110.3	10.2	0.0	1802.2	2162.3

* Sum of monthly medians.
# Median of annual rainfall values for complete years.

[vp\gorai\tab3-18]

TABLE 3.20
80% Dependable Monthly Rainfall (mm)

Station No.	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann*	Ann#
R - 403	Bhanga	0.0	0.0	3.0	70.4	95.3	250.6	273.4	146.2	150.0	50.5	0.0	0.0	1039.4	1581.4
R - 404	Bhusna (Boalmari)	0.0	0.0	0.0	41.7	83.3	167.4	202.9	142.0	131.0	34.4	0.0	0.0	802.7	1421.3
R - 406	Faridpur	0.0	0.0	4.5	67.8	165.6	225.3	228.1	173.9	143.5	66.3	0.0	0.0	1075.0	1530.1
R - 407	Fatehpur	0.0	0.0	1.8	65.9	124.7	210.4	206.3	164.8	124.6	46.9	0.0	0.0	945.4	1445.1
R - 409	Haridaspur	0.0	0.0	0.0	40.1	88.9	221.0	205.6	191.7	148.5	47.0	0.0	0.0	942.8	1403.2
R - 411	Madhukhali	0.0	0.0	0.0	13.5	78.1	214.5	120.8	83.8	129.8	7.9	0.0	0.0	648.4	1506.2
R - 414	Shibchar	0.0	0.0	0.0	85.0	92.0	257.5	239.1	142.3	136.1	35.8	0.0	0.0	987.8	1604.7
R - 451	Abhoynagar	0.0	0.0	0.0	27.7	63.9	182.2	251.3	212.6	128.8	24.7	0.0	0.0	891.2	1436.4
R - 456	Jessore	0.0	0.0	0.0	10.7	103.4	145.5	212.1	177.8	128.0	61.1	0.0	0.0	838.6	1279.6
R - 458	Kaliganj (Jessore)	0.0	0.0	0.0	22.1	87.2	154.3	226.1	189.0	117.7	49.5	0.0	0.0	845.9	1245.4
R - 460	Magura	0.0	0.0	0.0	38.6	133.3	223.1	202.4	195.8	171.2	26.1	0.0	0.0	990.5	1415.8
R - 461	Narail	0.0	0.0	0.0	17.8	82.5	183.8	204.3	147.5	121.0	33.3	0.0	0.0	790.2	1361.0
R - 462	Salikha	0.0	0.0	0.0	18.0	67.1	153.6	164.6	140.2	98.3	29.7	0.0	0.0	671.5	1369.1
R - 511	Mollahat	0.0	0.0	0.0	27.9	55.9	182.7	224.8	224.2	110.6	34.8	0.0	0.0	860.9	1556.2

[vp\gorai\tab3-20]

* Sum of 80% dependable monthly rainfall.
# 80% dependable annual rainfall estimated from all annual rainfall values for complete years.

TABLE 3.21
Design Storm Frequencies - 1 Day Maximum Rainfall (mm)

Station No.	Station Name	Return Period (years)							Fitted Distribution
		2	5	10	20	50	100	200	
R - 403	Bhanga	115	160	190	219	256	283	311	EV. 1
R - 404	Bhusna (Boalmari)	116	147	169	190	217	238	259	GEV. 2
R - 406	Faridpur	117	161	184	203	223	235	245	GEV. 3
R - 407	Fatehpur	126	173	208	245	298	343	391	GEV. 2
R - 409	Haridaspur	125	165	195	226	271	308	349	GEV. 2
R - 411	Madhukhali	145	181	195	205	213	217	220	GEV. 3
R - 414	Shibchar	95	140	170	200	239	269	300	GEV. 2
R - 451	Abhoynagar	121	177	222	270	342	405	476	GEV. 2
R - 456	Jessore	127	184	223	263	317	359	403	GEV. 2
R - 458	Kaliganj (Jessore)	116	165	202	241	298	346	398	GEV. 2
R - 460	Magura	119	162	191	218	253	280	306	EV. 1
R - 461	Narail	129	182	221	261	319	365	415	GEV. 2
R - 462	Salikha	125	175	209	243	287	322	357	GEV. 2
R - 511	Mollahat	116	177	226	282	370	450	542	GEV. 2

TABLE 3.22
Design Storm Frequencies - 2 Day Maximum Rainfall (mm)

Station No.	Station Name	Return Period (years)							Fitted Distribution
		2	5	10	20	50	100	200	
R - 403	Bhanga	157	210	246	279	323	356	389	EV. 1
R - 404	Bhusna (Boalmari)	161	214	248	280	321	351	380	GEV. 3
R - 406	Faridpur	146	207	248	287	338	376	414	EV. 1
R - 407	Fatehpur	179	241	284	327	384	428	474	GEV. 2
R - 409	Haridaspur	179	248	298	349	421	480	542	GEV. 2
R - 411	Madhukhali	172	240	285	328	384	426	468	EV. 1
R - 414	Shibchar	137	193	228	260	299	326	352	GEV. 3
R - 451	Abhoynagar	179	272	348	434	568	689	830	GEV. 2
R - 456	Jessore	176	252	303	351	414	461	508	EV. 1
R - 458	Kaliganj (Jessore)	153	232	294	363	468	560	666	GEV. 2
R - 460	Magura	157	226	271	314	371	413	455	EV. 1
R - 461	Narail	170	246	300	355	431	492	556	GEV. 2
R - 462	Salikha	182	250	297	345	409	459	511	GEV. 2
R - 511	Mollahat	176	272	348	433	564	679	811	GEV. 2

[vp\gorai\tab3-21]

TABLE 3.23
Design Storm Frequencies - 5 Day Maximum Rainfall (mm)

Station No.	Station Name	Return Period (years)							Fitted Distribution
		2	5	10	20	50	100	200	
R - 403	Bhanga	212	291	343	394	459	508	556	EV. 1
R - 404	Bhusna (Boalmari)	229	318	376	432	503	556	609	GEV. 3
R - 406	Faridpur	204	288	344	398	467	519	571	EV. 1
R - 407	Fatehpur	220	311	388	479	627	765	932	GEV. 2
R - 409	Haridaspur	245	340	408	477	572	649	729	GEV. 2
R - 411	Madhukhali	221	326	396	463	549	614	679	EV. 1
R - 414	Shibchar	217	296	338	372	409	431	451	GEV. 3
R - 451	Abhoynagar	263	395	498	610	777	922	1084	GEV. 2
R - 456	Jessore	241	343	414	484	577	649	722	GEV. 2
R - 458	Kaliganj (Jessore)	229	336	410	483	581	657	736	GEV. 2
R - 460	Magura	217	312	379	445	535	606	679	GEV. 2
R - 461	Narail	242	343	412	479	568	637	706	GEV. 2
R - 462	Salikha	249	345	418	495	606	700	803	GEV. 2
R - 511	Mollahat	271	403	500	603	749	870	1000	GEV. 2

TABLE 3.24
Design Storm Frequencies - 10 Day Maximum Rainfall (mm)

Station No.	Station Name	Return Period (years)							Fitted Distribution
		2	5	10	20	50	100	200	
R - 403	Bhanga	277	368	428	486	561	617	672	EV. 1
R - 404	Bhusna (Boalmari)	294	401	472	540	627	693	759	EV. 1
R - 406	Faridpur	264	362	427	489	570	630	691	EV. 1
R - 407	Fatehpur	283	391	485	596	777	949	1157	GEV. 2
R - 409	Haridaspur	317	412	475	535	615	675	735	GEV. 2
R - 411	Madhukhali	271	393	473	550	650	725	800	EV. 1
R - 414	Shibchar	290	405	474	535	607	656	702	GEV. 3
R - 451	Abhoynagar	339	480	581	685	831	949	1074	GEV. 2
R - 456	Jessore	303	419	497	571	668	740	813	GEV. 2
R - 458	Kaliganj (Jessore)	293	409	487	561	657	728	800	EV. 1
R - 460	Magura	283	402	480	556	654	727	800	EV. 1
R - 461	Narail	297	404	471	533	610	665	718	GEV. 3
R - 462	Salikha	320	447	537	628	755	855	961	GEV. 2
R - 511	Mollahat	359	510	610	706	831	924	1017	EV. 1

[vp\gorai\tab3-23]

TABLE 3.25
Mean Monthly Temperature (°C) (1965-1990)

Month	Faridpur (E-20)			Jessore (E-17)		
	Maximum	Mean	Minimum	Maximum	Mean	Minimum
Jan	24.6	18.4	12.1	25.8	18.9	11.6
Feb	27.8	21.1	14.2	28.9	21.6	14.2
Mar	32.7	25.9	19.1	33.3	26.4	19.5
Apr	34.2	28.6	23.0	35.8	29.8	23.7
May	33.5	29.0	24.3	35.1	30.1	25.0
Jun	32.0	28.8	25.6	32.9	29.4	25.8
Jul	31.3	28.6	25.8	31.9	28.9	25.9
Aug	31.3	28.7	26.0	31.9	28.9	25.9
Sep	31.6	28.7	25.8	32.3	29.0	25.6
Oct	31.2	27.6	23.8	31.9	27.7	23.3
Nov	28.7	23.8	18.9	29.7	23.9	18.0
Dec	25.2	19.5	13.6	26.4	19.5	12.4
Annual	30.3	25.7	21.0	31.3	26.2	20.9

Source: BMD

TABLE 3.26
Mean Monthly Relative Humidity (%), Wind Speed (Knots) and Bright Sunshine Hours (1965-1990)

Month	Relative Humidity (%)		Wind Speed (Knots)		Bright Sunshine Hours	
	Faridpur	Jessore	Faridpur	Jessore	Faridpur	Jessore
Jan	75	71	3	5	8.0	7.8
Feb	68	65	3	5	8.4	8.1
Mar	64	63	3	6	7.8	8.0
Apr	70	68	5	9	7.9	8.1
May	79	75	4	8	7.6	7.7
Jun	87	85	4	7	5.4	5.2
Jul	88	88	4	7	4.1	4.0
Aug	87	87	4	7	5.4	4.8
Sep	86	86	3	6	5.2	5.0
Oct	82	81	3	5	7.6	7.1
Nov	78	75	2	5	8.0	7.8
Dec	77	73	2	5	8.1	7.7
Annual	78	76	3.3	6.3	7.0	6.8

[vp\gorai\tab3-25]

Source: BMD

Note: Wind speed is reported as the mean 24 hourly value in the predominant direction at 10 m height

Rainfall data was available for about 25 years except at Modhukali (R-411) where only 6 years of complete rainfall records were available. The mean, median and 80% dependable monthly rainfall are summarised in Tables 3.18 to 3.20 and annual Isohyets lines are shown in Figure 3.6 to 3.8. The mean annual rainfall in the project area ranges from 1696 mm to 2203 mm and the 80% dependable annual rainfall ranges from 1245 mm to 1605 mm. Figure 3.9 shows the monthly rainfall pattern at selected stations. The annual rainfall increases from the north-west to the south-eastern part of the study area and reaches a peak in July. As would be expected in this region, approximately 71% of the annual rainfall occurs in the monsoon season from June to September. Box plots of the annual rainfall data at selected stations are shown in Figure 3.10.

Frequency analysis of daily rainfall data was carried out to compute the storm rainfall frequencies. Extreme value analysis was done by fitting General Extreme Value distributions to the data and the distribution which gave the best fit was chosen for the station. The results of the 1 day, 2 day, 5 day and 10 day rainfall totals for various return periods are shown in Tables 3.21 to 3.24.

3.3.2 Climate

The nearest climatic stations to the project area are located at Jessore (E-17) and at Faridpur (E-20). Climatic parameters including monthly maximum, minimum and mean temperature data, mean monthly relative humidity data, mean monthly wind speed data, mean monthly sunshine data and monthly evaporation data were available at the two climatic stations. The records were available for the period 1965 to 1990 and generally, the records at Jessore were longer than at Faridpur. Climatic parameters at both stations are shown in Tables 3.25 to 3.28 and Figures 3.11 and 3.12.

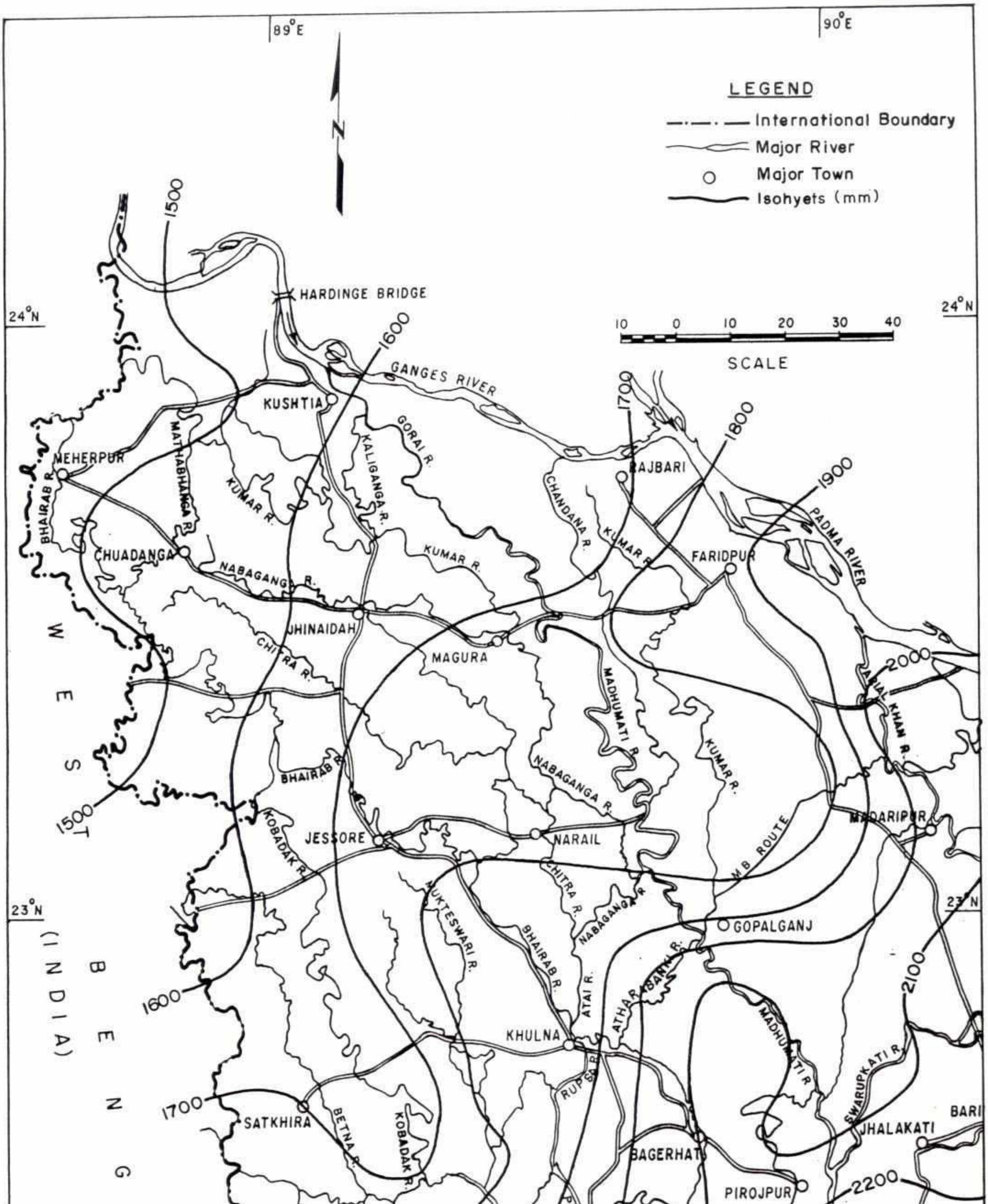
TABLE 3.27

Mean Monthly Evaporation (mm) (1965-1990)

	Faridpur	Jessore
Jan	55	61
Feb	63	70
Mar	102	113
Apr	119	132
May	111	120
Jun	87	93
Jul	71	78
Aug	73	79
Sep	75	73
Oct	77	80
Nov	68	71
Dec	57	66
Annual	957	1037

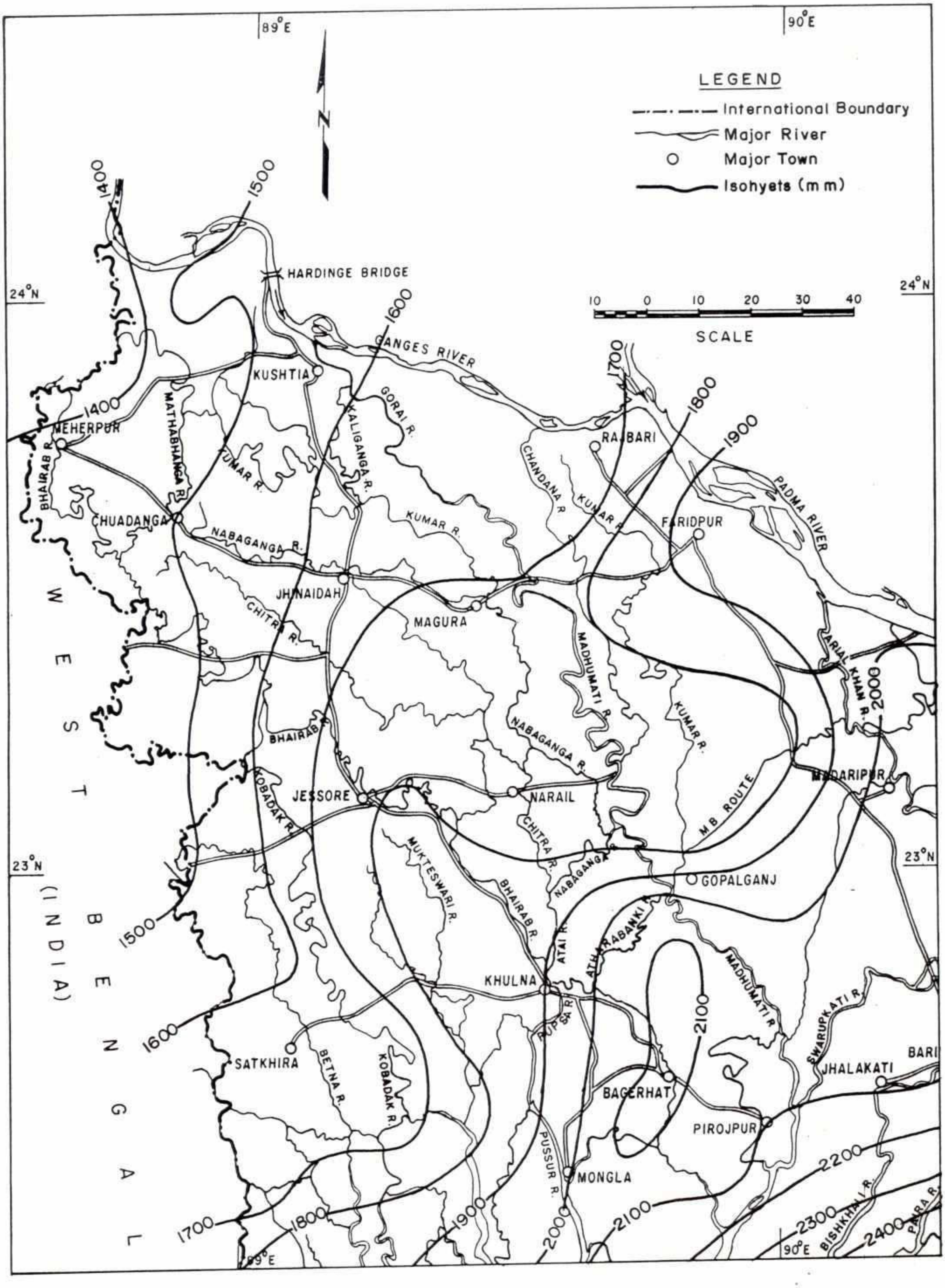
Source : BWDB, MPO

Figure 3.6



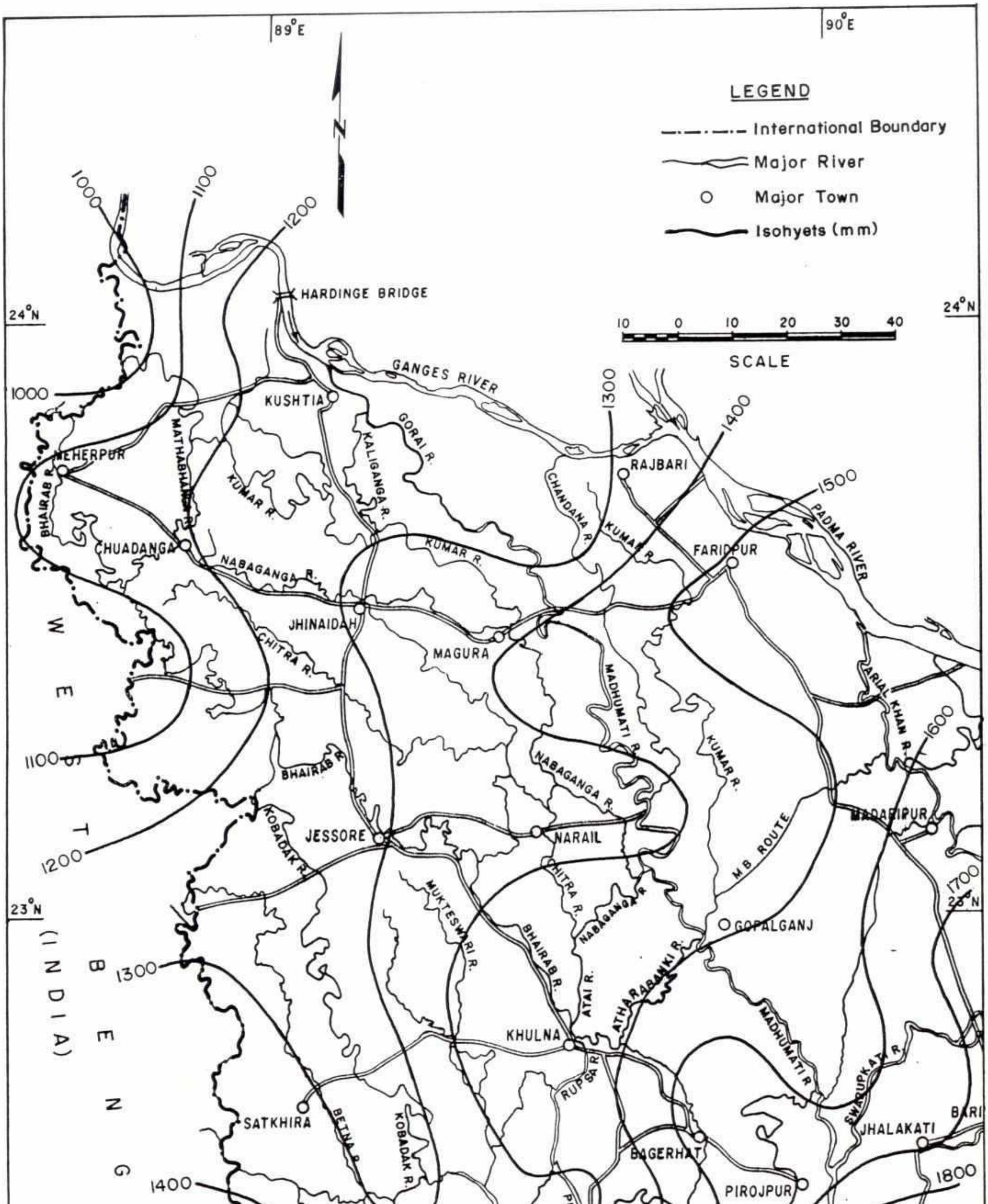
Mean Annual Rainfall

Figure 3.7

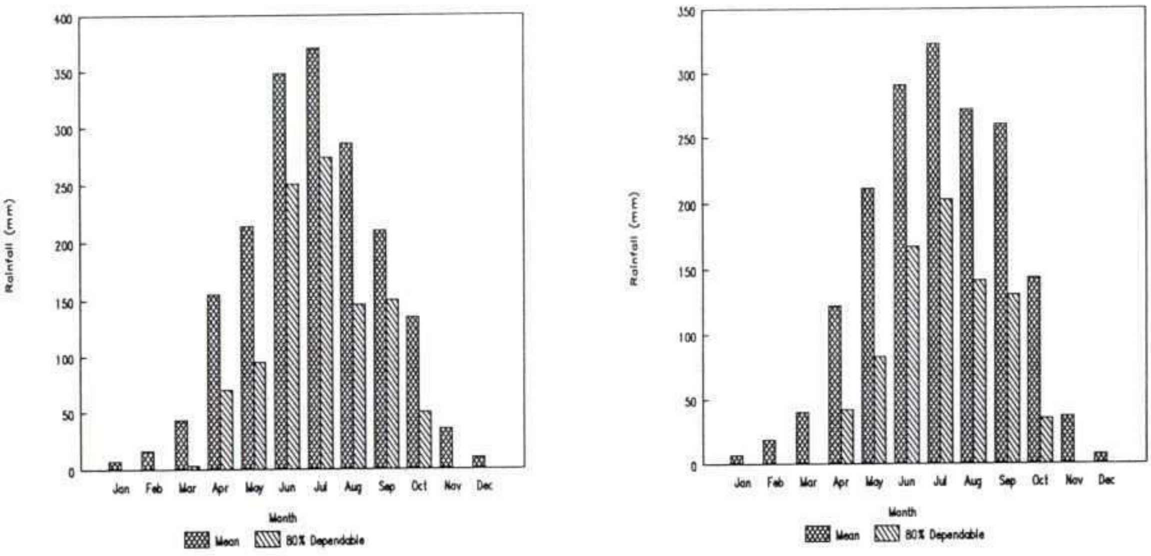


Median Annual Rainfall

Figure 3.8



80% Probable Annual Rainfall



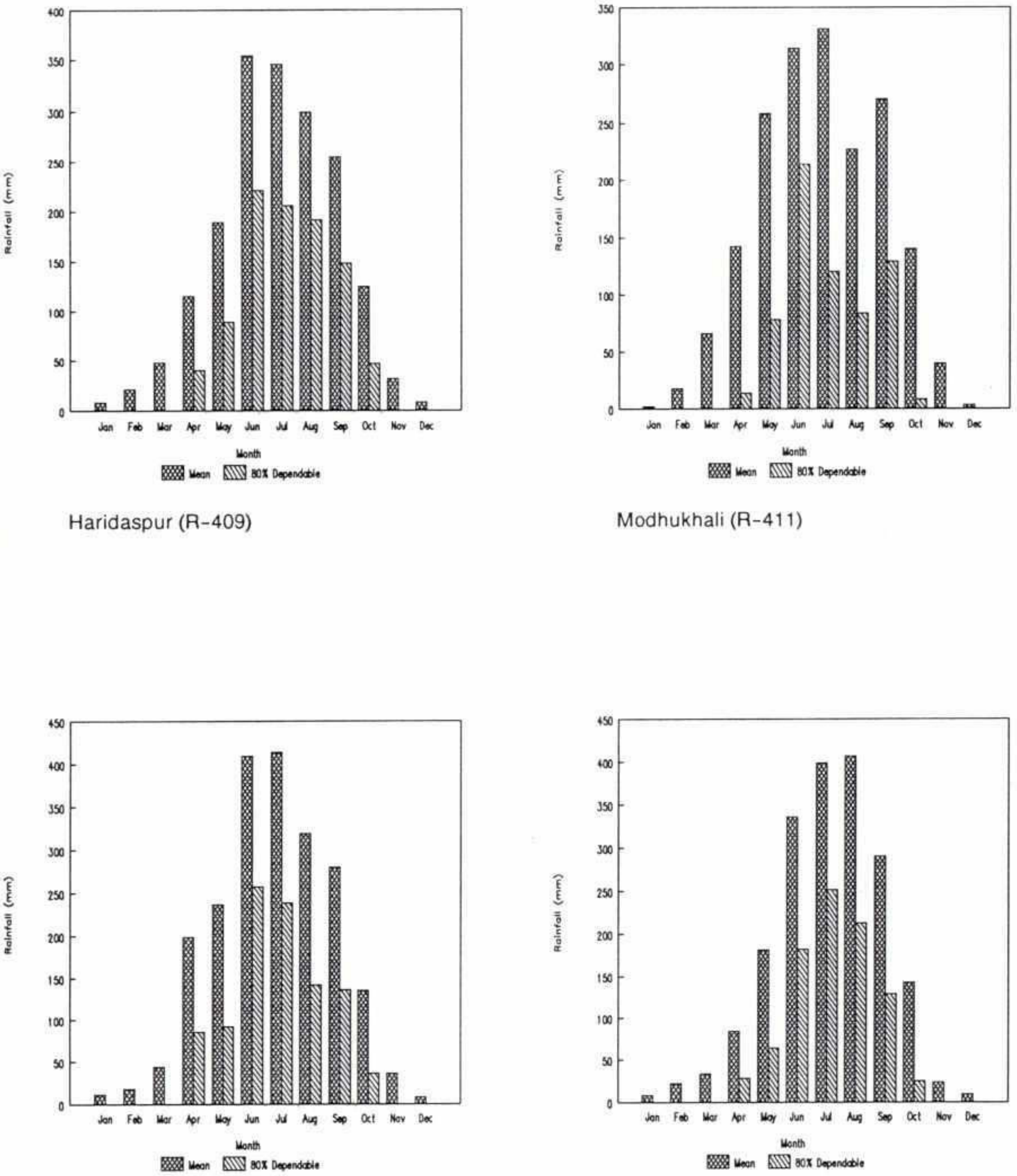
Bhanga (R-403)

Bhusna (Boalmari) (R-404)

Faridpur (R-406)

Fatehpur (R-407)

Monthly Rainfall



Haridaspur (R-409)

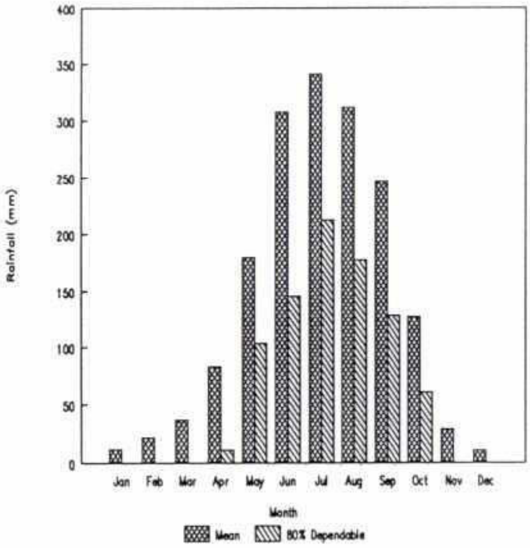
Modhukhali (R-411)

Shibchar (R-414)

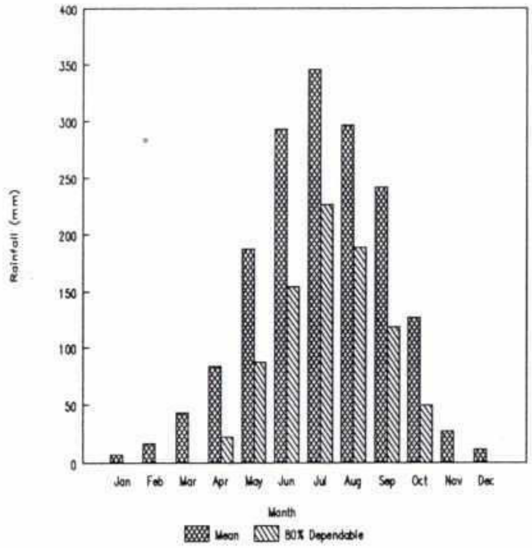
Abhoynagar (R-451)

Monthly Rainfall

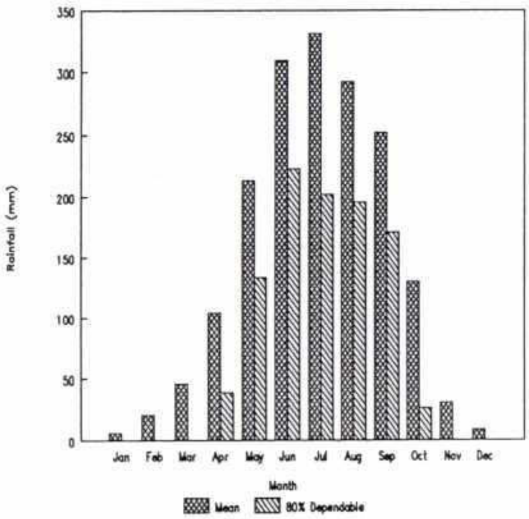
Figure 3.9c



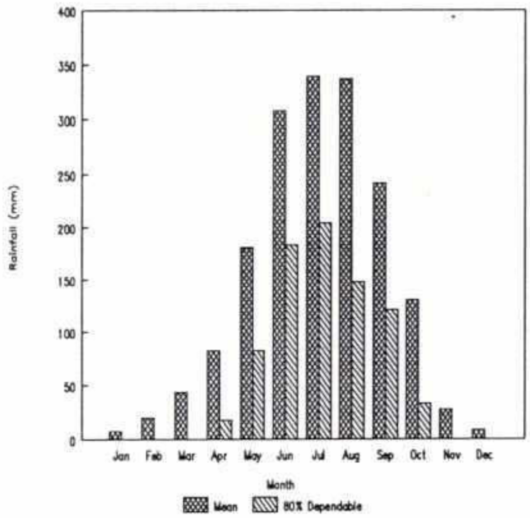
Jessore (R-456)



Kaligang (Jessore) (R-458)



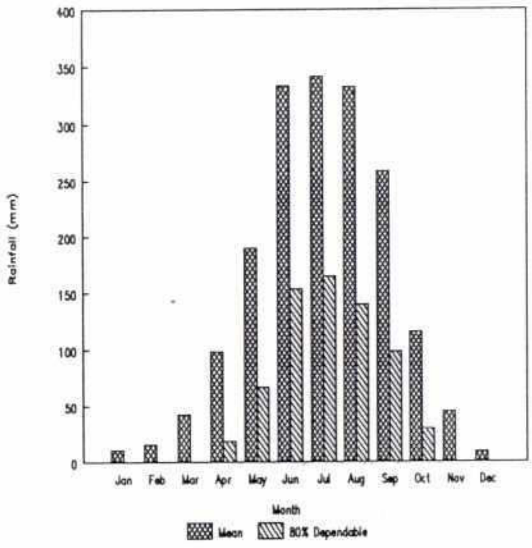
Magura (R-460)



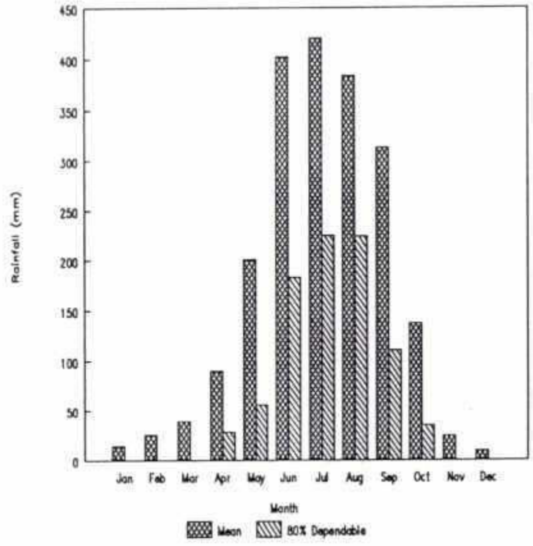
Narail (R-461)

Monthly Rainfall

Figure 3.9d



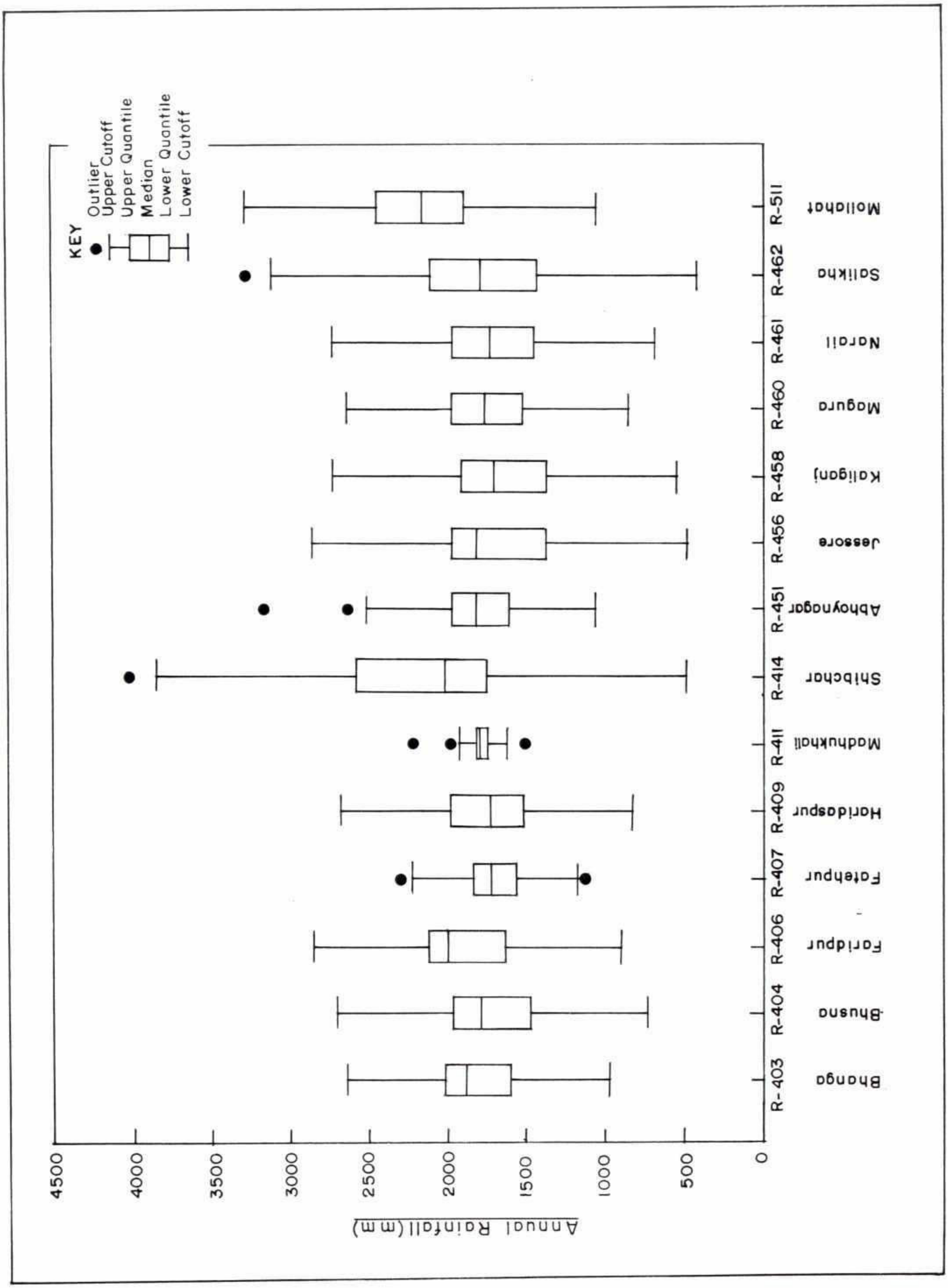
Salikha (R-462)



Mollahat (R-511)

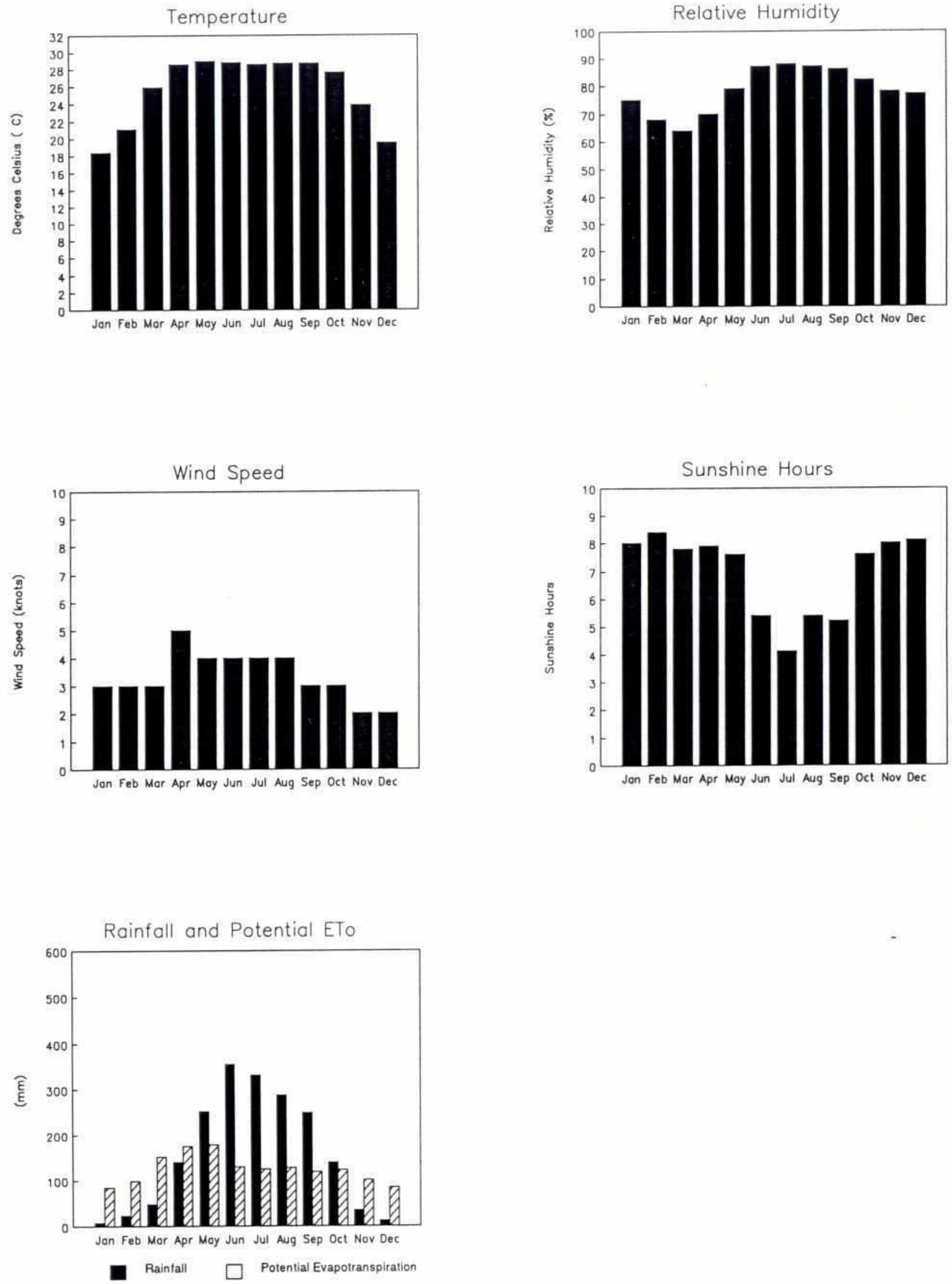
Monthly Rainfall

Figure 3.10



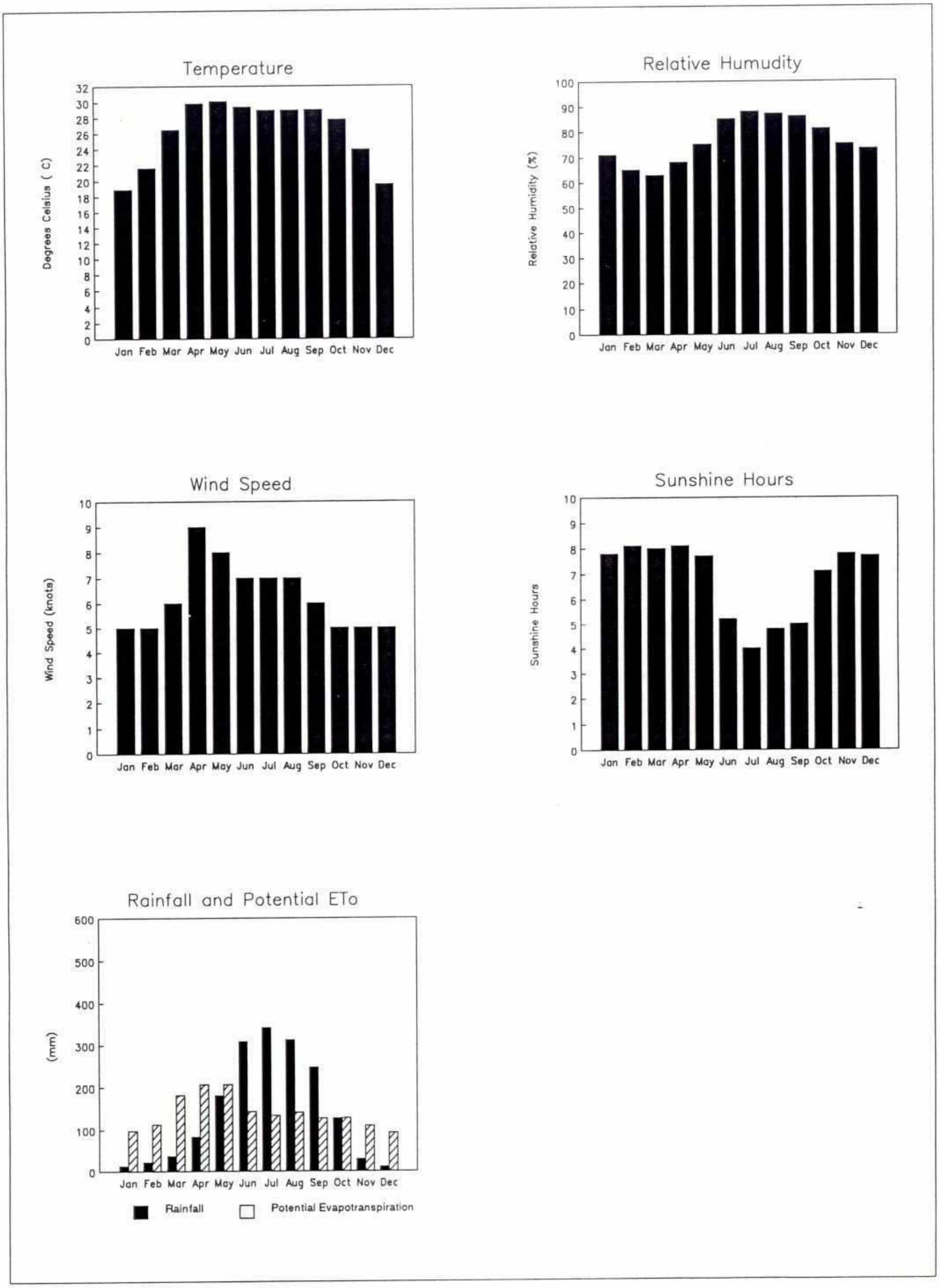
Box Plots of Annual Rainfall

Figure 3.11



Climatic Data at Faridpur

Figure 3.12



Climatic Data at Jessore

TABLE 3.28

Modified Penman Potential Evapotranspiration (mm)

	1		2	
	Faridpur	Jessore	Faridpur	Jessore
Jan	84	98	85	92
Feb	99	113	96	109
Mar	151	181	146	168
Apr	176	206	174	214
May	179	206	183	216
Jun	130	143	122	140
Jul	125	133	137	139
Aug	128	140	137	137
Sep	119	127	127	123
Oct	123	128	125	126
Nov	101	109	129	100
Dec	84	92	81	85
Annual	1498	1675	1541	1648

1. Source : Computed from recent climatic data
2. Source : BARC Soils and Irrigation Publication No. 11, 1982.

The mean monthly temperature varies from a minimum in January of approximately 18.5°C to a peak of 30°C in May. Between April and October, the temperature remains fairly constant with changes of about 2°C only. Average wind speed at Jessore is 6.3 knots and at Faridpur it is 3.3 knots with a peak occuring in April. The region experiences an average of 7 hours of sunshine including 7 months with more than 7.5 hours of sunshine.

Evaporation in Bangladesh is usually measured using a modified Class A Pan which has an extra 5 inches of freeboard above the water surface as compared to a normal Class A Pan. A pan coefficient of 0.7 is used by BWDB to convert pan evaporation to open water evaporation. The mean annual evaporation at Jessore is 1037 mm with a peak occurring in April. At Faridpur the mean annual evaporation is slightly less at 957 mm.

Evapotranspiration was calculated from mean monthly values of climatic data. The Doorenbos and Pruitt modification of the Penman method as outlined in the FAO Irrigation and Drainage Paper No.24 is widely applied in Bangladesh and was used for estimating the potential evapotranspiration. Estimates of solar radiation and mean duration of maximum possible sunshine hours were made from standard tables based on latitudes. A reflection coefficient of 0.25 was used. Wind speed data is reported by BMD as an average for the day in knots for the predominant wind direction at 10 m height. Estimates of potential evapotranspiration are sensitive to wind data and efforts should be made to corroborate the results with actual field measurements in the future. Monthly evapotranspiration computed at Jessore and Faridpur are shown in Table 3.28. The annual modified Penman potential evapotranspiration at Jessore is 1675 mm and at Faridpur is 1498 mm. Previous estimates made by BARC are also shown in Table 3.28. It can be seen that the recent calculations of potential evapotranspiration are higher at Jessore than estimates made previously by BARC. This discrepancy may be due in part to the availability of longer climatic records which result in better estimates.

TABLE 3.29

Long Term Rainfall-Runoff Simulation in NAM Catchments (1965-1991)

Catchment	Parameter		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann	% of RF
SW10	Rainfall (mm)	Mean	8.13	18.08	46.26	102.67	201.97	304.69	339.70	307.38	254.20	123.92	29.78	9.24	1746	
		Median	3.80	11.80	32.70	85.30	204.10	261.30	308.60	289.80	218.80	104.30	16.90	0.10	1538	
		80%	0.00	1.90	2.80	42.70	127.50	206.10	238.30	189.10	177.20	61.10	0.00	0.00	1047	
	Runoff (mm)	Mean	0.89	0.00	0.37	1.91	11.25	45.91	99.37	153.69	183.11	158.81	56.19	12.27	724	41.5
		Median	0.00	0.00	0.00	0.49	5.53	28.40	72.11	136.14	164.01	154.83	45.22	6.87	614	39.9
		80%	0.00	0.00	0.00	0.00	1.34	16.90	52.08	100.15	123.02	110.02	30.80	4.92	439	42.0
	Recharge (mm)	Mean	0.08	0.18	1.06	6.99	26.19	49.53	59.77	61.45	58.13	51.09	17.68	3.07	335	19.2
		Median	0.00	0.00	0.00	2.80	26.80	54.10	61.50	62.00	60.00	62.00	10.50	0.00	340	22.1
		80%	0.00	0.00	0.00	0.00	13.20	39.90	60.50	62.00	60.00	45.60	2.40	0.00	284	27.1
SW11	Rainfall (mm)	Mean	6.94	20.18	45.57	125.02	221.69	287.45	330.74	282.42	259.56	126.60	35.90	10.27	1752	
		Median	0.40	12.20	35.50	105.20	219.20	277.20	278.80	240.30	247.40	89.20	14.60	0.10	1520	
		80%	0.00	1.50	2.70	52.70	139.40	189.70	225.80	189.30	159.00	57.20	0.10	0.00	1017	
	Runoff (mm)	Mean	1.92	0.00	0.70	5.13	15.67	56.03	110.55	158.61	177.89	152.55	58.89	15.67	754	43.0
		Median	0.00	0.00	0.00	0.87	9.49	37.22	103.85	147.60	162.98	140.90	45.49	8.21	657	43.2
		80%	0.00	0.00	0.00	0.12	3.79	18.58	56.79	106.07	130.59	94.54	28.72	2.50	442	43.4
	Recharge (mm)	Mean	1.11	2.22	4.98	16.28	34.34	41.85	46.04	46.38	44.36	40.49	19.52	7.12	305	17.4
		Median	0.00	1.00	2.60	12.90	35.80	44.80	46.50	46.50	45.00	46.50	18.10	0.80	301	19.8
		80%	0.00	0.10	0.10	5.40	25.20	38.90	46.50	46.50	45.00	34.20	4.40	0.00	246	24.2
SW12	Rainfall (mm)	Mean	7.04	17.42	47.29	143.13	238.82	315.39	347.26	278.17	238.98	135.34	38.32	9.79	1817	
		Median	1.40	15.90	45.70	115.40	251.70	285.70	312.40	253.40	211.60	107.30	19.00	0.70	1620	
		80%	0.00	1.50	4.00	71.10	160.00	235.70	266.10	194.50	172.60	60.70	0.00	0.00	1166	
	Runoff (mm)	Mean	1.25	0.00	0.34	6.22	21.47	68.43	136.82	172.36	175.45	148.28	56.58	13.66	801	44.1
		Median	0.00	0.00	0.00	0.50	10.94	50.00	141.20	171.48	165.69	135.86	45.30	5.90	727	44.9
		80%	0.00	0.00	0.00	0.09	3.47	19.29	87.29	114.28	145.49	109.74	26.60	1.75	508	43.6
	Recharge (mm)	Mean	1.28	2.18	6.00	22.20	46.79	55.63	61.61	62.00	59.73	52.70	21.85	6.69	399	21.9
		Median	0.20	1.30	5.10	18.10	48.40	58.00	62.00	62.00	60.00	59.00	19.50	0.40	394	24.3
		80%	0.00	0.10	0.20	8.80	35.20	51.10	62.00	62.00	60.00	49.10	6.80	0.00	335	28.8
SW14	Rainfall (mm)	Mean	10.12	21.02	41.09	87.42	190.35	317.38	359.14	334.13	257.88	129.31	28.62	10.83	1787	
		Median	4.60	13.80	29.10	73.60	171.30	275.10	338.80	308.30	206.50	123.00	18.60	0.00	1563	
		80%	0.00	0.80	2.40	35.90	118.60	203.00	266.60	214.30	157.20	74.60	0.70	0.00	1074	
	Runoff (mm)	Mean	0.05	0.04	0.26	0.74	6.68	41.04	126.89	174.15	166.34	124.24	34.92	2.84	678	37.9
		Median	0.00	0.00	0.00	0.11	3.30	20.90	120.88	160.07	134.01	114.59	17.90	0.00	572	36.6
		80%	0.00	0.00	0.00	0.00	0.48	6.31	53.81	127.93	110.31	53.04	1.90	0.00	354	32.9
	Recharge (mm)	Mean	2.12	2.34	4.53	13.18	49.92	91.05	116.79	120.17	107.86	80.52	19.63	5.70	614	34.3
		Median	0.50	0.30	0.60	12.80	43.40	93.70	123.90	124.00	112.20	92.10	10.30	0.10	614	39.3
		80%	0.00	0.00	0.00	0.70	28.60	69.30	115.40	117.10	97.60	43.30	0.40	0.00	472	44.0
SW17	Rainfall (mm)	Mean	8.03	19.40	48.61	127.54	213.44	333.96	354.42	288.68	241.82	126.50	34.54	9.50	1806	
		Median	1.70	12.20	36.90	114.00	213.40	334.10	326.50	250.40	230.70	92.40	22.20	0.00	1635	
		80%	0.00	0.90	1.80	80.10	135.10	241.80	250.20	206.40	151.90	49.80	0.20	0.00	1118	
	Runoff (mm)	Mean	1.17	0.09	0.51	4.05	18.96	66.69	138.21	172.50	174.39	141.99	53.10	11.97	784	43.4
		Median	0.00	0.00	0.00	1.62	13.71	65.31	133.20	165.87	166.26	123.18	47.91	4.77	722	44.2
		80%	0.00	0.00	0.00	0.09	3.78	34.47	105.48	123.36	124.38	81.87	18.39	1.56	493	44.1
	Recharge (mm)	Mean	0.70	0.67	2.13	9.90	25.15	34.92	39.75	40.27	39.00	35.91	18.94	4.80	252	14.0
		Median	0.00	0.00	0.10	8.00	26.00	37.30	40.10	40.30	39.00	40.30	20.30	0.00	251	15.4
		80%	0.00	0.00	0.00	1.50	18.40	33.60	39.80	40.30	39.00	35.30	8.40	0.00	216	19.3
SC1	Rainfall (mm)	Mean	10.59	21.21	52.00	194.09	254.96	377.38	387.43	312.97	252.09	132.49	40.56	9.17	2045	
		Median	3.20	11.00	40.60	184.30	234.20	348.10	360.70	297.00	209.30	134.00	17.00	0.20	1840	
		80%	0.00	0.10	8.80	90.90	149.80	275.00	271.50	178.20	165.90	59.90	0.00	0.00	1200	
	Runoff (mm)	Mean	4.77	0.52	0.46	9.14	21.38	49.60	93.11	135.92	176.21	157.70	70.52	22.47	742	36.3
		Median	2.99	0.17	0.00	1.49	13.28	33.68	87.30	130.92	152.13	143.16	64.43	17.70	647	35.2
		80%	1.09	0.00	0.00	0.17	4.14	17.13	48.28	100.81	126.78	108.51	37.87	9.66	454	37.9
	Recharge (mm)	Mean	0.25	0.19	1.42	21.23	58.96	80.52	91.20	91.33	84.95	72.29	30.32	4.92	538	26.3
		Median	0.00	0.00	0.00	13.10	61.50	88.10	93.00	93.00	90.00	86.10	22.60	0.00	547	29.8
		80%	0.00	0.00	0.00	2.20	34.70	74.90	92.80	93.00	86.90	51.50	0.50	0.00	437	36.4

[vp\gorai\tab3-29]

It may be noted here that the calculated annual potential evapotranspiration values are higher than the reported annual pan evaporation values by as much as 64%. This discrepancy cannot be explained and needs to be looked at carefully if pan evaporation data is to be used. A higher reliability is attached to the computed potential evapotranspiration as it is a function of a number of climatic parameters and does not rely on the measurement of a single parameter.

3.3.3 Drainage Parameters

The irrigation area is covered by 7 NAM catchments, namely SUW9 to SUW12, SUW14, SUW17 and SUC1. The results of the simulation runs of the NAM model for the 25 year series from 1964 to 1989 were analysed and the long term monthly means are presented in Table 3.29. The mean annual runoff from the NAM catchments ranges from 678 mm to 801 mm. This is equivalent to between approximately 36% to 44% of the annual rainfall in the region. The 1 in 5 year and 1 in 10 year, 1 day and 10 day maximum runoff was also analysed and the results are shown in Table 3.30. It can be seen that there is little difference between a 10 day maximum runoff rate and a 1 day maximum runoff rate for various return periods in the individual NAM catchments. The 10 day maximum runoff rate for a 1 in 5 year event ranges from 9.2 mm/day to 12.2 mm/day. The 1 in 10 year 10 day maximum runoff rate ranges from 10.7 mm/day to 14.5 mm/day. The runoff rate for a 1 day maximum runoff for a 1 in 5 year event on the other hand ranges from 9.6 mm/day to 12.5 mm/day as compared to a 1 in 10 year event which ranges from 11.2 mm/day to 14.8 mm/day. The lowest runoff rate is observed in NAM catchment SUW12 and the highest in NAM catchment SUC1.

TABLE 3.30

Simulated Maximum Runoff Rates

NAM Catchment	Area (sqkm)	10 day maximum runoff (mm/day)		1 day maximum runoff (mm/day)	
		1 in 5 year	1 in 10 year	1 in 5 year	1 in 10 year
SW 9	928	9.5	11.4	9.9	11.9
SW 10	638	10.1	12.1	10.5	12.6
SW 11	445	9.7	11.4	10.1	11.9
SW 12	1142	9.2	10.7	9.6	11.2
SW 14	1471	10.0	11.9	10.4	12.5
SW 17	868	9.9	11.6	10.3	12.0
SC 1	451	12.2	14.5	12.5	14.8

3.3.4 Flow in Rivers in the Region

From the 25 year 1-D hydrodynamic simulation run for the current scenario, the flows at various nodes in the study area were analysed and the results are shown in Tables 3.31 and 3.32 and Figure 3.14. There are 18 model flow analysis nodes within the project area and their location is shown in Figure 3.13. The long term average flows in the rivers and their direction of flow are shown in Figure 3.15. The major rivers in the area are the Arial Khan, Kumar, Chandana, Gorai-Madhumati and Nabaganga. The MB Route is another major channel bordering the area.

TABLE 3.31
Long Term Monthly Average Flow (cumecs)

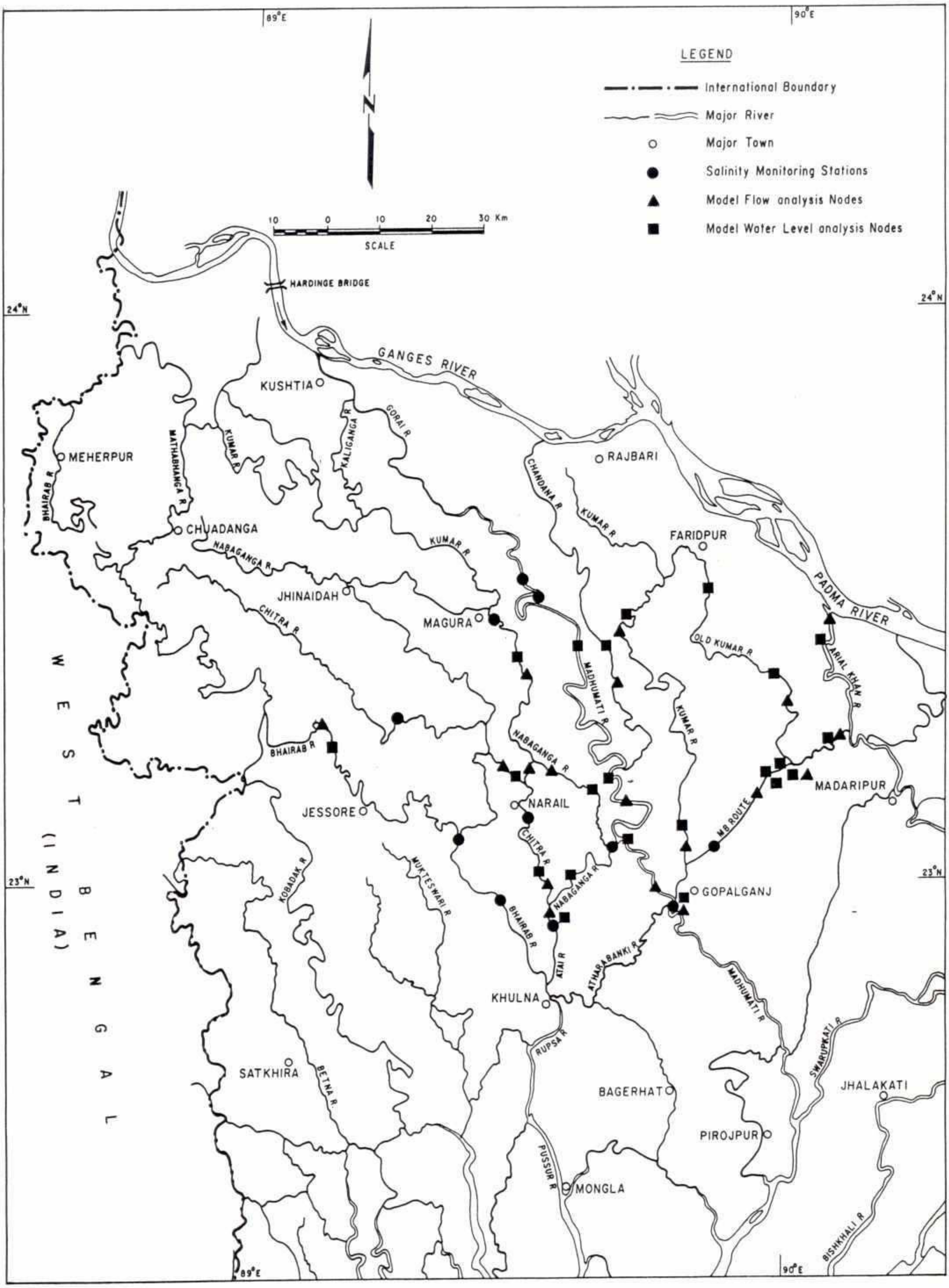
No.	River	Chainage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
23	Nabaganga_L	27.5	187	132	92	103	179	593	2522	4625	4573	2452	835	362	1388
30	Madhumati	153.3	183	125	86	93	155	546	2647	5011	4828	2373	797	353	1433
31	Madhumati	199.4	9	6	5	2	-2	-2	123	319	267	39	11	10	
32	Madhumati	207.3	31	23	23	34	75	175	425	748	775	438	141	58	246
40	Bhairab U	33.2	0	0	0	0	0	1	3	6	7	6	2	0	2
42	Gobrakhal	4.5	0	0	0	0	1	4	-4	-37	-31	7	4	0	
43	Chitra	125.8	2	1	1	2	10	38	85	141	179	133	37	8	53
44	Chitra	155.8	2	1	1	2	10	43	84	112	158	149	43	9	51
46	Nabaganga_U	128.3	2	1	1	2	9	33	62	89	125	106	30	6	39
47	Nabaganga_U	157.0	0	0	0	0	0	-1	-15	-39	-37	-12	-2	-1	-9
48	Kumar	48.6	0	0	0	0	1	5	19	41	40	20	5	1	11
49	Kumar	103.9	1	1	0	2	9	30	69	113	126	93	31	7	40
50	Sitalakhya	18.6	1	1	1	1	4	13	52	105	88	24	6	3	25
51	Sitalakhya	63.6	1	0	0	1	4	14	37	72	93	77	21	4	27
53	MBR	7.5	21	16	17	30	66	143	264	329	329	217	85	38	130
54	Barasia_Arbt	31.9	1	0	-1	0	5	21	247	721	702	238	32	8	
56	Arialkhan	1.8	115	98	102	150	288	655	1496	2124	1868	838	290	166	683
73	Kumar-1	10.3	20	15	17	29	61	126	223	260	232	130	58	33	100
74	Kumar-2	15.5	0	0	0	0	-2	-11	-33	-52	-45	-15	-2	-1	-13

TABLE 3.32
80% Dependable Monthly Flow (cumecs)

No.	River	Chainage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
23	Nabaganga_L	27.5	72	39	21	21	88	363	1925	3752	3868	1941	506	201	1066
30	Madhumati	153.3	62	33	11	6	53	317	2033	3973	3987	1766	478	188	1076
31	Madhumati	199.4	3	3	1	5	3	6	64	222	177	70	22	2	48
32	Madhumati	207.3	25	19	19	27	56	131	367	609	611	325	103	44	195
40	Bhairab U	33.2	0	0	0	0	0	0	1	2	5	3	0	0	1
42	Gobrakhal	4.5	0	0	0	0	0	6	3	-15	-9	20	6	-1	
43	Chitra	125.8	1	0	0	1	3	11	32	93	136	87	19	4	32
44	Chitra	155.8	1	0	0	0	2	12	27	44	100	106	20	4	26
46	Nabaganga_U	128.3	1	1	1	1	2	8	19	47	81	71	15	3	21
47	Nabaganga_U	157.0	0	0	0	0	0	0	-11	-28	-28	-5	-1	0	-6
48	Kumar	48.6	0	0	0	0	0	2	14	27	27	14	2	0	7
49	Kumar	103.9	1	0	0	0	3	12	52	77	99	73	17	3	28
50	Sitalakhya	18.6	1	1	1	1	2	7	33	66	58	13	4	2	16
51	Sitalakhya	63.6	0	0	0	0	1	4	26	49	65	56	7	1	17
53	MBR	7.5	18	14	16	26	52	113	232	276	278	167	62	33	107
54	Barasia_Arbt	31.9	0	2	1	1	9	29	153	503	523	128	14	4	114
56	Arialkhan	1.8	108	90	93	133	227	491	1178	1508	1420	578	246	150	519
73	Kumar-1	10.3	17	14	16	26	50	96	200	215	196	97	49	30	84
74	Kumar-2	15.5	0	0	0	0	-2	-6	-25	-35	-34	-8	-2	0	-9

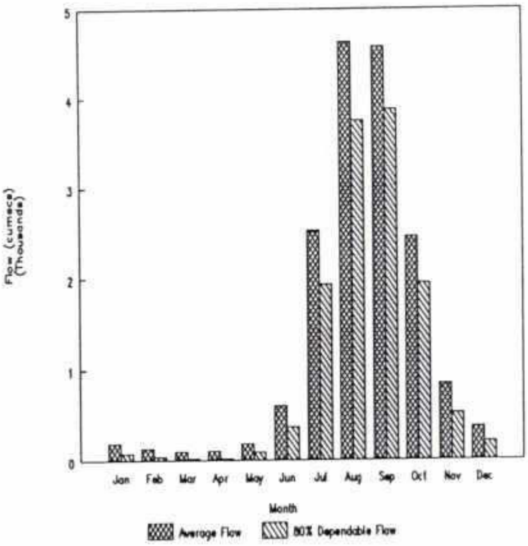
[vp\gorai\tab3-31]

Figure 3.13

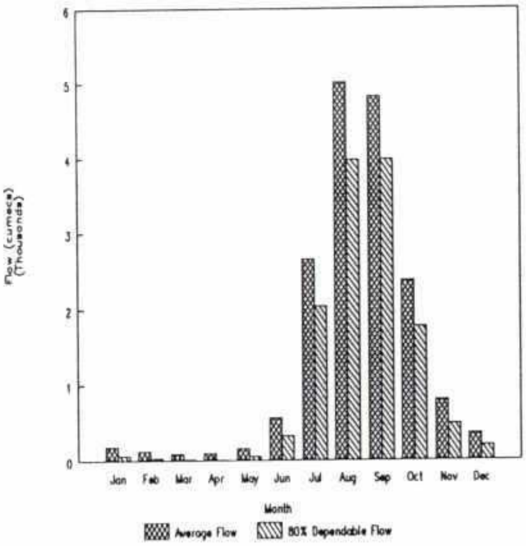


Location of Model Nodes and Salinity Monitoring Stations

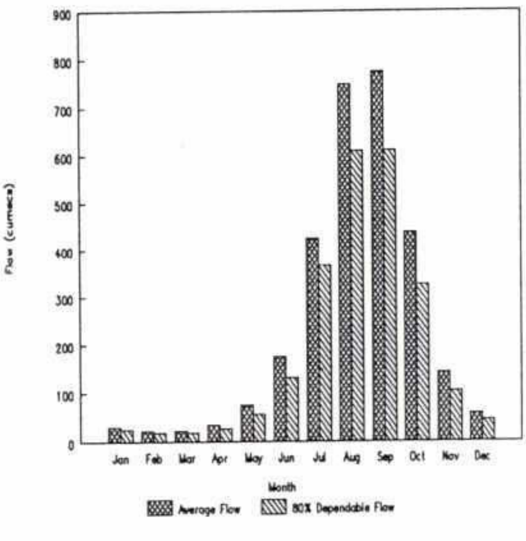
Figure 3.14a



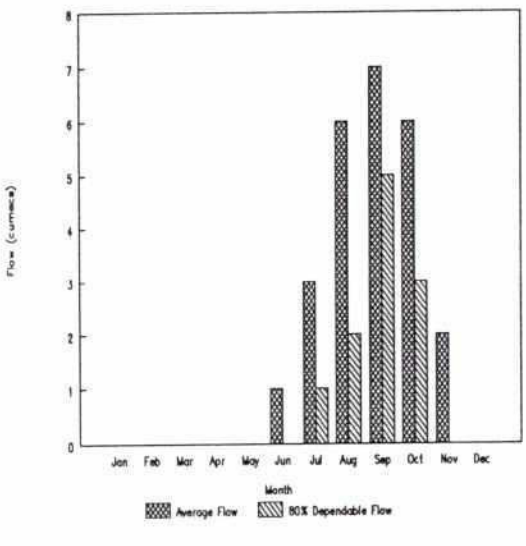
Node No. 23 Nabaganga_L (Ch. 27.5 km)



Node No. 30 Madhumati (Ch. 153.3 km)



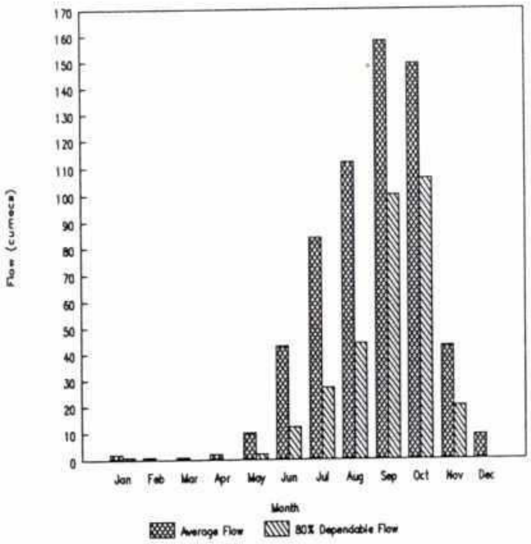
Node No. 32 Madhumati (Ch. 207.3 km)



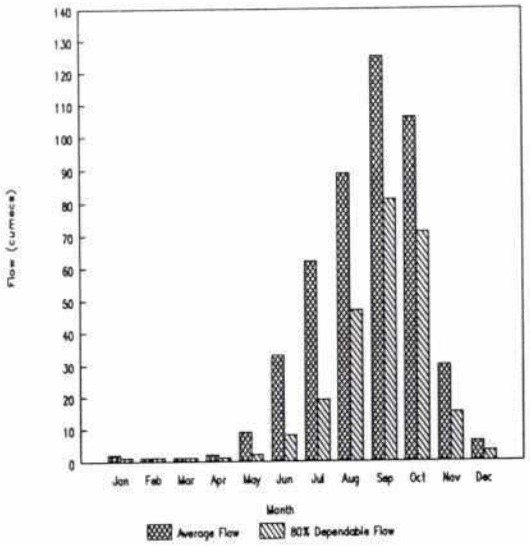
Node No. 40 Bhairab U (Ch. 33.2 km)

Note: (–)ve flows indicate that the direction of flow in the channel is opposite to that in the main drainage channels in the region.

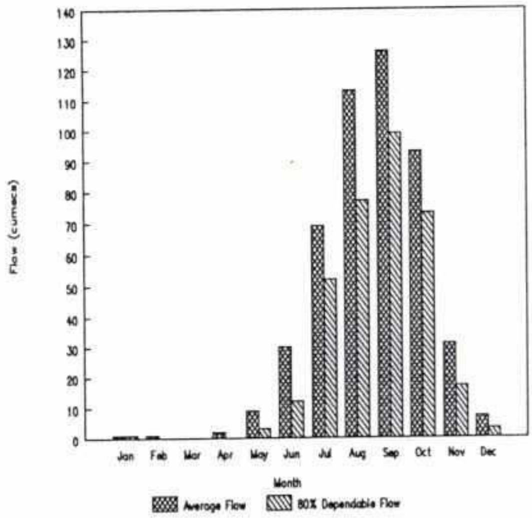
Monthly Flows



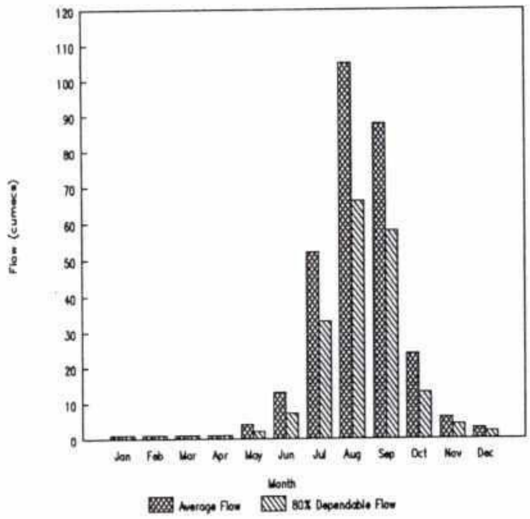
Node NO. 44 Chitra (Ch. 155.8 km)



Node No. 46 Nabaganga_U (Ch. 128.3 km)



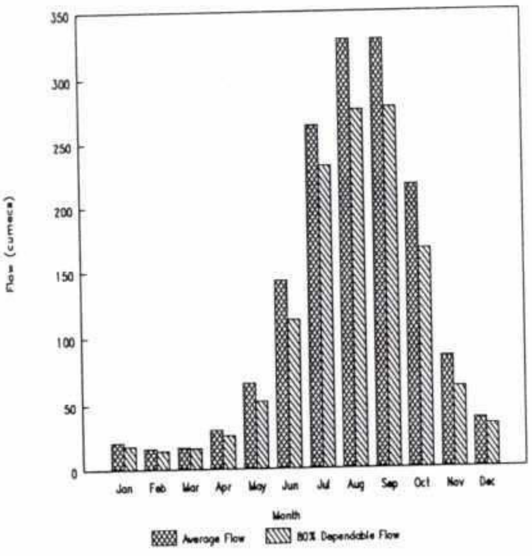
Node No. 49 Kumar (Ch. 103.9 km)



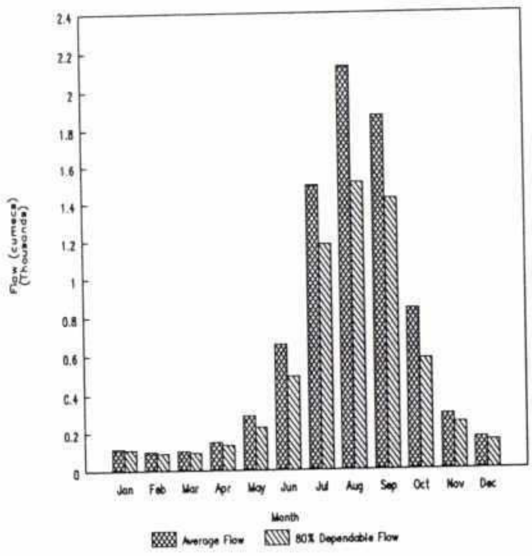
Node No. 50 Sitalakhya (Ch. 18.6 km)

Note: (–)ve flows indicate that the direction of flow in the channel is opposite to that in the main drainage channels in the region.

Monthly Flows



Node No. 53 MBR (Ch. 7.5 km)

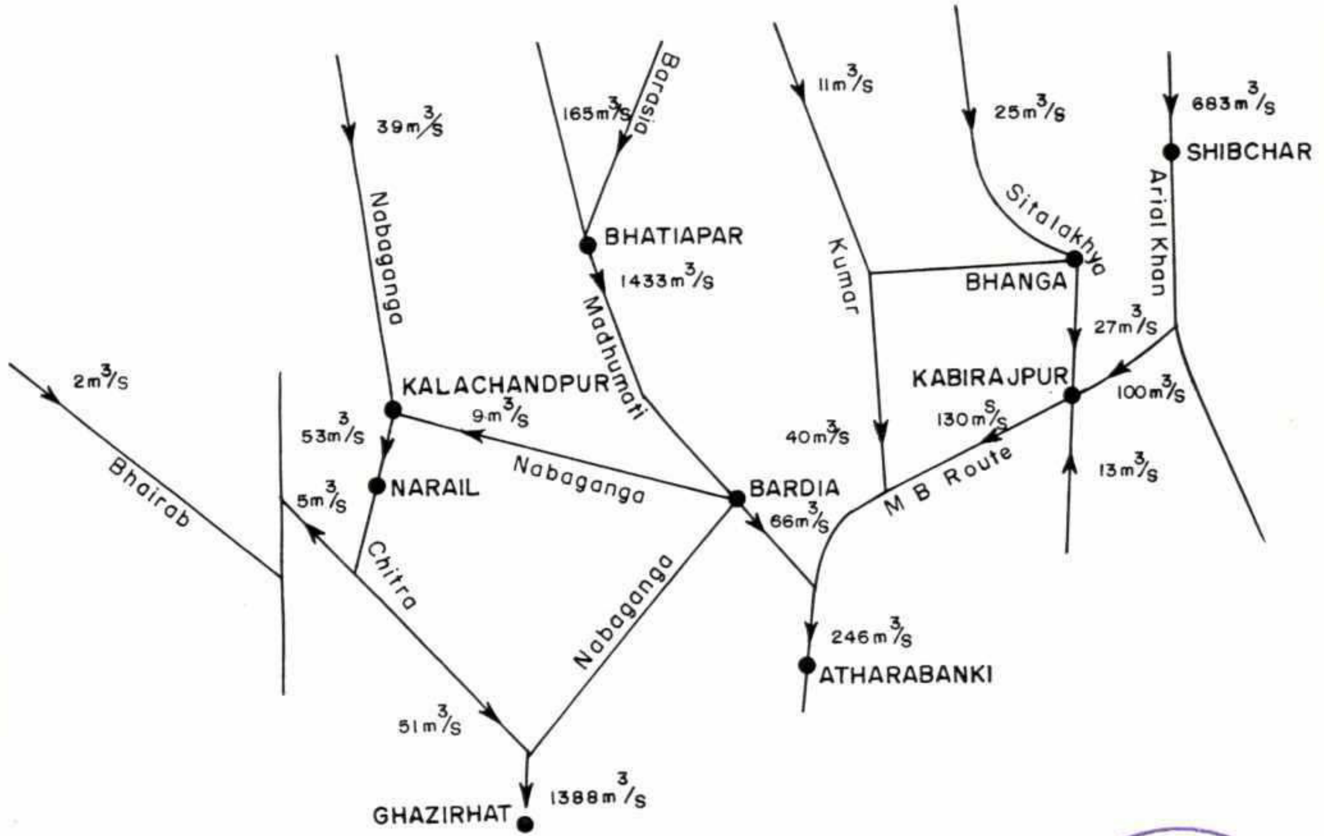


Node No. 56 Arialkhan (Ch. 1.8 km)

Note: (–)ve flows indicate that the direction of flow in the channel is opposite to that in the main drainage channels in the region.

Monthly Flows

Figure 3.15



Note: Flows shown are long term average annual flows computed at Hydrodynamic model modes

Schematic Map of Major Rivers in the Project Area

The long term mean annual flow in the Arial Khan at the offtake is 683 m^3/s. Flows into the region in the Madhumati at Bhatiapara are of the order of 1433 m^3/s and in the Chandana-Barasia route the flow is 165 m^3/s. The mean annual flow in the Kumar before the junction with MB route is 40 m^3/s. The flow in the Chitra at Kalachandpur is 53 m^3/s and by the time it rejoins the Nabaganga at the downstream end of the project area, the flow in the Nabaganga is 1388 m^3/s. The flow in the Madhumati at the downstream end of the project area reduces to 246 m^3/s.

The 80% dependable annual flow in the Arial Khan is 519 m^3/s and in the Madhumati at Bhatiapara it is 1076 m^3/s. The 80% dependable annual flow in the Chandana-Barasia route is 114 m^3/s. At the downstream end of the project area, the flow in the Nabaganga is 1066 m^3/s and in the Madhumati it is 195 m^3/s.

3.3.5 Peak Water Levels

Peak water levels at 22 model water level analysis nodes in the study area were available from the 25 year 1-D hydrodynamic model simulation run for the current scenario. The locations of these nodes is shown in Figure 3.13. Frequency analysis of peak water levels was done by fitting a 3 Parameter Log-Normal distribution to the simulated data as recommended by FAP-25. The results are shown in Table 3.33.

The 1 in 100 year peak water levels in the region range from 8.08 m on the Madhumati to 3.77 m on the Bhairab U at the downstream end of the project area. On the Madhumati the level is 8.08 m at the upstream end of the project area and at Bhatiapara the level is 6.41 m. On the Chitra at Kalachandpur, this level is 4.32 m and on the Nabaganga at the downstream end of the project area the level is 4.25 m.

3.3.6 Salinity

Salinity is being monitored at 11 stations in the rivers in the study area and their locations are shown in Figure 3.13. Long term surface salinity data was available from the Ganges study from 1976 to 1990. Data is sampled at high and low water slacks on a fortnightly basis. Monthly maximum salinity data has been compiled and is shown in Table 3.34. The effects of salinity intrusion are felt in a large part of the study area and to a lesser degree in the north-eastern corner. Whilst the quality of water in the rivers rarely exceeds the threshold for low-medium salinity for irrigation water, the stations perform an important task of monitoring the movement of the saline front. This is important when the effects of increased flow of fresh water into the region, particularly down the Gorai-Madhumati and Arial Khan river systems is being considered as a means of controlling the movement of the saline front.

It may be noted that salinity values recorded during 1988-89 and 1990-91 at all stations were much higher than the data recorded in earlier years. There is evidence of an increasing trend in the salinity in the region.

TABLE 3.33
Simulated Annual Peak Water Levels for Different Return Periods (m. PWD)

Model Node No.	River	Chainage (km)	Return Period (Year)						
			2	5	10	20	25	50	100
16	Nabaganga_L	29.000	3.63	3.80	3.91	4.01	4.05	4.15	4.25
17	Nabaganga_M	17.250	3.75	3.95	4.08	4.20	4.24	4.35	4.47
22	Madhumati	108.000	7.27	7.53	7.69	7.82	7.86	7.97	8.08
23	Madhumati	149.500	5.38	5.74	5.94	6.10	6.15	6.28	6.41
24	Madhumati	181.500	4.16	4.42	4.57	4.71	4.75	4.88	5.00
26	Madhumati	207.000	3.37	3.61	3.74	3.86	3.89	4.00	4.09
35	Bhairab U	39.853	3.26	3.42	3.52	3.60	3.62	3.70	3.77
38	Chitra	131.500	3.70	3.89	4.00	4.10	4.13	4.23	4.32
39	Chitra	151.505	3.64	3.83	3.94	4.05	4.08	4.18	4.28
41	Nabaganga_U	123.000	4.09	4.43	4.65	4.86	4.93	5.14	5.34
42	Nabaganga_U	164.000	3.97	4.22	4.37	4.50	4.54	4.65	4.77
44	Kumar	42.900	5.16	5.72	6.08	6.40	6.50	6.81	7.11
45	Kumar	99.300	3.71	3.99	4.15	4.29	4.33	4.45	4.56
47	Sitalakhya	24.800	5.29	6.01	6.46	6.88	7.02	7.42	7.81
48	Sitalakhya	46.000	4.63	5.03	5.28	5.50	5.57	5.78	5.99
49	MBR	0.000	4.07	4.35	4.52	4.69	4.74	4.89	5.05
50	Barasia_Arbt	25.500	5.44	5.81	6.01	6.17	6.22	6.36	6.49
53	Arialkhan	9.000	6.47	6.85	7.07	7.27	7.33	7.52	7.69
69	Kumar-1	12.300	5.05	5.37	5.56	5.73	5.78	5.93	6.08
70	Kumar-1	20.500	4.07	4.35	4.52	4.69	4.74	4.89	5.05
71	Kumar-2	0.000	4.07	4.35	4.52	4.69	4.74	4.89	5.05
72	Kumar-2	10.333	3.96	4.23	4.40	4.56	4.61	4.76	4.90

[vp\gorai\tab3-33]

TABLE 3.34
Mean Monthly Maximum Salinity (Micro-Mhos at 25 Degree Celsius)

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Abhoynagar	602	673	1357	4720	2522	425					389	464
Afrahat	558	607	999	2274	2991	369					369	460
Amaisor	470	482	528	505	438	327					346	377
Arpara	518	552	586	541	480	399					365	470
Atharobanki	486	583	921	1376	1267	438					321	449
Bardia	423	480	763	1640	2316	494					335	380
Bhatiapara	403	408	440	441	432	338					321	387
Gazirhat	495	577	1809	3993	3239	674					320	371
Gobraghat	598	616	617	637	634	374					419	532
Haridaspur	480	426	437	378	288	240					367	391
Kamarkhali	423	456	491	481	418	314					344	392
Magura	420	400	520	420	440	250					280	440

[vp\gorai\tab3-34]

4 RIVER HYDRAULICS AND MORPHOLOGY

4.1 Morphological Perspective

A slow decline of distributary rivers of the Ganges is part of the process of development of the delta and has been seen for other rivers such as the Bhagirathi (in India), the Matabhanga and the Bhairab and Kobadak. The decline of the Gorai however has been greatly hastened by upstream abstractions and control of the Ganges at Farakka to rejuvenate the Bhagirathi Hooghly system. The Ganges appears to follow a cyclical trend of movement with a periodicity of 40 to 50 years favouring and then moving away from the Gorai causing a cycle of improvement and deterioration. The Gorai is currently suffering from an adverse alignment of the Ganges and displaying the longest decline recorded. The river also exhibits many of the features observed when rivers are in terminal decline giving rise to concern about the eventual decline of monsoon flows. The impact of such a decline would have catastrophic impacts on the Khulna area and the viability of Mongla port and would severely affect the poldered areas around Khulna.

The planform and bedform changes in the Ganges, including its meander geometry, are discussed in detail in the Morphology Report (Volume 3 of the Main Report of the Southwest Area Water Resources Management Project).

4.2 Channel Characteristics

4.2.1 Dominant Discharge

There are two gauging sites on the Gorai, the Gorai railway bridge (11 km from mouth) and Kamarkhali (about 88 km from mouth). The railway bridge site has the longer period and records the flow entering the river whereas there may be some overbank flow during high floods over the left bank before Kamarkhali. The railway bridge record, therefore, normally shows higher flood peaks as in Figure 4.1.

The dominant flow in a river may be defined as the flow doing the greatest amount of work in terms of sediment transport (as described by Wolman and Miller 1957). The gross features of the channel such as bar tops, width, meander wavelength etc are adjusted to the dominant flow. This means that if the flows or sediment regime in a channel are altered then changes to the channel size can be expected until it is again adjusted to the new regime. The calculation of dominant discharge for Gorai railway bridge (Figure 4.2) shows a dominant peak at 4250 m^3/s.

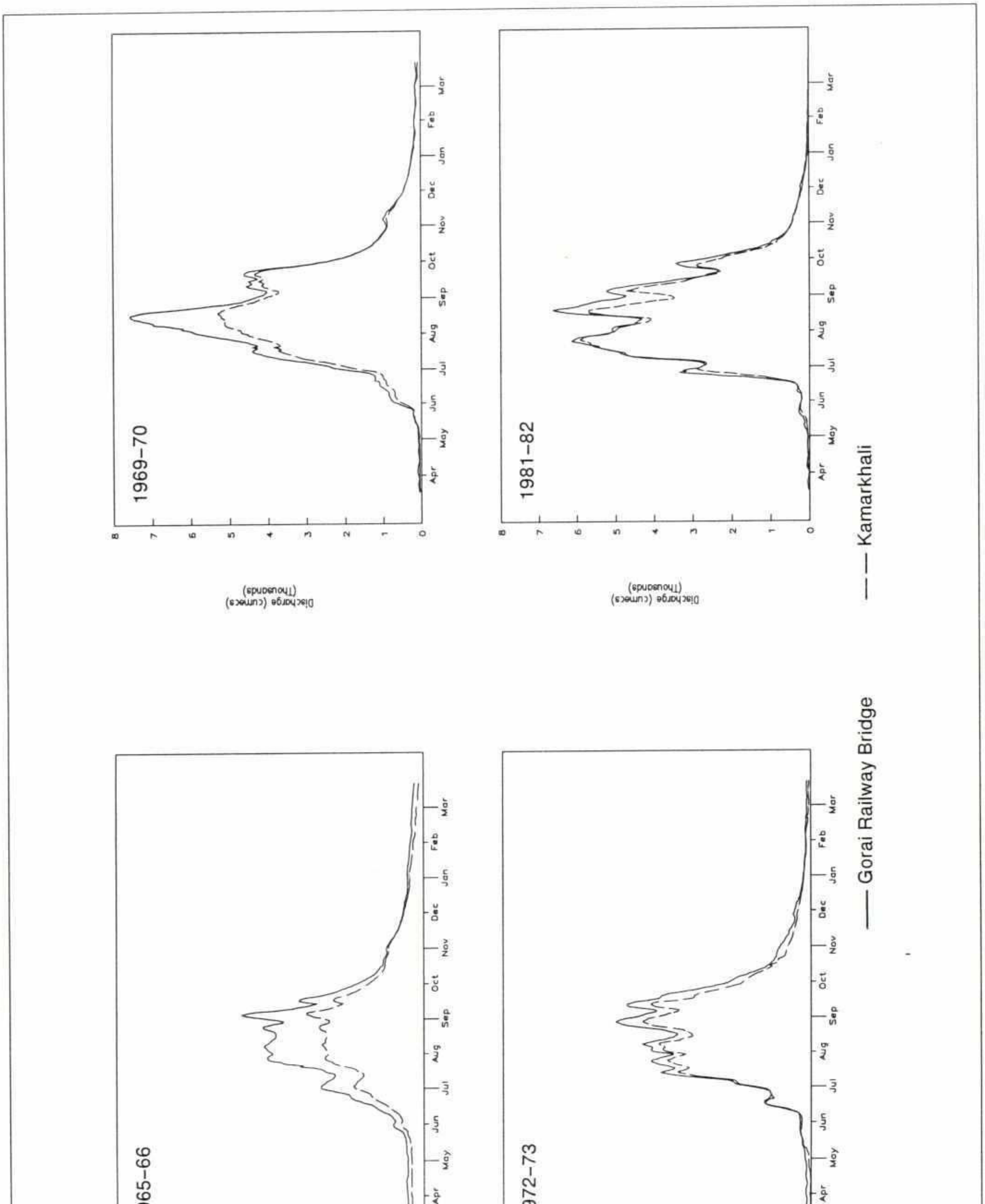
A similar calculation for the Ganges gives a dominant flow of 37500 m^3/s.

4.2.2 Post Farakka Changes in Dominant Flow

The post-Farakka dominant discharge curve for the Gorai railway bridge (Figure 4.3) shows large reductions in the sediment moved by low flows (less than 2,000 cumecs) and high flows (greater than 6,500 cumecs). The lack of low flow transport could be responsible for raised bed levels, especially at crossings between meander bends, since low flows scour bars and fill pools. Disconnection of the Gorai early on the falling limb and delayed re-connection in the spring, both due to the failure of flows entering the mouth to dissect the bar and maintain a low flow channel, could also be partially responsible.

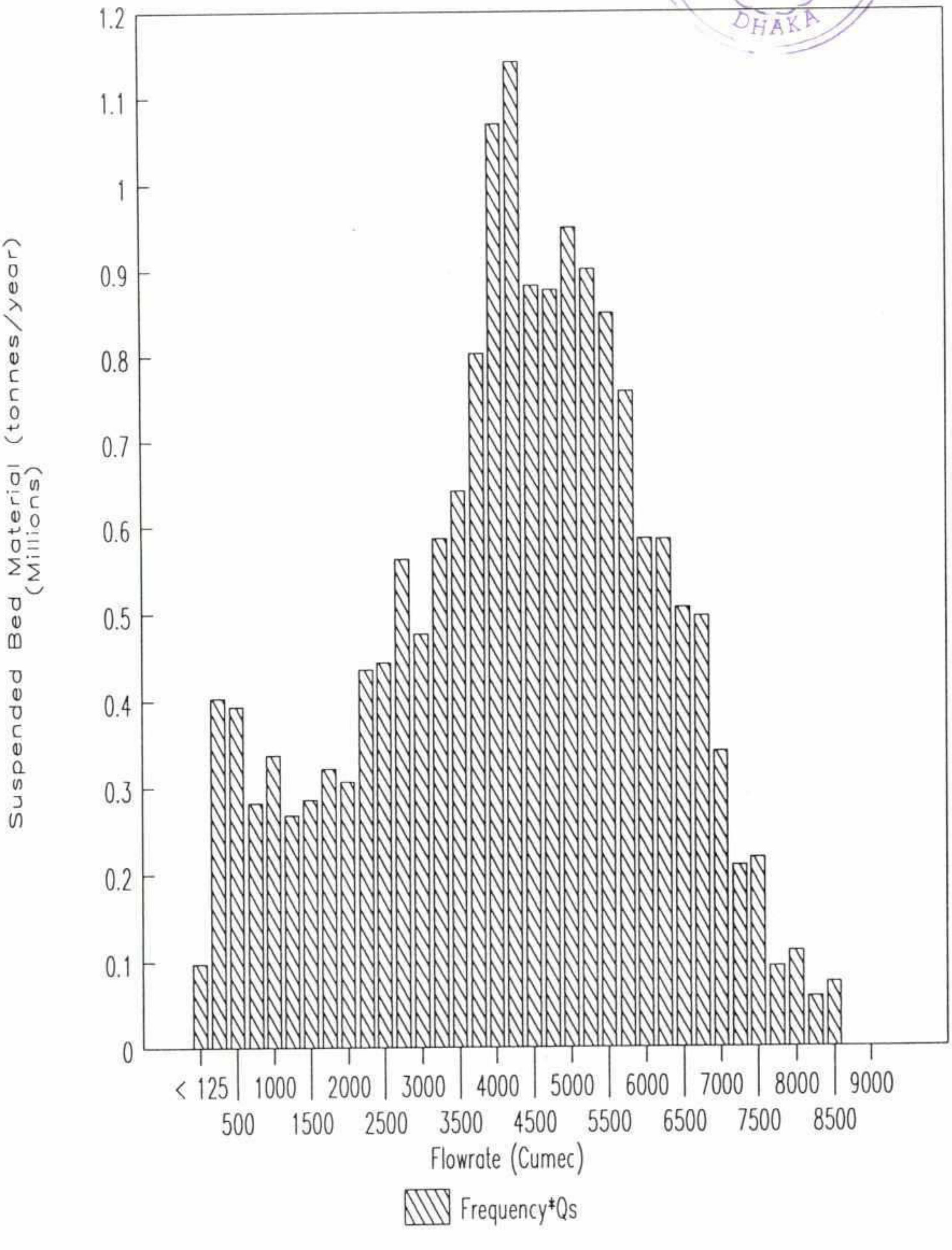
It can be concluded that the change in the dominant discharge curve for flows in the 200 to 2,000 cumecs range is entirely consistent with the arguments put forward to explain the present hydrologic and sedimentary conditions.

Figure 4.1



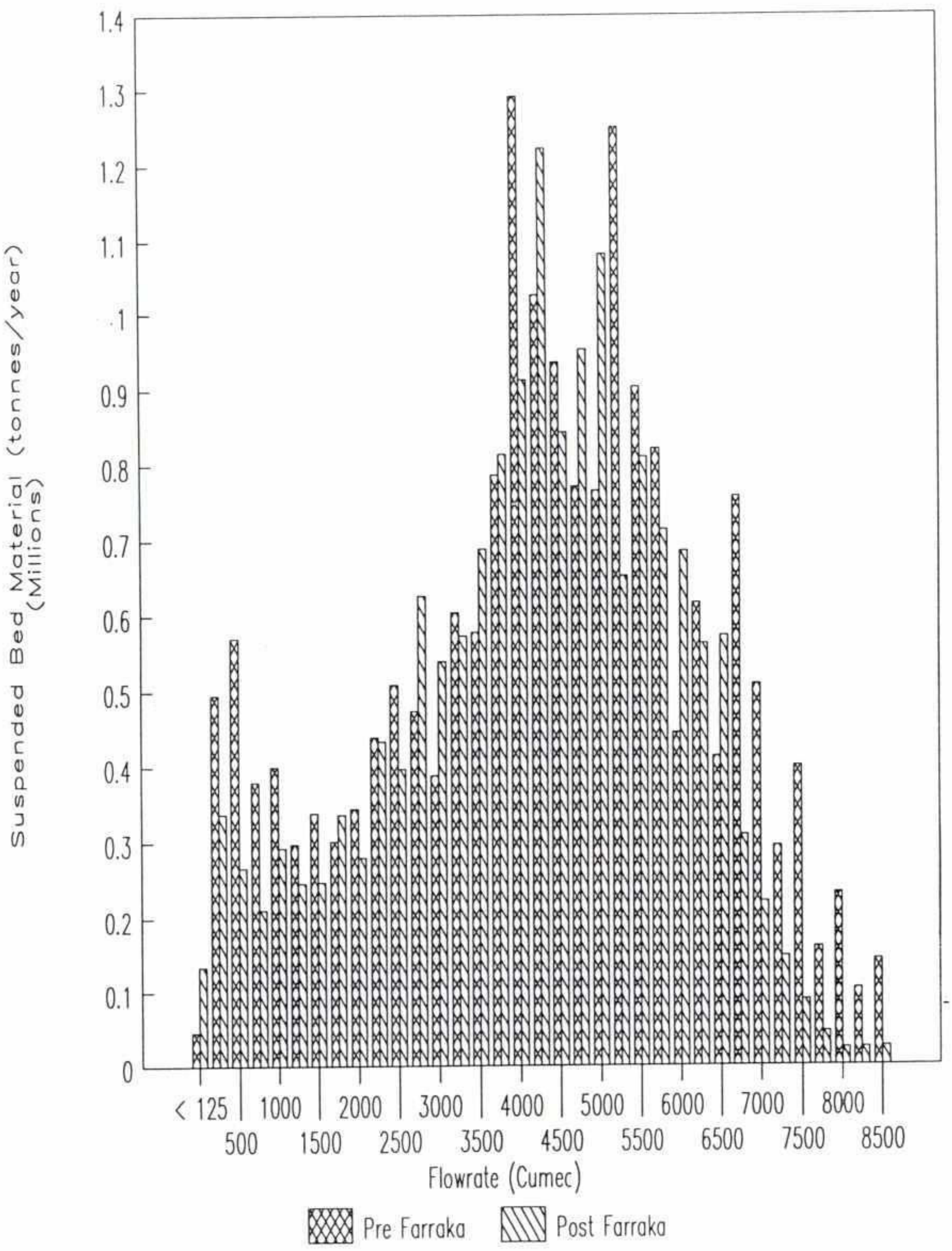
Comparison of Flows on River Gorai

Figure 4.2



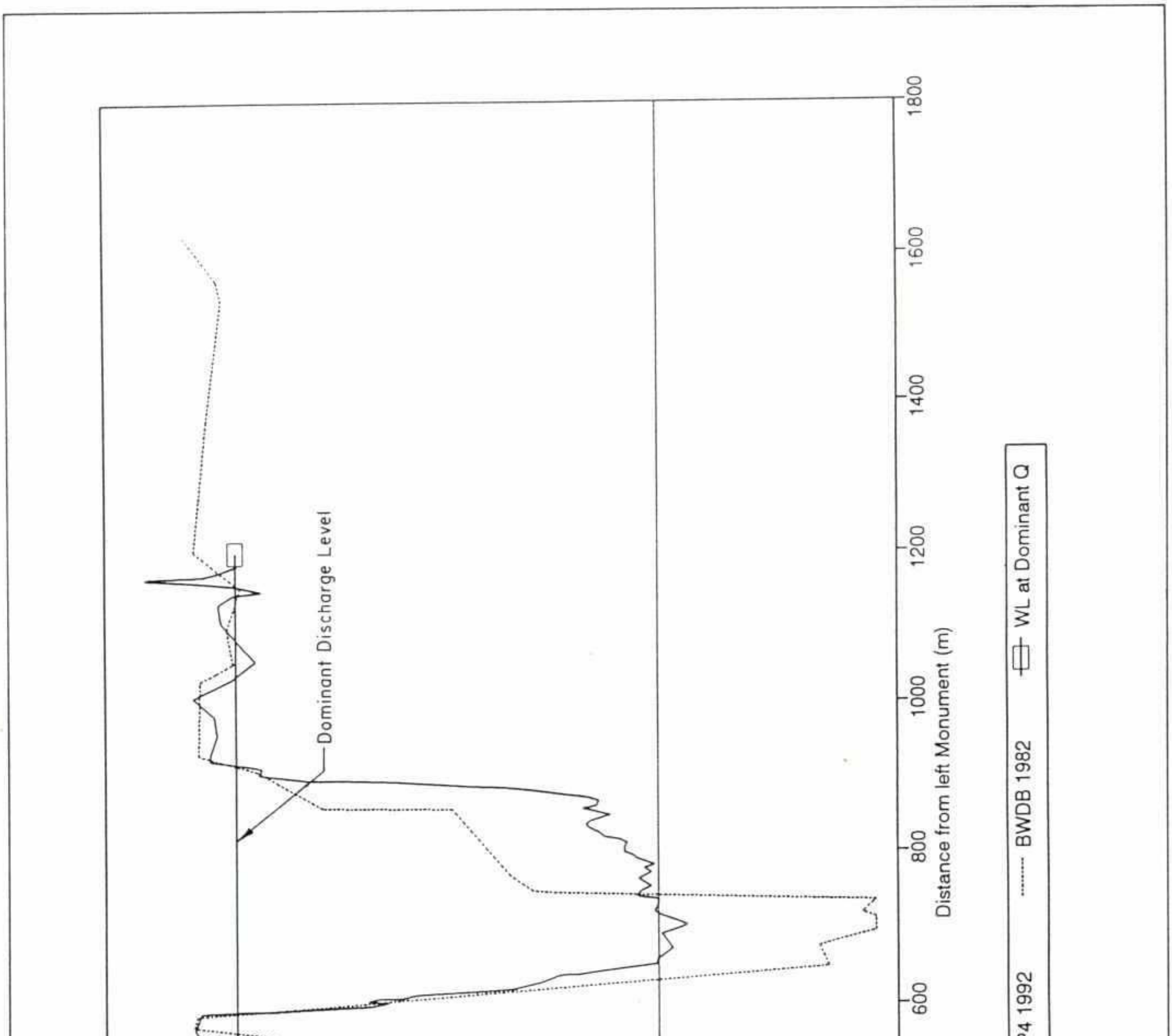
Dominant Discharge in Gorai River at Gorai Railway Bridge 1965–1989

Figure 4.3



Dominant Discharge in Gorai River at Gorai Railway Bridge , Post Farakka

Figure 4.4



Gorai Cross Section at Ch. 28 Km
Dominant Discharge Level

There is some decrease in effectiveness of high flows cannot be a product of the river regulation at Farakka, because large flows in the Ganges are transmitted downstream with little modification. Some other explanation must be found for the change, which would be expected to have some significant morphological impacts. It may be a function of the flood events since 1975. Events in the Ganges lead to an increase in the effectiveness of high flows (greater than 50,000 cumecs) post-Farakka. Presumably, less of this water (and sediment) is now entering the Gorai and so the importance of high flows in the Gorai is diminishing relative to intermediate flows.

4.2.3 Cross Section Analysis

The Gorai cross-sections have been obtained from the BWDB. The water surface profile corresponding to dominant discharge (4,250 cumecs) has been generated using the 1-D model and the water levels marked onto the cross-sections as shown in Figure 4.4.

In its upper course the dominant flow is close to, but a little less than, bankfull stage which is consistent with the hydraulic geometry of a regime type river. This finding is also consistent with the long profile in this reach, which is concave upwards, and the planform of the river which shows a meandering course that has not altered greatly in the last 140 years.

The relationship of dominant flow to bankfull stage changes downstream of Kamarkhali. In the bend reaches the channel is incised, but the reaches downstream are under-sized, so that dominant flow involves overbank spillage. This is in agreement with the findings of the morphologic modellers that there may be a great loss of conveyence in this reach.

4.2.4 Width-Depth Relationship

The ratio of width/hydraulic radius depends on the bed and bank material. This was calculated for the 1979 and 1989 sections. This indicated significant variatiion along the river possibly controlled by the erosivity of the bank. This was compared with predictions based on a study by Schumm (1971), which correlated the % bank silt/clay relationship with width at the dominant flow it shows and reasonable agreement. This analysis was used in developing the morphological model of the Gorai and also in the derivation of a suitable low flow channel and crossing arrangement for the mouth.

4.2.5 Bed Sediment

Samples of bed sediments were collected at the Gorai mouth, Kushtia, Gorai rail bridge, Kanarkhali, Bhatiapara and Bardia to determine any size grading along 200Km of the Gorai and Madhumati. The sediment was found to be a fine sand with an average d_{60} = 0.15mm. This did not vary significantly along the reach but more significant variations are observed depending on the local bed features.

4.2.6 Long Profile Analysis

Long profiles have been drawn from cross sections for all the available data from 1963 BIWTA survey to BWDB surveys 1966-1989 and surveys by FAP 4 in May and June 1992.

The long profile of Gorai using the most up to date sections for each reach is shown in Figure 2.3. This illustrates that for dominant flows the high banks in the upper reaches are above dominant flow levels but in the lower tidal reaches, the channel capacity is lower suggesting that significant spill would normally result. Four distinct reaches may be discerned : the mouth reach to about 20 km which is relatively flat and at a high level, the reach to Kamarkhali which is at a lower level, the bend and following straight reach from km 87 to km 139, and finally the increasingly meandering tidal reach to Bardia.

A long-profile was also made by echo-sounder in August 1992 during monsoon flow and this is shown in Figure 4.5. The profile shows several salient features. Although this is a 'snapshot' in time representing conditions over one short period, the profile gives an excellent idea of recent conditions. It must be borne in mind that this profile does not follow the thalweg, which would be impossible in a moving boat, but represents a profile along the navigation route. Hence, some points may not be actual lowest points in the cross-section. This must be borne in mind when interpreting and analysing this data.

In geomorphology a long profile is classified as graded when the slope at each point along the river is adjusted so that the section is just able to transmit the sediment load supplied to it from upstream, plus any sediment supplied by local erosion. In a dynamically stable river, with discharge increasing in the downstream direction due to increasing catchment area and bed material size decreasing downstream due to sediment sorting, the long profile is described by a semi-log curve which is concave upwards. In a stable river with a constant discharge the slope should be uniform.

Overall the profile of the Gorai is in fact concave upwards between the mouth and Kamarkhali, which is indicative of a 'graded' alluvial river with active sediment transport and no geological controls. However, since the river is a distributary, it is questionable whether discharge does increase significantly in the downstream direction. Also, sediment size is almost constant with downstream distance (in the fluvially dominated reach). Hence, the profile may be indicative of overall dynamic disequilibrium because the slope in the lower part of the river is too mild to transmit the bed material load from upstream. This could be associated with the development of overly tortuous meandering in the lower course of the river. In fact, downstream of Kamarkhali there is practically no drop in the profile, and if anything, an adverse bed slope. This is not commensurate with a dynamically stable channel and it is doubtful if such a reach could transport bed load effectively enough to be geomorphologically graded. It would be expected that such a reach would be dynamically stable.

There are also local problems relating to high points that break up the concave profile and these are discussed in detail in the Morphology Report (Volume 3).

4.2.7 Siltation in the Upper Reaches

Analysis of the long profiles for 1963 to 1992 show that greatest changes in the thalweg level have occured in the upper reach of the Gorai indicates they also that the thalweg has risen significantly over the past 30 years.

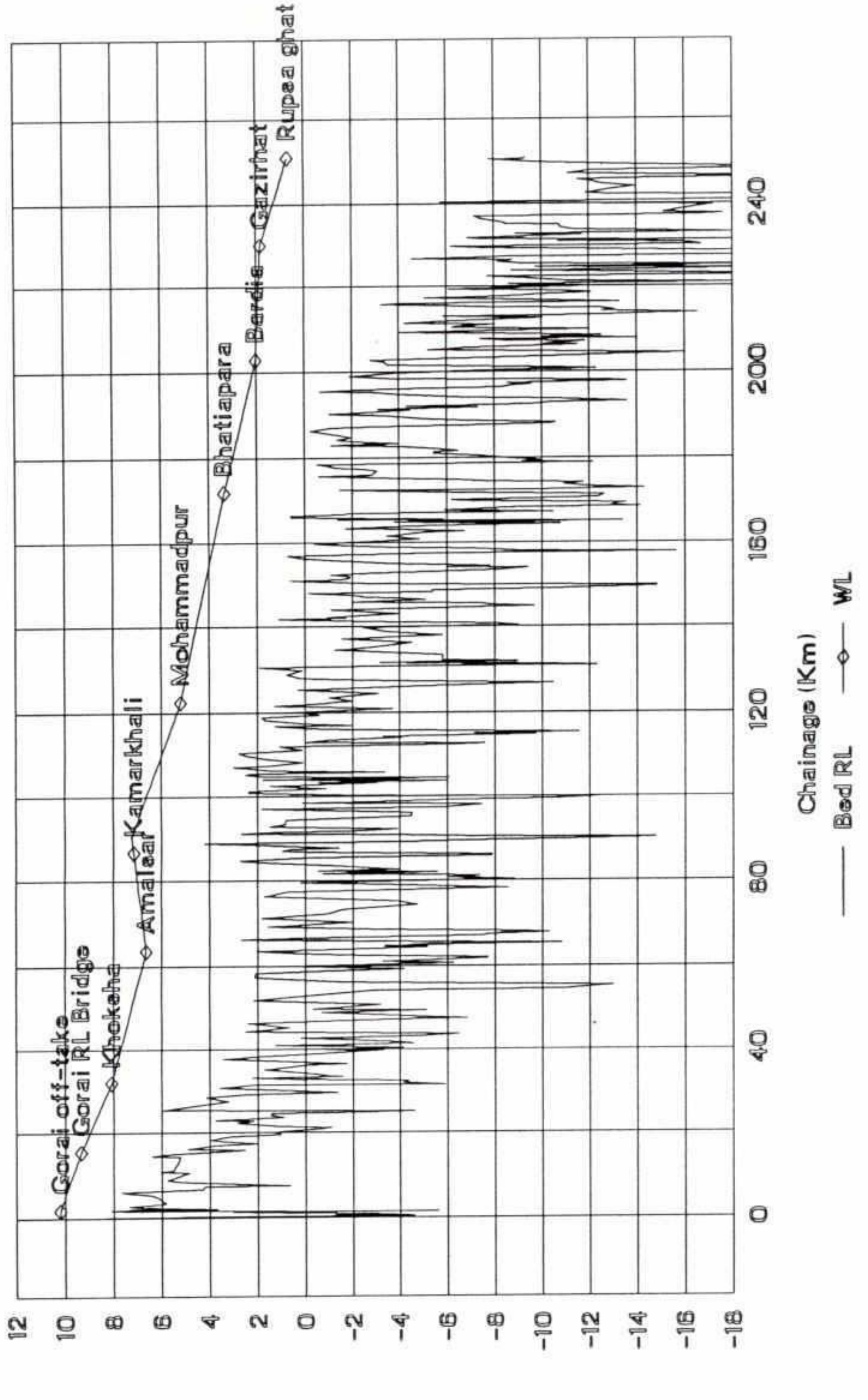
It is concluded that there have been major changes in the low flow channel near the mouth such that even if the level in the Ganges were to increase, there would be little flow into the Gorai unless there is some intervention.

4.3 Studies of the Gorai River Mouth

4.3.1 Bankline Changes in Ganges at Gorai Mouth

The Ganges has a wandering planform that exhibits elements of both meandering and braided patterns. The macro-form of the river in recent years changes downstream of the

Figure 4.5



Source: FAP-4 Survey 1992

Gorai Long Profile

Gorai off-take. Upstream of the off-take the planform consists of a braided channel that follows large, sweeping meanders with a wavelength of about 35 km. Downstream of the Gorai the planform shows a meandering thalweg channel within a braid belt that displays nodes at about a 16 km spacing.

The Gorai off-take is situated just downstream of the first node in the right bank of the braided pattern, at Talbaria point. This is significant, because it means that the mouth of the Gorai is actually in the right bank embayment of a sediment storage reach between two quite well defined nodes. The sequence of satellite images from 1973 to 1992 shows how the channel pattern in the Ganges changes in response to the passage of sediment bars through the node-embayment-node geomorphic unit around the off-take.
The bankline changes in the Ganges and their implications to flows through the Gorai mouth are discussed in detail in the Morphology (Volume 3).

4.3.2 Gorai Mouth-Crossings

The recent satellite images show extensive bars and the lack of a distinct thalweg to provide a low flow channel upstream of the railway bridge. While the problem may not be at the bridge, and is probably not caused by the bridge itself, there is serious channel problem in the vicinity. This may tentatively ascribed to a poor channel alignment leading to the lack of properly spaced, short and well defined crossings between scour pools on opposite sides of the channel. This may at least in part be due to the effects of the groynes at Kushtia. Groyne tip scour produces a deep water thalweg in the centre of the channel at the bend exit. Not only does this tend to promote deposition of scoured sediment just downstream where the flow leaves the groynes, but also truncates the curvature of the flow opposite Kushtia. As a result, the flow crosses the channel from the right (south) bank too early and too abruptly. The deep water channel then follows an uncertain and shifting path along the centre-left of the channel downstream of Kushtia. This appears to disturb the entrance conditions for the tight right hand bend just upsteam of the railway bridge.

The Gorai originally developed into a large river when the alignment of the Ganges came past Kushtia. This alignment gives a strong crossing point in the approach to the bend at the railway bridge. The retreat of the Ganges from the anabranch past Kushtia seems to have caused intermittant problems for the Gorai since but these may have been made worse by the three T-groynes built to protect Kushtia.

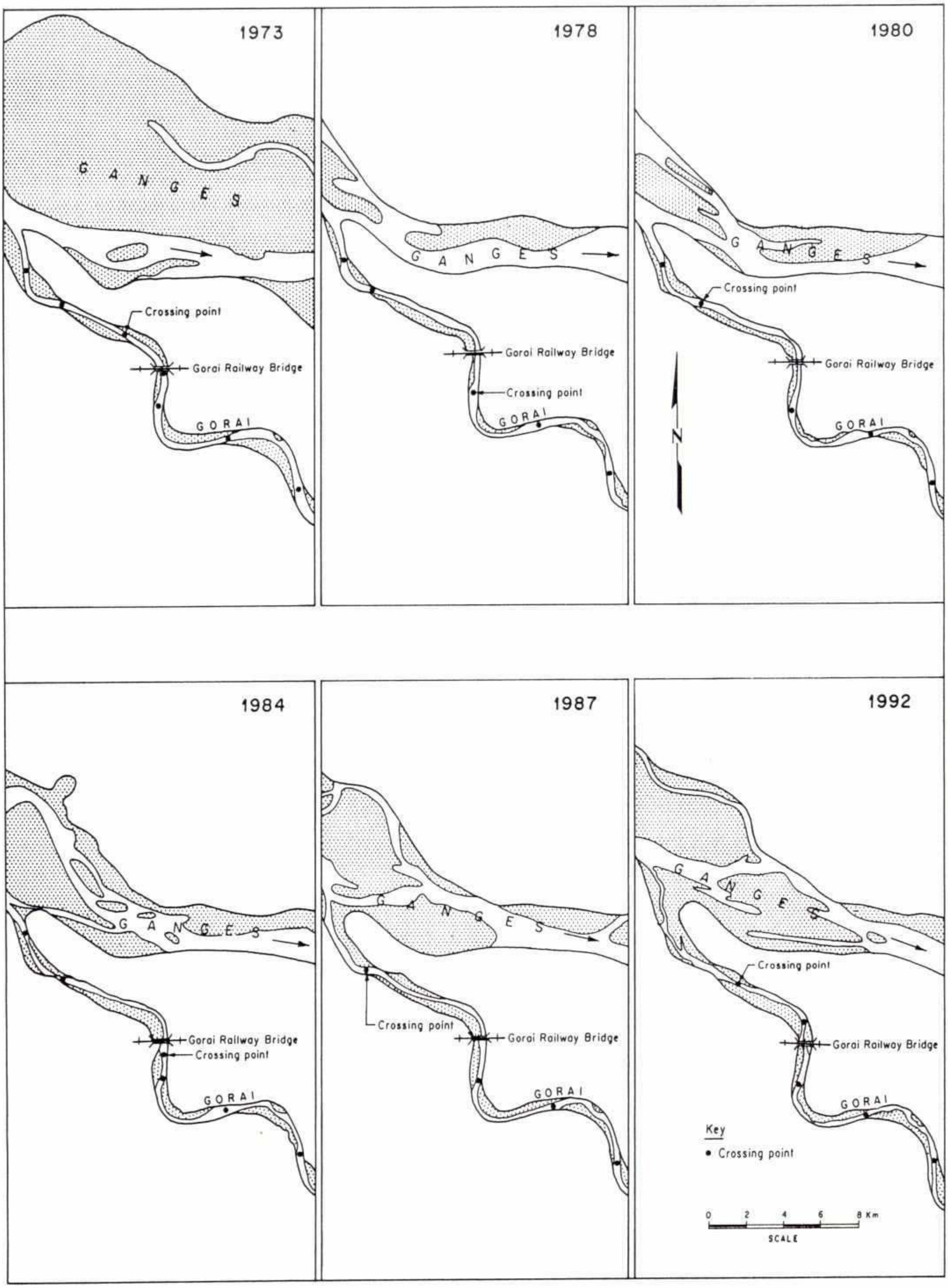
As shown in Figure 4.6 prior to the groynes the reach between the offtake and the railway bridge had reasonably well spaced crossings and the bend upstream of the bridge almost always had a well developed scour pool at the outer bank. The recent images (post-1987) show a wandering thalweg and the 1992 image shows the flow making a chute channel at the inner bank, with heavy sedimentation at the outer bank, and the introduction of short radius, tight bends, new crossings and extra sinuosity to the low flow channel. All of this will make the problems of siltation worse.

Bend Morphology and Crossing Spacing

Data were taken from the planform of the Gorai to define the average spacing of crossings between bends and to test whether the bed topography at a bend could be predicted from its planform geometry and flow hydraulics using the BENDFLOW computer model.

For the first 20 bends downstream of the offtake the crossing spacings are listed in Table 4.1.

Figure 4.6



Gorai River
Location of Crossing Points

TABLE 4.1

Bend Spacing

Bend No.	Spacing (km)	Comments
1	5	railway bridge bend-well developed
2	4	bid bend, very stable
3	4.6	Kumarkhali-long bend, stabilised
4	2.9	long bend-very stable
5	4.6	very long bend-flat apex
6	1.9	short bend, wide point bar
7	1.4	low sinuosity bend
8	4.0	very long bend
9	1.9	short bend, low sinuosity
10	1.6	low sinuosity, almost straight
11	2.1	low sinuosity, almost straight
12	1.8	low sinuosity, almost straight
13	1.7	low sinuosity, almost straight
14	4.4	long bend
15	2.6	sinuous bend
16	1.9	low sinuosity, short bend
17	1.5	short bend, local scour at crossing
18	1.9	low sinuosity bend
19	4.4	very long bend, some extra crossings
20	1.5	very tight bend
Spacing	Frequency	
0.0 - 0.5	0	
0.5 - 1.5	1	
1.5 - 2.5	10	
2.5 - 3.5	2	
3.5 - 4.5	4	
4.5 - 5.0	3	
5+	0	

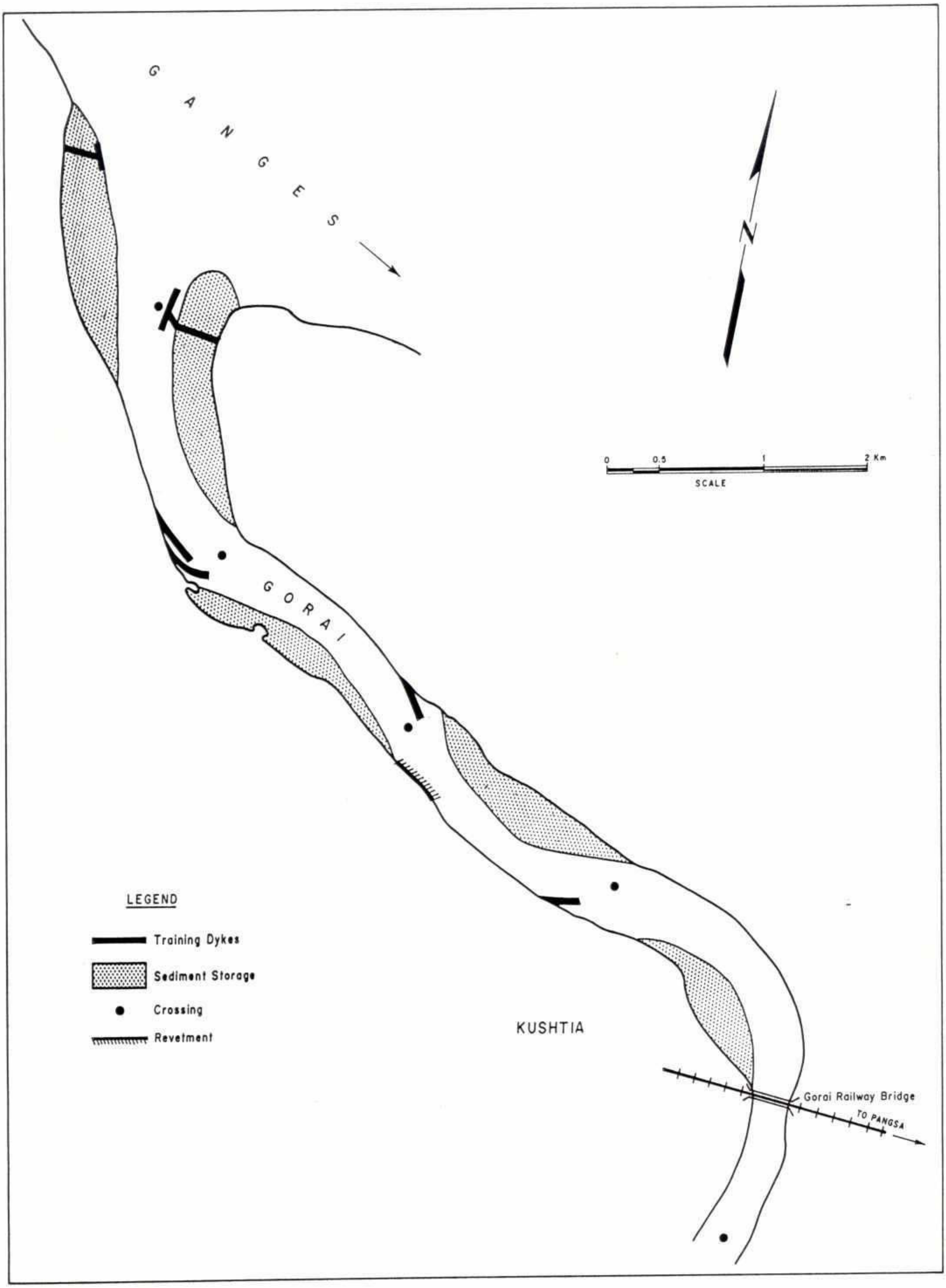
These results show a bi-modal distribution of crossing spacings with characteristic spacings at about 2 km and 4.5 km. Examination of the crossing spacings with the bend geometries shows that as a general rule long bends correspond to the 4.5 km crossing spacing, while the low sinuosity, straighter alignments have crossings spaced at about 2 km.

On this basis, it is suggested that morphologically, any schemes to train or stabilise the Gorai should be laid out with a sinuous alignment that maintains the characteristic crossing spacing for the chosen planform pattern. Where a low sinuosity channel is required the flow should cross the channel at 2 to 2.5 km intervals. Spurs or longitudinal kicker dykes should be used to ensure that the flow crosses at the desired points. If big bends are to be used then these should mimic the geometry of natural bends on the Gorai, with crossings at 4 to 5 km intervals.

These planform patterns allow the river to store sediments in an orderly arrangement of point and crossing bars. This helps the river to maintain a coherent low flow channel and to be self-cleansing with regard to sedimentation. This will minimise (but not eliminate) maintenance dredging, since dredging should only be necessary at crossings and spoil can be disposed of on and behind point bars.

The analysis shows serious problems with the planform and bed topography in the reach around and upstream of the Railway Bridge. Poorly positioned pools, bars and crossings in relation to the planform bends are apparent, and may well be partly responsible for medium and longterm aggradational trends in bed elevations. The present groyne structures in the channel, while effective in protecting the town of Kushtia from bank erosion, may be contributing to the problem. Serious consideration must be given to properly laid out

Figure 4.7



Proposed Layout for Groynes & Crossings

training works for this reach that would produce a better flow alignment with a bed topography (pools, bars and crossings) that is matched to the planform of the river.

A suggested layout for groynes and crossings is given in Figure 4.7.

4.3.3 Findings

The mouth of the Gorai in the last 20 years has changed radically. In the 1970s although the Ganges anabranch channels were not always in favourable positions for dry season spillage to the Gorai, there was always sufficient distributary flow to maintain a steep enough water surface slope to scour a cross-bar channel that linked the Gorai to a low flow Ganges channel.

The 1980s saw a braid bar move downstream into embayment containing the Gorai off-take. First the Ganges flow divided to support anabranches on both sides of the bar, but then it abandoned its southern anabranch completely. Still a low flow channel to the Gorai survived due to the ability of spill flows to scour a sub-channel across the bar from the northern anabranch.

By the 1990 the Ganges had cut through the centre of the bar in the Gorai embayment, straightened its course and abandoned the divided anabranch channels of the 1980s. Flow into the Gorai was unable to scour and maintain a cross-bar channel and the mouth became entirely disconnected from the Ganges low flow channel. Subsequently, sinuosity developing in the single-thread channel has taken the low flow channel further away from the Gorai offtake and this trend looks set to continue. There is at present no prospect for an early re-connection of the Gorai at low flow without engineering intervention.

4.4 Development of the Kamarkhali Bends

A striking feature of the Gorai is the tortuous 20 km loop in the river at Kamarkhali. The development of the bends is illustrated in Figure 4.8. It is remarkable that such a feature should have been apparent even in 1770 before the Gorai was formed and illustrates the erosion resistance of some of the clay/silt layers in the southwest.

A cutoff channel in the bend seen in 1960 and 1973 has now been abandoned and the full loop is again developing similar to that seen in the 1924 mapping. The radius of curvature of such a cutoff was probably too small to be sustainable. Because the bend has been stationary for such a long period the upstream meander bends have also become very tight small radius bends at which a high headloss can be expected. The calculted headloss due to bend losses was over 1.0 m at dominant flow and clearly a cutoff or some realignment would have a beneficial effect on upstream water levels and hence upstream bed levels.

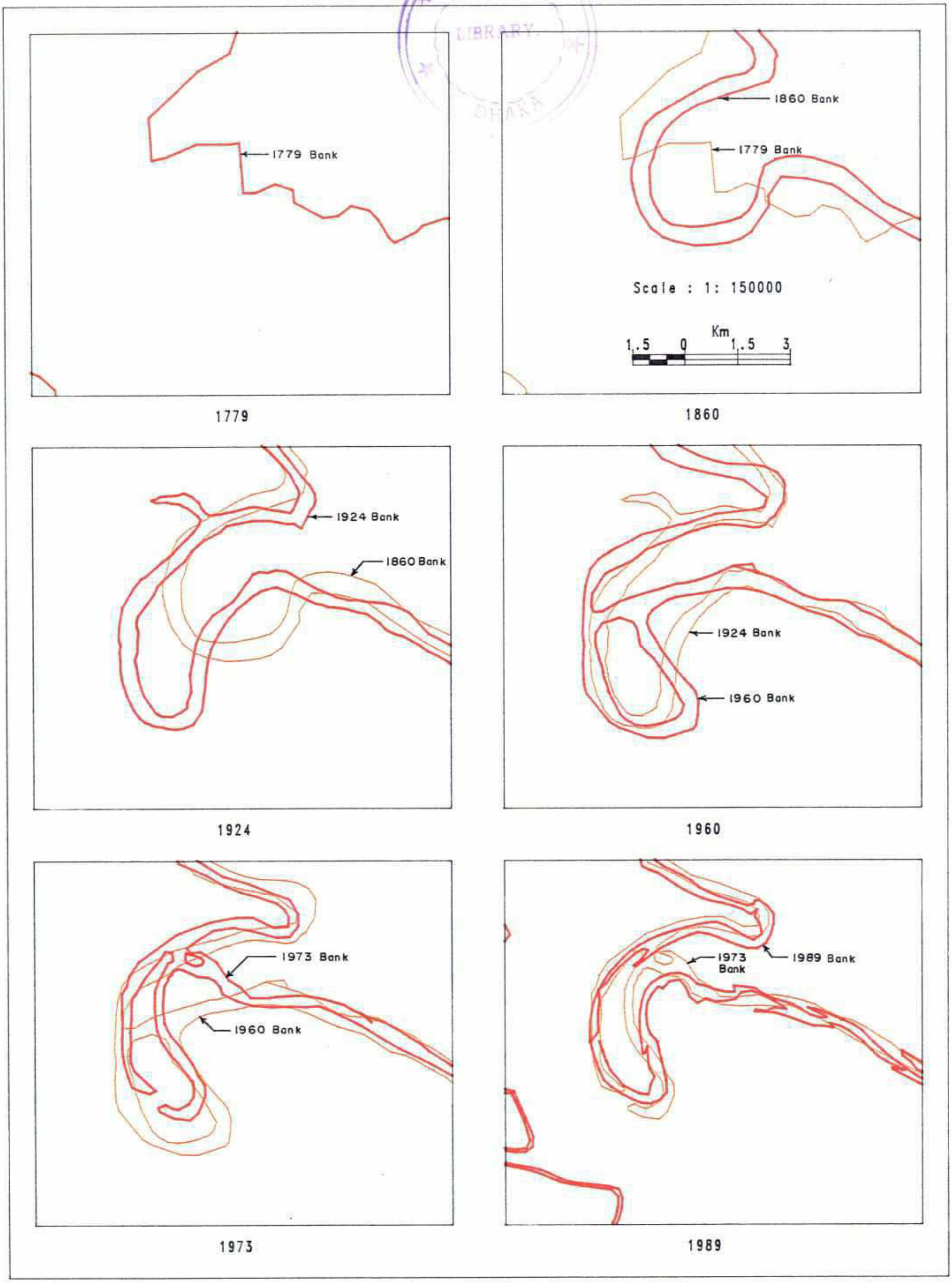
4.5 Development of the Halifax Cut between the Madhumati and Nabaganga

The Halifax cut has developed significantly over recent years such that what was a small navigation channel cut with a width of 20 m is now taking more than 90% of the flow that comes down the Madhumati.

The flow geometry at the bifurcation is very peculiar and must result in a comparitively high headloss. The upstream bends are also very active possibly due to the changes at the cut. The change between 1924 and 1953 was relatively minor, and it is only since that the Nabaganga has started to dominate.

Hydrodynamic modelling of the area shows that with the current cross section geometry for flows less than 1000 m^3/s in the Gorai practically all of the net flow passes down the Nabaganga to Khulna. This has important implications for salinity control in the area. Because tidal flows dominate the total flows in the area it is not easy to measure the flow split in the field.

Figure 4.8



Development of Kamarkhali Bends 1779–1989

5 EXISTING SITUATION IN IRRIGATION AREA

5.1 Land Resources

5.1.1 Agroecological Regions

A study carried out by FAO in 1988 has differentiated five agroecological regions (AEZ). These are : the Active Ganges River Floodplain, the High Ganges River Floodplain, the Low Ganges River Floodplain, the Gopalganj - Khulna beels and the Old Meghna Estuarine Floodplain (Figure 5.1). Each agroecological region has characteristically different physiography, soils and proportion of land types. As a result, there are some differences presently between the present dominant cropping patterns relating to each region.

Within the project area the Low Ganges River Floodplain occupies about two-thirds of the area whereas the other four regions together occupy a little more than one-third of the area.

A brief description of each of the five agroecological regions is given below.

The Active Ganges River Floodplain is a recently formed new landscape adjacent to the bank of the Ganges and the Madhumati rivers. The area has an irregular ridges and depressions, relatively less developed stratified soils and sparse settlements and has dominantly medium highland (F1 land).

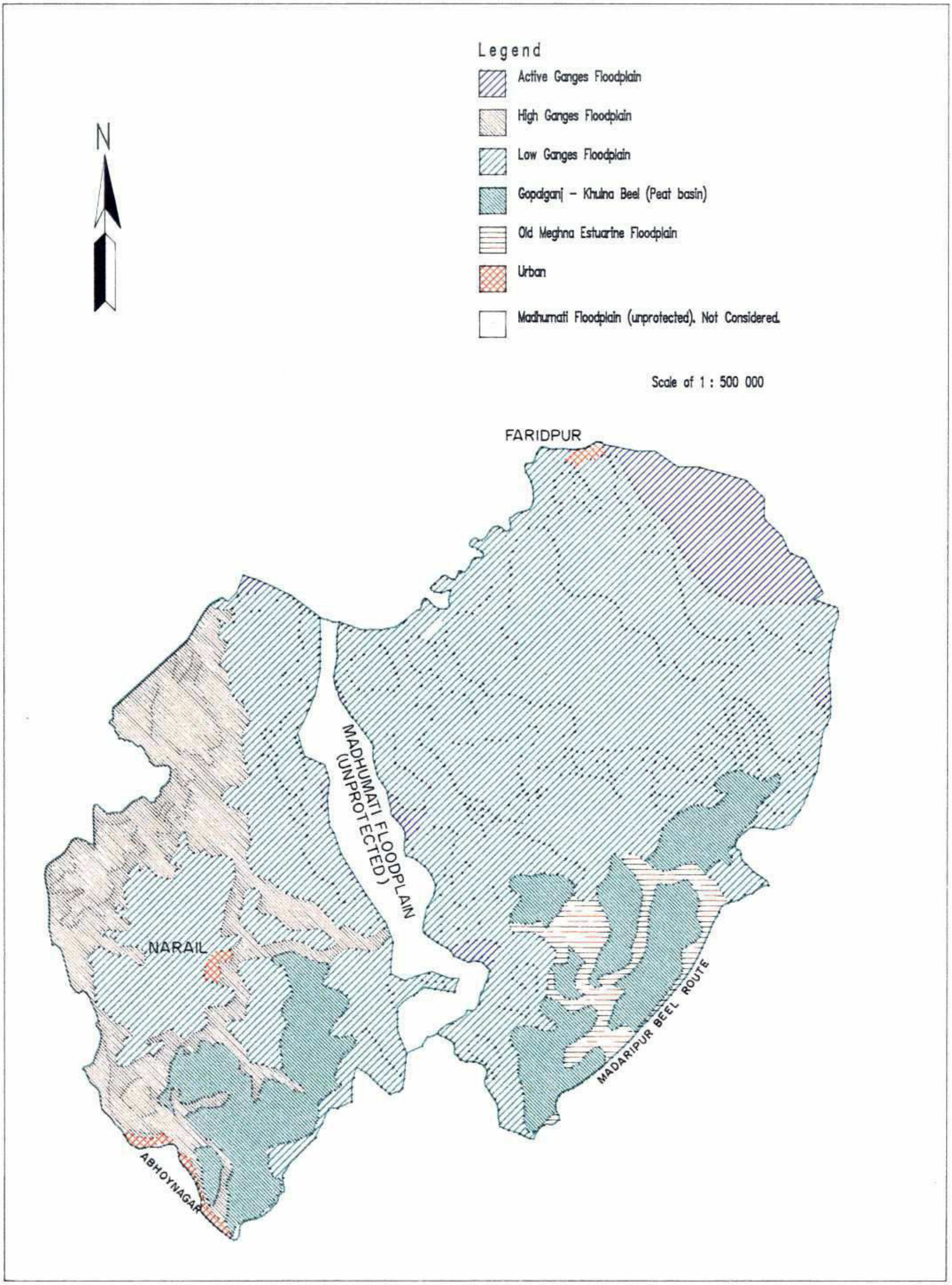
The High Ganges River Floodplain areas are the oldest landscape where the flow of the Ganges river has been practically cutoff. Proportion of highlands (F0 land) and medium highlands (F1 land) are much more than the medium lowlands (F2 land) and lowlands (F3 land). Most part of the highlands and a good portion of medium highlands have permeable loamy soils whereas lowlands have predominantly heavy clays which stay wet early dry season and then quickly become dry, limiting their suitability for rabi crops. High permeability of the soils of highland and medium highland limit irrigated boro cultivation.

The Low Ganges River Floodplain areas have a typical meander landscape of broad ridges and basins. Differences in elevation between the top of the highland ridges and lowland basin bottoms are generally in the ranges of 3-5 meters. The region occupies a higher proportion of medium lowlands (F2 land) and lowlands (F3 land) than highlands (F0 land) and medium highland (F1 land). Highlands and medium highlands have predominantly permeable loamy soils and medium lowlands and lowlands have predominantly moderately permeable to impermeable clayey soils.

The Gopalganj-Khulna beels are low lying swamps (mostly F2 land) formed by the age-old thick deposition of decomposed weeds and grasses. The area stand only 30-60 cm above sea level. Prior to present empolder these basins used to be deeply to very deeply flooded. These basins which are empoldered have reduced flood, mostly from accumulation of rainwater from local run-off. Peat soils occupy most of the area. In few places peat occur at the surface but in most places it is underlying below mineral soils at a shallow depth. The bearing capacity of these soils are low when wet.

The Old Meghna Estuarine Floodplain is formed by the sediments of Meghna river. The landscape is almost level, predominantly medium lowland. Sediments are highly silty and finely stratified. Some depressions have clay soils.

Figure 5.1



AGRO ECOLOGICAL REGIONS

The area of each agroecological regions in the project is given in Table 5.1 below.

TABLE 5.1

Agroecological Regions

AEZ No.	Aroecological Region	Area (ha)	Percent of total Area
10	Active Ganges River Floodplain	16309	5.2
11	High Ganges River Floodplain	47395	14.9
12	Low Ganges River Floodplain	198467	62.7
14	Gopalganj-Khulna beels (peat basins)	44136	13.9
19	Old Meghna Estuarine Floodplain	10637	3.3

Note: The above area excludes area under Madhumati Floodplain (unprotected) which is about 23050 ha.

5.1.2 Soils

General Characteristics of the Soils

Except soils of the Peat basins and Old Meghna Estuarine Floodplain, all soils have developed from calcarious Gangetic alluvium deposited at different times. These soils show different degree of development, mainly due to different ages of sedimentation, drainage condition and texture of the sediments.

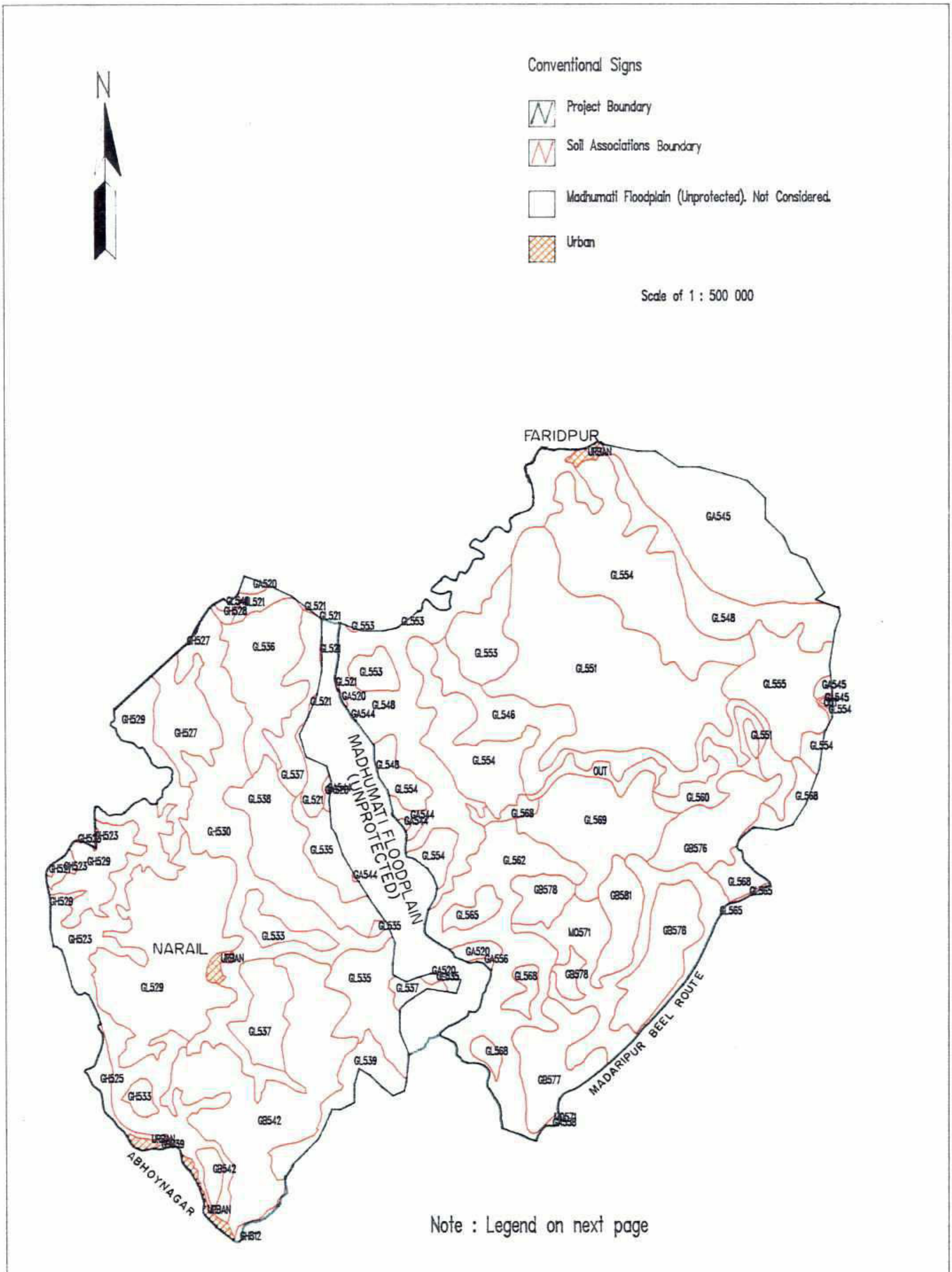
Permeable, brown silty clay loam soils predominate in the High Ganges Floodplain areas. In most of the areas Organic matter content is less than 1.5 percent though some basin soils contain 2-5 percent Organic matter. Top soils often crack and develop big clods.

Low Ganges Floodplain soils are relatively less permeable, well developed, poorly drained and dark gray clays. Organic matter in most of the soils ranges from 2-3 percent though in some soils it is as low as 0.6 percent. In some basin soils Organic matter may contain as high as 5.0 percent. The natural fertility of the soils of this area is relatively higher than the soils of the High Ganges Floodplain.

Peat soils have developed on peat or muck underlain by a layer of 10-50 cm thick top mineral soils. The thickness of the peat is variable but ranges near a meter or so. Top soil are acidic (PH 5.3-5.8), rich in Organic matter content (10-50%) but low in Nitrogen Content (0.5-1.5%), dark grey to very dark grey in colour and silty clay loam to clay in texture. The general natural fertility of this soils are poor and give high response to use of nitrogenous and phosphatic fertilisers.

The soils of the Old Meghna Estuarine Floodplain have developed on old landscape of broad, nearly level basin sites from Meghna sediments. On the relatively higher sites soils are heavy silt loam throughout the profile. Top soils are dark gray to very dark gray, friable slightly acidic silt loam. On relatively lower sites, soils are dark grey to very dark grey silty clay overlying on silt loam at a depth of about 50 cm. Both these soils contain high organic matter content but low in nitrogen content. They are acidic at the top but alkaline below 30-50 cm. The natural fertility of these soils are low.

Figure 5.2



Soil Associations

5.1.3 Soil associations

During soil survey the main soil unit recognised in the field was soil series, covering a range of soils derived from similar parent material developed under similar environmental condition and resembling each other in their physical and chemical properties. Because of intricate pattern of soils that occur in a small area of land and because of the scale of the soil map published in the Reconnaissance Soil Survey Reports (Scale 1:125,000), it was not possible to map individual soil series, instead soil associations have been mapped. Therefore, soil association is a group of two or more soils series regularly occurring together in the landscape, usually related to each other by topography. The dominant soil series appear in the name of the soil association. This do not preclude other soils those occur in an area of soil association.

Within the project area a total of 48 soil series have been identified and mapped in 33 soil associations (Figure 5.2). The detailed morphological characteristics and chemical composition of each of the soil series occurring in a soil association can be obtained from three Reconnaissance Soil Survey Reports (R.S.S.) of Jessore District (1970), Sadar and Goalanda Subdivision of Faridpur District (1969) and Madaripur and Gopalganj Subdivision of Faridpur District (1970).

MAP LEGEND (Reference Figure 5.2)

Active Ganges River Floodplain

GA 520	Silty Ganges alluvial Complex
GA 545	Ishurdi-Gopalpur Association and Medium Textured Ganges Alluvium
GA 556	Medium Textured Ganges alluvium Complex, severe river erosion hazard.

High Ganges River Floodplain

GH 523	Amjhupi - Darsana Association
GH 525	Darsana - Mirpur - Garuri Association
GH 527	Gagni-Garuri, Medium Highland Phase
GH 529	Ghior - Batra - Gagni association
GH 530	Sara - Ishurdi - Garuri Association
GH 533	Ghior - Ramdia Association

Low Ganges River Floodplain

GL 529	Ghior-Batra-Gagni Association
GL 535	Ishurdi-Sara-Gopalpur Association
GL 536	Gagni-Garuri, Medium Lowland Phase
GL 537	Garuri-Pakuria, Medium Lowland Phase
GL 538	Garuri - Ghior Association
GL 539	Ghior - Batra Association
GL 546	Ishurdi - Gopalpur Association
GL 548	Ishurdi - Pakuria Association
GL 551	Ghior - Ishurdi Association
GL 553	Ghior - Pakuria Association
GL 554	Ghior - Garuri Association
GL 555	Batra - Ghior Association
GL 560	Ishurdi-Gopalpur Association
GL 562	Pakuria-Ishurdi, Shallowly flowed phase
GL 565	Garuri - Pakuria Association

GL 568	Ghior - Garuri Association
GL 569	Batra - Garuri Association
GL 521	Sara - Gopalpur - Ishurdi Association

Gopalganj - Khulna beels (Peat Basins)

GB 542	Narail - Harta Association
GB 576	Pirojpur tidal clay
GB 577	Pirojpur tidal clay - Harta Association
GB 578	Rajoir - Pirojpur tidal
GB 581	Satla - Harta, Flood hazard phase

Old Meghna Estuarine Floodplain

MO 571	Magra - Paysa

5.1.4 Land Capability

Land Capability Assessment

Land capability assessment was made in the field simultaneously with reconnaissance soil survey carried out in 1969 and 1970 by Soil Resource Development Institute (SRDI). After 1969-70 some agricultural development projects have been completed resulting in improvement of the then agricultural land use. Consequent to this development activities, the past land capability ratings of these areas have been changed. During field visits the Consultant reviewed the present condition of some of those project areas. Based on field visit experience and from secondary sources of information the land capability rating of the project area has been updated.

Of the total agricultural land in the project area about 30 percent is Good Agricultural Land, 66 percent is Moderate Agricultural Land and only 4 percent is Poor Agricultural land.

The good agricultural lands are mostly highlands with diverse cropping patterns and have relatively higher cropping intensity and have lesser further development potential, other than increase in present crop yield through better agricultural management practices.

The moderate agricultural lands are mostly medium highlands and medium lowlands which still have higher potential for agricultural development through flood control, drainage and irrigation. If irrigation could be provided it is expected that the farmers will grow boro. Areas suitable for irrigated boro is shown in Figure 5.2.

Almost all poor agricultural lands are in the bottom sites of peat basins. With FCDI project, only one crop of boro could be grown but still will remain susceptible to risk of crop damage at mature stage from local rainfall runoff.

Land Capability Association

Land capability association are groups of land capability classes and subclasses. Because of scale limitation each land unit rated could not be mapped. Instead, they are shown in association as in case of soil association. Altogether 9 land capability associations have been differentiated in the project area. The area, land capability associations and major land characteristics of each associations are given in Table 5.2.

TABLE 5.2

Land Capability Associations and their Major Characteristics

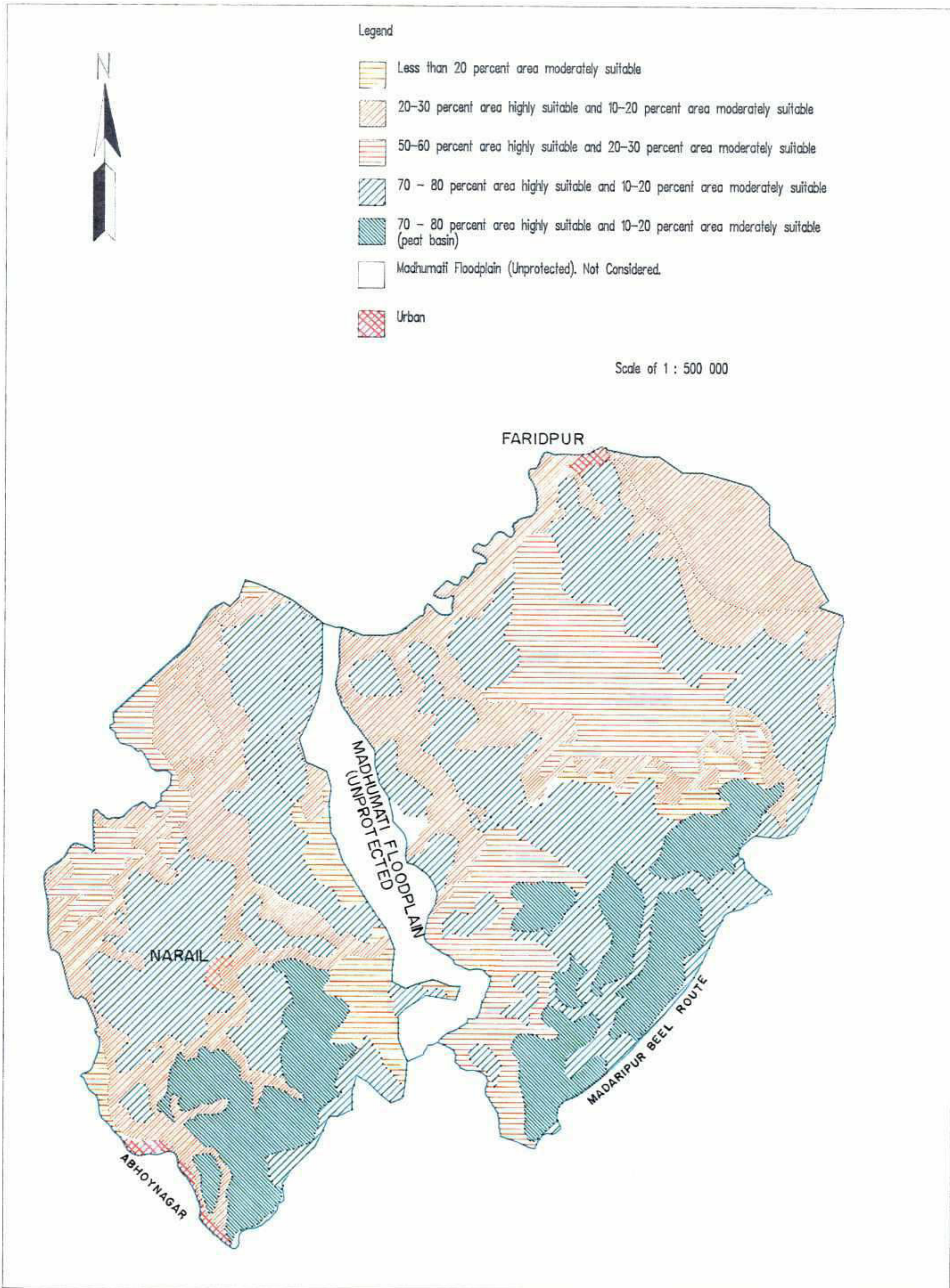
Land Capability Association names	[1] Area (Ha)	Soil Assoc Nos	Major Characteristics
GOOD AGRICULTURAL LAND 1. Predominantly good agricultural land	69616	GH 523 GH 530 GI 546 GI 548	Mainly imperfectly drained, broad highland ridges with some medium highland inter-ridge depressions and small basins
2. Mainly good with some moderate agricultural land	4913	GH 527	Mainly imperfectly drained highland with some medium lowland slow draining basins
3. Good and moderate agricultural land	20848	GH 525	Mainly imperfectly drained highland with some medium highland (1184 ha)
		GL 560 GL 562	Medium highland and Medium lowland (19664 ha)
MODERATE AGRICULTURAL LAND 4. Predominantly moderate agricultural land	79208	GL 538 GL 539 GL 554 GL 555 GL 565 GL 568 GL 569 MO 571 GB 576	Medium lowland and lowland; dry season; part dry season slow drainage
5. Mainly moderate with some good agricultural land	83205	GL 529 GL 535 GL 536 GL 537	Mainly medium highland and medium lowland with some highland; part slow draining in dry season (51069 ha)
		GL 551 GL 553	Medium lowland and lowland with some medium highland; part slow draining in dry season (32136 ha)
6. Mainly moderate with some poor agricultural land	31229	GA 520 GH 533	Mainly medium lowland with some medium highland and; part slow draining (5784 ha)
		GB 542 GB 577	Mainly medium lowland with some lowland; slow draining in dry season, part perennially wet and low bearing capacity (25445)
7. Poor and moderate agricultural land	14969	GA 545	Mainly medium highland with moderate to severe risk of river erosion
POOR AGRICULTURAL LAND 8. Predominantly poor agricultural land	3490	GB 581	Slow draining medium lowland; major part of the area low bearing capacity and part with perennially wet peat; risk of flash flood
9. Mainly poor with some moderate agricultural land	9307	GB 578	Slow draining lowland; smaller part of the area low bearing capacity; risk of flash flood.

[1] Area means Agricultural land area plus areas in other uses.

Source: (1) Reconnaissance Soil Survey Reports of Jessore district (1970), Faridpur Sadar and Goalanda Sub-division (1969) and Madaripur and Gopalganj Sub-division of Faridpur district (1970).

(2) Consultant's estimation.

Figure 5.3



SUITABILITY FOR IRRIGATED BORO

5.1.5 Crop Suitability

Crop Suitability Classification

Crop suitability classification is a method of rating soils in terms of the relative suitability for production of specified crops. Each soil has certain physical and chemical characteristics and each crop has also specific requirements to grow.

Suitability for Irrigated Boro

Suitability for irrigated boro in the project area has been rated against the identified soils. A suitability map for irrigated boro is illustrated in Figure 5.3. The two ratings-highly suitable and moderately suitable refer, in addition to suitability to grow boro crops, also to irrigation efficiency in terms of retaining water for longer period on the soils on which it will be grown.

5.2 Drainage

5.2.1 Drainage Area

The gross area covered by the proposed Gorai Augmentation Project is about 2200 km^2. The drainage study not only covers this area but also the upstream catchments which contribute flows to the rivers that pass through the irrigation area. The total drainage area considered is about 9500 km^2.

The main rivers which impact on the composite drainage area are the Bhairab, Chitra, Begabati, Nabaganga, Gorai/Madhumati, Chandana/Barasia and Kumar. The boundary rivers are the Ganges in the north, the Padma and Arial Khan in the east and the Madaripur Beel Route (MBR) canal in the south (eastern half only). It is seen from the available cross section data for these internal rivers that the Begabati - Bhairab combination acts as the main drainage line in the western part of the study area, while the Kumar functions in a similar manner in the eastern side.

5.2.2 NAM Catchments and Drainage Complexes

SWMC has sub-divided the drainage basins of the entire country into a number of catchments (NAM) to facilitate its hydraulic modelling exercise. The composite drainage area of the Gorai Augmentation Project is covered by 14 NAM catchments. For the purpose of the present study, the composite area has been divided into the following four drainage complexes (reference numbering of the complexes is based on a division of the entire Southwest Area) by taking into consideration the topography, soil characteristics and the catchment boundaries.

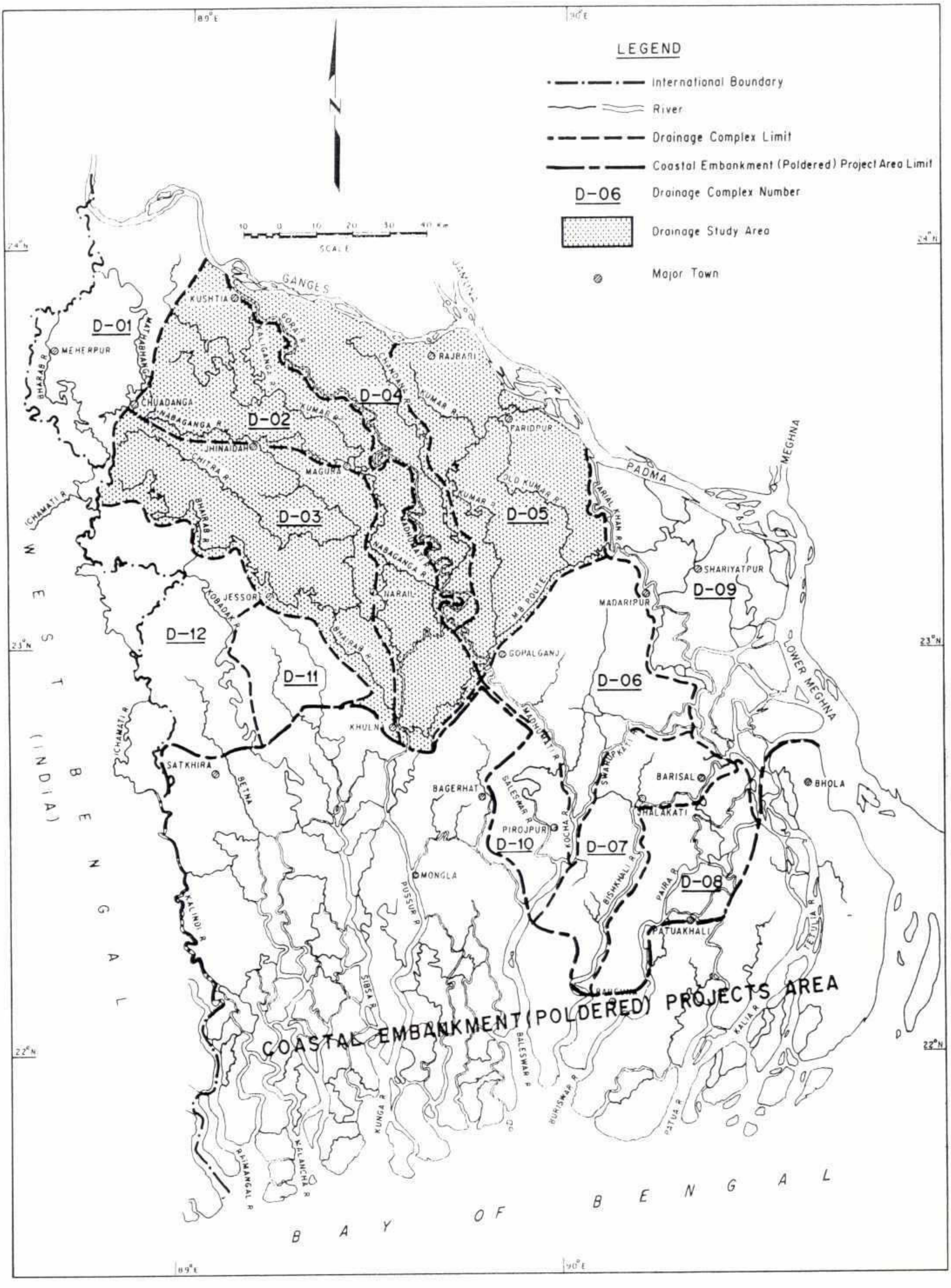
D 02 : Kaliganga - Kumar - Nabaganga Complex
D 03 : Begabati - Chitra - Bhairab Complex
D 04 : Gorai - Madhumati - Chandana Complex
D 05 : Kumar - MBR Canal Complex

Figure 5.4 shows the drainage complexes.

5.2.3 Coefficient of Runoff

Previous studies (including that carried out by FAO in 1988) have considered some relevant agroecological criteria and divided the composite drainage area into two, the northern High

Figure 5.4



Drainage Study Area

Ganges Floodplain (HGF) and the Southern Low Ganges Floodplain (LGF). The HGF, which is predominantly high and medium high land, has a smooth landscape of nearly level to very gently sloping broad ridges, inter-ridge depressions and nearly level to very gently undulating broad basins. Ground level varies from El.15.0m PWD at the high land to El. 1.0m PWD at the lower end. The LGF is predominantly high and medium high land and has typical meander landscape: relief along the sides of the rivers crossing the area is somewhat irregular, comprising narrow ridges, inter-ridge depressions, broad low lying basins (particularly in the south) and cut-off channels. The difference in elevation between the ridge top and the corresponding basin bottom generally varies between 3.0 and 5.0m.

The northern half of the composite area could be considered as having a rolling topography when compared with the fairly flat terrain in the southern half. Furthermore, the southern areas have a number of extensive low lying lands (beels), particularly in the central parts of the project area.

Drainage complexes D 02 and D 03 fall within HGF. 60-70% areas of these complexes are covered by broad ridges and inter-ridge depressions; their soils are mainly loamy to well textured clay and moderately permeable. Broad basins cover the remaining complexes, particularly in the south, and their soils are generally low permeable clay.

Drainage complexes D 04 and D 05 belong to LGF. Except for about 30-40% areas of these complexes in the north which have generally narrow ridges with wide inter-ridge depressions, the remaining areas are usually covered by wide, low lying basins that have silty clay loams to heavy clay soils of low permeability. Some basins also have peat soils.

In view of the variations in the reliefs and soil texture, the different drainage complexes and the integral NAM catchments show differences in their runoff and groundwater recharge capabilities. Results of catchment model simulation based on mean annual rainfall are given in Table 5.3 and they illustrate the variation in runoff coefficients (0.36 to 0.51).

These coefficient of runoff values relating to annual rainfall are considered high but appear realistic on the basis of a comparison of simulated runoff with measured flow in rivers at selected locations made by FAP 25.

5.2.4 Mean River Stage

Plots of the river stage contours for the study area for the months July, August and September based on the results of the simulation of measured daily flows corresponding approximately to a 1 in 5 year return period shows that about half the total area that lies south of Magura - Faridpur would be subjected to drainage congestion in view of the relatively lower land levels there. The simulation results further showed that the drainage congestion in these southern areas on an average lasts for periods ranging from 5 to 8 weeks (during July to September). Flood area information gathered during field visits do generally show similarity to that obtained through interpretation of simulation results.

Furthermore, the simulation results also seem to indicate that rivers such as the Begabati, Chitra, Nabaganga (the reach between Magura and the Halifax cut), Barasia and Kumar have substantial backwater effects due to high water levels in the Madhumati up to the Halifax cut and in the Lower Nabaganga. Except the Gorai - Madhumati - Lower Nabaganga conveyance system that receives high flood flows from the Ganges during the monsoon, the other rivers are almost entirely dependant on internal runoff. The model studies indicate that if the flood inflow through the Gorai mouth could be limited to its dominant discharge (4250 m^3/s), the backwater effects could be appreciably reduced.

A comparison of the 1987 flow levels in these rivers with those corresponding to a situation that would exist if the Gorai flow is kept to a maximum of 4250 m^3/s, indicates that the water levels could be lowered by between 0.3m to 0.6m in the river network within the proposed irrigation areas (Table 5.3).

TABLE 5.3

Rainfall - Runoff - Recharge Analysis in NAM Catchments and Drainage Complexes

Drainage Complex No.	NAM Catchment	NAM Catchment Portion %	NAM Catchment Area Km²	Annual Mean Rainfall in NAM Catchment mm	Annual Mean Rainfall in Drainage Complex Mm³	Annual Mean Runoff in NAM Catchment mm	Annual Mean Runoff in Drainage Complex Mm³	Annual Mean Recharge in NAM Catchment mm	Annual Mean Recharge in Drainage Complex Mm³	Runoff Co-efficient in NAM Catchment	Runoff Co-efficient in Drainage Complex (Weighted)
1	2	3	4	5	6	7	8	9	10	11	12
	SUW - 02	100	681.0	1562		569	387.5	331		0.36	
	SUW - 03	100	615.0	1714		876	538.7	495		0.51	
D - 02	SUW - 07	100	396.0	1597		641	253.8	392	1178.6	0.40	0.423
	SUW - 10	100	638.0	1746	4867.0	724	461.9	335		0.41	
	SUW - 14B	45	186.0	1787		678	126.1	614		0.38	
	SUW - 15	100	297.0	2062		979	290.8	558		0.47	
TOTAL			2813.0		4867.0		2058.8		1178.6		0.423
	SUW - 08	100	456.0	1595		555	253.0	422		0.35	
	SUW - 09	100	926.0	1727		688	637.0	470		0.40	
D - 03	SUW - 13	45	285.0	1576		572	163.0	557	1077.8	0.36	0.379
	SUW - 14a	60	247.8	1787	3628.0	678	168.0	614		0.38	
	SUW - 14B	55	227.0	1787		678	153.9	614		0.38	
TOTAL			2141.8		3628.0		1374.9		1077.8		0.379
D - 04	SUW - 04	100	1177.5	1659		820	965.5	521		0.49	0.464
	SUW - 11	100	890.0	1752	3527.0	754	671.0	305	884.9	0.43	
TOTAL			2067.5		3527.0		1636.5		884.9		0.464
	SUW - 05	100	620.0	1756		806	499.7	571		0.46	
	SUW - 12	100	1255.4	1817		801	1005.6	399	1068.1	0.44	
D - 05	SUW - 16	20	69.1	2036	4482.0	934	64.5	550		0.46	0.438
	SUW - 17	50	347.2	1806		784	272.2	252		0.43	
	SUC - 01	50	163.1	2045		742	121.0	538		0.36	
TOTAL			2454.8		4482.0		1963.0		1068.1		0.438

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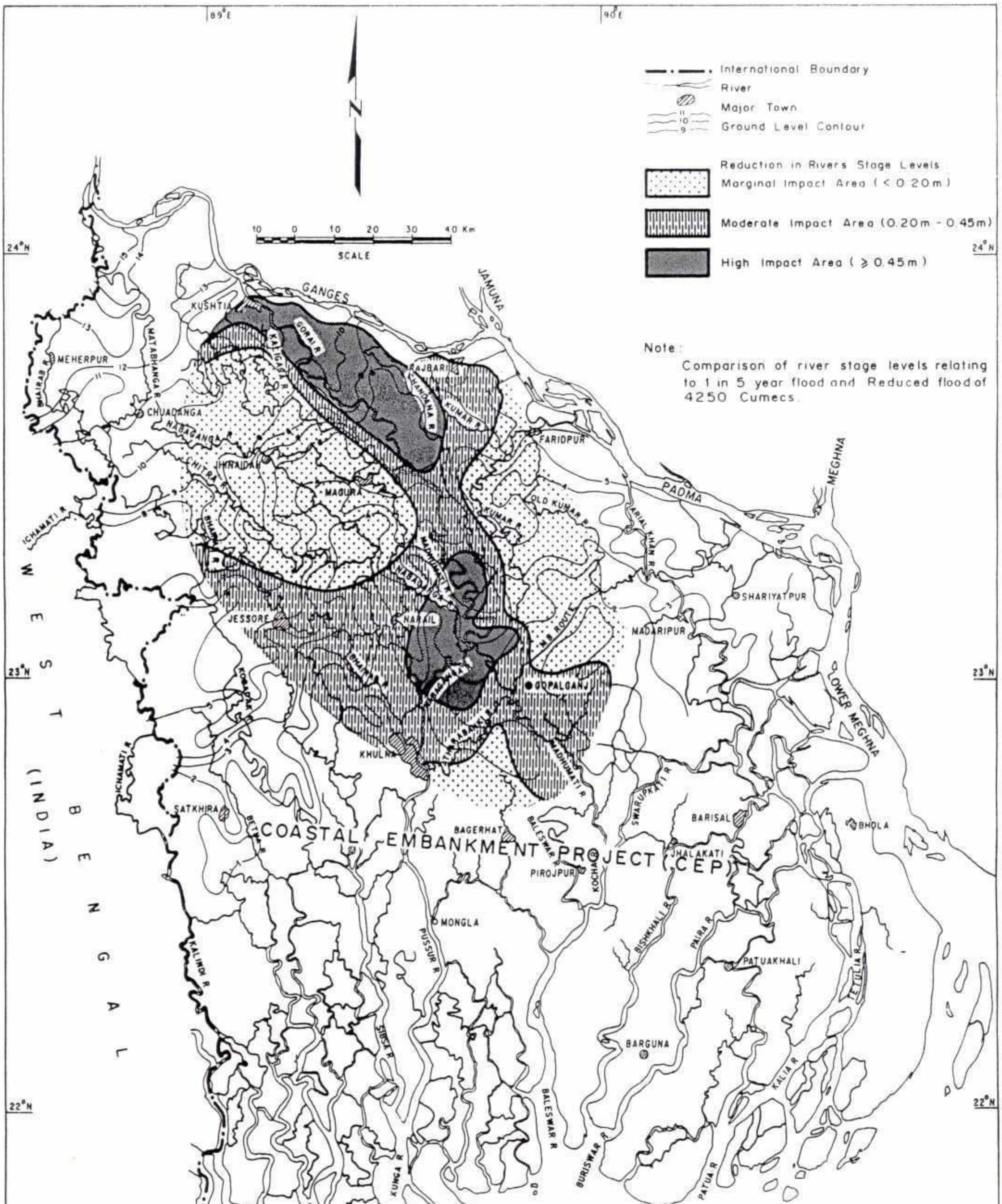
Figure 5.5



Impact of Reduced Flood Flow Through Gorai

Consequently, by maintaining the Gorai flood flows to a maximum of 4250 m^3/s the drainage congestion could be relieved in areas not only within the composite drainage area being examined here, but other surrounding areas as shown in Figure 5.5. These areas which total about 10,900 km^2 could be brought to enhanced agricultural production.

5.3 Existing Agriculture

5.3.1 Land Use and Cropping Patterns

At present, out of the total NCA of 303,883 hectare 51,635 ha is irrigated which is about 17% of the total NCA.

Rice is the predominant crop in the project area. Broadcast aus and aman are the major crops grown. Transplanted aman is locally important, particularly where supplementary irrigation is available. Recent trends show that jute generally replace t. aus. wheat, gram, kheshari, lentil, mustard, chilies, onion, garlic and vegetables are the main rainfed rabi crops. Locally boro is grown with irrigation. Sugarcane is the most important perennial crop.

The major factors determining the types of crops, cropping patterns and intensity are the elevation of land in relation to flooding during rainy season and drainage and soil moisture content in the dry season. Availability of irrigation water determine growing of boro crop.

The main cropping patterns in the project area are double with some single and triple cropping. A field survey conducted in 80 villages selected randomly and spread over all the thanas in the project area reveals that 72 percent of the total area is under double cropping and 14 percent is under single and triple cropping system. Within double cropping system, mixed broadest aus and aman occupy about 85 percent of the total double cropped land.

The dominant single, double and triple cropping patterns are as follows:

(i) Single cropping pattern:

1) Boro - Fallow
2) Mixed aus and aman - Fallow
3) Broadest aman - Fallow
4) Sugarcane

(ii) Double cropping pattern:

1) Mixed B. Aus and B. Aman - Rabi crops (wheat, pulses, oilseeds, spices, etc)
2) Mixed B. Aus and B. Aman - Boro
3) B. Aus/Jute - Rabi crops (mustard, wheat, lentil, etc)
4) T. Aman(L) - Boro (HYV)

(iii) Triple cropping pattern:

1) B. Aus (L) - T. Aman (L) - pulses

The cropping intensity ranges between 148 to 164 percent in different planning units. The average cropping intensity of the project area is 156 percent. A summary of present cropping area by Planning Units is shown in Table 5.4.

TABLE 5.4

Summary of Present Cropping and Area by Planning Units

CROP	Area in Km²																		Percent of Total NCA
	SW 4			SW 5			SW 6			SW 7			SW 10			Grand Total			
	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	
Kharif																			
B Aus	0	69	69	0	190	190	0	110	110	0	389	389	0	211	211	0	604	604	31
M Aus	11	0	12	23	6	29	15	4	19	15	7	22	18	1	19	34	8	42	2
B Aman	0	26	26	0	152	152	0	93	93	0	467	467	0	273	273	0	743	743	38
L T Aman	22	27	49	34	25	58	21	5	26	43	3	45	24	162	186	68	165	233	12
M Aman	28	17	44	31	29	60	17	14	31	21	33	54	31	50	81	53	84	137	7
Jute	0	22	22	0	42	42	0	23	23	0	73	73	0	39	39	0	113	113	6
Sugarcane	2	4	7	1	19	20	0	11	12	0	30	31	2	9	11	2	40	42	2
Rabi																			
L Boro	1	0	1	3	2	5	1	1	2	2	21	23	8	18	25	10	39	48	3
M Boro	34	0	34	48	0	48	29	0	29	183	0	183	61	0	61	245	0	245	13
M Wheat	14	8	23	26	28	54	17	18	35	5	79	84	22	6	28	27	85	113	6
Potato	1	1	2	1	3	3	0	1	1	0	9	10	1	24	25	2	33	35	2
Pulses	4	34	38	3	98	100	1	57	58	8	217	225	3	100	102	10	319	329	17
Oilseeds	3	18	21	3	48	51	1	26	28	13	114	127	12	104	116	25	219	244	13
Spices	1	1	2	1	8	9	1	5	6	6	18	24	1	2	3	7	21	27	1
Minor crops	5	3	8	5	11	16	2	7	9	1	28	29	7	13	20	8	41	49	3
Orchards	0	3	3	0	7	7	0	4	4	0	9	9	0	13	13	0	22	22	1
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Totals	126	234	360	179	667	846	107	380	486	296	1497	1793	190	1025	1215	490	2535	3025	
Total NCA	62	158	220	90	479	569	54	273	327	203	897	1100	107	716	823	312	1622	1934	
Average CI	201%	149%	164%	199%	139%	149%	199%	139%	149%	146%	167%	163%	178%	143%	148%	174%	151%	156%	

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5.3.2 Irrigation

The present modes of irrigation in the project area are primarily Shallow Tubewells (STW) and Deep Tubewells (DTW). Due to scarcity of surface water the use of Low Lift Pumps (LLP) are very limited and number of units are decreasing every year. On the other hand the number of STWs are rapidly increasing while the use of deep tubewells is decreasing.

A comparative trend of use of STWs and DTWs have been studied by the Consultant. The use of these two modes of irrigation from 1984-85 to 1990-91 in the project area is tabulated below. During field visit it was revealed that the farmers prefer surface water irrigation by LLPs rather than groundwater irrigation because:

- groundwater contains more iron which reduce soil fertility;
- cost of use of surface water is less than the groundwater; and
- groundwater irrigation equipment is difficult to handle and repair.

Growth of Shallow and Deep Tubewells

Mode	Number						
	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91
Shallow Tubewell	1950 (100)	2289 (117)	2795 (143)	4033 (207)	4891 (251)	4988 (256)	5998 (308)
Deep Tubewell	84 (100)	82 (98)	80 (95)	91 (108)	106 (126)	117 (139)	79 (94)

Figures in parenthesis represent the trend of change in percentage, taking on 1984-85 figures as 100.

5.3.3 Inputs, Yields and Production

Crop yields under both irrigated and rainfed condition have been calculated based on the average of five years BBS data. The present production based on the yield for different crops under irrigated and rainfed condition by Planning Units is presented in Table 5.5. It is observed that the total production for individual crops vary among different planning units mainly due to variation of cropped areas.

5.3.4 Crop Damage and Production Problem

A major part of the area remains flooded during rainy season. Only about 20% of the net cultivated area is above flood level. Consequence to this particular topographic condition t. aman cannot be grown other than on highland. However, highlands become very dry even in rainy season when there is no rain for about a week or so and t.aman fails to develop and produce satisfactorily. Because of this shallow to moderately/deeply flooding local varieties of aus and broadcast aman either simply or mixed together, are grown in about 80% of the project area with low yield and long growing period. The crop is sometimes damaged due to submergence from sudden rise of flood water. A major part of

TABLE 5.5
Prosent Crop Production by Planning Units

Crop	SW 4			SW 5			SW 6			SW 7			SW 10			Grand Total		
	Production in Tonne																	
	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall
Kharif																		
B Aus	0	8310	8310	0	22810	22810	0	13231	13231	0	46713	46713	0	25271	25271	0	116335	116335
M Aus	3281	131	3412	6620	1744	8364	4283	1195	5478	4434	1959	6393	5294	309	5603	23912	5338	29250
B Aman	0	3147	3147	0	18282	18282	0	11111	11111	0	56038	56038	0	32776	32776	0	121354	121354
L T Aman	4267	5093	9360	6375	4718	11093	4030	996	5026	8116	495	8611	4607	30748	35355	27395	42049	69444
M Aman	8821	5359	14180	9949	9181	19130	5510	4454	9965	6699	10627	17326	10021	16003	26025	41001	45624	86625
Jute	0	3708	3708	0	7113	7113	0	3922	3922	0	12391	12391	0	6626	6626	0	33759	33759
Sugarcane	11544	17344	28889	5519	74685	80205	550	45800	46350	1926	120938	122864	10260	36050	46309	29799	294818	324617
Rabi																		
L Boro	127	56	183	512	433	945	283	182	466	390	3956	4347	1445	3396	4840	2757	8023	10780
M Boro	14751	16	14767	21203	0	21203	12918	0	12918	80405	0	80405	26715	0	26715	155993	16	156009
M Wheat	3450	1382	4832	6352	4699	11050	4068	3033	7101	1147	13394	14541	5283	1023	6306	20299	23531	43830
Potato	872	765	1637	757	2247	3004	384	560	944	494	7317	7811	1345	19292	20637	3853	30181	34034
Pulses	267	2325	2592	186	6639	6825	85	3887	3972	520	14755	15275	182	6777	6959	1240	34382	35622
Oilseeds	229	1494	1723	283	3976	4259	105	2181	2287	1076	9453	10529	964	8669	9633	2658	25773	28431
Spices	322	350	671	374	3066	3440	185	2028	2213	2063	6756	8819	372	891	1263	3316	13091	16407
Minor crops	53	26	79	52	110	162	23	68	90	6	280	286	73	133	206	207	615	823
Orchards	8	877	885	0	1844	1844	0	943	943	0	2358	2358	0	3352	3352	8	9373	9380

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the project area is slow draining causing delay in sowing rabi crops. In areas of well drained soils where rabi crops could be grown on time, soil moisture is depleted quickly affecting wheat, pulses, oilseeds and vegetables.

5.4 Existing Fisheries

5.4.1 Introduction

Fisheries in the Gorai Augmentation Project area comprise inland openwater capture fisheries in rivers, beels and floodplains and culture fisheries, mainly for carp production in freshwater ponds and other closed water bodies. The only detailed sequence of data covering these fisheries are the annual fish production statistical bulletins published by the Department of Fisheries (DOF), which are considered to be assessments of at least the correct orders of magnitude and a reasonably accurate reflection of production trends and changes in fish stock abundance during the recent years.

MPO (Technical Report No. 17, 1985) and other sources, the most recent of which is the FAP-12 Agricultural Impact Evaluation Study have identified fisheries as one of the sectors affected by flood control developments throughout Bangladesh. The negative impacts arise mainly because flood control structures also block the spawning and feeding migrations of many species of fish to and from the floodplains, beels, rivers and khals and have thus reduced the beeding stocks and reproduction to a stage where several species of fish may be verging on extinction. In the interests of increasing the area of rice land inside FCD project boundaries, many permanently flooded beel areas have also been completely drained or converted to seasonal floodland which dries out during the winter months, thus causing the destruction of resident breeding stocks of fish. Rivers flows have been altered, in terns of both depth and duration of flooding and the pattern of siltation has changed to the probable detriment of riverine fish species or the food organisms on which they depend, Fishermen's catches and earnings have inevitably been badly affected by these changes and consequently some erstwhile fulltime fishermen have had to seek other work or move elsewhere.

5.4.2 Present Status of Fisheries

Capture Fisheries

Capture fishing takes place in the rivers, beels and floodplain areas. It is the subsector most severely affected by FCD works because of the obstruction to fish spawning and feeding migrations, the draining of many formerly productive beel fisheries, the consequent reduction in recruitment and natural stocking of floodplains and the enforced concentration of artisanal fishing effort onto the already diminished river fisheries. Fish production from openwater capture fisheries of proposed project area shown on Table 5.6.

Riverine Fisheries

DOF's data for SWA riverine production confirm the virtual collapse of freshwater river fish species. Further confirmation of these changes was obtained during interview with fishermen who pointed to beel drainage, embankments, excessive river siltation in recent years and interference with river flows such as Kumar River regulator near Faridpur as the primary causes of decline, in fish stocks, catches and fishermen earnings. The total area of river included in the project area being 20760 ha. Table 5.6 shows that the 1983/84 catch of 6004 tonnes was reduced by 4632 tonnes or 77%, to 1372 tonnes in 1988/89.

TABLE 5.6

Capture Fisheries Production

PU Code	PU Gross Area (Km²)	Rivers			Beels			Floodlands		
		Area (ha)	Production (Tonnes)		Area (ha)	Production (Tonnes)		Area (ha)	Production (Tonnes)	
			1983/84	1988/89		1983/84	1989/90		1983/84	1989/90
SW 4	286	730	327	66	289	129	72	5623	333	319
SW 5	719	3370	1437	267	729	328	182	27153	1920	1685
SW 6	415	3480	865	216	144	66	30	15472	1095	361
SW 7	1438	10900	2662	675	553	250	87	106543	7544	2489
SW 10	1094	2280	713	148	288	130	72	71902	5072	4314
Overall Total	3952	20760	6004	1372	2003	903	443	226693	15964	9168

Source : DOF Fish Catch Statistics of Bangladesh.

Beel Fisheries

Beel fisheries in SWA are not as numerous as in some other parts of Bangladesh and were assessed by SPARRSO, during their 1983 surveys to total about 9600 ha out of which about 2000 ha existed within the project area. In the meantime as a consequence of various FCD or irrigation projects some beels have drained altogether with the aim of creating additional rice growing land and others converted from perennial to only seasonal water bodies. DOF data show that beel fish production in SWA declined by about 45%, from 4300 to 2400 tonnes and in the project area declined by 51% from 903 to 443 tonnes between 1983/84 and 1989/90 (Table 5.6). It seems likely that this may be an underestimate of the decline, whereas FAP-12 findings suggested losses of upto 75%. Fishermen stated that they are often denied access to areas which they once fished because the remaining small water bodies, after drainage are claimed as private property by neighboring farmers. In consequence, the fishermen have been forced to concentrate on catching on riverine fish.

Floodplain Subsistence Fisheries

Most of the fishing in this area during the floodseason is carried out on a subsistence basis by the local population as whole rather than by professional fishermen, and the customary right of free access to catch fish has been of particular importance to the poorest families.

Floodplain fish stocks originate each year from fish which have over wintered in the beels or from the rivers, either as fry in the case of fish which spawn prior to monsoon flood, or as adult fish seeking suitable spawning areas in the newly flooded lands. It follows that beel draining and riverside embankment greatly reduces the annual recruitment of fish which constitute the floodplain catch.

The impact of FCD in reducing even further the areas of former floodplain subject to inundation, and in reducing F4 and F3 land into F1 or F2 will cause further reductions in floodplain fish production to the detriment of many of the poorest families who have relied on this freely available food source during monsoon season hitherto. Table 5.6 shows that floodplain fish production has declined by about 43% between 1983/84 and 1989/90, from 15964 to 9168 tonnes, indicating that the decline in fish stocks was continuing and that the shortfall in annual floodplain fish production had grown to about 1133 tonnes per year.

5.4.3 Culture Fisheries

The culture fisheries in SWA, which are at least positive beneficiaries of FCD comprise freshwater ponds fish farming. Fish farming in SWA is being conducted at a relatively higher level of technology than in many other parts of the country, and cultured ponds in Jessore greater district are recorded as producing 2262 kg/ha/year, which must be one of the highest averages in Bangladesh. DOF demonstrations have shown that, by stocking the right combinations of fish species coupled with systematic feeding and pond water fertilization, or by integrating fish farming with poultry or duck production, yields and profitability can be increased still further to at least 4200 kg/ha/year. Fish production from closed water culture fisheries in the proposed project area shown on Table 5.7.

TABLE 5.7

Closed Water Fisheries Production

PU Code	PU Gross Area (Km^2)	Baors			Ponds		
		Area (ha)	Production (Tonnes)		Area (ha)	Production (Tonnes)	
			1983/84	1989/90		1983/84	1989/90
SW 4	286	120	20	35	440	437	814
SW 5	719	390	72	121	860	861	1693
SW 6	415	70	11	14	390	266	345
SW 7	1438	190	27	38	1630	962	1422
SW10	1094	160	28	43	830	826	1508
Overall Total	3952	930	158	251	4150	3352	5782

Source : DOF Fish Catch Statics of Bangladesh

Fresh Water Fish Ponds

Freshwater pond fish farming yielded 48,000 tonnes of fish during 1989/90 and has made a steady progress during recent years in SWA. The area of ponds in the region is estimated at about 38,000 ha, of which 24,400 ha or 64% are being cultivated. FAP 12 studies show that an expansion of interest and investment in pond fish farming was possible in areas which became less vulnerable to flooding as a result of FCD developments. However, although signs of new pond construction were observed in several project impacted areas the overall increase in farmed fish production and pond area and reduction in proportion of derilict ponds, fall short of expectations. Among the reasons given were the lack of any effective rural credit system to assist with the cost of pond rehabilitation, and DOF's inability to fill the necessary scale of extension effort to ensure that appropriate technical knowledge was disseminated to the pond owners concerned.

In the proposed project area there are 4150 ha of pond waters. DOF data show that pond fish production between 1983/84 and 1989/90 increased by 48%, from 32,156 to 47,735 tonnes in SWA, whereas in the project area increased by 72%, from 3352 to 5782 tonnes. Production per hectare increased from 806 kg in 1983/84 to 1391 in 1989/90.

Fish Production from Baors

A feature of the northern and north-western parts of the region are a number of ox-bow lakes, known locally as baors, which have become separated from their parent rivers. Unlike beels which are shallow depressions in the floodplain rarely exceeding more than a few feet in depth, baors can hold upto 40 feet of water and are perennial lakes of considerable potential. There are 5,490 ha of these waters in SWA which yielded 1,357 tonnes of fish during 1989/90, equivalent to 247 kg/ha. The IDA Ox-bow Lakes Fishery Project which was completed in 1986, demonstrated that fish stock enhancement using culture based technology and effective fishery management can enable productivity to be increased to at least 950 kg/ha/year. This experience is now being extended to other baors under a new IFAD/DANIDA development project just started.

The area of baors in the proposed project area is estimated at about 930 ha. DOF data show that baor fish production between 1983/84 and 1989/90 increased by 59%, from 158 to 251 tonnes.

5.5 Groundwater

The potential of groundwater in the SWA was studied as part of the hydrogeological study under FAP-4. Its conclusions may be summarised as follows:

(a) Due to a general southwards fining of the deltaic sediments and particularly thick upper clay layer in some areas, hydrogeological conditions are generally less favourable for groundwater development in the Southwest Area than elsewhere in most of Bangladesh.

(b) Limited potential for groundwater development exists in the north and north eastern parts of the Southwest and South Central Regions particularly in Planning Units SW2, SW3, SW4, SW5, SW6, SW7 (part), SW9 (part), SW10 (part) and SC1.

(c) Saline intrusion is already a problem particularly in the Khulna region and saline fronts are present in deep and shallow aquifers, which will move inland if abstraction is not controlled. Some freshwater lenses used for potable water supply are already saline.

(d) In some areas notably in the north-western parts of the Southwest Region, groundwater abstractions currently exceed the estimates of available recharge.

(e) The quality of water supply at Khulna is deteriorating due to saline intrusion. It is unlikely that the long term water supply requirements for Khulna can be met by groundwater.

From these it can be concluded that although there is limited potential for groundwater development exists in the northeastern part of the Southwest Region, the exploitation must be carefully managed due to the threat of saline intrusion. Further, studies of food grains requirements to year 2020 indicate that even with full exploitation of groundwater resource for agriculture, the requirements cannot be met.

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6 AUGMENTATION OF GORAI DRY SEASON FLOWS

6.1 Introduction

Augmentation of dry season flows is a necessity for long term food security and sustainability of the Southwest Region whereas flows to the South Central Region are relatively abundant. Augmentation to the SWR in theory could be achieved from groundwater resource and/or surface water resource. The studies undertaken show that there is limited potential for groundwater development in the north and northeast areas of the region. However, even with full exploitation of this resource there will be shortfalls in the food grain sufficiency and augmentation from surface water resource becomes paramount.

To meet the current dry season requirement for water in the Southwest Region, flow from the boundary rivers must be effectively transferred to the areas of demand. A wide variety of options of how to do this have been considered including consideration of extractions at various points from the Ganges or from the Padma as illustrated in Figure 6.1. The dry season water levels in the Padma and Meghna are low and to develop these sources extensive pumping against the gradient of the land would be required to command much of the area. The Ganges, therefore provides the most suitable source of surface water for augmenting the water supply to the Southwest Region and part of the South Central Region.

The distribution of water from the boundary rivers should ideally utilise existing rivers. The older Ganges spill rivers such as the Chandana and Matabhanga however are at too high a level for gravity flow with the current levels in the Ganges and in the last 25 years only the Gorai River has carried significant dry season flow.

6.2 Need for Augmentation and Potential Benefits

6.2.1 Need For Augmentation

The strongly perceived need for augmentation comes from a variety of sectors. These requirements have been studied and the potential benefits and alternative means of achieving the desired objectives have been considered. Because the costs of supplying water are likely to be relatively high, unrealistic expectations can be quickly identified and the approach has been to consider the use of water in the best way as a scarce and limited resource.

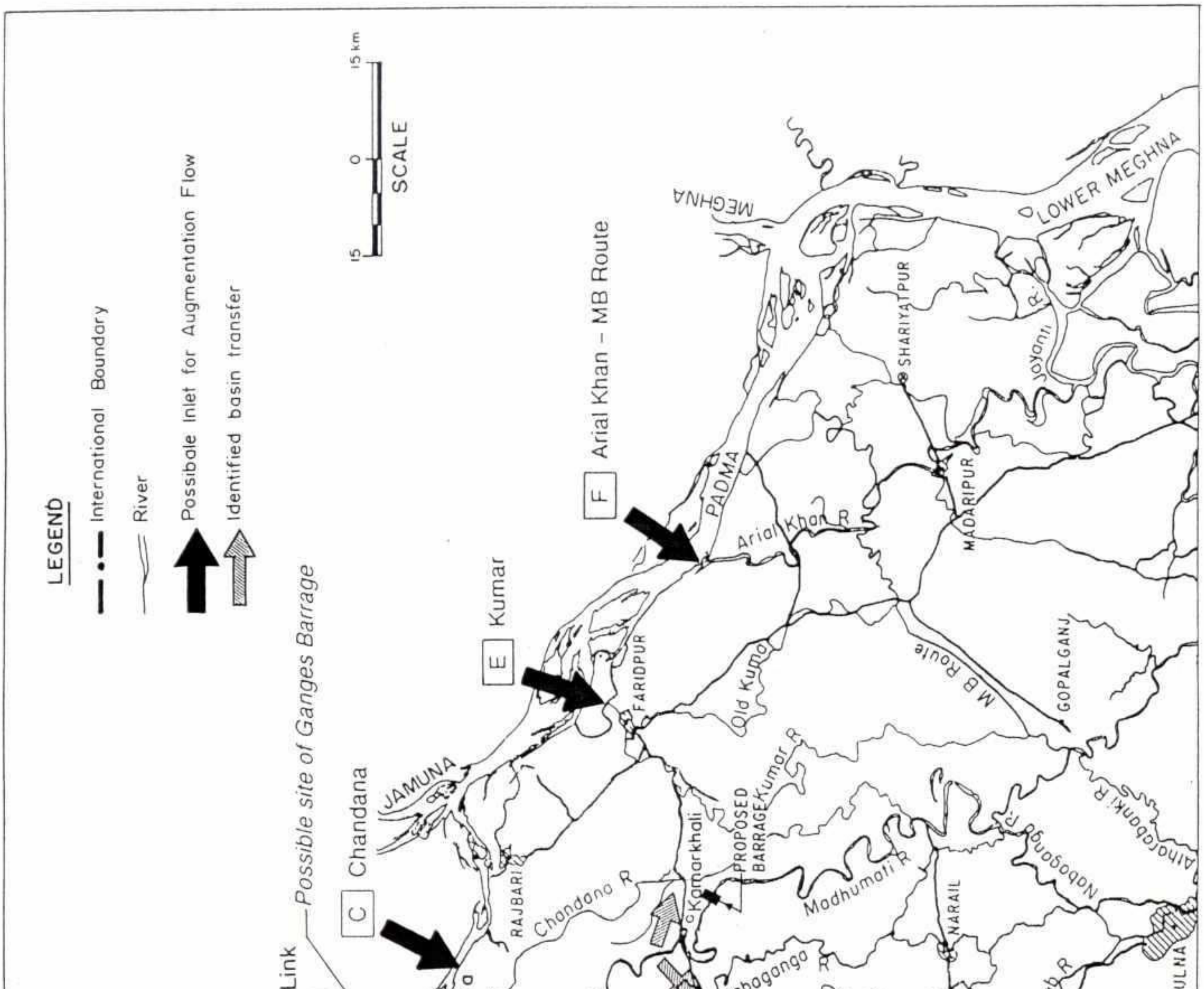
Through extensive data collection and analysis it has been possible to quantify most of the requirements and benefits of augmentation to prioritise the needs and timing of the development. The perceived needs are summarized in Table 6.1.

TABLE 6.1

Identification of needs for Augmentation of Dry Season Flows

Sector	Requirement	Desirable Flow rate in Dry Season (m^3/s)
Agriculture	Irrigation	1000
Water Supply for Khulna (Domestic and Industry)	(a) Salinity Control or (b) For direct supply	150 - 200 5 - 6
Forestry	Commercial Production of Sundri in Sundarbans	> 250
Transportation	Mongla Port	1000

Figure 6.1



Augmentation Choices

The actual requirements must be considered in light of what is practically attainable and it is therefore, worth summarising the options for augmentation.

A comparison of the mean of the monthly average flow in the driest month for the period since the expiry of the Agreement (1989-92) with that for the periods when the Agreement was in force (1976-88) and the Pre-Farakka years (1934-75) is summarised as follows :

Condition	Flow Rate (m^3/s Monthly Average) Driest Month		
	Post Agreement 1989-1992	During Agreement with India (1976-1988)	Pre-Farakka 1934 - 1975
Minimum	517	664	1260
Mean	576	1063	2031

The record since the expiry of the Agreement with India is too short to perform a valid statistical analysis and given the early monsoon of 1988 and the unusual dry nature of 1991 and 1992, the lowest expected mean monthly flow in the Ganges has been taken as 576 m^3/s for the period, when there was no agreement with India.

The recorded minimum daily flows in the Ganges at Hardinge Bridge during the dry season (March/April) in 1992 have been significantly lower than that recorded for the same months during the period 1976-1988 (during Agreement). A further decline in the minimum daily flows was seen in March 1993.

The amount that may reasonably be extracted without control on the Ganges is therefore estimated as 350 m^3/s if there is 576 m^3/s in the river leaving 226 m^3/s flow downstream. The amount extractable with control in the Ganges can be much higher.

6.2.2 Benefits of Augmentation

Augmentation of dry season flows in the Gorai / Madhumati river system could have beneficial impacts on the following :

(a) further areas totalling 165000 ha to 175000 ha could be brought under irrigated agriculture where by the cropping intensity could be raised from the present 156% to 191%;

(b) salinity in the rivers around Khulna could be controlled (Figure 6.2) if at least 150 cumecs could be sent down the Gorai for this purpose;

(c) fresh water could be supplied directly to Khulna from an upstream river (if (b) cannot be achieved);

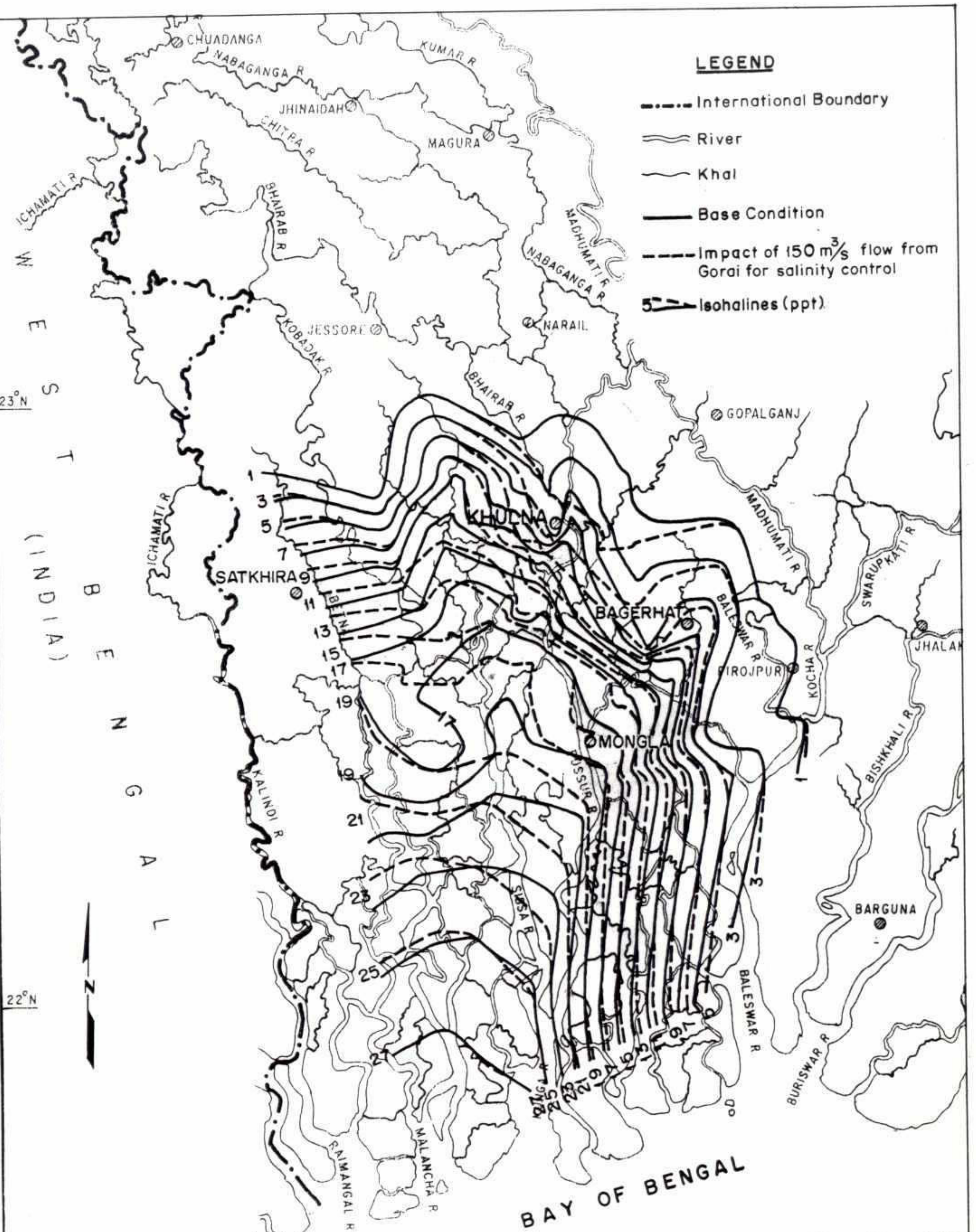
(d) pollution in the rivers, including agrochemicals, could be flushed down the river system, thus improving the environment and public health;

(e) navigation (country boats) in the Gorai-Madhumati system, particularly in the internal rivers such as Nabaganga, Chitra, Kumar, etc. could be improved.

6.3 Development Options

It is apparent that currently the water available in the Ganges is very limited. The G-K irrigation system already has a requirement for 100-120 m^3/s leaving a maximum of about

Figure 6·2



Simulated Assessment of Impact on Salinity ($150\ m^3/s$ Flow from Gorai)

250 m^3/s that could be used elsewhere. Other possible options to increase this figure would be:

- Pumping from the Ganges or Padma with large pump stations (another 50 to 100 m^3/s could possibly be extracted from the Ganges).
- Improving the Arial Khan/Kumar/MBR link, however simulations show this could provide only 50 m^3/s.
- Storage of water in beels, silted rivers etc. Given the difficulty in finding suitable sites, the water supplied would only be limited and at a low level.
- Development of a barrage on the Ganges.
- Storage dams in the upstream catchment.
- Long Term Agreement with India and other upstream users on the sharing of the low flows in the Ganges.

The final two "options" may be taken as desirable but require cooperation of the countries involved and are the subject of current Inter-Governmental negotiations the results of which will not be available during FAP-4. For planning purposes the existing condition (no agreement) is assumed with no deterioration in the current flows.

6.4 Choices for Augmentation Routes

6.4.1 General

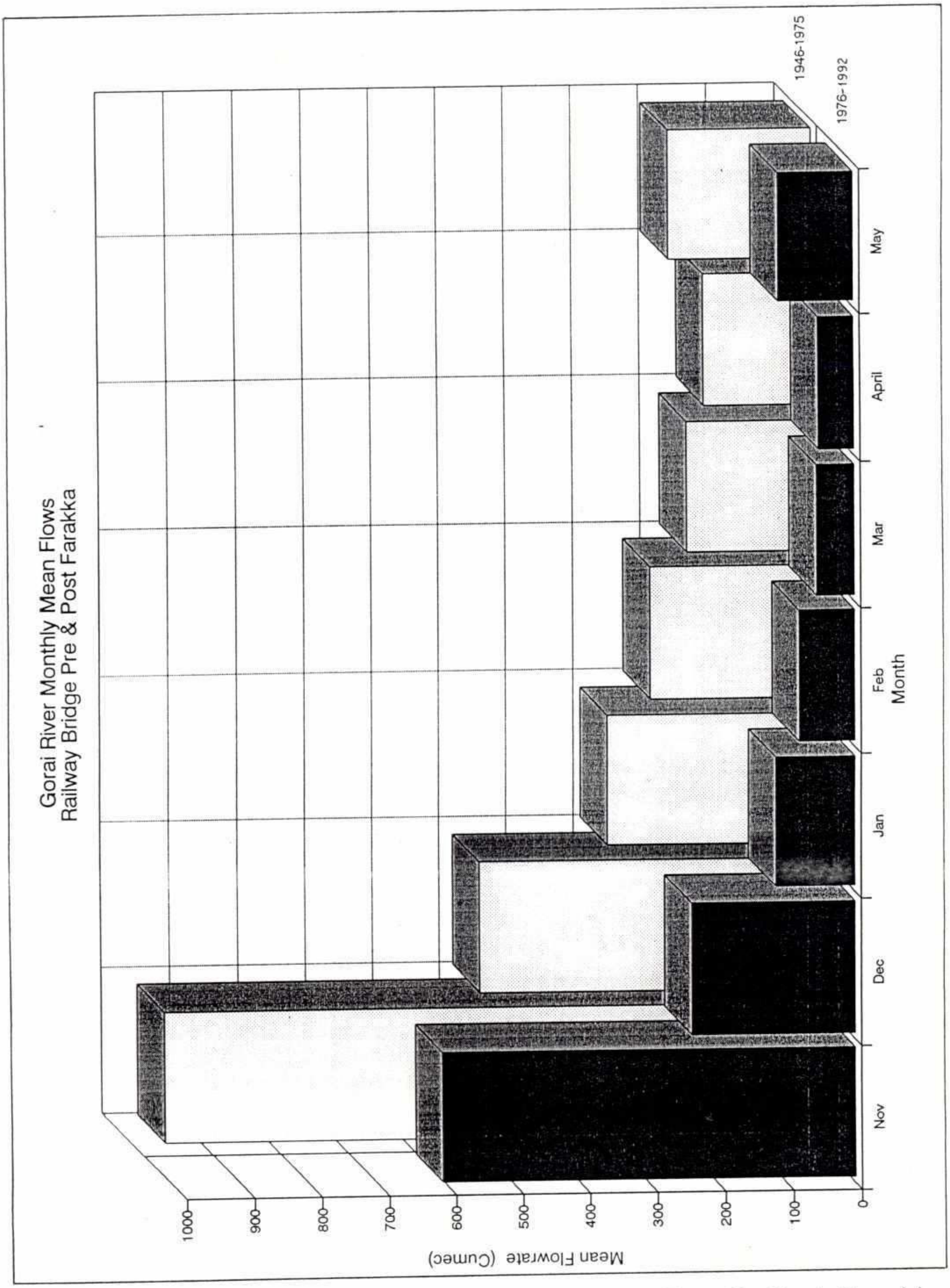
As discussed in section 6.2 there are a limited number of possible routes for major augmentation of dry season flows. There is the possibility of developing a number of schemes for smaller irrigation areas such as now being completed on the Nabaganga at Magura or as proposed for the Mathabanga/Upper Bhairab. Without development of a major augmentation route such development will be limited.

The choices for main augmentation routes that are shown in Figure 6.1 are summarised in Table 6.2. The preferred route is through the Gorai for which more detailed description of the proposed works, costs and estimates of the capital and maintenance costs have been prepared.

6.4.2 Gorai Schemes Routes A & B

The Gorai is the most suitable conveyor of flow to the Southwest Area given its position, the higher level of Ganges water at its offtake and the relatively lower bed level compared with any other spill river. The Gorai has carried minimum dry season flows of the order of 150 m^3/s in the pre-Farakka years (except during the cyclical low years) but in the past ten years flow has declined to practically zero and the river was dry throughout January to May in 1992) (Figure 6.3).

Figure 6.3



Gorai River Monthly Mean Flows, Pre & Post Farakka
(Railway Bridge)

TABLE 6.2

Low Flow Augmentation Schemes and Indicative Costs

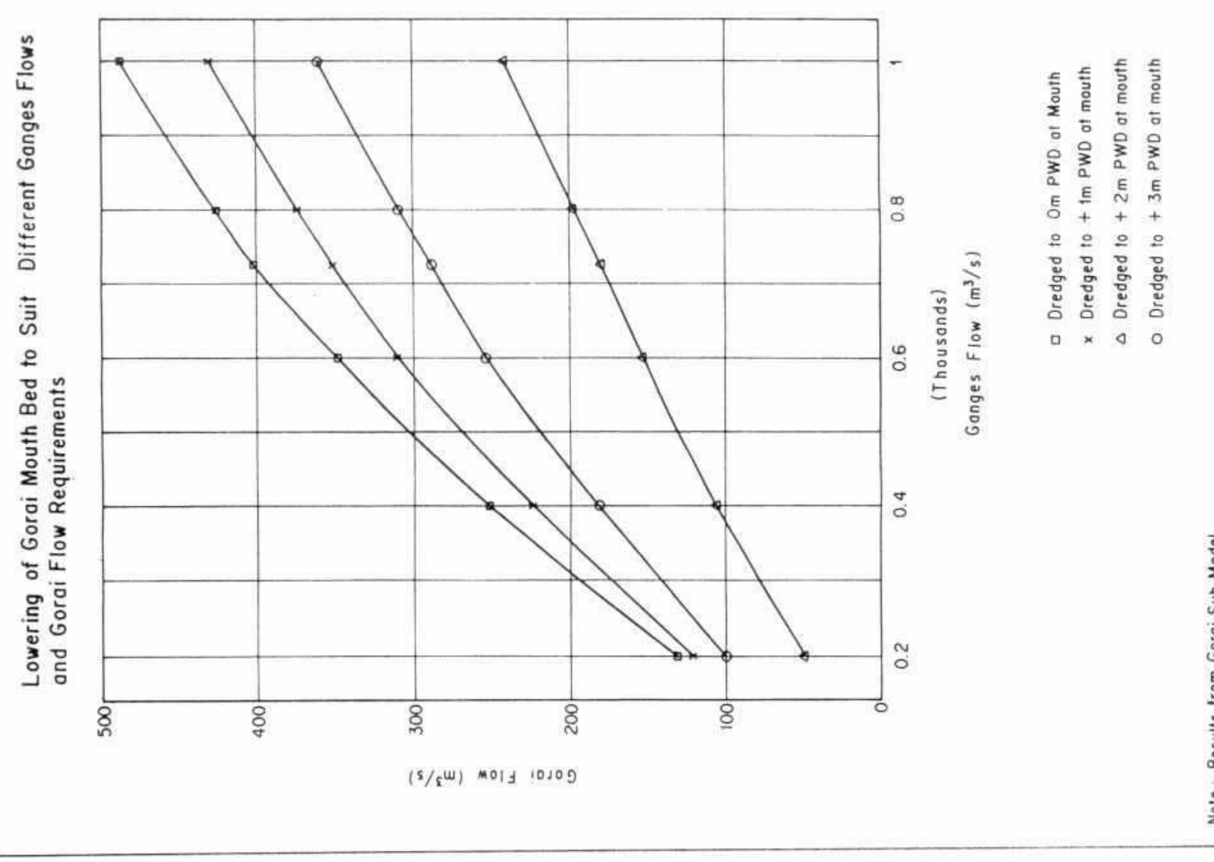
Distributor	Reference No	Description	Capital Costs (Annual Cost)* MTK (1991 prices) For Augmentation Flowrate (m^3/s) 50	100	150	250	Remarks
Gorai	A1 Gravity Flow	Dredging of first 30 km of Gorai & disposal of Spoil. For 250 m^3/s augmentation river realignment at Kamarkhali necessary.	-	1785 (46)	2056 (71)	3453 (176)	Could be implemented quickly. Maintenance Dredging requirement should reduce if spoil disposal outside river system.
	A2 Gravity Flow	Control structure and Training embankment. Dredging of first 30 km of Gorai disposal of spoil. For 250 m^3/s augmentation realignment at Kamarkhali necessary.	-	4593 (31)	4892 (46)	6189 (116)	Control structure capacity in Flood = 4250 m^3/s to maintain size of channel in Madhumati; Gates to restrict flow post monsoon to induce slower recession of flow in Gorai.
	A3 Gravity Flow	Control structure set back and works as option A1.	-	3391 (42)	3690 (61)	4987 (151)	Increased maintenance before implementation of Ganges Barrage.
	A4 Gravity Flow	Training Groynes in Gorai + Dredging Realignment as option A1.	-	2600	3300	4200	Training Groynes restricts width of Gorai to induce deeper section and reduce maintenance dredging.
	B1 Gravity	Link Canal (8.5 km) to Kumarkhali Dredging & Kamarkhali realignment for Q = 250 m^3/s. Control structure at take off position in Ganges Right Embankment.	-	-	-	8300 (352)	Augments flow but does not improve Gorai mouth. Greater excavation than to improve Gorai.
	B2 Pumped	Pumping station to link canal alignment as B1. New rail bridge. No works in Gorai river.	-	1050 (164)	1800 (181)	2400 (204)	Major Pumping station and link canal. Land acquisition 105 ha. Significant construction time, possible power generation requirement.
Chandana	C1 Gravity	Excavation of deep channel along course of Chandana River. Control structure at Intake and upstream dredging to Ganges.	-	-	-	15000 (460)	Large Excavation required.
	C2 Pumped	Construct pumping station at existing embankment. Improve channel for higher flow rates than 50 m^3/s. Excavate upstream channel for Ganges	610 (96)	-	3000 (195)	4025 (236)	Existing channel most suited to flow of 50 m^3/s. Realignment of upstream channel could be considered.
Hisni/ Mathabhanga	D1 Pumped	Construct pumping station and link to supply dry season Flow to Mathabanga. Control structure on Mathabanga and improved link to Bhairab/Chitra.	1830 (110)	2560 (130)	3215 (200)	4470 (256)	Supplies area not easily reached by other schemes. Significant upstream dredging at mouth of Mathabanga.
Arial Khan	F1	Dredging of Kumar River linking Arial Khan and MBR. Construct half tide weir on Madhumati and dredge Atharbanki.	1600 (60)	-	-	-	Low flow only as low head available in Padma. Flow reduces if there is inflow from Gorai. Arial Khan rises earlier than Ganges.
	F2	Dredge Kumar and construct weir on Madhumati. Dredge Madhumati from Halifax cut to MBR.	-	2780 (125)	-	-	As option F1. Large amount of dredging in Madhumati.
Various + Link canals	G	Ganges Barrage at nodal point near to Chandana. Control at Gorai mouth necessary.	58000 - 87000 —— 600* m^3/s				8-10 years construction period. Storage capacity could be used for balancing peak water demands.

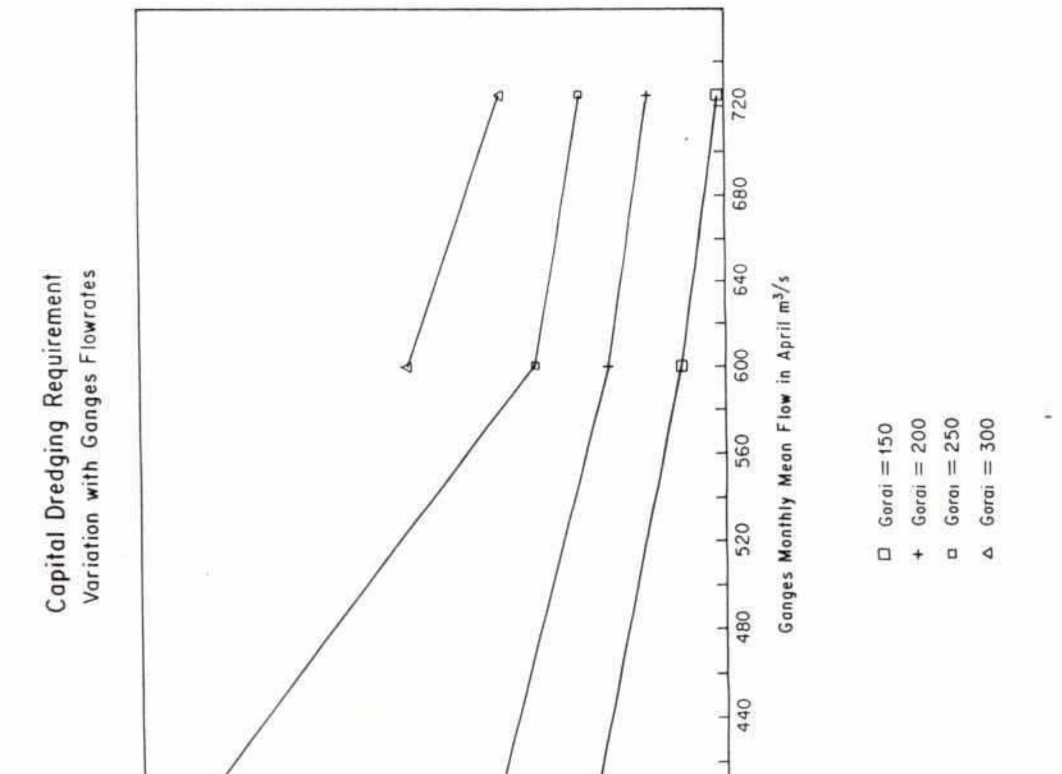
* Annual Costs Shown in paranthesis include maintenance dredging

Note: Financial Capital Costs given for development of water source but not including costs of distribution system.

Gravity schemes on the Gorai (as opposed to pumped options) improve both the dry season flow regime as well as the discharge and therefore may be expected to have benefits to the

Figure 6.4





Flow in Gorai for Different Dredging Options general "health" of the river. Having control over the flow rates at high flood levels may also have flood control and drainage benefits, but the capacity of any control structure has to be set to allow flows greater than dominant discharge. This is to ensure that the morphology of the downstream reaches are not affected, as they form a critical part of the Pussur/Sibsa system upon which the land drainage of a large area is dependent. As a result, whilst some measure of improved flood protection appears possible, improvements to drainage are likely to be small. The morphology and hydraulics of the Ganges and Gorai have been studied including analyses of cross sections, planform changes and changes in rating curves at Hardinge Bridge, Gorai railway bridge and Kamarkhali. Further details of the comprehensive studies are presented in the final morphological report (Volume 3). Quantities of excavation required for the schemes were based on surveys carried out in 1992 as part of the study. The options for interventions that were identified with the component parts of an intervention are given in Table 6.3.

Extracting a significant proportion of the Ganges flow at the Gorai will slightly lower the water level at the G-K irrigation scheme intake, consequently increasing power requirements. This has been studied and the results show the effect is at most of the order of 0.1m depending on the flows in the Ganges and Gorai. This is a small impact compared to changes due to lowering of flows in the Ganges (the impact of Farakka has been to lower levels at Bheramara by approximately 1.5 m).

Capital dredging is a component common to all schemes for increased flow into the Gorai mouth and is a significant cost. The sensitivity of the capital dredging requirement to the flow in the Ganges is shown in Figure 6.4. This was derived using model simulation results from surveys of bed levels in the Ganges and Gorai with cross-sections at 500m intervals to locally supplement the BWDB cross-sections which are more coarsely spaced. Results of the survey carried out by FAP-4 in the Gorai mouth and the Ganges are shown in Figure 6.5.

By disposing spoil in the Ganges near the constriction (Figure 6.5) it may be possible to raise water levels slightly giving more flow into the Gorai. The need for such measures is dependent on the flow in the Ganges and further measures such as bandaling to induce silting of the river where desired (as studied by FAP-21) could be considered as a way of increasing water levels and thereby reducing dredging requirements. The constricted sections move each year and surveys would need to be done in early October each year for work to be started later that month.

The disposal of spoil from the capital works would be partially in the Ganges, some at the Gorai near the railway bridge and a very limited amount on land bordering the Gorai. For maintenance works, disposal could be within the river.

The various options considered for augmentation of the Gorai are discussed below :

Option A1-Dredging Only

This option entails a major dredging and spoil disposal programme some of which will be on land and some pumped into the Ganges. Three flow rates have been considered,100, 150 and 250 m^3/s, for the highest flow a loop cutoff at Kamarkhali is necessary to improve flow conditions which should also help to maintain lower bed levels upstream. The cutoff is not essential for the lower flowrates and is therefore omitted, but could be desirable for reducing maintenance dredging. By dredging the upper reaches of the Gorai, the river realignment at Kamarkhali should not induce significant siltation downstream : morphological modelling of this aspect has shown this to be the case. The dredging component for obtaining a minimum flow of 150 m^3/s comprises 12 million m^3 in the first 30 Km. Although there are parts of the river further down which do not have sufficient cross-sectional area, others, particularly near bends, have greatly excess capacity and it is assumed that with increased low flow some sediment will be redistributed by normal sediment transport.

TABLE 6.3

Options for Interventions at Gorai Mouth

	WORK COMPONENT	DRY SEASON AUGMENTATION OPTIONS											
		A1	A2	A3	A4	B1	B2	C1	C2	D1	F1	F2	G1
(a)	**Control Structures**												
a1	Control structure in Gorai Mouth		■										■
a2	Control structure at entrance to the Mouth			■									
a3	Weir on Madhumati									■			
a4	Control Structure on Matabhanga										■	■	
(b)	**Groynes in Gorai / Madhumati**												
b1	T - Groynes in Gorai Mouth (at intervals) up to Kushtia			■	■								
b2	Forward T - Groynes at entrance to the Mouth				■								
b3	Groynes at upstream and downstream of railway bridge	▒	▒	▒	▒								
b4	Kicker Groynes at flow cross-over locations	▒	▒	▒	▒								
(c)	**Capital Dredging**												
c1	Gorai dredging from Mouth to Kumarkhali (km 16)	■	■	■	■								
c2	Gorai dredging downstream of Kumarkhali (km 14)	■	■	■	■	■							
c3	Chandana dredging upstream of embankment												
c4	Hisni dredging upstream of embankment												
c5	MRB/Kumar dredging & Atharabanki dredging												
c6	MBR/Kumar & Madhumati dredging												
(d)	**Link Canal**												
d1	Kumarkhali link canal with control structure and railway bridge					■	■						
d2	Chandana link canal with new control structure							■	◧				
d3	Hisni P.S. to Matabhanga/Link to Chitra/Bhairab									■			
(e)	**River Realignment / Bend Cutoff - Gorai River**												
e1	Kamarkhali bend	◧	◧	◧	◧	◧							
e2	Lower reach bends (Gorai)	▒	▒	▒	▒	▒							
(f)	**Pump Station**												
f1	Kumarkhali Pump Station						■						
f2	Chandana Pump Station								■				
f3	Hisni Pump Station									■			
(g)	**Ganges Control**												
g1	Ganges Barrage												■
g2	Low cost measures in Ganges at Gorai Mouth	▒	▒	▒	▒								
g3	Training Groynes in Ganges at Gorai Mouth	▒	▒	▒	▒								

■ Component part of Intervention, ▒ Optional Component,
◧ Required for Higher Flowrates

[vp\gorai\tab6-3]

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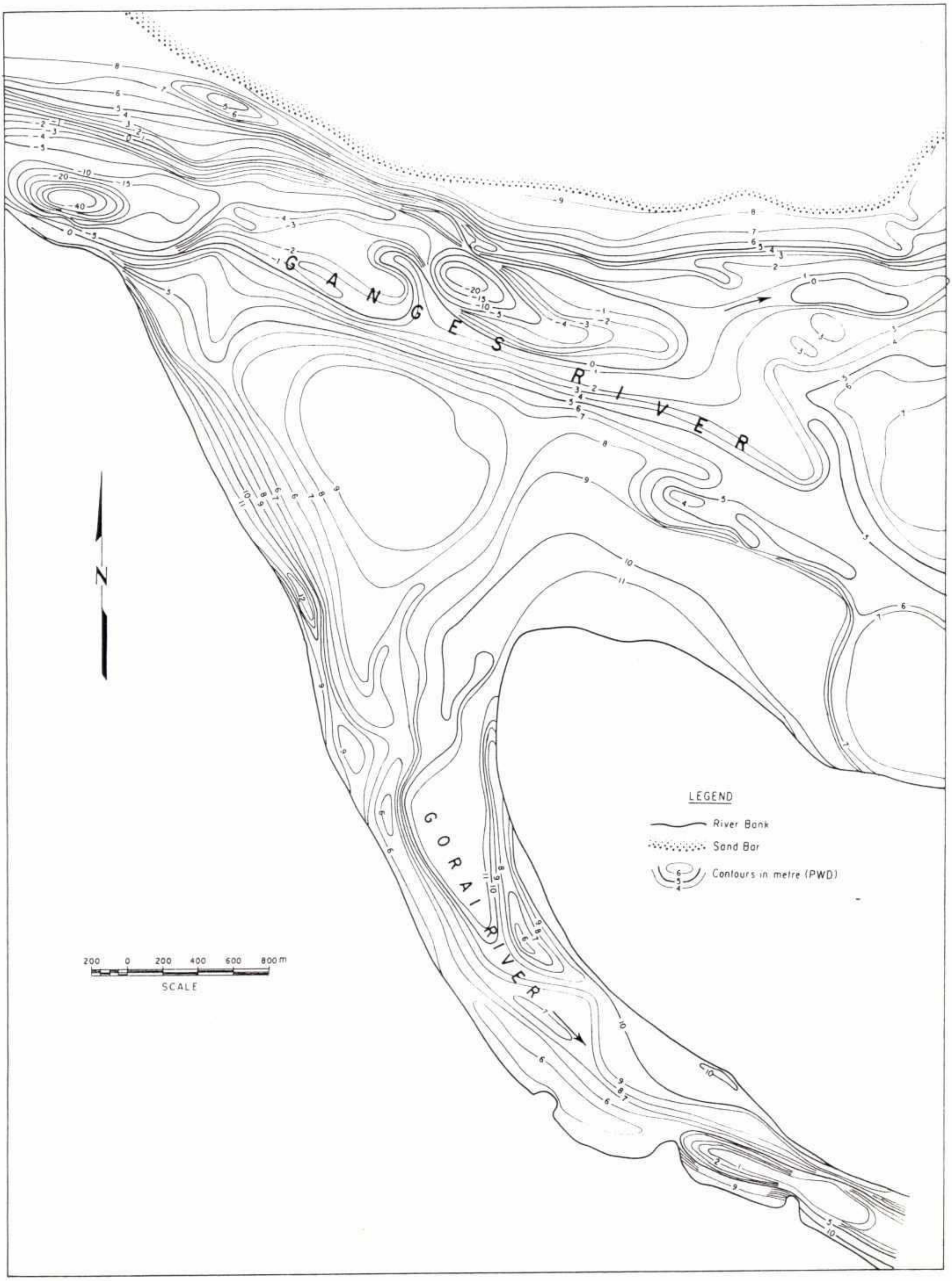
Figure 6.5



Bathymetry Survey, July 1992

For 150 m^3/s, annual maintenance dredging is estimated as around 0.62 million m^3 though this will reduce as the Ganges orientation becomes more favourable and the condition of the Gorai improves. The costs of maintenance dredging have been included in the annual costs given in Table 6.2. The logistics involved in this amount of dredging is significant.

There will be an increased flood flow due to the increase in the flow cross-section near the mouth which would result in increased flood peaks of about 10%. Towards the end of the wet season there need to be a fairly high level of commitment to dredging at key points though a greater part of the spoil could be retained in either the Ganges or the Gorai river system.

Option A2 - Control Structure

To reduce flooding in areas downstream and to give the opportunity to control the rate of recession of Gorai flows, a control structure could be provided in the mouth of the Gorai in a similar location to that proposed by IECO in 1980. The site is close to the Ganges to minimise maintenance requirement (Figure 6.6). At present the channel length that would need to be dredged in front of the structure is 500m though this can be expected to reduce as the Ganges returns to a more North-South orientation at Talbaria in about 2005 as preduced as a result of the morphological studies. For 150 m^3/s the annual maintenance dredging quantity is estimated as 0.4 Million m^3. It is not sufficient to have a control structure alone and extensive capital dredging (components c1 & c2) is required. With the increase in section proposed, the potential for higher discharges in the wet season is about 10% and the control structure therefore has the additional advantage of preventing any increases in flooding. As well as dredging to chainage 30 Km the bend cut off at Kamarkhali has been considered as this gives significant reduction in maintenance dredging. However the expense of cutting off the Kamarkhali bend seem to outweigh the benefits.

The normal flood peak design flowrate for the control structure is 4250m^3/s the dominant discharge of the Gorai. A high design discharge for the structure ensures flexibility for relieving the Padma and maintaining the size of channel in the tidal part of the Gorai (Madhumati), which provides an important part of the tidal volume of the Pussur - Sibsa system. Limiting flows to 4250 m^3/s has advantages for structure protection works and for reducing maintenance.

The requirement for maintenance dredging that was identified in the Second Interim Report was high and improved estimates have been made together with morphologically based proposals for intervention. Four guide banks in the reach to the Gorai railway bridge are proposed. These will have the effect of ensuring well defined cross over points to aid the formation of a stable meandering flow channel. Currently the low flow channel is shifting each year giving a wide section and causing high bed levels. By stabilising the alignment of the channel a deeper, narrower, low flow channel will be formed reducing the maintenance requirements.

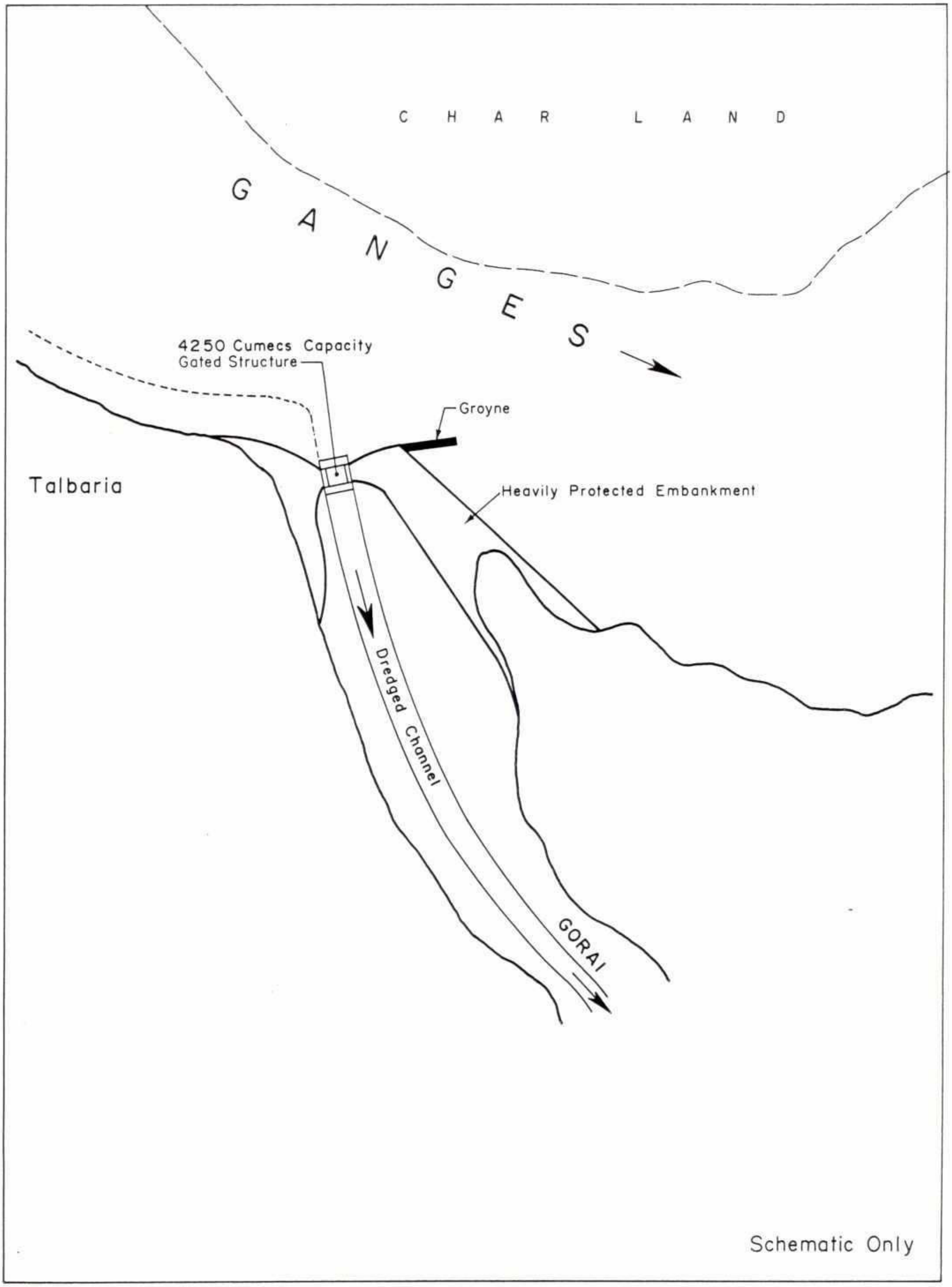
Option A3-Control Structure Set Back

This is essentially similar to option A2 but the structure is set back into the Gorai (Figure 6.7). This gives a reduced need for protection works but greater and less predictable maintenance costs.

Option A4-Groynes only

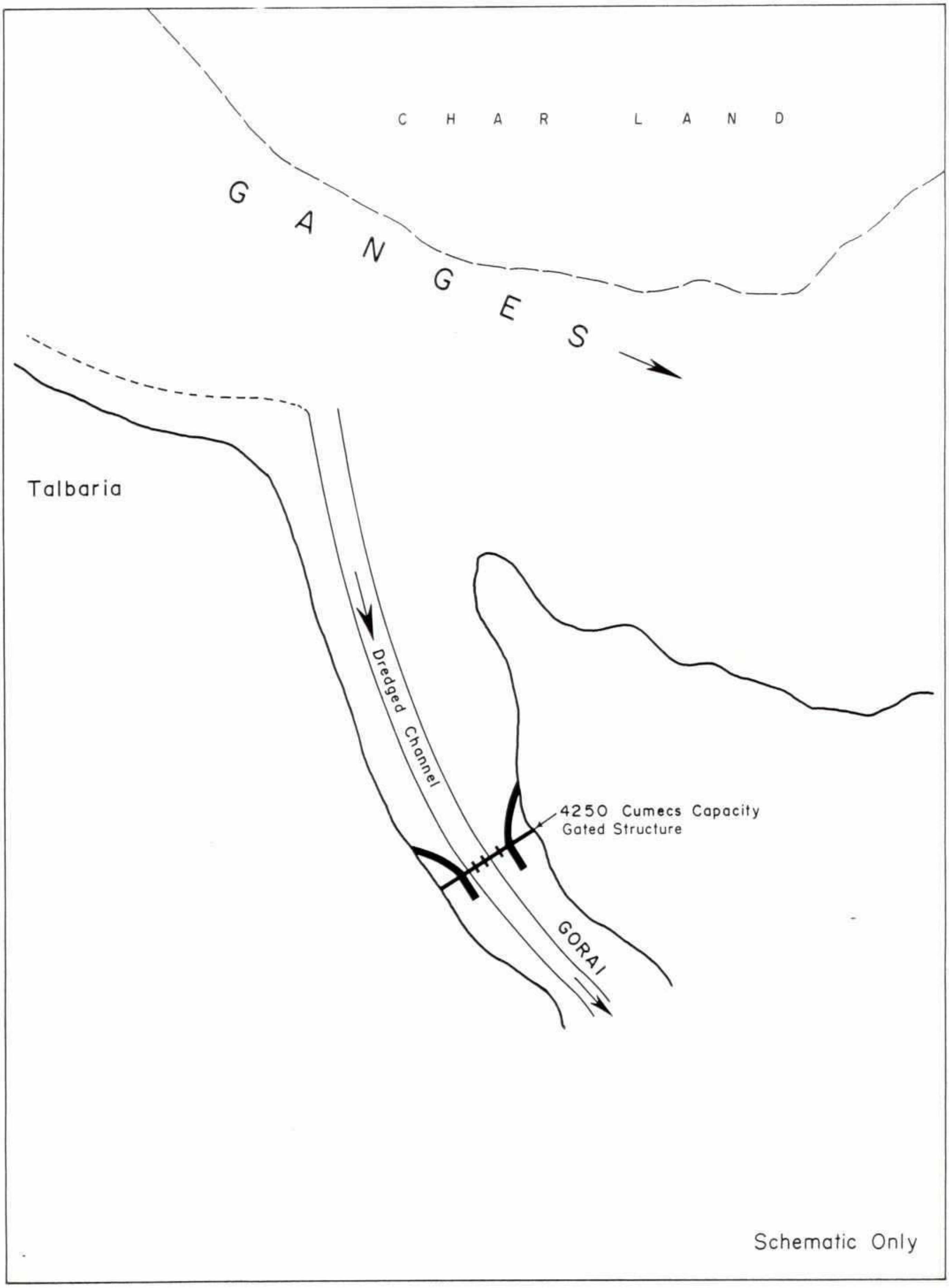
Where the channel is wide it can be expected that the channel bed will be shallow. The change in the Ganges alignment has left a very wide channel at the mouth through which the Gorai flow passes. It may also be seen that around the tip of the T-groynes at Kushtia there is a deep channel due to local scour effects. This option therefore comprises construction of two groynes in the mouth plus some training banks to restrict the flow

Figure 6.6



Possible Interventions at Gorai Mouth
Option A2 Forward Control Structure

Figure 6.7



Possible Interventions at Gorai Mouth
Option A3 Control Structure

areas with local scouring producing a deep low flow channel (Figure 6.8). The area from the mouth to Talbaria would need to be dredged annually.

In addition, there is a need for initial capital dredging of the first 30 km reach to Kamarkhali and a control structure at Kamarkhali.

If a Ganges Barrage is constructed, a control structure would be required at the Gorai mouth.

Option B1-Link canal to Kumarkhali

Because many and the most serious of the Gorai problems arise in the mouth, a suitable alternative site (though not as good as Talbaria where the Ganges has always flowed adjacent to the right bank) could be developed some 16 Km downstream. A link canal from here, some 150m wide, combined with dredging downstream, gives a possible option. The canal would be closed with a control structure at high Ganges flow to reduce siltation which, like the A3 control structure would require scour protection.

This option reduces the amount of dredging required in the upper reaches of the Gorai although to ensure that wet season flows do not continue to decline some dredging/excavation would be needed. A railway crossing would also be required.

Unfortunately the amount and cost of earthwork required to build the canal at low level across virgin ground (at high level) is comparable to that needing to be excavated from the Gorai upper reach and thus this is unlikely to be a viable option.

On completion of the Ganges Barrage this option would become obsolete.

Option B2 - Link Canal to Kumarkhali with Major Pumping Station

If a similar route is adopted as B1 for a link canal with booster pumping station (Figure 6.9) then the size of the canal can be reduced to a base width of 50 m and can be designed to give the desired flows without intervention on the Gorai. The capital costs of such a scheme are lower but there is no improvement in the river. There is a requirement for continuing dredging upstream of the Pump House (in similar fashion to that carried out for the G-K scheme). Given the experience of the G-K scheme with shortage of power, large pumping station should not be favoured.

This option would become obsolete when the Ganges Barrage is built.

6.4.3 Other Schemes

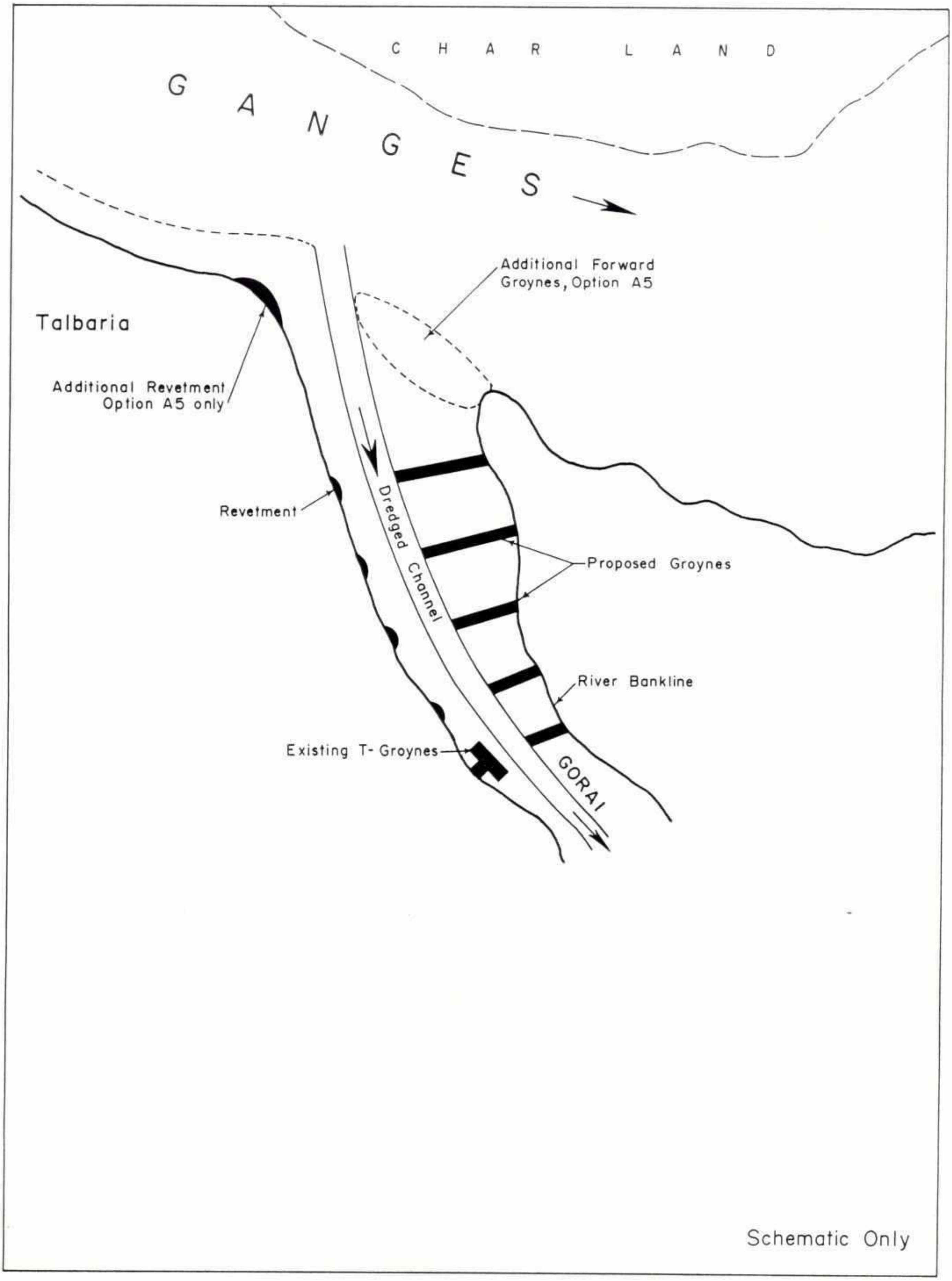
Offtakes

A number of other possible supply routes such as increased pumping at the G-K inlet works to supply areas outside the scheme and using the Kaliganga were examined and rejected as being impractical with the present conditions of low flow in the Ganges. The possibility of helping the Gorai to open a new mouth was also considered but rejected on the basis of morphological studies of the Ganges, which indicate that, although not currently in a favourable orientation, in the longer term there is no better position for an offtake.

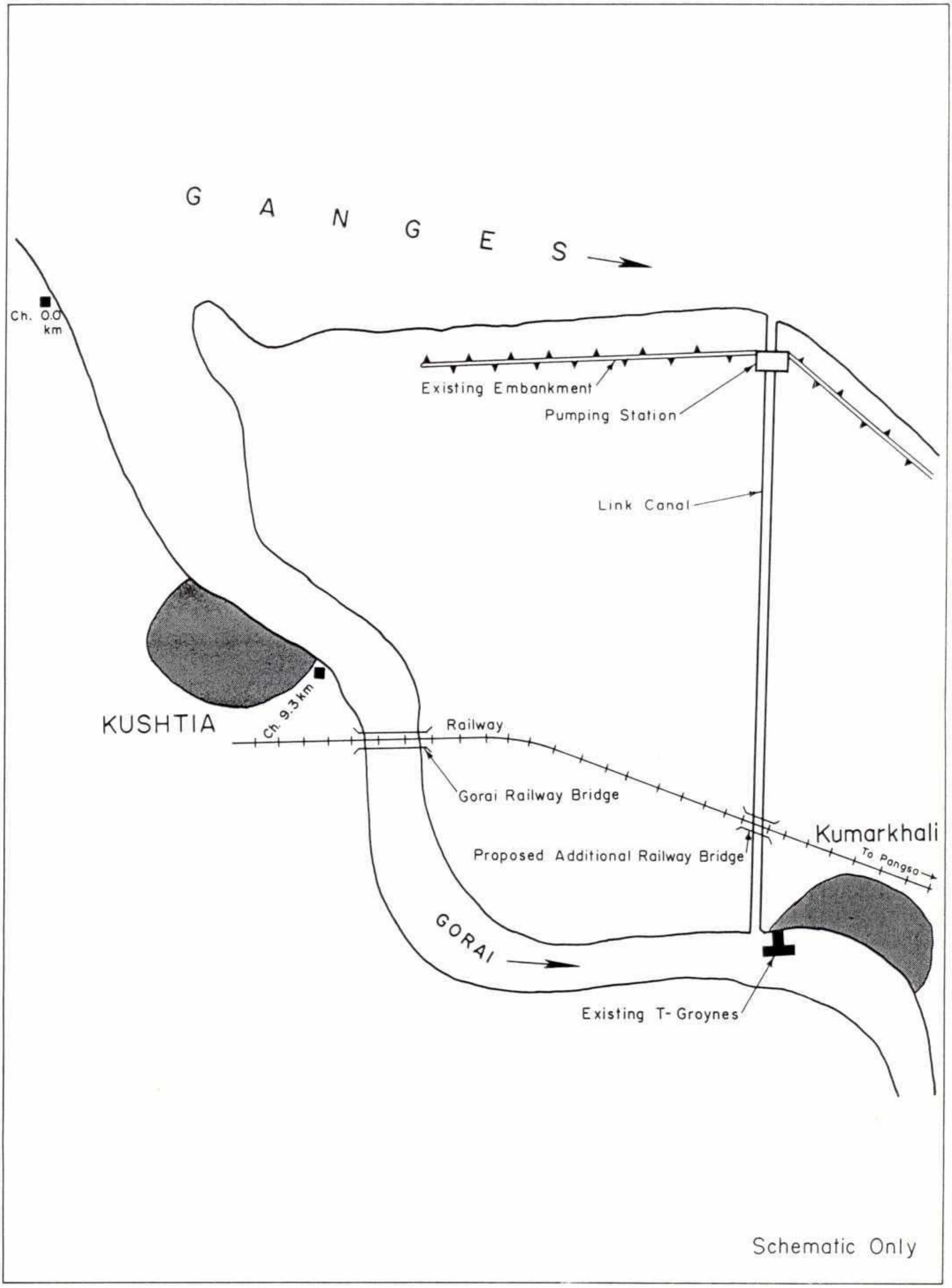
Gorai Lower Reach Bend Realignments

The length of the lower reach has increased by some 10 km since 1973. Accretion of the river bed due to changes upstream together with the additional lengthening is probably causing an increase in bed level upstream, as shown by a rise in the rating curve at Kamarkhali. Measures could be taken to reduce the river length but there would be

Figure 6.8



Possible Interventions at Gorai Mouth
Option A4 (A5) Groynes to Increase Depth



Possible Interventions at Gorai Mouth
Option B2 (Pumping) No Improvement to Gorai

difficulties in trying to stabilise this mobile part of the river and pilot cuts alone would probably be satisfactory. This option could be considered if monitoring shows that further measures are required.

Training Groyne in the Ganges

It is clear that some of the problems of the Gorai are caused by fluctuation in the Ganges' alignment. Consideration has therefore been given to whether training the River Ganges permanently into a favourable alignment is a possible option. This is a relatively high risk option that would be probably best be implemented when the Ganges next takes up a favourable alignment which could be maintained.

6.4.4 Preferred Option

For augmentation through the Gorai various options have been considered as above and from these, Option A2 - Control Structure at the mouth emerges as the preferred scheme.

Principal reasons for selecting Option A2 in preference to the others are summarised below:

Option	Reason for rejecting
A1 - Dredging only	High maintenance cost.
A3 - Control structure set back	High maintenance cost.
A4 - Groynes only	High capital cost; a control structure would be required on construction of the Ganges Barrage.
B1 - Link canal to Kumarkhali	High capital cost; does not improve the Gorai mouth; scheme would become obsolete on completion of the Ganges Barrage.
B2 - Link canal with pump station	Significant construction time; high maintenance costs for pump station and possible power generation requirement.

6.5 Sustainability

Gorai Augmentation Project proposed as a 'stand alone' project offers a worthwhile investment and a necessity which addresses the immediate risks associated with the closure of the Gorai mouth. With the current rate of flow in the Ganges the Project is technically and economically feasible (Section 11) and offers the opportunity to develop a significant area for irrigated agriculture in the SW Region. This will also enable to secure the dry season fresh water supplies for Khulna by transferring about 10 m^3/s through the Chitra. However, the project's success depends on the commitment to annual maintenance dredging, which is a significant amount (about Tk 59.0 m/year), at the mouth and to about 15 km downstream. Dredging requirements in the initial years will be much less as the project is developed in phases and the channel required to carry about 60 m^3/s will be smaller and therefore requires less dredging.

The Project alone cannot meet the Area's food requirement and further development is required to maximise opportunity and narrow the widening gap. This is therefore dependent on further abstractions from the Ganges, which in turn is dependent on releases from the Farakka barrage. An agreement on the sharing of the Ganges water with India therefore becomes paramount. With an Agreement and assuming a level of flow similar to that agreed in the 1984 Memorandum of Agreement, over 1 Mha of land could be brought under irrigated agriculture. However this needs political will on both sides to achieve. In the absence of any Agreement and with the current flows, water levels in the Ganges need to be controlled for long term sustainability. This would give opportunities for development of additional areas in addition to securing water supplies to existing schemes, notably to the G-K Project, where the storage levels in the Ganges will ensure higher levels at the pumping station.

6.6 Augmentation Choices

The principal choices for augmentation of the dry season flows may be summarised:

(a) Pumping schemes : Hisni/Chandana, Gorai etc.
(b) Gorai Augmentation
(c) Ganges Barrage

The pumped schemes though apparently economically attractive the experience with large scale pumping at the G-K Project and in the Barisal Irrigation Scheme makes these schemes unattractive.

Gorai augmentation is favoured as it improves the general 'health' of the river which is now thought to be deteriorating. For the Gorai augmentation the preferred scheme is Option A2 with control structure at the mouth, guide banks and capital dredging. Annual maintenance dredging is required but is manageable.

The major augmentation option is the Ganges Barrage which though initially has a high capital cost, the technology is proven and the advantages offered cannot be gained by other means. Even with the current low level of flows in the Ganges, long term sustainability can be improved and large areas (than the Gorai scheme) will be benefitted. In addition salinity control at Khulna could also be achieved.

6.7 Development Programme

A phased development for the Gorai Augmentation Project is proposed which is summarised as follows:

1 - 3 yrs	-	Construction of the Gorai mouth works to allow about 60 cumecs to pass; construction of the Kamarkhali Barrage.
4 - 6 yrs	-	Area Development of about 60,000 ha.
7 - 10 yrs	-	Further dredging of the Gorai to increase flow to 170 cumecs. Development of additional area of about 105,000 ha.
11 yrs +	-	Development of additional areas is contingent upon a Ganges Barrage and/or Agreement with India on sharing of the Ganges water.

7 PROPOSED AGRICULTURE DEVELOPMENT

7.1 Changes in Land Types

Controlled flooding and drainage incorporating compartmentalisation will bring major changes in the land type according to flood depth. The average flooding conditions in the pre-project (from MPO) and post-project condition (derived by Consultants) are shown in Table 7.1. From the Table it can be seen that there will be more land available under F0 and F1 land type where the agricultural productivity will be much higher.

At present 19.4% of the net cultivated area is highland (F0 land), 31.9% of the area is medium highland (F1 land), 33.1% of the area is medium lowland (F2 land) and 15.6% of the area is lowland (F3 land) (Table 7.1).

With project, the proportion of land types is estimated to change to 49.6%, 43.6% and 6.8% of F0, F1 and F2 land respectively. The change in land type will convert a high proportion of mixed aus and b. aman area into t. aman area, a major part of which will be suitable for HYV varieties. With irrigation the land use and cropping pattern will also change considerably.

TABLE 7.1

Present and Future Land Types

Planning Unit	NCA in Hectare						
	Present				With Project		
	F0	F1	F2	F3 + F4	F0	F1	F2
SW4	10481	7851	2846	822	12100	8800	1100
SW5	13909	24446	14513	4036	31297	22771	2845
SW6	6957	14980	8197	2539	17971	13069	1634
SW7	11527	30319	38369	29785	44000	55000	11000
SW10	15995	19393	36602	10319	45268	32922	4115
Total	58869	96989	100527	47501	150636	132562	20694
Average % of Total	19.4	31.9	31.1	15.6	49.6	43.6	6.8

Source : Present from MPO & Future Consultants' estimate.

7.2 Crops and Cropping Patterns

On the basis of changes in the land type, the cropped area is expected to change assuming that more irrigation in the rabi season and supplementary irrigation in the wet season will be available though there will be no major change in cropping patterns (Table 7.2). With the availability of irrigation water, the area under modern high yielding boro varieties will increase. Low yielding broadcast aus will be replaced substantially by transplanted rice. In F0 and F1 land, there will be more areas of modern and local transplanted aman rice under supplementary irrigated condition. BRRI has developed a number of high yielding rice varieties suitable for aus, aman and boro seasons having variable life cycles and seedlings and plant heights. There will be no restrictions in selecting rice varieties to fit into the future cropping patterns.

A summary of future cropping area in each Planning Unit is shown in Table 7.3. A typical future crop calendar for SW5 is given as an illustration in Figure 7.1.

TABLE 7.2

Crop Distribution per Ha (average) Form

Crops	Land use	
	At present (ha)	Future project (ha)
B. Aus	0.32	0.26
HYV Aus	0.03	0.15
B. Aman	0.33	0.05
L.T. Aman	0.12	0.23
HYV Aman	0.09	0.33
Jute	0.07	0.06
Sugarcane	0.03	0.05
L. Boro	0.02	-
HYV Boro	0.12	0.29
HYV Wheat	0.07	0.16
Potato	0.01	0.01
Pulses	0.17	0.13
Oilseeds	0.11	0.11
Spices	0.02	0.03
Minor Crops	0.03	0.05
Orchards	0.01	0.02
Total Cropped Area	1.56	1.91
Net Cropped Area	1.00	1.00
Cropping Intensity	156%	191%

Jute is not an irrigated crop and the market price is low and unattractive to the farmers. However, some areas of jute have been shown in the future pattern so that it may meet the farmer's individual and local demands.

Wheat requires much less water than boro and as such there will be substantial increase in the wheat area. Varieties developed by BARI specially like 'Agrahayan' for late planting will be more suitable in the project area. Introduction of irrigation will considerably reduce the area under pulses and oilseeds because of their low yield and the non availability of high yielding varieties. However farmers will continue to grow these crops due to land suitability and increase of high market price in recent years. There will be also some increase of areas under sugarcane, orchard crops, potato and vegetables due to change of land type and development of irrigation facilities.

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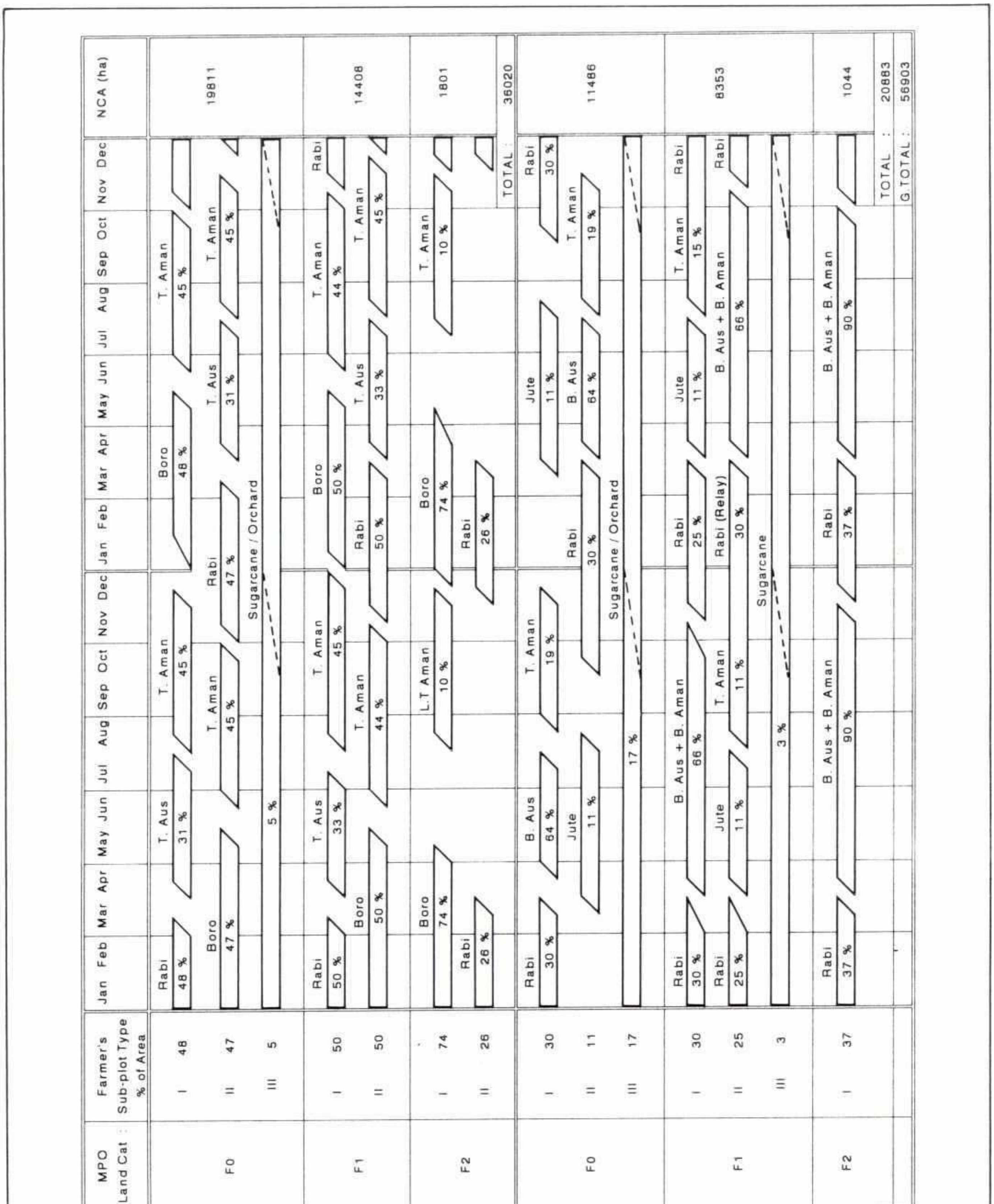
TABLE 7.3
Summary of Future Cropping and Area by Planning Units

Crop	Area in Km²																		Percent of Total NCA
	SW 4			SW 5			SW 6			SW 7			SW 10			GRAND TOTAL			
	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	
Kharif																			
B Aus	0	34	34	0	115	115	0	85	85	0	377	377	0	193	193	0	805	805	26
M Aus	28	0	28	109	3	112	64	3	67	110	12	122	130	2	132	442	19	461	15
B Aman	0	6	6	0	19	19	0	14	14	0	73	73	0	30	30	0	142	142	5
L T Aman	52	14	66	114	13	127	51	3	54	150	5	155	133	161	294	500	196	696	23
M Aman	75	8	83	196	21	217	106	13	118	215	61	276	224	71	295	815	173	989	33
Jute	0	11	11	0	22	22	0	15	15	0	84	84	0	38	38	0	170	170	6
Sugarcane	7	2	9	9	15	25	1	12	14	9	61	70	15	13	29	42	104	145	5
Rabi																			
L Boro	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M Boro	80	0	80	185	0	185	92	0	92	328	0	328	189	0	189	874	0	874	29
M Wheat	35	2	38	119	10	129	67	8	76	37	53	90	136	5	142	395	79	473	16
Potato	2	0	2	2	2	4	1	1	2	8	10	18	6	10	15	18	22	40	1
Pulses	10	15	25	12	43	55	5	30	35	33	165	198	16	56	72	76	310	386	13
Oilseeds	6	9	15	15	20	34	5	13	18	71	73	145	58	60	117	155	174	329	11
Spices	2	0	3	6	4	10	3	3	6	38	26	64	7	3	10	55	37	93	3
Minor crops	13	1	14	20	5	26	6	4	11	3	36	39	39	12	51	82	59	141	5
Orchards	0	2	2	0	7	7	0	5	5	0	22	22	0	22	22	0	58	58	2
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Totals	310	106	416	788	300	1088	401	208	610	1003	1058	2061	953	675	1628	3454	2348	5802	
Total NCA	150	70	220	360	209	569	180	147	327	450	650	1100	415	408	823	1555	1484	3039	
Average CI	206%	152%	189%	219%	144%	191%	223%	142%	187%	223%	163%	187%	230%	166%	198%	222%	158%	191%	

[vp\gorai\tab7-3]

Figure 7.1



Future Crop Calender : Planning Unit - SW 5

7.3 Cropping Intensity

The present and future cropping intensity in different planning units under irrigated and rainfed condition is presented in Table 7.4. In all planning units the cropping intensity is expected to be increased both under irrigated and rainfed condition but the overall increase is more in case of irrigated (28%) than rainfed (5%) condition. However, the average cropping intensity will change from 156% at present to 191% in future. This increase of cropping intensity will be mainly attributed to change of areas from rainfed to irrigation.

TABLE 7.4

Cropping Intensity : Present and Future

Planning Unit	Cropping Intensity (%)					
	Present			With Project		
	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall
SW 4	201	149	164	206	152	189
SW 5	199	139	164	219	144	191
SW 6	199	139	149	223	142	187
SW 7	146	167	149	223	163	187
SW 10	178	143	163	230	166	198
Average	174	151	148	222	158	191

7.4 Inputs

With the irrigation facilities, high yielding varieties will be grown and higher quantities of manures, fertilisers and pesticides will be used. To realise the optimum yield potentials and to retain a stable productivity of various crops the demand for institutional credit for purchasing high production inputs will increase.

Therefore, in order to achieve the increased crop yields under irrigated agriculture, proper use of seeds, fertilisers, pesticides as well as appropriate management practices are needed. A comparative statement of present and future inputs is given in Table 7.5. The table shows that the requirement of all kinds of inputs for all crops except B. Aus, B. Aman and Jute seeds will increase substantially with the project.

With project, the requirement of modern rice and wheat seed would be more than three times and two times of the present use respectively. At present BADC through its seed multiplication farms and contact growers system produces quality seeds for distribution among farmers. But the supply of quality seeds is highly inadequate to meet the farmers present demand. As a result, farmers are forced to use their own seeds or buy locally produced seeds which are often mixed or of substandard quality. To ensure optimum yield it is required to strengthen the seed sub-sector to produce and supply the required quality seeds through public and private sector.

TABLE 7.5

Present and Future Inputs of Major Crops

Inputs	Present (Tonne)	With Project (Tonne)	Change (%)
Urea	15099	34173	226
TSP	6575	17010	259
MP	2494	6232	250
Pesticides	114	314	275
Seeds			
a. Rice (L)	17093	10609	62
b. Rice (M)	2179	6972	320
c. Wheat	2899	6155	212
d. Jute	199	170	85
e. Sugarcane	7966	14546	183

Source: Consultant's estimate

At present the application of fertilisers in the project area is low. With project, it is expected that the demand for fertiliser will increase by between 2-3 times. In the project area due to continuous flooding in the past (and some areas also at present) in certain low lying areas, particularly in Planning Units SW 5, SW 7 and SW 10, there are deficiencies in of Zn and S which cause sterility of grain. These deficiencies can be arrested by applying organic manures and other micro nutrients (like Copper, Manganese, Molyledenum etc.).

With the increase in the area of HYV crops, it is expected that the use of pesticides and other agro-chemicals will increase substantially (Table 7.5). Generally farmers use pesticides indiscriminately due to lack of proper knowledge of application. Besides due to the private trading of agro-chemical, very often low quality products are marketed. So it is required to train the farmers in applying agro-chemicals in proper time and appropriate dozes and type. At the same time efforts should be made to ensure quality of the agro-chemicals now marketed through the private sector.

7.5 Crop Production

The present and future production of various crops and their change is presented in Table 7.6. From this Table it is seen that after development of irrigation facilities in the project area there will be an additional cereal production of 498,463 Tonnes. This increase of production is mainly due to increase in HYV areas under irrigated condition. For understandable reasons pulses, oilseeds and jute production will decrease. There will be increases in production of sugarcane, orchard crops (banana, papaya) and potato.

TABLE 7.6

Changes in Crop Production : Present and Future

Figure in Tonne

Crop	Present Production			Future Production			Change		
	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall
Kharif									
B Aus	0	116335	116335	0	96595	96595	0	-19740	-19740
M Aus	23912	5338	29250	128091	5637	133728	104179	300	104478
B Aman	0	121354	121354	0	17000	17000	0	-104354	-104354
L T Aman	27395	42049	69444	95075	37222	132296	67680	-4827	62853
M Aman	41001	45624	86625	260851	55515	316367	219850	9892	229742
Jute	0	33759	33759	0	28835	28835	0	-4925	-4925
Sugarcane	29799	294818	324617	208430	415086	623517	178631	120269	298900
Rabi									
L Boro	2757	8023	10780	0	0	0	-2757	-8023	-10780
M Boro	155993	16	156009	384696	8	384703	228702	-8	228694
M Wheat	20299	23531	43830	94747	13372	108118	74448	-10159	64288
Potato	3853	30181	34034	21685	17792	39477	17832	-12389	5444
Pulses	1240	34382	35622	5176	21055	26231	3936	-13327	-9391
Oilseeds	2658	25773	28431	12831	14469	27300	10173	-11304	-1131
Spices	3316	13091	16407	20500	13788	34288	17184	697	17881
Minor crops	207	615	823	831	590	1421	624	-25	598
Orchards	8	9373	9380	24	14833	14857	16	5460	5476

The future production based on yield for different crops under irrigated and rainfed condition by planning units is shown in Table 7.7. The total production for different crops vary among the Planning Units which is mainly due to variation of cropped areas.

TABLE 7.7
Future Crop Production by Planning Units

Crop	Production in Tonne																	
	SW 4			SW 5			SW 6			SW 7			SW 10			GRAND TOTAL		
	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall	Irrigated	Rainfed	Overall
Kharif																		
B Aus	0	4071	4071	0	13844	13844	0	10222	10222	0	45264	45264	0	23194	23194	0	96595	96595
M Aus	8174	64	8238	31682	900	32581	18544	747	19291	31941	3429	35370	37750	498	38248	128091	5637	133728
B Aman	0	705	705	0	2294	2294	0	1649	1649	0	8771	8771	0	3580	3580	0	17000	17000
L T Aman	9883	2689	12572	21639	2505	24144	9713	592	10305	28572	904	29476	25268	30532	55799	95075	37222	132296
M Aman	23977	2704	26681	62602	6753	69355	33783	4016	37798	68802	19465	88267	71687	22578	94265	260851	55515	316367
Jute	0	1862	1862	0	3723	3723	0	2476	2476	0	14275	14275	0	6499	6499	0	28835	28835
Sugarcane	33695	8689	42384	47246	60591	107837	6231	49148	55379	44454	243533	287987	76805	53126	129930	208430	415086	623517
Rabi																		
L Boro	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M Boro	35098	8	35106	81589	0	81589	40642	0	40642	144198	0	144198	83169	0	83169	384696	8	384703
M Wheat	8500	373	8873	28530	1733	30263	16162	1404	17566	8846	8956	17802	32709	905	33614	94747	13372	108118
Potato	1894	397	2290	2502	1259	3762	846	684	1530	9351	7828	17178	7092	7624	14716	21685	17792	39477
Pulses	647	1054	1701	833	2929	3762	350	2016	2366	2251	11233	13484	1094	3823	4917	5176	21055	26231
Oilseeds	538	707	1246	1207	1644	2852	376	1089	1465	5914	6085	12000	4795	4943	9737	12831	14469	27300
Spices	833	183	1017	2128	1585	3714	1024	1283	2307	14100	9623	23723	2415	1112	3528	20500	13788	34288
Minor crops	128	14	142	207	55	262	65	41	106	35	360	395	395	121	516	831	590	1421
Orchards	24	430	454	0	1785	1785	0	1250	1250	0	5705	5705	0	5662	5662	24	14833	14857

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7.6 Farm Employment

At present with 156 percent cropping intensity, mostly with local varieties of crops under rainfed condition, the annual labour requirement is about 58.4 million man-days. The labour requirement is expected to increase to about 84.0 million man-days with the development of project facilities in future (Table 7.8). Increased area under labour intensive high yielding varieties (specially in the case of modern T. Aman and HYV Boro crops the increase is about 300-400%) and high cropping intensity (191%) would promote the farm employment opportunities by about 43% over the present level leading to the reduction in the rural unemployment in the project area.

TABLE 7.8

Farm Employment : Present and Future

CROP	Number of Mandays/ha	Present		Future	
		Area (ha)	Total Mandays ('000)	Area (ha)	Total Mandays ('000)
Kharif					
B Aus	130	96946	12603	80496	10464
M Aus	180	10086	1816	46113	8300
B Aman	102	101128	10315	14166	1445
L T Aman	125	36549	4569	69630	8704
M Aman	160	27070	4331	98865	15818
Jute	180	19858	3575	16962	3053
Sugarcane	263	7966	2095	14546	3826
Rabi					
L Boro	167	5674	948	0	0
M Boro	188	35457	6666	87433	16437
M Wheat	121	22300	2698	47343	5729
Potato	213	4094	872	4031	859
Pulses	64	52385	3353	38575	2469
Oilseeds	79	34254	2706	32892	2598
Spices	188	4434	834	9267	1742
Minor crops	105	8192	860	14077	1478
Orchards	185	3662	678	5801	1073
Totals			58917		83996
Percent change					143

7.7 Impacts of Proposed Development on Fisheries

7.7.1 General

This project which aims to increase year-round flows down the Gorai, with associated irrigation and drainage development across 3038 km^2 should be generally beneficial to culture fisheries, but with provisos.

Various points along the Gorai from Kushtia as far south as Gopalganj have been centres for the collection of the spawn and fry of wild stock major and minor carps. As far as is known these fish do not breed in the Gorai but rather at some point along the Ganges River between Hardinge Bridge and Farakka Barrage, and the resultant concentrations of floating spawn and pelagic fry are swept back downstream, some to continue on down the Padma and some diverted with the flood into the Gorai. It follows that the construction of a regulator across the river mouth could be detrimental to fisheries in SWA unless the regulator design is such as will permit the upstream movement of adult fish earlier in the year and the return flow of fry. FAP 17 is conducting a study into "fish friendly" structures and should be consulted during the next phase.

According to the maps there are a number of beel areas situated close to the river line and it is hoped that these areas can be retained and improved for fish production and maintenance of carp breeding stocks, as part of the project. This would involve either diverting the main riverine flood embankment behind the beel, so leaving it with unrestricted connecting khal with a secondary dyke so that early floodwater can be allowed to flow into the beel without endangering the surrounding croplands. In the latter case, other arrangements would have to be made for the later transfer of fry from the river to the dyked beel.

There may be other perennial beels within the project area but more distant from the river. Clearly it is not feasible to maintain a river connection in all such cases but they can still be preserved and developed for enhanced fisheries production by excavation and embanking to increase depth and water storage capacity and restocking with an appropriate species mix to enhance the surviving natural fish stocks and yields.

The project proposals include by-passing the Kamarkhali Bend, thus creating an isolated ox-bow lake some 6.5 km long by 600 m wide and 5m deep. With good management the yield of such a fishery could be increased, from the riverine average of about 40 kg/ha to 400 kg/ha, thereby providing a livelihood for at least 150 additional fishermen.

To the extent that the associated drainage and irrigation scheme will reduce the area of seasonally inundated fishable floodland, so will there be corresponding reductions in opportunities for subsistence fishing, especially by the poorer classes, and a decline in the range of floodplain fish species as well as in volume of catches. On the other hand, any ponds in this area which were previously vulnerable to over-flooding, could become suitable for rehabilitation, subject to provision being made for credit to cover re-excavation costs and to support the necessary extension work.

There is a further proposal that additional flows be directed down the Gorai/Madhumati/Rupsa route past Khulna, aimed at pushing back the saline front. If this were done it is possible that salinity could be depressed over a sufficient length of Pussur River as to seriously affect Penaeid shrimp post-larval survival in that area. This would be highly detrimental to large areas of tidal shrimp farms in the Khulna, Mongla and Bagerhat districts, which are at the heart of the shrimp farming industry.

7.7.2 Capture Fisheries

There has been a growing awareness amongst the authorities in Bangladesh and the donor community that FCD/FCDI developments and polder type projects, have been having a cumulative negative impact on the fisheries sector. Consequently with the implementation of FCD projects, local fishermen and DOF staff have reported falling catch rates from the inland capture fisheries in rivers, beels and floodplains virtually throughout the country, and increasing hardship amongst the fishing communities dependent on these fisheries. In consequence, fish production in the proposed project area reduced by 35%, from 26,381 to 17,016 tonnes, that is fish production reduced by 9,365 tonnes per year. However FCD/I developments are not the only cause of reduced production.

Inland capture fisheries contributed 22,871 tonnes (87%) of the total fish production 26,381 tonnes in 1983/84, whereas it contributed 10,983 mt (65%) of the total fish production of 17,016 tonnes in 1989/90. In case of capture fisheries production, floodplain fisheries contributes presently 83% of the total annual catch and recruitment to floodplain fisheries dependent on riverine and beel fisheries. Any damage to riverine and beel fisheries creating manmade obstructions to fish spawning and feeding migration will have adverse impacts on recruitment and natural stocking of floodplains.

River Fisheries

Area of river in the Gorai Augmentation Project is estimated about 20,760 ha, the annual production of which reduced from 6004 to 1372 tonnes over the six years to 1988/89, primarily due to the impact of existing FCD/FCDI interventions. The proposed project will reduce the size of the floodplain by 60% and depth and duration of flooding will be reduce significantly. Natural recruitment and stocking of river waters will be reduced and the present riverine fish production will decline by 40%, from 1372 to 824.

Beel Fisheries

The area of beels in the proposed project area estimated at about 2000 ha. Production reduced by 51%, from 903 to 443 tonnes between 1983/84 and 1989/90. The proposed project will reduce the depth of water level and duration of flooding, spawning and feeding migration will be obstructed and recruitment and natural stocking will be correspondingly reduced. Present level of production will further decline by 50%, from 443 to 222 tonnes.

Floodplain Fisheries

Floodplain fisheries area estimated to be reduced in the proposed project area from 213306 ha to 86450 ha and the water level be reduced from F3 and F2 level to F2 and F1 level resulting in a significant reduction in the productivity of floodplain fisheries in particular and inland capture fisheries in general. Floodplain fisheries which contribute 83% of the inland capture fisheries of the project area, will however be reduced from 8855 to 1667 tonnes, loss of 7188 tonnes of fish per year.

7.7.3 Culture Fisheries

FCD projects normally benefit culture fisheries. The positive impacts of FCD are increased control over manageability of pond water bodies and increased maintenance of dry season water levels.

Pond Fisheries

The area of ponds in the project area is estimated at about 4150 ha, of which 2510 ha, or 60%, are being cultured. Production from pond fisheries increased by 72%, from 3352 tonnes in 1983/84 to 5782 tonnes in 1989/90. The average production of culture fisheries is 1390 kg/ha. Production of culture fisheries can however be increased more than two-fold just by adoption of semi-intensive polyculture technology as it has recently been demonstrated under Aquaculture Extension Project, Mymensingh (GOB/DANIDA). Both men and women participated in this programme undertaken in 1990 - 92 with credit facilities and extension services provided by the DANIDA in collaboration of DOF Thana Fisheries Officers. The yield per hectare in case of semi-intensive carp polyculture varied from 2,692 to 8,546 kg.

7.7.4 Conclusion

The Gorai Augmentation Project will have some negative impacts on the capture fisheries within and outside the project area, whereas culture fisheries will derive positive benefits. Floodplain fisheries habitat will be reduced by about 59%, which presently contributes 83% of the total capture fisheries production of 10,670 tonnes and 53% of the total inland fisheries production of 16,703 tonnes (1990).

Table 7.9 shows present and future annual fish production, population, fish requirement and per capita availability of fish in proposed Gorai Augmentation Project area. This area was a surplus one in the past, but presently it turned into a deficit area. Per capita availability of fish is about 5 kg/head/year against the national level of consumption of 7.5 kg/head/year. The per capita availability of fish will be reduced to about 3 kg/head/year due to negative impact of the proposed project by the year 2000. There is however a potential for development of culture fisheries in the project area in existing fish ponds, beels and borrow-pits after necessary rehabilitation. Just by adoption of semi-intensive polyculture with right combination of local and exotic carps, annual fish production can be increased to about 29,300 tonnes ensuring per capita availability of fish 8 kg/head/year by the year 2000.

TABLE 7.9

Area of Fisheries and Total Production

Production in Tonnes

Project Status	PU Code	PU Gross Area Km²	Rivers 1988 - 89 Area (ha)	Rivers Production	Beels 1989 - 90 Area (ha)	Beels Production	Flood Lands 1989 - 90 Area (ha)	Flood Lands Production	Baors 1989 - 90 Area (ha)	Baors Production	Ponds 1989 - 90 Area (ha)	Ponds Production	Total Production	Population	Fish Requirement (Tonnes)	Per Capita Availability of Fish (Kg)
	SW 4	286	740	66	290	72	5620	319	120	35	440	814	1306	232214	1742	5.62
Present	SW 5	719	3370	267	730	182	27150	1685	400	121	860	1693	3948	503077	3773	7.85
(1990)	SW 6	415	3480	216	140	30	15470	361	70	14	390	345	966	307537	2307	3.14
	SW 7	1438	10890	675	550	87	93160	2176	190	38	1630	1422	4398	1123590	8427	4.19
	SW 10	1094	2280	148	290	72	71900	4314	160	43	830	1508	6085	867764	6508	7.01
Overall Total		3952	20760	1372	2000	443	213300	8855	940	251	4150	5782	16703	3034182	22757	5.50
Future	SW 4	286	740	40	290	36	3900	110	120	53	440	1206	1445	280323	2102	5.15
(2000)	SW 5	719	3370	160	730	91	11200	346	400	182	860	2540	3319	607302	4555	5.47
Without	SW 6	415	3480	130	140	15	7500	87	70	21	390	518	771	371251	2784	2.08
Fisheries	SW 7	1438	10890	405	550	44	43500	506	190	57	1630	2130	3142	1356370	10173	2.32
Project	SW 10	1094	2280	89	290	36	20440	618	160	64	830	2259	3066	1047543	8457	2.93
Overall Total		3952	20760	824	2000	222	86540	1667	940	377	4150	8653	11743	3662789	28071	3.21
Future	SW 4	286	740	252	290	289	3900	312	120	95	440	1317	2265	280323	2102	8.08
(2000)	SW 5	719	3370	1158	730	729	11200	896	400	317	860	2589	5689	607302	4555	9.37
With	SW 6	415	3480	1196	140	144	7500	600	70	58	390	1185	3183	371251	2784	8.57
Fisheries	SW 7	1438	10890	3737	550	553	43500	3480	190	158	1630	4884	12812	1356370	10173	9.45
Project	SW 10	1094	2280	780	290	288	20440	1635	160	128	830	2496	5327	1047543	8457	5.08
Overall Total		3952	20760	7123	2000	2003	86540	6923	940	756	4150	12471	29276	3662789	28071	8.00

Source : Consultant's estimate based on DOF Fish Catch Statistics of Bangladesh

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8 PROJECT WORKS

8.1 Project Formulation

The formulation of the Gorai Augmentation Project is based on the findings of the preceding chapters. As discussed in Chapter 6, the preferred augmentation option follows a route through the Gorai and involves interventions at the Gorai mouth and some dredging and training works in the upper reaches of the river.

Potential for increased agricultural production through irrigation has been identified in Chapter 7, and the augmented dry season flows in the Gorai would be utilised for providing the required irrigation. Since the expected dry season flow levels are low compared with the ground levels of the proposed irrigation areas south of Kamarkhali, a barrage is required at this location to raise the flow and distribute it through the river networks on the left and right banks of the Gorai. Appropriate structures are necessary at selected locations in the river networks to ensure control in water distribution. Potential for increased agricultural production through drainage congestion relief has been suggested in Section 5.2. This can be further enhanced if the drainage flows (rainfall runoff) within the irrigation areas could be controlled to limit the area of excessive inundation.

Potable and industrial water supply to Khulna through a direct conduit from the tail end of the Chitra, by-passing the Bhairab whose salinity rises appreciably during the dry season, has been identified as the cheapest alternative (Section 6.2.2).

A favourable augmentation inflow from the Ganges during the driest months of March and April, considering the Ganges flows of 80% probability of exceedance (based on pre and post Farakka flows measured at the Hardinge Bridge), is about 180 m^3/s. However, the Ganges discharges in the driest months in 1992 and 1993 have reached record low levels for short periods that could reduce the possible augmentation to a low 160 m^3/s.

Taking the above and related capital/maintenance costs into account, a phased development is proposed. Also, there is limitation of topography on command area for irrigated agricultural development considering the low flow levels of the Gorai : areas totalling about 165,000 ha (NCA) have been identified.

It is proposed that for the initial stage to the year 2000, the augmentation during the driest months would be about 60 cumecs. This could support irrigated agriculture programmes covering a total area of about 60,000 ha. Water for domestic and industrial supply to Khulna will also be available starting at this initial development. The second stage development to the year 2005 would increase the augmentation to 170 cumecs and this could bring upto 165,000 ha under irrigated agriculture.

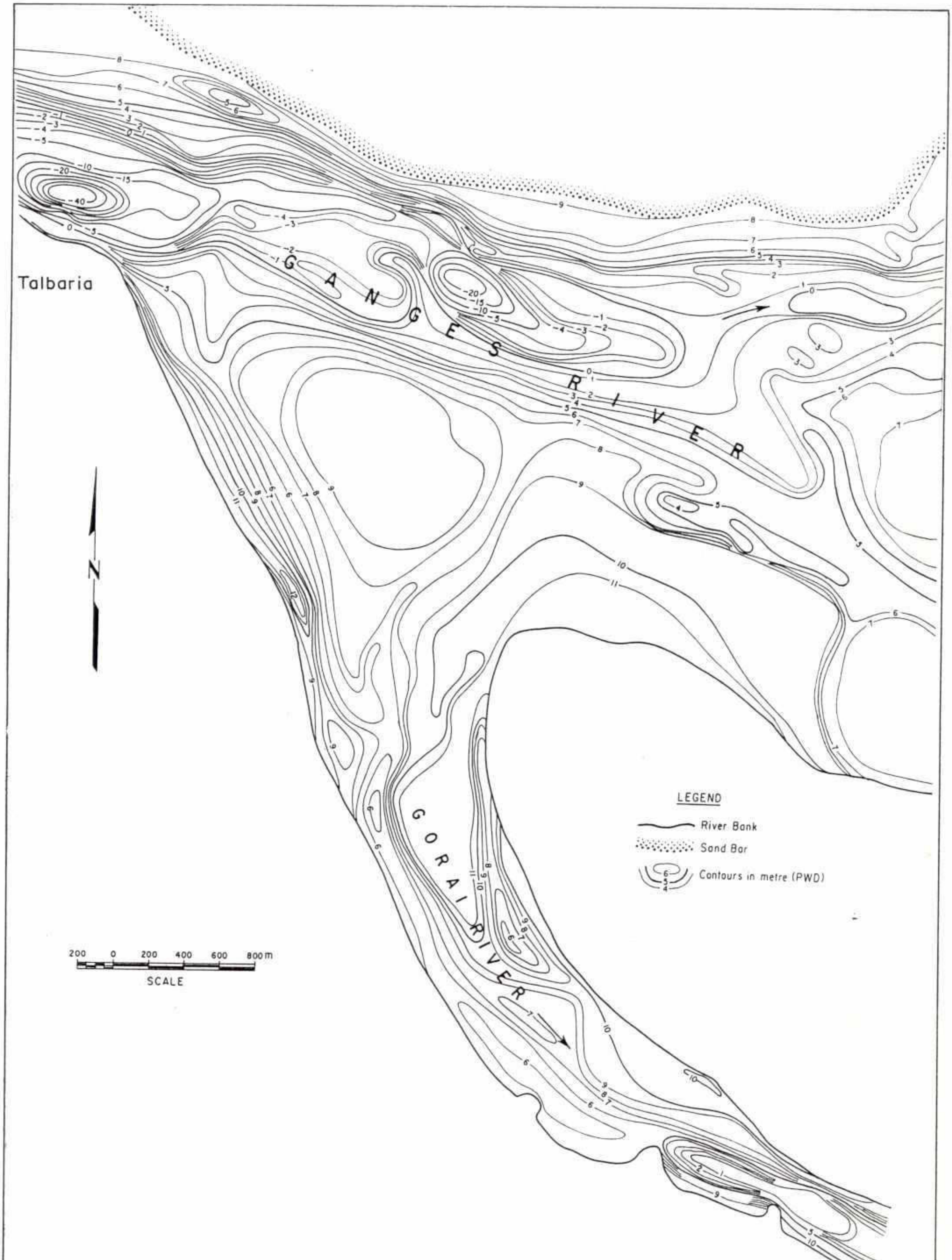
8.2 Gorai River Intervention

8.2.1 Control Structure at Gorai Mouth

The length of channel to be maintained upstream of the Gorai intake control structure will be dependent on the Ganges alignment and can be expected to vary from year to year. Because of the much greater movement of sediment in the main river, the channel will quickly be filled in during high flows, and will therefore have a high maintenance requirement. Locating the structure at the very mouth minimises this requirement. However, the exact positioning of the structure and the associated works (embankments, slope and scour protections, etc) would require further detailed studies, including site investigation and physical and computer model examination.

The 1992 site survey of the mouth shows a localised deep erosion hole to (-) 40m PWD at the toe at Talbaria (Figure 8.1) with an average slope of about 1:4 (vertical : horizontal).

Figure 8.1



Site Survey of Gorai Mouth, July 1992

As far as the morphology of the Ganges/Gorai is concerned, Talbaria should continue as a stable point. Thus, it should be possible to tie in the structure in this area. However, the problem of locating a structure at this point will be the angle of approach of the main Ganges flow during the dry season and thus the angle of the structure itself.

The structure has to be designed to allow high and low flows but reduce the intake of bed load. A preliminary layout and profiles of a suitable structure and associated works are shown in Figures 8.2, 8.3 and 8.4. It has been sized to pass a maximum of 4250 cumecs down the Gorai during the monsoon period based on upstream water level corresponding to the Ganges flows in an average year.

The final layout of the structure including the protection works can only be decided after extensive mathematical and physical modelling.

8.2.2 Gorai River Capital Dredging

It is proposed to carry out the required capital dredging in stages to suit the phased development considered in Section 8.1. According to the dredging estimates prepared based on 1D-Hydrodynamic model simulation for different Gorai flow requirements, about 13.2 Mm^3 of excavation is necessary to enable the augmentation flow of 170 cumecs to pass. However, the necessary dredging corresponding to the initial flow requirement of 60 cumecs is about 9 Mm^3. These estimates are based on dredging the Gorai upto Ch. 29.0 km.

The disposal arrangement for this large quantity of dredged material has been examined and the following proposal evolved:

(a) Material in the first 8.0 km of the Gorai would be used in the construction of the embankments associated with the control structure at the Gorai mouth, and this amounts to about 6.1 Mm^3.

(b) Material from Ch.8.0 km to 20.0 km would be discharged into the Ganges, and this amounts to about 5.5 Mm^3; the discharging pipeline could follow the shortest direct route to the Ganges. Extra booster arrangements would however be required for this and has been taken into account in the cost estimate.

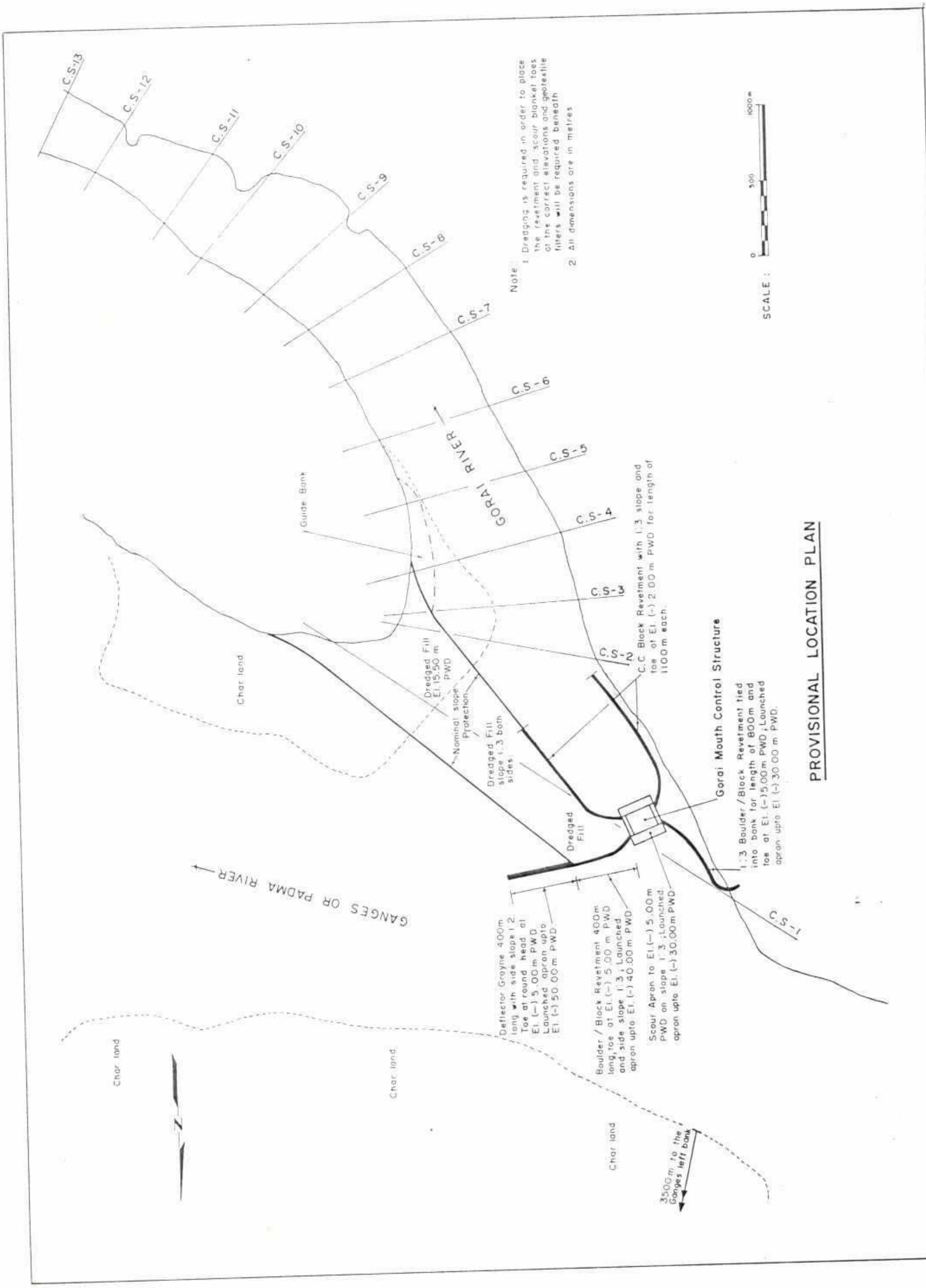
(c) Material from Ch.20.0 km to 29.0 km which amounts to about 1.6 Mm^3 would be used for refilling existing unused borrow pits on the right and left banks and also strengthening the associated flood control embankments from Ch.15.0 km to 34.0 km.

8.2.3 Guide Banks and Groynes

Guide banks and groynes at selected locations along the Gorai would be required to sustain the dredged low flow channel in reasonable shape and also to improve the flow conditions at the railway bridge location. Careful consideration should be given to the design that would establish and maintain a stable geomorphic pattern. This would require physical and mathematical model studies.

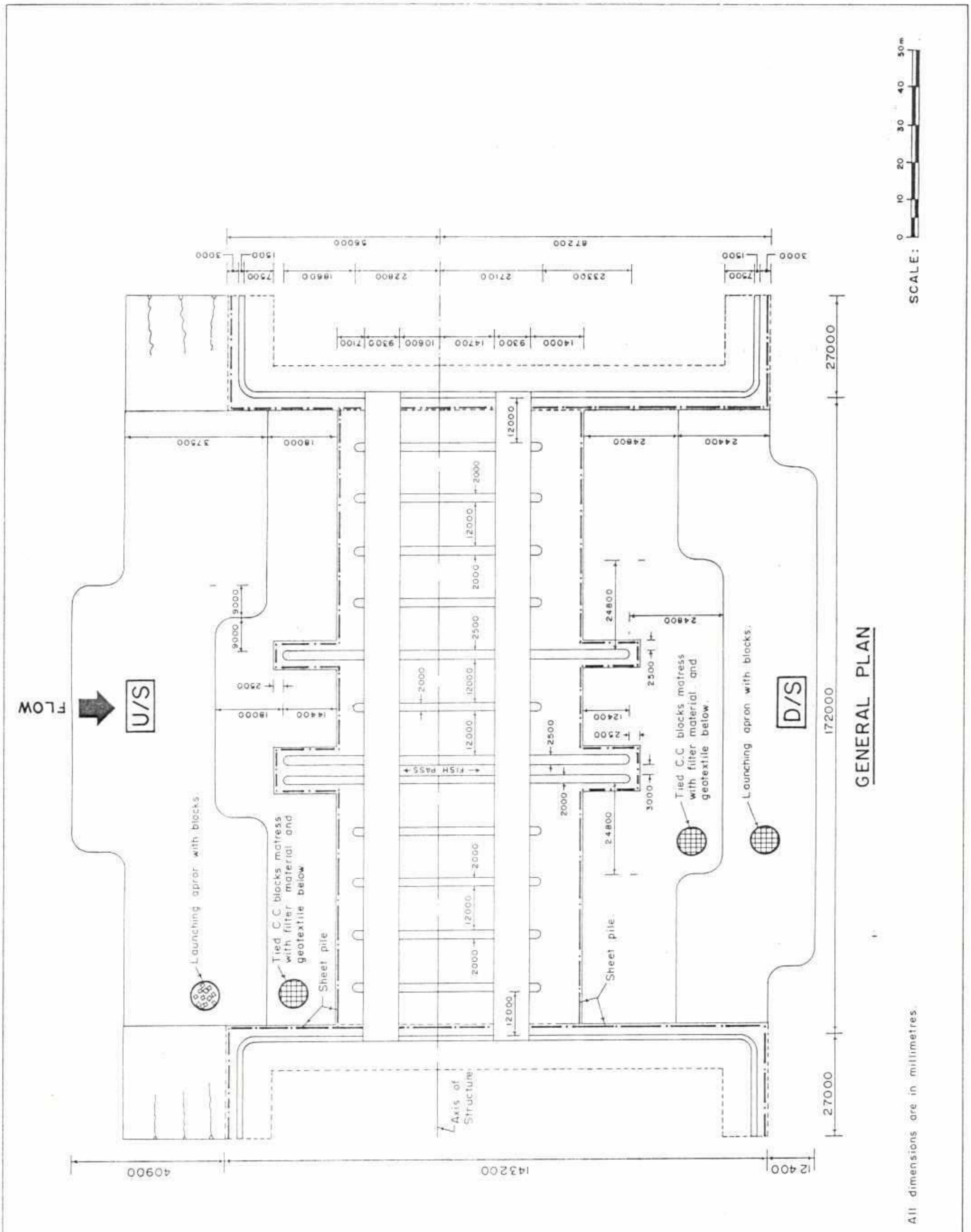
A preliminary location plan of these guide banks and groynes is shown in Figure 8.5. They are placed to improve the cross over of the flow from one side to the other at the river bends and at the same time maintain a deep channel as lengthy as possible at each bend. When this deep channelisation at the bends (including certain lengths upstream and downstream of the bends) are achieved it would greatly reduce the maintenance dredging requirements.

Figure 8.2



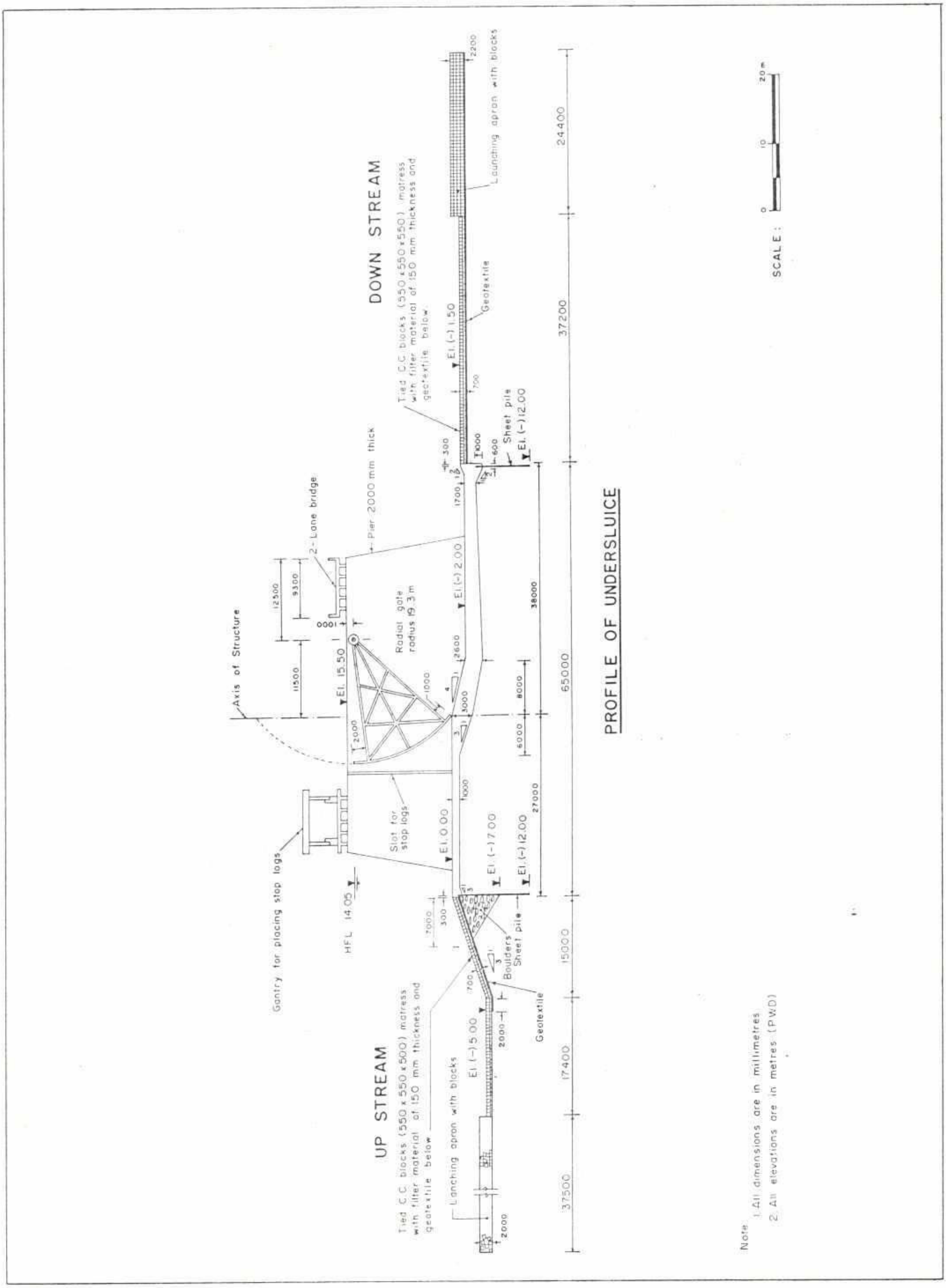
Gorai Mouth Control Structure Provisional Location Plan

Figure 8.3



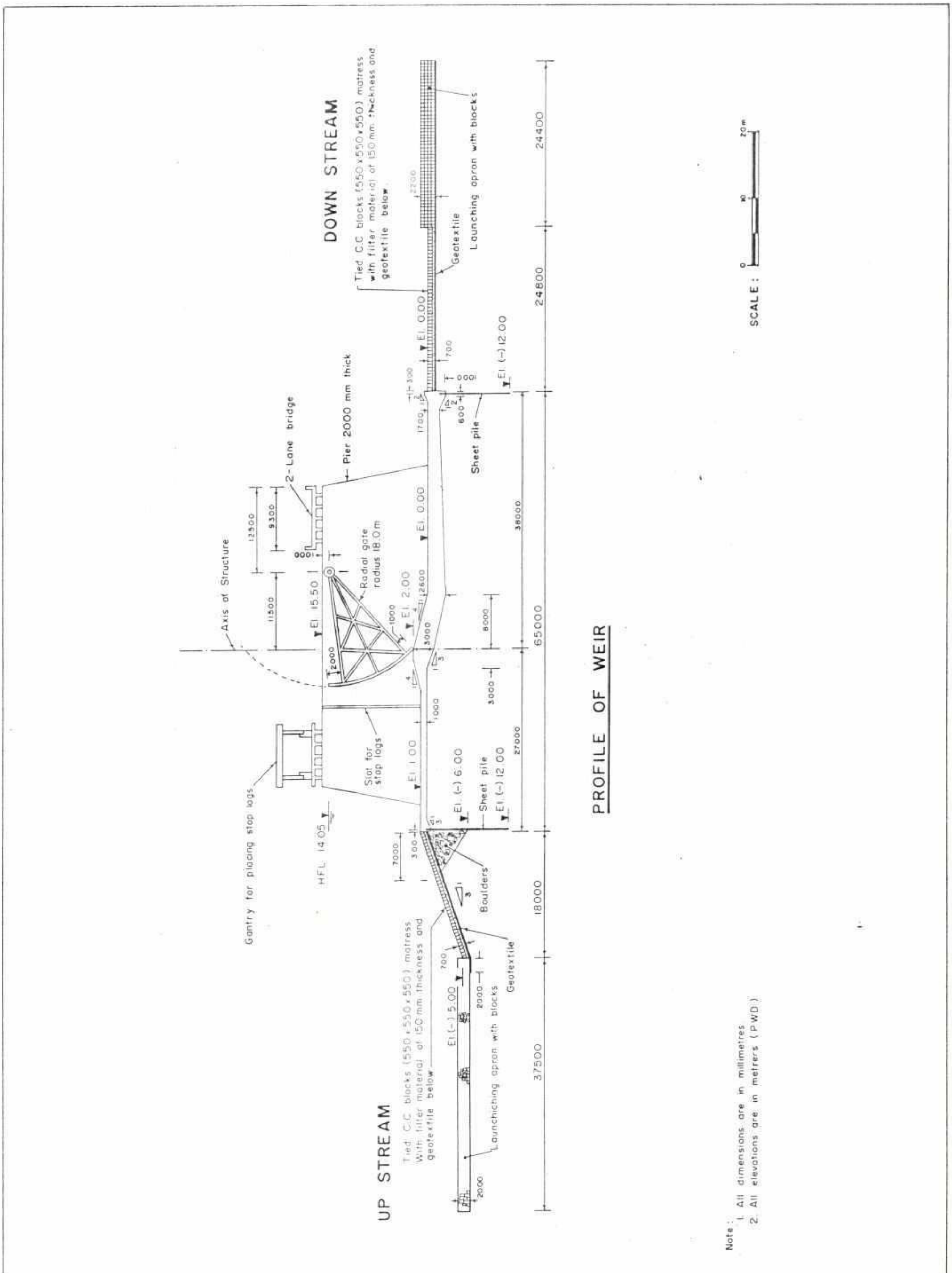
Preliminary Layout of Gorai Mouth Control Structure

Figure 8.4a



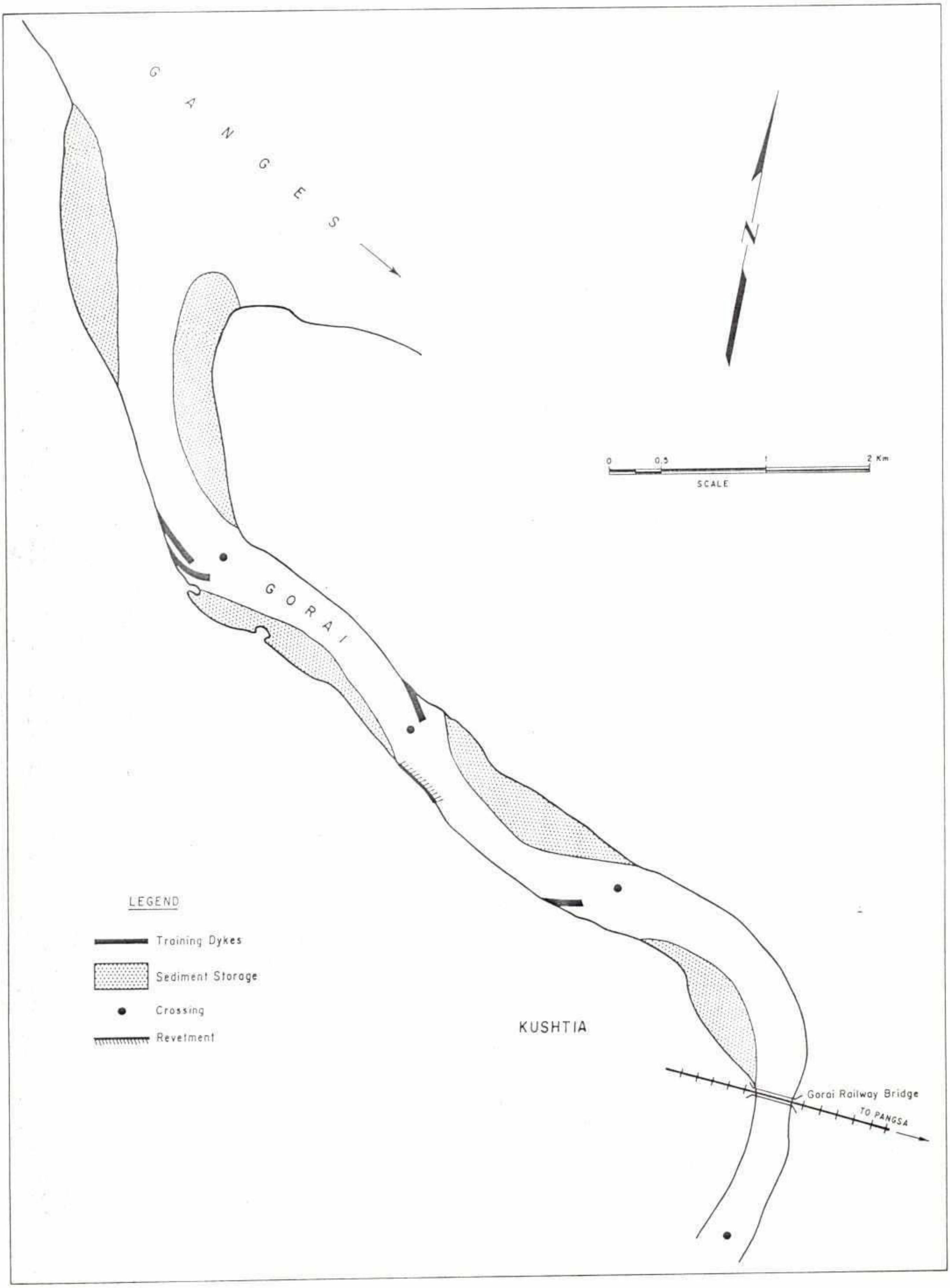
Gorai Mouth Control Structure: Profile of Undersluice

Figure 8.4b



Gorai Mouth Control Structure: Profile of Weir

Figure 8.5



Proposed Locations for Groynes and Guide Banks

8.3 Kamarkhali Barrage

A barrage at a convenient location on the Gorai/Madhumati, downstream of the Kamarkhali loop (bend), is required to raise the water level of the dry season flows for diversion into the left and right bank irrigation areas, and also allow the flood flow to pass down the river during the monsoon.

Considering the stability of the banks of the Gorai in this reach, a possible location has been identified which adjoins the Mohammadpur Thana. Site surveys and geotechnical investigations would have to be carried out when detailed studies are undertaken in the future. Figure 8.6 shows the proposed location of the Kamarkhali Barrage and the associated link canals to convey the water to the left and right bank irrigation areas. Also, approximate locations for new regulators to control river water levels are shown in Figure 8.6. These structures would have sufficient capacities to allow monsoon flows to pass through.

Considering the provision of a control structure at the Gorai mouth, the flood flow capacity of the Kamarkhali Barrage has been set at 4250 cumecs. If, however, no structure is provided at the Gorai mouth, the required capacity would be about 9,000 cumecs. This would increase the cost of the barrage by about 40%.

The programme for the construction of major works is given in Table 8.1.

8.4 Irrigation and Drainage Development

8.4.1 Options for Irrigation Development

Available information on existing projects indicate that although about 48% of the area proposed for irrigation development has already been provided with some flood control and drainage, irrigation is currently practiced in only 16% of the area. About 73% of which is from groundwater.

According to the hydrogeological assessments, only areas in Planning Units SW5 and SW7 have some potential for further expansion of groundwater, but it will mainly be dependent on deep tubewells (DTW). Preliminary cost estimates indicate that compared with the other modes of irrigation development (low lift pumping, shallow tubewells, etc), DTW development has the highest cost per unit area developed. Furthermore, extensive DTW development would cause many of the rural water supply tubewells (which are based on hand pumps) to become unproductive.

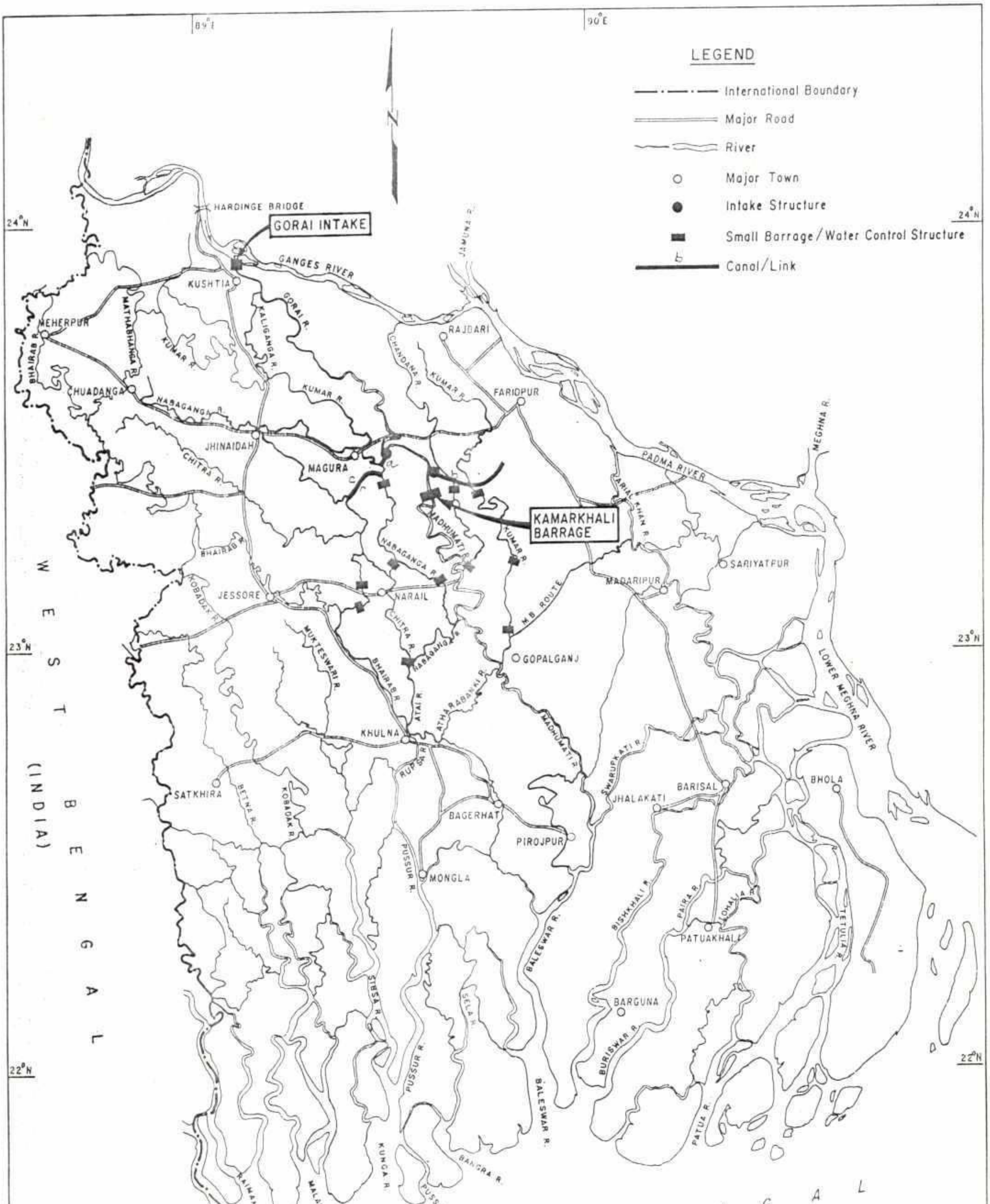
Any accelerated development of irrigation should, therefore, be based on surface water. Two options for using surface water were considered :

(a) a full gravity system incorporating high level network of canals; additional network of drains will be required for drainage purposes;

(b) a low level network of channels that could convey either the irrigation or drainage flow to suit the dry/wet season; low lift pumping would have to be adopted by the farmers to irrigate their farms.

The low level system has the potential to attract private (and farmer) sector investment inthe form of low lift pump provision. This support from the private sector will reduce some of the burden on the government. Taking this and the cost of development into account, the low level system has been recommended for the area development associated with the Gorai Project.

Figure 8.6



Location of Canal Links and Major Structures

TABLE 8.1
Development Programme

Description of Works	Cost (MTk.)	Phasing of Development (Costs in MTk.) Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Gorai Intake	3236	1080	1080	1076							
Gorai Capital Dredging	1850		550	550			250	500			
Gorai Guide Banks/Groynes	290			290							
Kamarkhali Barrage	1860		710	650	500						
River Links	660			170	140	140	150	60			
River Control Structures	835			60	200	200	200	175			
Irrig. / Drainage Systems	4307		314	314	524	445	864	1047	537	262	
Area Development			*12,000 ha*	*12,000 ha*	*20,000 ha*	*17,000 ha*	*33,000 ha*	*40,000 ha*	*20,500 ha*	*10,000 ha*	

Note : Irrigation & Drainage System Cost includes Area Development Cost.

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8.4.2 Compartmentalisation for Controlled Drainage

The concept of compartmentalisation for controlled drainage is based on temporary retention of local runoff within each sub-compartment, or any other smaller operational unit, to avoid accumulation of the runoff from the entire development area at the main outfall location. Compartmentalisation will also facilitate integrated water management for irrigation, drainage and fisheries.

The contribution of controlled drainage in transforming the deeply flooded areas (F2, F3 and F4) into lands of moderate flooding that suits enhanced agricultural production has been assessed. This assessment has been carried out for a sample area (the existing Chenchuri Beel FCD Project: gross area is about 25,600 ha) based on field information and computer simulation of the flow routing process.

The results from the above computer simulation formed the basis for estimating the expected extent of the different land categories (flood depths) resulting from the proposed project interventions for the other areas within the Gorai Augmentation Project.

8.4.3 Area Development

The selection of areas for irrigation and drainage development and their phasing have been based on the Resources Allocation and Optimisation Model studies. The studies identity the incremental net benefits that would accrue, as a result of the augmentation flows, from irrigated agriculture, domestic and industrial water supply, navigation, etc.

The proposed areas of development in the selected Planning Units and their phasing are illustrated in Table 8.2. A total of about 165,000 ha would be brought under (new) surface water irrigated agriculture. About 69,000 ha within this proposed development have already been provided with flood control and some drainage measures under previous FCD programmes of BWDB. In the preparation of cost estimates for the proposed development, these existing measures/facilities have been taken into account.

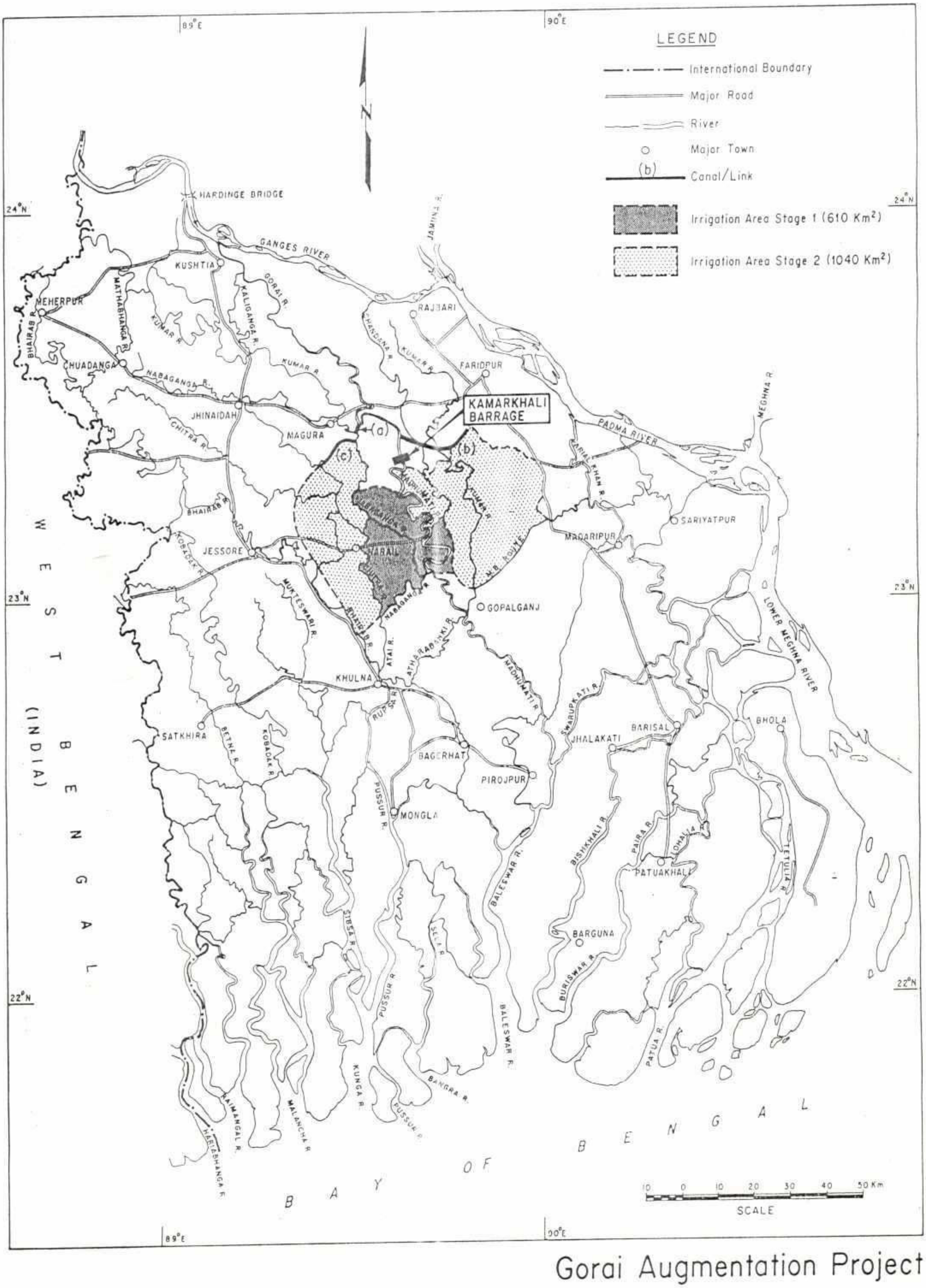
Suitable areas totalling about 93,000 ha has been identified on the right bank of the Madhumati (and further west) and another 63,000 ha on the left bank which extends upto the Old Kumar River (Figure 8.7). It is expected that some areas along the Gorai/Madhumati floodplains which are outside the protection of the existing FC embankments would come under irrigated agriculture during the dry seasons by the farmers own initiative. Since these pockets of floodplain areas (estimated to total 9,000 ha from Kushtia to the Halifax Cut) lie outside the Planning Unit boundaries, they have not been taken into account in the above totals.

8.5 Maintenance Dredging in the Gorai

At the Interim Reporting stage in November 1992 estimates of maintenance dredging for the various Gorai flow requirements were prepared based on assumptions made from quoted annual dredging costs for the G-K pump station intake channel which is a relatively small reach. However, further studies which take into account the deepening of channels at river bends and the contribution of groynes at strategic locations to sustain reasonable channel cross-sections have shown that the annual maintenance dredging requirement would be much less.

The recent studies included the BENDFLOW Computer Program using Bridges Method and estimation was made of the reduction in dredging requirements due to existence of eight bends between the Gorai mouth and Ch. 29.0 km. It is estimated that the annual maintenance dredging for a 170 cumecs capacity Gorai River dry flow channel would be about 0.5 M m^3 costing about Tk 58 million.

Figure 8.7



Gorai Augmentation Project
Proposed Irrigation Areas

TABLE 8. 2
Proposed Development Areas

Planning Unit	Irrigable Area (Km^2) Existing FCD	New	Total	Phasing of Development (Area in Km^2) Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
SW 4	40	110	150						75	75			
									37	60	38	15	
SW 5	360	--	360	120	120	120							
						180	108	72					
SW 6	68	112	180				30	75	75				
							15	46	66	38	15		
SW 7	--	450	450					120	120	120	90		
								60	96	120	105	51	18
SW 10	222	193	415			55	120	120	120				
						27	77	107	120	60	24		
MISC.	--	90	90			25	20	15	10	10	10		
						13	20	15	11	12	8	9	2

[vp\gorai\tab8-2]

Note :

120 (solid bar) Irrigation and Drainage Channel Development; Area in Km^2

27 (dashed bar) LLP Installation; Area in Km^2

The BENDFLOW program has been recently used in Bangladesh on the Brahmaputra Right Bank Training Studies (FAP-1) and on other large rivers elsewhere.

Although the annual maintenance dredging requirement of 0.5 Mm^3 appears to be high it is comparable with the current annual dredging requirement of 0.4 Mm^3 in the G-K Project to keep the inlet channel to the pump stations open. During the early days of the G-K Project (in the 1970s) it was reported that the maintenance requirement was nearly 1.0 Mm^3. It can therefore be concluded that the maintenance dredging requirements for the Gorai is within the capacity of the BWDB who will eventually be responsible for the operation and maintenance of the project including control structure of the Gorai mouth.

8.6 Water Supply to Khulna

Various options were considered for securing water supply to Khulna, including using existing beels as freshwater reservoirs and the diversion of flow from Gorai appears to be a better option.

The proposed option is based on diverting the required flow from the Chitra River just upstream of its confluence with the Lower Nabaganga and conveying it to Fulbari-gate (just north of the city of Khulna) through a buried reinforced box conduit (3.0m x 1.6m). The conduit would follow a route along the right bank of an existing khal (Figure 8.8) upto the Bhairab left bank and then cross it via an inverted syphon. Pumping may be required to convey the water further to Fulbari-gate. Appropriate treatment will be necessary for the domestic supply.

The total estimated cost of the civil, electrical and mechanical works associated with the diversion, conveyance, pumping and treatment (treatment to meet domestic demand upto the year 2000) is 1400 M Tk.

8.7 Cost Estimate

The total estimated cost of all the engineering interventions for the proposed Gorai Augmentation Project, including the cost of the low lift pumps (LLP) is about 13,000 M Tk. This does not include the cost of works for the supply of water to Khulna. A summary of the development cost is given in Table 8.3.

The costs have been estimated based on relevant BWDB unit rates for mid 1991. Unit rates pertaining to major items of work are listed in Table 8.4.

The annual maintenance costs for the various types of works are as follows :

(a)	Maintenance dredging in the Gorai (0.5 mM^3/Year)	=	58 M Tk
(b)	Maintenance of Barrages	=	2% of capital cost
(c)	Maintenance of earthworks (embankments, canals, drains, link canals)	=	3% of capital cost
(d)	Maintenance of water control structure	=	2% of capital cost

TABLE 8.3

Summary of Development Cost

Component	Quantities of Major works			Total Cost (M Tk)
	Earthwork (M^3)	Concrete (1000 m^3)	Steel (1000 T)	
Gorai Intake/Control Structure	0.5	202	14	3236
Gorai Capital Dredging	13.2	-	-	1850
Gorai Guide Banks/Groynes	-	65	-	290
Kamarkhali Barrage	0.5	192	14	1860
River Links	9.2	-	-	660
River Control Structures	2.6	119	9	835
Provision of Irrig/Drain				
Earthwork	17.0	-	-	768
Structures	-	362	5	2258
LLP	-	-	-	551
Land Acquisition (20 km^2)	-	-	-	730
Total				13038

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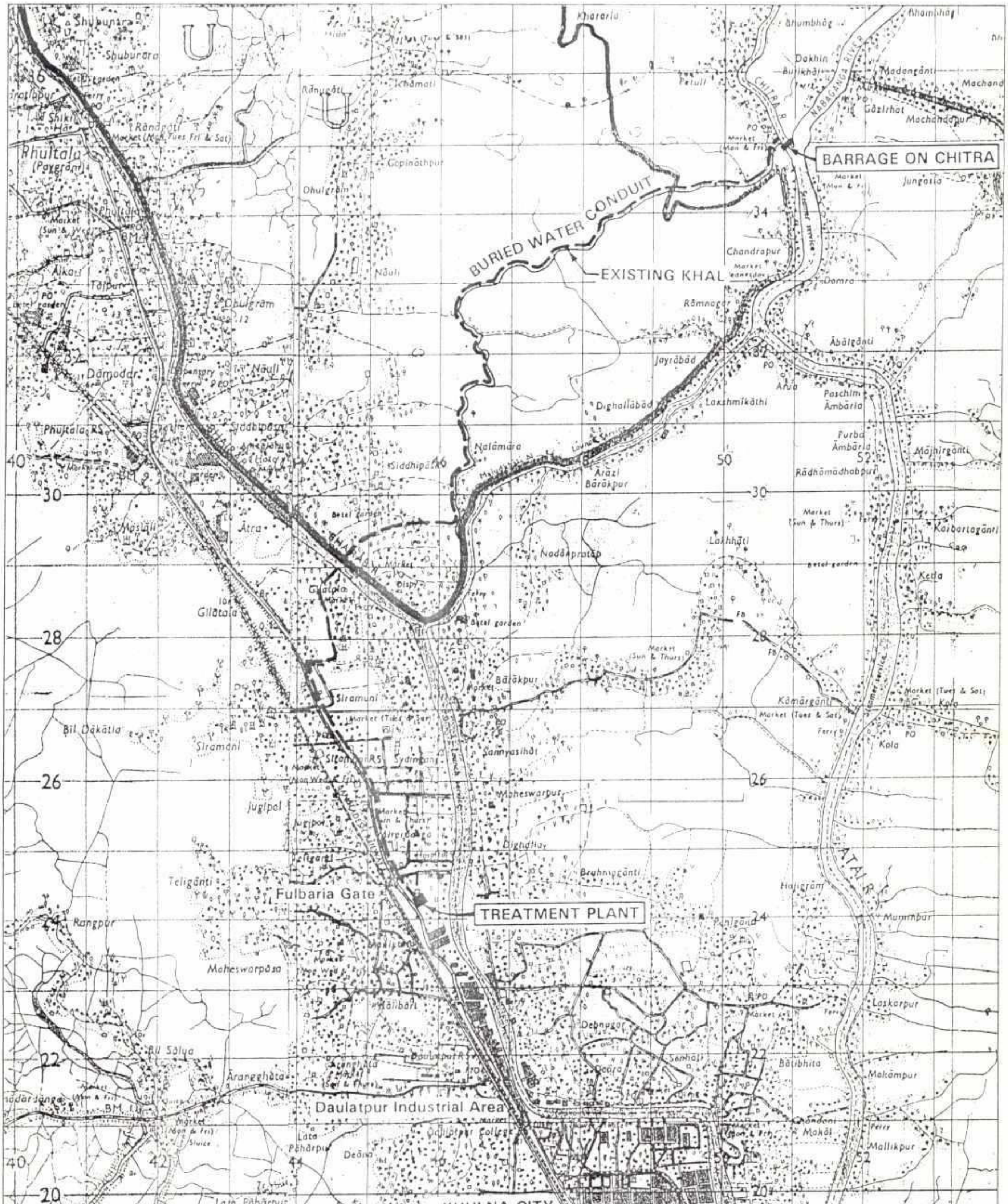
TABLE 8.4

Unit Rates of Major Items of Work

Sl No	Item of work	Unit	Rate (Tk)
1	Earth work		
(a)	Embankment construction including minimal		
	machine compaction upto a height of 3.0 m		
	" of 4.5 m	m^3	29.95
	" of 5.5 m	m^3	33.60
		m^3	35.90
	Dyke construction adopting manual compaction		
(b)	upto a height of 2.5 m		
	" 3.0 m	m^3	25.50
	" 4.5 m	m^3	27.80
	" 5.5 m	m^3	31.40
		m^3	33.75
	Excavation of drainage channels/ canals by		
(c)	manual labour including formation of		
	embankment/dyke as per item 1(b) upto a		
	(i) Lift of 1.50 m		
	(ii) Extra for every additional		
	lift of 1.0m beyond the	m^3	20.00
	initial lift of 1.5m	m^3	1.50
	(iii) Extra rate for every		
	additional lead of 15.0m	m3	
	beyond the initial lead of		2.50
	30.0m		
	Concrete:		
	Mass concrete 1:3:6		
2	Reinforced concrete 1:2:4	m^3	
(a)		m^3	1820.00
(b)	Supplying and placing brick blocks 38cm x 38cm		2480.00
	x 30cm	m^2	
3			500.00
	M.S. Reinforcement		
		Kg	
4	Structural Steel		26.50
		Kg	
5	Formwork		30.60
		m^2	
6	First class/picked jhama brick chips [25 - 38mm]		209.00
		m^3	
7	Backfilling of hydraulic structure		672.00
	by earth -		
	by sand -		
8		m^3	
	RCC pipe - 0.60m dia	m^3	21.50
	- 0.90m dia		183.00
		m	
9	1.63mx1.93m steel flap gate	m	900.00
	- do - steel slide gate		1980.00
		each	
10	Land acquisition	each	26000.00
			60000.00
		ha	
11			250000.00

Figure 8.8



Water Supply to Khulna

9 O & M, COST RECOVERY AND INSTITUTIONAL ISSUES

9.1 General

Preliminary assessment of existing FCD/I schemes in the project area shows inadequacies in the operation and maintenance (O&M) of the flood control and drainage system. The reason generally quoted by the concerned government staff for the poor O&M status is the non-availability of the required funds. Apparently, annual O & M budget allocations to BWDB, the government agency that is responsible for these field activities in addition to project implementation, are used mainly for paying staff salaries. However, an equally important reason for the poor O&M status is that there are no separate offices or staff at district level (and lower levels) for project implementation and O&M, and all the available staff at these offices are almost fully committed to only project implementation work. The assessment also revealed that the project beneficiaries do not pay any annual charges for the existing facilities; the project in fact does not generate its own funds to meet the cost of any O & M activities.

Cost recovery from the beneficiaries of water resources cum irrigated agricultural development projects is a complex issue. FCD/I projects do not have the same and/or equal impact on all beneficiaries: benefits could vary from one project to another, also vary from one plot to another within the same project. Moreover, in Bangladesh the provision of flood control and drainage (implementation, maintenance, etc) has been traditionally considerd the responsibility of the government.

Though there have been statutory provisions since 1976 for collection of water rates from farmers benefitting from any BWDB sponsored FCD/I developments, the actual collection has been next to nothing in the whole of Bangladesh, possibly in keeping with the above traditional view. However, recent field surveys, including the one the Consultant conducted in some of the existing projects (the Chenchuri Beel, Bamankhali-Barnali and Alfadanga-Boalmari), indicate that the farmers appear to appreciate the linkage between poor O&M and low agricultural production (reduced area, yields, etc) and show willingness to at least participate (providing free labour) in maintenance work. However, the present statutory provision by which the BWDB is responsible for both the assessment of water rates and their collection does not appear to be the correct procedure to achieve cost recovery in view of the slow confidence build-up between government agencies and beneficiaries. It would be prudent to involve the beneficiaries, as well as others who would be expected to subsequently provide support facilities to the beneficiaries, when determining the water rate for each project.

The government, on the other hand, appreciating the importance of cost recovery for project sustainability has initiated a number of studies through its relevant agencies to identify suitable mechanisms for achieving it.

9.2 Related O&M Studies

BWDB have been carrying out the following four major programmes under external aid to study the present status of O&M in various projects and identify suitable measures for improved O&M and cost recovery:

(a) Systems Rehabilitation Project

(b) Second Small Scale Flood Control, Drainage and Irrigation Project

(c) G-K Rehabilitation Project

(d) Early Implementation Project

In addition, LGEB has been carrying out similar studies with particular emphasis on participation of thana and other lower level local government institutions (Unions) in promoting these activities.

There is on-going pilot programme of the Systems Rehabilitation Project to formulate and operate suitable measures for achieving cost recovery. This is attached to the Ichamati Unit of the Karnafuli Irrigation Project (near Sylhet, Northeast Region of Bangladesh). However, the progress in implementing the required measures has been slow. The programme endeavours to enlist the support of the relevant staff of the local government institutions (thanas and unions) and NGOs to form viable Water User Groups which would then take responsibility for collecting the water rates as well as participating in O&M activities.

9.3 Constraints to Operation and Maintenance

A preliminary assessment of the existing FCD/I projects in the Southwest Area and a more detailed examination of the Chenchuri Beel FCD Project show that generally the major constraints for operation and maintenance are the lack of trained O&M staff and necessary funds to meet the requirement. In addition, in some of the existing projects the following constraints have been noted:

- inadequate capacity of some of the drainage structures, particularly due to the prevalence of high river stages outside the embankments;
- social conflicts of different interested groups inside the project, particularly in polder areas, and also influence of the local elites;
- conflicts between farmers on high and low lands and between farmers within the protected area and outside;
- lack of specific and clear demarcation of responsibility among the operational staff;
- lack of adequate coordination between the different government agencies that hold responsibilities for giving specific services/support to the project beneficiaries;
- lack of beneficiary participation;
- theft of fall boards used in water control structures.

9.4 Routine and Remedial Maintenance

Routine maintenance is a periodical exercise to keep a system in optimal working condition at all times. The importance of routine maintenance for a system's longevity should not noticeably vary for different systems, whether they are pump stations, water control structures or flood control embankments. considering that routine maintenance needs to be carried out on a regular basis, the related activities should be scheduled in the same manner as that for activities relating to system operation.

Remedial maintenance relates to any repairs to a system after a failure, fault or damage. Its cost could be comparatively very high depending on the extent of the failure/damage. It is generally a one-off failure brought about by a catastrophic event; but failures due to poor design are not uncommon.

Any proposed measures for cost recovery from beneficiaries need to consider the above difference in the two types of maintenance and should not pass the cost of remedial maintenance to the beneficiaries.

9.5 People's Participation

The importance of beneficiary or people's participation in planning, implementation, operation and maintenance of projects relating to water and agricultural development cannot be over emphasised, particularly in hydrologically and hydromorphologically complex areas in the Southwest Area. The generally conflicting needs of the people in the area (agricultural, fisheries, domestic and industrial) make the development issues further complex. The people of the area have much to offer to the technocrats to enable them identify possibly the local issues and negative impacts of certain interventions, and importantly understand the people's needs. These issues and conflicting needs are much in evidence in the existing projects in the study area.

Evidence from many FCD/I schemes suggests that project implementation, operation and overall socio-economic benefits are better when people are involved at all stages of project development, and people's participation could be achieved more effectively in small-scale projects than large-scale projects.

9.6 Support of NGOs

The interviewed farmers in the project area value the support they receive from various non-governmental agencies (NGO) and consequently place a lot of confidence on them. Indeed, NGOs operating at the village and thana level may provide the best option for helping to organise farmers' groups and to link them to the local government institutions in the area.

Furthermore, the experience gained by some of the NGOs in terms of identifying and realising local community needs has enabled them to achieve considerable insight into appropriate methodology and measures for successful development at local level.

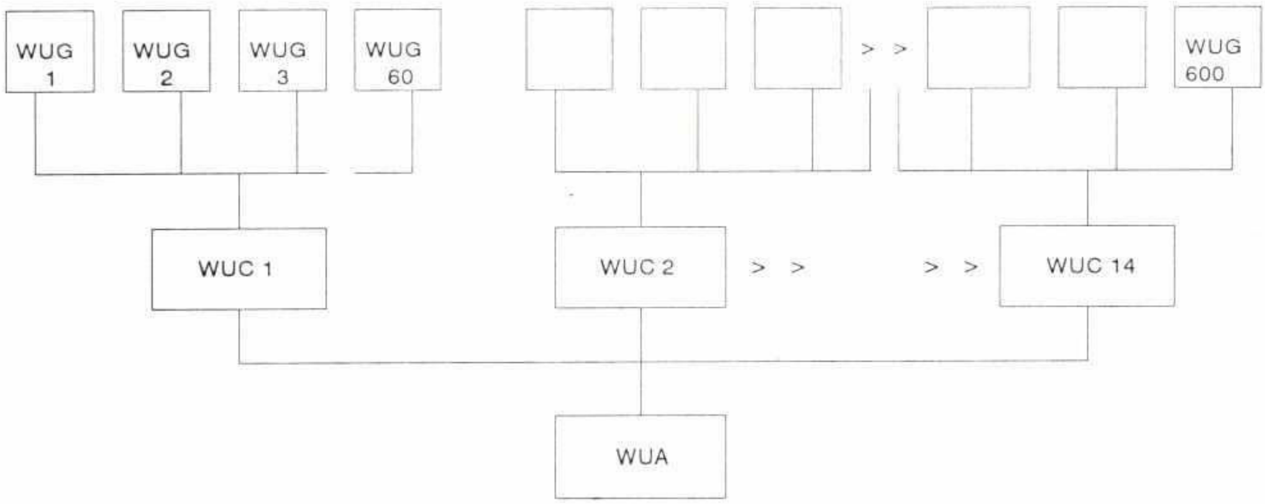
9.7 Proposed Measures for Implementation, O&M and Cost Recovery

It is recommended that BWDB should establish separate offices for project implementation and O&M at district levels. In addition to their primary responsibilities, these offices shall encourage beneficiary participation at the implementation and O&M stages for which the staff will need to coordinate with other relevant government agencies and local NGOs.

The cost of operation and routine maintenance should be recovered from the beneficiaries. This could be accomplished by imposing appropriate water rates that reflect the benefits that result from the project works and associated infrastructure. Further studies may be needed to identify a more balanced procedure for determining water rate for each project that takes into account not only the individual farmer's landholding but also its potential for enhanced agricultural production.

Taking cognisance of the related issues discussed herein above and the need to have an effective O&M programmes, an institutional set-up as proposed for a sample area (Table 9.1) is recommended for individual schemes that would be taken up under the Gorai Augmentation Project. The Table summarises the composition and responsibilities of each tier of the institutional set-up allows for beneficiary participation not only in O&M activities but also in the initial activities relating to project planning and implementation.

TABLE 9.1
Recommended Institutional Arrangement for
Implementation, Operation & Maintenance And Cost Recovery



Note :
The number of WUGs & WUCs relates to Chenchuri Beel Rehabilitation Project (NCA = 17,900 ha) for which this sample study was done.

Name of Water User Units	Composition of Water User Units	Responsibilities of Water User Units	Participating Agencies
Water User Group (WUG)	20-50 ha Canal Unit. 10-20 farmers associated with a LLP or outlet to form Water User Group.	Responsible for provision of watercourses / field channels / pumps and their O & M.	Supported by field extension staff involved in Agriculture, Fisheries etc. and NGOs.
Water User Committee (WUC)	500-1500 ha sub-compartment. One representative from each WUG within a sub-compartment.	Participate in main, secondary and tertiary canals/drains network planning;	BWDB staff supported by Union Parishad staff & NGOs.
		Organise WUGs to participate in tertiary canals/drains construction on the basis of payment for work done.	-- Do --
		Responsible for cost recovery to finance O & M of the main, secondary and tertiary network.	Union Parishad staff supported by BWDB staff and NGOs.
		Organise WUGs to participate in all O & M activities on the basis of payment for work done.	-- Do --
Water User Association (WUA)	Covers the entire project / compartment area of 1,000 to 20,000 ha.	Participate in formulating O & M criteria and work programme for each of the sub compartments.	
	WUA comprises a representative from each WUC, SDE of BWDB and a representative from relevant government agencies (DAE, BRDB, LGED, BADC etc.). WUA shall be chaired by the XEN of BWDB O & M Division.	Coordinate and supervise the activities of all WUCs and WUGs. Liaise with relevant Government and other agencies.	----

[vp\gorai\tab9-1]

10 IMPACT STUDIES

10.1 Social Impacts

10.1.1 General

The socio-economic assessment of the existing situation is based on field visits, field survey and observations and group discussions with the people living within the project area. Names of the 47 villages where the survey was carried out are tabulated below:

District	Thanas	Villages
	Bhanga	Madhayapara, Shilardharchar, Chowdhuridanga, Bharoitanga, Pukuria, Nurpur
	Sadarpur	Horinna, Nurullahganj, Natundangi
	Boalmari	Golaynagar, Sarokanda, Dhulpukuria, Mohishala
	Kotwali	Purbagangabardi, Bokail, Talugram, Jair, Kajudha, Habilidyarampur
	Alfadanga	Kamargram, Char Kamargram, Alfadanga, Jhatikgram
Faridpur	Nagarkanda	Bashnaqari, Lashkadia, Majikanda, Kashikanda, Bilgobindapur, Singapratap
	Modhukhali	Mechardia, Utali
	Moksudpur	Batikamari, Moharajpur, Padmakanda, Kohaldia, Nonikheer
Gopalganj	Kasiani	Barashpur, Chapta, Bishwanathpur
	Rajoir	Purbanagardi, Tatikandi
Magura	Mohammedpur	Dhoail, Joshpur, Mohammedpur, Binodpur, Tollabaria, Mousha, Jangalia

For the purpose of this study, the households have been stratified into 7 socio-economic groups. The categories of household and their holding size are given below.

Household Category	Operated land (ha)
Landless	0.00 - 0.20
Marginal Farmer	0.21 - 0.50
Small Farmer	0.51 - 1.00
Medium Farmer	1.01 - 2.00
Large Farmer	2.00 +
Female Headed Household	----
Fishermen	----

10.1.2 Existing Situation

Demographic characteristics

The total population of the sample household is estimated as about 703 comprising some 105 households (Table 10.1). This roughly works out to about 6 persons per hectare of crop land and the population is continuing to grow.

TABLE 10.1

Population and Literacy

Groups	No of Resp	Population				Family size	Education %		
		Male (M) No	Female (F) No	Total No	Ratio (M/F)	No	Illiterate	Primary	Class VI and above
Landless	15	41	40	81	1.03	5.4	73.3	26.7	-
Marginal	15	43	35	78	1.23	5.2	53.3	26.7	20.0
Small	15	51	56	107	0.91	7.1	26.7	26.7	46.6
Medium	15	61	67	128	0.91	8.5	33.3	46.7	20.0
Large	15	84	70	154	1.20	10.3	6.6	26.7	66.7
Women	15	50	35	55	0.57	3.7	93.3	6.7	-
Fishermen	15	51	49	100	1.04	6.7	66.7	6.7	26.6
All	105	351	352	703	1.00	6.7	50.5	23.8	25.7

Source : Consultants' field survey

The proportion of male and female is almost same. The average family size in the project area is estimated to be 6.7 persons which is higher than the Chencuri Beel Project, the SWA and the national average. However, the large and medium farm households category shows a much higher size of 10.5 and 8.5 persons respectively. This probably reflects the influence of the joint family system in the upper category of farm family.

Literacy and Education

The overall literacy rate of the population in the project area is about 50 per cent, which is much higher than the SWA and the national average. The literacy rate increases with the size of landholding. Among all household categories, 93 percent of the female headed households and 67 percent of the fishermen communities are illiterate. The number of literate persons increases as the economic condition of the family improves. The highest literacy rate is found in the large farmers household category (about 94 percent).

The survey also indicates that basic literacy among females is much lower than among males. The majority of the literate persons, about 48 per cent have had only primary education, while 38 per cent have had secondary education and 10 per cent higher secondary.

Labour Forces, Occupation and Employment

The labour force in the project area is predominantly agricultural, generally self- employed and suffers from low productivity and high underemployment due to seasonality of activities, high level of landlessness and lack of non-farm employment opportunities. Broadly speaking, some 68 per cent of the employed labour force is occupied in agriculture, of which 42 percent on own farm, 25 per cent on own and others farm and 14 per cent as day labour. About 14 percent is engaged in full time fishing (Table 10.2).

Non-agricultural occupations account for some 5 per cent of the total employment. Important among these are : business, services and professions.

The occupation distribution of the employed labour force by landowning categories shows that about 47 per cent of the landless work as agricultural day labour. Agricultural labour is drawn primarily from the landless households. About 46 per cent of the small farm households farm their own and share cropped land and also work on others land; some 28 per cent are occupied in non-agricultural activities like service, business, and transportation.

In all, about 41 per cent of the total employed labour force has secondary occupations. The highest proportion, 60 percent, falls in the marginal farmers category. About 7 percent of the marginal farmers also take up fishing as their secondary occupation. Wage labour and business appear to be the most important second occupation (Table 10.3). The seasonal nature of agricultural labour demand affects the employment pattern. During the slack season more than half of the labour suffers from under-employment. On the other hand, during peak seasons, over two-third of the employed force work more than normal working hours.

The wage rates are closely related to supply and demand. The average wage rate per day is Tk 32 for male and Tk. 24 for the females. They vary from Tk 45 per day in the peak season to Tk 24 per day in the off season.

The land tenure system in the project area is broadly similar to that prevailing in other parts of Bangladesh. Owner operators are the most predominant. The terms of share cropping are the same for all crops in the project area; i.e, full cost of cultivation is borne by the tenant who receives one half of the total output in return.

Income and Expenditure

The Gorai project area shows a better picture (compared to the average of SWA) as far as the per capita income and expenditure levels are concerned. The Table below shows that the average per capita income of the people of this area is approximately Tk 5729 whereas the farmers' average is Tk 6083. Mainly the very high per capita income differential is responsible for the discrepancy here. The per capita income of the large farmers is significantly high, Tk 12013, among the respondants while the landless group stands at the bottom of all groups with only Tk 3581.

Income and Expenditure

	Landless	Marginal	Small	Medium	Large	Farmers	Women	Fishermen	Ave for all
Per capita income	3581	4095	5139	5587	12013	6083	4176	6929	5729
Per capita Expenditure	3749	4193	5179	5779	12719	6324	4632	6829	5928

Source: Field observation

Per capita expenditure is Tk 5928 for all groups while that for the farmers' group is a bit higher - Tk 6324.

TABLE 10.2

Main Occupation

Main Occupation	Landless Farmer		Marginal Farmer		Small Farmer		Medium Farmer		Large Farmer		Farmer Total		Women		Fisherman		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Agriculture	8	53.3	15	100	15	100	15	100	15	100	68	90.7	3	20.0			71	67.7
Fishery Capture															15	100	15	14.2
Agri Labour	7	46.7									7	9.3	7	47.0			14	13.3
Non-Agri Labour																		12.5
Business													2	13.3			2	2.0
Others													3	20.0			3	3.0
Total	15	100	15	100	15	100	15	100	15	100	75	100	15	100	15	100	105	100

TABLE 10.3

Secondary Occupation

Secondary Occupation	Landless Farmer		Marginal Farmer		Small Farmer		Medium Farmer		Large Farmer		Farmer Total		Women		Fisherman		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Agriculture													1	20.0			1	2.23
Fishery Capture			3	33.3							3	8.5					3	6.98
Agri Labour	1	14.2			1	12.5					2	5.8	1	20.0			3	6.98
Non-Agri Labour	2	28.6	1	11.1	1	12.5					4	11.5	1	20.0			5	11.7
Business	4	57.1	3	33.3	6	75.0	2	33.3	3	60.0	18	51.4	1	20.0	2	66.7	21	48.9
Others			2	22.2			4	66.7	2	40.0	8	22.9	1	20.0	1	33.3	10	23.2
Total	7	100	9	100	8	100	6	100	5	100	35	100	5	100	3	100	43	100

Quality of Life

Malnutrition is a widespread, persistent, and apparently increasing problem in the project area. Less than 5 percent of the population consume an adequate quantity and quality of food. Malnutrition most severely affects children under five years of age, and also pregnant and lactating women. Evidences show that the daily per capita calorie consumption has deteriorated significantly in the last two decades, compared with an estimated minimum daily requirement of 2,200 calories per capita per day, which reveals that average consumption is well below 20 percent of the requirements specially for the landless, marginal, small, female headed households and the fishermen communities, even ignoring unequal distributions of food between and within families (Table 10.4).

TABLE 10.4

Caloric Intake (per person/day)

	Landless	Marginal	Small	Medium	Large	Farmers	Women	Fishermen
Cereals	1631 (81)	1552 (70)	2202 (74)	2556 (69)	2950 (72)	2178 (73)	2131 (72)	2417 (68)
Fish/Meat/ Pulses	165 (8)	283 (13)	344 (12)	499 (14)	567 (14)	372 (12)	295 (10)	528 (15)
Vegetables	223 (11)	373 (17)	415 (14)	635 (17)	585 (14)	446 (15)	550 (10)	596 (17)
Total	2019 (100)	2208 (100)	2961 (100)	3690 (100)	4102 (100)	2996 (100)	2976 (100)	3541 (100)

Note : Values in brackets are percentages relating to total caloric intake of each group

Source: Field survey results

Although the field survey data shows a reasonable level of per capita caloric intake, the proportion or the percentage of main nutrients, the major sources of energy, is fairly low compared to the recommended level. Only 12% protein and 15% vegetables are consumed on an average by the farmers' group.

The low protein intake is attributed primarily to a decline in the consumption of pulses which has again resulted from the dominance of rice in the cropping patterns. The survey indicates an estimated 77 percent of the household were deficit in protein consumption. Furthermore, due to the calorie deficiencies, part of the protein consumed is converted for energy purposes, thus exacerbating the protein deficiencies. Average daily consumption of dietary fat was also severely deficient at about 5 gram per capita, representing only about 35 percent of the recommended level.

Deficiencies in essential micronutrient also characterize the typical diet in the project area. The high proportion of cereals (about 71 percent) in the diet, the low amount of protein, and the absence of fish, meat,milk, fruits and vegetables, all exacerbate the chronic situation of caloric insufficiency. Indeed, the survey results show that an increasing proportion of households specially from the landless, small and marginal farmers consume significantly less than the minimum requirements of all the major micronutrient.

The major determinants of food consumption in the project area are household income and wealth, which primarily depend on the ownership and the size of the landholding, employment and the price of rice. The survey reveals that the relationship between landholding and food intake is directly related. But cereal intake showed an inverse relation - it goes down with the size of land holding. Among food groups fish, meat, fruits and vegetables consumption was found to be directly related to income. Most of the nutrients showed a rising trend with the increase in the land holding size and a positive correlation was found between them. Malnutrition is, therefore, essentially a poverty and rural employment generation problem. The situation for the rural landless and the female headed families and those in the informal labour market is particularly difficult, reflecting the over-supply of labour and the declining average daily real wage rates of agricultural labour. Improving employment opportunities and increasing real income through income generating activities are of overriding importance in significantly improving the nutritional status of the poor in the project area.

The high incidence of diarrhoeal disease and intestinal parasites (Table 10.5) further compromises nutritional status in the project area, particularly among children under five, by limiting both the availability and absorption of food for metabolic use. Measles is also a major factor in precipitating severe or life threatening malnutrition.

Vulnerable Groups

Causes of landlessness are a complex set of socio-economic, demographic and institutional factors. A fundamental reason is the rapid growth in population, placing extreme pressure on already limited resources . Also the fragmentation of land holdings, low agricultural productivity, the deteriorating employment situation, the declining real income and the resultant economic hardship have led among other things to increasing landlessness.

In general, most of the landless are absolutely poor; their annual per capita income is low and they are characterized by extremely low health and poor nutritional status, which also affects their capacity to work. They have problems of access to institutional sources of credit and depend almost entirely on non-institutional sources. They have no interest in being members of any organized group. To the landless, making and eking out a living is a way of life.The self-perpetuating plight of the absolute poor has tended to cut them of from whatever economic progresses has taken place elsewhere in their own society. They have remained largely outside the development effort; able neither to contribute much to it, nor to benefit from it.

Female headed households, fishermen, landless, marginal and the small farmers are the most vulnerable social groups in the project area. According to official estimates, in Bangladesh about 16 percent of the households are headed by females, this percentage may be even higher in the project area. Under the present sociological condition, while men have power and authority over women, they are also normally obliged to provide women with food, clothing and shelter. The reality of this arrangement diverges from the ideal. Certain women have always been vulnerable to being left exposed and without protection. Increasing poverty is placing strains even on the bonds of obligations and sometimes males from very poor households, who cannot fulfill their obligations towards their family, abandon them and their offsprings and migrate elsewhere.

Widow-hood, separation or sheer abandonment are generating an increasing number of women who must fend for themselves - and their children - in an environment which presents very few opportunities for doing so. Most of these women and their household members live in sub-human conditions. Although the total number of these "distressed" women is not known, they are estimated to be significant. Data collection specific to this matter has to be undertaken during any future feasibility study of the project. It is anticipated that with the project intervention, the plight of these women group will be improved through the increased farm and off-farm activities.

Marginal and small farmers living in the project area is another vulnerable group. Not only the physical process of annual flooding, land erosion and accretion create an increasing population of landless or landpoor households requiring employment support and appropriate development policies, but the rapid environmental changes also tend to enhance social polarization.

TABLE 10.5

Diseases by Respondents

Diseases	Landless Farmer		Marginal Farmer		Small Farmer		Medium Farmer		Large Farmer		Farmer Total		Women		Fisherman		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Chicken Pox	11	73.3	9	60.0	11	73.3	8	53.3	6	40.0	45	60.0	11	73.3	5	33.3	61	58.1
Dysentry	1	6.7			4	26.7	2	13.3	4	26.7	11	14.7					11	10.5
Diarrhoea	14	93.3	13	86.7	12	80.0	12	86.7	11	73.3	63	84.0	12	80.0	11	73.3	85	81.9
Gastric			4	26.7	5	33.3	4	26.7	5	33.3	18	24.0					18	17.1
Fever	10	66.7	6	40.0	6	40.0	10	66.7	7	46.7	39	52.0	5	33.3	5	33.3	49	46.6
Others	1	6.7	2	13.3	1	6.7	2	13.3	5	33.3	11	14.7	2	13.3	2	13.3	15	14.2
Total Respondents	15	100	15	100	15	100	15	100	15	100	15	100	15	100	15	100	15	100

Peoples Participation

The survey finding confirms that the people in the project area in large numbers are willing to participate in the project interventions. Their participation was qualified by enquiring about their willingness to provide land for the system implementation by the executing agency. About 66 percent of the respondents expressed their willingness to provide land.

10.1.3 Future Sociological Impacts

The study area is presently characterised by low levels of agricultural production causing acute level of poverty. Economic and social benefits are expected to accrue from the proposed Gorai Augmentation Project. The envisaged physical improvements from the interventions proposed under the project and other associated developments within the project area can be summarised as follows :

During the monsoon period :

(a) Controlled monsoon flows through the Gorai to a maximum of its present dominant discharge which would remove drainage congestion in substantial areas in the Southwest Region north of Khulna;

(b) Controlled drainage and internal water management through compartmentalisation;

(c) Controlled flooding through construction of FC embankments and outfall regulators, and associated developments;

(d) Controlled flood flows directed to beels to improve fisheries potential;

During the dry season :

(e) Improved flow down the Gorai / Madhumati in support of irrigated agriculture;

(f) Allocation of potable water use in the industrial town of Khulna;

(g) Improved navigability particularly for the country boats;

(h) Allocation of water to beels to maintain minimum storage for fisheries needs.

The group that will mainly benefit from the project is the farmers who would not only have opportunity to increase HYV cultivation during all seasons and thereby increase the cropping intensity but also better category of lands when inundation depths are reduced. There will also be opportunities to improve fisheries in most beels.

Improvement in the agricultural production and fish productivity will accelerate the mobility of the economic activities. As a consequence, increase in employment opportunities for the agricultural and non-agricultural population, improvement in the wage situation, improvement in the standard of living etc will take place implying a step forward towards poverty alleviation - the major concern of most of the projects. Undoubtedly, the most vulnerable social groups, the landless and the marginal farmers, will be positively benefitted, to a great extent, through the process of being taken up from below the absolute poverty line and will develop entrepreneurial ability of some people also.

Improved standard of living will enable the rural people to afford better health and sanitation facilities in addition to achieving better nutritional levels. They are expected to enjoy improved quality of life if they are guided in the correct direction as far as the health and hygiene are concerned.

Construction of some new embankments and proper maintenance of the old ones as required by the implementation of the project will provide an improved rural transport and land communication facilities to the inhabitants which will, probably, also create some new jobs in this area. The project would also reduce inundation (local runoff) of the low lying areas, thus giving further security to life and agricultural production.

As far as the operation and maintenance of the project is concerned the beneficiaries of the project will participate spontaneously with the view to protect themselves from any further devastation and their agricultural benefits.

About two percent of land will have to be acquired for the construction of the canal and drain network and short lengths of new embankments, which will still be considered as a disbenifit by the beneficiaries. But this is an inevitable situation which goes with implementing any structural project. Compensatory measures will have to be provided for the affected people.

Another major disbenefit identified is with the fisheries. It is estimated that the area of floodplains for fisheries will be reduced by approximately 37% due to the implementation of the project which needs to be assessed with greater emphasis in any future feasibility studies. Embankments will create hindrance to the natural movement of the open water fisheries and therefore will affect the traditional capture fishing community which, eventually, will likely to lead them to change their profession. However, there would be potential for fisheries programmes in the secured beels and in the canal/drain network.

10.2 Environmental Impacts

10.2.1 Introduction

As part of the pre-feasibility an Initial Environmental Impact Evaluation (IEE) has been carried out in accordance with the FPCO Guidelines on Project Assessment - May 1992. In carrying out the IEE the FPCO Guidelines on Environmental Impact Assessment and the draft Manual on EIA have been consulted and adopted where appropriate.

10.2.2 Scoping

The Important Environmental Components (IECs) that have been used for the Regional Plan assessment are used here; in addition to which are three IECs reflecting the economic and operational aspects of the project, at this pre-feasibility stage.

The IECs used here allow an environmental evaluation to be made, and highlight the major areas of concern, which will need to be expanded and assessed in more detail at the feasibility stage.

The description of the IECs and the methodology used for the Impact Evaluation are given in Volume 9 - Impact Studies.

10.2.3 Impact Evaluation

The project has been assessed by considering each IEC and ascribing a value to each component on a scale of ± 5. The evaluation taken into account the impact that the project would have on the environmental component in terms of its importance; it spatial magnitude; the permanence of the impact; reversibility and whether there are cumulative affects. It has not been possible at this pre-feasibility stage to attempt to weight values or rank the IECs.

The values have been presented in a matrix form, to allow the pattern of beneficial/negative effects to be simply demonstrated (Table 10.6).

10.2.4 Consideration of Potential Project Impacts

Table 10.6 demonstrates that the beneficial effects of the project are largely due to the irrigation provided to agriculture.

The project will rapidly benefit a number of areas starting with SW5 and SW10. Construction of the Mohammedpur barrage and link canal 6 will alow further irrigation in SW6 and SW7. Finally link 8 will bring in areas in SW4 and further irrigation in SW10. this sequence will provide a greater distribution of agricultural income to farms of all sizes through the benefits of irrigation. During the construction period, local labour will be required for all construction works, which will add to the distribution of income throughout local communities.

With the development of the link canals, a new road network along the berms will be developed, which will have most benefit in the transport of produce and goods.

Riverine communities that rely on boat transport will be disadvantaged by the barriers to movement posed by barrages and structures. Isolation of some villages by the river closures and diversions needed for the Nabaganga intake will be a further negative impact.

Improved agriculture should improve the diet of local communities. Conversely, the increase in open water surfaces brought about by the canal network, may increase the risk from water borne diseases, especially insect vectors. The problems of water related disease will increase if people use the canals for bathing and drinking purposes.

If enforcement of the ban on timber in brick-making is not enforced, then it is likely that considerable felling in village groves will occur during the construction phase. In any case, with the availability of irrigation water, more land will be turned over to crops, and tree clearance can be expected.

The main negative impacts relate to the damage caused by capital and maintenance dredging, and in particular to the river environments.

Dredging is expected to be considerable, moving an estimated 12.2 mm^3 for the Gorai offtake works, and up to 30 km downstream in the Gorai. This degree of substrate displacement will severely affect the river fishery during construction, with fish either being killed or migrating to other waters. The fish-spawn industry around Kushtia would be particularly affected, which in turn will reduce the economic returns from local fish culture.

Some thought has been given to the use of dredged material, particularly by pumping the spoil into the Ganges, and building up the left bank of the Gorai near the mouth. However, this increase of sediment in the Ganges may cause some downstream problems, particularly for navigation by the reduction of channel depths.

Maintenance dredging will pose considerable problems for spoil disposal, year on year. The sand dredged from the Gorai is an unsuitable medium for agriculture, and is really only of value in raising land for flood proofing. Maintenance dredging is very necessary to the long-term success of the project, and this increases the complexity of the project and the risk of failure (if only temporarily) if maintenance works are not efficiently carried out, for whatever reason.

TABLE 10.6

Multi-Criteria Impact Assessment

TABLE GORAI AUGMENTATION (PRE-FEASIBILITY)											
ENVIRONMENTAL COMPONENT	IMPACT ANALYSIS : MULTI-CRITERIA VALUES										
	+5	+4	+3	+2	+1	0	-1	-2	-3	-4	-5
PHYSICAL/CHEMICAL											
PC1.Erosion of river banks					X						
PC2.FCD works						X					
PC3.Containment of flood						X					
PC4.Intervention land loss							X				
PC5.Change in salinity						X					
PC6.Change in water quality								X			
PC7.Dredging impacts									X		
BIOLOGICAL/ECOLOGICAL											
BE1.Floodplain fisheries						X					
BE2.Spawn/shrimp capture								X			
BE3.River fisheries								X			
BE4.Shrimp/fish culture								X			
BE5.Social forestry								X			
BE6.Sundarbans						X					
BE7.Wildlife/bio-diversity								X			
SOCIOLOGICAL/CULTURAL											
SC1.Security of homesteads					X						
SC2.Agriculture livelihoods		X									
SC3.Fishery livelihoods									X		
SC4.Artisanal transport							X				
SC5.Commercial transport					X						
SC6.Nutrition				X							
SC7.Water supplies			X								
SC8.Water related disease							X				
ECONOMIC/OPERATIONAL											
EO1.Distribution of income					X						
EO2.Benefit generation rate				X							
EO3.Operational complexity									X		

Whilst land acquisition is small compared to the size of the total irrigated areas, there is an estimated 14 M m^3 of material that will be excavated during the construction of the link canals and irrigation system.

The diversion of 10 cumecs into the Chitra river, to serve as a take-off point for Khulna municipal water supply, is beneficial, and helps resolve a major problem. However, with the increase in agriculture, and the switch to HYV that irrigation tends to cause, there is likely to be a fall-off in surface water quality due to dissolved agrochemicals. The diffuse nature of the return flows into the lower Gorai and Madhumati is unlikely to alter the extent of the saline wedge.

10.2.5 Mitigation of Negative Impacts

The project's negative environmental impacts can be offset by some degree of mitigation. Regrettably, the major impacts on the river environment, largely as result of the considerable dredging requirements, do not allow for any significant mitigation.

Dredging impacts on the river environment in two ways, by

(i) physically disturbing the bottom substrate, increasing suspended solids in localised areas to a level damaging to most fish, and sending a plume of solids downstream which, though not damaging, does disturb fish species and usually encourages migration out of the river stretch;

(ii) removing bed material that has to be disposed of in some other area.

Damage and disturbance to fish cannot be avoided either by the capital dredging or year-on-year during maintenance dredging. There is no mitigation that can be used. As a result the fisheries in the top end of the Gorai will suffer continuously, and fishing livelihoods will be seriously affected.

The only means by which this dredging impact could be avoided would to have a sufficient flow of water that would scour the bed naturally, and provide volumes that would dilute the suspended solids to a level tolerable to fish.

This solution is unavailable to the augmentation project on its own, and there appear to be only two additional requirements to this project if this mitigation is to be successful:

(a) a long-term water sharing agreement with India, that provided sufficient Ganges water to allow significant dry season flows down the Gorai;

(b) the construction of a Ganges barrage downstream of the Gorai offtake, with a system that guarantees the maintenance of a sufficient head of water behind the barrage in the dry season.

A water-sharing agreement is still the best option if it can be achieved. However, recent experience, coupled with an increasing upstream demand for Ganges water, suggest that there can be little confidence in an effective long-term agreement.

The possibility of constructing a Ganges barrage must therefore be seriously considered. This option cannot be advocated simply as a mitigation against dredging impacts. The wider environmental need for a Ganges barrage has been discussed in Volume 9 of the Final Report.

Disposal of spoil

Disposal of dredged spoil has been considered in the project design and the following scheme has been suggested, and costed into the project:

- dredged material in the first 8 km of the Gorai offtake would be used to construction the offtake embankments

- material dredged between 8-20 km downstream of the offtake would be pumped, through a pipeline, into the Ganges river. Whilst this removes the material from the Gorai and the surrounding agricultural land, its impact on the Ganges needs further study at the feasibility stage.

- dredged material from up to 30 km downstream of the offtake would be used to in-fill existing borrow bits and widen river embankments.

Material excavated in the course of Irrigation and Drainage works will largely (about 80%) be used in providing raised banks and roadways along the channels. The remainder would be used for re-sectioning village roads, as part of compartmentalisation within the irrigation areas. Land acquisition costs have been included for this purpose.

Loss of timber in brick making

Although the use of timber as a fuel in brick making is prohibited, many kilns (in early 1993) were seen still to be using timber. If legal enforcement cannot be guaranteed, then recourse to clauses on the contractor laid down in ICB contracts and enforced by the Engineer, may be used. Such clauses would require bricks to be purchased from only coal fired kilns, and require inspection and certification of such by the Engineer, throughout the construction phase. A further mitigation would be an insistence on the use of stone for revetments and aggregate, accepting the increase in capital costs this would entail.

Artisanal transport

This problem primarily relates to the use of small country boats, as the road network is likely to be improved by the project. On the main rives, incorporation of small locks would provide an adequate technical means of overcoming this problem. There are both maintenance and administrative costs associated with this mitigation. It is probable that a lock-keeper may be required in each case, to collect any tolls and to ensure locks are efficiently used to conserve water loss.

Water quality

The degree of pollution from agrochemicals is impossible to quantify; neither can any systems for mitigation be proposed at this stage. What will be necessary is for a monitoring programme to be set in place to monitor agrochemical pollution, and react to water quality changes. Development of this programme should be considered in detail as part of the feasibility study.

Water related diseases are always more probable with any increases in water surfaces, or freshwater bodies. Insect vector larvae that breed in water can be controlled by chemical means, or by ensuring surface disturbance. Where local hydraulic heads allow, channels should have mini-weirs and riffles to break up the water surface by turbulence. This has the added advantage of increasing dissolved oxygen levels which will aid in the self-purification of dissolved organic pollutants in the water.

Diseases transmitted in water can be avoided by good personal hygiene. Ensuring that villages have access to year-round groundwater supplies for drinking will ensure that irrigation and drainage channels are not used for potable purposes. Villages should also have sufficient pit latrines to ensure that open defecating in or near the channels does not occur. These measures, coupled with hygiene education, could be put in place by suitable NGOs as a mitigation component of the project.

Bio-diversity

The gharial pollution could be re-established by the release of captive bred populations. Before such a step in mitigation is undertaken, a study as to their survival chances must be undertaken. As the species is fish eating, and the project as devised with impact severely on the fisheries, it is not at all certain that re-introduction in the Gorai/Ganges would be successful without mitigation measures to reduce dredging.

Risks to project viability

The project will cause some environmental impacts, particularly in the river environments, most of which cannot be fully mitigated. Acceptance of this cost can only be justified if the overall benefits of the projects are great, and there is a guarantee that these benefits will occur.

Surface water irrigation will be required if the Southwest Area is to avoid escalating food shortages, and no alternative can be offered. The benefits of the project are in the provision of irrigation to about 160,000 ha in the north and central parts of the Southwest Region, and in providing a flow to the Chitra river, which can allow a piped water supply to Khulna. The project will also ensure the continued viability of the Gorai river channel, but will not greatly improve dry season flows to the transitional and saline zones.

The alternative of not intervening at the Gorai may result in losing the wet season flows in the Gorai and the environmental damage that will cause can be colossal. On balance, therefore, the Project provides the best choice available to arrest total environmental degradation and offers the opportunity to increase agricultural development during the dry season. The benefits to the agriculture by providing irrigation during the dry season however depends on adequate flows in the Ganges and therefore at risk.

10.2.6 Recommendations for Feasibility Study

A full Environmental Impact Assessment (EIA) is necessary at the feasibility study stage.

The project has wider implications than simply the provision of irrigation, and it is essential that the views of local communities in the project areas be fully taken into account and incorporated into plan drawn up at the feasibility stage.

It is suggested that the feasibility stage EIA should include consideration of the following in addition to the standard assessments made:

- people's participation to determine the communities/groups that will require project modifications to ensure mitigation from negative impacts

- targeting of fishing communities for detailed assessment of impact/compensation
- full assessment of the use of the Gorai river to local communities, and the impact of the project on this value
- detailed studies of the fish capture and culture industries in the area
- modelling of the effects of spoil return into the Ganges river
- modelling to determine the impact of the augmentation on the saline wedge in the Southwest and South Central Regions
- consideration of viable options for maintenance of river bio-diversity post-project
- incorporation into project plans public health measures to include groundwater supplies, sanitation and education on hygiene and vector control
- assessment of the means to maximise transport options in (road and water) through the project.

10.3 Other Impacts

10.3.1 G-K Irrigation System Pumphouse

The largest irrigation system in Bangladesh, the Ganges-Kobadak system is served by two large pump house at Bheramara taking off up to 120 m^3/s from the Ganges just downstream of the Hardinge rail bridge.

The pump houses were designed and constructed in the early 1960's as the first stage of full development of the Ganges including a barrage. At that time the levels in the river were significantly higher as there was less abstraction upstream and in particular the Farakka barrage had not been built. With the low levels in the Ganges that are now being experienced, there are already problems with the operation of the system. Any further significant decrease in level would therefore have serious consequences.

The level at the pump house entrance is determined by the level in the Ganges and the headloss in the approach channel which should be kept low by the dredging fleet permanently stationed in the channel for reducing headloss and also ensuring that silt settles in the approach channel where it is easily removed rather than in the canal system where disposal is more problematic. The Ganges level at Bheramara is controlled by the hydraulics of the downstream channel. At low flows the Ganges becomes a series of pools and narrows that shift each year (see Figure 2.1). Some years there may be a constriction in the low flow channel near to Bheramara which could result in higher levels for the same flow and other years there is not. This natural variability must be taken into account in the analysis.

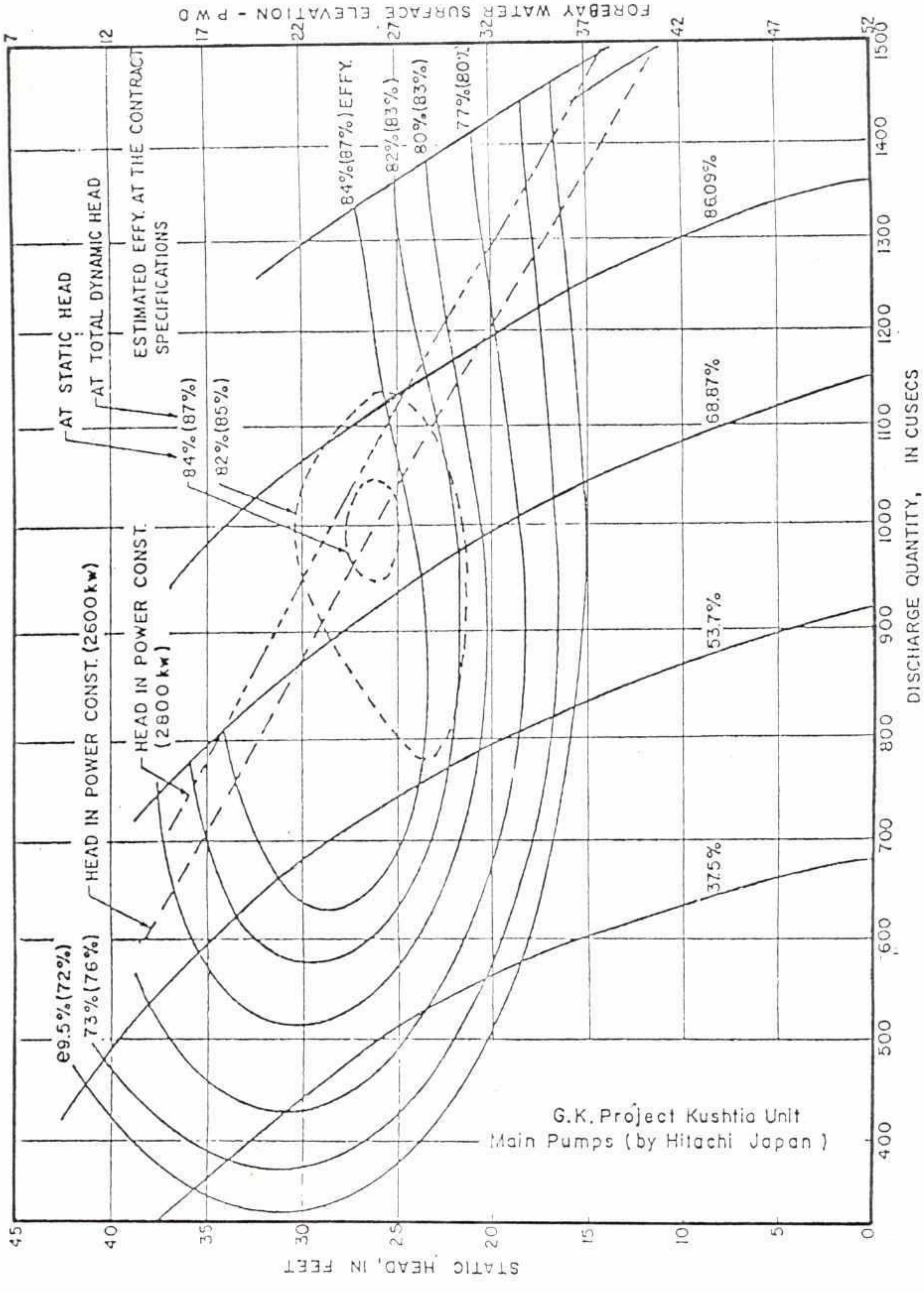
Using the latest available surveys of the Ganges (1989 BWDB sections and 1992 sections measured by FAP 4) a hydrodynamic model was used to test the impact of different flows in the Gorai on the levels at Hardinge Bridge. The results firstly indicate that level at Hardinge bridge is primarily dependant on the total flow in the Ganges downstream of Bheramara and also that drawing off 150 m^3/s at the Gorai will cause a decrease in level of 0.1m at Talbaria with a flow of 400 m^3/s in the Ganges which is as low as may reasonably be expected. The impact is smaller for larger flows in the Ganges and less critical to Bheramara.

The critical levels at Bheramara are determined by the Net Positive Suction Head (NPSH) requirements of the axial flow pumps and also by the need to avoid air entrainment at the intakes. The main pump house has a history of problems even at its design phase and the pumps were performing badly with vibration problems and low efficiencies until the recent rehabilitation works. The pump curves for the main pump house are shown in Figure 10.1 and unfortunately NPSH requirements are not available. According to Nedeco (1983) the minimum suction level for the pumps is 3.94m PWD though the pump house operators work to a higher level of +4.3m PWD and report seeing bubles in the delivery pipe work at this level which could be an indication of cavitation though most likely air entrainment or air release with decreased pressure in the delivery pipework.

The subsidiary pump house works to similar levels, and according to Nedeco (1983) the minimum operating level of the subsidiary pump house is +4.3m PWD.

Examining the difference in recorded levels between Talbaria and Hardinge Bridge, it can be seen as shown in Figure 10.2 that there is quite a high variation that is not directly related to flowrate. It is therefore concluded that although augmentation of flow through the Gorai would have a minor effect on water levels at the G-K pump houses, the effect is much smaller than the natural variation in levels for the same flowrate. The G-K pumphouses will still be most affected by the total flow in the Ganges, as controlled by releases from Farakka barrage.

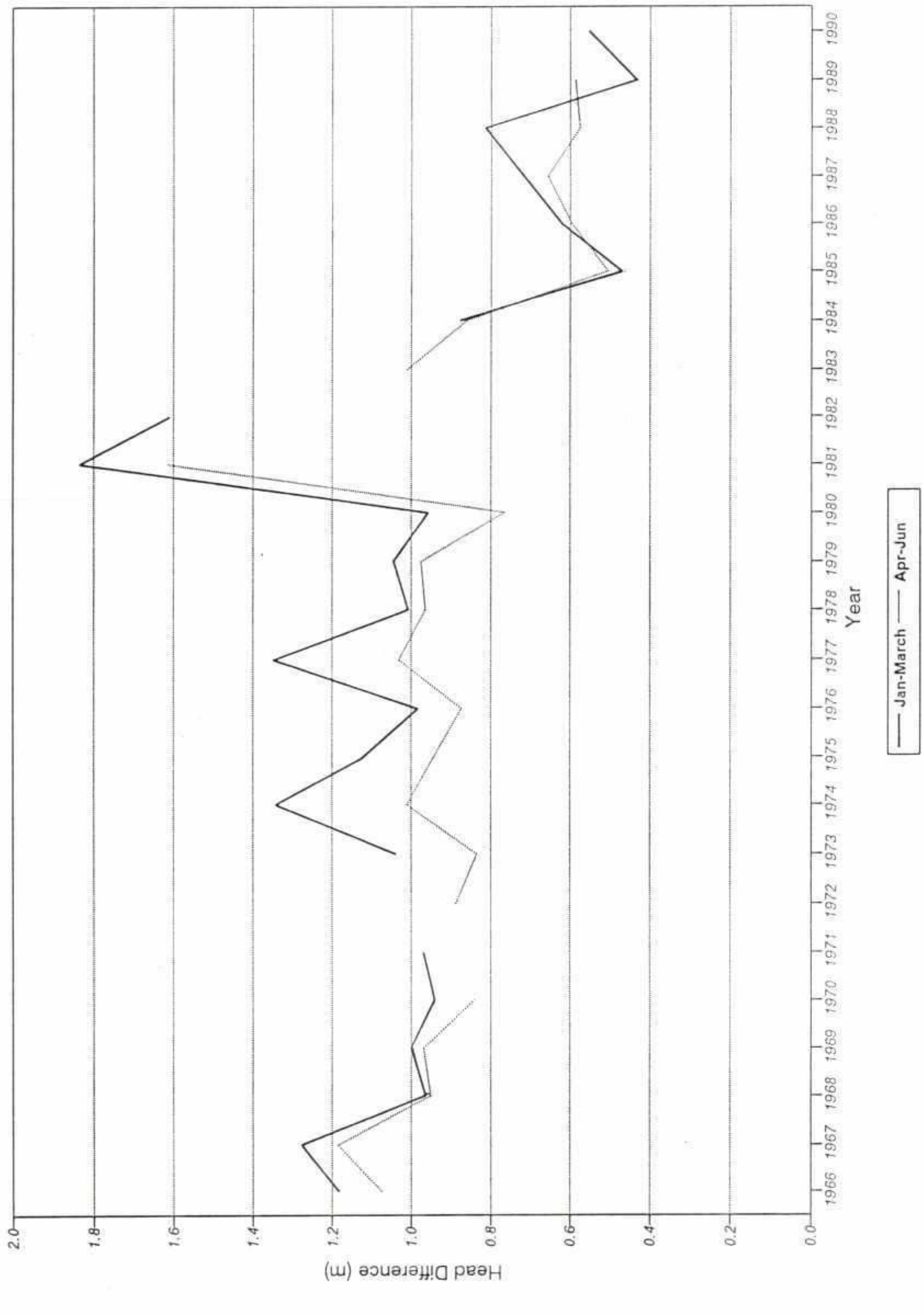
Figure 10. 1



Source: Reproduced from GK Project Report.

Main Pumps Characteristic Curves

Figure 10.2



Head Difference between Hardinge Bridge and Talbaria Gauging Stations

11 ECONOMIC ANALYSES

11.1 Introduction

The analyses of the economic benefits from the proposed Gorai Augmentation Project are based on MPO and BBS data supplemented by the Consultants' own field studies. The analyses are preliminary and at a pre-feasibility level. They follow the May 1992 FPCO Guidelines for Project Assessment. The approach to the evaluation of costs and benefits is described in detail in Volume 10, Economics.

11.2 Project Area and Scope

The agricultural, water and other resources in the project area are described in Chapter 5. The project is designed to increase and control flows in the Gorai river which will affect a net cultivable area (NCA) of almost 312,900 ha. Within this there will be provision for 105,200 ha of low lift pump (LLP) irrigation.

The area includes all or part of five main PUs; SW4, SW5, SW6, SW7 and SW 10. It is also expected to benefit about 9000 ha along the Gorai river course outside these PUs. This area is designated as Miscellaneous PUs (Misc PU) in this chapter.

The present condition of the Planning Units that will be affected is summarised in Table 11.1 in terms of the NCA by flood category and type of cultivation, whether rainfed or irrigated. At present about 259,420 ha are rainfed and 53,460 ha irrigated within the total project area of 312,880 ha. Without the project it is expected that a further 12,150 ha will become irrigated from groundwater and surface water sources during the next decade. This is an estimate conservatively based on an assessment of available groundwater resources. The forecast changes are also set out in the table. These form the basis for the derivation of the without project position for the study analyses.

TABLE 11.1

Gorai Augmentation Project Without Project
Present and future Net Cropped Areas (1) (Ha)

	F0	F1	F2	F3/4	Total	TOTAL
PRESENT						
Rainfed						
Misc PU	1910	2189	2059	1015	7173	
SW4	7840	4889	2318	704	15751	
SW5	11864	19437	13009	3600	47910	
SW6	6083	11713	7203	2307	27306	
SW7	10747	25002	28466	25444	89659	
SW10	13286	16233	33732	8371	71622	
Total	51730	79463	86787	41441	259421	
Irrigated						
Misc PU	478	747	426	176	1827	9000
SW4	2641	2962	528	118	6249	22000
SW5	2045	5009	1504	435	8993	56903
SW6	874	3267	994	232	5367	32673
SW7	780	5317	9903	4341	20341	110000
SW10	2709	3160	2870	1946	10685	82307
Total	9527	20462	16225	7248	53462	312883
TOTAL	61257	99925	103012	48689	312883	312883
FUTURE (1)						
Rainfed						
Misc PU	1724	1975	1858	916	6473	
SW4	7840	4889	2318	704	15751	
SW5	11195	18342	12276	3397	45210	
SW6	5929	11417	7021	2249	26616	
SW7	10160	23636	26910	24053	84759	
SW10	12700	15516	32243	8002	68461	
Total	49548	75775	82626	39321	247270	
Irrigated						
Misc PU	661	1033	589	244	2527	9000
SW4	2641	2962	528	118	6249	22000
SW5	2659	6513	1955	566	11693	56903
SW6	986	3687	1122	262	6057	32673
SW7	968	6598	12288	5387	25241	110000
SW10	3510	4095	3719	2522	13846	82307
Total	11425	24888	20201	9099	65613	312883
TOTAL					312883	312883

Source: Consultants estimated derived from MPO and BBS data.

(1) Assumes there will be additional future without project irrigation of 12150 Ha by year 10.

11.3 Costs

11.3.1 Financial and Economic Prices

In accordance with FPCO's requirements 1991 prices have been used in all the study analyses. Financial prices have been converted to economic values using the conversion factors (CF) provided by FPCO in its Guidelines for Project Assessment noted earlier. A full account of the basis for costs is given in Volume 10, Economics.

11.3.2 Capital and Operation and Maintenance Costs

Development costs were derived from a number of sources and where necessary inflated to 1991 prices.

Construction costs were based on unit rates supplied by BWDB O & M Circles in SWA and the Khulna Zone Highways Department. Unit rates from the five different sources within SWA showed no great divergence and average rates were used for all projects. The prevailing rate for earthworks used by BWDB is based on manual labour. While it has been accepted that a large part of the work will continue to be labour intensive the standard of materials, fill procedures and compaction will have to be raised especially for the proposed works on the Gorai and the unit rate of Tk 40/m^3 has been adopted for embankments, drains and canals to allow for this.

Irrigation development and equipment costs are based on prices supplied by BADC and a number of private sector equipment suppliers and contractors.

Operation and maintenance costs include an amount of 3% pa of the capital cost for earthworks and 2% pa for structures from the year following the capital expenditure.

The capital and recurrent dredging costs were derived from Bangladesh Inland Waterways Transport Authority (BIWTA) data.

Land acquisition for civil works was priced at a compensation rate of Tk 250,000 a hectare in the financial analysis and at the approximate value of production forgone of Tk 8720/ha a year in the economic analyses.

Details of engineering costs are given in Chapter 8. The capital and operating costs for LLPs (2 cusec capacity irrigating 20 ha) used in the analyses are given in Tables 11.3 and 11.4 respectively. Capital and O & M costs assume 40% electric and 60% diesel powered pumping as illustrated in Table 11.2 below. Provision is made for LLP replacement every eight years.

TABLE 11.2

Capital and O & M Costs for Diesel and Electric Pumps

	10%E/100D		Proportion	40%E/60%D	
	Financial	Economic		Financial	Economic
Capital: Electric	64650	40646	0.40	25860	16258
Diesel	50000	31000	0.60	30000	18600
Total				55860	34858
O & M: Tk/ha/yr Electric	1925	2613	0.40	770	1045
Diesel	2600	1775	0.60	1560	1065
Total				2330	2110

TABLE 11.3

Capital Costs LLP (54 l/s, 2 cusec) (1991 values)

Taka

Item	Financial			Conv'n Factor	Economic		
	Local	Foreign	Total		Local	Foreign	Total
Electric:							
Pump etc	10000	0	10000	0.62	6200	0	6200
Engine	25000	0	25000	0.62	15500	0	15500
Accessories	5000	0	5000	0.62	3100	0	3100
Power supply(2)	24650	0	24650	0.64	15846	0	15846
Total	64650	0	64650	0.63	40646	0	40646
Diesel:							
Pump etc	1000	0	1000	0.62	6200	0	6200
Engine	3625	31375	35000	0.62	2248	19453	21700
Accessories	5000	0	5000	0.62	3100	0	3100
Total	18625	31375	50000	0.62	11548	19453	31000

Source: Consultants estimates.
Notes : (1) 541/s sufficient for 20 Ha
(2) Costed separately on basis of Tk160000/Km and 0.14Km distribution system costs and Tk2250 connection cost each LLP

Distribution system	Financial	Conv'n factor	Economic
Capital			
Connection	2250	0.87	1958
Distribution	22400	0.62	13888
Total	24650	0.64	15846

TABLE 11.4

LLP Operating Costs (54 l/s, 2 cusec) (1991 values)

Taka/Year

Item	Financial			Conv'n Factor	Economic		
	Local	Foreign	Total		Local	Foreign	Total
Electric:							
Operator	9000	0	9000	0.87	7830	0	7830
Repair/pa	900	600	1500	0.87	783	522	1305
Energy	28000	0	28000	1.54	43120	0	43120
Total	37900	600	38500	1.36	51733	522	52255
Tk/Ha			1925				2613
Diesel:							
Operator	9000	0	9000	0.87	7830	0	7830
Repair/pa	1440	960	2400	0.87	1253	835	2088
Energy	40600	0	40600	0.63	25578	0	25578
Total	51040	960	52000	0.68	34661	835	35496
Tk/Ha			2600				1775

Source: Consultants estimates.

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11.3.3 Project Capital Costs

The Gorai Augmentation Project will be developed over 11 years and require an investment of M Tk 12780 at 1991 prices inclusive of 25% for physical contingencies and 15% for engineering overheads. At 1991 economic values (ref Volume 10, Economics) this is equivalent to M Tk 8938.

The phasing and breakdown of capital investment is given in Table 11.5. In addition there will be an annual investment varying from M Tk 18 to M Tk55 (MTk 11 to M Tk 35 economic value) from year 12 to replace LLPs.

TABLE 11.5
GORAI AUGMENTATION PROJECT COSTS (M Tk)

	1	2	3	4	5	6	7	8	9	10	11	12	Total
IrriIrrigable Area	0	0	0	6460	17160	32340	52200	70800	87440	98800	105220	105220	
Lost Area (1)	200	652	928	1192	1604	2276	2920	2920	2920	2920	2920	2920	
COSTS													
Financial .													
Capital :													
land aquisition	50	113	69	66	103	168	161	0	0	0	0	0	730
offtake	1080	1080	1076	0	0	0	0	0	0	0	0	0	3236
barrage (2)	0	710	650	500	0	0	0	0	0	0	0	0	1860
dredging	0	550	550	0	0	250	500	0	0	0	0	0	1850
river links	0	0	170	140	140	150	60	0	0	0	0	0	660
earthworks	0	50	48	94	63	157	207	103	46	0	0	0	768
major struct.(3)	0	0	350	200	200	200	175	0	0	0	0	0	1125
minor struct.	0	146	142	275	184	465	606	304	136	0	0	0	2258
pumps (4)	0	0	0	18	30	42	55	52	46	32	18	0	294
pump repl'ment	0	0	0	0	0	0	0	0	0	0	0	18	18
sub-total	1130	2649	3055	1293	720	1432	1764	459	228	32	18	18	12799
Recurrent :													
pumping	0	0	0	15	40	75	122	165	204	230	245	245	
offtake	0	22	43	65	65	65	65	65	65	65	65	65	
barrage	0	0	14	27	37	37	37	37	37	37	37	37	
dredging	0	0	0	48	48	48	48	58	58	58	58	58	
river links	0	0	0	5	9	14	18	20	20	20	20	20	
earthworks	0	0	2	3	6	8	12	19	22	23	23	23	
major struct.	0	0	0	7	11	15	19	23	23	23	23	23	
minor struct.	0	0	3	6	11	15	24	36	42	45	45	45	
sub-total	0	22	62	176	227	276	345	422	470	501	516	516	
Economic													
Capital :													
offtake	821	821	818	0	0	0	0	0	0	0	0	0	2459
barrage	0	540	494	380	0	0	0	0	0	0	0	0	1414
river links	0	0	124	102	102	110	44	0	0	0	0	0	482
earthworks	0	35	33	65	43	108	143	71	32	0	0	0	530
major struct.	0	0	266	152	152	152	133	0	0	0	0	0	855
minor struct.	0	112	109	212	142	358	467	234	105	0	0	0	1739
pumps	0	0	0	11	19	26	35	32	29	20	11	0	183
pump repl'ment	0	0	0	0	0	0	0	0	0	0	0	11	11
dredging	0	379	379	0	0	173	345	0	0	0	0	0	1277
sub-total	821	1887	2224	922	458	927	1166	338	165	20	11	11	8949
Recurrent :													
pumping	0	0	0	14	36	68	110	149	184	208	222	222	
dredging	0	0	0	36	36	36	36	44	44	44	44	44	
offtake	0	16	33	49	49	49	49	49	49	49	49	49	
barrage	0	0	11	21	28	28	28	28	28	28	28	28	
river links	0	0	0	4	7	10	13	14	14	14	14	14	
earthworks	0	0	1	2	4	5	9	13	15	16	16	16	
major strct.	0	0	0	5	8	11	14	17	17	17	17	17	
minor struct.	0	0	2	4	9	12	19	28	33	35	35	35	
land loss	2	6	8	10	14	20	26	26	26	26	26	26	
sub-total	2	22	55	146	192	240	305	369	411	438	451	451	

Source : consultants estimates .

[vp\gorai\tab11-5]

(1) Cumulative area lost from total infrastuctural works .
(2) Khamarkhali barrage .
(3) Including Gorai quide banks and groynes .
(4) Costs are based on - 54 l/s capacity low lift pumps , replaced every 8 years .
- Coverage 20 Ha .
- 90% LLP uptake = 90% area irrigated at full development
- 40% electric , 60% diesel @ Tk55860
Details in Volume 10 , Economics .

The investment costs are equivalent to almost Tk. 40850/ha NCA at financial prices and Tk 28570/ha NCA at economic values. The broad division of the capital costs for each NCA hectare are summarised in Table 11.6.

TABLE 11.6

Capital Costs Per Unit Area (NCA) (1991 Prices)

Cost	Financial				Economic			
	Mtk	%	Tk/Ha NCA	Tk/Ha irrigated NCA	Mtk	%	Tk/Ha NCA	Tk/Ha irrigated NCA
Gorai intake	3236	25	10343	30755	2459	28	7859	23370
dredging	1850	14	5913	17582	1277	14	4081	12136
other Gorai works	2985	23	9540	28369	2270	25	7254	21570
river links	660	5	2109	6273	482	5	1541	4581
irrigation	3320	26	10611	31553	2452	27	7837	23303
land acquisit(1)	730	6	2333	6938	(1)	0	0	0
Total	12781	100	40849	121469	8940	100	28572	84961

Source: Consultants' estimates.
(1) Land valued at its opportunity cost in the economic analyses.

The proposed surface irrigation development will cost Tk 31550/ha (Tk 23300/ha economic) excluding the Gorai intake and related river works.

The phasing of the development is discussed in Chapter 8. For the economic analysis it has been assumed that not all farmers who have the opportunity to purchase and install LLPs will do so. The area of project LLP irrigation is calculated as the maximum irrigable area less existing tubewells and LLPs then assuming that 90% of this resulting area is used for project LLP irrigation. The remaining 10% allows for farmers who will not wish to invest in LLPs as to join the groups that will be needed if each pump set is to irrigate a full 20 ha. On this basis the number of project LLPs installed will reach 5261, 90% of the possible, designed total. Table 11.7 shows the expected schedule of LLP installation.

TABLE 11.7

LLP Installation Schedule

Project year	SW4		SW5		SW6		SW7		SW10		Misc PU		Total LLP No	LLP Irrigation	
	%	No	%	No	%	No	%	No	%	No	%	No		New Area Ha	Cumul. Area Ha
1													0	0	
2													0	0	0
3													0	0	0
4			15	190					6	91	13	42	323	6460	6460
5			17	215	8	47			13	198	23	75	535	10700	17160
6			17	215	25	146	12	140	13	198	18	60	759	15180	32340
7	25	100	17	215	36	210	20	230	13	198	12	40	993	19860	52200
8	25	101	17	214	22	130	20	230	14	213	13	42	930	18600	70800
9	25	101	17	214	9	53	19	220	14	214	9	30	832	16640	87440
10	25	101					19	220	14	214	10	33	568	11360	98800
11							10	114	13	200	2	7	321	6420	105220
Total	100	403	100	1263	100	586	100	1154	100	1526	100	329	5261	105220	
		403		1263		586		1154		1526		329	5261		

Source: Consultants estimates
(1) Assumes that LLP is installed (capital cost) and used (benefit) in the same year.

The project irrigated area will rise from 6460 ha in year 4, after the construction of the Gorai river intake and major control structures, to 105220 ha in year 11. the number of pump sets fielded in any year will rise from 323 (year 4) to a maximum of 993 (year 7), but no more than 230 LLPs in any one PU. This will require very active promotion and an effective distribution and credit system. The number of LLPs required is derived from the use of 2 cusec capacity pumps with a net command area of 20 ha, a 90% uptake rate and a maximum project irrigated area calculated as the total identified irrigable land less the area at present irrigated by tubewells and LLPs but including present gravity irrigation. The present area irrigated by different modes is summarised in Table 11.8.

TABLE 11.8

Present Irrigated Area by Modes

Mode	Irrigated Area (Ha)						
	SW4	SW5	SW6	SW7	SW10	Misc. PU	Total
DTW	1430	210	450	1533	180	247	4050
STW/DSSTW	4371	6499	3468	10259	4462	1124	30183
LLP	235	1230	1069	7570	2951	326	13381
Gravity	212	1054	380	978	3091	130	5845
Total	6248	8993	5367	20340	10684	1827	53459

11.3.4 Recurrent Costs

Table 11.5 sets out the division of recurrent, operation and maintenance costs for the first 12 years of the project. These exclude direct crop production expenses and institutional costs. The latter is expected will be borne by the implementing agencies; BWDB, DOA and a number of NGOs. But is possible that these organisations will have to provide some services to the project beyond their present capacity. At this, pre-feasibility stage it has not been possible to quantify this requirement and provision is included in the 25% physical contingency built into the costs in Table 11.5.

Recurrent costs will rise to Tk 516M (Tk 451M economic) a year by year 12. This excludes the cost of replacement LLPs which are shown as a capital cost from year 12 in the cost flow set out in Table 11.5.

11.4 Benefits

11.4.1 General

The project benefits will arise from flood protection and drainage with year round irrigation. The assessment of benefits are confined to those arising from these factors. These direct quantifiable benefits may be considered the minimum that can be expected. However they can be enhanced if improvements are made in other sectors : credit, production support services, institution strengthening for example. Such developments are not confined to the augmentation project however and are not, therefore, included in the present analyses. The direct benefits fall into two categories:

(i) higher output arising from improved water regimes and land resource conditions, particularly from changes in flood categories from deeper to shallower and more briefly flooded areas, and

(ii) the reduction in agricultural and non-agricultural damage from floods that do not occur every year.

Penalties can also be expected from changes in water resource conditions which particularly affects capture fisheries.

Sections 11.4.2 and 11.4.3 summarise the basis for the figures used in the project analyses and these are presented in greater detail in Volume 10, Economics. Section 11.4.4 sets out the results for the Gorai Augmentation Project used in the analyses.

11.4.2 Production Benefits

The projects principal benefits are those expected from crop production. Three possible sources of benefit were considered; yield, cropping pattern and annual flood damage.

Yield

Under in-field conditions annual variations in water regimes, including flooding, are such that it is not possible to measure FCD benefits in terms of yield changes within each type of crop.

Cropping patterns

Each flood zone category; F0, F1 etc; is associated with a distinct cropping pattern as illustrated in Chapter 5. These relate to both annual cropping intensity and to the types of rice and other crops that are grown. In the kharif season there is an increase in the proportion of sugarcane and HYV rice and a decrease in the other major crops, jute and local rice varieties from the deeper flooded areas (F2, F3/4) to shallower areas (F0, F1).

Under rainfed conditions, areas within the project will lose the boro rice crop that is grown in the F3/4 areas. The proportion of high value spices and vegetables - mainly sweet potatoes will rise. The wheat area will decrease as a result of the lower soil moisture regimes in F0 and F1 areas.

Irrigation, whether in conjunction with FCD works or not, leads to benefits from a higher cropping intensity, in particular a major increase in boro rice production.

When irrigated areas are within FCD development, where F0 and F1 areas predominate, there is a major shift from local to HYV boro rice as illustrated by the following data from SWA as a whole:

Variety	F0 %	F1 %	F2 %	F3/4 %
Irrigated Rice:				
Local	0	5	2	43
HYV	100	95	98	57

Under irrigation in the less deeply flooded areas rabi cropping also exhibits higher proportions of wheat, spices and other high value crops such as vegetables and potatoes.

A description of the changes in the project area is given in Chapter 5.

Unusual flood damage

Table 11.9 sets out the extent of damage to crops from unusual floods. Damage is expressed as the proportion of the total crop area and is the average reported during the 19 years, from 1971 to 1989. In the study analyses the economic value of these crop losses, at 1991 prices, has been added to the benefit from changes in cropping patterns discussed above. The benefits do not accrue if irrigation is provided without FCD works.

TABLE 11.9

Kharif Season Average Crop Losses due to Floods 1971-1989
Percent total crop area

Planning Unit	Aus L	Aus M	Aman B	Aman TL	Aman TM	Jute	Sugarcane
SW 4, 5, 10	3.04	3.3	6.25	1.32	3.4	4.06	0.25
	3.02	2.21	4.73	0.23	0.24	1.86	0
Sw 6, 7	3.74	5.06	7.68	23.16	15.85	2.35	3.54

Source: Derived from BBS data.

11.4.3 Penalties

Previous studies including FAP 12/13 have established that reduction in flood levels adversely affects capture fisheries. Detailed information on the likely effect from the operation of the Gorai river and related irrigation works are not available. However using data from FAP 12/13 and the SWA data that are available for the project PUs an assessment of the losses in production value have been made and included as a cost of the augmentation project.

The basis for the loss estimates is given in Table 11.10.

TABLE 11.10

Capture Fisheries Losses Resulting from FCD Development (1991 Prices)

Source of Loss	Loss Kg/Ha	Financial				Economic				
		income Tk/Kg	costs Tk/Kg	G M Tk/Kg	G M Tk/Ha	income Tk/Kg	costs Tk/Kg	G M Tk/Kg	G M Tk/Ha	G M Tk000/Km²
Flood Plain:										
not flooded before	0	0	0	0	0	0	0	0	0	0
flooded before but dry now	37	35	10	25	925	44	7	37	1356	136
still flooded	20	35	10	25	500	44	7	37	733	73

Sources: Consultants estimates and FAP 12/13 reports.

In the study analyses the following has been assumed:

Flood Plain: F3/4 and F2 areas that are eliminated by FCD works are lost completely and F2 areas that remain suffer the partial loss quantified in Table 11.10.

Since it is considered unlikely that the PUs are now fully productive as a result of already existing works and the present and declining flows in the Gorai, the analyses assumed that 15% of the estimated full fisheries losses are applied as a penalty to the development.

As far as possible project works will avoid adversely affecting the area of beels and baors. It has been taken that such losses that do occur will be offset by improved production from the increased control and flows in the Gorai river itself.

11.4.4 Project Benefits

Benefits will accrue to the project from year 4, as soon as the Gorai river intake and the major river protection and control structures are in place Table 8.1 in Chapter 8 sets out the construction schedule. From year 4 controlled flows will reduce flooding and improve drainage throughout the project area resulting in the virtual elimination of F3/4 land and reduce the extent of F2 land. Benefits from FCD will then be realised over almost 312,900 ha. Irrigation from LLPs installed as a result of the project will then be phased in as illustrated previously in Table 11.7.

By year 11 at full development the benefits will accrue to 105,220 ha of project FCD and surface irrigation and FCD only benefits from a further 207,660 ha of which 160,050 ha will be rainfed and 47,620 ha irrigated by the present and future tubewells and existing LLPs. The division of these areas by PU is shown in Table 11.11.

TABLE 11.11

Net Cropped Areas

Planning Unit	Rainfed	Non Project Irrigation	Total	Project Irrigation	Total	Total Rainfed	Total Irrigation
SW4	7903	6037	13940	8060	22000	7903	14097
SW5	23704	7939	31643	25260	56903	23704	33199
SW6	15966	4987	20953	11720	32673	15966	16707
SW7	67557	19363	86920	23080	110000	67557	42443
SW10	44193	7594	51787	30520	82307	44193	38114
Misc SW	723	1697	2420	6580	9000	723	8277
Total	160046	47617	207663	105220	312883	160046	152837

The resulting benefits from the improved cultivation conditions are summarised in Table 11.12. Table 11.13 shows the additional benefits from reduced crop damage from flooding that can be expected. This will occur from year 4.

TABLE 11.12

Cost/Benefit Flow (M Tk)

Project year	SW4	SW5	SW6	SW7	SW10	SW Misc	Total
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	36.35	127.60	66.94	434.67	271.02	72.33	1008.91
5	36.35	146.93	69.85	428.55	290.26	73.12	1045.06
6	36.35	188.62	87.23	436.19	178.21	80.83	1007.42
7	41.24	231.36	125.85	475.59	362.87	87.63	1324.54
8	54.32	274.04	172.03	538.90	402.33	92.79	1534.41
9	70.75	316.62	204.53	607.13	443.40	97.07	1739.49
10	87.20	345.58	217.88	673.72	485.19	100.73	1910.30
11	98.72	354.63	220.77	735.36	528.64	103.99	2042.10
12	102.01	354.63	220.77	768.44	558.21	105.33	2109.38
13-30	102.01	354.63	220.77	775.90	566.50	105.51	2125.32

Source: Consultants' estimates.

TABLE 11.13

Reduced Crop Flood Damage (M Tk)

Project year	SW4	SW5	SW6	SW7	SW10	SW Misc	Total
4	5.47	13.04	17.89	50.59	20.15	2.71	109.86
5	5.47	13.12	17.96	50.89	20.22	2.74	110.39
6	5.47	13.19	18.02	51.18	20.29	2.76	110.91
7	5.47	13.27	18.08	51.47	20.36	2.79	111.44
8	5.47	13.34	18.15	51.77	20.43	2.81	111.96
9	5.47	13.42	18.21	52.06	20.50	2.84	112.49
10	5.47	13.49	18.27	52.35	20.57	2.86	113.02
11	5.47	13.57	18.34	52.65	20.64	2.89	113.55
12	5.47	13.64	18.40	52.94	20.71	2.91	114.07
13-30	5.47	13.72	18.47	53.23	20.78	2.94	114.60

Source: Consultants' estimates.

Appendix 2 presents the detailed build up of benefits for each Planning Unit. The benefits are derived from the detailed cropping patterns given in Chapter 5 and the crop budgets for each PU set out in Appendix 3, which also sets out the average annual crop losses from flooding between 1971 and 1989 in the project PUs.

For fisheries losses the following figures are used in the analyses:

	M Tk/year
SW4	0.65
SW5	3.52
SW6	2.04
SW7	3.39
SW10	9.18
Misc Pu	0.71
Total	29.48

11.5 Economic Analysis

11.5.1 Base Case

The benefit-cost flow at 1991 economic values is set out in Table 11.14. The proposed development will have an EIRR of 15.6% over a 30 year period with a net present value (NPV) of Tk 1800 M assuming the opportunity cost of capital is 12% as specified in FPCO's GPA. The benefit/cost ratio will be 1.22. The Augmentation project is characterised by a moderate rate of benefit build-up and high investment costs in the first years and a modest rate of return is to be expected.

TABLE 11.14

Gorai Augmentation Project Cost Benefit Flow Base Case (1991 economic values)

(M Tk)

Year	Capital	Recc't	Costs			Benefits		
			Fishery Loss	Total	Crop Benefits	Flood Damage	Incr'tal Benefits	Net Benefits
1	820.80	1.76	0.00	822.56	0.00	0.00	0.00	-822.56
2	1886.82	22.15	0.00	1908.97	0.00	0.00	0.00	-1908.97
3	2223.82	55.07	0.00	2278.89	0.00	0.00	0.00	-2278.89
4	922.07	145.96	29.48	1097.51	1008.91	109.86	1118.77	21.26
5	458.00	192.04	29.48	679.52	1045.06	110.39	1155.45	475.93
6	926.84	240.22	29.48	1196.54	1007.42	110.91	1118.33	-78.21
7	1165.86	304.53	29.48	1499.87	1324.54	111.44	1435.98	-63.89
8	337.57	368.96	29.48	736.01	1534.41	111.96	1646.37	910.36
9	165.46	410.89	29.48	605.83	1739.49	112.49	1851.98	1246.15
10	19.80	437.90	29.48	487.18	1910.30	113.02	2023.32	1536.14
11	11.19	451.45	29.48	492.12	2042.10	113.55	2155.65	1663.53
12	11.26	451.45	29.48	492.19	2109.38	114.07	2223.45	1731.26
13	18.65	451.45	29.48	499.58	2125.32	114.60	2239.92	1740.34
14	26.46	451.45	29.48	507.39	2125.32	114.60	2239.92	1732.53
15	34.61	451.45	29.48	515.54	2125.32	114.60	2239.92	1724.38
16	32.42	451.45	29.48	513.35	2125.32	114.60	2239.92	1726.57
17	29.00	451.45	29.48	509.93	2125.32	114.60	2239.92	1729.99
18	19.80	451.45	29.48	500.73	2125.32	114.60	2239.92	1739.19
19	11.90	451.45	29.48	492.83	2125.32	114.60	2239.92	1747.09
20	11.26	451.45	29.48	492.19	2125.32	114.60	2239.92	1747.73
21	18.65	451.45	29.48	499.58	2125.32	114.60	2239.92	1740.34
22	26.46	451.45	29.48	507.39	2125.32	114.60	2239.92	1732.53
23	34.61	451.45	29.48	515.54	2125.32	114.60	2239.92	1724.38
24	32.42	451.45	29.48	513.35	2125.32	114.60	2239.92	1726.57
25	29.00	451.45	29.48	509.93	2125.32	114.60	2239.92	1729.99
26	19.80	451.45	29.48	500.73	2125.32	114.60	2239.92	1739.19
27	11.90	451.45	29.48	492.83	2125.32	114.60	2239.92	1747.09
28	11.26	451.45	29.48	492.19	2125.32	114.60	2239.92	1747.73
29	18.65	451.45	29.48	499.58	2125.32	114.60	2239.92	1740.34
30	26.46	451.45	29.48	507.39	2125.32	114.60	2239.92	1732.53

EIRR	%	15.62	
NPV (12% Mtk	1799.51		
NPV costs Mtk	8125.97		
NPV benefits	Mtk	9925.48	1799.51
B/C ratio		1.22	

11.5.2 Sensitivity Analyses

The results of sensitivity analyses carried out are given below:

	Base Case	Costs x1.2	Benefits x0.8	Costs x1.2 + Benefit x0.8	Benefits delayed 2 years
EIRR	15.62	12.31	11.60	8.58	11.92
NPV Mtk	1799.51	174.32	(185.58)	(1810.78)	(44.50)
B/C ratio	1.22	1.02	0.98	0.81	0.99

The project is sensitive to both increases in costs and reduction of benefits. However if cost change by about 20% the EIRR will still be, marginally above the 12% discount rate required. If benefits fall by 20% or are delayed by two years with no change in the phasing of development expenditure the EIRR will fall very slightly below 12%. However if both costs rise by 20% and benefits are reduced by a similar amount the EIRR falls to 8.6%.

The switching values, the amount by which costs or incremental benefits increase or decrease to reduce the EIRR to 12% are:

Costs increased by 22%

Benefits decreased by 18%.

11.5.3 Non-Agricultural Flood Damage

In the Base case analysis above, no allowance have been made for agricultural flood damages avoided, and if these are taken into account the economic return (EIRR) becomes more attractive. The basis of computation of non-agricultural flood damages is described in Appendix J of Volume 10 - Economics.

The results of the Cost Benefit flows for the case with non-agricultural flood damages avoided are given in Table 11.15. As can be seen the EIRR increases from 15.62% for the Base case to 19.52%.

A series of sensitive analyses have been undertaken with decrease in benefits, increase in costs and with delay in benefits. The results are summarised in Table 11.16.

TABLE 11.15

Economic Analysis: Regional Plan Development with Gorai Augmentation
M Tk (1991 Economic Values)

Year	Capital Costs	Recurrent Costs	Fishery Loss	Total Costs	Agri Benefits	Agri Flood Damag Avoided	Non-Agri Flood Damag Avoided	Total Benefits	Net Cash Flow
1	820.80	1.76	0.00	822.56	0.00	0.00	0.00	0.00	-822.56
2	1886.82	22.15	0.00	1908.97	0.00	0.00	0.00	0.00	-1908.97
3	2223.82	55.07	0.00	2278.89	0.00	0.00	0.00	0.00	-2278.89
4	922.07	145.96	29.48	1097.51	1008.91	109.86	0.00	1118.77	21.26
5	458.00	192.04	29.48	679.52	1045.06	110.39	0.00	1155.45	475.93
6	926.84	240.22	29.48	1196.54	1007.42	110.91	0.00	1118.33	-78.21
7	1165.86	304.53	29.48	1499.87	1324.54	111.44	0.00	1435.98	-63.89
8	337.57	368.96	29.48	736.01	1534.41	111.96	0.00	1646.37	910.36
9	165.46	410.89	29.48	605.83	1739.49	112.49	0.00	1851.98	1246.15
10	19.80	437.90	29.48	487.18	1910.30	113.02	0.00	2023.32	1536.14
11	11.19	451.45	29.48	492.12	2042.10	113.55	0.00	2155.65	1663.53
12	11.26	451.45	29.48	492.19	2109.38	114.07	0.00	2223.45	1731.26
13	18.65	451.45	29.48	499.58	2125.32	114.60	1479.39	3719.31	3219.73
14	26.46	451.45	29.48	507.39	2125.32	114.60	1538.57	3778.49	3271.10
15	34.61	451.45	29.48	515.54	2125.32	114.60	1600.11	3840.03	3324.49
16	32.42	451.45	29.48	513.35	2125.32	114.60	1664.11	3904.03	3390.68
17	29.00	451.45	29.48	509.93	2125.32	114.60	1730.68	3970.60	3460.67
18	19.80	451.45	29.48	500.73	2125.32	114.60	1799.90	4039.82	3539.09
19	11.90	451.45	29.48	492.83	2125.32	114.60	1871.90	4111.82	3618.99
20	11.26	451.45	29.48	492.19	2125.32	114.60	1946.78	4186.70	3694.51
21	18.65	451.45	29.48	499.58	2125.32	114.60	2024.65	4264.57	3764.99
22	26.46	451.45	29.48	507.39	2125.32	114.60	2105.63	4345.55	3838.16
23	34.61	451.45	29.48	515.54	2125.32	114.60	2189.86	4429.78	3914.24
24	32.42	451.45	29.48	513.35	2125.32	114.60	2277.45	4517.37	4004.02
25	29.00	451.45	29.48	509.93	2125.32	114.60	2368.55	4608.47	4098.54
26	19.80	451.45	29.48	500.73	2125.32	114.60	2463.29	4703.21	4202.48
27	11.90	451.45	29.48	492.83	2125.32	114.60	2561.82	4801.74	4308.91
28	11.26	451.45	29.48	492.19	2125.32	114.60	2664.30	4904.22	4412.03
29	18.65	451.45	29.48	499.58	2125.32	114.60	2770.87	5010.79	4511.21
30	26.46	451.45	29.48	507.39	2125.32	114.60	2881.70	5121.62	4614.23
SUM	9362.80	11208.48	795.96	21367.24	51977.37	3070.49	37939.57	92987.43	71620.19
NPV	5915.80	2043.51	166.66	8125.97	9289.08	636.40	3496.12	13421.61	5295.63

EIRR	19.52%
NPV M Tk	5295.63
NPV Benefits	13421.61
NPV Costs	8125.97
B/C Ratio	1.65

TABLE 11.16

Sensitivity Analysis: Gorai Augmentation

Effect on the EIRR:

Chang in Cost	Change in Benefits -20%	-10%	0%	10%	20%
-20%	19.52%	21.58%	23.56%	25.46%	27.30%
-10%	17.59%	19.52%	21.36%	23.12%	24.83%
0%	15.96%	17.78%	19.52%	21.18%	22.78%
10%	14.55%	16.30%	17.95%	19.52%	21.03%
20%	13.32%	15.00%	16.58%	18.08%	19.52%

Effect on the NPV (M Tk):

Chang in Cost	Change in Benefits -20%	-10%	0%	10%	20%
-20%	4236.51	5578.67	6920.83	8262.99	9605.15
-10%	3423.91	4766.07	6108.23	7450.39	8792.55
0%	2611.31	3953.47	5295.63	6637.80	7979.96
10%	1798.72	3140.88	4483.04	5825.20	7167.36
20%	986.12	2328.28	3670.44	5012.60	6354.76

Effect on the B/C Ratio:

Chang in Cost	Change in Benefits -20%	-10%	0%	10%	20%
-20%	1.65	1.86	2.06	2.27	2.48
-10%	1.47	1.65	1.84	2.02	2.20
0%	1.32	1.49	1.65	1.82	1.98
10%	1.20	1.35	1.50	1.65	1.80
20%	1.10	1.24	1.38	1.51	1.65

Effects of Delay in the maturing of Project Benefits

Delay (Yrs)	EIRR	NPV @12%	B/C Ratio
0	19.52%	5295.63	1.65
1	16.89%	3704.97	0.46
2	14.88%	2288.06	0.28
3	13.26%	1026.10	0.13
4	11.88%	-97.58	-0.01
5	10.68%	-1097.93	-0.14

Effects of Increased Recurrent Costs:

Change in Costs	EIRR	NPV @12%	B/C Ratio
0%	19.52%	5295.63	1.65
10%	19.23%	5091.28	1.61
20%	18.94%	4886.93	1.57
30%	18.65%	4682.58	1.54
40%	18.36%	4478.23	1.50
50%	18.07%	4273.88	1.47

Switching Values:
For an EIRR of 12%,
The Costs will have to increase by 65.12%, or Benefits decrease by 39.45%.

12 TERMS OF REFERENCE FOR FEASIBILITY STUDY

12.1 Introduction

The proposed Gorai Augmentation Project consists of a regulator and associated protection works at its off-take with the Ganges; excavation of the downstream channel mainly by dredging so that it can pass low flow of about 150 m^3/sec; spurs and revetments, training the river for the dominant discharge of 4250 m^3/s; and an off-take structure downstream of Kamarkhali to distribute low flows for irrigation and water supply during the dry season.

The present study has shown that economic and social advantages will stem from the regulating of flows in the mouth of the Gorai. The most crucial benefit being that, if nothing is done, low flows in the Gorai will continue to decline, possibly being revived for a short period in about 10 years time, when flows in the Ganges are more equitable. However, not only will they decline again, but it is possible that during this period the entrance will be closed and the Gorai will revert to being an inland river. Thus, not only will the low flows be lost, but the high flows as well, which are essential for flushing out the saline tidal waters from the south of Khulna area at the end of the dry season. The process of the demise of the Gorai appears to have been accelerated by the operation of the Farakka Barrage, which has adversely affected the falling limb of the flood hydrograph, severely limited the dry season flows and thus low flow morphology of the Gorai.

It would be possible with specific intervention such as dredging, loop-cuts, groynes and revetments, to revitalise the Gorai without the need for a regulator. However, such a scheme would be more expensive than the one proposed, have a lower level of assurance of low flows and higher maintenance costs and would not allow the economic use of low flows for agricultural development and water supply.

As part of the pre-feasibility study several options were considered for intervention at the mouth and the favoured option consists of a regulator and associated protection works at the mouth together with excavation of downstream channel.

The chosen position of the proposed regulator is as close to Talbaria as possible in order to minimise the distance between the structure and the main flow in the Ganges. Morphological studies show Talbaria to be a stable point on the Ganges and, while flow directions and depths may change in this area, water should be available. Placing the structure in this position does expose it to the considerable erosion and thus variations in the bed elevations known to take place in the Ganges, but even if it were retired into the mouth of the Gorai, it would still have to be protected from the same amount of erosion. This is because just over 100 years ago Kushtia lay on the right bank of the Ganges. The channel to any structure within the mouth would have to be maintained over a period of many months from the peak to the end of the flood season and possibly throughout the dry season. Thus, maintenance dredging would be a significant requirement.

The design is based on the present dry season flows and water levels in the Ganges, which are considerably lower than those agreed with India on completion of the Farakka Barrage. Should the previously agreed minimum flows of about 1200 m^3/s be restored, then the design of the regulator and downstream works including both the river training and off-take works would have to be revised, resulting in considerable savings.

The design of the regulator would have to be carried out contemporaneously with the downstream river works which depend on it. However, as the design flow conditions of structures is known, apart from the most upstream river control structures, their finalisation should not have to await that of the regulator.

A programme covering the main design activities can be seen in Figure 12.1. The programme would change, depending on the start date in relation to the monsoon period. The proposed layout of the regulator, off-take and river control structures can be seen on Figures 8.2, 8.5 and 8.6.

12.2 Study Requirements

12.2.1 Review of Existing Data

Review all existing reports and data, including the March 1981 IECO Soils Report and the test result for the regulator and off-takes and any existing data on agricultural soils.

12.2.2 Project Options

Review critically the option recommended for the Project and other options considered in the pre-feasibility study stage and select the best option considering the technical, economical, social and environmental aspects. Particular attention should be paid for the operation and maintenance of the scheme taking into consideration the limitations of the institutional capability of the operating organisation (BWDB).

12.2.3 Data Collection

Hydraulic River Data

Obtain field data for high and low flows both in the Gorai mouth and in other areas of the Ganges which, in time, are likely to exist at Talbaria. This will include bed surveys, current metering, sediment sampling of the bed and the water column and the use of depth specific floats. In particular, secondary currents should be examined in some detail.

Collect similar data in the Gorai for existing structures and at the proposed off-take site.

The data will be required both for the design of the regulator, river training structures, off-take and the modelling.

Agriculture Data

Collect data on land use, land tenure, land suitability, cropping pattern, intensity, yields, inputs and crop damage.

Other Sectoral Activities

Collect data on beel, baor areas, fish habitation/biology/resources, fish production, yields, marketing, inputs etc.

Collect data on existing navigation in the wet and dry seasons particularly the informal sector (country boats).

Socio-Economic Data

Carry out RRA type surveys to collect socio-economic data including population, landholding, education, income distribution, employment, credit, attitude towards FCD/I projects, flood damage, etc.

Surveys should include different social groups including farmers, fishermen, landless and women groups.

Environmental Data

Collect existing data on water quality, pollution, sanitation, health, etc to carryout EIA analysis.

12.2.4 River Morphology

Conduct a detailed critical re-assessment of all the morphological data for the Ganges and the Gorai. This should include the dominant discharge and the likely morphological changes associated with it; rates of char movement, impact of existing structures etc.

12.2.5 Hydrology

As part of 2.3 above, critically re-examine all data on flows, rating curves, etc., including the critical low water levels and flows in the Ganges and of the dominant discharge of the Gorai.

12.2.6 Geotechnical Investigation

Carryout geotechnical investigation with testing in the foundation areas of the regulator and off-take and the toe areas of the main river-side revetments and deflector groyne.

This investigation should be deferred until the position of the regulator and its associated works and the off-take have been finalised. It is likely that investigation for the off-take will proceed first.

Samples of agricultural soils should be taken and tested.

12.2.7 Hydraulic Impacts

Carry out a further analysis of the impact of Farakka and of the proposed Ganges Barrage on the operation of the regulator and its impact on the river morphology and other structures in the Gorai.

In addition, re-examine the impact of the proposed regulated flows on the long term morphology of the Gorai and of the proposed river control structures and dredging requirements downstream. This should include the possible impacts of excavating a cut across the Kamarkhali loop.

Once the design flows and sediment loads have been established, carry out a detailed examination of the probable maintenance dredging costs both in the short and long term, including with the Ganges Barrage. These figures may have to be updated in light of the detailed examination of the morphological changes in the Ganges and detailed analysis of the Ganges flows and the hydraulic design of the regulator.

12.2.8 Hydraulic Modelling

Carryout both one dimensional mathematical modelling of the Ganges and Gorai for various long term scenarios and a physical hydraulic model of the regulator and its local environs.

A hydraulic model may also be required for the off-take. The models should be calibrated against field data and use to refine the hydraulic design of the structures (including sediment control structures) and the design and layout of the revetment and deflector groyne. This should also include the stilling basin behind the regulator and the first set of guide structures for the Gorai.

The mathematical model should also be used to assist in the design of the river control structures and assessment of maintenance dredging requirements and to see if the Ganges channel, in the area of the Gorai mouth, can be stabilised by a deflector groyne downstream of Bheramara.

12.2.9 Structural and Hydraulic Design

Carry out a detailed study of the design of the regulator and its associated works, the off-take and the river control structures in the Gorai using all the data from the previous studies.

The off-take and regulator structures should also include a bridge, means of allowing country boats passage during high and low flows, sediment excluders etc.

12.2.10 Irrigation

Critically re-examine the low flow water requirements and water distribution system associated with the off-take. Evaluation of the groundwater potential and impact on the groundwater table should also be carried out.

Prepare preliminary designs and costs for all conveyance and drainage structures, based on earlier surveys etc.

12.2.11 Agriculture

Assess the likely changes in cropping patterns and net value added in agriculture in the project area 'with' and 'without' the project, distinguishing carefully the benefits deriving from the project (increased cropping intensities improved cropping pattern, higher yields, reduced crop damage etc) from these that would have taken place anyway (eg. changes due to some minor irrigation development) and taking full account of the variations in land suitability in the project area.

12.2.12 Fisheries

Assess the likely impact of the project on capture and culture fisheries in the area (including shrimp culture); identify and cost measures to limit any detrimental effects of the project on capture fisheries and investments necessary for the development of culture fisheries; estimate the overall impact of the project on net value added in fisheries.

Recommend ways of improving the development of culture fisheries in the area.

12.2.13 Navigation

Assess the likely impact of the project on Navigation, particularly on country boats in the area; identify and cost measures to limit any detrimental effects of the project on navigation.

12.2.14 Infrastructure

Establish the infrastructural requirements associated with the off-take and regulator, including the impact of the bridge, additional local roads, etc and the needs during construction.

12.2.15 Social Impact Study

Ensuring beneficiary participation in the planning and design phases and subsequently in the implementation and the O & M of the Project will be fundamental to the Project's ultimate succss. The social impact study will identify the target population noting the absorptive capacity of the various groups, identify particularly the vulnerable groups (eg: landless, fishermen, women, boatmen etc), make an assessment of the percentage of the population living below the poverty level. Identify the target group beneficiaries and priorities and recommend appropriate implementation strategies; clearly identify the needs and constraints on agricultural development as perceived by the targetted beneficiaries, qualify the losses being experienced by the targetted beneficiaries due to inadequatee water resource infrastructure or communication network; identify NGOs active in the sub-project area and assess their capabilities; assess the institutional setting from the beneficiaries perspective (eg: access to extension services, credit etc), recommend institutional strengthening measures. Prepare a monitoring plan to asses the project's social impacts and develop a plan and implementation arrangements for land acquisition; prepare the beneficiary participation plan for both the detailed design and subsequent implementation stages; particular attention to women in development (WID) will be discussed in the Plan.

12.2.16 Environmental Impact Assessment (EIA)

A full EIA would be carried out for the Project. The project has wider implications than the provision of irrigation, and therefore it is essential that the views of local communities in the project areas and adjacent affected areas be fully taken into account and incorporate into the plan drawn up at the feasibility stage.

The EIA should conform to the relevant GOB (FAP) and World Bank guidelines and include the following:

- people's participation to determine the communities/groups that will be affected to ensure mitigation from negative impacts
- targeting of fishing communities for detailed assessment of impact/compensation
- detailed studies of the fish capture and culture industries, especially shrimp, in the area
- full assessment of the current uses of the Gorai river to local communities, and the impact of the project on this value
- study of the impact of the augmentation on the saline wedge in the Southwest and South Central Regions
- comparative studies to determine the appropriate environmental/economic option for long-term water supply to Khulna
- consideration of viable options for maintenance of river bio-diversity post-project

- assessment of the impact on navigation and mitigation of negative impacts

- consider in detail the means by which dredging and spoil disposal can be carried out in the most environmentally sympathetic manner

- assessment of resettlement and land acquisition requirements and measures to minimise these

- provide an initial baseline for agrochemicals in the upper reaches of the Gorai river, and make recommendations for the control and monitoring of agrochemicals in this catchment

- consider major impacts outside the project area including the impacts and mitigation measures for the people and economy of the Ganges left bank.

Proposal for long term environmental data collection and monitoring programme should be prepared which should include the Sundarbans.

12.2.17 Temporary Works

Carryout a full analysis, including seasonal effects, of a number of alternative strategies for all aspects and areas of construction. This should include temporary protection as the work proceeds and its incorporation into the final works, as well as the transport of construction materials.

Consideration should also be given to the construction of the downstream works.

12.2.18 Construction Plant

Examine the available construction plant for the regulator and other structures, the revetments and the dredging requirements. Establish their likely availability, suitability and the impact of seasonal working, working in dewatered areas etc. Consider the alternatives available.

12.2.19 Costs

Carryout an analysis of the likely construction costs and their sensitivity to variations in materials, types of plant, seasonal working etc.

12.2.20 Operation and Maintenance

Establish a strategy including institutional arrangements, procedures and costs for a number of operation and maintenance scenarios for the whole scheme from the regulator to the end point for the water supply. Identify critical areas.

Recommend methods and strategy for cost recovery.

12.2.21 Programming and Terms of Reference

Prepare an outline programme and Terms of Reference covering the detailed design, contract documents, tendering and the phased construction, its cost and the economic returns.

12.2.22 Economic Analyses

Carryout economic analyses of the whole scheme to the adopted option. Based on an assessment of "with" and "without project" situation, carry out cost and benefit analysis. The benefits should include those of agriculture, reductions in flood damage, fisheries etc. A comprehensive analysis of the sensitivity of the scheme to changes in costs, benefits and to the less tangible impacts such as any social or environmental constraints or those from navigation etc is required.

A preliminary appraisal will be required initially as to the assumptions made on the flows as well as later into the viability of the whole scheme. The additional costs resulting from the reduction of low flows in the Ganges should be assessed.

12.2.23 Feasibility Study

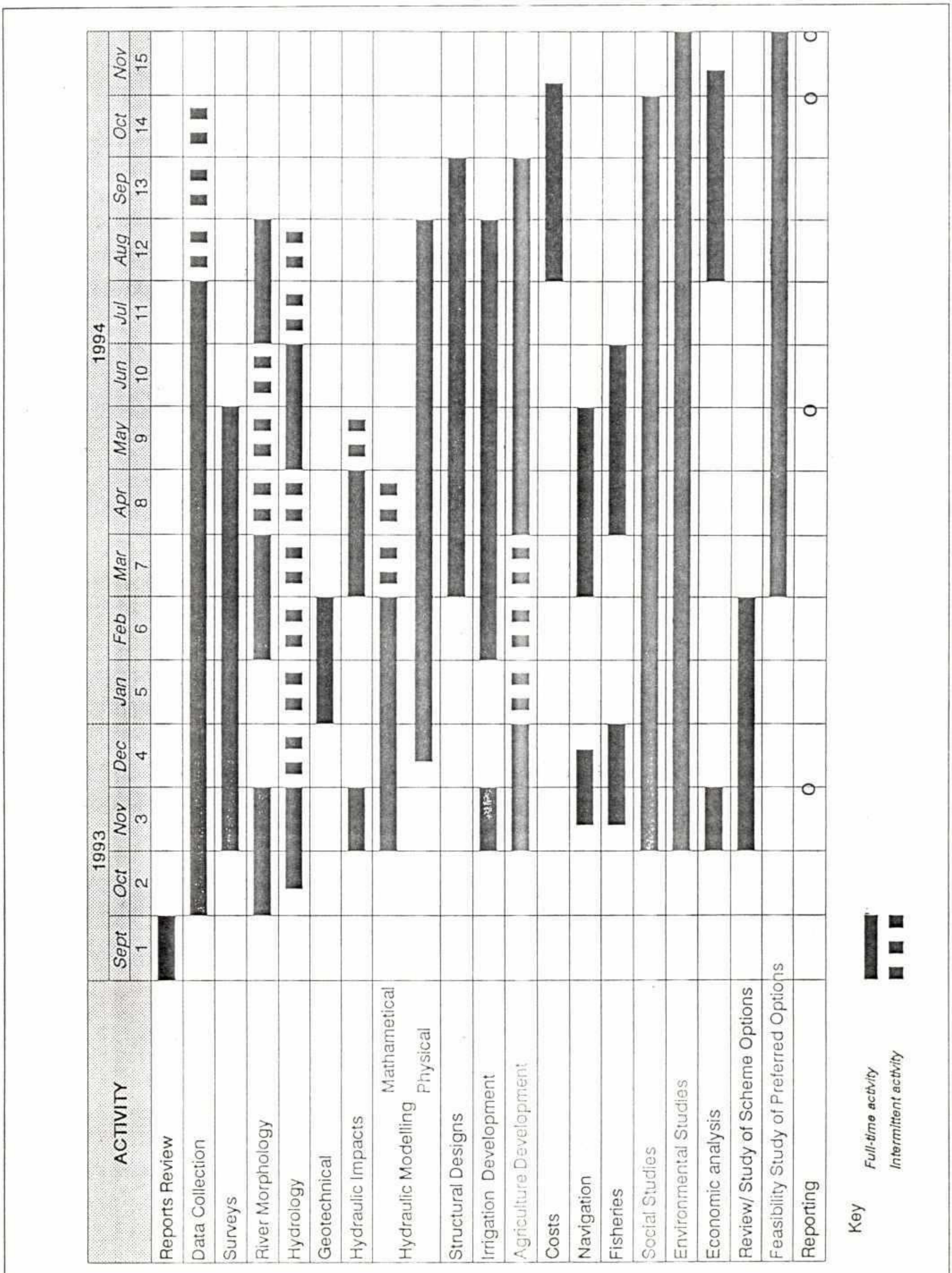
Based on the foregoing, prepare detailed feasibility study report for the Gorai Augmentation Project. This should include the justification for the project in accordance with GOB development strategy and confirm the viability of the selected scheme in terms of technical, social and environmental aspects.

12.3 Reporting

An Inception Report will be required 3 months after the start of the project and a Final Report on completion. Two progress reports will be presented at the end of months 6 and 9.

Separate reports will be required for the Soils Investigation, Mathematical and Physical Modelling, Environmental and Social Studies and the results of these studies should be incorporated in the various main project reports.

Figure 12.1



Work Programme for Feasibility Study

Appendices

Appendix 1

Morphological Modelling

Morphology Modelling

Gorai River Preliminary Analyses

Table of Contents :

Source : Surface Water Modelling Centre, Report KWO 1/2/93

1. Introduction

This note deals with morphological aspects of the Gorai - Madhumati River. The note summarises some observations and findings from preliminary analysis of selected data from the river and analysis of hydrodynamic and preliminary morphological model simulations for the river.

From a morphological modelling point of view the Gorai - Madhumati River is difficult to deal with. The most important reasons for that are discussed in Section 4 of this note. The river and its recent history is summarised in Section 2. Selected data are presented and discussed in Section 3.

2. The River

The Gorai - Madhumati River is the principal right bank distributary of the Ganges River within Bangladesh. The dry season flow of the Gorai has been steadily reduced during the recent years. This is claimed to be caused by reduced dry season flow in the Ganges due to diversion of water at the Farakka Barrage and changes of the topography at the bifurcation. The dry season flow in Gorai River is a key parameter for the water resources in the South West Region due to the impact of the dry season flow rate on the salinity levels in the region.

The Gorai-Madhumati River did not have any significant distributaries or tributaries before the Halifax cut was excavated near Bardia around 1910 connecting the Gorai River via the Nabaganga River to the Pussur River. After establishment of the Halifax Cut the discharge in the Nabaganga river slowly increased. After approximately 1940 this development seemed to continue with increasing speed, so that now the Madhumati River downstream of its bifurcation with the Nabaganga River only carries about 20 % of the water.

The Gorai River has a bankfull discharge of about 3500 m^3/s. From the mouth at the Ganges to the bifurcation the length of the river is approximately 200 kilometres with a mean slope during the monsoon period of about 5-6 10^{-5}. The river is gauged at Gorai Railway Bridge only 11 km downstream of the off-take from the Ganges, at Kamarkhali about 85 kilometres from the off-take, and at Bardia, the bifurcation between the Gorai-Madhumati and the Nabaganga.

3. Selected Available Data and Analysis

3.1 Planform Data

The planform evolution and channel shifting of the Gorai River is discussed in detail in FAP 4's First Interim Report. The key finding is that the river channel seems to be remarkably stable in the upper reaches, whereas in the downstream end (approx. downstream of Chainage 125) channel shifts are quite large. Comparison of channel alignments from 1973 and 1989 in the lower reach (extracted from satellite imagery) are shown in Fig. 1. It is noticed from Fig. 1 that the channel length increases substantially from 1973 to 1989. Between GM 22 (in General Model corresponding to chainage 127.016) and the bifurcation into Nabaganga and Madhumati Rivers the river length increases about 18 % (from about 68 km to 80 km).

This change could possible be a part of a natural (cyclic) process, ie. meander bends increase their sinuosity via bank erosion, thereby increasing the channel length until, a neck cut-off takes place and the river is shortened again. (For instance a neck cut-off at Kamarkhali would restore the river to its 1973 length.) Further analysis of historical planform data are required in order to substantiate this.

An other potential reason could be changed "boundary conditions" for the river, eg.:

1) changed water level at Bardia
2) changed inflow from Ganges
3) changed sediment load

ad 1) In Fig.2 the difference between simulated and observed water levels at Bardia is depicted. During the simulation the model topography was kept unchanged, thus the simulated water levels do not include any effects of morphological changes, but only the effect of the variability of the flow conditions (eg. tide and discharge variations). Thus, any consistent shift of water level at Bardia (caused by morphological changes) would be noticeable in Fig.2.

Figure 2 seems to suggest that there is no trend in the water level variations at Bardia. The figure, however, shows a distinct cyclic behaviour of the water level difference, which probably is associated with the silting up of the off-take during the dry season, and re-erosion during flood season.

ad 2) FAP 4 has documented a reduction of the dry season flow, but not in the monsoon flow rate.

ad 3) The amount and quality of sediment data are insufficient for conclusions regarding potential changes of sediment load in the river.

It is noteworthy that the stable reach of the river seems to coincide with the non-tidal reach, and the area with channel shifts is tidal (during the dry season).

3.2 Cross-Section Analysis

The measured cross-sections on the Gorai have been analyzed previously to determine the variability of the cross-sections used in the model. The result (equi-conveyance profile) is shown in Figure 3. An alluvial river running in more or less uniform sediment, without any significant spills or tributaries, would normally take a reasonably uniform slope. Figure 3 indicates that this is not the case for the Gorai river, where a rise in bed level just upstream of Kamarkhali is seen.

The variability of the cross-sections and the river slope have been further analyzed. MIKE 11 has been used to establish the water surface profiles for a discharge of Q=3000 m^3/s (which is slightly smaller that bankfull discharge) for both the 1989 and 1979 topography. Using these water surface profiles the width depth ratio and the width have been extracted from the cross-sections. The result is depicted in Figure 4 and 5, respectively.

ad Fig. 4) The cross-sectional area, hydraulic resistance and surface width have been calculated. With these parameter the width-depth ratio can be calculated in several ways, eg.

(cross-sectional area)/(resistance radius)^2
(surface width)/(resistance radius)
(surface width)^2/(cross-sectional area)

The first method has been used for Figure 4, but all three methods suggest the same trend, but slightly different numerical values.

Planform stability is very closely associated with the width-depth ratio. Wide-shallow rivers tend to be unstable, whereas narrow-deep rivers are stable. This is consistent with Figure 4 and the planform analysis (see above).

ad Fig. 5) The surface width and the area/resistance radius (mean width) show the same variation as Figure 4, however less pronounced.

The variation indicated by Figure 5 can be roughly schematized into the following variation:

Chainage (km)	Width (m)
0	500
50	300
80	350
130	700
200	400

Table 3.1 Schematized width variation.

There is no apparent explanation for the observed variation of width-depth ratio and width along the river. A possible reason is variation in bank resistance to erosion caused by different soil conditions, or maybe artificial protection of the banks.

4. Morphological Model Simulations

Preliminary model simulations at SWMC has indicated that quite a large calibration coefficient (6.7) is required in the model to represent the observed sediment rating curve at Gorai Railway Bridge. This may be associated with the very uncertain estimate of the bed sediment grain size. With the Engelund-Hansen formula the calculated sediment rate is inversely proportional to the grain size, which has been assumed to be 0.16 mm, corresponding to the observed grain diameter in the Ganges River around the off-take. The NEDECO Report (1983) suggest a somewhat smaller bed material size (d_{50} around 0.08 mm), thus accounting for a factor 2. Moreover, the use of the Engelund-Hansen formula in the JGP-model has suggested that the Engelund-Hansen formula underestimates the transport rate for small grain diameters.

Since the calibrated sediment transport formula reproduces the observed rating curve reasonably well, it can be used with some confidence, and is not the key source of uncertainty in the following model simulations.

In view of the distinct variation of cross-sectional properties, it is not possible to make the schematisation (smoothing) used in the JGP model. Only rectangular cross-sections, with the width given by Table 3.1, in combination with a constant discharge and sediment inflow has been used in the morphological model simulations. To get the correct time scale for morphological evolution the approximate mean annual sediment transport rate has been used as a boundary condition. Via the sediment rating curve, the discharge corresponding to this sediment transport rate has been estimated and used as the upstream boundary condition. The mean water level at Bardia has been used as the downstream model boundary condition. The boundary conditions used are:

$S = 0.53 \ m^3/s$

$Q = 3000 \ m^3/s$

$H = 2.30 \ m$

Running the model for 30 years results in an equilibrium bed profile as shown in Figure 6. This figure clearly reflects the hump also observed in the equi-conveyance profile depicted in Figure 3. This is an indication that the model represents the overall features of the system, and can be used for predicting changes (if the width of the river does not change).

4.1 Bend Cut-Off

The proposed bend cut-off at Kamarkhali has been represented in the (equilibrium) model setup as a 4 kilometres long section between Chainage 86.8 and 104.3, thus a net shortening of the river of 13.5 kilometres. The width of the cut-off channel has been determined by interpolation between the starting point and endpoint of the cut-off channel in the Gorai.

Results in terms of bed level variations at selected cross-sections are shown in Figure 7. Upstream of the cut-off the river bed is eroding, while downstream deposition followed by re-erosion (temporary overloading) takes place. Upstream of the cut-off the river is responding relatively fast. After the first year more than 20 cm of erosion has already taken place at Gorai Railway Bridge.

The model simulations suggest an erosion of about 0.6 m upstream the cut-off. However, the simulation is carried out under the assumption that mean sediment transport and discharge remain unchanged at the off-take with Ganges. With a net erosion at the off-take, this is not the case: the discharge and the sediment load will increase. The actual morphological development of the river after the cut-off will depend on in which way the discharge and sediment load increases. Since the sediment transport rate is a non linear function of the discharge with an exponent of approximately 1.25 (see Figure 8) then a simple linear relation for the increase between sediment transport and discharge at the off-take (corresponding to a constant sediment concentration) would lead to underloading, thus further erosion.

The above clearly indicates the key difficulty in running the morphological model: how to determine the sediment split criterion at bifurcations!

5. Preliminary Conclusions

The conclusions and findings from this short preliminary analysis presented here can be summarized as follows:

1. The lower end of the Gorai River has become substantially longer in the period from 1973 to 1989. The unstable part of the river is (weakly) tidal during the dry season.

2. Recorded water level variations at Bardia do not suggest any morphological changes.

3. The width-depth ratio and width exhibit a very pronounced variation along the river.

4. The sections with dynamic planform have shallow and wide cross-sections.

5. The slope of the river varies along the river, resulting in a "hump".

6. With the observed width variation imposed on the morphological model, the model can reproduce the observed hump in the river bed profile. Thus 3. and 7. could be explained by erosion resistant bank material (or bank protection) in the reach approximately from Chainage 30 to 100 km.

7. The key difficulty in running the morphological model is to determine the sediment split criteria at bifurcations.

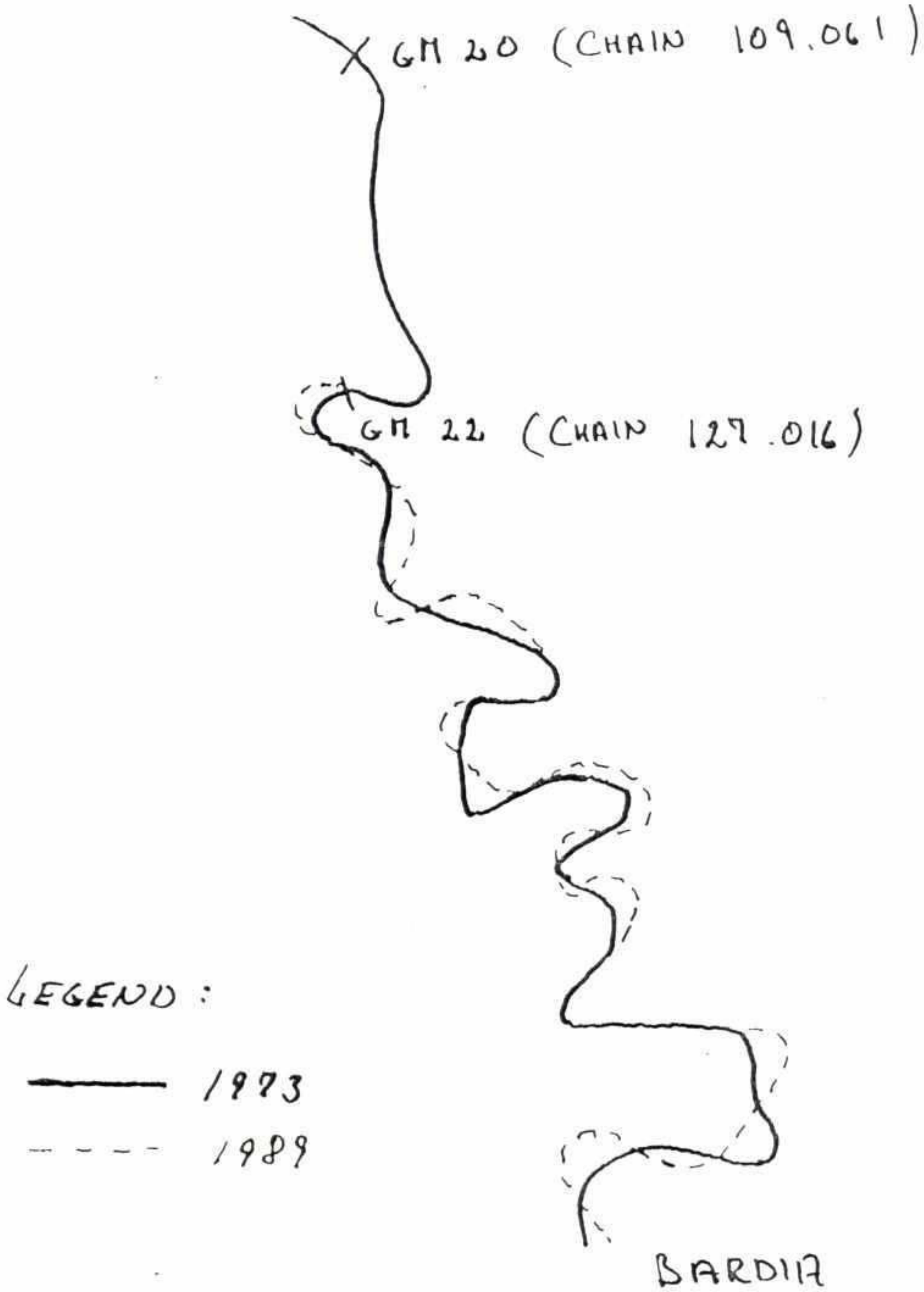
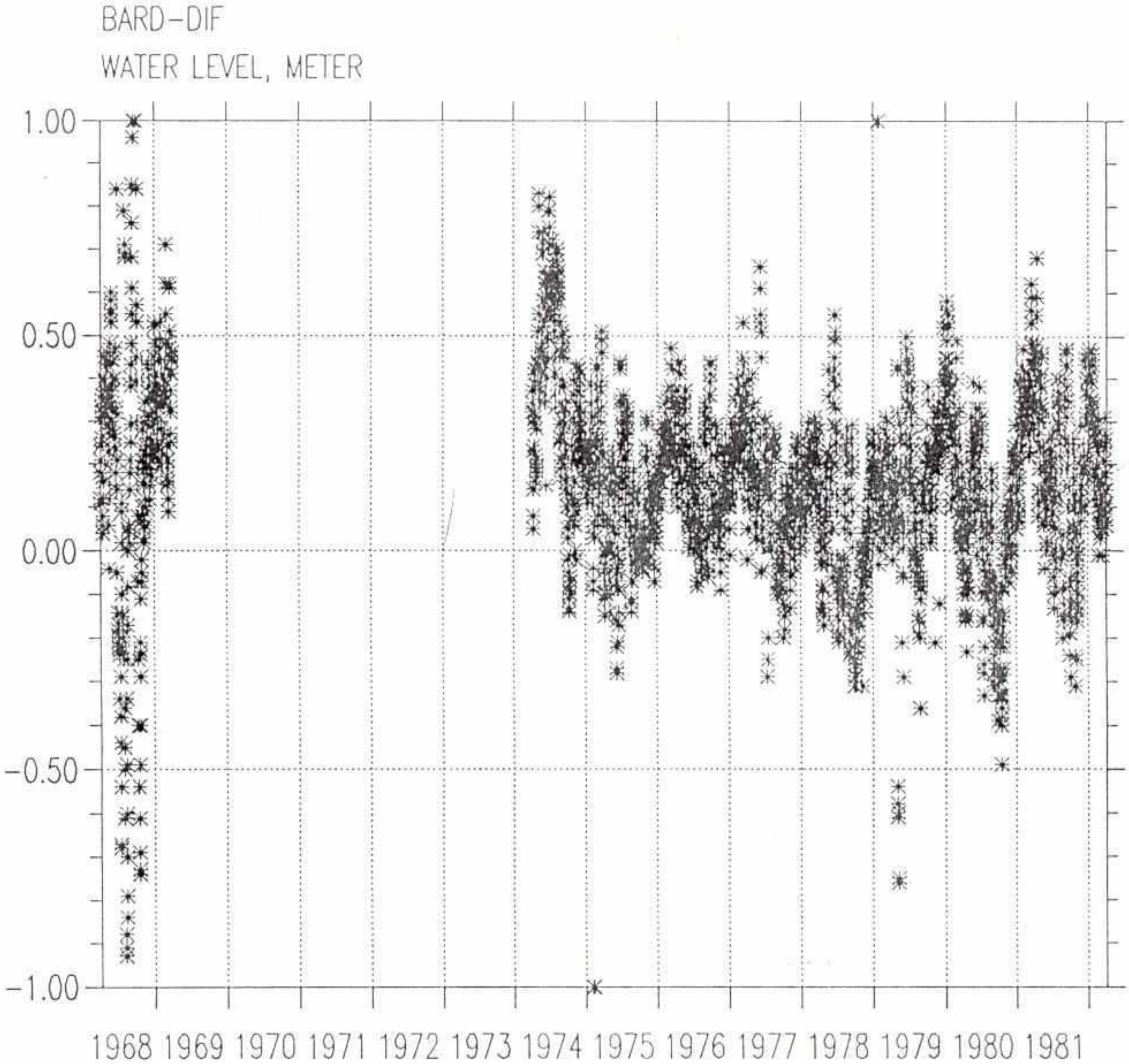

GM 20 (CHAIN 109.061)
GM 22 (CHAIN 127.016)
BARDIA
LEGEND:
1973
1989

FIGURE. 1.



	Difference Between Observed and Simulated Water Level
	MIKE 11 Dwg no.: 2

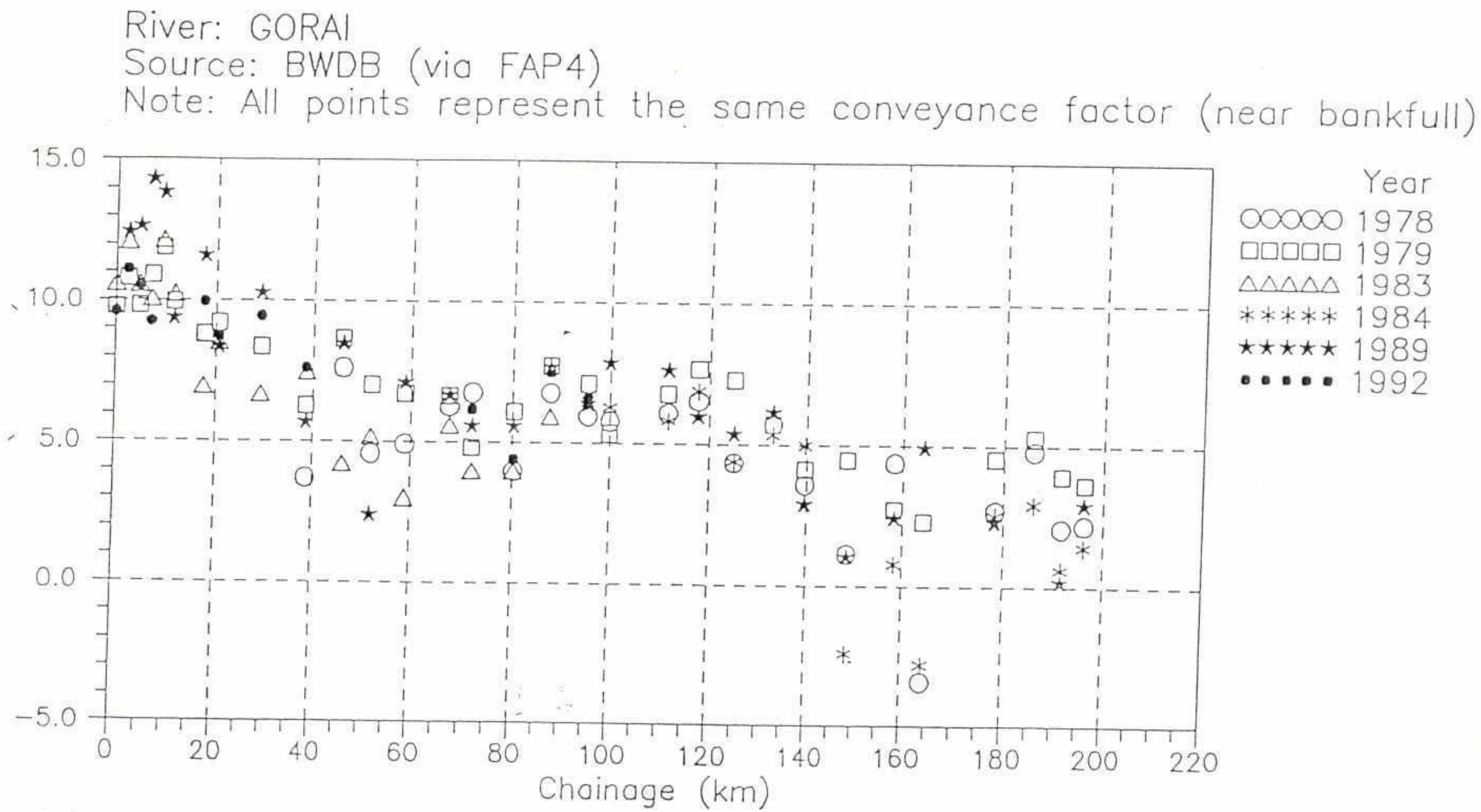
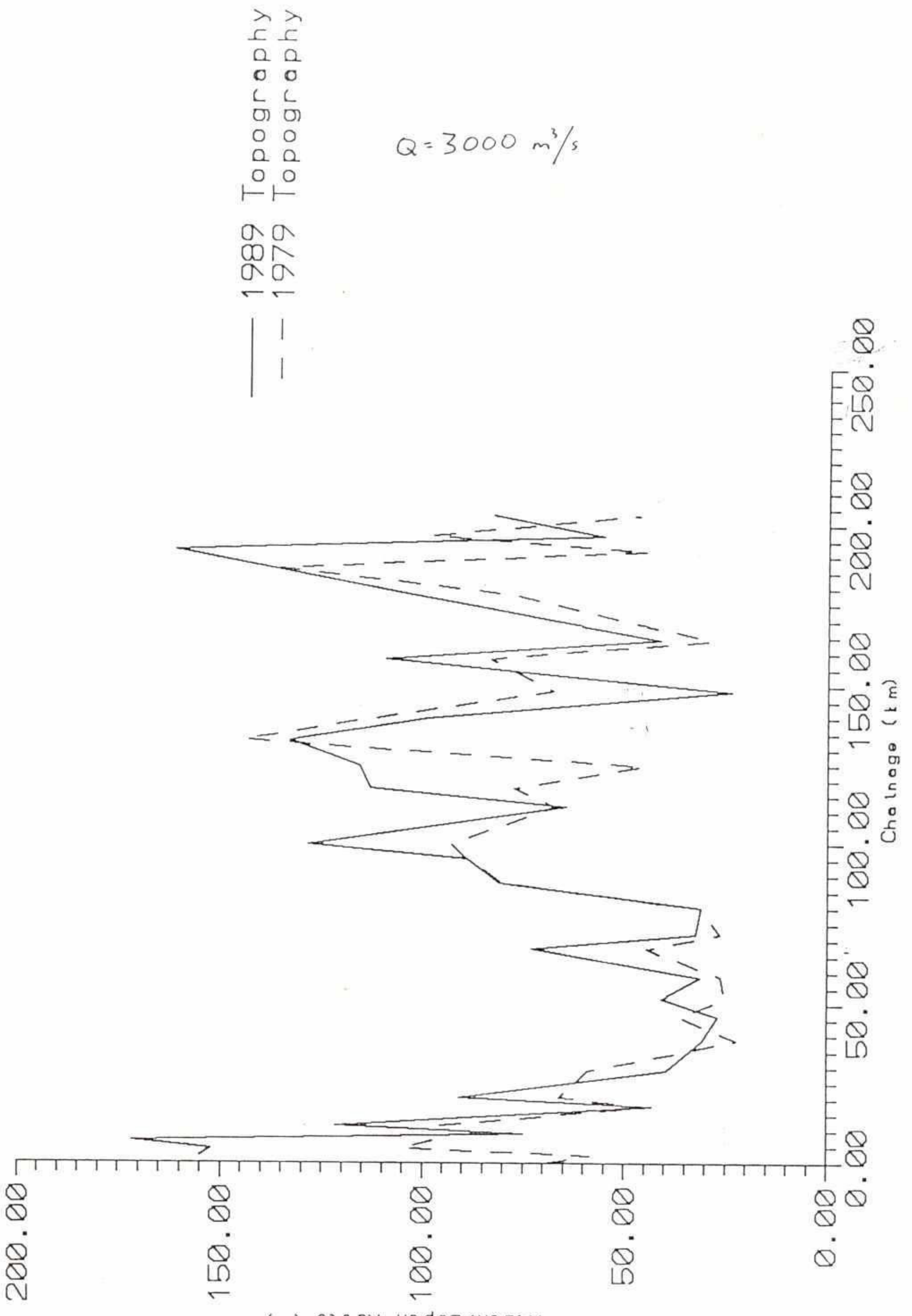


Figure 3: Historical Equi-conveyance Levels in the Gorai River



1989 Topography
1979 Topography
Q = 3000 m³/s
Chainage (km)
Width/Depth Ratio (-)
0.00
50.00
100.00
150.00
200.00
250.00
0.00
50.00
100.00
150.00
200.00

FIGURE 4

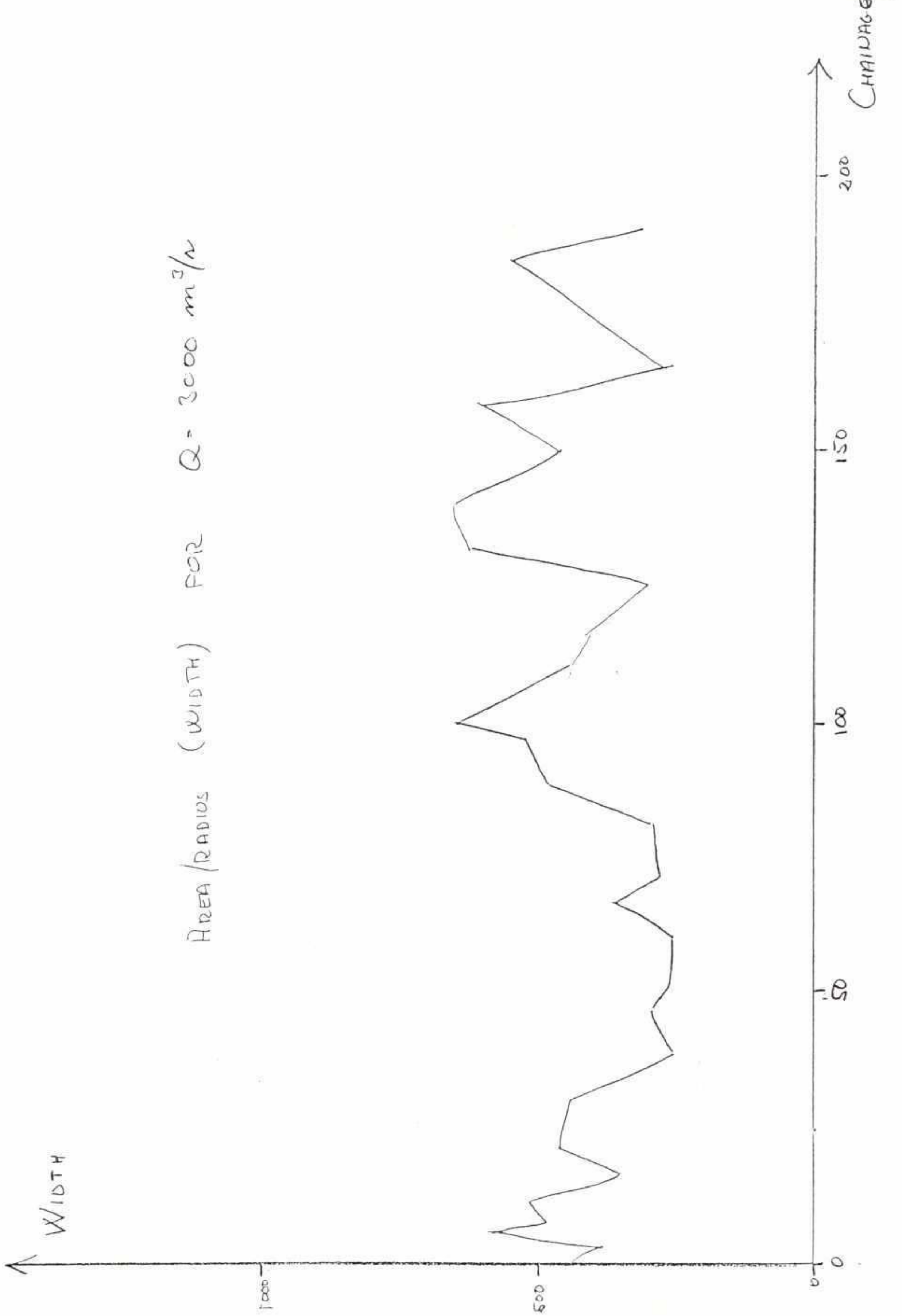
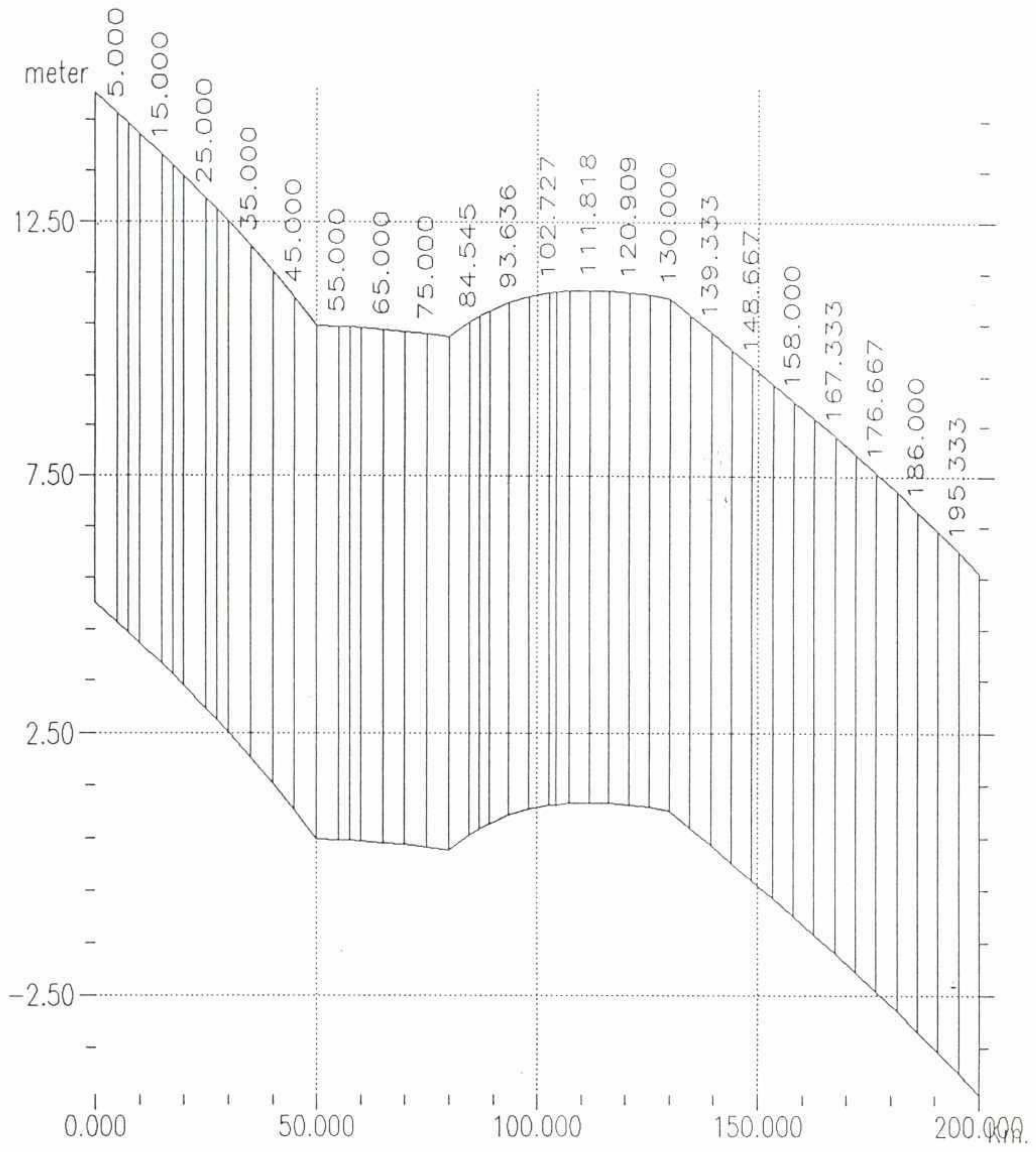


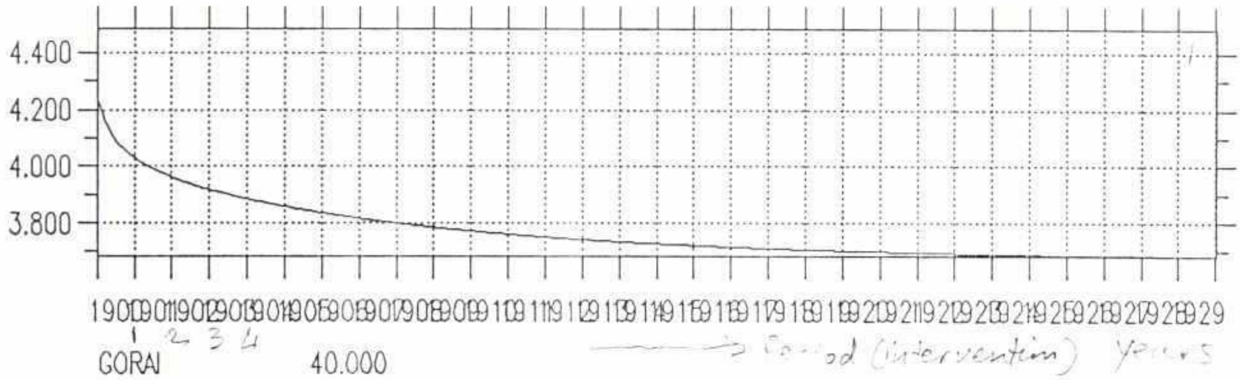
FIGURE 5 A1.14



	Line 1 end Line 2 Line 3
	MIKE 11 Dwg no.: 6

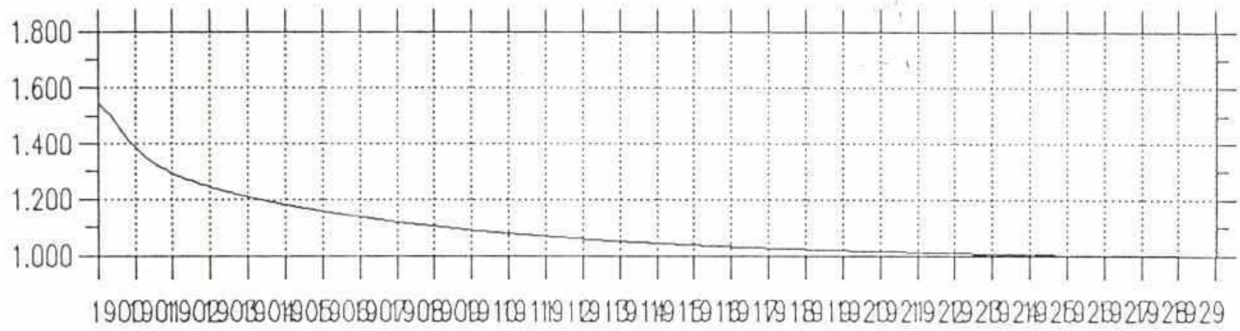
GORAI 10.000

— Bottom level, m



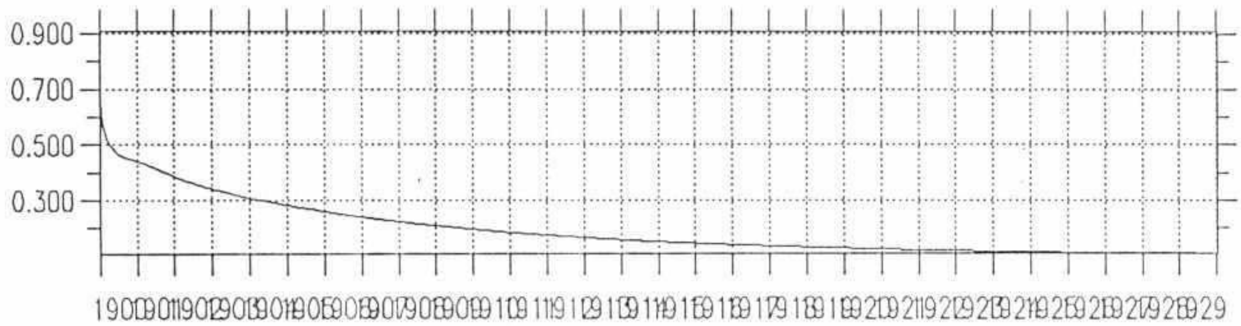
GORAI 40.000

— Bottom level, m



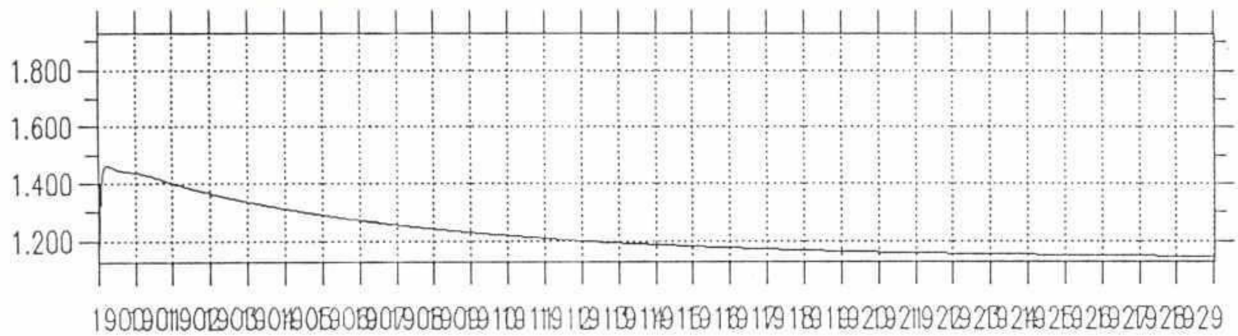
GORAI 86.800

— Bottom level, m



GORAI 104.300

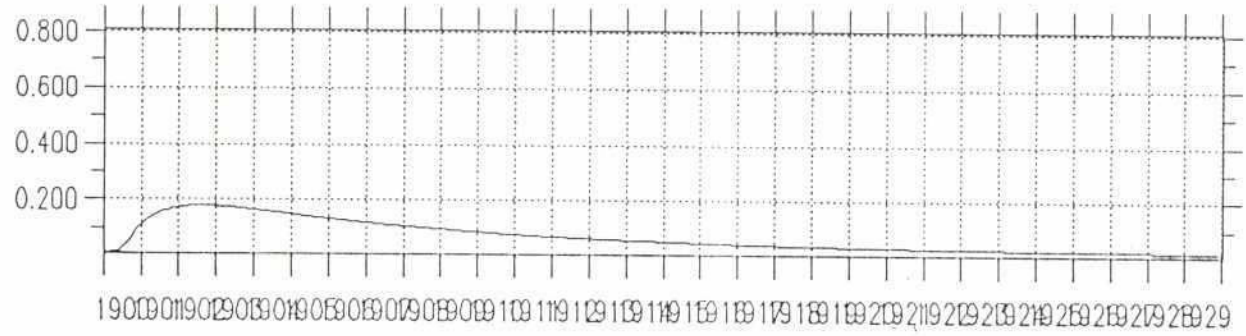
— Bottom level, m



	Simulated Bed Level Changes After Bend Cut-Off
A1.16	MIKE 11 Dwg no.: 7A

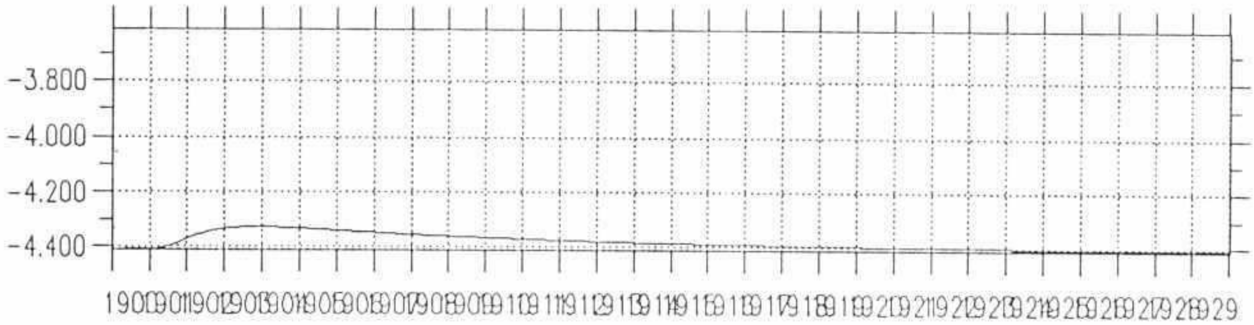
GORAI 144.000

— Bottom level, m



GORAI 200.000

— Bottom level, m



Simulated Bed Level Changes
After Bend Cut-Off

A1.17

MIKE 11

Dwg no.: 7B

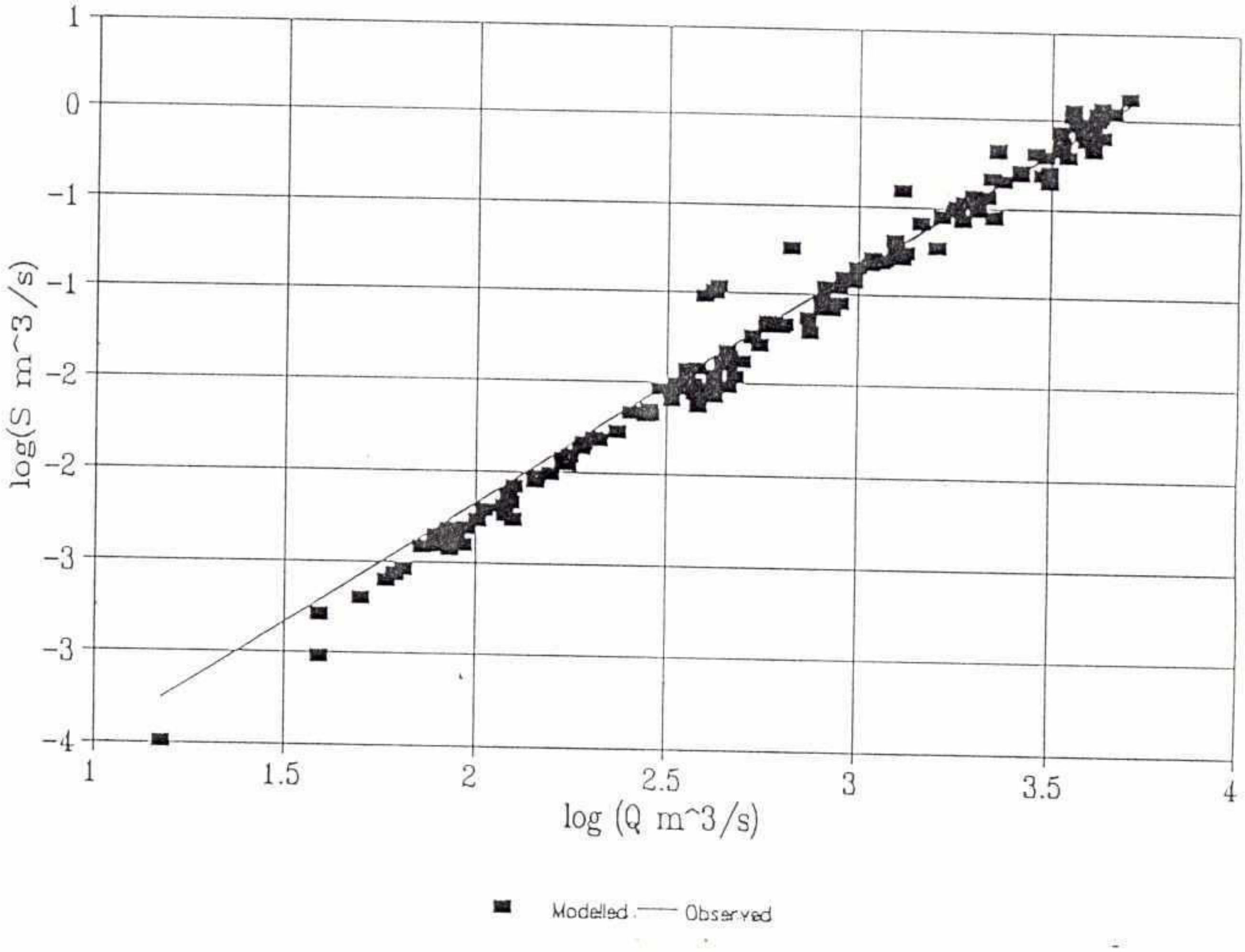


Figure 8 : Sediment Transport Calibration at Gorai Railway Bridge

Appendix 2

Crop Production Values - With and Without Project

APPENDIX 2

Gorai Augmentation Project

Present and future without Project Crop Production Values and Build up of with Project Crop Production Value (1991 Economic Values).

1. Without Project

Tables A1 to A6 set out the present and future crop areas by flood category and whether rainfed or irrigated for each of the Planning Units affected by the Project (SW4, SW5, SW6, SW7, SW10 and Misc PU along the Gorai river).

2. With Project

Tables A7 to A12 provide similar data for the project case and Tables A13 to A18 show the expected built up of project irrigation and project FCD only area benefits that were applied to the economic analyses in this volume.

Table A 1
GORAI AUGMENTATION PROJECT NET BENEFIT
FROM CROP PRODUCTION (without project)
PLANKING UNIT SW4 (1991 economic values)

	Rainfed						Irrigated				
	F0	F1	F2	F3\4	Total		F0	F1	F2	F3\4	Total
Present						Present					
Ha						Ha					
SW4	7840	4889	2318	704	15751	SW4	2641	2962	528	118	6249
Tk\Ha						Tk\Ha					
SW4	8814	8557	5580	4274		SW4	21371	19949	10254	7927	
Mill Tk						Mill Tk					
SW4	69.102	41.835	12.934	3.009	126.880	SW4	56.441	59.089	5.414	0.935	121.879
Future - project						Future			less irrig. costs		18.912
Ha						Ha					
SW4	7840	4889	2318	704	15751	SW4	2641	2962	528	118	6249
Tk\Ha						Tk\Ha					
SW4	8814	8557	5580	4274		SW4	21371	19949	10254	7927	
Mill Tk						Mill Tk					
SW4	69.102	41.835	12.934	3.009	126.880	SW4	56.441	59.089	5.414	0.935	121.879
Source : consultants' estimates									less irrig. costs		18.912

Tk/Ha present	10448
Tk/Ha future	10448

AVERAGE ANNUAL CROP DAMAGE 1971-1989

	Loss	Present Value	Loss	Loss	Future Value	Loss
	%	MTk/an	MTk/an	%	MTk/an	MTk/an
SW4	2.38	229.848	5.470	2.38	229.848	5.470

Year	Loss Value MTk/an
1	5.470
2	5.470
3	5.470
4	5.470
5	5.470
6	5.470
7	5.470
8	5.470
9	5.470
10	5.470

Table A 2
GORAI AUGMENTATION PROJECT NET BENEFIT
FROM CROP PRODUCTION (without project)
PLANNING UNIT SW5 (1991 economic values)

	Rainfed						Irrigated					
	F0	F1	F2	F3\4	Total		F0	F1	F2	F3\4	Total	TOTAL
Present						Present						
Ha						Ha						
SW5	11864	19437	13009	3600	47910	SW5	2045	5009	1504	435	8993	56903
Tk\Ha						Tk\Ha						
SW5	8668	7238	5309	4161		SW5	22299	20012	10954	8491		
Mill Tk						Mill Tk						
SW5	102.837	140.685	69.065	14.980	327.567	SW5	45.601	100.240	16.475	3.694	166.010	470.767
Future - project						Future			less irrig. costs		22.810	
Ha						Ha						
SW5	11195	18342	12276	3397	45210	SW5	2659	6513	1955	566	11693	56903
Tk\Ha						Tk\Ha						
SW5	8668	7238	5309	4161		SW5	22299	20012	10954	8491		
Mill Tk						Mill Tk						
SW5	97.038	132.759	65.173	14.135	309.106	SW5	59.293	130.338	21.415	4.806	215.852	495.300
									less irrig. costs		29.658	

Source : consultants' estimates

Tk/Ha present	8273
Tk/Ha future	8704

AVERAGE ANNUAL CROP DAMAGE 1971-1989

	Loss %	Present Value MTk/an	Loss MTk/an	Loss %	Future Value MTk/an	Loss MTk/an
SW5	2.77	470.767	13.040	2.77	495.300	13.720

Year	Loss Value MTk/an
1	13.040
2	13.116
3	13.191
4	13.267
5	13.342
6	13.418
7	13.493
8	13.569
9	13.644
10	13.720

Table A 3
GORAI AUGMENTATION PROJECT NET BENEFIT
FROM CROP PRODUCTION (without project)
PLANNING UNIT SW6 (1991 economic values)

	Rainfed						Irrigated					
	F0	F1	F2	F3\4	Total		F0	F1	F2	F3\4	Total	TOTAL
Present						Present						
Ha						Ha						
SW6	6083	11713	7203	2307	27306	SW6	874	3267	994	232	5367	32673
Tk\Ha						Tk\Ha						
SW6	7331	6191	5117	4035		SW6	25569	22237	14677	8095		
Mill Tk						Mill Tk						
SW6	44.594	72.515	36.858	9.309	163.276	SW6	22.347	72.648	14.589	1.878	111.463	260.076
Future - project						Future			less irrig. costs		14.663	
Ha						Ha						
SW6	5929	11417	7021	2249	26616	SW6	986	3687	1122	262	6057	32673
Tk\Ha						Tk\Ha						
SW6	7331	6191	5117	4035		SW6	25569	22237	14677	8095		
Mill Tk						Mill Tk						
SW6	43.465	70.683	35.926	9.075	159.149	SW6	25.211	81.988	16.468	2.121	125.787	268.389
Source : consultants' estimates									less irrig. costs		16.548	
		Tk/Ha present		7960								
		Tk/Ha future		8214								

AVERAGE ANNUAL CROP DAMAGE 1971-1989

	Loss %	Present Value MTk/an	Loss MTk/an	Loss %	Future Value MTk/an	Loss MTk/an
SW6	6.88	260.076	17.893	6.88	268.389	18.465

Year	Loss Value MTk/an
1	17.893
2	17.957
3	18.020
4	18.084
5	18.147
6	18.211
7	18.274
8	18.338
9	18.402
10	18.465

Table A 5
GORAI AUGMENTATION PROJECT NET BENEFIT
FROM CROP PRODUCTION (without project)
PLANNING UNIT SW10 (1991 economic values)

	Rainfed F0	Rainfed F1	Rainfed F2	Rainfed F3\4	Rainfed Total		Irrigated F0	Irrigated F1	Irrigated F2	Irrigated F3\4	Irrigated Total	TOTAL
Present						Present						
Ha						Ha						
SW10	13286	16233	33732	8371	71622	SW10	2709	3160	2870	1946	10685	82307
Tk\Ha						Tk\Ha						
SW10	11412	10275	5716	5069		SW10	23109	22501	12161	5736		
Mill Tk						Mill Tk						
SW10	151.620	166.794	192.812	42.433	553.659	SW10	62.602	71.103	34.902	11.162	179.770	711.852
Future - project						Future			less irrig. costs		21.576	
Ha						Ha						
SW10	12700	15516	32243	8002	68461	SW10	3510	4095	3719	2522	13846	82307
Tk\Ha						Tk\Ha						
SW10	11412	10275	5716	5069		SW10	23109	22501	12161	5736		
Mill Tk						Mill Tk						
SW10	144.932	159.427	184.301	40.562	529.222	SW10	81.113	92.142	45.227	14.466	232.947	734.211
									less irrig. costs		27.959	

Source : consultants' estimates

Tk/Ha present	8649
Tk/Ha future	8920

AVERAGE ANNUAL CROP DAMAGE 1971-1989

	Loss %	Present Value MTk/an	Loss MTk/an	Loss %	Future Value MTk/an	Loss MTk/an
SW10	2.83	711.852	20.145	2.83	734.211	20.778

Year	Loss Value MTk/an
1	20.145
2	20.216
3	20.286
4	20.356
5	20.427
6	20.497
7	20.567
8	20.638
9	20.708
10	20.778

Table A 4
GORAI AUGMENTATION PROJECT NET BENEFIT
FROM CROP PRODUCTION (without project)
PLANNING UNIT SW7 (1991 economic values)

	Rainfed F0	Rainfed F1	Rainfed F2	Rainfed F3\4	Rainfed Total		Irrigated F0	Irrigated F1	Irrigated F2	Irrigated F3\4	Irrigated Total	TOTAL
Present						Present						
Ha						Ha						
SW7	10747	25002	28466	25444	89659	SW7	780	5317	9903	4341	20341	110000
Tk\Ha						Tk\Ha						
SW7	11168	8408	7084	5609		SW7	33083	27346	19239	17545		
Mill Tk						Mill Tk						
SW7	120.022	210.217	201.653	142.715	674.608	SW7	25.805	145.399	190.524	76.163	437.890	1056.233
									less irrig. costs		56.265	
Future - project						Future						
Ha						Ha						
SW7	10160	23636	26910	24053	84759	SW7	968	6598	12288	5387	25241	110000
Tk\Ha						Tk\Ha						
SW7	11168	8408	7084	5609		SW7	33083	27346	19239	17545		
Mill Tk						Mill Tk						
SW7	113.467	198.731	190.630	134.913	637.742	SW7	32.024	180.429	236.409	94.515	543.377	1111.300
									less irrig. costs		69.819	

Source : consultants' estimates

Tk/Ha present	9602
Tk/Ha future	10103

AVERAGE ANNUAL CROP DAMAGE 1971-1989

	Loss %	Present Value MTk/an	Loss MTk/an	Loss %	Future Value MTk/an	Loss MTk/an
SW7	4.79	1056.233	50.594	4.79	1111.300	53.231

Year	Loss Value MTk/an
1	50.594
2	50.887
3	51.180
4	51.473
5	51.766
6	52.059
7	52.352
8	52.645
9	52.938
10	53.231

Table A 5
GORAI AUGMENTATION PROJECT NET BENEFIT
FROM CROP PRODUCTION (without project)
MISCELLANEOUS PLANNING UNI (1991 economic values)

	Rainfed					Irrigated						
	F0	F1	F2	F3\4	Total		F0	F1	F2	F3\4	Total	TOTAL
Present						Present						
Ha						Ha						
SW	1910	2189	2059	1015	7173	SW	478	747	426	176	1827	9000
Tk\Ha						Tk\Ha						
SW	9478	7733	5777	4630		SW	25086	22409	12457	9559		
Mill Tk						Mill Tk						
SW	18.103	16.928	11.895	4.699	51.625	SW	11.991	16.740	5.307	1.682	35.720	82.243
Future - project						Future			less irrig. costs		5.102	
Ha						Ha						
SW	1724	1975	1858	916	6473	SW	661	1033	590	243	2527	9000
Tk\Ha						Tk\Ha						
SW	9478	7733	5777	4630		SW	25086	22409	12457	9559		
Mill Tk						Mill Tk						
SW	16.340	15.273	10.734	4.241	46.587	SW	16.582	23.148	7.350	2.323	49.403	88.933
Source : consultants' estimates									less irrig. costs		7.057	
		Tk/Ha present		9138								
		Tk/Ha future		9881								

AVERAGE ANNUAL CROP DAMAGE 1971-1989

	Loss %	Present Value MTk/an	Loss MTk/an	Loss %	Future Value MTk/an	Loss MTk/an
SW Misc	3.3	82.243	2.714	3.3	88.933	2.935

Year	Loss Value MTk/an
1	2.714
2	2.739
3	2.763
4	2.788
5	2.812
6	2.837
7	2.861
8	2.886
9	2.910
10	2.935

Table A 7
WITH PROJECT BENEFITS SW 4 (1991 economic values)

Future Irrigated by Project Alone at 90% Project Uptake .

Total Ha present	Irrig Area	Irrigable Maximum	Balance for Project
SW4	6037	15000	8963
(see Gorai I)			

	F0	F1	F2	F3/4	Total	#LLP	exact
Total irrigation	4930	3585	448	0	8963	403	403
Project irrigation	4433	3224	403	0	8060		

SW4

Future + project Ha	Non Project Cropping (rainfed+TW irrig) F0	F1	F2	F3/4	Total	Future Ha	F0	F1	Irrigated (LLP only) F2	F3/4	Total	
Ha r'fed	4347	3161	395	0	7903	SW4	4433	3224	403	0	8060	22000
Ha irrig	3320	2415	302	0	6037	Tk\Ha						
Tk/Ha r'fed	8814	8557	5580	4274		SW4	21371	19949	10254	7927		
Tk/Ha irrig	21371	19949	10254	7927		Mill Tk						
MTk r'fed	38.311	27.050		0.000	65.362	SW4	94.738	64.316	4.132	0.000	163.186	163.186
MTk irrig	70.959	48.173	3.095	0.000	122.227							
non project irrigation costs				MTk	18.913							
benefit net of non project irrigation costs				MTk	168.676							
Project irrig bene	Tk/Ha	20246										
non prjt gross ben	Tk/Ha	13457	net Tk/Ha	10324								
non prjt net ben	Tk/Ha	12100										

Table A 8
WITH PROJECT BENEFITS SW 5 (1991 economic values)

Future Irrigated by Project Alone at 90% Project Uptake .

Total Ha present	Irrig Area	Irrigable Maximum	Balance for Project
SW5	7939	36000	28061
(see Gorai I)			

	F0	F1	F2	F3/4	Total	#LLP	exact
Total irrigatio	15434	11224	1403	0	28061	1263	1263
Project irrigat	13893	10104	1263	0	25260		
SW5							

Future + proje	Non Project Cropping (rainfed+TW irrig)					Future	Irrigated (LLP only)					
Ha	F0	F1	F2	F3/4	Total	Ha	F0	F1	F2	F3/4	Total	
Ha r'fed	13037	9482	1185	0	23704	SW5	13893	10104	1263	0	25260	56903
Ha irrig	4366	3176	397	0	7939	Tk\Ha						
Tk/Ha r'fed	8668	7238	5309	4161		SW5	22299	20012	10954	8491		
Tk/Ha irrig	22299	20012	10954	8491		Mill Tk						
MTk r'fed	113.006	68.628		0.000	181.634	SW5	309.800	202.201	13.835	0.000	525.836	849.926
MTk irrig	97.367	63.550	4.348	0.000	165.266							
non project irrigation costs				MTk	22.810							
benefit net of non project irrigation cost				MTk	324.090							
non pjt gross b	Tk/Ha	10963		8090								
Project irrig b	Tk/Ha	20817										
non pjt net ben	Tk/Ha	10242										

Table A 9
WITH PROJECT BENEFITS SW 6 (1991 economic values)

Future Irrigated by Project Alone at 90% Project Uptake .

Total Ha present	Irrig Area	Irrigable Maximum	Balance for Project
SW6	4987	18000	13013

(see Gorai I)

	F0	F1	F2	F3/4	Total	#LLP	exact
Total irrigatio	7157	5205	651	0	13013	586	586
Project irrigat	6446	4688	586	0	11720		
SW6							

Future + projeNon Project Cropping (rainfed+TW irrig)						Future	Irrigated (LLP only)					
Ha	F0	F1	F2	F3/4	Total	Ha	F0	F1	F2	F3/4	Total	
Ha r'fed	8781	6386	798	0	15966	SW6	6446	4688	586	0	11720	32673
Ha irrig	2743	1995	249	0	4987	Tk\Ha						
Tk/Ha r'fed	7331	6191	5117	4035		SW6	25569	22237	14677	8095		
Tk/Ha irrig	25569	22237	14677	8095		Mill Tk						
MTk r'fed	64.376	39.538	4.085	0.000	107.999	SW6	164.818	104.247	8.601	0.000	277.666	489.152
MTk irrig	70.132	44.358	3.660	0.000	118.150							
non project irrigation costs				MTk	14.663							
benefit net of non project irrigation cost				MTk	211.486							
Project irrig b	Tk/Ha	23692										
non pjt gross b	Tk/Ha	10793 net Tk/Ha		7853								
non pjt net ben	Tk/Ha	10093										

Table A 10
WITH PROJECT BENEFITS SW 7 (1991 economic values)

Future Irrigated by Project Alone at 90% Project Uptake .

Total Ha present	Irrig Area	Irrigable Maximum	Balance for Project
SW7	19363	45000	25637

(see Gorai I)

	F0	F1	F2	F3/4	Total	#LLP	exact
Total irr	14100	10255	1282	0	25637	1154	1154
Project i	12694	9232	1154	0	23080		

SW7

Future Ha	+Non Project Cropping (rainfed+TW irrig) F0	F1	F2	F3/4	Total	Future Ha	Irrigated (LLP only) F0	F1	F2	F3/4	Total	
Ha r'fed	37156	27023	3378	0	67557	SW7	12694	9232	1154	0	23080	110000
Ha irrig	10650	7745	968	0	19363	Tk\Ha						
Tk/Ha r'	11168	8408	7084	5609		SW7	33083	27346	19239	17545		
Tk/Ha ir	33083	27346	19239	17545		Mill Tk						
MTk r'fed	414.962	227.208	23.929	0.000	666.099	SW7	419.956	252.458	22.202	0.000	694.616	1887.198
MTk irrig	352.322	211.800	18.626	0.000	582.749							

non project irrigstion costs			MTk	56.265
benefit net of non project irrigatio			MTk	1192.583
Project i	Tk/Ha	30096		
non pjt g	Tk/Ha	14368 net Tk/Ha	11462	
non pjt n	Tk/Ha	13720		

Table A 11
WITH PROJECT BENEFITS SW 10 (1991 economic values)

Future Irrigated by Project Alone at 90% Project Uptake .

Total Ha present	Irrig Area	Irrigable Maximum	Balance for Project
SW10	7594	41500	33906

(see Gorai I)

	F0	F1	F2	F3/4	Total	#LLP	exact
Total irr	18648	13562	1695	0	33906	1526	1526
Project i	16786	12208	1526	0	30520		

SW10

Future +Non Project Cropping (rainfed+TW irrig)

Ha	F0	F1	F2	F3/4	Total
Ha r'fed	24306	17677	2210	0	44193
Ha irrig	4177	3038	380	0	7594
Tk/Ha r'	11412	10275	5716	5069	
Tk/Ha ir	23109	22501	12161	5736	
MTk r'fed	277.382	181.633	12.630	0.000	471.645
MTk irrig	96.519	68.349	4.618	0.000	169.486
non project irrig costs				MTk	21.576
benefit net of non project irrigatio				MTk	619.556

Future Irrigated (LLP only)

Ha	F0	F1	F2	F3/4	Total	
SW10	16786	12208	1526	0	30520	82307
Tk\Ha						
SW10	23109	22501	12161	5736		
Mill Tk						
SW10	387.908	274.692	18.558	0.000	681.158	1300.713

Project i	Tk/Ha	22318		
non pjt g	Tk/Ha	12380	net Tk/Ha	9539
non pjt n	Tk/Ha	11964		

Table A 12
WITH PROJECT BENEFITS Misc PU (1991 economic values)

Future Irrigated by Project Alone at 90% Project Uptake .

Total Ha present	Irrig Area	Irrigable Maximum	Balance for Project
SW misc	1697	9000	7303

(see Gorai I)

	F0	F1	F2	F3/4	Total	#LLP	exact
Total irr	4017	2921	365	0	7303	329	329
Project i	3619	2632	329	0	6580		

SW misc

Future +Non Project Cropping (rainfed+TW irrig)						Future	Irrigated (LLP only)					
Ha	F0	F1	F2	F3/4	Total	Ha	F0	F1	F2	F3/4	Total	
Ha r'fed	398	289	36	0	723	SW misc	3619	2632	329	0	6580	9000
Ha irrig	933	679	85	0	1697	Tk\Ha						
Tk/Ha r'	9478	7733	5777	4630		SW misc	25086	22409	12457	9559		
Tk/Ha ir	25086	22409	12457	9559		Mill Tk						
MTk r'fed	3.769	2.236		0.000	6.005	SW misc	90.786	58.980	4.098	0.000	153.865	194.444
MTk irrig	23.414	15.211	1.057	0.000	39.682							
non project irrig costs				MTK	5.108							
benefit net of non project irrigatio				MTK	40.579							
Project i	Tk/Ha	23384										
non prjt	Tk/Ha	18879	net Tk/Ha	15869								
non prjt	Tk/Ha	16768										

Table A 13
WITH PROJECT BENEFIT BUILD UP SW 4 (1991 economic values)

									Total	
90% LLP uptake	%pa appro	25	25	25	25	0	0	0	100	
Ha\LLP =	20	100.75	100.75	100.75	100.75	0	0	0	403	
	rounded	100	101	101	101	0	0	0	403	
Build-up rate area\annum x			0.3	0.8	1	1	1	1	1	1
Project year	New LLP #	4	5	Area Ha 6	7	8	9	10	11	12
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	100	0	0	0	600	1600	2000	2000	2000	2000
8	101	0	0	0	0	606	1616	2020	2020	2020
9	101	0	0	0	0	0	606	1616	2020	2020
10	101	0	0	0	0	0	0	606	1616	2020
11	0	0	0	0	0	0	0	0	0	0
Total irrigated	403	0	0	0	600	2206	4222	6242	7656	8060
Total rainfed	22000	22000	22000	22000	21400	19794	17778	15758	14344	13940
Net Benefit (crops) Mill Tk										
4		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7		0.000	0.000	0.000	12.148	32.394	40.493	40.493	40.493	40.493
8		0.000	0.000	0.000	0.000	12.269	32.718	40.898	40.898	40.898
9		0.000	0.000	0.000	0.000	0.000	12.269	32.718	40.898	40.898
10		0.000	0.000	0.000	0.000	0.000	0.000	12.269	32.718	40.898
11		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total		0.000	0.000	0.000	12.148	44.663	85.480	126.378	155.006	163.186

RAINFED AREA WITH PROJECT

Area Ha		22000	22000	22000	21400	19794	17778	15758	14344	13940
Tk/Ha		12100	12100	12100	12100	12100	12100	12100	12100	12100
Total MTk		266.203	266.203	266.203	258.943	239.510	215.116	190.674	173.564	168.676
TOTAL BENEFIT MTk		266.203	266.203	266.203	271.090	284.173	300.596	317.051	328.570	331.861
WITHOUT PROJECT	1	2	3	4	5	6	7	8	9	10-30
Area Ha	22000	22000	22000	22000	22000	22000	22000	22000	22000	22000
Tk/Ha	10448	10448	10448	10448	10448	10448	10448	10448	10448	10448
Total MTk	229.856	229.856	229.856	229.856	229.856	229.856	229.856	229.856	229.856	229.856

NOTES
Area = gross area covered by project from year 4 when project works in place to reduce flooding from the river and improved drainage resulting from lower river levels .
Tk/Ha 10448 throughout the project period , no change in irrigated areas .

Table A 14
WITH PROJECT BENEFIT BUILD UP SW 5 (1991 economic values)

90% LLP uptake%pa appro		15	17	17	17	17	17	0	100		
Ha\LLP =	20	189.45	214.71	214.71	214.71	214.71	214.71	0	1263		
rounded		190	215	215	215	214	214	0	1263		
Build-up rate area\annum x			0.3	0.8	1	1	1	1	1	1	1
Project	New LLP			Area Ha							
year	#	1	2	3	4	5	6	7	8	9	10
4	190	1140	3040	3800	3800	3800	3800	3800	3800	3800	3800
5	215	0	1290	3440	4300	4300	4300	4300	4300	4300	4300
6	215	0	0	1290	3440	4300	4300	4300	4300	4300	4300
7	215	0	0	0	1290	3440	4300	4300	4300	4300	4300
8	214	0	0	0	0	1284	3424	4280	4280	4280	4280
9	214	0	0	0	0	0	1284	3424	4280	4280	4280
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
Total irrigated	1263	1140	4330	8530	12830	17124	21408	24404	25260	25260	25260
Total rainfed	56903	55763	52573	48373	44073	39779	35495	32499	31643	31643	31643
Net Benefit (crops) Mill Tk											
4		23.731	63.284	79.104	79.104	79.104	79.104	79.104	79.104	79.104	79.104
5		0.000	26.854	71.610	89.513	89.513	89.513	89.513	89.513	89.513	89.513
6		0.000	0.000	26.854	71.610	89.513	89.513	89.513	89.513	89.513	89.513
7		0.000	0.000	0.000	26.854	71.610	89.513	89.513	89.513	89.513	89.513
8		0.000	0.000	0.000	0.000	26.729	71.277	89.097	89.097	89.097	89.097
9		0.000	0.000	0.000	0.000	0.000	26.729	71.277	89.097	89.097	89.097
10		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total		23.731	90.138	177.568	267.081	356.469	445.649	508.017	525.837	525.837	525.837

RAINFED AREA WITH PROJECT

Area Ha	56903	52573	48373	44073	39779	35495	32499	31643	31643	31643
Tk/Ha	10242	10242	10242	10242	10242	10242	10242	10242	10242	10242
Total MTk	582.801	538.453	495.436	451.396	407.417	363.540	332.855	324.088	324.088	324.088
TOTAL BENEFIT MTk	606.532	628.590	673.005	718.477	763.886	809.189	840.872	849.925	849.925	849.925
WITHOUT PROJECT Year	1	2	3	4	5	6	7	8	9	10-30
Area Ha	56903	56903	56903	56903	56903	56903	56903	56903	56903	56903
Tk/Ha	8273	8321	8369	8417	8465	8512	8560	8608	8656	8704
Total MTk	470.759	473.484	476.209	478.934	481.659	484.384	487.109	489.834	492.559	495.284

NOTES

Area = gross area covered by project from year 4 when project works in place to reduce flooding from the river and improved drainage resulting from lower river levels .

Tk/Ha = project year 1 Tk8273 to Tk 8704 in year 10 in even annual stages .

Table A 15
WITH PROJECT BENEFIT BUILD UP SW 6 (1991 economic values)

90% LLP uptake%pa appro		8	25	36	22	9	0	0	100		
Ha\LLP =	20	46.85	146.50	210.96	128.92	52.74	0	0	586		
rounded		47	146	210	130	53	0	0	586		
Build-up rate area\annum x			0.3	0.8	1	1	1	1	1	1	1
Project year	New LLP #	Area Ha 1	2	3	4	5	6	7	8	9	10
4	0	0	0	0	0	0	0	0	0	0	0
5	47	0	282	752	940	940	940	940	940	940	940
6	146	0	0	876	2336	2920	2920	2920	2920	2920	2920
7	210	0	0	0	1260	3360	4200	4200	4200	4200	4200
8	130	0	0	0	0	780	2080	2600	2600	2600	2600
9	53	0	0	0	0	0	318	848	1060	1060	1060
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
Total irrigated	586	0	282	1628	4536	8000	10458	11508	11720	11720	11720
Total rainfed	32673	32673	32391	31045	28137	24673	22215	21165	20953	20953	20953
Net Benefit (crops) Mill Tk											
4		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5		0.000	6.681	17.816	22.270	22.270	22.270	22.270	22.270	22.270	22.270
6		0.000	0.000	20.754	55.344	69.179	69.179	69.179	69.179	69.179	69.179
7		0.000	0.000	0.000	29.851	79.604	99.505	99.505	99.505	99.505	99.505
8		0.000	0.000	0.000	0.000	18.479	49.279	61.598	61.598	61.598	61.598
9		0.000	0.000	0.000	0.000	0.000	7.534	20.090	25.113	25.113	25.113
10		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total		0.000	6.681	38.570	107.465	189.532	247.767	272.642	277.665	277.665	277.665
RAINFED AREA WITH PROJECT											
Area Ha		32673	32391	31045	28137	24673	22215	21165	20953	20953	20953
Tk/Ha		10094	10094	10094	10094	10094	10094	10094	10094	10094	10094
Total MTk		329.801	326.955	313.368	284.015	249.049	224.238	213.640	211.500	211.500	211.500
TOTAL BENEFIT MTk		329.801	333.636	351.938	391.480	438.581	472.005	486.282	489.165	489.165	489.165
WITHOUT PROJECT Year		1	2	3	4	5	6	7	8	9	10-30
Area Ha		32673	32673	32673	32673	32673	32673	32673	32673	32673	32673
Tk/Ha		7960	7988	8016	8045	8073	8101	8129	8158	8186	8214
Total MTk		260.077	260.999	261.921	262.843	263.765	264.688	265.610	266.532	267.454	268.376

NOTES
Area = gross area covered by project from year 4 when project works in place to reduce flooding from the river and improved drainage resulting from lower river levels .
Tk/Ha = project year 1 Tk7960 to Tk 8214 in year 10 in even annual stages .

Table A 16
WITH PROJECT BENEFIT BUILD UP SW 7 (1991 economic values)

90% LLP uptake %pa appro		12	20	20	19	19	10	0	100		
Ha\LLP =	20	138.48	230.8	230.8	219.26	219.26	115.4	0	1154		
rounded		140	230	230	220	220	114	0	1154		
Build-up rate area\annum x			0.3	0.8	1	1	1	1	1	1	1
Project	New LLP			Area Ha							
year	#	1	2	3	4	5	6	7	8	9	10
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	140	0	0	840	2240	2800	2800	2800	2800	2800	2800
7	230	0	0	0	1380	3680	4600	4600	4600	4600	4600
8	230	0	0	0	0	1380	3680	4600	4600	4600	4600
9	220	0	0	0	0	0	1320	3520	4400	4400	4400
10	220	0	0	0	0	0	0	1320	3520	4400	4400
11	114	0	0	0	0	0	0	0	684	1824	2280
Total irrigated	1154	0	0	840	3620	7860	12400	16840	20604	22624	23080
Total rainfed	110000	110000	110000	109160	106380	102140	97600	93160	89396	87376	86920
Net Benefit (crops) Mill Tk											
4		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

RAINFED AREA WITH PROJECT

Area Ha		0	0	-840	-3620	-7860	-12400	-16840	-20604	-22624	-23080
Tk/Ha		0	0	0	0	0	0	0	0	0	0
Total MTk		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TOTAL BENEFIT MTk		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WITHOUT PROJECT	Year	1	2	3	4	5	6	7	8	9	10-30
Area Ha		110000	110000	110000	110000	110000	110000	110000	110000	110000	110000
Tk/Ha		0	123	247	370	494	617	741	864	988	1111
Total MTk		0.000	13.583	27.165	40.748	54.330	67.913	81.495	95.078	108.660	122.243

NOTES

Area = gross area covered by project from year 4 when project works in place to reduce flooding from the river and improved drainage resulting from lower river levels .

Tk/Ha = project year 1 Tk9602 to Tk 10103 in year in even annual stages .

Table A 17

WITH PROJECT BENEFIT BUILD UP SW 10 (1991 economic values)

										Total	
90% LLP uptake %pa appro		6	13	13	13	14	14	14	13	100	
Ha\LLP =	20	91.56	198.38	198.38	198.38	213.64	213.64	213.64	198.38	1526	
rounded		91	198	198	198	213	214	214	200	1526	
Build-up rate area\annum x			0.3	0.8	1	1	1	1	1	1	1
Project	New LLP			Area Ha							
year	#	1	2	3	4	5	6	7	8	9	10
4	91	546	1456	1820	1820	1820	1820	1820	1820	1820	1820
5	198	0	1188	3168	3960	3960	3960	3960	3960	3960	3960
6	198	0	0	1188	3168	3960	3960	3960	3960	3960	3960
7	198	0	0	0	1188	3168	3960	3960	3960	3960	3960
8	213	0	0	0	0	1278	3408	4260	4260	4260	4260
9	214	0	0	0	0	0	1284	3424	4280	4280	4280
10	214	0	0	0	0	0	0	1284	3424	4280	4280
11	200	0	0	0	0	0	0	0	1200	3200	4000
Total irrigated	1526	546	2644	6176	10136	14186	18392	22668	26864	29720	30520
Total rainfed	82307	81761	79663	76131	72171	68121	63915	59639	55443	52587	51787
Net Benefit (crops) Mill Tk											
4		12.186	32.496	40.169	40.169	40.169	40.169	40.169	40.169	40.169	40.169
5		0.000	26.514	70.705	83.381	83.381	83.381	83.381	83.381	83.381	83.381
6		0.000	0.000	26.514	70.705	83.381	83.381	83.381	83.381	83.381	83.381
7		0.000	0.000	0.000	26.514	70.705	83.381	83.381	83.381	83.381	83.381
8		0.000	0.000	0.000	0.000	28.523	76.061	95.076	95.076	95.076	95.076
9		0.000	0.000	0.000	0.000	0.000	28.657	76.418	95.523	95.523	95.523
10		0.000	0.000	0.000	0.000	0.000	0.000	28.657	76.418	95.523	95.523
11		0.000	0.000	0.000	0.000	0.000	0.000	0.000	26.782	71.419	82.274
Total		12.186	59.010	137.388	220.769	306.159	395.030	490.463	584.111	647.853	658.708
RAINFED AREA WITH PROJECT											
Area Ha		81761	79663	76131	72171	68121	63915	59639	55443	52587	51787
Tk/Ha		11963	11963	11963	11963	11963	11963	11963	11963	11963	11963
Total MTk		978.107	953.008	764.615	863.382	814.932	764.615	713.461	663.265	629.098	619.528
TOTAL BENEFIT MTk		990.293	1012.018	902.003	1084.151	1121.091	1159.645	1203.924	1247.376	1276.951	1278.236
WITHOUT PROJECT	Year	1	2	3	4	5	6	7	8	9	10-30
Area Ha		82307	82307	82307	82307	82307	82307	82307	82307	82307	82307
Tk/Ha		8649	8679	8709	8739	8769	8800	8830	8860	8890	8920
Total MTk		711.873	714.352	716.830	719.308	721.787	724.265	726.743	729.222	731.700	734.178

NOTES

Area = gross area covered by project from year 4 when project works in place to reduce flooding from the river and improved drainage resulting from lower river levels .

Tk/Ha = project year 1 Tk8649 to Tk 8920 in year 10 in even annual stages .

Table A 18
WITH PROJECT BENEFIT BUILD UP Misc PU (1991 economic values)

										Total	
90% LLP uptake %pa appro		13	23	18	12	13	9	10	2	100	
Ha\LLP =	20	42.77	75.67	59.22	39.48	42.77	29.61	32.9	6.58	329	
rounded		42	75	60	40	42	30	33	7	329	
Build-up rate area\annum x			0.3	0.8	1	1	1	1	1	1	1
Project	New LLP			Area Ha							
year	#	1	2	3	4	5	6	7	8	9	10
4	42	252	672	840	840	840	840	840	840	840	840
5	75	0	450	1200	1500	1500	1500	1500	1500	1500	1500
6	60	0	0	360	960	1200	1200	1200	1200	1200	1200
7	40	0	0	0	240	640	800	800	800	800	800
8	42	0	0	0	0	252	672	840	840	840	840
9	30	0	0	0	0	0	180	480	600	600	600
10	33	0	0	0	0	0	0	198	528	660	660
11	7	0	0	0	0	0	0	0	42	112	140
Total irrigated	329	252	1122	2400	3540	4432	5192	5858	6350	6552	6580
Total rainfed	9000	8748	7878	6600	5460	4568	3808	3142	2650	2448	2420
Net Benefit (crops) Mill Tk											
4		5.893	15.714	19.642	19.642	19.642	19.642	19.642	19.642	19.642	19.642
5		0.000	10.523	28.061	35.076	35.076	35.076	35.076	35.076	35.076	35.076
6		0.000	0.000	8.418	22.448	28.061	28.061	28.061	28.061	28.061	28.061
7		0.000	0.000	0.000	5.612	14.966	18.707	18.707	18.707	18.707	18.707
8		0.000	0.000	0.000	0.000	5.893	15.714	19.642	19.642	19.642	19.642
9		0.000	0.000	0.000	0.000	0.000	4.209	11.224	14.030	14.030	14.030
10		0.000	0.000	0.000	0.000	0.000	0.000	4.630	12.347	15.433	15.433
11		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.982	2.619	3.274
Total		5.893	26.237	56.121	82.778	103.638	121.409	136.982	148.487	153.210	153.865

RAINFED AREA WITH PROJECT

Area Ha	9000	7878	6600	5460	4568	3808	3142	2650	2448	2420
Tk/Ha	16768	16768	16768	16768	16768	16768	16768	16768	16768	16768
Total MTk	150.912	132.098	110.669	91.553	76.596	63.853	52.685	44.435	41.048	40.579
TOTAL BENEFIT MTk	156.805	158.335	166.790	174.331	180.234	185.262	189.667	192.922	194.258	194.444
WITHOUT PROJECT Year	1	2	3	4	5	6	7	8	9	10-30
Area Ha	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000
Tk/Ha	9138	9221	9303	9386	9469	9551	9634	9717	9799	9882
Total MTk	82.242	82.986	83.730	84.474	85.218	85.962	86.706	87.450	88.194	88.938

NOTES
Area = gross area covered by project from year 4 when project works in place to reduce flooding from the river and improved drainage resulting from lower river levels .
Tk/Ha = project year 1 Tk9138 to Tk 9882 in year 10 in even annual stages .

Appendix 3

Crop Gross Margins

APPENDIX 3

Crop Gross Margins

The attached crop gross margins for each of the projects planning units at 1991 economic values were used in the calculation of benefits to the Gorai Augmentation Project. Detailed background to the budgets are given in Volume 6 - Land Resources, Agriculture and Fisheries and Volume 10, Economics. The gross margins are net of direct growing costs. The figures used in the analyses for irrigated crops in addition have deducted the costs of irrigation by 2 cusec capacity LLP for all with project LLP irrigation and for non-project irrigated areas by the costs for each hectare of different pump type mixes found in each PU. The unit costs applied to arrive at these were:

	Diesel powered		Electric powered
DTW			
Tk/ha/a	3795		4957
ratio	0.8		0.2
Combined Tk/ha/a		4027	
STW/DSSTW			
Tk/ha/a	2835		3097
ratio	0.9		0.1
Combined Tk/ha/a		2861	
LLP 1 cusec (1)			
Tk/ha/a	2765		3910
ratio	0.9		0.1
Combined Tk/ha/a		2880	
LLP 2 cusec (1)			
Tk/ha/a	1775		2613
ratio	0.8		0.2
Combined Tk/ha/a		1943	

The final tables provide a breakdown of the average annual crop losses in the five main Planning Units that have been used in the analyses.

Irrigated Jute and B Aman changed to rainfed and total irrigated and rainfed areas adjusted to 1991 estimates

CROP GROSS MARGINS BY PLANNING UNIT (1991 Economic Values)

(Crop Areas File : SWSCAR-3.wk1)

Taka

SW4	IRRIGATED				NON-IRRIGATED				Totals		
CROP	F0	F1	F2	F3	F0	F1	F2	F3	Irrigated	Rainfed	Overall
Kharif											
B Aus	0	0	0	0	5,712,883	3,210,301	796,542	0	0	9,719,726	9,719,726
M Aus	22,457,976	30,663,057	0	0	2,120,731	0	0	0	53,121,033	2,120,731	55,241,764
B Aman	0	0	0	0	0	16,256,806	38,661,137	12,632,237	0	67,550,180	67,550,180
L T Aman	31,871,312	80,616,135	2,710,410	0	57,773,313	76,458,095	3,286,738	0	115,197,857	137,518,146	252,716,003
M Aman	133,707,524	78,703,174	0	0	107,223,430	21,805,376	0	0	212,410,697	129,028,806	341,439,503
Jute	0	0	0	0	90,410,469	74,787,350	12,032,179	0	0	177,229,998	177,229,998
Sugarcane	39,850,680	9,217,883	0	0	62,712,023	8,947,898	0	0	49,068,563	71,659,921	120,728,484
Rabi											
L Boro	0	0	0	4,164,649	0	0	0	1,829,060	4,164,649	1,829,060	5,993,708
M Boro	90,634,974	105,122,758	25,794,705	2,419,856	236,257	0	0	0	223,972,293	236,257	224,208,550
M Wheat	33,086,742	40,376,164	4,064,400	0	2,112,450	6,375,458	11,743,472	3,674,113	77,527,305	23,905,493	101,432,798
Potato	1,707,377	7,591,397	713,237	0	7,216,086	4,425,393	68,474	17,330	10,012,010	11,727,283	21,739,293
Pulses	5,971,793	4,701,413	2,309,780	418	63,742,981	30,539,634	16,344,517	2,361,640	12,983,405	112,988,771	125,972,176
Oilseeds	2,995,186	4,428,266	939,040	383	21,481,824	24,643,595	7,836,382	608,857	8,362,876	54,570,658	62,933,533
Spices	7,984,921	7,546,952	0	0	9,971,915	6,933,391	0	0	15,531,873	16,905,306	32,437,179
Minor crops	25,340,393	45,641,124	1,488,164	0	12,240,263	19,203,165	0	0	72,469,681	31,443,428	103,913,109
Orchards	414,919	0	0	0	41,996,746	0	0	0	414,919	41,996,746	42,411,665
Totals	396,023,795	414,608,323	38,019,737	6,585,306	484,951,371	293,586,462	90,769,441	21,123,237	855,237,161	890,430,510	1,745,667,670
Total NCA	18,531	20,783	3,708	831	55,020	34,309	16,266	4,942	43,852	110,537	154,390
Tk/ha(NCA)	21,371	19,949	10,254	7,927	8,814	8,557	5,580	4,274	19,503	8,055	11,307

SW5	IRRIGATED				NON-IRRIGATED				Totals		
CROP	F0	F1	F2	F3	F0	F1	F2	F3	Irrigated	Rainfed	Overall
Kharif											
B Aus	0	0	0	0	4,935,990	6,365,430	1,244,027	0	0	12,545,446	12,545,446
M Aus	4,280,631	10,990,141	0	0	642,826	3,380,514	0	0	15,270,771	4,023,340	19,294,111
B Aman	0	0	0	0	0	9,863,880	34,610,347	11,438,624	0	55,912,851	55,912,851
L T Aman	2,136,730	21,306,968	1,100,097	0	4,382,970	12,287,853	1,491,769	0	24,543,795	18,162,592	42,706,387
M Aman	17,118,167	17,019,746	0	0	17,892,098	13,609,915	0	0	34,137,912	31,502,013	65,639,925
Jute	0	0	0	0	14,655,638	24,209,815	9,588,066	0	0	48,453,519	48,453,519
Sugarcane	2,789,428	553,565	0	0	31,159,690	12,811,272	0	0	3,342,992	43,970,962	47,313,954
Rabi											
L Boro	0	0	0	2,394,888	0	0	0	2,028,164	2,394,888	2,028,164	4,423,052
M Boro	11,405,910	29,019,211	12,600,679	1,307,553	0	0	0	0	54,333,353	0	54,333,353
M Wheat	4,581,776	10,321,258	2,166,701	0	989,176	5,714,692	3,055,092	163,997	17,069,735	9,922,957	26,992,692
Potato	87,753	955,492	71,421	0	1,743,942	162,391	1,436,024	0	1,114,666	3,342,357	4,457,023
Pulses	266,577	746,301	60,589	0	7,418,564	20,882,221	9,069,910	900,754	1,073,467	38,271,449	39,344,916
Oilseeds	273,636	784,213	130,005	0	2,800,954	8,884,662	4,537,419	446,264	1,187,853	16,669,299	17,857,153
Spices	1,062,644	1,514,046	0	0	5,102,363	13,418,218	2,585,792	0	2,576,690	21,106,373	23,683,063
Minor crops	1,595,145	7,021,429	343,587	0	2,545,482	9,101,674	1,447,461	0	8,960,160	13,094,617	22,054,778
Orchards	0	0	0	0	8,565,913	0	0	0	0	8,565,913	8,565,913
Totals	45,598,396	100,232,368	16,473,079	3,702,441	102,835,606	140,692,537	69,065,907	14,977,803	166,006,284	327,571,853	493,578,138
Total NCA	2,045	5,009	1,504	436	11,864	19,437	13,009	3,600	8,993	47,910	56,903
Tk/ha(NCA)	22,299	20,012	10,954	8,491	8,668	7,238	5,309	4,161	18,459	6,837	8,674

Irrigated Jute and B Aman changed to rainfed and total irrigated and rainfed areas adjusted to 1991 estimates

CROP GROSS MARGINS BY PLANNING UNIT (1991 Economic Values)

(Crop Areas File : SWSCAR-3.wk1)

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SW6	*IRRIGATED*				*NON-IRRIGATED*				*Totals*		
CROP	F0	F1	F2	F3	F0	F1	F2	F3	Irrigated	Rainfed	Overall
Kharif											
B Aus	0	0	0	0	(1,938,719)	(2,760,371)	(483,032)	0	0	(5,182,123)	(5,182,123)
M Aus	3,185,941	10,490,065	0	0	578,195	3,239,079	0	0	13,676,006	3,817,274	17,493,280
B Aman	0	0	0	0	0	5,949,234	20,245,416	7,784,292	0	33,978,942	33,978,942
L T Aman	294,626	9,338,571	473,823	0	287,185	2,208,568	0	0	10,107,020	2,495,753	12,602,773
M Aman	8,135,370	10,775,991	0	0	7,427,942	7,853,192	0	0	18,911,361	15,281,135	34,192,496
Jute	0	0	0	0	7,049,902	13,801,467	5,862,428	0	0	26,713,798	26,713,798
-Sugarcane	250,694	6,940	0	0	18,666,087	8,305,259	0	0	257,635	26,971,346	27,228,981
Rabi											
L Boro	0	0	0	879,571	0	0	0	566,408	879,571	566,408	1,445,978
M Boro	7,039,205	28,479,866	12,332,599	998,585	0	0	0	0	48,850,256	0	48,850,256
M Wheat	2,477,305	7,521,952	1,611,054	0	654,373	3,835,708	1,753,158	160,216	11,610,310	6,403,455	18,013,765
Potato	0	632,636	0	0	506,854	20,478	35,109	0	632,636	562,442	1,195,078
Pulses	90,877	353,303	0	0	3,012,470	12,019,865	4,683,148	518,111	444,180	20,233,594	20,677,775
Oilseeds	65,003	376,248	0	0	1,281,586	5,250,357	2,332,308	280,056	441,251	9,144,306	9,585,558
Spices	452,266	832,316	0	0	3,137,878	8,974,413	1,832,767	0	1,284,583	13,945,057	15,229,640
Minor crops	354,782	3,833,411	177,109	0	985,592	3,818,114	593,217	0	4,365,302	5,396,923	9,762,224
Orchards	0	0	0	0	2,946,745	0	0	0	0	2,946,745	2,946,745
Totals	22,346,070	72,641,300	14,594,584	1,878,156	44,596,091	72,515,362	36,854,520	9,309,082	111,460,111	163,275,055	274,735,166
Total NCA	874	3,267	994	232	6,083	11,713	7,203	2,307	5,367	27,306	32,673
Tk/ha(NCA)	25,569	22,237	14,677	8,095	7,331	6,191	5,117	4,035	20,768	5,979	8,409

SW7	*IRRIGATED*				*NON-IRRIGATED*				*Totals*		
CROP	F0	F1	F2	F3	F0	F1	F2	F3	Irrigated	Rainfed	Overall
Kharif											
B Aus	0	0	0	0	(558,269)	(1,401,645)	(1,720,004)	0	0	(3,679,919)	(3,679,919)
M Aus	3,349,700	17,886,505	0	0	3,771,494	5,611,683	0	0	21,236,205	9,383,177	30,619,382
B Aman	0	0	0	0	0	8,049,100	138,729,540	122,508,507	0	269,287,148	269,287,148
L T Aman	278,810	24,160,295	7,375,796	0	912,530	1,026,576	0	0	31,814,901	1,939,105	33,754,006
M Aman	11,069,664	23,478,187	0	0	26,024,171	28,779,218	0	0	34,547,851	54,803,389	89,351,240
Jute	0	0	0	0	15,171,650	67,219,901	31,596,584	0	0	113,988,135	113,988,135
Sugarcane	1,225,103	0	0	0	61,296,244	34,860,785	0	0	1,225,103	96,157,029	97,382,132
Rabi											
L Boro	0	0	0	1,753,305	0	0	0	17,772,468	1,753,305	17,772,468	19,525,773
M Boro	12,798,435	98,238,195	246,963,314	101,018,940	0	0	0	0	459,018,884	0	459,018,884
M Wheat	1,055,090	3,217,603	688,831	0	1,528,495	18,766,734	7,501,115	16,786,375	4,961,524	44,582,718	49,544,243
Potato	850,498	241,511	0	0	2,205,977	3,248,091	4,426,852	0	1,092,009	9,880,920	10,972,929
Pulses	233,927	2,831,587	1,061,060	0	8,117,792	45,699,523	44,091,564	19,154,802	4,126,573	117,063,681	121,190,254
Oilseeds	754,560	5,586,686	1,147,379	75,282	5,981,451	17,044,053	26,898,832	16,520,080	7,563,906	66,444,415	74,008,321
Spices	3,091,110	19,276,110	0	0	23,600,458	33,508,396	16,156,659	0	22,367,220	73,265,513	95,632,732
Minor crops	128,219	1,449,066	67,612	0	4,094,724	21,468,273	4,651,243	0	1,644,897	30,214,240	31,859,137
Orchards	0	0	0	0	9,946,679	0	0	0	0	9,946,679	9,946,679
Totals	34,835,115	196,365,746	257,303,991	102,847,526	162,093,396	283,880,687	272,332,384	192,742,232	591,352,378	911,048,698	1,502,401,077
Total NCA	1,053	7,181	13,374	5,862	14,514	33,765	38,442	34,362	27,470	121,083	148,553
Tk/ha(NCA)	33,083	27,346	19,239	17,545	11,168	8,408	7,084	5,609	21,527	7,524	10,114

Irrigated Jute and B Aman changed to rainfed and total irrigated and rainfed areas adjusted to 1991 estimates

CROP GROSS MARGINS BY PLANNING UNIT (1991 Economic Values)

(Crop Areas File : SWSCAR-3.wk1)

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SW10	*IRRIGATED*				*NON-IRRIGATED*				*Totals*		
CROP	F0	F1	F2	F3	F0	F1	F2	F3	Irrigated	Rainfed	Overall
Kharif											
B Aus	0	0	0	0	4,689,246	4,526,738	4,683,120	0	0	13,899,103	13,899,103
M Aus	6,129,457	4,230,641	0	0	536,929	66,916	0	0	10,360,099	603,845	10,963,944
B Aman	0	0	0	0	0	6,383,419	74,920,174	18,935,628	0	100,239,221	100,239,221
L T Aman	4,289,224	11,348,750	2,099,519	0	27,023,853	70,229,048	21,125,001	0	17,737,494	118,377,902	136,115,396
M Aman	22,918,228	15,350,561	0	0	36,227,703	24,884,645	0	0	38,268,789	61,112,348	99,381,137
Jute	0	0	0	0	15,027,250	18,054,719	12,049,430	0	0	45,131,399	45,131,399
Sugarcane	4,373,268	1,840,993	0	0	14,531,670	6,692,625	0	0	6,214,261	21,224,295	27,438,556
Rabi											
L Boro	0	0	0	0	0	0	36,020	15,181,408	0	15,217,428	15,217,428
M Boro	11,914,842	17,639,272	27,743,224	11,160,906	0	0	0	0	68,458,244	0	68,458,244
M Wheat	7,617,310	5,248,939	2,211,696	0	518,906	996,805	541,709	102,855	15,077,944	2,160,274	17,238,218
Potato	735,996	752,313	506,855	0	8,349,558	218,638	32,681,085	0	1,995,164	41,249,281	43,244,445
Pulses	431,294	373,097	142,350	0	7,256,935	6,512,900	18,062,475	3,446,517	946,742	35,278,827	36,225,569
Oilseeds	1,265,190	2,866,496	1,219,522	0	8,370,592	11,817,856	23,140,829	4,766,943	5,351,208	48,096,220	53,447,428
Spices	978,994	1,528,826	0	0	2,222,815	3,718,992	67,011	0	2,507,820	6,008,818	8,516,638
Minor crops	1,945,535	9,918,091	981,606	0	4,480,918	12,687,974	5,497,541	0	12,845,232	22,666,433	35,511,665
Orchards	0	0	0	0	22,383,149	0	0	0	0	22,383,149	22,383,149
Totals	62,599,340	71,097,979	34,904,773	11,160,906	151,619,525	166,791,274	192,804,395	42,433,351	179,762,997	553,648,545	733,411,542
Total NCA	2,709	3,160	2,870	1,946	13,286	16,233	33,732	8,371	10,685	71,621	82,306
Tk/ha(NCA)	23,109	22,501	12,161	5,736	11,412	10,275	5,716	5,069	16,824	7,730	8,911

Average Annual Crop Losses Due to Flooding at 1991 Economic Values

	Planning Area : SW 4			Planning Area : SW 5			Planning Area : SW 6		
Crop	1991 Value Tk. '000	Loss %	Loss Value Tk. '000	1991 Value Tk. '000	Loss %	Loss Value Tk. '000	1991 Value Tk. '000	Loss %	Loss Value Tk. '000
Aus L	9720	3.04	295	12545	3.04	381	5128	3.74	192
Aus M	55242	3.3	1823	19294	3.30	637	17493	5.06	885
Aman B	67550	6.25	4222	55913	6.25	3495	33979	7.68	2310
Aman TL	252716	1.32	3336	42706	1.32	564	12603	23.16	2919
Aman TM	319440	3.4	10861	65640	3.40	2232	34192	15.85	5420
Boro L	5994	0.1	55	4423	0.91	40	1446	0.00	0
Boro M	224209	0.54	1211	54333	0.54	293	48850	0.69	337
Jute	177230	4.06	7196	48454	4.06	1967	26714	2.35	628
Sugarcane	120728	0.25	302	47314	0.25	118	27229	3.54	964
TOTAL	1232829	2.38	29301	350622	2.77	9727	207634	6.88	13655

	Planning Area : SW 7			Planning Area : SW 10		
Crop	1991 Value Tk. '000	Loss %	Loss Value Tk. '000	1991 Value Tk. '000	Loss %	Loss Value Tk. '000
Aus L	3680	3.74	138	13899	3.04	423
Aus M	30619	5.06	1549	10964	3.30	362
Aman B	262287	7.68	20144	100239	6.25	6265
Aman TL	33754	23.16	7817	136115	1.32	1797
Aman TM	89351	15.85	14162	99381	3.40	3379
Boro L	19526	0.00	0	15217	0.91	138
Boro M	459019	0.69	3167	68458	0.54	370
Jute	113988	2.35	2679	45131	4.06	1832
Sugarcane	97382	3.54	3447	27439	0.25	69
TOTAL	1109606	4.79	53103	516843	2.83	14635

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