Category 8: F2-F4 > 50%, cropping intensity < regional average, high crop damage - such areas will be amongst the poorest in the region. Such areas would appear to need flood control as a priority, but there is a further question as to whether the low cropping intensity is due to the deep-flooded nature of the area. If so, full flood control may not be attainable, and partial measures, along with measures to boost fisheries, may be preferable.

Review of the map of composite flooding indicators (Figure 3.5) comfirms the general picture described above and allow certain more detailed conclusions to be reached. The map confirms that flooding problems are generally not severe in the north and west whilst there is severe flooding along the Brahmaputra and at the downstream end of the Teesta. Flooding is severe in the Lower Atrai but problems are less on the left bank of the Ganges and in the Pabna Scheme. In the Mohananda basin problems lie on the right bank. The left bank of the Mohananda, and the adjacent Western Barind Tract, do not suffer from flooding.

These general conclusions are taken up in the next section, in the discussion of individual planning units and specific options.

3.4 Regional Planning

The following sections describe the major options under consideration for each planning unit. In many cases several other options were considered but were not carried forward for further work. Details are to be found in Volume 2 and Volume 3 of the Draft Final Report, larger scale maps of the planning units and layouts of the exsiting and proposed projects are given in Apendix 3 of this report. The problems and possible options for all the planning units covering the whole region are given in table 3.2 at the end of this section.

3.4.1 Thakurgaon (Planning Unit 1)

Planning unit 1 (Thakurgaon) is an independent drainage basin. However improvements in the area may have a direct impact on conditions downstream in India.

Flooding and Drainage Problems

No information is available on changes to flows coming from India. Data and flooding conditions under present circumstances were therefore investigated.

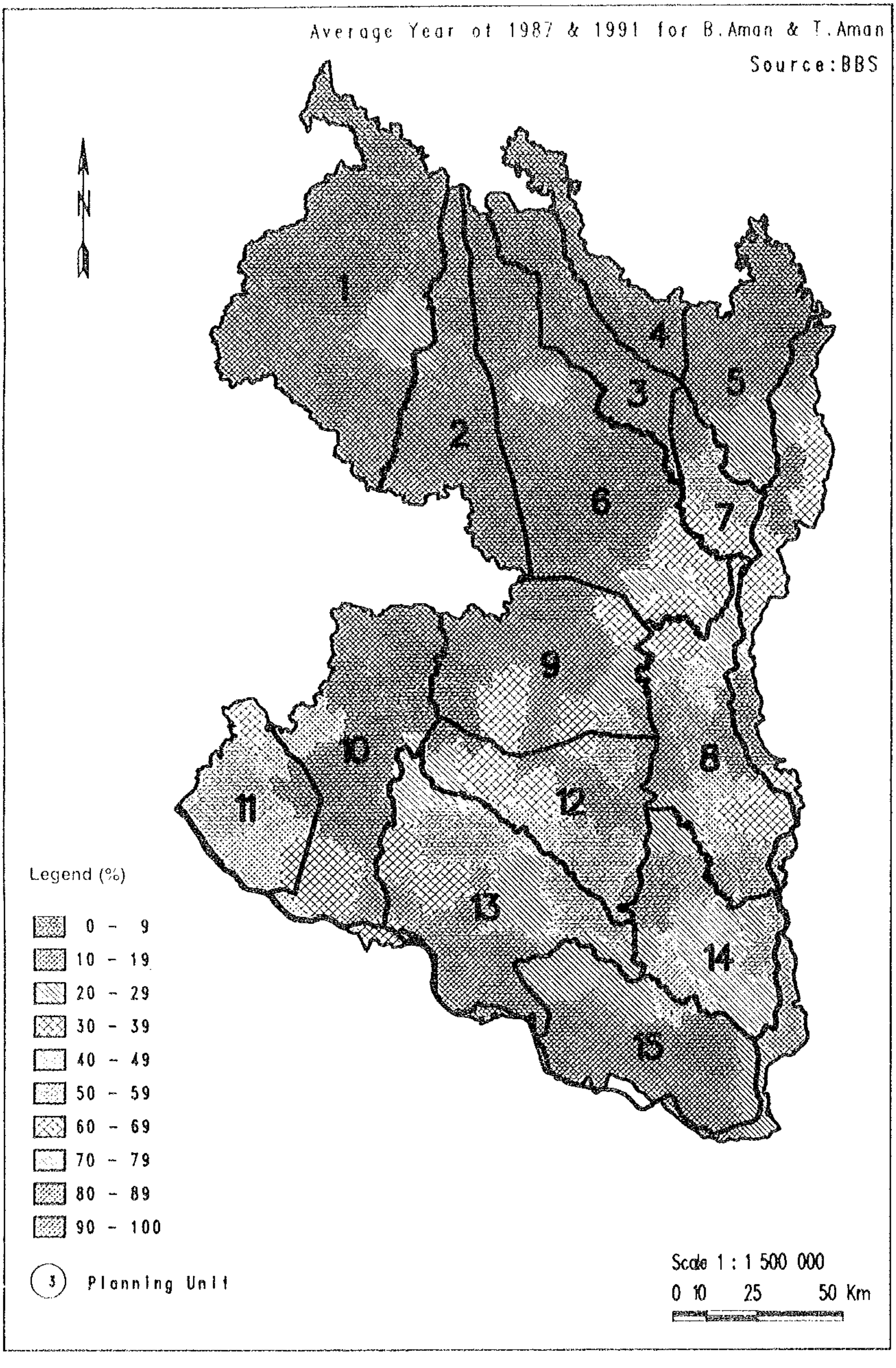
Analysis of the GIS statistics indicates that there is virtually no F2-F4 land in the planning unit. Therefore the area in general is not subject to prolonged and deep flooding. This assumption is supported by the cropping patterns found, which have a relatively high proportion of t. aman.

The area experiences inundation due to flash floods from the upper reaches of the drainage channels in India. These flash floods tend to generate spillage which cause damage both to crops and infrastructure. However, since the duration of inundation is short, agricultural damage through crop submergence is generally on the low side. It tends to be more severe in the south of the unit.

Infrastructure damage data indicates that the main problems in this unit from flash flooding lie along the Dhepa and Punarbhaba rivers. This is dealt with in planning unit 2. Further west, damage along the Tangon is relatively minor, indicating that this river is not susceptible to flash flooding.

Figure 3.4

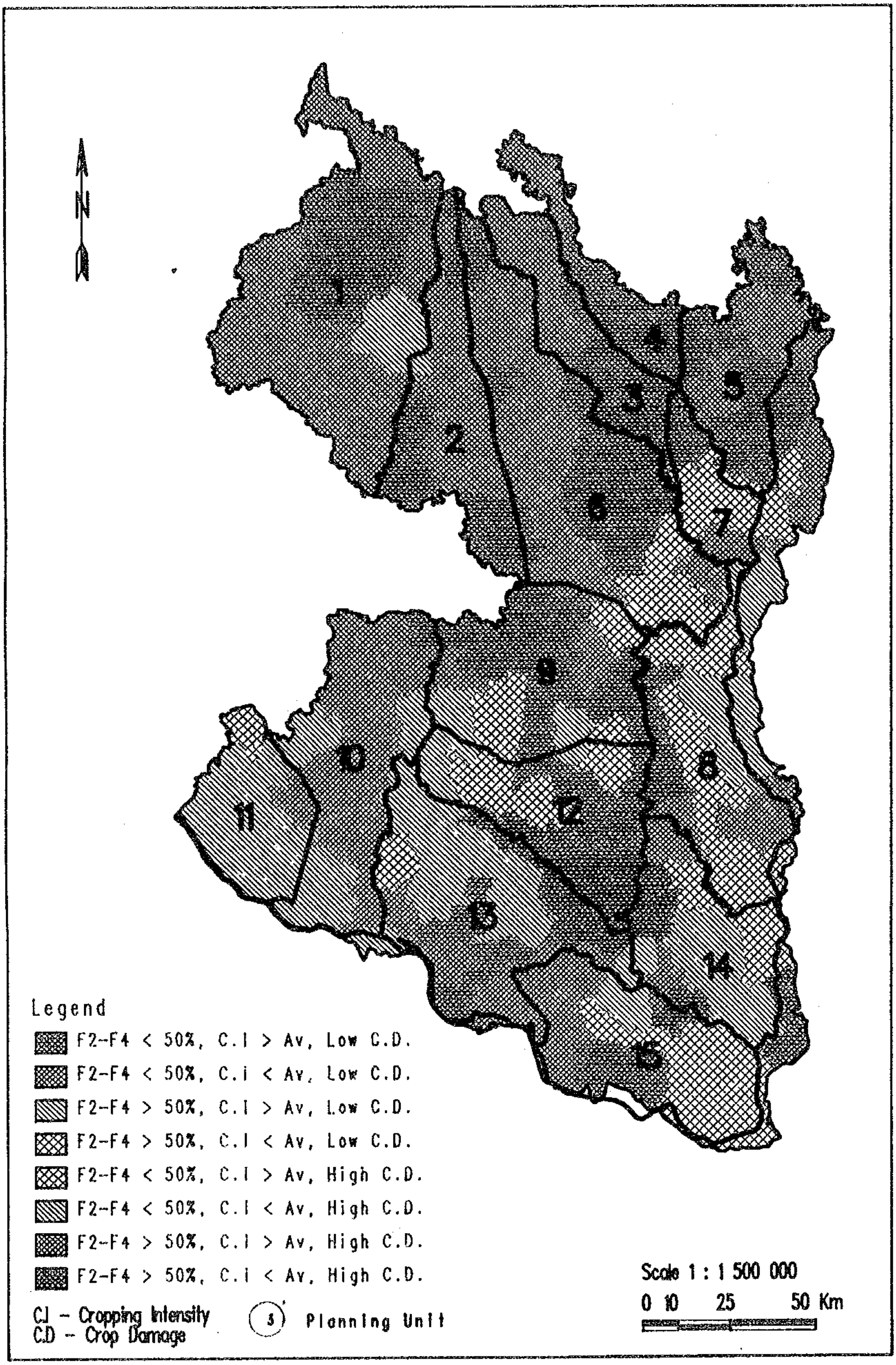
Crop Damage


Average Year of 1987 & 1991 for B.Aman & T.Aman

Source:BBS

Figure 3.5

Flood Indicators



Development Options

In planning unit 1 flooding generally takes the form of flash floods of relatively short duration. The main benefits from flood control would therefore be reduced crop and infrastructure damage and even this damage appears to be relatively slight. It is therefore felt that in general major structural works are not appropriate at present. This also takes into account the undesirability of increasing cross-border flows into India and to the downstream of the Atrai where it re-enters Bangladesh.

Panchagarh town is under threat from the Upper Karatoya (Atrai) and a part of the town has been already lost through erosion. FAP-9A has proposed an integrated plan for flood control, drainage and river training. The proposed scheme involves construction of flood embankments along the Karatoya, drainage improvement and construction of river training works.

Localised flooding a round Thakurgaon also appears to be a problem. Appropriate counter-measures could be implemented. The measures suggested would not have significants downstream impacts in regional terms.

3.4.2 Upper Atrai (planning unit 2)

Planning unit 2 (Upper Atrai) has an extensive catchment area in India and is directly influenced by the situation in India. Again improvement of the area may have direct impacts on flooding condition in India as river flows pass downstream. The area of this unit has relatively steep ground slopes compared to the remainder in the region.

Flooding and Drainage Problems

In its flooding characteristics, this unit is similar to planning Unit 1

Infrastructure damage in 1987 indicates that the main problems in this unit arise from flash flooding along the Dhepa and Punarbhaba rivers and in the lower part of the Upper Atrai. There are also problems of river erosion at Dinajpur town which is under active threat from the Punarbhaba.

The comparison of theoretical discharges and conveyance capacity for rivers in the planning units confirms the likelihood of some flooding problems along the Atrai, and along the Dhepa-Punarbhaba where 20-year probable discharges exceed the carrying capacity of the rivers. There do not appear to be flooding problems in the upper reaches of the Little Jamuna.

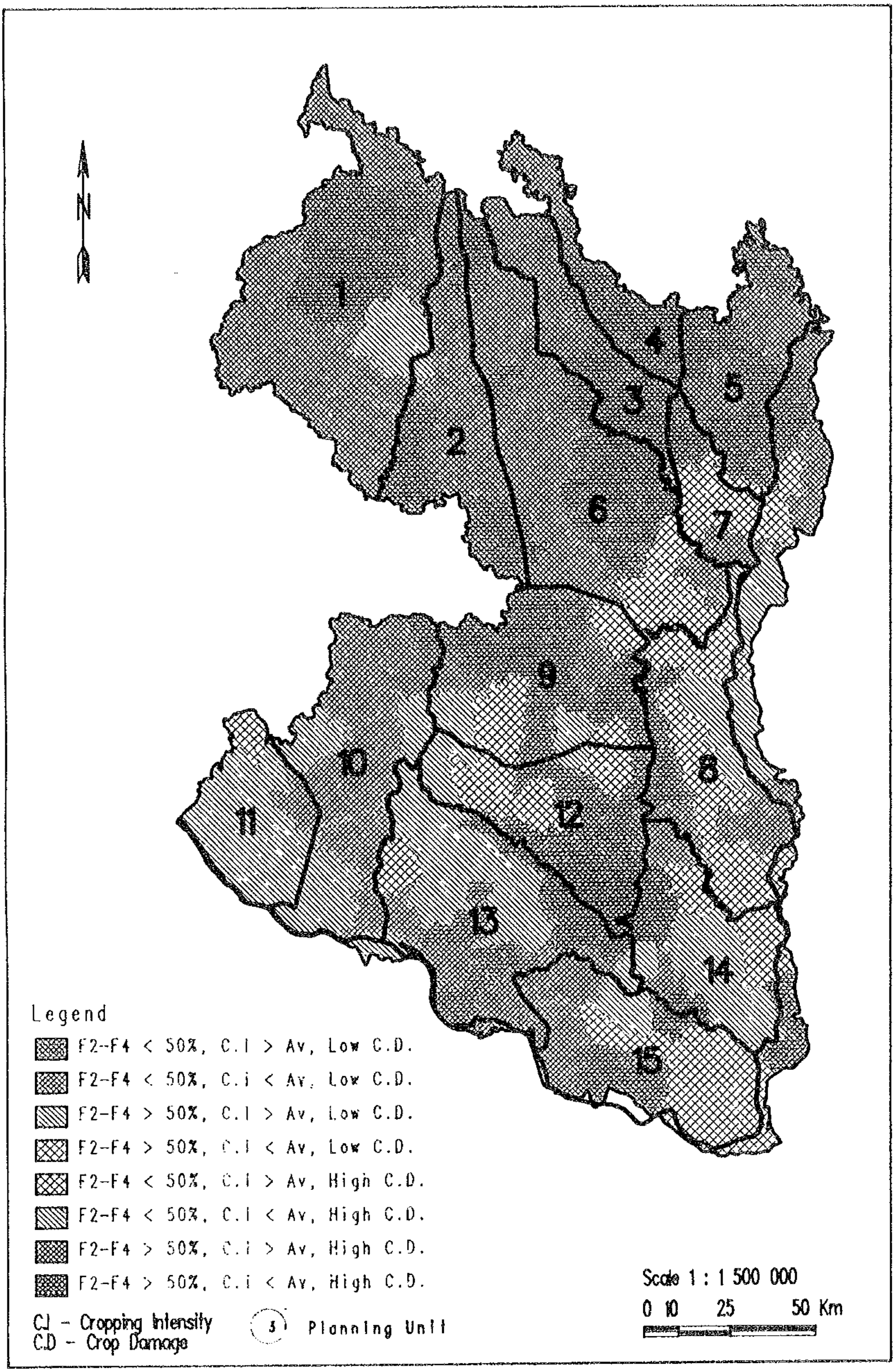
Options for Development

As in the case of Unit 1, it is felt that in general major structural works are not appropriate at present.

In the case of the Atrai-Punarbhaba basins, flood analysis indicates that 20 year flows are likely to cause some flooding since the theoretical discharges are above conveyance capacity. These problems could be solved by embanking the rivers, which would cause a resultant increase in discharges downstream of 5-600m^3/s. In the case of the Atrai this would appear to be an unacceptable increase as it would add to cross-border flows and ultimately contribute to flooding in the lower Atrai. The situation of the Punarbhaba is somewhat different since there is an extensive area of beels where the river forms the international border in the south west of the region. These beels act as a natural storage basin. Increasing flows in the Punarbhaba would therefore not have detrimental effects region-

Figure 3.5

Flood Indicators



wide, although increasing downstream flows into India is undesirable.

However, although the 20-yr discharge exceeds the estimated conveyance capacity, the duration of exceedance is only a few days, resulting in rather small crop damage. In view of this and the adverse affect of increasing cross-border flows it is suggested that no measures are urgently required except town protection works for Dinajpur being dealt with under FAP-9A. Apart from these town protection works, it is felt that in general major structural works are not appropriate at present.

No changes are proposed in the facilities designed to be provided under the Atrai-Kakra project in the unit.

3.4.3 Teesta Right Bank (Planning Unit 3)

Flooding and Drainage in the Planning Unit

The GIS data indicates that there is practically no F2-F4 land in the planning unit so that prolonged and serious flooding is not a general problem. Cropping intensities are about the regional average, and there is a high proportion of HYV t.aman.

Hydrodynamic modelling and evidence from the field confirms that spills from the Teesta contribute to flows in the Ghagot and Karatoya and flooding downstream on those rivers. Infrastructure damage tends to be severe along the Teesta, which is to be expected in view of the high cost of the infrastructure there. Severe damage also occurs along the Ghagot to both crops and infrastructure.

Options for Development

Flood control measures on the Teesta are therefore a relatively high priority because of the contribution of Teesta spills to flooding and damage downstream.

Modelling results indicate that reinstatement of the Teesta right embankment would result in a significant reduction in damage and human discomfort along the Teesta as well as reducing downstream discharges in the Ghagot. They will also provide protection for part of the Teesta Irrigation Project Area. Impacts of the increased discharges on the Brahmaputra, on the other hand, would not be significant.

The proposed measures require the rehabilitation and/or strengthening of the Teesta Right Embankment at several locations from downstream of the Teesta barrage to Kaunia. River bank protection works are proposed at several locations, together with the construction of a section of retired embankment. Since the embankment has an average height of around 4m and is in many locations constructed of sandy soil, it is threatened by erosion even in a normal flood. Hence, the existing embankment itself needs to be strengthened and resectioned.

3.4.4 Teesta Left Bank (Planning Unit 4)

Planning unit 4 (Teesta Left Bank) has an extensive drainage basin in India. Downstream, the area is bounded by the Teesta river and accordingly improvements in the area will not have a significant adverse effect on downstream areas.

Flooding and Drainage Problems

Cropping intensities are about average for the region, and there is little broadcast or deep water aman grown. In terms of flood phases, F2 and F4 land forms only about 2% of the total area of the unit. It is therefore evident that there is not a serious and prolonged flooding and drainage problem in the unit.

Crop and infrastructure damage occurs as a result of flash flooding from the river Teesta when the embankment is subject to breaching. There are also some problems due to overland flows from India and drainage congestion through an inability of these flows to easily drain into the River Teesta.

Options for Development

The main proposals for this unit involve sealing of the Teesta Left Bank and rehabilitation of the Sati Nadi Scheme behind the embankment. This was considered as an SRP project but has been dropped. It does not appear that there are feasible solutions within Bangladesh to reducing damage due to overland flow from India.

The flood embankment along the Teesta left bank needs to be constructed, heightened or strengthened, and river training works against bank erosion may also be considered.

It is proposed to construct a retired embankment to minimize silt deposition in the Sati river, which is caused by intrusion of the Teesta flood water through the breaches of the Teesta left embankment, Since the bank erosion is severe in this location provision of bank protection works by concrete blocks placement on the embankment is recommended.

There are two options for rehabilitation of the Sati Nadi Scheme and treatment of the outfall of the Sati river to the Teesta. One is to keep it open and construct a backwater embankment along the Sati. The other is to close the outfall of the Sati and to construct a drainage regulator there. In addition, drainage of some areas of the basin comprising the Sati Nadi project area needs improvement, and the Sati river needs to be re-excavated in order to enable swift drainage and retention of water for surface irrigation purposes.

3.4.5 Kurigram (Planning Unit 5)

Planning unit 5 (Kurigram) has the same characteristics as Planning unit 4. Downstream the area is bounded by the rivers Teesta, the Dharla and the Brahmaputra.

Flooding and Drainage Problems

Cropping intensities are about average for the region. During the monsoon season the main crop grown is transplanted rather than deep water or broadcast aman, so that prolonged and deep flooding is not generally a serious problem throughout the planning unit. However, statistics shows that 8% of the unit is F2-F4 land, which is higher than for other units within the upper reaches. The area is also suffering from drainage congestion due to long-lasting high river stages and insufficient conveyance capacities of drainage channels. Erosion, breaches and spills from the major rivers are also major problems. Erosion is a particular problem round Kurigram town itself.

This unit is included in the eastward basins of the Teesta. Basic flooding characteristics are the same as the others in the basins eastward of the Teesta. But the difference of this unit from other unit in the basins eastward of the Teesta is that this unit is influenced by the long-lasting high flow of the Brahmaputra, and hence the backwater in the Dudhkumar, Dharla and Teesta rivers. In addition this unit is suffering from serious erosion on the right bank of the Dharla and Brahmaputra, and the left bank of Teesta. Erosion is the main cause of the breaches of the flood embankment.

Development Options

The Kurigram FCDI Project is divided into two units, a north unit and a south unit. The north unit is located upstream of the confluence of the Brahmaputra and Dharla. The south unit is located upstream of the confluence of the Brahmaputra and Teesta. Flood protection measures in this planning unit will not cause any noticeable adverse effect to other areas in terms of flood discharge or river stage. Therefore full CFD development can be applied to this planning unit. In fact most of the embankment works have already been implemented.

Strengthening of embankments on the major rivers (Brahmaputra, Teesta, Dharla) together with improvements of internal drainage and the supply of irrigation facilities are being considered as options under JICA - funded projects.

In 1991, a feasibility study for the South Unit was started by JICA and is scheduled to be completed in 1993. Most of the basic FCD facilities were completed during 1973-1984 based on the study conducted in 1969/71, and the existing flood embankment is functioning, though some rehabilitation works are required. The report proposes some alternatives on the flood control component, drainage improvement component and irrigation development component.

The study has been making extensive use of the findings of FAP12 and other FAP supporting studies and its conclusions are expected to be broadly in line with FAP philosophy.

Kurigram town is covered by the Secondary Towns Integrated Flood Protection study (FAP-9A). The Draft Final Report of FAP-9A was issued in February 1992. According to the report, the following works are proposed:

- construction of some 1,000 m of bank revetment works;
- construction of two new groynes;
- extension and rehabilitation of the existing groyne;
- localised repairs to the flood embankment;
- rehabilitation, enlargement and extension of the surface water drainage system .

3.4.6 Upper Karatoya Basin (Planning Unit 6)

Planning unit 6 (Upper Karatoya) has a small catchment area in India. Improvements in the area may have adverse effects downstream in the Bangali basin.

Flooding and Drainage Problems

The GIS statistics show that there is effectively no F2-F4 land within the planning unit. This would indicate that there are few areas where prolonged and deep flooding regularly occurs.

Cropping intensities are around 150%, so that some increase may be possible, but the proportions of transplanted aman grown are also high, hence flooding may not be an important constraint to production.

Infrastructure damage in 1987 and 1988 appears to be fairly widely distributed throughout the planning unit. Significant damage was found near Badarganj (see the map for the planning unit given in Appendix 3) reportedly caused by flows in the Chikli river. Serious flooding occurred during September 1991 when a cut was made on the right bank of the Upper Karatoya at its downstream end to relieve problems upstream. In general infrastructure and crop damage has been relatively severe in the downstream reaches of the Upper Karatoya.

A comparison of theoretical discharges and conveyance capacity for the Upper Karatoya indicates that upstream of Siraj, conveyance capacities are generally sufficient. Downstream this is not the case and some flooding may occur. This is born out by the reported damage.

Options for Development

The main rivers in this planning unit are the Karatoya, Jamuneswari, and Alai. The Jamuneswari, and Alai are tributaries of the Karatoya. The catchment of the rivers in the planning unit lies mostly within Bangladesh. However, spillage from the Teesta river in India flows overland and augments the river discharges. It is assumed that this augmentation will continue as at present.

The flooding in this planning unit is quite extensive in terms of crop damage and human discomfort, especially when augmented by Teesta flows. However, CFD responses would increase downstream discharges. Consideration was given to providing off-stream flood retention in the upstream reaches but this was found to be impractical and not considered further. Increased downstream discharges should be drained directly to the Jamuna through the shortened interceptor known as the "Bangali Floodway" if the principle of avoiding increased downstream disbenefits is to be adhered to. Thus the main option under consideration for this unit is full CFD of Upper Karatoya and Alai, with the Bangali floodway. CFD developments along the Upper Karatoya would also reduce flood damage due to overland flow on its right bank.

Some development along the Karatoya is under implementation by EIP through the Upper Karatoya Project.

3.4.7 Gaibandha (Planning Unit 7)

Options in the Gaibandha planning unit are the subject of the detailed Project Preparation Study.

The proposed works are intended to prevent inflow from the Teesta, Brahmaputra and Ghagot rivers into the area, and to improve drainage from local khals into these rivers. Along the Teesta, this option is in fact a continuation of the Teesta Right Bank strengthening, since breaches in this embankment have occurred in this reach also. However, this work is included in the Gaibandha Improvement Project since the project area forms a contiguous set of compartments for which comprehensive planning can be carried out. The project will also provide protection for Gaibandha town. Downstream of Gaibandha, improvements in the configuration of the Ghagot and Alai rivers are proposed.

For regional planning, key features relate to:

- the sealing of the Teesta right embankment, river training and reduction in downstream discharges in the Ghagot,

- the increase of discharges from the Ghagot to the Brahmaputra, thus reducing downstream flows to the Alai and Bangali.

3.4.8 Middle Bangali Basin (Planning Unit 8)

Flooding and Drainage Problems

Analysis of available statistics indicates that cropping intensities are reasonably high at 158% and that transplanted aman is widely grown. Only 18% of the land is F2-F4, so that the problem of deep and prolonged flooding is not widespread. In the upper part of the unit there are problems caused by the Bogra-Gaibandha railway line which in effect forms a compartment preventing good drainage to the south through the Gazaria/Ichamoti river.

In the middle and lower parts of the planning unit the flooding problems become more acute. Not only is there spillage from the rivers Bangali and Karatoya but large breaches occur in the River Brahmaputra. One breach at Mathurapara in 1991 was four miles long, bringing large discharges into the area. This also potentially alters the morphological conditions in the smaller rivers in the unit with large deposits of silt and sediment, thus exacerbating the problem further.

The planning unit is outside the backwater effect of the Hurasagar.

Planning Concepts

The major flooding problems in this planning unit are the result of breaches in the BRE. Sealing of the BRE would considerably reduce flooding problems. Rehabilitation and strengthening of the BRE is being studied under FAP1. Regional planning for FAP2 assumes that the BRE will be effectively sealed.

In the northern part of the planning unit provision of better drainage in this area is the main requirement. Desilting of the old Karatoya and Bangali and also the re-excavation of the drainage system between them would improve movement of water through the unit and reduce over-spillage onto the surrounding land. This is being considered as part of the Gazaria-Ichamati SRP project, which is also looking at dry season supplies.

Spillage from the Alai has been considered under potential EIP projects.This will be considerably reduced by proposals made under NWRS for the Gaibandha Project.

The most important measure to reduce flooding conditions in the southern part of the region is the sealing of the BRE, as described above. Consideration has also been given to providing a second line of defence against breaches in the BRE. Possible measures would include the Bogra-Baghabari road, an embankment along the right back of the Ichamati, of the use of compartments as flood cells between the Brahmaputra and Ichamati. This is discussed further in Section 4.3.

3.4.9 Joypurhat (Planning Unit 9)

Planning Unit 9 (Joypurhat) is the area just upstream of the Atrai Left Bank and outside the backwater area from the Brahmaputra. However, improvements may affect the downstream area where serious flooding is already taking place.

Flooding and Drainage Problems

Flood phase data indicates that most of the land in this planning unit is F0 and F1, so that serious and prolonged flooding does not occur. Overall cropping intensities are high, at around 170%.

The comparison of theoretical discharges and conveyance capacities confirms that, in this planning unit, conveyance capacities are generally sufficient for the 20-yr probable discharge, and that flooding problems are relatively minor.

Crop and infrastructure damage, however, indicates that spills from the right bank of the Little Jamuna downstream of Joypurhat may be significant. Overland flow from the Atrai in India may also be a contributory factor.

Planning Options

According to the information of EIP and crop damage data, some areas near Badalgachi in the basin of the Little Jamuna suffer from flooding. The river cross-sections in this reach used for the estimate of present conveyance capacities of the river are limited in number. Thus, even though the results based on the cross-sections show the adequacy of the present capacities, some reaches may be under capacity.

Accordingly the extension of the right embankment of the Little Jamuna to the upstream reaches river may improve the flooding situation of the area. It may even improve the situation of the Naogaon Polder to some degree since part of this area forms a drainage basin of the Naogaon Polder Project.

3.4.10 Western Barind Tract (Planning Unit 10)

Flooding and Drainage Problems

Planning unit 10 (Western Barind Tract) is relatively high and not affected by other areas.

Published statistics indicate that cropping intensities are low, but this is primarily the result of lack of water in the dry season, rather than flooding and drainage problems. About 10% of the area is F2-F4 land, mainly situated along the margins of the planning unit, on the Punarbhaba to the west, or the Shib to the east. Crop damage is also more serious along the river Shib than elsewhere.

Planning Options

Relief of flooding problems along the Shib is considered in Planning Unit 13 (Atrai Right Bank).

3.4.11 Mohananda Basin (Planning Unit 11)

Planning unit 11 (Mohananda Basin) has an extensive drainage basin in India. However, downstream is the Ganges and improvement of the area will not cause significant adverse effect to other adjacent or downstream areas.

Flooding and Drainage Problems

The left bank of the Mohananda is adequately protected by the Chapai Nawabganj-Rohanpur road,

and supplied with sufficient regulators.

An area on the right bank of Mohananda suffers from flooding. Spillage water from Pagla and Mohananda river is mainly responsible for the flooding in this planning unit although restricted drainage is also a problem.

Development Options

CFD development on the right bank requires construction of a flood embankment along the right side of the Mohananda and the left side of the Pagla. No additional provision of drainage regulators is proposed since the present drainage regulators have sufficient capacity to drain out the internal rain water.

Flooding also occurs between the Pagla river and the Ganges due to the high stages of the Ganges, but the area is so small that no protective works are proposed. Some flood proofing could be considered.

Upstream Areas

The upstream area of the confluence of the Mohananda and the Punarbhaba is also composed of a very extensive beel area along the international border, forming a natural retarding basin. Even in the dry season a large quantity of water remains in the beel area, which extends into Indian territory across the border with Bangladesh. No works are proposed for this area since these would also have impacts in India.

3.4.12 Lower Atrai and Lower Bangali (Planning Units 12,13 and 14)

These units form a complex area of deep flooding where individual options have significant impacts on adjacent and downstream areas. They are considered as a whole in the development scenarios discussed in Section 4.4.

3.4.13 Pabna (Planning Unit 15)

Flooding and Drainage

Flooding in the scheme area has reportedly reduced very significantly since the construction of the main embankment (160 km length) around the area. Previously a large part of the area had been flooded by spills into the area from the major rivers, as well as through backflow up the natural drainage channels of the Atrai and Baral rivers.

Current flooding is experienced through the spillage of water from the River Ganges which passes through the cross drainage culverts on the railway line and hence into the scheme area. However, this is a relatively minor problem.

Another source of overland flooding results from spillage from the Nandakuja channel in the north; these flows pass through Chalan Beel Polder A, then into the scheme area. This latter occurrence is infrequent, significant flows having only reportedly taken place in the severe monsoon floods of 1988.

Planning Options

The area has fairly effectively been provided with major (1:100 year) flood protection facilities. Drainage facilities have also been provided both by gravity and pumped means. Impacts have already been experienced both to fisheries and navigation. Further development options are focused on securing the existing facilities and to provide further works to address shortcomings in the existing system.

This area is located at the downstream end of the region and flood protection facilities do not have any adverse effects on any other area. Accordingly further flood protection and drainage measures proposed for the scheme would not have any adverse regional implications, and can be considered on their own merits.

3.4.14 Summary

The problems and possible options in each individual planning unit are summarised in Table 3.2.

Table 3.2 Planning Units, Problems and Options

Planning Unit No.	Name of Planning Unit	Major causes of Flooding	Possible structural measures
1 & 2	Thakurgaon & Upper Atrai	Flash floods	Infrastructure protection.
3	Teesta Right Bank	Breach of TRE due to bank erosion and poor quality of construction	Strengthening of embankment/river training works against bank erosion.
4	Teesta Left Bank	Breach of TLE due to bank erosion and poor qualityof construction	Strengthening of embankment/river training works against bank erosion
5	Kurigram	Breach of flood embankment due to bank erosion and/or public-cut	Strengthening of embankment/river training works against bank erosion
6	Upper Karatoya	Insufficient conveyance capacity of the rivers	Construction of embankment/Bangali floodway or provision of flood retention area
7	Gaibandha	Breach of BRE/TRE due to bank erosion, insufficient conveyance capacity of the Ghagot and insufficient capacity of Manas drainage regulator.	Strengthening of TRE/river training works against bank erosion/Strengthening of Ghagot embankment/new configuration of Ghagot/ Brahmaputra confluence
8	Middle Bangali	Breach of Brahmaputra embankment	Bangali floodway.
9	Joypurhat	Insufficient coneyance capacity of the little Jamuna upstream of Badalgachi	Extension of embankment upstream of Badalgachi town.
10	Western Barind Tract	No flooding problem except in localised areas along the Shib river.	Included in comprehensive proposals for lower Atrai.
11	Mohananda	Prolonged inundation due to high backwater stage of the Ganges and insufficient conveyance capacity of the Mohananda and Pagla.	Construction of embankment along the Mohananda and Pagla.
12	Atrai Left Bank	Prolonged inundation due to long-duration high back water stage in the Brahmaputra and insufficient conveyance capacity of river channels	Construction of embankment for CFD area and/or provision of flow area for Green River.
13	Atrai Right Bank	Prolonged inundation due to long-duration high back water stage in the Brahmaputra.	Construction of embankment for CFD area, overflow weir and dwarf embankment for Green River.
14	Lower Bangali	Breach of BRE due to bank erosion, breach in the embankment of Hurasagar, Bangali, and public cut of SIRDP west embankment.	Strengthening of BRE and construction of embankment for CFD area and provision of flow area for Green River in southern areas of Hurasagar and SIRDP project areas.
15	Pabna	Occassional spillage into northern parts of project area through Nandakuya channel etc.	Pabna Phase II Project proposal

3.5 Flood Proofing

3.5.1 Introduction

Where no protective measures or interventions can be justified for economic or socio-economic reasons the provision or improvement of flood proofing is seen as the alternative solution.

Historically communities and institutions in Bangladesh have been fully aware of the need to ensure that a degree of flood proofing is inherently part of their decision making process. However, the degree provided is influenced by financial constraints.

Rural communities build their homesteads above a "reasonable" flood level accepting a degree of risk for a saving in cost and sometimes improved convenience. Infrastructure is designed to have it's functional portion above highest flood level, however this might not accommodate a peak flood. The changing of the regime of the flood hydraulics of an area can be imposed by a natural change in river course or by a man-made intervention. This change in regime can easily compromise the flood proofing previously undertaken.

Flood proofing effectiveness is therefore constrained by:

- the financial resources available,
- the accuracy of the knowledge of the flood regime,

An additional important factor is the degree of public participation which can be harnessed to ensure that effective community level proofing is undertaken.

The need for flood proofing is generally greatest in deeply flooded areas, severely flood prone areas and the charlands. These are areas characteristically populated by the poorer communities who cannot as individuals move away to other areas. These poorer communities by definition have no spare financial resources and are able to provide for themselves only the most rudimentary of flood proofing measures. In addition the measures themselves are at risk of damage during flood events necessitating high maintenance costs to ensure effectiveness from year to year.

It should be emphasised that the most appropriate method of addressing flood proofing of the most flood prone areas is through a concerted effort of poverty alleviation.

3.5.2 Possible Flood Proofing Measures

There is no definite list of flood proofing measures because effective flood proofing is based on local needs and the availability of public and private resources to undertake the different measures. However, possible structural flood proofing measures include: (from FAP23 Interim Report).

- raising floor levels of houses/homesteads
- improving the quality of housing
- provision of flood shelters
- provision of storage areas
- local small-scale flood protection and drainage schemes
- protective embankments and drainage for small urban areas
- protection of commercial premises
- raising ground levels at markets, schools and other communal areas

- ensuring key infrastructure (roads, railways, public buildings etc.) are above specific flood levels
- ensuring different modes of transport can operate effectively during floods.

These flood proofing measures would be implemented through private channels, government agencies and non-government organisations (NGOs). NGOs would be involved in the more local level assistance to rural poor to improve housing and construct shelters. NGOs and government agencies would address improvements to schools, health centres, and the provision of latrines, emergency tubewells and community centres. Government agencies would be primarily responsible for the communication systems (road, rail, telephone, main water supplies, public buildings). The private (enterprise) sector would protect commercial and industrial installations unless they were government owned.

Donor assistance in flood proofing would therefore be directed both through NGO's and the Government system to address different needs.

Apart from the structural measures, non-structural measures are very important. The following are the non-structural measures which require appropriate institutional arrangements :

- strengthening of flood warning and evacuation system,
- support of food and medicare facilities to the evacuees during floods and use of existing public buildings as emergency shelters,
- provision of seeds and loan facilities after the flood to the affected people to restart farming and rebuild houses,
- promotion of embankment surveillance,
- promotion of flood proofed houses, and strengthening of government policy to have flood proofed public buildings,
- implementation of land use regulations based on flood hazard zoning and publication to inhabitants.

Non structural interventions/developments have been covered both by FAP23 as well as FAP14 and relate particularly to institutional and motivational programmes.

3.5.3 Flood Proofing Demand, Service Provision and Unit Costs

The populations estimated to be affected by the different flooding situations are presented in Table 3.3 These values are derived from information evaluated by FAP 16 together with estimates by the NWRS team. The number should be considered to be upper limits, in many cases some degree of flood proofing would be assumed to be already accessible by them, particularly those in the Atrai floodway and in the Middle Bangali areas. No information on population on the Teesta and Ganges chars is currently available but the numbers are believed to be small.

Table 3.3 Population Requiring Flood Proofing

	Lower Atrai	Whole Brahmaputra	Brahmaputra Right Bank	Gaibandha
People living outside BRE (charlands)		1,700,000	-	(100 000)
People living on BRE (right bank) and TRE		-	350,000	(70 000)
People affected by breaches in the BRE in the Middle Bangali		-	900,000	-
Atrai floodway	380,000		-	-

Note: Gaibandha figures included within Brahmaputra figures.

Source: FAP-16 & NWRS.

Unit costs are given in Table 3.4. The costs quoted are approximate estimates and do not include any element of contribution from beneficiaries. However, it is felt that some elements of flood proofing should involved such contributions as a form of self-help, which will both reduce initial costs and facilitate maintenance. Examples of such contributions are voluntary labour to build raised platforms, training of groups of embankment dwellers to fabricate low-cost latrines on-maintain tube wells etc. Involvement of local Government and NGOs would probably be necessary to organise such beneficiary involvement.

Table 3.4 Unit Rates for Basic Flood Proofing Facilities

Items	Unit	Unit Rate	Note
Installation of tubewell for drinking water	each	7,000	Some payment contribution to be encouraged
Installation of sanitary latrine with construction of plinth	each	2,200	Ditto
Construction of high elevated platform for 100 families of size 1500 sqm (shelter area)	each	400 000	Includes single building.
Raising and Strengthening of Road Embankment	km	50,000	
Relief Centre	each	300 000	For food storage etc

3.5.3 Recommended Flood Proofing Initiatives

The flood proofing initiatives recommended should be focused on

a) in the charland areas
  - raised platforms
  - flood shelters (to serve as school/health centres)
  - tubewells and pit latrines
  - relief centres (in nearby potected areas) for storage of flood, medical supplies etc

b) on the major embankments
  - offset platforms for tubewell locations and pit latrines

c) in the Middle Bangali Area
  - raised platforms
  - flood shelters (modified schools)
  - pit latrines on the raised platforms
  - raising and strengthening of road embankments

d) in the Atrai area
  - NGO assistance to improve existing flood proofing effectiveness, particularly in more destitute families.
  - government initiatives to improve flood proofing effectiveness of public sector facilities.

Since the size and cost of the overall programme could become very large it is recommended that an initial programme is developed with a budget of about Tk 100 million, made up of about Tk 40 million for flood shelters on the charland, Tk 40 million for flood proofing the area of the middle Bangali basin affected by BRE breaches, and Tk 10 million each for improving service provision on offset platforms along the main embankments, and flood proofing along the Lower Atrai as a pilot experiment to assess whether this would be effective in reducing embankment cutting. About Tk 10 million of the total could be associated with the Gaibandha Improvement Project, mainly related to Brahmaputra chars, the construction of relief centres, and improved services for those living on the embankment in the Gaibandha area. This is discussed for these in the Gaibandha Final Report.

CHAPTER 4

REGIONAL DEVELOPMENT SCENARIOS

4.1 Basic Assumptions

A number of basic assumptions were made in formulating the regional plan. These are described below.

National border

The region is bordered on the north and west by India, on the east by the Brahmaputra and on the south by the Ganges. The perennial rivers in the region come from India and accordingly their drainage basins extend into India. In other words, the hydrological boundary is not the national border. Under this situation, flooding in the region is much affected by the situation in India and to a certain extent the Himalayas.

For a comprehensive flood control plan, the whole drainage basin and the river system should be considered. However, since information from India is not available, the present situation in India is taken as the base condition for regional planning. Accordingly, if the flood control situation in India changes in future, the plan should be reviewed at that stage. If the plan is already implemented, the projects should be reviewed, taking into account the new situation.

The Brahmaputra river

The present situation is that there are many breaches in the BRE. For formulation of the regional plan, sealing of the BRE is taken as a given condition since this is under intensive study and implementation through FAP1.

The present situation on the left bank of the Brahmaputra (BLE) is that only certain reaches of the embankment exist. Even though a study on sealing the BLE is going on, it is not clear that a policy of sealing the BLE will definitely be undertaken. Therefore the formulation of a plan for the NWR is made according to the present situation on the Brahmaputra Left Bank.

The construction of Jamuna bridge over the Brahmaputra is now at the stage of tender advertisement. Flood water levels of the Brahmaputra are likely to rise if the bridge is completed. The impacts of the bridge construction are not considered directly in the regional plan, but a sensitively analysis has been carried out to assess these impacts.

Impacts on Adjacent Areas

Improvement in particular areas may have negative impacts on adjacent or downstream areas. The basic policy for formulation of the regional plan is that improvements in a particular area should not cause adverse effects on to other or adjacent areas. If it is clear that the development scenario in a certain area may cause adverse impacts other areas, countermeasures should be included in the scenario.

4.2 Brahmaputra Right Bank

4.2.1 Introduction

The Brahmaputra Right Embankment (BRE) is the most significant flood control infrastructure in the region (Figure 4.1).

The construction of the BRE started in 1957 and was completed by 1968, providing an overall length of embankment of 220 km. The purpose of the BRE - to ensure flood protection of the right bank floodplain of the Brahmaputra river - while initially successfully met, has more recently been seriously threatened by the constant erosion of the banks of the river and consequent frequent breaching. During the last 20 years, some 140 km of retired embankment has been built. The progressive retirement of the BRE demonstrates the severity of the natural bank erosion of the Brahmaputra river.

In the years following the construction of the BRE, additional measures have been taken at various points, in the attempt to maintain the security of the flood defence. These measures have included:

- cross-bars and groynes, with the aim of creating zones of low velocity flow immediately adjacent to the bank.

- bank revetment, with the aim of hardening the bank sufficiently to withstand near bank velocities.

Serious breaches occurred in 1987 and 1988 and there was severe flood damage to the area behind the embankment. Breaches have continued to occur since then. In 1991 breaches occurred at Mathurapara and south of Kazipur. In 1992, however, which was a low flood year, there were no further serious breaches.

Considerable investment has been made in bank stabilisation measures over the past 20 years, but the only examples of relative success, now also under threat, is the Serajganj town protection and the groyne at Sariakandi, consisting primarily of multiple layers of randomly dumped concrete cubes.

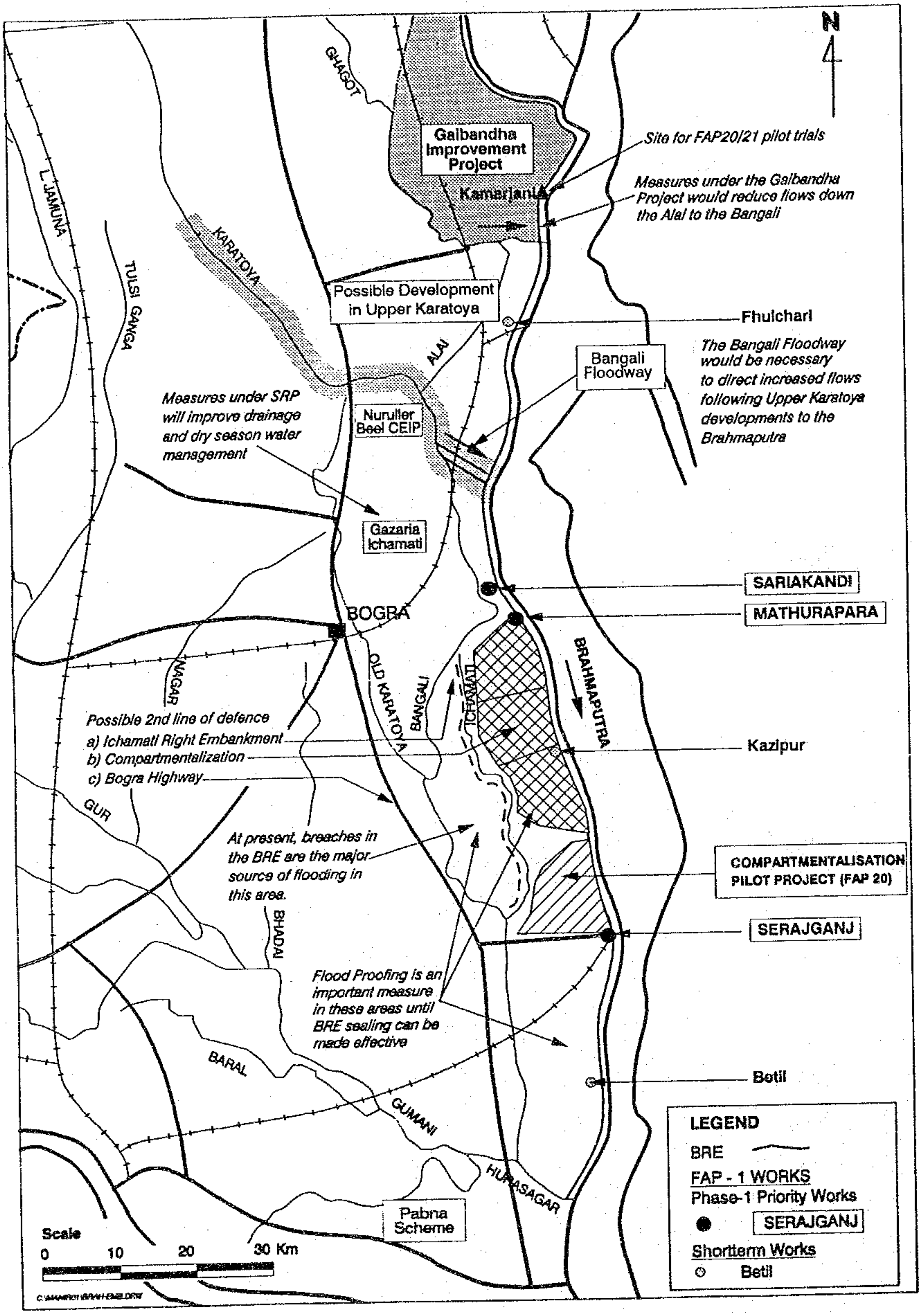
Cross-Drainage

Drainage towards the BRE is considered to be significant only over a length of about 20 to 25 km, with the Ghagot River forming the approximate southern limit and the Teesta the northern limit. In this stretch the general land slope is towards the Brahmaputra and the embankment can therefore restrict drainage. The problem does not, however, seem to be particularly serious except for pockets of low-lying land. The situation is exacerbated by the occasional breaching of the flood embankment on the right bank of the Teesta, and public cuts are made in the BRE from time to time to relieve flooding when homesteads or crops are threatened.

Cross flow control structures were incorporated over the full length of the original BRE, mostly in order to provide the facility for releasing water from the Brahmaputra into what were originally distributary channels for irrigation and fisheries. These channels have in the main become silted up, presumably because of insufficient incentive for the proper operation of the regulators, and their function is consequently in many cases now ill defined.

Figure 4.1

Brahmaputra Right Bank and Bangali Basin



Of the 31 existing structures, 26 are one gated and 3 are two gated. The major structures are the 12 gated Manas Regulator on the Ghagot River which is currently threatened by bank erosion, and a narrower 12 gated structure north of Kamarjani. Some 20 of the smaller structures have been rebuilt on the retired embankments.

4.2.2 The FAP12 Studies of the BRE

Two transects of the BRE were included in the RRA programme of FAP12, one in the northern reach near Kamarjani, and one at the south near Kazipur.

The RRA at Kamarjani found that the primary objective of protection against flooding from the Brahmaputra had been achieved (except when the area was flooded from the Teesta in 1988), resulting in increased t.aman on high and medium high lands. There was also increased vegetable production. On the other hand, it found that lack of drainage facilities in some places on the embankment had increased localised drainage congestion leading to a decline in pulses and oilseeds. Capture fisheries in beels and khals decreased. Culture fishery was not been able to compensate, due to the inadequacy of support services. The RRA found that the BRE had some positive social impact in improving communications and generating employment.

Whilst this picture is generally favourable, the RRA at Kazipur was not so. This is an unstable section, and the situation has much deteriorated since 1984. The area is now subject to severe and unpredictable floods. The BRE has been retired several times in the reach but problems have arisen through the use of poor material and lack of compaction, delays in starting work, non-payment of land compensation, and poor O&M. In 3 years out of 5, t.aman is not possible and, in years of early floods, 10-15% of the HYV boro is damaged. Livestock and fisheries have both declined. As at Kamarjani, the BRE has had some positive social impact, in improving communication and generating employment.

4.2.3 The FAP1 & FAP21/22 Studies

The security of the Brahmaputra Right Embankment (BRE) and consequently the area protected by the BRE has been seriously threatened by continued bank erosion. In view of this, the FAP1 study is preparing a Master Plan for the protection of the BRE between the Teesta and the Hurasagar. In addition, the design of short term measures at critical sections along the right bank for early implementation forms part of the study.

The Master Plan, which will be issued early in 1993, is required to address possible alternative measures to river training works, such as embankment retirement or combinations of both types of measures, for ensuring the BRE's performance.

Short Term and Priority Works

Six possible locations for river bank protection were identified: these locations are Fulchari, Sariakandi, Mathurapara, Kazipur, Serajganj and Betil, primarily based on the degree of economic loss or damage and social dislocation arising from active bank erosion. However, the nature and rate of bank erosion, together with the amount of capital investment required at the different locations, were also important considerations.

In addition, there is a very real concern that the Brahmaputra may break through to the Bangali River (if bank protection and river training works are not implemented at Sariakandi and Mathurapara). This would result in a large proportion of the BRE project area being affected by prolonged inundation as well as posing a major threat to the morphological characteristics of the whole natural drainage system. The subsequent restoration of the continuity of the BRE without interruption of local drainage would require an expensive and socially disruptive realignment of the Bangali River.

The Role of the Priority and Short Term Works

The scope of the short term works involving river training works and associated strategic embankment retirement at the six priority locations conforms with the policy of giving precedence to bank protection measures that will fit as closely as possible into a long term strategy for river stabilisation.

While the primary objective in selecting the most appropriate set of measures at each location was to satisfy the aim of safeguarding the BRE in the medium to long term in that vicinity, consideration was also given to the long term goal of full river channel stabilisation.

A full economic and sociological assessment of the six locations was prepared and presented in the BRTS Second Interim Report (December 1991). This showed very clearly that, in conventional economic evaluation terms, investment priorities for bank stabilisation were Serajganj and the reach of bankline between Sariakandi and Mathurapara, where serious bank erosion was making a breakthrough into the Bangali an increasingly likely probability. While investment at these locations showed reasonable internal rates of return, the financial and economic returns to bank protection works at the other three locations were very poor.

It was consequently agreed between the Government and IDA that the Phase 1 Priority Works should comprise bank protection works at Serajganj and Sariakandi/Mathurapara only, as shown in Figure 4.1 . These works are now included in the River Bank Protection Project.

FAP21/22, in their search for sites to test newly developed designs for bank protection, reviewed the Brahmaputra over its total length to identify areas which are expected to be under continuous threat of being eroded in the next few years and on the other hand, are worthwhile to be defended. On the right bank the area scoring highest under these two aspects was Kamarjani situated in the Gaibandha improvement project area. The test structures that are planned at the site include 5 partially permeable groynes to be built north of the Manas regulator in the dry season 1993/94. Physical model tests and preliminary design have been undertaken whereas detailed design and construction are subject to a final decision by GoB.

FAP 21/22 further investigated the areas of Sariakandi and Kazipur to a pre-feasibility level as alternative(s), in case the selected test areas at Kamarjani and Bahadurabad (on the left bank) had to be dropped due to sudden morphological changes.

The Master Plan for the BRE

In the medium term FAP1 recommended a programme of development of " hard points" along the BRE, the works at Sariakandi and Serajganj being the first in the programme, with planned retirement as an interim measure for the reaches in between the hard points. All areas preselected by FAP 21/22 for possible bank protection test structures would also be "hard points" for an eventual overall river training/bank stabilization programme for the river.

4.2.4 Areas outside the Scope of FAP1

There are three stretches of embankment along the Brahmaputra which are outside the scope of FAP1:

- Kurigram N, between the Dharla and the Dudhkumar rivers,
- Kurigram S, between the Dharla and the Teesta rivers,
- Pabna, south of the Hurasagar river.

It should be mentioned that the embankment on the right bank of the Teesta, from its confluence with the Brahmaputra to the Kaunia Railway Bridge, is also formally called the BRE. Proposals for this reach are discussed in Section 4.5.

The embankment in the Kurigram reaches was not generally under severe threat in 1992 although localised erosion and breaches have taken place.These are under study through the JICA project for this area (section 3.4.5).

The recent Second Pabna Feasibility Study has reviewed problems along the Brahmaputra embankment in the Pabna area. This followed a BWDB report of 1989 in identifying potentially serious problems of scour attack at particular sections, some of these causing concern for both Bera and Kaitola pump stations.

The general desirability of protecting the embankment and preventing breaches is clear. It is therefore recommended that appropriate measures are taken as they become necessary. If funds or implementation capacity require priorities to be established, then costly infrastructure such as the Pabna pump stations obviously have a high priority, though the severity of the attack must first be determined. The work of FAP21/22 is important in this respect.

4.3 The Upper Karatoya/Middle Bangali Basin

These two basins are considered together since they are contiguous. In addition flooding conditions in the Middle Bangali are very much affected by breaches in the BRE, as discussed in the previous section. Flows from the Teesta basin also contribute to flooding in the Bangali via the connection through the Alai: this is discussed in Section 4.5.

4.3.1 The Upper Karatoya

Hydrological analysis based on NAM model results and a review of available cropping statistics indicates that the lower reaches of the Upper Karatoya are the most seriously affected by flooding of all the internal rivers in the upper part of the region. Flooding in this location is a regular occurrence: it was again serious in 1991 when a cut was made at the offtake of the old Karatoya, which flows past Bogra, in order to relieve flooding on the left bank of the Upper Karatoya.

Proposals under consideration for this area involve further embanking on both banks of the Karatoya, with drainage provision particularly on the left bank where the land slopes are towards the river. However, such measures would have the effect of increasing downstream discharges because the left bank in particular acts as a flood retention area. Therefore it is proposed that they should be associated with the Bangali Floodway, which would be a new man-made drain connecting the Bangali direct to the Brahmaputra. The Bangali floodway is in fact the downstream part of the Interceptor Drain, as originally conceived for the region in the Flood Policy Study. Like the Interceptor, the

Floodway would be designed to pass flood discharges direct to the Brahmaputra, but to maintain a residual downstream flow for domestic and agricultural purposes. The residual would mitigate adverse impacts on fisheries, navigation and the environment and would also minimise morphological changes.

The Bangali Floodway is designed to carry flow in excess of a predefined magnitude directly to the Brahmaputra with the residual flow being diverted into the Middle Bangali system. A high residual flow would mean that the Bangali Floodway would only function occasionally and may result in both increased flooding and morphological change in the Middle Bangali basin. A low residual flow would mean that the Bangali Floodway would function most of the time and would reduce the flooding risk in the Middle Bangali basin. A low residual flow may also result in major siltation problems in the rivers of the Middle Bangali system. Based on a consideration of morphology and flooding risk in the Middle Bangali basin a residual flow of 500 $m^3/$ was selected. It was assumed that all flow in excess of this passed along the Bangali Floodway directly to the Brahmaputra.

Initially two routes for the Bangali Floodway were considered (see Volume 3, Regional Plan Engineering, of the Draft Final Report). Based on the cost of construction, Route 2, the situation with the outfall further upstream on the Brahmaputra, was preferred.

Two channel cross-section shapes were considered:

- trapezoidal which is the most hydraulically efficient shape; this involves excavation and re-sectioning along approximately 100 km of channel,
- a two stage channel; this involved no change to the natural low flow channel of the Upper Karatoya river.

Both cross-section shapes also involved the construction of flood embankments.

Interception of Karatoya/Bangali flood flows and their passage to the Brahmaputra via the Bangali floodway would form part of the strategy of passing flows to the Brahmaputra as far upstream in the region as possible. The objective of this policy is to avoid the accumulation of flood waters in the Lower Atrai/Lower Bangali basins. Another part of the strategy would be the proposed change in the configuration of the Ghagot/Alai/Brahmaputra confluence under the Gaibandha Improvement Project. (discussed in Section 4.5)

The arrangement to provide the required flow division has been based on low level fixed weirs across the two channels, the Bangali floodway and the Karatoya/Bangali river channel. The elevation of the cross weir on the floodway would be set at a higher level then that on the Karatoya/Bangali; the former would also be made as long as possible to induce a greater proportional flow per unit rise in upstream channel water level. Consideration would also be given to a low flow section in the floodway weirs to allow for fish movement to and from the Brahmaputra.

4.3.2 Middle Bangali Basin

Contributions to flooding in the Middle Bangali basin come primarily from breaches in the BRE. Analysis described in Section 5.2 indicates that, if the breaches can be properly sealed, there will effectively no flooding in the basin. As described above, developments on the Upper Karatoya would potentially increase discharges to the Bangali, so these should only be considered in conjunction with the Bangali floodway. Contributions to flows in the Bangali via the Alai will reduce following implementation of the Gaibandha project.

Establishing and maintaining the integrity of the BRE is a major element of FAP and of flood policy in Bangladesh. It is therefore not possible to justify major flood protection projects in the area behind the BRE: such justification would depend on achieving long-term benefits from the measures which would also theoretically accrue to work on the BRE itself. This approach is supported by rapid rural appraisals carried out in the area (volume 11 of the Draft Final Report): local people maintained that all their flooding problems came direct from the Brahmaputra.

There is, however, potential for some drainage improvements, particularly in the upper part of the basin. The main area is Gazaria-Ichamati (which was identified as a problem by the rapid rural appraisals) where proposals for improvement are in hand under SRP. This would be in conjunction with augmentation of dry season supplies via the old Karatoya, as part of an overall water management strategy for the area.

The major problem with a strategy of limited intervention in the middle Bargali basin lies in uncertainty relating to the BRE work, both as regards timing and effectiveness. The main solution to this problem lies in flood proofing of the area affected by breaches. Flood proofing works in the area would comprise both structural and non-structural component (Section 3.5). The structural measures would include the provision of flood shelters and the improvement and raising of 100 km of rural roads; the estimated cost of implementing these measures would be approximately Tk. 40 million.

In addition, consideration was given to a "second line of defence" against breaches. Possibilities include the Nagarbari-Bogra road, the right bank of the Ichamati (Bangali) river or compartmentalisation to the east of the Ichamati. Use of the road as a flood defence is not a practical option. In the event of very severe floods, maintenance of vital road links has the highest priority. This requires that the road be designed to pass flood flows with minimum constraint, rather than being used as a flood barrier. Indeed, since 1988 the number of bridges along the road has been increased with this in mind.

The second alternative comprises three compartments along BRE from Sariakandi to Kazipur as shown in Fig. 4.1. The compartment embankments are along the left bank of the Ichamati, mostly following the existing road. In case of a breach, only a single compartment will be damaged rather than the whole area. Since the normal drainage is along the Ichamati, during breaches in the BRE there would be possibility of opening the drainage regulators or making a cut in the west embankment of the compartment to get flood relief.

The third alternative is to construct an embankment on the right bank of the Ichamati from Laksimpur to Nalkasengati. The purpose of the embankment would be to protect the area situated to the west of Ichamati river and to allow drainage of the breach flood to the Bangali at Nalkasengati. The Ichamati right embankment will cause some drainage congestion; as such flooding may increase on left bank.

The estimated cost of this embankment is about Tk. 710 million, protecting on area of approximately 20,000 ha from major sheet flooding. It should be pointed out that the performance of such an embankment against a breach of the BRE and the ensuing wave flow from an unknown location would be difficult to predict.

Development of an embankment on the Ichamati as a second line of defence would be practical but it would be expensive, would add to drainage congestion in normal years, and would be difficult to justify. Experience from the FAP 20 pilot studies will also be of value in assessing the use of compartments as flood cells for storage of breach flows. In the meanwhile it would seem more appropriate to concentrate investment on containing the Brahmaputra on the BRE itself.

4.4 The Lower Atrai/Lower Bangali Basins

4.4.1 Present Situation

The Planning Units 12 (Atrai Left Bank), 13 (Atrai Right Bank), 14 (Lower Bangali) and 15 (Pabna) form a connected river basin system which must be considered as a whole. Units 12,13 and 14 as well as 8 (Middle Banglali) are covered by the sub-regional hydrodynamic model used by the NWRS study team (Section 5.1).

These reaches include the areas of deepest and most persistent flooding, and they are regarded as areas of high priority within the NW region.

Lower Atrai Left Bank (Planning Unit 12)

This unit consists of Naogaon Polder, and Bogra Polders 2,3 and 4. Polders 2 and 3 have been developed and contain, respectively, the Roktadoha - Lohachura and Nagor Valley Schemes, and the Nagor river schemes. Polder 4 is not developed.

In Bogra Polders 2 and 3 a clear distinction can be made between the effectiveness in the upper reaches and the lower reaches. In the upper reaches, embankments have not been breached or cut, suggesting that they are relatively effective in keeping out floods. However, this land is higher and less susceptible to flooding in any case.

In the lower reaches, a number of cuts and breaches have occured in the Roktadoha-Lohachura scheme, Nagor Valley and Nagor River projects. In the R-L scheme breaches occurred at Rasulpur in 1991 due to piping failure and these breaches have not been repaired. People living in the vicinity of the Nagor Valley project also cut the embankment to relieve their b. aman crops from submergence, and this water rushes into the Nagor River, causing either breaches or public cuts of the Nagor River embankment also, in the vicinity of Khorsuti. The result, according to FAP 12, is that the Nagor River project to date has been very ineffective : instead of protecting the b. aman crop, the crop is destroyed every year. The only benefit has been the protection of the boro crop from early flash floods, but these floods only occur in some years.

The lowland areas are therefore the areas of main flooding, as would be expected. The main flooding problems at present, however, seem to be those caused by failure of the flood protection infrastructure. Farmers in these areas have indicated that they would be satisfied if they could grow b. aman and get a crop most years: this is currently not possible in the nominally protected parts of the planning unit, as levels of risk would appear to have increased. This is probably du to the more rapid rise in water levels associated with embankment breaches rather than normal river level rises.

In addition, since most of the now unprotected lowland is at the downstream end of the planning unit, it is affected by the confinement effect of all the FCD works carried out on both sides of the Lower Atrai. This impact may have made conditions worse for growing b. aman.

The flooding problems in the highland areas do not appear to be very great, although in the transitional zone there is a possibility of flooding causing damage to t. aman, and early flash floods damage to boro in some years. The existing schemes do appear to provide effective protection against this type of damage.

Lower Atrai Right Bank (Planning Unit 13)

This unit contains the Chalan Beel Polders (A,B,C,D), the Barnai project and the Baral project.

Between 1982 and the present there were over 100 public cuts in the Chalan Beel polders: most of these have been in Polders C and D. The latter polders have therefore not functioned according to design. Most public cuts have been made by people living outside the polders, but it should be recognised that a high proportion of people with land inside the polders actually live on the river bank outside: this is particularly the case in Polder C. It is therefore not simply a case of gainers inside and losers outside: if water enters into the polders through a breach or cut, it is often necessary for people inside the polder to make a further cut to drain the water out. It is clear that, at least in Polder C, the drainage structures are inadequate to drain out the water that collects inside the polder. This particularly applies when the polders are flooded due to cuts: drainage designs can not be expected to accommodate such situations.

The case of Polder D is rather more straightforward: the main public cuts are made on the western embankment by outsiders whose lands and houses are severely flooded almost every year by the Shib River. The cuts cause a large volume of water to rush into the polder, causing extensive crop damage.

Therefore, although in Polders C and D there appears to have been some switch on basin margins from b. aman to t. aman, this switch is not secure, and both b. aman and t. aman are now being extensively damaged. Farmers express a common desire to be able to get a secure b. aman crop: this aim may now be more important than taking the risk of trying to plant a t.aman crop.

Polder A has also not been effective, but that is partly because it has never been completed, and the main regulator has to be rebuilt. Polder B has been more effective but has been cut on some occasions, and the drainage system is not fully effective.

The Lower Bangali Basin (Planning Unit 14)

The existing FCD infrastructure in this planning unit has generally not proved effective. In particular the west embankment of the Serajganj Integrated Rural Development Project (SIRDP) is regularly cut while the southern embankment of the Hurasagar project has been completely eroded due to its exposed location. Flooding is extensive and regular throughout the lower parts of the area. Planning is therefore primarily concerned with redesign of the original projects, the Serajganj Integrated Rural Development Project and the Hurasagar Project.

Summary

In addition to the problems within each polder, these are compounded by the interaction between polders, and between these polders and other FCD works in the basin. The construction of the Bogra Polders, for example, has combined with the Chalan Beel Polders to give a significant rise in Atrai water levels during flood events (in effect the major part of the monsoon season). Further downstream the SIRDP embankment continues the confinement effect. The cuts in Polder D cause an onrush of water that ultimately drains into the Fakirni River and results in cuts and breaches in Polder C.

4.4.2 Major Engineering Interventions

The Major Drains

An important element in the analysis of the possible development scenarios for the Lower Atrai was the investigation into the major drains. These were intended to make full flood protection possible by completely changing the hydrological regime in the lower Atrai. These drains were first identified at the time of the Flood Policy Study, and subsequently clarified in concept during the Preliminary Study for NWRS. Two drains were originally conceived:

- the Interceptor which is intended to divert water from the northern reaches of the Atrai and pass it eastward to the Brahmaputra, intersecting the Jamuneswari and Upper Karatoya rivers en route and,

- the Diversion Drain, off taking from the lower Atrai, flowing down the Shib before outfalling to the Ganges west of Rajshahi.

Both of these drains were expected to make a major change in the hydrological regime of the lower Atrai by diverting a significant portion of the flows which cause flooding due to the outfall constraints at Hurasagar.

A large number of alternatives were investigated for each of the drains. This was done to ensure that the best possible plan was analysed for its feasibility. The alternatives covered alignment, section and capacity, as discussed briefly in the following sections. This analysis, and its subsequent economic and impact assessment, were fully described in the Interim Main Report and are summarised here.

Five different alignments of the Interceptor and two for the Diversion were considered, Figure 4.3. Two different capacities were considered for each of the main alignments, "large capacity" and "small capacity". The large capacity drain was designed to divert all of the discharge in the rivers with which it intersects, apart from a small residual flow which is allowed downstream for fisheries, navigation, irrigation and domestic purposes. The small capacity drain was sized approximately according to the mean monthly maximum flow of the rivers with which it intersects.

Alternative cross-sections were also considered, including:

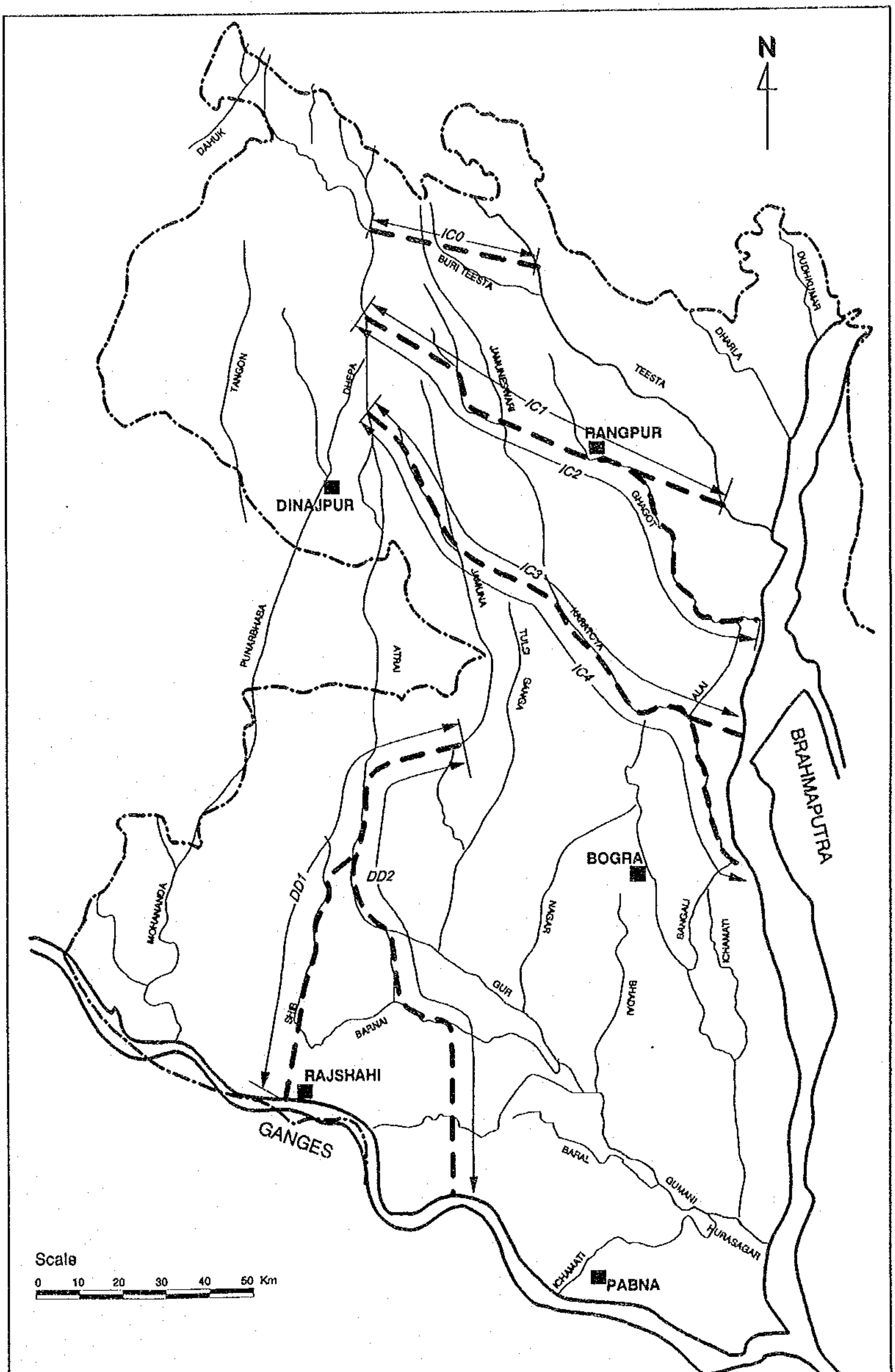
- a single trapezoidal cross-section or a compound cross-section, with a low water channel and high flows carried between flood berms;

- the channel section designed so that flood flows were carried at or near ground level, compared to a channel section designed to carry low flows at ground level, with peak flows at up to 2m above ground level.

Capital and O&M costs for of the main alternatives considered are given in Table 4.1. Costs of the drains were of the order of Tk 15 billion ($ 500 million) or more, based on outline costing principles determined during the Interim Report stage. Economic returns were low, 2% for DDI and negative for IC4. Whilst the more accurate analysis methods available during the second stage of the study would have changed both costs and benefits somewhat, the overall returns would not change significantly. In addition these would be very large projects with uncertain environmental impacts. It was therefore concluded that the major drains should not form part of the regional plan.

Figure 4.3

Major Drain Alignments



Source : NWRS Interim Report

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Table 4.1 COST COMPARISON OF ALTERNATIVE ROUTES OF MAJOR DRAINS

(Unit : Tk Million)

Description	Interceptor Drain										Diversion Drain		
	IC0	IC1	IC2	IC3	IC4					IC4	DD1		DD2
					Case 1	Case 2	Case 3	Case 4	Case 5	Shortened	Case 1	Case 2	
I. Length of Major Drain (km)	49.5	129.2	179.6	159.2	176.4	176.4	176.4	176.4	176.4	48.5	102.7	102.7	119.4
II. Project cost													
1. Construction Cost	7,000	15,747	25,804	15,549	64,146	27,729	17,628	11,729	4,393	2,576	7,661	4,410	8,953
a) New channel construction and river improvement work including flood embankment	5,660	11,973	21,794	12,414	55,432	19,725	14,296	8,879	2,421	2,148	5,988	2,837	7,141
b) Regulating weirs													
• Nos. of weirs	2	6	6	8	8	8	8	8	8	2	6	6	8
• Cost	700	2,569	2,728	2,318	3,357	3,213	2,389	2,075	1,637	360	1,274	1,271	1,461
c) New bridge construction													
• Nos. of bridges	5	10	11	12	14	14	14	14	10	2	8	8	9
• Cost	244	863	929	646	4,310	3,785	772	616	273	68	399	302	351
d) Syphon for Teesta Irrigation Project													
• Nos. of syphons	1	2	2	1	1	1	1	1	1	0	0	0	0
• Cost	396	342	353	171	1,047	1,006	171	159	62	0	0	0	0
2. Land acquisition cost													
a) Area (sq.km)	56.0	113.0	222.0	112.0	761.0	475.0	133.0	72.0	36.0	17.0	53.0	29.0	61.0
b) Cost	1,680	3,390	6,660	3,360	22,830	14,250	3,990	2,160	1,080	510	1,590	870	1,830
3. Physical contingency (25 % of Total of Items 1 and 2.)	2,170	4,784	8,116	4,727	21,744	10,495	5,405	3,472	1,368	772	2,313	1,320	2,696
4. Engineering service (15 % of Total of Items 1. to 3.)	1,628	3,588	6,087	3,545	16,308	7,871	4,053	2,604	1,026	579	1,735	990	2,022
Grand Total	12,478	27,509	46,667	27,181	125,028	60,345	31,076	19,965	7,867	4,437	13,299	7,590	15,501
(Equivalent million US$)	(347)	(764)	(1,296)	(755)	(3,473)	(1,676)	(863)	(555)	(219)	(123)	(369)	(211)	(431)
III. Operation and maintenance cost per annum	350	749	1,348	770	3,751	1,810	932	599	236	131	366	176	435
IV. Cost per km	252	213	260	171	709	342	176	113	45	91	130	74	130

The Hurasagar Tail Regulator

A further possibility considered for the Lower Atrai has been the Hurasagar Tail Regulator. This would be situated at the outfall of the Hurasagar and would prevent inflows or backwater from the Brahmaputra. Simple calculations described in the Hydrology section of volume 10 of the Draft Final Report show, however, that this structure would be very costly (Tk 2.8 billion) and that it would have negligible effect on levels in the Lower Atrai because of the large volumes of run-off accumulating at this outfall. In effect the drainage congestion problems of the Hurasagar Outfall are caused by backwater effects not backflow (Section 2.1.5) and therefore regulation at this point would have little effect. The calculations show that, if the regulator were kept closed during the monsoon, the levels behind it would rise to about +14m pwd, flooding very large areas of land to a considerable depth. The possibility of the tail regulator was therefore discarded, and not considered further for the Regional Plan.

4.4.3 The Green River

Planning Approaches

The options considered for the regional plan are based on the identification of current problems as being closely associated with:

- the confinement effect on the Atrai, and
- the non-functioning of parts of the schemes already constructed.

In general, therefore, full CFD which was studied in the first part of NWRS, was rejected as a viable development scenario for the Lower Atrai, even with the possible intervention of the major engineering interventions (The Interceptor and Diversion Drains, and the Hurasagar Tail Regulators).

A general approach of allowing flow into parts of some polders, providing full CFD protection in more upland areas, and sub-dividing polders to facilitate drainage, was therefore adopted for these planning units. This is known as the "Green River" scenario. It is shown in Figure 4.4 and can be compared in Figure 4.5 with the 1987 peak flooding in the Lower Atrai. In this scenario the Atrai is allowed to spread across the flood plain during the peak monsoon so that overland flow takes place (as at present). This reduces the confinement effect and lowers water levels, so that the operational difficulties of flood control are reduced. In addition it reduces the negative impacts on flood plain fisheries and increases groundwater recharge. In these scenarios the peak flows are contained within embankments which are some 5 to 10 km from the river channel. The alignment of these embankments is determined by existing infrastructure, particularly village roads.

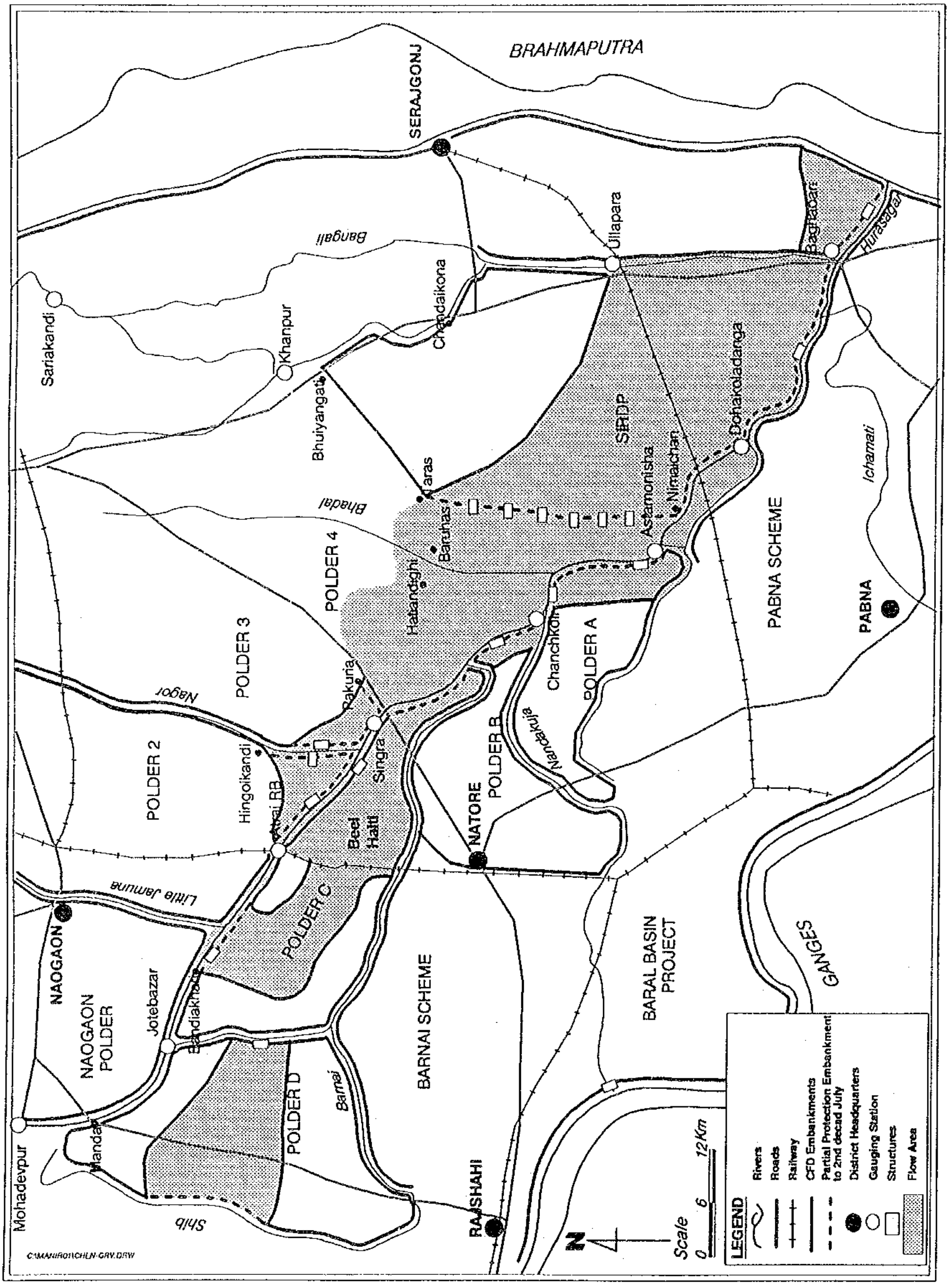
In areas where full CFD is not considered practical, an option is to provide partial protection and improved drainage. This might have two objectives:

- protection of the boro harvest from flash floods (as in NE Bangladesh)
- control of the rate of rise of monsoon water levels so that TDW aman can be grown.

The need for pre-monsoon protection of boro is not as critical in the north-west region because of the different climatological conditions. These influence the onset of flooding and the planting/harvesting timings for crops.

Figure 4.4

The Green River



Source : NWRS

Figure 4.5

1987 Flooding in the Lower Atrai

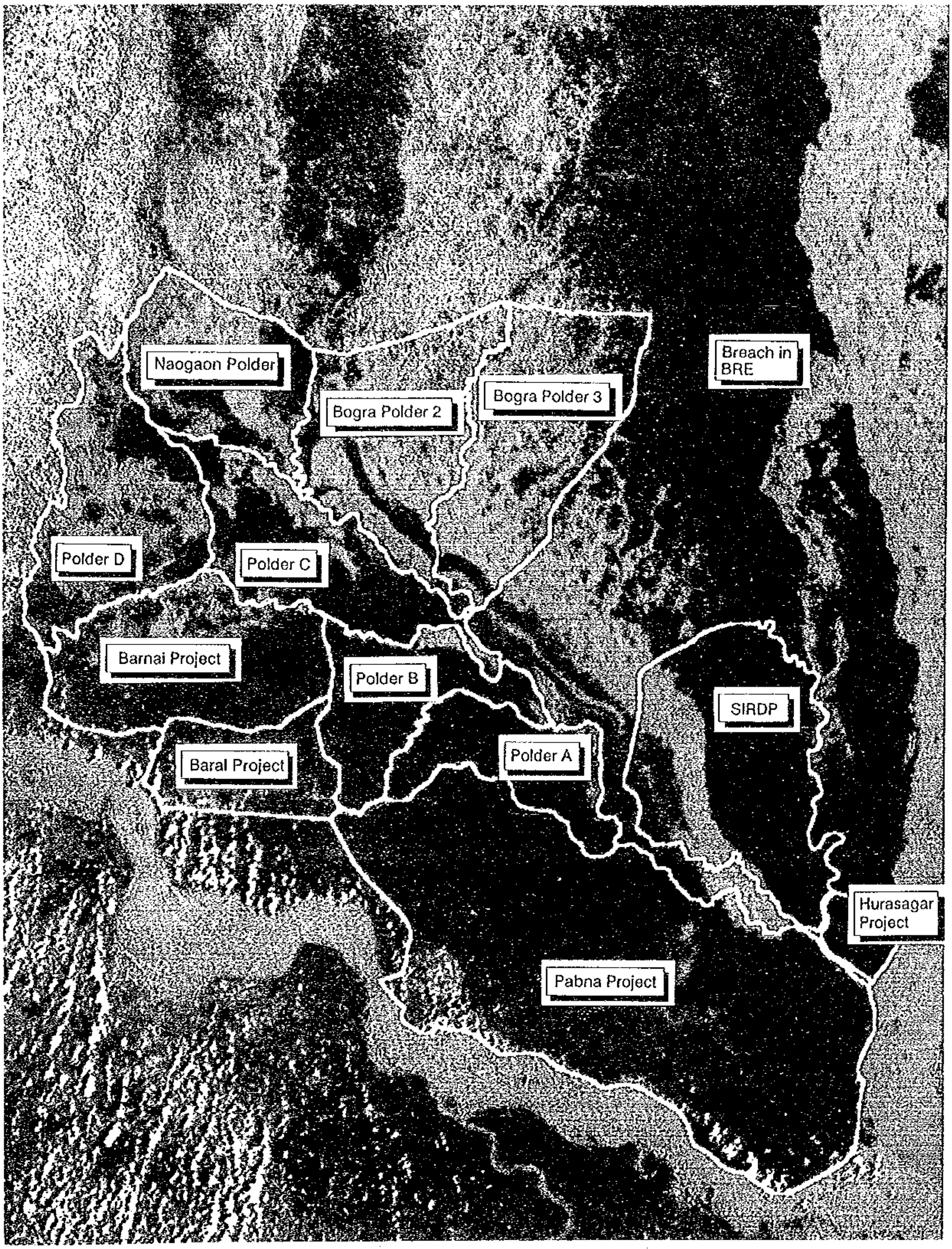


Image produced by FAP19 ISPAN from data supplied by SPARRSO

For the CFD areas a form of compartmentalisation is envisaged whose primary functions is to prevent transfer of flood flows across drainage basin boundaries within protected areas. As far as possible, such flows are routed to the main or internal rivers bordering the compartments. Maximum use is made of existing infrastructure such as local roads to provide compartment boundaries and control structures.

Flow into the CFD areas is by means of appropriate structures set into the existing embankments. At the present state of development, it is proposed that these structures should be considered as fixed weirs. At some future date, as water management improves and institutional processes strengthen, flexible regulating structures may replace fixed weirs. The crest of the weir would be set at a suitable level to provide protection against the 1 in 20 water level in the first decad in June, thus allowing harvesting of the boro crop or at the 1 in 20 water level in the second decad of July to provide protection of TDW aman and to control the rate of rise thereafter. In middle and some downstream reaches, no protection for the boro is needed and the crest level would be at ground level for boro protection.

It should be noted that, at this stage, many farmers would be satisfied if they could get a b. aman crop in most years. Instead of ambitious plans to replace b. aman by t. aman, in some areas neither crop can now be obtained because of the impact of breaches and cuts. It is worth emphasising that there has been remarkable growth in paddy output in the Chalan Beel area, but this has mostly been a result of introducing irrigated HYV boro, which is not dependent on flood control (except for occasional flash floods). Farmers are generally dependent on HYV boro to give them food security and a surplus, while the aman crop is now seen as an important supplementary crop. A safe, if lower-yielding crop, in the monsoon season would probably satisfy most farmers.

In addition, when the needs of capture fisheries and navigation are taken into account, a strong case emerges for a system which allows more scope for the gradual flooding which used to occur before polderisation. The proposed options for development are based on these considerations.

The implications of all the options considered are that the level of nominal protection and size of protected area will be less, but the benefits basin-wide should nonetheless be greater. The principle to be aimed at is to reduce the confinement effect while at the same time allowing productive activity (probably b. aman and fisheries). In some more upland areas where t. aman could be grown, there is a case for providing more effective flood control. Moreover, as the situation stabilises and circumstances change, further developments might take place. Examples of such possible developments in Polder A, Bolder B and Polder 4 were modelled during NWRS. The results are discussed in Chapter 5. In areas where only partial protection is provided, and flow is allowed at peak monsoon, flood proofing measures to deal with severe floods would be important.

Planning in the basin assumed certain existing development, including the Pabna scheme, in the extreme south-east of the region, the Barnai Project in the south-west, and the Naogaon polder, in the north-west. The reason for this is that the Pabna embankment has been found in the most part to be an effective structure whilst the other two projects are currently under major implementation phases. However, both the Naogaon and Barnai projects may not prove to be fully effective (for the same reason as other developments in the Lower Atrai). Moreover the Barnai project will have adverse impacts in raising levels in the Shib, thus contributing to problems on the west bank of Polder D. Both these projects should be closely monitored as they begin operations.

4.4.4 Detailed Options for the Green River

Atrai Left Bank

On the Atrai Left Bank sub-units have been based on the earlier division into Bogra Polders 2, 3 and 4. (Polder 1 has become Naogaon polder, while Polder 5 is partly occupied by the Serajganj Integrated Rural Development Project, to be discussed below). A considerable amount of FCD development has already taken place in this planning unit, mainly under the EIP programme. This includes the Roktodah-Lohachura scheme and the Nagor Valley and Nagor River projects, in Polders 2 and 3. EIP also formulated plans for Polder 4, but these were not carried further.

The major options which were considered were as follows:

Naogaon Polder

Option 1 - Full CFD

As Naogaon polder is nearing completion, this option covers its full completion to CFD facilities. Two sub-polders for improving the agriculture and distributing the rainfall run-off, through effective flood management, were also studied. The boundary of the sub-polders follows the Manda-Naogaon road.

The polder is receiving flows from upstream areas. Options to improve this were studied as part of the Little Jamuna right bank project under planning unit 9.

Option 2 - Partial Protection

Option 2 studied the possibility of reducing peak water levels in the Atrai by allowing storage through partial protection only of the downstream unit of the polder. In this option CFD facilities would be provided in the unit located at higher elevation as for Option 1.

Bogra Polder 2

Partial protection is proposed for the lower unit and CFD facilities in the upper unit. An embankment behind the lower unit is needed because otherwise the backwater would extend well inside the upper unit. This embankment would have facilities for controlled flooding into the upper unit.

Accordingly a flood control embankment is planned from Atrai railway bridge to Hingolkandi crosses a drainage line following a village road. Since the embankment crosses a drainage line a drain is proposed to collect the drainage flow. Sub-poldering through Raninagar to Parghate following a village road is also planned. In total, seven units are planned to reduce the drainage load on the lower reaches, by diverting upland flow to the internal rivers.

Bogra Polder 3

As for polder 2 it may be noted that public cuts are made in the lower reaches of the polder, but not upstream. Therefore flooding through partial protection is proposed for the lower unit and CFD facilities are proposed in the upper units.

CFD embankments are planned from Hingolkandi to Pakuria following a village road, with necessary structures for controlled flooding and drainage.

Sub-poldering is recommended to reduce the drainage load to downstream reaches.

Bogra Polder 4

Option 1

Historically this area is a flood storage area, and any flood control development will reduce the storage capacity of the basin. No embanking is proposed under this option. Flood proofing facilities would be provided to reduce suffering and discomfort and to minimise damage to infrastructure.

Option 2

In this option the lower part of the area would remain un-embanked as at present. In the upper reaches full controlled flooding and drainage provision would be made. Possible alignments for these embankments include the Pakuria-Hatiandighi road, and the Taras-Baruhas road. Embanking of the upper reaches of the Badai may also be required.

Atrai Right Bank

The Atrai right bank is divided into the Chalan Beel polders and the Barnai and Baral Schemes. Downstream is the Pabna scheme which is considered under Planning Unit 15.

Polder A

Option 1

The area has been divided into three sub-units based on topographic features. A sub-unit adjacent to the Atrai is provided with partial protection only; crops in this area are frequently damaged due to the onrush of flood waters. In the remaining areas, controlled flooding and drainage facilities will be provided. Provision of the controlled flooding area will reduce the confinement effect. Drainage improvements are also proposed.

Option 2

Controlled flooding and drainage measures were considered for the whole area of Chalan Beel A. Since the area provided with partial protection under Option 1 is quite small, Option 2 would have little effect on raising levels. However the area which would be enclosed under Option 2 is an area of deep flooding and an important area for fisheries.

Polder B

Option 1

Polder B is divided into four sub-units based on its topographic features. Partial protection is proposed in the low lying area adjacent to the Atrai and Barnai rivers. More comprehensive controlled flooding and drainage measures are planned for the remaining area.

Option 2

If sufficient flow width and flood storage are made available on the left bank of the Atrai, opposite Polder B, this may enable the more comprehensive flood control and drainage measures to be considered for the whole of Polder B including the low-lying area adjacent to the Atrai and Barnai rivers.

Polder C

A large part of polder C would be allocated to allow flood flows at peak monsoon.

A structure is proposed at Bandiakhari to allow flood flows in the polder C and natural flood flows to the beel Halti. Since the driving head along the Atrai is more than the Barnai there will be an outfall structure on the Atrai upstream of Singra.

Three small areas of Polder C which are on higher ground may be divided into three sub-polders for controlled flooding and drainage measures. The embankment would be strengthened with a berm for improvement and stability. In this polder brick mattressing work in embankments to prevent wave attacks will be considered.

Flood proofing are proposed for unprotected areas inside the polder and affected areas outside the polder. Due to the importance of boat transport in the Lower Atrai, adequate navigation facilities are planned. Beel Halti is also an important location for public lestoching of fisheries under the Fisheries project (section 2.3).

Polder D

The main requirement in Polder D is to make provision for drainage from the Shib river on the western boundary across the polder to the Fakirni in the east. (This proposal is similar in concept to that of the Chalan Beel study discussed in section 2.3).

The area is divided into three sub-polders. The northern and southern components would be provided with CFD facilities. However the middle compartment, which allows drainage of Barind Tract west of Polder D, will be provided with dwarf embankment for protection of TDW aman. The crest level of the dwarf embankment is fixed at water level of 5 year return period in 3rd decad of July, providing protection of TDW aman. This adjustment in the plan will improve the drainage problem of the west of the Polder D area and improve the low area of the Polder D by protecting TDW aman.

All of these options would require sub-poldering within Polder D, with the intention of maximising agricultural, fisheries and navigation benefits as appropriate. Andasuria beel in the northern part of Polder D is an important area for a possible conservation project since it contains at present a wide diversity of species.

Barnai Project

This project is nearing completion. As its effect on confinement levels in the Atrai is small, no alternative plans have been prepared. However, it has significant impact on levels in the River Shib, and therefore has implications for planning in Polder D. Thus its impacts should be monitored.

Baral Basin Project

This project is under study. Proposals being made include strengthening of the Ganges left embankment. As the effect of the proposed project on confinement levels and other scheme areas in the Atrai is small, no alternative plans have been prepared.

Lower Bangali Basin

SIRD Project

The SIRDP area is divided into 3 sub-units for effective flood control and flood management. The upstream units 1 and 2 are proposed for controlled flooding and drainage and unit 3 is proposed for offstream flood storage and partial protection.

Opening of existing six closed bridge gaps is proposed along the Taras-Nimaichara embankment for allowing flows across the lower sub-unit adjacent to the Atrai. The CFD embankment would follow the Taras-Ullapara road. The lower area will also be suitable for capture fisheries. Flood proofing facilities should be provided.

For adopting full flood control in the northern sub-units, it is proposed to construct a new embankment along the right bank of Karatoya river from Ullahpara to Chandaikona without disturbing the roads and highway boundary to protect the flow from Karotoya. The right embankment of Karatoya will protect the area from flooding and will close off distributaries (such as the Durgadah) which currently drain through the project area.

The northern portion would be divided into two compartments in respect of drainage facilities and topographical pattern; the area west of the Durgadah river, bounded by Taras-Ullapara road (gross area 11,210 ha) and the area east of the Durgadah river bounded by the Dharail-Ullapara road and the Karatoya on the east (gross area 15,358 ha). For details see Appendix 3 to this report.

Hurasagar North Unit

The following are the main flooding problems in the Hurasagar North unit.

- breaches in the BRE,
- backwater effect of Brahmaputra,
- upland drainage from the River Karatoya.

The protection of the north unit depends on the strengthening of BRE south of Serajganj. Full CFD embankment is also an option along left bank of Karotoya river from Baghabari to Nalkasengati. The bridge openings along the proposed northern boundary require to be closed (Serajganj/ Chandganti/ Komajpur road), so that no intrusion of water enters the project area. To divert the rainfall run-off upstream of the Serajganj road, a drainage channel could be constructed following an existing channel.

Hurasagar Southern Unit

Option 1

This area is nominally covered by the Hurasagar FCD project. However, the project is largely ineffective and the embankments are regularly breached. The area could be an important conservation area for fish recruitment and wild life etc. This option would therefore provide partial protection only to the South Unit, so that it would be subject to flooding during the monsoon period after harvesting boro crops.

Flood proofing would be provided as appropriate to mitigate the suffering of the area.

Option 2

Evidence from Landsat imagery is that, even at the peak of the 1987 floods, the Hurasagar southern unit was not seriously flooded since the Hurasagar at this point has a wide, deep section. Consideration could therefore be given to comprehensive controlled flooding and drainage measures to the Hurasagar area, provided that appropriate designs and methods of construction were applied. Since the area is at the lower end of the Atrai basin, major embankment protection measures would not contribute significantly to adjacent or downstream impacts.

4.4.5 Green River Scenarios

Within the broad concepts and range of detailed options discussed above, a number of different scenarios could be distinguished.

Under the basic Green River scenario the following options were modelled:

Left Bank

Naogaon Polder - CFD. Assume completion of the present project.

Polder 2 - The part of the polder adjacent to the Atrai will be used for flood flows. The upper part of the polder will be CFD.

Polder 3 - As for Polder 2.

Polder 4 - The area is deeply flooded area. No developments are proposed (flood proofing only).

SIRDP	-	Flow through the lower unit. Upper two units to be CFD. Closure of drainage channels from the right bank of the Karatoya.
Hurasagar	-	Flow through lower unit (the Hurasagar scheme area). This area would be designated a conservation area for fish recruitment, wild life etc. The northern part of Hurasagar would be provided with CFD facilities.

The Right Bank

Polder D	-	Provision of a drainage path from the Shib to the Fakirni.
Polder C	-	Flow through the polder with higher areas sub-poldered for CFD protection. Flood proofing as appropriate.
Polder B	-	Sub-poldering. CFD in higher areas with CFD across the lower areas.
Polder A	-	As for Polder B
Barnai Project	-	Completed.
Baral Basin Project	-	Completed.
Pabna Scheme	-	Completed.

A number of additional variations on this basic scenario were analysed during the course of the study, the major one being that of providing additional CFD developments in Polder 4 and Polder A and B. These are discussed in Chapter 5.

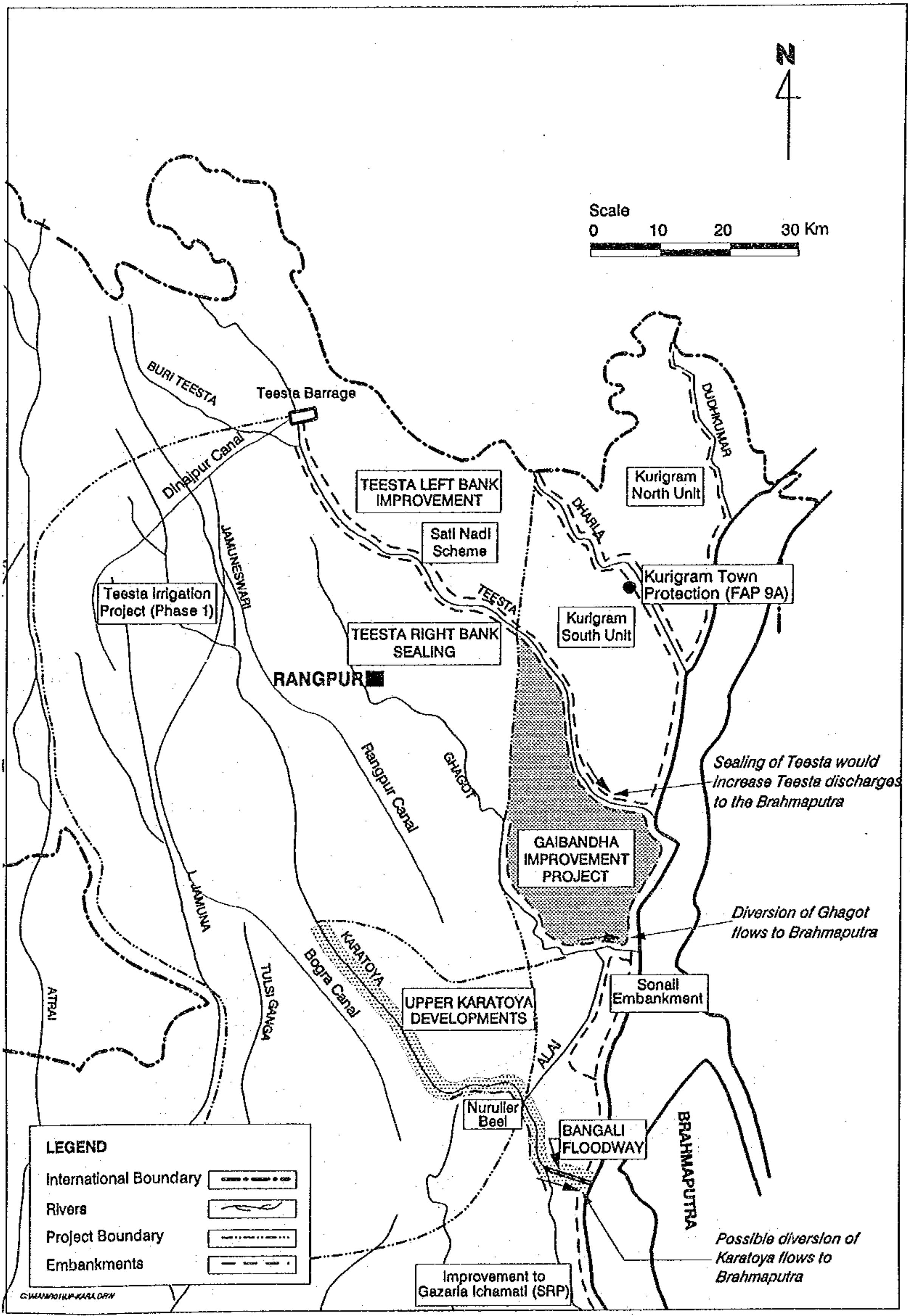
4.5 The Teesta Basin

The Teesta has the largest discharge of the internal rivers within the NW region. However, flood planning for the Teesta is relatively easier than for other rivers elsewhere in the region, such as the Atrai, because it outfalls directly to the Brahmaputra, and there are no outfall constraints. Moreover, although the Teesta discharges are the largest in the region, they are very small compared to discharges in the Brahmaputra: hence flood protection measures which might increase discharges to the Brahamputra can effectively be treated as having no downstream impacts.

The main flooding problems along the Teesta in Bangladesh are associated with overbank spills when the embankments, which exist along both banks of the river along most of its length, are eroded and breached. As discussed in Section 3.4, these spills cause problems both on the left bank, where they inundate the Sati Nadi and Kurigram south scheme, and on the right bank, where they contribute to flows in the Ghagot, and cause flooding downstream in the area between the Ghagot and the Karatoya. Basic measures being proposed therefore include rehabilitation and sealing of the embankments on both banks (Figure 4.6).

Figure-4.6

The Teesta and Upper Karatoya Basins



Source : NWRS

In the case of the left bank, such rehabilitation measures have a clearly-defined impact area, of which the majority is formed by the Sati-Nadi scheme. However, as the land in this area drains from north to south towards the river, the embankment will cause some drainage congestion, and necessary mitigating measures will have to be taken.

On the right bank the situation is somewhat different. As the drainage lines here are away from the river, sealing of the Teesta right bank has potential impacts far downstream within the region. These impacts have been analysed in detail in relation to the Gaibandha Improvement Project. Sealing of the embankment upstream of Rangpur will significantly reduce flows in the Ghagot. This benefits the Gaibandha Project Area and also makes possible the discharge of Ghagot flows direct to the Brahmaputra, by regulating the offtake of the Alai from the Ghagot. This is in accordance with a general strategy for the NW region that drainage flows should, as far as possible, be passed eastwards to the Brahmaputra where possible, rather than flowing downstream within the region to contribute to flooding problems in the Lower Atrai and Lower Bangali. The sealing of the Teesta Right Embankment as part of the Gaibandha Improvement Project can be seen as a major part of such a strategy, as a complement to the Teesta Irrigation Project.

In addition overland flows downstream between the Ghagot and the Karatoya are reduced, thus reducing the drainage load on the Karatoya and Bangali. Further analysis of this situation could lead to developments on the right bank of the Ghagot, improvements to the Sonail Embankment scheme, and further possible developments downstream on both banks of the Alai.

Sealing of the Teesta is generally likely to be welcomed by local people who are affected by it. It is not expected to have serious adverse environmental impacts on the region itself, although care must be taken to ensure that impacts on fish migration routes between the river and the floodplain are mitigated as far as possible. At the present time, however, it is believed that the fish affected are minor species, and not of very great social or economic significance. Access for navigation between the Teesta and the inland rivers should also be provided wherever possible.

One aspect of this strategy does, however, need attention. Within the Teesta basin, the desire of local people to be protected from flooding from the river itself is clear. This is also the case along th Brahmaputra right bank, where the sealing of the BRE is seen as the single most important measure by all the people affected by it. If this situation is repeated in other parts of Bangladesh, long stretches of the main rivers may become embanked. The consequences of this need to be carefully evaluated. Impacts may be felt within regions, for instance in relation to flood plain fertility (though it is believed that this may not be of major significance). Impacts on the main rivers themselves are likely to be much more important. The practicality and long-term morphological stability of this strategy must be determined.

4.6 Other Upstream Reaches

The review of flooding problems in the region confirmed that the most serious and persistent flooding is along the Brahmaputra and in the downstream basins. Some flooding does occur in the upstream reaches, particularly in the Upper Atrai. However the floods are short duration, flash floods; in some locations they cause significant crop and infrastructure damage, but they do not permanently constrain cropping.

Measures to deal with such problems would have the effect of increasing downstream discharges and further contributing to flooding downstream. This is particularly important in the case of the Atrai, not only because the increased flows would eventually accumulate in the Lower Atrai Basin but also because the Middle Atrai flows through India. Any increase should be avoided, since it appears that there is already considerable spillage from the Atrai in India. If discharges were increased further, a programme of flood mitigation in India which might result would have adverse impacts on the Lower Atrai.

Therefore, on the upstream reaches, it is recommended that flood protection measures are considered only in relation to the protection of important towns, and significant infrastructure if necessary. The two towns particularly affected are Dinajpur and Panchagarh, both on the Upper Atrai. They are included within the FAP9A Secondary Towns Protection Project. Analysis indicates that some measures may also be needed on the Tangon at Thakurgaon: these could be implemented without serious downstream impacts.

The Kurigram area bounded by the Dharla and Dudhkumar can be included in the consideration of upstream reaches. In this case, however, both rivers drain directly to the Brahmaputra. Proposals for the Kurigram area can therefore be considered independent of downstream impacts, in a similar way to those on the Teesta. JICA has been involved with development of the Kurigram north and south units and funded a feasibility study for the south unit which is due for completion in 1993.Town protection for Kurigram is also being initiated under FAP9A.

CHAPTER 5

HYDRAULIC STUDIES

5.1 Introduction

5.1.1 Objectives

The hydraulic studies have a central rôle in the assessment of the impact of the major river and drainage engineering proposals in the development of the regional plan. These studies involve the use of a computer-based hydraulic model, MIKE11, to provide quantitative predictions of the changes in flow patterns, rates and levels that may arise from the implementation of the engineering proposals and an assessment of the morphological effects of the flood control and drainage proposals. The modelling provides parameters for the design of the engineering works.

5.1.2 Modelled Areas

The MIKE11 modelling system was used throughout the modelling studies. This consists of a rainfall-runoff element, NAM and a hydrodynamic module, MIKE11-HD. A sediment transport module, MIKE11-ST, is also available.

The models were initially developed at the SWMC but final calibration was carried out by the NWRS modellers. However, the NWRS team worked closely with the SWMC at all stages of model development.

In the first phase of the NWRS a pilot model of the entire North West region was used for the hydraulic studies. The full model for the region was not available at the commencement of the second phase of the study and would not be available in sufficient time for use in the study. Because of this a different approach was used to that in the first phase of the NWRS.

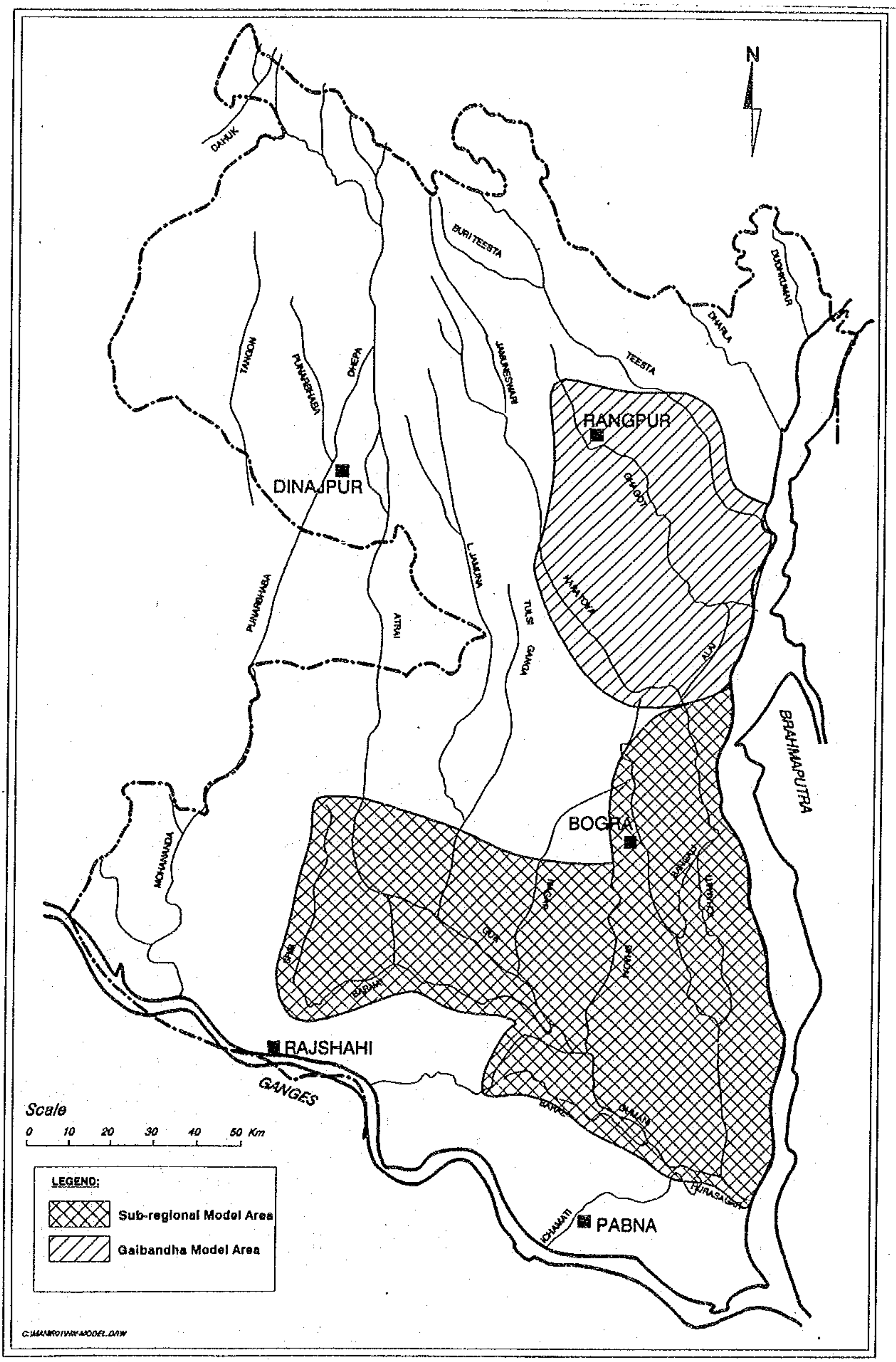
Hydraulic models were developed for priority areas in the region. The sub-regional model covered the Lower Atrai, Lower Bangali and Middle Bangali basins; this area has the most complex hydraulic regime in the region. A more detailed model was developed of the Gaibandha Improvement Project area, Figure 5.1. The Bangali Floodway was also investigated using a hydraulic model.

The hydraulic problems in other parts of the region were assessed using non-modelling approaches. Discharge assessment in these areas was based on observations and the runoffs estimated by the NAM rainfall-runoff model.

This chapter covers the hydraulic studies which have been carried out in the second phase of the study, that is, since the submission of the Interim Report. Full details of the hydraulic studies are given in Volume 9 'Hydraulic Studies' of the Draft Final Report.

Figure 5.1

Modelled Area



Source : NWRS

5.1.3 Methodology

Application of the hydraulic models

Due to the complexity of the Bangladesh Delta and the interaction of the various flood causing factors, the definition of design events of a given return period in terms of standardised boundary conditions is impossible. In an attempt to overcome these problems FAP-25 recommended a rationale which involved long term simulations of regional models for the period 1965-89. In detail the rationale required:

- calibration of the model over one or two flood seasons, 1990 and 1991
- verification of the model over further flood seasons, generally for 1985-89
- baseline, 25 year, simulation for the *future without* project conditions (these may differ from the present conditions due to on-going or planned works)
- development option simulations based on selected years or a range of years selected from the analysis of the 25 year run
- *future with* project condition simulation, 25 year, for comparison with the base line simulation
- statistical analysis of the results, aimed at assigning return periods to peak, seasonal or sub-seasonal values of selected design variables
- sensitivity analyses for assessing the effects of developments external to the region

Post-processing

Standard output from MIKE11 produces water level and discharge hydrographs at all model nodes at a preselected time interval. Further post-processing can be undertaken on these results to assist other disciplines within the study and to gain additional insight in to the impacts of proposed interventions. A suite of programs were developed to achieve these aims. A brief description of these utilities is given below.

Hydrologic analysis : Analysis of return period levels and discharges for differing time (1-day, 3-day, 10-day, etc.) duration. This information was extensively used by the engineering team to investigate the impact of proposed developments on the level and timing of flood events and to define engineering work design levels.

In addition, the results of the model simulations were analysed on a 10 day (decad) basis to give minimum, mean and maximum water levels for each decad. Return period water levels have been calculated for 2, 5, 10, 20, 50 and 100 years. This output can be obtained for any cross-section location, or water level node, within the modelled area.

Water/flood phase analysis : Flood levels on the flood plains can be represented by water levels at one or more points within the modelled area. These water levels together with the area/elevation relationships for the flood plains allows the flood/water phases to be calculated on the flood plain areas. The generally quoted flood phase figures (MPO) are not quoted with respect to time whereas the model output and flood levels at each node are produced as a time series. Post-processing software was developed to calculate water phases (time dependent) at the following depth categories; 0-0.3, 0.3-0.7, 0.7-1.0, 1.0-1.5, 1.5-3.0 and > 3.0 m. These can easily be converted into the more widely used flood phase categories.

Cropping pattern analysis : Based on the flood phase results described above, software was written to generate potential cropping patterns. This software was based on the flood tolerance criteria of the various crops; these criteria were defined by the project agriculturist after discussions with various specialists. In areas where it was confirmed that the generated cropping patterns agreed reasonably with observations this analysis was used to investigate how the cropping patterns in the project areas would be affected by the proposed developments. This approach was used as a secondary source of information on which changes in agricultural output due to different interventions could be assessed. Other methodologies, using a modified MPO approach based on changes in flood phases, were used as the main basis of benefit assessment.

Fisheries analysis : Based on the water phase results, software was written to generate potential fisheries areas. The specifications for these areas were defined by the project fisheries expert and were dependent on the depth and duration of flooded areas. This analysis was used to investigate how the fisheries areas in the project areas would be affected by the proposed developments.

5.2 The Impact of Sealing the BRE

5.2.1 Introduction

The impact of sealing the BRE was investigated by undertaking a 25 year model simulation of the present situation but with the breaches in the BRE sealed. This simulation was to provide a baseline (or Future Without project condition) against which the impacts of internal developments within the region could be gauged. In addition, however, this simulation provided a means of assessing the impacts of sealing the BRE breaches by comparing it with simulation results for the present conditions, including breaches.

Sealing the BRE prevents spills passing through the breaches and into the region. Removing these spills will increase discharges in the Brahmaputra itself but this increase in discharge is small compared with the overall flow in the river. Changes in water levels in the Brahmaputra due to this intervention would be minimal, particularly in comparison to other major interventions such as the Brahmaputra Left Embankment (BLE).

By far the greatest impacts of sealing the BRE will be experienced in the Middle Bangali basin where deep flooding occurs due to the increased discharge which the rivers system needs to convey due to the spillage. In the lower reaches of the Bangali water levels are dominated by backwater effects from the Brahmaputra and will not be affected. Similarly, the lower reaches of the Lower Atrai are dominated by backwater effects and will not be affected.

In 1991 six main breach sites were in evidence along the reach of the BRE between Haripur and Bera. These were located at Fulchari, Mathurapara, Kazipur, Sonali, Sirajganj and Betil, respectively. The impacts of sealing all of these breaches is discussed in the following sections. The morphological impacts of sealing the BRE are discussed in Section 5.6.

5.2.2 Impact on water levels behind the BRE

The area where the sealing of the BRE has the greatest impact is the Middle Bangali basin; here water levels are significantly reduced.

Sariakandi is immediately downstream of the location where the flow through the main BRE breaches at Mathurapara enter the Bangali system. At this location the reduction in peak water level as a result of sealing BRE is in excess of 1 m (Figure 5.2). Similar trends were found throughout most of the Middle Bangali. At Khanpur and Raiganj which are about 15 km to 20 km west of the BRE, the impact of sealing the breaches again reduced peak levels by approximately 1 m. Much of the water which flows through the BRE breaches flows as overland flow across the flood plains and along minor drainage channels in an northeast-southwest direction. Sealing the BRE breaches prevents much of this overland flow and also reduces spillage on the right bank of the Ichamati which would have entered the Bangali in the vicinity of Khanpur and Raiganj.

Moving further downstream, to the Lower Bangali basin, the impact of sealing the breaches becomes less marked due to the backwater influence imposed by the Brahmaputra at the outfall of Bangali to the Hurasagar.

5.2.3 Impact on discharges behind the BRE

At Sariakandi the peak discharge in the Bangali, in 1987, is reduced from about 5000 m^3/s to less than 1000 m^3/s as a result of sealing the BRE (it must be noted that these discharges include considerable overland/floodplain flows and not just those in the river system itself). Similar reductions in flow were also seen at Khanpur, where the peak discharge is reduced by approximately 50%. Despite having only a minor impact on water levels, Ullapara discharges are reduced significantly and average flood season discharge is again reduced by around 50 % with peak discharge reduced from 2500 m^3/s to 700 m^3/s.

It is clear therefore that sealing of the BRE results in a significant reduction in peak flows throughout the Middle Bangali basin. Reductions in discharges in the Lower Bangali will also give some relief to the drainage congestion at the outfall of the Hurasagar although water levels will not be significantly affected.

5.2.4 FAP-1 assessment of flooding due to breaches

FAP-1 undertook a MIKE11 model study of the right bank floodplain of the Brahmaputra, which included the Middle and Lower Bangali basins, to determine the impact of flooding due to breaches occurring at different locations in the BRE. The impact of breaches at six sites, indicated in Section 5.2.1, were investigated. The study considered the impact of individual breaches and also the composite impact of all breaches.

Compared with a sealed BRE, the total flooded land increased by approximately 30 % when all six breaches in the BRE were considered. The total flooded area was not significantly increased by the opening of any single breach, but for some of the breaches the areas flooded to different depths did change significantly.

The breaches at Sonali, Sirajganj and Betil have little impact on the distribution of land flooded to different depths. The breaches at Kazipur, Fulchari and Mathurapara result in an increase in deeper flooded land relative to shallower flooded land. The breach at Mathurapara has the greatest single

Figure 5.2

Impact on water levels at Sariakandi in the Bangali

due to Sealing of BRE breaches

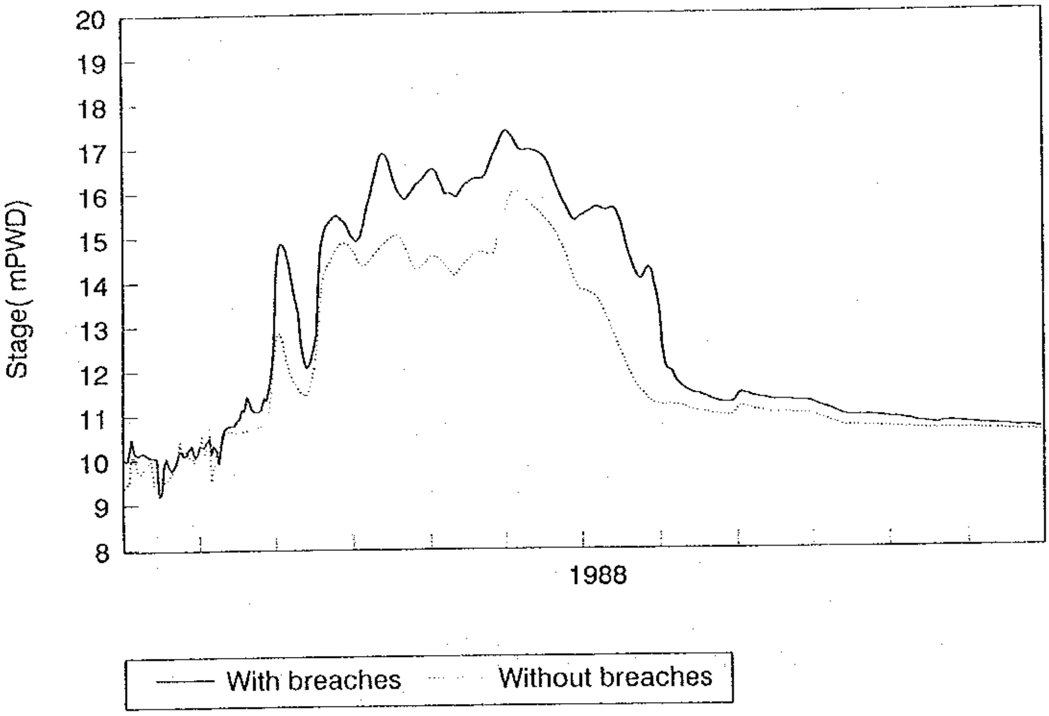
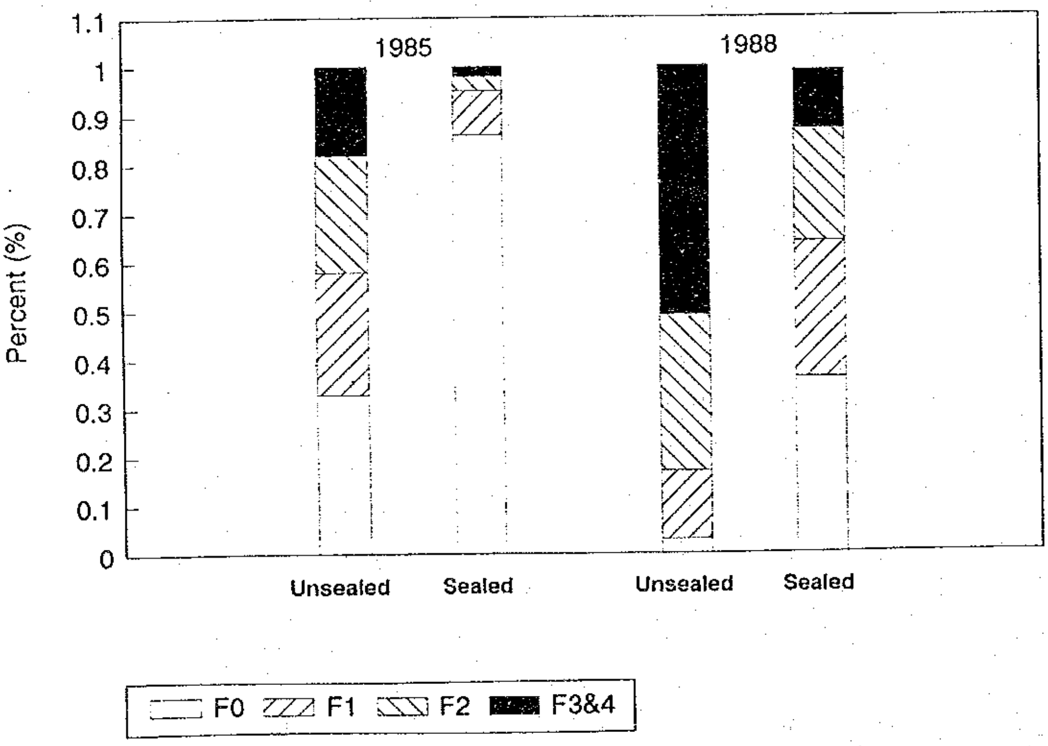


Figure 5.3

Change in Flood Phase

due to Sealing of BRE breaches



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effect; this single breach results in a twofold increase in land flooded to a depth of more than 0.6 m. The breaches at Fulchari and Kazipur respectively have the next greatest effects on the proportion of deeply flooded land.

With all the BRE breaches open approximately 80 % of the flooded land is flooded to depths in excess of 0.6 m. Once sealed, only 30 % of the flooded land is flooded to depths in excess of 0.6m with most of this area lying in the lower reaches of the Bangali where backwater influences still dominate. In terms of the total area, the area of flooding was reduced by 30 % due to sealing all six breaches.

5.2.5 Flood phase analysis

Flood phases along the Middle Bangali floodplains for present conditions and with the BRE breaches sealed were also calculated during the regional study. In an average flood year, 1985, the area of F0 and F1 land is greatly increased from less than 60% to over 90%, Figure 5.3. In a much more severe flood year, 1988, the proportion of F0 and F1 land is changed from below 20% to over 60% if the breaches in the BRE are sealed.

This analysis supports the results reported by FAP-1 that the area of deeply flooded land is significantly reduced by the sealing of the breaches in the BRE. With the BRE sealed, a very large percentage of the Middle Bangali project area falls within the F0 and F1 flood phase categories. Flooding within these flood phase categories is not, in general, a restriction to agriculture and the sealing of the BRE therefore reduces the flooding in the Middle Bangali project area to such an extent that it effectively eliminates flooding as a major problem in average flood years.

5.3 Upper Karatoya and Bangali basin

5.3.1 Sealing the BRE

In Section 5.2 it was shown that the single most effective measure to reduce flooding problems in the Middle Bangali was to seal the breaches in the BRE. This would effectively remove the constraints which at present restrict agricultural development in the area and would greatly reduce the damage caused by unpredictable flooding.

Other factors do, however, have an impact on the flooding regime in the Middle Bangali. In particular these relate to developments in the upstream reaches. Developments in the Upper Karatoya are of particular relevance in this respect but the Middle Bangali flood regime will also be affected by developments further north (such as sealing the TRE breaches) and developments in the Ghagot/Alai river system, which relate to the GIP project area.

5.3.2 Upper Karatoya developments

If CFD developments take place in the Upper Karatoya basin the flows in the Middle Bangali basin will increase. CFD development and confinement of the Upper Karatoya will prevent the present spilling, on both the left and right banks, thus reducing the attenuating affects of this spillage as flow is taken in to temporary storage on the floodplains.

Under confined, CFD, conditions the peak discharges at the lower end of the Upper Karatoya will increase, thereby increasing the discharges which enter the Middle Bangali. Without mitigating measures, peak flows at Mohimaganj could be increased twofold. Figure 5.4 shows the discharge hydrographs at Mohimaganj with and without CFD developments in the Upper Karatoya for the 1987 flood season. Peak discharges are increased by more than 100%, from 600 to $1400m^3/s$ by the developments in the Upper Karatoya.

The conveyance capacity of the Bangali river varies considerably, some areas having adjusted their carrying capacity due to the persistent breaches along the BRE, but in general the conveyance capacity is around $300\text{-}500m^3/s$. Large increases in discharge due to the upstream developments will therefore lead to a significant worsening of the flooding conditions in the Bangali.

A long profile comparing peak levels along the Bangali with and without CFD developments in the Upper Karatoya is shown in Figure 5.5. Water levels increase throughout the Bangali system but the greatest impact is seen in the more northerly reaches of the Middle Bangali. The depth of flooding increases in the order of 1m throughout much of the river reach and it is only in lower reaches where the impact is less marked, due to the backwater influences of the Brahmaputra.

5.3.3 Bangali Floodway

The adverse downstream effects of developments in the Upper Karatoya are counter to the general FAP-2 policy of not introducing significant benefits to upstream areas at the expense of large areas downstream. The problems associated with CFD development in the Upper Karatoya can be countered by passing some of the increased discharge to the Brahmaputra thereby reducing flows, in particular peak flows, in the Middle Bangali by the construction of the Bangali floodway.

Whilst the combination of CFD developments in the Upper Karatoya together with the Bangali Floodway are desirable from the viewpoint of flooding problems in the Middle Bangali, its function is not to divert all waters to the Brahmaputra but to provide relief at times of peak flood flows. During other periods the flow would continue to pass directly down the Bangali. The operational strategy of the Bangali Floodway should therefore be to allow a limited maximum residual flow down the Bangali with the residual limit being assessed on hydraulic/morphological grounds and structure design, but also taking in to account other factors such as the degree of flooding that is acceptable downstream.

For these studies a residual of $500m^3/s$ was selected as the cutoff limit. This maintains peak levels around the bankfull level for much of the Bangali and does not significantly affect the dominant discharge, in comparison with the baseline situation with the BRE sealed. It will therefore lessen the morphological impacts of the flow diversion.

The impact of the Bangali Floodway on discharges in the Middle Bangali are shown in Figure 5.4. in the associated discharge hydrographs, for 1987, near Mohimaganj. The peak discharge is decreased by approximately 15% falling from around 600 to $500m^3/s$. This leads to a corresponding reduction in peak levels although this is relatively marginal throughout most of the Bangali system, see Figure 5.5.

Figure 5.4

Discharges in the Middle Bangali

With and Without Bangali Floodway

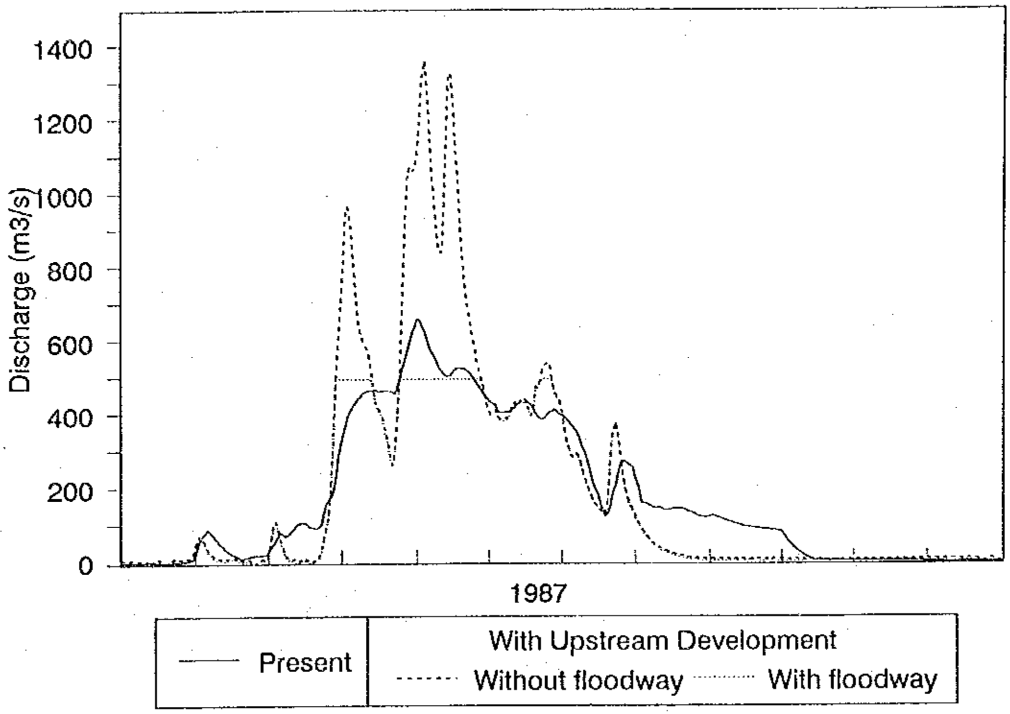
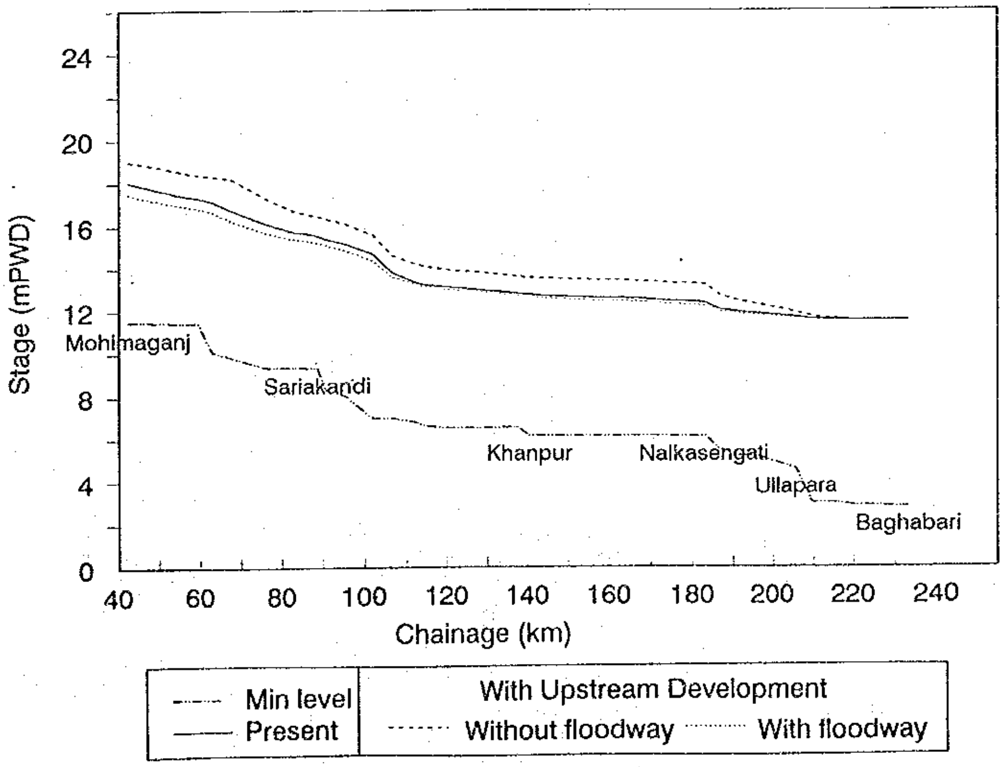


Figure 5.5

Impact of Development in Upper Karatoya

Long profile along the Bangali



5.4 The Lower Atrai basin

5.4.1 Impact of confinement in the Lower Atrai

Construction of polders in the Lower Atrai basin and confinement of the river system in general has been going-on for many years. As described in Chapter 4 the present status of the embankments varies from polder to polder but in general none of the embankments are fully complete and most suffer from annual breaches and public cuts. The effect of this is to allow considerable spillage on to the flood plains adjacent to the river system and for large storage and flow areas to be available which attenuate the discharge peaks passing through the system. The overall effect of these breaches and public cuts is to reduce water levels in the Lower Atrai basin.

The current situation in the Lower Atrai basin can be thought of as consisting of three parallel drainage paths with the central one being the Atrai. On the southern side the drainage path is across the Chalan Beel Polders whilst on the northern side it is across the Bogra Polders and into SIRDP.

Full confinement in the Lower Atrai basin refers to the completion of all existing polder developments and the embanking of areas, as yet unplanned, along the left bank of the Atrai including Bogra Polder 4. This represents a worst case in that it will result in the maximum rise in water levels in the Lower Atrai basin.

A number of model simulations were carried out to investigate the impact confinement would have on water levels in the Lower Atrai. The results of these simulations are presented in Figures 5.6 and 5.7 in the form of peak water level profiles along the Atrai. The figures also show the present condition water levels, from observations, as a comparison.

Full confinement : This simulation assumed full confinement throughout the Lower Atrai basin. Along the Atrai river the maximum spacing between embankments was taken to be approximately 500 m. Elsewhere, the embankments were assumed to be located at the river bank; this resulted in embankment spacings of less than 300 m in general. Full confinement results in a substantial increase in peak water levels, relative to present conditions, from approximately 10 km upstream of Baghabari to Jotebazar (locations are shown in Figure 4.4) where the Fikirni spills from the Atrai (Figure 5.6); an increase in peak water levels occurs over a distance of some 130 km. The maximum rise in peak water level is between 2 m and 3 m; this occurs in the vicinity of Chankchoir. The maximum water levels are only raised marginally in the upper reaches of the Atrai where the flow is dominated by fluvial flow. In the lower reaches there is again only a minor rise in level because of the backwater influence of the Brahmaputra.

Full confinement except in SIRDP : This simulation assumed full confinement throughout the Lower Atrai basin except for the SIRDP area which was assumed to be left open. This results in marginally lower water levels in the Lower Atrai than with full confinement, Figure 5.7. The water levels are lowered in the reaches downstream of Astamonisha, the maximum reduction being in the order of 0.5m, but there is no impact in the upper reaches.

Full confinement except in SIRDP and Bogra Polder 4 : This simulation assumed full confinement throughout the Lower Atrai basin except for the SIRDP area and Bogra Polder 4 which were assumed to be left unembanked, Figure 5.7. This results in large reductions in peak water level in the middle reaches of the Lower Atrai compared to fully confined conditions. The maximum reduction in water level relative to fully confined conditions is between 2 m and 3 m. All the rise in water level due to confinement as far upstream as Chankchoir can be accounted for by SIRDP and Bogra Polder 4. Between Chankchoir and Jotebazar approximately 50 % of the rise in water level which results from full confinement can be attributed to Bogra Polder 4.

Figure 5.6

Impact of Full Confinement

Long profile along the Atrai

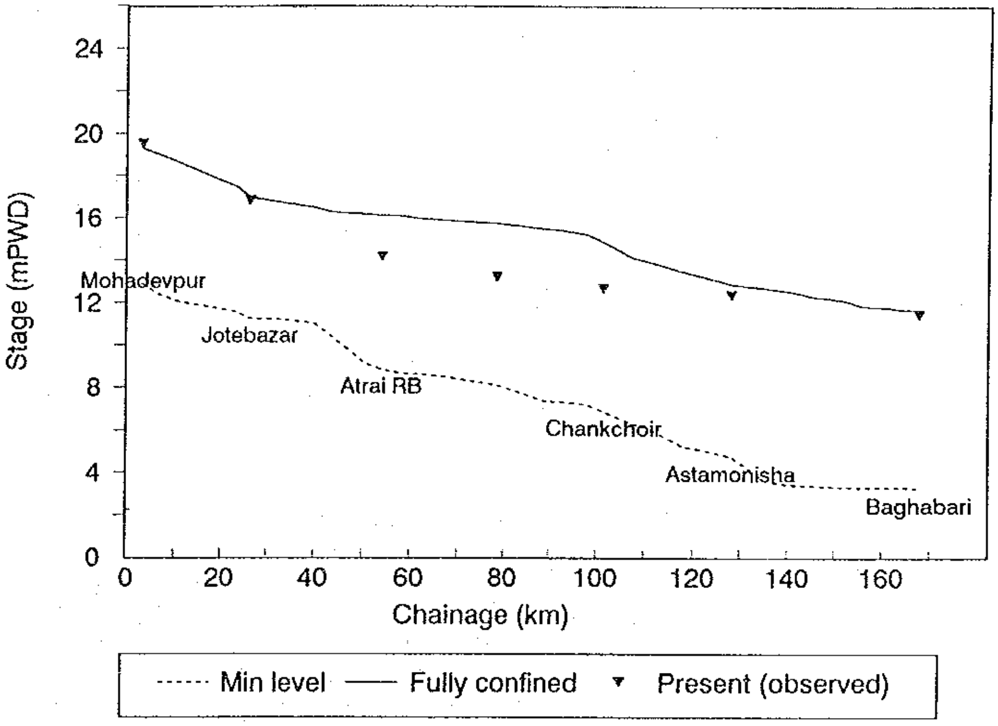
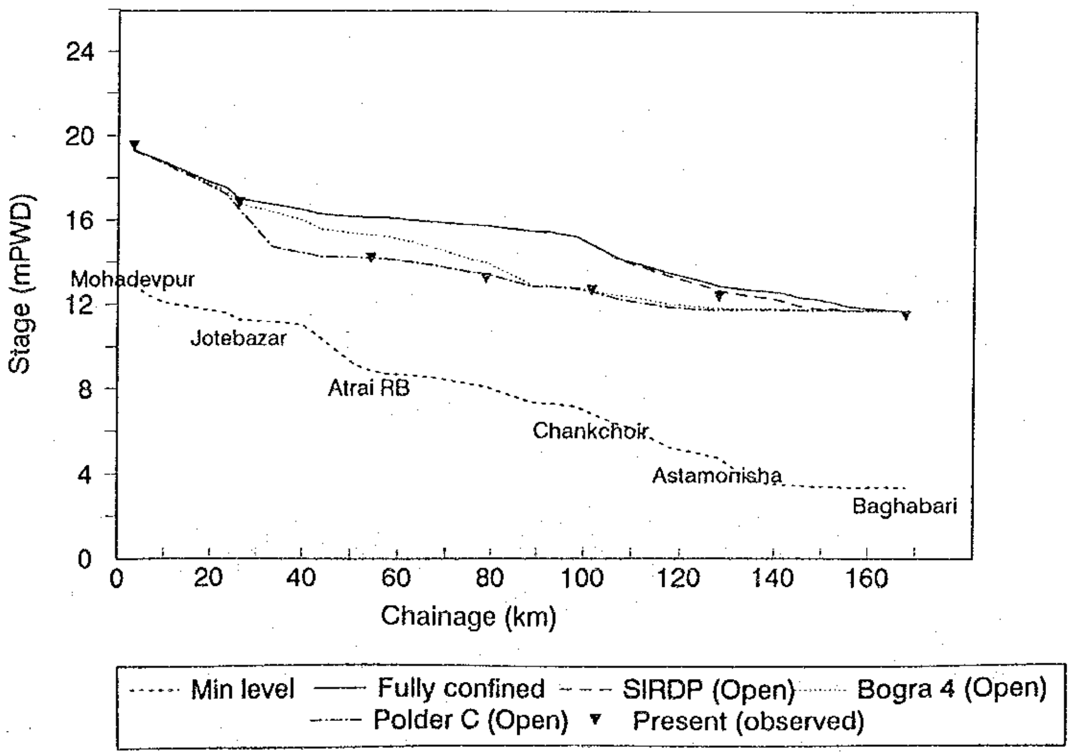


Figure 5.7

Sensitivity to Confinement in Different Reaches

Long profile along the Atrai



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Full confinement except in SIRDP, Bogra Polder 4 and Chalan Beel Polder C : This simulation assumes full confinement throughout the Lower Atrai basin except for the SIRDP area, Bogra Polder 4 and Chalan Beel Polder C which are assumed to be left unembanked, Figure 5.7. Leaving Chalan Beel Polder C open results in a maximum reduction in peak water level of between 1m and 2m, see between Chankchoir and Jotebazar. The rise in water level between Chankchoir and Jotebazar which does not result from sealing Bogra Polder 4 can therefore be attributed to the closure of Chalan Beel Polder C.

These results clearly demonstrate the adverse affects of confinement in different reaches of the Lower Atrai basin and how their interaction can contribute to unacceptable rises in water levels. The closure of Bogra Polder 4 has the greatest single effect with the sealing of SIRDP resulting in a further increase in peak water level in the lower reaches of the Atrai. Closure of Chalan Beel Polder C results in a further increase in water level in the middle reaches of the Atrai. It must be stressed that as well as affecting water levels in the Atrai, river confinement will result in a significant rise in water level in all the tributaries and distributaries of the Lower Atrai system which will adversely affect drainage from the floodplains to the river system.

5.4.2 On-going developments

In the Lower Atrai there are a number of on-going projects which are nearing completion. The most important of these are the Naogaon Polder and the Barnai projects. For the Future Without, baseline, conditions it was assumed that these projects were complete and functioned as planned. However the impact that these projects may have on the hydraulic regime in the Lower Atrai were first investigated.

Naogaon Polder

Under present conditions Naogaon Polder acts as a flood storage area on the north bank of the Atrai. As water levels in the Atrai rise flood waters spill into Naogaon Polder. This water is stored in the polder until a reduction in water levels in the Atrai permit drainage. By acting as a flood storage area Naogaon Polder will cause some degree of flood attenuation along the downstream reaches of the Atrai.

Figure 5.8 illustrates the impact of closing Naogaon Polder on water levels in the Atrai. This figure shows water level hydrographs for 1987, with Naogaon Polder open and closed, at Rasulpur which is adjacent to the Naogaon Polder regulators. Hydrographs for 1987 are used in this figure since in 1987 flooding problems resulted from high river flows rather than backwater effects. The parts of the Atrai basin which may be affected by the closing of Naogaon Polder are in the fluvial zone where water levels depend on the flow in the river.

Completion of Naogaon Polder does not have a dominant effect on water levels in the Atrai. Under present conditions water passes into storage in Naogaon Polder as the Atrai levels rise. Closure of the polder results in a increase in water levels on the rising limbs of the hydrograph. Under present conditions, as water returns from storage the recessions limbs have a slower fall off rate, and this can be particularly seen on the final recession. At peak levels, completion of Naogaon Polder has little affect. The impact of sealing Naogaon Polder on water levels further downstream is likely to diminish because in these lower reaches the levels become dominated by backwater effects rather than fluvial flows entering from upstream reaches.

Figure 5.8

Impact of Completion of Naogaon Polder

Water level on Atrai at Rasulpur

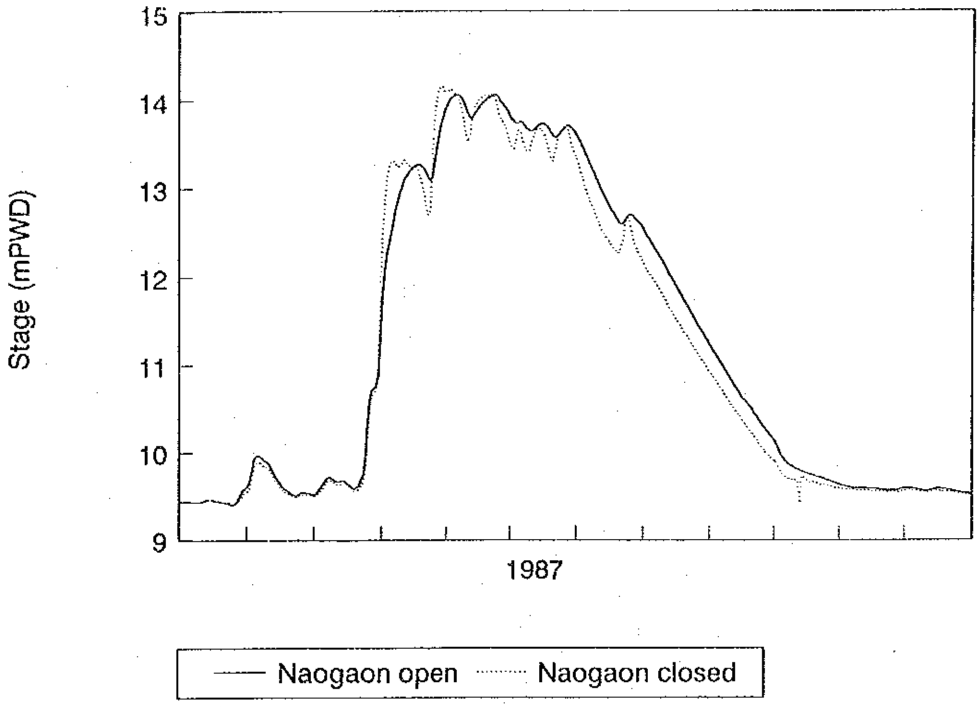
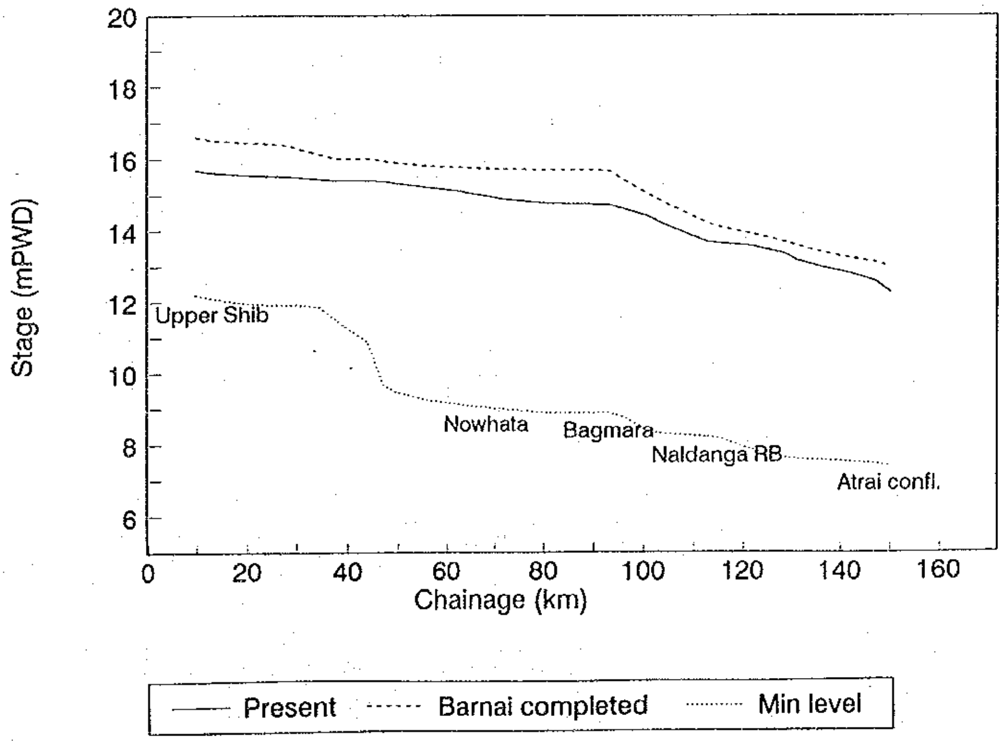


Figure 5.9

Impact of Completion of Barnai Project

on peak levels in Shib-Barnai



Barnai Project

Under present conditions the area covered by the Barnai project acts as a floodplain which, under monsoon conditions, conveys flow parallel to the Shib-Barnai river. The sealing of the Barnai project will eliminate this flood plain as an area of flow. This will result in a reduced cross-sectional area of flow and, probably, a rise in water level.

Figure 5.9 illustrate the predicted impact of completion of the Barnai project on water levels in the Shib-Barnai. The figure presents a longitudinal profile of peak water levels, in 1987, from its confluence with the Atrai to the upper limit of the Shib north of Pearpur, some 13 km upstream of the furthest extent of the Barnai project embankments. It is clear from this figure that the closing of the Barnai project has a major impact on water levels. It results in increases of up to 1 m over at least 70 km of river. Figure 5.9 also indicates that the completion of the Barnai project results in an increase in water level along the western embankment of Chalan Beel polder D where public cuts already regularly occur.

5.4.3 The Green River

Confinement in the Lower Atrai results in large rises in water level throughout most of the system. In particular the closure of SIRDP, Bogra Polder 4 and Chalan Beel Polder C will result in large increases in water level in different reaches of the Lower Atrai as discussed in Section 5.4.1 above.

The Green River concept (Section 4.4) of the Lower Atrai basin is designed to bring the river system close to its original drainage conditions and hydraulic characteristics prior to the development of the area by empoldering and embanking. The drainage paths within the Green River are taken to be similar to those which occur at present and are simulated in the Without project run. These drainage paths are in part due to breaches and public cuts; the Green River formalises these as the main drainage paths.

Within the Green River concept partial protection is provided in areas where it is viable; this protection is designed to prevent damage to the boro crop (which is not a major problem in the Lower Atrai due to the late rise of the flood waters) and/or to prevent rapid rises in water level until late July to allow the establishment of a TDW aman crop. The partial protection is located close to the river banks and gives protection to the area between the river and the full CFD embankments which are generally located some 5-10 km away from the river, see Figure 4.4. This allows a large flood storage and conveyance area for the peak flood flows thereby mitigating the adverse affects of confinement. The alignment of the CFD embankments followed existing infrastructure, roads and embankments, where possible, so as to provide a relatively low cost solution to the problem.

A ten year design option run was carried out with the sub-regional model to simulate the Green River concept (Figure 4.4) with partial protection. The key features are given in Table 5.1.

Although predicted river levels are important in the design of engineering proposals, it is the changes in flood phases, and hence agricultural benefits, within the project area which are likely to indicate more fully the benefits of the differing schemes. For the purposes of comparison, flood phase figures are presented to indicate the relative merits of the schemes.

Table 5.1 Conditions Simulated in Green River Concept Run with Partial Protection

	Full CFD in Upper Units	Flow in Lower Unit	Partial Protection in Lower Units	Closure of Drainage Channels
Chalan Beel Polder A	X	X	X	
Chalan Beel Polder B	X	X	X	
Chalan Beel Polder C	X	X	X	
Bogra Polder 2	X	X	X	
Bogra Polder 2	X	X	X	
Bogra Polder 3	X	X	X	
Bogra Polder 4				
SIRDP	X	X		X

The flood phases in three project areas of the Lower Atrai for the Green River with partial protection are presented in Table 5.2. In brackets in this table are the corresponding figures for Without project conditions. In areas where flow occurs the flood phases were calculated directly from the model results. In areas of full CFD the flood phases were calculated by engineering drainage analysis. This drainage analysis uses model-predicted water levels in the external rivers at the drain outfalls. The flood phases for the entire project area are combination of those calculated directly from model results and those calculated by engineering drainage analysis.

Under this scenario there is no development in Bogra Polder 4 and the flood phases remain approximately unchanged, as expected. In Polder A the results again indicate little or no change to the flood phasing. It is in Polder B that there is relatively substantial change in the flood phases with an overall increase of 7% in the F0+F1 land.

Table 5.2 Flood Phases in Green River Concept Run with Partial Protection

	F0	F1	F2	F3 + F4
Bogra Polder 4	40 % (39 %)	6 % (8 %)	9 % (14 %)	45 % (39 %)
Chalan Beel Polder A	54 % (51 %)	9 % (13 %)	14 % (16 %)	23 % (20 %)
Chalan Beel Polder B	66 % (51 %)	17 % (25 %)	8 % (16 %)	9 % (8 %)

Notes:
1. Green River figures based on a probable 5 year level from a 10 year (option run) simulation.
2. Future Without figures given in brackets. Figures based on a 5 year probable flood from a 25 year (baseline) simulation
3. Due to notes 1 and 2, figures are not exactly comparable but are indicative.

5.4.4 The Green River with additional CFD protection

The Green River with partial protection excludes any poldering in the deepest flooded areas adjacent to the Atrai; the polder embankments are assumed to be at the limits of this deeply flooded zone. Within the Green River concept, a second scenario was considered with the construction of embankments to polder some of these deeply flooded areas thereby giving additional CFD protection. A 10 year design option simulation was carried out for this scenario with the key changes between this and the first option simulation were:

- Chalan Beel Polder A : Full CFD.
- Chalan Beel Polder B : Full CFD.
- Bogra Polder 4 : Upper part of polder full CFD. Flow in part adjacent to Atrai.

The conditions simulated in this run are illustrated in Figure 5.10 and summarised in Table 5.3.

Table 5.3 Conditions Simulated in Green River Concept Run with Partial Protection and Additional CFD Areas

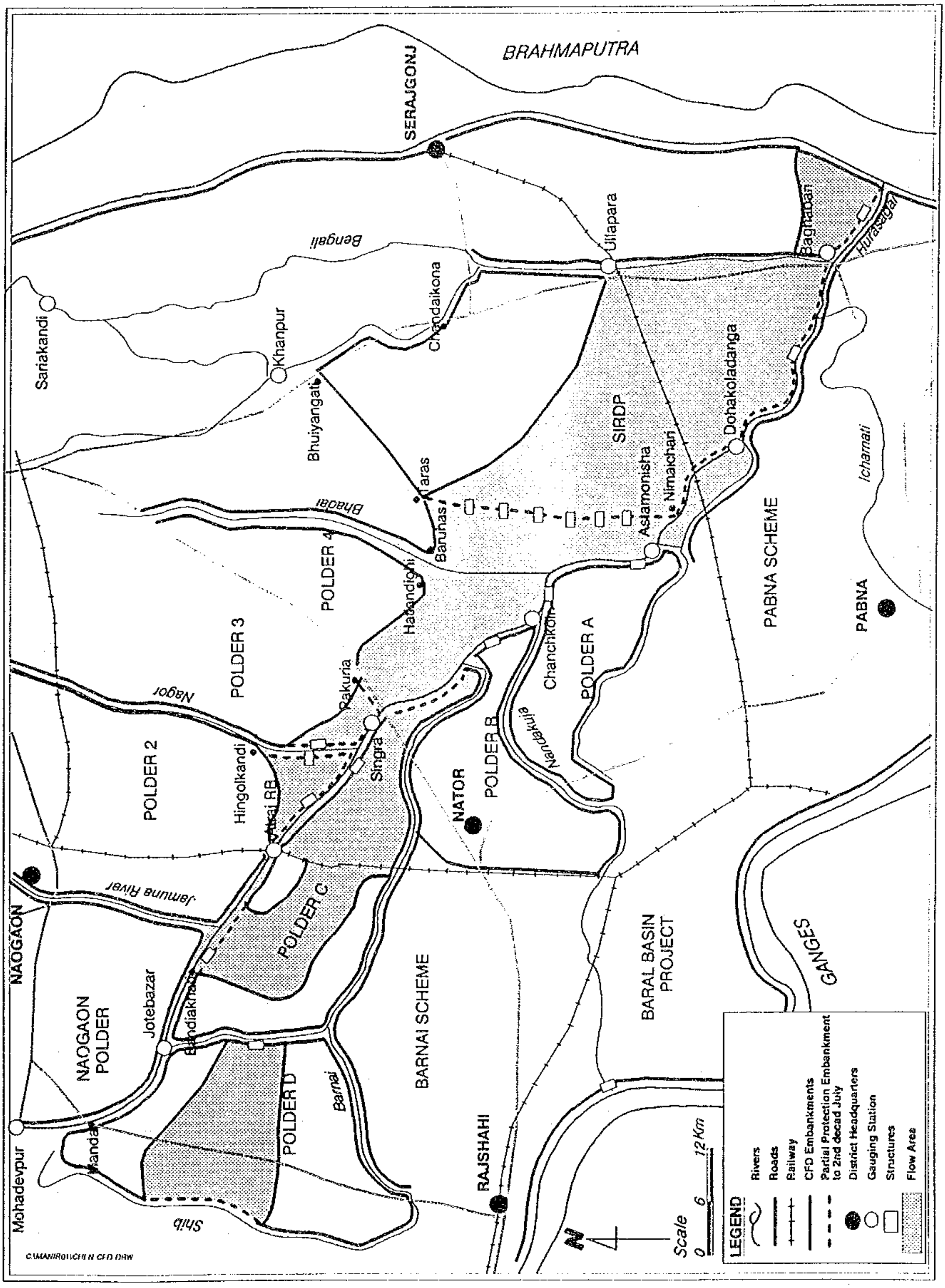
	Full CFD in upper units	Flow in lower units	Partial protection in lower units	Closure of drainage channels	Full CFD
Chalan Beel Polder A					X
Chalan Beel Polder B					X
Chalan Beel Polder C	X	X	X		
Chalan Beel Polder D	X	X	X		
Bogra Polder 2	X	X			
Bogra Polder 3	X	X			
Bogra Polder 4	X	X			
SIRDP	X	X		X	

The flood phases for the project areas of the Lower Atrai with the Green River with partial protection and additional CFD protection are presented in Table 5.4. In brackets in this table are the corresponding figures for Without project conditions.

In comparison with the Future Without conditions, the provision of additional CFD protection leads to a substantial increase in F0+F1 land in all three project areas of between 5% and 20%. Compared with the first option simulation (Table 5.2), the F0+F1 land increased significantly in Bogra Polder 4 and Polder B, and to a lesser extent in Polder A.

Figure 5.10

The Green River with Partial Protection and additional CFD areas



Source : NWRS

Table 5.4 Flood Phases in Green River Concept Run with Partial Protection and Additional CFD Protection

	F0	F1	F2	F3 + F4
Bogra Polder 4	47 % (39 %)	10 % (8 %)	13 % (14 %)	30 % (39 %)
Chalan Beel Polder A	71 % (51 %)	14 % (13 %)	9 % (16 %)	6 % (20 %)
Chalan Beel Polder B	62 % (51 %)	19 % (25 %)	13 % (16 %)	6 % (8 %)

Notes:
1. Green River with additional CFD protection figures based on a probable 5 year level from a 10 year (option run) simulation.
2. Future Without figures given in brackets. Figures based on a 5 year probable flood from a 25 year (baseline) simulation
3. Due to notes 1 and 2, figures are not exactly comparable but are indicative.

5.4.5 Proposed scenario

Analysis of the results of the two ten-year design option simulations for the Green River concept indicated that peak water levels were very similar for both the options tested. However, selection of the preferred option cannot be made purely on hydraulic grounds and it is important that all aspects are considered in the selection process.

In terms of flood phases, the results with additional CFD protection are an improvement on those without the additional CFD areas. However, CFD in Chalan Beel polder A and B may not be feasible since this involves poldering deeply flooded areas which experience has shown to be unsuccessful.

There is currently no development in Bogra Polder 4 and due to the limited existing infrastructure in the area the proposed sub-poldering would be expensive and would only have limited benefits, approximately a 10% increase in F0+F1 land. The confinement studies presented in Section 5.4.1 have also shown that extending the area of CFD protection in Bogra Polder 4 closer to the banks of the Atrai would have a major impact on water levels throughout the middle Atrai and is therefore undesirable.

The Green River concept with partial protection was selected as the With project condition. This differed from the design option simulation in that the heights of the partial protection embankments/structures were increased to provide protection of the TDW aman crop during its initial stages of growth. The heights of these embankments/structures were based on the results of the design option simulation of the Green River with partial protection such that they were not over-topped until the second decad in July.

The flood phases for the Lower Atrai under With project conditions are presented in Table 5.5. Also given, in brackets, are the corresponding figures for Without project conditions.

Table 5.5 Flood Phases in the Sub-regional Model Project Areas under With-Project Conditions

	F0	F1	F2	F3 + F4
Bogra Polder 2	49 % (50 %)	18 % (23 %)	20 % (19 %)	13 % (8 %)
Bogra Polder 3	67 % (80 %)	8 % (9 %)	12 % (7 %)	13 % (4 %)
Bogra Polder 4	39 % (39 %)	5 % (8 %)	12 % (14 %)	44 % (39 %)
Chalan Beel Polder A	56 % (51 %)	8 % (13 %)	14 % (16 %)	22 % (20 %)
Chalan Beel Polder B	65 % (51 %)	17 % (25 %)	9 % (16 %)	9 % (8 %)
Chalan Beel Polder C	27 % (37 %)	17 % (13 %)	23 % (18 %)	33 % (32 %)
Chalan Beel Polder D	67 % (27 %)	13 % (17 %)	13 % (25 %)	7 % (31 %)
SIRDP	27 % (20 %)	7 % (8 %)	28 % (24 %)	37 % (48 %)

Note : Figures in brackets are for Without-Project conditions

In half of the project areas the percentage of F0+F1 land is increased under With project conditions whereas in some areas the percentage remains unchanged or is slightly worse. In part this may appear to indicate a worsening of the situation. In fact, the benefits are achieved during the early monsoon period when the partial protection removes vulnerability of crops to the rapid early monsoon water level rises and unpredictable nature of the flooding due to breaches and public cuts. The flood phase figures, on the other hand, refer to the maximum depth of flooding. It should also be noted that both full CFD and partial protection can result in some drainage congestion so the improvement relative to Without project conditions may not be as great as might be expected.

Analysis of the longitudinal profiles of 20 year return period water levels along the Atrai river for With and Without project conditions showed that water levels in the middle reaches of the Lower Atrai increase by up to 1 m. This is accounted for by a number of factors. Firstly, the partial protection embankments/structures for Chalan Beel Polder C are set at a higher level than would occur through public cutting of the embankment, which is considered in the Future Without situation. This partly restricts the flow through the polder and diverts more water down the Atrai. Secondly, remedial works on the right bank of the Little Jamuna means that more flow enters the Atrai system under the With conditions whereas much of this flow had previously passed on to the adjacent floodplain and into the Nagor project areas. Finally, the completion of the Barnai project leads to an increase in the levels along the Barnai river which results in less flow passing down the Fakirni and more flow being diverted along the Atrai.

5.4.6 Sensitivity Analysis

Confinement of the Upper and Middle Atrai

Both the magnitude and temporal distribution of flows in the Lower Atrai will be affected by confinement of the Middle Atrai in India. To investigate the sensitivity of water levels in the Atrai to these changes a model simulation was undertaken with the discharge hydrograph at the Mohadevpur boundary replaced by that at Bushirbandar, a discharge gauging site in the upper reaches of the Atrai north of the Indian border. This represents a case whereby there is no attenuation of the discharges in the Middle Atrai, which is very significant feature of the river system at present.

Confinement of the Middle reaches of the Atrai, in particular through India, results in an increase in peak water level in the upper reaches on the Lower Atrai of about 1m. The maximum rise in level occurs at Mohadevpur. The impact diminishes further downstream but extends to around Atrai RB/Singra. There is no increase in water level downstream of this is because of backwater effects from the Brahmaputra.

Rise in Brahmaputra Water Level

Developments external to the North West region are likely to have an effect on water levels in the Brahmaputra. At the outfall of the Hurasagar, the introduction of a Brahmaputra Left Embankment will have some impact on peak levels. The FAP 25 study which investigated this scenario indicated that peak levels would rise about 0.5m at the Hurasagar outfall.

A sensitivity analysis was carried out to investigate the impact of a rise in peak water level of 0.5 m in the Brahmaputra; it was assumed that the minimum water level did not change. The increase in peak water level in the Brahmaputra results in an increase in peak water level in the lower reaches on the Lower Atrai since it extends the influence of the backwater effect. The maximum increase in water level, which is 0.5m, occurs at the downstream boundary, Baghabari. Upstream the influence of the rise in Brahmaputra levels diminishes and is almost negligible at Singra, which is the limit of the backwater zone. There will be no significant impact upstream of Singra.

5.5 The Teesta basin

5.5.1 Sealing the TRE

The Teesta Right Embankment is presently breached in two prominent locations, upstream and downstream of Kaunia These contribute flows to the Ghagot and Upper Karatoya river basins, and eventually to the Middle Bangali.

Upstream of Kaunia the breaches allow spillage from the Teesta, at high river stages, to pass in to the Ghagot river system. Due to the limited conveyance capacity of the Ghagot, this excess flow spills out of the right bank, making its way eventually to the Upper Karatoya and Middle Bangali basins, and also spills along the left bank in to the GIP project area. Again, the left bank spills generally flow to the Middle Bangali basin. The limited discharge capacity of the existing Manas regulator and high stages in the Brahmaputra mean that excess flows can not pass directly to the Brahmaputra, and instead flow down the Alai to the Bangali.

Downstream of Kaunia, the large breach location allows flows in to the Gaibandha area which moves in a southerly direction towards the Manas regulator site. Due to the same reasons as above, some of the spills through this major breach eventually flow to the Middle Bangali river basin.

Model simulations have shown that sealing of the breaches in the TRE upstream of Kaunia has a large impact on water levels in the Ghagot river. Peak water levels are reduced by 1.5 m in the upstream reaches of the Ghagot. In the lower reaches of the Ghagot the reduction in water level is less because backwater effects from the Brahmaputra exert an influence. The peak discharge in the Ghagot is reduced by 210 m^3/s and the spills on both the left and right banks of the Ghagot are reduced, but not eliminated, by the sealing of the TRE breaches upstream of Kaunia.

Peak discharges of the order of 500 m^3/s enter the Gaibandha area through breaches in the TRE downstream of Kaunia. This flow passes down the internal drainage system of the area. The sealing of the TRE breaches downstream of Kaunia eliminates this flow and results in a reduction in the water level in the internal drainage channels of up to 0.6 m. The sealing of the TRE breaches downstream of Kaunia has no impact on peak water levels in the Ghagot river.

The impact of a combination of sealing the TRE both upstream and downstream of Kaunia gives a combined effect, as described above, thereby giving some relief to the discharges passing down the Alai and to the Middle Bangali basin.

5.5.2 Gaibandha Improvement Project

A large number of options were investigated during the feasibility study for the Gaibandha project. Based on model simulations of the design options it was concluded that:

- sealing of the TRE upstream and downstream of Kaunia improves the internal flooding conditions in the project area by reducing water levels in the Ghagot and also reducing inflows into the area.

- the removal of the existing Manas regulator will improve drainage from the area as the current regulator is undersized but without protection of the Manas basin inflows from the Brahmaputra will occur

- the reductions in water level in the Ghagot which results from sealing the TRE does not prevent spillage from the Ghagot into the project area; an extension of the left embankment from Bamandanga to the Alai Kumari confluence is required to achieve this.

- the proposed Ghagot right embankment reduces spillage in the right bank but increases water levels in the Ghagot which caused greater drainage congestion in the project area. The Ghagot right embankment has no benefits for the project area. Since the Manas regulator is removed a backwater embankment is required to prevent spillage on the Ghagot right bank due to high water levels in the Brahmaputra.

- a regulator at the tail of the Manas is required to prevent inflow from the Brahmaputra into the Manas basin.

- a regulator at the head of the Alai Nadi is required to prevent an unacceptable increase in discharge in this river.