the spillage through the TRE does not have a major impact on the potential for agricultural productivity.

In the cells adjacent to the Brahmaputra and the lower reaches of the Ghagot the percentage of F0+F1 land is also reduced; this reflects the problems of drainage congestion when water levels in the external rivers are high. This drainage congestion can only be partially countered by the increasing of regulator ventage.

With the very important exception of the south-eastern part the flood phases analysis suggests that flooding is not a major restriction of agricultural productivity in the GIP area. Sudden surges of water through breaches and public cuts will however result in serious problems of crop and infrastructure damage.

12.3 Morphology

12.3.1 The Teesta river

The river Teesta forms the northern boundary of the GIP model area; it is a major braided river draining from India into the Brahmaputra. It is characterised by relatively steep slopes and high sediment loads.

High flood levels in the Brahmaputra can cause a backwater effect in the lower reaches of the Teesta. This is likely to lead to sediment deposition in these areas. The occurrence of chars in these areas is consistent with sediment deposition.

Analysis of historic survey data indicates that there has been a general trend of movement of the river to the South-West. The cause of this movement is not clear. A study of the topography of the area, particularly along the right bank of the river, indicates that there are no effective natural constraints to prevent further movement to the South-West. If this movement continues then the frequency of breaching of the present Teesta right embankment will increase and any further embankments or structures constructed along the right bank will be threatened by erosion. Further development of the TRE must address the issue of river training as well as the construction of an embankment to prevent ingress of flood waters.

The location of the mouth of the Teesta is strongly influenced by channel movement within the Brahmaputra. Over the past 30 years the mouth has had a general movement in a South-Westerly direction.

Analysis of historic data reveals that the current channel pattern of the river Teesta and the evolution of this pattern is similar to that found by FAP-1 in their study of the morphology of the Brahmaputra. There appear to be a sequence of locations along the river where the anabranches come together to form a more or less single channel. These locations appear to be fixed in space and the river at these points is relatively stable. Between these fixed points the river divides into a number of anabranches, each of which has a sinuous form. These areas are characterised by a large belt width and a highly variable plan form. The fixed locations or nodes are located at Belka, Kaunia, upstream of Kaunia and Purba Chihandi. Between these locations the belt width of the river is approximately 10 km. Where the anabranches have a sinuous form the wavelength is of the order of 5 or 6 km or more. If there were to be a dramatic change of course of the Teesta due, for example, to a major earthquake it is likely to take place at one of the nodes.

At present spills occur from the right bank of the Teesta; these spills contribute water and sediment to the Ghagot and Upper Karatoya river systems. The magnitude of these spills is small in comparison with the discharge of the Teesta.

The Teesta Drainage Project is presently under construction. The barrage confines the width of the river but as the selected site corresponds with one of the stable nodes of the river it is unlikely to have a significant impact on the plan form of the river. As the storage at the barrage is relatively small in comparison with the discharge of the river it is not expected to have a significant impact on the overall morphology of the Teesta. There may, however, be local impacts confined to the neighbourhood of the structure.

The time for morphological re-adjustment in the river Teesta is likely to be 20 to 50 years.

12.3.2 The Ghagot river

The Ghagot river forms the western and southern boundary of the GIP area.

The river rises close to the right bank of the Teesta and then flows south-east towards the Brahmaputra which it enters through the Manas regulator. Flow which does not pass through the regulator flows south through the Alai Nadi river into the Bangali river system. The principle tributary of the Ghagot is the Alai Kumari, which also rises close to the Teesta right bank.
A comparison, for the 1991 flood season, of the water level hydrographs at Jafarganj on the Ghagot and Kaunia on the Teesta indicate that while the low flows in the Ghagot appear to be independent of those in the Teesta the high flows correspond to flood peaks in the Teesta, Figure 12.5. This suggests that during high flows in the Teesta significant spills take place into the Ghagot. There is also evidence to suggest that spill flows from the Teesta enter the Alai Kumari and thence the Ghagot.

The opinion has been expressed during the NWRS public participation exercises that the bed level of the Ghagot is rising with time. The evidence given to support this was lower water depths and drying out of the river bed during the dry season. This is more likely to be indicative of lower discharges during the dry season. It has been suggested that sediment should be removed from the bed of the river to restore earlier bed levels and to provide greater conveyance.

To investigate this the water level records at Jafarganj, Islampur and Gaibanda were examined. The lowest water levels for each season were plotted through time. It is likely that these changes in low water level reflect changes in bed level. Care must be taken, however, since low water levels will also be influenced by pumping for irrigation purposes. Low water level readings will also be affected if the gauge site is moved; it is known that in some areas water level readings are taken at the nearest point to the gauge site at which water is found.

At Jafarganj low water levels were available from 1977. These showed a progressive rise until 1987 of approximately 0.5 m, that is approximately 0.05 m per year. In 1988 and 1989 the levels fell by approximately 0.2 m. The reduction in 1988 is likely to be caused by the flood discharge of that year causing scour locally in the neighbourhood of the gauging site.

The low water levels at Islampur from 1965 and at Gaibanda from 1960 do not exhibit any discernible trend. This suggests that there has not been a significant change in bed level at these locations over this period.

All the locations show a reduction in level between 1987 and 1989 of approximately 0.2 m at Jafarganj and Islampur and 0.5 m at Gaibanda. This reduction is likely to be due to scour in the neighbourhood of the gauging station caused by the high flows.

The data suggests that net deposition is taking place in the Jafarganj region. It does not indicate any significant bed level changes in the region of Islampur and Gaibanda. This was supported during field visits when no evidence of significant deposition at these locations was found.

Using the output from the GIP model to provide information on flow velocities, depths and water surface slopes, sediment transport calculations were performed at various locations along the Ghagot river. The Ackers and White sediment transport theory was used to predict the movement of the non-cohesive sediment. The cumulative sediment transport rate during the 1985 flood season was determined. This year was selected since the flows have a return period of 2 to 5 years; these are the dominant flows as far as the determination of channel geometry is concerned.

The results indicated that substantial quantities of sediment were transported at Jafarganj but that at Islampur the amount transported was significantly less. A similar calculation indicated that transport immediately upstream of the Alai Kumari confluence was less than that at Islampur. Immediately downstream of the Alai Kumari confluence, however, the sediment transport rate was significant. Calculations showed that at Mirajpur the sediment transport rate had reduced, while at Gaibanda the sediment transport rate was negligible.

This pattern of sediment movement is consistent with spills from the Teesta introducing large quantities of sediment into the Ghagot which is deposited in the reach immediately downstream of Jafarganj. The difference in calculated transport at Jafarganj and Islampur is consistent with the inferred bed level rise at Jafarganj of approximately 0.05 m per year. The low sediment transport at Islampur suggests little opportunity for bed level change, which is consistent with the inferred stability of bed levels. The calculations immediately upstream and downstream of the confluence with the Alai Kumari suggest that this tributary brings significant quantities of sediment into the Ghagot. The reduction in the quantity of transported sediment from this confluence to Gaibanda suggests that this sediment inflow is deposited in this reach of the river. The low sediment transport at Gaibanda implies little opportunity for bed level change which is consistent with the observed low water level behaviour.

The pattern is thus of spill flows from the Teesta into the Ghagot bringing in sediment which is then deposited in the reach of the river downstream. The present rate of accretion in the reach at Jafarganj would appear to be of the order of 0.05 m per year. The rate of accretion in the reach at Mirajpur is likely to be comparable though the amount deposited per year will depend upon the quantity of spills from the Teesta.

During field visits evidence of sedimentation was observed in the reach of the Alai Kumari immediately upstream of the confluence. This would seem to be caused by backwater effects from the Ghagot which reduce the flow velocities and increase the depth of flow and so cause sediment deposition.

The overall regime characteristics of the Ghagot river was investigated. The measured flows together with the MIKE11 flow calculations suggest a dominant discharge of approximately 200 m^3/s. If a sediment size of 0.2 mm and a sediment concentration of 200 ppm are assumed the regime conditions corresponding to this data give a channel of width 44m, depth 4.5m and slope of 0.00009

The valley, or straight line, slope of the river is approximately 0.00019. This would suggest a sinuosity of approximately 2.1. The observed sinuosity is likewise 2.1. The regime theory, therefore, provides an adequate description of the current plan form of the Ghagot river.

The plan form of the river as taken from 1991 SPOT images was compared with topographic maps originally prepared in the 1970's. A study was made of the number of meander cut-offs that had occurred in this period and the number of new meander loops that had developed. The number of cut-offs (10) exceeded significantly the number of new meander loops (2). This suggests that during this period the sinuosity of the river had reduced leading to a reduction in the overall length of the river. This change in plan form would be consistent with a reduction in the dominant discharge of the river. This could have been caused by the construction in the late 1960's of the Teesta Right Embankment. By reducing the spillage from the Teesta into the Ghagot this would have had the effect of reducing the flows in the river and hence the dominant discharge. Predominantly, but not exclusively, the cut-offs occur downstream of the confluence with the Alai Kumari. This might suggest that the construction of the present Teesta Right Embankment has reduced flows in the Alai Kumari more than in the Ghagot upstream.

It has been reported that since approximately 1985 the spills through the Teesta Right Embankment have increased. If this is happening then increases in the flow are likely to cause further changes in the Ghagot river system.

It is noticeable that very little change in plan form has taken place in the reach immediately upstream of Gaibanda. The results of the flow and sediment transport calculations suggest that this area is affected by backwater effects from the Brahmaputra and the Manas regulator and so the reduced velocities reduce the likelihood of plan form change.

The time for morphological re-adjustment in the Ghagot and Alai Kumari rivers is likely to be less than 20 years.

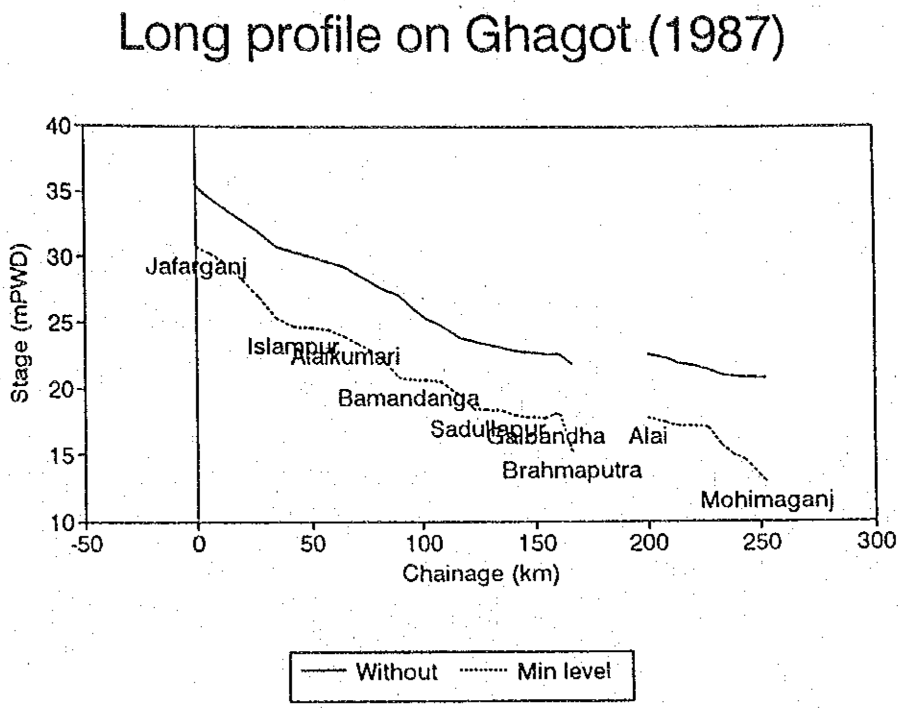


Figure 12.1 **Long profile along the Ghagot - Future Without**

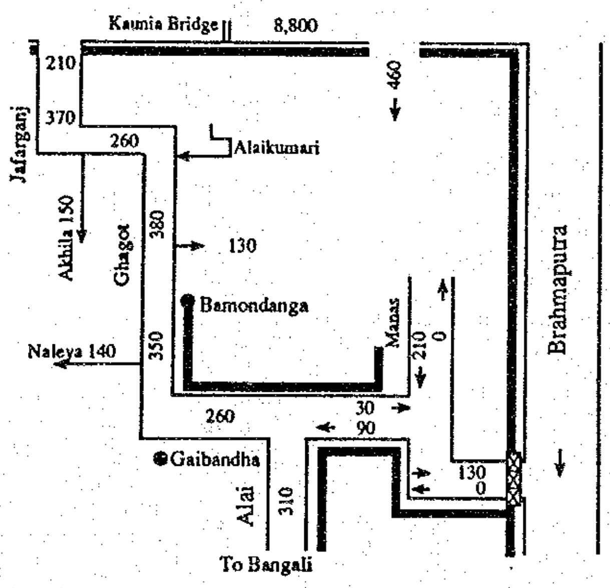
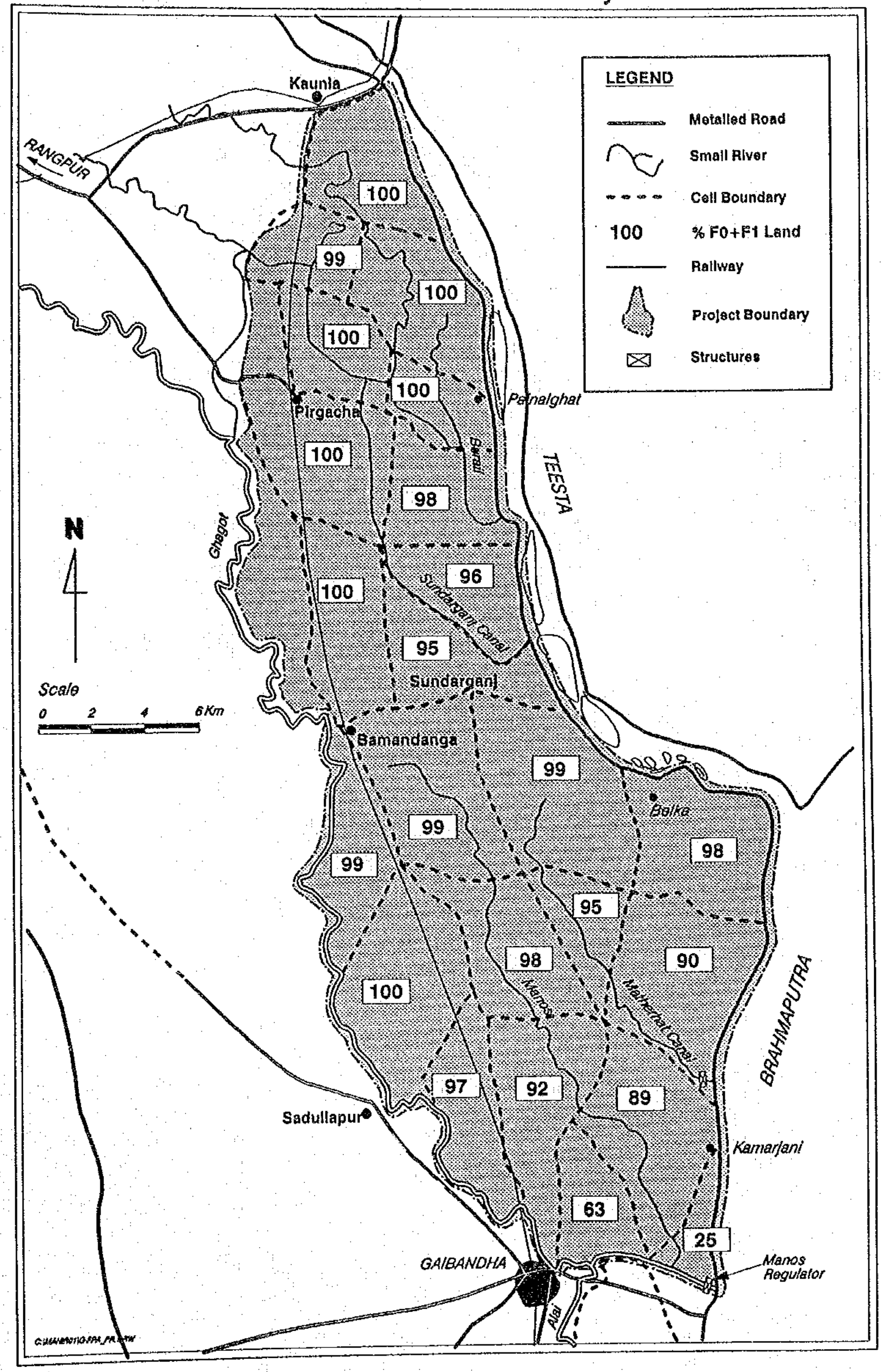


Figure 12.2 **Discharge distribution - Future Without**

Figure 12.3

Flood Phase Analysis - Future Without



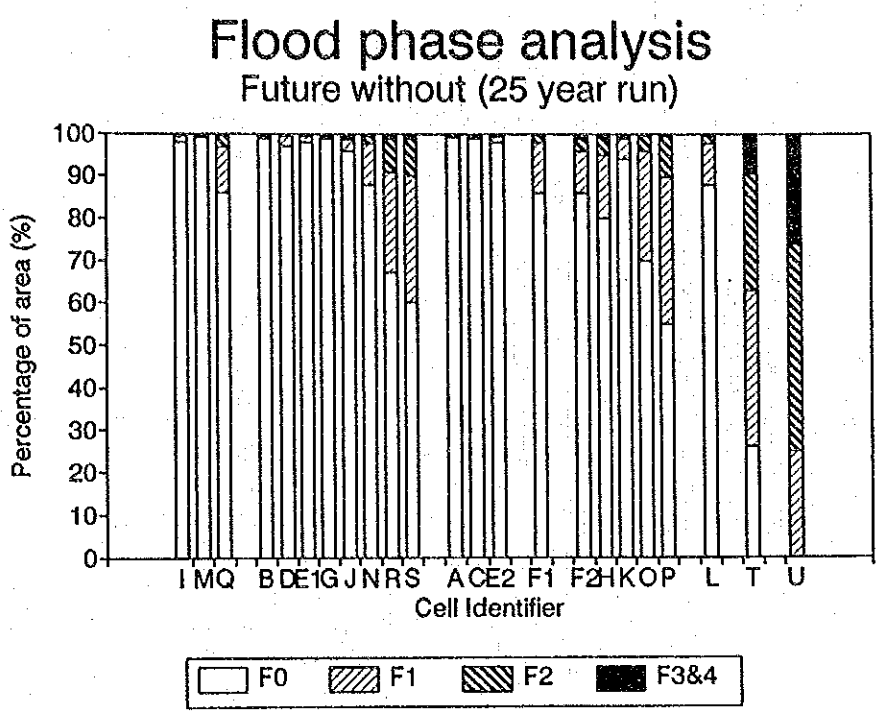


Figure 12.4 Flood phase analysis - Future Without

CHAPTER 13

GAIBANDHA MODEL DESIGN OPTION SIMULATIONS

13.1 Selection of design years

For the purposes of assessing the relative merits of different options prior to the With Project model run, which will include the selected options, representative years have been selected for the GIP area. For the purposes of this analysis the GIP area was sub-divided into four sub-areas; these sub-areas are known as A, B,C and D, as they go from north to south. The selected years represent the closest approximation available to the 1 in 20, 1 in 10, 1 in 5 and 1 in 2 year events, averaged over each part of the GIP area. The procedure is summarized below, together with the list of years selected.

Within each of the GIP area a number of model nodes were selected to represent conditions across the area of the unit. This ranged from 7 nodes in sub-area C to 12 nodes in sub-area D.

For each node the model results were analysed to determine the maximum levels exceeded in each year for a range of durations from 1 day to 90 days, and the years were ranked. The rankings calculated for each selected node within the planning unit were then averaged; this information may alternatively be given as a return period for each year for each duration.

For each sub-area the years most closely approximating to the four required return periods were selected; this was based on the results for a duration of 10 days, but note was taken of other durations. The estimated return periods of the years selected as "1 in 20 year" range from 13 years to 39 years, but the difference in water level between these and the actual 20 year event would be fairly small. For the 2 year return period there are a number of potential years in each sub-area. The years selected are given in Table 13.1 below.

TABLE 13.1
Selected design years for the sub-areas

Sub-area	1 in 20	1 in 10	1 in 5	1 in 2
A	1988	1987	1985	1981
B	1988	1987	1985	1981
C	1987	1988	1985	1981
D	1987	1988	1985	1981

Initial design options were only investigated for two years 1985 and 1987. 1985 has a return period of 1 in 5 years throughout the GIP area. The return period for 1987 is between 1 in 10 and 1 in 29 years throughout the GIP area.

The final design options were analysed by carrying out a ten year model simulation which covered all the selected design years. For the Without Project simulation the 25 years of hydrological data were divided into five blocks each of which consisted of 5 years. To simplify the running of the final

design option simulations it would be convenient if the GIP model could be run for two five year blocks of hydrological years. Based on the analysis described above the 1980-84 and 1985-89 blocks were selected for the design option simulations of the GIP model.

TABLE 13.2

Estimated return periods of years selected for option assessment

Year	GIP sub-area			
	A	B	C	D
1981	2	2	2	2
1985	5	5	4	4
1987	7	10	13	39
1988	22	16	13	15

Notes : Underlining indicates years selected as design years for each planning unit.

13.2 Initial design options

13.2.1 Description

The initial options were conceived with the main features of the GIP area in mind. The GIP is bounded to the north and east by embankments on the major rivers and these were key features in the planning for the area. Embankments are also being constructed along the left bank of the Ghagot which may protect the project area itself but which may be disadvantaging people living on the right bank. Manas regulator has insufficient capacity; having initially been designed to drain only the Manas river catchment whereas the Manas/Ghagot link now greatly increases the drainage flows. Furthermore, the Manas regulator is itself under severe attack from erosion and may not survive for more than a few years. The excess drainage which cannot be handled by the Manas regulator flows down the Alai Nadi. Areas on the right bank of the Alai suffer badly from river spillage and drainage congestion.

Considering these, and many other factors, a set of initial design options were investigated. These are described below and summarised in Table 13.3.

Option A : Removal of current Manas regulator

Option B : Sealing of the TRE upstream of Kaunia

Option C : Sealing of the TRE downstream of Kaunia

Option D : Sealing of the TRE both upstream and downstream of Kaunia

Option E : Extension of the Ghagot left embankment from Bamandanga to the Alai Kumari confluence. Construction of a regulator on the Ghagot immediately upstream of the Manas confluence. Embankment on the right bank of the Ghagot from Gaibandha to the Alai Nadi spill.

TABLE 13.3
Summary of initial Gaibandha design options

	A	B	C	D	E	F	G	H	I	J	K	L	M
Removal of Manas regulator	X						X			X	X	X	X
Sealing TRE upstream		X		X				X	X	X	X	X	X
Sealing TRE downstream			X	X				X	X	X	X	X	X
Extension of Ghagot left embankment					X	X	X	X	X	X	X	X	X
Regulator on Ghagot upstream of Manas					X	X		X	X		X	X	
Ghagot right embankment - Gaibandha to Alai Nadi					X	X	X	X	X	X	X	X	X
Ghagot right embankment - Jafarganj to Alai Nadi						X	X		X	X		X	X
Regulator at tail of Manas							X			X	X	X	X
Regulator at head of Alai Nadi							X			X			
Backwater embankment on Ghagot right bank	X						X			X	X	X	X

Option F : Extension of the Ghagot left embankment from Bamandanga to the Alai Kumari confluence. Construction of a regulator on the Ghagot immediately upstream of the Manas confluence. Embankment on the right bank of the Ghagot from Jafarganj to the Alai Nadi spill.

Option G : Removal of current Manas regulator. Construction of regulators at the tail of the Manas and the head of the Alai Nadi. Extension of the Ghagot left embankment from Bamandanga to the Alai Kumari confluence. Embankment on the right bank of the Ghagot from Jafarganj to the Alai Nadi spill.

Option H : Option E with the TRE sealed both upstream and downstream of Kaunia.

Option I : Option F with the TRE sealed both upstream and downstream of Kaunia.

Option J : Option G with the TRE sealed both upstream and downstream of Kaunia.

Option K : Option H with the current Manas regulator removed. Construction of a new regulator at the tail of the Manas river.

Option L : Option K with an embankment on the right bank of the Ghagot from Jafarganj to the Alai Nadi spill.

Option M : Option L without the regulator on the Ghagot immediately upstream of the Manas confluence.

Model simulations were carried out for each of these design options for two hydrological years 1985 and 1987. 1985 has a return period of 1 in 5 years throughout the GIP area. The return period for 1987 is between 1 in 10 and 1 in 39 years throughout the GIP area. The results of each of these simulations were compared with the Without Project simulation for the same year.

Schematic diagrams for each of the initial options are shown in Figures 13.1 to 13.4. These figures also show the impact that the initial design options have on peak discharges. This presents the peak discharges with the design option in place together with the peak discharge for the Without project simulation. The impacts on peak levels in the Ghagot river are also shown in Figures 13.5 to 13.8.

13.2.2 Discussion of results

Design option A : It is predicted that the Manas regulator will be carried away by severe erosion in the Brahmaputra. This design option investigates the impact of this happening.

Removal of the current Manas regulator results in a reduction in peak water levels in the downstream reaches of the Ghagot and the Manas river of up to 0.8 m. Since the removal of the current Manas regulator effectively creates a breach in the BRE there is a need to provide a backwater embankment to prevent spillage due to high water levels in the Brahmaputra. Since this is effectively a major river embankment the backwater embankment needs to provide protection against 100 year return period water levels in the Brahmaputra; the proposed backwater embankment would extend to upstream of Gaibandha town.

In the absence of the Manas regulator water can pass from the Brahmaputra into the Ghagot when water levels in the Brahmaputra are higher than those in the Ghagot. This flow would have been a peak of 250 m^3/s in 1987. This flow from the Brahmaputra must pass down the Alai Nadi worsening the flooding and drainage problem along this river. The capacity of the Alai Nadi is less than 100 m^3/s due to a very gentle slope.

Design option B : 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. Figure 13.5 presents a longitudinal profile along the Ghagot for the Without Project simulation and with the breaches in the TRE upstream of Kaunia sealed.

The peak discharge in the Ghagot is reduced by 210 m^3/s as a result of sealing the TRE breaches upstream of Kaunia. 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.

Design option C : Peak discharges of the order of 500 m^3/s enter the GIP 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.

Design option D : The impact of design option D is a combination of those for design options B and C which are described above.

Design option E : Embanking of the Ghagot river on the left bank from Bamandanga to the Alai Kumari combined with the regulator on the Ghagot immediately upstream of the Manas confluence results in increases in water level in the Ghagot of up to 0.5 m relative to the Without project conditions. Water levels are increased as far upstream as Islampur. The water level increase in the Ghagot is partly due to the confinement which results from the extension of the left embankment as far as the Alai Kumari confluence.

Design option F : The construction of a Ghagot right embankment from Jafarganj to Gaibandha town further confines the river. It results in peak water levels which are 1 m higher than those for design option E. Figure 13.6 presents longitudinal peak water level profiles along the Ghagot river for the Without project simulation and design option F.

Design option G : Design option G reduces water levels in the reach between the Ghagot outfall and Gaibandha town. Peak water levels upstream of Gaibandha town are increased by up to 1.2 m relative to Without project conditions.

Design option H : This is design option E with the TRE sealed both upstream and downstream of Kaunia. The sealing of the TRE breaches more than counters the impact of confinement caused by the construction of the left embankment extension. Peak water levels in the Ghagot are decreased by up to 1.5 m; the greatest impact is in the upstream reaches of the Ghagot. Further downstream the water level decrease in the Ghagot is smaller than in design options B and D because of the confining effect of the extension to the left embankment.

Design option I : This is design option F with the TRE sealed both upstream and downstream of Kaunia. The sealing of the TRE breaches more than counters the impact of confinement caused by the construction of the left embankment extension and the Ghagot right embankment. Peak water levels in the Ghagot are decreased by up to 1.5 m; the greatest impact is in the upstream reaches of the Ghagot. Further downstream the water level decrease in the Ghagot is smaller than in design options B and D because of the confining effect of the extension to the left embankment and the right embankment. Figure 13.7 presents longitudinal peak water level profiles for the Ghagot for Without project conditions and design options F and I.

Design option J : This is design option G with the TRE sealed both upstream and downstream of Kaunia. The results of this design option are effectively identical to those from design option I.

Design option K : This is design option H with the existing Manas regulator removed. It is predicted that this regulator will be carried away by severe erosion in the Brahmaputra. Upstream of the regulator which is immediately upstream of the Manas confluence the water levels are similar to those in design option H, that is, water levels in the Ghagot are reduced by up to 1.5 m with the greatest reductions in the upstream reaches. Downstream of the Manas confluence there is a reduction in

water level of up to 0.8 m, relative to Without project conditions, as a result of removing the Manas regulator.

Design option L : This is design option K with the Ghagot right embankment from Jafarganj to Gaibandha town. The results upstream of the regulator immediately upstream of the Manas confluence are similar to those of design option I, that is, water levels in the Ghagot are reduced by up to 1.5 m with the greatest reductions in the upstream reaches. Downstream of the Manas confluence there is a reduction in water level of up to 0.8 m, relative to Without project conditions, as a result of removing the Manas regulator.

Design option M : For design option L most of the flood discharge from the Ghagot is diverted down the Alai Nadi. These flows are significantly greater than the capacity of this river. They are likely to result in flooding problems on the right bank of the Alai Nadi worse than those which currently occur. To alleviate this problem design option M was carried out, this is the same as design option L but with the regulator on the Ghagot upstream of the Manas confluence removed. The removal of the regulator only reduces the peak flow in the Alai Nadi by a small amount. Peak water levels in the Ghagot and Alai Nadi are very similar for design options L and M.

13.2.3 Summary of initial design option simulations

Based on the design options described above it can be concluded that,

- sealing of the TRE upstream and downstream of Kaunia improve the internal flooding conditions in the GIP by reducing water levels in the Ghagot and also reducing inflow discharge into the GIP area.

- the reductions in water level in the Ghagot which results from sealing the TRE does not prevent spillage from the Ghagot into the GIP 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 GIP area. The Ghagot right embankment has no benefits for the GIP 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.

A scheme which included these features formed the basis for the refined design options. These were run for the 10 year simulations in order to assess more thoroughly their performance against a wide range of hydraulic conditions.

13.3 Refined design option simulations

13.3.1 Design options investigated

The following ten year design options simulations were carried out with the GIP model,

Option N : Removal of current Manas regulator. Backwater embankment to prevent spillage on the Ghagot right bank when Brahmaputra levels are high. Sealing of the TRE upstream and downstream of Kaunia. Extension of the Ghagot left embankment from Bamandanga to Jafarganj. Regulator at the tail of the Manas and head of the Alai Nadi.

Option O : Option N with compartmentalisation in the GIP area. Compartmentalisation eliminates cross drainage basin water transfers.

Option P : Option N with the regulator at the tail of the Manas removed.

13.3.2 Results of analyses

Model simulations were carried out for each of these design options for two five year blocks, 1980-84 and 1985-89. The results of each of these simulations were compared with the Without Project simulation for the same period.

Figure 13.9 presents a schematic representation of each of these design options. Table 13.4 summarises each of the options. The impact that the design option has on peak discharges in the system is shown schematically in Figure 13.9. This presents the peak discharges with the design option in place together with the peak discharge for the Without project simulation.

TABLE 13.4
Summary of refined Gaibandha design options

	Option N	Option O	Option P
Removal of Manas regulator	X	X	X
Sealing of TRE upstream of Kaunia	X	X	X
Sealing of TRE downstream of Kaunia	X	X	X
Extension of Ghagot left embankment	X	X	X
Regulator at tail of Manas	X	X	
Regulator at head of Alai Nadi	X	X	X
Backwater embankment on Ghagot right bank	X	X	X
Compartmentalisation		X	

The results of the ten year design options are presented by comparing the flood phases with the design option in place with those for the Without Project simulation. Figures presenting these comparisons show the percentage of F0+F1 land for each of the GIP area model cells. The flood phase results for the GIP area are summarised in Table 13.5.

Design option N : The flood phases for the Without project simulation and design option N are presented in Figure 13.10. Throughout the northern two-thirds of the GIP area the pattern is one of no change or a reduction in the area of deeper flooded land. The conditions in the areas adjacent to the TRE are significantly improved by the sealing of the TRE breaches downstream of Kaunia. In the southern parts of the GIP area, to the north of the Ghagot river the percentage of F0+F1 land is lower for design option N than under the Without Project conditions. At the Ghagot outfall the percentage of F0+F1 land is significantly increased by the proposed developments.

When the flood phases for the entire GIP area are considered the conditions Without project and with design option N are very similar.

TABLE 13.5
Flood phases for the GIP area for refined design option simulations

	F0	F1	F2	F3+F4
Without project	78 %	14 %	6 %	2 %
Option N	79 %	13 %	7 %	1 %
Option O	84 %	11 %	4 %	1 %
Option P	85 %	10 %	4 %	1 %

Design option O : This is design option N with internal compartmentalisation in the GIP area. Compartmentalisation isolates drainage basins by eliminating cross basin water transfers.

The flood phases for the Without project simulation and design option O are presented in Figure 13.11. The pattern is one of improved conditions throughout almost the entire GIP area. The greatest changes occur in the Manas basin where the percentage of F0+F1 land is significantly increased. The reason for this is that compartmentalisation reduces the north to south flow of water in the GIP area and thus reduces the quantity of water which enters the Manas basin.

In some of the cells which are adjacent to the outfalls of the internal drains the conditions are made slightly worse by compartmentalisation. The reason for this is that compartmentalisation eliminates southward flow out of these cells; drainage congestion caused by high water levels in the external rivers leads to the reduction in F0+F1 land.

If the entire GIP area is considered the flood phases for design option O are an improvement on those for Without project conditions.

Design option P : This is design option N with the regulator at the tail of the Manas river removed.

The flood phases for the Without project simulation and design option P are presented in Figure 13.12.

For this design option the percentage of F0+F1 land is either the same or greater in each of the GIP area flood cells than it is under Without project conditions.

If the entire GIP area is considered the flood phases for design option P are better than those under Without project conditions and very similar to those for design option O.

13.3.3 Summary of refined design options simulations

Design option O and P result in greater areas of F0 and F1 land than either the Without project conditions or design option N. In design option P the percentage of F0+F1 land either remains the same or is increased in each of the flood cells in the GIP area. In design option O the percentage of F0+F1 is increased significantly in the southern parts of the area but in the areas near the outfalls of the drainage channels the percentage of F0+F1 land is decreased. If the GIP area is considered as a whole the percentage of F0+F1 land is the same for design options O and P.

Design option P involves leaving the Manas river unregulated. This creates a potential path for the Brahmaputra to enter the Manas basin; it effectively creates a breach in the BRE. This solution is felt to be unacceptable from a flood protection point of view.

Design option O was selected for the With project simulation; the key features of this design option are,

- Sealing of the Teesta right embankment both upstream and downstream of Kaunia.
- Removal of the Manas regulator.
- The construction of a new regulator at the outfall of the Manas to the Ghagot.
- The construction of a backwater embankment along the Ghagot upstream of its confluence with the Brahmaputra.
- Construction of a regulator at the head of the Alai Nadi.
- An extension of the Ghagot left embankment upstream from Bamandanga as far as the Alai Kumari confluence.
- Compartmentalisation within the GIP area.

In addition to these features the capacity of regulators in the GIP was increased for the With project simulation in an attempt to alleviate drainage congestion. A meander cut-off in the vicinity of Gaibandha town was also included to reduce bank erosion and flooding problems.

Figure 13.1 DISCHARGE DISTRIBUTION FOR OPTIONS A TO D UNDER PRESENT DRAINAGE CONDITION

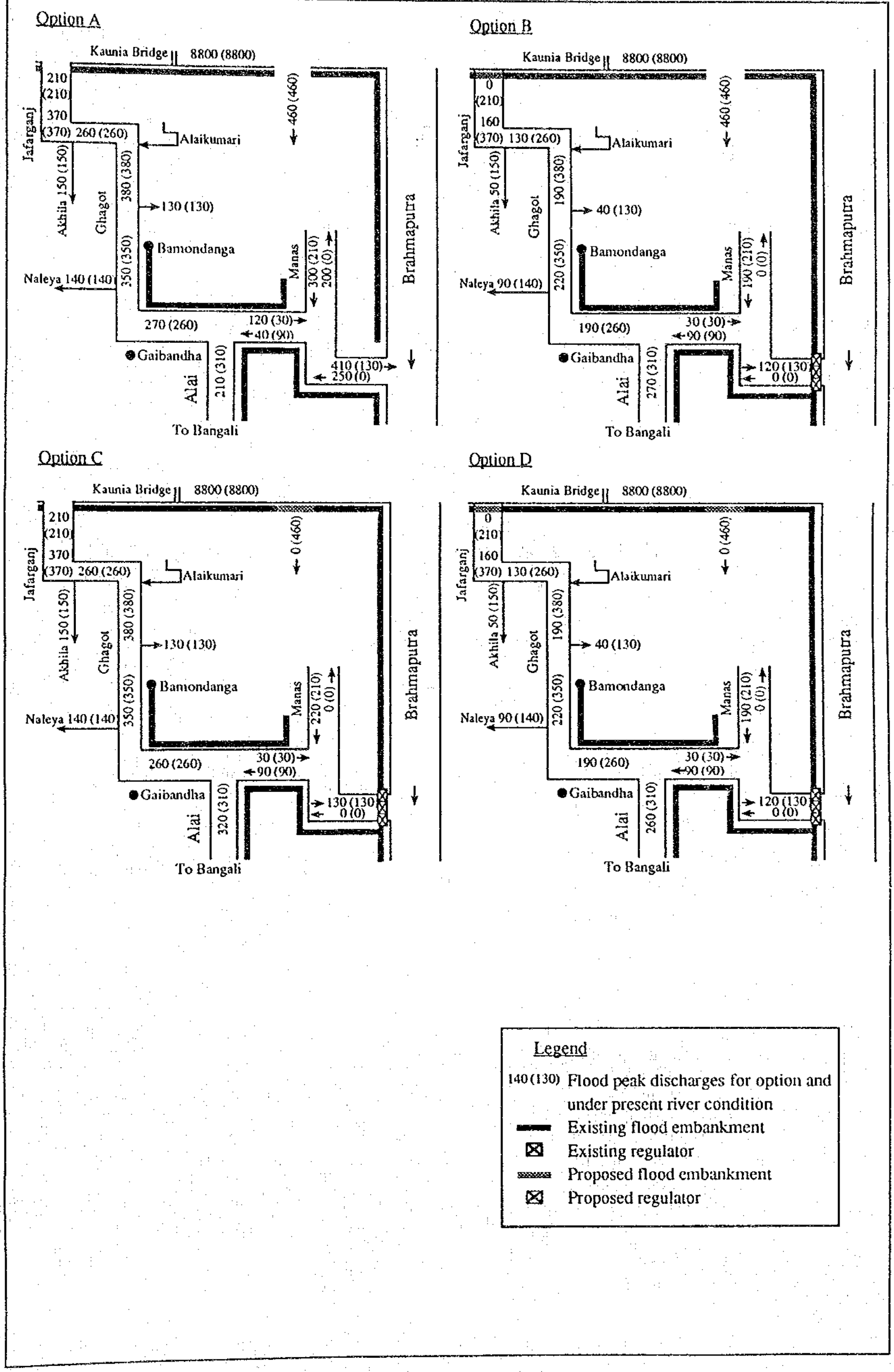


Figure 13.2 DISCHARGE DISTRIBUTION FOR OPTIONS E TO J UNDER PRESENT DRAINAGE CONDITION (1/2)

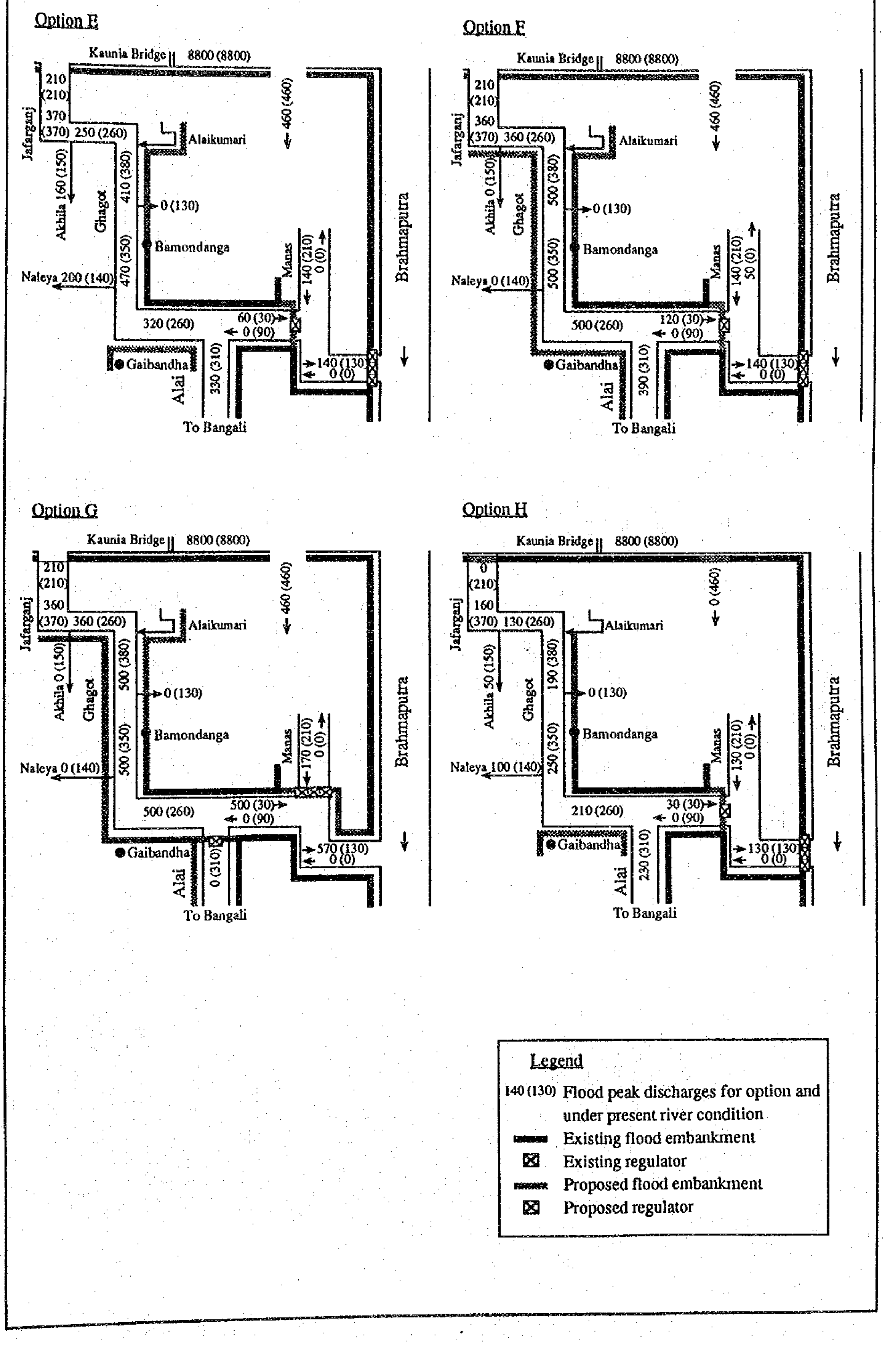
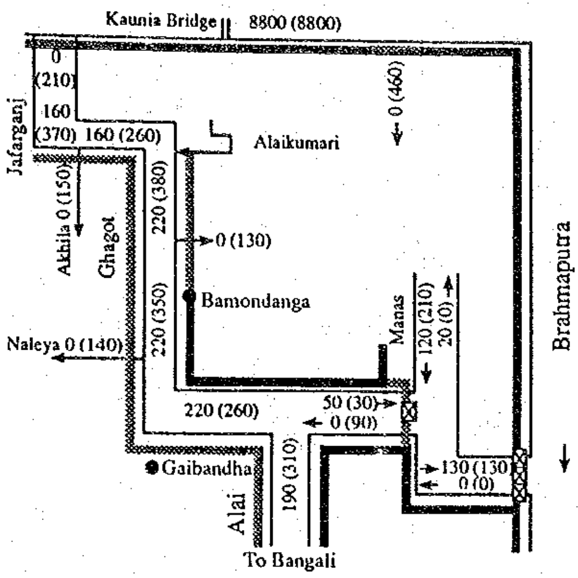
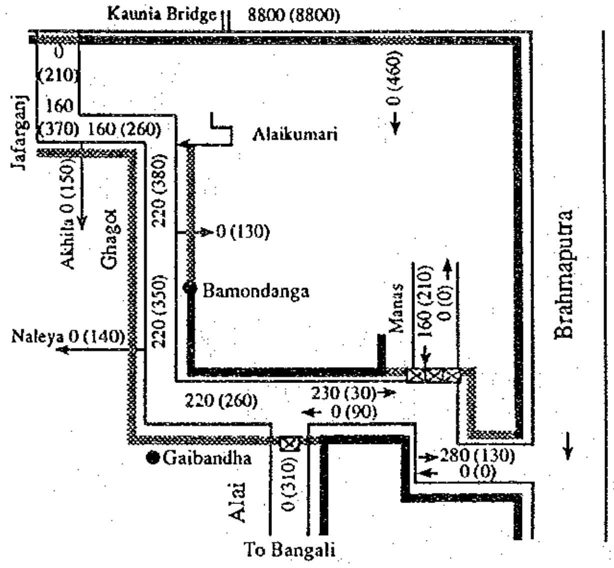


Figure 13.3 DISCHARGE DISTRIBUTION FOR OPTIONS E TO J UNDER PRESENT DRAINAGE CONDITION (2/2)

Option I



Option J



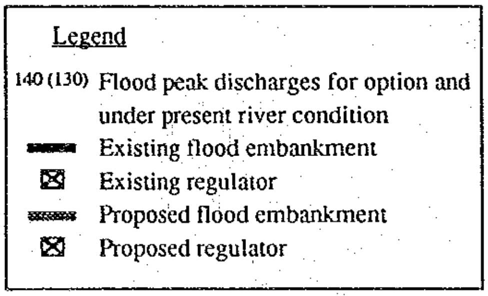
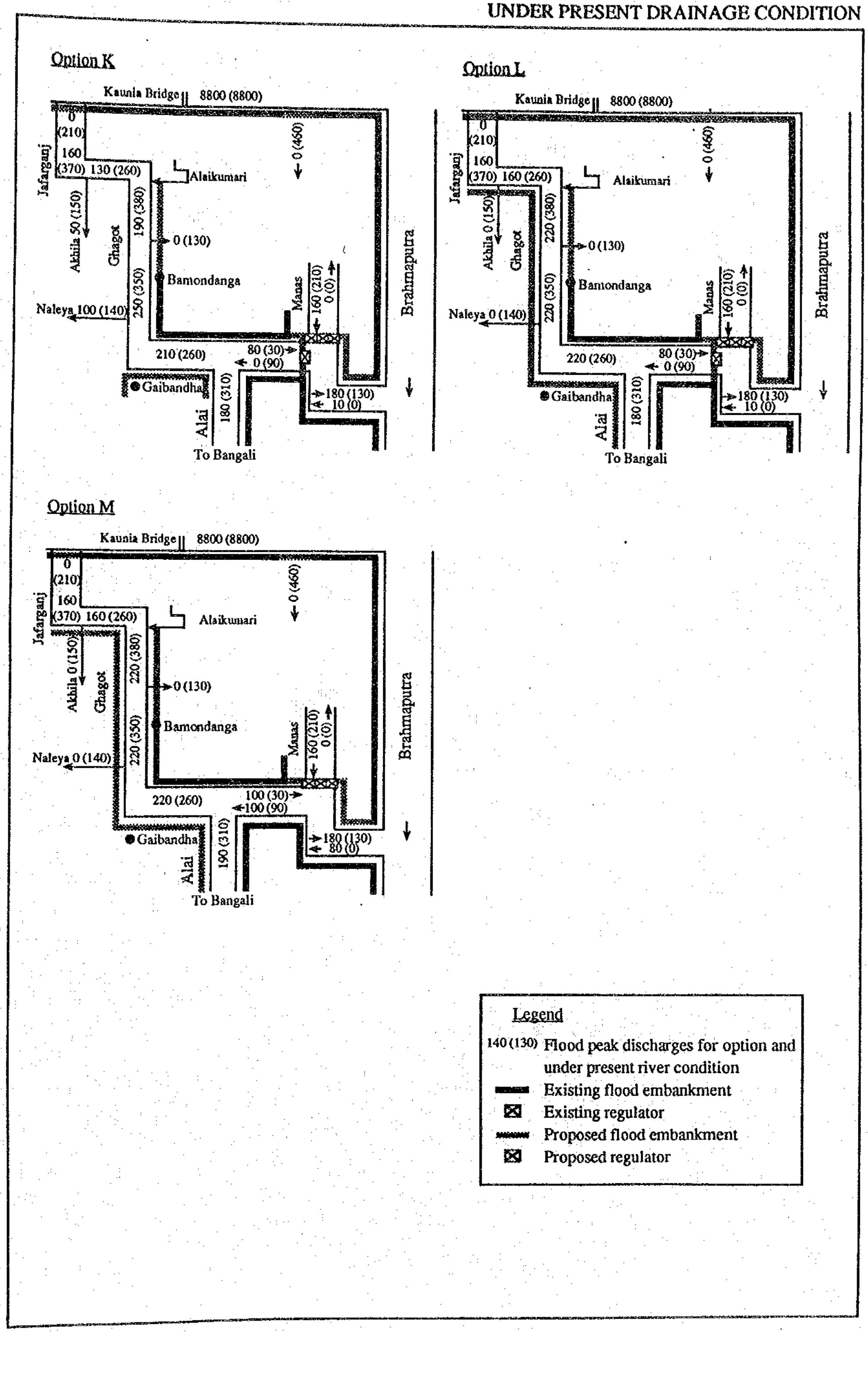


Figure 13.4 DISCHARGE DISTRIBUTION FOR OPTIONS K TO M UNDER PRESENT DRAINAGE CONDITION



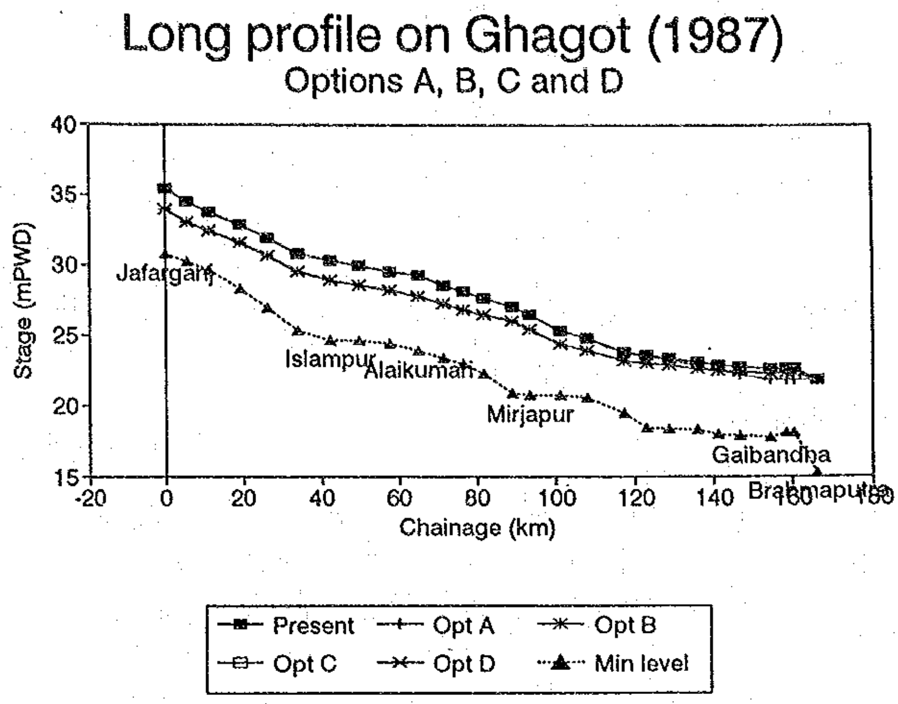


Figure 13.5 Long profile along Ghagot - Options A to D

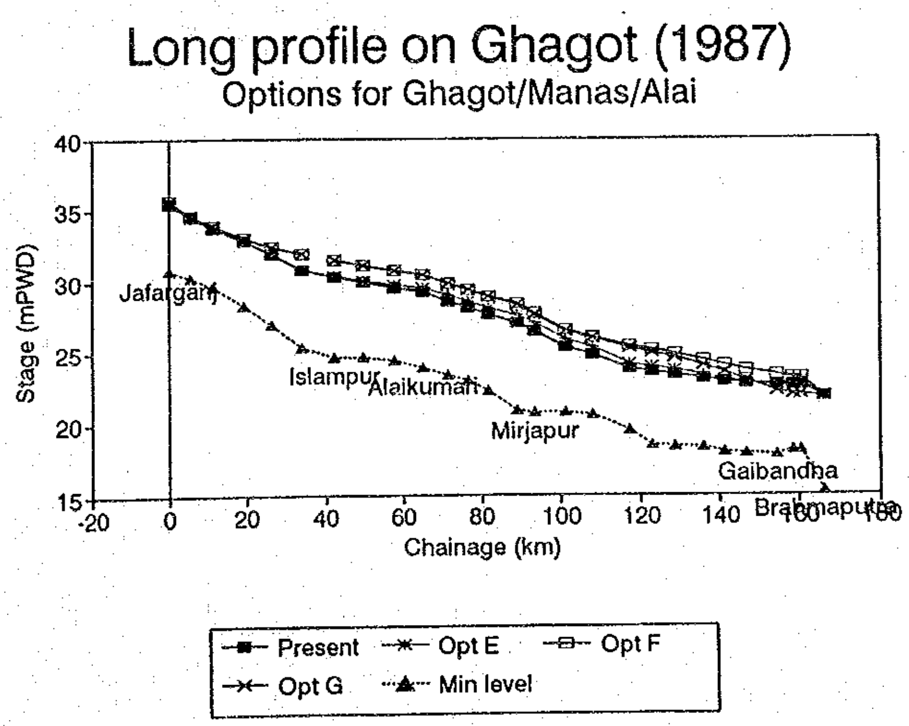


Figure 13.6 Long profile along Ghagot - Options E to G

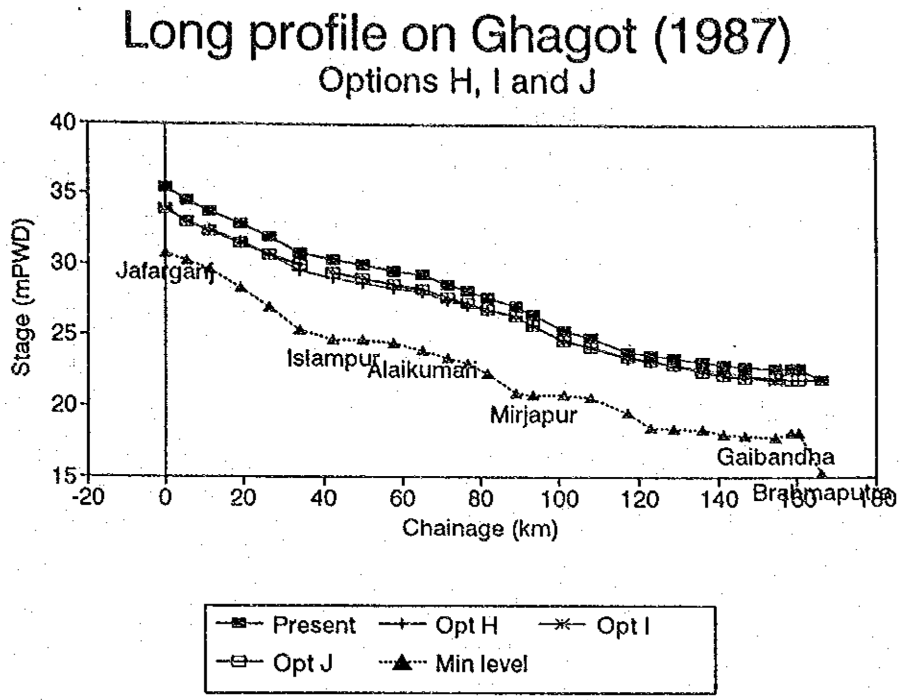


Figure 13.7 **Long profile along Ghagot - Options H to J**

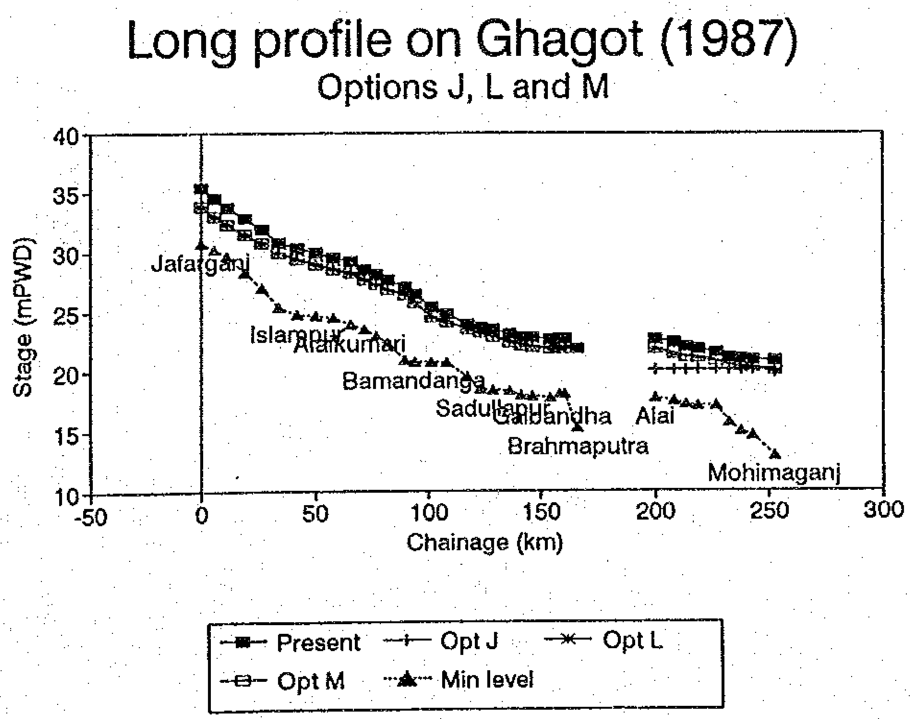
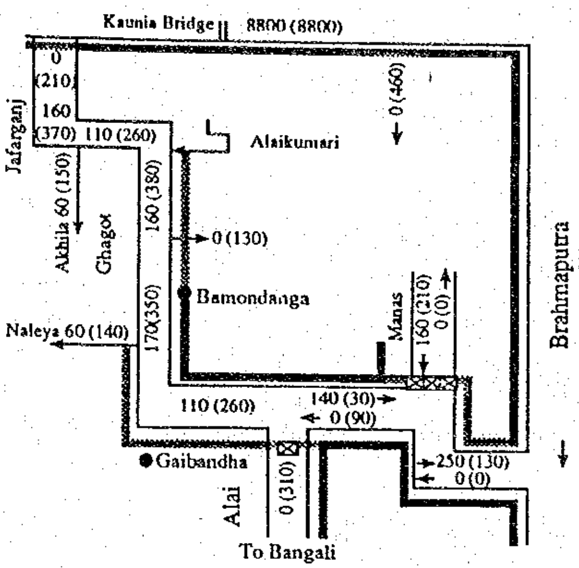


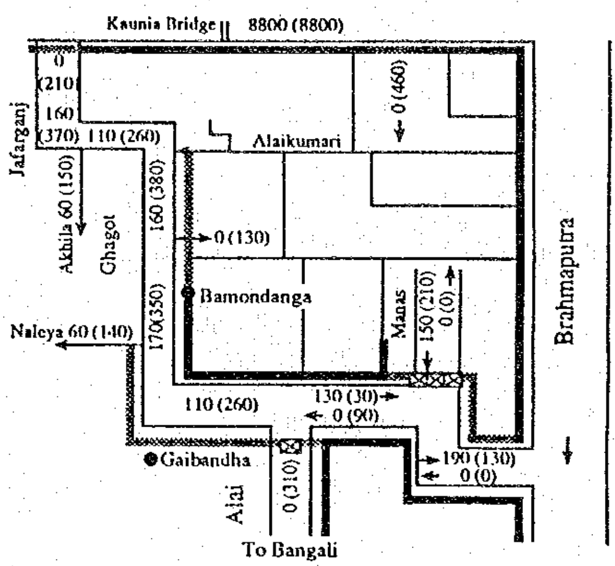
Figure 13.8 **Long profile along Ghagot - Options J to M**

Figure 13.9 DISCHARGE DISTRIBUTION FOR OPTIONS N TO Q UNDER PRESENT DRAINAGE CONDITION (2/2)

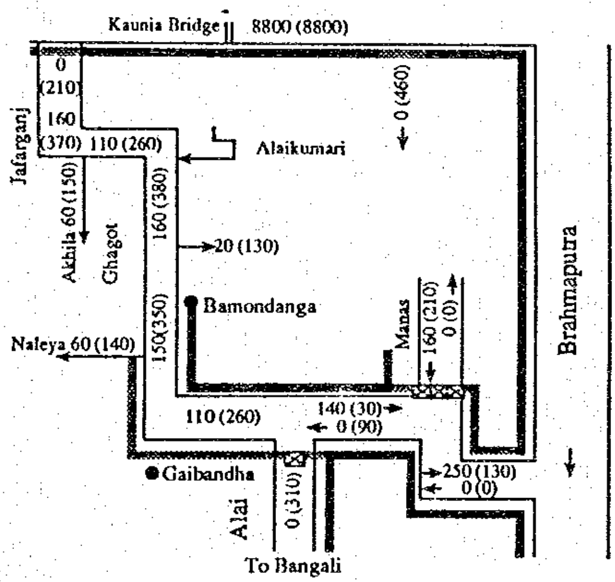
Option N



Option O



Option P



Legend

140 (130) Flood peak discharges for option and under present river condition

Existing flood embankment

Existing regulator

Proposed flood embankment

Proposed regulator

Figure 13.10

Flood Phase Analysis - Option N

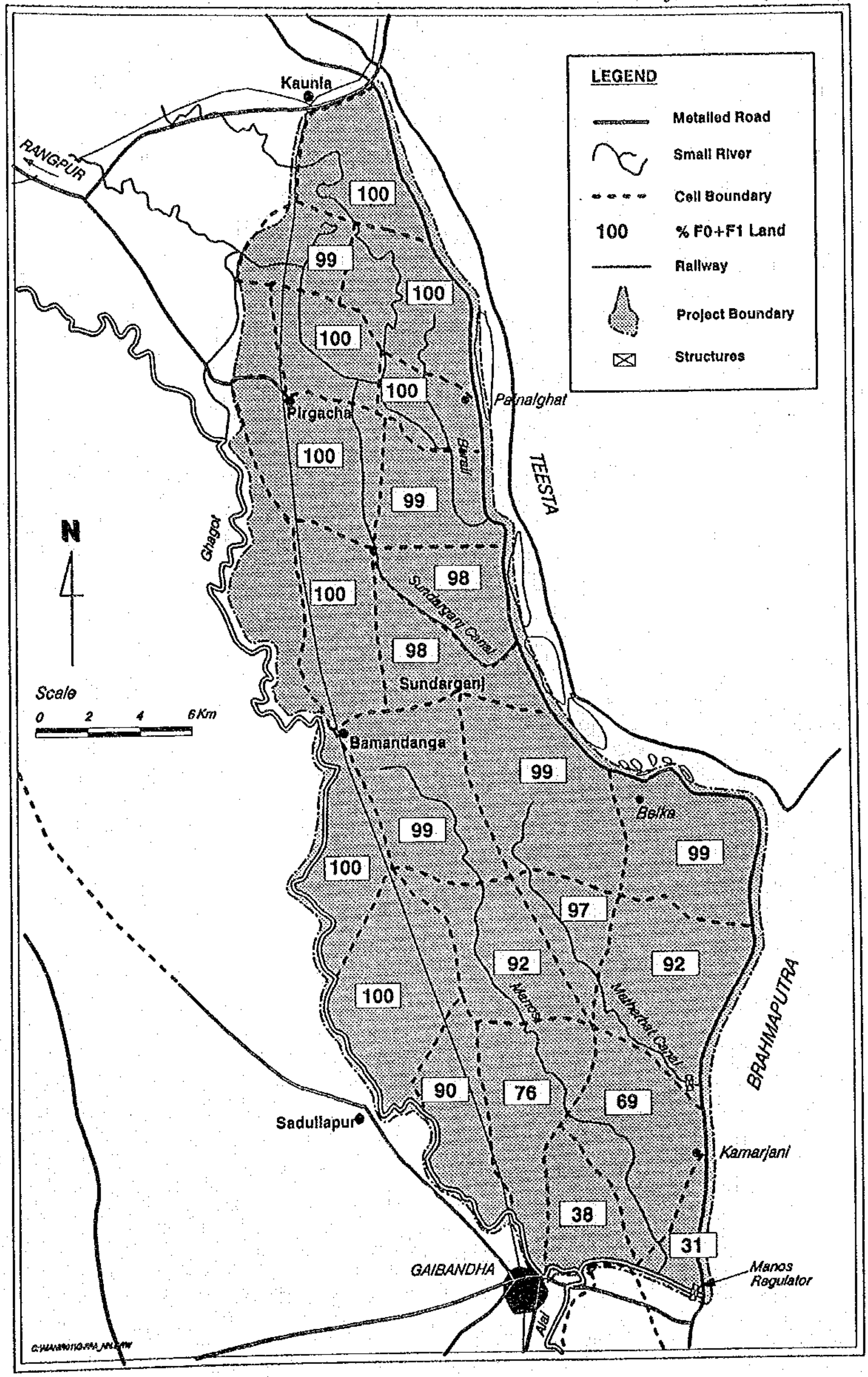


Figure 13.11

Flood Phase Analysis - Option O

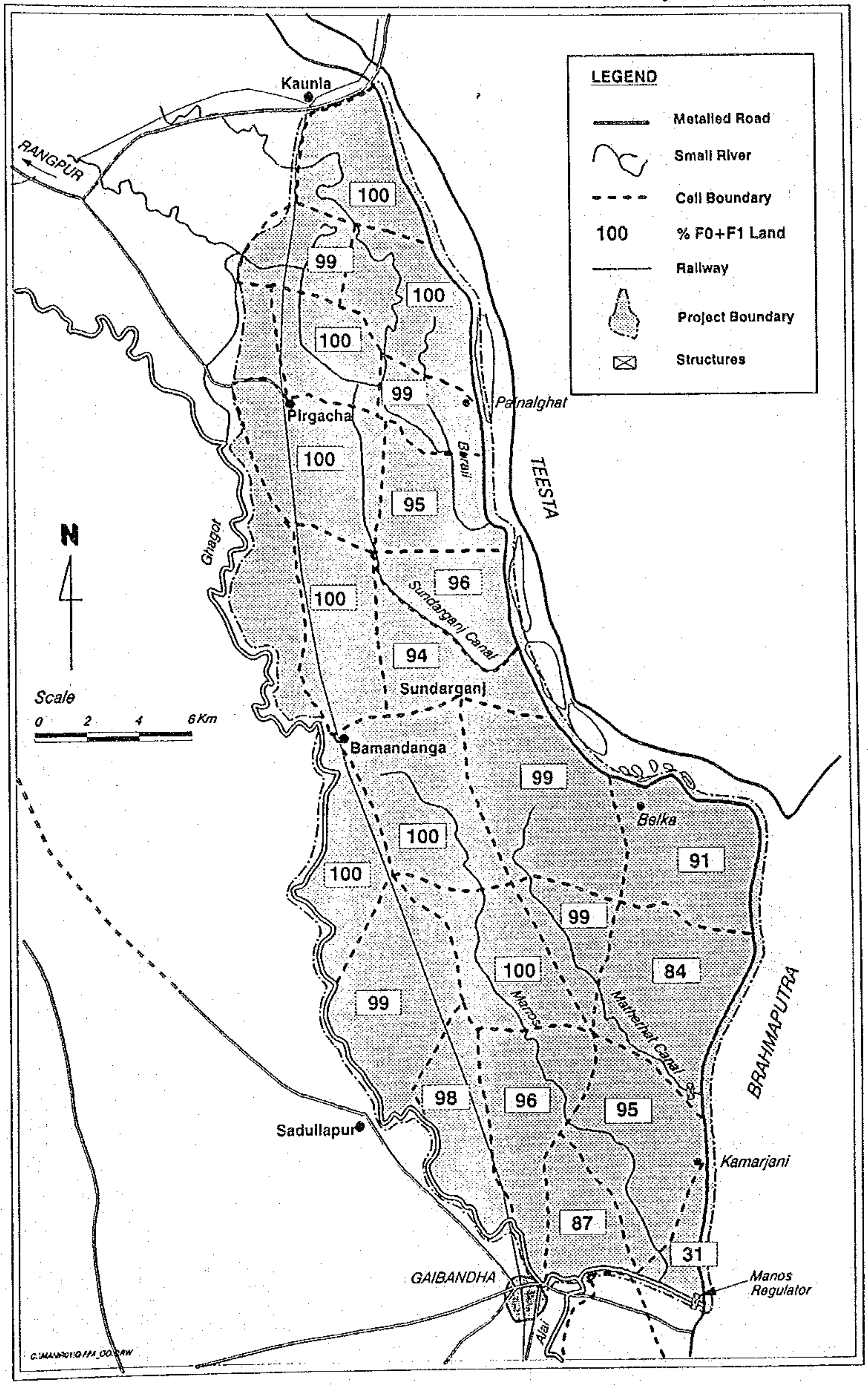
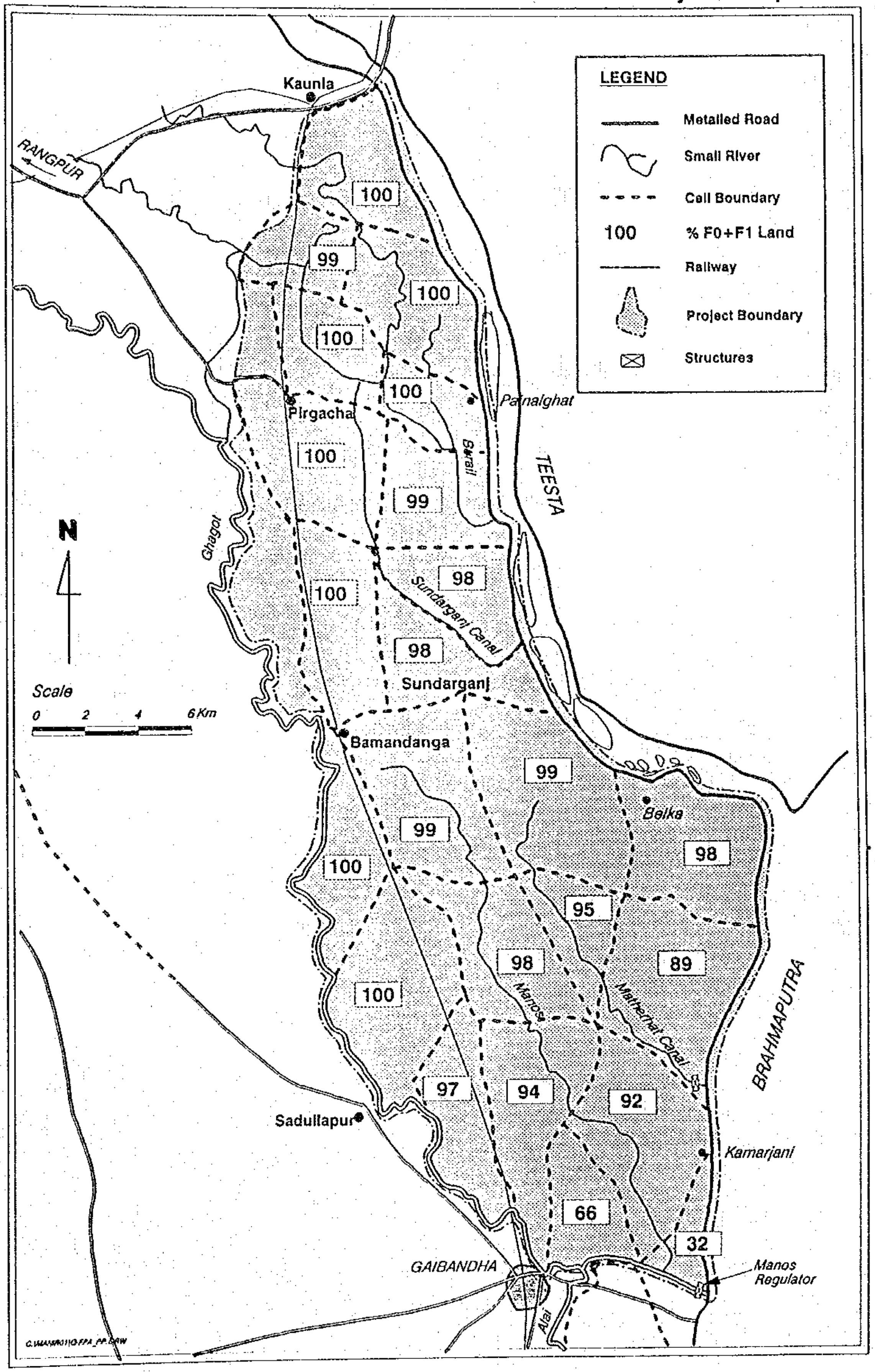


Figure 13.12

Flood Phase Analysis - Option P



CHAPTER 14

GAIBANDHA WITH PROJECT SIMULATION

14.1 Description

14.1.1 General

Following the initial and refined design option simulations a development plan for the GIP area was formulated. A With Project simulation was carried out with this development plan in place.

The With Project simulation used the hydrological data for the period from 1965 to 1989. The impact of the proposed development plan was investigated by comparing the results of the With Project simulation with the results of the Without Project simulation.

The With Project simulation looked at the impact of proposed developments within the modelled area. For the With Project simulations the same external developments, the sealing of the Brahmaputra right embankment, as for the Without Project simulation were assumed.

14.1.2 Proposed developments

The formulated plan for the GIP area consisted of the following features,

- Sealing of the Teesta right embankment both upstream and downstream of Kaunia.

- Removal of the Manas regulator. The Manas regulator is located at a site of active bank erosion by the Brahmaputra; it is likely to be destroyed in the near future. Constructing a new (larger) regulator at this site would be extremely expensive because of the need for extensive river training works on the Brahmaputra.

- The construction of a new regulator at the outfall of the Manas to the Ghagot.

- The construction of a backwater embankment along the Ghagot upstream of its confluence with the Brahmaputra. This embankment would effectively be an extension of the BRE providing protection against 100 year return period water levels in the Brahmaputra.

- Construction of a regulator at the head of the Alai Nadi. This regulator would prevent everything other than a sweetening flow passing down the Alai Nadi.

- An extension of the Ghagot left embankment upstream from Bamandanga as far as the Alai Kumari confluence. This embankment would provide protection against 20 year return period water levels in the Ghagot.

- Compartmentalisation within the GIP area. The GIP area can be divided into a number of drainage basins which, under present conditions, are likely by cross basin drainage paths. Compartmentalisation involves isolation of these internal drainage basis by cutting off the cross basin drainage paths.

- Increasing regulator capacity. It is known that, at present, some of the regulators within the GIP area are under sized. The development plan includes increasing

regulator ventage. The regulators have been designed to allow the drainage of impounded water within two weeks whenever external water levels allow.

- A meander cut-off in the vicinity of Gaibandha town. This will move the main channel of the Ghagot some distance to the north of the town and reduce the problems of bank erosion and flooding from the Ghagot.

Figure 14.1 presents the proposed developments in the GIP area schematically.

14.2 Results of With Project simulation

Water levels

Figure 14.2 shows a long profile along the Ghagot river for a typical higher flow year, 1987. The impact of the with project simulation is to reduce peak water levels by over a metre throughout almost the entire reach. This impact is dominantly due to the sealing of the Teesta right embankment upstream of Kaunia and thereby preventing Teesta water contributing to those in the Ghagot. The overall hydrograph shapes in the upper and middle reaches of the Ghagot also showed a much less peaky form after the sealing of the TRE.

Figure 14.2 also illustrates the impact on water levels in the Alai Nadi of constructing a regulator at the head of this river. The construction of this regulator has no significant impact on water levels in the Ghagot since at the point where the Alai Nadi spills from the Ghagot water levels are determined by backwater effects from the Brahmaputra. With the regulator in place, water levels are reduced by about 2m at the former confluence between the Ghagot and Alai. Near the confluence with the Karatoya water levels are not changed since at this location the backwater effect from the Karatoya dominates. The Alai Nadi regulator would effectively remove problems of spillage on its right bank and allow the rainfall-runoff from the surrounding area to drain more freely down the Alai.

The operation of the new Manas regulator is shown in Figure 14.3 for the 1988 flood season. The drainage capacity is seen to be sufficient as the regulator allows rapid drainage to return internal levels to those of the external, Brahmaputra, in a relatively short time span. The figure also demonstrates how the internal levels can be alleviated from the Brahmaputra spilling in to the area during high stages.

Discharges

The maximum discharges, simulated in the With Project run during 1987, in the main drainage channels of the GIP area are shown in Figure 14.4. Also shown in Figure 14.9 are the magnitude of the spills from the rivers. The figures in bracket represent the corresponding discharges from the Without Project area.

The peak discharges in the Ghagot, Alai Kumari and the drainage channels which enter the north of the GIP area are significantly reduced by the sealing of the TRE. This reduction in flow is reflected throughout the Ghagot river system. The peak discharge in the Alai Nadi is also greatly reduced by the construction of the regulator at the head of this river.

The elimination of cross basin water transfers by compartmentalisation results in an increase in flows in the internal drainage channels. These channels discharge into the Teesta and Brahmaputra; the flow can only pass to the external rivers when the water levels in these rivers is lower than in the internal drainage channels.

Flood phases

Figure 14.5 presents the areal distribution flood phases for the With Project GIP model simulations. This figure shows the percentage of F0+F1 land for each of the model cells. This full flood phase distribution is shown in Figure 14.6. Figure 14.7 shows the difference in F0+F1 land for each cell between the With and Without project simulations.

The proposed developments have resulted in a significant improvement in the situation in the southern parts of the GIP area. The With project simulation shows an increase in the percentage of F0+F1 land in this area in excess of 50 %. Elsewhere in the GIP area the proposed developments have had a limited impact on the flood phases. This is not totally surprising since the predicted percentage of F0+F1 land in these areas was already extremely high.

The one exception to this general rule is in the eastern part of the area where the drainage channels outfall to the main rivers. Despite the sealing of the breaches in the TRE and BRE the percentage of F0+F1 land in these areas has reduced. The reason for this is that the construction of the compartmentalisation embankments have prevented flow out of these cells to the south. High water levels in the external rivers result in the impounding of water in these areas and a reduction in the percentage of F0+F1 land. The benefit of eliminating the southerly flow from these cells has been the increase in the F0+F1 land in the southern parts of the GIP area which is mentioned above. Even in the areas where the proposed developments have resulted in a decrease in the percentage of F0+F1 land this land still forms more than 90 % of the total land area.

14.3 Sensitivity analysis

The sensitivity of the results presented above to different components of the proposed developments and also to external factors was assessed using a number of 10 year model simulations.

Compartmentalisation

This simulation assumed that cross basin transfers of water between the internal drainage basins of the GIP area could still occur. The results are presented in Figure 14.8.

The major impact is a decrease, relative to the With project simulation, in the percentage of F0+F1 land in the southern parts of the GIP area. This occurs because water from the northern part of the area drains southward and results in an increase in flood depth and drainage congestion in this area.

In the eastern part of the area where the drainage channels outfall to the external rivers the percentage of F0+F1 land increases. This is because without compartmentalisation water from these areas can drain to the south thereby reducing the local flood depths.

Extension of the Ghagot left embankment

This simulation assumed that the extension of the Ghagot left embankment from Bamandanga to the confluence with the Alai Kumari is not constructed. The results are presented in Figure 14.9.

The impact on peak water levels in the Ghagot is minimal even for the high flow conditions that occurred in 1987. Analysis of the flood phases for this scenario also indicated minimal change in the F0+f1 land even at the locations immediately behind the proposed extension to the Ghagot left embankment.

Sealing of TRE downstream of Kaunia

This simulation assumes that the TRE downstream of Kaunia remains open. The sealing of the TRE upstream of Kaunia is assumed to be complete. The results are presented in Figure 14.10 in terms of changes in the F0+f1 flood phases.

The impact of not sealing the TRE downstream of Kaunia on flood phases is relatively minor. In the areas adjacent to the Teesta the percentage of F0+F1 land is decreased slightly but throughout the majority of the region the flooding patterns remain unaltered. An area adjacent to the TRE is also shown to have a beneficial impact. This suggests that the regulator ventage at the outfall of this cell is likely to undersized and impeded drainage is occurring due to the high external levels.

Rise in Brahmaputra water level

Developments external to the GIP area are likely to have an effect on water levels in the Brahmaputra. It was estimated that the combined impact of the proposed Brahmaputra left embankment and the Jamuna bridge will be a rise in peak water level at the Ghagot outfall by less than 10 cm. It is not felt that a rise in water level of this magnitude will have a significant impact on the conditions in the GIP area.

A sensitivity analysis, however, was carried out to investigate the impact of a rise in peak water level of 0.5 m in the Brahmaputra in the vicinity of the GIP area; it was assumed that the low water level did not change.

A long profile along the Ghagot river is presented in Figure 14.11. A rise in 0.5m in the Brahmaputra level will result in a rise of a similar order of magnitude throughout most of the backwater dominated zone. This stretches back some 70km from the outfall location. The overall influence will extend mid-way between Sadullapur and Bamandanga.

14.4 Morphological Impact

14.4.1 Impact of sealing the Teesta Right Embankment

Impact on the Ghagot river

If spillage from the Teesta into the Ghagot is prevented by the completion and rehabilitation of the TRE then the results of the MIKE11 simulations suggest that the dominant discharge will be reduced to approximately 50 m^3/s. The regime conditions for these revised conditions would be a width of 22m, depth 2.7m and a slope of 0.00013.

These results suggest that, in the long-term, the channel would reduce significantly in both width and depth. The change in equilibrium slope suggests that the sinuosity of the river would reduce to approximately 1.4. Thus the river course would become much less tortuous than at present.

The time for these morphological re-adjustments is likely to be less than 20 years.

Impact on the Alai Kumari river

The effect of sealing the TRE downstream of Kaunia would be to reduce flows in the Alai Kumari, as spills into this river from the Teesta would be prevented. This would result in less flow and

sediment entering the Ghagot. The backwater effects in the lower reaches of the Alai Kumari would be reduced, but not eliminated, with a resulting reduction in siltation in the lower reaches of the Alai Kumari.

The time for these morphological re-adjustments is likely to be less than 20 years.

Impact on Teesta river

The long-term effectiveness of sealing the TRE will depend upon the future morphological change of the Teesta river. If the right bank of the river moves to the south-west, towards the TRE then breaches are likely to occur with increasing frequency. This can be avoided for some considerable period of time by allowing a large set-back distance between the embankment and the river. Unfortunately this would be at the cost of not providing flood protection to a large area of land adjacent to the Teesta. This is also not a viable option in the reach where the Ghagot comes close to the right bank of the Teesta.

For the TRE to be effective in reducing flooding down the Ghagot it is imperative that the TRE separates the Teesta from the Ghagot. It is therefore necessary to prevent any further moving westwards by the right bank of the Teesta in this area. Unfortunately this critical location coincides with one of the unstable reaches of the Teesta river.

The policy to protect this and other reaches of the TRE could be based upon that proposed by FAP-1 for protection of the BRE. In this approach it is not proposed to provide non-erodible protection for the full length of the BRE. Instead it is proposed to establish a number of hard points along the river. If the distance between these hard points is less than the natural wavelength of the anabranches then the incursions of the anabranches can be controlled. Though erosion may occur between the hard points, deep incursions will not occur. The same philosophy could be adopted for the Teesta based on the observed wavelength and utilising the natural fixed points along the length of the river.

14.4.2 Impact of removing the Manas regulator

The removal of the Manas regulator is unlikely to have a major morphological impact on the Ghagot river; it will have no impact on the morphology of the Brahmaputra.

Removal of the Manas regulator will allow some flow from the Brahmaputra to enter the Ghagot river; this flow will carry sediment with it. This flow will only penetrate a short distance up the Ghagot; any sedimentation will be in this area. Any sediment deposited in the lower Ghagot as a result of flow from the Brahmaputra is likely to be eroded by flows from the Ghagot into the Brahmaputra; this is likely to occur for at least 10 months of the year including the majority of the flood season.

The opening of the Ghagot to the Brahmaputra creates a potential route for the Brahmaputra to flow into the internal rivers of the North West region. Great care must be taken to reduce this risk to a minimum. The construction of the regulator at the head of the Alai Nadi will help to reduce this risk. It is recommended that further detailed design studies, possibly using physical models, are carried out to investigate this problem.

14.4.3 Impact of constructing regulator at the tail of the Manas river

The morphological impact of constructing this regulator is likely to be minimal. Under present conditions the lower Manas river suffers from backwater effects from the Brahmaputra; this will not

change. If the proposed regulator is of insufficient capacity and results in further drainage congestion it could result in an increase in sediment deposition in the lower reaches of the Manas river. The regulator will eliminate the possibility of sediment which originates in the Brahmaputra entering the Manas basin.

14.4.4 Impact of constructing regulator at the head of the Alai Nadi

The construction of this regulator will reduce the flow and sediment entering the Alai Nadi. There will be a reduction in dominant discharge in the river. The morphological response to this would be a significant reduction in both width and depth. If it assumed that the valley slope does not change, the resulting change in equilibrium slope suggests that the sinuosity of the river would reduce. Thus the river course would become straighter.

14.4.5 Impact of compartmentalisation

Compartmentalisation will result in the increase in flows in some internal drainage channels and a decrease in flows in others. Where flows are increased the channels are likely to become wider, deeper and more meandering. Where flows are decreased the depth and width of the drainage channels are likely to decrease; the channels are also likely to become straighter.

14.4.6 Impact of cutting meander loop at Gaibandha

If the meander loop at Gaibandha is cut-off but the Manas regulator is retained then there would be little morphological impact in the area. If the Manas regulator is removed then the backwater effects will be reduced and sediment transport rates increased. This would increase the potential for a morphological impact resulting from the cut-off of the meander loop.

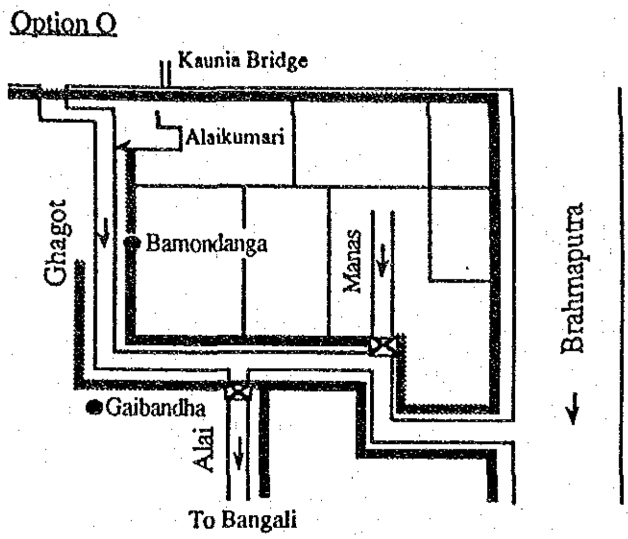


Figure 14.1 **Schematic plan - Future With**

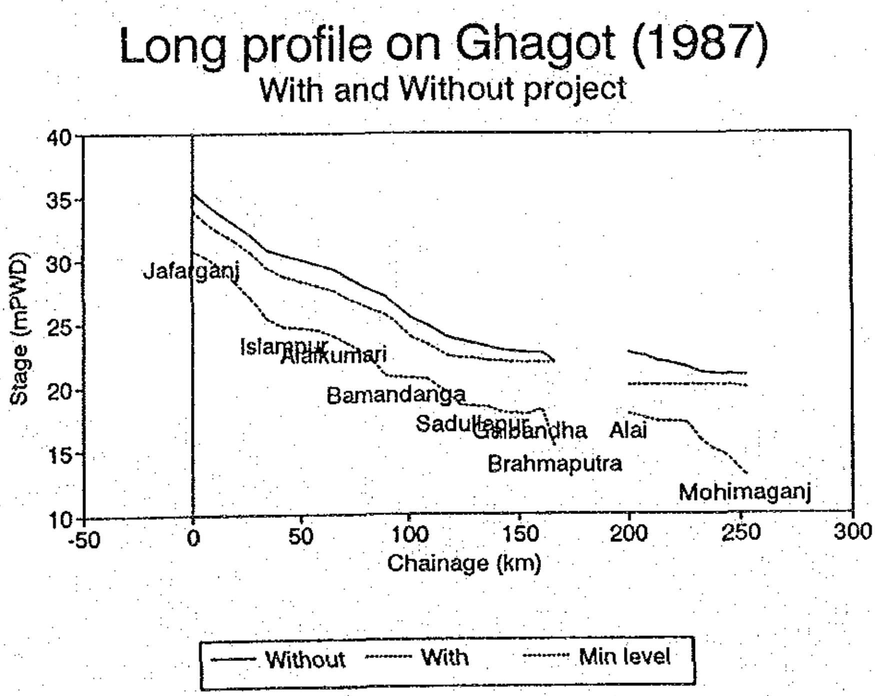


Figure 14.2 **Long profile along Ghagot - Future With**

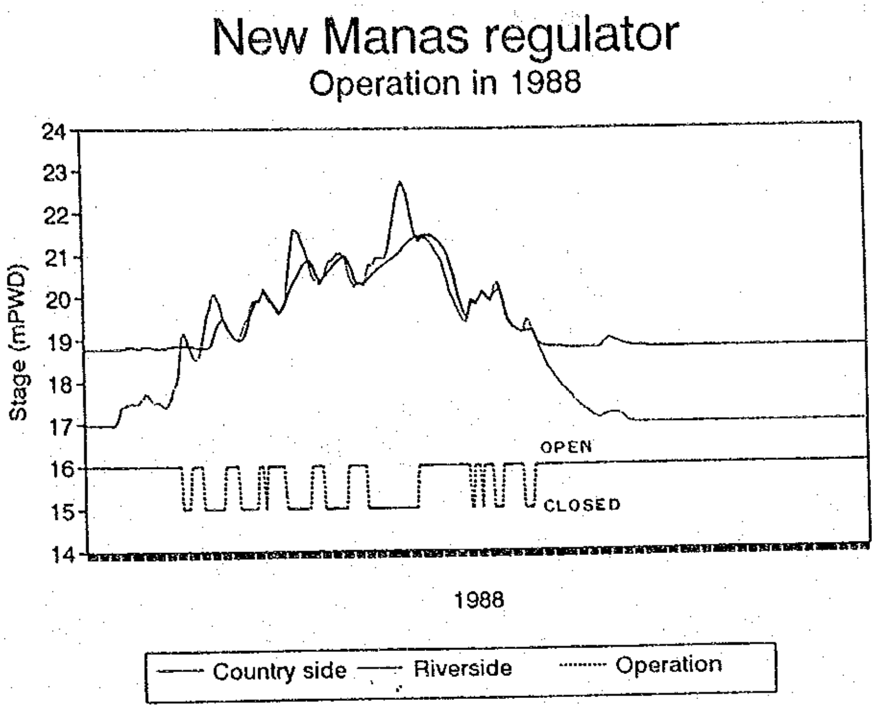


Figure 14.3 **Operation of New Manas regulator**

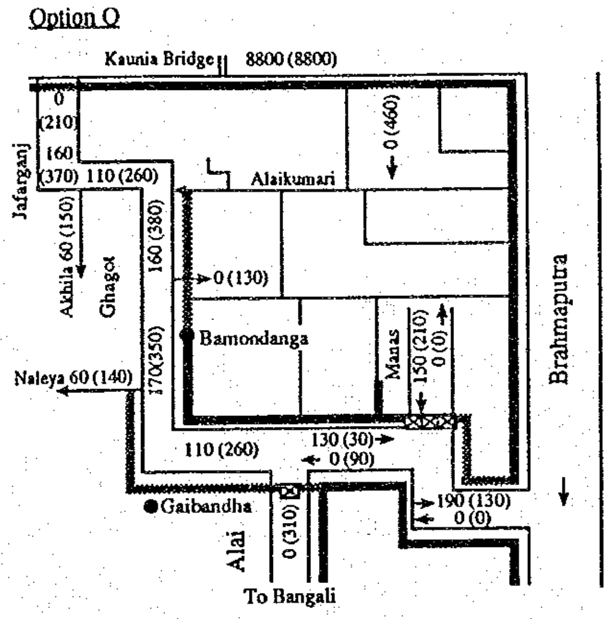
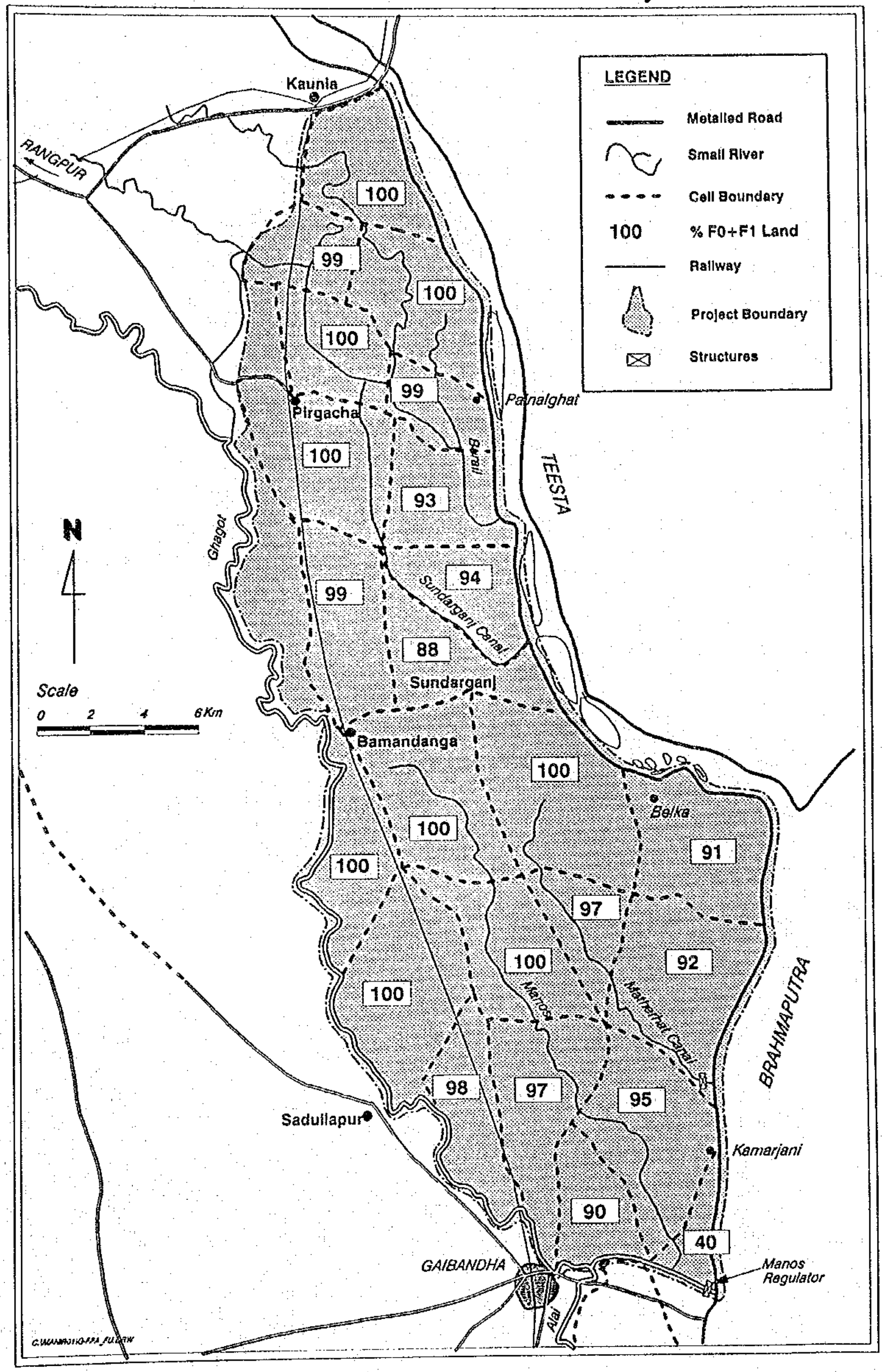


Figure 14.4 **Discharge distribution - Future With**

Figure 14.5

Flood Phase Analysis - Future With



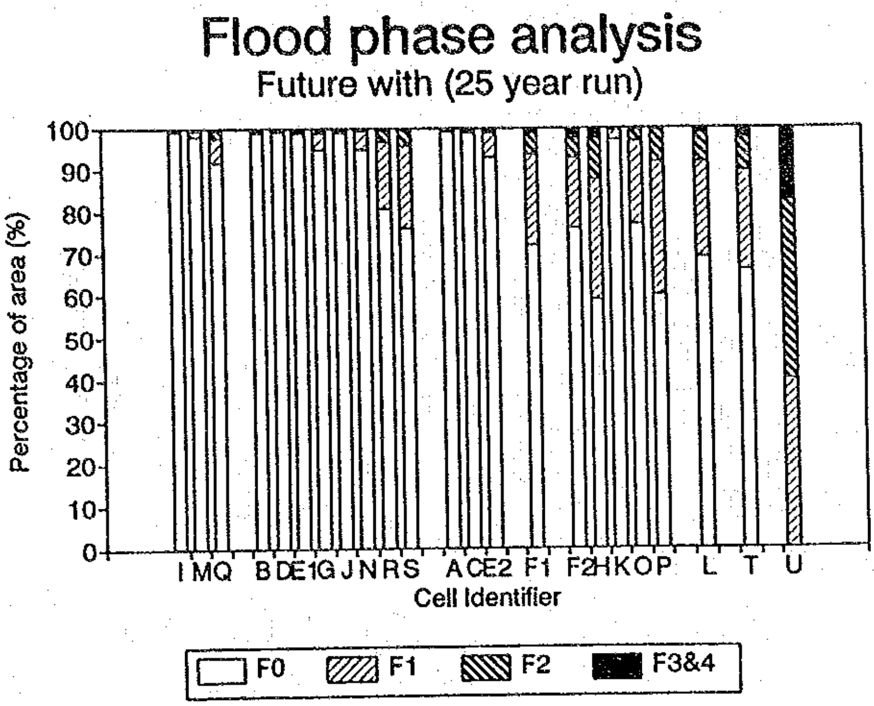


Figure 14.6 **Flood phase analysis - Future With**

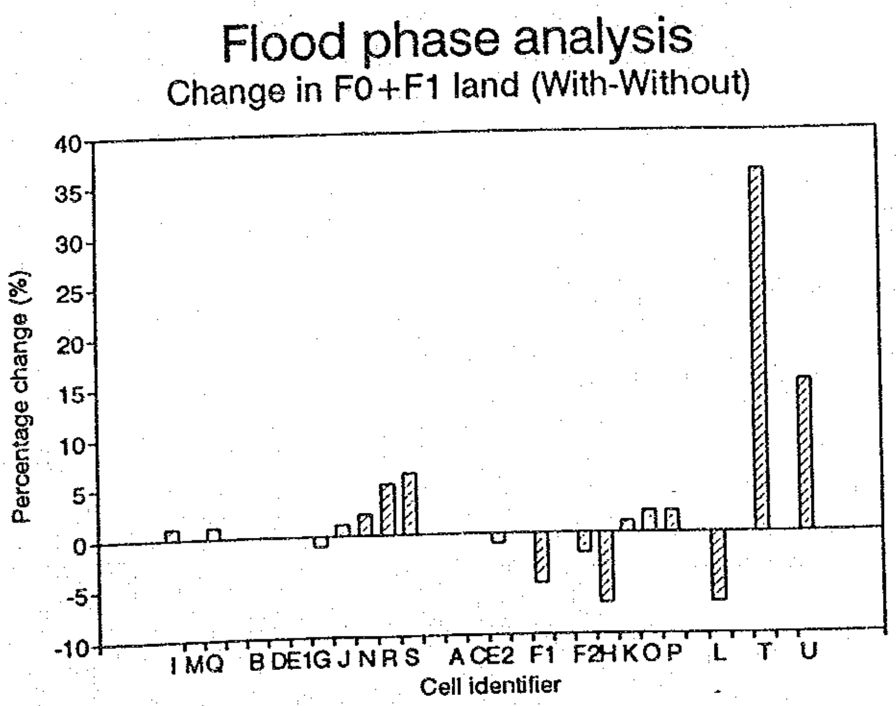


Figure 14.7 **Change in flood phase - With vs Without**

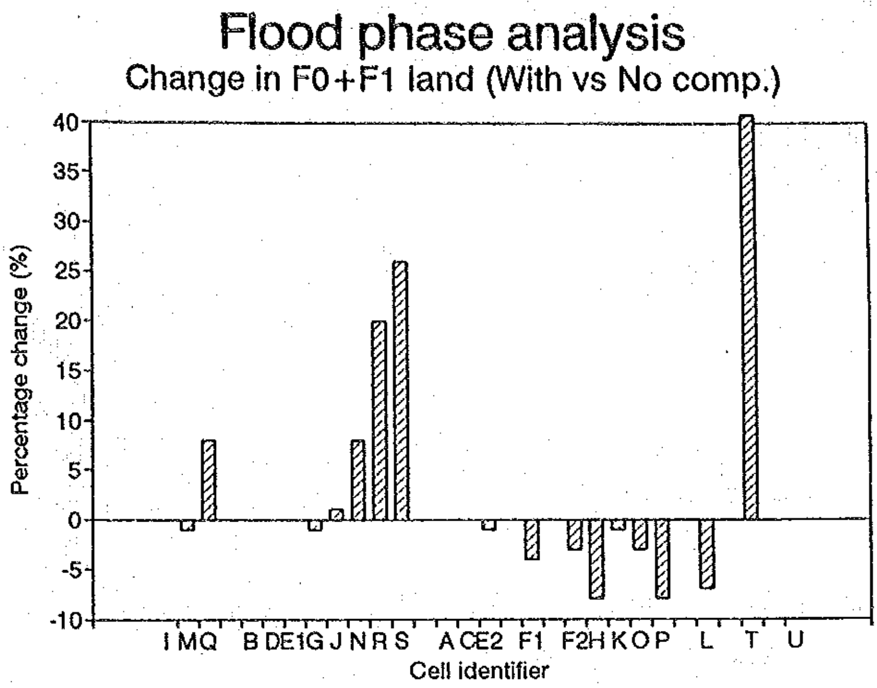


Figure 14.8 Sensitivity to compartmentalisation

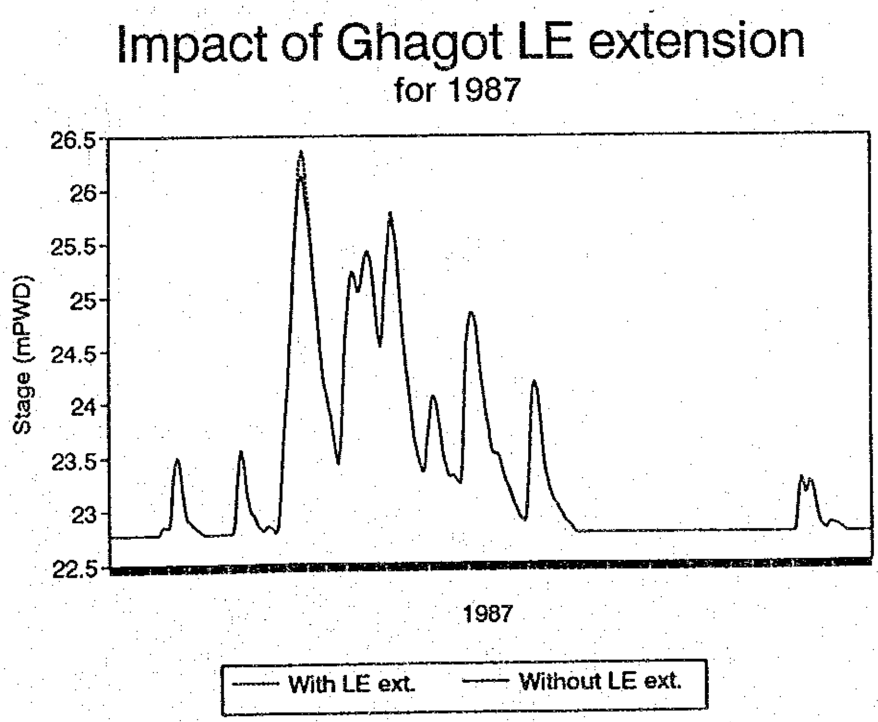


Figure 14.9 Sensitivity to Ghagot Left Embankment extension

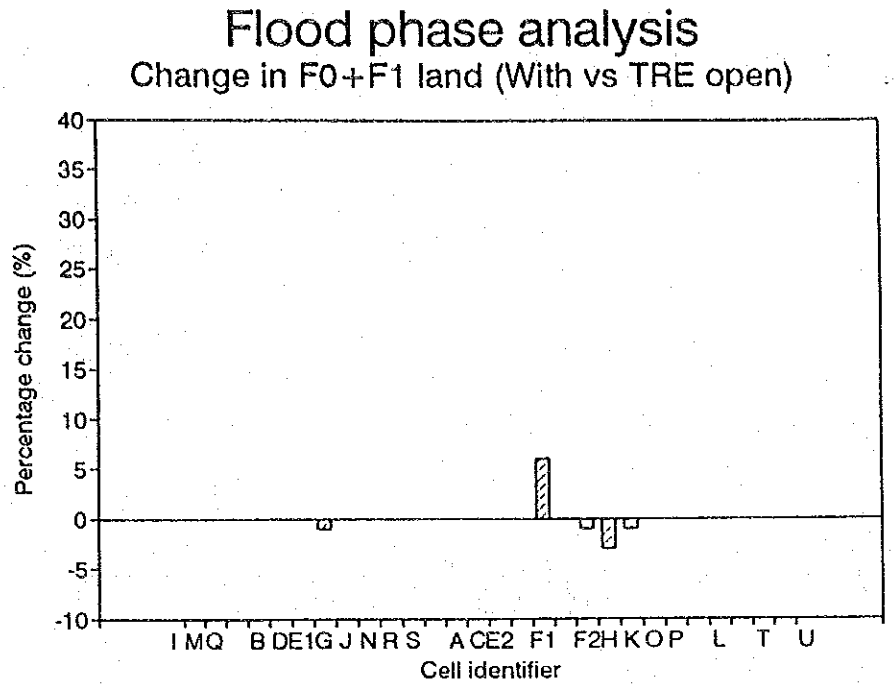


Figure 14.10 Sensitivity to sealing of TRE downstream of Kaunia

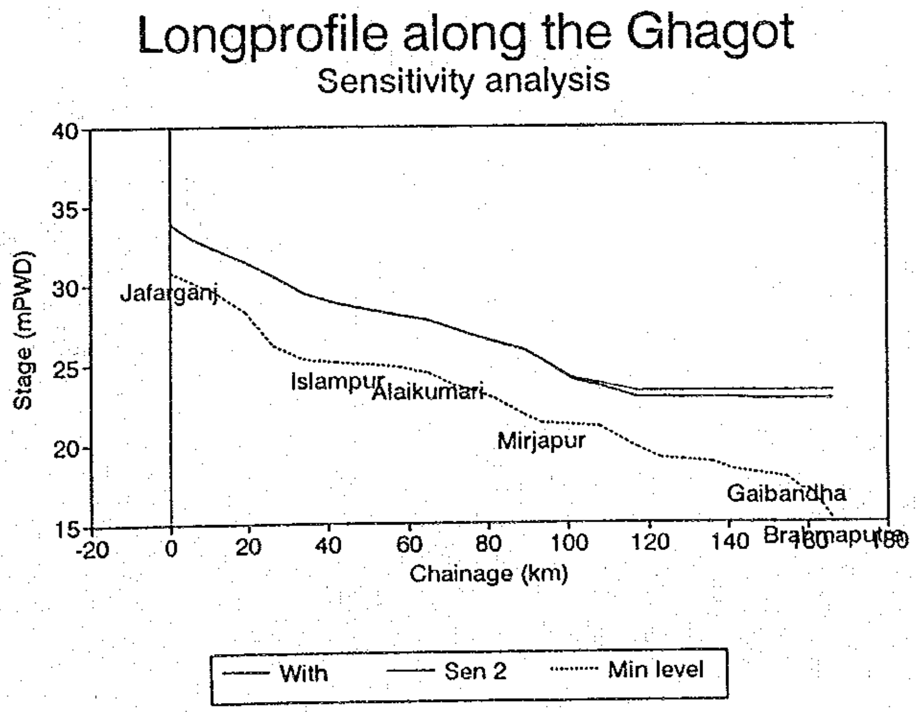


Figure 14.11 Sensitivity to rise in Brahmaputra levels

SECTION E

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 15

CONCLUSIONS AND RECOMMENDATIONS

15.1 Conclusions

The Lower Atrai basin

A reasonably good calibration between observed and modelled levels and discharges was achieved in the sub-regional model with tolerances lying within those prescribed by the FAPMCC for pre-feasibility study. Model predicted flood phases were also found to give reasonable agreement with MPO data thereby giving greater confidence in the model as a tool to predict future changes.

The present drainage paths in the Lower Atrai basin tend to follow natural drainage courses but this is achieved mainly due to public cuts; these cuts occur because embankments have been constructed across natural drainage paths. Hydraulically 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.

Sediment transport rates in the Lower Atrai system are high but the river is also relatively large. This means that the time for morphological re-adjustment in the system is likely to be between 20 and 50 years. At present the Lower Atrai system is more or less in dynamic equilibrium.

The completion of Naogaon Polder will have a minimal effect on peak water levels in the Atrai whereas model simulations predict that the completion of the Barnai project will raise river levels in the Shib-Barnai river and the lower reaches of the Fikirni river. This will make the flooding conditions in Chalan Beel Polder D significantly worse, assuming the embankments continue to be breached or cut.

Following completion of the Barnai project, the majority of the sediment which passes into the Fikirni is likely to be deposited in the lower reaches of this river and in the Shib-Barnai immediately downstream of Bagmara with subsequent morphological re-adjustment likely.

Confinement in the Lower Atrai would result in large rises in water level throughout most of the system. In particular the closure Bogra Polder 4 and Chalan Beel Polder C will result in large increases in water level in the Lower Atrai. The large rises in water level which could result from closure of the various polders is likely to cause drainage congestion within the embanked areas and are also likely to increase the likelihood of public cutting. Given these conditions full confinement in the Lower Atrai basin is an unacceptable development scenario for this area.

The Green River concept of the Lower Atrai basin is designed to bring the river system closer to its original drainage conditions and hydraulic characteristics; prior to the development of the area by empoldering and embanking.

The Green River concept of partial protection in the low lying areas adjacent to the Atrai and CFD measures in the upper reaches were found to give overall benefits in terms of beneficial shifts in flood phase. Depending on the level of partial protection, however, they can result in a rise in water level in the middle reaches of the Lower Atrai.

Embanking of the middle reaches of the Atrai river, within India, will raise peak levels at Mohadevpur by about 1m. The impact will lesser further downstream with peak levels being unaffect below Atrai RB.

Sensitivity to increases in Brahmaputra peak levels indicate that this will lead to a rise in water levels throughout the lower area of the Atrai basin. The influence will extend to Singra.

The Bangali Floodway

CFD developments in the Upper Karatoya basin will result in increases in discharge in the Bangali river and produce a worsening of the flooding situation. The construction of a new outfall to the Brahmaputra, the Bangali Floodway, could alleviate these problems.

Based on a consideration of morphology and flooding risk in the Middle Bangali a residual peak flow down the Bangali of 500 m^3/s was selected. Any excess flow from the upper reaches passes along the Bangali Floodway directly to the Brahmaputra.

Two cross-sectional shapes were considered, trapezoidal and two stage channel. The trapezoidal channel reduces peak levels slightly from those of the natural channel although in the downstream reaches the impact of cross-section shape is minimal due to backwater effects from the Brahmaputra.

The quantity of sediment deposited in the Bangali Floodway with the two stage channel is less than that with the trapezoidal channel shape. But the small width in the lower stage of the two stage channel means that the rate of bed level rise will be greater.

The Middle and Lower Bangali

The cause of the flooding problems in the Middle Bangali basin derives from breaches in the BRE. If these breaches can be prevented flooding will not restrict development in the Middle Bangali basin. If spillage from the Jamuna through breaches cannot be prevented the problems of the Middle Bangali must be reassessed.

The opening of the Upper Karatoya to the Brahmaputra by the construction of the Bangali Floodway creates a potential route for the Brahmaputra to flow into the internal rivers of the North West region. Great care must be taken to reduce this risk to a minimum. The careful selection of structures in the Bangali Floodway will help to reduce this risk.

CFD developments in the Upper Karatoya without the Bangali Floodway will increase the flows and water levels in the Middle Bangali basin and may result in the channel becoming deeper, wider and more meandering.

The cut-off of drainage channels from the right bank of the Bangali will increase discharges and sediment transport rates in the downstream reaches and this may cause some morphological change leading to an increase in the channel conveyance.

Sedimentation is likely to occur in the Durgadah and Barnai if they are cut-off from the Bangali and they will tend to become narrower, shallower and straighter due to the reduction in dominant discharge.

The Gaibandha Improvement Project

The GIP model gave a reasonable agreement between modelled and observed discharges. Comparisons between model predicted flood depths and field observations for the internal area of the GIP gave additional confidence in the models use in predicting the changes from present to future conditions.

The flow in the internal drainage channels of the GIP area is basically north to south; this means that the water which spills through the breaches in the Teesta right embankment eventually reaches the Manas basin in the south of the GIP area. In the south of the GIP area there is drainage congestion due to the backwater influence from the Brahmaputra. This is the area that suffers from the deepest and most prolonged flooding.

With the very important exception of the south-eastern part of the area, the flood phase analysis for the GIP area suggests that flooding is not a major restriction on agricultural productivity. Sudden surges of water through breaches and public cuts or from overbank spillage may however result in serious problems of crop and infrastructure damage.

The impact of the sealing the Teesta right embankment upstream of Kaunia is to lead to a marked reduction in peak flows in the Ghagot and a reduction in the peak water levels, by more than 1 m. Sealing the Teesta downstream of Kaunia will reduce inflows to the GIP area and help to alleviate some of the drainage congestion in the southern part of the area.

Compartmentalisation redistributes the volumes of flood waters in the GIP area and has an overall beneficial impact on the flood regime. In particular, it was found that there were substantial benefits in the southern part of the area.

The constructing of a regulator at the head of the Alai Nadi river results in a decrease in peak water levels of more than 1 m in the upper reaches of this river and will also help to reduce the flood flows which enter the Bangali basin further downstream.

The extension of the Ghagot left embankment, upstream of Bamondanga, has a relatively small impact on the GIP area as a whole.

Sensitivity to increases in Brahmaputra levels of 0.5m indicate that the influence will extend to a point midway between Sadullapur and Bamondanga.

Analysis of historic survey data indicates that there has been a general trend of movement of the Teesta river to the south-west. If this movement continues then the frequency of breaching of the present Teesta right embankment will increase and any further embankments or structures constructed along the right bank will be threatened by erosion. Further development of the TRE must address the issue of river training as well as the construction of an embankment to prevent ingress of flood waters.

There appear to be a number of locations on the Teesta river which are relatively stable. Between these fixed points the river divides into a number of anabranches, each of which has a sinuous form. If there were to be a dramatic change of course of the Teesta due, for example, to a major earthquake it is likely to take place at one of the nodes.

The Teesta barrage confines the width of the river but as the selected site corresponds with one of the stable nodes of the river it is unlikely to have a significant impact on the plan form of the river.

As the storage at the barrage is relatively small in comparison with the discharge of the river it is not expected to have a significant impact on the overall morphology of the Teesta. There may, however, be local impacts confined to the neighbourhood of the structure.

Analysis of data suggests that net deposition is taking place in the Ghagot river in the Jafarganj region, whereas there appears to no significant bed level changes in the region of Islampur and Gaibandha. The rate of deposition is dependent on the spills from the Teesta.

The opening of the Ghagot to the Brahmaputra creates potential route for the Brahmaputra to flow into the internal rivers of the North West region. Great care must be taken to reduce this risk to a minimum. The construction of the regulator at the head of the Alai Nadi will help to reduce this risk.

15.2 Recommendations

The application of hydrodynamic models has proved to be an invaluable tool with which to assess and understand present flooding problems and to assess the impacts of measures to alleviate these problems. Further detailed hydrodynamic modelling of project areas should be carried out at the feasibility stage of all projects. The boundary conditions for these models should be provided by the most appropriate hydrodynamic model of the area which is available at the time.

At the detailed design stage the hydrodynamic model should update the models using the latest topographic and calibration information. To obtain the maximum benefits this model should also be linked to a GIS.

Throughout the modelling, hydraulic structures have been represented in a crude manner. The suitability of this representation should be investigated and improved where appropriate.

Linking the model output results to other post processing programs has enabled the models to be used in a much wider context than that of simply predicting water levels and discharges within the modelled river reaches and drainage channels. Further work should be undertaken on these applications. This would require multi-disciplinary team including a hydrologist, a hydraulic engineer, a environmentalist, a sociologist and an agricultural economist.

It is recommended that further detailed design studies are carried out, possibly using physical models, to investigate the risk posed by opening the Ghagot or the Bangali Floodway to the Brahmaputra.

More detailed analyses should be carried out, at the design stage, to quantify, as far as possible, the morphological changes which will be induced by projects in the North West region.

Within the Lower Atrai system flow across submersible embankments has been simulated. Further research into the hydraulics of these structures and their representation in hydrodynamic models is required.

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