Government of the Peoples Republic of Bangladesh
Flood Action Plan

North West Regional Study (FAP-2)

DRAFT FINAL REPORT

VOLUME 6

GAIBANDHA IMPROVEMENT PROJECT ENGINEERING

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VOLUME 5

ENGINEERING ON GAIBANDHA IMPROVEMENT PROJECT

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1. BACKGROUND

Through the FAP 2 interim regional study carried out in 1991, the Gaibandha area was selected as the priority project on which the project preparation study was scheduled in the next year at a level of a feasibility study. The project, called "the Gaibandha Improvement Project (GIP), aimed primarily at drainage improvement in the Gaibandha area. In the interim regional study stage, the major FCD works proposed for GIP were the Teesta right embankment strengthening for a reach from Kaunia railway bridge to the outfall to the Brahmaputra, provision of river training works such as spur dikes and rehabilitation of existing groynes along the Teesta, provision of embankment for compartmentalization of the GIP area, and the drainage improvement works including provision of six new regulators. But, it did not include the Brahmaputra right embankment strengthening since it was covered by FAP 1.

The regular engineering study on the Gaibandha Improvement project has started in early March 1992. Prior to the detailed examination on alignment of the major FCD works based on the hydraulic Modelling analysis, the field survey works comprising the topographical survey, geotechnical investigation and detailed site reconnaissance on the present situation of the project area have been performed in relation to the project features set up in the interim regional study. The main studies carried out in connection with the engineering are itemized as follows;

- Topographic survey and geotechnical investigation: These are described in Volume 7 of the Draft Final Report,

- Site reconnaissance for confirming the present situations in the GIP area in light of the flooding and drainage conditions, and participation in the public consultation in collaboration with the non-engineering disciplines,

- Collection of data and information related to FCD planning, design standards in Bangladesh, implementation plan, operation and maintenance, and unit rates of construction works, etc. in order to supplement those collected in the interim regional study,

- Planning and design of major FCD structures at the feasibility study level based on the results of the topographic survey and geotechnical investigation as well as hydraulic modelling analysis, including structural and drainage analyses,

- Examination and preparation of implementation plan taking into account those practiced in Bangladesh and through incorporation of the policy of the FAP,

- Construction cost estimates and construction planning,

- Examination of operation and maintenance for GIP in collaboration with the non-engineering disciplines with reference to the FAP 13's study, and

- Preparation of technical notes for the subsequent detailed design for GIP.

In the subsequent detailed design stage, the engineering studies are to be carried out in more elaborated manner in accordance with the technical notes stated in the succeeding Chapter 9 in order to carry forward the project to the construction stage.

2. PRESENT SITUATION

2.1 Topography

The Gaibandha Improvement project (GIP) covering an area of about 576 km^2 is situated between 89°20' and 89°30' in longitude and between 25°20' and 25°50' in north latitude. It is bounded on the north and eastern parts by the Teesta and Brahmaputra rivers, and on the south by the Ghagot-Manas.

The surface soils of the GIP area are developed in recent and sub-rescent alluvial flood plain sediments carried by the river Teesta. The topography of the GIP area is characterised by the typical meander flood plain pattern and shallow basins with local areas of irregular relief near the channels, but generally it is sloped from the west to the east. Therefore, rainfall taking place inside the GIP area, which is now enclosed by the flood embankments along the Teesta right bank (TRE), the Brahmaputra right bank (BRE) and the Ghagot left bank (Satdamua Katler Beel project) with several breaches, tends to collect at the southwestern low-lying area near the confluence of the Ghagot and Manas rivers, causing the habitual drainage congestion thereat.

The existing topographic maps at a scale of 1 to 15,840, which were produced in 1960's, cover the whole project area. In the present project preparation study on GIP, the topographic surveys including levelling and traversing were carried out over the GIP area to modify contour lines therein as described in "Part II : Topographic survey" of the Volume 7, since a lot of flood embankments, elevated homesteads and infrastructures such as public roads which would have an influence on the FCD planning were built in the GIP area after the mapping. On the other hand, it is confirmed through the ground survey works that there are not any significant difference in contour lines between the both maps except the areas where such man-made earth works were provided thereafter.

Figure 2.1 shows area-elevation curve of the GIP area constructed using new maps with contour lines of 0.5 m interval. As seen in the Figure, ground level of the Gaibandha south varies from about 18.5 m to over 30 m (PWD).

2.2 Geology

In Bangladesh, there are three morphological zones, namely;hill areas, terrace areas and flood plain areas. The flood plain sediments are being deposited as piedmont plains, meander flood plain, tidal flood plain and estuary flood plain. The piedmont plains comprise gently sloping areas of colluvial and alluvial sediments derived from the nearby hills, which occur throughout most of Dinajpur and part of Rangpur district located adjacent to the GIP area on the northwestward.

Within the three major geomorphological zones especially in the flood plain area, as many as twenty physiographic units have been identified with fairly uniform physical characteristics. The GIP area falls within the physiographic unit No. 2, the Teesta flood plain.

The Teesta flood plain is composed of the younger part of the Teesta alluvial fan and flood plain, comprising a variety of landscapes which were created as the Teesta river formed and abandoned successive channels across the area. At various times in the past, the Teesta has occupied the channels now followed by the Mohananda, Punarbhaba, Atrai, Little Jamuna, Karatoya and Ghagot since two hundred years ago.

The physiographic unit No.2 mainly comprises young alluvial land within and adjoining the Teesta river

(and other smaller rivers crossing the unit). The surface deposits are predominantly grey, stratified silts with some sands. They occupy a low, generally smooth, but locally irregular, relief of ridges, depressions and partly infilled channels. Seasonal flooding is generally shallow, but all the rivers are subject to flash floods during which inundation is deeper for a few days and when crops may be drowned, buried by new alluvium or damaged by rapidly flowing currents. The Teesta alluvium is rich in weatherable minerals, especially mica. An important feature is the instability of the alluvial formations, both in outline and in relief. Shifting river channels erode large areas of river banks and islands (chars) during the monsoon season and deposit large areas of alluvium as new land within the channels or on top of older deposits.

About 85% of the country is a plain land covered with unconsolidated Holocene sediments. The rest of the country is underlain by the early to late Tertiary rocks in the north east region and Neogene sedimentary rocks in the eastern folded belts. The GIP area geologically falls within the alluvial fan deposits and represented by map unit "afy - Young Gravelly Sand". The eastern part of the fan is active, flooded annually by the Teesta river and its distributaries. On the other hand, sand depositing in the GIP area is generally finer and contains more silt in the shallower subsurface.

2.3 Geotechnics

According to the results of the geotechnical investigation performed for the GIP area which include core boring, auger boring and test as well as the laboratory tests on soil samples collected therefrom, strata of the subsurface in the GIP area where flood embankments are planned to be provided under GIP are largely divided into two soil layers, namely: upper silty soil and lower sandy soil layers, although the other strata formation such as clayey soil appears place by place in a strict sense. In general, thickness of the silty layer is more than 2 m beneath the ground surface and it is underlaid by the sandy silty layer. The stratific condition of subsurface is commonly recognized all over the investigated area, since most of the GIP area is formed by the sediment transport by the Teesta as aforementioned. Moreover, it is confirmed through the geotechnical investigation that soil material sampled from the same soil layer tends to exhibit the quite similar characteristics in view of the soil mechanical engineering.

In the upper silty soil layer, the average specific gravity is derived to be 2.67 as a result of the laboratory test to clarify engineering values of soil material. The mean particle size and fine particle content ratio fall within 72 to 88 % and 0.030 to 0.050 mm, respectively. Concerning the consistency, the soil material is mostly non-plastic. Most of the soil material is classified mainly into ML in accordance with the unified soil classification. The natural moisture content in the silty soil layer shows a rather wide range mainly due to different depths of groundwater table from ground surface, since the geotechnical investigation works were performed in the dry season of year 1991.

In the sandy soil layer, the average specific gravity is 2.66, which is almost same as that of the aforesaid silty soil. The average fine particles content ratio and mean particle size are 12 to 21 % and 0.14 to 0.16 mm respectively, which are obviously different from those of the silty soil revealing the soil mechanical characteristics of the silty soil. Most of the soil material is classified into SM, SP-SM and SP. The average natural moisture content ranges from 22.2 to 26.5 %.

The average wet and dry density values in surface layer are 1.61 and 1.25 tf/m^3, respectively. Coefficient of permeability of the silty soil and sandy soil layers are derived to be 2.5×10^{-5} to 1.1×10^{-3} cm/sec and 1.7×10^{-3} to 1.2×10^{-2} cm/sec, respectively. The rather low permeability coefficient of order of 10^{-5} was observed in the soil layer which contain comparatively a lot of clayey soil locally, while the higher one in the sandy soil layer which is relatively loosed containing coarser sand.

The silty soil layer have a wide range of N values of 2 to 21. The average N values of the silty soil layer come to between 6.1 and 8.4. While, N values of the sandy soil layers increased ranges from 4 to 38. In most of the GIP area where the flood embankment is planned to be provided under GIP, the firm soil layer with N value of more than 10 is identified at 5 to 10 m below from ground surface. As far as the construction drawings of existing regulators in the GIP area show, they were built at present locations without any piling foundations, and it appears that they have not suffered from any damage attributed to the insufficient bearing capacities of the foundation soil layers. Judging from the standard penetration test conducted this time, as a whole the sandy soil layer seems to have the comparatively high bearing capacity. However, the massive concrete structure would need to be founded on the firm sandy soil layer taking into account the seismic force as well as erosion of foundation due to water flow in the monsoon season.

In view of the soil mechanical engineering characteristics clarified, the silty soil is suitable for use of the embankment material. Therefore, the embankment material for flood embankment needs to be obtained from the surface soil layer over the entire GIP area. However, in the TRE between Tambulpur and Tarapur where it is breached at present, the subsurface soil seems to be of poorly graded with less finer particles. Therefore, in the construction stage some adjustment of particle size distribution may have to be made through mixture with finer particles soil in using the subsurface soil in the area as the embankment material.

As a whole, soil material depositing in the GIP area has a sufficient specific gravity of 2.6 to 2.7 for use of fine concrete aggregate. However, soil material of the silty soil layer is considered to be inappropriate for the use since it contains much finer particles less than 75 m. Although soil material of the sandy soil layer have little finer particles, its particle size distribution is very poor. Therefore, the sandy soil will need to be mixed with other source of material after sieving so as to utilize it as concrete aggregate. However, it is recommended that the concrete aggregate is procured from other sources, since the required quantity of concrete aggregates for concrete placement for GIP is comparatively small so that those to be produced in such process will result in higher rate of price. One of the promising source is upstream sand deposit of Kaunia. Besides, gravel imported from India will be used as coarse aggregate as usually practiced in the region.

2.4 River System and River's Carrying Capacity

The river system in the GIP area is illustrated in Figure 2.2. The GIP area is bounded on the north and east by the major rivers of the Teesta and Brahmaputra, and on the west and south by the Ghagot and Alaikumari. The Ghagot, a distributary of the Teesta, was disconnected by the construction of Teesta Right Embankment in 1960's. While, internal rainfall runoff in the GIP area is mainly drained by the rivers such as the Burail and Masankura/Harhalia outfalling to the Teesta, and the Matherhat and Manas to the Brahmaputra.

2.4.1 Brahmaputra

The Brahmaputra has a braided river channel and one of the river channels divided by large sand dunes flows for about 25 km long river reach the eastern side of the GIP area eroding the river bank severely. In this river reach, the Brahmaputra has a river channel with depth of 6 m to 10 m and distance of 300 m to 600 m between river bank line and the nearest sand dune.

Figure 2.3 shows the eroded river bank in about 8 years of 1983 to 1990, which is identified based on

the aerial photographs. The river channel of the Brahmaputra has been shifting to west eroding the river bank along the GIP area. Especially, about 3.5 km long river bank from Kamarjani to Manas regulator and the outfall of the Teesta at Horipur were severely eroded in this period. The eroded width and average erosion rate expressed in m per year in the Brahmaputra right bank for the aforesaid period are as follows derived by location based on the aerial photographs;

Location	Eroded Width (m)	Bank Erosion Rate for 1983 to 1990 (m/year)
Horipur	750	100
Kamarjani	900	120
Manas	1,500	190

2.4.2 Teesta

The Teesta has its origin in the eastern part of India where the annual rainfall amounts to 3,000 to 4,000 mm even in the average hydrologic years. It joins the tributaries of the Buri Teesta and Sati and reaches the Kaunia bridge after passing the Teesta Barrage 100 km upstream of the outfall to the Brahmaputra, which is an intake weir for the Teesta Irrigation Project with an irrigable area of 316,559 ha. Flowing down 45 km long river reach along the GIP area on the right bank, it finally debouches to the Brahmaputra. The flood embankment was provided on the right and left banks by BWDB. The river length in Bangladesh is about 135 km.

Figure 2.4 shows the riverbed profile, river width, and bankful capacity of the Teesta. The average riverbed slope is 1:5,000 in the downstream reach 70 km long. It comes 1: 2,400 at Kaliganj water level gauging station and 1:1,050 in the upstream reach of the confluence with the Buri Teesta. The river width between both river banks is about 1 km on average in both the downstream and upstream reaches of the Kaunia bridge. The setback distance of the existing flood embankments is more than 1 km from the river bank but it is abruptly narrowed at the Kaunia railway bridge site to about 500 m. The depth from the riverbed to the river bank is about 5 m and becomes deeper near the confluence with the Brahmaputra. The average height is about 2 to 3 m and 4 m downstream and upstream of the Kaunia bridge, respectively. The bankful flow capacity is estimated to be more than 4,000 m^3/sec in most of reaches in Bangladesh but that at Kaunia railway bridge site and site of just upstream Kaliganj water level gauging station is as small as about 2,000 m^3/sec.

The Teesta river is characterized by the meandering and formation of sand dune due to huge amount of sediment inflow from the Himalayan piedmont. The meandering width is about 2 km to 3 km and the river course has been shifted by flood flow conveying much sediment so that the river bank erosion and collapse of the existing flood embankment take place at several places in both the river bank sides.

Based on the aerial photographs taken in 1983 and 1990, of about 45 km long river stretch from Horipur to Kaunia railway bridge, the river banks for a distance of about 30 km downstream of Painalghat has been eroded place by place as shown in Figure 2.5. As a result, the flood embankment has repeated retirement to date. The eroded width and erosion rates of the Teesta right bank between 1983 and 1990 are identified based on the aerial photographs as follows:

Location	Eroded Width (m)	Bank Erosion Rate for 1983 to 1990 (m/year)
Painalghat	2,000	260
Downstream of Sundarganj	1,200	150
Horipur	400	50

2.4.3 Ghagot

The Ghagot river was a distributary of the Teesta originally but the branching point was closed by the construction of the Teesta Right Embankment. The river originates in the northern part of the Barind Terrace with altitude of about 40 m and an annual rainfall of about 2,000 mm. The Ghagot river generally flows southeast and it joins the Alaikumari which constitutes a catchment boundary of the GIP on the northwest after passing Rangpur city. Afterward, it takes the river course along the GIP area till Gaibandha city. At Gaibandha, the Ghagot river branches off two river channels. One outfalls to the Brahmaputra through the Manas Regulator provided on BRE. The other river channel, called as the Alai river, meets the Karatoya river. The total river length is about 240 km from the origin to the branching point of the Ghagot and Alai and about 210 km from the origin to the Manas Regulator site at the outfall to the Brahmaputra.

The average riverbed slope, river width, and flow capacity of the Ghagot, Ghagot-Manas, and Alai are shown in Figures 2.6 and 2.7 and summarized as follows:

River	Riverbed Slope	Width between banks (m)	Flow Capacity (m^3/s)
Ghagot	1:12,000	40 to 120	50 to 300
Ghagot-Manas	1:12,000	30 to 100	150 to 450
Alai	1:21,000	50 to 100	50 to 90

The river course of the Ghagot remarkably meanders and many oxbows are left as beel along the river reach, especially along the downstream reach between Bamondanga and Gaibandha.

2.4.4 Internal rivers

The GIP area covering an area of 576 km^2 is divided into 30 drainage basins by the natural topography and existing rural road system as shown in Figure 2.8, which mainly consist of the major five internal river basins, and small drainage basins covered by the regulators surrounded by the rural road embankment.

The five major internal rivers are the Manas, Matherhat, Masankura, Kata, and Burail rivers which cover 70 % of the GIP area. Among these rivers, a part of the drainage basin of the Burail is located outside the GIP area. The river length and catchment area of these internal rivers are as follows:

No.	Name of River	Length in the GIP Area (km)	Drainage Area in the GIP area (km^2)
1.	Manas	44.0	150.68
2.	Matherhat	31.4	85.52
3.	Masankura	25.8	112.20
4.	Kata	6.0	15.81
5.	Burail	56.5	71.05
		(Outside GIP area : 22.5)	(Outside GIP area : 25.0)

The drainage areas are interlinked by the canals and/or openings in the related structures such as bridges and culverts, so that flooding water accumulated in the downstream end of the drainage basin flows into other basins during the peak monsoon season. Especially, the Manas river basin, which is the lowest area in the GIP area, catches the flooding water from other basins. Therefore inundation situation in the Manas river basin is the most serious.

There are many beel areas along the river course. These beels function as retention ponds for inland flood runoff and prevents concentration of flood water in the low-lying area downstream of the basin. Major perennial beels in the GIP area is Harudanga beel on the Burail, Bherbherir, Kalsahar and Chaprar beels on the Masankura, Satirian Kumar Chala and Nalgari beels on the Matherhat, Bamondanga, Chakata and Kumaria beels on the Manas.

Figure 2.1 AREA ELEVATION CURVE OF THE GIP AREA

Elevation (m, PWD)	Area (km²)	Storage (mill. m³)
18.5	1.1	0
19.0	3.7	1
19.5	10.0	5
20.0	16.1	11
20.5	39.0	25
21.0	74.3	53
21.5	118.9	102
22.0	167.5	173
22.5	230.8	273
23.0	277.0	400
23.5	313.9	547
24.0	352.1	714
24.5	388.7	899

Elevation (m, PWD)	Area km²	Storage (mill. m³)
25.0	418.1	1101
25.5	444.2	1316
26.0	463.9	1543
26.5	489.4	1782
27.0	514.3	2033
27.5	526.3	2293
28.0	545.8	2561
28.5	558.0	2837
29.0	567.8	3118
29.5	574.3	3404
30.0	574.8	3691
30.5	575.9	3979

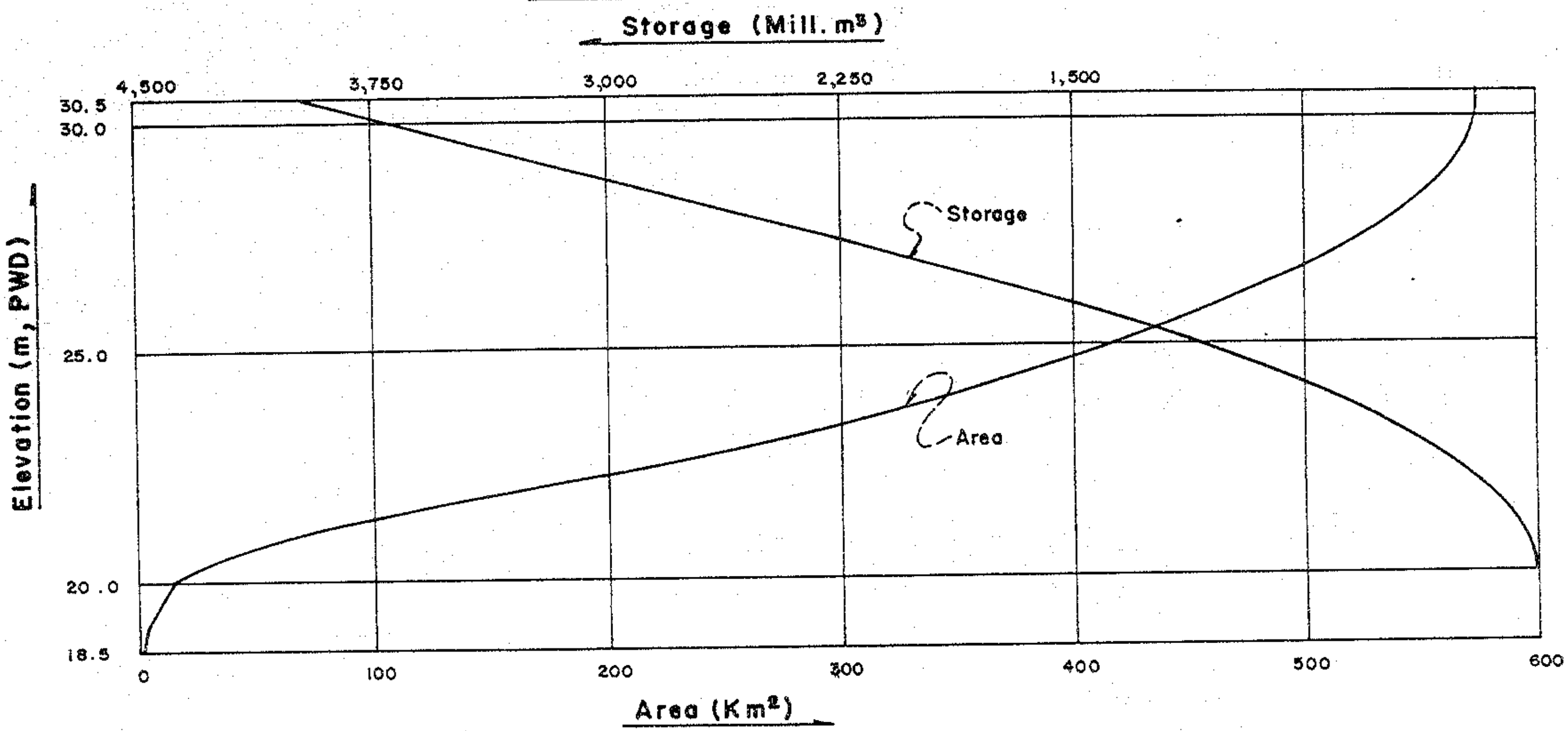


Figure 2.2 RIVER SYSTEM AND EXISTING FCD STRUCTURES IN THE GIP AREA

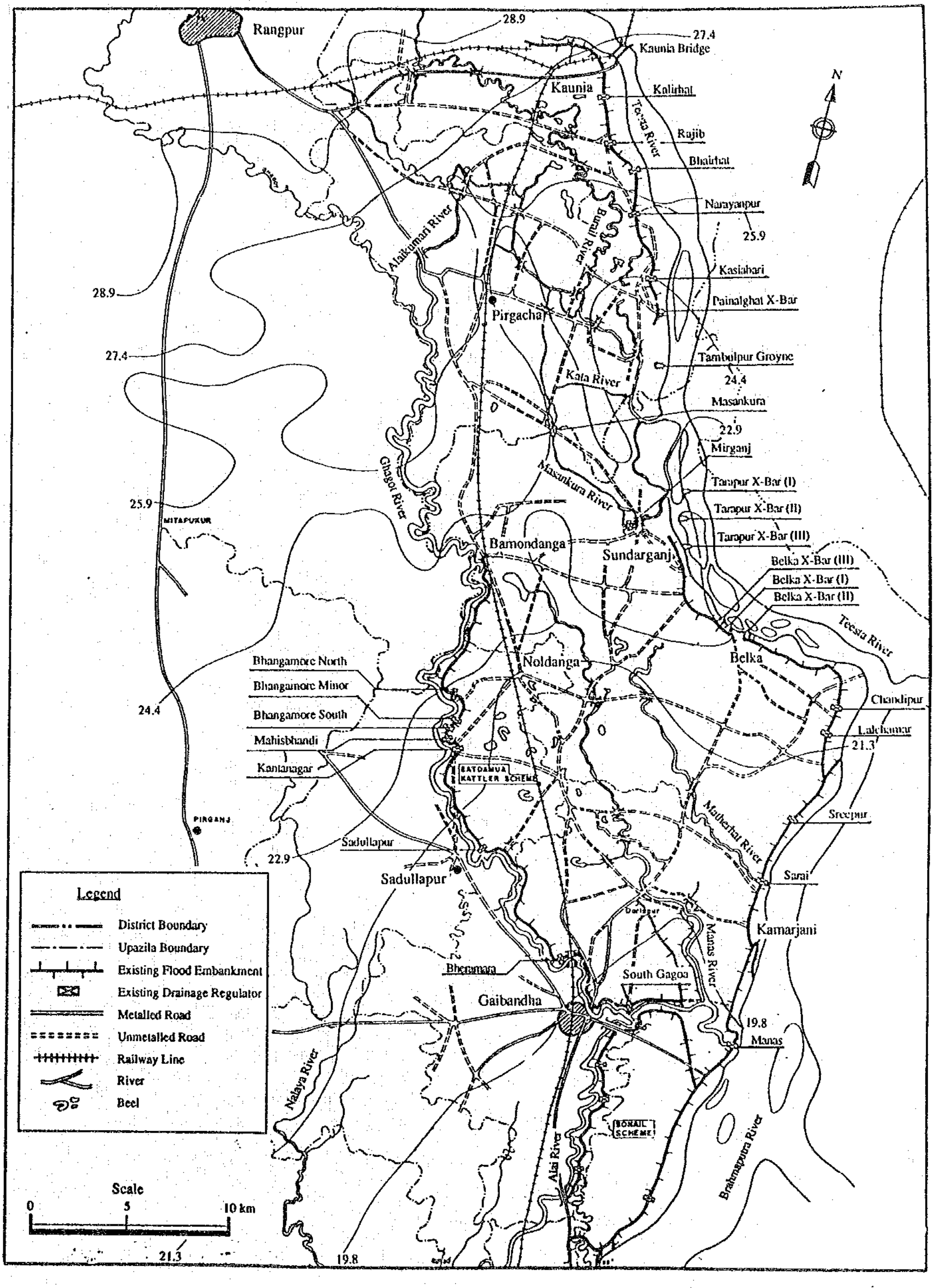


Figure 2.3 RIVER BANK EROSION ALONG THE BRAHMAPUTRA

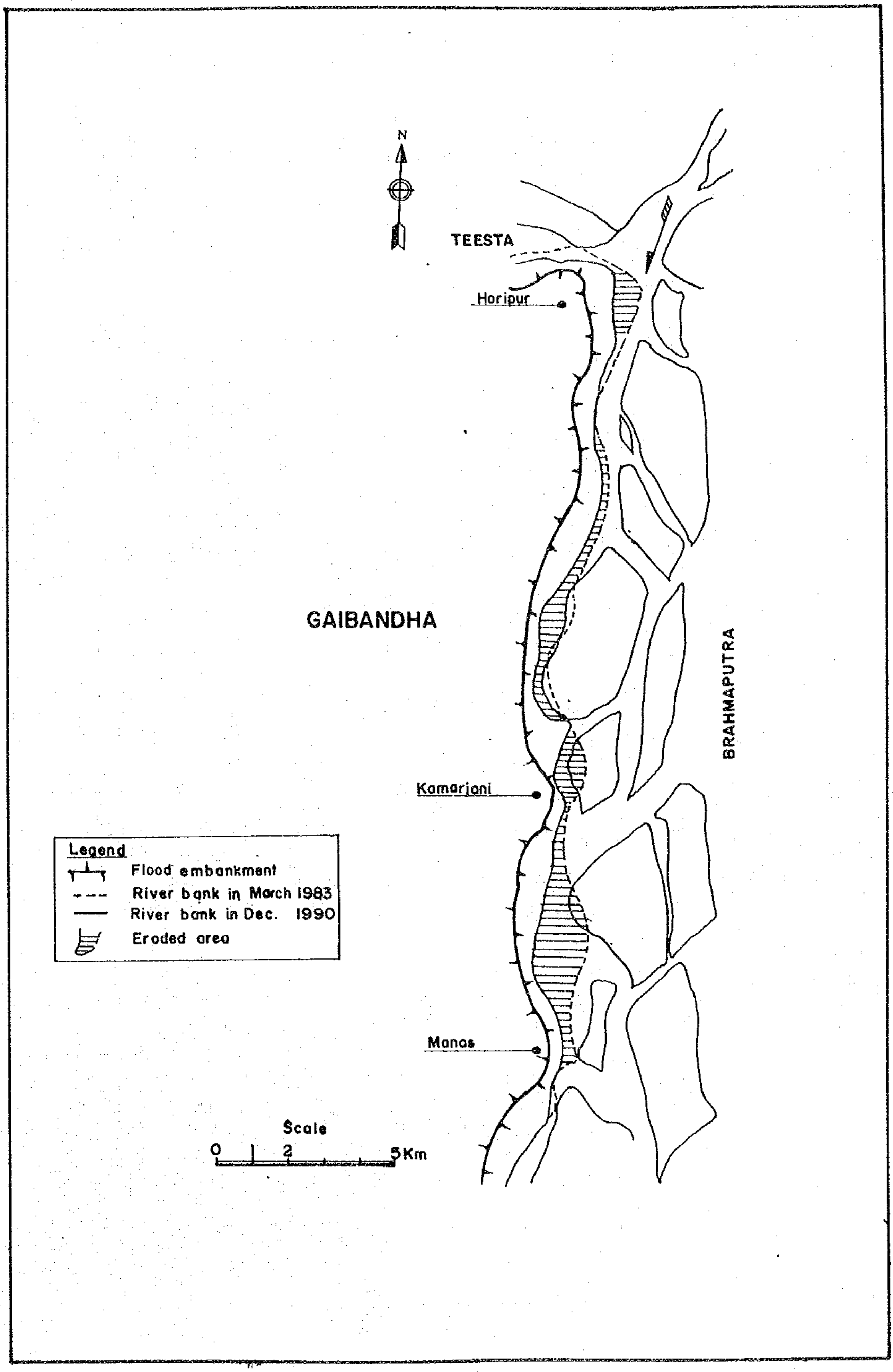


Figure 2.4 RIVER FEATURES OF THE TEESTA RIVER

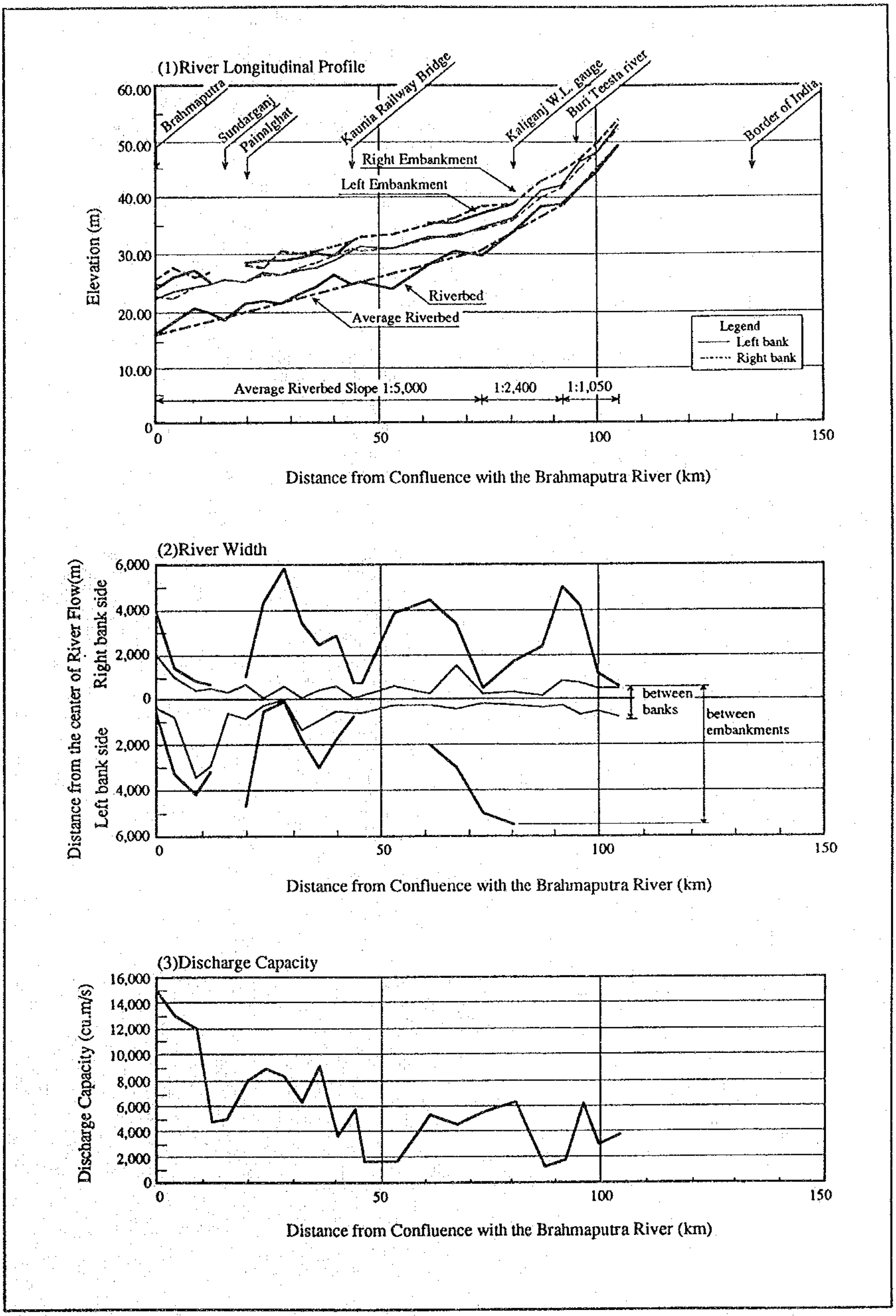


Figure 2.5 RIVER BANK EROSION ALONG THE TEESTA

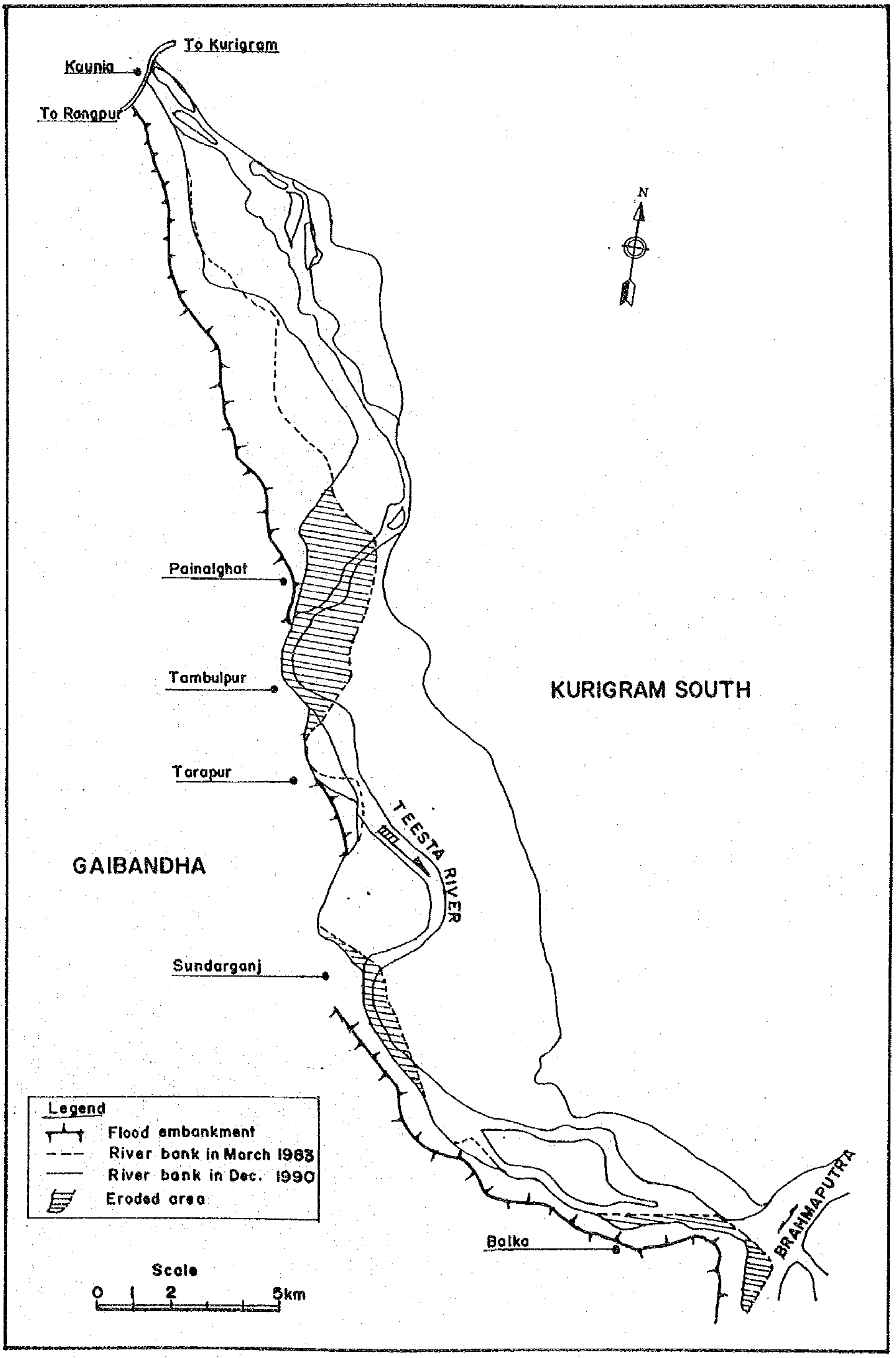


Figure 2.6 RIVER FEATURES OF THE GHAGOT TO THE MANAS

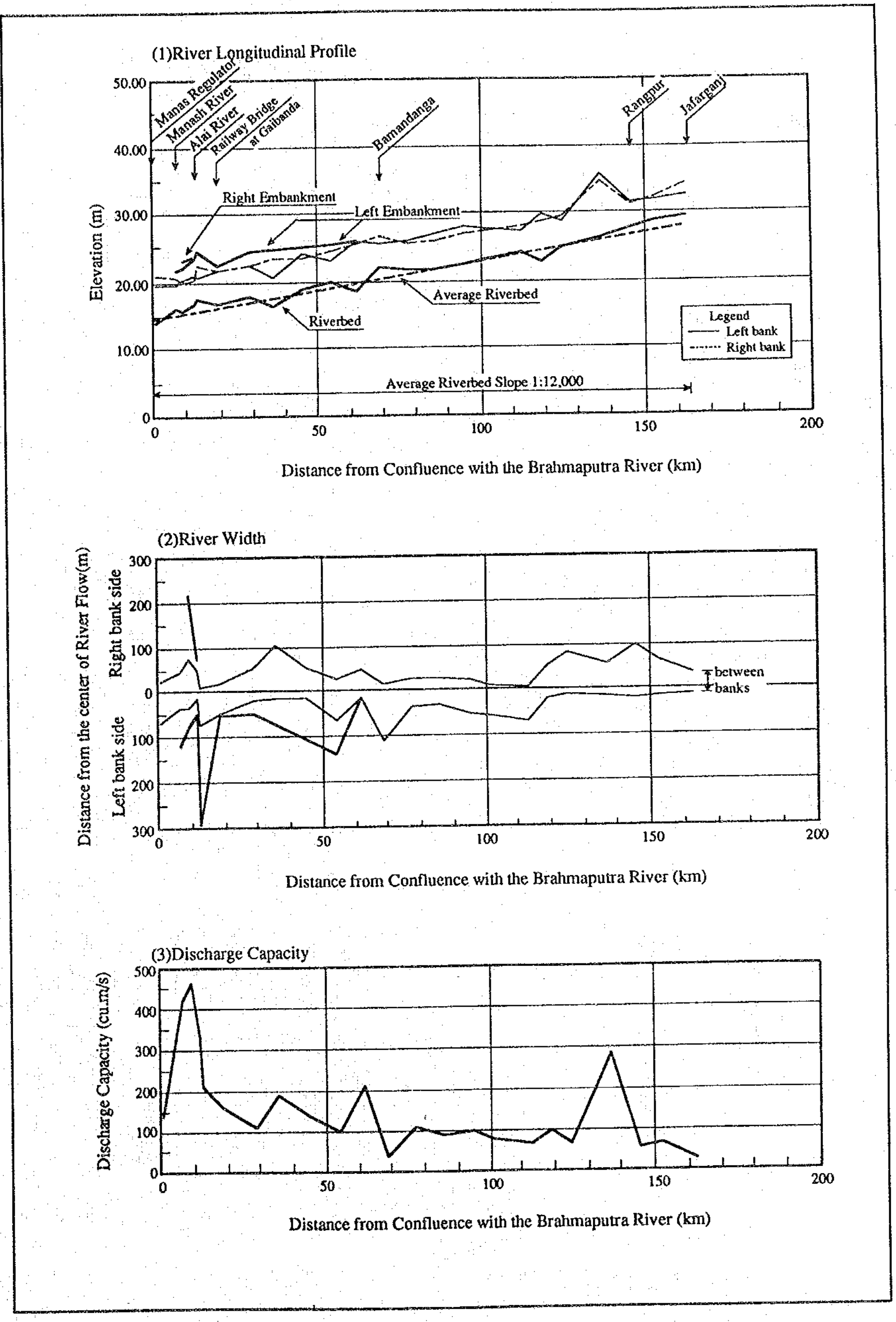


Figure 2.7 RIVER FEATURES OF THE GHAGOT AND THE ALAI

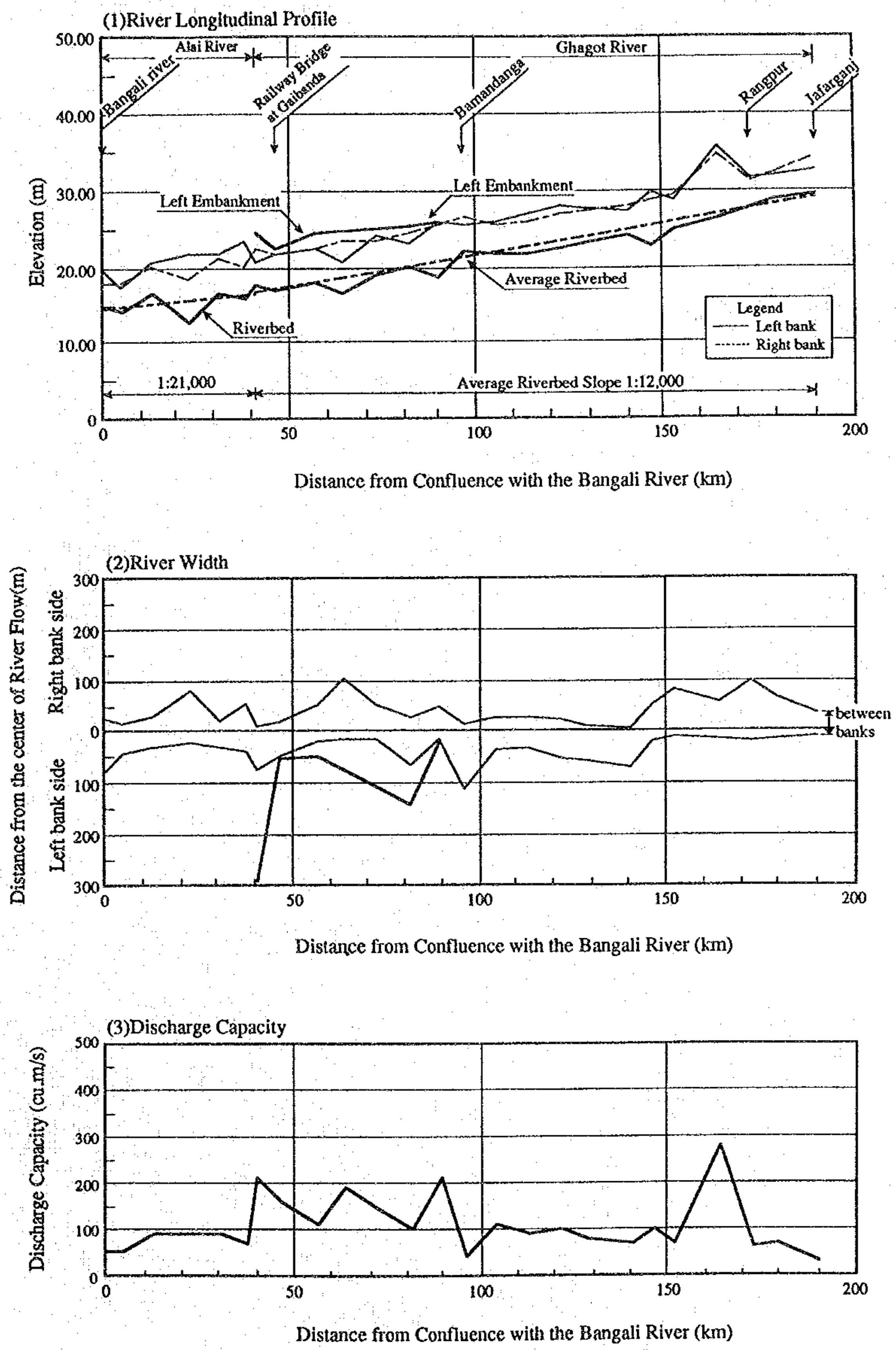
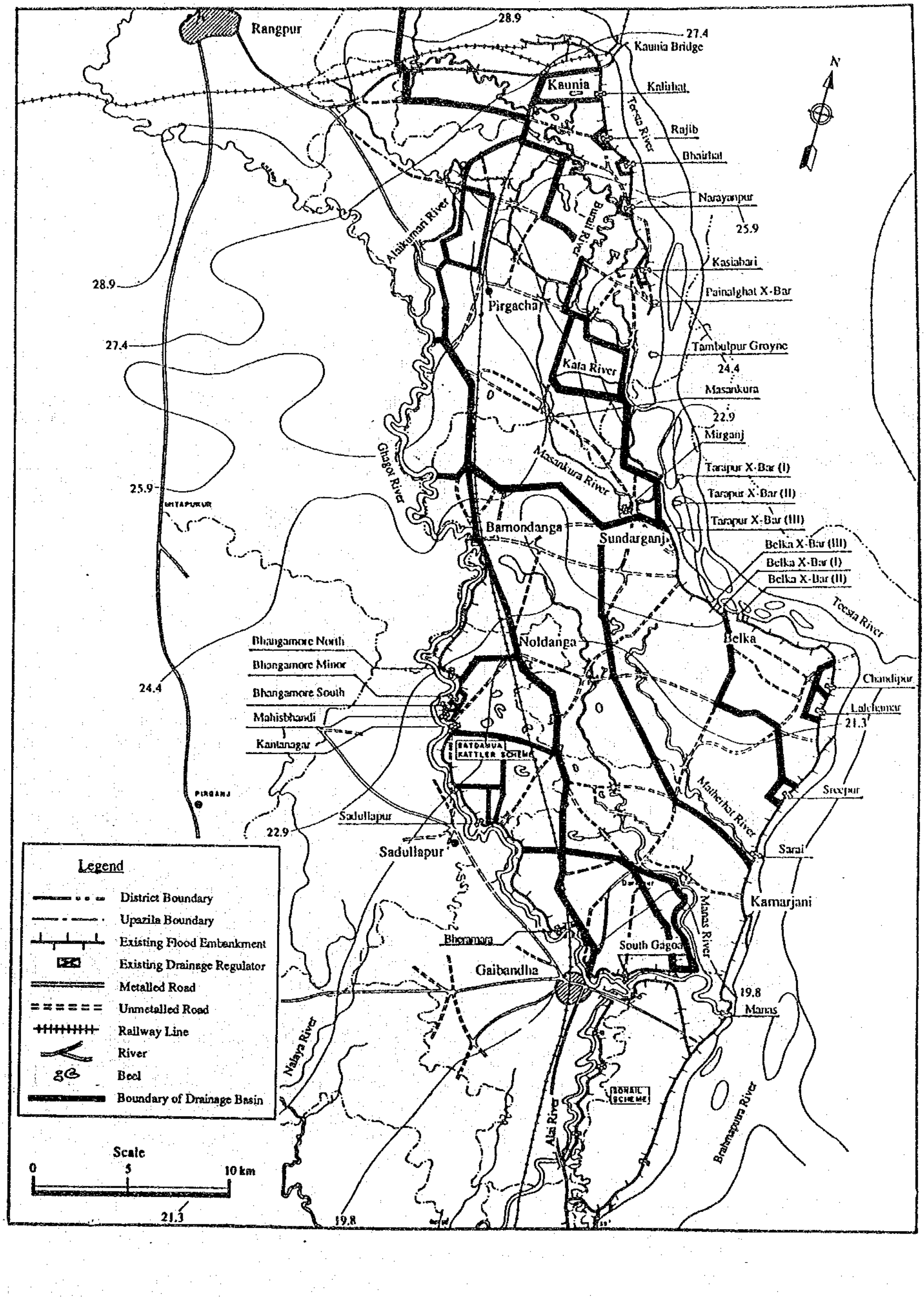


Figure 2.8 INTERNAL RIVER BASINS IN THE GIP AREA



3. EXISTING FCD STRUCTURES

The existing FCD structures in and around the GIP area were provided under FCD and/or FCD/I project of Brahmaputra Right Embankment (BRE), Teesta Right Embankment (TRE), Satdamua Katler Embankment (SKE) on the left bank of the Ghagot between Gaibandha and Bamondanga, Komarnai Bundh scheme (KBS) and Sonail Embankment scheme south of the Ghagot-Manas.

The System Rehabilitation Project (SRP) is going on to improve the drainage situation in the area enclosed by the flood embankment provided by KBS and the existing road embankment connecting Gaibandha town with Belka, and the east and north by the road embankment.

The existing FCD structures provided by the above projects are summarized in Table 3.1 and described as follows:

3.1 Brahmaputra Right Embankment

Brahmaputra Right Embankment (BRE) was constructed in 1960's to protect the agricultural land along the Brahmaputra between the confluences with the Hurasagar and the Teesta (219 km) from flood with frequency of 1 in 100 years return period. The length of BRE along the GIP area is about 24 km from Rasulpur, joining point of BRE and Sonail embankment, to Horipur. Figure 3.1 shows the profile of the BRE.

The BRE has a height of 2.6 m to 5.0 m, a crest width of 3.0 m to 5.0 m, and side slopes of 1:1.6 to 1:3.4 at the country side and 1:1.5 to 1:3.0 at the river side. During the monsoon season or through a year, inhabitants living in the river side area settle on and behind the BRE excavating BRE body to build their houses. In addition, BRE is used as traffic road. Utilization for these purposes deteriorates the structural strength of BRE against seepage and sliding. Besides, embankment slope is easily eroded by rainfall, wind, wave, and animals due to uncompacted embankment body. Erosion also deteriorates the structural strength of BRE against seepage and sliding. As a result of the mentioned activities and natural phenomenon, the side slope and crest width of BRE are presently less than the designed ones (1:3 for slope) at the most of parts.

There exist five drainage regulators on BRE, namely: the Manas regulator draining out the flood water from the Ghagot and Manas rivers, Sarai regulator for the Matherhat, and Chandipur, Lalchamar and Sreepur regulators for isolated basins with a drainage area less than about 4 km^2.

3.2 Teesta Right Embankment

Teesta Right Embankment (TRE) downstream of Kaunia was constructed in 1960's as a part of the BRE. The length of TRE from Kaunia to the outfall is about 43 km but flood embankment about 11 km long was breached by the 1987 and 1988 floods. The profile of existing TRE is shown in Figure 3.2.

The flood embankment at breached portions situated at Painalghat, Sundarganj and Belka is under construction to connect it to the existing village road but its height is less than the design flood water level (1 in 20 years return period). BWDB provided impermeable groynes of 8 nos. at Painalghat, Tarapur, Tambulpur, and Belka along the breached embankment to protect the river bank from erosion but 6 nos. of these groynes were washed away partly or totally within a few years after the completion

of construction and some were reconstructed or repaired. At Belka, the TRE breached in the post-monsoon season of 1991 over a length of about 300 m due to bank erosion.

The TRE has a height of 2.0 m to 4.4 m, a crest width of 2.5 m to 5.2 m, and side slopes of 1:1.8 to 1:3.5 at the country side and 1:1.6 to 1:3.5 at the river side. Since the TRE is also utilized for housing and traffic road, and eroded by natural phenomenon as well as the aforesaid BRE, the embankment body has rather deteriorated.

There are 7 regulators on the TRE, namely: Mirganj and Masankura at the outfall of the Masankura river, Kasiabari, Narayanpur, Bhairhat, Rajib, and Kalirhat for the isolated small basins along the TRE. Among these regulators, the Masankura regulator with 1 vent is constructed for storing water for irrigation and fisher purposes.

Also in the upstream TRE outside the GIP area, there is a breach about 7 km long located downstream of the confluence with the Buri Teesta. Some of the flood water and sediment of Teesta flow into the Ghagot through the breach and induce rise of flood water level and siltation of riverbed of the Ghagot.

3.3 Ghagot Left Embankment

The Ghagot Left Embankment (GLE) was or is being constructed under the two projects; one is the Satdamua Katler Beel project funded by EIP and the other is the Gaibandha Town Protection. The Satdamua Katler Beel project is providing flood embankment with total length of about 35 km which consists of new flood embankment 6 km long and resectioning of road embankment 29 km long on the left bank for a section from Gaibandha to Bamondanga. The project is scheduled to be completed in 1992/1993 fiscal year. Also under the Komarnai Bundh scheme (KBS), the flood embankment with a length of 5 km was built for a section from the existing road bridge to the confluence of the Manas river to prevent intrusion of flood flow of the Ghagot and Manas into the GIP area including the Gaibandha town area. The profile of the GLE is shown in Figure 3.3.

The GLE has a height of 0.5 m to 4.6 m, a crest width of 1.0 m to 5.0 m, and side slope of 1:0.4 to 1:2.5 in the country side and 1:0.9 to 1:2.6 in the river side. However in the downstream reach from the confluence of the Manas, flood embankment is not provided. The GLE was designed to have both side slopes of 1:2 but the present slopes are steeper than designed one at the most of part thereof.

There are 9 regulators along the GLE, out of which the Manas regulator aims to drain out flood water of the Ghagot and Manas with a catchment area of about 1,300 km^2). The South Gagoa regulator is used for the drainage for the Gaibandha Town Protection area, and others for the area of 6,200 ha of the Satdamua Katler Beel project which is bounded by the railway line and the Ghagot.

3.4 System Rehabilitation Project

The System Rehabilitation Project mainly funded by EEC, IDA and WFP has an intention to improve the drainage situation in the area of Komarnai-Bundh scheme. Presently, this area suffers the drainage congestion due to the insufficient drainage capacity of the existing South Gagoa regulator, flood flow coming from the Manas river through the river channels located at the northern part of the area and high water stage of the Brahmaputra with a long duration.

The detailed information related to the project features for the required FCD structures planned or to be planned is not available for FAP-2 study. It is considered that it will be necessary for the SRP to follow the FCD plan proposed by FAP-2 for the objective area of the SRP or that GIP will revise the proposed FCD plan in the detailed design stage taking into account the definitive FCD plan to be established by the SRP.

3.5 Sonail Embankment

The Sonail Embankment scheme is a completed project by funding of EIP. A total of 19.4 km long flood embankment is situated on the left bank of the Alai and on the right bank of the Ghagot-Manas, of which 4 km long one is aligned along the Ghagot-Manas to be linked with the BRE. The Sonail embankment along the Ghagot-Manas has a height of 2.2 m to 3.4 m, a crest width of 3.0 m to 5.4 m, and side slope of 1:1.7 to 1:2.9 in the country side and 1:1.8 to 1:2.4 in the river side.

At present, most of the flood taking place in the Ghagot flows into the Alai during the peakmonsoon season since the capacity of the Manas regulator depends on the water levels of the Brahmaputra and it is difficult to drain out flood water of the Ghagot through the Manas regulator when the stage of the Brahmaputra comes to higher than the inland water level. On the other hand, the flow capacity of the Alai is less than 100 m^3/s. Therefore the project area of the Sonail Embankment as well as the right bank area suffers severe inundation due to the insufficient drainage capacity of the Manas regulator.

Table 3.1 EXISTING FCD AND RELATED STRUCTURES (1/2)

(1) Flood Embankment

	Existing Embankment	Total Length (km)	Crest Width (m)	Height (m)	Breach Length (km)	Embankment Slope	
						Country Side	River Side
1.	Teesta (TRE)	43	2.5 to 5.2	2.0 to 4.4	11	1:1.8 to 1:3.5	1:1.6 to 1:3.5
2.	Brahmaputra (BRE) along the Project area	24	3.0 to 5.0	2.6 to 5.0	0	1:1.6 to 1:3.4	1:1.5 to 1:3.0
3.	Ghagot Left Embankment	35	1.0 to 5.0	0.5 to 4.6	0	1:0.4 to 1:2.5	1:0.9 to 1:2.6
4.	Ghagot - Manas on the left bank	5	3.3 to 4.0	2.4 to 3.7	0	1:1.6 to 1:2.0	1:1.9 to 1:2.4
5.	Sonail Embankment on the right bank of Ghagot	4	3.0 to 5.4	2.2 to 3.4	0	1:1.7 to 1:2.9	1:1.8 to 1:2.4

(2) Groyne

No.	Location	Dimension			Protection Work	Remark
		Length (m)	Height (m)	Crest Width (m)		
1	Belka (II)	314	3.8	5.0	brick	
2	Belka (I)	(200)	(2.5)	(5.5)	brick	completely washed away
3	Belka (III)	(200)	(2.5)	(5.5)	brick	completely washed away
4	Tarapur (II)	370	3.5	7.5	brick	
5	Tarapur (I)	(240)	(3.0)	(6.0)	brick	completely washed away
6	Tarapur (III)	(36)	(4.3)	(6.0)	brick	completely washed away
7	Tambulpur	(500)	(1.5 to 3.0)	(6.0)	brick/concrete block	completely washed away
8	Painalghat	600	2.6	5.0	brick/concrete block	

Note : Figures in parenthesis show designed dimensions.

(3) Regulators/sluices

No.	Name	Vent		Sill Level (m)	Crest Level (m)	Outer River	Drainage Area (km^2)
		Nos.	Size (m)				
1.	Kalirhat	1	1.52x1.83	27.80	31.87	Teesta	7.45
2.	Rajib	1	1.52x1.83	26.56	30.98	Teesta	1.88
3.	Bhairhat	1	1.52x1.83	26.69	31.11	Teesta	0.10
4.	Narayanpur	1	1.52x1.83	25.74	30.41	Teesta	0.35
5.	Kasiabari	1	1.52x1.83	24.78	30.37	Teesta	0.67
6.	Chandipur	2	1.52x1.83	21.17	25.51	Brahmaputra	0.97
7.	Lalchamar	1	1.52x1.83	20.40	25.58	Brahmaputra	3.26
8.	Sreepur	1	1.52x1.83	20.88	25.91	Brahmaputra	1.80
9.	Sarai	6	1.52x1.83	18.77	25.18	Brahmaputra	85.52
10.	Manas	12	1.52x1.83	16.34	25.48	Brahmaputra	150.68
11.	South Ghagoa	2	1.52x1.83	19.87	23.07	Ghagot-Manas	27.26
12.	Bheramara	1	1.52x1.83	18.87	25.27	Ghagot	10.47
13.	Kantanagar	1	1.52x1.83	20.73	25.49	Ghagot	21.81
14.	Mahisbhandi Sluice	1	1.52x1.83	21.86	25.82	Ghagot	0.25
15.	Bhangamore South	1	1.52x1.83	21.73	26.15	Ghagot	0.18
16.	Bhangamore Minor	2	1.52x1.83	20.42	25.33	Ghagot	0.24
17.	Bhangamore Minor North	1	0.91x0.61	22.75	26.78	Ghagot	12.87
18.	Sadullahpur	1	1.52x1.83	21.03	-	Ghagot	2.85
19.	Mirganj	5	1.51x1.83	21.64	-	Teesta	112.20
20.	Masankura	1	1.52x1.83	22.55	-	Masankura	65.35

Table 3.1 EXISTING FCD AND RELATED STRUCTURES (2/2)

(4) Drainage Channels

No.	Name of River	Length in the Project Area (km)		Catchment Area (km^2)	
1.	Manas	44.0		150.68	
2.	Matherhat	31.4		85.52	
3.	Masankura	25.8		112.20	
4.	Kata	6.0		15.81	
5.	Burail	Outer basin :	22.5	Outer basin :	25.00
		Project area :	34.0	Project area :	46.05
				Total	71.05

(5) Major Bridges

No.	Name	Total Span Length (m)	Width (m)	Lowest Girder Elevation (m)	Name of River
1.	Kaunia	640.0	5.0	33.4	Teesta
2.	Railway Bridge at Gaibandha	67.5	5.0	25.6	Ghagot
3.	Road Bridge at Gaibandha	-	-	-	Ghagot

Figure 3.1 LONGITUDINAL PROFILE OF THE EXISTING BRE

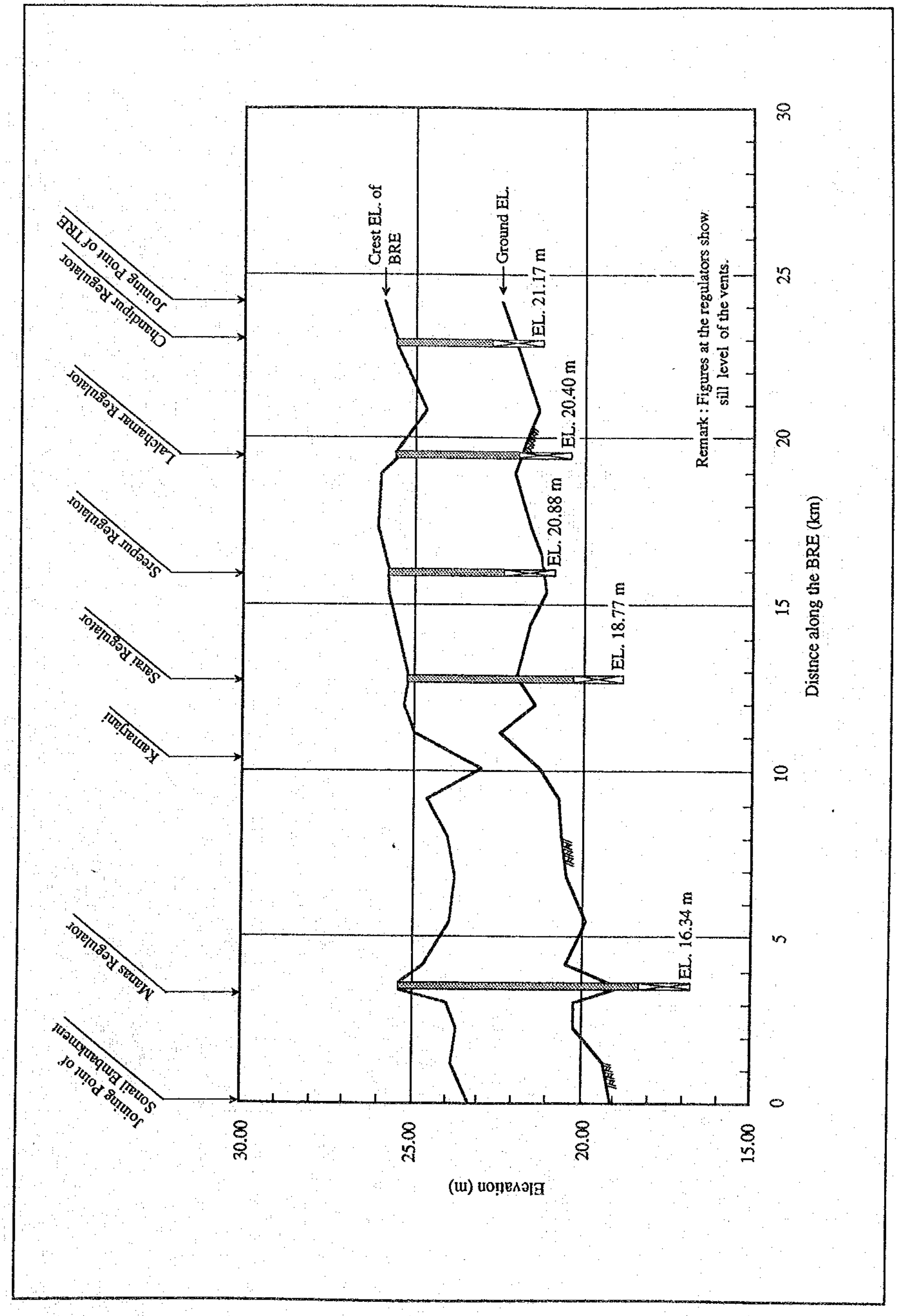


Figure 3.2 LONGITUDINA PROFILE OF THE EXISTING TRE

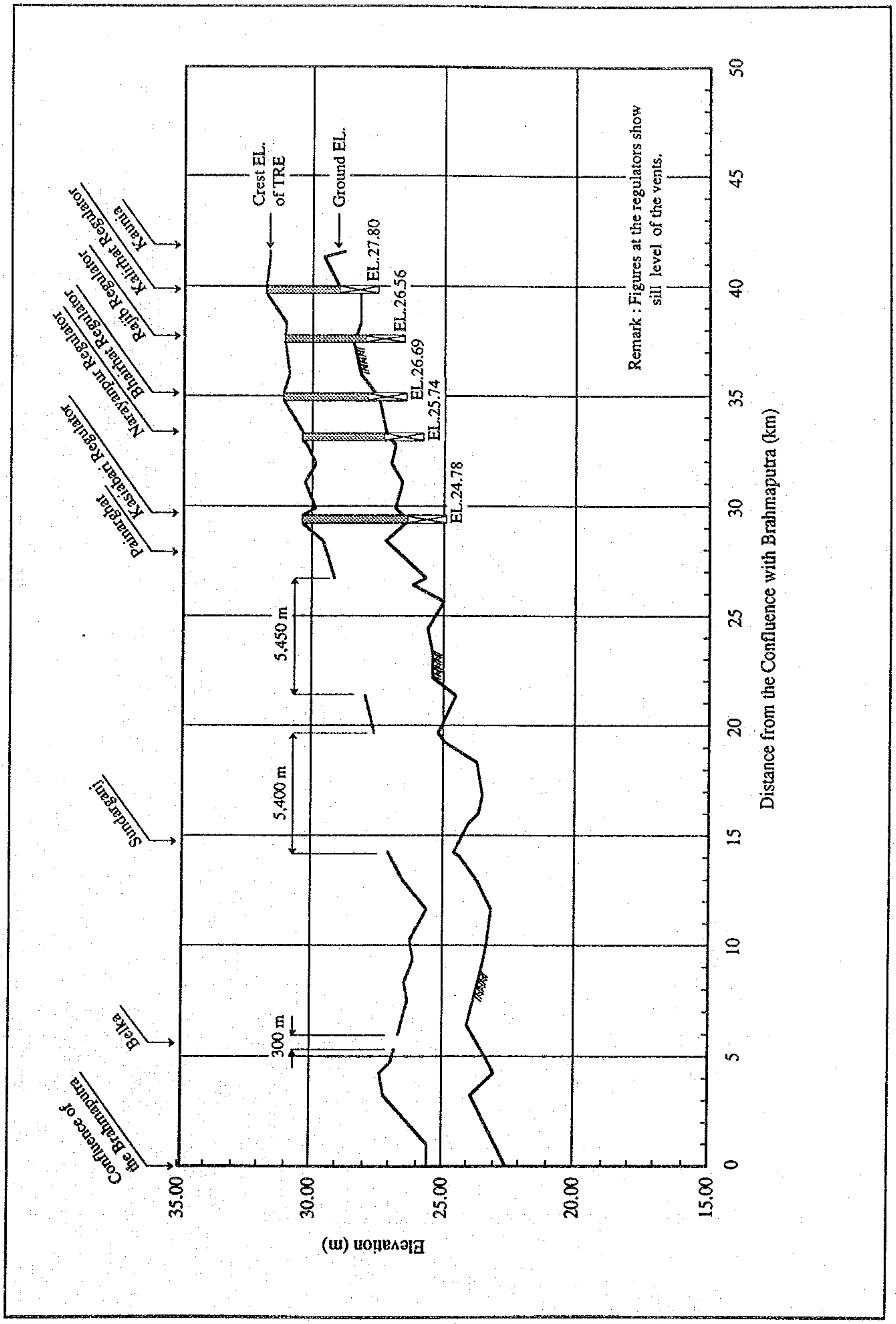
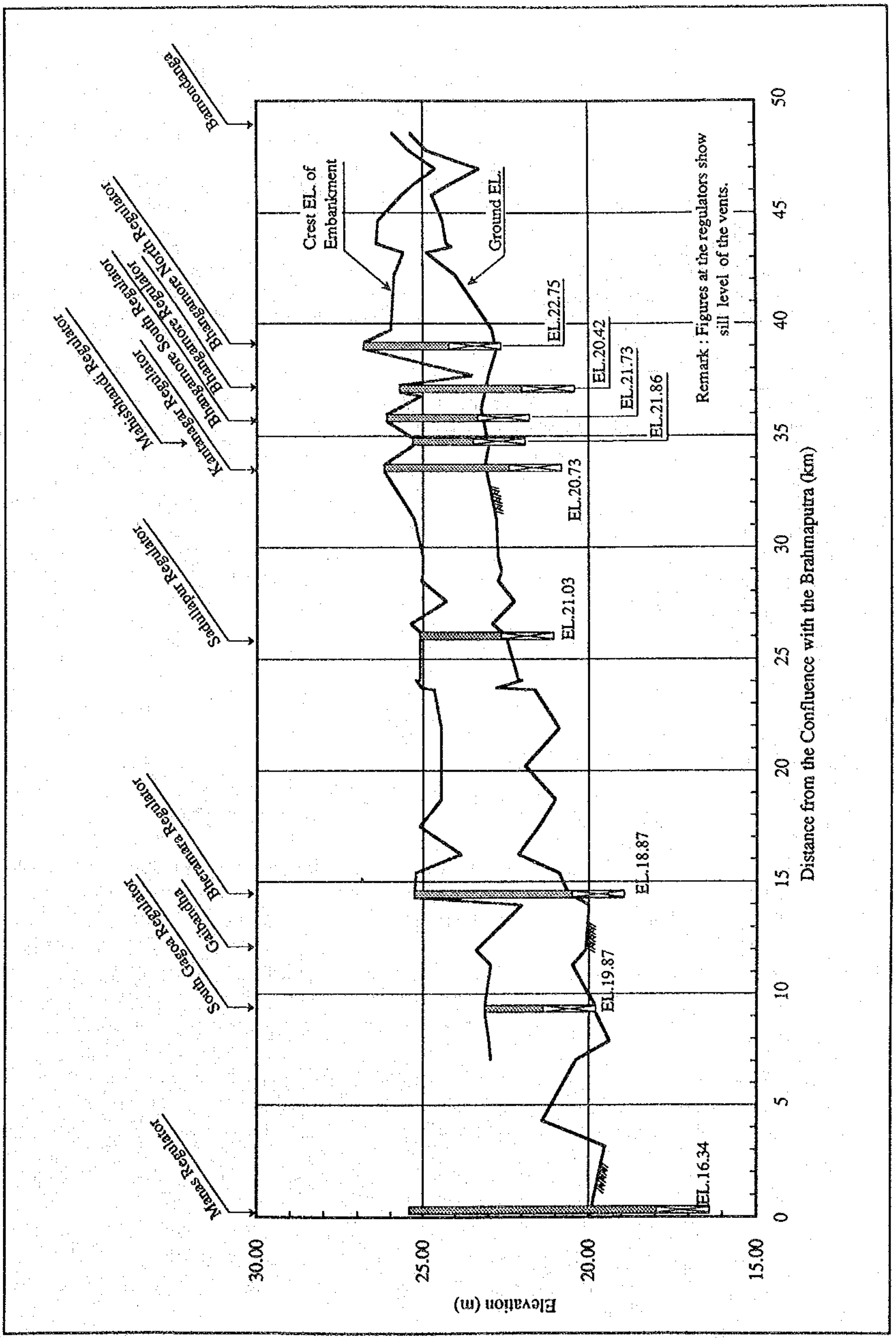


Figure 3.3 LONGITUDINAL PROFILE OF THE EXISTING GLE



4. FLOOD CONTROL AND DRAINAGE OPTIONS FOR GIP

4.1 Present Flooding and Drainage Problems in the GIP Area

The flooding and drainage problems were carefully identified through the field investigation, public consultation to the local government staffs and inhabitants in the GIP area, and data collection and engineering studies and analyses for them as mentioned in the following sub-sections:

4.1.1 The Brahmaputra

The river channel of the Brahmaputra has been shifting to the west eroding the river banks from Horipur to Kajarhat in the project area so that retirement of the flood embankment has been repeated to date. Especially, the upstream river bank of the existing Manas regulator is being severely eroded in these years and predicted to be washed away within a few years.

However, flood damage in the GIP area due to flood water intrusion of the Brahmaputra, after the Manas regulator be washed away, is considered to be be rather small taking into account that the general ground slope of the GIP area is from the west to the east and that flood water levels of the Brahmaputra are rather lower than those of the Ghagot and Teesta.

According to FAP-12 study which assesses the Kamarjani reach along the BRE, provision of the BRE has improved the living conditions and minimized a flood damage to inhabitants and their properties during the monsoon season. Whilst, the BRE has worsened drainage situation in the monsoon season due to the lack of drainage facilities caused by the repeated retirement of the flood embankment. In these years, the drainage congestion has continued and causes crop damage to T.Aman, Jute plants and jute for several weeks a year, and to HYV Boro and Aus not only during the peak monsoon season but also in the pre-monsoon season.

4.1.2 The Teesta

River bank erosion due to shifting of the main stream is the most serious problem for the Teesta. Presently, there is about 11 km long breach between Painalghat and Sundarganj due to the river bank erosion, and flooding water spilled therefrom are rushing into the GIP area through the downstream reaches of the Burail, Kata and Masankura rivers causing damage to crops such as jute and paddy. Especially, the spilled water causes habitual flooding along the Masankura river where the Masankura regulator with 1 vent is provided to store internal runoff to utilize it for irrigation purpose during dry season. To drain out the excessive flood water stored in the storage area, inhabitants cut the embankment connected with the regulator every year. Besides, the flood water released from the Masankura regulator attacks the Mirganj regulator with 5 vents which is situated at the downstream end of the Masankura river. Thereat also, the cut of embankment is done by the inhabitants for the drainage purpose since the capacity of the regulator is insufficient to drain out the excessive flood water.

The TRE at Belka was breached by river bank erosion for a length of about 300 m in 1991. Once flood water comes through the breach into the Matherhat river, flooding water will cause severe flood damage to the monsoon season's agricultural crops cultivated in the basin as well as drainage congestion in the downstream reach where the Sarai regulator exists on the BRE but its capacity is dominated by water level of the Brahmaputra.

Outside the GIP area, there is a breach about 7 km long downstream of the confluence with the Buri Teesta. Some of the flood water and sediment of Teesta flows into the Ghagot through the breach and induces rise of flood water level and siltation of riverbed of the Ghagot.

4.1.3 The Ghagot

Presently, at the upstream end of the Ghagot it is linked with the Teesta through the aforesaid breach about 7 km long, which was formed by the 1988 flood. As a result, flood water and vast sediment conveyed by the Teesta easily enter the Ghagot. Besides, the excess flood water from the Teesta is retarded in the upstream reaches so that sediment is deposited in the upstream riverbed and flood plain.

Under the Satdamua Katler Beel System funded by EIP flood embankment is provided on the left bank between Gaibandha and Bamondanga. Since the upstream reach of Bamondanga is still unprotected by the flood embankment and there exist 11 openings in bridges and culverts provided into the existing railway embankment between Kaunia and Bamondanga, flood water from the Ghagot-Alaikumari intrudes into the GIP area mainly through the Bamondanga beel and those openings along the railway line, causing flood damage in the drainage areas of the Masankura and Manas where the flood discharge of the Ghagot is augmented by water spilled from the Teesta.

The existing flood embankment on the left bank is severely eroded on both the side slopes and the flood embankment in the downstream reach is considered to be rather unstable against seepage and sliding failures considering a long duration of deep inundation lasting in the monsoon season.

On the right bank of the Ghagot BWDB provided the flood embankment with about 1 m height and 1 m crest width for a section from Gaibandha to Sadullahpur before 1987. There exist many excavated portions and severely eroded slopes in the flood embankment, so that allows the intrusion of flood water into the right bank side area through these portions. The inhabitants claim that the flooding situation in the area has become more severe due to the construction of the left embankment of the Ghagot. The inundation depth in the area is 1 m in normal year and in 1987 all the area was inundated.

There are many beel areas on the right bank surrounded by the Ghagot, national highway, the Alai, and the Bangali, in which flood water spilled from the Ghagot through the Akhira and Naleya rivers is retained. These causes the drainage congestion in those beel areas due to insufficient capacity of their downstream drainage rivers (khals) finally flowing into the Karatoya/Bangali.

At present, the Gaibandha town area situated on the right bank of the Ghagot, of which the river channel inside the flat town area is remarkably meandered, is unprotected by the flood embankment. Therefore, the Gaibandha town is subject to the habitual flooding due to flood water spilled from the Ghagot.

4.1.4 Internal drainage

The GIP area is divided into 31 drainage basins based on topography and the existing rural road and railway embankments. These basins are inter-linked through bridges, culverts, and drainage canals identifiable only during the monsoon season. Along most of the drainage routes, there are many beels which function as retention ponds regulating flood runoff during monsoon season, and small ponds for irrigation or fishery propose in dry season.

Major drainage problems are:

a) excessive flood water of the Teesta and Ghagot flowing down into the GIP area through breaches or openings against the insufficient capacities of existing regulators,

b) insufficient drainage capacities of the existing regulators/sluices due to influx of excessive rainfall runoff into the drainage basin through interlinked canals or natural channels,

c) closure of natural drainage routes by construction of rural road embankments. The number of such places closed by improper alignment of rural roads reach 450 based on the topographic maps at a scale of 1:20,000 produced by FAP2. Especially, this creates a lot of sub-drainage areas where it is hardly possible to drain water during the monsoon season.

d) localized drainage congestion along the existing embankments due to lack of drainage facilities, which leads to public-cut of the flood embankment.

4.2 Conceived FCD Options

Taking into account the present severe inundation in the GIP area which is caused mainly due to spilling of flood water from the Teesta and Ghagot thereto as well as river bank erosion along the Teesta and Brahmaputra especially upstream of the Manas regulator, the following FCD options were conceived to solve the flooding problems:

4.2.1 Teesta Right Embankment (TRE)

The river bank erosion is a serious problem on TRE, which requires regular maintenance of the existing flood embankment and provision of retired embankment in order to protect the land along the river. This causes a habitual loss of agricultural land and homestead areas along TRE. The erosion rate of land along the Teesta is estimated to be about 260 m/year for a section from Painalghat to Tambulpur, 150 m/year at Sundarganj, and 50 m/year at Horipur based on aero photographies shot in the past as explained in Chapter 2. Especially, about 11 km long TRE from Painalghat to Sundarganj was breached by the above severe bank erosion during the 1987 and 1988 floods. Also, the TRE at Belka was breached in 1991. Figure 4.1 shows the river bank lines which would be left after 5, 10 and 15 years from now on the assumption that river bank is eroded with the current bank erosion rates thus estimated. Assuming that river bank erosion goes on with those rates, in other words the area of 1.8 km^2 is estimated to be lost every year.

In order to solve the flooding problems in the GIP area, it is essential that TRE with the flood protection level (1 in 20 years return period) always lies over the whole river stretch related with the flooding therein, since one of those main causes is intrusion of the Teesta flood water through TRE. The following two options to keep on TRE are conceivable:

Option 1 : to maintain the present river bank line and to prevent loss of land by means of providing proper and sufficient river training works;

Option 2 : to abandon the lands to be eroded by the flood flows, where it is not economic to protect them, and to repeat retirement of flood embankment without river training work.

Of the above, the Option 1 requires the higher capital and O&M costs as a result of provision of costly river training work such as groynes and revetment, as compared with those in Option 2. Also in case of the Option 2, the considerably high capital costs need to be disbursed at certain intervals for repeating construction of new flood embankment, new regulators/sluices and land acquisition. Besides, it has to be noted that the Option 2 would induce such social problems as; i) increase of landless people due to land acquisition of new flood embankment as well as loss of the land; ii) resettlement of the existing towns and villages developing along the existing flood embankment; iii) compensation for inhabitants and farmers residing in the river side of new retired embankment, who are presently protected from the

flood by the existing flood embankment more or less but will be inundated due to retirement of the flood embankment.

A preliminary study is carried out to select the optimum option among the above two ones applying the least cost method in consideration of disbenefit attributable to land loss which is assessed as the production foregone. Concerning the Option 2, the comparison study was made for three different cases in terms of the maintenance period of existing flood embankment until the completion of the next retired embankment, namely 5, 10 and 15 years. Thus, in these cases for the Option 2, the flood embankment needs to be newly constructed at intervals of every 5, 10 and 15 years taking set-back distance corresponding to that eroded in the maintenance period on the condition of project life being 30 years. The result of the comparative study is summarized as follows:

Items	Unit	Option 1	Option 2		
			5 years	10 years	15 years
A. Construction work					
a) New flood embankment	km	13.2	163.6	89.8	66.9
b) Resectioning/heightening of the existing embankment	km	33.4	32.6	28.6	24.0
c) Regulator	nos.	4	20	12	8
d) Sluice	nos.	5	25	15	10
e) Groyne	nos.	26	-	-	-
f) Revetment	km	4.2	-	-	-
B. Total construction cost	TK.m	612.7	1510.6	839.5	624.9
C. Construction period	year/cycle	4	2	2	2
D. O&M cost (percent to construction cost)	%	5	3	3	3
E. Land acquisition	km²	0.94	7.89	4.42	3.10
F. Loss of land	km²	0.0	54.0	54.0	54.0
G. Production foregone	TK.m/km²	2.0	2.0	2.0	2.0
H. Total present value	TK.m	423	702	585	541

The above table indicates that the Option 2 requires the new flood embankment over the significantly long distance of 70 km to 164 km as well as reconstruction of the drainage structures thereon such as regulators and sluices and that area to be lost for the project life of 30 years reaches 54 km^2 corresponding to about 10 % of the GIP area.

Moreover, economic evaluation clarifies that the Option 1 gives the lower present value than the Option 2 taking into account the values of the production foregone resulted from loss of land due to erosion. Considering the economic indices as well as social adverse impact, maintaining the present bank line by means of river training work is recommendable as the most favourable option for TRE.

In addition, the public participation performed by the FAP2 Study Team in the GIP area in 1992 has clarified that the FCD measure which the local people are the most strongly hoping is to maintain the present bank line to avoid further increase of landless people therein.

4.2.2 Brahmaputra Right Embankment (BRE)

The Manas regulator site located at outfall of the Manas river to the Brahmaputra has severely been eroded in these years due to shifting of the river channel to the west and is predicted to be washed away within a few years. On the other hand, it is forecast that, flood damage due to flood water intrusion of the Brahmaputra through the downstream end would be rather small even after it is washed away,

taking into account that the general ground slope of the GIP area is from the west to the east and that flood water levels of the Brahmaputra are rather lower than those of the Ghagot and Teesta. In fact, the peak water level in 1988 at the Manas regulator was about El. 21.0 m which covers about 13 % of the GIP area. This means that, even if the BRE is breached at the Manas regulator site on other any portions of BRE, only 13 % of the GIP area will be inundated in the river stage.

FAP 1 study recommended in the Second Interim Report that repeating retirement of the existing flood embankment is suitable rather than maintaining the present river bank line for the upstream BRE between Fulchari and Horipur from the view point of economic effectiveness taking into account the degree of flood damage. It is appears that the FAP-1's recommendation is endorsed by the lesser flooding area in case BRE is non-existent.

In addition, the existing BRE secures a set-back distance which would ensure its maintenance for about 10 years in terms of the annual bank erosion rates estimated by the past aero photographies taken in the past as discussed in the foregoing Chapter 3. At the section close to the Manas regulator, it is proposed to provide the embankment under GIP taking the set-back distance to the same extent with the existing section.

On the other hand, FAP 21 and 22 is planning to carry out the pilot construction of the river training works just upstream of the existing Manas regulator. It is recommended that the river training works be taken into consideration after viability has been fully verified from the technical and economic aspects through the study.

Following the recommendations of FAP 1, it is determined to adopt the repeated retirement of flood embankment concerning BRE.

4.2.3 Ghagot

Strengthening of the TRE to prevent intrusion of the excess flood water with much sediment into the GIP area is a priority option obviously since the flow capacity of Ghagot is as small as less than 200 m^3/s and the excess flood water rises flood water level along the Ghagot. This option would have a favourable impact not only on the GIP area but also on the right bank area along the Ghagot with respect to the flooding and silting.

The insufficient drainage capacity of the Manas regulator, which is forecast to be washed away in near future, has an adverse effect on the inland water levels in the downstream areas along the Ghagot, where the inundation situation is the most severe in the GIP area because of the low ground elevation and backwater of the Brahmaputra. Therefore, non-existence of the Manas regulator is considered to be one of the options for the Ghagot to improve drainage congestion in the low-lying areas.

Further, extension of the present Ghagot Left Embankment to the upstream reach of Bamondanga is required to protect the GIP area from the flood flow overtopping the left side river bank along the Ghagot. But provision of the new flood embankment will result in a rise of inundation water level in the right bank area which is of depression area surrounded by the Ghagot, Alai, Karatoya and national highway. Provision of the flood embankment on the right bank along the mentioned rivers is therefore required to cope with such a flooding problem in the right bank area of the Ghagot.

On the other hand, full confinement along the Ghagot might induce increase of flood peak discharge and rise of flood water level in the downstream reaches, especially along the Alai of which flow capacity is less than 100 m^3/s and drainage congestion occurs every year. To mitigate the adverse effect on the full confinement a combination of two FCD measures; one is to divert flood of the Ghagot to the

Bangali through the Alai by embanking along these rivers; the other is proposed to divert flood of the Ghagot directly to the Brahmaputra.

Gaibandha town, a capital town of Gaibandha district, is located at branching point of the Alai on the right bank of the Ghagot and habitually inundated by the flood of the Ghagot. In addition, there is a remarkably meandering river channel in the neighborhood of the town area and its top of the meandered channel is severely eroded. To improve these situation, short-cut channel with flood embankment is required to be provided since land acquisition of the town area is rather difficult. Besides, a new road bridge over the new shortcut channel has to be constructed in order to maintain the existing trunk road in the GIP area crossing the route of the shortcut channel.

4.2.4 Internal drainage

The drainage plan for GIP aims to enable the internal water to be drained out to the surrounding rivers by gravity flow through rehabilitation of existing regulators and/or new provision thereof within two weeks immediately after water level at the outfall of drainage channel becomes lower than the outer river water stage. Besides, to avoid concentration of internal rainfall runoff in the low-lying areas inside polders, large drainage basins with drainage area of about 100 km^2, are planned to be divided into smaller size compartments by provision of new embankment or heightening the existing small roads with reference to the study of FAP 20.

In consideration of the present situation of internal drainage patterns in the GIP area as well as the aforesaid objectives of the interval drainage improvement, the following options are worked out:

Option A : improved drainage by means of provision of drainage structures such as regulators and sluices and expansion of drainage capacities of existing regulators.

Option B option A with compartmentalization to avoid the concentration of internal rainfall runoff in the low-lying areas inside polders.

The following measures are taken into account in the both:

a) use of the existing beels as retention ponds, which mitigates concentration of rainfall runoff in the downstream areas under the present condition,
b) rehabilitation of the existing regulator and provision of new regulators as required,
c) provision of small sluices with side ditch along the foot of flood embankment to collect rainfall runoff from each drainage area, which is to be led to regulator or sluiceway. It is considered that this measure contributes to mitigation of localized drainage congestion and to refraining public cut,
d) provision of drain pipe in the existing roads embanked which presently interrupts the natural drainage since there is no provision of the drainage structures concerning most of the rural roads and to drain out rainfall runoff gradually to downstream but re-excavation of the existing drainage channels is not included since it will largely reduced the retardation effect against flood and worsens inundation situation downstream of each drainage basin.

In making compartmentalization of the GIP area, the following are taken into account:

a) The drainage area covered by the existing regulators/sluices which are mostly equipped with 1 or 2 vents is delineated by the topographic drainage boundary and rural road embankment with a sufficient height for the purpose.

b) Interlinked drainage basins which are created by opening on the embankment need to be separated by providing the drainage structures such as regulator and sluices or closing the openings. Especially, drainage basins interlinked to the Manas river is recommended to be separated in order to decrease drainage area of the Manas river by changing the present drainage courses into the other surrounding rivers as far as possible.
c) The Burail river is divided into two basins by proving drainage canal about 400 m long at a location 400 m north of Narayanpur regulator site, which were originally separated but interlinked since the TRE provision.

Figure 4.2 shows the compartment boundaries set up based on the above principles.

4.3 Setting-up and Selection of Combined Options

4.3.1 Basic concept

The individual options conceived which are described above are summarized as follows:

Teesta
1. Strengthening of TRE downstream of the Kaunia with river training works
2. Strengthening of TRE upstream of the Kaunia with river training works

Brahmaputra
1. Retirement of existing flood embankment

Ghagot
1. Non-existence of the Manas regulator
2. Extension of Ghagot Left Embankment
3. Option 2 with right embankment along the Ghagot and Alai
4. Option 2 with diverting flood discharge directly to the Brahmaputra together with backwater levee
5. Regulators on the Manas and Alai
6. Gaibandha town protection

Internal Drainage
1. Improved drainage by provision of new regulator or additional regulator
2. option 1 with compartmentalization

To selecting the optimum FCD options for GIP, a lot of FCD options set up combining the individual option above were examined since every options above has a significant impact on the river and internal water levels of the GIP area which is a key factor for benefit attributable to mitigation of flood damages to agricultural crops and infrastructures, and other associated benefits.

Therefore, setting and selecting of the combination of individual options are carried out examining hydraulic impacts on water level and inundation area, construction costs and their benefits, and social impacts. As the design years for examining hydraulic impacts and estimating construction costs are selected in 1987 with 1 in 20 years return period for flood control, and flood in 1985 with 1 in 5 year return period for internal drainage.

4.3.2 Setting-up and selection of combined options for GIP

Since strengthening of the upstream and downstream TRE will give the largest effects such as reduction of water levels along the Ghagot and decrease of water volume flowing into GIP, it is considered to be favourable option for GIP. Concerning BRE, the river bank about 40 m upstream of the Manas regulator is being severely eroded so that the regulator would be washed away in near future as discussed in this chapter. Loss of the existing Manas regulator is also fundamental option for the GIP

from view point of hydraulic effect on reduction of river and internal water levels around Manas regulator. Effect of these individual options is necessary to be carefully examined since construction cost for river training work along TRE is rather expensive and it is high possibility that the Manas regulator will be carried away by the erosion. Accordingly, the following options are examined as fundamental options for GIP.

A : without Manas regulator

B : Strengthening of the upstream TRE including sealing of the upstream breach (Kaunia bridge to the Teesta Barrage)

C : Strengthening of the downstream TRE including sealing of the downstream breach (Horipur to Kaunia bridge)

D : Strengthening of both the upstream and downstream TRE including sealing of breaches

Figure 4.3 shows schematic configuration of the above options with flood discharge distribution and Figure 4.4 illustrates flood water level profile of each option along the Teesta and Ghagot for 1987 flood.

Under the present situation, flood peak discharge of 210 m^3/s flows into the Ghagot through the upstream breach of TRE and therefore water level along the GIP area is considerably lowered within about 1 m by sealing of the breach. Through the downstream breach, flood peak discharge of 460 m^3/s enters directly and indirectly into the Burail, Masankura, Kata and Matherhat drainage basins of GIP through the interlinked drainage system. While, sealing of the both breaches of TRE does not affect flood water levels largely in the downstream of the Teesta since the increased flood peak discharge along the Teesta due to sealing of these breaches is rather small as compared with flood peak discharge and wide river channel of the Teesta.

Along the Ghagot, Option A reduces the river water level downstream of the Ghagot and Manas within an extent of 0.8 m. But, option A is considered to pass the flood water from the Brahmaputra into the Ghagot, Alai and Manas when the water level of the Brahmaputra is higher than that of these rivers. This inflow from the Brahmaputra would worsen flooding and drainage situations along the Alai of which flow capacity is less than 100 m^3/s due to very gentle river bed slope of 1:21,000. Option B has large effect on reduction of water level to an extent of about 1.5 m along the Ghagot and water volume flowing into the GIP area and the right bank side. Sealing of upstream breaches of the TRE in the Options C and D is not able to prevent spilling from the Ghagot into both bank areas although peak discharge of the Ghagot is significantly decreased.

On the other hand, the maximum internal water level and inundation area for the Options A to D are listed as follows:

Option	Inundation Area			
	1987 flood with 20-year probability		1985 flood with 5-year probability	
	(km^2)	(%)	(km^2)	(%)
Present condition	287.3	58	189.9	38
A	252.2	50	171.7	34
B	269.6	54	158.6	32
C	274.5	55	177.6	35
D	229.8	46	107.9	21

Note : Percent of area is based on total area of GIP is 495.0 km^2 excluding the area between the existing railway line and Ghagot upstream of Bamondanga

As indicated in the above table, the Options A to C do not improve the inundation situation in the GIP area since spilling from the Teesta and/or Ghagot still takes place. On the other hand, strengthening of both upstream and downstream TRE significantly reduces inundation area equivalent to 12 % and 17% of the whole GIP area in 1987 and 1985 floods respectively although spilling discharge of 40 m^3/s spilled from the Ghagot still flows into the area overtopping the left bank upstream of Bamondanga.

From the above, strengthening of upstream and downstream TRE is judged to be indispensable for GIP from the view point of the flood damage reduction.

On the other hand, the following combined options are further set up for GIP so as to clarify the confinement effect along the Ghagot due to extension of the left embankment and provision of right embankment:

- E : extension of left embankment upstream of Bamondanga and closure of Ghagot-Manas without strengthening of TRE, and Gaibandha town protection on the right bank of the Ghagot.
- F : option E but including right embankment upstream of Gaibandha
- G : Ghagot diversion to discharge all the flood of the Ghagot to Brahmaputra without strengthening of TRE. This option needs back-water levee along the Ghagot and a regulator on the Alai.
- H : option E but including strengthening of TRE.
- I : option F but including strengthening of TRE.
- J : option G but including strengthening of TRE.

Figure 4.5 shows schematic configuration of the above options with flood discharge distribution and Figure 4.6 illustrates flood water level profile of the Ghagot for the 1987 flood in each option.

Extension of the left embankment of the Ghagot (Option E) raises water level of about 0.5 m and increase discharge of 120 m^3/s from the present condition and embanking on the both banks (Option F) further heightens it about 1 m and increases discharge of 150 m^3/s. Option G reduces water level in the river reach between the outfall and railway bridge at Gaibandha but upstream water level of the railway bridge raises about 1.2 m in maximum as compared with that under the present condition. The inundation areas in the 1987 and 1985 floods are shown as follows:

Option	Inundation Area			
	1987 flood with 20-year probability		1985 flood with 5-year probability	
	(km^2)	(%)	(km^2)	(%)
Present condition	287.3	58	189.9	38
E	294.5	59	184.9	37
F	310.1	62	210.5	42
G	287.0	57	187.5	37
H	229.8	46	116.6	23
I	221.5	44	114.9	23
J	226.4	45	122.0	24

Note : Percent of area is based on total area of GIP is 495.0 km^2 excluding the area between the existing railway line and Ghagot upstream of Bamondanga

The above table indicates that, if the breaches of the TRE are not sealed, inundation situation in the GIP area will not be improved or will be worsen in case of the flood embankment is provided on the both banks of the whole Ghagot.

Through the above examination for the Options A to J, strengthening of both the upstream and downstream TRE is judged to give the most significant benefit not only for the GIP area but also the planning units of the Upper Karatoya and to mitigate the confinement effect.

The following Options K to M are set up taking into account the present situation of the Manas regulator which is being severely eroded and forecast to be washed away, since maintaining the existing Manas regulator against the severe bank erosion needs high construction cost for river training and/or bank protection works such as large scale groynes and revetment. Considering the cost effectiveness, provision of new embankment about 2 km long linking of the existing flood embankments of BRE and GLE on the left bank of the Ghagot, and heightening of the Sonail embankment against back-water of the Brahmaputra, and construction of new regulator on the Manas is considered to be more favourable than provision of the river training works to maintain the present river bank line along BRE as explained in the foregoing sub-section 4.2.2.

- K : option H without the existing Manas Regulator but including back-water levee and a regulator upstream of the confluence of the Ghagot and the Manas to prevent the back-water intrusion to the Alai and Ghagot.
- L : option K but including flood embankment on the right bank of the Ghagot upstream of Bamondanga.
- M : option J without closure of the Alai, distributing the Ghagot discharge to the Karatoya through Alai, and the Brahmaputra through the Ghagot-Manas.

Figure 4.7 shows schematic configuration of the above options with flood discharge distribution and Figure 4.8 illustrates flood water level profile of the Ghagot in the 1987 flood in each option.

The water levels along the Ghagot in the Options K to M are almost at same level but the flood discharge distributed to the Alai is 180 m^3/s to 190 m^3/s corresponding to double of flow capacity of the Alai. On the other hand, inundation area in each option is also in the same order as shown below:

Option	Inundation Area			
	1987 flood with 20-year probability		1985 flood with 5-year probability	
	(km^2)	(%)	(km^2)	(%)
Present condition	287.3	58	189.9	38
K	229.8	46	116.6	23
L	223.2	45	117.1	23
M	225.3	45	120.7	24

Note : Percent of area is based on total area of GIP is 495.0 km^2 excluding the area between the existing railway line and Ghagot upstream of Bamondanga

Hydraulic impacts of provision of regulator of the Alai proposed in option G and J is also analyzed as shown in Figure 4.9. According to the Figure, water levels along the Alai in 1985 flood with 1 in 5 years return period is lower than the bank elevation. The provision of regulator will improve flooding and drainage situations along the Alai of which affected area is estimated at about 390 km^2 including the project area of the Sonail embankment.

Through examinations of the hydraulic impacts of the options set up, the following components are judge to be indispensable for GIP in views of mitigation of the present flooding situation:

(1) *Strengthening of both the upstream and downstream TRE*, which gives the maximum benefit for the GIP area and improves present flooding and drainage situations in the planning unit of Upper Karatoya.

(2) *Diverting Ghagot discharge directly to the Brahmaputra* together with provision of back-water levee on both banks of the Ghagot and a regulator on the Alai taking into account the erosion condition at the Manas regulator and drainage congestion along the Alai. This option could get the benefit in the downstream area of 390 km^2 corresponding to about 70 % of the GIP area. The right embankment of the Ghagot is discarded from the components for GIP since strengthening of TRE will improve the flooding and drainage situations on the right bank area so that the GIP will not give any disbenefit thereto.

(3) *Extension of left embankment along the Ghagot* which is necessary for protection of the agricultural crops from the flooding since even if both the upstream and downstream TRE is sealed, flood water with peak discharge of 40 m^3/s and volume of 20 million m^3 comes from the Ghagot into the GIP area in the flood with 1 in 20 years return period. But, this option was further examined on the benefit and construction cost since the spilling discharge in the flood with 1 in 5 years return period is rather small.

In succession, the following options are further examined, which are set up by combining the aforesaid FCD components with drainage improvement options, options on the Manas regulator being threatened to destruction, and extension of the Ghagot left embankment (Figures 4.10 and 4.11).

N : Strengthening of TRE, Ghagot diversion, and back-water levee with regulator on the Alai with improved drainage by the additional regulators
O : Option N but including compartmentalization using the existing road embankment.
P : Option N but excluding extension of the Ghagot left embankment.
Q : Option N but excluding new Manas regulator on the Manas

To clarify the economic viability of the compartmentalization and extension of GLE which differentiate the Option O and P from the Option N respectively, an economic analysis was made for these individual FCD options at the preliminary level using their incremental costs and benefits to be occurred. As a result, economical internal rate of return (EIRR) for those individual FCD options are derived to be about 26% and 9%, respectively. This implies that the compartmentalization has a significantly favourable effect on alleviation of flooding problem in the GIP area from the economic aspect. While, the EIRR value for the extension of GLE is slightly lower than 12% which corresponds to the opportunity cost in this country. However, the construction cost required for the extension of GLE is estimated to be about 17 x 10^6 Taka which accounts for only 1.6 % of total investment cost of GIP. Thus, a reduction in the economic viability of GIP that takes place due to inclusion of the individual option is negligibly small. Moreover, it is necessary for stabilizing social life in the GIP area to manage flood water as well as rainfall inland runoff, but social life of inhabitants in the GIP area will be threatened to flooding in case the upstream Ghagot left bank is left without any provision of embankment. For these reasons, it is judged to be essential that the extension of GIP is incorporated into the components of GIP in formulating optimum FCD.

The Option Q gives higher than cropping benefits than either N or O, since it allows faster drainage for the flood with 1 in 5 years return period. In case of the Option Q, however, the low-lying areas extending both banks of the Manas will always be affected by back-water of the Brahmaputra when the Brahmaputra river stage is higher than the inland stage. Consequently, the back-water levee on both banks along the Manas as well as such drainage structures therein as regulators and sluice ways will have to be newly provided to protect there from a flood of 1 in 100 years return period in the

Brahmaputra. Thus the case without new Manas regulator is not necessarily economical than the case with that. In addition, it is expected that a pond to be created by new Manas will function for the irrigation and domestic water supply in the post monsoon season. Therefore, it is preferred to install the new Manas regulator at its outfall to the Ghagot.

From the above, option O is selected as an optimum option for GIP.

Figure 4.1 PREDICTED BANK EROSION ALONG THE TEESTA

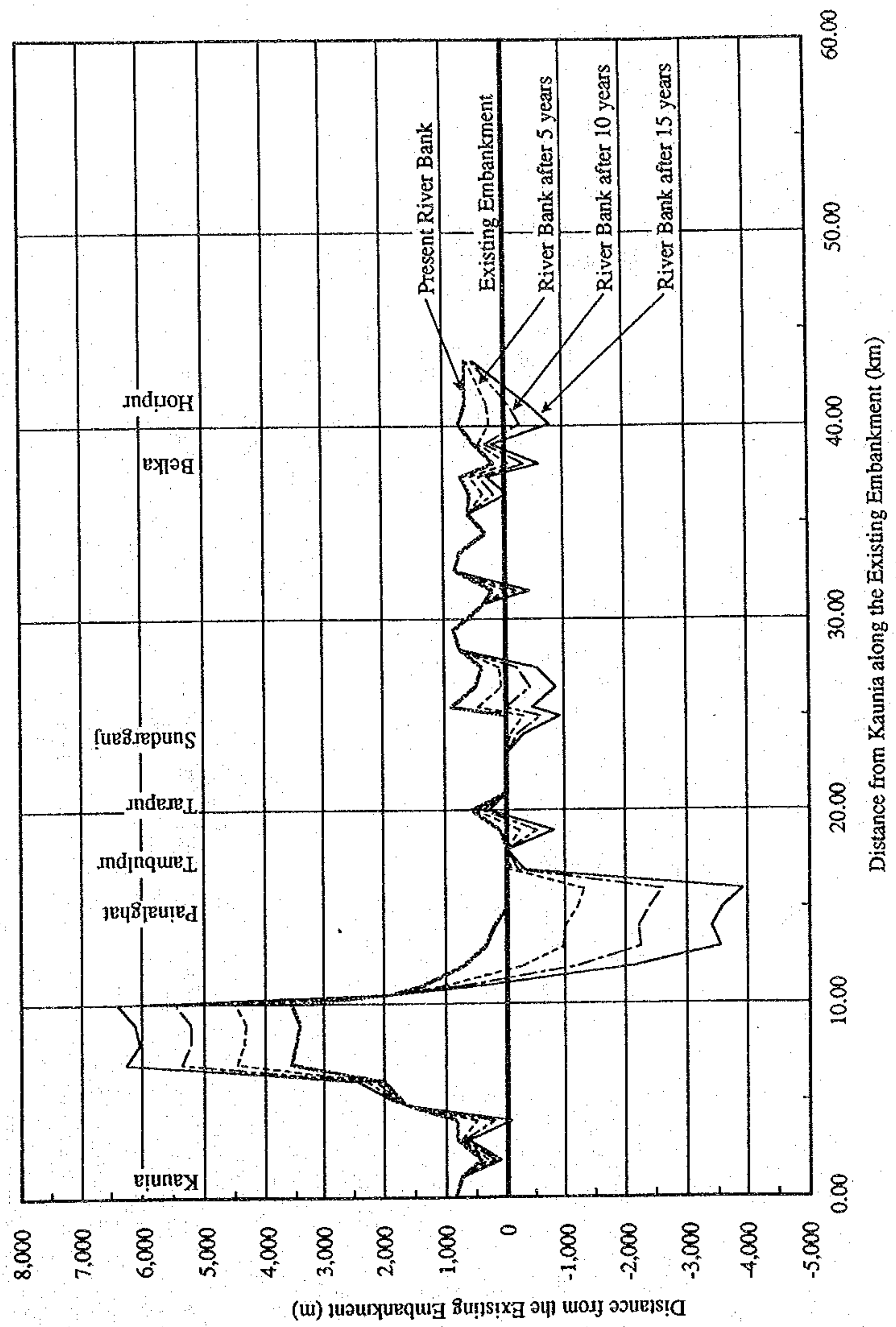


Figure 4.2 DIVISION OF COMPARTMENTS IN THE GIP AREA

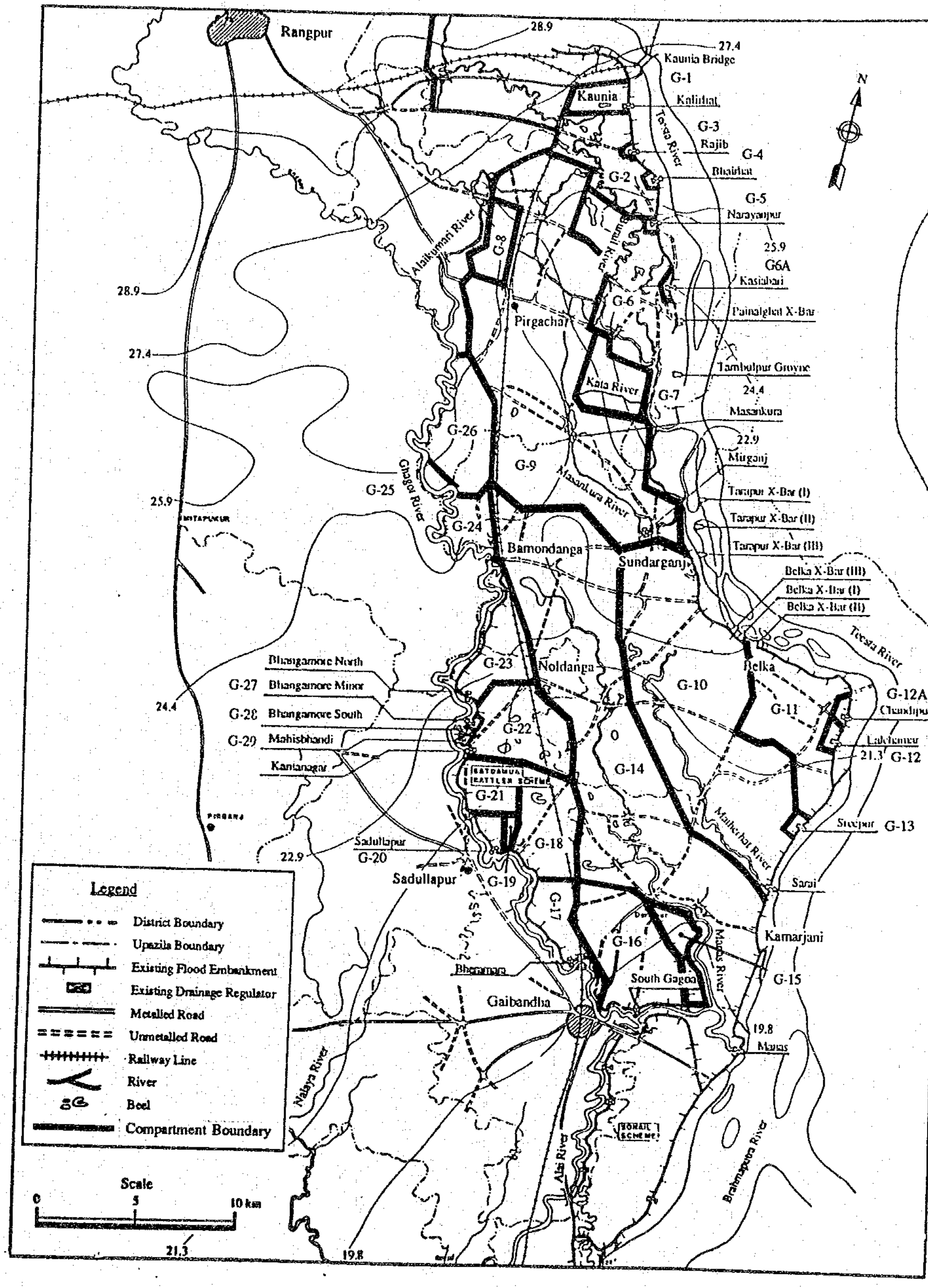


Figure 4.3 DISCHARGE DISTRIBUTION FOR OPTIONS A TO D UNDER PRESENT DRAINAGE CONDITION

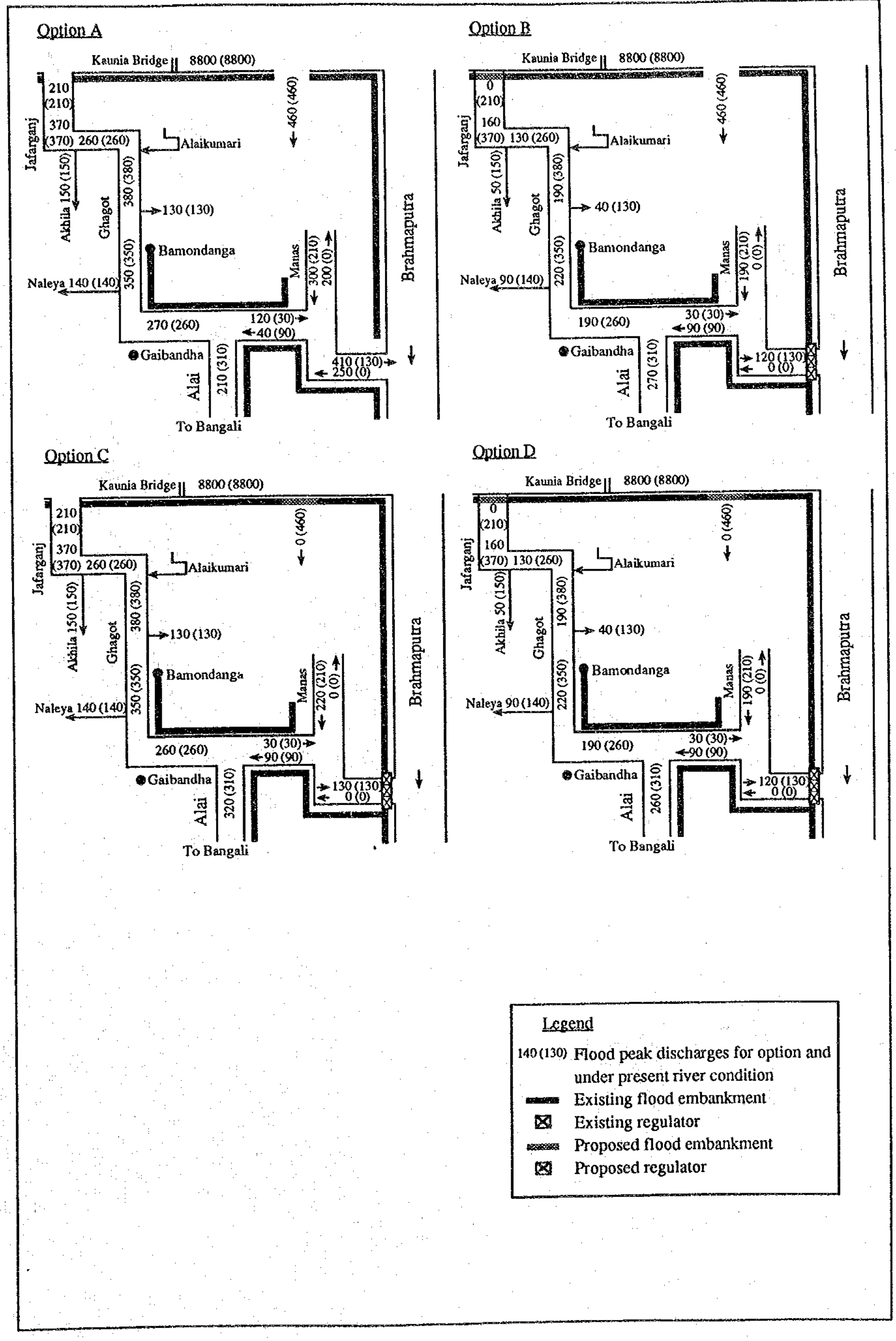
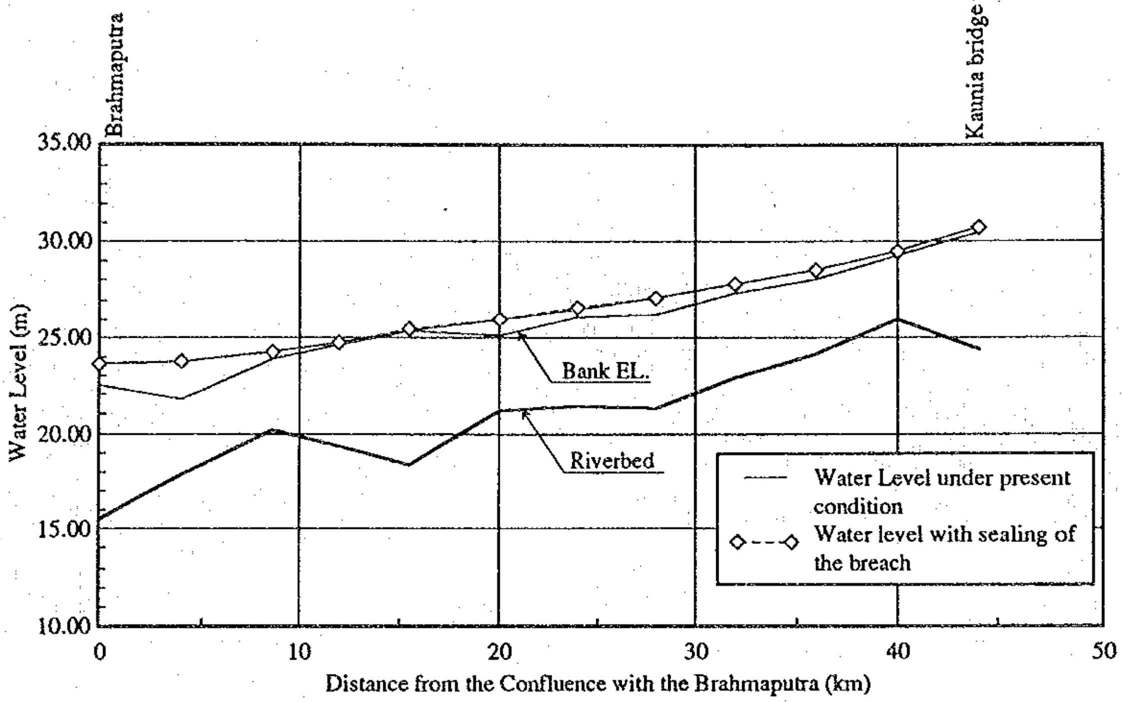


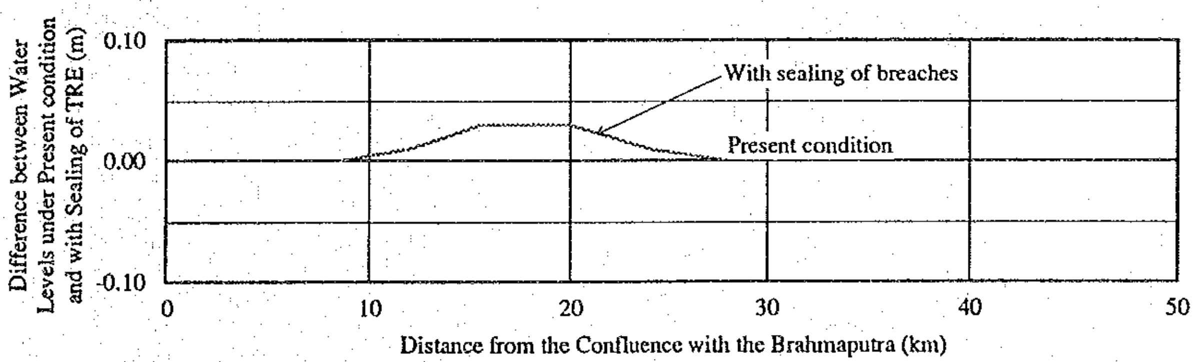
Figure 4.4 MAXIMUM FLOOD WATER LEVEL ALONG THE TEESTA AND GHAGOT FOR OPTIONS A TO D(1/2)

Teesta River

(1) Water level profile

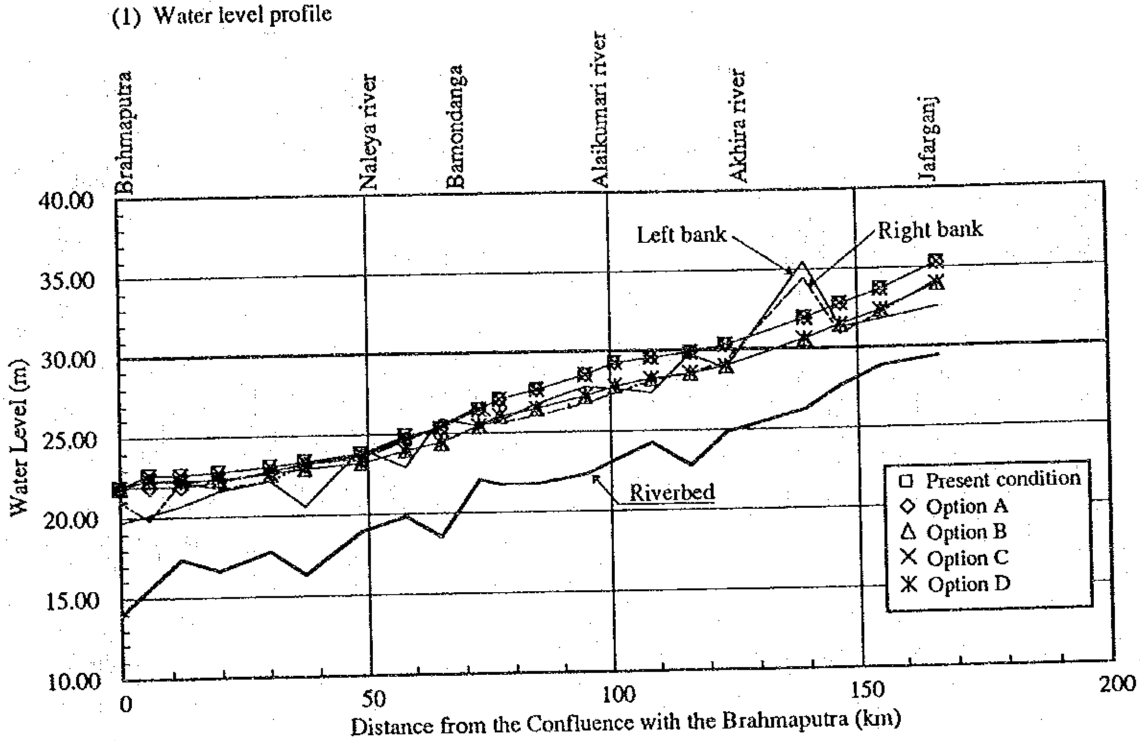


(2) Difference between water levels under the present condition and with sealing of the TRE



Ghagot River

(1) Water level profile



(2) Difference between water levels under the present condition and with options

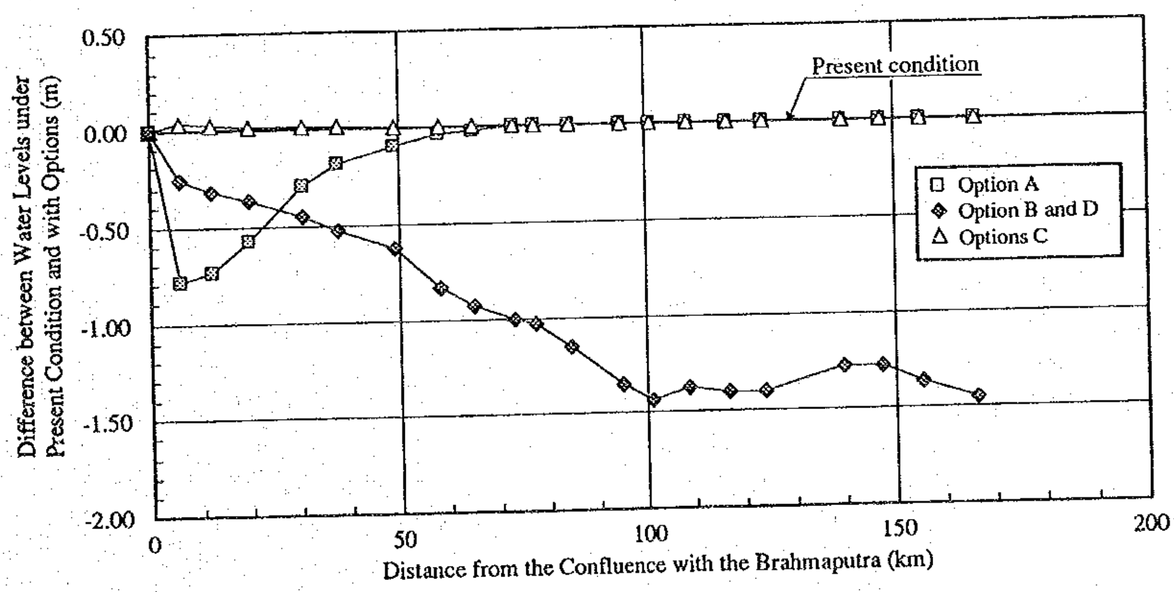


Figure 4.5 DISCHARGE DISTRIBUTION FOR OPTIONS E TO J UNDER PRESENT DRAINAGE CONDITION (1/2)

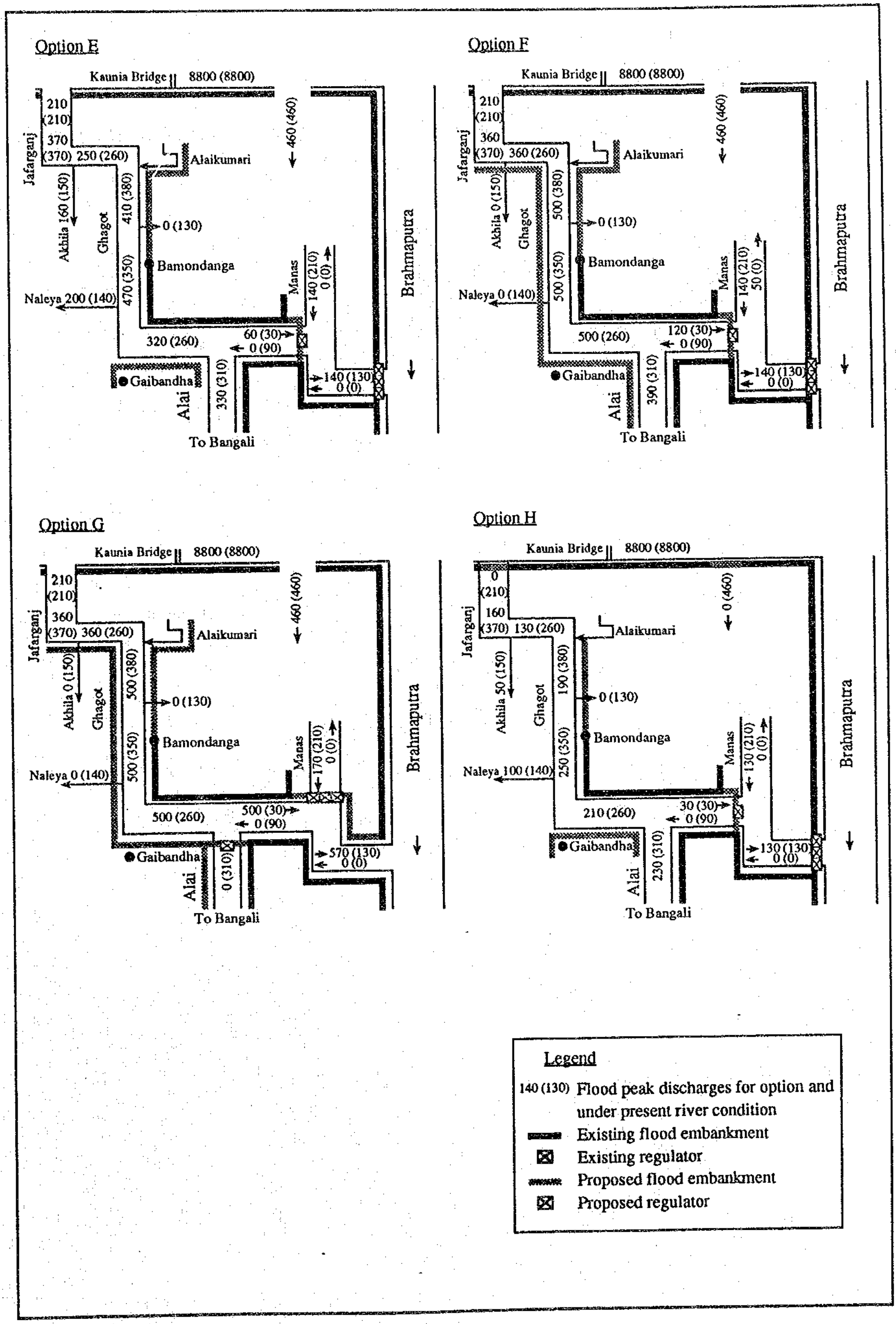


Figure 4.5 DISCHARGE DISTRIBUTION FOR OPTIONS E TO J UNDER PRESENT DRAINAGE CONDITION (2/2)

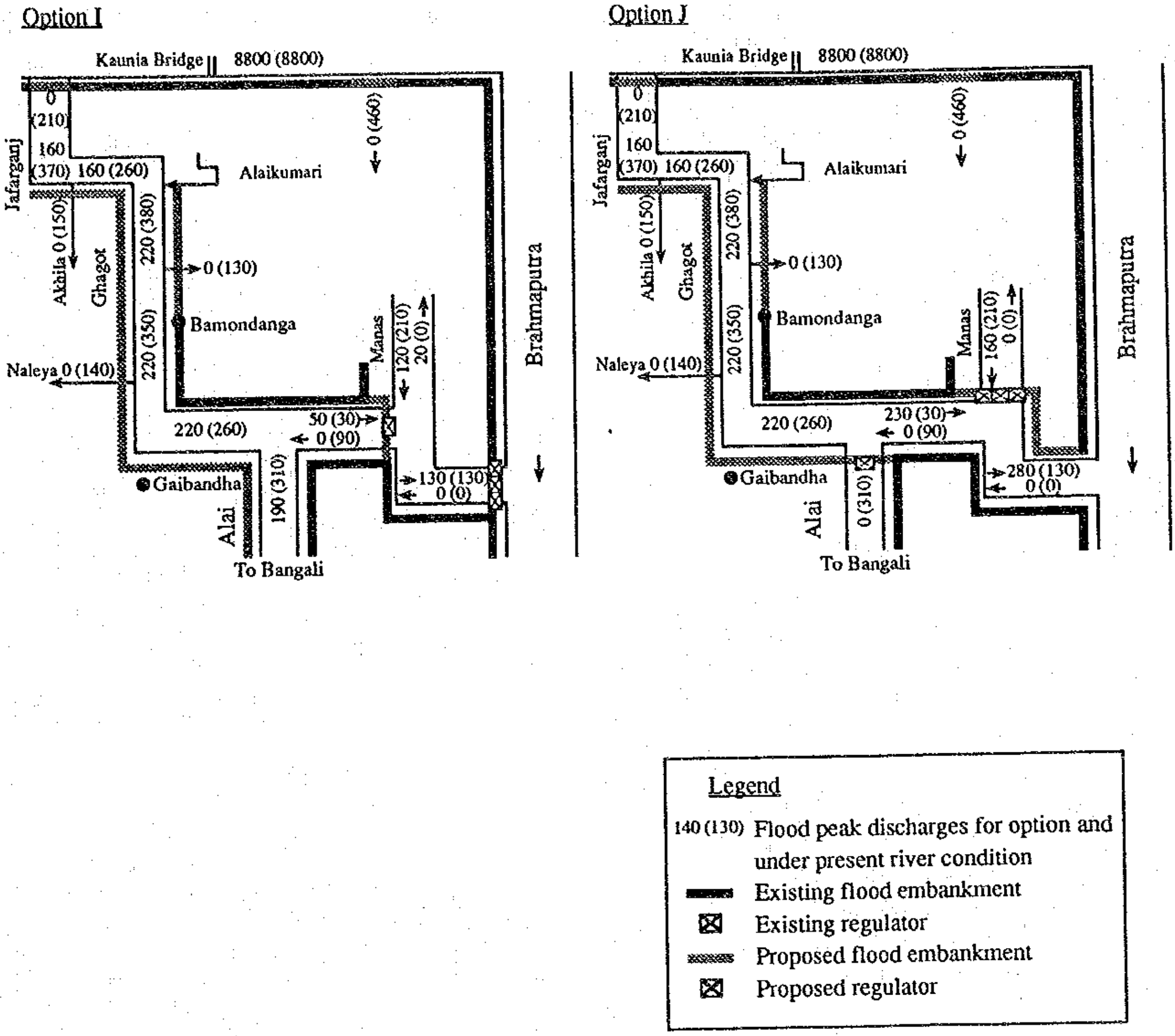
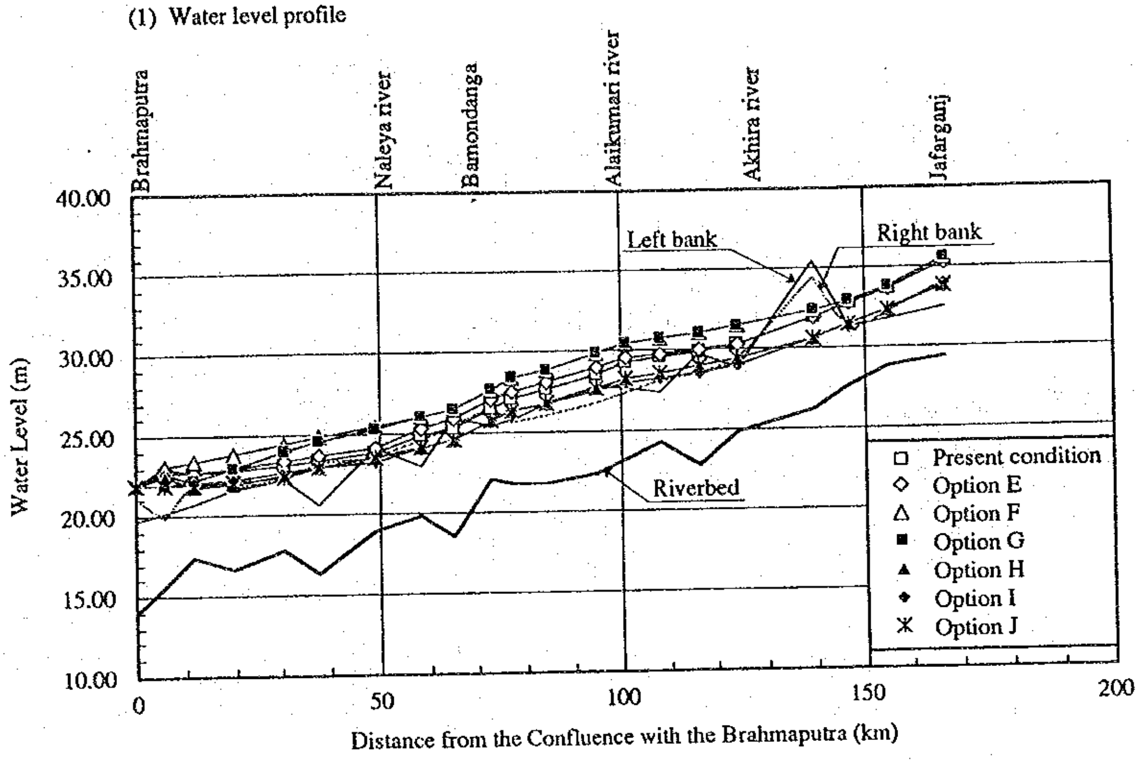


Figure 4.6 MAXIMUM FLOOD WATER LEVEL ALONG THE GHAGOT FOR OPTIONS E TO J

(1) Water level profile



(2) Difference between water levels under the present condition and with options

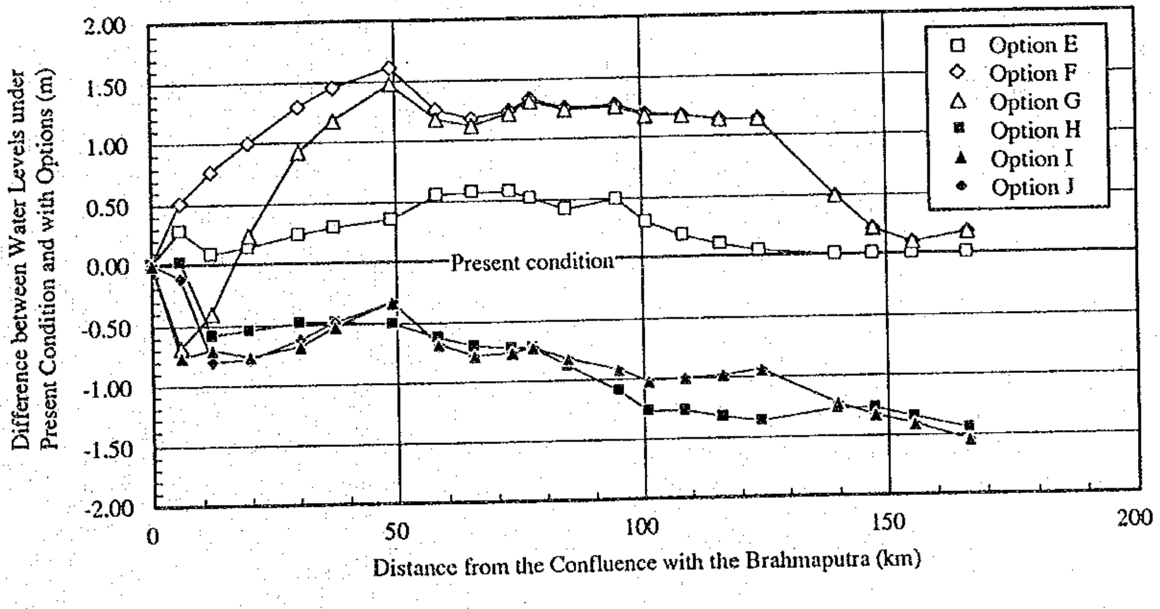


Figure 4.7 DISCHARGE DISTRIBUTION FOR OPTIONS K TO M UNDER PRESENT DRAINAGE CONDITION

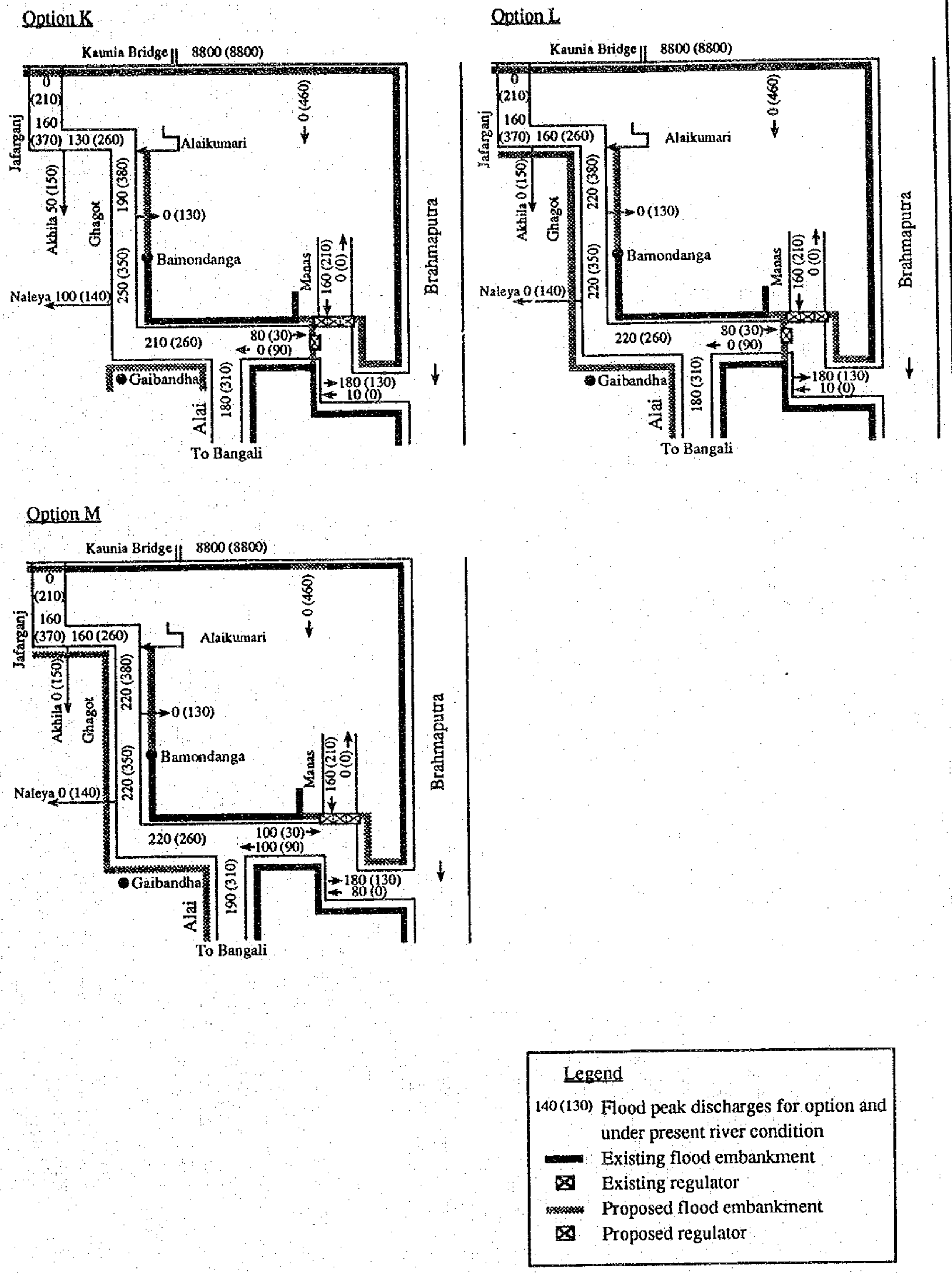
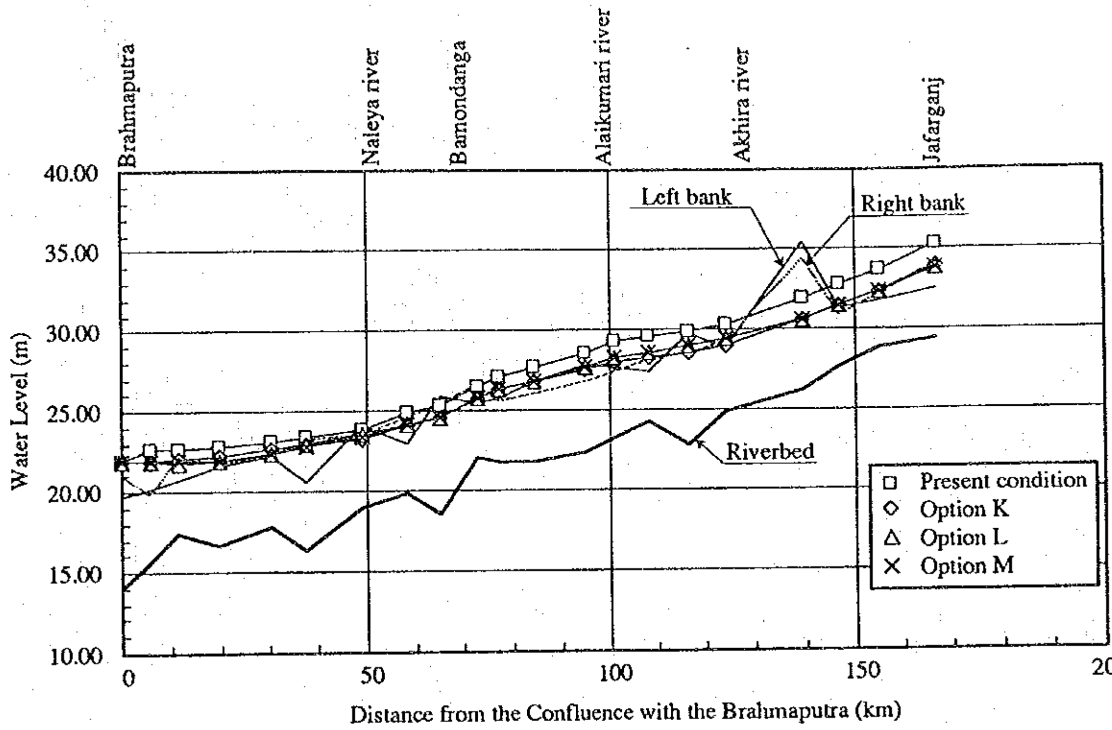


Figure 4.8 MAXIMUM FLOOD WATER LEVEL ALONG THE GHAGOT FOR OPTIONS K TO M

(1) Water level profile



(2) Difference between water levels under the present condition and with options

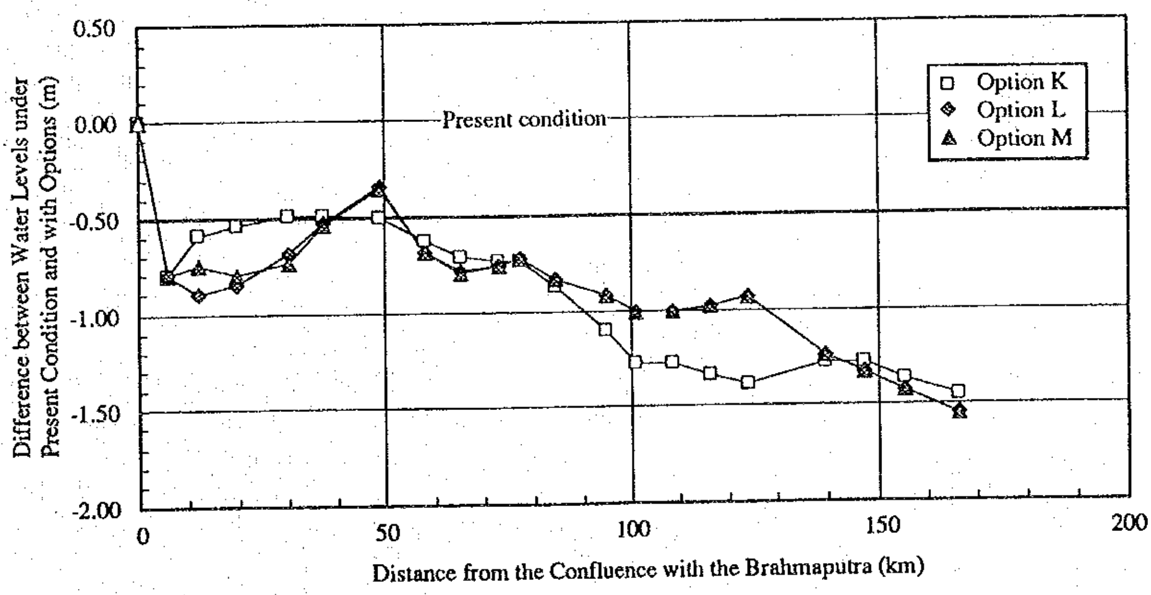


Figure 4.9 MAXIMUM FLOOD WATER LEVEL ALONG THE ALAI

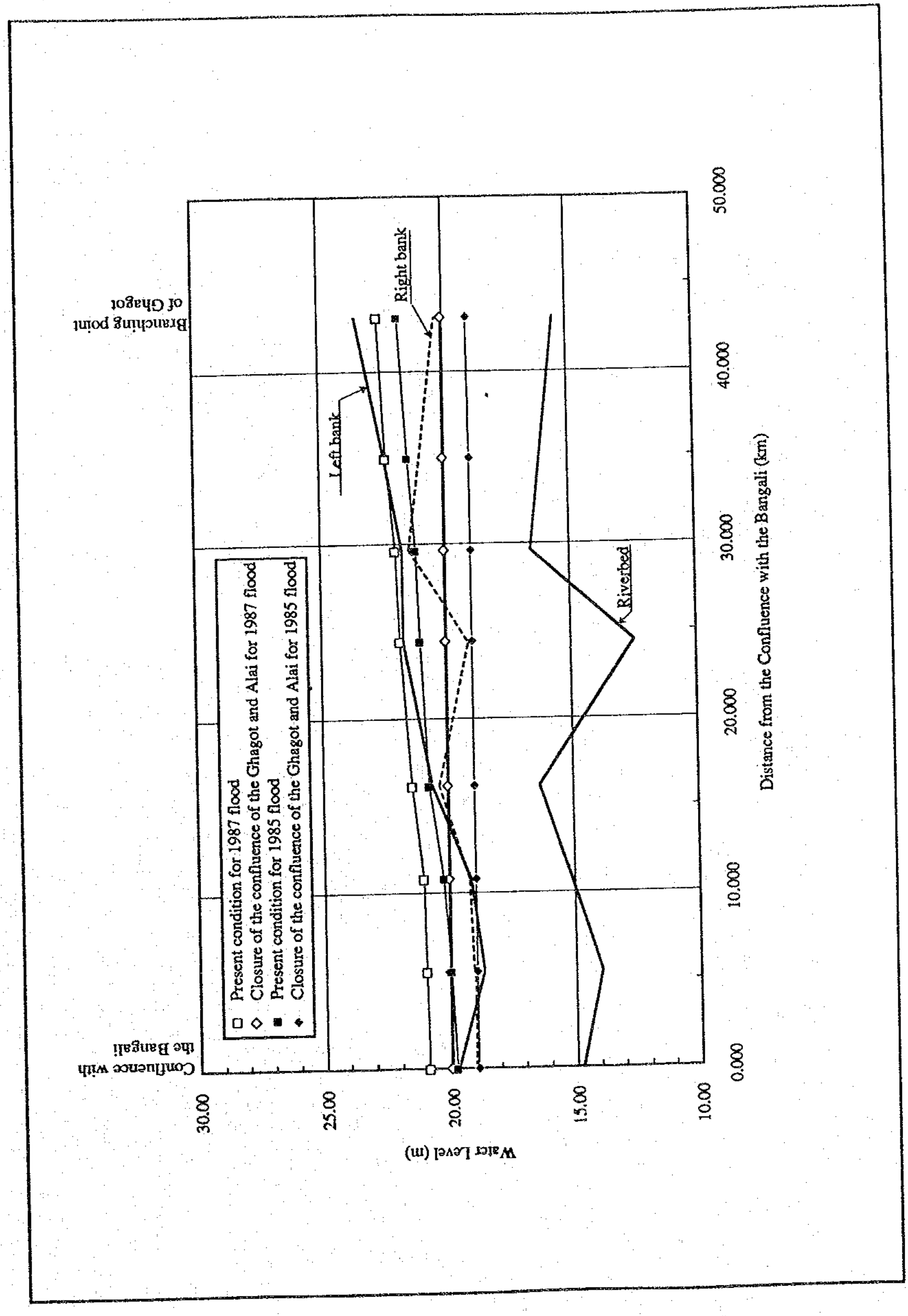


Figure 4.10 DISCHARGE DISTRIBUTION FOR OPTIONS N TO Q UNDER PRESENT DRAINAGE CONDITION

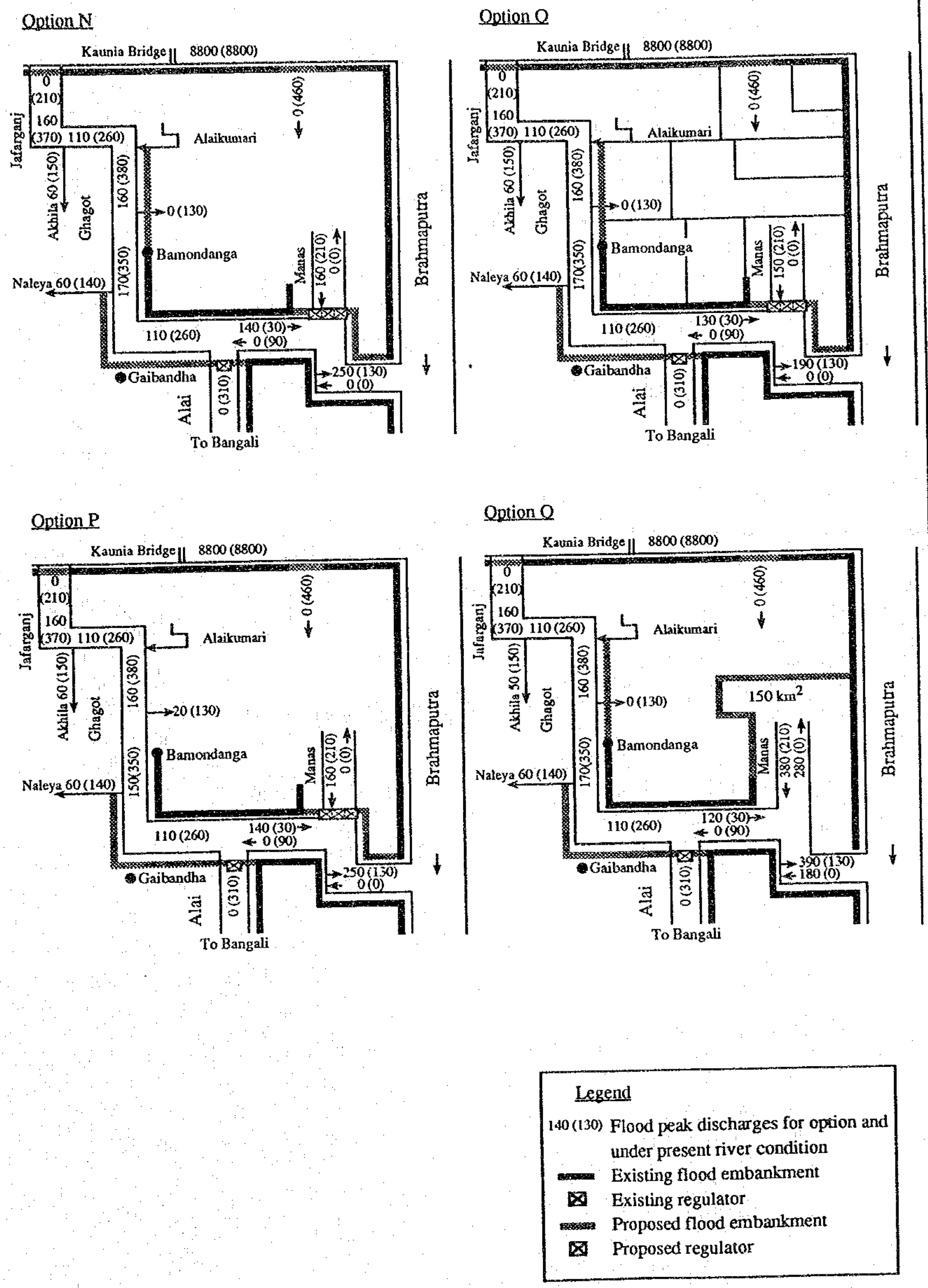
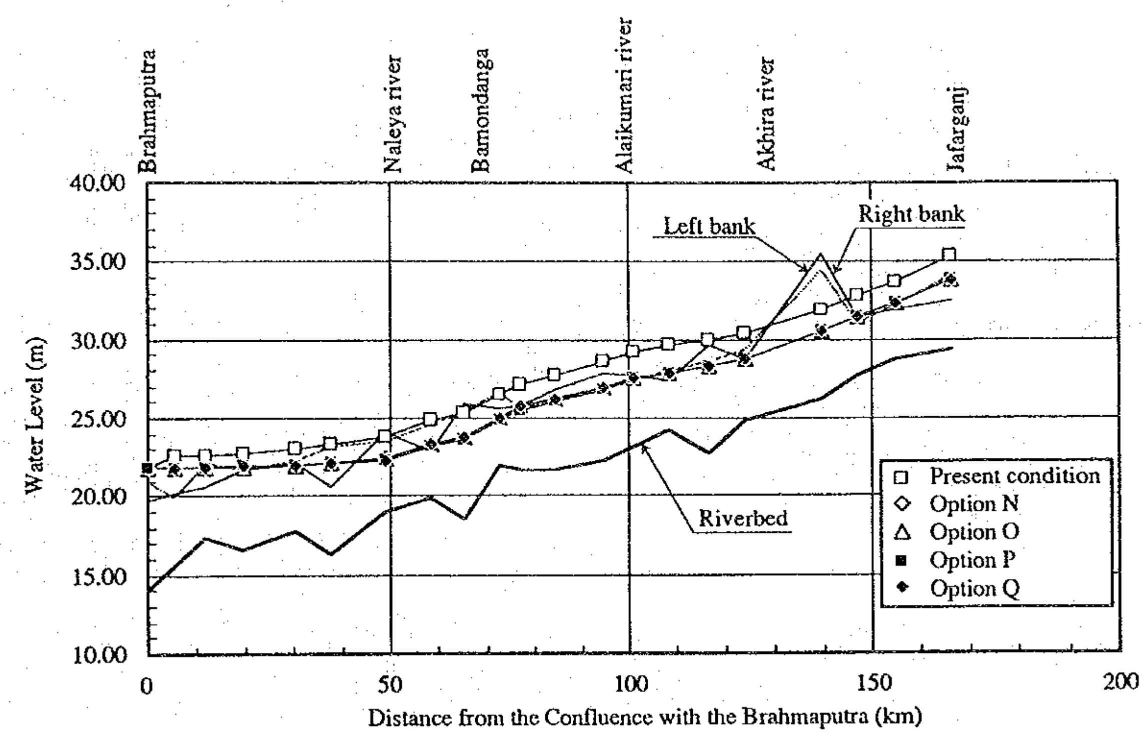


Figure 4.11 MAXIMUM FLOOD WATER LEVEL ALONG THE GHAGOT FOR OPTIONS N TO Q

(1) Water level profile



(2) Difference between water levels under the present condition and with options