PEOPLE'S REPUBLIC OF BANGLADESH

JAMUNA RIVER BRIDGE CONSTRUCTION PROJECT

FEASIBILITY STUDY REPORT

VOLUME II

RIVER CONTROL

AUGUST 1976

JAPAN INTERNATIONAL COOPERATION AGENCY

PEOPLE'S REPUBLIC OF BANGLADESH

JAMUNA RIVER BRIDGE CONSTRUCTION PROJECT

FEASIBILITY STUDY REPORT

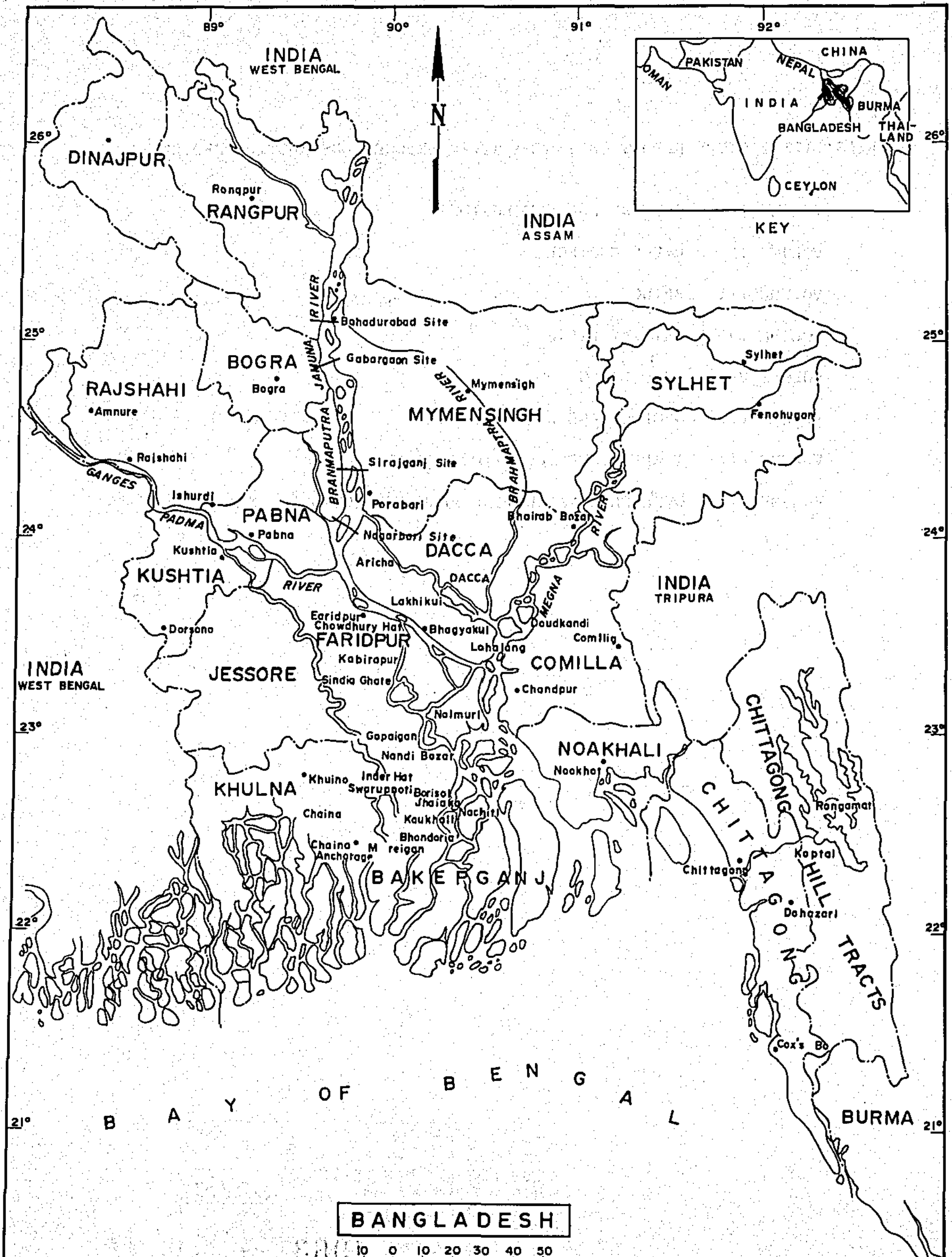
VOLUME II

RIVER CONTROL

AUGUST 1976

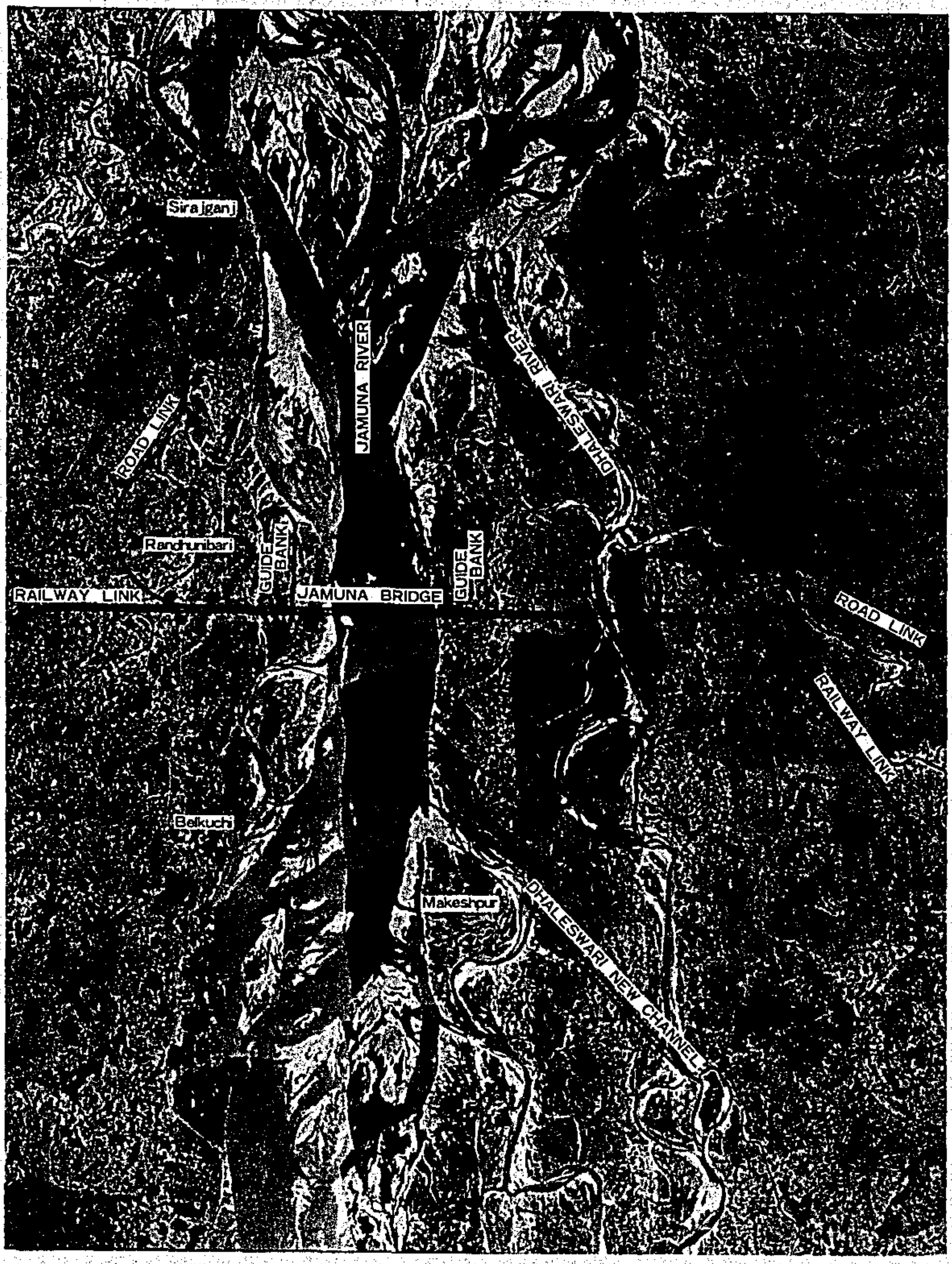
JAPAN INTERNATIONAL COOPERATION AGENCY

FEASIBILITY STUDY REPORT ON JAMUNA RIVER BRIDGE CONSTRUCTION PROJECT



INDIA
WEST BENGAL
INDIA
ASSAM
INDIA
TRIPURA
INDIA
WEST BENGAL
PAKISTAN
NEPAL
CHINA
OMAN
INDIA
BURMA
BANGLADESH
THAI-LAND
CEYLON
KEY
DINAJPUR
Rangpur
RANGPUR
BOGRA
Bogra
RAJSHAHI
Amnure
Rajshahi
GANGES
Ishurdi
PADMA
PABNA
Pabna
Kushtia
KUSHTIA
RIVER
Dorsana
JESSORE
KHULNA
Khulna
Chaina
Chaina Anchorage
JAMUNA RIVER
BRAHMAPUTRA
Bahadurabad Site
Gabargaon Site
Sirajganj Site
Porabari
Nagarbari Site
Aricha
MYMENSINGH
Mymensingh
BRAHMAPUTRA RIVER
DACCA
DACCA
Bhairab Bazar
MEGNA RIVER
Lakhikul
Faridpur
Chowdhury Hat
FARIDPUR
Bhagyakul
Lohajang
Kabirapur
Sindia Ghate
Nalmuri
Gopalganj
Nandi Bazar
Inder Hat
Swarupkati
Barisal
Jhalakati
Kaukhali
Nachit
Bhondaria
Mreigan
BAKERGANJ
SYLHET
Sylhet
Fenchuganj
Daudkandi
Comilla
COMILLA
Chandpur
NOAKHALI
Noakhali
CHITTAGONG
Chittagong
CHITTAGONG HILL TRACTS
Rangamati
Kaptai
Dohazari
Cox's Bazar
BURMA
BAY OF BENGAL
89°
90°
91°
92°
26°
25°
24°
23°
22°
21°
N
BANGLADESH
10 0 10 20 30 40 50
SCALE IN MILES

THE JAMUNA RIVER
SIRAJGANJ SITE FOR BRIDGE CROSSING



ABBREVIATIONS, DEFINITIONS AND UNITS

Bangladesh	The People's Republic of Bangladesh.
MOC	Ministry of Communications.
R & H	Roads and Highways Directorate of the Ministry of Communications.
WAPDA	Water and Power Development Authority.
BWDB	Bangladesh Water Development Board.
SOB	Survey of Bangladesh.
JICA	Japan International Cooperation Agency, Government of Japan.
OTCA	Former name of JICA.
Jamuna River	The Brahmaputra-Jamuna River.
Jamuna Bridge Project	Jamuna River Bridge Construction Project.
Jamuna Bridge	Tentative name of the bridge in the present project.
Preliminary Study Report	Preliminary Report on the Jamuna River Bridge Construction Project prepared by the Preliminary Study Team of the OTCA, Mar., 1973 (written in Japanese).
Inception Report	Inception Report on Feasibility Study of Jamuna River Bridge Construction Project submitted by the OTCA.
Interim Report	Interim Report on Feasibility Study of Jamuna River Bridge Construction Project submitted by the JICA.
Feasibility Report Volume I	Feasibility Study Report on Jamuna River Bridge Construction Project, Volume I, Summary and Conclusions.
Feasibility Report Volume II	Feasibility Study Report on Jamuna River Bridge Construction Project, Volume II, River Control.

Feasibility Report Volume III	Feasibility Study Report on Jamuna River Bridge Construction Project, Volume III, Bridge.
Feasibility Report Volume IV	Feasibility Study Report on Jamuna River Bridge Construction Project, Volume IV, Railway links.
Feasibility Report Volume V	Feasibility Study Report on Jamuna River Bridge Construction Project, Volume V, Road links.
Feasibility Report Volume VI	Feasibility Study Report on Jamuna River Bridge Construction Project, Volume VI, Geology and stone material.
Feasibility Report Volume VII	Feasibility Study Report on Jamuna River Bridge Construction Project, Volume VII, Traffic and economic benefits.
Feasibility Report Volume VIII	Feasibility Study Report on Jamuna River Bridge Construction Project, Volume VIII, Overall construction plan and economic analysis.
Main construction works	Construction works comprizing Jamuna Bridge, River control, Railway links and Road links.
Approach	Railway and/or road between an abutment of the bridge and a point at which it almost descends to the normal formation; 5,100 m respectively from the abutments.
Railway link	Railway between the end of the approach and a connection point on the existing railway.
Road links	Road between the end of the approach and a connection point on the existing road.
Guide bank	Bank built in the river to guide stream.
Cross dike	Dike built in the river to check river flow and support the function of the guide bank.
Cross dam	Embankment built across the Dhaleswari river to close.
WL	Water level.
HWL	High water level.
LWL	Low water level.

DHWL	Design high water level.
PWD	Datum of Public Works Department.
GL	Ground level.
km	kilometer.
m	meter.
cm	centimeter.
mm	milimeter.
mi	mile.
yd	yard.
f, ft	foot.
in	inch.
cub.	cubic.
sq.	square.
ac	acre.
kl	kiloliter.
l	liter.
IG	imperial gallon.
m^3/s, cub.m/s	cubic meter per second.
cfs	cubic foot per second.
t, ton	metric ton.
kg	kilogram.
lb	pound.
KV	kilovolt.
KW	kilowatt.
KVA	kilovolt-ampere.
yr	year.
mon	month.
h, hr	hour.
s, sec	second.

1 mi = 5280 ft = 1.6093 km.

1 yd = 0.9144 m.

1 ft = 0.3048 m.

1 in = 2.54 cm.

1 ac = 0.4046 ha = 0.004046 sq.km.

1 sq.ft = 0.0929 m^2.

1 cub.ft = 0.0283 cub.m.

1 cfs = 0.0283 cub.m/s.

1 in/mi = 1/63,360.

1 ft/mi = 1/5,280.

1 IG = 4.546 liters.

$ = U.S. Dollar.

Tk = Bangladesh Taka

$1 = Tk13

Tk1 = ¥36 (used in the First Stage)

Tk1 = ¥23 (used in the Second Stage)

SUMMARY

1. *Objective and progress of the study.*

The objective of this report is to study suitability of the four candidate sites for bridge crossing from the viewpoints of geomorphology and river morphology; to find an optimum plan for river control and estimate the cost thereof; and to study scour depth at piers and make a plan for protection against the scour.

In December 1972, a team composed of Japanese-government officials was dispatched to Bangladesh with a view of making a preliminary study on the Jamuna River Bridge Construction Project. The Preliminary Study Team, after having returned to Japan, proposed four candidate sites for bridge crossing; namely downstream of Bahadurabad, near Gabargaon, about 10 km downstream of Sirajganj and about 20 km upstream of Aricha.

The present study was undertaken by the River Study Team headed by Dr. Seiichi Sato, NIKKEN Consultants, Inc., who and/or whose staff visited Bangladesh over ten times to inspect the river, collect necessary data and meet the staffs of the authorities concerned for discussions.

On the other hand, in the 1973 flood season, topographic maps of the four candidate sites were prepared by another surveying team and discharges were measured at the same time.

Using these data, preliminary designs for the four sites were made in Tokyo and, in the meeting held in Dacca from October 28, 1974 to November 6, 1974, Sirajganj site was chosen as the most suitable one.

In December 1974, the bridge axis was located at the Sirajganj site based on aerial photographs newly taken by the Surveying Team in November 1974, and following this survey, in the 1974/75 dry season, new topographic surveying including cross levelings over river widths were conducted by the above Team. Using the new topographic maps and cross profiles of the Sirajganj site, the plan of river control and treatment of the Dhaleswari was completed. The results of the study are briefly mentioned below.

2. *Natural features of the river.*

The Brahmaputra River takes its rise in Lake Monosarwar which is located in the northern part of the Himalaya Mountains, running through *the Tibetan Plateau from west to east, traversing the Himalayas in the* eastern part and running through the Assam Plain from east to west, turns to the south in the west of the Shillong Plateau. After that, passing through the national border, enters into Bangladesh and, joining the Tista River, running almost straight to the south, joins with the Ganges River near Aricha. The river is called the Brahmaputra-Jamuna in its part from the northern border to the confluence with the Ganges. After the joining, changing its name to the Padma, the river goes down to the southeast about 100 km and after joining the Meghna River near the town of Chandpur, pours into the Bay of Bengal. The drainage area stretches over the three countries of China, India and Bangladesh. This river is one of the largest in the world.

On the other hand, the Ganges River originates in the glacier of Mt. Gangotori (6,614 m), runs through the Hindustan Plain from west to east and turns to the southeast at the edge of the Rajmahal Hill and then, flowing down in the Ganges Plain, joins with the Brahmaputra-Jamuna River at Aricha.

The Catchment area and the length of the Brahmaputra-Jamuna River at the confluence with the Ganges are 580,000 km^2 (224,000 mi^2) and 2,600 km (1,620 mi) while those of the Ganges at the confluence are 977,000 km^2 (377,000 mi^2) and 2,200 km (1,370 mi).

Meteorology of Bangladesh belongs to the tropical and has a clear distinction of two seasons, the dry and the wet. At Sirajganj, the minimum of monthly mean temperature, 18° C, appeared in January and the maximum, 29°C occured in April or May. The lowest and the highest in the past are 7.2°C and 42.8°C. The monthly mean humidity exceeds 80% in the rainy season and about 50 to 70% in the dry season.

Most of the cyclones which are born in the Bay of Bengal attack the land of Bangladesh. However, their courses are mostly turned to the east as they move on toward the land, hence they usually do not affect much the northwestern part of Bangladesh.

Annual rainfall in Bangladesh ranges from 1,520 mm (60 in) to 6,350 mm (250 in) and is heavy in the northeastern part and coastal zone and relatively light in the area of the Jamuna. About 80% of the annual rainfall take place in the monsoon season of May to September, about 20% fall in the other months and almost no rain in December, January and February.

In the monsoon season, the river water coming from the enormous catchment area outside Bangladesh is usually superposed on the rain water fallen in the land of Bangladesh causing an extensive and severe inundation which reportedly covers about 30% of the land on the average. The area surrounding the Jamuna is habitually inundated over a width of about 100 km. The peak of the discharge of the Jamuna usually appears in July or August while that of the Ganges usually occurs in August or September. Namely there is a time lag of about one month between them. The largest discharge in the past at Bahadurabad is 3,210,000 cfs in 1974 and that at Hardinge Bridge is 2,582,000 cfs in 1961.

The land of Bangladesh consists of Chittagong Hills, Western and Eastern Barind Terraces, Tippera Surface formed in the Holocene Period and alluvial plains. The alluvial plains consist of alluvial fans, natural levees with back-swamp and tidal deltas (Sundarbans).

The geological borings conducted by the Japanese Geological Survey Team show that gravel layers are located at very deep places and covered by very thick fine sand or silt layers. Further, the Team found fossil wood buried just below the surface of the gravel layers. Its absolute age was estimated at 28,000 years of carbon dating. It may be interpreted from these facts that the gravel layers were formed during the Würm Ice Age and the thick fine sand and silt covering the gravel layers were deposited during the Holocene Period.

It is interpreted that the Berind Terraces were formed by the upheaval of the earth from the Pleistocene onward and the Tippera Surface was formed during the Holocene Period, whereas the alluvial plains along the Jamuna, the Ganges and the Meghna are located in the subsiding zones. The Sylhet Depression is also interpreted to have been formed by continued ground dipping.

During the time of Major James Rennel who surveyed the rivers of Bengal between 1764 and 1779, the main course of the Brahmaputra was the present channel of the Old Brahmaputra. The course of the present Jamuna was called the Jhinai in its upper part and the Jamuna in its lower part. In 1810, Buchanan Hamilton observed the Brahmaputra threatening to divert to the present course of the Jamuna River. McIntire suggests that the diversion is attributable partly to tilting of the East Barind Terrace and partly to shifting of the Tista River to the present course which was caused by tilting of the West Barind Terrace.

3. Comparison of the four sites by the natural features of the river

As a result of the diversion, new alluvial fans are being formed over the old alluvial plain which was formed by natural levees and back swamps. Bahadurabad and Gabargaon are located in the alluvial fan, Sirajganj is located in the natural-levee region and Nagarbari and Aricha are located in a natural-levee or delta region. As the alluvial-fan region has been being formed only since about 1830, it is still changing though it is being stabilized little by little having small and narrow natural levees developing along the banks of river courses in this region. On the other hand, the natural-levee region has no geomorphological change. But the Aricha and Nagarbari area is being remarkably influenced by the confluence of the Ganges and the Jamuna. Near Sirajganj in the natural-levee region, there is an old narrow whose width is about 6 miles.

From the river-morphological study, it was found that the four candidate sites are rightly located at the nodes of variation of river width and that the variation of the banklines is comparatively stable at these nodes. As a result of the study of river width and banklines at the four sites, it was found that the river widths at the four sites are almost constant except the Nagarbari site and displacement of banklines are almost constant except the early 30 years from 1830, while the variation at the Nagarbari site is quite large.

After all, from the geomorphological viewpoint, the Sirajganj site is the most suitable one among the four, the Gabargaon site comes closely next, the Bahadurabad site compares unfavorably with the former two and the Nagarbari site falls behind any of the others. From the river-morphological viewpoint, the Nagarbari site is the worst one while the other three are almost equal judging from the fact that the variation of the displacement of banklines is almost constant since nearly 1860, but the Gabargaon site is best and the Bahadurabad and the Sirajganj sites are almost equal from the aspect of the size of width between the banks.

Therefore, from both the geomorphological and river-morphological points of view, there is nothing to choose between the two sites of Sirajganj and Gabargaon.

4. Strategy of river control.

In general, braiding of a river is associated with steeper slopes and larger sediment loads than meandering, and if the slope of a stream is excessive or the discharge is increased to a relatively large magnitude, the local rate of bank scour and deposition may be of sufficient magnitude to cause the stream to braid.

The present Jamuna River is a typically braided one. But at the present stage, we can find no sufficient study why the Jamuna is thus braided. However, major causes for braiding may be sought in the facts that (1) the discharge of the Jamuna was suddenly increased by the change in courses of the Brahmaputra-Jamuna River and the Tista River, (2) the present Jamuna has taken its course along a depression running almost straight from north to south, on account of which the slope of the Jamuna is steep compared with large rivers as the Ganges class and (3) length of the river in this alluvial plain is still short compared with the magnitude of discharge and sediment load.

A braided river is presumed to be transformed eventually to a meandering one in the very remote future. The present Jamuna River also must have this nature. Even if the Jamuna has this nature, a state of meandering can not be encountered within 100 or 200 years from now, because it is only less than 200 years since the Old Brahmaputra shifted its course to the present Jamuna. Therefore, the construction of the bridge should be planned on the premise of braiding.

In this river, the braiding produces cliffy banks almost on the whole length of the river at least within the land of Bangladesh. The space between both cliffy banks is regarded as an effective width for flood flow.

Notwithstanding both the banks form cliffs, such clayey bank as seen at Sara on the Ganges is not found on the Jamuna River. In other words, no portion of the banks has resisting power to erosion. It means that no portion of the banks can be fixed without any artificial protection. This holds at nodes of braiding as well as at loops.

The Japanese Preliminary Study Team recommended that four nodes of braiding as sites to be proposed for bridge crossing. This is certainly appropriate since the nodes have been standing at the present places at least for about one hundred years. However, this is only based upon statistics and it is very regrettable to say that, at the present stage, we cannot elucidate the reason why such nodes have been produced and standing for such a long time as one hundred years.

Although it is very appropriate to choose a node as a bridge site, we can find no guarantee that these nodes will forever stand at the same places without any change in the forms. On the contrary, the fact is that incessant erosion at banks has been occuring even at the nodes of braiding; it is a well-known fact that severe erosion has been occuring at the bank of Sirajganj and costly protection works are being carried out every year. Therefore, even in case a bridge is spanned at such sites, some revetment works will be inevitable so as to protect the abutments of the bridge.

On the other hand, in every high-water season, flood water habitually spills over both the banks and the lowlying land located between the two Barinds is always inundated irrespective of the river channels and the lands. This phenomenon not only facilitates spilling to tributaries but also produces incessant erosion at banks. In this meaning this river may be called a river having no banks. Since it is very difficult or, at the present stage, almost impossible to revet the whole stretches of both the banks, only the stream channel at the bridge crossing site must be fixed and protected from spilling or braiding.

For this purpose, the river flow which is extending over the whole valley must be interrupted by cross dikes on both sides and confined to run through a fixed opening between the cross dikes. In other words, we must guide the river flow into a fixed opening by making use of the water-stage difference between the interrupted area or the dead water and the opening space. In this case, two guide banks are inevitably needed at both the edges of the opening space in order to protect the edges and guide the flow into the opening as smoothly as possible and without any destructive influence on both the cross dikes. In conclusion, guide-bank system must be taken as far as a bridge is not spanned over a quite long distance which far exceeds the whole river width.

In planning the guide-bank system, it will become important problems to determine the width of the opening space, the length and the shape of the guide banks and the method of protection of the guide banks and the cross dikes. Cross dikes will also be used for the approaches of the bridge.

The Inception Report gives three factors, (a) stability of river channel, (b) construction cost of the bridge and (c) traffic volume, in selecting the most suitable site for bridge crossing from among the four candidate sites recommended by the Japanese Preliminary Study Team. The second factor, construction cost of the bridge, should be composed of cost of river control works and cost of super- and substructures of the bridge. On the other hand, it is easily expected that the cost of the bridge works will be increased almost proportional to length of total span or river width, while river control works will have a tendency to decrease. Accordingly there may be a minimum cost with respect to river width. If there is a river width which minimizes the cost, it must be compared with such a minimum river width as suggested by Lacey. For this purpose, the minimum river width or the lower limit of river width must be known beforehand.

If the Lacey formula is also applicable to the Jamuna River, the minimum stable width is calculated to be 1,500 m (4,900 ft) for the discharge 90,000 cub.m/s. This width is unpractical from the viewpoint of maintenance of structures as well as construction works because the depth at thalweg between both guide banks will attain to 78 m below the ground level if this width is actually formed. Therefore the Lacey formula should not be applied to the present case.

On the other hand, the Inglis formula gives a width of 2,700 m or 8,700 ft at the same discharge. The two formulas give a quite large difference. In the present planning, therefore, we studied it, without using those formulas, from the aspect of natural features peculiar to the Jamuna River itself. Based on a study of the relationship between river width at the ground level and the corresponding water area, it was found that a minimum river width exists corresponding to a given discharge. For instance, for a discharge of 90,000 cub.m/s, the minimum river width was estimated at 3,900 m. We decided to adopt this method.

5. Design discharge for bridge construction.

For determination of minimum river width and design high-water level, we must set design discharge at each of the four sites. The design discharge for each site should have a magnitude not less than 100-year return period in view of importance and scale of the projected bridge.

Since there are no long-term records of flood discharges except those at Bahadurabad, we had to derive the design discharge for each site from the return period of flood discharges at Bahadurabad in consideration of branching of the Old Brahmaputra River and the Dhaleswari River and joining of the Hurassagar River.

Probabilistic discharge at Bahadurabad was estimated at 3,278,000 cfs or 92,770 cub.m/s for 100-year return period and 3,358,000 cfs for 150-year return period. Since it was found that the influence due to the difference between the two discharges is negligible, it was decided to adopt the 100-year discharge.

The 100-year discharge at each site was determined on the assumption that the discharge to be diverted to the Old Brahmaputra will be controled to 30,000 cfs by a barrage to be built on the river, joining of discharge of the Hurasagar will be stopped by the back-water of the Jamuna and the discharge of the Jamuna will be confined within both levees to be built in the future. The allocated discharges on the Jamuna are as follows.

3,420,000 cfs or 96,850 cub.m/s for the reaches from the branching point of the Old Brahmaputra to the branching point of the Dhaleswari.

3,160,000 cfs or 89,490 cub.m/s for the reaches from the branching point of the Dhaleswari to the confluence with the Ganges.

6. Scour at bridge piers.

Scour depth at bridge piers was studied using several formulas. It was found from the study that the Andru formula is applicable to a pier larger than about 10 m in width.

If we adopt a well type as substructure, the width of the diameter will be of the order of 12 m. It was found in this case that the depth of scour ranges from about 60 m to about 100 m below the water surface according as the guide-bank span and bridge site.

Bridge piers should be sunk deep enough to stand by themselves without any protection around them. If there are some reasons that this is technically very difficult or too uneconomical, we must consider some protection works although undesirable. For this purpose, a study was made of range of protection and size of stones to be placed around piers.

Cross sections of the river were surveyed near every bridge site every year from 1965/66 to 1971/72. Superposing these sections at every site, it was ascertained that changes of chars and thalwegs are so remarkable that the position of thalweg is not fixed within a section. Therefore, depth of the piers must be the same over the whole guide-bank span.

7. Preliminary design and comparison of the four sites.

For comparison of the construction costs of the project, preliminary design of the river control works was made using topographical and hydrological data which had been obtained before the flood season of 1974. For the convenience of comparison of the river control works, three kinds of guide-bank span were considered at every site. Type-A guide-bank span is 2,000 m which is a minimum river width in the dry season at the nodes of braiding, Type-B is about 4,000 m which is a minimum river width corresponding to the design discharge, and Type-C is the natural river width at every site averaging about 5,500 m.

The length and the alignment of the guide banks were designed after Gales and falling-apron system was adopted in consideration of lowering of river bed which will occur due to the constriction formed by the guide banks and local scouring which will possibly occur due to thalweg. Size of stones for the apron was studied and it was verified that so-called one-man stone is enough for apron works. But it was recommended to use stones ranging from 60 kg to 100 kg for pitching the face of the riverside slope of the guide bank. The cross dikes were designed so as to support the function of the guide banks.

Concrete blocks and soil cement blocks were also studied as alternative materials for stone. The former necessitates a large quantity of cement and aggregate, and the latter necessitates quite large size or some connecting device such as steel jacks because of shortage of durability and less specific weight. Both the methods are technically unreliable and uneconomical compared with the method of stone at the present stage. We decided therefore to use stone in the present plan. However, it is strongly recommendable to exploit stone material in the Bangladesh territory or develop other methods not to necessitate stone material before entering implementation of the project.

The guide banks were planned to be built with dredged sand. Stone pitching work, when executed on the ground, was planned to be carried out in the order; (1) loading by tractor shovels, (2) carrying by dump trucks and (3) pitching by man-power. But in places where ground work is impossible, the following method was planned; (1) loading by tractor shovels and dump trucks, (2) carrying by bottom-hopper barges and (3) placing in the water from the barges. Principal construction machinery required for these works were tractor shovels, dump trucks, tire dozers, bull dozers, vibro-pile drivers, crawler cranes, engine dynamos, bottom-hopper barges and pump dredgers. Besides this, a large quantity of stones, sheet piles, fuel and other materials were required.

Thus the construction costs of the river control works were estimated for three kinds of guide-bank span at every bridge site and are shown in Table 5-14. The estimates were made on the condition mentioned in 8, Chapter V but do not contain costs required for such facilities as construction bases, motor pools, materials stock yards, temporary roads and temporary railways.

The Inception Report mentions that three factors, (a) stability of river channel, (b) construction costs and (c) traffic volume must be taken as the condition for selecting the most suitable site for bridge crossing. From the viewpoint of the first factor, it was ascertained that the two sites of Sirajganj and Gabargaon are the best among the four and there is nothing to choose between them. Taking into consideration the other two factors together, that is, further considering the total construction costs including those of the river control works and the traffic volume estimated at the stage of the preliminary design, it was decided to take the Sirajganj site as the most suitable one for the bridge crossing.

8. River control works at the Sirajganj site and treatment of the Dhaleswari River.

Based on topographical and geomorphological consideration of the aerial photographs taken by the Surveying Team in November 1974, the bridge axis was chosen about 12 km downstream of the town of Sirajganj. This site has advantages of having only one main stream and lying under the protection of the Sirajganj bank protection works as well as the narrow of Sirajganj. In accordance with the idea mentioned previously, guide-bank system was adopted. Arrangement of the guide banks and the cross dikes are shown in Fig.8-1.

In this case, the bridge approach on the left side of the river must cross the Dhaleswari River. If the approach will cross the river by a bridge, the opening on this approach may have a possibility of inducing flood flow thereto and causing serious damages to the approach and the bridge as well. In order to protect the approach from this menace, we will have to place another pair of guide banks around this opening, and that the pair of guide banks will have to be built nearly on the same scale as the main guide banks. Especially, the right guide bank on the Dhaleswari will have to be connected with the left guide bank of the Jamuna. This system ought to need another huge cost and, in spite of this treatment, will not be able to escape from the menace of strong flood flow to run through the opening. Therefore, we decided to cross the Dhaleswari by a cross dam and to connect the Dhaleswari with the Jamuna by excavating a new channel making use of a branch located about 6 km downstream of the bridge axis. The new channel is shown in Fig.8-1.

The guide-bank span was set at 4,680 m or 15,354 ft arranging 26 piers of 13 m in diameter and 27 spans 177.5 m in each length adjusting minimum river width calculated based on the design discharge of 3,420,000 cfs. The design high-water level at the bridge axis was calculated at 15.25 m or 50.033 ft PWD assuming that the design discharge is confined within the levees on both sides of the river until it diverts to the Dhaleswari through the new channel located about 6 km downstream of the bridge axis. From the calculation of water levels, we found that the constriction due to the guide banks and the replacement of the inlet channel of the Dhaleswari will cause a rise of water level of only 9 cm at a point closely upstream of the bridge and loss of head due to piers is only 2.5 cm.

The alignment and the length of the guide banks with falling apron are shown in Fig.8-1 and DRW No.VIII-1. Standard cross section of them are shown in Fig.8-6 and DRW No.VIII-1. Weight of stone for apron was determined as 30 to 70 kg, but 60 to 100 kg is necessary for revetment on river-side faces.

The Dhaleswari River may easily be closed, since the river almost runs out of flow in the dry season. The river shall be closed by a cross dam and road-cum-railway approach shall be banked thereon. A typical cross section of the cross dam is shown in Fig.9-1. The new inlet channel of the Dhaleswari must secure the same water area as the present one. Considering this matter, standard cross section of the new channel was determined as shown in Fig.9-2.

Quantity of the guide-bank works and the Dhaleswari new channel works are shown in Table 10-1, but quantity of the cross dam works is incorporated in the bridge construction works as a part of the left bridge approach.

One guide bank shall be completed in two years. The works shall be started with right bank and shall be shifted to the left bank after completion of the right bank. Opening works of the Dhaleswari new channel shall be commenced in the year following completion of the left guide bank and completed in three years. In order to avoid being filled up by sediment during the flood season, the new channel shall be opened in the first year over the whole length in a small width and completed by widening in the following two years. Further, in the year of commencement of the cross dam works, the left road link as well as the left bridge approach shall be completed contemplating that these structures will prevent disturbances of streams located over the area in the north of the new channel and assist the new channel to function as a floodway without being filled up by sediment. The execution schedule of the river works is shown in Fig.10-2.

For the purpose of communication and transportation, the right railway link, a road on the right side of the river, main and branch construction bases, stone stock yards and a field office for the new channel shall be connected as shown in Fig.10-3.

Banking of the guide banks was planned to be executed by dredging in a way shown in Fig.10-4 and 10-5. Stone pitching was planned to be carried out by loading by tractor shovels in the stock yards, carrying by heavy-duty dump trucks and pitching by manpower with the assistance of tiredozers. Opening works of the Dhaleswari new channel was planned to be carried out by the dredger which was used in the guide-bank works. Spoil was planned to be dumped in adjacent depressions separated by sheet piles from the new channel. Number of principal machinery required for these works are summarized in Table 10-2. Quantity of major materials and daily maximum number of labor at work sites are shown in Tables 10-3, 4 and Table 10-5.

In estimating the costs of the river works comprising the guide banks and the Dhaleswari new channel, unit prices of materials, equipment and labor to be procured locally and to be imported from abroad were set based on the results of surveying of the Price Survey Team organized by the JICA in July 1975. Accordingly the costs estimated in this report are those as of July 1975.

As mentioned previously, we decided to use stone for protection of guide banks and piers. However, at present, neither exploitation plan of hard rock is found in the Five Year Plan nor start has yet been made with the exploitation. Therefore, in this study, we decided to plan to import it from abroad. Estimation of cost of stone was made, based on the results of surveying of the Stone Material Survey Team, on the assumption that stone material would be imported from India.

We assumed that import and excise taxes will not be imposed upon the materials and equipment to be imported for this project. The unit prices used in this report are summarized in Table 10-7.

The costs of the river works are shown in Table 10-8. The costs required for cross-dike works and cross dam works are incorporated in the costs of bridge construction as a part of the bridge approaches.

It was planned to import major equipment and materials required for the river works. But transportation costs are included in the present cost estimation.

Maintenance costs for the river facilities will contain those required for inspection, surveying, repair of the guide banks, maintenance of the Dhaleswari new channel and management including maintenance of offices. Therefore, the maintenance costs, together with those required for the bridge, will be dealt with in Volume VIII OVERALL CONSTRUCTION PLAN AND ECONOMIC ANALYSIS.

C O N T E N T S

FIGURES

TABLES

CHAPTER I

INTRODUCTION

1. Objective.

The objective of this report is to study suitability of the four candidate sites for bridge crossing from the viewpoints of geomorphology and river morphology; to find an optimum plan for river control and estimate the cost thereof; and to study scour depth at piers and make a plan for protection against the scour.

The study was made by the River Study Team headed by Dr. Seiichi Sato, NIKKEN Consultants, Inc. during the period from August 1973 to March 1976 in accordance with the Inception Report submitted by the Japan International Cooperation Agency to the People's Republic of Bangladesh in August 1973.

2. Progress of the Study.

The Preliminary Study Team for the Jamuna River Bridge Construction Project dispatched in December 1972 by the Overseas Technical Cooperation Agency, the Government of Japan proposed four candidate sites for the bridge crossing, namely, from upstream to downstream, downstream of Bahadurabad, near Gabargaon, about 10 km downstream of Sirajganj and about 20 km upstream of Aricha.

For the purpose of inspecting the Jamuna River and collecting data required for the study on the above-mentioned four sites, Dr. S. Sato, N. Jitsuhiro and T. Nobe were sent to Bangladesh from September 3, 1973 to October 18, 1973. Next, K. Adachi and K. Kurosawa were sent to Bangladesh from November 8, 1973 to December 22, 1973 with a view to inspect the Jamuna River and collect data required for planning the execution of the river-control works, and M. Ohya was sent to Bangladesh three times from January 4, 1974 to 16th of the same month, from March 16, 1974 to 30th of the same month and from January 5, 1975 to January 19, 1975 in order to inspect the Jamuna River and collect data from the viewpoint of geomorphology. Further, Dr. Sato was sent from February 18, 1974 to 27th of the same month with a view to inspect a dry state of the river basin.

Using the data collected both in Bangladesh and in Japan and further using the data on discharges measured in the 1973 flood season and the topographic maps prepared by the surveyings in the same season, studies were made in Japan of the features of the river, river control works for the bridge construction, scouring around piers, execution of the works, equipment for them, and preliminary design for the river control works was made together with rough estimate of the costs.

At the stage of completion of the draft report, Tokyo Meeting was held from August 31, 1974 to September 13, 1974 to discuss the selection of the most suitable site for bridge crossing and several problems in every study field of each study team. This discussion was further continued in Dacca Meeting which was held from October 28, 1974 to November 6, 1974. In this meeting, Sirajganj site was chosen as the most suitable one.

During the stay in Dacca from November 29, 1974 to December 14, 1974, Interim Report was submitted to the Ministry of Communications and the bridge axis was located at the Sirajganj site based on the aerial photographs newly taken by the Japanese Surveying Team in November 1974.

Following the above aerial survey, new topographic surveying including cross levelings over river widths were made at the Sirajganj site by the above-mentioned surveying team in the 1974/75 dry season. Based on these surveying results and using additional data on 1975-flood, studies were made to complete the plan of river control for the bridge crossing and the plan of treatment of the Dhaleswari River.

Of these studies, the studies before sellection of Sirajganj site are described in Phase I as the first stage of the study. And the studies after sellection of Sirajganj site are described in Phase II as second stage of the study.

3. Staffs of the River Study Team.

This study was undertaken by NIKKEN Consultants, Inc. Major staffs who were engaged in the study were as follows.

Seiichi Sato, Dr. Eng.	Team leader
Masahiko Ohya, Dr. Sc.	Geomorphology
Shoji Kawabata	Planning of river works
Noboru Jitsuhiro	Hydraulics
Takayuki Nobe	Hydrology
Ken Mitani	Execution of the works
Kenji Adachi	Construction equipment
Kazuo Kurosawa	Construction equipment

4. Acknowledgement.

The Study Team wishes to extend its highest appreciation for the cooperation offered by the authorities concerned of the Government of the People's Republic of Bangladesh, especially its whole-hearted gratitude to the staffs of the counterpart team, and the Team wishes to express its gratitude to the Embassy of Japan in Dacca for their kind cooperation and encouragement.

Phase I First stage of the study

CHAPTER II

THE BRAHMAPUTRA-JAMUNA RIVER

1. General Features of the Brahmaputra-Jamuna River.

The Brahmaputra River as shown in Fig.2-1 takes its rise in Lake Monosarwar which is located in the northern part of the Himalaya Mountains, running through the Tebetan Plateau from west to east, and traversing the Himalayas in the eastern part, running through the Assa, Plain from east to west, turns to the south in the east of the Shillong Plateau. After that, passing through the national border, enters into Bangladesh and, joining the Tista River, running almost straight to the south, joins with the Ganges River near Aricha. The river is called the Brahmaputra-Jamuna in its part from the northern border to the confluence with the Ganges. After the joining, changing its name to the Padma, the river goes down to the southeast about 100 km and after joining the Meghna River near the town of Chandpur, pours into the Bay of Bengal. The drainage area stretches over the four countries of China, Bhutan, India and Bangladesh. This river is one of the largest in the world.

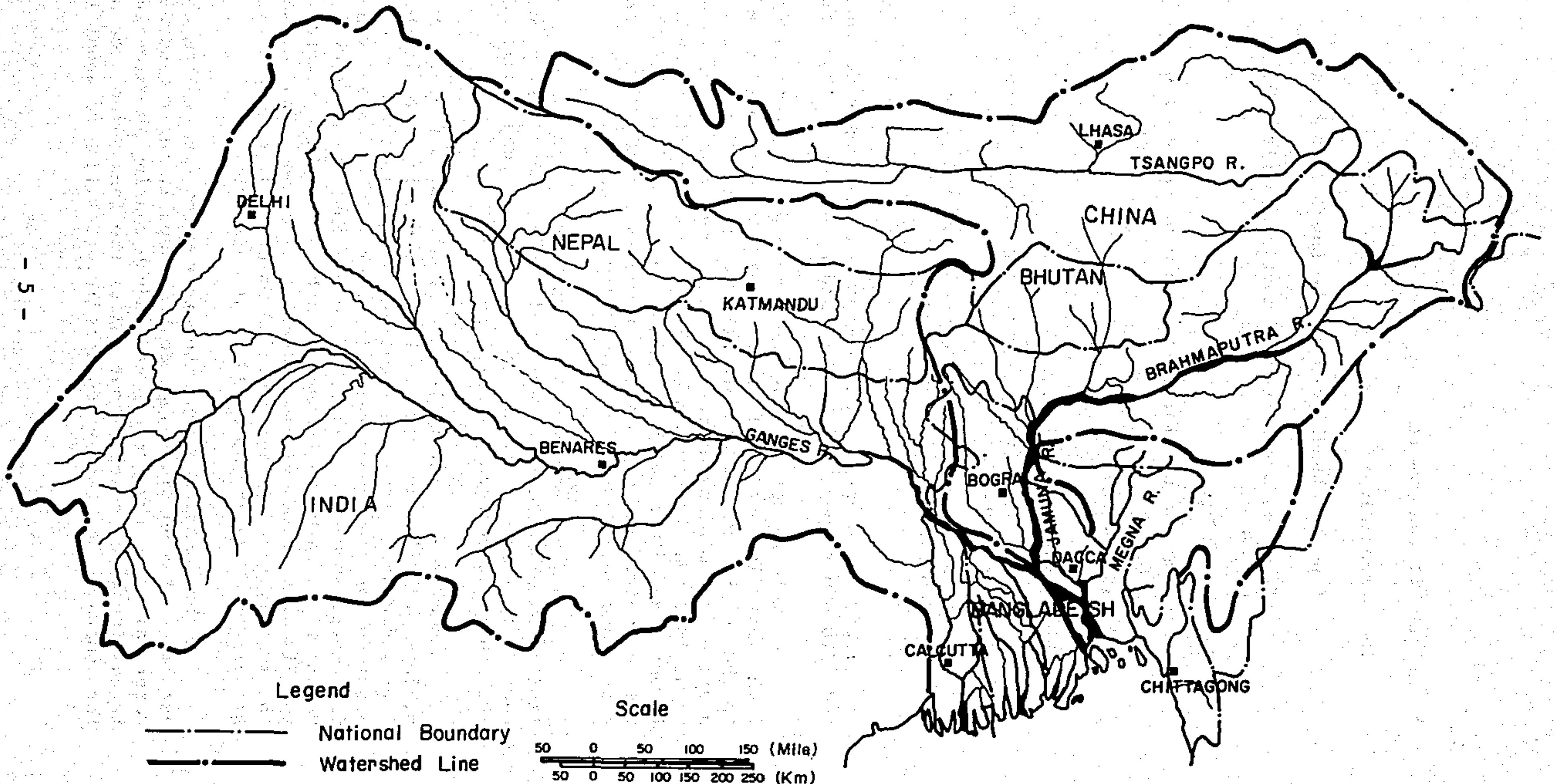
On the other hand, the Ganges River originates in the glacier of Mt. Gangotori (6,614 m), runs through the Hindustan Plain from west to east and turns to the southeast at the edge of the Rajmahal Hill and then, flowing through the Ganges Plain, joins with the Brahmaputra-Jamuna River at Aricha.

The catchment areas and the lengths of the two rivers are as follows.

a. Catchment areas.

The Jamuna River:	
from the headwaters to the Bangladesh border	533,000 km^2 (206,000 mi^2)
from the border to the confluence with the Ganges	47.000 km^2 (18,000 mi^2)
The Ganges River:	
from the headwaters to the confluence with the Jamuna	977,000 km^2 (377,000 mi^2)
The Padma River	13,000 km^2 (5,000 mi^2)
The Meghna River:	80,000 km^2 (31,000 mi^2)
Total :	1,650,000 km^2 (637,000 mi^2)

Fig 2-1 Basin Map of Ganges, Brahmaputra (Jamuna) & Megna Rivers



b. Lengths of the rivers.

The Jamuna River:	
from the headwaters to the Bangladesh border	2,350 km (1,460 mi)
from the border to the confluence with the Ganges	250 km (160 mi)
The Ganges River:	
from the headwaters to the confluence with Jamuna	2,200 km (1,370 mi)
The Padma River:	100 km (60 mi)
The Padma-Meghna River:	
from the confluence with the Meghna to the Bay of Bengal	130 km (80 mi)
The total length of the Jamuna River (up to the confluence with the Ganges)	2.600 km (1,620 mi)

The river slopes of the Jamuna and the Ganges are about 1/15,000 and 1/20,000 respectively. The Jamuna is steeper than the Ganges.

The meteorology of Bangladesh belongs to the tropical and there is a clear distinction of two seasons, the dry and the wet. According to the records of temperature measured at the Sirajganj meteorological station, the minimum of monthly mean temperature appears in January at about 18°C and the maximum occurs in April or May at about 29°C. The lowest temperature and the highest in the past are 7.2°C and 42.8°C respectively. The monthly mean humidity exceeds 80% in the rainy season and about 50 to 70% in the dry season.

Most of the cyclones which are born in the Bay of Bengal attack the land of Bangladesh. However, their courses are mostly turned to the east as they move on toward the land, hence they usually do not affect much the northwestern part of Bangladesh.

Annual mean rainfall in Bangladesh ranges from 1,520 mm (60 in) to 6,350 mm (250 in) as shown in Fig. 2-2 and is heavy in the northeastern part and coastal zone and relatively light in the area of the Jamuna. About 80% of the annual rainfall occur in the monsoon season of May to September, about 20% fall in the other months and almost no rain in December, January and February. According to the records at the Bogra and Sirajganj meteorological stations located on and around the Jamuna, the monthly rainfall is about 330 mm or 13 in on the average and occasionally-exceeds 760 mm or 30 in at maximum.

In the monsoon season, the river water coming from the enormous catchment area outside Bangladesh is usually superposed with the rain water fallen in the land of Bangladesh causing an extensive and severe inundation which covers about 30% of the land. The area surrounding the Jamuna is habitually inundated over a width of about 100 km.

Fig.2-2 Annual Rainfall and Cyclone Paths

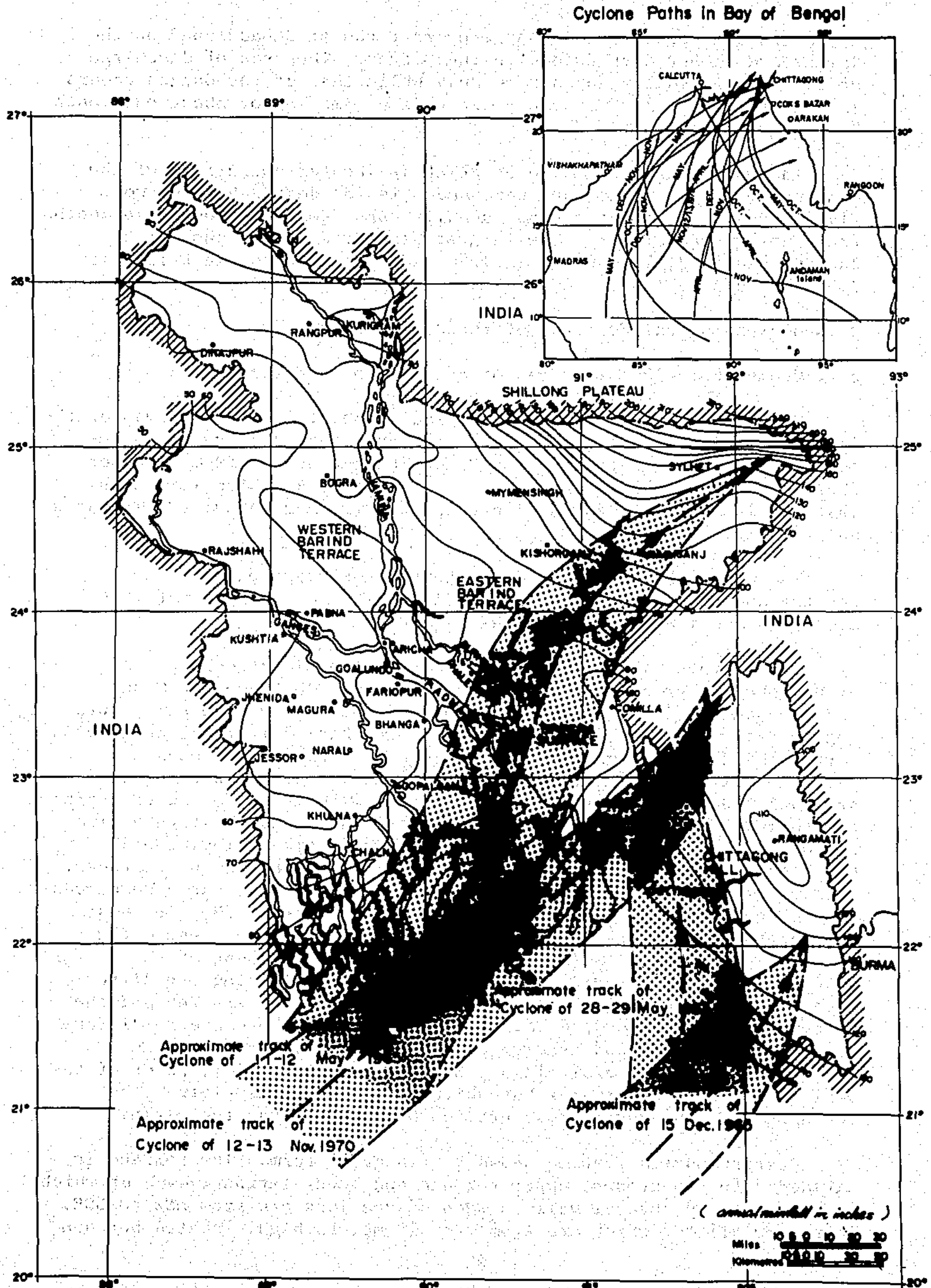


Fig. 2-3 shows the discharge hydrographs at Bahadurabad on the Jamuna and at Hardinge Bridge on the Ganges. The peak of discharge of the Jamuna usually appears in July while that of the Ganges occurs in August or September. Namely there is a time lag of about one month between them.

The water stage at Goalundo which is located downstream of the confluence of the Jamuna and the Ganges is influenced by the two rivers and the high-water stage usually continues for about five months from June up to October. The largest discharge in the past at Bahadurabad is 3,210,000 cfs in 1974 and that at Hardinge Bridge is 2,582,000 cfs in 1961.

2. Geomorphological Features of the Jamuna River

2.1. Geomorphological features of the land of Bangladesh.

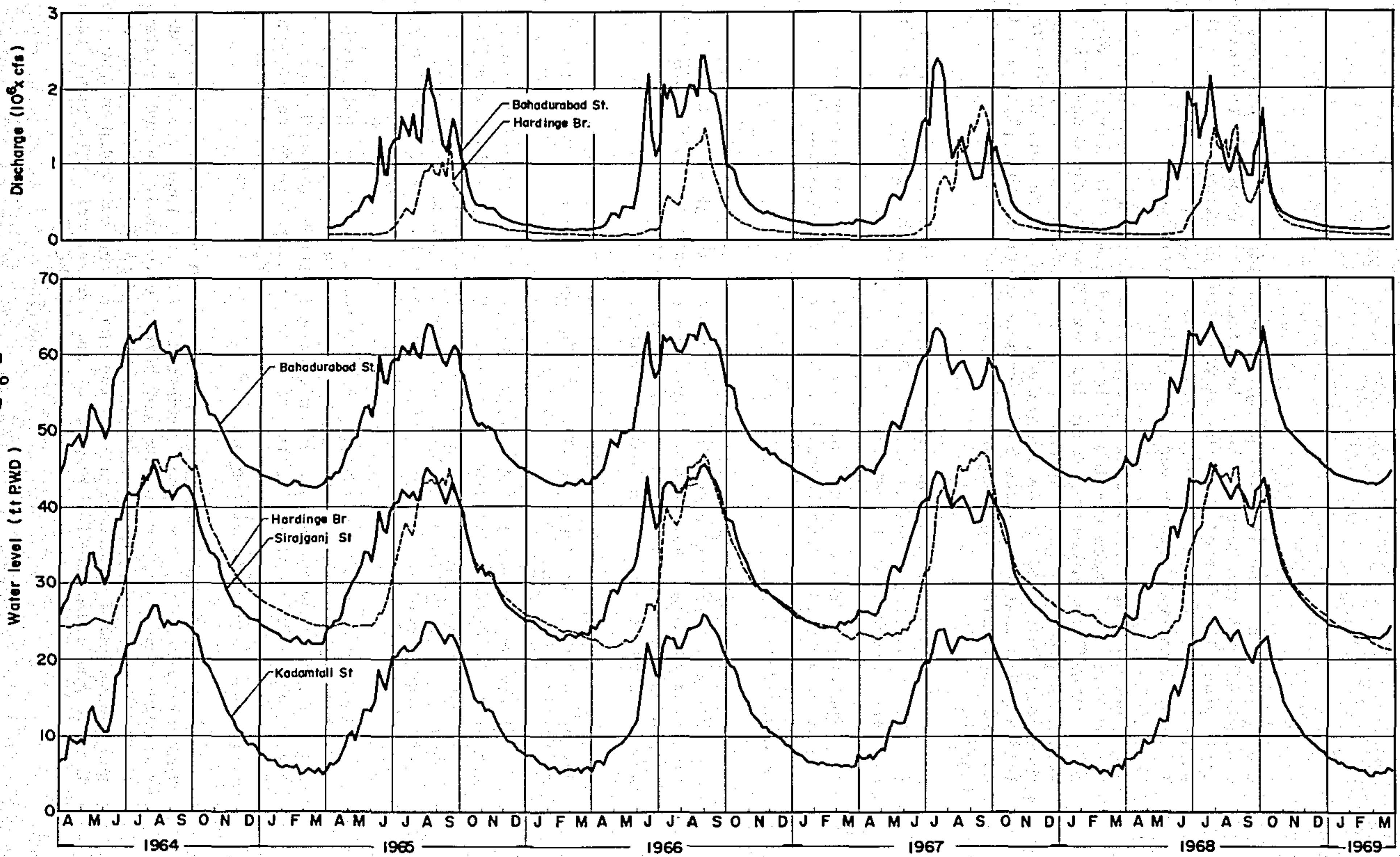
M. Ohya prepared a geomorphological land classification map of the land of Bangladesh utilizing the photographs taken by the Earth Resources Technology Satellite (ERTS) during the period from December 1972 to February 1973. This is shown in Fig. 2-4, which indicates that the land is divided into three parts: (1) mountains, (2) Terraces and (3) plains.

The mountains are located in the south-eastern part of the country and called the Chittagong Hills. The mountains are folded mountains and its dip is from NNW to SSE.

The terraces which were formed during the Pleistocene period by an upheaval ground movement occupy the space between the Ganges and the Jamuna Rivers, and the Jamuna and the Meghna Rivers. According to Prof. McIntire, the former is called Barind Terrace, and the latter, Maduhupur Jungle (136 GM). Both of them are surrounded by several fault scarps. But according to Prof. Mohamed, both of them are called Barind Terrace. In this paper, we want to follow the opinion of Prof. Mohamed (137 GE) and further call the former Western Barind Terrace and the latter Eastern Barind Terrace. The alluvial plain has plenty of ground water but there is little water in the terraces. This was revealed by infrared photographs taken by the Earth-Resources Technology Satellite from December 1972 to February 1973. On these photographs, the terraces were indicated in white color, while the alluvial plains were indicated in black color on account of the differences in the condition of ground water. Utilizing the difference in color, the writer divided the area into the terraces and the alluvial plain. According to McIntire (136 GM), there are no differences in grain size and species of minerals of soil between the terraces and the alluvial plain. But due to oxidization, color of the soil is red in the terraces but white in the alluvial plain. The terraces are stronger against erosion by streams than the plain.

Eastern Barind Terrace shows a triangular form. The terrace is divided into two groups, upper terrace and lower terrace, each of which is dissected by several valleys whose directions are from NNW to SSE. There are cliffs, which are from 2 to 10 meters high, located between

Fig. 2-3 Discharge and Stage Hydrograph of the Jamuna and the Ganges



the terraces and the alluvial plain. The cliff is very clear along the western edge of the terrace, but along the eastern part of the terrace it is gradually shifted from the terraces to the alluvial plain. This shows that Eastern Barind Terrace is tilted blocks. The city of Dacca is located on the southern edge of the lower terrace.

There are several shallow valleys from north to south in Western Barind Terrace. These shallow valleys are former river courses which originated in the Himalayan Mountains and flowed to the Ganges River. Western Barind Terrace is spread on the left side of the Ganges but small part is spread to the right bank, i.e. southern part of the Ganges. This implies that the Ganges is antecedent river in this place and the part of the terrace was upheaved after the Ganges took the present river course.

There is Tippera Surface whose height is from 3 to 6 meters on the left bank of the Meghna River. The surface was formed during the Holocene Period by an upheaval of the ground.

The whole area of Bangladesh is an alluvial plain except for the above-mentioned, the terraces which were formed during the Pleistocene Period and the other terraces which were formed during the Holocene Period.

Generally speaking, alluvial plains that are located in the Orogenic Zone like Japan consist of the following geomorphological elements: alluvial fan, natural levee, back-swamp and delta (138 GM). Bangladesh is located in the Alps-Himalaya Orogenic Zone. And there are the same four geomorphological elements as in Japan.

Alluvial fans were developed in the northern part of Western Barind Terrace, the upper reaches of the Jamuna River and the foot of Shillong Plateau.

There are many alluvial fans at the foot of Shillong Plateau. But area of each alluvial fan is small. Furthermore, the apexes and central parts of the fans are located in the Indian territory. Only lower edges of the fans are located in the Bangladesh territory. There are gravels in the apex and central part but few in the lower edge of fan.

The northern part of Western Barind Terrace is covered by alluvial fans which have been formed by the Tista River, the Karatoya River and the Atrai River which originate in the Himalaya Mountains. Almost all of the deposition layers in the fans are composed of sand and some few gravels, because chemical weathering is strong in the tropical or sub-tropical region.

From a geomorphological viewpoint, we can divide the Jamuna River into two parts, (1) the upper reaches and (2) the lower reaches. By the upper reaches, we mean from the border between India and Bangladesh to Sirajganj and by the lower reaches from Sirajganj to the junction of the Ganges and Jamuna Rivers. In the upper reaches, width of the river is wide and composed of a network of smaller streams. The upper reaches of the river are characteristic of those in the alluvial fan but the

EXPLANATORY NOTES

- BOUNDARY OF TOPOGRAPHY
- S — STEEP SLOPE IN THE MOUNTAIN
- GS — GENTLE SLOPE IN THE MOUNTAIN
- PS — PIEDMONT GENTLE SLOPE
- H — HILL
- UT — UPPER TERRACE
- LT — LOWER TERRACE
- VP — VALLEY PLAIN
- SF — SANDY ALLUVIAL FAN WITH GENTLE SLOPE
- NL — NATURAL LEVEE
- UD — FORMER OR UPPER DELTA
- B — BACK SWAMP OR DELTA
- DT — DELTA INFLUENCED BY TIDE
- FR — FORMER RIVER COURSE
- DR — DRY RIVER BED
- MARSH
- TD — TIDAL FLAT
- S — SAND SPITS

Fig. 2-4 GEOMORPHOLO[G]Y OF THE R. BRAHMAPUTRA–JAMUNA

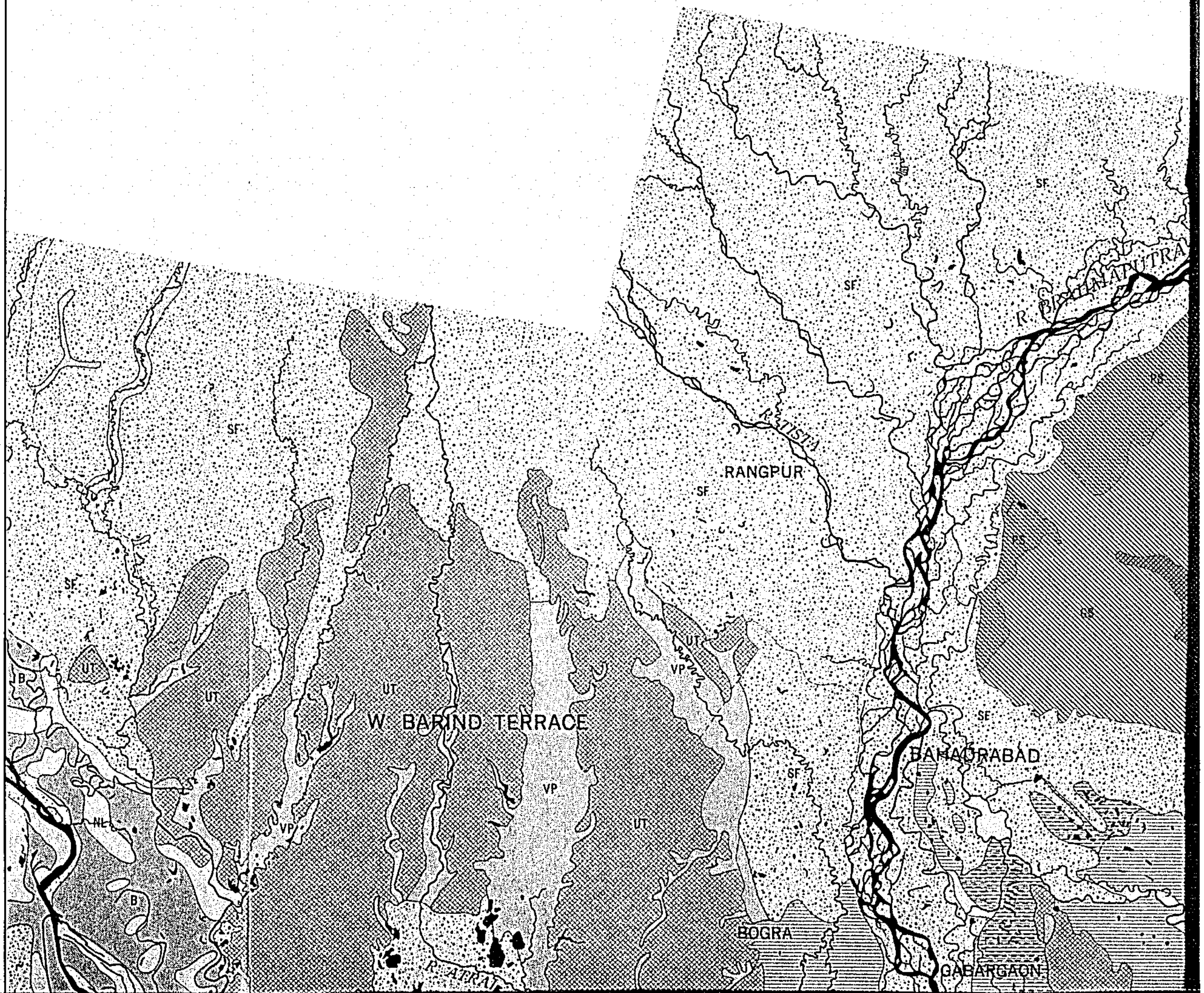
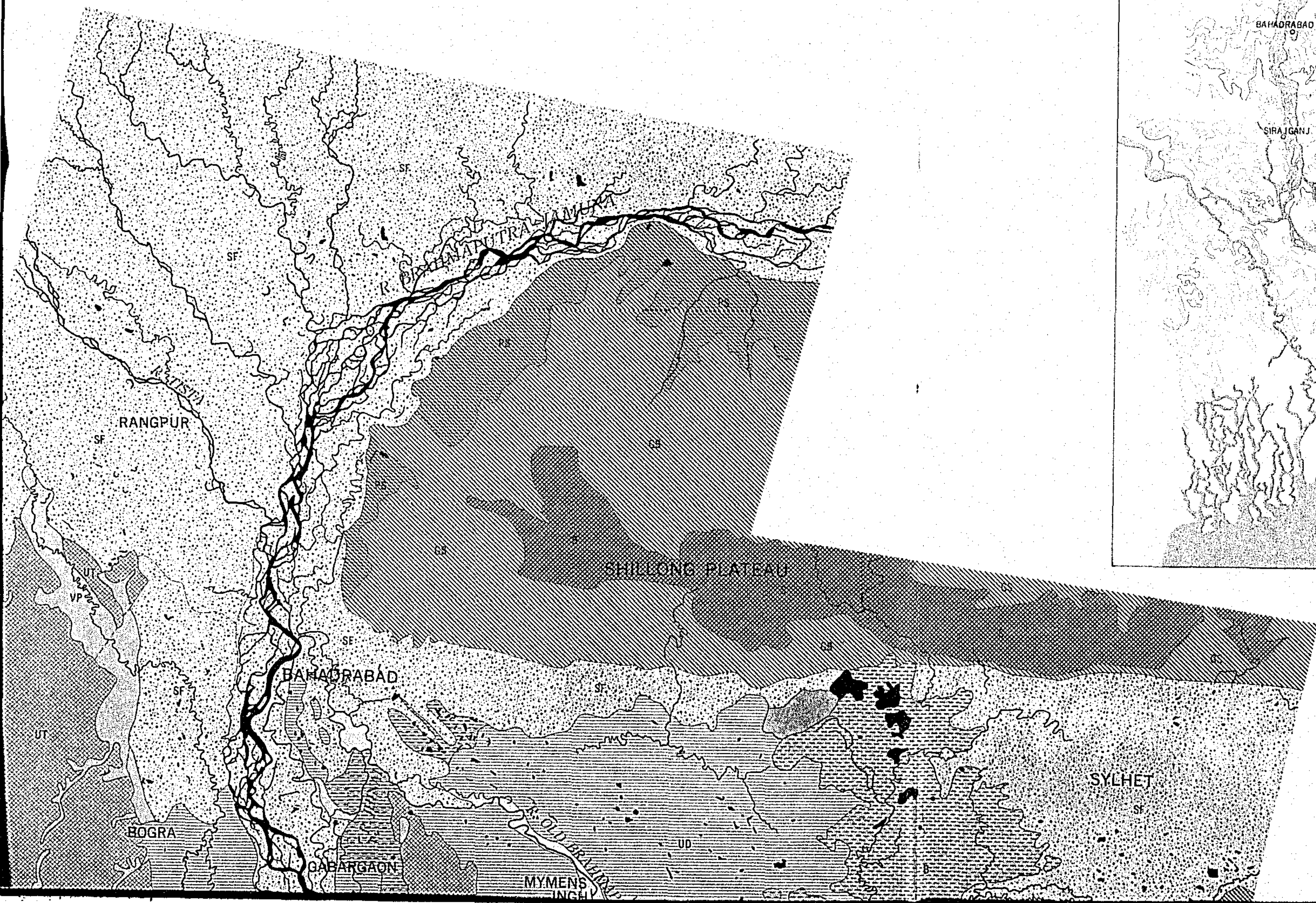
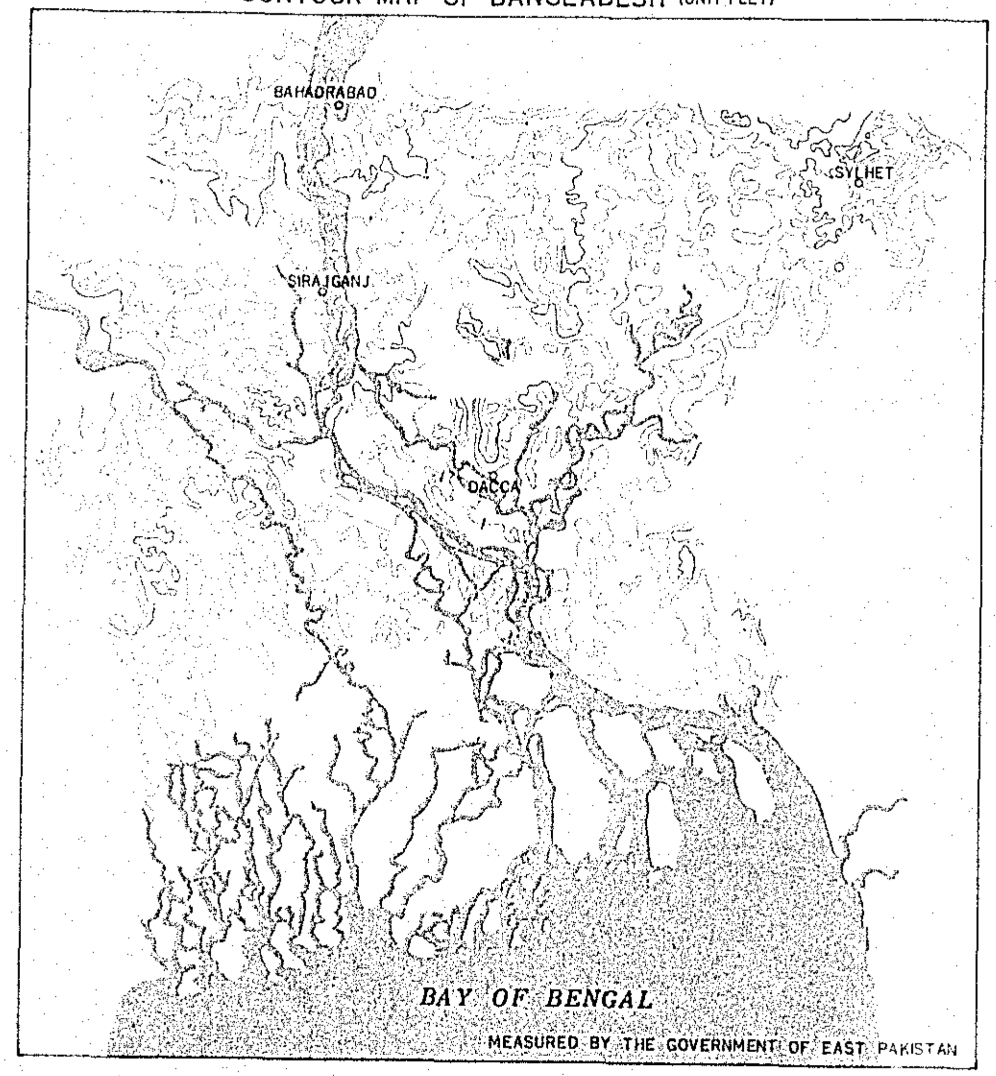
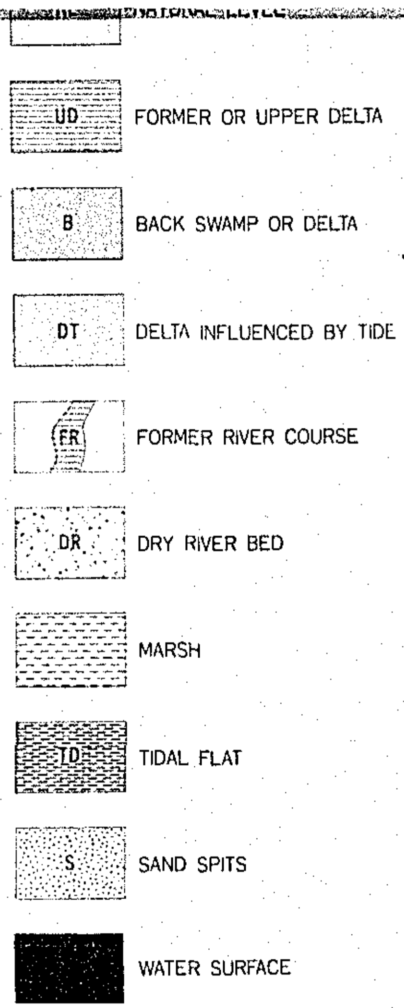


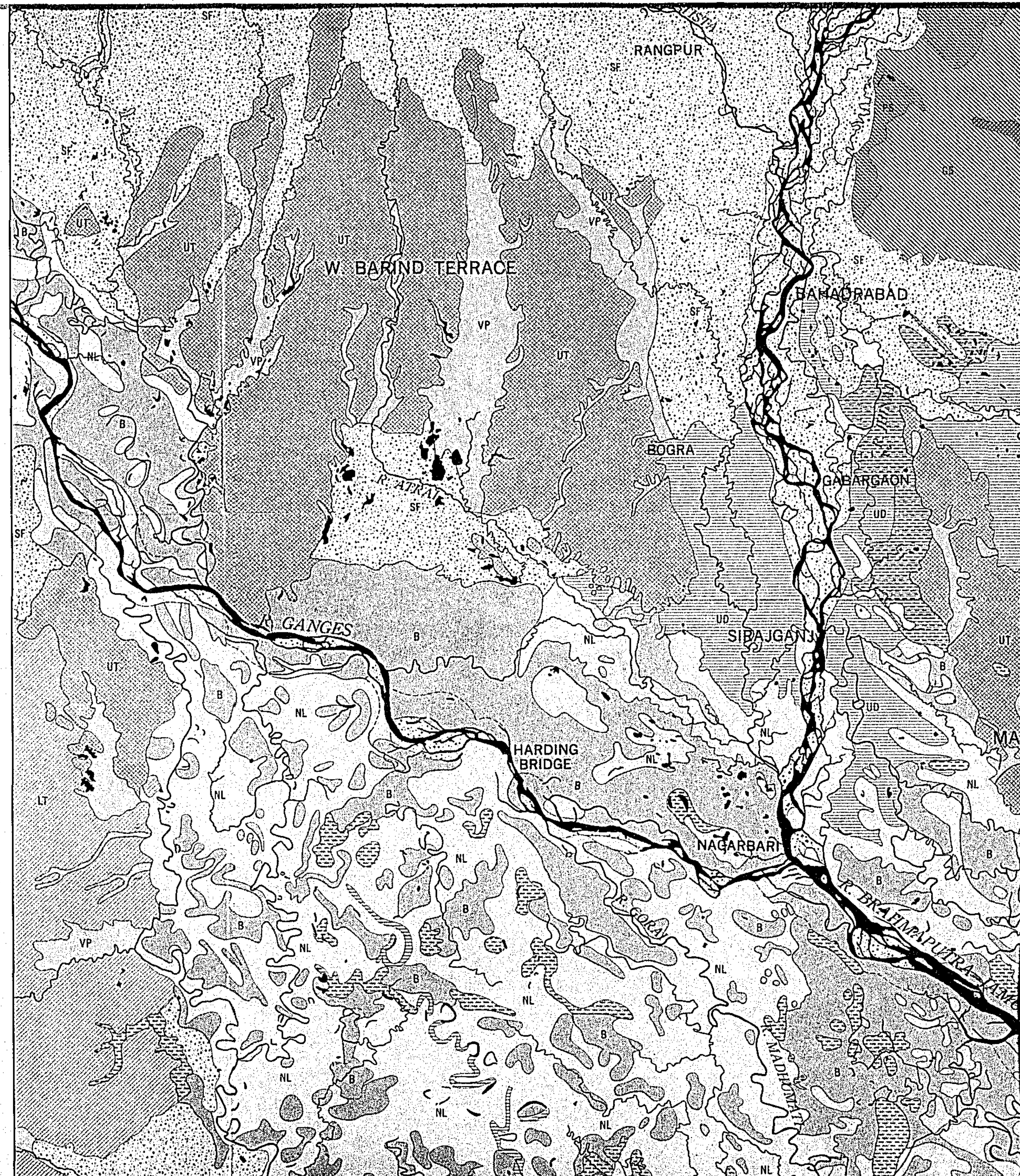
Fig. 2-4 GEOMORPHOLOGIC MAP OF BRAHMAPUTRA–JAMUNA AND R. GANGES PLAIN



CONTOUR MAP OF BANGLADESH (UNIT FEET)







Explanation of the geomorphologic map

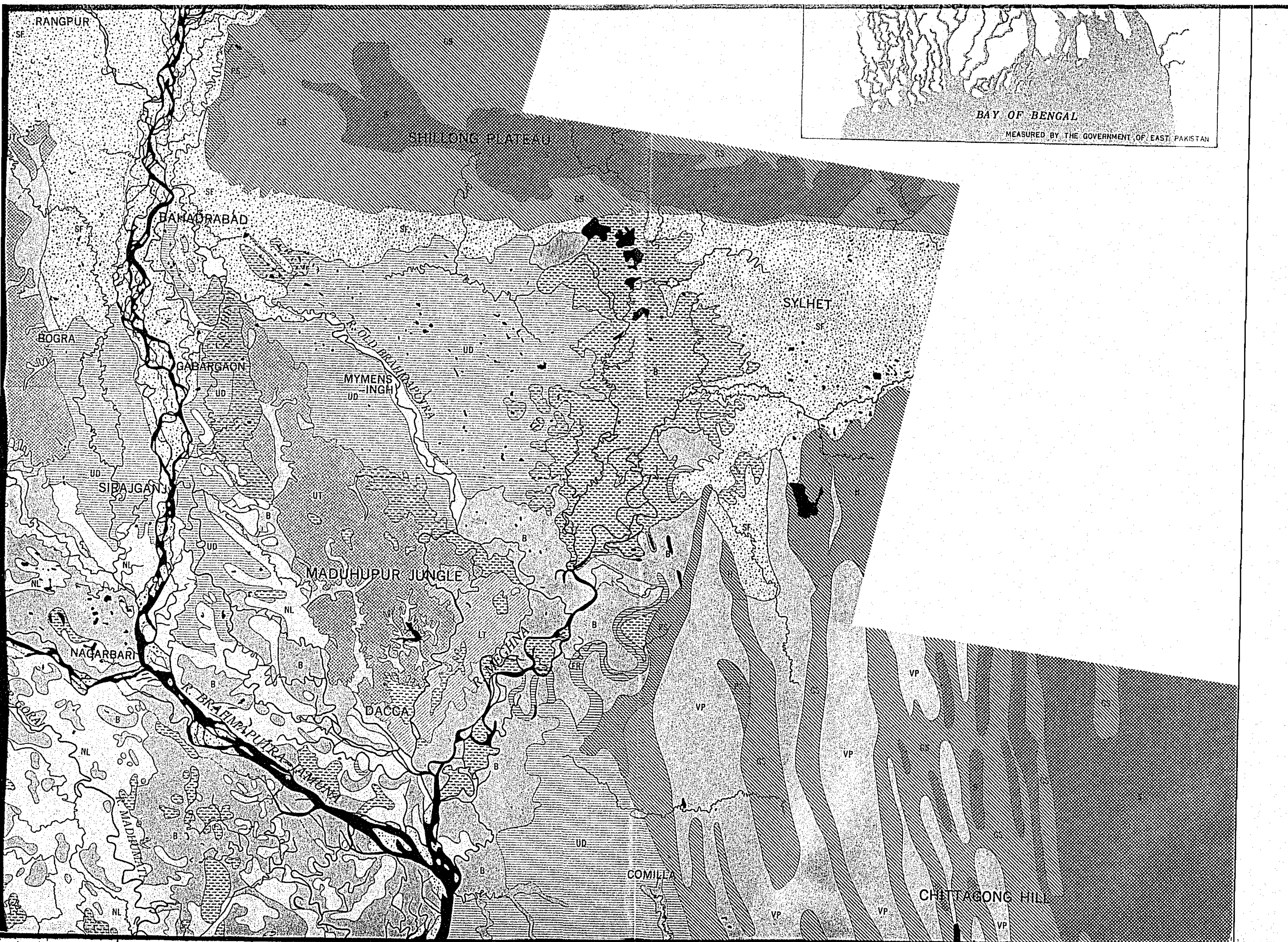
The geomorphologic map has been prepared utilizing the mozaic of the photographs of Earth Resources Technology Satellite as a base map. The photographs were taken in the dry season in 1972.

Utilizing the photographs of the ERTS, the topographic maps or geological maps and field observation by helicopter and jeep, one could classify the area into the geomorphologic elements as shown in the explanatory notes.

In the photo-interpretation of ERTS for geomorphologic land classification, near-infrared photographs are most suitable. Because in the photographs, the water surface i, e, river, lake, sea etc. is photographed as a black colour and the marshy land i, e, back-swamp, tidal flat etc. and the dry area i, e, terrace, natural levee etc. is photograhed as a white colour. So, by distinguishing the contrast of the colours, one can classify the area.

The violet line designates the boundaries of topographic divisions. The dotted violet line shows the variation of the slopes in each topographic division.

The area consists of three groups of topography. One is mountainous regions, i, e, Shillong Plateau and Chittagong Hill. The area consists of hard rock. The second is terrace or dissected fan. The former is Eastern Barind Terrace or Maduhupur Jungle. The city of Dacca


RANGPUR
BAY OF BENGAL
MEASURED BY THE GOVERNMENT OF EAST PAKISTAN
SHILLONG PLATEAU
BAHADRABAD
SYLHET
BOGRA
GABARGAON
MYMENSINGH
R. OLD BRAHMAPUTRA
SIRAJGANJ
MADUHUPUR JUNGLE
NAGARBARI
R. MEGHNA
R. BRAHMAPUTRA-JAMUNA
DACCA
R. GORAI
R. MADHUMATI
COMILLA
CHITTAGONG HILL

Explanation of the geomorphologic map

The geomorphologic map has been prepared utilizing the mozaic of the photographs of Earth Resources Technology Satellite as a base map. The photographs were taken in the dry season in 1972.

Utilizing the photographs of the ERTS, the topographic maps or geological maps and field observation by helicopter and jeep, one could classify the area into the geomorphologic elements as shown in the explanatory notes.

In the photo-interpretation of ERTS for geomorphologic land classification, near-infrared photographs are most suitable. Because in the photographs, the water surface i, e, river, lake, sea etc. is photographed as a black colour and the marshy land i, e, back-swamp, tidal flat etc. and the dry area i, e, terrace, natural levee etc. is photograrahed as a white colour. So, by *distinguishing the contrast of the colours*, one can classify the area.

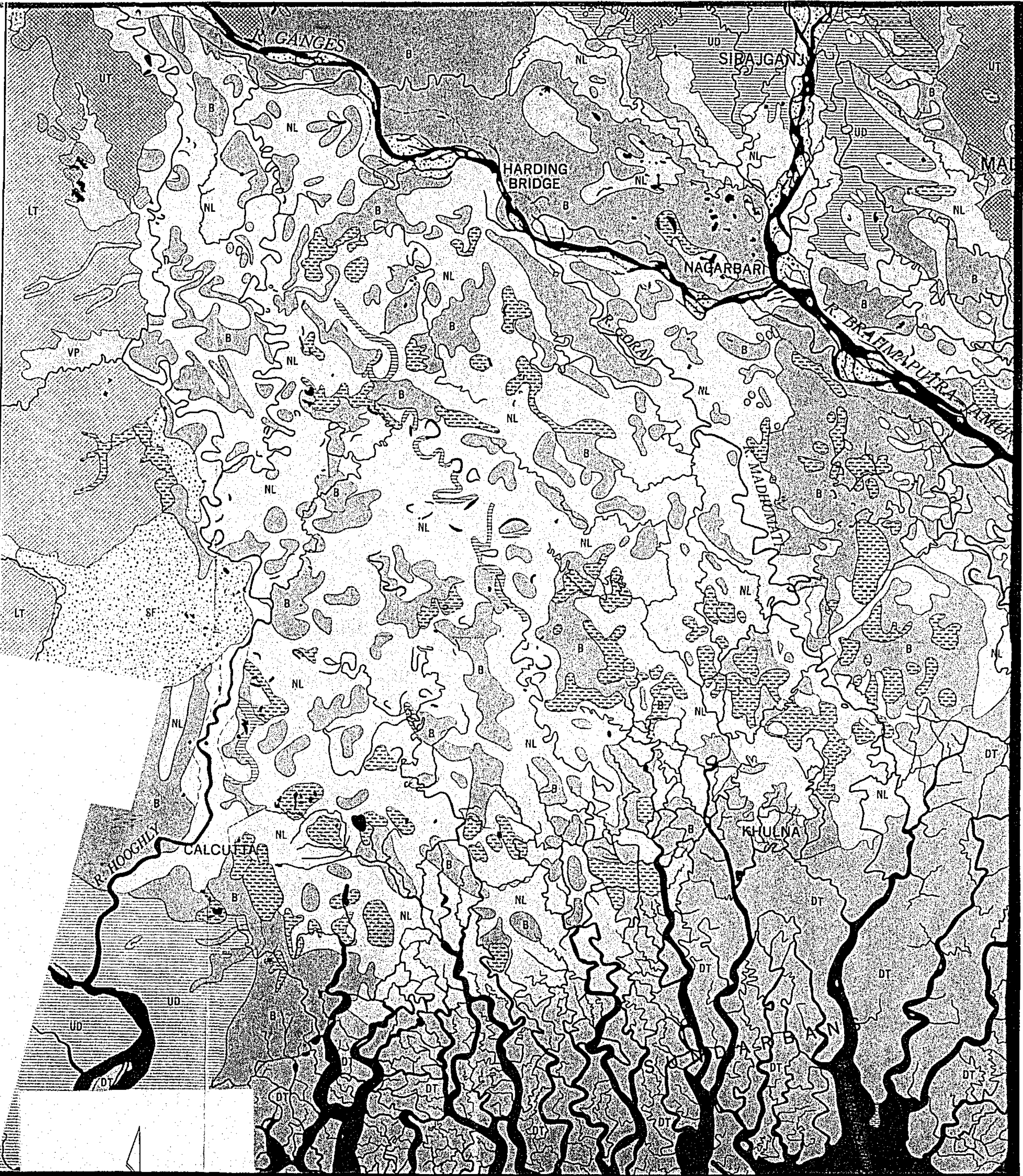
The violet line designates the boundaries of topographic divisions. The dotted violet line shows the variation of the slopes in each topographic division.

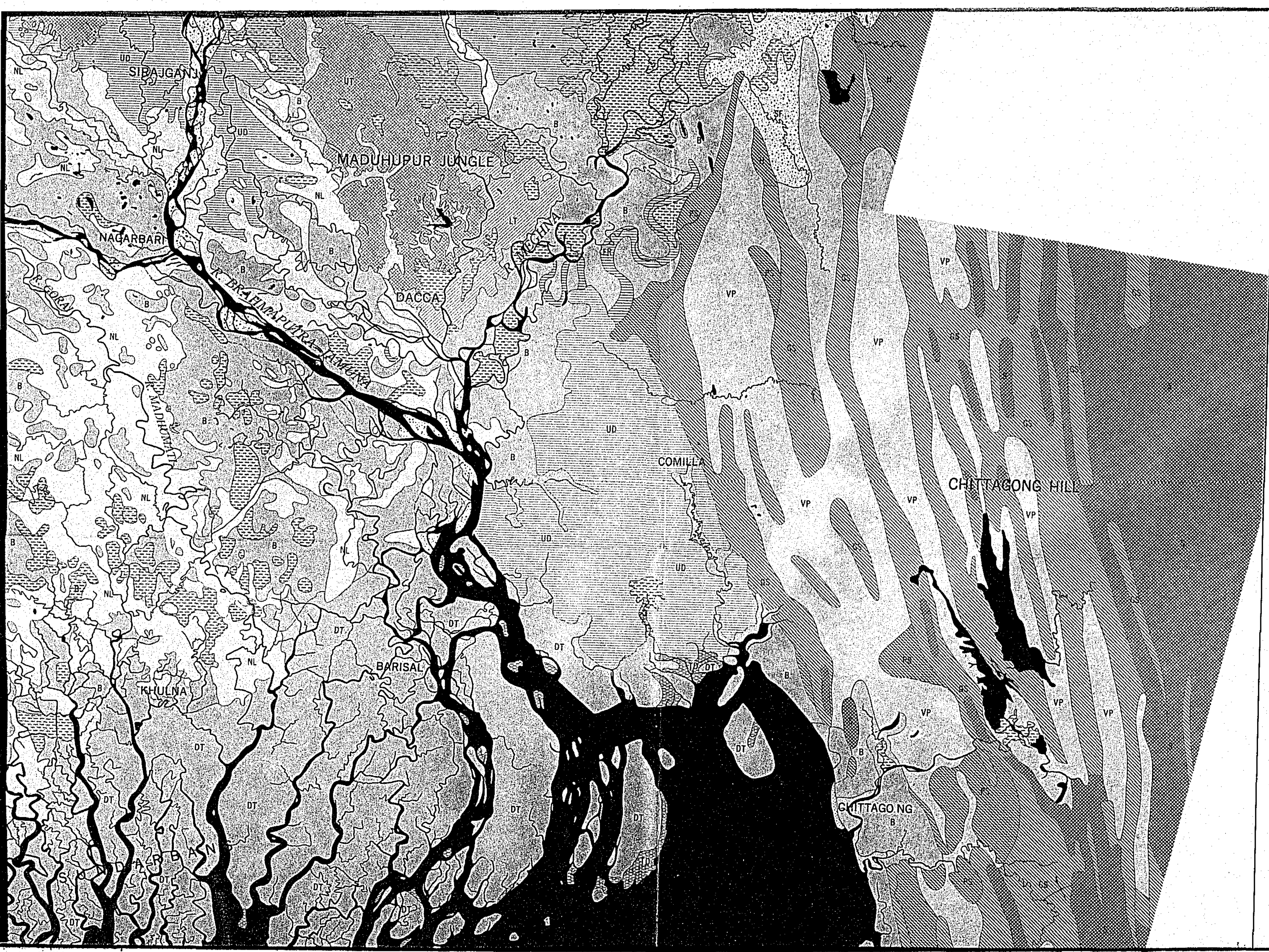
The area consists of three groups of topography. One is mountainous regions, i, e, Shillong Plateau and Chittagong Hill. The area consists of hard rock. The second is terrace or dissected fan. The former is Eastern Barind Terrace or Maduhupur Jungle. The city of Dacca is situated on the terrace. The latter is Western Barind Terrace. These terraces have been formed by upheaval ground movement. Surface geology of the terrace or dissected fan is harder than that of the alluvial plain.

The third is alluvial plain. The plain consists of fan, natural levee, back-swamp, upper delta and delta. The fan in this region is composed of sand and has gentle slope. A remarkable difference is seen between the fan in the area and the fan in Japan which consists of sand and gravel with steep slopes. The former or older delta is located in the lower reaches of the Old Brahmaputra and Sirajganj and its surrounding, and the upper delta is located in the western part of Comilla. The former has been formed before 1830, by Old Brahmaputra and Tista etc. the latter has been formed by the upheaval ground movement.

The geomorphologic map serves not only the purpose of studying geomorphology and geomorphologic development, but also the purpose of estimating the flooding, condition of the ground water at a level close to the surface of the ground. The geomorphologic maps will also help one to investigate the conditions of soil, because the result of geomorphologic classification coincides with that of the soil classification.

And that is very useful for the purpose of establishing plans for land development (i, e, road construction, bridge construction etc.) land conservation and improvement project.




SIRAJGANJ
NAGARBARI
MADUHUPUR JUNGLE
R. MEGHNA
DACCA
R. GORAI
R. BRAHMAPUTRA-JAMUNA
R. MADHUMATI
COMILLA
CHITTAGONG HILL
BARISAL
KHULNA
SUNDARBAN
CHITTAGONG
UD
NL
UT
LT
B
DT
VP
GS
PS

The area consists of three groups of topography. One is mountainous regions, i, e, Shillong Plateau and Chittagong Hill. The area consists of hard rock. The second is terrace or dissected fan. The former is Eastern Barind Terrace or Maduhupur Jungle. The city of Dacca is situated on the terrace. The latter is Western Barind Terrace.

These terraces have been formed by upheaval ground movement. Surface geology of the terrace or dissected fan is harder than that of the alluvial plain.

The third is alluvial plain. The plain consists of fan, natural levee, back-swamp, upper delta and delta. The fan in this region is composed of sand and has gentle slope. A remarkable difference is seen between the fan in the area and the fan in Japan which consists of sand and gravel with steep slopes. The former or older delta is located in the lower reaches of the Old Brahmaputra and Sirajganj and its surrounding, and the upper delta is located in the western part of Comilla. The former has been formed before 1830, by Old Brahmaputra and Tista etc. the latter has been formed by the upheaval ground movement.

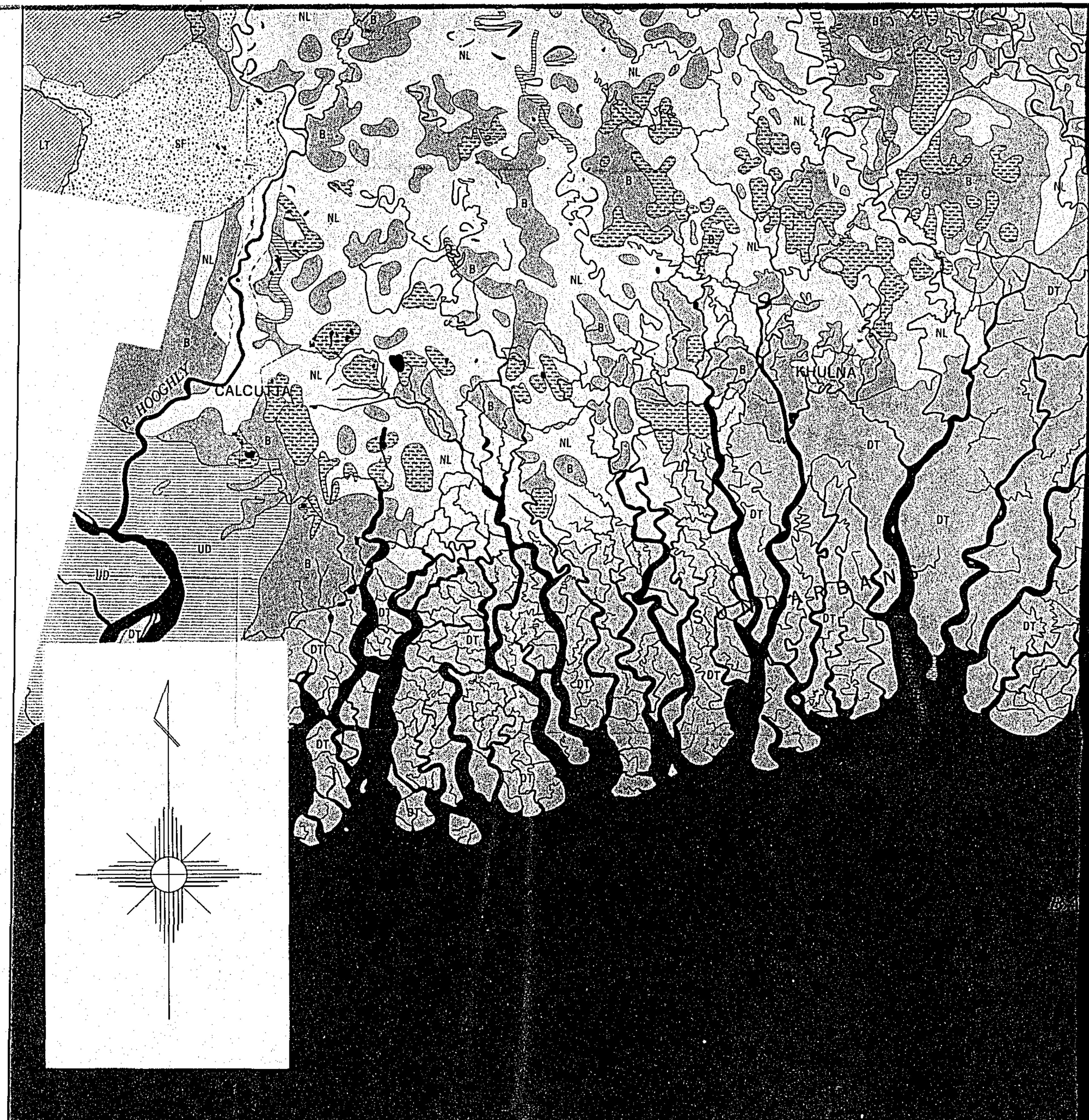
The geomorphologic map serves not only the purpose of studying geomorphology and geomorphologic development, but also the purpose of estimating the flooding, condition of the ground water at a level close to the surface of the ground. The geomorphologic maps will also help one to investigate the conditions of soil, because the result of geomorphologic classification coincides with that of the soil classification.

And that is very useful for the purpose of establishing plans for land development (i, e, road construction, bridge construction etc.) land conservation and improvement project.

SCALE 1:1,000,000

SURVEYED, COMPILED AND CARTOGRAPHED
BY MASAHIKO OHYA

PRINTED BY KOKUDO CHIZU CO. LTD. TOKYO 1976



COMILLA
CHITTAGONG HILL
KHULNA
BARISAL
CHITTAGONG
COXS BAZAR
SUNDARBANS
BAY OF BENGAL
NL
B
UD
DT
TD
VP

features of the lower reaches are characteristic of those in a natural levee region.

But the pattern of the geomorphological elements in the protected area or inland area far from the Jamuna River is different. For example, on the left bank of the Jamuna River, the lower edge of the alluvial fan is located at the town of Gabargaon. There are natural levees and back-swamps in the fan region. Also the lower edge of the alluvial fan along the river is extended further than that of the protected area or the inland region. This shows that the natural levees and back-swamps were first formed by the Tista River etc.; but after this, the Jamuna River formed a new course and a new fan in the above-mentioned area.

The alluvial plains which are located in the southern part of the Ganges River were formed mainly by the Ganges River. From a geomorphological view point, the area is divided into two parts; (1) natural-levee region and (2) the tidal-delta region. The border line between these regions is the line connecting the City of Calcutta, Khulna, Gopalganj and Madaripur. Back-swamps occupy the space between these natural levees.

The tidal-delta region is called Sundarbans. The area is covered by dense forests. And we can see mangroves, nippa palms, geaa etc.

A big swampy region is located in the south-western part of Sylhet i.e. in the upper reaches of the Meghna River. The swampy region was formed by ground dipping.

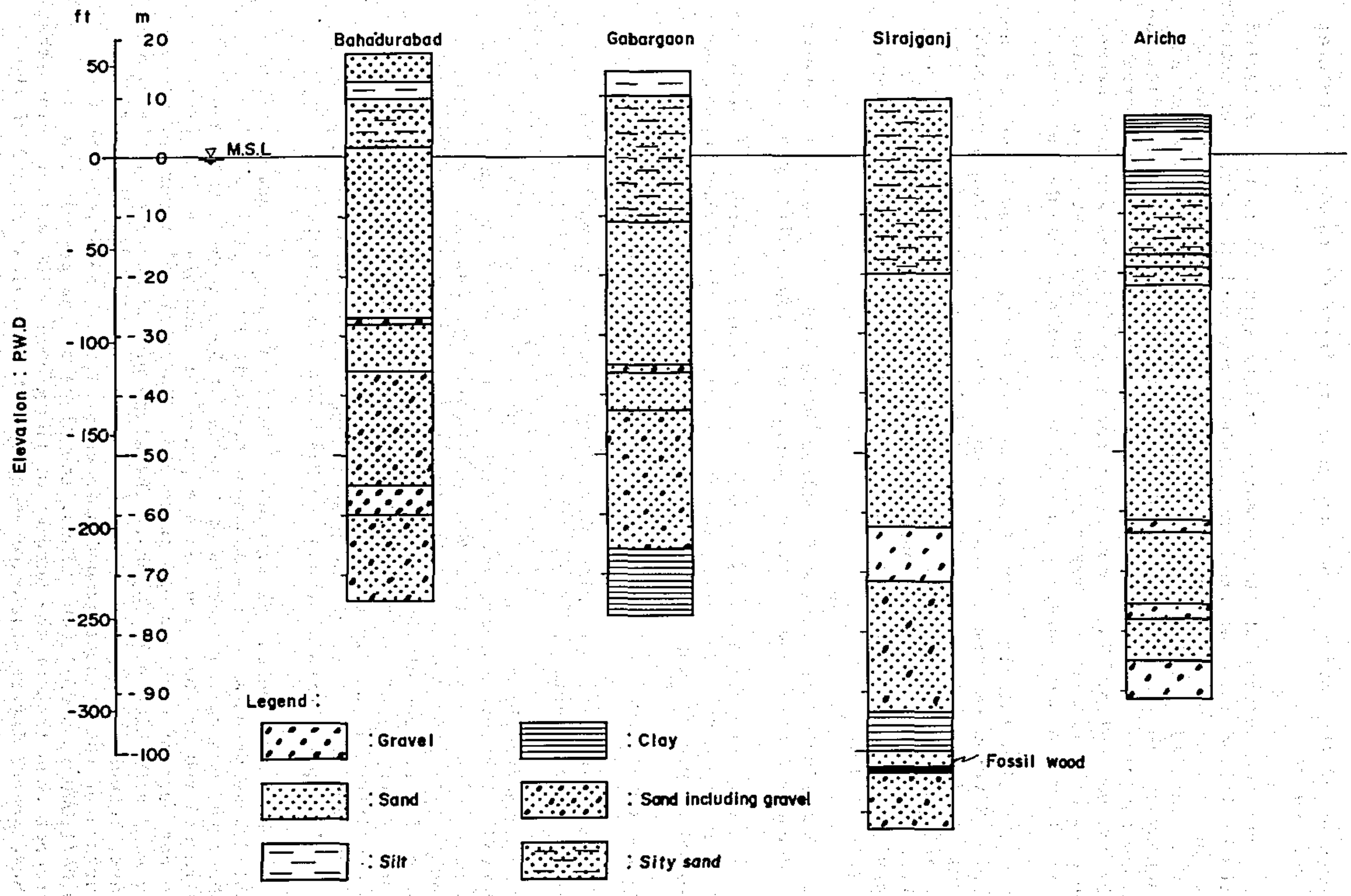
2.2. *Geomorphological development in the plain of the Jamuna.*

2.2.1. Influence of the glacial eustasy to the geomorphological development.

As noted the glacial eustasy occupied during the Pleistocene Period. The lowest water level during the Würm Ice Age was -100 meters below sea level (25,000 years ago). At that time, a large quantity of sand and gravel was transported by the rivers from the mountains because of the extensive mechanical weathering caused by the low temperature. The large amount of sand and gravel which were transported by the rivers developed large fans at the foot of the mountains. We can trace the gravel layers by the geological boring logs in Japan, Korea, Formosa and Vientiane Plain in Laos.

There are geological records of borings along the Jamuna River, which were prepared by the Japanese Geological Survey Team. Fig.2-5 shows the geological records of borings at Bahadurabad, Gabargaon, Siraganj and Aricha. You can see gravel or sand and gravel layers at deeper part of each geological record. These gravel layers are covered by sand and thick silt layers. The slope of the surface of the gravel layer between Sirajganj and Aricha is 0.36/1,000. The slope of the surface of the present ground between Sirajganj and Aricha are from 0.04/1,000 to 0.05/1,000. Thus, the slope of the gravel layer is steeper than that of the surface of the ground. The writer thinks that these gravel layers which are seen in each geological record of the

Fig. 2-5 Geological Records of Borings at Bahadurabad, Gabargaon, Sirajganj and Aricha



Compiled from the data of the Japanese Geological Survey Team borings were formed during the Würm Ice Age. Because the absolute age of buried fossil wood which were found just below the gravel layer was 28,000 years of carbon dating. The sand and silt layers on the top of the gravel layers were deposited during the Holocene Period.

In the case of Japan and Korea, there are marine layers on these gravel layers. However there is no marine layer in this region partly because the deposition of the Jamuna River prevented the invasion of sea water, partly because Aricha is located far from the sea coast.

2.2.2. Influence of the ground movement on geomorphological development.

The ground movement in this region is large. Barind Terraces had been formed by the upheaval of the earth from the Pleistocene onwar and Tippera Surface was formed during the Holocene Period. On the other hand, the alluvial plains along the Jamuna, the Ganges, and the Meghna are located in the ground dipping or subsiding zone. We have the records of earthquakes in 1762, 1775, 1812, 1888, 1897, 1912 etc. And the ground movements which resulted from the earthquakes are also reported.

The ground height of Sylhet Depression is only 3 meters in spite of the fact that this depression is located far from the coast (about 250 Km). The depression was formed by the continuation of the ground dipping. Based on the geomorphological features, we can assume that the north-western part of Ganges Plain was upheaved and the south-eastern part of it was downwarped. The above-mentioned remarkable ground movement caused the shifting of the river courses.

2.3. Shifting of the Ganges River.

The shiftings of the river courses of the Ganges and the Brahmaputra-Jamuna were remarkable partly because the gradient of the plain is gentle and crustal movement of the ground is large, partly because deposition by the river is large, the annual variation of flood discharge is big, and there are few artificial river conservancies.

Two different theses on the shifting of the Ganges River were presented at the Symposium of the Scientific Problems of the Humid Tropical zone Deltas and their Implications which were held at Dacca in 1964.

V.N. Nagaraja, Department of Irrigation, the government of India stated that the river course of the Ganges shifted from west to east. During ancient times, the Hoogly River which runs through the City of Calcutta was the main stream of the Ganges. When the British invaded India, the main harbor was located in the upper reaches above Calcutta. And the Ichamati, Jalang, Garai rivers etc. which are located between the Hooghly and the Ganges were formed during the shifting. This thesis has been supported by the Geological Survey Institute of India and the geographers of India.

Prof. M.I. Chowdhury stated a different view of the development (140 GM). The present Ganges River (Padma) is already seen in Ptolomy's map prepared in 150 A.D. And according to the map of Thomas Kitchin, "A new and accurate map of Bengal drawn from the best authorities", the bifurcation of the Ganges is shown near Rajmahal; the eastern course, that is, the Padma channel, is named the great Ganges and the Bhagirathi-Hooghly channel the little Ganges. Secondly Chowdhury experimented at the hydraulic laboratory in Cambridge, and observed that a natural flow of water, when entering into a plain, loses its gradient and the main course bifurcates into two or more branches. Based on these studies he assumed that the Ganges and the Hooghly were situated as they were from ancient times. M. Ohya (141 GM) researched Sundarbans and found the following features. Some differences in the topography of the eastern and western parts of Sundarbans are quite noticeable. The natural levees in the western part are higher than in the eastern part. The western part was upheaved and the eastern part is newer than the western part. From the above-mentioned phenomena, he presumes that, the Hooghly River has become smaller but the Ganges River has become larger.

2.4. Shifting of the Brahmaputra-Jamuna River and effects of the diversion.

During the t ime of Major James Rennell who surveyed the rivers of Bengal between 1764 and 1779, the main course of the Brapmaputra was the present channel of the Old Brahmaputra. The course of the Jamuna which is now the main channel of the Brahmaputra was called the Jhinai in its upper course and the Jamuna in its lower course.

According to Hirst, the diversion of the Brahmaputra from the old course to the present one was completed by 1830, that is, approximately fifty years after Rennell's mapping. Buchanan Hamilton observed in 1810, however, that the Brahmaputra threatened to divert to its present course. In 1810, the discharge of the Jhinai had already become so large relative to its size that it resulted in accelerated erosion and flooding.

Fergusson suggested the possibility of the Brahmaputra flowing through the present channel once before. Morgan and McIntire reported the presence of large Brahmaputra-size-river scars flanking the southern edge of the Shillong Plateau in Mymensing and Sylhet basin.

M. Ohya observed outcrop of the fluvial layers at Jamalpur shown in Fig.2-6-1. As seen in Fig.2-6-2, the lower part is a sand layer and the upper layer is silt.

The former had been deposited at the time of the mainstream of Brahmaputra and the latter had been deposited after the river shifted.

Concerning the diversion of the Brahmaputra, Hirst attributed it to the tectonic activi-

Fig.2-6-2 Outcrop of fluvial layers of the Old Brahmaputra River at Jamalpur

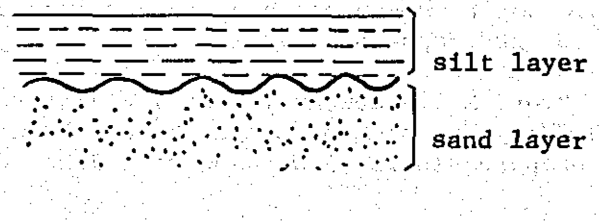
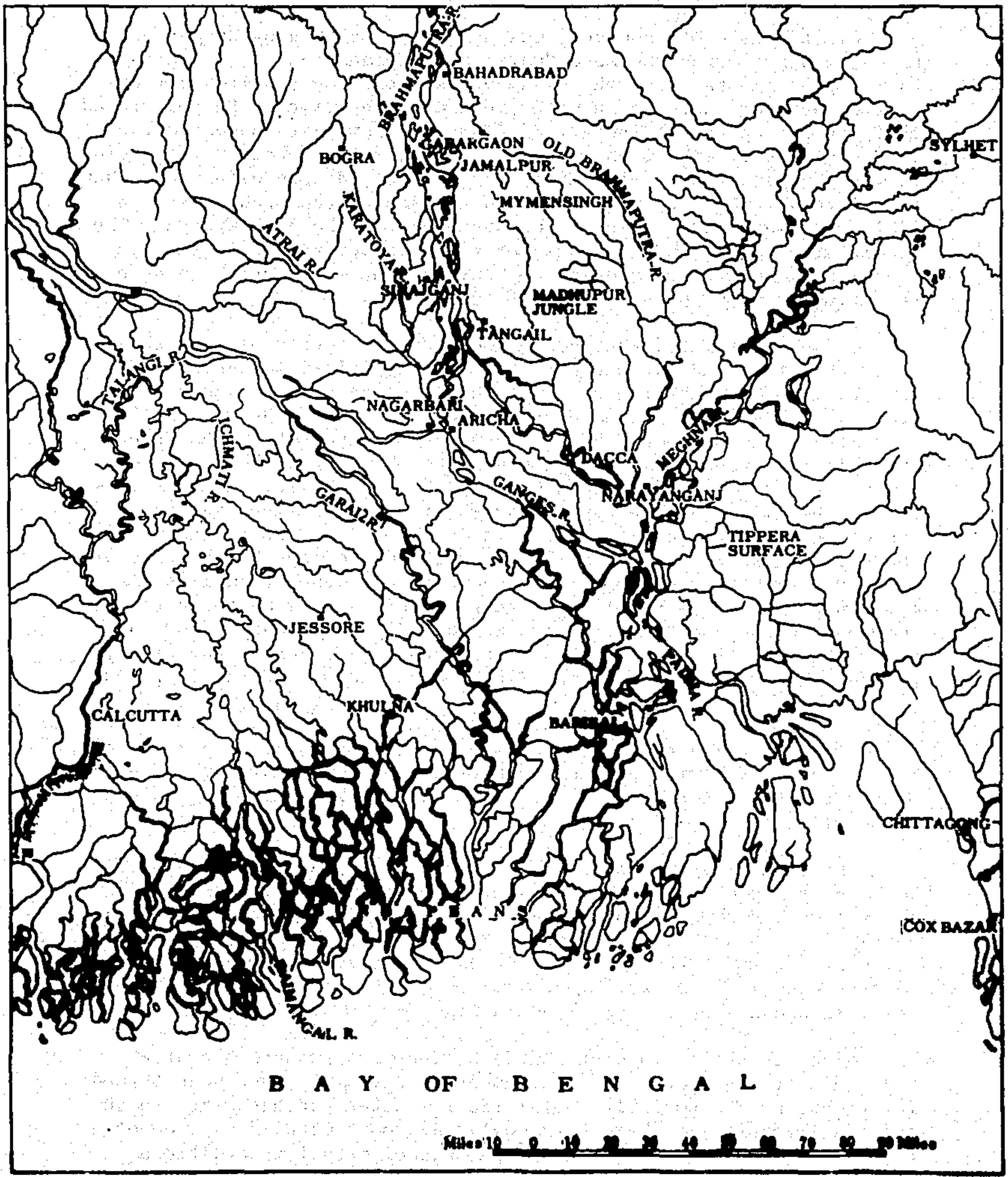


Fig. 2-6-1 River System in the Ganges - Jamuna Plain



ties i.e. the uplift of the Barind Terrace and lowering of the valleys of the Jamuna River.

Hirst's concept, however, was severely attacked by Hayden and Pasco, who preferred the more "rational" explanation of La Touche. La Touche suggested that the Brahmaputra diversion resulted directly from a major increase in water volume of the river. He postulated that the Dihang as a tributary of a small Brahmaputra beheaded the Tsangpo River of Tibet, and through the resulting "enormous accession of water began to exert itself". Furthermore, he suggested that when the Tista diverted its water from the Ganges to the Brahmaputra in 1787, more water was added to the discharge of the Brahmaputra. The accelerated water, in the course of time, opened a passage through the Jhinai and gradually began to increase the width of the channel, resulting into the present form of the Jamuna.

Gregory estimated that big piracies had occurred between the Tibetan Plateau and the northern part of the Indo-China Peninsula. According to him, the Yantze River beheaded the upper reaches of the Red River, the Mekong beheaded the upper reaches of the Mae Nam Chao Phya River, the Salween beheaded the upper reaches of the Mae Ping which is the tributary of the Mae Nam Chao Phya, and the Irrawaddy River beheaded the upper reaches of the Sittang River. At that time, the Tsanpo River was the upper reaches of the Chindwin River which is one of the tributaries of the Irrawaddy River, but was beheaded by the Brahmaputra River. Hirst has been influenced by the theories of Gregory. But the studies of Gregory were only done by small scale map. Recently Dr. Mutsumi Hoyanagi published papers on the piracy between the Red and Yantze Rivers which had been researched by the geographers of the People's Republic of China and denied the piracy between the Brahmaputra and the Tsanpo occurred within the last 200 years.

Prof. McIntire suggested that the diversion occurred partly because of the tilting of Eastern Barind Terrace and partly because of the shifting of the Tista River caused by the tilting of Western Barind Terrace.

The diversion of the Tista increased the water discharge of the Brahmaputra which exceeded the capacity of the rivers, thus causing great floods near the confluence. Some of the excess water could be carried by the Jhinai which during Rennell's time was a narrow distributary of the Brahmaputra. This distributary was gradually enlarged and its discharge increased from year to year until it became the main channel of the Brahmaputra itself.

Also, as the Tista contributed on enormous amount of coarse sediments to the Brahmaputra, a number of bars must have been formed in its channel, especially during the low water period. The growth and stabilization of these bars could have obstructed free flow of flood water down the Old Brahmaputra channel creating conditions favourable for its diversion. The Brahmaputra now follows a shorter route to the sea than it did through its older course past Mymensing town.

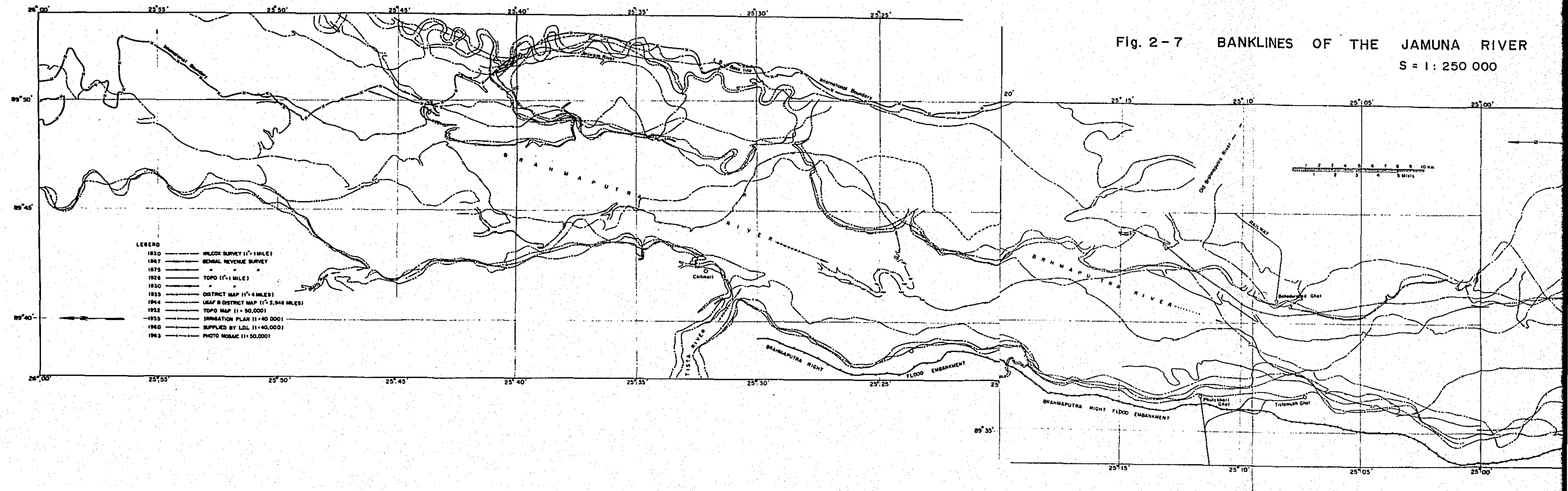
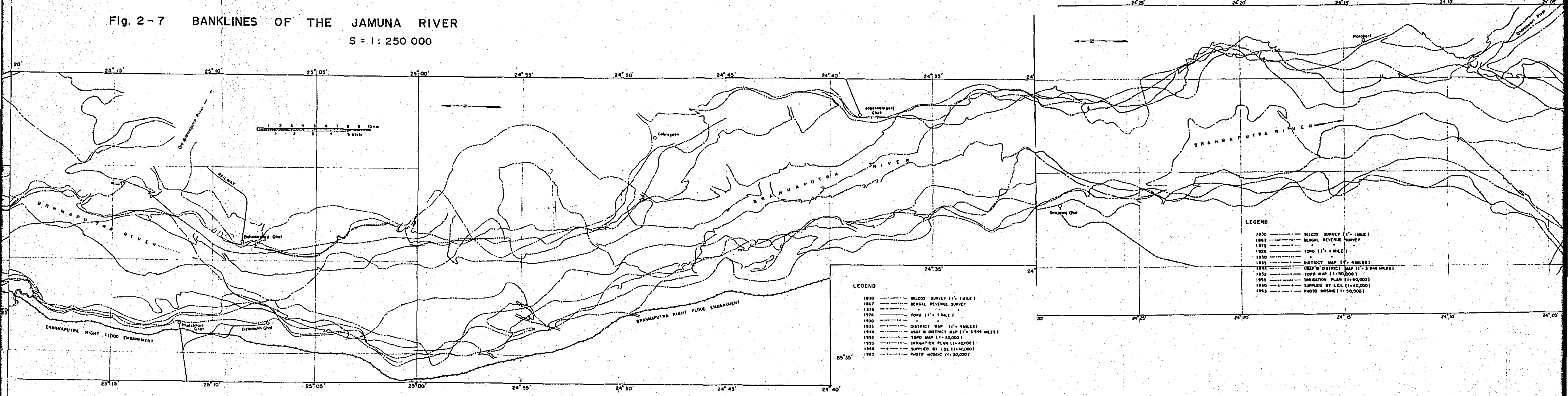


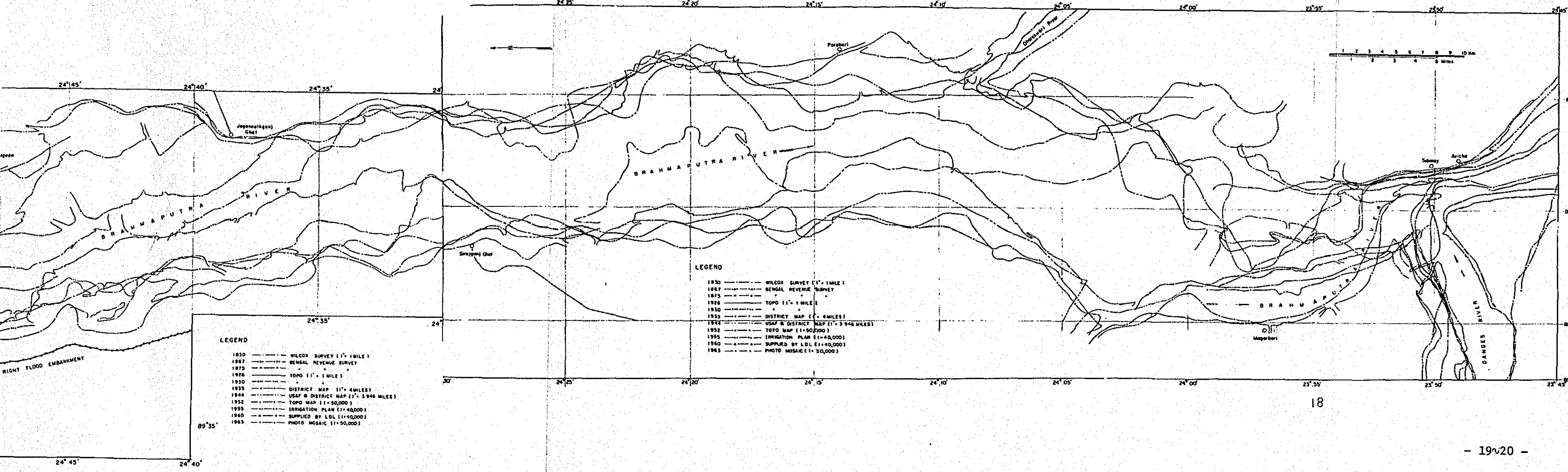
Fig. 2-7 BANKLINES OF THE JAMUNA RIVER
S = 1 : 250 000

Fig. 2-7 BANKLINES OF THE JAMUNA RIVER

S = 1 : 250 000



NES



BRAHMAPUTRA RIVER
BRAHMAPUTRA RIVER
BRAHMAPUTRA RIVER
GANGES RIVER
RIGHT FLOOD EMBANKMENT
Jagannathganj Ghat
Sirajganj Ghat
Porabari
Sabosay
Aricha
Magarbari
LEGEND
1850 WILCOX SURVEY (1" = 1 MILE)
1867 BENGAL REVENUE SURVEY
1875 " " "
1926 TOPO (1" = 1 MILE)
1930 " "
1935 DISTRICT MAP (1" = 4 MILES)
1944 USAF & DISTRICT MAP (1" = 3.946 MILES)
1952 TOPO MAP (1:50,000)
1955 IRRIGATION PLAN (1:40,000)
1960 SUPPLIED BY LDL (1:40,000)
1963 PHOTO MOSAIC (1:50,000)
24°45'
24°40'
24°35'
24°25'
24°20'
24°15'
24°10'
24°05'
24°00'
23°55'
23°50'
23°45'
89°35'
89°50'
89°45'
89°40'

18

Rennell's map shows a number of right-bank distributaries of the Brahmaputra which, from west to east, are the Jhinai, the Bansi, and the Banar. The major distributaries draining the flood plain were the Jhinai and the Bansi and their distributaries like the Lohajang, the Nanglai, the Atrai and others. As a result of this diversion, the head-waters of these distributaries were choked by increasing quantities of coarse sediments that flowed into them from the Brahmaputra. In the course of time, the flood plain distributaries disconnected themselves from the master stream. Consequently their discharge decreased considerably and they became minor streams. At present, streams like the Lohajang, the Atrai, and some older courses of the Jhinai are only underfed streams with small flow channels occupying parts of larger channels which were previously occupied by them when they were active streams of much larger voluem.

The Old Brahmaputra channel still continues to carry some water of the Brahmaputra River but is diminishing quantities. During the dry period, however, the discharge is reduced to a mere trickle.

With the passing of the coarse alluvial fan, sediments of the Tista River in the Jamuna together with similar sediments contributed by the Tista, the Jaldhaka, and other alluvial fan tributaries, the Jamuna sediments became much coarser than before.

3. River-morphological Features of the Jamuna River.

3.1. Changes in banklines.

According to the Prefeasibility Report, IWTA had collected data on banklines of the Jamuna River surveyed in the period from 1830 to 1963 and arranged them in a diagram showing the changes in banklines as given in Fig.2-7. It is seen from our study mentioned in the next article 3.2. that these banklines show the outer lines given by small waterways or anabranches which take off from the main Jamuna and join again with the main.

Making use of these data, changes in banklines and river widths were studied in reference to those in 1830. The first figure of Fig. 2-8 shows variations of river widths at every point one minute north latitude along the Jamuna river course. The second and third figures show respectively the displacement of the right and left banklines from those in 1830 at intervals of one minute north latitude along the river.

3.2. Changes in chars and thalwegs.

We found that, among the aerophotographs taken by SOB, those taken in the dry seasons of 1952, 1963, and 1970/71 cover almost the whole stretch of the Jamuna River. Figs.2-9-1 and 2-9-2 show superposition of all waterways comprizing the main channel and smaller one which join the main after taking off.

It is seen from these figures that (1) the Jamuna River is a typically braided one, (2) the river is almost stable at the proposed four sites compared with the other reaches, and (3) the width of the

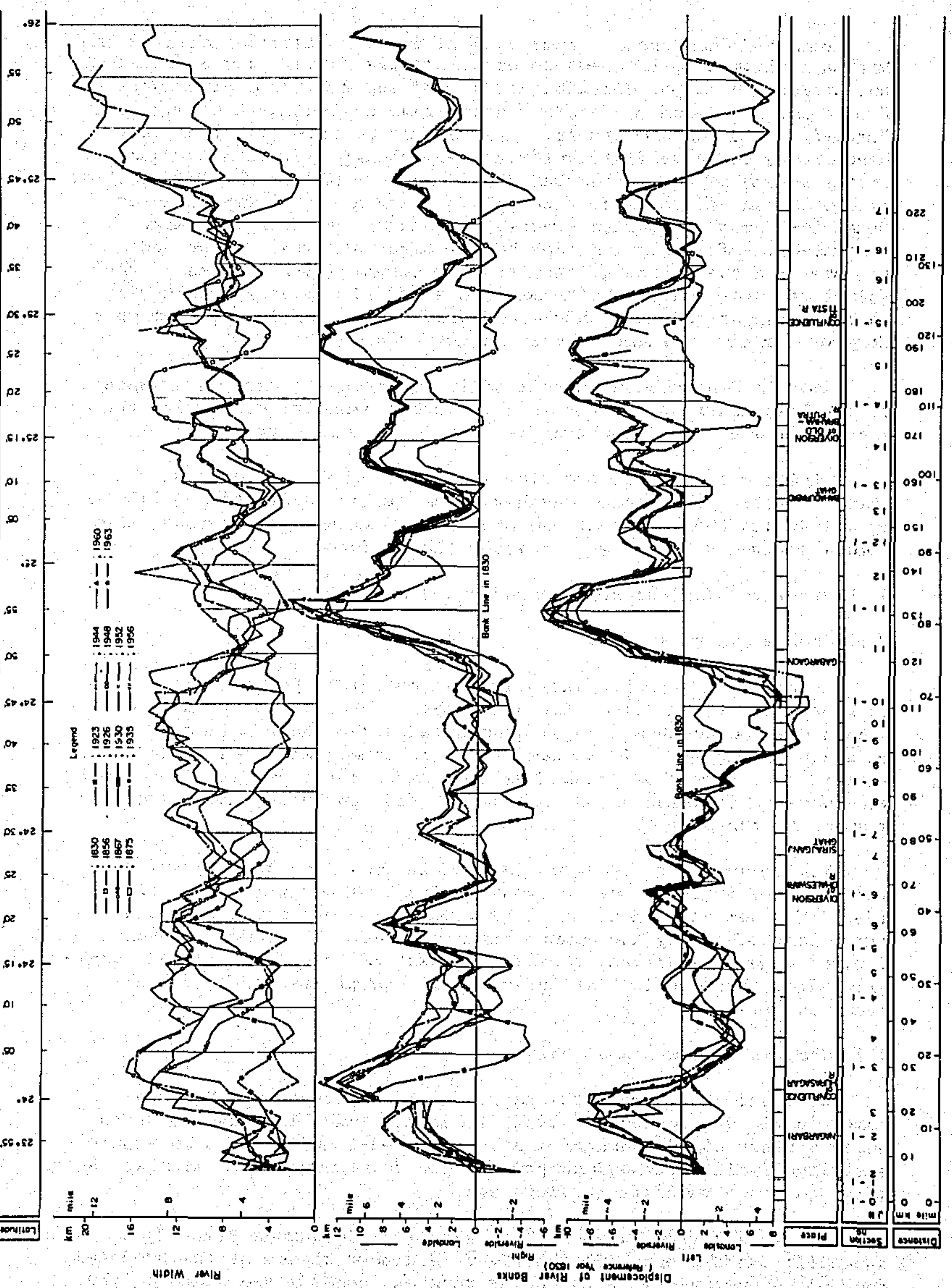


Fig.2-8 Displacement of River Banks

Fig. 2-9-1 Change in Waterways

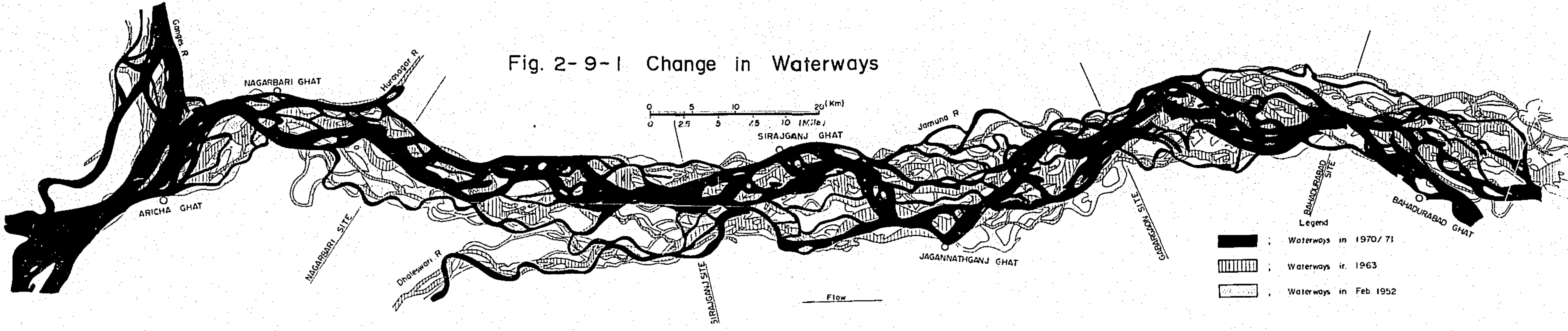


Fig. 2-9-2 Change in Waterways

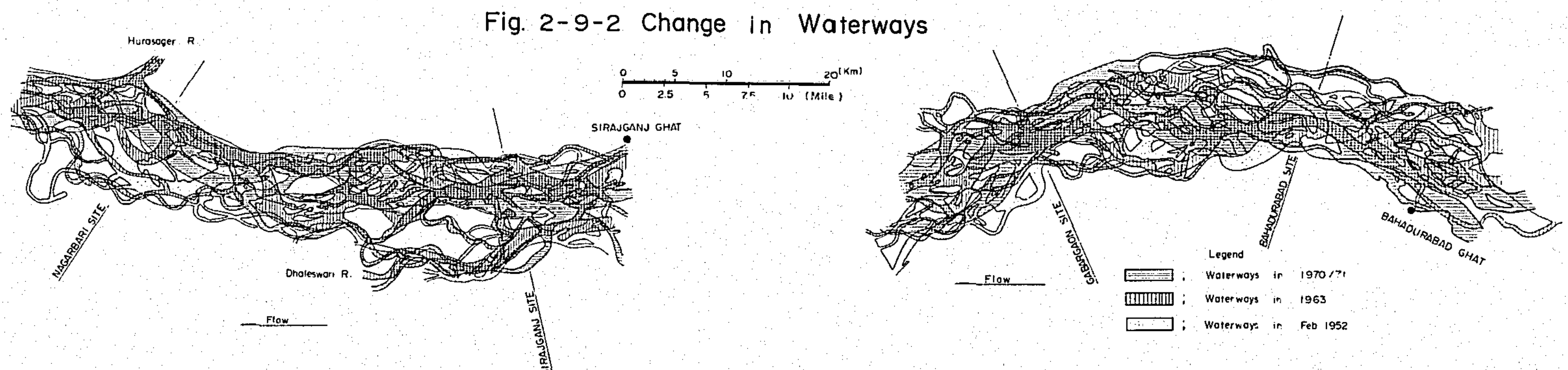


Table 2-1 Cross Section Surveyings on Jamuna River

Sect.No.	1965	65-66	66-67	67-68	68-69	69-70	70-71	71-72	72-73
J#-0-1		MAY	NOV	MAR	MAY	NOV		FEB	DEC
1	FEB	DEC	NOV	MAR	MAY	NOV		FEB	DEC
1-1		DEC	NOV	MAR	MAY	NOV		FEB	DEC
2	MAR	DEC	NOV	FEB	MAY	NOV			DEC
2-1		JAN	NOV	FEB	APR	NOV		MAR	DEC
3	MAR	FEB	NOV	FEB	APR	DEC		MAR	NOV
3-1		FEB	NOV	MAY	APR	DEC		MAR	
4	MAR	MAY	APR	APR	FEB	JAN		MAR	
4-1		MAY	APR	FEB	FEB				
5	MAR	MAR	FEB	FEB	FEB	FEB		MAY	MAY
5-1		FEB	FEB	JAN	FEB	FEB		MAY	
6	APR	FEB	JAN	DEC	JAN	MAR		MAY	
6-1		JAN	DEC	DEC	NOV	MAR		APR	
7	MAR	JAN	NOV	NOV	NOV	APR		APR	
7-1		JAN	NOV	NOV	MAY	APR		APR	
8	APR	DEC	FEB		MAY	JUNE		MAY	DEC
8-1		DEC	FEB	FEB	MAY	MAY		MAY	JAN
9	APR	NOV	JAN	JAN	MAY	MAY		MAY	JAN
9-1		DEC	JAN	JAN	MAY	MAY		APR	
10	APR	NOV	FEB	JAN	APR	MAY		APR	
10-1		MAR	JAN	DEC	APR	MAY		APR	
11	JAN	MAY	FEB	DEC	APR	MAY		APR	
11-1		FEB	JAN	DEC	MAR	MAY		MAY	
12	MAY	OCT	JAN	DEC	MAR	MAY		MAY	
12-1		JAN	DEC	MAR	FEB				
13	APR	JAN	DEC	MAY	FEB	MAY			
13-1		JAN	DEC	MAR	FEB	JAN			
14	MAY	DEC	DEC	FEB	JAN	APR		MAR	
14-1		JAN	DEC	JAN	JAN	MAR		APR	
15	MAY	DEC	DEC	JAN	JAN	MAR		MAY	
15-1		DEC	NOV	DEC	DEC	MAR			
16	MAY	OCT	NOV	NOV	DEC	NOV		FEB	
16-1	MAY	NOV	NOV	DEC	NOV			MAR	
17	MAY	NOV	NOV	NOV	NOV			APR	
Total	18	34	34	33	34	30	0	28	10

main stream in the dry season is roughly 2 km (1.2 mi).

3.3. Changes in cross sections.

The cross-leveling surveys were carried out by BWDB periodically at the cross sections shown in Fig.2-10 at intervals of about 8 miles with supplement ones between them. The section numbers and the surveying dates of the cross sections collected by us are shown in Table 2-1. Out of these, the cross sections in 1965/66, 1966/67, 1967/68, 1968/69, 1969/70, and 1971/72 were selected for our study.

Fig.2-11 shows longitudinal variations along the river course, from the confluence with the Ganges River, Section J# 0-1, to the upstream of the confluence of the Tista River, Section J# 17, of (1) mean ground surface, (2) deepest river bed, (3) maximum water depth below the ground surface, (4) hydraulic mean depth below the ground surface, (5) ratio of mximum water depth to hydraulic mean depth, (6) river width at ground level and (7) cross sectional area below the ground surface.

It is seen from these figures that (1) the slope of the land is almost 1/13000 along the rivef course except 1/20,000 on the lowest stretch of 9 km, (2) the deepest river bed is almost parallel to the ground surface, namely, the maximum water depth is almost constant, about 15 m (49 ft) on the whole stretch of the river though there is a tendency of slight increasing downwards, (3) the hydraulic mean depth is almost constant, 5 m (16 ft) on the whole stretch, (4) the river width and the cross-sectional area below the ground level has a tendency to increase upstream with quite large variations.

Next, selecting the section J# 3-1 as a representative one at Nagarbari site, the section J# 6 at Sirajganj site, J# 11-1 at Gabargaon site and J# 13 at Bahadurabad site, cross sections surveyed in 1965/66, 1967/68, 1969/70 and 1971/72 were superposed at each of the four sites. This comparison is shown in Figs. 2-12-1 to 2-12-4.

It is found from these figures that changes in chars and thalwegs are quite remarkable and the location of the thalweg is not always fixed within a cross section.

4. Hydrological Features of the Jamuna River.

4.1. General aspect of water level.

River system around the Jamuna is shown in Fig. 2-13. BWDB has two systems of stream-gaging networks, one of which is controlled by Surface Water Section and the other by River Morphology, Research and Training Section. Major stations in the area surrounding the Jamuna are shown in Fig. 2-14 and availability of data at these stations are listed in Table 2-2. As seen in Table 2-2, data on water level over a relatively long period are available at Bahadurabad and Sirajganj Stations, while those on discharge are available at Bahadurabad Station.

Data on water level since 1964 have already been arranged by BWDB

Fig. 2-10 Location of River Section Survey

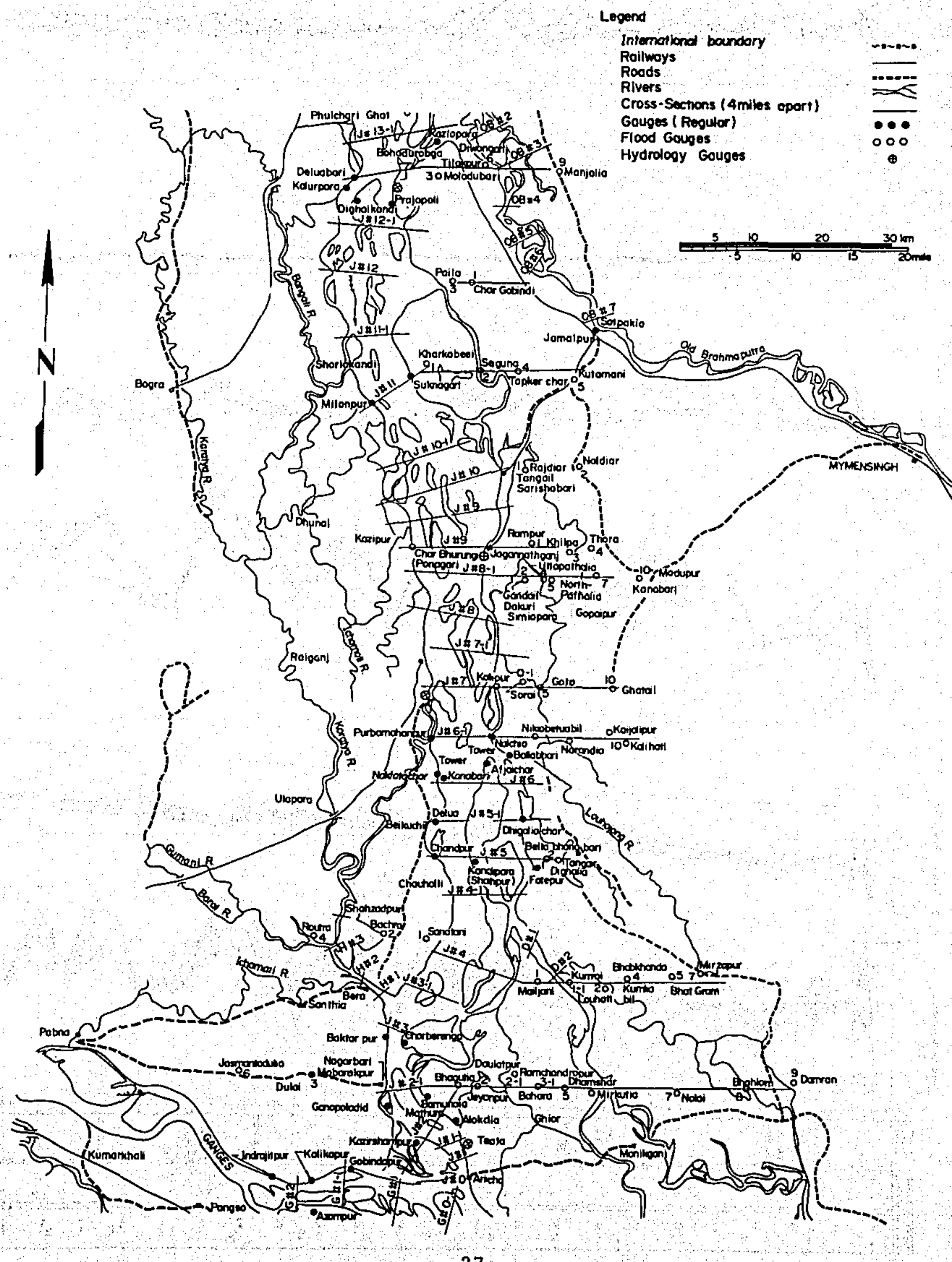


Fig. 2-11 Channel Features of the Jamuna River

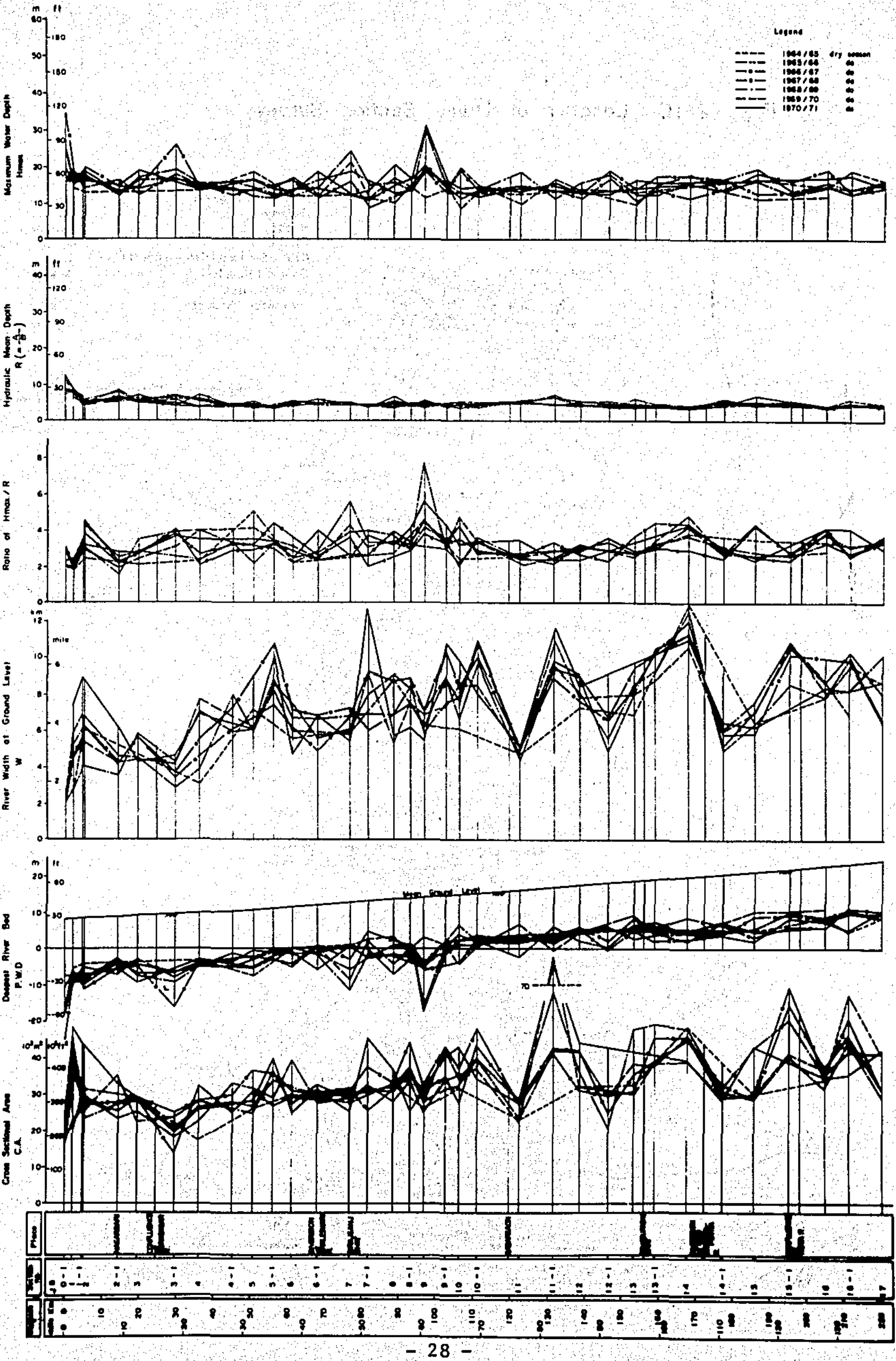


Fig. 2-12-1   Cross Section Near Nagarbari Site (J# 3-1)

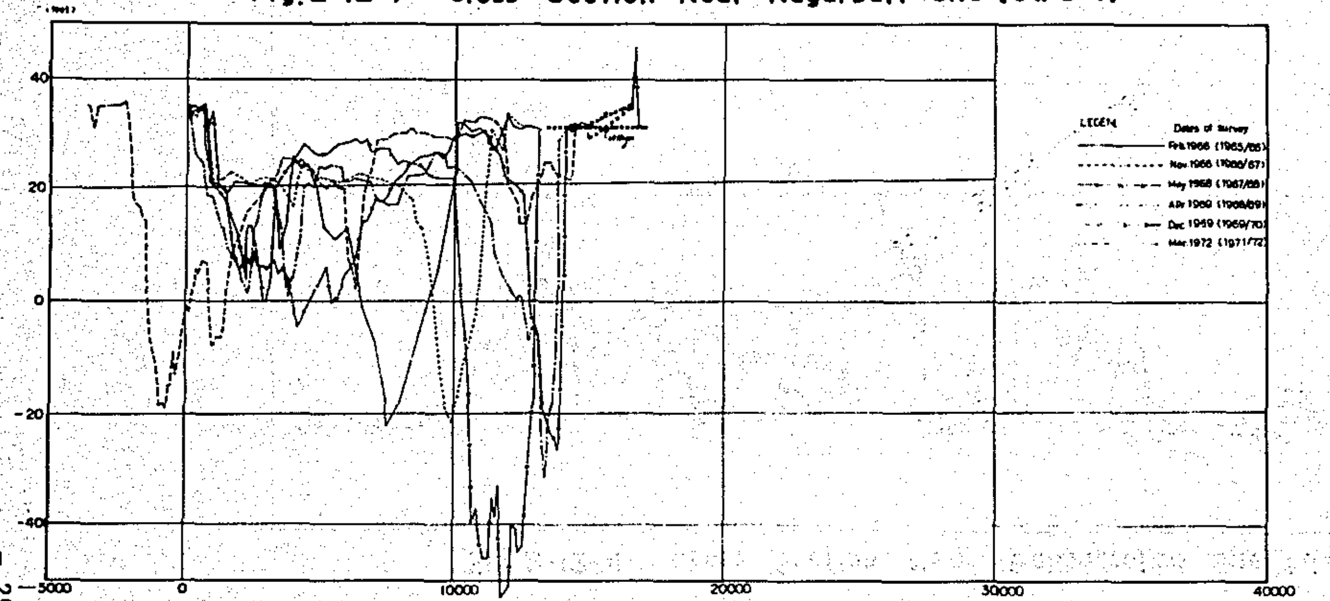


Fig. 2-12-2   Cross Section Near Sirajganj Site (J# 6)

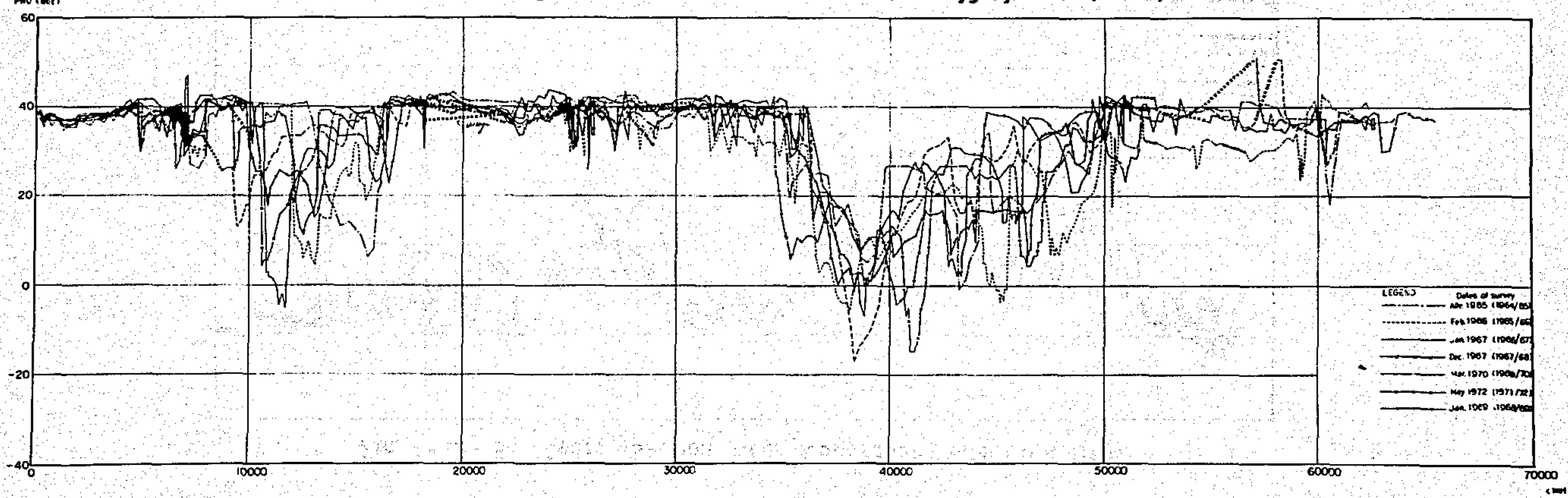


Fig. 2-12-3 Cross Section Near Gabargaon Site (J # 11-1)

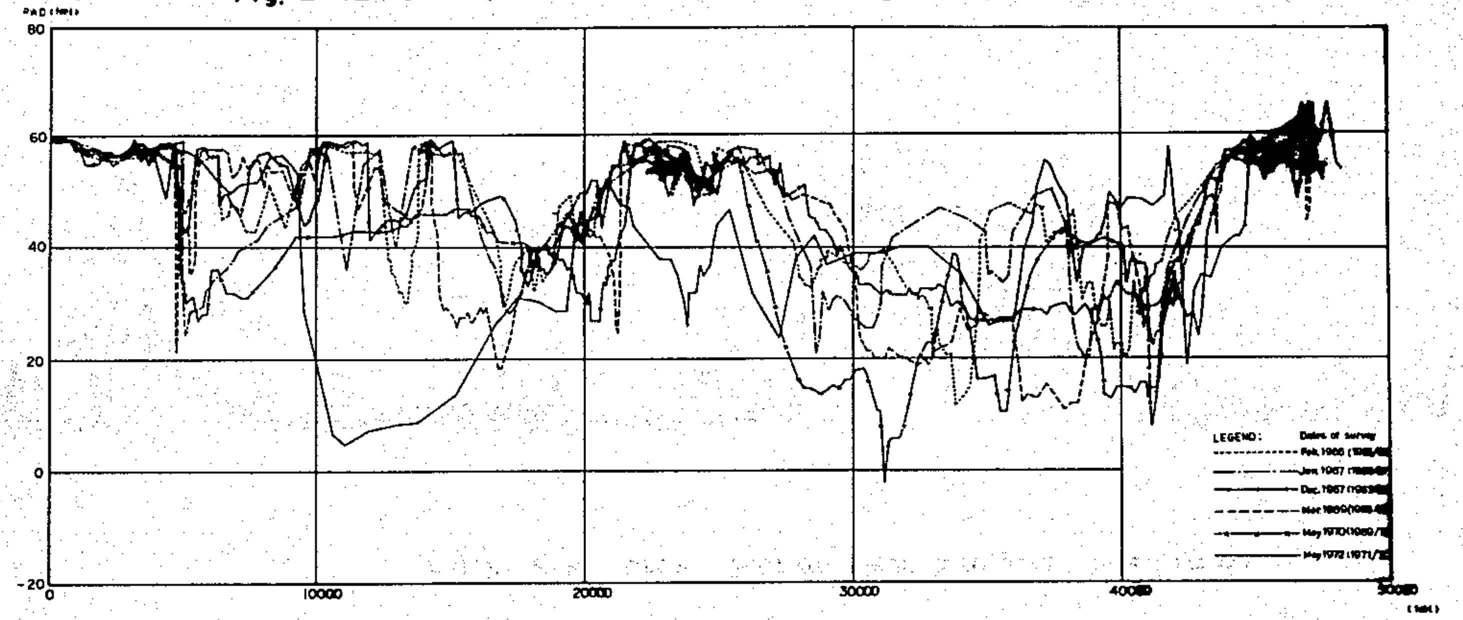


Fig. 2-12-4 Cross Section Near Bahadurabad Site (J # 13)

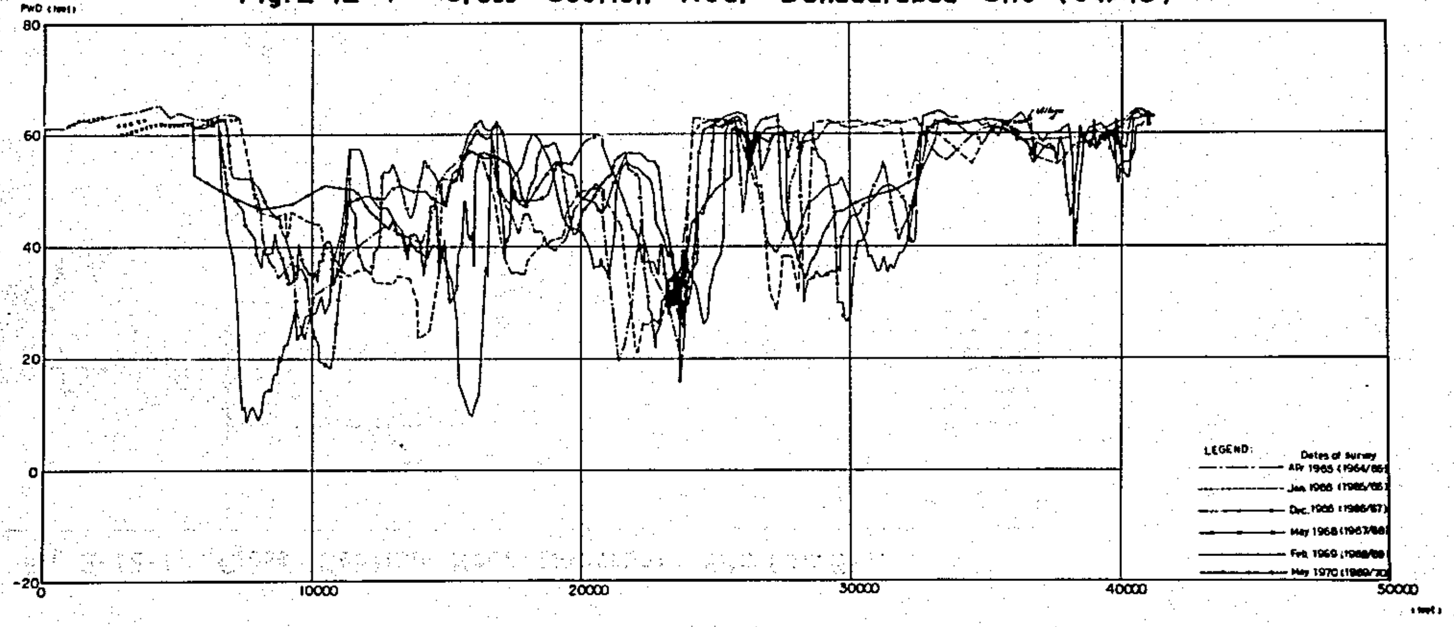


Fig. 2-13 River System Around the Jamuna River

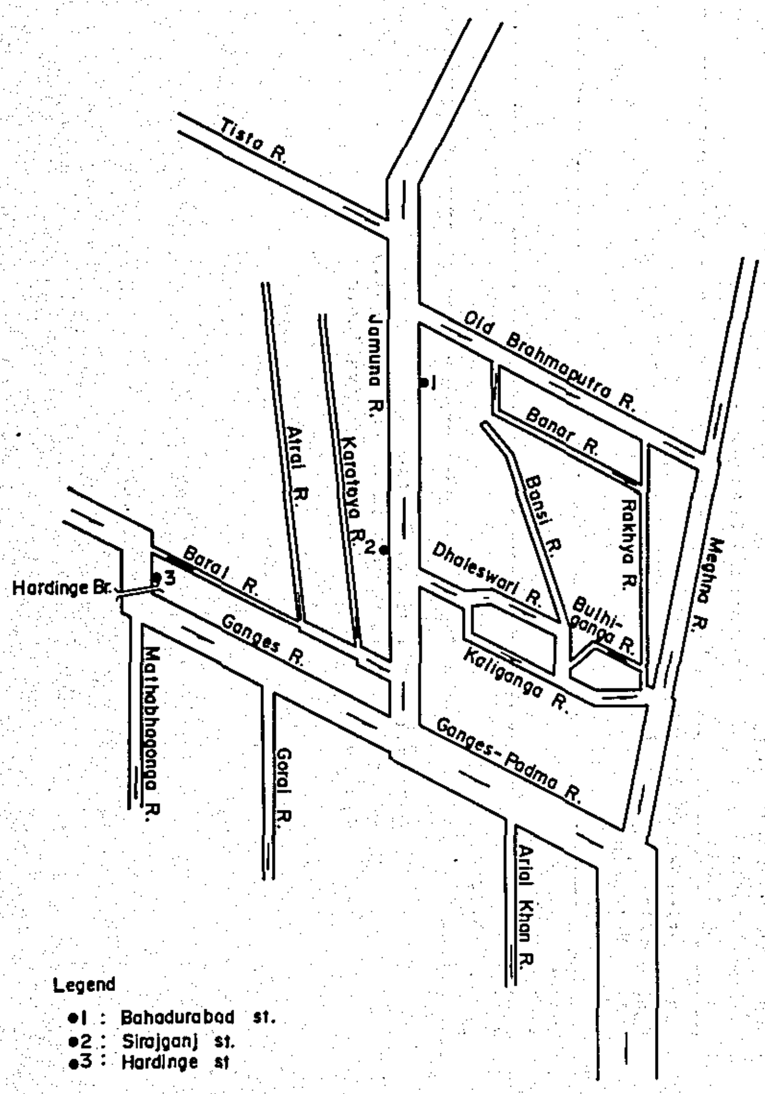


Fig. 2-14 Location of Gauging Stations

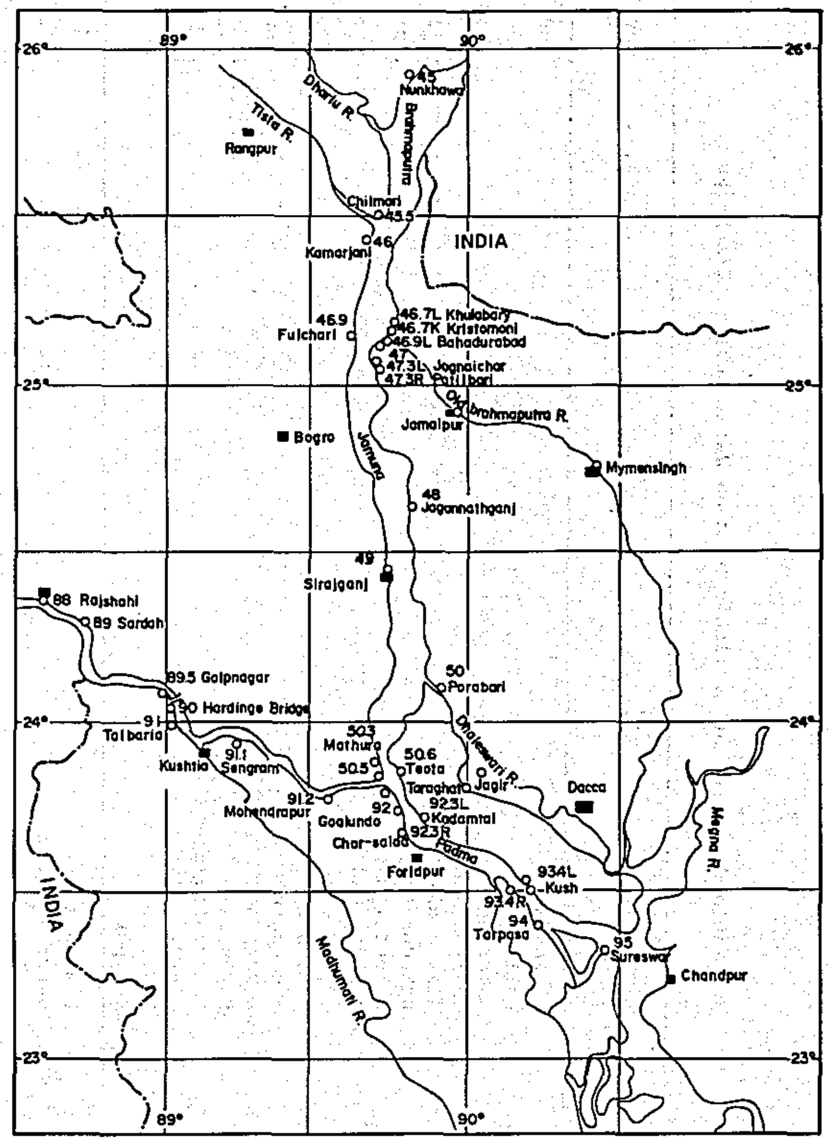


Table 2-2 List of Available Data on Water Level & Discharge

Item	River	Station	1957	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	Lack of Data
WATER LEVEL	JAMUNA	Nunkhawa	○	○	○	○	○	○	⊖	○	○	○	○	○	○				1957 Jan.-Apr.
		Chilmari	○	○	○	○	○	○	⊖	○	○	○	○	○	○				
		Kamarjani			○	○	○	○		○	○	○	○	○	○				
		Khulabary char							⊖	○	○	○	○	○	○				1963 Jan.-June
		Kristomoni char							⊖	○	○	○	○	○	○				1963 Jan.-June
		Bahadurabad tr.								○	○	○	○	○	○				1965 Apr.-July
		Fulcharighat								○	○	○	○	○	○				
		Bahadurabad From Jan.'49	○	○	○	○	○	○		○	○	○	○	○	○				Jan.-May '56, Feb '57
		Jognai char									○	○	○	○	○				1965 Jan.-Mar.
		Patilbari								○	○								
		Jagannathganj				○	○	○		○	○	○	○	○	○				1960 Jan.-Mar.
		Sirajganj From June'45	○	○	○	○	○	○	⊖	○	○	○	○	○	○				1960 2,3,4 Apr. '63 '64 Jan.-Mar.
		Porabari			○	○	○	○	⊖	○	○	○	○	○	○				
		Mathura(Nagarbari)							⊖	○	○	○	○	○	○				
		Alukdia char								○	○	○							
		Teota								○	○	○	○	○	○				
		Kazipur											○	○	○				
	GANGES	Urakanda								○	○	○		○	○				'67 '68 Apr.-Mar.
		Baruria tr.								○	○	○	○	○	○				"
		Goalundo								○	○	○	○	○	○				"
		Goalundo				○	○	⊖	○	○	○	○	○	○	○				
		Kadamtari								○	○	○	○	○	○				
		Char-Salda								○	○	○	○	○	○				
DISCHARGE	Jamuna	Bahadurabad	⊖	⊖	○	○	○	○			⊖	⊖	⊖	⊖					
		Sirajganj				○	○	○											
	Ganges	Hardinge br. From 1934	○	○	○	⊟	⊟	⊟	○		⊖	⊖	⊖	⊖					
		Baruria	Baruria & Goalundo were combined →								⊖	⊖		⊖					
		Goalundo										⊖		⊖					
	Old-Brahmaputra	Off-take of Banshi								○	○	○							1964 Jan.-Mar.
		Off-take of Sutia								○	○	○		○					1964-'68 Jan.-Mar.
		Mymensingh												○					1968 Jan.-Mar.
		Rly br.												○					"
	Dhaleswari	Jagir								○	○	○		○					1964 & '68 Jan.-Mar.
	Kaliganga	Taraghat								○	○	○		○					1964 & '68 Jan.-Mar. / 1965 Feb.-Mar.

○ : daily data are available
⊖ : max. & min. values in a year are available
⊟ : only annual max. values are available

in every Water Year begining in April and ending in the next March, which were also used in the present study.

To clarify whether water level is affected by variation of river bed, annual variation of water level of several kinds of frequency was studied using the data obtained at Bahadurabad, Sirajganj and Kadamtali Stations in the latest five years from 1964/65 to 1968/69 and for the purpose of examining statistical longitudinal profile of water level of the Jamuna, water levels of the same frequency at Nunkhawa, Chilmari, Kamarjani, Bahadurabad, Jagannathganj, Sirajganj, Porabai, Mathura, Teota and Kadamtali Stations were selected and studied with respect to the year 1968/69. The results are shown in Figs. 2-15 and 2-16.

With regard to annual minimum water levels at Bahadurabad St., they seem to have a trend of gradual rising. If there is a similar trend with respect to large discharges, reliability will be decreased in using the rating curve when we estimate large discharges using high water levels actually measured. Fig. 2-17 shows the variation of water levels corresponding to several kinds of discharges which were estimated using rating curves drawn based on water-level and discharge records from 1956 and 1968. This figure indicates that water levels in larger discharges do not seem to have a trend of rising but be constant though they scatter within about 3 ft and, on the other hand, water levels in smaller discharges seem to have a rising trend. Judging from these facts and aerophoto mosaics, one of the important causes of rising trend of low water level can be sought in expanding of river width or braiding of river channels at Bahadurabad St. According to the aerophoto mosaics, river width including chars at this station varies from about 5 km in 1952 to 10 km in 1970 and number of major stream channels varies from 2 in 1952 to 6 in 1970. It can be said from these facts that the relationship between large discharges and high water levels is fairly in a stable state notwithstanding the condition of river channel is being changed.

4.2. Discharges at Bahadurabad.

It is supposed that the daily discharges given in Water Supply Paper and Hydrological Year Book were computed using observed water level and the rating curves which were prepared every year by using data on stream gagings frequently made in a year. However, paying attention to the discharges actually measured at Bahadurabad Station during the period from 1956 to 1962, relationship between water level and discharge was examined, which is shown in Fig. 2-18. This figure indicates that the relationship between them is fairly stable, notwithstanding the conditions of river channel were largely varied.

Data on annual maximum discharges at Bahadurabad are available for the fifteen years from 1956 to 1970, whereas water level at Bahadurabad has alraddy been measured since November 1949. It is, therefore, very favorable for the analysis of return period if we can supplement the data mentioned above by those on water levels and the rating curve for the period from 1950 to 1955.

Fig. 2-15 Time Variation of Water Level (1964/65 ~ 1968/69)

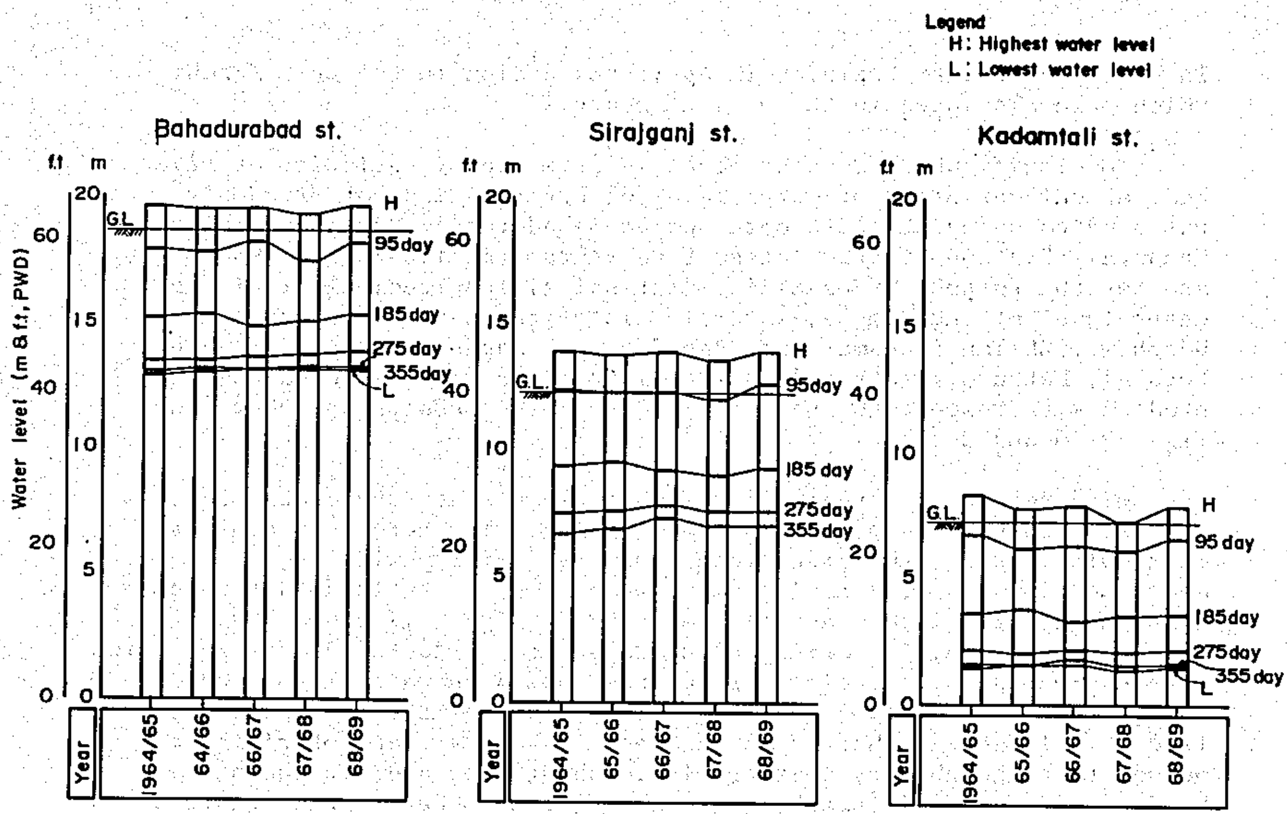


Fig. 2-16 Longitudinal Profile of Water Level of the Same Frequency in 1968/69

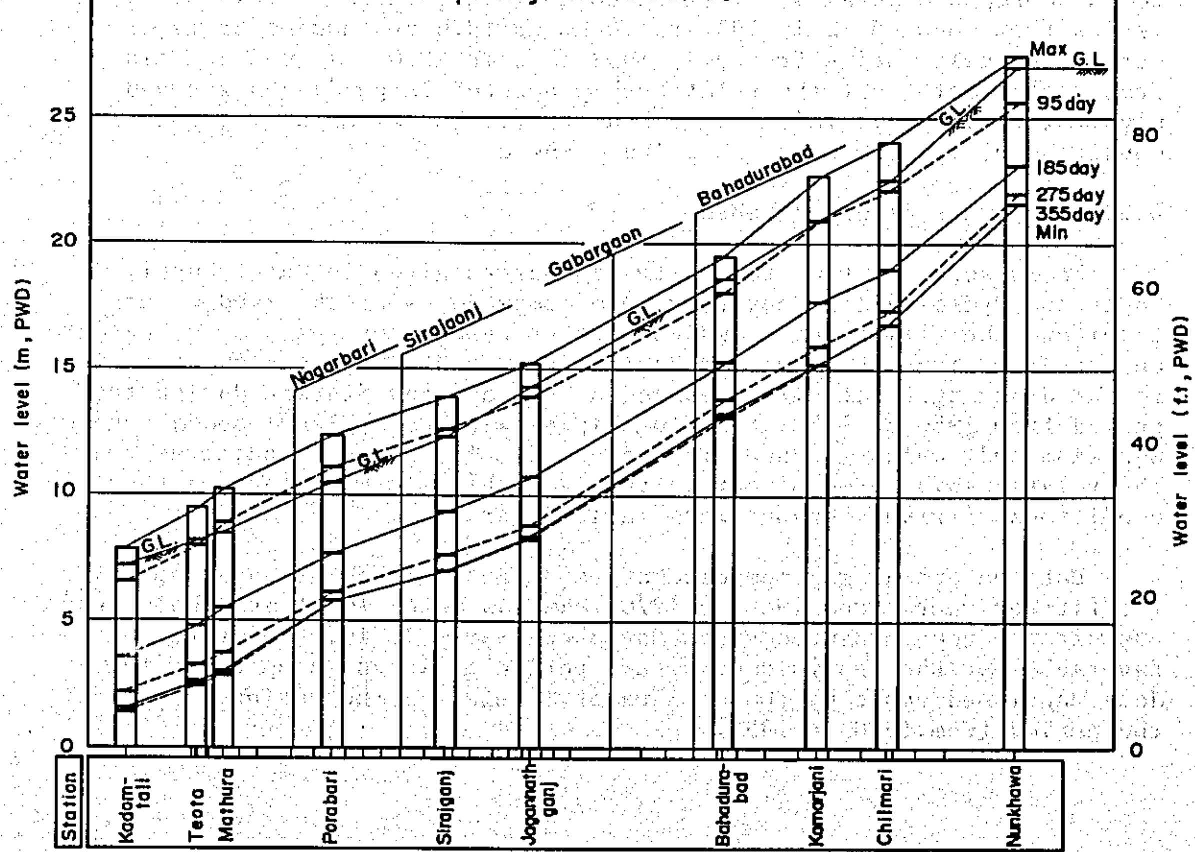


Fig. 2-17 Variation of Water Level

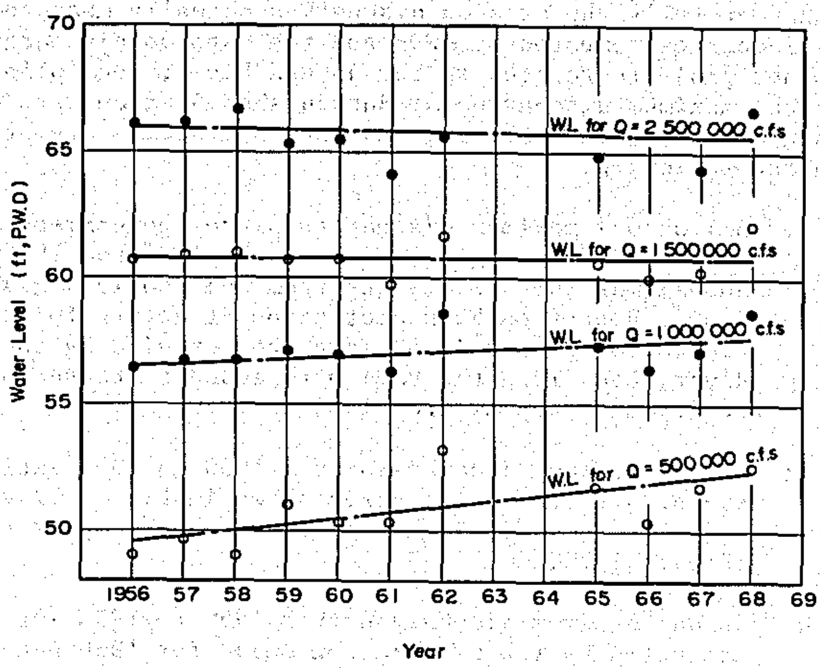
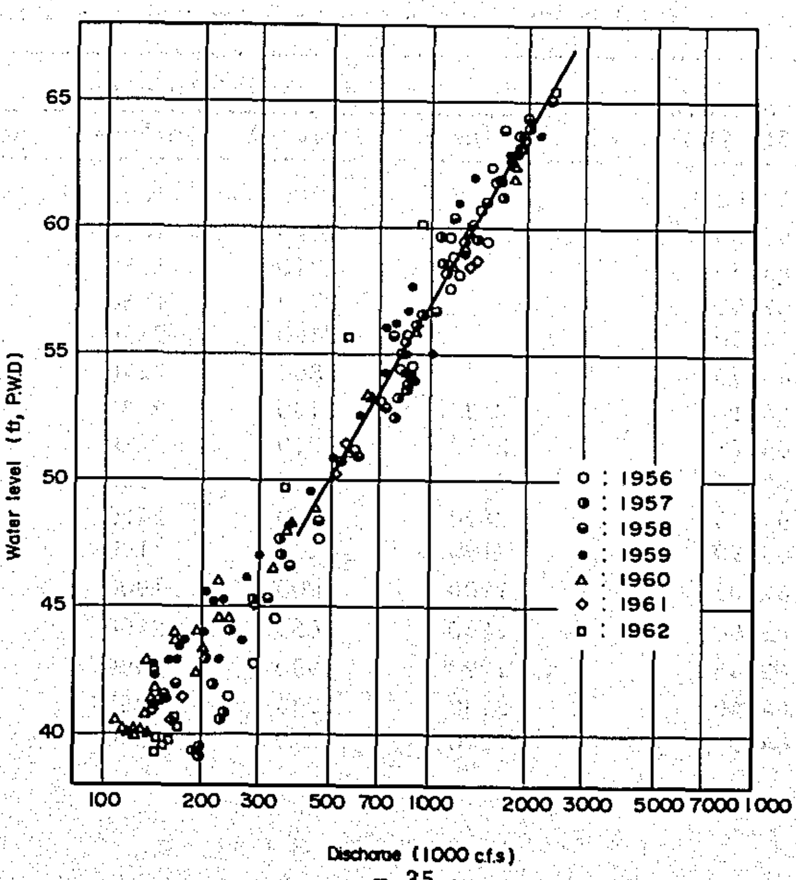


Fig. 2-18 Stage Discharge Relation
(Bahadurabad on Jamuna River)



Examining carefully the data on discharges actually measured by BWDB, the data on discharges computed by BWDB and the data on discharges studied in several other projects related to the Jamuna River, the following four series of annual maximum discharges at Bahadurabad Station were obtained. Numerical data are shown in Table 2-3 and the four series are briefly described in the following.

(a) Series 1: All annual maximum discharges since the commencement of stream-flow gaging; Fifteen samples from 1956 to 1970.

(b) Series 2: Annual maximum discharges from 1950 to 1955 given in Design Report on Bank Protection Structure for the Protection of Sirajganj Town from Erosion by the Jamuna River, Dec. 1970 (32 PJT) were added to those in Series 1; twenty-one samplew from 1950 to 1970.

(c) Series 3: Annual maximum discharges from 1950 to 1955 estimated by the average rating curve shown in Fig. 2-17 were added to those in Series 1; twenty-one samples from 1950 to 1970.

(d) Series 4: Annual maximum discharges from 1950 to 1955 were estimated by the BWDB rating curve for 1966 because the correlation between annual maximum discharges and water levels from 1956 to 1970 is almost in good accord with the above rating curve, and these data were added to those of Series 1; twenty-one samples from 1950 to 1970.

Table 2-3 Annual Maximum Discharges at Bahadurabad Station

Date	Water level (ft, PWD)	Discharge (10^3cfs)			
		Series-1	Series-2	Series-3	Series-4
50. 7.20	62.02		1730	1680	1870
51. 7.19	62.80		2020	1800	2050
52. 7.15	63.55		2310	1950	2230
53. 7.31	62.00		1730	1680	1890
54. 7.31	64.50		2660	2140	2450
55. 8. 1	64.95		2800	2240	2600
56. 6.24	64.18	2130	2130	2130	2130
57. 8.12	64.78	2210	2210	2210	2210
58. 8.18	65.65	2520	2520	2520	2520
59. 6.26	64.15	2420	2420	2420	2420
60. 9.18	63.90	2190	2190	2190	2190
61. 7.19	62.03	1900	1900	1900	1900
62. 8.23	65.60	2460	2460	2460	2460
63. 7.16	63.43	1990	1990	1990	1990
64. 8. 4	64.40	2230	2230	2230	2230
65. 8.15	64.00	2270	2270	2270	2270

66. 8.31	64.05	2430	2430	2430	2430
67. 7.12	63.43	2460	2460	2460	2460
68. 7.25	64.22	2200	2200	2200	2200
69. 7.23	64.65	1980	1980	1980	1980
70. 7.28	65.20	2700	2700	2700	2700

Computation of return period was made by Thomas' plotting for the above four series, the results of which are shown in Fig. 2-19 and Table 2-4.

Since there is nothing to choose among these four series from the viewpoint of number of samples and reliability of estimation, mean values of them were taken as the return periods at Bahadurabad Station, which are shown in Fig. 2-20.

Table 2-4 Return Period of Discharge at Bahadurabad

(by Thomas method)

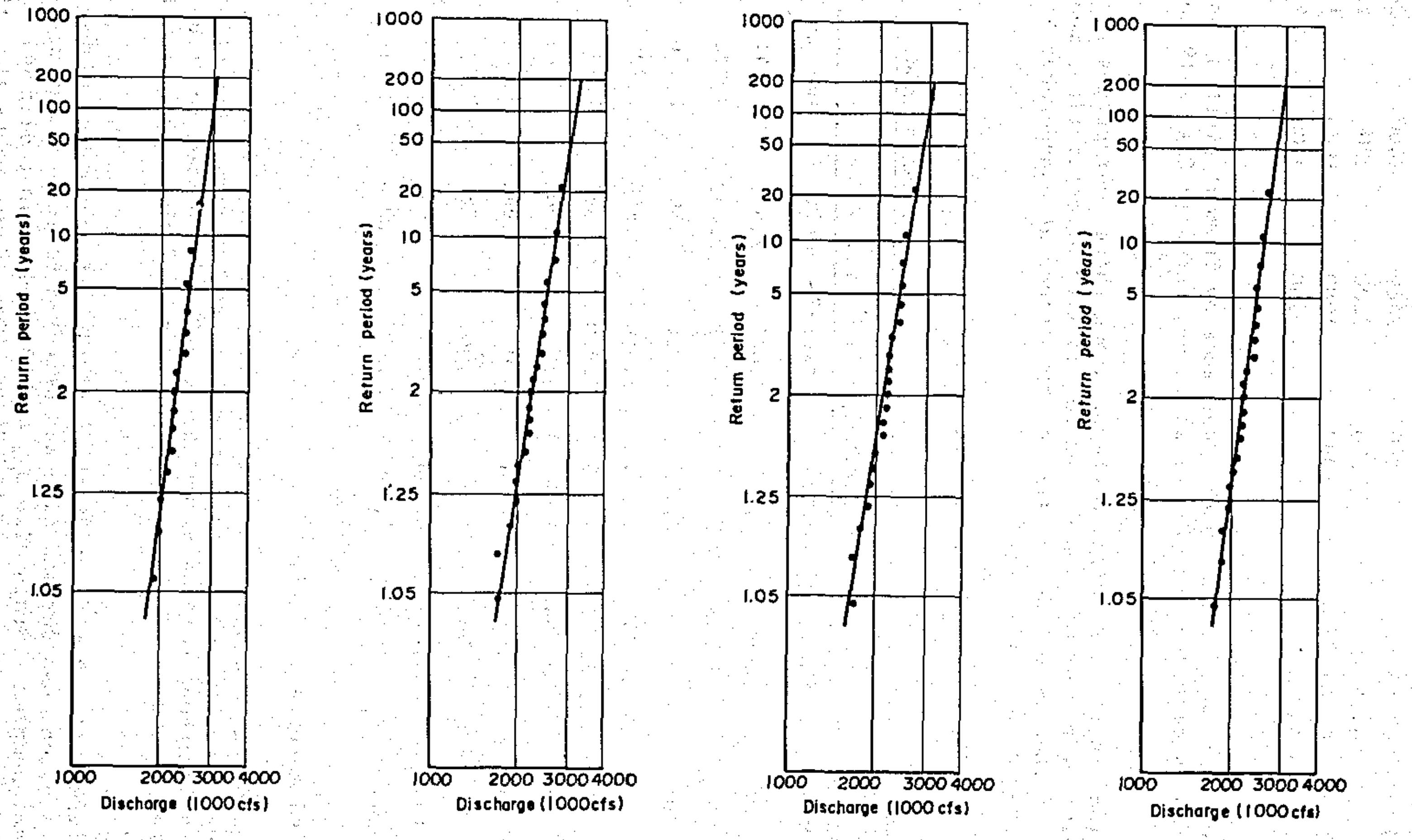
Return period (year)	Discharge (10^3 cfs)				
	Series-1	Series-2	Series-3	Series-4	Average
10	2,624	2,717	2,604	2,618	2,641
20	2,738	2,871	2,748	2,739	2,774
30	2,798	2,955	2,826	2,804	2,846
40	2,840	3,013	2,880	2,848	2,895
50	2,871	3,056	2,920	2,881	2,932
60	2,896	3,091	2,952	2,908	2,962
80	2,934	3,114	3,002	2,949	3,007
100	2,963	3,185	3,041	2,980	3,042
150	3,014	3,258	3,108	3,036	3,104
200	3,050	3,309	3,155	3,074	3,147

4.3. Bed materials.

Samplings and analysises of bed materials have been made by BWDB at many locations on the major rivers in the country. Out of these, we selected sixteen stations shown in Fig.2-21 with a view to studying the features of bed materials on both the rivers of the Jamuna and the Padma.

First, in order to study the variation of grain size within a cross section, Bahadurabad site was selected because of having relatively abundant samples. Grain size D_{65} was plotted against distance from the left bank, which is shown in Fig.2-22. This figure shows that the grain size is almost constant on the same cross section.

Fig. 2-19 Return Period of Discharge at Bahadurabad



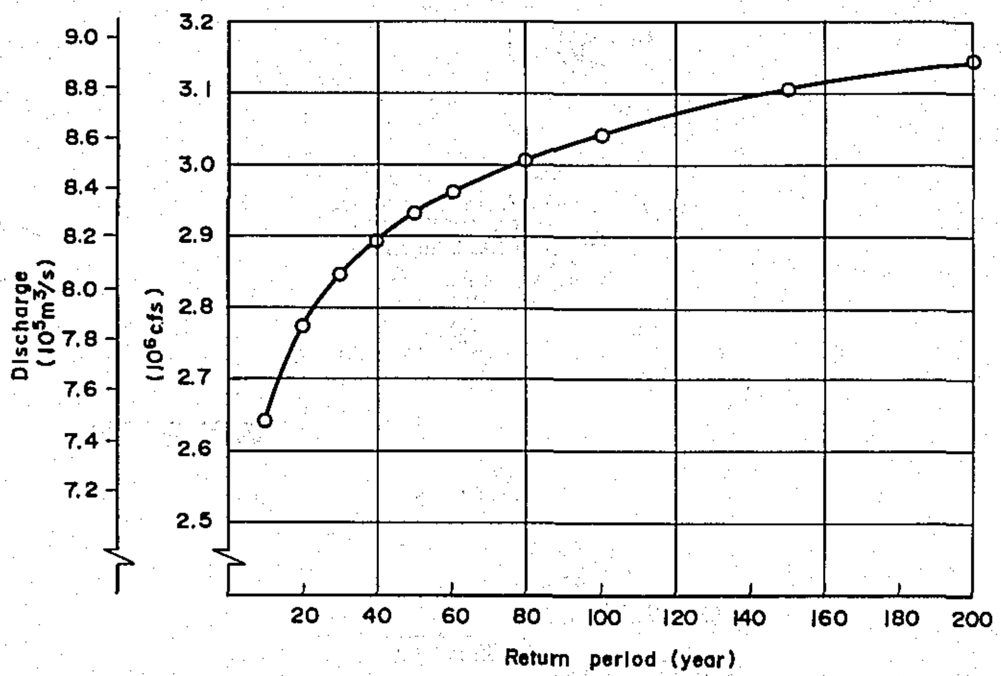
Series-1 Data from 1956 to 1970 n = 15

Series-2 : Adding the data used in Sirajganj town protection report n = 21

Series 3 : Average rating curve from 1956 to 1962 was applied for the estimation of discharge from 1950 to 1955 n = 21

Series 4 : Rating curve for 1966 prepared was applied for estimation of discharges from 1950 to 1955 n = 21

Fig. 2-20 Return Period of Discharge at Bahadurabad



Return period (year)	Discharge (10^3 cfs)	(10^3 m^3/s)	Remarks
10	2641	74.79	
20	2774	78.56	
30	2846	80.60	
40	2895	81.99	
50	2932	83.04	
60	2962	83.89	
80	3007	85.16	
100	3042	86.15	
150	3104	87.91	
200	3147	89.12	

Fig. 2-21 Location of Sampling of Bed Materials

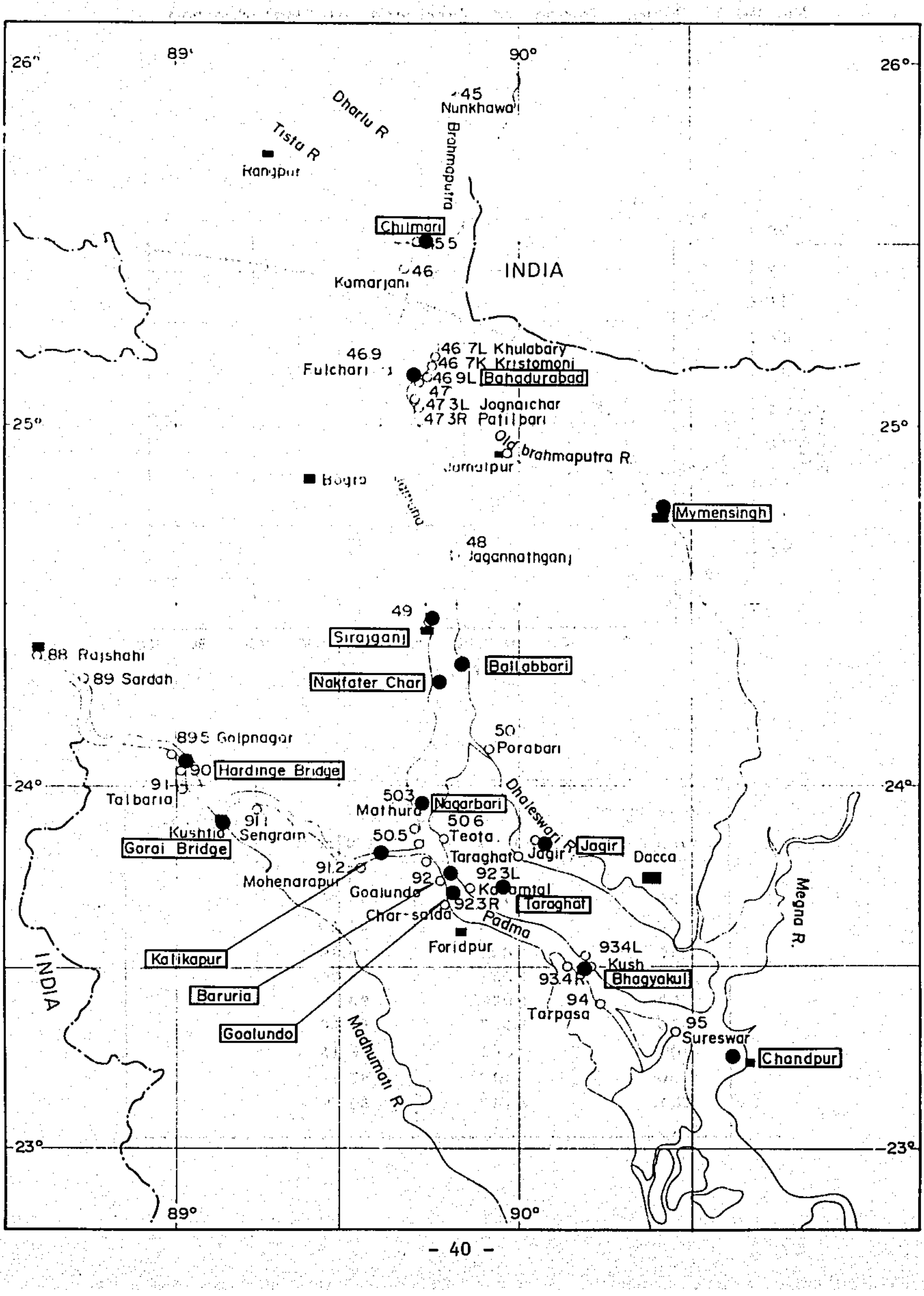


Fig. 2-22 Cross Sectional Variation of D_{65}

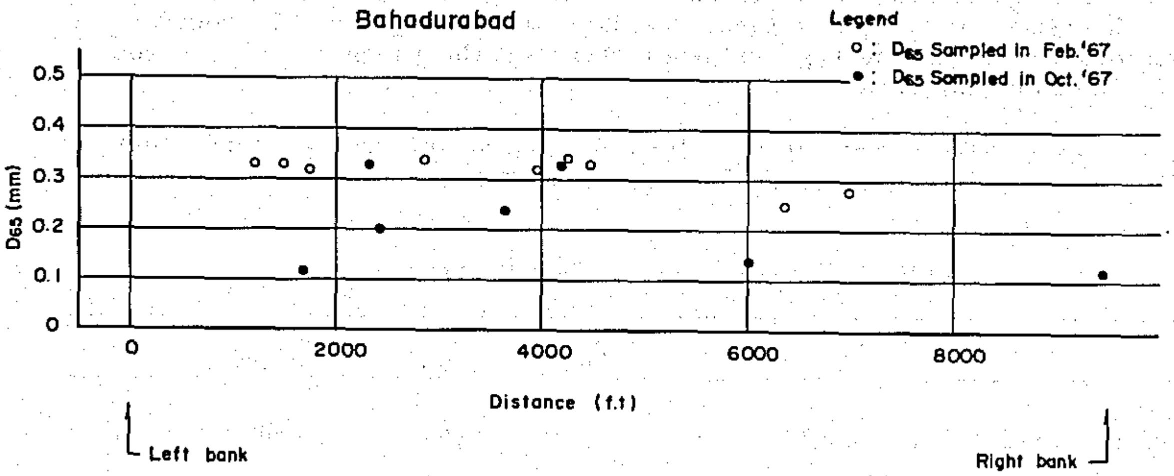
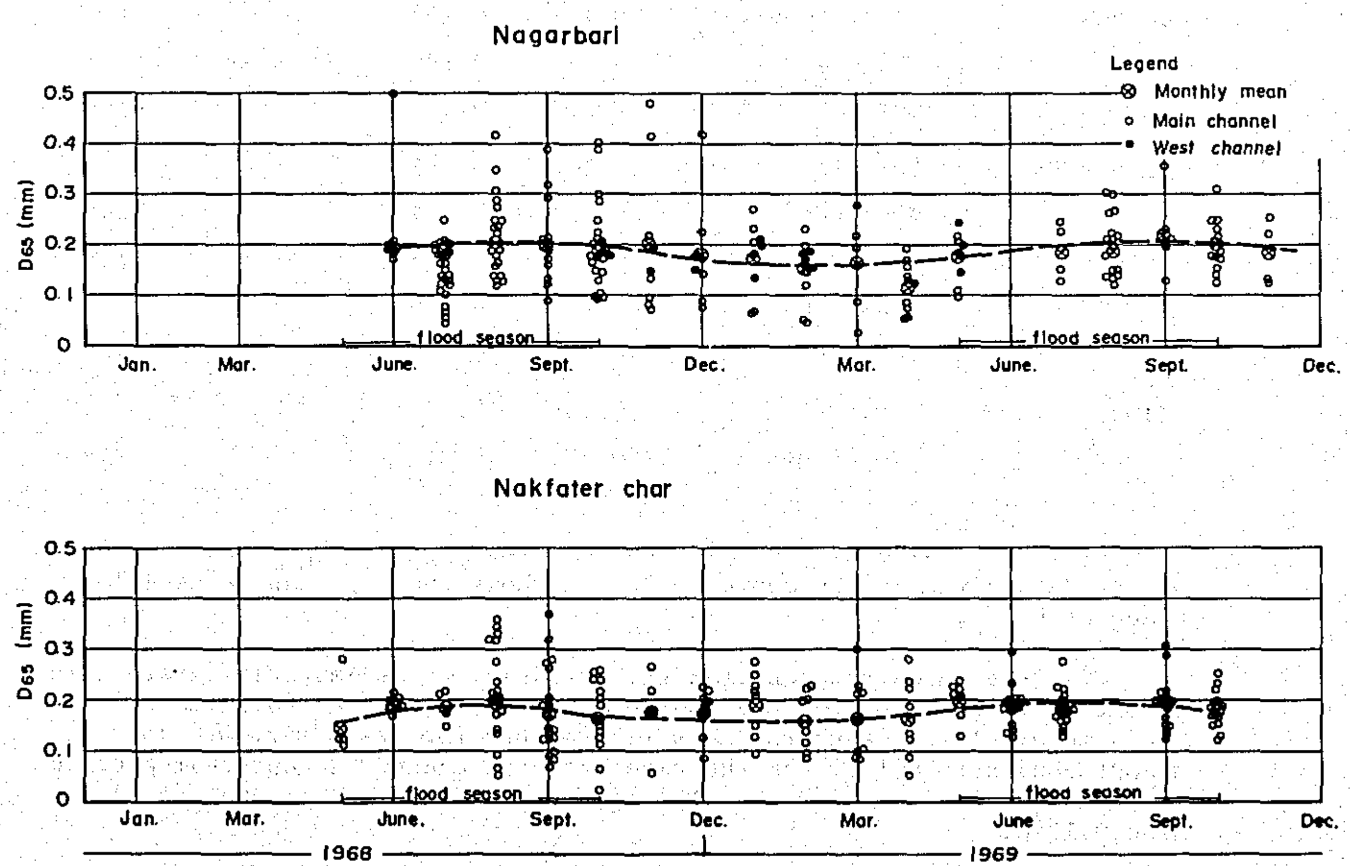


Fig. 2-23 Seasonal Variation of D_{65}



Next, in order to study the seasonal variation of grain size, two sites of Nakfater char and Nagarbari were selected because of availability of data. Grain size D_{65} was plotted against months in the years of 1968 and 1969, which is shown in Fig.2-23. According to this figure, grain size of bed material seems to have a tendency to become slightly larger in the flood season and slightly smaller in the dry season. However, we decided to use the average value of them for the present study because of scattering of data.

The average values of D_{65}, D_{60}, D_{mean} and uniformity coefficient U.C. at the sixteen locations are given in Table 2-5.

Table 2-5 Grain Size of Bed Materials

	Place	D_{65}	D_{60}	D_{mean}	U.C
Brahmaputra -Jamuna	Chilmari	0.266	0.249	0.261	1.9
	Bahadurabad	0.270	0.259		1.8
	Sirajganj	0.171	0.149	0.172	1.9
	Ballabbari	0.166	0.161	0.162	2.0
	Nakfater Char	0.186	0.174	0.176	1.8
	Nagarbari	0.181	0.172	0.176	2.0
Ganges	Hardinge Br.	0.181	0.163		4.6
	Kalikapur	0.134	0.126	0.131	2.1
	Gorai	0.193	0.187		1.8
Ganges-Padma	Baruria	0.164	0.153		2.6
	Goalundo	0.153	0.144		2.5
	Taraghat	0.139	0.129		1.8
	Bhagyakul	0.187	0.175		2.1
	Chandpur	0.180	0.129		1.9
Other river	Jagir	0.165	0.162		2.2
	Mymensingh	0.222	0.210		2.6

Fig.2-24 indicates the relation between D_{mean} and D_{60}, D_{65} presented by the data given in the above table and shows that D_{65} can be used in place of D_{mean}.

Fig.2-25 shows the longitudinal variation of bed-material grain size on the river stretch from Chandpur on the Padma upstream to Chilmari on the Jamuna. It is seen from this figure that the grain size D_{65} is almost constant, 0.17mm, on the river stretch except the upstream portion from Bahadurabad to Chilmari. The mean value of D_{65} on the Ganges is also 0.17mm.

Fig. 2-24 Relation between Grain Sizes

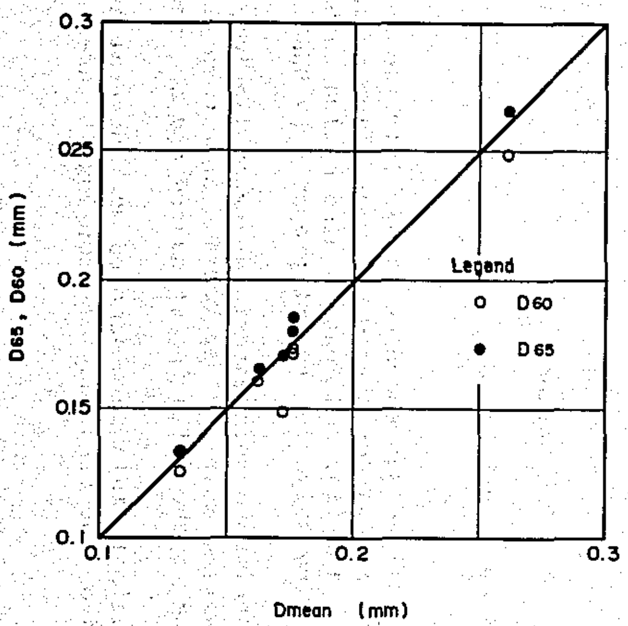
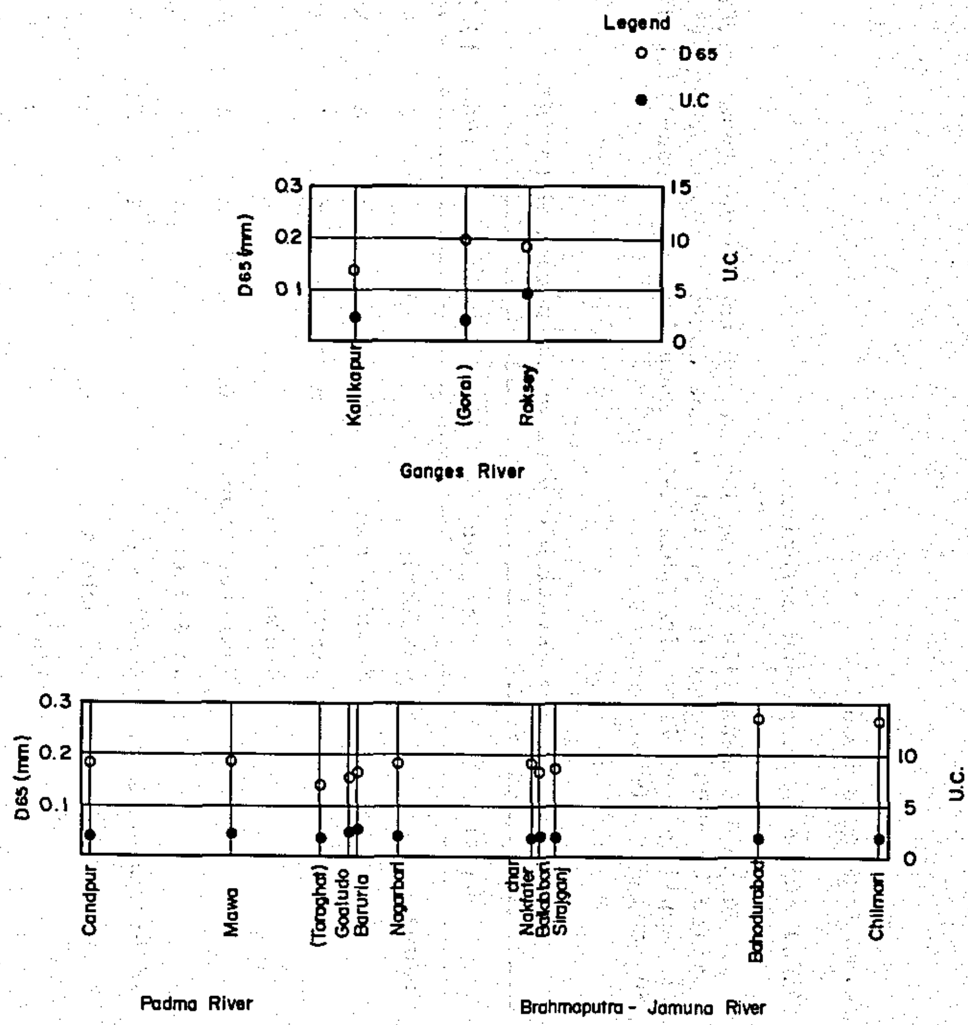


Fig. 2-25 Longitudiral Variation of Bed Materials (D_{65}, Uniformity Coefficient)



4.4. Suspended load.

4.4.1. Data on suspended materials.

Suspended materials of the Jamuna and the Ganges-Padma Rivers were sampled by BWDB except the period of low water. Years and stations of sampling are listed in Table 2-6. Samplings were made with Binkley Suspended Sediment Sampler.

Table 2-6 Available Data on Suspended Materials

River	Station	1965	1966	1967	1968	1969	1970
Jamuna R.	Chilmari		A	A	A	A	
	Bahadurabad		A	A	A	A	A
	Sirajganj	A	A	A	A	A	
	Radhunibari			A			
	Nakfater Char	A	A	A	A	A	
	Nagarbari			A	A	A	A
Old Brahmaputra R.	Mymensingh		A	A	A	A	A
Dhaleswari R.	Ballabbari	A		A	A	A	
	Jagir			A	A	A	A
	Taraghat			A	A	A	A
Ganges R. &	Hardinge Br.		A	A	A	A	A
Ganges-Padma R.	Kalikapur				A	A	A
	Baruria				A	A	A
	Goalundo		A	A	A	A	A
	Bhagyakul		A	A	A	A	A
Gorai R.	Gorai Br.		A	A	A	A	A
	Kamarkhari			A	A	A	A

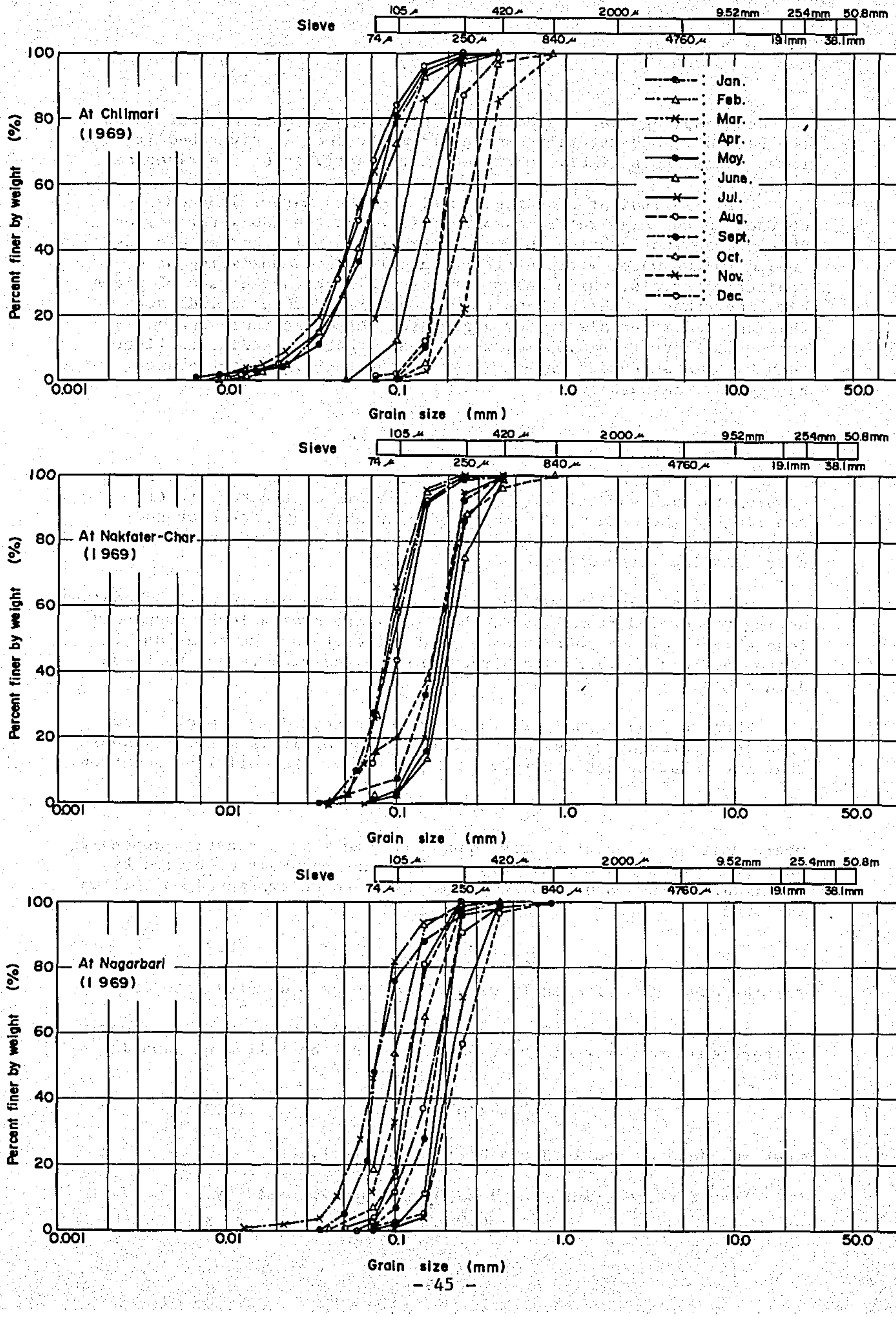
Note: A means available.

BWDB classified suspended materials into two categories, coarse sediment which is coarser than 0.05 mm and fine sediment which is finer than 0.05 mm. The fine sediment is also called wash load in the sediment-load investigation report prepared by BWDB.

Grading curves of bed materials are available at three sites of Chilmari, Nakfater Char and Nagarbari. Some were extracted out of them according to the following standards and are shown in Fig.2-26.

a. In case bed materials were sampled over several days in a month, data obtained on the first day of sampling is taken.

Fig. 2-26 Grading Curves of Bed Materials
(Jamuna River : 1969)



b. When samplings were made at several points in a river section on the same day, bed material sampled from the deepest river bed is taken since it is likely to represent the activity of the river bed.

Fig.2-26 indicates that grain size of bed material becomes coarser in the high-water season and finer in the low-water season. This means, that, during the low-water season, finer materials suspended in the water will settle on the river bed consisting of coarser materials, which makes the materials on the surface of river bed finer than in the high-water season. Fig.2-26 also indicates that the bed materials in the high-water season scarcely contain sediments finer than 0.05 mm, which means that the sediments finer than 0.05 mm suspended in the water during the high-water season can be regarded as wash load.

4.4.2. Some considerations on suspended load.

M.L. Rasul and others have prepared data on sediment discharges passing through whole flow areas on the basis of the results of samplings. The data at Chilmari, Bahadurabad, Nakfater Char and Nagarbari are plotted in Fig.2-27 with regard to sediment discharge and corresponding water discharge.

Out of all data shown in this figure, those obtained at Bahadurabad during the period from 1966 to 1969 alone are available as suspended load which does not contain wash load. Therefore, the relation of suspended load to water discharge were studied with regard to these data alone.

When suspended load per unit time with regard to a whole flow area is denoted by Q_s and water discharge by Q, it is generally known that the relation between them is expressed by the following equation.

$$Q_s = KQ^n \qquad (2.1)$$

where n is an exponent nearly equal to 2 and K is a constant depending on river regime and bed material. This fact has been clarified by H. Kikkawa in his study on suspended load and he expressed as follows (131 GB)

$$Q_s = KQ^2/A \qquad (2.2)$$

for the case of sufficiently wide river, where A denotes flow area.

On the other hand, S. Sato has indicated that bed load is nearly proportional to water discharge and given by the following equation (132 GB)

$$Q_b = K'Q^{0.9} \qquad (2.3)$$

where Q_b denotes bed load and K' is a constant.

Therefore, bed-material load Q_t can be expressed by

$$Q_t = Q_b + Q_s = K'Q^{0.9} + KQ^2/A \qquad (2.4)$$

Fig. 2-27 Relationship between Liquid Discharge and Sediment Discharge

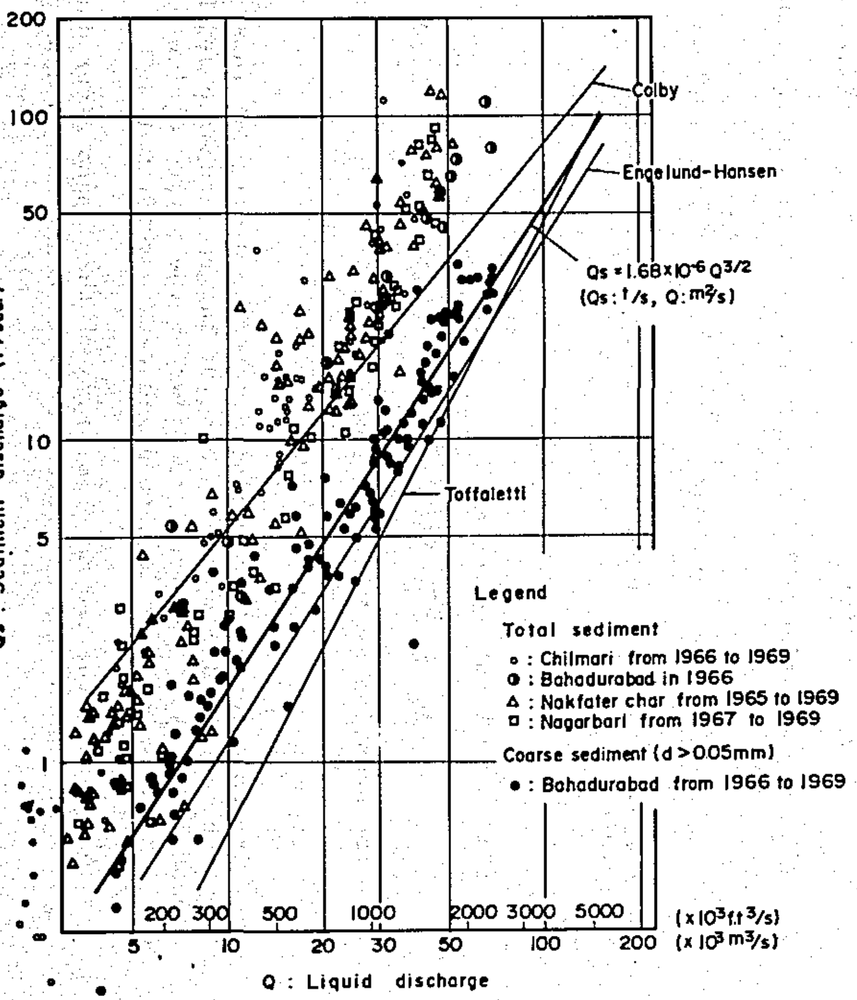
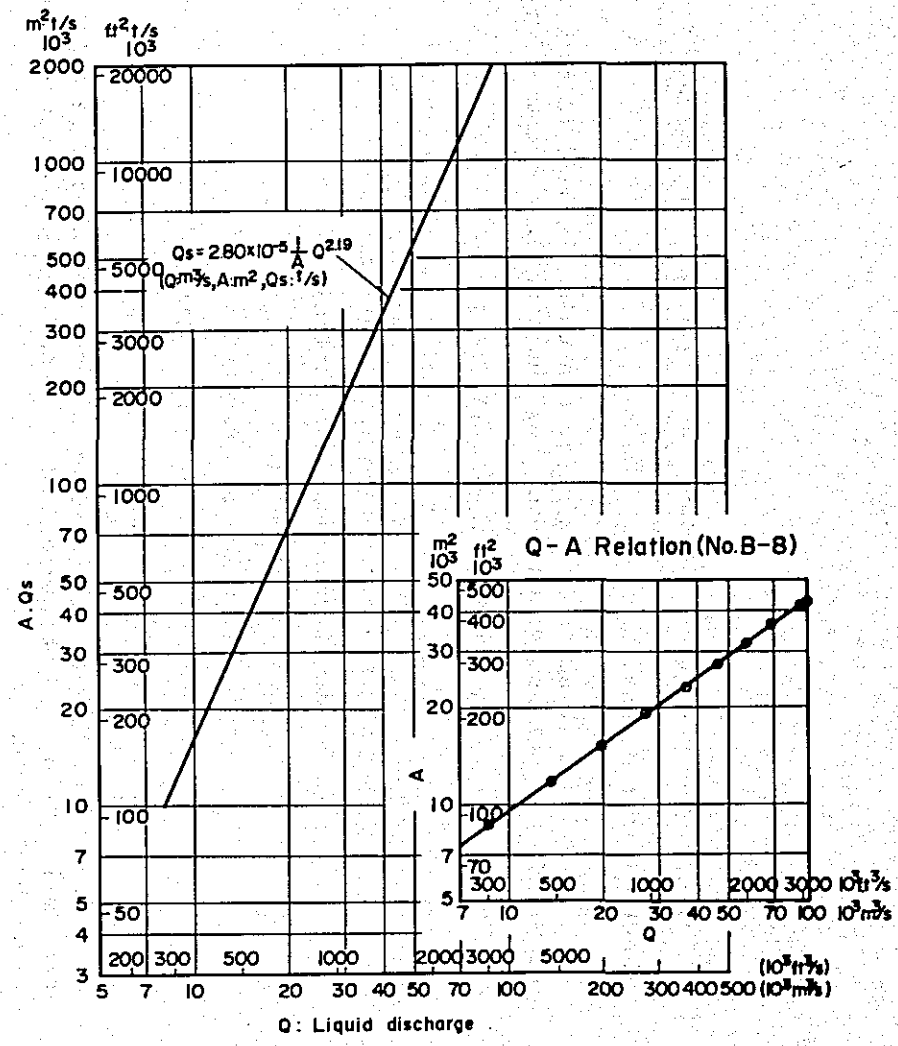


Fig. 2-28 Q - AQs Relation (Coarse Sediment at Bahadurabad)



This equation means that the suspended load will predominate in the high-water season while bed load will play an important part during the low-water season.

We will now examine Brown's formula which is said to give not only bed load but suspended load when the discharge becomes larger

$$q_t/u_*d = 10u_*^4(\sigma/\rho - 1)^2\ (gd)^2 \qquad (2.5)$$

where
- u_* = friction velocity
- d = grain size of sediment particle
- σ = density of sediment particle
- ρ = density of water
- g = acceleration of gravity
- q_t = sediment discharge per unit width (in net volume).

When river width is denoted by B, mean depth by R (R = A/B), mean velocity by v, coefficient of roughness by n and water-surface slope by I, we get

$$v = (1/n)R^{2/3}\ I^{1/2} \qquad (2.6)$$

$$Q = Av \qquad (2.7)$$

$$u_* = (gRI)^{1/2} \qquad (2.8)$$

Applying the equations (2.6), (2.7) and (2.8) to the equation (2.5), we get

$$Q_t = aQ^{2.25}/A^{5/4} \qquad (2.9)$$

where Q_t is sediment discharge in net weight with regard to a whole water area

$$Q_t = q_t B\,\sigma\, g$$

and a is a constant expressed by

$$a = 10\ \sigma\, n^{9/4} g^{3/2} I^{11/8}/d(\sigma/\rho - 1)^2 \qquad (2.10)$$

thus the equation (2.9) can be rewritten as

$$Q_t = a(Q/A)^{5/4}Q.$$

The equation (2.9) may indicate that bed-material load will almost be proportional to Q square in case of larger discharge and become almost linearly proportional to Q during the period of low water if Q/A is nearly constant in case discharge is very small.

After all, the bed-material load of the Jamuna River during its high-water season will be expressed by an equation containing Q^n where n is nearly equal to 2, or can be expressed by suspended load Q_s.

Now, we examine an equation

$$Q_s = KQ^n/A \qquad (2.11)$$

with regard to the case of the Jamuna River where its discharge exceeds about 5,000 m^3/s. For this purpose, Q and A curve was prepared with regard to the section No. B-8 which is located near the sampling station and was surveyed by the Japanese Surveying Team during the flood season of 1973. The curve is shown in Fig.2-28.

Using this curve, the constants in the equation (2.11) were examined and also shown in Fig.2-28. The suspended-load formula for the Jamuna River can thus be expressed by the following equation

$$Q_s = 2.80 \times 10^{-5} Q^{2.19}/A \qquad (2.12)$$

where Q_s is in t/s and Q in m^3/s.

On the other hand, "Task Committee for Preparation of Sediment Manual Committee of Sedimentation of the Hydraulics Division in the Proceedings of the American Society of Civil Engineers" recommends three formulas as consistently better agreement. Those are Colby, Taffalleki and Engelund-Hansen formulas. The results by above mentioned manners are shown in Fig.2-27. It is found from Fig.2-27 that Engelund-Hansen formula has the best tendency in the three formulas except a formula (2.12). So, we recommend the equation (2.12) as the best formula of sedimentation for Jamuna River.

4.5. Discharge measurements at the four proposed sites.

Discharge measurements were made by another Japanese team in the flood season of 1973 at Section N-12 near Nagarbari on Oct. 4, Section S-12 near Sirajganj on Sept. 24, Section G-8 near Gabargaon on Oct. 17 and Section B-8 on Oct. 11. These measurements are of great use for determining coefficient of roughness, although studies on such matters as decrease of peak discharge cannot be made because the measurements were not on the same day.

Fig.2-29 shows the stage hydrographs measured by BWDB at the four stage-gaging stations, Char-Bharenga, Nakfater-Char, Milanpur and Projapati which are located near the four proposed bridge sites respectively. On this figure, we can read the water stage on the measurement day at every measurement site.

Velocity measurements were made at every one-meter depth downwards from the water surface on seven or eleven verticals on each section of the proposed sites by using an electric current meter.

Fig.2-30 shows vertical distribution of velocity on each cross section, Fig.2-31 shows distribution of mean velocities on verticals on each cross section. Computation of discharges are shown in Table 2-7. The measured discharges at the four sites are as follows.

Fig. 2-29 Stage Hydrograph from Sept. to Oct., 1973

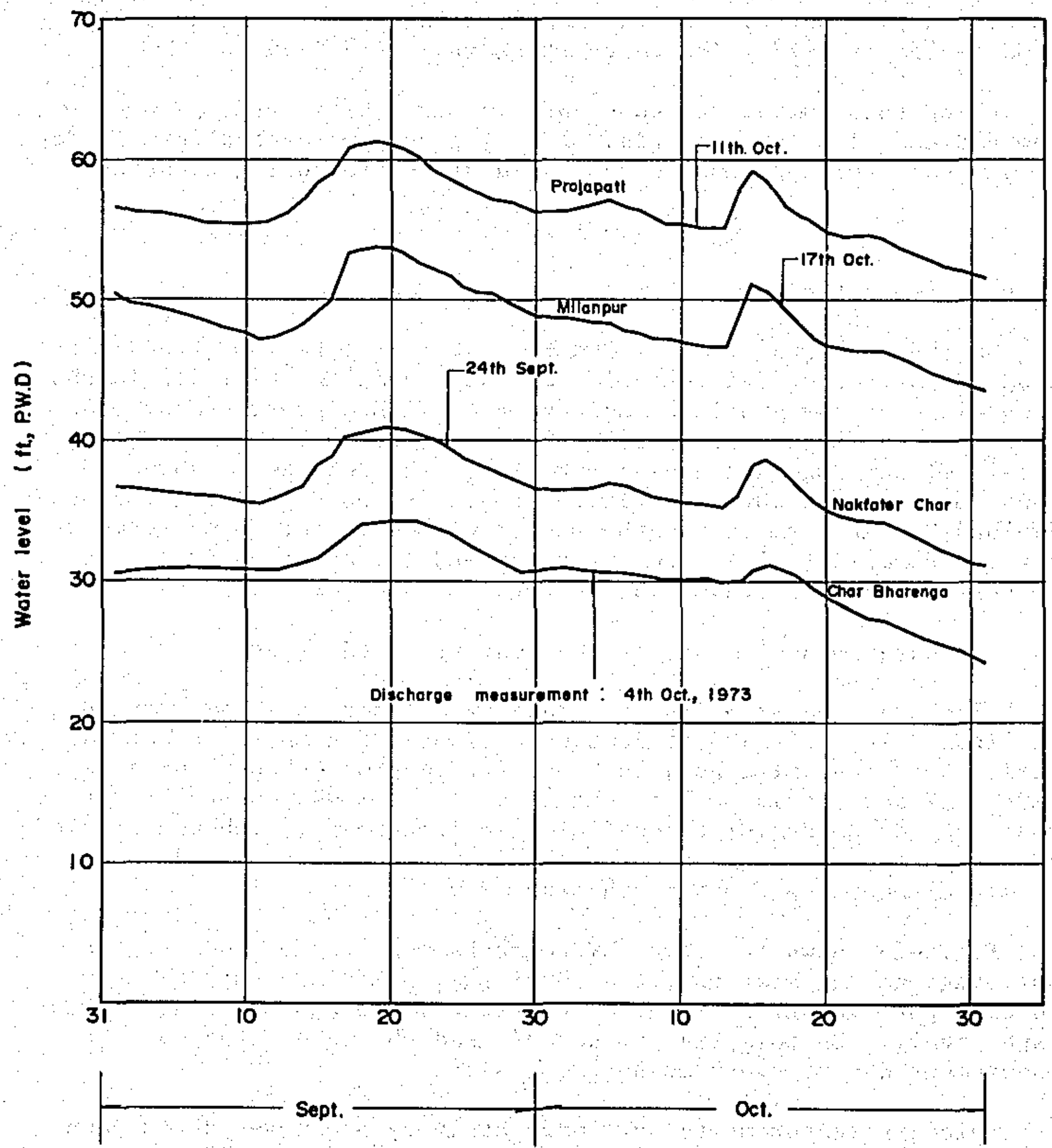


Fig. 2-30 Vertical Distribution of Velocity

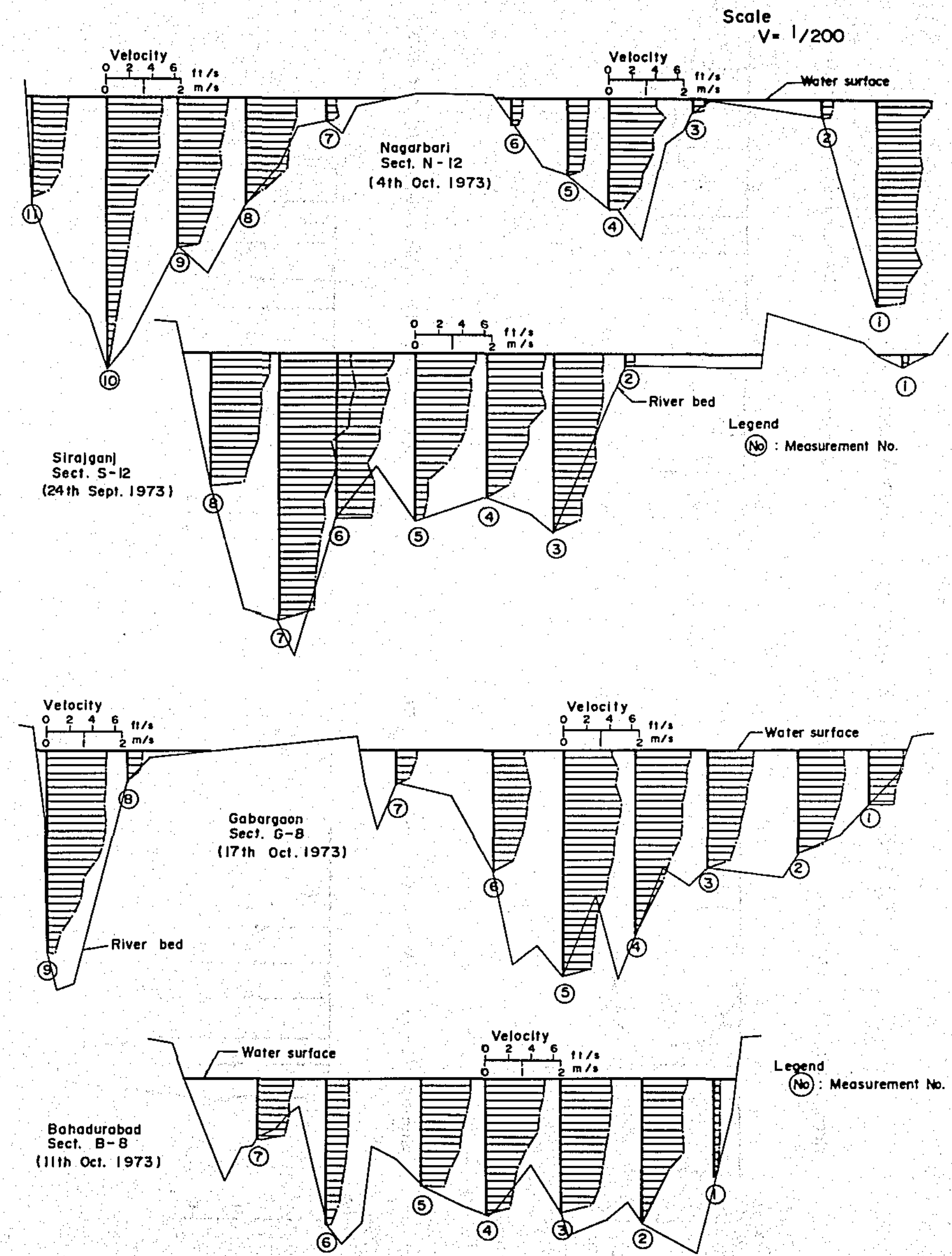


Fig. 2-31 Lateral Distribution of Mean Velocity ; Vm

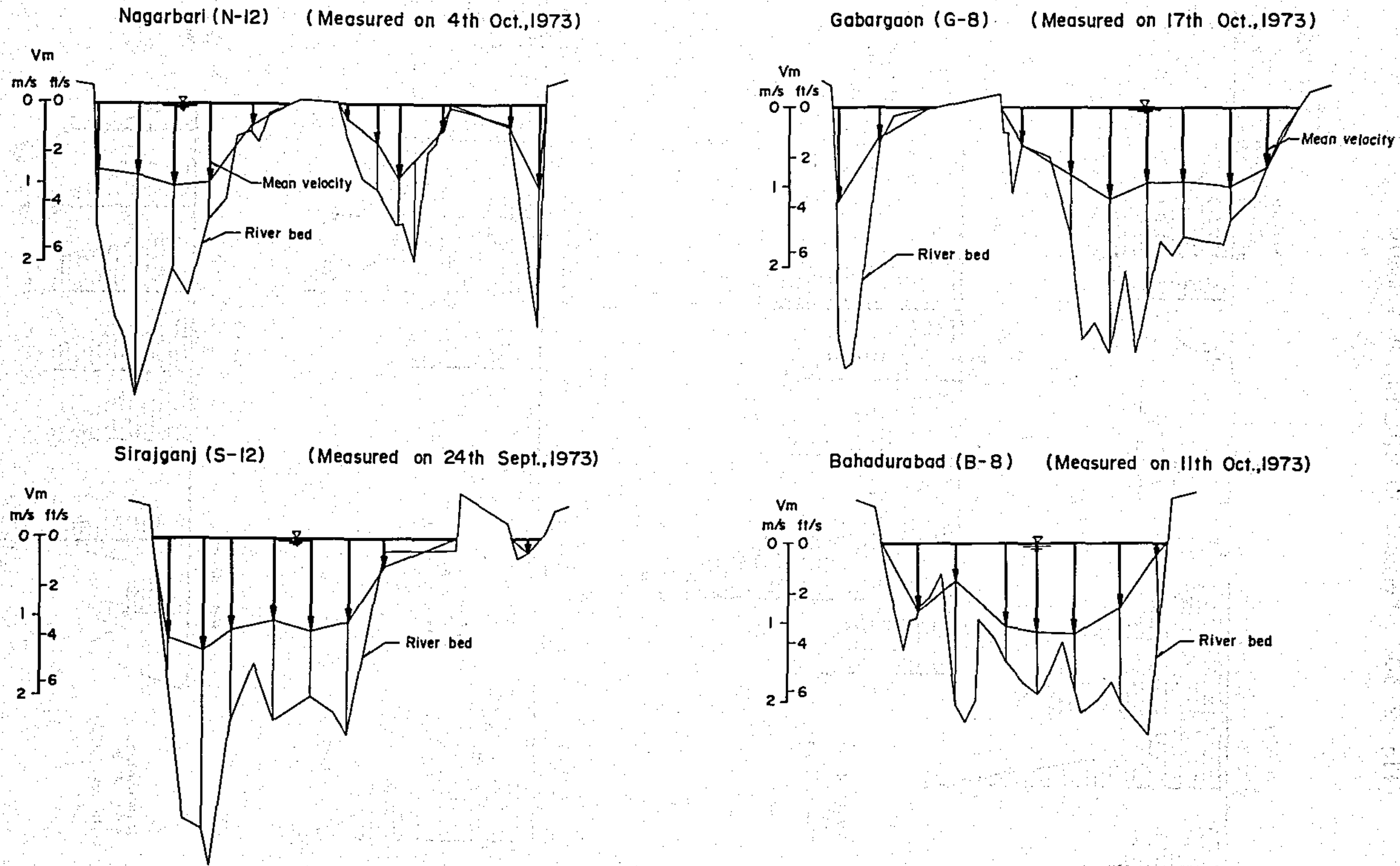


Table 2-7 Discharge at Proposed sites

Nagarbari on 4th Oct. 1973

Measurement	Mean velocity (m/s)	Segment area (m^2)	Discharge (m^3/s)	Remark
1	1.08	2,164	2,337	Mean velocity = 0.858 m/s Q = 21,556m^3/s = 761,500 cfs
2	0.28	1,020	287	
3	0.35	733	257	
4	0.97	2,665	2,585	
5	0.50	1,364	682	
6	0.22	568	125	
7	0.26	829	216	
8	1.01	2,966	2,966	
9	1.04	4,617	4,802	
10	0.91	5,936	5,402	
11	0.83	2,261	1,877	
Total		25,127	21,566	

Gabargaon on 17th Oct. 1973

Measurement	Mean velocity (m/s)	Segment area (m^2)	Discharge (m^3/s)	Remark
1	0.78	1,337	1,074	Mean velocity = 1.178 m/s Q = 26,733m^3/s = 934,940 cfs
2	0.99	3,238	3,206	
3	0.94	3,639	3,421	
4	0.95	4,378	4,159	
5	1.17	5,001	5,851	
6	0.86	3,761	3,234	
7	0.47	1,293	608	
8	0.40	2,036	814	
9	1.19	3,669	4,366	
Total		22,687	26,733	

Sirajganj on 24th Sept. 1973

Measurement No.	Mean velocity	Segment area	Discharge	Remark
1	0.16	119	19	Mean velocity = 1.166 m/s Q = 31,195 m^3/s = 1.101,500 cfs
2	0.36	1,182	426	
3	1.06	3,865	4,097	
4	1.16	3,752	4,352	
5	1.05	4,031	4,233	
6	1.16	4,264	4,946	
7	1.42	6,387	9,070	
8	1.28	3,166	4,052	
Total		26,766	31,195	

Bahadurabad on 11th Oct. 1973

Measurement No.	Mean velocity	Segment area	Discharge	Remark
1	0.13	2,486	323	Mean velocity = 0.83 m/s Q = 18,236m^3/s = 643,910 cfs
2	0.83	4,192	3,479	
3	1.16	3,648	4.232	
4	1.14	3,075	3.506	
5	1.05	2.926	2.068	
6	0.49	3,416	1,674	
7	0.89	2,309	2.-55	
Total		21,952	18,236	

Site	Discharge	
Nagargari	761,500 cfs	21,566 m^3/s
Sirajganj	1,101,500 cfs	31,195 m^3/s
Gabargaon	943,940 cfs	26,733 m^3/s
Bahadurabad	643,910 cfs	18,236 m^3/s

4.6. Mean velocity and surface velocity.

Correlation between mean velocity and surface velocity is studied in this section. We define v_m as mean velocity on a vertical, v_s as surface velocity, $v_{m\,max}$ as the maximum value of v_m on a cross section, v_M as mean velocity averaged on a cross section, v_S as mean surface velocity, $v_{0.2H}$ and $v_{0.6H}$ as velocity respectively at 0.2 and 0.6 of water depth downwards from the water surface on a vertical.

Fig.2-32 shows the correlations between velocities, v_m and $v_{0.6H}$, v_m and v_s, and v_m and $v_{0.2H}$ measured in the Jamuna River in the flood season of 1973. Fig.2-33 shows the correlation between v_m and v_s measured at Hardinge Bridge, as given in Table 2-8 (refer to Prefeasibility Report).

It is seen from these figures that velocity at 0.6 depth is equal to mean velocity

$$v_{0.6H} = v_m,$$

ratio of mean velocity to surface velocity is

$$v_m / v_s = 0.78$$

on the Jamuna River and the ratio is

$$v_m / v_s = 0.83$$

at Hardinge Bridge on the Ganges.

On the average, we get

$$v_m / v_s = 0.8.$$

According to the Prefeasibility Report (117JB), maximum discharge water levels, maximum mean velocities on verticals $v_{m\,max}$ and surface velocities on verticals v_s measured at Hardinge Bridge on the Ganges from 1950 to 1971 are as follows.

Fig. 2-32 Relation between Velocities

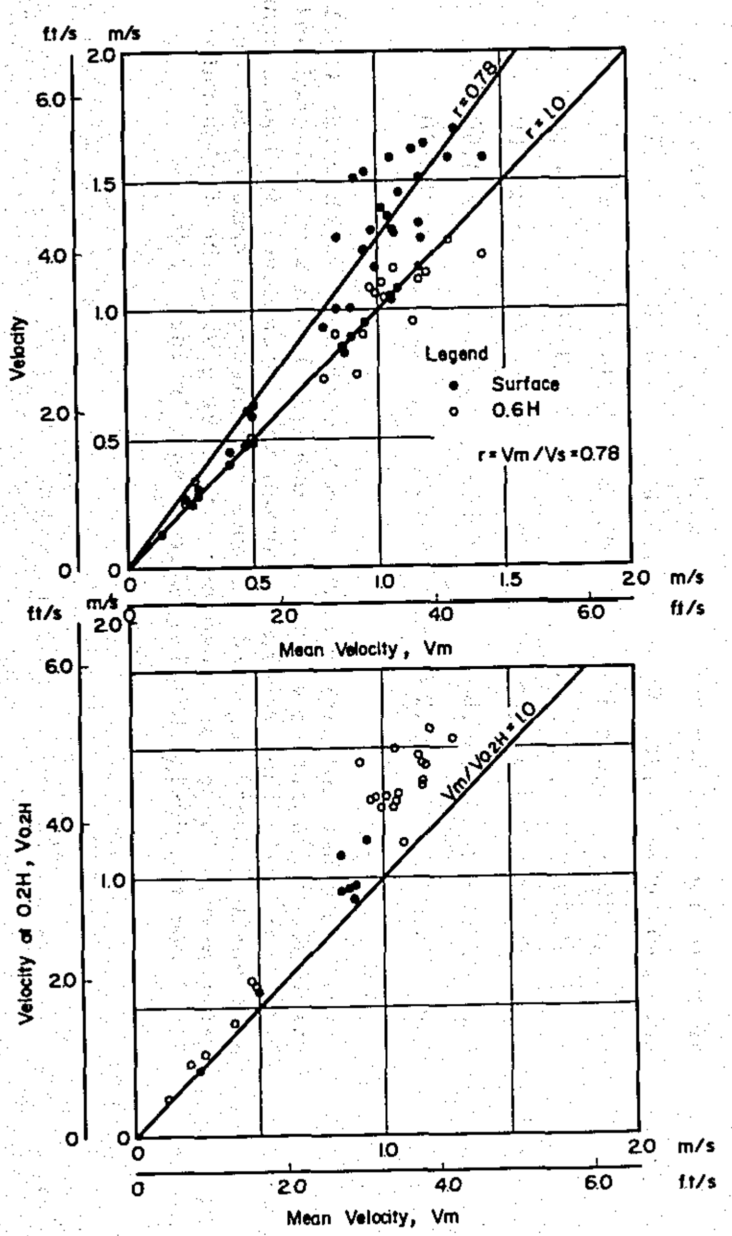


Fig. 2-33 Relation between Velocities

Ganges River, Hardinge Bridge

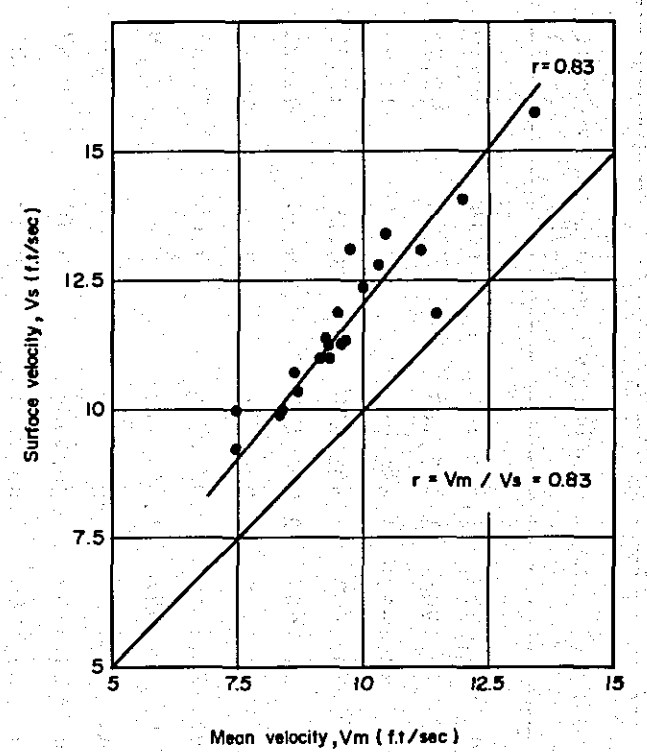


Table 2-8 Discharge and Velocity at Hardinge Bridge

Date	Max. discharge (cfs)	Mean velocity (f/s)	Surface velocity (f/s)	Water level (R.L. ft)
Aug. 19,1950	1,815,158	11.14	13.10	246.50
Aug. 29,1951	1,487,707	8.63	10.72	244.80
Aug. 30,1952	1,654,063	9.31	11.25	246.50
Aug. 30,1953	1,833,286	10.29	12.80	246.50
Aug. 25,1954	2,006,438	9.56	11.25	246.80
Aug. 23,1955	2,085,524	9.27	11.35	247.20
Sept. 22,1956	2,028,366	9.65	11.35	246.10
Sept. 7,1957	1,541,722	8.41	9.99	244.30
Aug. 15,1958	1,094,755	8.33	9.90	245.70
Aug. 23,1959	1,762,436	8.70	10.37	245.50
Aug. 23,1960	1,687,261	9.32	11.00	245.50
Aug. 9,1961	1,892,246	7.45	9.25	246.40
Sept. 8,1962	1,547,055	7.46	9.99	246.00
Sept. 7,1963	1,902,571	9.99	12.36	245.50
Aug. 7,1964	1,807,006	9.56	11.25	244.90
Sept. 16,1965	1,521,838	9.49	11.84	243.50
Aug. 30,1966	1,808,899	9.15	10.98	245.10
Sept. 24,1967	2,066,198	11.95	14.06	245.30
Aug. 31,1968	1,721,796	9.73	13.10	244.30
Aug. 23,1969	1,952,475	10.43	13.40	246.00
Sept. 24,1970	1,957,002	11.43	11.84	243.90
Aug. 26,1971	2,162,707	13.39	15.75	248.00

From other hydrologic data, three records in which water level, discharge and water area are simultaneously known were selected and, from Table 2-8, four records in which the water level is higher than R.L. 246.0 ft were selected for the convenience of computation of water area. These data together with that giving the design water level and the design discharge are shown in Table 2-9.

Table 2-9 Discharge and Mean Velocity at Hardinge Bridge

Date	R.L. (ft)	A ($10^3 ft^2$)	Q ($10^3 cfs$)	v_M (ft/s)	(m/s)
Design	250.0	294	2,500	8.50	2.59
Aug. 26, 1971	248.0	285	2,163	7.58	2.31
Sept. 16, 1970	242.5	237	1,577	6.66	2.03
Aug. 15, 1970	243.2	254	1,637	6.43	1.96
Aug. 23, 1969	246.0	277	1,952	7.05	2.15
Sept. 22, 1956	246.1	277	2,028	7.32	2.23
Aug. 23, 1955	247.2	282	2,086	7.40	2.26
Aug. 25, 1954	246.8	280	2,006	7.17	2.18

Using the data given in Tables 2-8 and 2-9, correlations between water level and discharge, water level and water area, and discharge and mean velocity v_M were studied, which are shown in Fig.2-34.

Table 2-10 v_M and $v_{m\ max}$ of the Jamuna and the Ganges

Date	Site	v_M (m/s)	(ft/s)	$v_{m\ max}$ (m/s)	(ft/s)	
Oct. 4, 1973	Nagarbari	0.86	(2.82)	1.08	(3.54)	Table 2-7
Sept. 24, 1973	Sirajganj	1.17	(3.84)	1.42	(4.66)	"
Oct. 17, 1973	Gabargaon	1.18	(3.87)	1.19	(3.90)	"
Oct. 11, 1973	Bahadurabad	0.83	(2.72)	1.16	(3.80)	"
Aug. 26, 1971	Hardinge	2.31	(7.57)	4.08	(13.38)	Table 2-8
Aug. 23, 1969	Hardinge	2.15	(7.05)	3.18	(10.43)	"
Sept. 22, 1956	Hardinge	2.23	(7.31)	2.94	(9.64)	"
Aug. 23, 1955	Hardinge	2.26	(7.41)	2.83	(9.28)	"
Aug. 25, 1954	Hardinge	2.18	(7.15)	2.92	(9.57)	"

Table 2-10 gives data obtained in the Jamuna River by the Japanese Survey Team (Table 2-7) and data obtained in the Ganges (Table 2-9 and 2-8) on values of v_M and $v_{m\ max}$. Using these data, correlations between v_M and $v_{m\ max}$ were studied, which are shown in Fig.2-35.

4.7. Coefficient of roughness.

Coefficient of roughness n was first derived from the discharge

Fig. 2-34 Correlation among Velocity, Water Stage, Water Area and Discharge at Hardinge Bridge

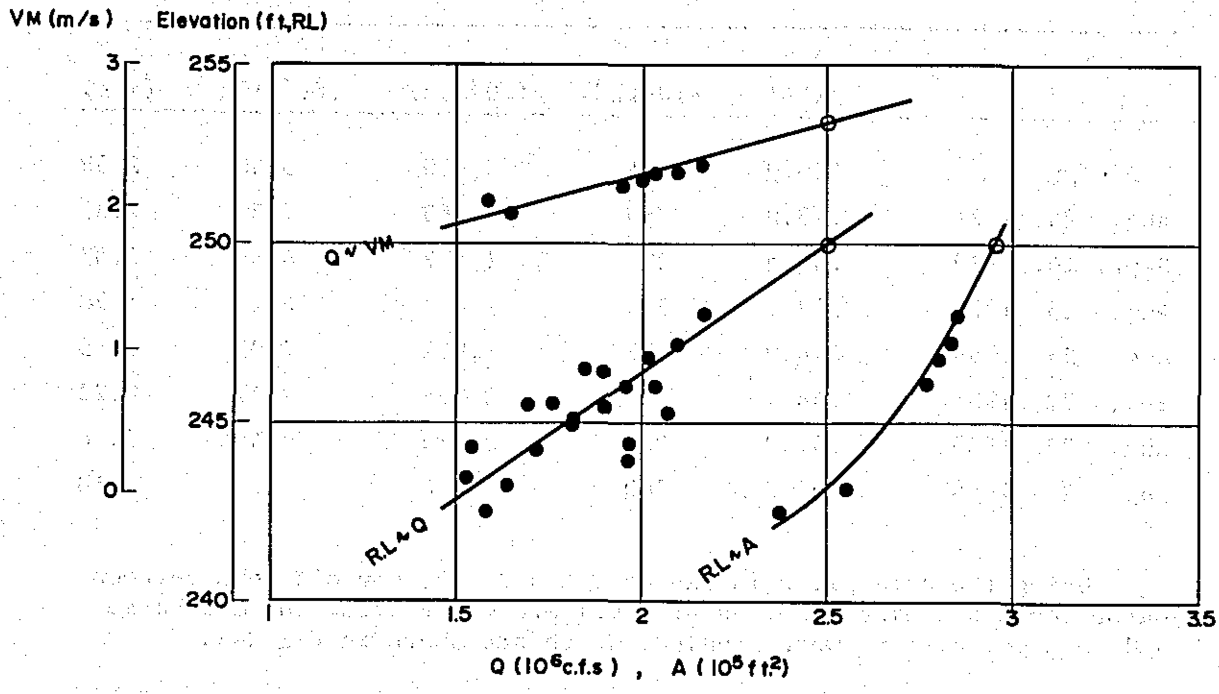
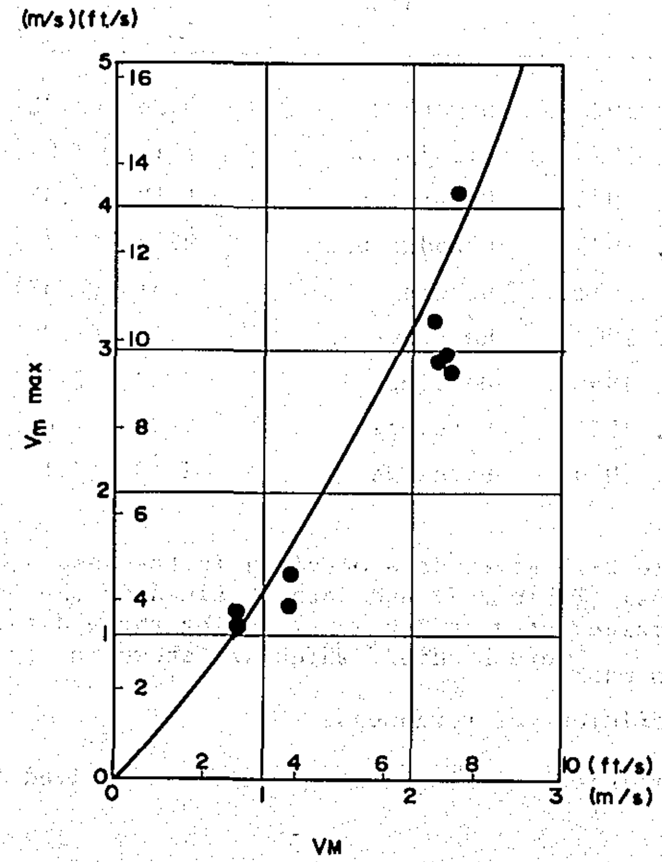


Fig. 2-35 Relation between V_m max. and V_M



measurements in 1973. In computing n value in the Manning formula,

$$v = \frac{1}{n} R^{2/3} I^{1/2}$$

v = mean velocity (m/s)
I = water surface slope
R = mean water depth (m)
n = coefficient of roughness

the values given in Table 2-7 were used for Q, A (v = Q/A) and R (= A/W, W denotes river width at water surface), and the value of I at each discharge-measurement site was read from the simultaneous water-stage profile, shown in Fig.2-36, which was made based on data on water stages measured at twenty-five gaging stations of BWDB during the discharge-measurement period.

Table 2-11 shows computation of n values at the four proposed bridge sites and Fig.2-37 gives distribution of n values on the Jamuna River. The average value of n on the river is 0.02 over the whole stretch except Bahadurabad.

Next, for the purpose of obtaining values of coefficient of roughness for cross sections surveyed in the dry season, water profiles were calculated on a stretch up-and-downstream of Bahadurabad where discharge records are regarded to correspond with those of water level. In making this calculation, three kinds of n values were used and it was assumed that the maximum flood discharge in 1970 (2,700,000 cfs at Bahadurabad Station on July 28, 1970) had flowed through cross sections measured in 1969/70 dry season. The results are shown in Fig.2-38.

This figure indicates that the most reasonable value lies between 0.015 and 0.018. On the other hand, mean value of n was taken at 0.017 in Flood Control Plan for East Pakistan, First Stage (113GN). Accordingly 0.017 may be taken as a reasonable value of n derived from cross sections in the dry season.

As mentioned above, n value derived from flood discharge and cross sections at the flood time was 0.020, while that derived from flood discharge and cross sections measured in a dry season nearest the flood time was 0.017. From these results, value of n during flood is likely to be 0.020. The cause may be sought in the fact that river depth is usually shallowed to a certain degree owing to sedimentation of suspended materials which takes place in general at the end of a flood. Further study is necessary until the accurate value is determined. In the present feasibility study, 0.02 was used expecting to obtain rather high water level.

Fig. 2-36 Water Surface Profile from Sept. to Oct., 1973

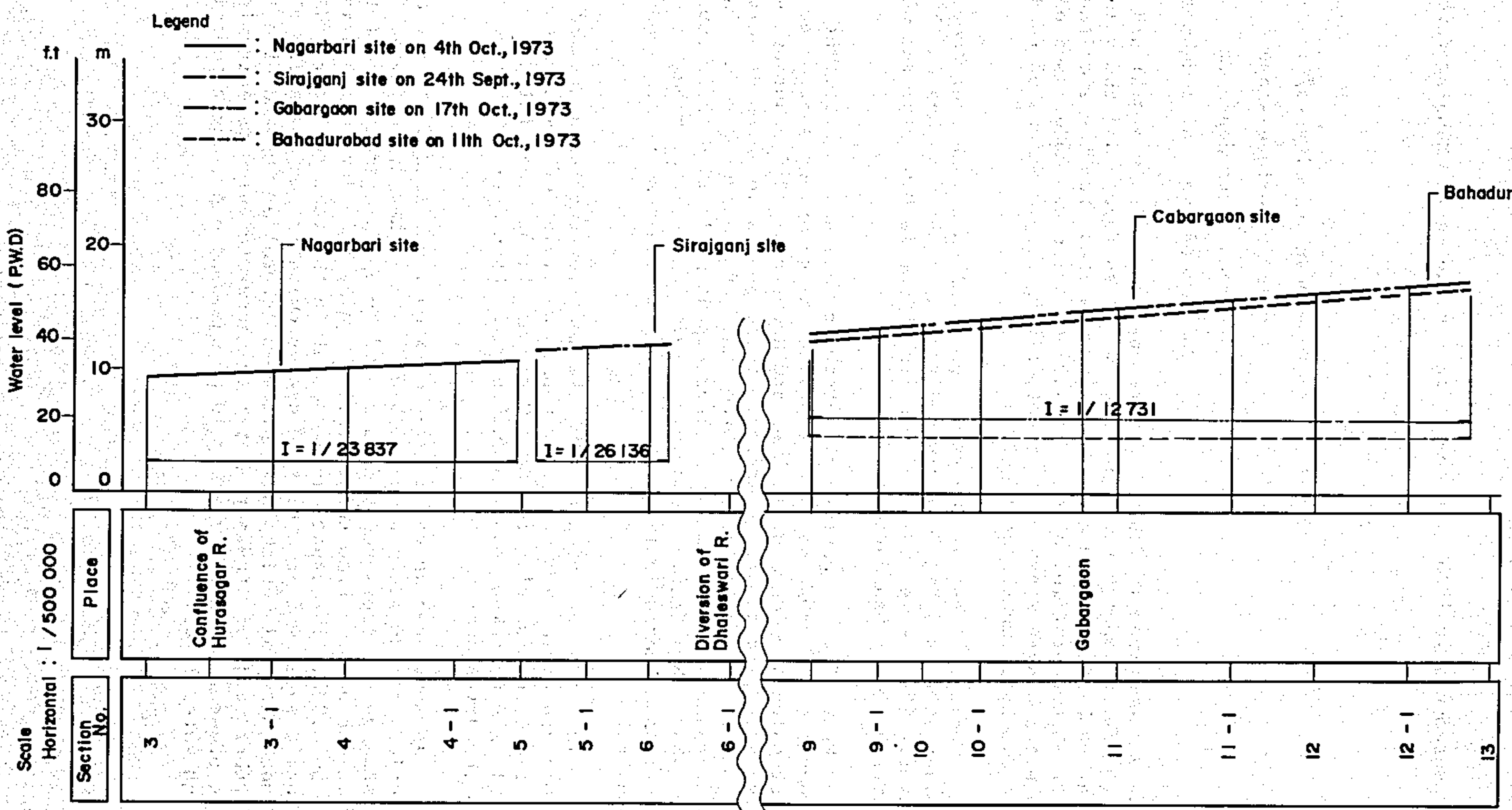


Fig. 2-37 Values of n Calculated from Discharge Measurements

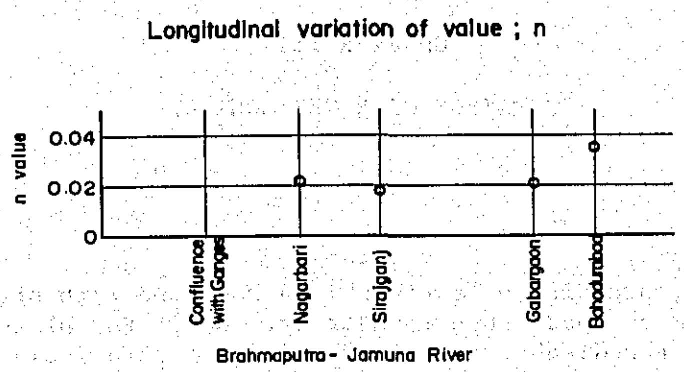
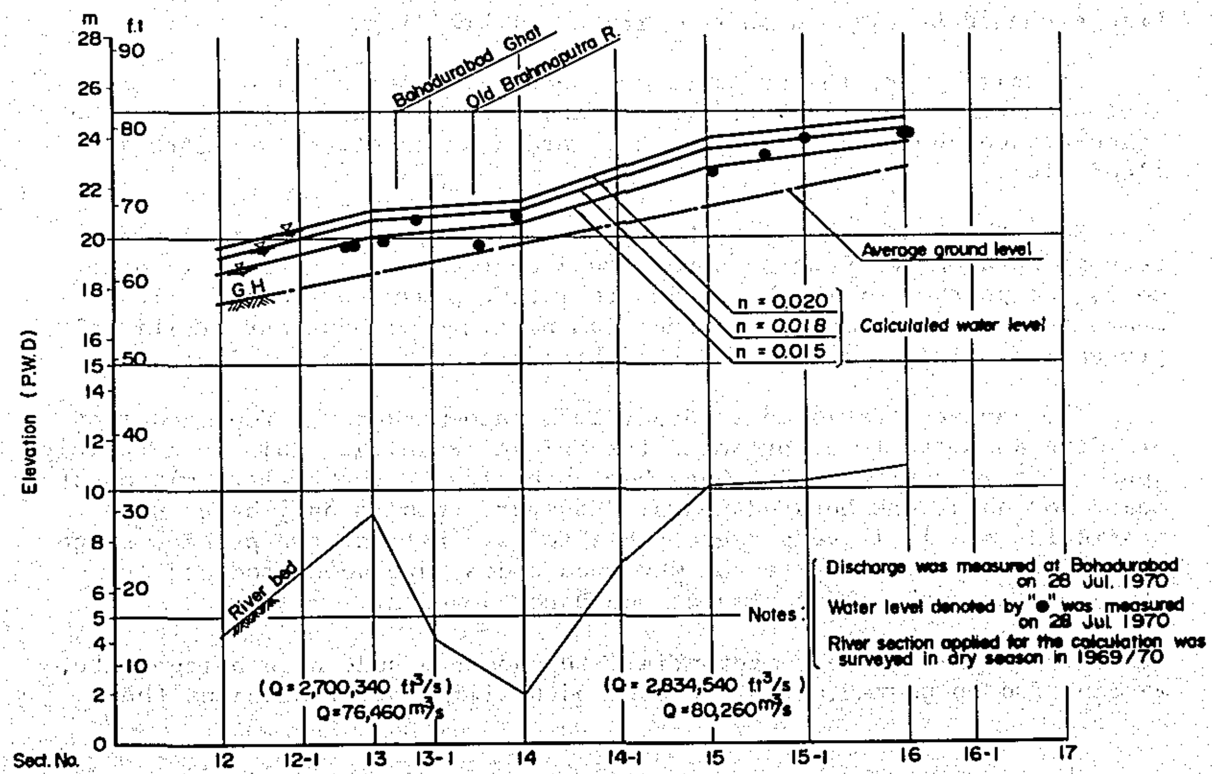


Table. 2-11 Calculation of Value ; n

	Site	Nagarbari	Sirajganj	Gabargaon	Bahadurabad	Remarks
Measured	Q/A	0.858 m/s	1.166 m/s	1.178 m/s	0.831 m/s	
	I	1/23840	1/26140	1/12730	1/12730	
R		4.87 m	6.34 m	4.56 m	5.97 m	A/B
$I^{\frac{1}{2}}$		0.006477	0.006185	0.008863	0.008863	
$R^{\frac{2}{3}}$		2.873	3.426	2.750	3.291	
n		0.022	0.018	0.021	0.035	

Fig. 2-38 Comparison of Calculated Water Level and Measured Water Level



CHAPTER III

STRATEGY OF RIVER CONTROL

1. Guide-bank System.

In general, braiding of a river is associated with steeper slopes and larger sediment loads than meandering, and if the slope of a stream is excessive or the discharge is increased to a relatively large magnitude, the local rate of bank scour and deposition may be of sufficient magnitude to cause the stream to braid.

The present Jamuna River is a typically braided one. But at the present stage, we can find no sufficient study why the Jamuna is thus braided. However, major causes for braiding may be sought in the facts that (1) the discharge of the Jamuna was suddenly increased by the change in courses of the Brahmaputra-Jamuna River and the Tista River, (2) the present Jamuna has taken its course along a depression running almost straight from north to south, on account of which the slope of the Jamuna is steep compared with large rivers as the Ganges class and (3) length of the river in this alluvial plain is still short compared with the magnitude of discharge and sediment load.

A braided river is presumed to be transformed eventually to a meandering one in the very remote future. The present Jamuna River also must have this nature. Even if the Jamuna has this nature, a state of meandering can not be encountered within 100 or 200 years from now, because it is only less than 200 years since the Old Brahmaputra shifted its course to the present Jamuna. Therfore, the construction of the bridge should be planned on the premise of braiding.

In this river, the braiding produces cliffy banks almost on the whole length of the river at least within the land of Bangladesh. The space between both cliffy banks is regarded as an effective width for flood flow.

Notwithstanding both the banks form cliffs, such clayey bank as seen at Sara on the Ganges is not found on the Jamuna River. In other words, no portion of the banks has resisting power to erosion. It means that no portion of the banks can be fixed without any artificial protection. This holds at nodes of braiding as well as at loops.

The Japanese Preliminary Study Team recommended the four nodes of braiding as sites to be proposed for bridge crossing. This is certainly appropriate since the nodes have been standing at the present places at least for about one hundred years. However, this is only based upon statistics and it is very regrettable to say that, at the present stage, we cannot elucidate the reason why such nodes have been produced and standing for such a long time as one hundred years.

Although it is very appropriate to choose a node as a bridge site, we can find no guarantee that these nodes will forever stand at the same places without any change in the forms. On the contrary, the fact is that incessant erosion at banks has been occuring even at the nodes of braiding; it is a well-known fact that severe erosion has been occuring at the bank of Sirajganj and costly protection works are being carried out every year. Therefore, even in case a bridge is spanned at such sites, some revetment works will be inevitable so as to protect the abutments of the bridge.

On the other hand, in every high-water season, flood water habitually spills over both the banks and the lowlying land located between the two Barinds is always inundated irrespective of the river channels and the lands. This phenomenon not only facilitates spilling to tributaries but also produces incessant erosion at banks. In this meaning, this river may be called a river having no banks. Since it is very difficult or, at the present stage, almost impossible to revet the whole stretches of both the banks, only the stream channel at the bridge crossing site must be fixed and protected from spilling or braiding.

For this purpose, the river flow which is extending over the whole valley must be interrupted by cross dikes on both sides and confined to run through a fixed opening between the cross dikes. In other words, we must guide the river flow into a fixed opening by making use of the water-stage difference between the interrupted area or the dead water and the opening space. In this case, two guide banks are inevitably needed at both the edges of the opening space in order to protect the edges and guide the flow into the opening as smoothly as possible and without any destructive influence on both the cross dikes. In conclusion, guide-bank system must be taken as far as a bridge is not spanned over a quite long distance which far exceeds the whole river width.

2. Minimum River Width.

In planning the guide-bank system, it will become important problems to determine the width of the opening space, the length and the shape of the guide banks and the method of protection of the guide banks and the cross dikes. Cross dikes will also be used for the approaches of the bridge.

The Inception Report gives three factors, (a) stability of river channel, (b) construction cost of the bridge and (c) traffic volume, in selecting the most suitable site for bridge crossing from among the four candidate sites recommended by the Japanese Preliminary Study Team. The second factor, construction cost of the bridge, should be composed of cost of river control works and cost of super- and substructures of the bridge. On the other hand, it is easily expected that the cost of the bridge works will be increased almost proportional to length of total span or river width, while river control works will have a tendency to decrease. Accordingly there may be a minimum cost with respect to river width. If there is a river width which minimizes the cost, it must be compared with such a minimum river width as suggested by Lacey. For this purpose, the minimum river width or the lower limit of river width must be known beforehand.

G. Lacey (114 GB) presented the following formula giving a minimum stable river width of large rivers in an alluvial plain based upon studies on the rivers and canals in India and Pakistan.

$$W = 2.67 \sqrt{Q} \qquad (3.1)$$

where W is minimum width in a stable channel in ft and Q is discharge in cfs.

According to the preliminary study in Chapter V, the average value of mean velocity on the stretch from Bahadurabad to the confluence with the Ganges is about 90,000 cub.m/s. If the Lacey formula is also applicable to the Jamuna River, the minimum stable width of this river will be calculated at 4,900 ft or 1,500 m. And if this width is actually formed, it will produce as high mean velocity as 2.7 m/s or 9 ft/s and the maximum mean velocity on a vertical will attain to 4.9 m/s or 16 ft/s according to Fig.2-35. This will also produce as high surface velocity as 6.1 m/s or 20 ft/s. According to the studies made in Chapter V, such high velocities will cause a severe lowering of river bed. The mean depth below the ground level will be as deep as 20 m and the depth at thalweg will attain to 78 m below the ground level. This is unpractical from the viewpoint of maintenance of structures as well as construction works of river control and bridge. Therefore, the Lacey formula should not be applied to the present case.

On the other hand, C. C. Inglis gave the following formula for calculation of width of a meandering river in a flood plain (115 GB).

$$W = 4.88 \sqrt{Q} \qquad (3.2)$$

where W is river width in ft and Q is discharge in cfs.

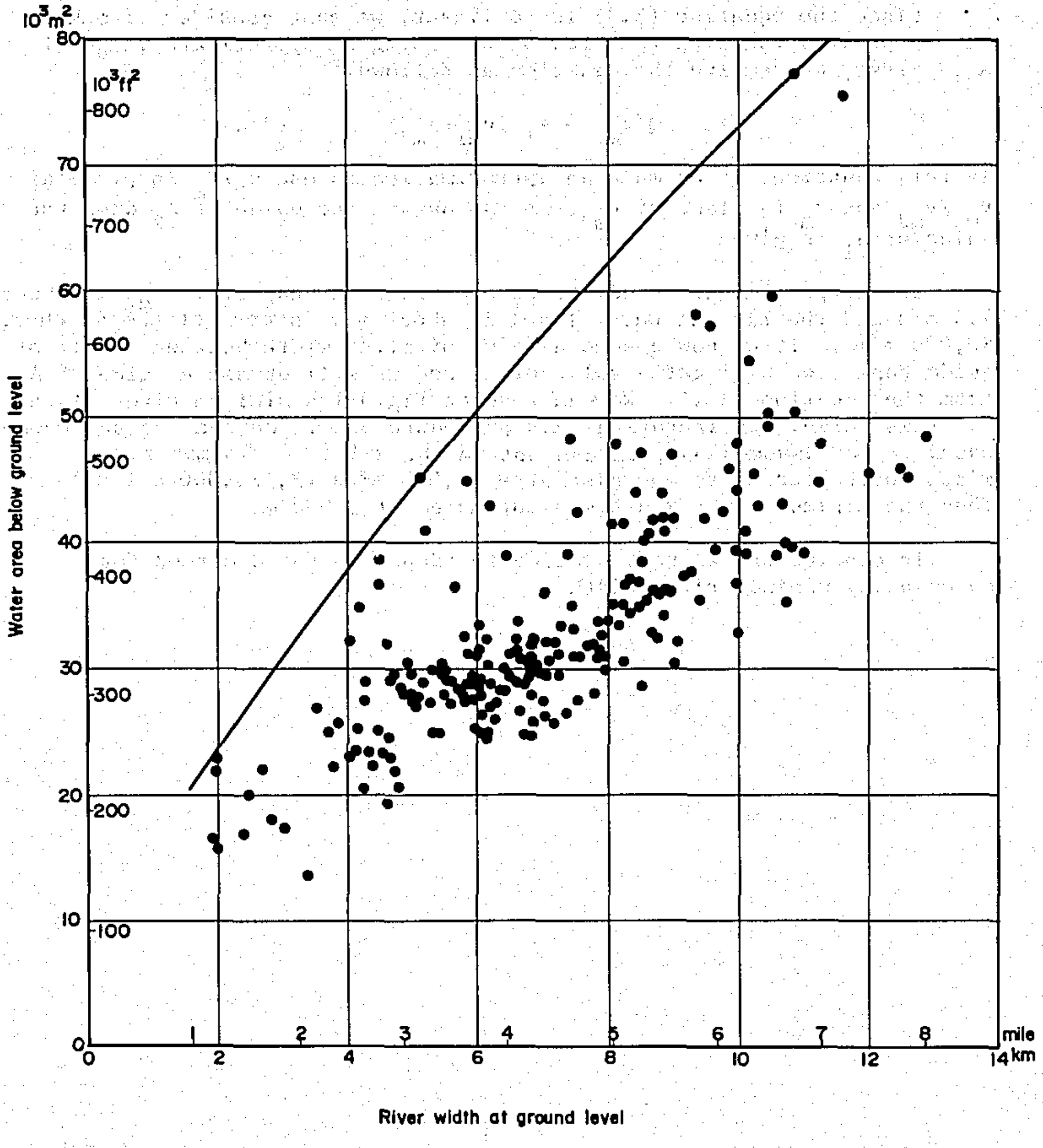
This formula gives a width W = 8,700 ft = 2,700 m at the same discharge mentioned above. The two formulas give a quite large difference. In the present planning, therefore, we must study it with regard to the natural feztures peculiar to the Jamuna River itself without regard to the above formulas.

For this purpose, relationship between river width at the ground level and the corresponding water area below the bround level was studied making use of the results of cross surveying made by BWDB over the stretch of about 220 km from the confluence with the Ganges to the upstream of Bahadurabad every year from the dry season of 1964/65 to the dry season of 1971/72. The relationship is shown in Fig.3-1.

This figure shows extensive scattering of points which is presumably caused by braiding and indicates existence of a minimum river width when a water area is given. This characteristics may be used for searching for a minimum river width.

We assume that flood flow is confined within two embankments on both banks and the water level is raised above the ground level. When discharge is denoted by Q, it may be expressed by

Fig. 3-1. Relation Between Water Area below Ground Level and River Width at Ground Level



$$Q = A_1 v_{m1} + A_2 v_{m2} \qquad (3.3)$$

where A_1 and v_{m1} are water area above the ground level and mean velocity of the water area, and A_2 and v_{m2} are respective values below the ground level. Giving the value of discharge Q, we are going to obtain the value of A_2 using the equation (3.3).

Since the equation (3.3) is nonlinear, we must consider of making some approximation with the view of obtaining an approximate value of A_2. First, we rewrite the equation as follows.

$$A_2 = Q/v_{m2} - A_1 \ (v_{m1}/v_{m2}) \qquad (3.4)$$

In this equation, if we make an approximation to use v_S/v_m in place of v_{m1}/v_{m2} and v_m in place of v_{m2}, we can obtain the value of A_2 when the value of A_1 is given.

In the preliminary study to be described in Chapter V, v_{m2} is about 1.6 m/s and the rise of water level is about 4 m in case of the discharge 90,000 m^3/s. If we now assume a value of river width between a pair of guide banks, we will get a value of A_1 and we will obtain a value of A_2 from the equation (3.4). We can read on Fig.3-1 a minimum river width for this value. By iterating this procedure until the read value becomes equal to the assumed one, we can obtain the value of minimum river width corresponding to the discharge 90,000 m^3/s (3,180,000 c.f.s.). Thus the minimum river width was estimated at 3,900 m.

In conclusion, we have decided to adopt the third method for calculating minimum river width.

CHAPTER IV

DESIGN DISCHARGE FOR BRIDGE CONSTRUCTION

1. Return Period of Flood Discharges at Bahadurabad.

In the present study, four sites (a) downstream of Bahadurabad, (b) near Gabargaon, (c) about 10 km downstream of Sirajganj and (d) about 20 km upstream of Aricha were taken up as the candidate sites for bridge crossing. In order to determine minimum river width and design high-water level for planning the bridge, we must set design discharge at each site. The design discharge at each site should have a magnitude not less than 100-year return period in view of importance and scale of the projected bridge.

On the other hand, we have no long-term records of flood discharges except those taken at Bahadurabad. Therefore, we must derive the design discharge for each site from the return period of flood discharges at Bahadurabad in consideration of branching of the Old Brahamaputra River and the Dhaleswari River and joining of the Hurasagar River.

The 100-year flood discharge at Bahadurabad is 3,278,000 cfs or 92,770 cub.m/s as already mentioned in 4.2 of Chapter II. If the 150-year flood is taken, the discharge is 3,358,000 cfs or 95,030 cub.m/s. This means an increment only of 2 %.

If we use the Manning formula, discharge Q is given by

$$Q = \frac{W}{n} H^{5/3} I^{1/2}$$

where W is river width, H is mean water depth and H = A/W, A is water area, n is coefficient of roughness and I is water surface slope. If the discharge Q is increased by xQ

$$Q' = Q + xQ = \frac{W}{n} H'^{5/3} I^{1/2}$$

where H' is the increased depth, while river width W, coefficient of roughness n and water surface slope I were assumed to be unchanged.

When we express the increased water depth by

$$H' = H + yH,$$

the above two equations give

$$1 + y = (1 + x)^{3/5}$$

or approximately

$$y = \frac{3}{5} x.$$

If we take the 150-year flood for the 100-year flood, the ratio of the increment of discharge, x, is only 2 % as mentioned above. Accordingly the increment ratio of water depth, y, will be 1.2 % by the above equation. If we assume that the 100-hear flood discharge is confined within the embankments to be built on both sides of the river, the mean water depth will be about 18m. Therefore, the increment of water depth when the 150-year discharge has been confined within the embankments will be only 0.2 m.

The magnitude of this increment is certainly within measurement error due to wind wave and variation of river bed, etc. From this viewpoint, we decided to adopt the 100-year flood, 3,278,000 cfs or 92,770 cub.m/s at Bahadurabad as the basic design discharge for the bridge planning.

2. Diversion of Discharge to the Tributaries.

2.1. Diversion to the Old Brahmaputra River.

Using data on discharges at Bahadurabad Station, Q_B, and discharges at Mymensingh Station, Q_M, correlation between them was studied with regard to the same day. This is shown in Fig.4-1. This figure indicates a fairly good correlation, which is expressed by the following equation.

$$Q_M = 0.0536\ Q_B - 10.5 \quad (Q_M, Q_B \text{ in } 10^3 \text{ cfs})$$

2.2. Diversion to the Dhaleswari River.

The Dhaleswari River is divided into two channels, the Dhaleswari River and the Kaliganga River, after branching from the Jamuna. Therefore, the discharge of the Dhaleswari River must be the sum of the two discharges at Jagir Station on the Dhaleswari and Taraghat Station on the Kaliganga. On the other hand, Sirajganj Station has no discharge data measured in the same years as the two stations on the Dhaleswari. Therefore, discharge data at Bahadurabad must be used in place of those at Sirajganj.

Since Jagir and Taraghat Stations are as far as 150 km from Bahadurabad Station, time lag must be considered in the study of correlation. After some trials, it was found that the most reasonable time lag was one day. Fig.4-2 shows the correlation of the two discharges under the time lag of one day, which is expressed by the following equation.

$$Q_{J+T} = 0.0789\ Q_B - 5.9 \quad (Q_{J+T}, Q_B \text{ in } 10^3 \text{ cfs})$$

where Q_{J+T} is discharge of the Dhaleswari (sum of the discharges at Jagir and Taraghat) and Q_B is discharge at Bahadurabad.

3. Design Discharges at the Four Bridge Sites.

In allocating discharge on the Jamuna, the following was taken into consideration.

Fig. 4-1 Correlation of Discharges

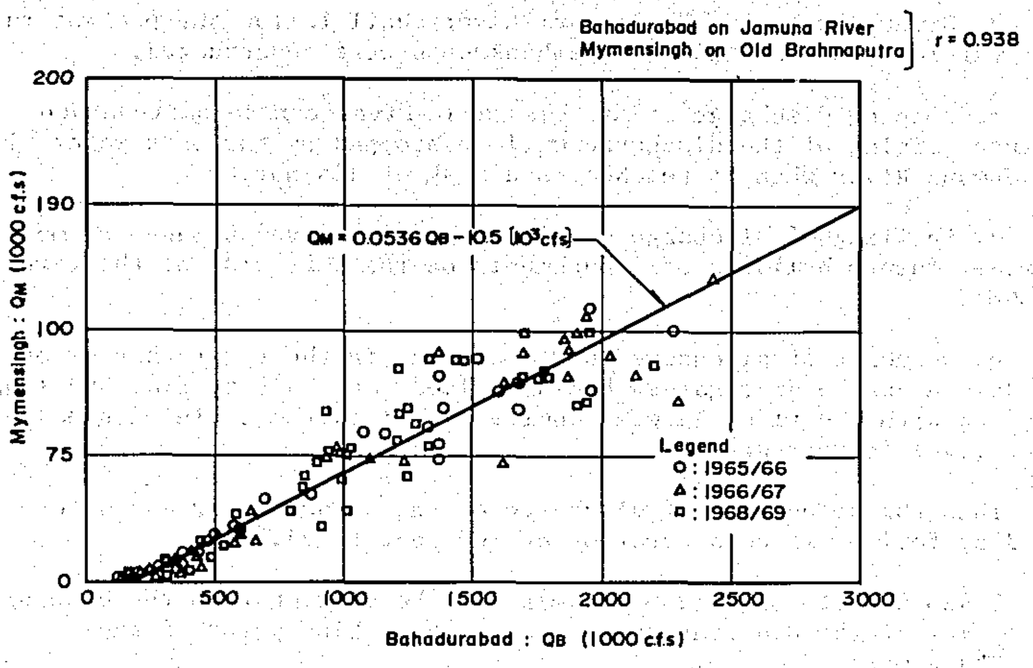
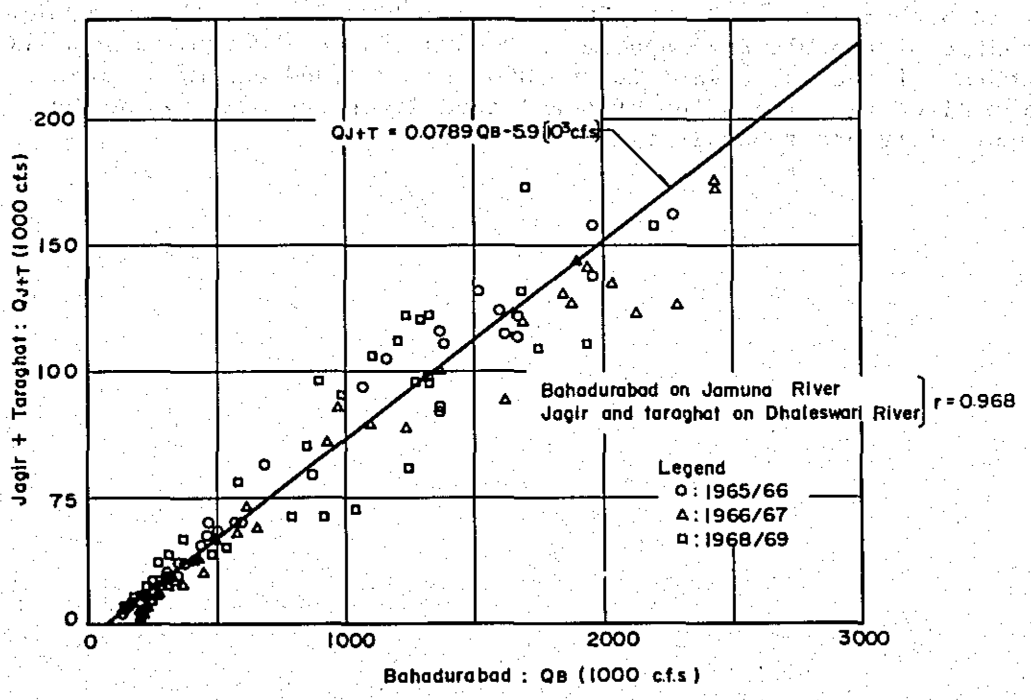


Fig. 4-2 Correlation of Discharges



※ 1 day is considered as time-lag between two stations

a. Diversion discharge to the Old Brahmaputra River shall be controlled to 30,000 cfs by a barrage to be built on the Old Brahmaputra River in the future (87 GN).

b. Diversion to the Dhaleswari River shall follow the present rule of diversion even when the left embankments were constructed.

c. Joining discharge of the Hurasagar River can be disregarded because joining of the discharge will be stopped by the back water of the Jamuna River when it reaches to a peak of discharge.

d. Spilling of discharge shall not be considered because we must consider future building of embankments on the left side of the river (87 GN).

e. Decrease of discharge due to storage in the river channel of the Jamuna can be disregarded because flood wave is very flat and long compared with the river length considered and further, rising speed of water level is very gentle.

Thus the allocation of discharge on the Jamuna River was determined as follows in consideration of 100-year flood.

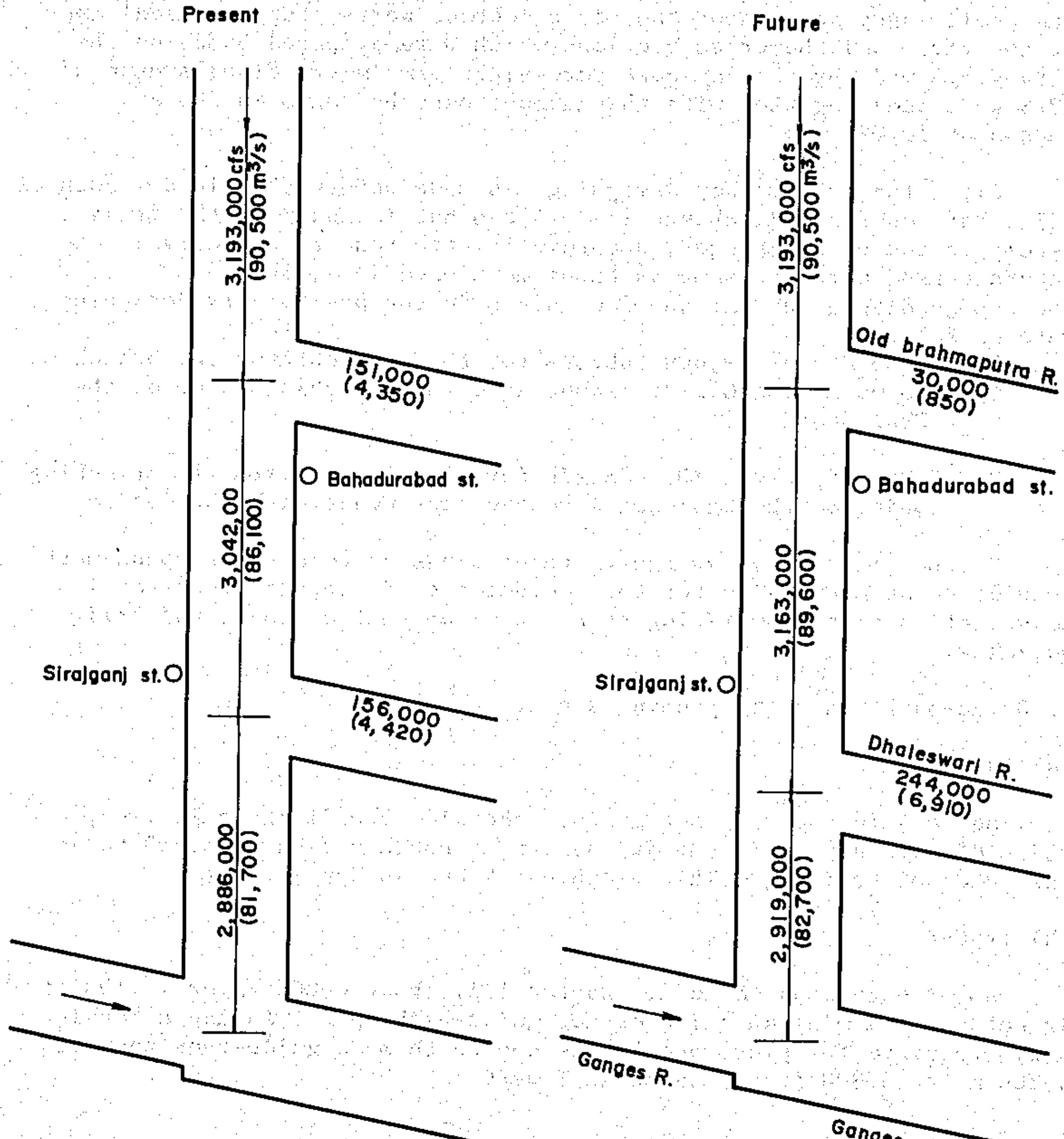
3,420,000 cfs or 96,850 cub.m/s for the stretch from the branching point of the Old Brahmaputra to the branching point of the Dhaleswari.

3,160,000 cfs or 89,490 cub.m/s for the stretch from the branching point of the Dhaleswari to the confluence with the Ganges.

For reference, the discharge upstream of the branching point of the Old Brahmaputra is 3,450,000 cfs or 97,700 cub.m/s, the controlled discharge of the Old Brahmaputra is 30,000 cfs or 850 cub.m/s and the discharge of the Dhaleswari is 260,000 cfs or 7,360 cub.m/s. This design-discharge allocation of the Jamuna River comparing with the present state are shown in Fig.4-3.

Fig. 4-3 Discharge Allocation of Jamuna River

(for 100yr. flood)



CHAPTER V

PRELIMINARY DESIGNS OF THE RIVER CONTROL WORKS

In accordance with the Inception Report, construction costs for river control works must preliminarily be estimated for comparison of suitability of the four proposed bridge sites shown in Fig.2-9. For the preliminary designs of the river control works, topographical maps of the river and the cross sections which were prepared based on the surveyings made by the Japanese Surveying Team in the flood season of 1973 were used together with the aerophotographs taken in the dry season of 1970/71.

Since the preliminary designing was made before the flood season of 1974, data on flood discharge in 1974 was not included in the study of return period of discharges; accordingly, the results of analysis of return period were the same as those mentioned in 4, Chapter II. The design discharges for the four sites in the preliminary designing were as follows.

3,163,000 cfs or 89,600 cub.m/s for the stretch from the branching point of the Old Brahmaputra to the branching point of the Dhaleswari.

2,919,000 cfs or 82,700 cub.m/s for the stretch from the branching point of the Dhaleswari to the confluence with the Ganges.

In the preliminary designs, three kinds of guide-bank spans were considered at every site for the convenience of comparison of total construction costs comprizing those of river control works and bridge building.

1. Guide-bank Spans at Spanning Sites.

(a) Type-A.

As seen in the aerophotographs taken in 1970/71 or in Fig.2-9, width of main stream in the dry season is roughly 2 km or 6,600 ft at the nodes of braiding. This width was taken as Type-A.

(b) Type-B.

As already studied in 2, Chapter III, about 4,000 km or 13,100 ft is needed as a minimum value of net guide-bank span. Adding a total width required for piers and losses due to them, a guide-bank span of 4,200 m or 13,800 ft was taken as Type-B.

(c) Type-C.

The width between both river banks (cliffs) at every site was taken as Type-C. These are as follows.

5,200 m (17,000 ft)	at Nagarbari site.
5,600 m (18,400 ft)	at Sirajganj site.

5,200 m (17,000 ft) at Gabargaon site.
5,600 m (18,400 ft) at Bahadurabad site.

2. Alignment of Guide Banks.

R.R. Gales proposed in his paper (118GB) alignments and lengths of guide banks necessary to lead flood flow toward between them so as to avoid damages to the approaches and protect piers by making the flow pass under the bridge as uniformly as possible. The standards of alignments and lengths given by him are shown in Fig.5-1. In this figure, Gales uses the words of permanent banks. However, these words do not seem to be quite suitable in the case of the Jamuna, although they may have been reasonably used in the case of the Ganges because of existence of clayey bank at Sara.

If we assume in the present case that the distance between two permanent banks is a width in which a river channel is moving freely, it is estimated at about 20 km (12.4 mi) according to the aerophotographs taken in the 1970/71 dry season.

Fig.5-1 indicates that the length of guide bank upstream from the bridge axis should be taken two times as long as the distance between the two guide banks in case the permanent-bank width is thirteen times as wide as the guide-bank span and a length equal to the guide-bank span is required in case the permanent-bank width is seven times as wide as the guide-bank span. For an intermediate, interpolation can be made.

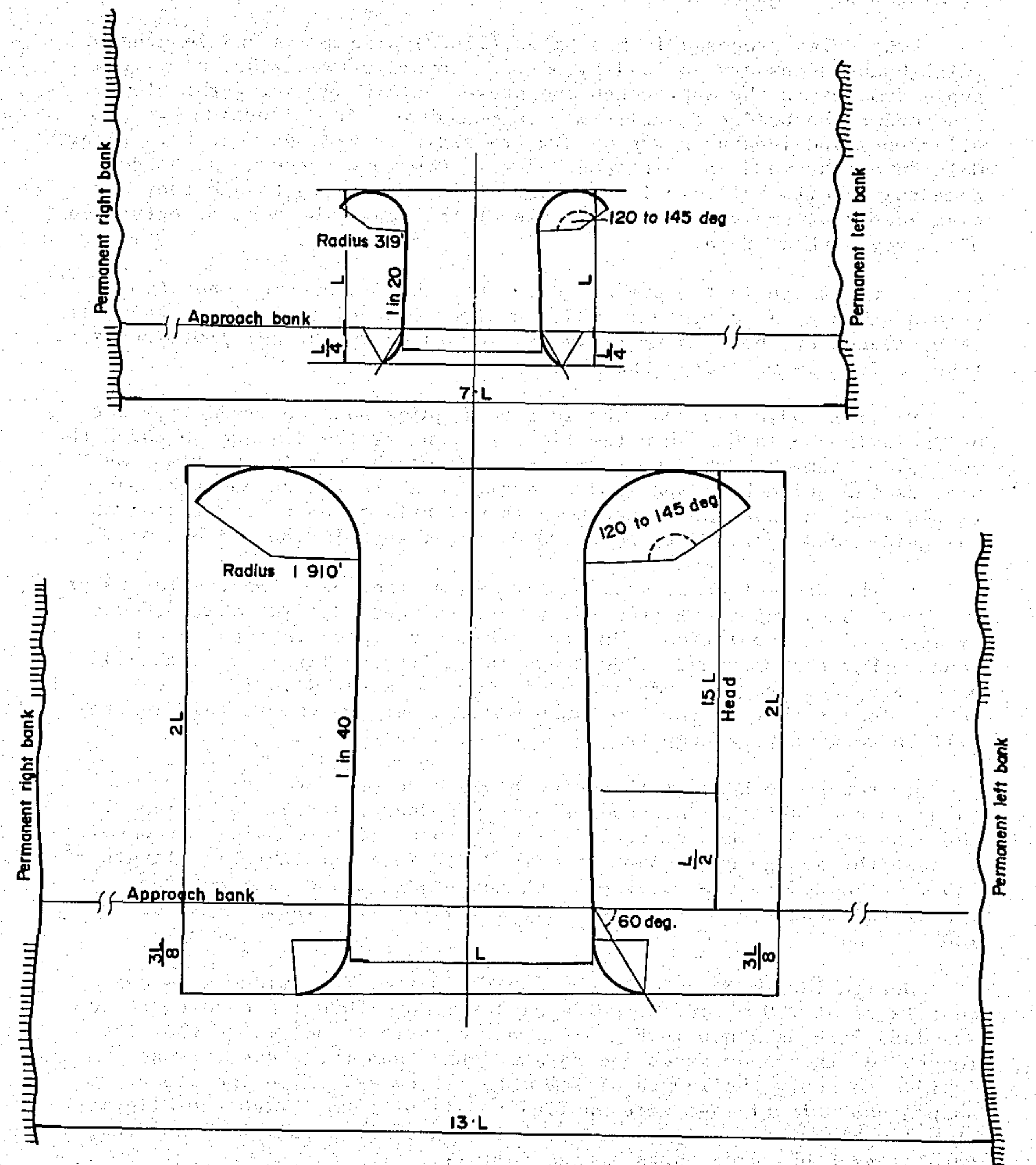
In the present case, Type-A alone lies inbetween. So the length of the guide banks upstream from the bridge axis was estimated at 3,000 m by means of interpolation. But the other two types lie outside the range. For these types, 3,000 m was taken irrespectively of the guide-bank span, because the same state of flow as expected in Type-A may occur along either of the two banks and, in our judgement, this length will be necessary to keep the function of guidance.

In regard to head of the guide bank, a shape of circular arc was taken in consideration of bending of river channels and the radius of the head arc was taken at 627 m (1910 ft) according to Gales' proposal. In case the design guide-bank span is 2,000 m, a straight-line length of 250 m was added to the outer edge of the head arc and, in the other types, the length of the arc was limited within the inner angle of 120°.

Design length of guide bank downstream from the bridge axis was calculated at 750 m for the guide-bank span of 2,000 m according to the standard 3L/8 as shown in Fig.5-1. Since there is no reason that the length for the other cases can be shortened than the above, it was decided to apply the length of 750 m to all cases. Also the plane shapes shown in Fig.5-1 were applied to all of them. Thus the alignment of guide banks was designed as shown in Figs.5-10-1 to 5-10-4 and the total length of guide banks are as follows.

5,495 m or 18,020 ft on one side, 10,995 m or 36,050 ft on both sides for the guide-bank span of 2,000 m.

Fig. 5-1 Dimension of Guide Bank (by Gales)



4,634 m or 15,190 ft on one side, 9,268 m or 30,390 ft on both sides for the other guide-bank spans.

Further in future, in making detail designs, hydraulic model tests are recommendable for determinning the alignment and the length of the guide banks.

3. Design High-Water level.

At first, we need to know general features of water-surface profile and velocity of the river in case flood discharge is confined within embankments on both banks. The calculation was made using discharges allocated on the stretch considered in consideration of diversion to the Old Brahmaputra River and the Dhaleswari River on the basis of the Bahadurabad flood discharge on July 28, 1970 which was the largest one before 1974 and using the cross sections surveyed by BWDB in the dry season of 1969/70.

These surveyings were made at large intervals of 4 mi. Therefore, nonuniform-flow method is not applicable to the calculation of water level. In this case, uniform-flow method was used considering that loss of head due to resistance should predominate in the total losses; and n = 0.02 was used in the calculation.

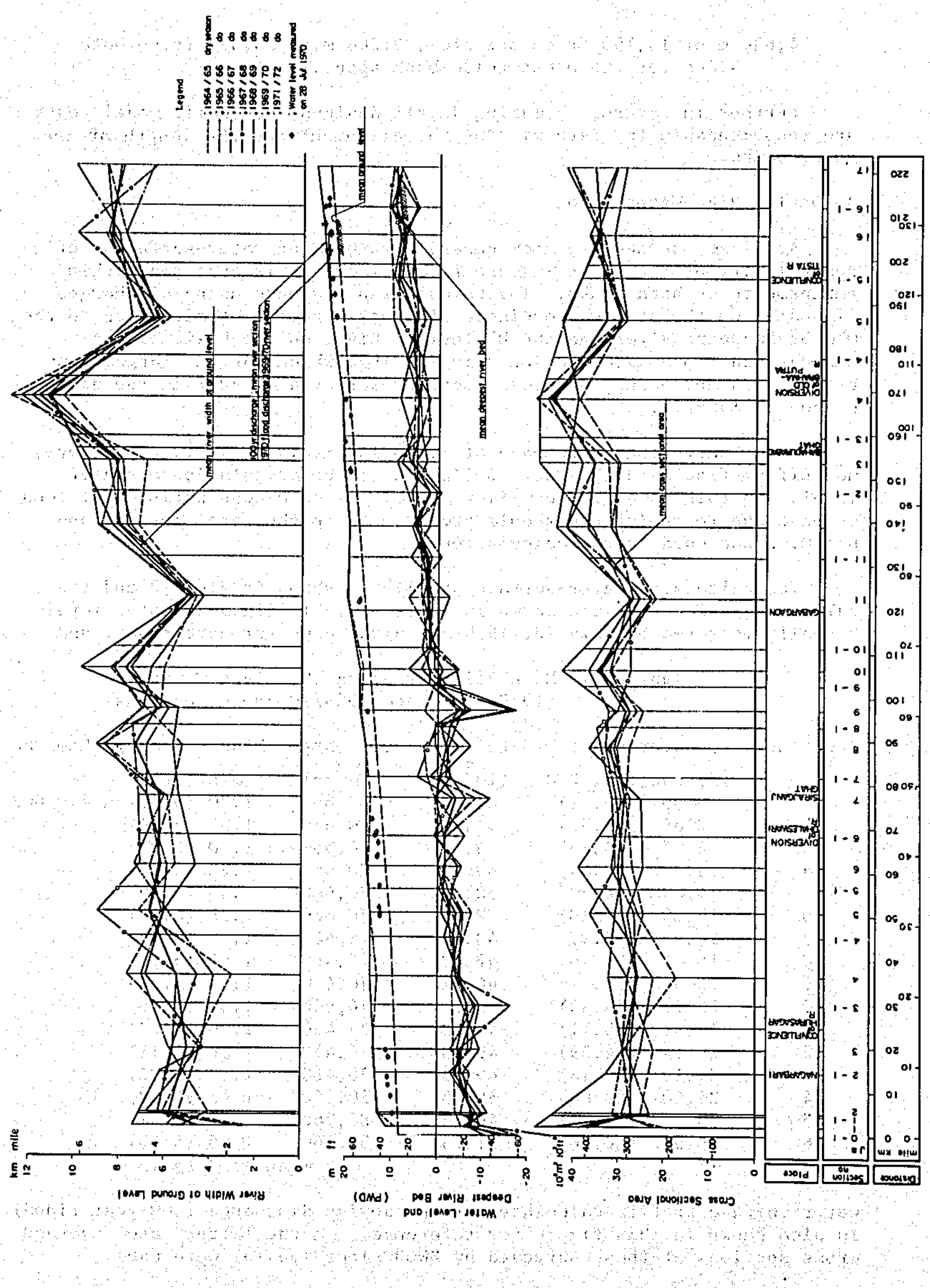
The calculated water-surface profile is shown in Fig.5-2 and the calculated velocities are shown in Table 5-1. In Fig.5-2, water levels actually measured on July 28, 1970 are also shown for comparison, and

Table 5-1 Mean Velocity along the River Course (1970 Flood and 1969/70 cross sections)

Sect. No.	Water stage		Water area	Discharge	Mean Velocity		Remarks
J#	(m, PWD)	(ft, PWD)	($10^3 m^2$)	(m^3/s)	(m/s)	(ft/s)	
1	9.00	(29.51)	41.52	70,660	1.70	(5.57)	n = 0.002
2	12.68	(41.57)	53.13	70,660	1.33	(4.36)	
3	14.07	(46.13)	44.13	70,660	1.60	(5.25)	
4	13.25	(43.44)	55.25	70,660	1.28	(4.20)	
5	14.83	(48.62)	50.34	70,660	1.40	(4.59)	
6	15.20	(49.83)	52.06	70,660	1.36	(4.46)	
7	14.93	(48.95)	43.47	76,460	1.76	(5.77)	
8	15.77	(51.70)	42.19	76,460	1.81	(5.93)	
9	16.96	(55.61)	46.71	76,460	1.64	(5.38)	
10	16.60	(54.43)	51.24	76,460	1.49	(4.89)	
11	19.86	(65.11)	40.33	76,460	1.90	(6.23)	
12	19.64	(64.39)	49.18	76,460	1.56	(5.11)	
13	21.10	(69.18)	49.93	76,460	1.53	(5.02)	
14	21.30	(69.84)	56.05	80,260	1.43	(4.69)	
15	23.67	(77.61)	46.92	80,260	1.71	(5.61)	
16	24.54	(80.46)	51.73	80,260	1.55	(5.08)	
				mean	1.57	(5.15)	

water surface profile calculated at the design discharge (100-year flood) is also shown in this figure for reference. In the latter case, average cross sections of those surveyed by BWDB since 1964/65 were used.

Fig. 5-2 Water Level Calculated by Manning's Formula



It can be seen from Fig.5-2 and Table 5-1 that (a) the rise of water level when the discharge is confined within embankments will attain to about 4 m above the ground level in the lower reaches and about 2.5 to 3 m in the upper reaches, whereas the rise when spilling of discharge is allowed remains to be about 2.5 m over the whole stretch considered and (b) the mean velocity will remain to be about 1.6 m/s except for a few sections.

Water surface profile at every bridge site was calculated using the design discharges previously mentioned and the cross sections which were surveyed by the Japanese Surveying Team at intervals of 1 km or 2 km. In this calculation, nonuniform flow equations were used on condition that the design discharge is confined within embankments and coefficient of roughness is 0.02. Water level at the end of the stretch of every bridge site was determined by a discharge-stage curve which was made by uniform-flow equation using the cross sections of lower 5-km stretch and water-surface slope obtained in the preliminary study mentioned above. Further, since the interval of 1 km or 2 km is still large for calculation by nonuniform-flow equation, interpolation was made between two successive sections at intervals of about 500 m.

The results of calculation are shown in Table 5-2. On the basis of these results, the design high water level was determined as follow.

a. Nagarbari site

DHWL = 14.01 m (45.94 ft), PWD at Sect. N-13
I = 1/25,400

b. Sirajganj site.

DHWL = 15.24 m (49.97 ft), PWD at Sect. S-11
I = 1/18,500

c. Gabargaon site.

DHWL = 19.44 m (63.74 ft), PWD at Sect. G-8
I = 1/15,000

d. Bahadurabad site.

DHWL = 20.86 m (68.40 ft), PWD at Sect. B-8
I = 1/15,000

The design high water levels are also shown in Table 5-2.

4. Standard Cross Section of Guide Banks.

4.1. Freeboard.

Freeboard should be provided in consideration of wind wave, future changes in design discharge and river bed, etc. In case of the right flood embankment of the Jamuna, five-foot freeboard was taken. Therefore, if we take about three-meter freeboard, it will be sufficient for this case. However, in order to make sure of it, run-up height of wind wave was studied in the following.

Maximum wind speeds in the past in Bangladesh are shown in Fig.5-3 and Table 5-3. It is evident from this figure that higher maximum wind

Table 5-2-1 Design High Water Level

Nagarbari - site

Section NO.	Distance (Km) between sections	Distance (Km) cumulative	Average G.H. (m,PWD)	Calculated W.L. (m,PWD)	Design H.W.L. (m,PWD)	L.W.L. (m,PWD)
N-23	0(km)	0(km)	9.100	13.550	13.608	44.62
22	1.14	1.14	9.139	13.595	13.647	44.75
21	1.10	2.24	9.178	13.638	13.695	44.91
20	0.90	3.14	9.209	13.668	13.730	45.02
19	1.15	4.29	9.249	13.704	13.775	45.17
18	1.05	5.34	9.285	13.748	13.816	45.30
17	1.22	6.56	9.327	13.814	13.864	45.46
16	1.00	7.56	9.362	13.860	13.903	45.59
15	0.88	8.44	9.392	13.894	13.937	45.70
14	0.80	9.24	9.420	13.934	13.968	45.80
13	0.98	10.22	9.454	13.978	14.006	45.93
12	0.68	10.90	9.478	13.999	14.033	46.01
11	0.80	11.70	9.505	14.030	14.064	46.12
10	1.10	12.80	9.543	14.092	14.107	46.26
9	1.22	14.02	9.586	14.123	14.154	46.41
8	1.05	15.07	9.622	14.135	14.195	46.55
7	1.01	16.08	9.657	14.162	14.235	46.68
6	0.92	17.00	9.689	14.210	14.271	46.79
5	1.18	18.18	9.730	14.233	14.317	46.95
4	1.01	19.19	9.715	14.293	14.356	47.07
3	0.75	19.94	9.791	14.370	14.385	47.17
2	0.76	20.70	9.817	14.391	14.415	47.27
1	0.95	21.65	9.850	14.403	14.452	47.39

Sirajganj - site

Section NO.	Distance (Km) between sections	Distance (Km) cumulative	Average G.H. (m,PWD)	Calculated W.L. (m,PWD)	Design H.W.L. (m,PWD)	L.W.L. (m,PWD)
S-20	0(km)	0(km)	10.650	14.620	14.700	48.20
19	1.07	1.07	10.728	14.689	14.758	48.39
18	1.09	2.16	10.808	14.724	14.877	48.78
17	0.96	3.12	10.879	14.764	14.869	49.75
16	1.14	4.26	10.962	14.813	14.930	48.95
15	1.18	5.44	11.049	14.862	14.994	49.16
14	1.01	6.75	11.145	14.919	14.065	49.39
13	1.28	8.03	11.238	15.008	15.134	49.62
12	1.28	9.31	11.332	15.069	15.203	49.85
11	0.66	9.97	11.380	15.108	15.239	49.96
10	0.71	10.68	11.432	15.128	15.277	50.09
9	0.54	11.22	11.472	15.166	15.307	50.19
8	0.57	11.79	11.514	15.187	15.337	50.29
7	0.88	12.67	11.578	15.278	15.385	50.44
6	1.27	13.94	11.671	15.343	15.454	50.67
5	1.11	15.05	11.753	15.442	15.514	50.87
4	1.02	16.07	11.827	15.512	15.569	51.05
3	0.90	16.97	11.893	15.586	15.617	51.20
2	1.09	18.06	11.973	15.605	15.676	51.40
1	1.05	19.11	12.050	15.653	15.733	51.58

Table 5-2-2 Design High Water Level

Gabargaon - site

Section NO.	Distance (Km) between sections	Distance (Km) cumulative	Average G.H. (m,PWD)	Calculated W.L. (m,PWD)	Design HWL (m,PWD)	Design HWL (ft,PWD)
G-14	0 (km)	0 (km)	15.350	18.710	18.950	62.14
13	2.04	2.04	15.512	18.879	19.086	62.58
12	1.64	3.68	15.641	18.989	19.195	62.94
11	1.87	5.55	15.789	19.083	19.320	63.35
10	1.81	7.36	15.933	19.202	19.441	63.75
9	1.52	8.88	16.053	19.294	19.542	64.08
8	1.30	10.18	16.156	19.381	19.628	64.36
7	1.30	11.48	16.259	19.464	19.715	64.65
6	1.10	12.58	16.364	19.557	19.788	64.89
5	1.34	13.92	16.452	19.640	19.878	65.18
4	1.56	15.48	16.576	19.779	19.982	65.52
3	1.55	17.03	16.698	19.923	20.085	65.86
2	1.70	18.73	16.833	20.034	20.198	66.23
1	1.48	20.21	16.950	20.126	20.297	66.55

Bahadurabad - site

Section NO.	Distance (Km) between sections	Distance (Km) cumulative	Average G.H. (m,PWD)	Calculated W.L. (m,PWD)	Design HWL (mPWD)	Design HWL (ft,PWD)
B-14	0 (km)	0 (km)	17.300	19.700	20.300	66.56
13	2.00	2.00	17.455	19.987	20.433	67.00
12	2.12	4.12	17.620	20.233	20.575	57.47
11	1.28	3.40	17.719	20.344	20.660	67.74
10	1.59	6.99	17.843	20.437	20.766	68.09
9	1.40	8.39	17.951	20.510	20.859	68.40
8	1.44	9.83	18.063	20.673	20.955	68.71
7	1.36	11.19	18.169	20.805	21.046	69.01
6	0.89	12.08	18.238	20.931	21.105	69.20
5	1.38	13.46	18.345	21.031	21.197	69.51
4	1.82	15.28	18.486	21.202	21.318	69.90
3	1.93	17.21	18.636	21.349	21.447	70.32
2	1.45	18.66	18.748	21.472	21.544	70.64
1	1.31	19.97	18.850	21.566	21.631	70.93

Fig. 5-3 Location of Wind-Speed Measuring Station and Record of the Highest

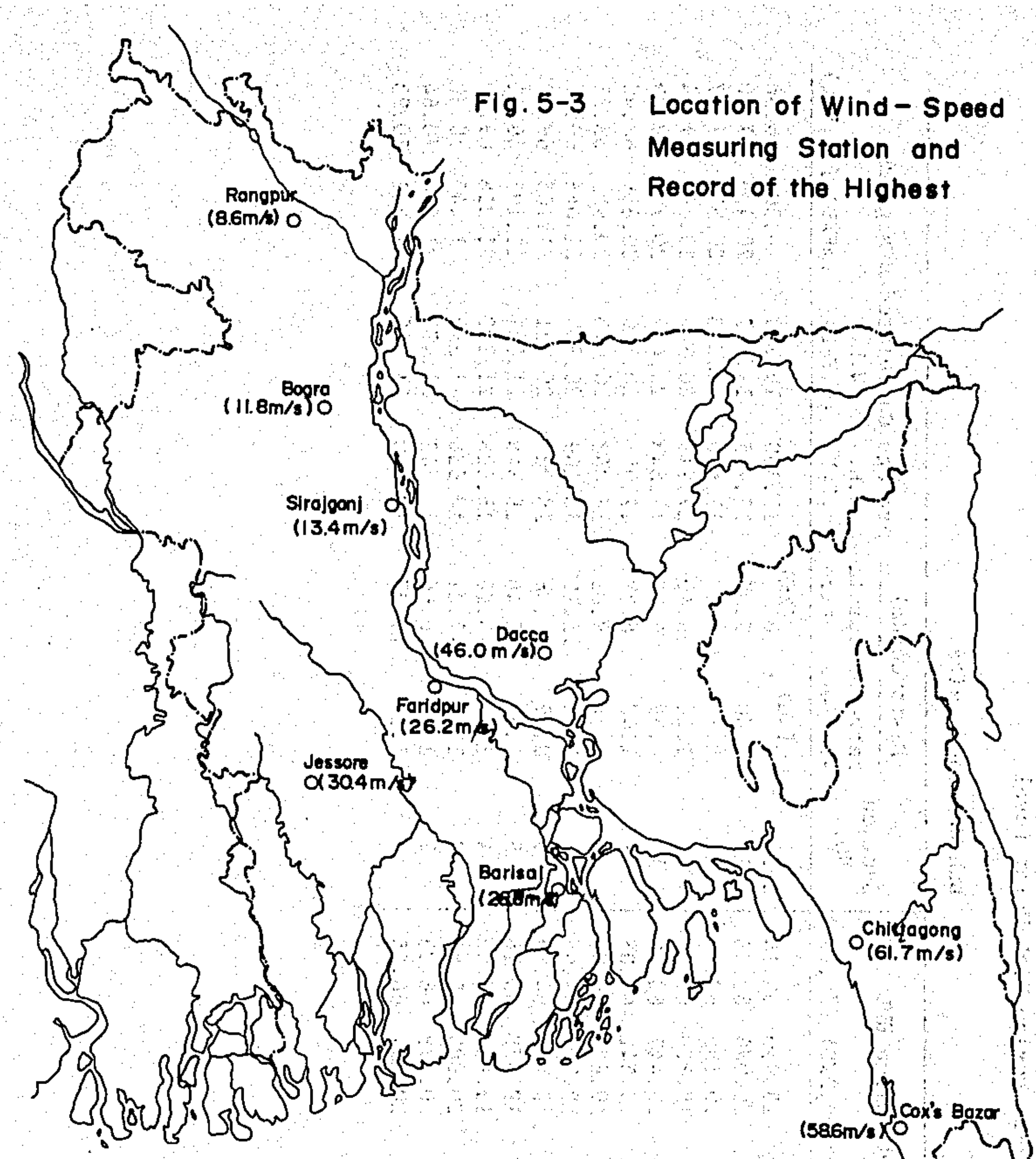


Table 5-3 Records of the Highest Wind-Speed

Station	Period of available data	Highest wind speed	
		(m/s)	(knot)
Rangpur	1960 ~ 1972	8.6	17
Faridpur	〃 〃	26.2	51
Sirajganj	〃 〃	13.4	26
Bogra	〃 〃	11.8	23
Dacca	1955 ~ 1970	46.0	89
Chittagong	〃 〃	61.7	120
Cox's Bazar	1960 ~ 1970	58.6	114
Barisal	1964 ~ 1970	26.8	52
Jessore	1960 ~ 1969	30.4	59

speed occurs on the southeastern coast such as Chittagong and Cox's Bazar, while it decreases to the west and to the inland; for instance, 13.4 m/s at Sirajganj, 11.8 m/s at Bogra and 8.6 m/s at Rangpur. In view of these values, wind speed for calculation of wave was taken as 15 m/s (49.2 ft/s). Fetch and water depth were taken as 10 km and 10 m in consideration of topographic features.

Significant wave height $H_{1/3}$ was calculated by Bretschneider' theory on shallow waves (119 GB) on condition that wind speed u_{10} = 15 m/s, fetch F = 10 km and water depth h = 10 m. The calculated dimensions of wave are as follows:

Wave height ($H_{1/3}$) : $gH_{1/3}/U_{10}^2 = 0.046 \therefore H_{1/3} = 0.946$ m

Wave period ($T_{1/3}$) : $T_{1/3} = 3.86\sqrt{H_{1/3}} = 3.75$ sec.

Wave length (L) : $L = \frac{gT_{1/3}^2}{2\pi}\tanh(\frac{2\pi h}{L}) \quad \therefore L = 21.9$ m

Wave celerity (c) : $C = L/T_{1/3} = 5.84$ m/s

Wave steepness ($H_{1/3}/L$) : $H_{1/3}/L = 0.043$

When number of waves is denoted by N, relation between significant wave height $H_{1/3}$ and the maximum wave height of N waves is given by Rayleigh as shown below.

N	50	100	200	500	1,000	10,000
$H_{max}/H_{1/3}$	1.42	1.53	1.64	1.77	1.86	2.15

When N is large, the following equation holds approximately.

$$H_{max}/H_{1/3} = 1.07\sqrt{\log_{10} N}$$

If we assume that wind of 15 m/s continues to blow for one hour, the number of waves will be 960. Hence we get

$$H_{max} = 1.85 \times 0.946 = 1.75 \text{ m} = 5.74 \text{ ft.}$$

Run-up height of wave on the slope of guide bank was estimated by Savil's study (119 GB). In case slope gradient of the bank is 1 : 3, ratio of run-up height R to that of corresponding deep-water wave H_0 is

1.5 for smooth slope, and
0.64 for slope protected by wave-absorbing works such as special precast concrete blocks

Since the wave height 0.946 m is nearly equal to that of deep-water wave, the run-up height will be

$R = 1.5 \times 0.946 = 1.42$ m (4.66 ft) for significant wave

$R = 1.5 \times 1.75 = 2.63$ m (8.62 ft) for maximum wave

in case of smooth slope. Actual run-up height will be less than the above since bank slope will be protected by stones or concrete blocks.

From the view point of wave run-up alone, 2.63 m are sufficient for freeboard even in case of maximum wave and smooth slope. In the present case, however, 3 m (9.8 ft) was adopted as freeboard in consideration of future changes that may possibly occur in design discharge and river bed, etc.

4.2. Crown width.

Ten meters were taken as crown width of guide bank taking into consideration the convenience of construction works and maintenance after completion.

4.3. Slope gradient.

Gradient 1:3 was adopted for river-side slope of the guide bank according to overall-apron system proposed by Gales, while gradient 1:2 was adopted for land-side slope keeping 1:3 as a whole providing with berms on the slope.

Rip-rap revetment with polyethylene mat was adopted as protection works for the river-side face and protection by polyethylene mat and sodding was considered for the land-side face. Weight of pitching stones on the river-side slope was examined by Hudson's formula in consideration of resistance to wave power. When we take unit weight of pitching stone as 2.65 t/m^3, unit weight of water as 1 t/m^3, wave height as 0.946 m and the value of constant for material covering the slope as 3.2, required height of one stone was calculated at 52.2 kg or 115.1 lb.

4.4. Apron.

4.4.1. Mean water depth between guide banks.

When a river channel is locally contracted by guide banks, velocity will be increased locally and river bed will be lowered at the constriction. The amount of lowering can be estimated on condition that quantity of silt transportation is the same in both the constriction and the stretches up-and-down-stream of it. When we solve simultaneously Manning's equation and equation for silt transportation on condition that discharge and quantity of silt transportation are constant between two successive sections. we obtain the ratio of water depths of the two sections as given in the following.

$$\frac{H}{H_0} = \left(\frac{B}{B_0}\right)^{-(1-\frac{1}{p})\frac{6}{7}}$$

where p is the exponent in the equation of silt transportation

$$Q_s = \alpha B u_*^p$$

Q_s = sediment load
α = constant
p = exponent
u_* = friction velocity

and

B, H = channel width and water depth
B_o, H_o = channel width and water depth at reference section.

The value of the exponent p is 3 in Sato-Kikkawa-Ashida's formula (119 GB) and 5 in Brown's formula (119 GB). Hence the above equation is expressed by

$$\frac{H}{H_o} = \left(\frac{B}{B_o}\right)^{-4/7} = \left(\frac{B}{B_o}\right)^{-0.57}$$: by Sato-Kikkawa-Ashida's formula for bed load transport

$$\frac{H}{H_o} = \left(\frac{B}{B_o}\right)^{-24/35} = \left(\frac{B}{B_o}\right)^{-0.69}$$: by Brown's formula for suspended load transport

On the other hand, E.M. Laursen (123 GB) proposes the following equations.

$$\frac{d_s}{H_o} = \left(\frac{B_o}{B}\right)^{0.59} - 1 \quad \text{for } u_*/w<1/2 \quad \text{(traction)}$$

$$\frac{d_s}{H_o} = \left(\frac{B_o}{B}\right)^{0.64} - 1 \quad \text{for } u_*/w = 1 \quad \text{(transition)}$$

$$\frac{d_s}{H_o} = \left(\frac{B_o}{B}\right)^{0.69} - 1 \quad \text{for } u_*/w>2 \quad \text{(suspension)}$$

where

d_s = scoured mean depth = $H - H_o$

u_* = friction velocity

w = settling velocity of sediment particle.

In case the loss of head due to contraction is small, we get

$$\frac{H}{H_o} = \frac{d_s}{H_o} + 1.$$

Hence we obtain the following equations for the above.

$$\frac{H}{H_o} = \left(\frac{B}{B_o}\right)^{-0.59} \quad \text{for } u_*/w < 1/2$$

$$\frac{H}{H_o} = \left(\frac{B}{B_o}\right)^{-0.64} \quad \text{for } u_*/w = 1$$

$$\frac{H}{H_o} = \left(\frac{B}{B_o}\right)^{-0.69} \quad \text{for } u_*/w\ 2$$

According to the study in 4.3, Chapter II, mean diameter of bed material of the river is 0.018 cm at Nagarbari, Sirajganj and Gabargaon sites and 0.027 cm at Bahadurabad. Since the ratio of friction velocity to settling velocity is larger than 2 in any case of Types-A, B, and C, Laursen's formula coincides with Brown's.

In general, changes in regimes of a river are so gradual that the regime can be considered to be in equilibrium state in the process of changes over a long time as far as some artificial impact is not given. Therefore, the applicability of the above formula may be examined by applying it to the natural state of the river.

Thus the equation

$$\frac{H}{H_o} = \left(\frac{B}{B_o}\right)^{-0.69} \qquad (5.1)$$

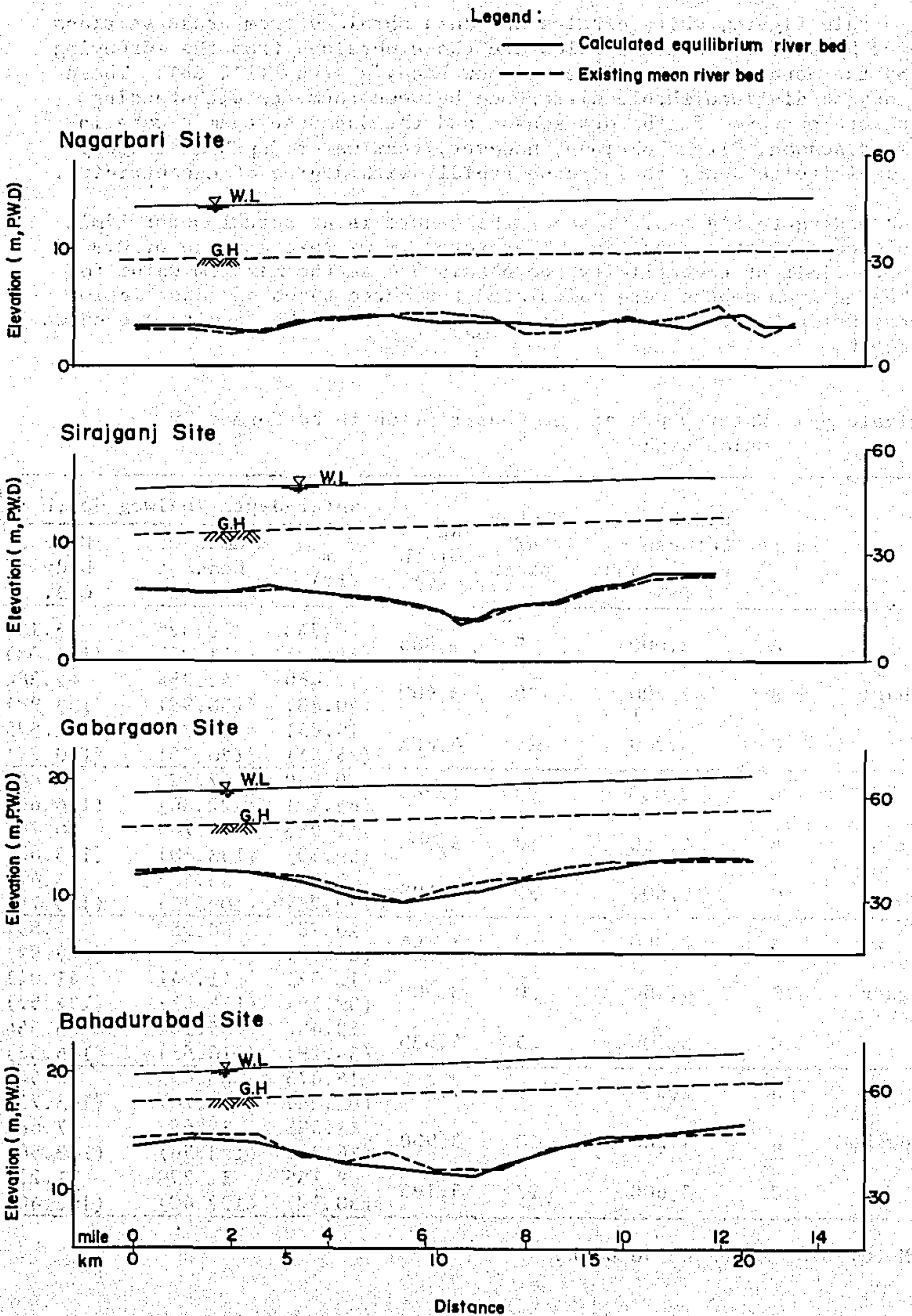
was applied to the present regimes of the river stretches which were surveyed by the Japanese Surveying Team. After some adjustment of water depth of the reference section at the lower end of a stretch, we obtained the results shown in Fig.5-4, which gives close agreement between surveyed and calculated values. Hence, it was decided to apply the equation (5.1) to the calculation of lowering of river bed due to constriction by guide banks. The calculation was made using the reference section adjusted in the above and such assumptions were made that one span of the bridge is 200 m or 656 ft, width of one pier is 12 m or 39.3 ft and the effective width on the bridge axis is reduced by 25 % of the total width of all piers. The results are shown in Table 5-4 and Fig.5-6.

4.4.2. Water depth at thalweg between guide banks.

It is evident that water depth at thalweg is larger than mean depth and the larger the eccentricity of thalweg is, the larger the depth is.

When river width is denoted by B, distance between the center of the width and thalweg by E, eccentricity of the thalweg by 2E/B, mean water depth by R, and the depth at the thalweg by H_{max}, the relation between 2E/B and H_{max}/R was studied with regard to some cross sections having remarkable eccentricity which were chosen from those surveyed by BWDB

Fig. 5-4 Comparison of River Beds Surveyed and Calculated



over the stretch from the confluence of the Ganges to the upstream 220 km from it and those surveyed in 1973 by the Japanese Surveying Team. The results are shown in Fig.5-5.

In this figure, white circles are data obtained from cross sections surveyed by BWDB and black circles are those obtained from the surveying made by the Japanese team. Crosses show Lacey's study (114 GB). These data show no distinguishable difference between them, notwithstanding BWDB's were surveyed in the dry season and the Japanese team's were in the flood season. It is obvious, however, that water depth at thalweg has a definite tendency to increase rapidly with degree of eccentricity.

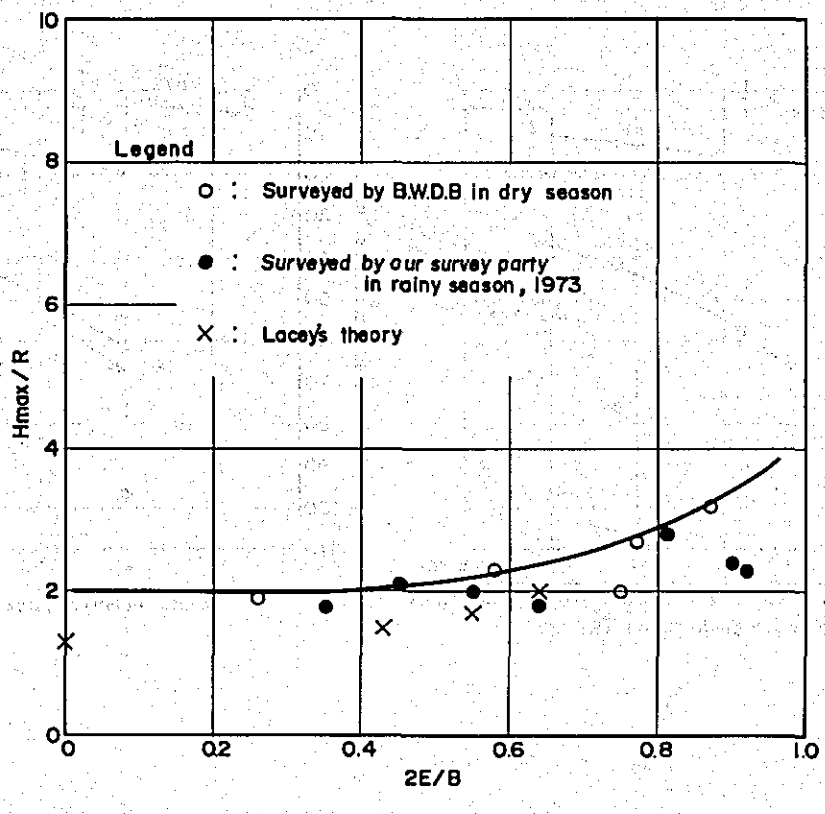
According to Fig.5-5, it seems that there is an actual upper limit in the eccentricity of thalweg. Therefore, if we take a value of 0.9 as the upper limit of eccentricity, we obtain 3.4 as the maximum value for it. The maximum depths were calculated for three types of constriction at every bridge site using the value $H_{max}/R = 3.4$. The results are shown in Fig.5-6.

Table 5-4 Water Depth at the Constriction to be Formed by Guide Banks

Site	type	Width between guide banks (m)	Number of piers	Net width (m)	Water depth m (ft)	Thalweg depth (m/ft) Hmax at head of G.B.	Thalweg depth (m/ft) Hmax at body of G.B.
Nagarbari	A	2,000	9	1,865	20.743 (68.02)	70.526 (231.26)	56.139 (184.08)
	B	4,200	20	3,900	12.466 (40.88)	42.384 (138.98)	42.384 (138.98)
	C	5,200	25	4,825	10.831 (35.51)	36.825 (120.75)	36.825 (120.75)
Sirajganj	A	2,000	9	1,865	19.949 (65.41)	67.820 (222.36)	53.862 (176.60)
	B	4,200	20	3,900	11.985 (39.30)	40.749 (133.60)	40.749 (133.60)
	C	5,600	27	5,195	9.845 (32.28)	33.473 (109.75)	33.473 (109.75)
Gabargaon	A	2,000	9	1,865	20.282 (66.50)	68.959 (226.12)	54.891 (179.99)
	B	4,200	20	3,900	12.071 (39.58)	41.041 (134.57)	41.041 (134.57)
	C	5,200	25	4,825	10.457 (34.29)	35.554 (116.58)	35.554 (116.58)
Bahadurabad	A	2,000	9	1,865	18.675 (61.24)	63.495 (208.20)	50.542 (165.73)
	B	4,200	20	3,900	11.083 (36.34)	37.682 (123.56)	37.682 (123.56)
	C	5,600	27	5,195	9.185 (30.12)	31.229 (102.40)	31.229 (102.40)

Note: G.B. means guide bank.

Fig. 5-5 Relation of H_{max}/R and $2E/B$



Data on Max. Depth in Existing River

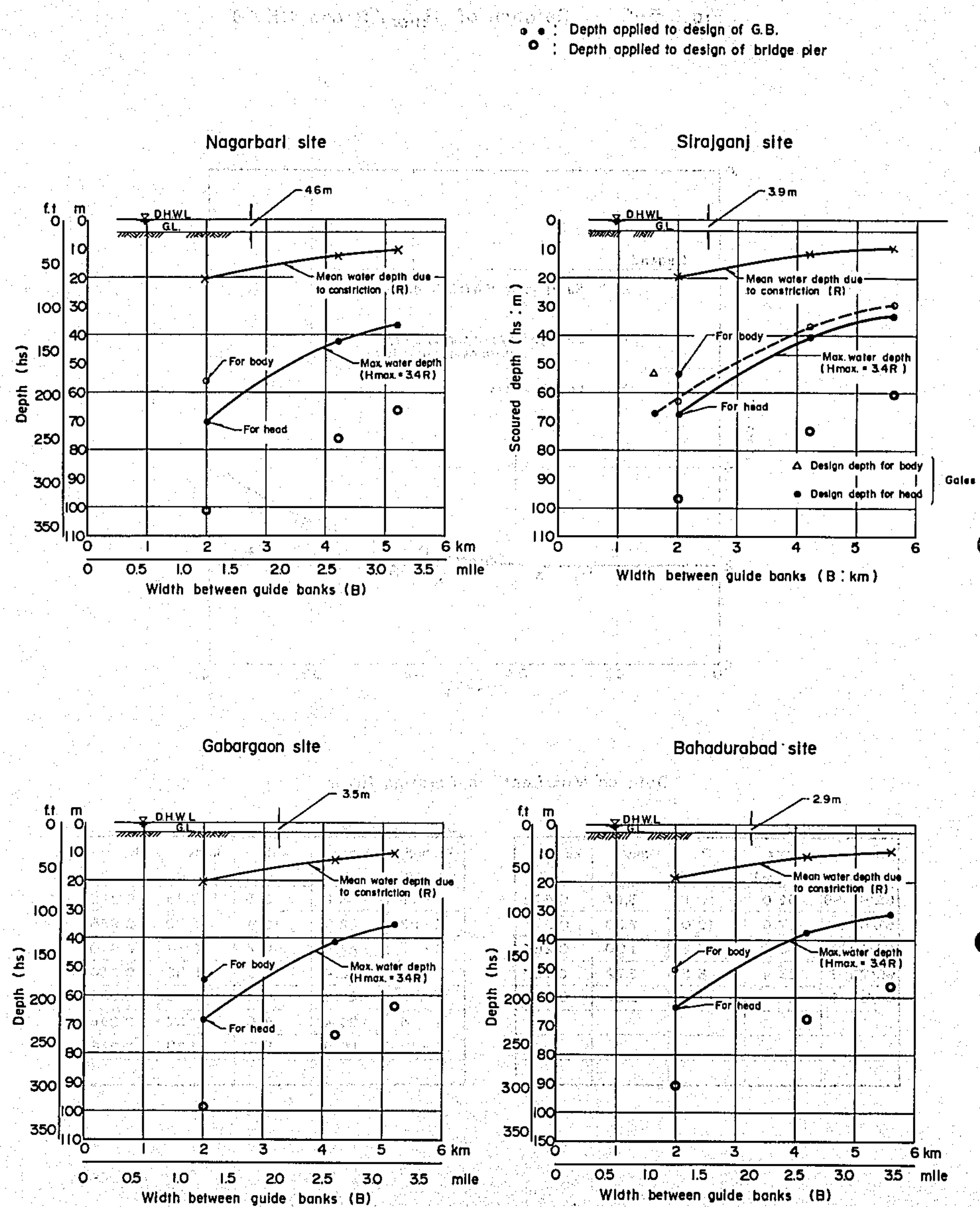
Data by B.W.D.B

Section NO.	Hmax (m)	R (m)	Hmax/R	2E/B
65/66 J-9	32.0	10.1	3.17	0.872
67/68 3-1	27.6	12.0	2.30	0.575
68/69 7	25.9	13.6	1.90	0.264
69/70 7	23.1	8.5	2.72	0.767
66/67 9	22.1	11.0	2.01	0.746

Data by our survey team

Section NO.	Hmax (m)	R (m)	Hmax/R	2E/B
S - 19	23.1	8.3	2.78	0.812
N - 22	22.9	12.9	1.78	0.636
S - 7	22.9	10.7	2.14	0.448
S - 9	22.4	12.3	1.82	0.350
S - 1	21.2	10.8	1.96	0.552
G - 4	20.4	8.6	2.37	0.896
B - 12	18.8	8.2	2.29	0.916

Fig. 5-6 Water depth at constriction due to guide bank



In these figures, crosses show mean water depth below the design high water level and black circles show the maximum water depth for $H_{max}/R = 3.4$. White circle in Fig.5-6 shows a maximum water depth in case a discharge 2,500,000 cfs, corresponding to the design discharge for Hardinge Bridge ran through the constriction considered. White circle with cross in the same figure shows the maximum water depth applied by Gales to the design of heads of guide banks at Hardinge Bridge and triangle shows the depth applied to the bodys of guide banks. This figure indicates that the maximum water depth proposed by Gales well accords with that calculated here.

Thus the maximum water depths for design of aprons was determined as follows.

a. Type-A.

Head of guide bank: maximum water depths calculated by the above method.

71 m (233 ft)	for Nagarbari site.
68 m (223 ft)	for Sirajganj site.
69 m (226 ft)	for Gabargaon site.
64 m (210 ft)	for Bahadurabad site.

Body and tail: design water depths for body and tail were determined by multiplying the above-mentioned design water depth for heads by Gales' ratio of water depth for body and tail to that of head.

57 m (187 ft)	for Nagarbari site.
54 m (177 ft)	for Sirajganj site.
55 m (180 ft)	for Gabargaon site.
51 m (167 ft)	for Bahadurabad site.

b. Type-B.

Since the width between both guide banks of this type is quite large, it is very difficult to expect that the banks can function to align river flow. Therefore, it was decided to give the same depth as calculated for head to body and tail as well.

43 m (141 ft)	for Nagarbari site.
41 m (134 ft)	for Sirajganj site.
42 m (138 ft)	for Gabargaon site.
38 m (125 ft)	for Bahadurabad site.

c. Type-C.

Based on the same idea as in the case of Type-B, the following values were adopted for design.

37 m (121 ft)	for Nagarbari site.
34 m (111 ft)	for Sirajganj site.
36 m (118 ft)	for Gabargaon site.
32 m (125 ft)	for Bahadurabad site.

4.4.3. Protection works of guide banks.

It is expected that stones placed in front of guide banks will fall with scouring at the foot and eventually achieve the purpose of revetment by covering the front of guide bank at a stable slope of 1:2. Based on this idea, an over all-apron system shown in Fig.5-7 was adopted.

(1) Length of apron.

According to the figure, length of the apron is taken as $L = 1.5D$ where D is water depth from the ground level of the apron to the prospective river bed.

(2) Thickness of pitching stones for apron.

It is necessary to provide a thickness enough to prevent leakage of sand through void of fallen apron stones. Thickness of 7 ft was taken for heads of guide banks, 6 ft 3 in for bodies and tails according to Gales' proposal. Let T_1 in Fig.5-7 be 7 ft and 6 ft 3 in, the required thickness T of the apron will be

$T = 1.5\ T_1 = 10$ ft 6 in for heads
$T = 1.5\ T_1 = 9$ ft 3 in for bodies and tails.

Considering an allowance, design thickness was taken as follows.

a. Type-A.

3.5 m for heads
3.0 m for bodies and tails

b. Type-B and C.

3.0 m for heads, bodies and tails

4.4.4. Size of pitching stones.

Size of stones which will not move even at the prospective maximum depth was calculated for each type of guide banks for each of the proposed four sites. Kramer's formula was used for the critical tractive force.

$$u_*^2 = 26.95\ d \quad \text{(c,g,s unit)}$$

The results of calculation are shown in Table 5-5. Furthermore, we calculated size of stones d' by S.V. Isbash formula as explained in 3.2, Chapter VI. Size of stones calculated by these two methods are shown in Table 5-5.

Table 5-5 Critical Size Calculated by Kramer's Formula

Site	Type	H (cm)	I	$u_* = \sqrt{gHI}$ (cm/s)	u_*^2	d (cm)	d' (cm)
Nagarbari	A, head	7052.6	1/25400	16.496	272.118	10	62
	A, body	5613.9	"	14.717	216.590	8	45
	B	4238.4	"	12.788	163.533	6	31
	C	3682.5	"	11.920	142.086	5	26
Sirajganj	A, head	6782.0	1/18500	18.945	358.903	13	81
	A, body	5386.2	"	16.883	285.038	11	59
	B	4074,9	"	14.685	215.644	8	41
	C	3347.3	"	13.309	177.139	7	31
Gabargaon	A, head	6895.9	1/15000	21.226	450.543	17	101
	A, body	5489.1	"	18.937	358.610	13	75
	B	4104.1	"	16.375	268.141	10	51
	C	3555.4	"	15.241	232.288	9	42
Bahadurabad	A, head	6349.5	1/15000	20.367	414.815	15	91
	A, body	5054.2	"	18.172	330.222	12	67
	B	3768.2	"	15.690	246.176	9	45
	C	3122.9	"	14.284	204.033	8	35

The size in Table 5-5 calculated applyed to each formula for the deepest river-bed. As shown in the same Table, there is quite differences between two groupes.

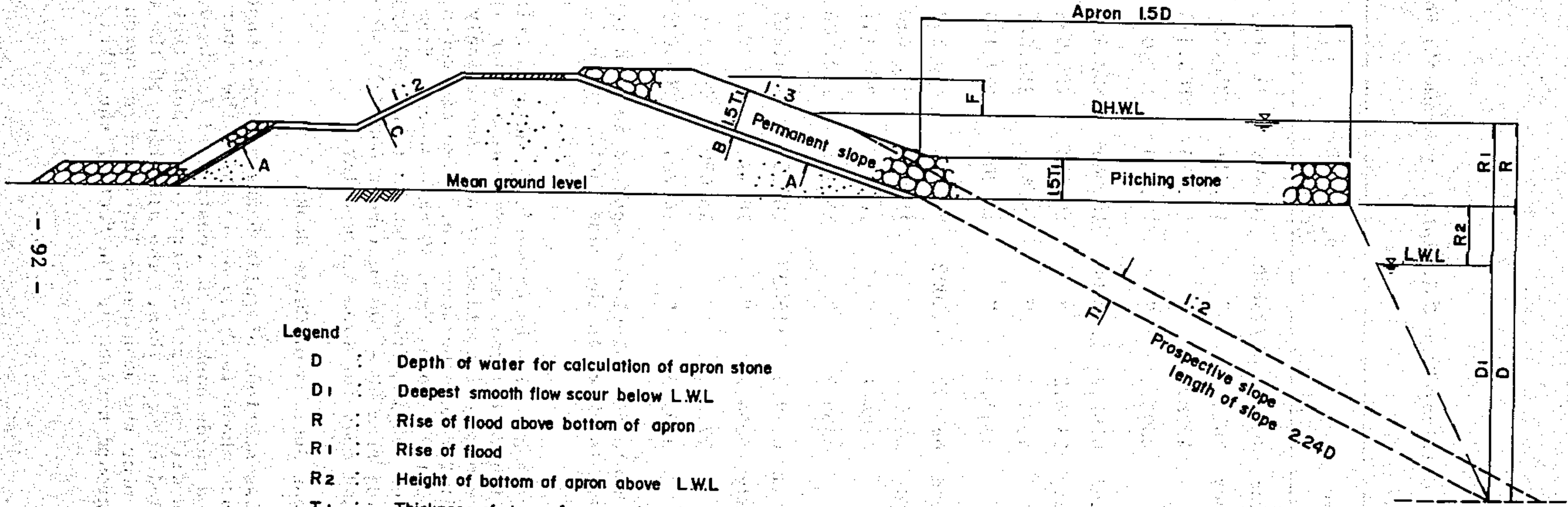
One of the reasons, size by Kramer's formula is critical size in tractive state which most stones move, whereas another size is critical one moving in case of the individual stone. Accordingly it is naturally that there is a differences between two. Size of stones was used in G.B. at Hardinge bridge ranges from 30 cm - 40 cm. From these points of view, we adopted ranging from 30 - 40 cm (about 60 Kg) for type B, C, and adopted ranging from 60 - 100 cm (about 800 Kg), 40 - 70 cm (about 300 Kg) at head and body for type A respectly.

4.5. Standard Cross Section of Guide Banks.

Standard cross sections of guide banks designed based on the studies mentioned above are shown in Fig.5-8, in which the lower diagram shows a cross section of a guide bank to be constructed in the water. In this case, stone dikes will be first constructed at both feet and then fine sand will be filled between them. The elevation of the top of the stone dike will be set near the mean water level and the apron will be placed on the existing ground surface at the foot of the dike.

Fig. 5-7 Diagram of Overall Apron

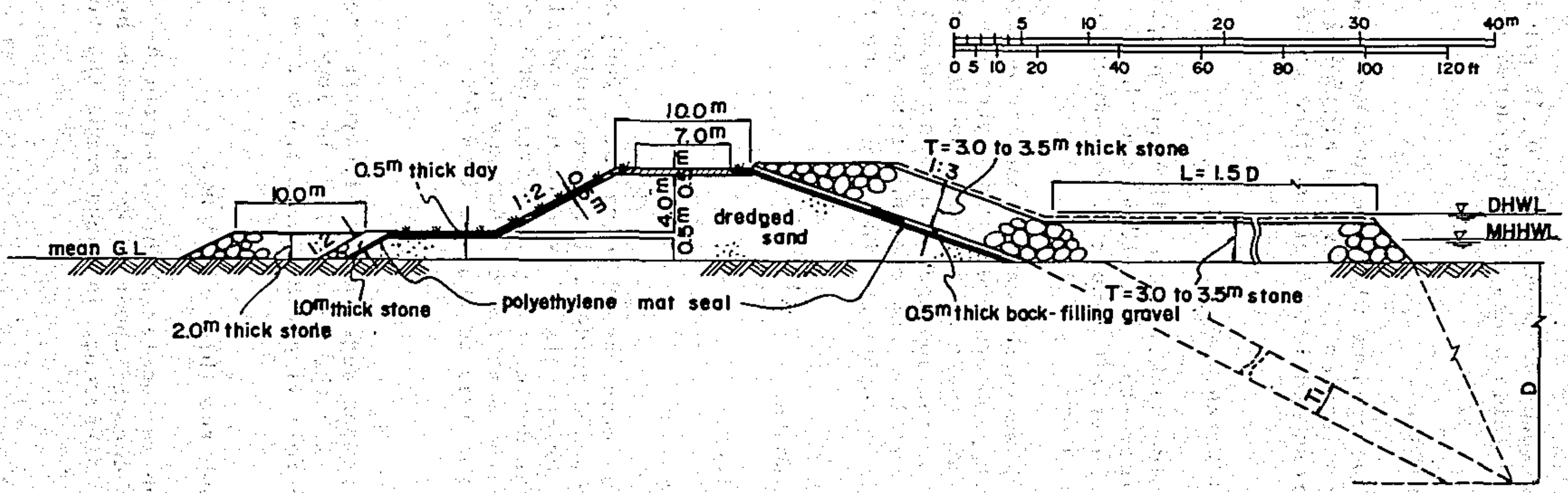
Scale 1 : 50,000



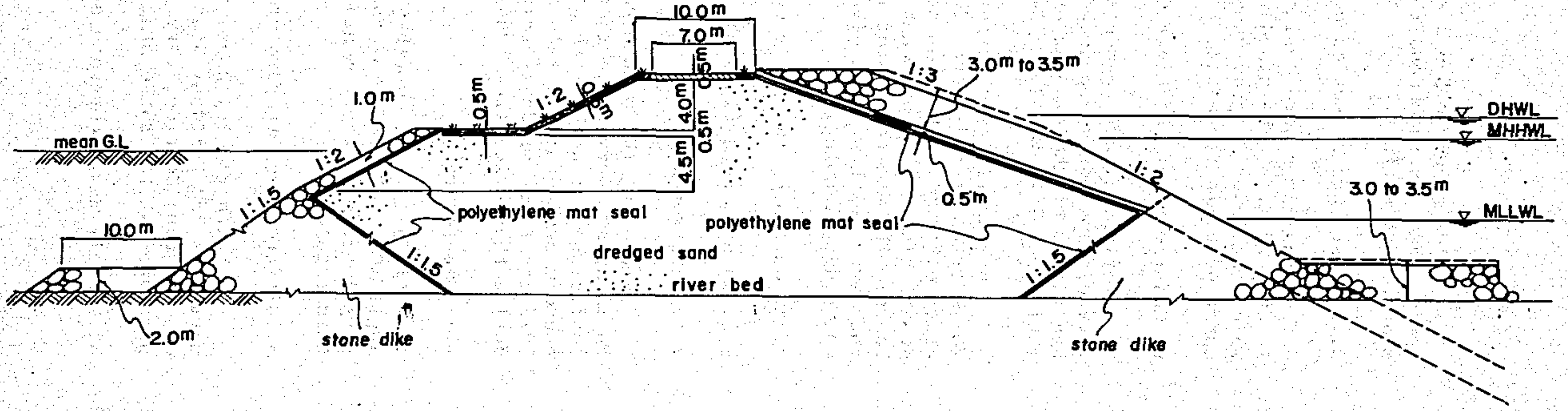
Legend

D	:	Depth of water for calculation of apron stone
D_1	:	Deepest smooth flow scour below L.W.L
R	:	Rise of flood above bottom of apron
R_1	:	Rise of flood
R_2	:	Height of bottom of apron above L.W.L
T_1	:	Thickness of stone of prospective slope below bottom of apron
$1.5T_1$	:	Thickness of stone of permanent slope and of apron
B	:	Thickness of ballast (0.5^m)
C	:	Thickness of clay (0.5^m)
F	:	Free-board : (3.0^m)
A	:	Thickness of asphalt mat

Fig. 5-8 Standard Cross Section of Guide Bank (Scale 1/500)



(In case of deep water)



Tables 5-6-1 to 5-6-3 show prospective scour depth D, length of apron L and its thickness T in case guide banks are constructed on the mean ground surface.

5. Standard Cross section of Cross Dikes.

Cross dikes were designed in accordance with the idea mentioned in 1, Chapter III. The standard cross section is shown in Fig.5-9-2 in which the lower diagram shows a cross section of cross dikes to be constructed in the water.

6. Quantities of the River Control Works.

Horizontal arrangements of guide banks, cross dikes and preparatory closing works are shown in Figs.5-10-1 to 5-10-4, and the quantities of those works and the materials required are summarized in Tables 5-7-1 to 5-7-2 and 5-8-1 to 5-8-2.

The quantities of materials shown in the tables contain allowances for settlement and losses during the construction. The materials of cross dikes given here do not contain those of the portion above the design high water level and those of the approaches outside both river banks. Those materials of the cross dikes and the approaches outside the river which are not given in this report are included in the report on bridge planning.

7. Execution of the River Control Works.

7.1. Natural conditions at work sites.

7.1.1. Mateorology.

Since the three meteorological stations at Bogra, Sirajganj and Faridpur are very close to the proposed bridge sites, meteorological conditions for works were studied using data on temperature and wind speed measured at the said stations during the period from 1960 to 1972 and those on daily rainfall also measured at the same stations during the period from 1964/65 water year to that of 1969/70.

(1) Temperature.

Fig.5-11 shows monthly mean temperature in the five years from April 1964 to March 1969 together with the highest and the lowest temperatures of every month. The following facts were found from this figure.

a. Difference of temperatures among the three stations.

Notwithstanding Bogra Station is located about 57 km north-northwest and Faridpur Station is located about 92 km south-southeast of Sirajganj Station, very little difference is found among the temperatures at the three stations.

b. Monthly mean temperature.

Table 5-6-1 Design Max. Scoured Depth : D
(Below Average Ground Level)

Site	Part of G.B.	D					
		Type A		Type B		Type C	
		m	ft	m	ft	m	ft
Nagarbari	Head	66	(216.4)	38	(124.6)	33	(108.2)
	Body, Tail	52	(170.5)	38	(124.6)	33	(108.2)
Sirajganj	Head	64	(209.8)	37	(121.3)	30	(98.4)
	Body, Tail	50	(163.9)	37	(121.3)	30	(98.4)
Gabargaon	Head	66	(216.4)	38	(124.6)	33	(108.2)
	Body, Tail	52	(170.5)	38	(124.6)	33	(108.2)
Bahadurabad	Head	61	(200.0)	35	(114.8)	29	(95.1)
	Body, Tail	48	(157.4)	35	(114.8)	29	(95.1)

Table 5-6-2 Design Length of Apron : L = 1.5 D

Site	Part of G.B.	1.5 D					
		Type A		Type B		Type C	
		m	ft	m	ft	m	ft
Nagarbari	Head	99	(324.6)	57	(186.9)	49.5	(162.3)
	Body, Tail	78	(255.7)	57	(186.9)	49.5	(162.3)
Sirajganj	Head	96	(314.8)	55.5	(182.0)	45	(147.5)
	Body, Tail	75	(245.9	55.5	(182.0)	45	(147.5)
Gabargaon	Head	99	(324.6)	57	(186.9)	49.5	(162.3)
	Body, Tail	78	(255.7)	57	(186.9)	49.5	(162.3)
Bahadurabad	Head	91.5	(300.0)	52.5	(172.1)	43.5	(142.6)
	Body, Tail	72	(236.1)	52.5	(172.1)	43.5	(142.6)

Table 5-6-3 Thickness of Stones of Slope, Apron (T)

Type	Permanent slope		Apron		Prospective slope	
	Head	Body, Tail	Head	Body, Tail	Head	Body, Tail
A	3.5(11.5)	3(9.8)	3.5(11.5)	3(9.8)	2.34(7.7)	2(6.6)
B	3 (9.8)	3(9.8)	3 (9.8)	3(9.8)	2 (6.6)	2(6.6)
C	3 (9.8)	3(9.8)	3 (9.8)	3(9.8)	2 (6.6)	2(6.6)

Fig. 5-9-1 Typical Cross Section of Approach Road (Scale 1/2,000)

(Double-track railway & four-lane road, in the vicinity of guide bank)

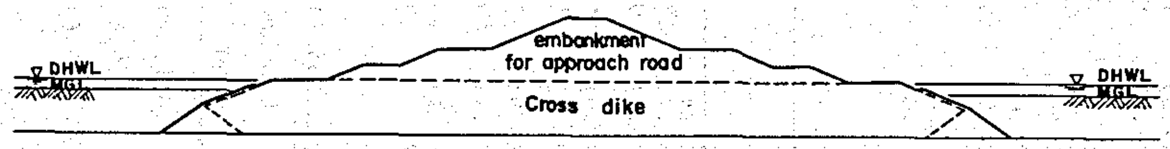


Fig. 5-9-2 Standard Cross Section of Cross Dike (Scale 1/500)

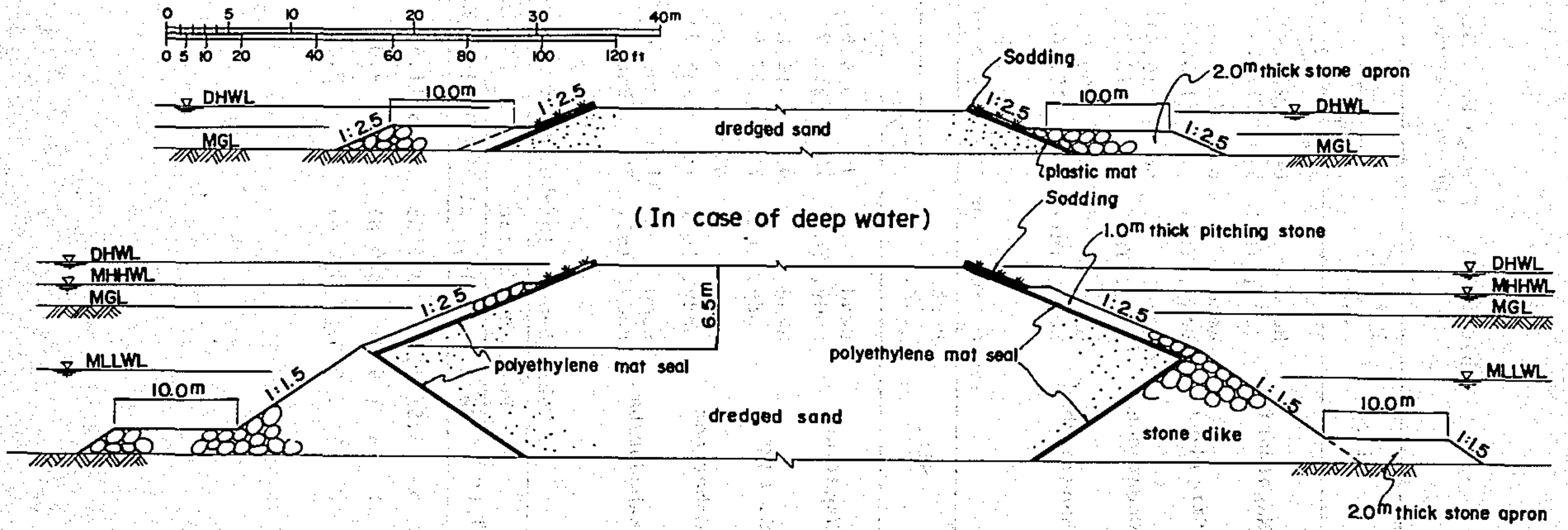
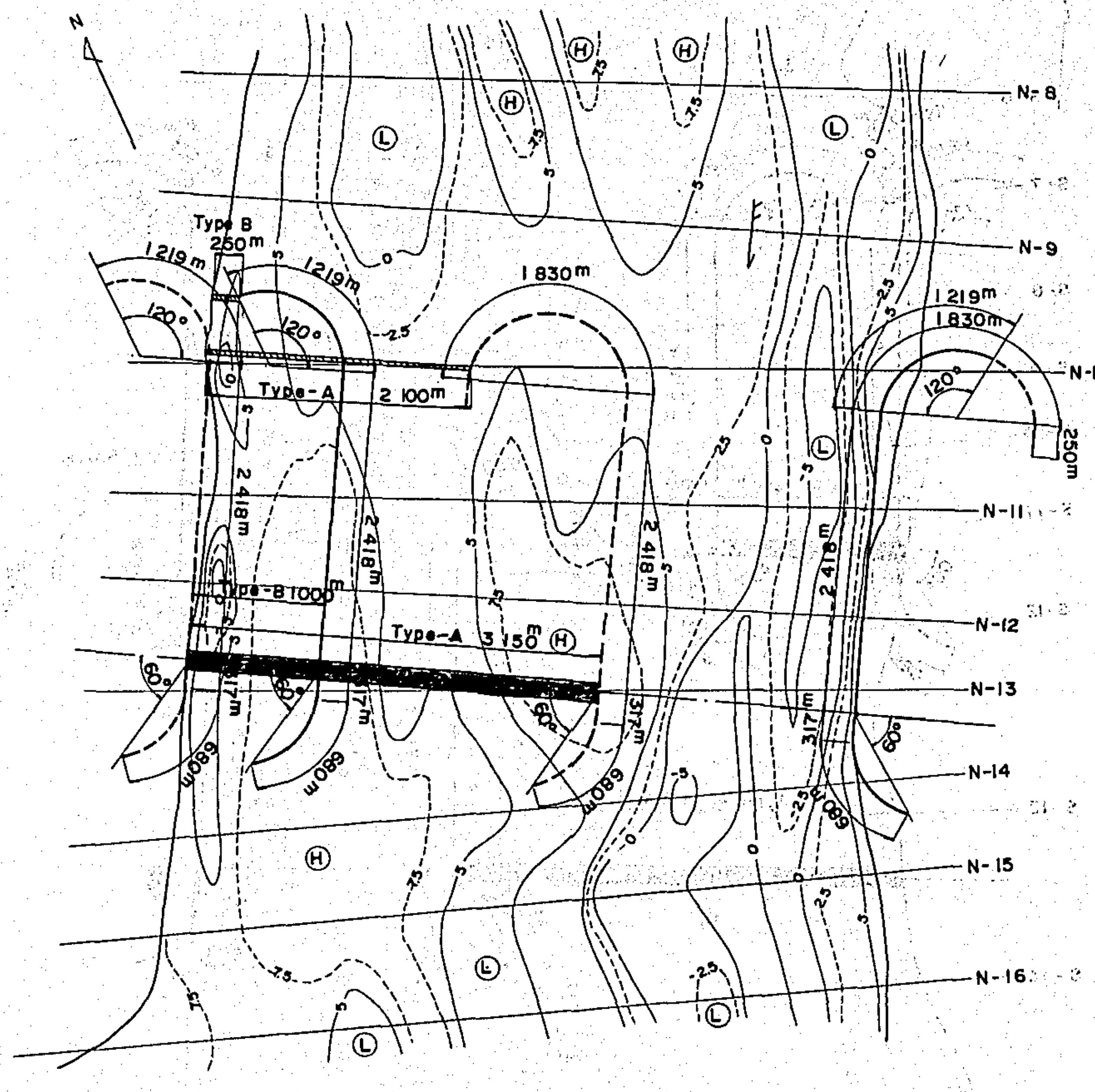


Fig.5-10-1 Arrangement of Guide Banks, Cross dikes and Closing Work

SITE : Nagarbari



SCALE : 1 / 50,000

0 1 2 3 4 5km

0 0.5 1 2 3 mile

LEGEND :

- ——— : Type - A }
- ——— : Type - B } Guide bank
- - - - - : Type - C }

- ▬▬ : Cross dike
- ═══ : Closing work
- —·— : Bridge axis

DIMENSION :

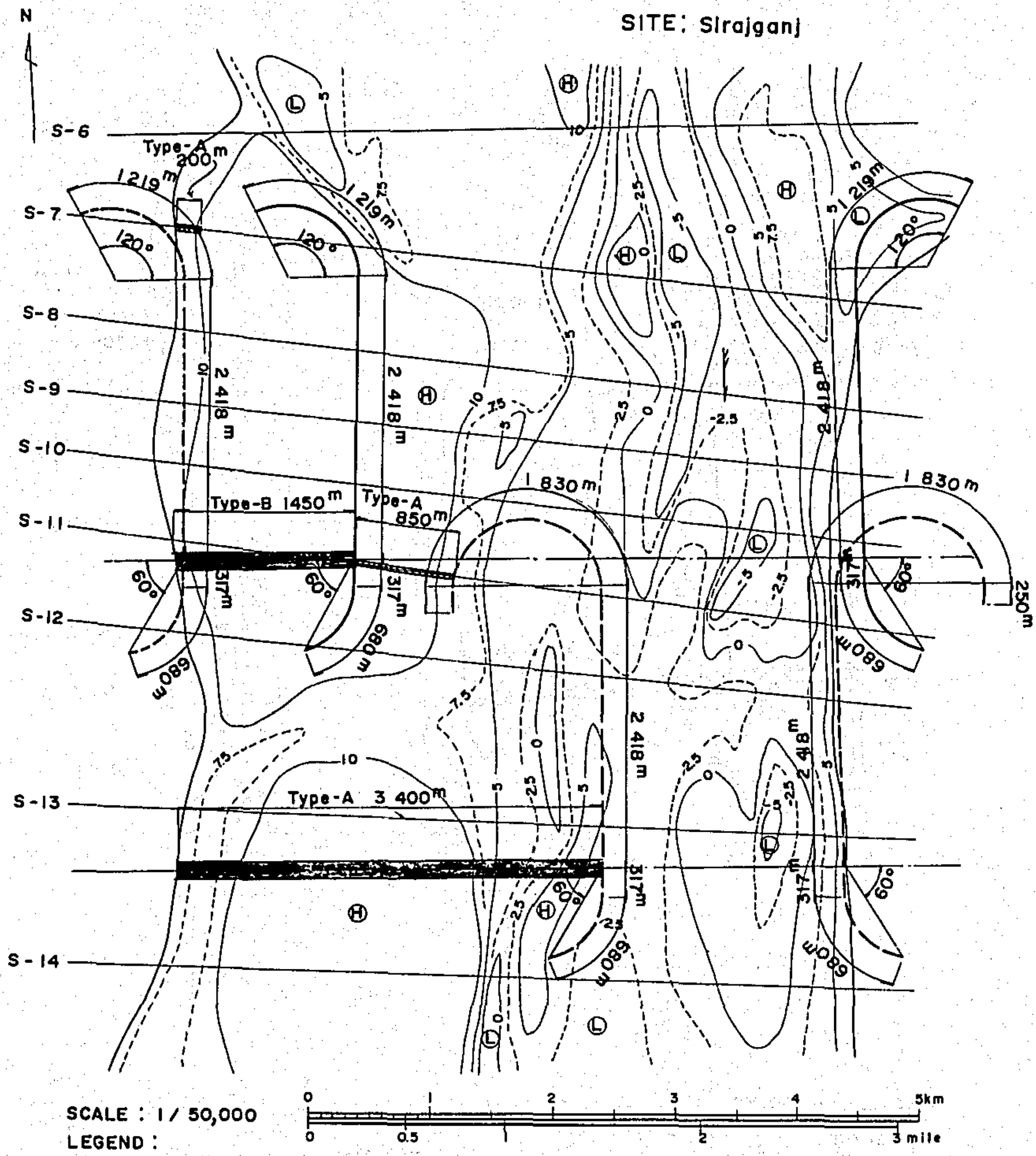
(unit : m)

TYPE	Guide bank		Cross dike		Closing work	
	Channel width	Length	Right side	Left side	Right side	Left side
A	2 000	5 495 x 2	3 150	0	2 100	0
B	4 200	4634 x 2	1 000	0	250	0
C	5 200	4 634 x 2	0	0	0	0

CONTOUR LINE : in m, PWD.

Fig. 5-10-2 Arrangement of Guide Banks, Cross dikes and Closing Work

SITE: Sirajganj



LEGEND :

- ——— : Type-A
- ——— : Type-B
- - - - : Type-C

(Type-A, Type-B, Type-C: Guide bank)

- : Cross dike
- : Closing work
- —·— : Bridge axis

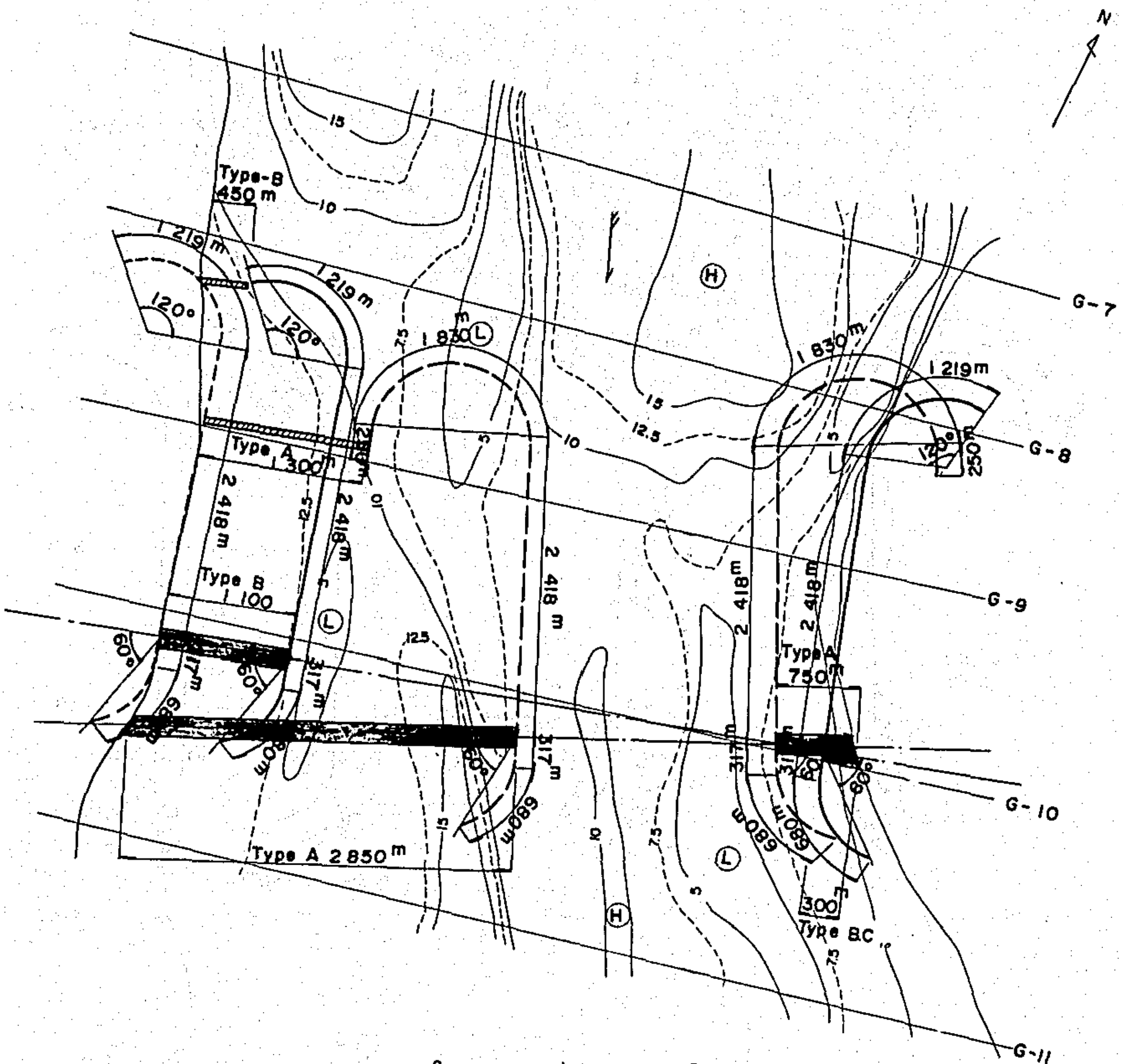
DIMENSION : (unit : m)

TYPE	Guide bank		Cross dike		Closing work	
	Channelwidth	Length	Right side	Left side	Right side	Left side
A	2 000	5 495 x 2	3 400	0	1 050	0
B	4 200	4 634 x 2	1 450	0	200	0
C	5 600	4 634 x 2	0	0	0	0

CONTOUR LINE : In m, PWD.

Fig.5-10-3 Arrangement of Guide Banks, Cross dikes and Closing Work

SITE : Gabargaon



SCALE : 1/ 50,000

0 1 2 3 4 5km
0 0.5 1 2 3 mile

LEGEND :

——— : Type - A }
——— : Type - B } Guide bank
- - - - : Type - C }

: Cross dike
: Closing work
—·— : Bridge axis

DIMENSION :

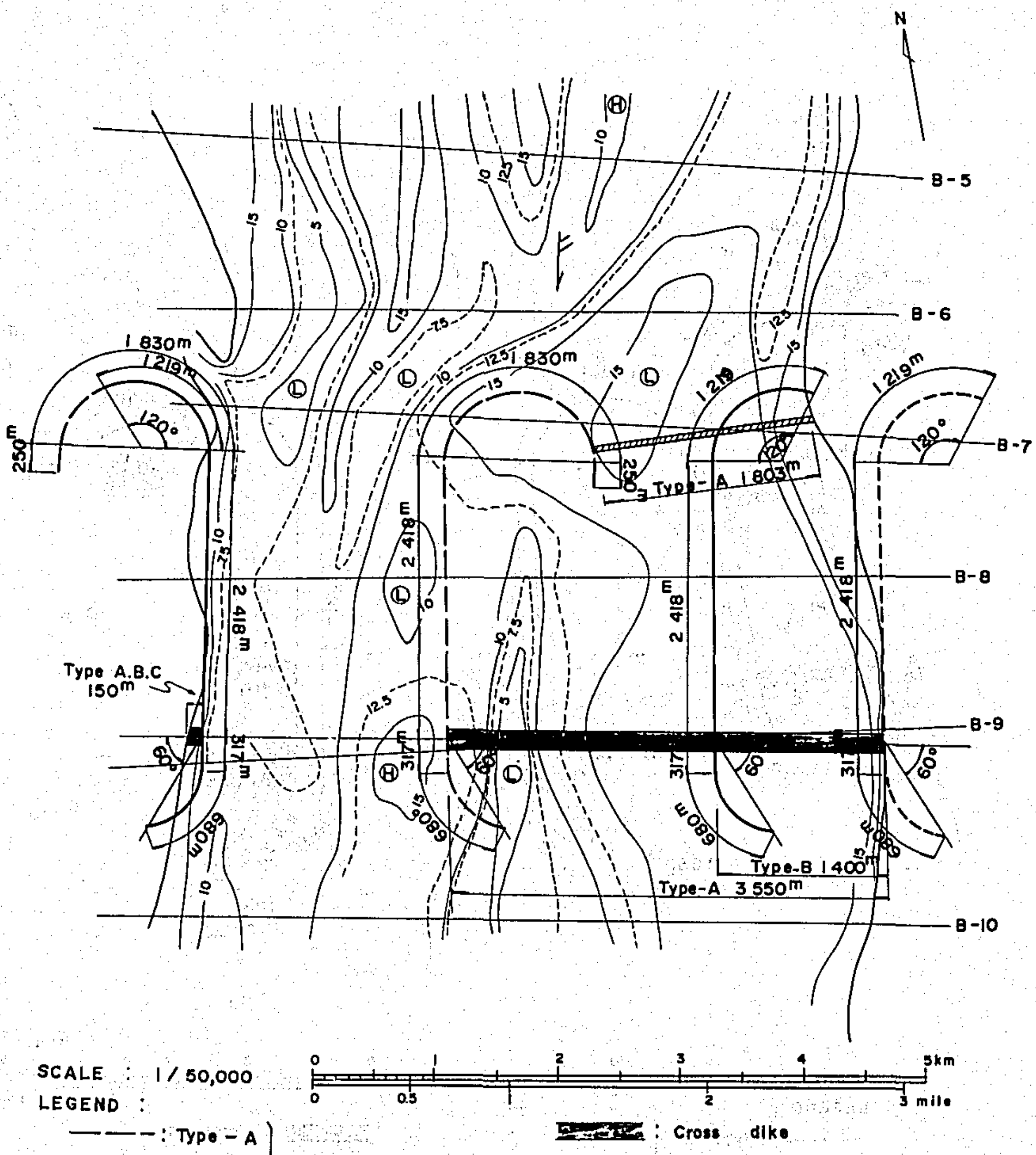
(unit : m)

TYPE	Guide bank		Cross dike		Closing work	
	Channel width	Length	Right side	Left side	Right side	Left side
A	2 000	5 495 x 2	2 850	750	1 300	0
B	4 200	4 634 x 2	1 100	300	450	0
C	5 200	4 634 x 2	0	300	0	0

CONTOUR LINE : in m, PWD.

Fig.5-10-4 Arrangement of Guide Banks, Cross dikes and closing Work.

SITE : Bahadurabad



LEGEND :

— — — : Type – A	Guide bank	Cross dike
——— : Type – B		Closing work
- - - - : Type – C		Bridge axis

DIMENSION : (unit : m)

TYPE	Guide bank		Cross dike		Closing work	
	Channel Width	Length	Right side	Left side	Right side	Left side
A	2 000	5 495 x 2	150	3 550	0	1805
B	4 200	4 634 x 2	150	1 400	0	0
C	5 600	4 634 x 2	150	0	0	0

CONTOUR LINE : in m , PWD.

Table 5-7-1 Quantity of Works

site: Nagarbari

	Works	Condition	Unit	Type A Left	Type A Right	Type B Left	Type B Right	Type C Left	Type C Right
Guide bank	Embankment	O.G.	km	5.5	2.8	4.6	4.6	4.6	4.6
		U.W.	km	0	2.7	0	0	0	0
		Σ	km	5.5	5.5	4.6	4.6	4.6	4.6
	Apron	O.G.	km	5.5	2.8	4.6	4.6	4.6	4.6
		U.W.	km	0	2.7	0	0	0	0
		Σ	km	5.5	5.5	4.6	4.6	4.6	4.6
	Pavement		km	5.5	5.5	4.6	4.6	4.6	4.6
Cross dike		O.G.	km	0	2.10	0	0.50	0	0
		U.W.	km	0	1.05	0	0.50	0	0
		Σ	km	0	3.15	0	1.00	0	0
Closing work		O.G.	km	0	2.1	0	0.25	0	0
		U.W.	km	0	0	0	0	0	0
		Σ	km	0	2.1	0	0.25	0	0
Construction road		O.G.	km	5.5	9.7	3.2	4.6	3.2	4.6
		U.W.	km	0	2.2	1.4	2.0	1.4	0
		Σ	km	5.5	11.9	4.6	6.6	4.6	4.6
Jetty			nos.	(0)	6 (6)	(0) 1	(1)	(0) 0	(0)

Site: Sirajganj

	Works	Condition	Unit	Type A Left	Type A Right	Type B Left	Type B Right	Type C Left	Type C Right
Guide bank	Embankment	O.G.	km	5.5	1.0	4.6	4.6	4.6	4.6
		U.W.	km	0	4.5	0	0	0	0
		Σ	km	5.5	5.5	4.6	4.6	4.6	4.6
	Apron	O.G.	km	5.5	1.0	4.6	4.6	4.6	4.6
		U.W.	km	0	4.5	0	0	0	0
		Σ	km	5.5	5.5	4.6	4.6	4.6	4.6
	Pavement		km	5.5	5.5	4.6	4.6	4.6	4.6
Cross dike		O.G.	km	0	2.30	0	1.45	0	0
		U.W.	km	0	1.10	0	0	0	0
		Σ	km	0	3.40	0	1.45	0	0
Closing work		O.G.	km	0	1.05	0	0.20	0	0
		U.W.	km	0	0	0	0	0	0
		Σ	km	0	1.05	0	0.20	0	0
Construction road		O.G.	km	5.5	12.3	3.3	6.9	3.3	1.5
		U.W.	km	0	0.6	1.3	0.5	1.3	3.1
		Σ	km	5.5	12.9	4.6	7.4	4.6	4.6
Jetty			nos.	(0)	10 (10)	(0) 0	(0)	(0) 0	(0)

O.G. : Works on the ground
U.W. : Works under water
Σ : Sum of O.G. and U.W.

Table 5-7-2 Quantity of Works

Site: Gabargaon

Works		Condition	Unit	Type A Left	Type A Right	Type B Left	Type B Right	Type C Left	Type C Right
Guide bank	Embankment	O.G.	km	1.4	0.3	4.6	4.6	4.6	4.6
		U.W.	km	4.1	5.2	0	0	0	0
		Σ	km	5.5	5.5	4.6	4.6	4.6	4.6
	Apron	O.G.	km	1.4	0.3	4.6	4.6	4.6	4.6
		U.W.	km	4.1	5.2	0	0	0	0
		Σ	km	5.5	5.5	4.6	4.6	4.6	4.6
	Pavement		km	5.5	5.5	4.6	4.6	4.6	4.6
Cross dike		O.G.	km	0.30	1.95	0.75	1.10	0	0
		U.W.	km	0.45	0.90	0	0	0	0
		Σ	km	0.75	2.85	0.75	1.10	0	0
Closing work		O.G.	km	0	1.30	0	0.45	0	0
		U.W.	km	0	0	0	0	0	0
		Σ	km	0	1.30	0	0.45	0	0
Construction road		O.G.	km	5.5	10.7	3.0	4.2	3.0	4.6
		U.W.	km	0	1.2	1.6	2.4	1.6	0
		Σ	km	5.5	11.9	4.6	6.6	4.6	4.6
Jetty			nos.	(9) 11	(11)	(0) 0	(0)	(0) 0	(0)

Site: Bahadurabad

Works		Condition	Unit	Type A Left	Type A Right	Type B Left	Type B Right	Type C Left	Type C Right
Guide bank	Embankment	O.G.	km	3.7	5.5	4.6	4.6	4.6	4.6
		U.W.	km	1.8	0	0	0	0	0
		Σ	km	5.5	5.5	4.6	4.6	4.6	4.6
	Apron	O.G.	km	3.7	5.5	4.6	4.6	4.6	4.6
		U.W.	km	1.8	0	0	0	0	0
		Σ	km	5.5	5.5	4.6	4.6	4.6	4.6
	Pavement		km	5.5	5.5	4.6	4.6	4.6	4.6
Cross dike		O.G.	km	3.10	0.15	1.40	0.15	0	0.15
		U.W.	km	0.45	0	0	0	0	0
		Σ	km	3.55	0.15	1.40	0.15	0	0.15
Closing work		O.G.	km	1.80	0	0	0	0	0
		U.W.	km	0	0	0	0	0	0
		Σ	km	1.80	0	0	0	0	0
Construction road		O.G.	km	11.9	5.5	7.4	4.6	4.6	4.6
		U.W.	km	0.8	0	0	0	0	0
		Σ	km	12.7	5.5	7.4	4.6	4.6	4.6
Jetty			nos.	(6) 6	(0)	(0) 0	(0)	(0) 0	(0)

O.G. : Works on the ground
U.W. : Works under water
Σ : Sum of O.G. and U.W.

Table 5-8-1 Quantity of Materials (1)

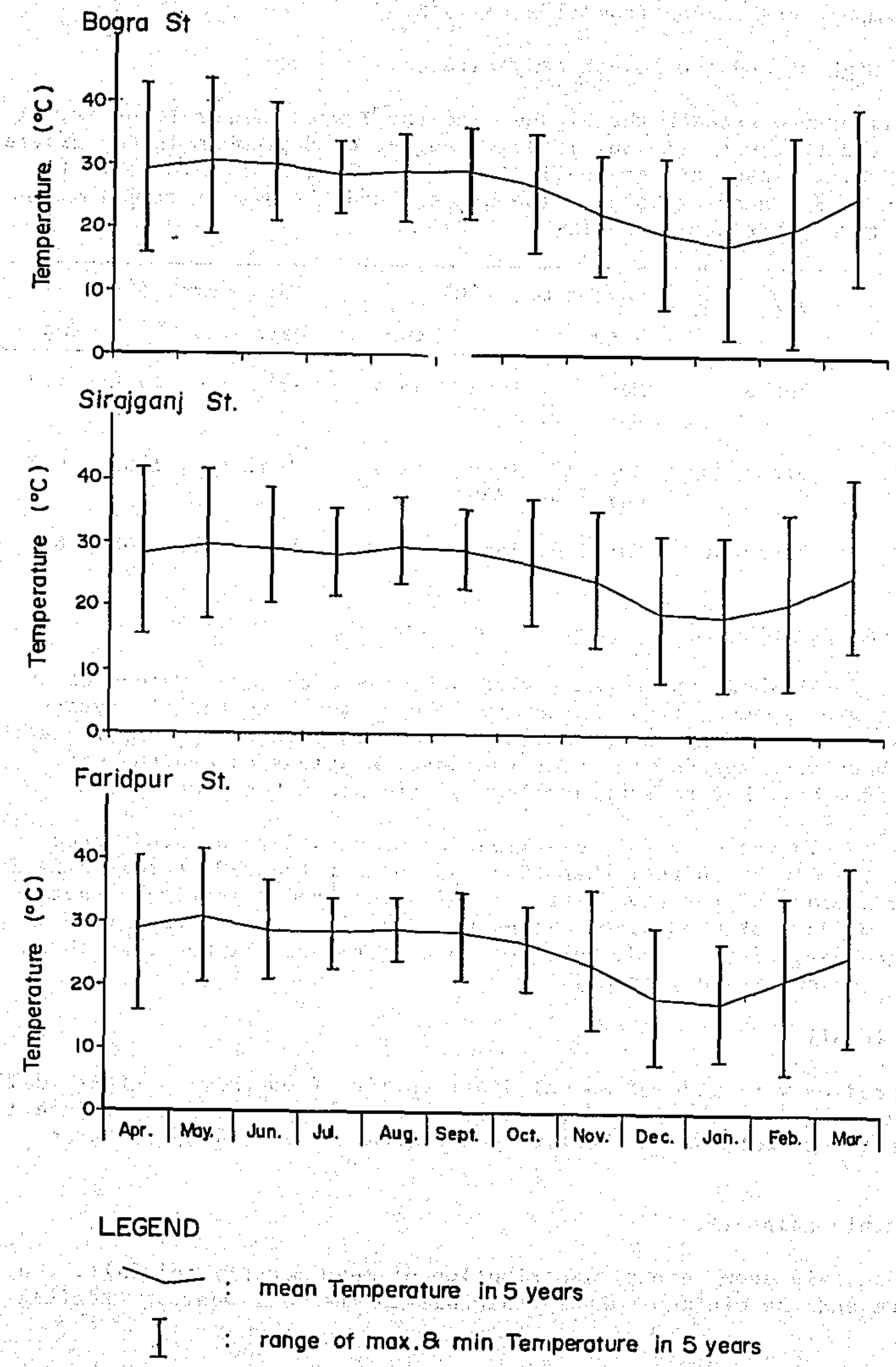
Site	Type	Side	Unit	Guide Bank			Cross Dike			Closing Work			Total		
				Stone	Chip	Dredged sand	Stone	Chip	Dredged sand	Stone	Chip	Dredged sand	Stone	Chip	Dredged sand
Bahadurabad	A	L	$10^3 m^3$	2615	225	2596	397	7	4428	139	8	–	3151	240	7024
		R		2309	219	1873	11	1	236	–	–	–	2320	220	2109
	B	L		1230	188	890	78	2	1092	–	–	–	1308	190	1982
		R		1290	174	1737	11	1	236	–	–	–	1301	175	1973
	C	L		1087	154	795	–	–	–	–	–	–	1087	154	795
		R		1146	174	1737	11	1	236	–	–	–	1157	175	1973
Gabargaon	A	L		2861	142	3300	78	3	1500	–	–	–	2939	145	4800
		R		2943	159	3903	341	9	4877	100	6	–	3384	174	8780
	B	L		1381	148	1649	21	1	473	–	–	–	1402	149	2122
		R		1471	187	2346	69	3	1129	56	3	–	1596	193	3475
	C	L		1255	148	1649	21	1	473	–	–	–	1276	149	2122
		R		1203	157	851	–	–	4975	–	–	–	1203	157	851
Sirajganj	A	L		2338	203	1082	–	–	–	–	–	–	2338	203	1082
		R		2905	176	3760	313	9	4975	78	4	–	3296	191	8735
	B	L		1312	150	1428	–	–	–	–	–	–	1312	150	1428
		R		1311	189	1086	79	2	1126	20	1	–	1410	192	2212
	C	L		1144	150	1428	–	–	–	–	–	–	1144	150	1428
		R		1210	160	1726	–	–	–	–	–	–	1210	160	1726
Nagarbari	A	L		2560	229	2299	–	–	–	–	–	–	2560	229	2299
		R		2952	216	3360	289	10	5176	293	15	315	3534	241	9951
	B	L		1422	171	1921	–	–	–	–	–	–	1422	171	1921
		R		1518	185	2349	111	3	–	–	1	–	1648	189	3971
	C	L		1290	171	1921	–	–	1622	19	–	–	1290	171	1921
		R		1230	167	1321	–	–		–	–	–	1230	167	1321

Table 5-8-2 Quantity of Materials (2)

Site	Type	Side	Guide Bank			Cross Dike		Closing Work			Total				
			Poly-ethylene mat ($x10^3m^2$)	Sod-ding ($x10^3m^2$)	Crown pave-ment ($x10^3m^2$)	Poly-ethylene mat ($x10^3m^2$)	Sod-ding ($x10^3m^2$)	Poly-ethylene mat ($x10^3m^2$)	Earth exca-vation ($x10^3m^3$)	Sheet pile ($x10^3m$)	Poly-ethylene mat ($x10^3m^2$)	Sod-ding ($x10^3m^2$)	Crown pave-ment ($x10^3m^2$)	Earth exca-vation ($x10^3m^3$)	Sheet pile ($x10^3m$)
Bahadurabad	A	L	251.0	107.5	38.5	66.2	81.8	54.7	75.8	2.09	371.9	189.3	38.5	75.8	2.09
		R	190.3	107.2	38.5	3.7	3.5	-	-	-	194.0	110.7	38.5	-	-
	B	L	116.8	90.3	32.4	14.6	32.2	-	-	-	131.4	122.5	32.4	-	-
		R	172.7	90.3	32.4	3.7	3.5	-	-	-	176.4	93.8	32.4	-	-
	C	L	103.4	90.3	32.4	-	-	-	-	-	103.4	90.3	32.4	-	-
		R	172.7	90.3	32.4	3.7	3.5	-	-	-	176.4	93.8	32.4	-	-
Gabargaon	A	L	270.3	107.3	38.5	25.3	17.3	-	-	-	295.6	124.6	38.5	-	-
		R	309.3	107.3	38.5	81.2	65.7	100.4	45.9	1.32	490.9	173.0	38.5	45.9	1.32
	B	L	162.8	90.5	32.4	7.4	6.9	-	-	-	170.2	97.4	32.4	-	-
		R	218.8	90.4	32.4	18.5	25.3	20.0	15.9	0.47	257.3	115.7	32.4	15.9	0.47
	C	L	162.8	90.5	32.4	7.4	6.9	-	-	-	170.2	97.4	32.4	-	-
		R	112.7	80.3	32.4	-	-	-	-	-	112.7	90.3	32.4	-	-
Sirajganj	A	L	161.2	107.1	38.5	-	-	-	-	-	116.2	107.1	38.5	-	-
		R	319.6	105.2	38.5	74.6	78.3	29.1	37.1	1.09	423.3	183.5	38.5	37.1	1.09
	B	L	148.0	90.4	32.4	-	-	-	-	-	148.0	90.4	32.4	-	-
		R	83.0	90.4	32.4	14.1	33.4	7.7	7.1	0.22	104.8	123.8	32.4	7.1	0.22
	C	L	146.0	90.4	32.4	-	-	-	-	-	146.0	90.4	32.4	-	-
		R	175.0	90.5	32.4	-	-	-	-	-	175.0	90.5	32.4	-	-
Nagarbari	A	L	182.6	107.3	38.5	-	-	-	-	-	182.6	107.3	38.5	-	-
		R	285.0	107.3	38.5	85.7	72.6	96.9	0	2.12=	467.6	179.9	38.5	74.1	2.12
	B	L	188.5	90.5	32.4	-	-	-	-	-	188.5	90.5	32.4	-	-
		R	211.9	90.5	32.4	26.8	23.0	7.1	8.8	0.27	245.8	113.5	32.4	8.8	0.27
	C	L	188.5	90.5	32.4	-	-	-	-	-	188.5	90.5	32.4	-	-
		R	147.8	90.3	32.4	-	-	-	-	-	147.8	90.3	32.4	-	-

Fig. 5-11 Mean Temperature

(according to date from Apr.1964 to Mar.1969)



Monthly mean temperature is almost constant in the rainy season from May to September at all of the three stations ranging from 28°C to 31°C. The mean temperature gradually falls after October attaining to the lowest in January and gradually rises again after it. The monthly mean temperature in January ranges from 17°C to 19°C. Annual difference of mean temperature ranges from 11°C to 13°C.

c. The highest and the lowest temperatures.

Difference between the highest and the lowest temperatures is, at a any of the stations, minimum in July, August or September in the middle of the rainy season and gradually increases after it attaining to the maximum in February or March. The highest and the lowest temperatures in the five years are as follows.

Met. sta.	Max. temp. (°C)		Min. temp. (°C)	
	Date	Temp.	Date	Temp.
Bogra	May 3, 1966 May 2, 1965	43.4	Feb. 4, 1968	1.7
Sirajganj	Apr. 17, 1966 May 3-5, 1966	41.7	Jan. 1-2, 1965	6.7
Faridpur	May 1-2, 1965	41.7	Feb. 4-5, 1968	6.7

(2) Wind speed.

Fig.5-12 shows the highest wind speeds and the mean values of the highest wind speeds at the three stations by month in the five years. According to this figure, no definite trend is seen in monthly variation of highest wind speeds at any of the three stations though the wind speed from November to February is a little lower than the others.

Fig.5-13 shows monthly distribution of wind days of wind speed higher than 10 kt, higher than 20 kt and higher than 30 kt respectively on the average of the five years. It is seen from this figure that number of days of wind speed exceeding 10 kt increases toward the northern part of the land, but there are no records higher than 10 kt between November and February.

(3) Rainfall.

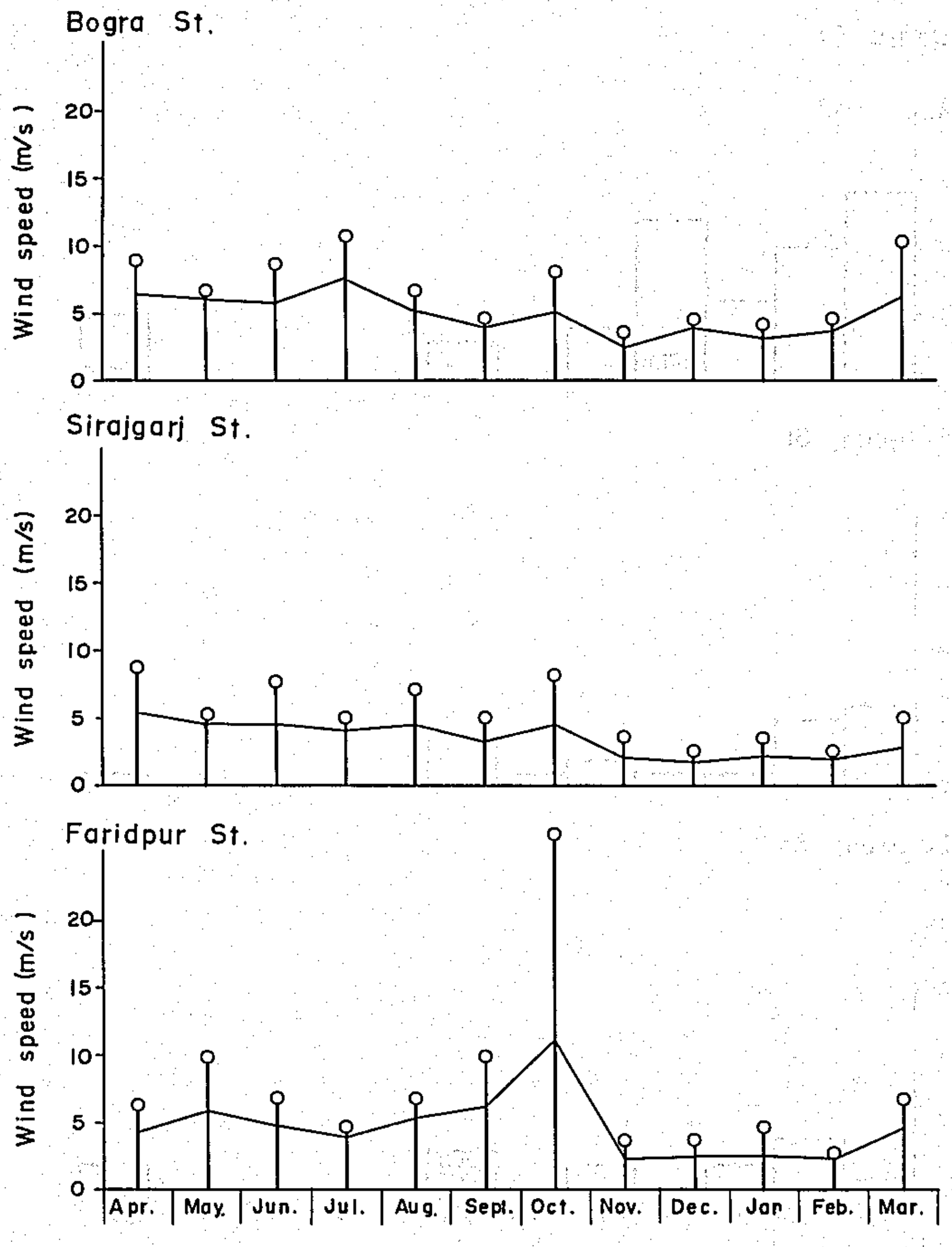
Studies were made of annual distribution of monthly rainfall, daily rainfall and distribution of rainfall days by height of daily rainfall at the three stations in the five years from April 1964 up to March 1969.

a. Monthly rainfall.

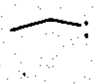
Fig.5-14 shows annual distribution of mean monthly rainfall, the maximum and the minimum monthly rainfall in the five years. Rainfall

Fig. 5-12 Maximum Wind Speed

(according to data from Apr 1964 to Mar. 1969)



LEGEND



o : max. wind speed in 5 years.

—: mean value of max wind speeds in 5 years.

Fig. 5-13 Frequency of Wind Speed

(According to data from Apr 1964 to Mar 1969)

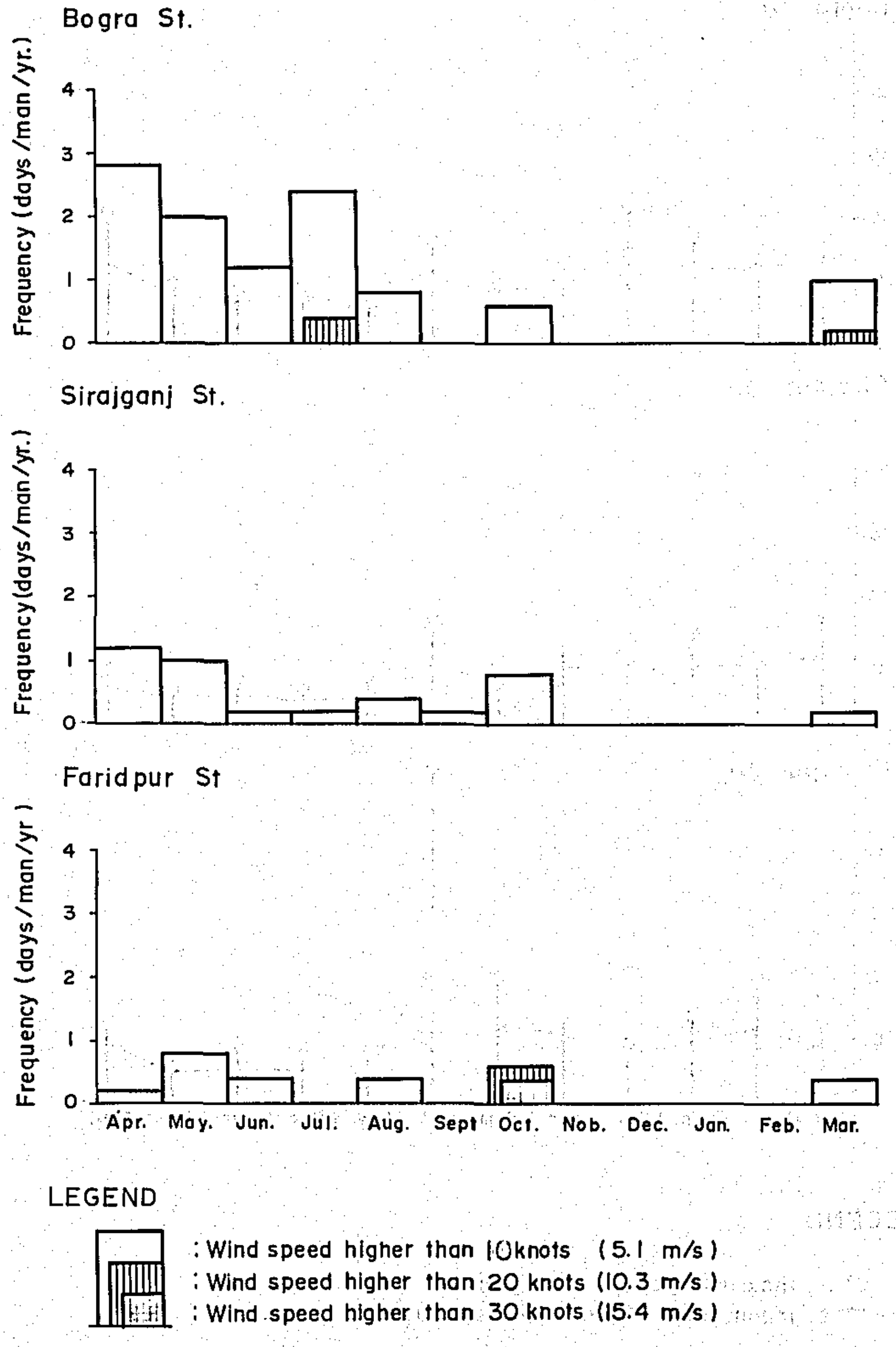
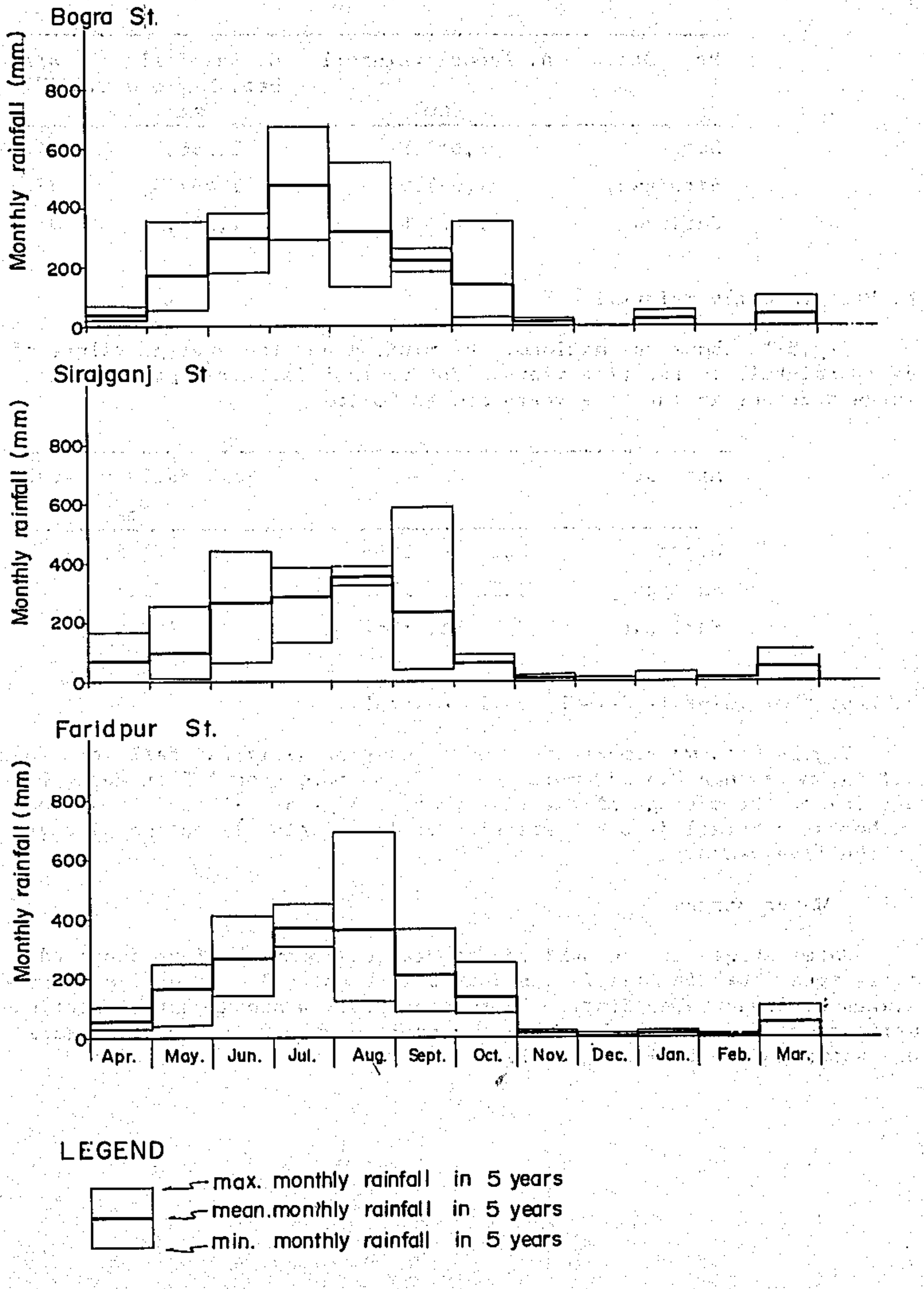


Fig 5-14 Mean Monthly Rainfall

(According to data from Apr. 1964 to Mar. 1969)



at every station reaches the maximum in August of September decreasing gradually before and after the months and major portion of the rainfall is concentrated on the period from May to October. Mean annual rainfall in the five years and ratios of the rainfall between May and October to the annual rainfall are given in the following table.

Met. Sta.	A. Annual rainfall (mm)	B. Rainfall bet. May & Oct. (mm)	B/A (%)
Bogra	1,651.9	1,566.1	94.8
Sirajganj	1,621.6	1,497.9	92.4
Faridpu	1,426.6	1,298.2	91.0

b. Maximum daily rainfall.

Fig.5-15 shows the maximum, the minimum and the average values of daily rainfall in the five years. The maximum daily rainfalls at the three stations in the five years are as follows.

Met. Sta.	Date	Max. daily rainfall (mm)
Bogra	Jul. 30, 1965	171.5
Sirajganj	Jul. 9, 1965	172.8
Faridpur	Jun. 15, 1964	152.4

c. Number of rainfall days by daily rainfall.

Fig.5-16 shows number of rainfall days of daily rainfall more than 0.1 in, more than 0.5 in, more than 1.0 in, more than 1.5 in and 2.0 in per day on the average of the five years. Figs.5-17-1 to 5-17-3 show number of rainfall days by intensity of daily rainfall on the average of the five years.

7.1.2. Water stages.

Water stages at the BWDB gaging stations near the four proposed sites were shown in Figs.2-15 and 2-16 in Chapter II. Significant water stages at Bahadurabad Station, Sirajganj Station and Kadamtali Station were selected from the above and the average values in the five years are shown in the following table.

Fig. 5-15 Daily Rainfall

(According to data from Apr.1964 to Mar.1969)

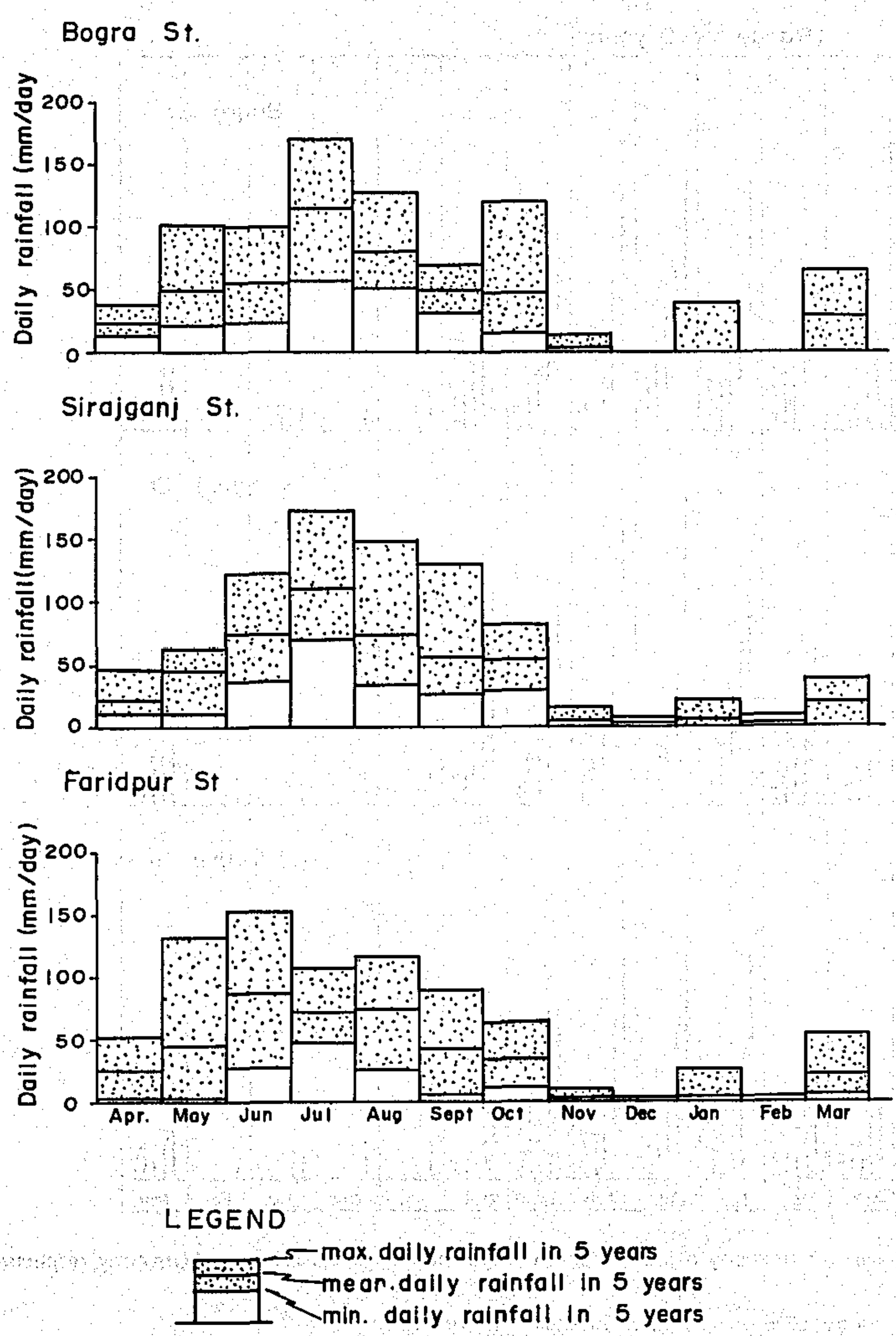
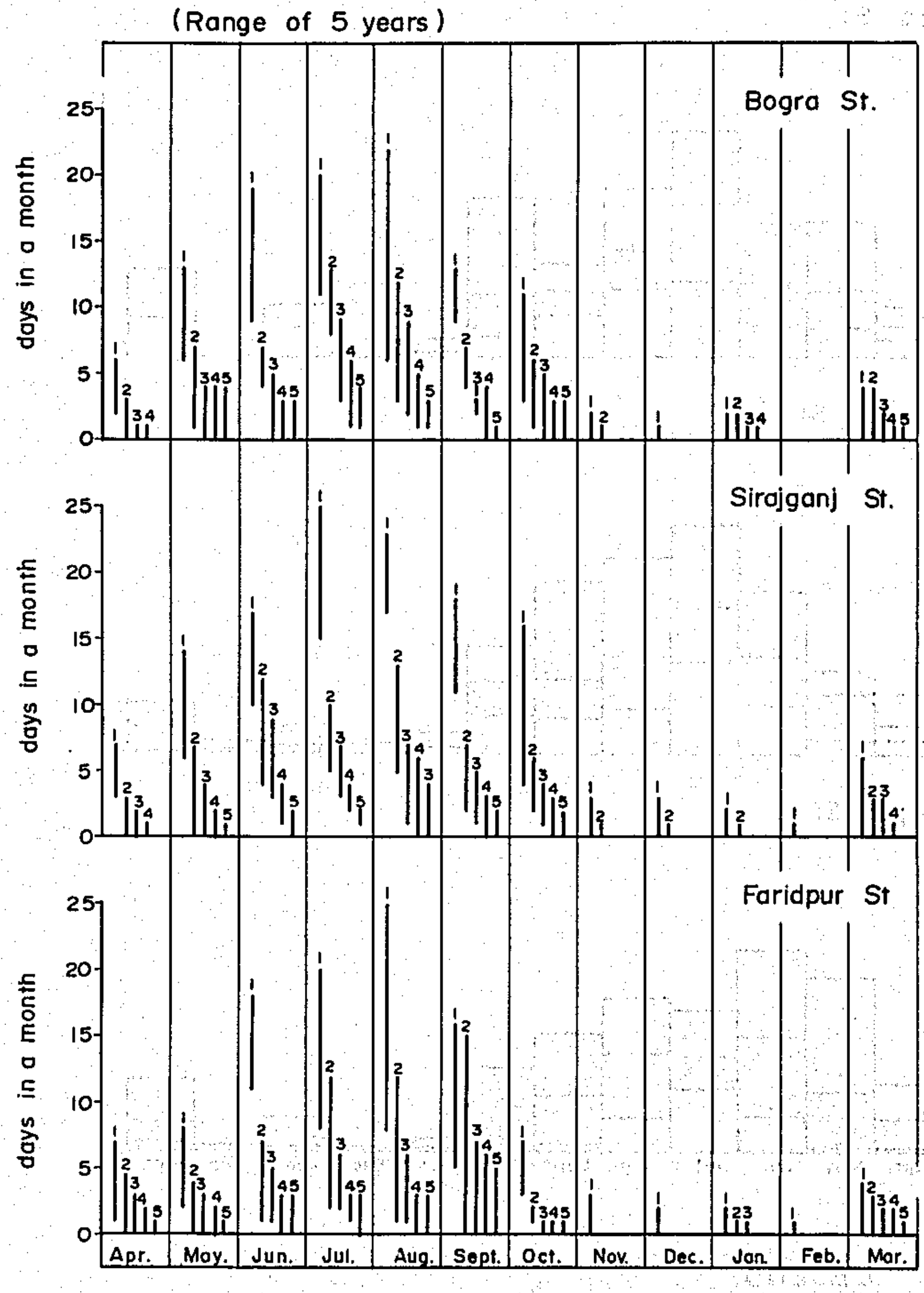


Fig. 5-16 Frequency of Rainfall by Each Month

(according to data from Apr.1964 to Mar. 1969)

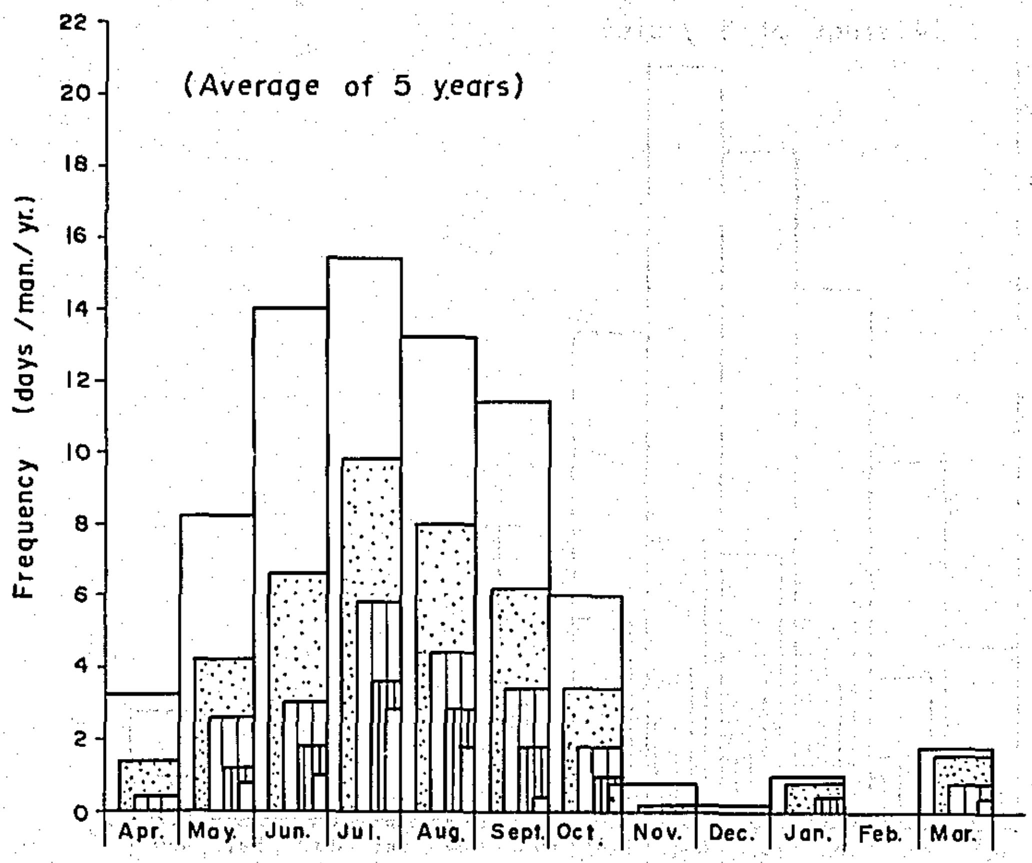


1,2,3,4,5: case of intensity of daily rainfall more than 0.1,0.5,1.0,1.5 and 2.0m/day, respectively

range of days at each intensity in 5 years.

Fig. 5-17-1 Frequency of Rainfall at Bogra St.

(according to data from Apr. 1964 to Mar. 1969)



LEGEND

— Days whose rainfall is more than 0.1 in/day (2.5mm/day)

— Days whose rainfall is more than 0.5 in/day (12.7 mm/day)

— Days whose raifall is more than 1.0 /in day (25.4 mm/day)

— Days whose raifalls more than 0.5 in day (38.1 mm/day)

— Days whose rainfall is more than 2.0 in/day (50.8 mm/day)

Fig 5-17-2 Frequency of Rainfall at Sirajganj St

(according to data from Apr. 1964 to Mar. 1969)

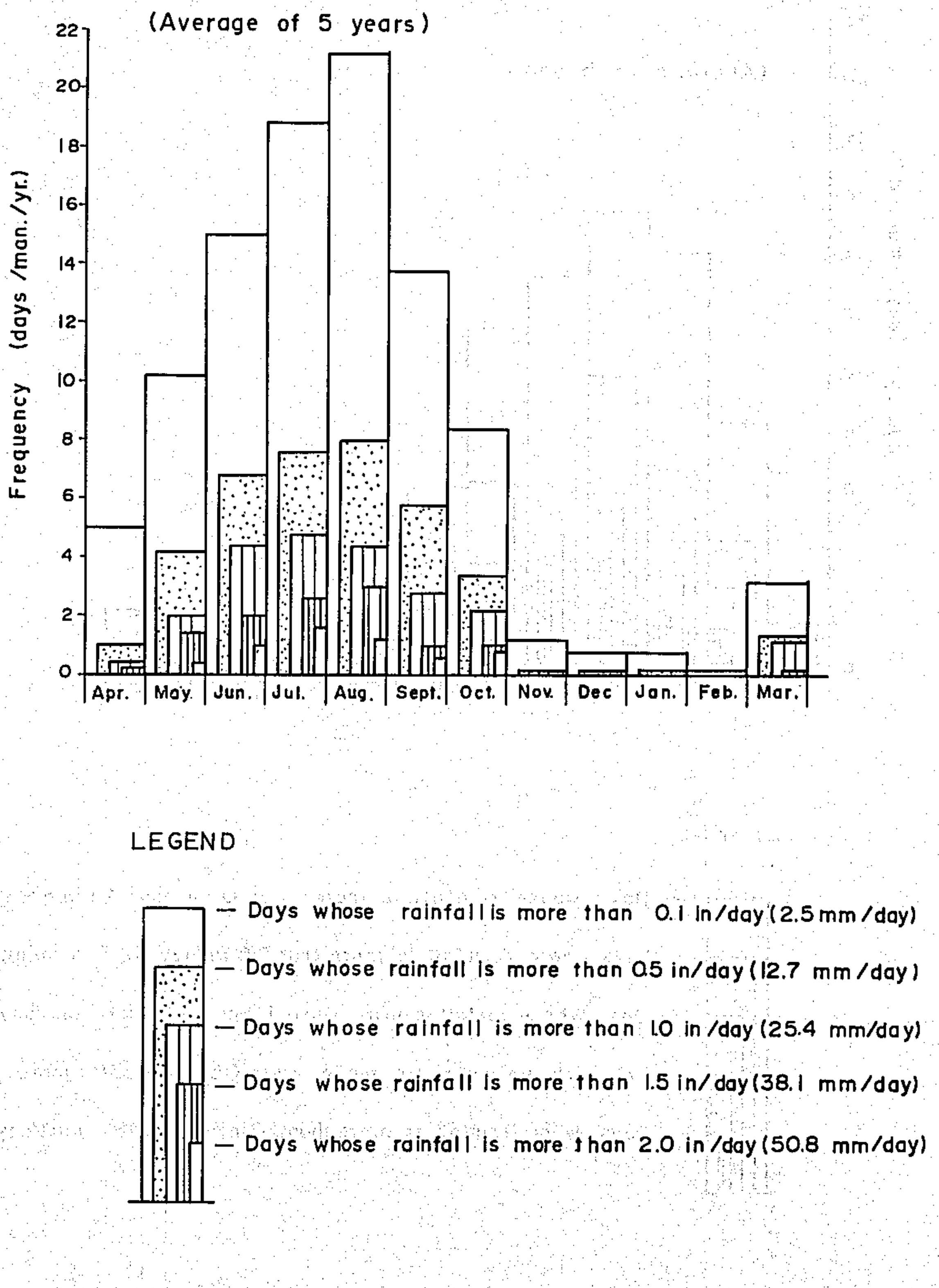
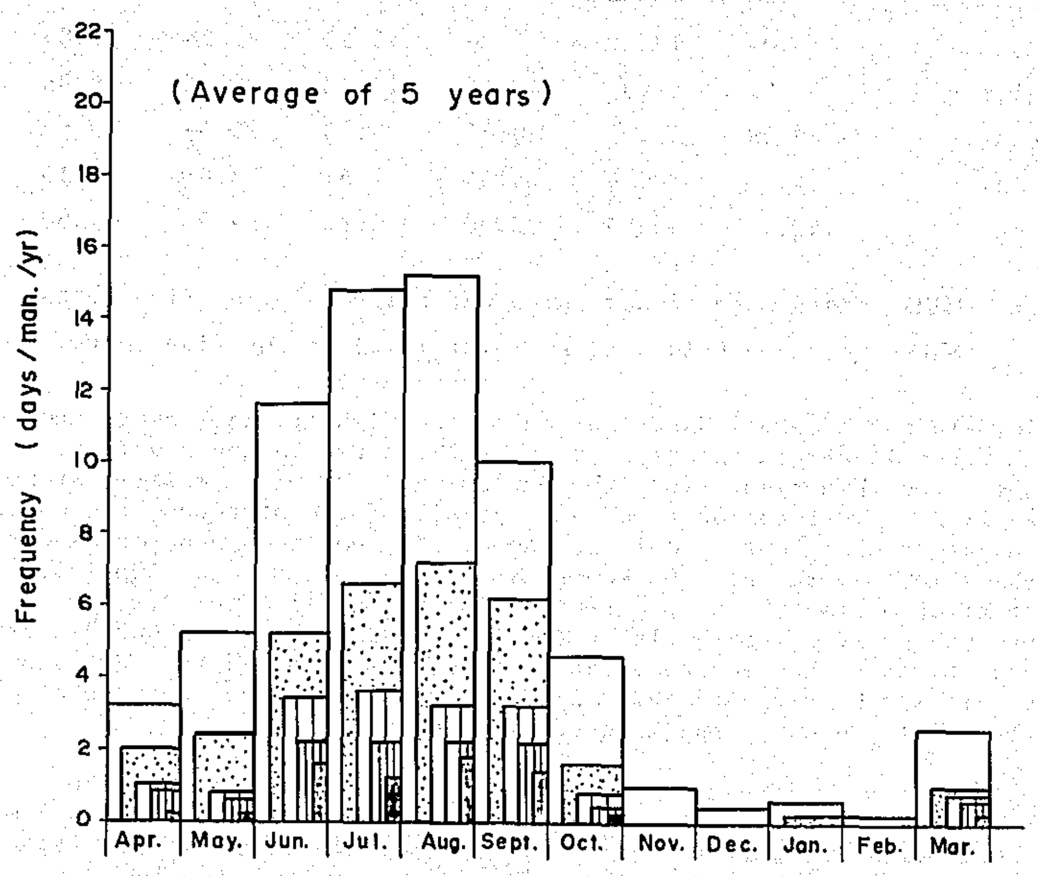
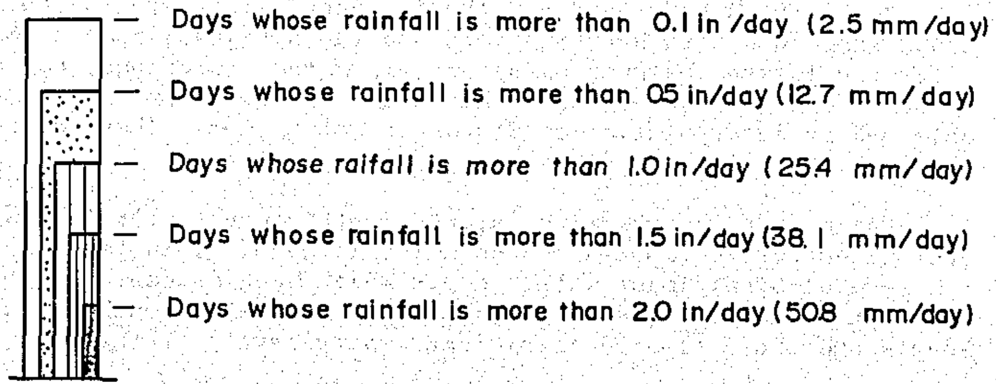


Fig. 5-17-3 Frequency of Rainfall at Faridpur St

(according to data from Apr. 1964 to Mar. 1969)



LEGEND



Days counted from the highest water stage	Bahadurabad St. ft. PWD	m, PWD	Sirajganj St. ft. PWD	m, PWD	Kadamtali St. ft. PWD	m, PWD
MHHWL	64.01	19.52	45.34	13.83	25.74	7.85
95-day	58.61	17.87	40.42	12.33	20.86	6.36
185-day	49.59	15.12	30.44	9.28	11.58	3.53
275-day	44.71	13.64	24.96	7.61	7.05	2.15
MLLWL	42.91	13.09	22.80	6.95	4.93	1.50

Note: MHHWL means mean highest high water level in the five years.
MLLWL means mean lowest low water level in the five years.

Fig.5-18 shows annual distribution of the highest, the lowest and the mean water levels in the five years at the three gaging stations. It is seen from this figure that the maximum and the minimum water stages occur earlier at upstream stations and, at all of the stations, the water level reaches the highest in July or August and, going down before and after these months, reaches the lowest in February or March. Amplitude of fluctuation of monthly mean water level is about 21.5 to 23.0 ft. The monthly highest water levels in the five years at the Bahadurabad and Sirajganj stations show scarce variation during the period from June to October. It may be presumed that this is attibuted to the decrease of the water level caused by spilling of flood water.

The amplitude of the monthly mean water level is, at any of the stations, minimum in February, while it is very large in the period from June to October. The latter indicates a possibility that abnormal high water level or abnormal low water level may occur in this period.

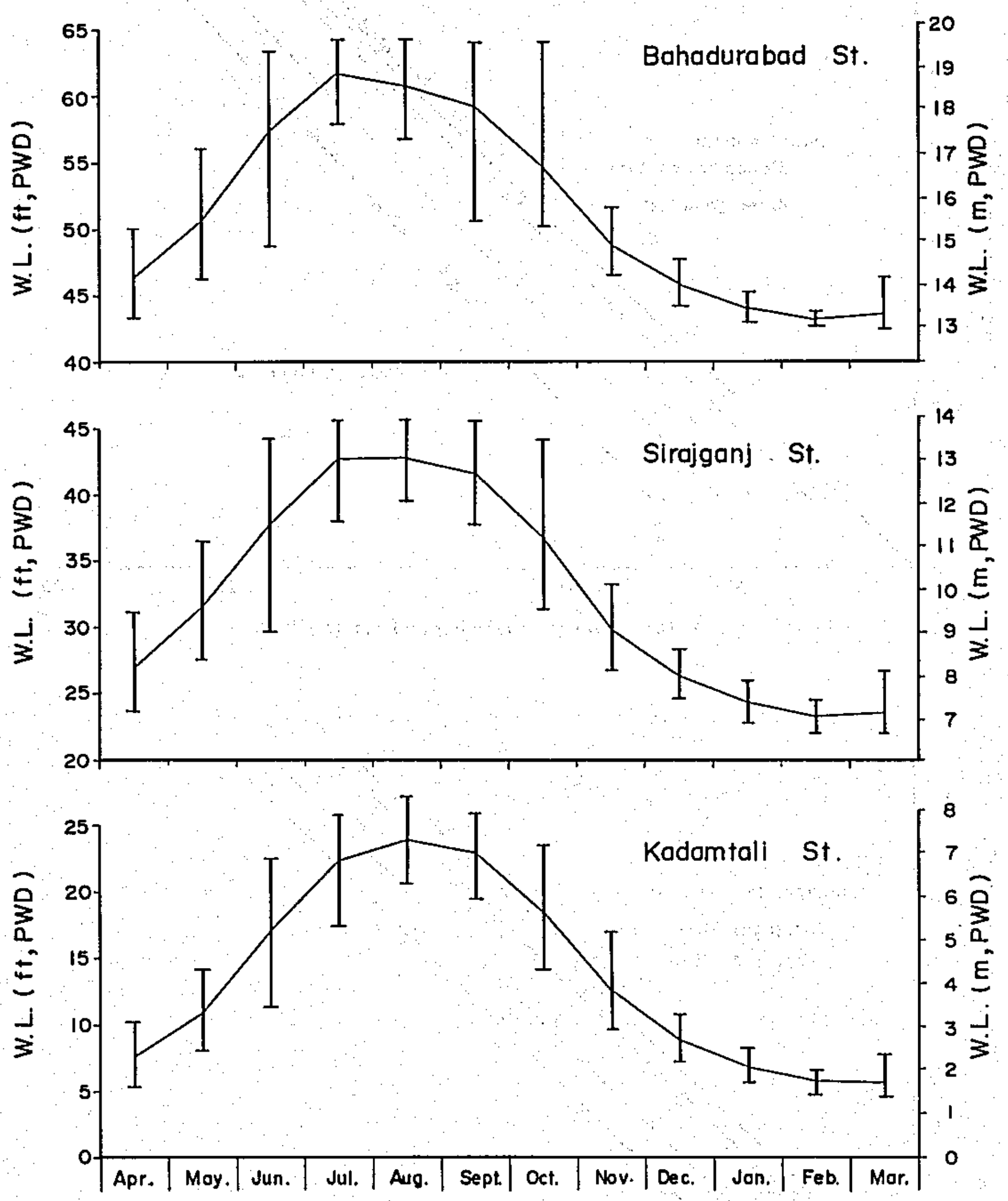
Correlations were examined between the monthly mean water levels in the Water Year 1968/69 at Bahadurabad St. and Jagannathganj St. and between those at Sirajganj St. and Mathura St. This indicates, as shown in Fig.5-19, existence of very close correlations between them.

Since the Bahadurabad and the Sirajganj sites are located between Bahadurabad and Sirajganj Stations and the Sirajganj and the Nagarbari sites are located between Sirajganj and Mathura Stations, correlations of water stages between the former two and the latter two sites were obtained by interpolation of distances among them. These correlations are also shown in Fig.5-19.

Using these correlation curves, monthly mean water levels at the four sites were estimated as shown in Fig.5-20. This figure also shows the several significant water levels which were estimated using the correlation curves. Table 5-9 shows the estimated monthly-mean-water levels and the estimated significant water levels at the four sites.

Fig. 5-18 Mean Water Level

(according to data from Apr. 1964 to Mar. 1969)

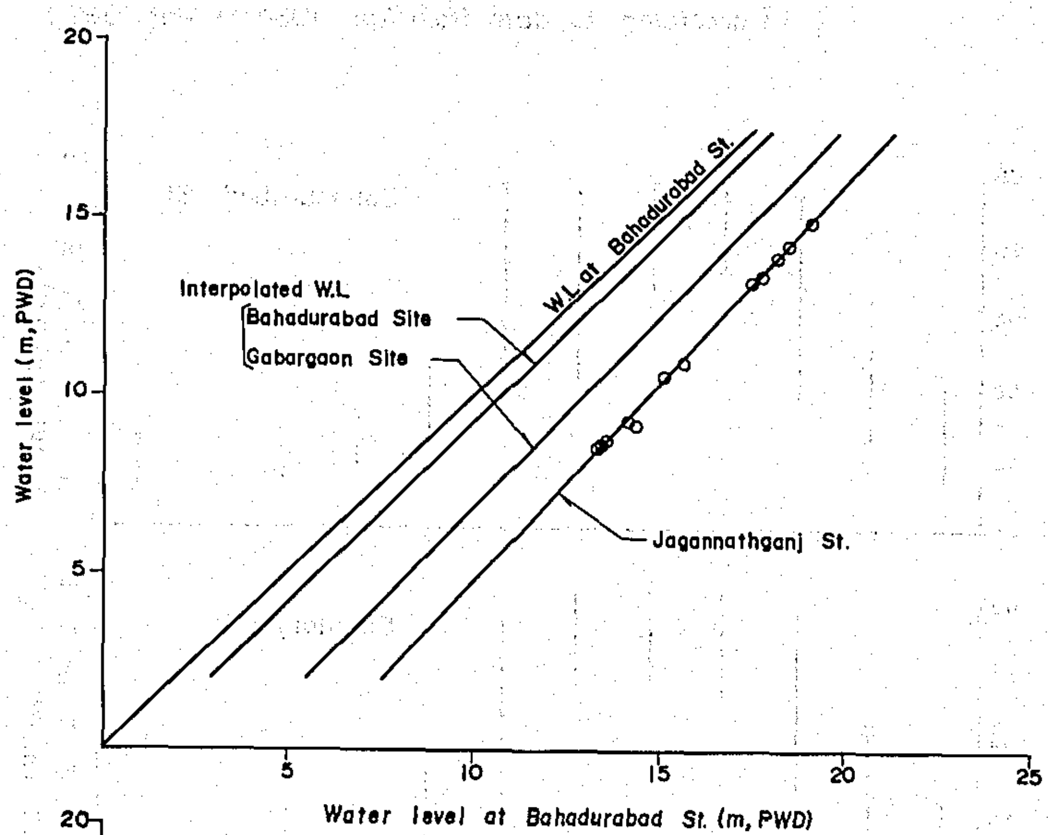


LEGEND

: mean of monthly mean water level in 5 years

: range of monthly max. & min water levels in 5 years

Fig. 5-19 Correlation Between Monthly Mean Water Levels
(according to data in 1968169)



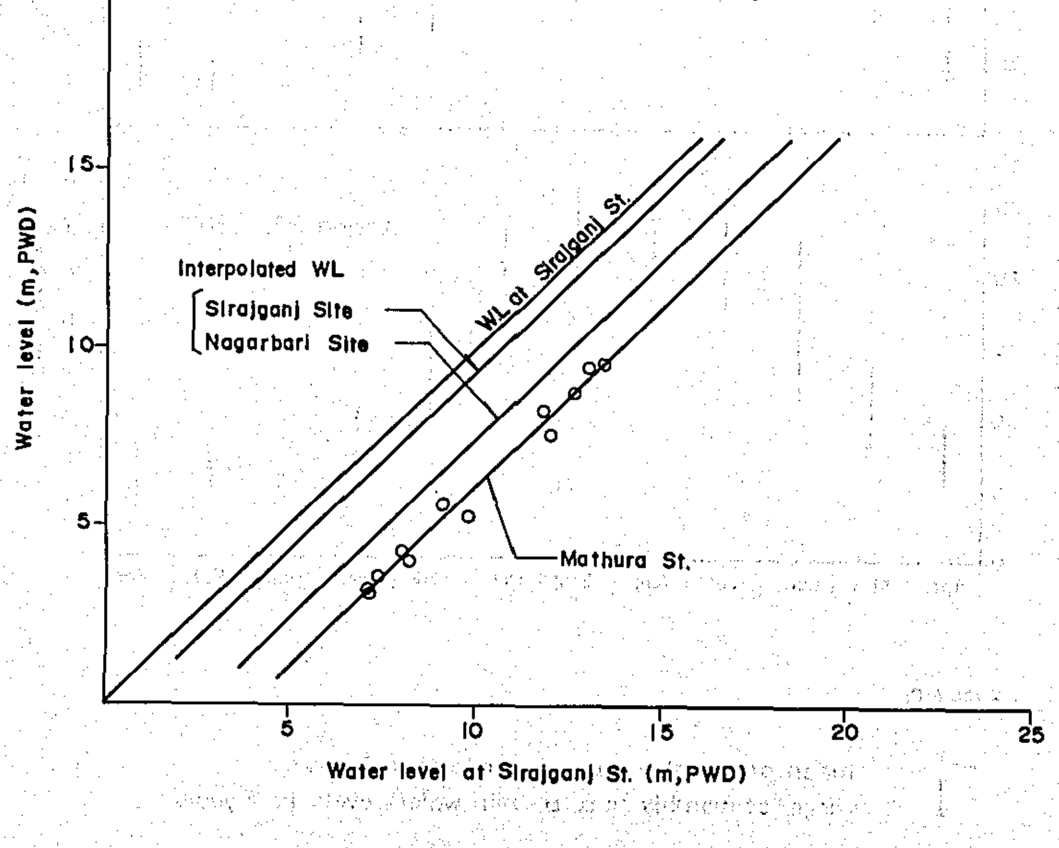


Fig. 5-20 Monthly Mean Water Level at Bridge Sites

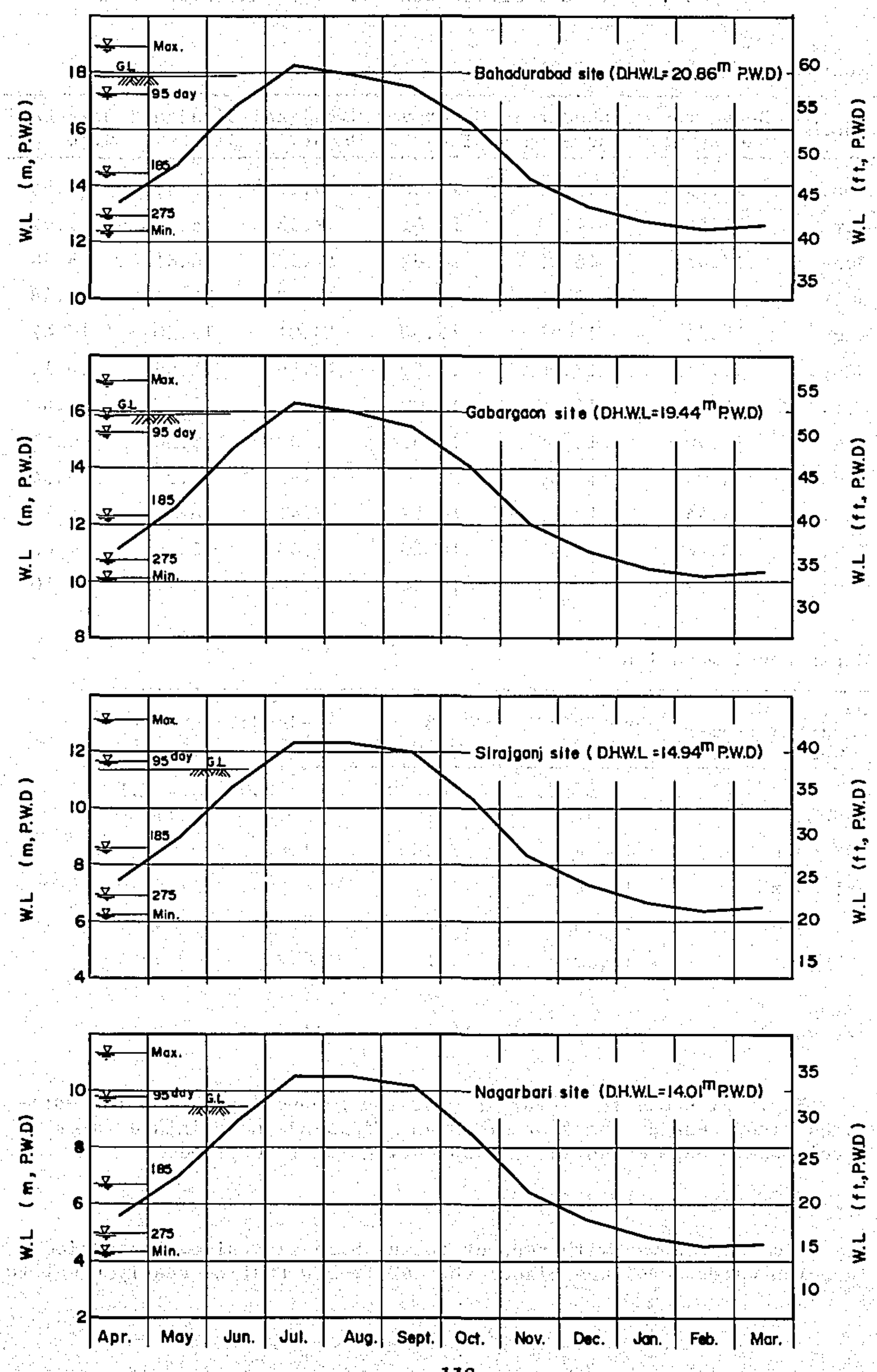


Table 5-9 Estimated Water Level at the Four Sites

Monthly Water Level (m,PWD)

Month	Bahadurabad WL St.	Bahadurabad Site	Gabargaon Site	Sirajganj WL St.	Sirajganj Site	Nagarbari Site
Apr.	14.09	13.41	11.20	9.19	7.46	5.55
May	15.40	14.78	12.61	9.58	8.85	6.97
June	17.45	16.82	14.82	11.53	10.81	8.96
July	18.84	18.29	16.30	13.02	12.31	10.48
Aug.	18.54	17.99	16.00	13.01	12.30	10.47
Sept.	18.11	17.50	15.50	12.66	11.95	10.11
Oct.	16.67	16.20	14.00	11.14	10.42	8.56
Nov.	14.90	14.25	12.06	9.03	8.30	6.41
Dec.	13.98	13.30	11.10	7.98	7.25	5.34
Jan.	13.44	12.77	10.52	7.41	6.67	4.76
Feb.	13.18	12.45	10.20	7.08	6.34	4.42
Mar.	13.29	12.60	10.34	7.16	6.42	4.50

Water Level Duration

Days of WL counted from HHWL	Bahadurabad Site	Gabargaon Site	Sirajganj Site	Nagarbari Site
	m,PWD	m,PWD	m,PWD	m,PWD
MHHWL	18.94	17.10	13.14	11.36
95 days	17.24	15.24	11.64	9.80
185 days	14.48	12.31	8.60	6.70
275 days	12.98	10.78	6.95	5.00
MLLWL	12.40	10.12	6.22	4.34
Mean ground level	17.95	15.93	11.38	9.45

Fig.5-21 shows the water levels, the ground levels and the estimated river beds at the four sites and Fig.5-22 shows inland water levels which were measured by BWDB during the 1970 flood.

7.1.3. Favorable period for work.

Fig.5-23 shows, with respect to the Sirajganj site, the period in which water level was higher than 40 ft PWD that is nearly equal to

Fig. 5-21 Water Level, Ground Level and River Bed

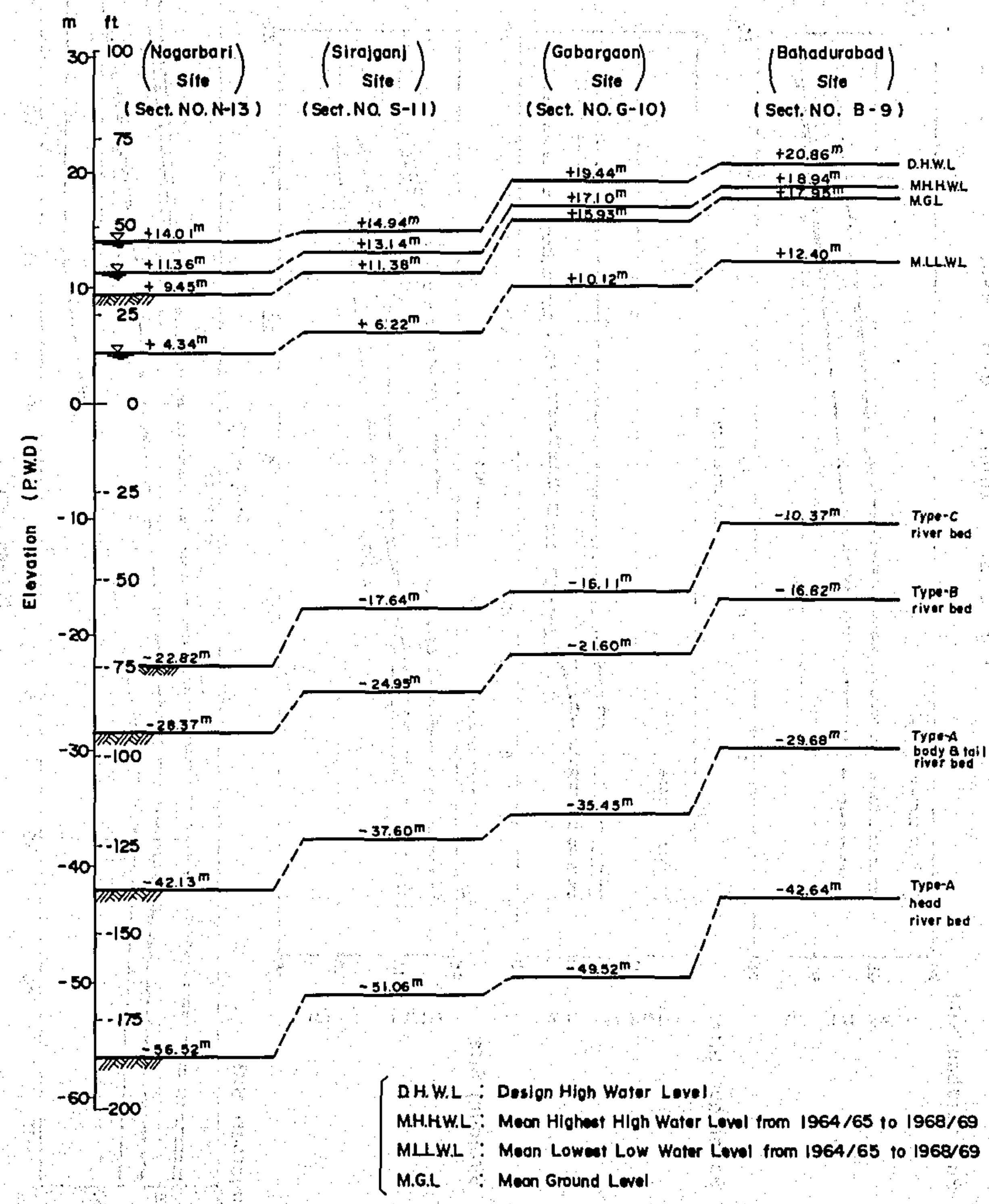


Fig. 5-22 Inland Water Level

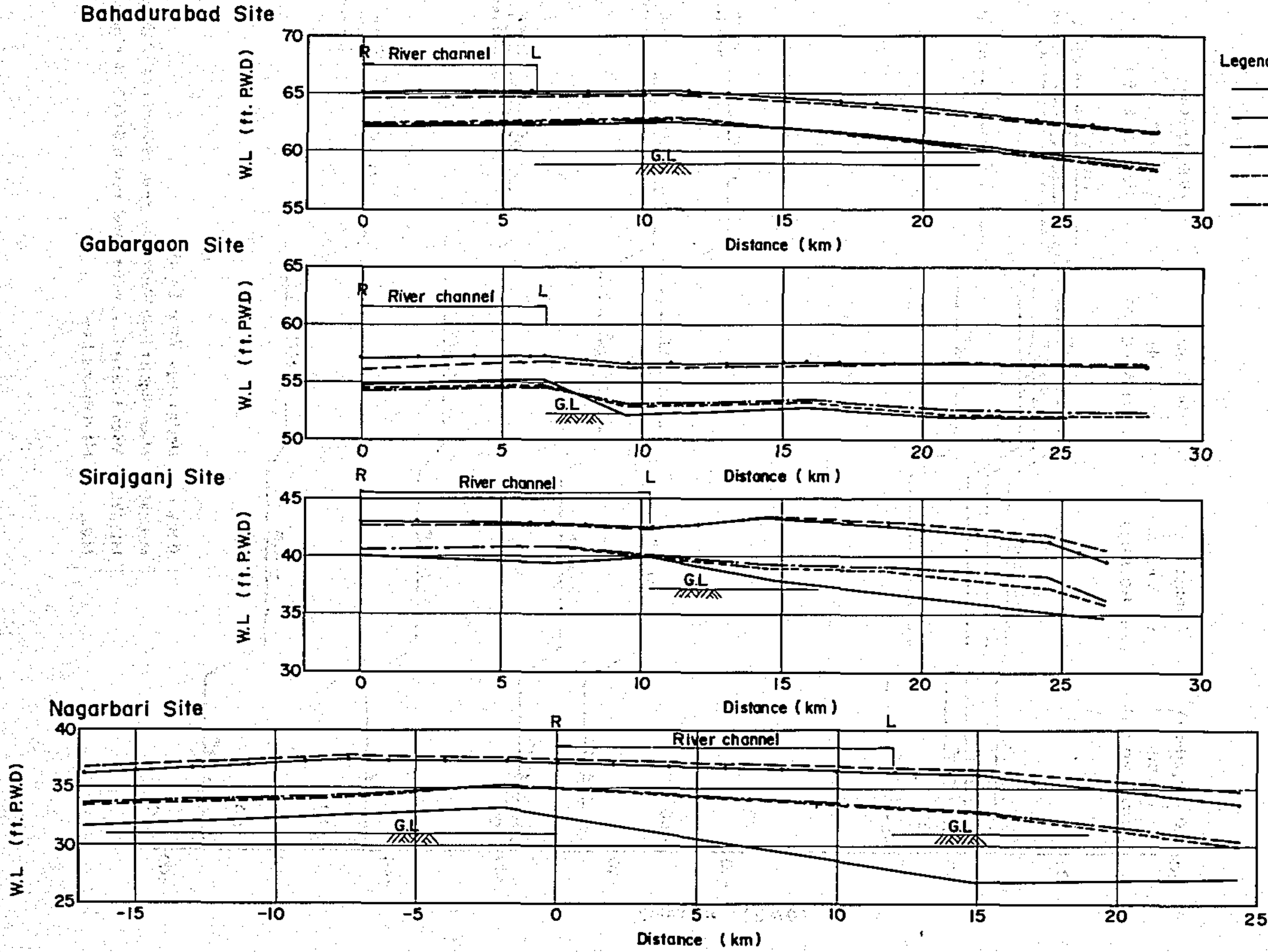
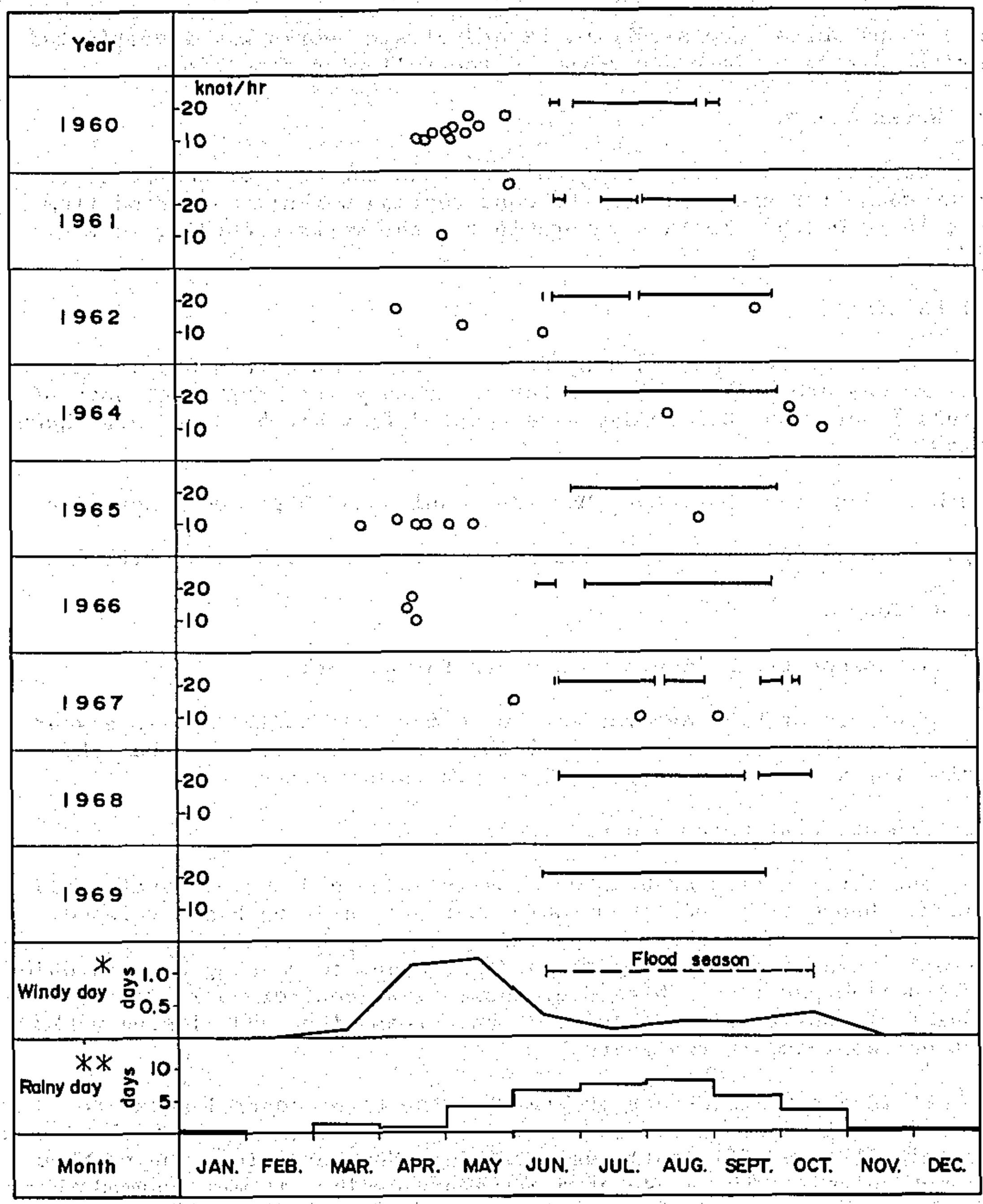


Fig. 5-23 Natural Condition at Sirajganj St.



* : Days of wind speed more than 10 knot

** : Days of rainy day more than 0.5 in day

├──┤ : Period water level is higher than 40 ft., P.W.D.

o : Day wind speed is higher than 10 knot.

the mean ground level at Sirajganj Station, days of wind speed higher than 10 knot on the average of nine years from 1960 to 1969 and days of rainfall more than 0.5 in/day on the average of the period from April 1964 to March 1969.

The period favorable for executing the construction works such as guide-bank works, cross-dike works and closing works was investigated for the Sirajganj site according to the following conditions.

(a) Water stage.

We assume that water stage higher than the mean ground level is unfavorable for execution of the construction works; the period from June 16 to October 15 is unfavorable for the works according to Fig. 5-23.

(b) Rainfall.

We assume that days having daily rainfall more than 0.5 in/day or 12.7 mm/day are unfavorable for work. Monthly mean number of days of rainfall more than 0.5 in/day were counted from Fig.5-23 and are shown below.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Days	0.2	0	1.4	1.0	4.2	6.8	7.6	8.0	5.8	3.4	0.2	0.2

(c) Holidays.

We assume two holidays in a month for no work.

Thus, favorable days for work were counted at 215 days in a year and the detail is shown in Table 5-10. We assumed further that this period for work is also applicable to the other sites.

7.2. Execution of works and equipment.

The construction area is habitually submerged during every flood season. Hence it is most desirable that one guide bank and related structures on one side are completed in one dry season in order to avoid losses of construction materials and works due to washing away in under-construction portion. Therefore, those river control works which consist of construction of guide banks, cross dikes and closing works must be completed in two years.

It is a very important problem for the river control works to extract required amount of stones and transport them to the work sites as economically and efficiently as possible. However, since the problem was not solved at the stage of preliminary design, it was assumed that the quantity of stones required for the river control works could be obtained at required places at speed required for the execution of the works.

7.2.1. Guide banks.

Table 5-10 Days Favorable for Work

Month	Days in month	Days off: High water days (H>MGL)	Days off: Rainy days (>0.5 in/day)	Days off: Holidays	Days off: Total days	Total work days
Oct.	31	15	3.4	2	17.7	13
Nov.	30	0	0.2	2	2.2	28
Dec.	31	0	0.2	2	2.2	29
Jan.	31	0	0.2	2	2.2	29
Feb.	28	0	0	2	2.0	26
Mar.	31	0	1.4	2	3.4	28
Apr.	30	0	1.0	2	3.0	27
May	31	0	4.2	2	6.2	25
June	30	15	6.8	2	19.4	10
July	31	31	7.6	2	31.0	0
Aug.	31	31	7.9	2	31.0	0
Sept.	30	30	5.8	2	30.0	0
Total	365	122	38.8	24	150.3	215

Structure of guide banks was already shown in 4, Chapter V. The bank body will be built with dredged sand. For the purpose of preventing dredged sand from washing away, polyethylene mats shall be put between dredged sand and pitching stones.

In building the portion below low water level, mainly in Type-A, stone dikes shall be built up to the height 1.0 m above the low water level. This was considered by reason that banking with dredged sand must be started in the water and with a view to securing stability of bank body. Further, in building the portion below the low water level, mainly in Type-A, a part of low-water channel will have to be closed by stone dikes.

For construction of apron, stock yards for stones and stone chips shall first be located near both ends of a guide bank, and a looped (endless) one-way road connecting the two stock yards shall be set along the apron part of the guide bank for the purpose of transporting and dumping stones and stone chips. Therefore, we shall have a two-lane road on the apron part.

The first layer of the construction road shall be made of stone chips 0.5 m thick overlaid on the ground surface. In case the first layer is underwater, stones shall be placed in the water up to the surface and then 0.5-meter thick stone chips shall be overlaid. The construction road for apron shall be raised by 0.5 m at a time with the progress of apron construction and shall be switched to new ones which shall be built beside the preceding ones.

Except for some special cases, stone pitching shall be carried out on the ground in the following order; (1) loading by tractor shovels, (2) carrying by dump trucks and pitching by manpower. On the other hand, in case ground work is impossible, another method of execution shall be taken; (1) loading by tractor shovels and dump trucks, (2) carrying by bottom-hopper barges and (3) placing in the water from barges. The ground work shall be applied to a part of construction where the ground is dried up during the dry season and the underwater work shall be applied to a part where water depth is enough for dump barges as seen in case of Type-A.

Principal machinery required for ground work of apron is as follows.

Loading: 5-cub.meter wheel-type tractor shovels.
Carrying: 32-ton heavy-duty dump trucks and 19-ton tiredozers.
Pitching: Manpower.

Principal machinery required for underwater work of apron is as follows.

Loading: 5-cub.meter wheel-type tractor shovels and 32-ton heavy-duty dump trucks.
Carrying: 1000-cub.meter bottom-hopper barges.
Pitching: Dumping by barges.

In banking the bank body, dredged sand shall be placed in blocks which shall be formed by sheet-pile partition walls. Length of one block shall be 500 m. Height of banking shall be 1.5 m at a time. In order to support sheet-pile walls, earth shall be moved and heaped up at the back of the walls by swamp-type bulldozers.

Machinery to be used for the banking works is as follows.

4,000 PS Diesel pump dredgers.
15 KW vibro-pile-drivers (drawer) with 20-ton crawler cranes.
125 KVA engine dynamos.
16-ton swamp-type bulldozers.

7.2.2. Cross dikes.

Structures of cross dikes was already shown in 5, Chapter V. The body of the embankment will be built with dredged sand. Faces of the slopes on both sides of the embankment shall be protected with pitching stones up to a height not lower than M.H.H.W.L.

Construction road for guide bank will also be used for the construction of cross dikes. The method of loading, carrying and pitching of stones and the method of banking with earth are all the same as those in guide bank construction.

7.2.3. Preparatory closing works.

In case there are branch low-water channel other than the main, these shall be closed by preparatory closing works in order to facilitate the construction works of the cross dikes. Crown height of the closing structure shall be set lower than the mean ground level and the body of the structure shall be covered with stones. Sheet piles shall be used in consideration of prevention of scour and facilitation of the works.

The construction road for guide banks will also be used for the preparatory closing works.

In case the ground surface of the branch channel is above water level, the works to be done will be as follows.

(a) Loading and carrying of pitching stones by 5-cub.meter wheel-type tractor shovels and 32-ton heavy-duty trucks.

(b) Driving of sheet piles by 15-KW and 37-KW vibro-pile drivers with 20-ton crawler cranes.

(c) Excavation and banking of sand by 16-ton swamp-type bulldozers.

(d) Stone pitching by manpower.

In underwater works, sheet piles shall first be drived by a floating platform and then dredged sand shall be banked with a moderate slope of about 1:10. After shaping by swamp-type bulldozers, stones shall be pitched.

In general cases, flow of the stream to be closed will not be so strong, since the stream will be a small branch and the closing works will be done in the dry season. But, in some cases where the flow is a little stronger, it may be necessary to place some stones before the driving of sheet piles so as to cut or weaken the energy of flow. Underwater works in these cases are as follows.

(a) Loading and Carrying of pitching stones by 5-cub.meter wheel-type tractor shovels and 32-ton heavy-duty dump trucks.

(b) Driving of sheet piles by 37-KW vibro-pile-drivers with 20-ton crawler cranes on a floating platform.

(c) Dredging and banking of sand by 4,000 PS Diesel dump dredgers and 16-ton swamp-type bulldozers.

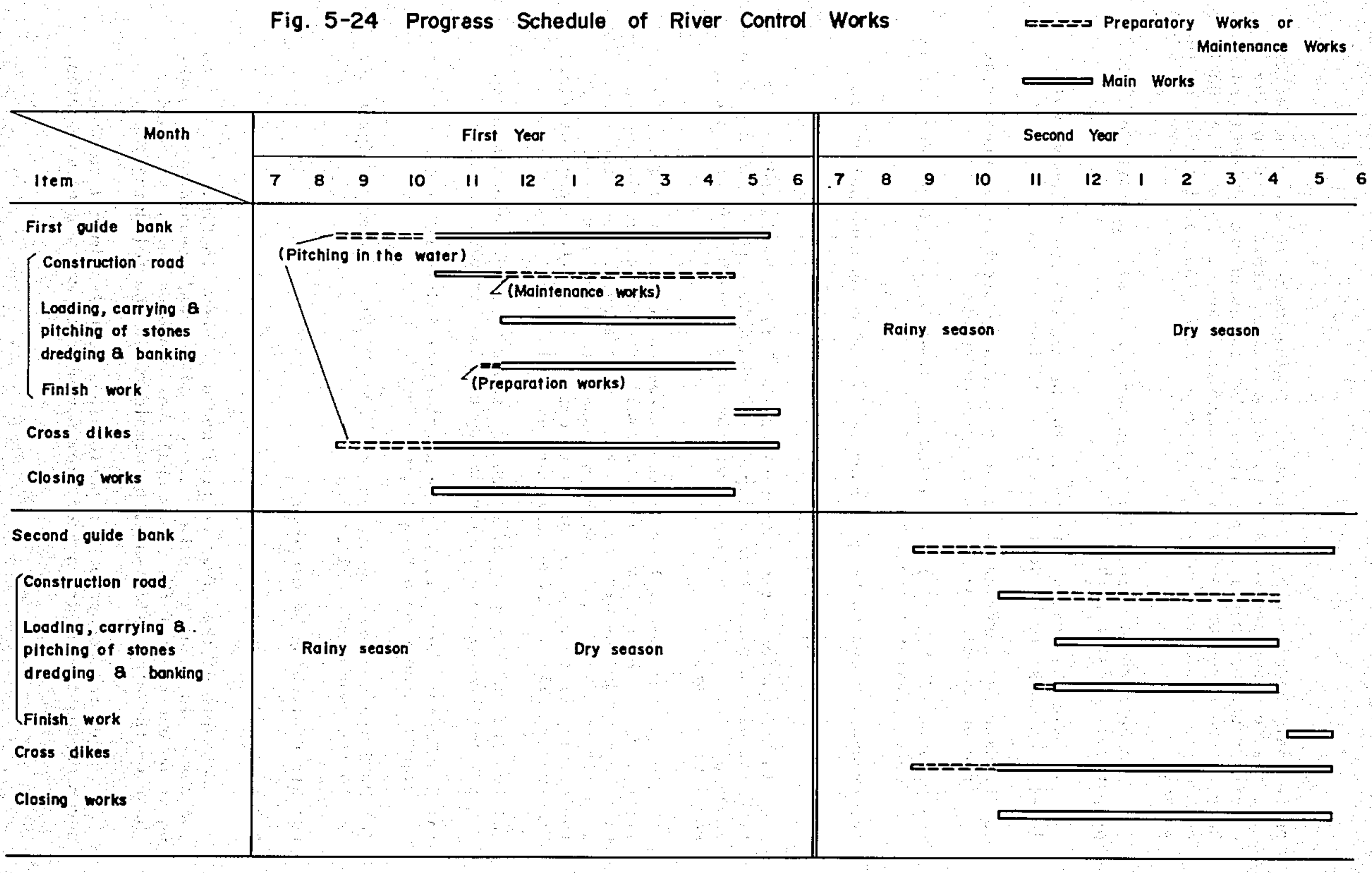
(d) Stone pitching by manpower.

7.2.4. *Schedule of construction works.*

Schedule of the river control works is shown in Fig.5-24. It is the basic plan that guide banks, cross dikes, and preparatory closing works on one side of the river shall be completed in one year and those on the other side shall be completed in the following year.

In general, construction period in a year is limited to about seven months in the dry season from November to May. But two months,

Fig. 5-24 Progress Schedule of River Control Works



September and October, may be added to the above-mentioned period for dumping pitching stones from barges in places where underwater construction is necessary.

7.2.5. Number of main machinery and quantity of fuel.

Necessary number of main machinery or maximum number in a day required for execution of the works was counted in accordance with the schedule mentioned above and is shown in Table 5-11. Maximum daily fuel consumption and the total quantity required for operation of the above-mentioned machinery are shown in Table 5-12.

7.2.6. Stock yards for materials.

In general, stock yards for materials shall be built at two sites up- and downstream of one guide bank in consideration of convenience of execution.

In case pitching stones must be dumped by barges as in the case of Type-A, one additional stock yard with jetties shall be planned at a favorable site within the range of 10 km upstream from the construction area of the guide bank.

The stock yards mentioned here shall be used not only for pitching stones but also for steels and other materials at need.

7.2.7. Necessary number of persons.

Daily maximum number of workers for stone pitching is in Table 5-13. The number was counted assuming that the maximum carriage distance by manpower is 40 m, one unit of workers consists of twenty persons and the units are distributed in the pitching area as uniformly as possible.

Personnel other than the above workers or personnel that are necessary for operation of construction machinery including pump dredgers and dump barges shall comprize foremen, operators, labors and crews. The number of those personnel is also shown in Table 5-11.

8. Construction Costs of the River Control Works.

The construction costs of river control works were estimated for three types at every bridge site on the following condition and are shown in Table 5-14. But they do not include costs of general facilities such as living quarters, motor pools, fuel storage, material storage, cargo handling facilities and electric power supply system.

(a) Unit price of stones to be delivered at the stock yards was estimated by the Quarry Survey Team at 6 Tk/cft for Bahadurabad site, 6.3 Tk/cft for Gabargaon site, 7 Tk/cft for Sirajganj site and 7.4 Tk/cft for Nagarbari site based on the first-stage survey.

(b) Unit prices or unit costs of materials, wage and works were assumed based on the results of the price survey as of the end of March of 1974.

Table 5-11 Necessary Number of Equipment and Personnel

Site	Type	Side	Equipment										Personnel			
			Tractor shovel ($5m^3$)	Dump truck (32t)	Tire-dozer (19t)	Bull-dozer (16t)	Vibro & crane (15KW+20t)	Vibro & crane (37KW+20t)	Engine dynamo (125KW)	Pump dredger (4000ps)	Dump barge ($1000m^3$)	Jetty	Foreman	Operator	Labor	Crew
Bahadurabad	A	L	15	109	12	18	121	1	33	6	9	6	482	467	8518	264
		R	15	72	5	13	91	-	23	3	-	-	475	331	8875	96
	B	L	9	48	8	9	54	-	15	2	-	-	281	216	5070	64
		R	9	38	5	13	59	-	16	3	-	-	277	219	5091	96
	C	L	7	31	5	4	41	-	11	1	-	-	227	174	4162	32
		R	8	34	5	13	59	-	16	3	-	-	250	199	4622	96
Gabargaon	A	L	16	36	5	17	115	-	30	5	15	9	225	357	3840	280
		R	23	54	12	18	174	-	45	7	20	11	294	533	4871	384
	B	L	8	36	5	13	63	-	17	3	-	-	270	225	4935	96
		R	11	49	7	14	73	1	20	3	-	-	319	273	5870	96
	C	L	8	32	5	13	63	-	14	3	-	-	246	215	4557	96
		R	8	34	5	4	41	-	11	1	-	-	249	159	4601	32
Sirajganj	A	L	15	71	5	8	60	-	15	2	-	-	470	256	8733	64
		R	20	74	13	18	140	2	38	10	18	10	358	484	6030	464
	B	L	8	34	5	8	50	-	13	2	-	-	264	205	4694	64
		R	10	52	8	10	54	1	16	2	-	-	296	226	5371	64
	C	L	7	29	5	8	50	-	13	2	-	-	222	178	4084	64
		R	8	32	5	4	41	-	11	1	-	-	232	149	4305	32
Nagarbari	A	L	16	78	5	8	82	-	21	2	-	-	521	318	10198	64
		R	16	103	12	17	173	3	47	8	11	6	550	585	9497	344
	B	L	9	39	5	8	60	-	15	2	-	-	294	212	5445	64
		R	11	52	7	14	86	-	23	4	1	1	324	304	5808	136
	C	L	9	36	5	8	60	-	15	2	-	-	294	209	5445	64
		R	8	35	5	4	41	-	11	1	-	-	255	160	4665	32

Table 5-12 Quantity of Main Fuel and Sheet Piles

Site	Type	Light Oil		Heavy Oil		Sheet Pile	
		Total Consumption (kl)	Max. Daily Consumption (kl)	Total Consumption (kl)	Max. Daily Consumption (kl)	Light Steel Type (t)	Heavy Steel Type (t)
Bahadurabad	A	8,255	35	13,055	92	8,959	1,485
	B	4,509	17	6,460	46	5,468	–
	C	3,554	16	4,408	46	3,952	–
Gabargaon	A	7,646	31	20,693	124	11,566	–
	B	4,906	20	7,706	46	7,353	1,057
	C	3,771	15	5,426	46	5,243	–
Sirajganj	A	7,505	31	14,300	156	8,076	330
	B	4,442	18	6,155	30	5.245	330
	C	3,452	12	4,514	30	4,076	–
Nagarbari	A	8,578	40	14,789	123	8,769	4,770
	B	4,876	22	7,781	62	6.262	–
	C	3,783	15	4,954	30	4,076	–

(c) Rent of main machinery was calculated based on the Rent List of Construction Machinery, Ministry of Construction, Japan, 1974 Edition.

(d) Unit prices of heavy (regular) and light sheet piles were assumed at 58,000 ¥/ton and 62,000 ¥/ton which were those in Japan as of the end of March of 1974.

Table 5-13 Necessary Number of Workers for Stone Pitching

(unit; persons per day)

Site	Type		Guide bank	Closing work	Cross dike
Babadurabad	A	L	6,400	620	650
		R	8,200	-	40
	B	L	4,400	-	280
		R	4,600	-	40
	C	L	3,900	-	-
		R	4,100	-	40
Gabargaon	A	L	2,900	-	170
		R	3,000	450	730
	B	L	4,400	-	80
		R	4,800	250	250
	C	L	4,000	-	80
		R	4,300	-	-
Sirajganj	A	L	8,300	-	-
		R	4,100	350	680
	B	L	4,300	-	-
		R	4,600	90	290
	C	L	3,700	-	-
		R	4,000	-	-
Nagarbari	A	L	9,100	-	-
		R	6,300	1,310	710
	B	L	5,000	-	-
		R	5,000	85	220
	C	L	4,500	-	-
		R	4,400	-	-

Table 5-14 Construction Costs at Four Sites

Conversion rate: Tk 1 = ¥ 36 Unit: crore TK

Bridge site	Guide-bank span km (mile)	River control
Bahadurabad	2.0 (1.2)	167
	4.2 (2.6)	83
	5.6 (3.5)	69
Gabargaon	2.0 (1.2)	194
	4.2 (2.6)	96
	5.2 (3.3)	79
Sirajganj	2.0 (1.2)	194
	4.2 (2.6)	93
	5.6 (3.5)	80
Nagarbari	2.0 (1.2)	217
	4.2 (2.6)	113
	5.2 (3.3)	93