バングラデシュ人民共和国

ジャムナ河架橋[illegible]書

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1976年8月

国際協力事業団

PEOPLE'S REPUBLIC OF BANGLADESH

STUDY REPORT

ON

JAMUNA RIVER BRIDGE CONSTRUCTION PROJECT

RIVER TRAINING WORKS

(FIRST STAGE)

MARCH 1975

JAPAN INTERNATIONAL COOPERATION AGENCY

NIKKEN CONSULTANTS, INC.

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ABBREVIATIONS AND UNITS

Bangladesh	The People's Republic of Bangladesh
MOC	Ministry of Communications
BIWTA	Bangladesh Inland Water Transport Authority
MFCWRP	Ministry of Flood Control, Water Resources and Power
BWDB	Bangladesh Water Development Board
SOB	Survey of Bangladesh
Jamuna River	The Brahmaputra-Jamuna River
JICA	Japan International Cooperation Agency
OTCA	Former name of JICA

Prefeasibility Report

Prefeasibility Report on the Jamuna River Bridge Construction Project prepared by the Preliminary Study Team of OTCA, Mar. 1973 (written in Japanese).

Inception Report

Inception Report on Feasibility Study for Jamuna River Bridge Construction Project submitted by the OTCA.

DHWL	Design high water level
GL	Ground level
WL	Water level
HWL	High water level
LWL	Low water level
PWD	Public Works Department
RL	Reduced level
m	meter
s, sec	second
cm	centimeter
km	kilometer
kg	kilogram
t, ton	ton (metric)
f, ft	foot
m^3/s	cubic meter per second
cfs	cubic foot per second
in	inch

yd	yard
mi	mile
ac	acre
hr	hour
mon	month
yr	year
sq.	square
cu.	cubic
max.	maximum
min.	minimum
B	Width
H	Water depth
I	Slope
R	Mean water depth
W	River width
L,l	Length
A	Water area
Q	Discharge
v	velocity
n	Coefficient of roughness

1 in = 2.54 cm

1 ft = 0.305 m

1 yd = 0.914 m

1 mi = 1.609 km = 5,280 ft

1 sq. ft = 0.0929 m^2

1 cu. ft = 0.0283 cub. m

1 cfs = 0.0283 m^3/s

1 ac = 0.4 ha = 0.004 sq. km

1 in/mi = 1/63,360

1 ft/mi = 1/5,280

TK 1 = ¥36

CONTENTS

CONCLUSTIONS AND PROBLEMS

The conclusions which we have obtained at the first stage of the feasibility study and the problems which have been clarified at this stage are as follows.

1. Characteristics of the four proposed sites.

All the four sites which have been proposed as bridge crossing points are certainly located at nodes of braiding, which suggests that any of them is favorable for spanning a bridge across the river.

From the geomorphological point of view, the Sirajganj narrow is most stable among the four, the Gabargaon site comes closely next, the Bahadurabad site compares unfavorable with the former two and the Nagarbari site falls behind any of the others.

From the river-morphological point of view, 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 bank lines 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 the river-morphological points of view, there is nothing to choose between the two sites, Sirajganj and Gabargaon.

The Sirajganj site has been chosen a little downstream of the Sirajganj narrow. This site lies under the protection of the narrow as well as the Sirajganj bank-protection works and has only one main flow with chars on both sides. This means that the site is very favorable for spaning a bridge. However, this site has also an unfavorable point that the left approach must cross one of the offtakes of the Dhaleswari. This offtake must be crossed over by a bridge or by a causeway. Fortunately, the entrances of the two offtakes lie with the proposed bridge axis between. Therefore, it will be the best way if the upper offtake may be closed and the lower one may be kept as the main to the Dhaleswari.

The influence of backwater on the upper stretch is negligible with respect to the types of B and C of guide banks.

2.Minimum length of bridge.

In selecting the river width for the bridge, it is most desirable to take a width larger than the present state, or it is undesirable to narrow the present one in view of future possible increase in discharge which will generally take place as river improvement works go forward and considering future river plans as well as future possible change in river bed and other regime. No matter how the river width may be narrowed, it should be larger than about 4000 m.

In case that the construction of guide banks is impossible from some circumstances or the bridge will have to be spanned long enough over the whole river width by other reasons, a site at the Sirajganj narrow is recommendable from the geomorphological point of wiew. This site may also be recommendable from the viewpoint of traffic volume.

3. Guide banks.

It is very appropriate to choose a node of braiding as a bridge site, but we can find no guarantee that these nodes will forever stand at the same places without any change of their forms. On the contrary, the fact is that there occurs incessant erosion at banks even at the nodes of braiding. Therefore, even in case a bridge is spanned at such sites from one bank to the opposite, some revetment works will be inevitable so as to protect the abuttments of the bridge. Furthermore, flood flow usually spills over the both banks. Therefore, the abuttments and the approaches must be designed so as not to be destryed no matter what erosion may occur at banks and no matter which course the thalweg may take. For this purpose, a pair of artificial banks with revetments and a pair of closing dikes connected with them are required so far as a bridge is not spanned over a quite long distance far exceeding the whole river width.

The standard structure of guide banks and closing dikes is shown in Fig.7-10 and Figs.7-13-1 and 7-13-2. The horizontal arrangement of them is shown in Figs.7-11-1 to 7-11-4. The bodies of guide banks and closing dikes will mainly be built with dredged sand and will be protected with revetments and aprons of stones.

The materials, construction machinery, other related facilities and personnel required for the construction works have been roughly estimated, on condition that the structures on one side shall be completed in one year. They are shown in Tables 9-2, 9-3, 9-4, 9-5, and 9-6 in the text. The construction costs are being estimated.

4. Depth of piers.

Any one of the bridge piers must be sunk deep enough anywhere on the river width because the thalweg is not fixed at a same place within the width, and they should be sunk down deep enough to stand by themselves without any protection around them. If there are some reasons that this is very difficult or too uneconomical, we may have to consider some protection works although it is never desired.

If we adopt a well-type substructure, the width or the diameter is supposed to be of the order of 12 m. In this case, the scour depth at piers is estimated to be about 1.8 times as deep as the water depth. On the other hand, if we adopt a multi-column-type substructure, the scour depth will be less than the above. We assumed it to be about 10 m in this case.

5. Problems

In designing of river trainning, some problems such as flow patterns of rivers, precise figuration and arrangement of guide banks and closing dikes, precise depth and shape of scour around multi-column-type piers, etc. can not be solved by calculation alone. For the purpose of solving such problems in detail, bydraulic model tests will be a promising method.

Feasibility study may be completed without hydraulic model tests partly because feasibility study generally requires estimation of costs based on basic designs and partly because the present feasibility study is limited to three years including the selection of the most suitable site from among the four proposed ones.

However, in making detail designs, it is most desirable to conduct the hydraulic model tests on a large scale and most carefully.

This type of bank structure needs a huge amount of stones and the construction was planned to be completed in two years in order avoid losses of materials and works on condition that required quantity of stones is obtainable at specified stock yards and at any time specified. Therefore, supply of stones is an important problem to be solved in the near future. If sufficient supply of stones is impossible, the bank structure itself must be reconsidered or the plan of guide-bank system may be abandoned according to circumstances.

Since a great number of construction machinery and a great amount of materials must be carried in within a short time, construction of large-scale cargo-handling facilities is necessary at the early stage of the whole construction period. These studies are not included in this report.

Fuel consumption by construction machinery was estimated to be about 200 kl per day at its maximum. Therefore, large-scale facilities for fuel supply are necessary on each side of construction area.

Large-scale motor pools for maintenance and repairing of various construction machinery is necessary on each side of the construction area. This is not included in the present report.

Since most of construction works are concentrated in the dry season and their amount of works is so huge, construction area is expected to be very crowded and complicated. Therefore, arrangement of construction machinery and management of personnel will be matters of importance and must be studied in detail at the stage of detail design.

The order of works for sand dredging and banking is 1. driving of sheet piles, 2. heaping up of sand at the back of sheet-pile walls, 3. dredging and filling, 4. drying up and 5, drawing of sheet piles. Among these works, period of drying up was estimated based on some data on soil. As the drying-up period has a great influence on the whole construction period and cost, more precise investigation of nature of soil must be made at the stage of detail design.

CHAPTER I
INTRODUCTION

1. General.

This report gives the results of the first-stage studies which were made by the River Study Team during the period from August 1973 to October 1974 in accordance with the Inception Report submitted by the Japan International Cooperation Agency (former Overseas Technical Cooperation Agency) People's Republic of Bangladesh in August 1973.

The Japanese Government Prefeasibility Study Team organized and sent by the JICA to Bangladesh in December 1972 proposed four sites for the Jamuna River Bridge Construction Project, namely, from upstream to downstream, downstream of Bahadurabad, near Gabargaon, about 10 km downstream of Sirajganj and about 20 km upstream of Aricha.

The objective of the River Study is to examine the priority order of the four proposed sites from the viewpoint of river engineering and to estimate rough costs for several river-training works to be considered at every site for bridge construction.

For this purpose, in order to inspect the Jamuna River and collect data, Dr. S. Sato, Mr. N. Jitsuhiro and Mr. T. Nobe were sent by the JICA to Bangladesh from Sept. 3, 1973 to Oct. 18, 1973. Next, Mr. K. Adachi and Mr. K. Kurosawa were sent to Bangladesh from Nov. 8, 1973 to Dec. 22, 1973 in order to inspect the Jamuna River and collect data from the view point of execution of river-training works and preparation of equipment for them, and Mr. M. Ohya was sent to Bangladesh two times from Jan. 4, 1974 to 16th of the same month and from Mar. 16, 1974 to 30th of the same month in order to inspect the Jamuna River and collect data from the viewpoint of geomorphology.

After collection of data both in Bangladesh and in Japan, studies were made in Japan on the features of the river, several river-training works for the bridge construction, local scouring around piers, execution of works and preparation of equipment for them, and, finally, the costs of the river-training works were roughly estimated for every three plans at each proposed site.

Chapter II mentions the present features of the river, Chapter III mentions the Team's opinion on the proposed four sites, Cahpter IV the disign discharge to be taken in this project, Chapter V coefficient of roughness to be taken in the river-training plan, Chapter VI the minimum river width to be considered in the plan, Chapter VII guide banks as river training works, Chapter VIII scouring at bridge piers, Chapter IX construction works of guide banks and closing dikes as river training works, Chapter X rough estimation of construction costs of river training works and Chapter XII bibliography and data collected in Bangladesh and in Japan and used in the present study.

2. Major Staffs.

Major staffs who were engaged in the study are as follows.

Dr. Eng. Seiichi Sato	Team leader, general
Masahiko Ohya	Geomorphology
Shoji Kawabata	Planning of river training
Noboru Jitsuhiro	Hydraulics
Takayuki Nobe	Hydrology
Ken Mitani	Planning of construction works
Keiji Adachi	Design of construction works
Kazuo Kurosawa	Construction equipment

CHAPTER II

NATURAL FEATURES OF THE RIVER

1. General.

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, and traversing the Himalayas in the eastern part, 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.

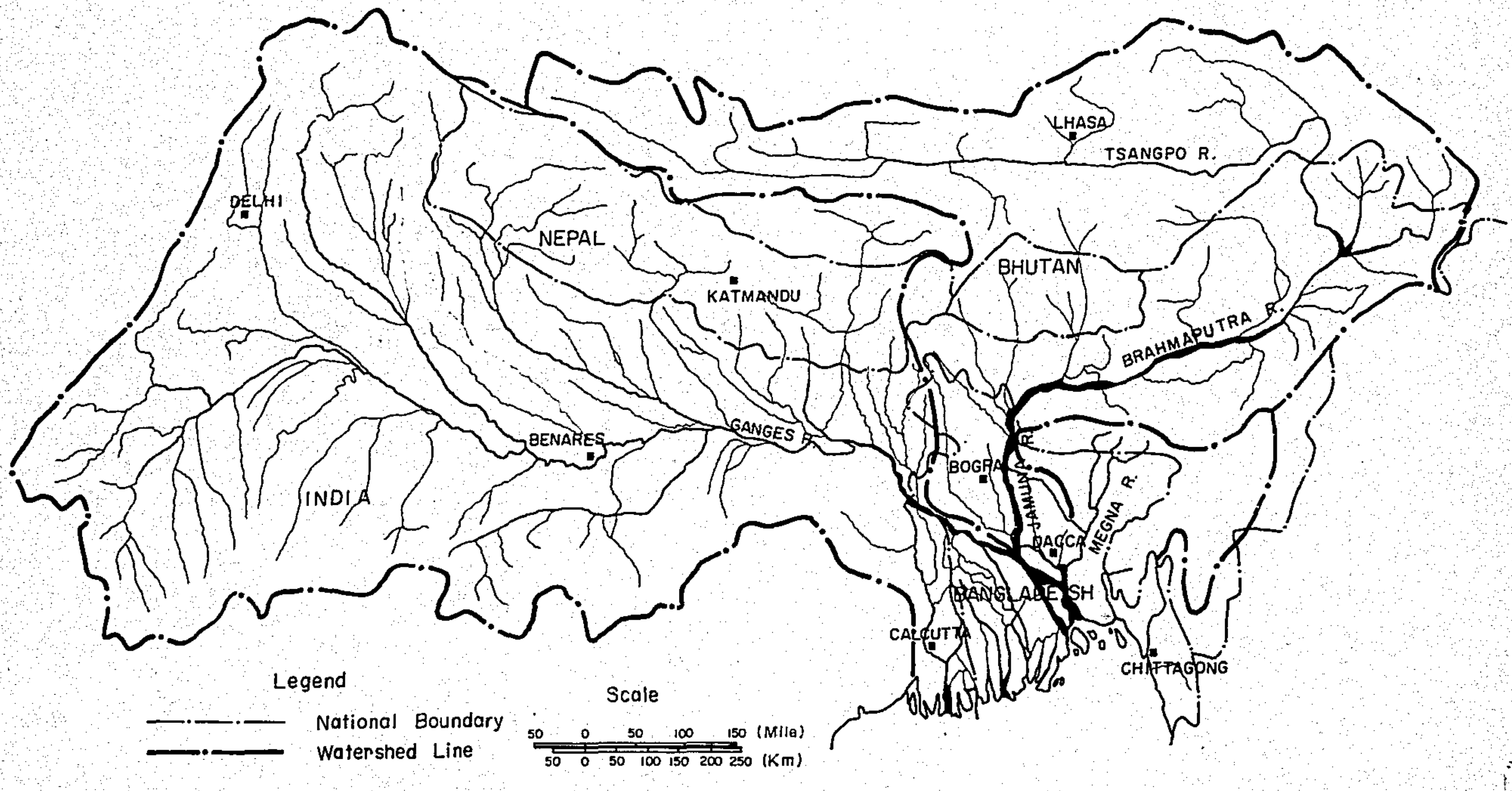
On the other hand, the Ganges River originates in the glacier of Mt. Gangotori (6,614 m), runs through the Hindustan Plain from west to east and turns to the southeast at the edge of the Rajmahal Hill and then, flowing down in the Ganges Plain, joins with the Brahamaputra-Jamuna River at Aricha.

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)

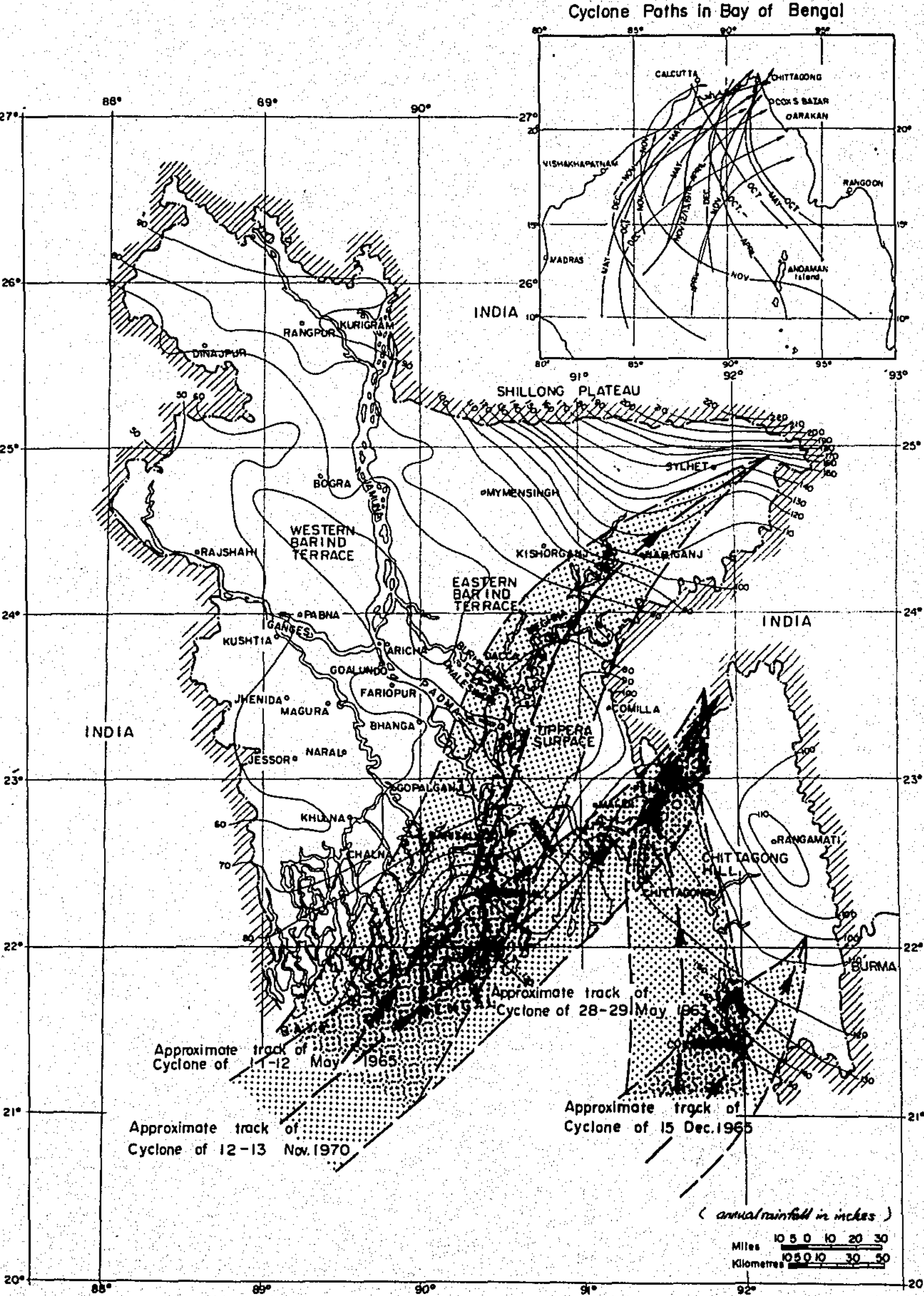
The river slopes of the Jamuna and the Ganges are about 1/15,000 and 1/20,000 respectively. The Jamuna is steeper compared with the Ganges.

The meteorology in Bangladesh belongs to the so-called 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 were 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 as is seen in Fig.2-2, hence they do not seem to 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 is 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

Fig. 2-2 Annual Rainfall and Cyclone Paths



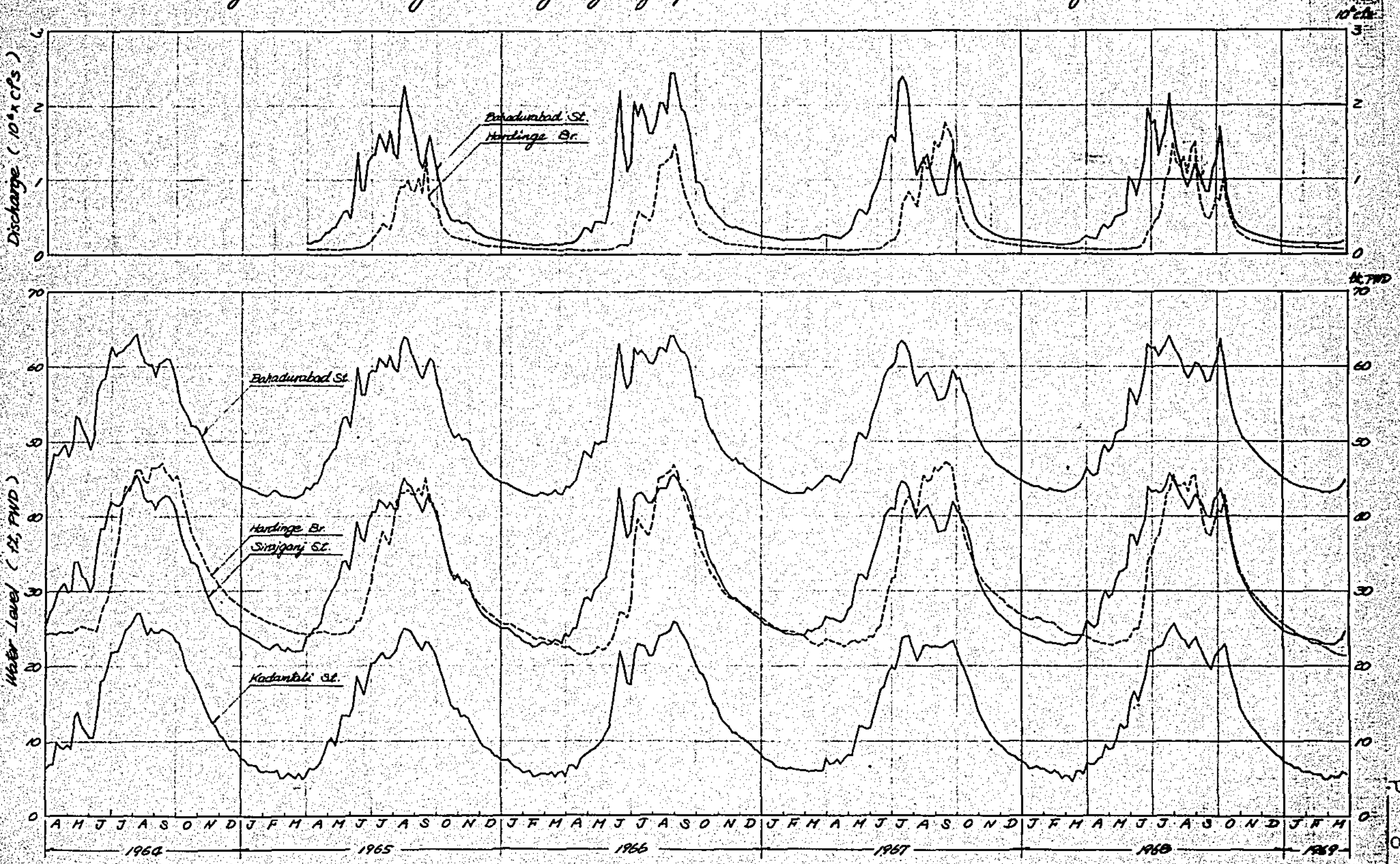
February. According to the records at the Bogra and Sirajganj meteorological stations located on and around the Jamuna, the mothly rainfall is about 330 mm or 13 in on the average and occasionally exceeds 760 mm or 30 in in the maximum.

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 reportedly covers about 30% of the land on the average. The area surrounding the Jamuna is havitually inundated over a width of about 100 Km.

Fig. 2-3 shows the discharge hydrographs at Bahadurabad of the Jamuna and at the Hardinge Bridge of the Ganges. 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 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 76,500 m^3/s or 2,700,000cfs in 1970 and that at the Hardinge Bridge is 73,500 m^3/s or 2,582,000 cfs in 1961. The maximum discharge of the Jamuna is a little larger than the Ganges.

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



2. Geomorphological features of the Jamuna River basin.

(1) Geomorphological land classification in Bangladesh.

Fig. 2-4 shows the geomorphological land classification in Bangladesh. From geomorphologic viewpoint, the area is diveded 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 terraces which have been formed during the pleistocene by the 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 has been called the Barind Terrace, and the latter, the Madhupur jungle (136 GM). Both of them are surrounded by several fault lines. But according to Prof. Mohamed, both of them are called the Barind Terrace. In this paper, we want to trace the opinion of Prof. Mohamed (137 GE) to decide that the former is the western barind terrace.

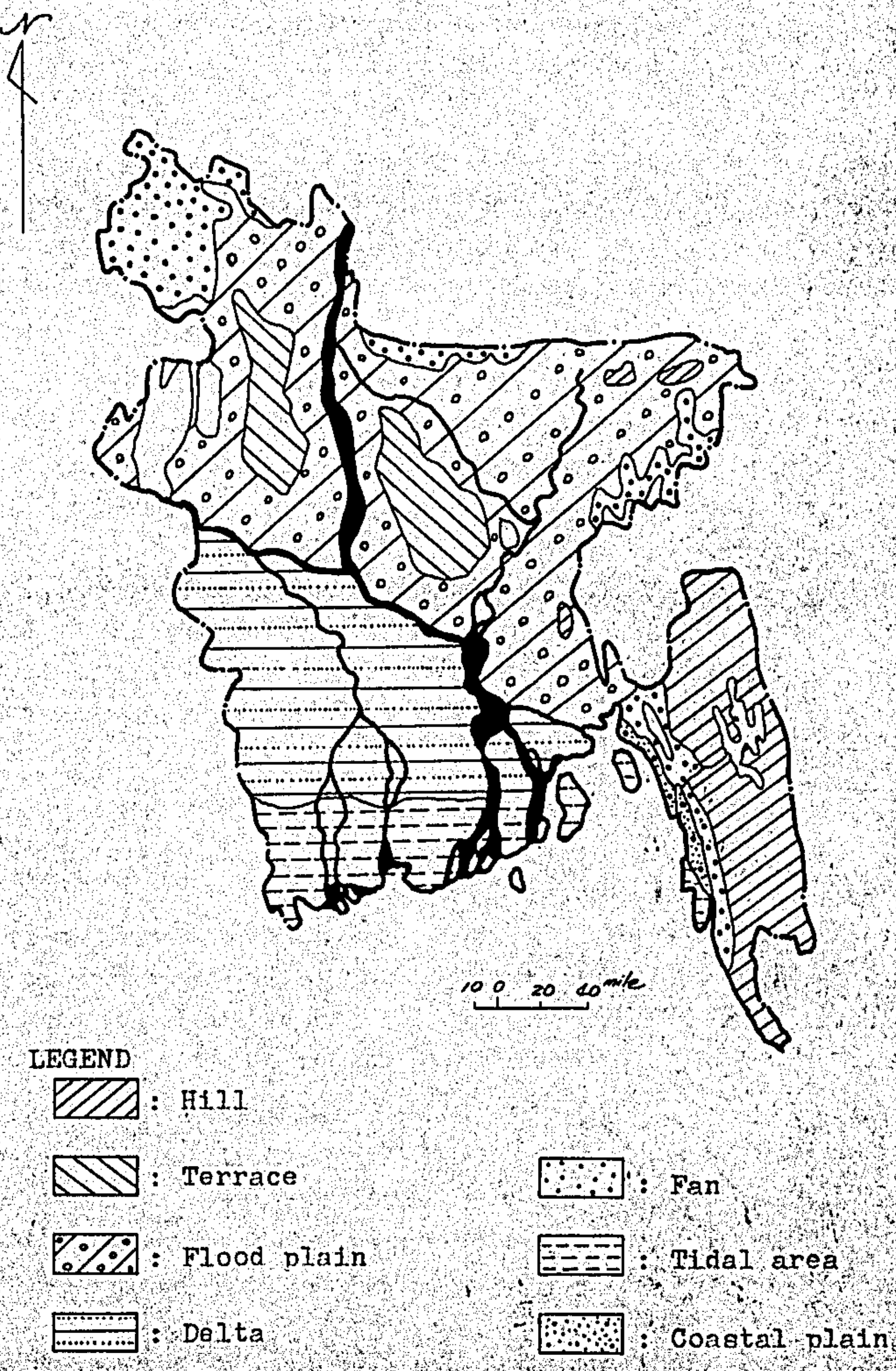
According to McIntire, (136 GM) there are no differences on grain size and species of minerals in the soil between the terraces and the alluvial plain. The alluvial plain has plenty of ground water but there is few water in the terraces. On account of the differences in the condition of the ground-water, the terraces have been taken in a white colour while the alluvial plains have been taken in a dark colour which was revealed infrared photography. The terraces are stronger against erosion by its streams than that of the plains. Due to oxidization, the colour of the soil is red in the terraces but white in the alluvial plains.

The city of Dacca is located on the southern edge of the eastern Barind terraces. There are cliffs, which are several to 10 meters high, and located between the terraces and the alluvial plains but some parts of these cliffs have gradually shifted from the terraces to the alluvial plains.

There is a Tippera Surface whose height is from 3 to 6 meters on the left bank of the Meghna River. The surface has been 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 mountains, the terraces which were formed during the pleistocence Period and the other terraces which were formed during the Holocene Period. Generally speaking, the alluvial plains that are located in the Orogenic Move-

Fig. 2-4 Geomorphological Land Classification Map in Bangladesh



ment Area like Japan consists of the following geomorphological elements; alluvial fan, natural levee, back-swamp and the delta (138 GM). Bangladesh is located in the Alps-Himalaya Orogenic Movement Area. And there are four geomorphological elements like Japan which was mentioned above.

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

The northern part of the western Barind Terrace is covered by alluvial fans which have been formed by the Tista River, Karatoya River and the Atrai River which originate from the Himalaya Mountains. Almost all of the deposition layer in the fan is composed of sand and some few gravels, because of the chemical weathering which is strong.

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 between the Ganges and Jamuna Rivers. In the case of the upper reaches, the width of the river is wide and composed of a network of smaller streams. On the other hand, the lower reaches is narrower compared with the upper. This shows that the upper reaches of the river are characteristic of those in the alluvial fan and the 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 south of the town of Gabargaon. There are natural levees and back-swamps in the fan region here and there (Fig. 2-7). This shows that the natural levees were formed by the Tista River etc. first, 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 south part of the Ganges River were formed mainly by the Ganges River. From a geomorphological viewpoint, the area is divided into two parts; (1) natural levee region and (2) the tidal delta region. The border line between the above-mentioned regions is the connected line between the City Calcutta, Khulna, Gopalganj and Madaripur.

occupy the space between these natural levees.

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

(2) Geomorphological development in the plain of the Jamuna.

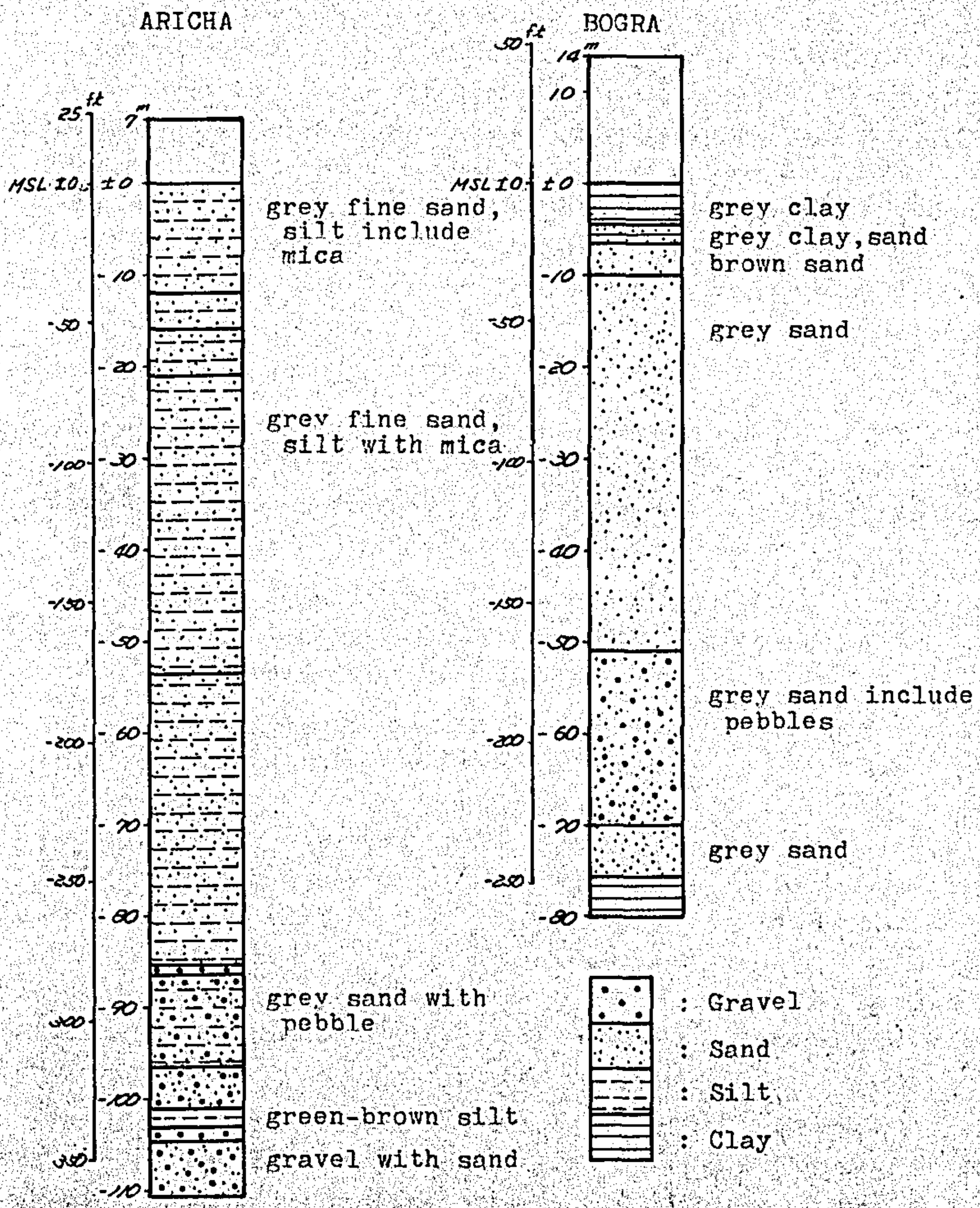
i. Influence of the glacial eustasy to the geomorphological development.

As noted the glacial eustasy occuppied during the Pleistocene Period. The maximum low water level during the Würm Ice Age was -100 meters below sea level (B.P. 25,000 years). 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. Because of the large amount of sand and gravel which were transported by the rivers, large fans developed at the foot of the mountains. We can trace the gravel layers by the geological boring-holes in Japan, Korea, Formosa and the Vientiane Plain in Laos.

There are geological records of boring-holes along the Jamuna River which have been prepared by the Japanese Geological Survey Team, the People's Republic of China etc. Fig. 2-5 shows the geological record of the boring-holes in Aricha and Bogra. You can see gravel layers about 20 meters thick at 78 meters below sea level in Aricha, 38 meters below sea level in Bogra. According to the geological record of these borings prepared by the Japanese Team, there are gravel layers 70 meters below sea level at Aricha, and 60 meters at Sirajganj. These gravel layers are covered by sand and thick silt layers. The slope of the surface of the gravel layer between Bogra and Aricha is 0.34/1000, Sirajganj and Aricha is 0.38/1000. The slope of the surface of the present ground between Bogra and Arich or Sirajganj and Aricha are from 0.04/1000 to 0.05/1000. 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 borings were formed during the Würm Ice Age. The sand and silt layers on the top of the gravel 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 Aricha is located in an inland area far from the sea coast and partly because the deposition of the Jamuna River has prevented the invasion of sea water. There are no gravel layers at Gabargaon and Bahadurabad. On this problem a

Fig. 2-5 Geological Record of the Bore Holes at Aricha and Bogra



detailed discussion will be presented in a report by the geological survey team.

ii. Influence of the ground movement on geomorphological development.

The ground movement of this region is large. Barind Terraces are formed by the upheaval of the earth from the Pleistocene onward and the Tippera Surface during Holocene Period. These terraces are surrounded by fault scarps. On the other hand, the alluvial plains along the Jamuna, Ganges, and Meghna Rivers are located in the ground dipping or subsiding zone. The ground height of the Sylhet depression is only 3 meters in spite of the fact that this depression is located far from the coast (250 Km). We have the records of earthquakes in 1762, 1775, 1812, 1888, 1897, 1912 etc. And the ground movements which has resulted from the earthquakes have also been reported and the north western part of the Ganges Plain has been upheaved and the south eastern part has been downwarped.

(3) The shifting of the Ganges River.

The shiftings of the river course of the Ganges and Brahmaputra (Jamuna) were remarkable partly because the gradient of the plain is gentle, also the deposition by the rivers is large, the annual variation of flood discharge is big, and there are few artificial river conservancies.

Two different thesis 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 Hooghly River which runs through the City of Calcutta was the mainstream of the Ganges. When the British invaded India, the main harbor was located in the upper reaches above Calcutta. But due to the shifting of the Ganges from west to east, the depth of the Hooghly River became shallow and the harbor moved from its upper reaches to Calcutta. And the Ichamati, Jalang, Garai rivers etc. which are located between the Hooghly and the Ganges were formed during this 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. The present Ganges River (Padma) is already seen in Ptolemy'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 has estimated that the Ganges and Hooghly Rivers were situated as they were from ancient times.

M.Oya researched the Sundarbans and found the following features. Some differences in the topography of the eastern and western parts of the Sundarbans are quite noticeable. The natural levees in the western part are higher than in the eastern part. In the western part the creek banks are more pronounced. This shows that the western part has been upheaved and the eastern part has been downwarped. The formation age of the plain in the eastern part is newer than that of the western part. From the above-mentioned phenomena, he presumes that, the Hooghly River has become smaller and smaller but the Ganges River has become larger.

(4) Shifting of the Brahmaputra-Jamuna River.

During the time of Major James Rennell 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 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 disharge 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.Oya observed outcrop of the fluvial layers at Jamalpur shown in Fig.2-6-1. As you can see, in Fig. 2-6-2, the lower part is a sand layer and the upper layer is silt.

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

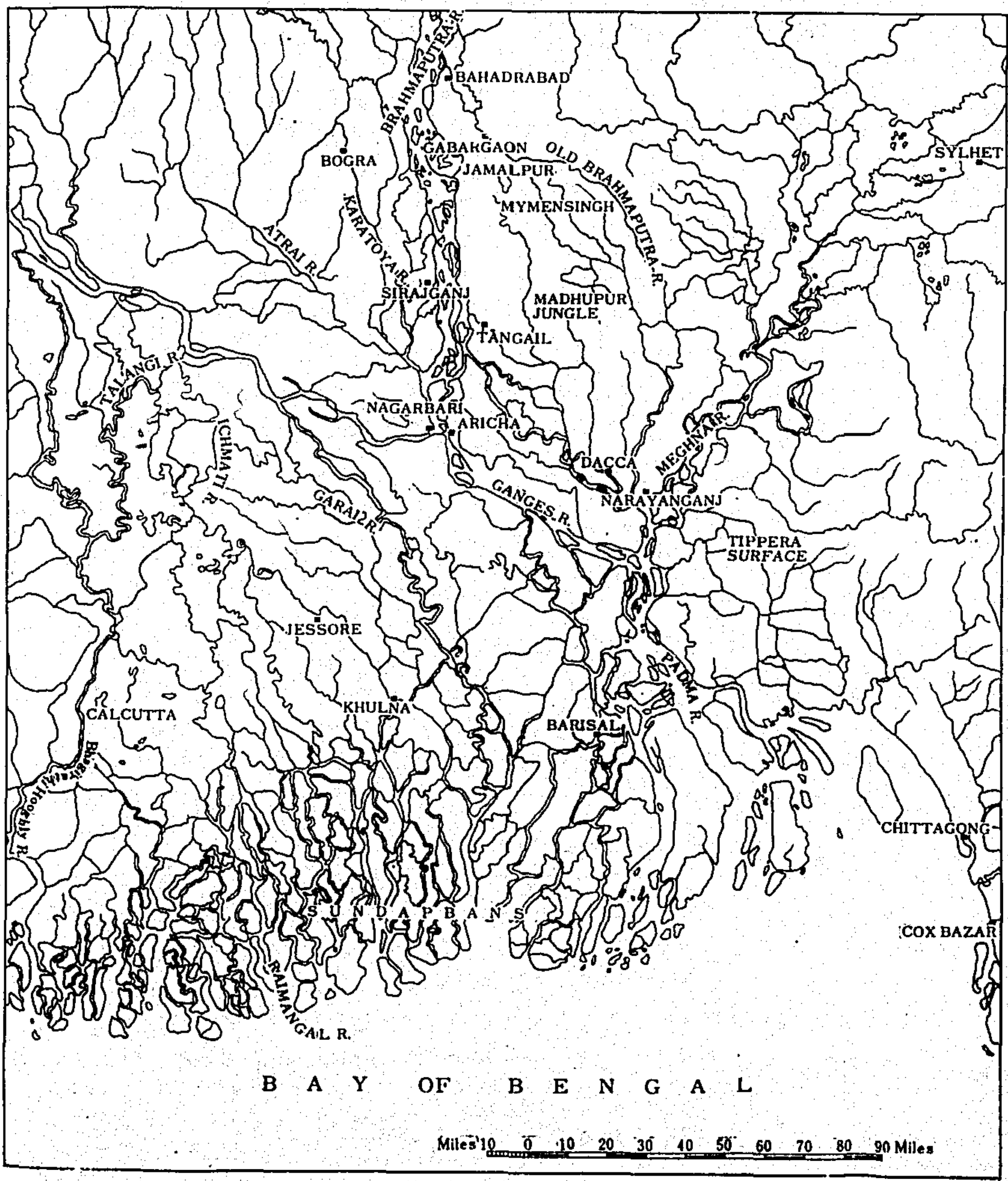
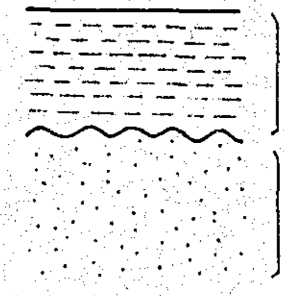


Fig. 2-6-2 Outcrop of fluvial layers of the Old Brahmaputra River at Jamalpur



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 activities 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 two rivers mentioned above. It cannot be believed that a big piracy between the Brahmaputra and the Tsanpo occurred within the last 200 years.

Prof. McIntire suggested that the diversion has occurred partly because of the tilting of the eastern Barind Terrace and partly because of the shifting of the Tista River caused by the tilting of the 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 confuluence. Some of the excess water could be carried by the Jhinai which during Rennell's time was narrow distributary of the Brahmaputra. This distributary was gradually enlarged and its discharge increased from year to yeat 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 formed in its channel, especially during the low water period. The growth and stabilization of these bars could have obstructed the free flow of flood waters 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.

(5) Effects of the diversion.

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 Bansi and their disstributaries like the Lohajang, Nanglai, Atrai and others. As a result of this diversion, the headwaters 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, 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 volume.

The Old Brahmaputra channel still continues to carry some water of the Brahmaputra River but in 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, Jaldhaka, and other alluvial fan tributaries, the Jamuna sediments became much coarser than before.

(6) Geomorphological comparison of the four sites.

M.Oya has prepared geomorphological land classification maps of the four proposed bridge sites in the Jamuna River basin indicating areas which will be subject to flooding by photointerpretation and field survey Fig.2-7, 2-8. The name of the geomorphological elements are shown in the following.

Alluvial fan
Natural levee
Back-swamp
Point-bar
Meander-scrol
Dry river bed
Former river course
Cliff
Paddy on the Char

The name of the geomorphological elements are the same in Japan but the characteristic of these elements are different.

i. Bahadurabad and its vicinity.

There are alluvial fans along both banks of the river. The alluvial fans of Japan consist of sand and gravel but it is mainly sand in the Bahadurabad region. The chemical weathering is more severe and because the area belongs to a sub-tropical region. Also the width of the fan is narrow but the length is short. Two alluvial fans have diveloped as long narrow strips along the left banks. The old alluvial plains which consist of natural levee and back-swamps are located in the above-mentioned fans. The old alluvial fans have been formed before 1830. The shape of the fan shows that formation process has not yet been completed.

Fig.2-7 Geomorphological Land Classification Map of the Jamuna River Basin

Bahadura bad, Gabargaon and It's Surrounding Area

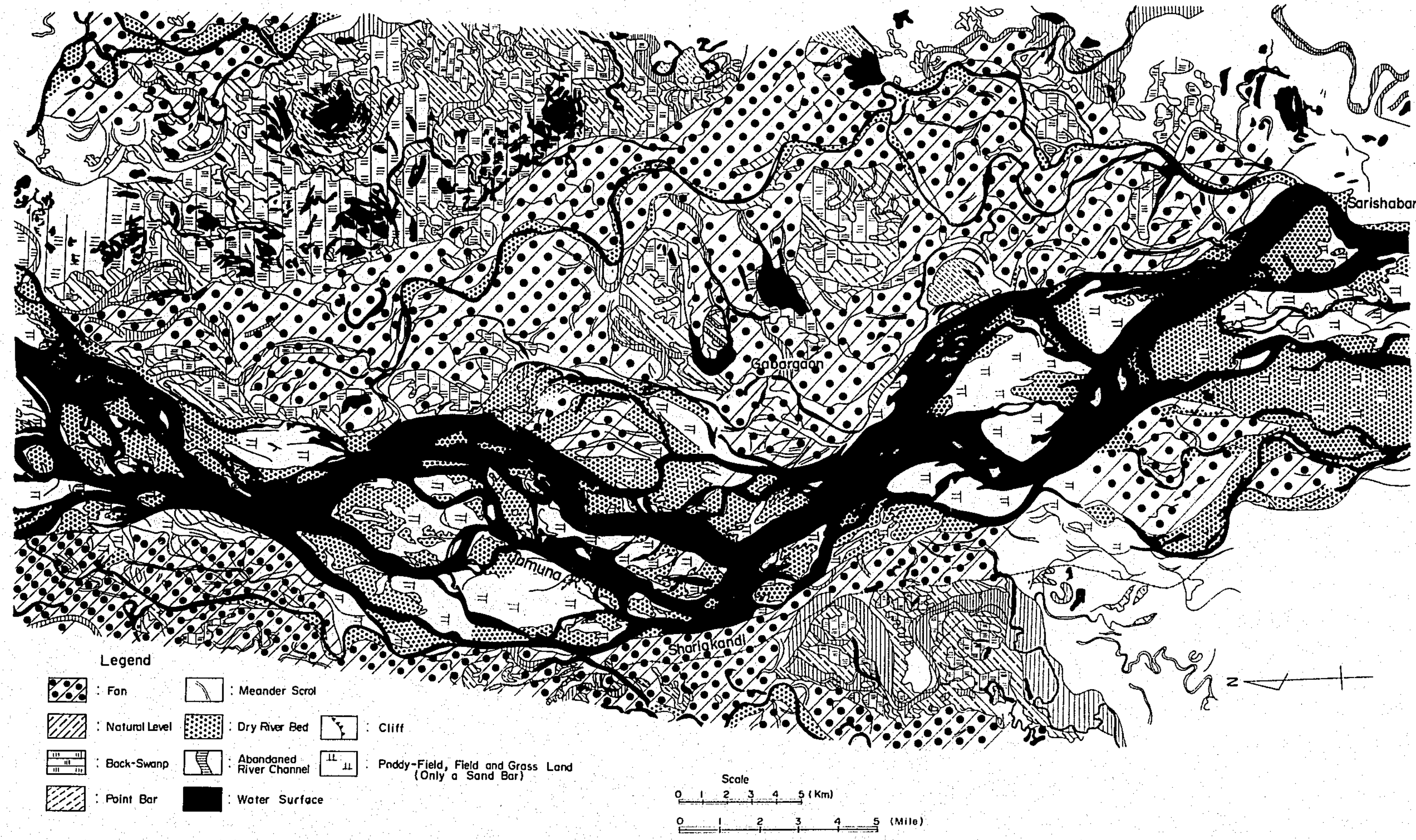
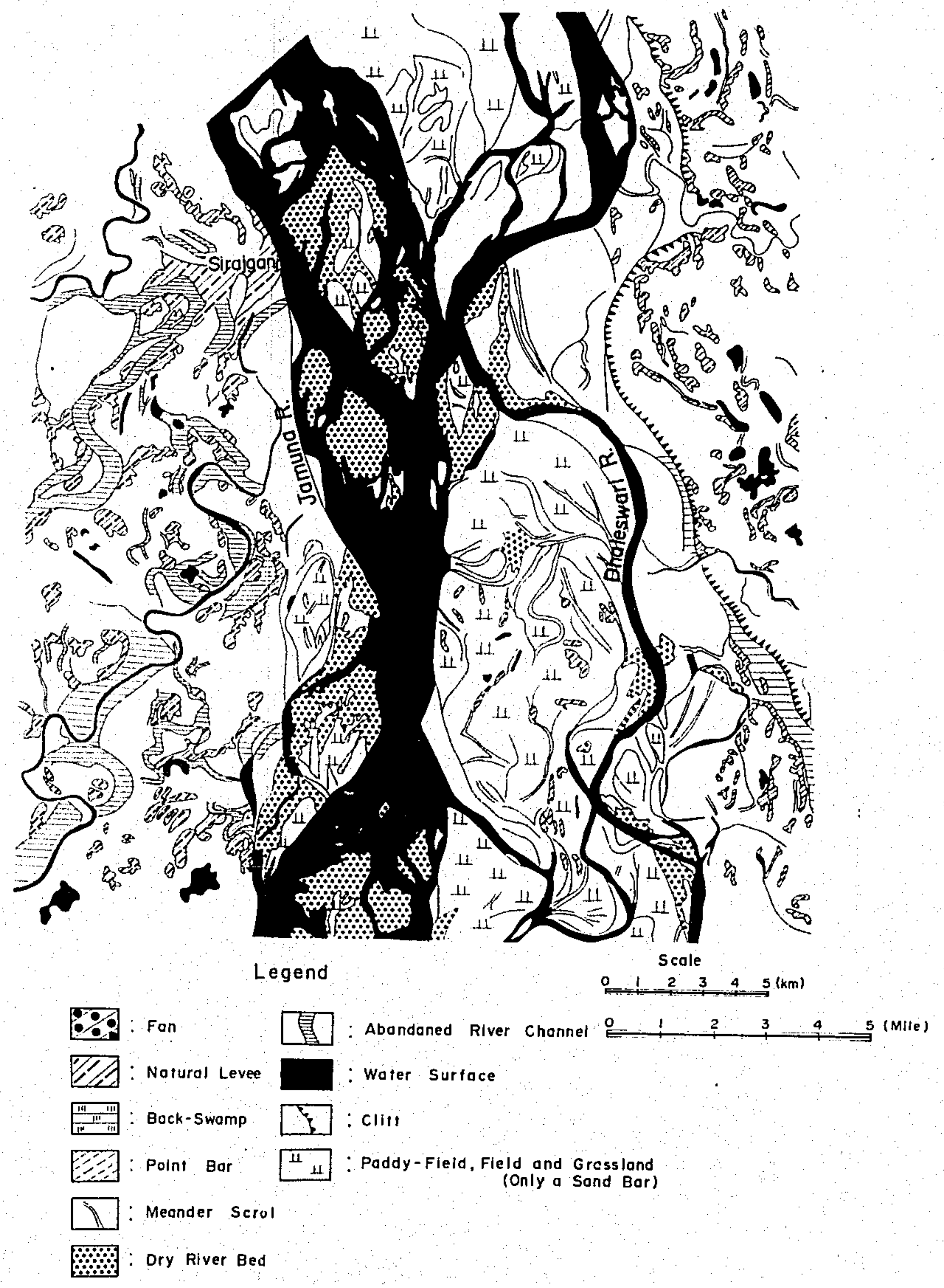


Fig.2-8 Geomorphological Land Classification Map of the Jamuna River Basin

Nagarbari, Aricha and its Surrounding Area

Sirajganj and its Surrounding Area



ii. Gabargaon and its vicinity.

The width of the alluvial fan in this area is wider than that of the Bahadurabad. We can see old alluvial plains which were formed before 1830 in the fan here and there. The old alluvial fan consisted of natural levees, back-swamps, former river courses, etc. There are a number of large former river course on the right bank.

iii. Sirajganj and its vicinity.

The above-mentioned two places are alluvial fans but the Sirajganj is a natural levee region. Several distributaries have diverted at Bahadurabad but astricted at the upper part of the Sirajgnaj. Namely the distributaries are formed as an anabranch. Thereafter distributaries have diverted again at the lower reaches of the Sirajganj. There are cliffs about 4 m high between the present alluvial plain and the old alluvial plain on the left bank of the Jamuna River. The town of Sirajganj is located on the old alluvial plain, that is, Sirajganj is located on the narrow part of the plain [about 10km (6.2mi) width] which was formed by the old alluvial plain. The villages located on the natural levees on the right banks were founded 150 or 200 years ago.

iv. Aricha, Nagarbari and its vicinity.

There are distinct regional geomorphological differences between the left and the right banks in this region. There is a big back-swamp area on the right bank. The area has been formed by the back-waters of the Ganges during a flood time. On the left bank, natural levees are developed. The levees have been formed not by the present Jamuna River but the former rivers. There is a distinct former river course whose width is about 3.5 km, (2.2 mi) on this left bank.

The above comparisons are summarized in Table 2.1. Namely, Bahadurabad, Gabargaon are located on the alluvial fan. Sirajganj is a natural levee and Nagarbari or Aricha are natural levees or delta regions.

Generally speaking, the shifting of the river courses in the alluvial fan is frequent. The width of the river in alluvial fan is wider than that of natural levee region because of the difficulties of flood control. Furthermore, the age of the formation of the alluvail fan is new namely since 1830. There are possibilities of the shifting of the river courses in the alluvial fan region, i.e. in Bahadurabad and Gabargaon regions.

Table 2.1. Comparison geomorphology among the four proposed bridge sites

Item of Comparison / Place Name	River morphology	Geomorphology of inland region			
		Left bank		Right bank	
		Geomorphological element		Geomorphological element	
		Deposition by Jamuna River	Deposition by former river	Deposition by Jamuna River	Deposition by former river
BAHADURABAD	Braided stream Alluvial fan	Alluvial fan Natural levee Back-swamp Point bar Former river course (big)	Natural levee Back-swamp Point bar	Alluvial fan Natural levee	Natural levee Back-swamp
GABARGAON	Braided stream Alluvial fan	Alluvial fan Natural levee Former river course (big)	Natural levee Back-swamp	Alluvial fan Natural levee Back-swamp	Natural levee Back-swamp
SIRAJGANJ	Natural levee	Natural levee Back-swamp	Natural levee (big) Back-swamp	Natural levee Back-swamp	Natural levee (big) Former river course (clear)
NAGARBARI	Natural levee Change of the river bank is remarkable	Natural levee Back-swamp Delta	Natural levee Back-swamp Delta	Natural levee Back-swamp Delta	Natural levee Back-swamp Delta

But we found that the stage of the river has advanced a little. There are small and narrow natural levees along the river courses. This shows that the river courses has stabilized a little.

The river course in the natural levee is more stable than that of the alluvial fan. The reason is as follows: natural levee has been formed not by the flood waters from the upper reaches to the lower reaches but from the overflow of the main channel into its adjacent regions. The natural levees which have been formed as strips show the stability of the river courses. In Japan, there are more bridges in natural-levee regions than in alluvial fan. From this view, we can estimate Sirajganj is the most stable place among the four places.

Aricha or Nagarbari are located on the natural levee or the delta region. But the region is remarkably influenced by the waters of the Ganges. We found that the changes of the river banks in this region are the largest among the four.

Based on the above-mentioned studies on the geomorphological land classifications, Sirajganj is the most stable place.

Next, we have considered the width of the alluvial plain and distribution of the old alluvial plain.

There are alluvial fans in the Bahadurabad, Gabargaon regions and its scattered. And the old alluvail plains in these regions are in the fans. The relative heights of the old alluvial plains are small. There are possibilities the old alluvial plains will be covered by alluvial fans in the future. Accordingly these areas especially Bahadurabad area seem to have a possibility of future change.

At Sirajganj, there is a narrow part which has been formed by the old alluvial plain, whose width is about 10 Km(6.2 mi). According to studies of plains in Japan, the narrow part is located in an anticline region but a wider area is located in a syncline region. When further geological research can be conducted in this region, we will be able to confirm the process for the formation of this narrow part.

From the geomorphological viewpoint based on the above-mentioned study of width of the alluvial plain and distribution of the old alluvial plain, we have obtained a conclusion that Sirajganj-narrow region is the most stable place among the four and Gabargaon region comes nearest after this.

3. River-morphological Features.

(1) Changes of banklines.

According to the Prefeasibility Report, BIWTA 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 of banklines as given in Fig. 2-9. It is seen from our study mentioned in the next article (2) that these banklines show the outer lines given by small rivers or anabranches which take off from the main Jamuna and join again with the main.

Making use of these data, changes of banklines and river widths were studied in reference to those in 1830. The first figure of Fig. 2-10 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.

It is seen from these figures that the proposed four sites are rightly situated at, so to say, nodes of width variation along the river and the variation of the banklines is comparatively stable at each of these nodes.

Fig. 2-11, 1 to 2 show time variation of river width and time variation of banklines at each proposed bridge site when the year of 1830 has been taken as the reference. It will be found from these figures that the river widths at Sirajganj, Gabargaon and Bahadurabad sites are almost constant except for Nagarbari and variations of displacement of banklines are also almost constant except the early 30 years, while the variation at Nagarbari is quite large.

(2) Changes of 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. 2-12-1 and 2-12-2 show superposition of all waterways comprizing the main channel and other smaller ones 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 main stream in the dry season is roughly 2 km(1.2 mi).

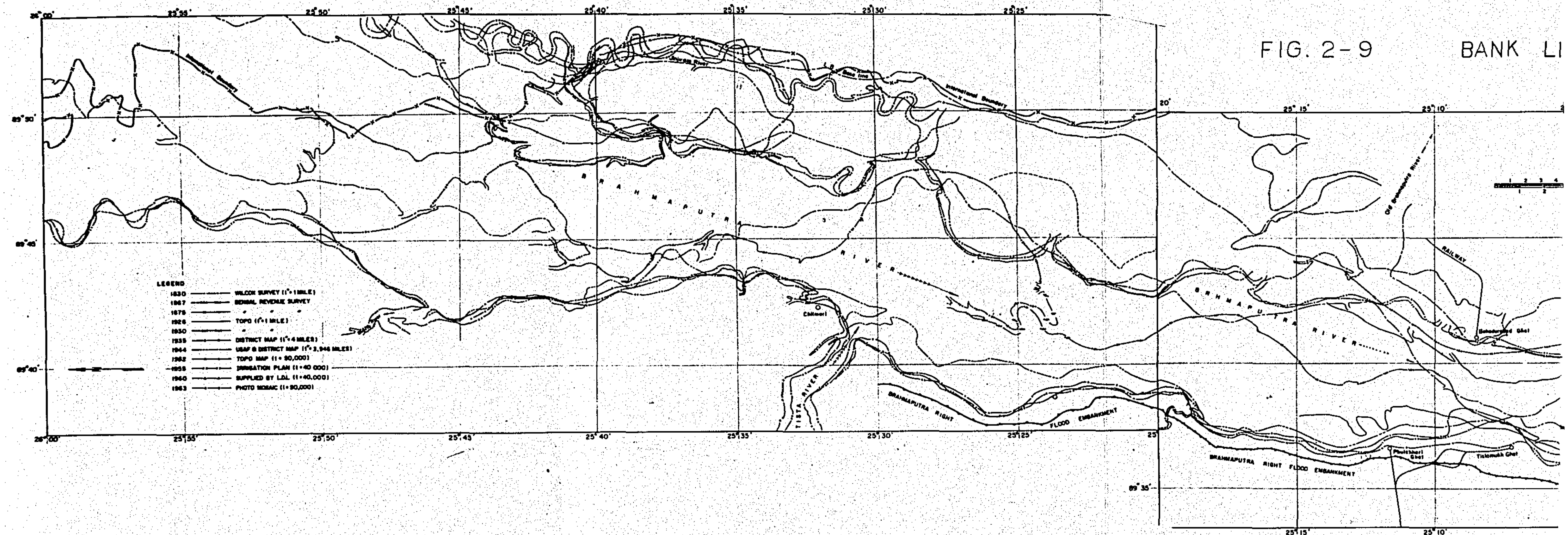
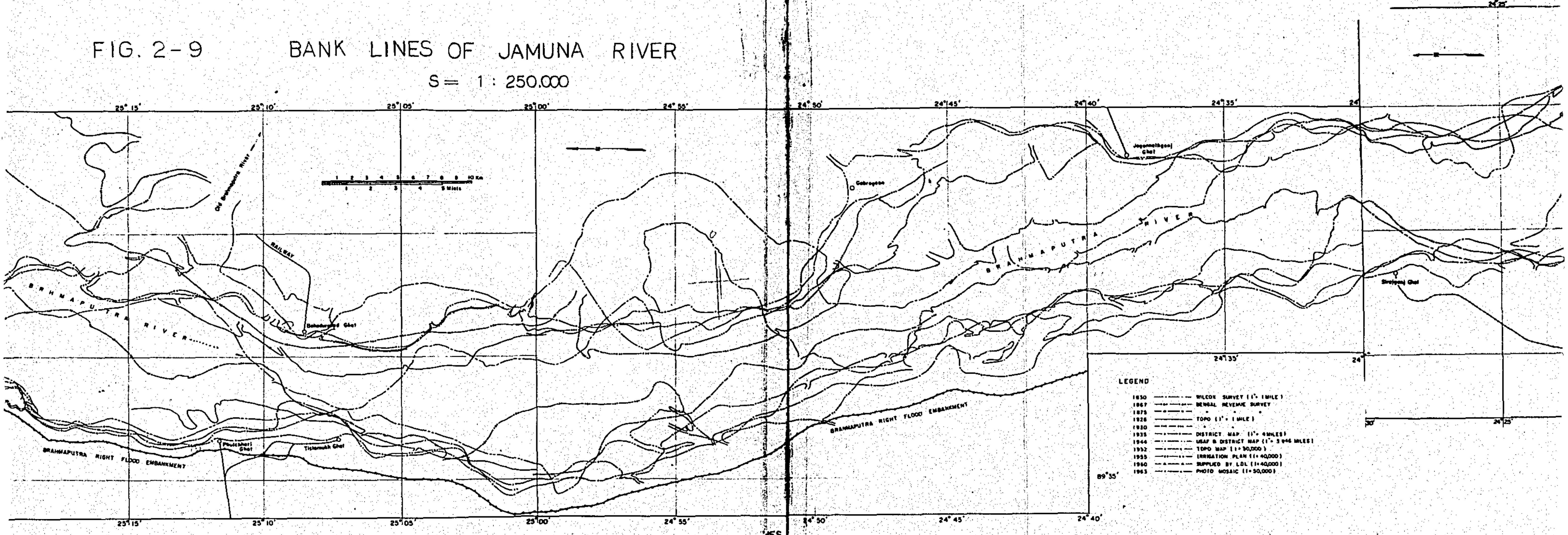
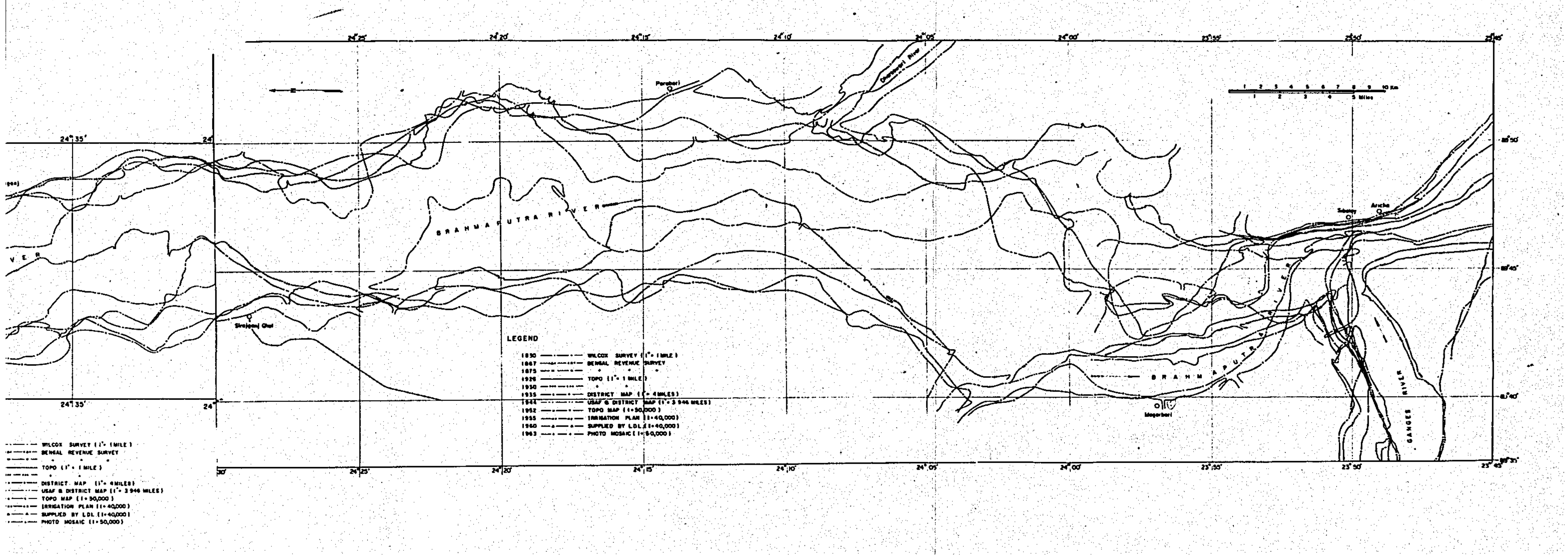


FIG. 2-9 BANK LI

FIG. 2-9 BANK LINES OF JAMUNA RIVER

S= 1 : 250,000





BRAHMAPUTRA RIVER
Dhaleswari River
Porabari
Sirajganj Ghat
Sibalay
Aricha
Mojarbari
GANGES RIVER
LEGEND
1830 WILCOX SURVEY (1" = 1 MILE)
1867 BENGAL REVENUE SURVEY
1926 TOPO (1" = 1 MILE)
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 L.D.L. (1:40,000)
1963 PHOTO MOSAIC (1:50,000)
Km
Miles
24°35'
24°25'
24°20'
24°15'
24°10'
24°05'
24°00'
23°55'
23°50'
23°45'

Fig 2-10 Displacement of River Banks

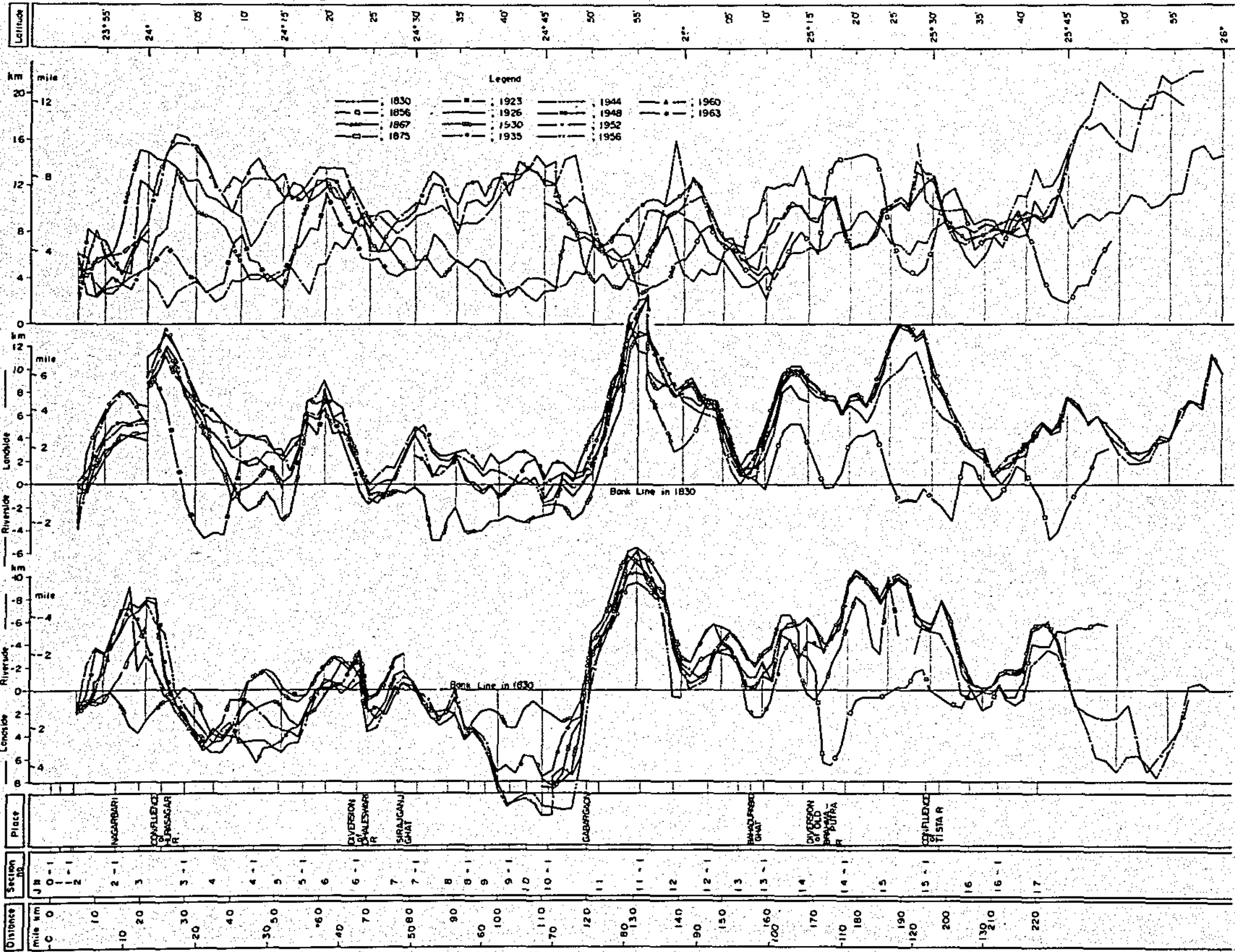


Fig. 2-11-1 Displacement of River Banks (1)

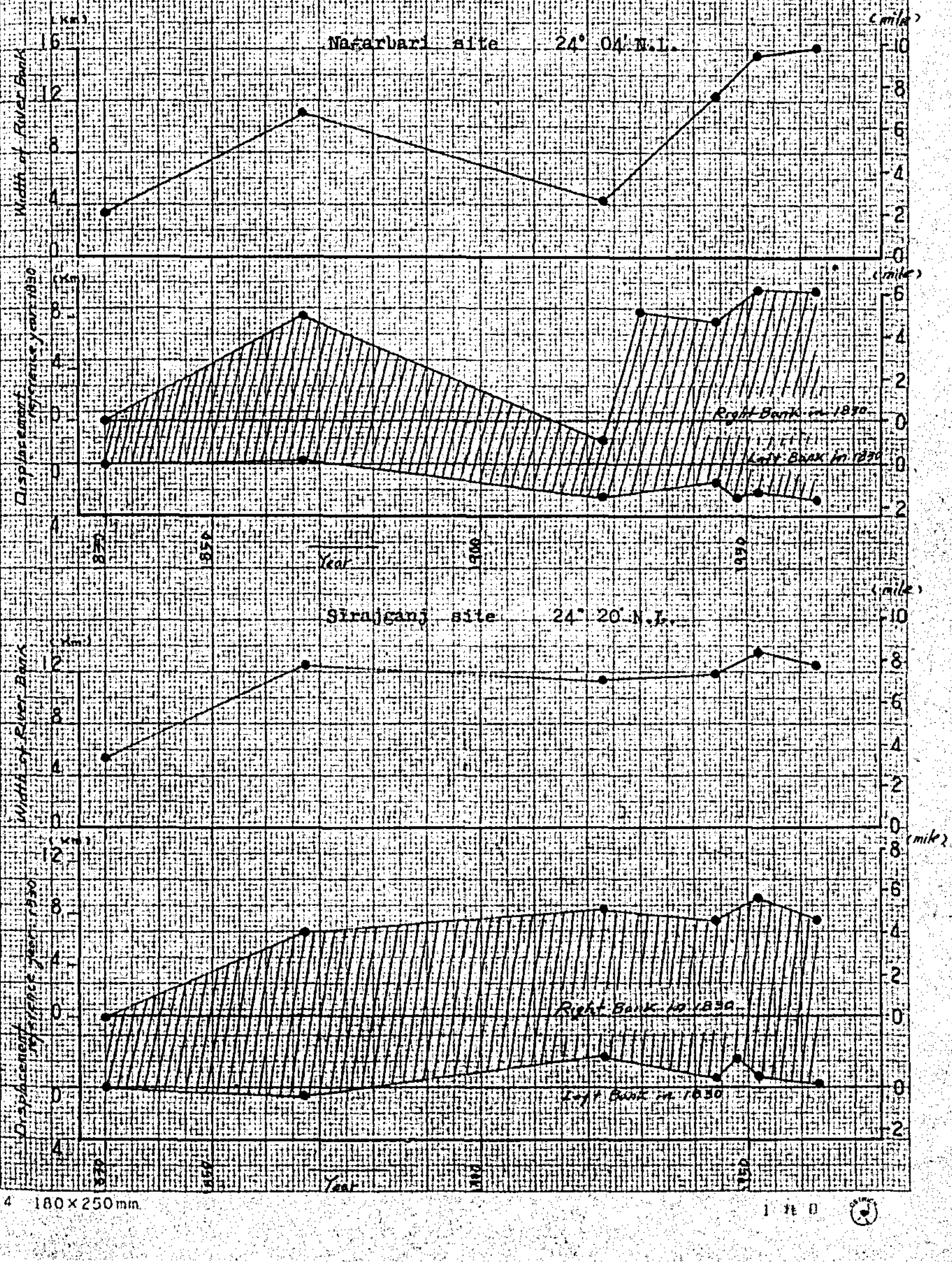


Fig. 2-11-2 Displacement of River Banks

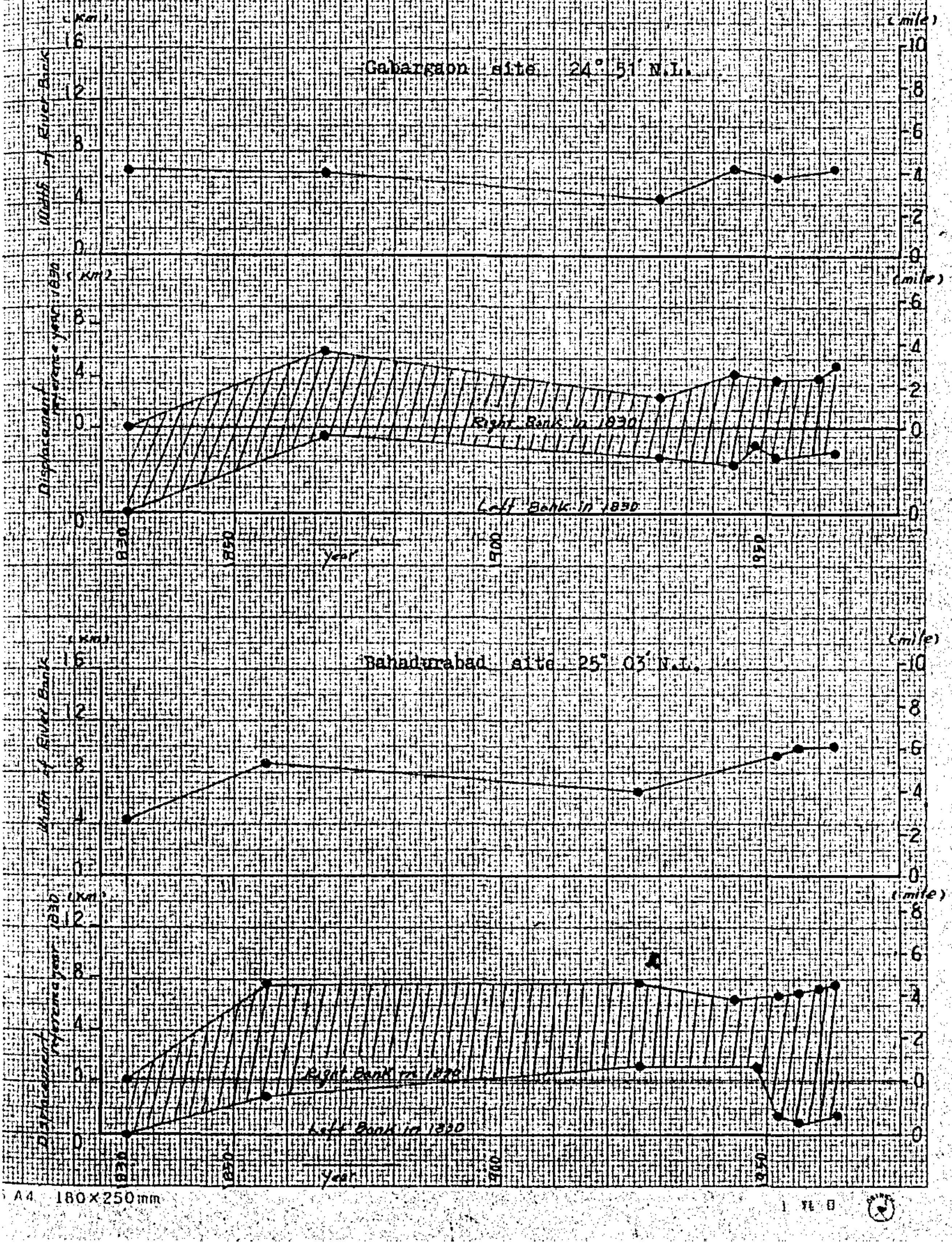


Fig. 2-12-1 Change of Waterways

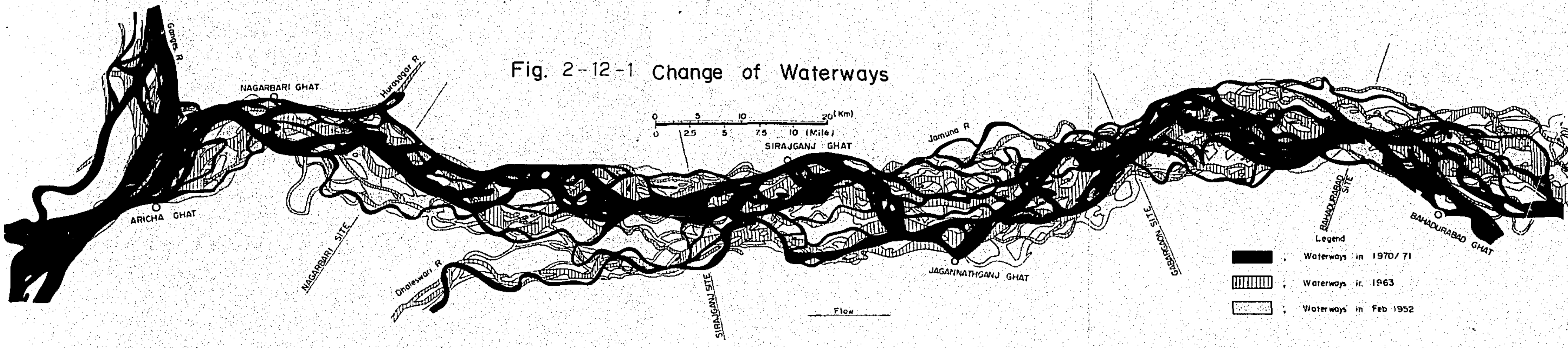
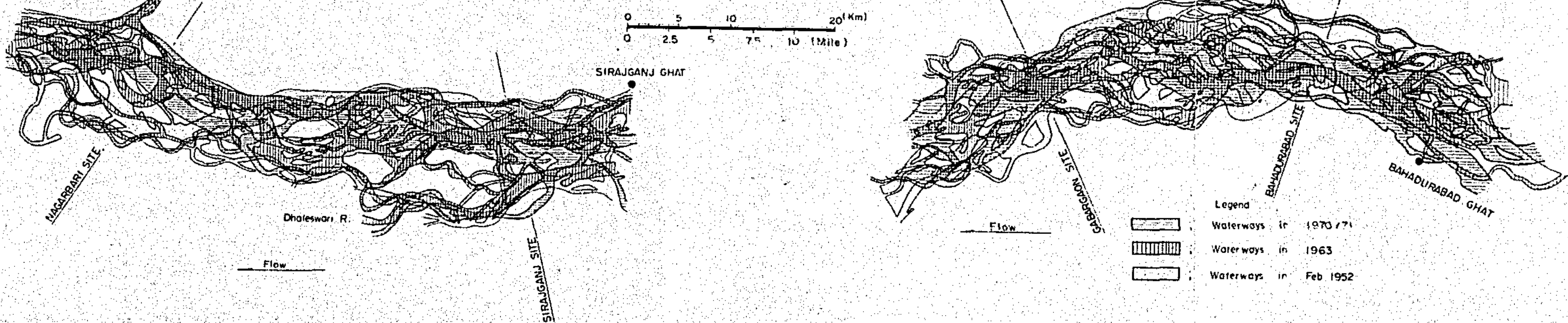


Fig. 2-12-2 Change of Waterways



(3) Changes of cross sections.

The cross-leveling surveys have been carried out by BWDB periodically at the cross sections shown in Fig. 2-13 at intervals of about 8 miles with supplement ones between them. The section numbers and the surveying dates of the cross sections collected this time are shown in Table 2-2. 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. 2-14 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 maximum 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 river 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. 2-15-1 to 2-15-4.

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

4. 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 the sixteen locations shown in Fig. 2-16 with a view to study the features of bed materials on the Jamuna and Padma rivers.

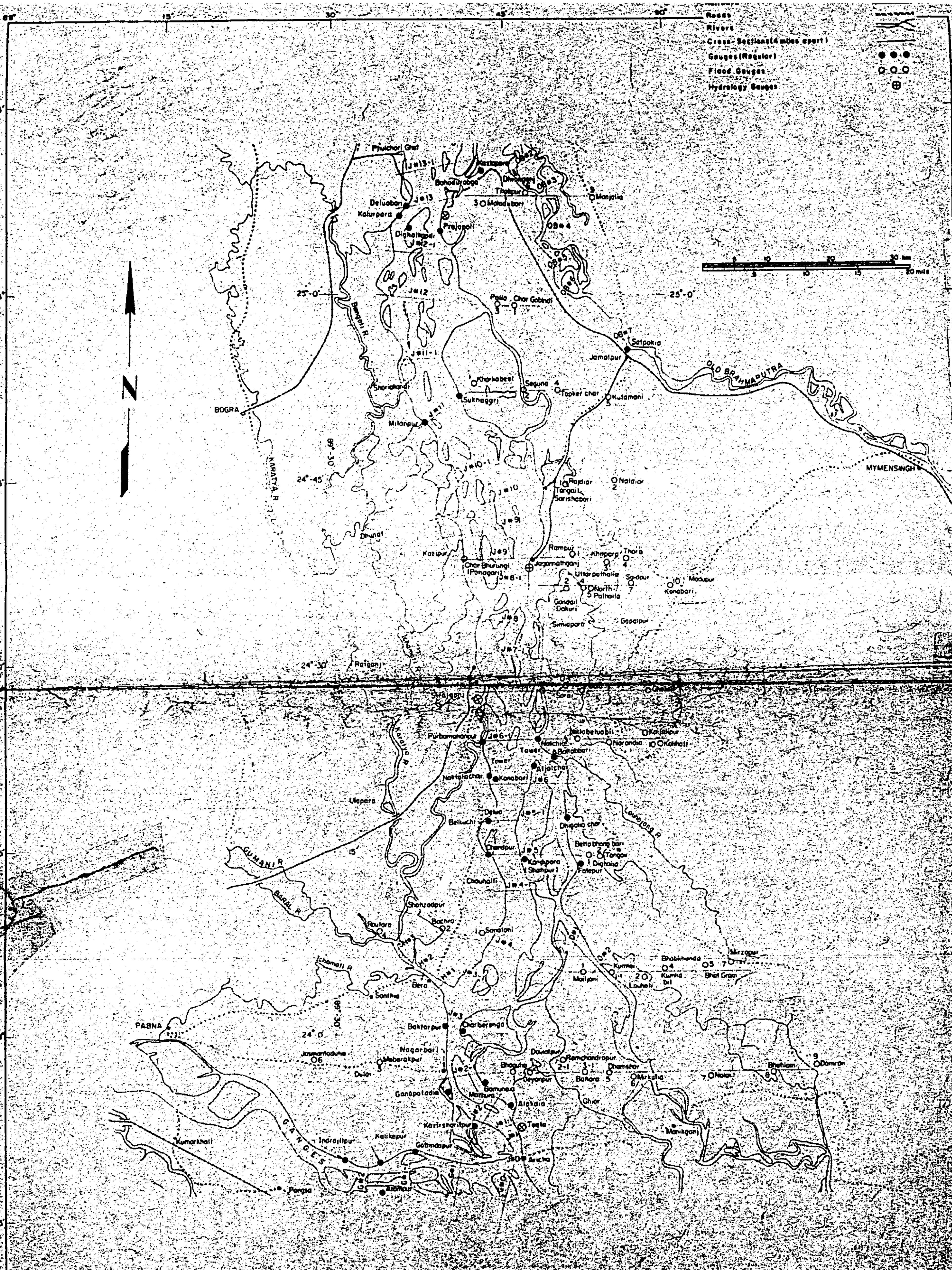


FIG. 2-13 LOCATION OF RIVER SECTION SURVEY
JAMUNA RIVER

Table 2 - 2 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

Fig. 2-14 Channel Features of Jamuna River

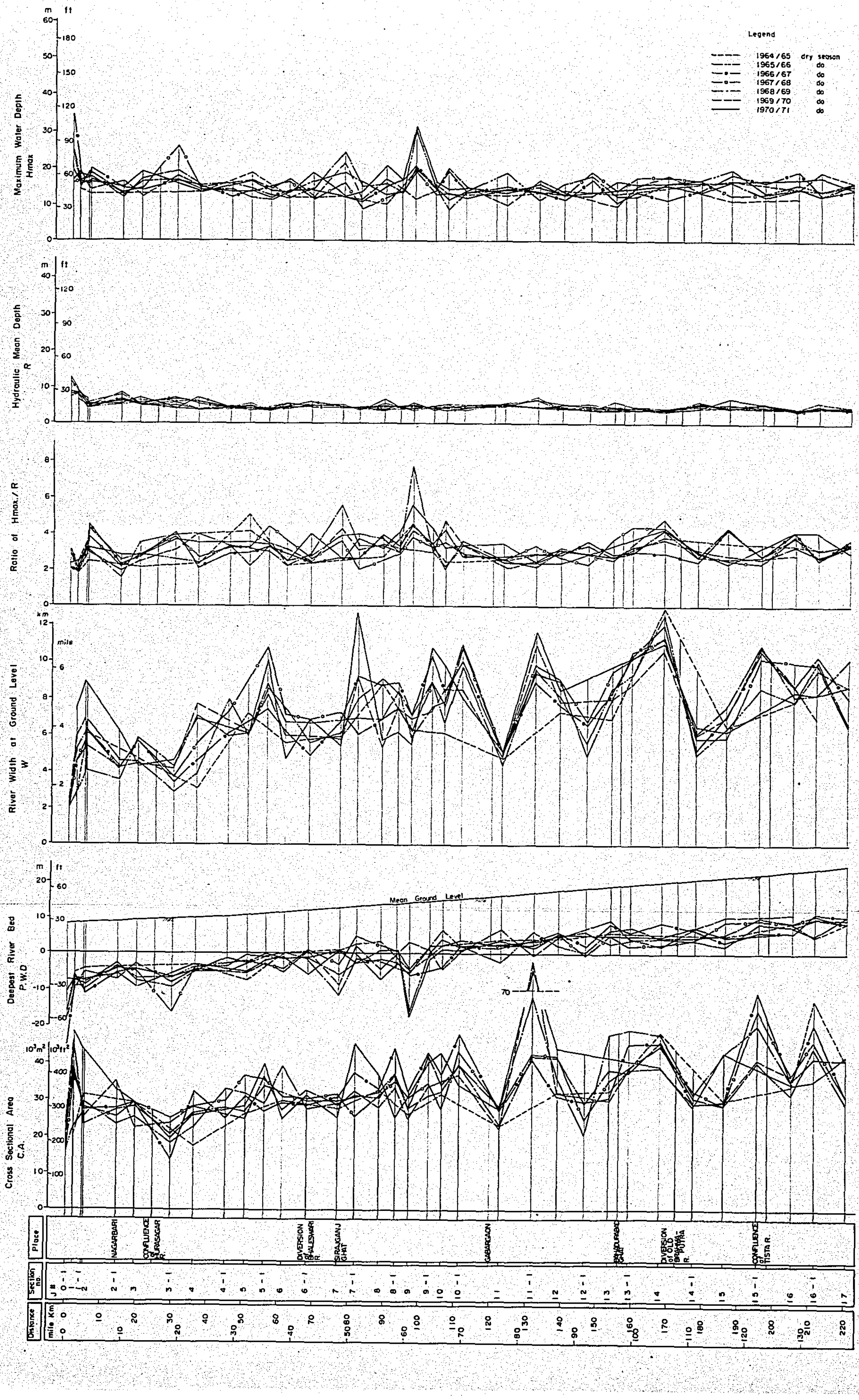


Fig 2-15-1 Cross Section Near Nyarberi Site (J+3-1)

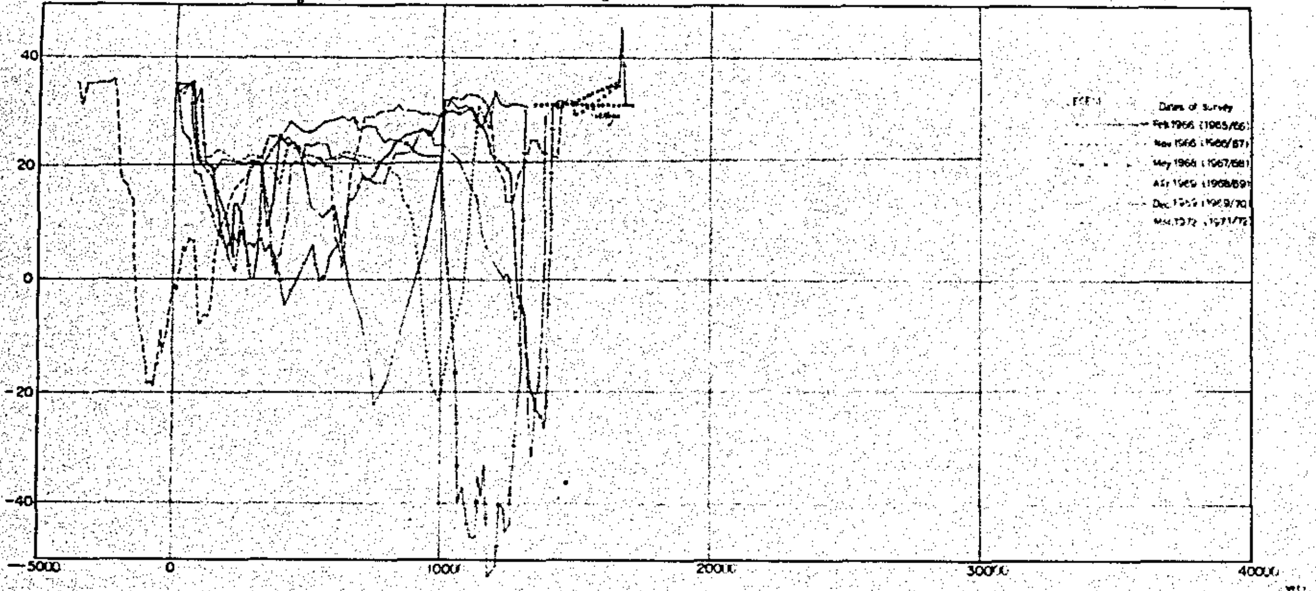


Fig 2-15-2 Cross Section Near Site (J+6)

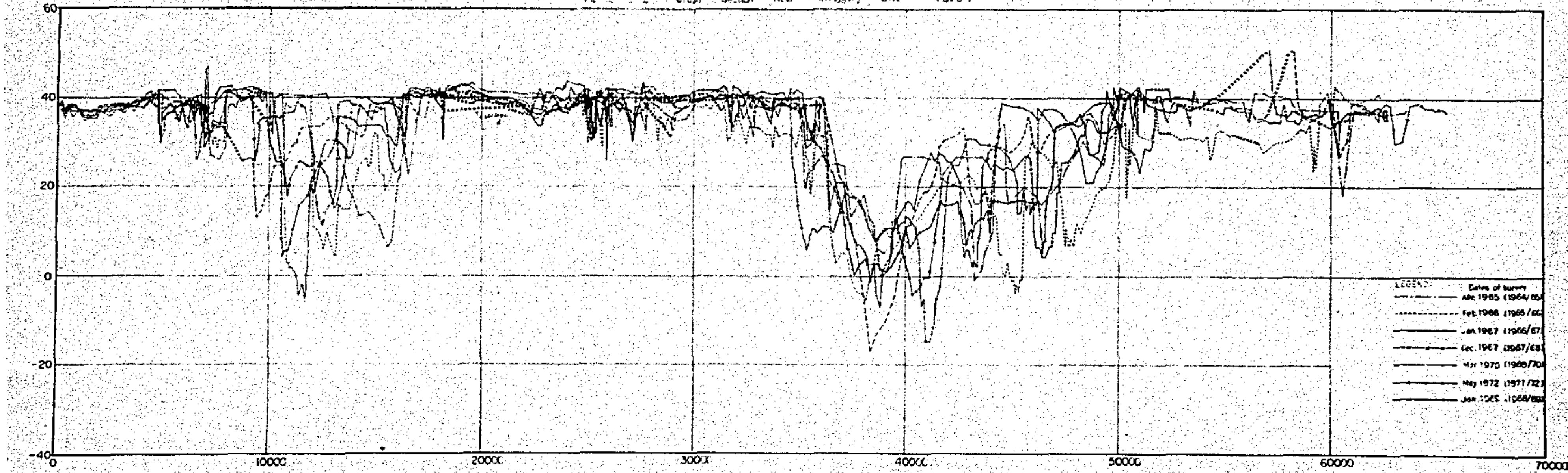


Fig 2-15-3 Cross Section Near Gabargaon Site (J-11-1)

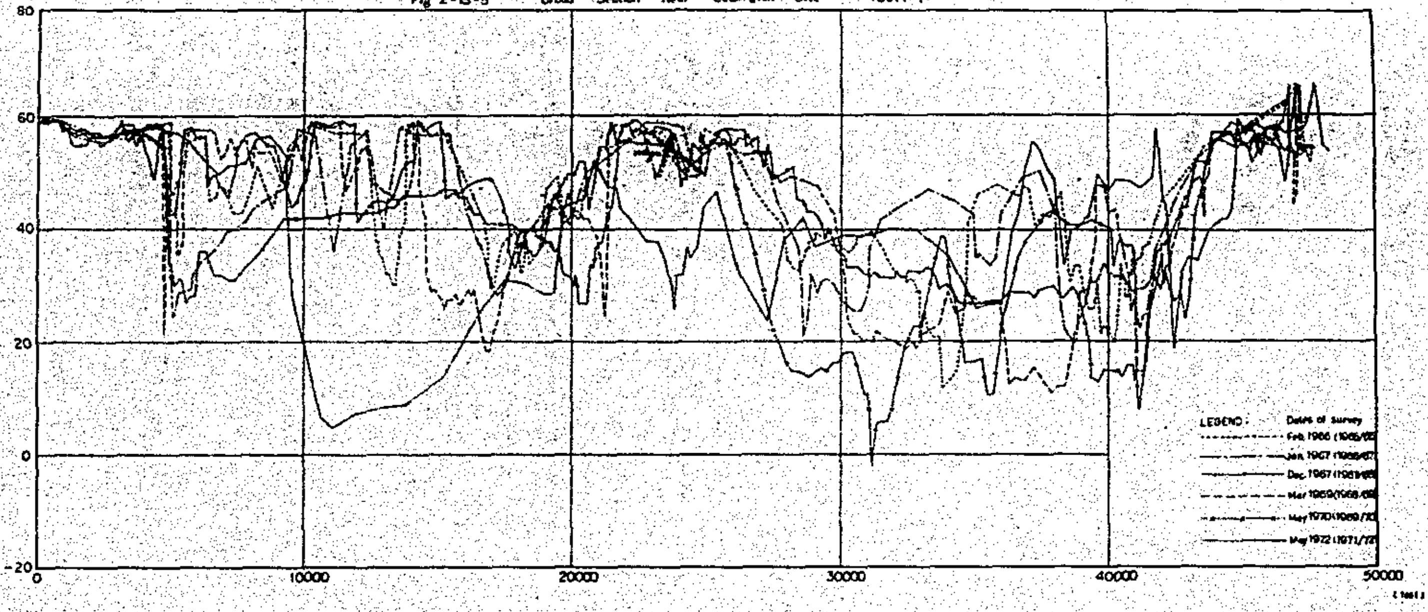


Fig. 2-15-4 Cross Section Near Banaduabad Site (J-13)

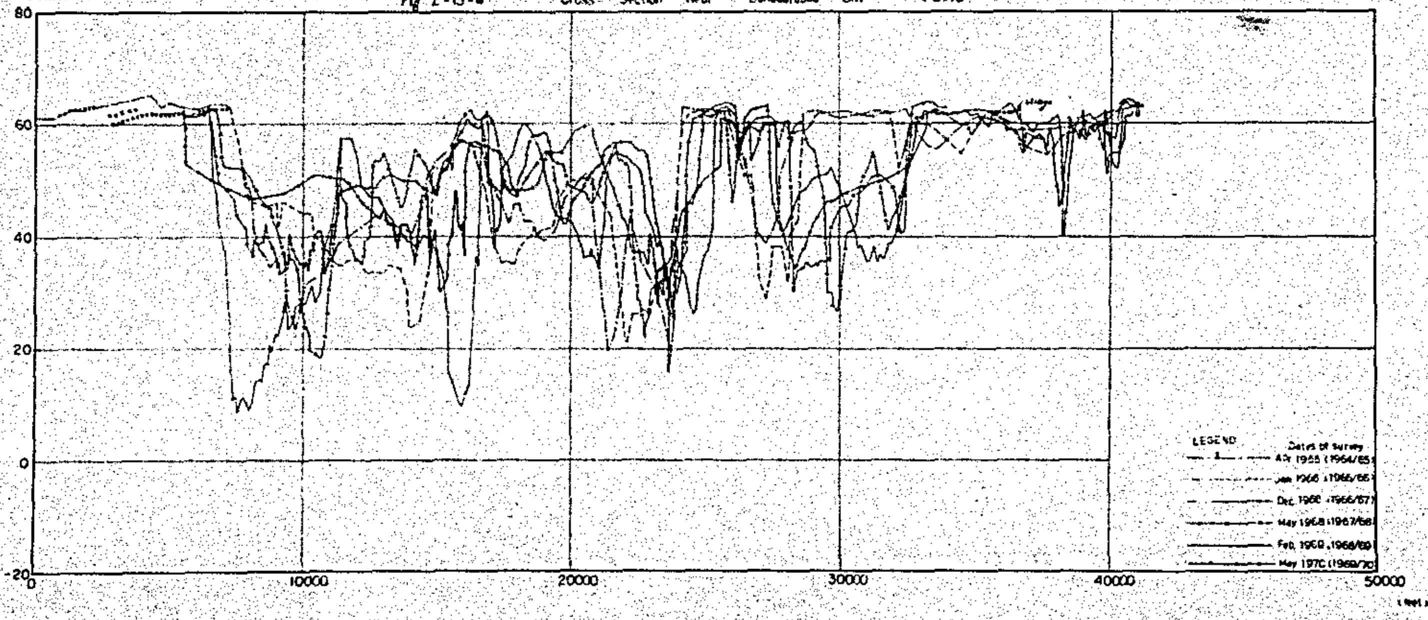
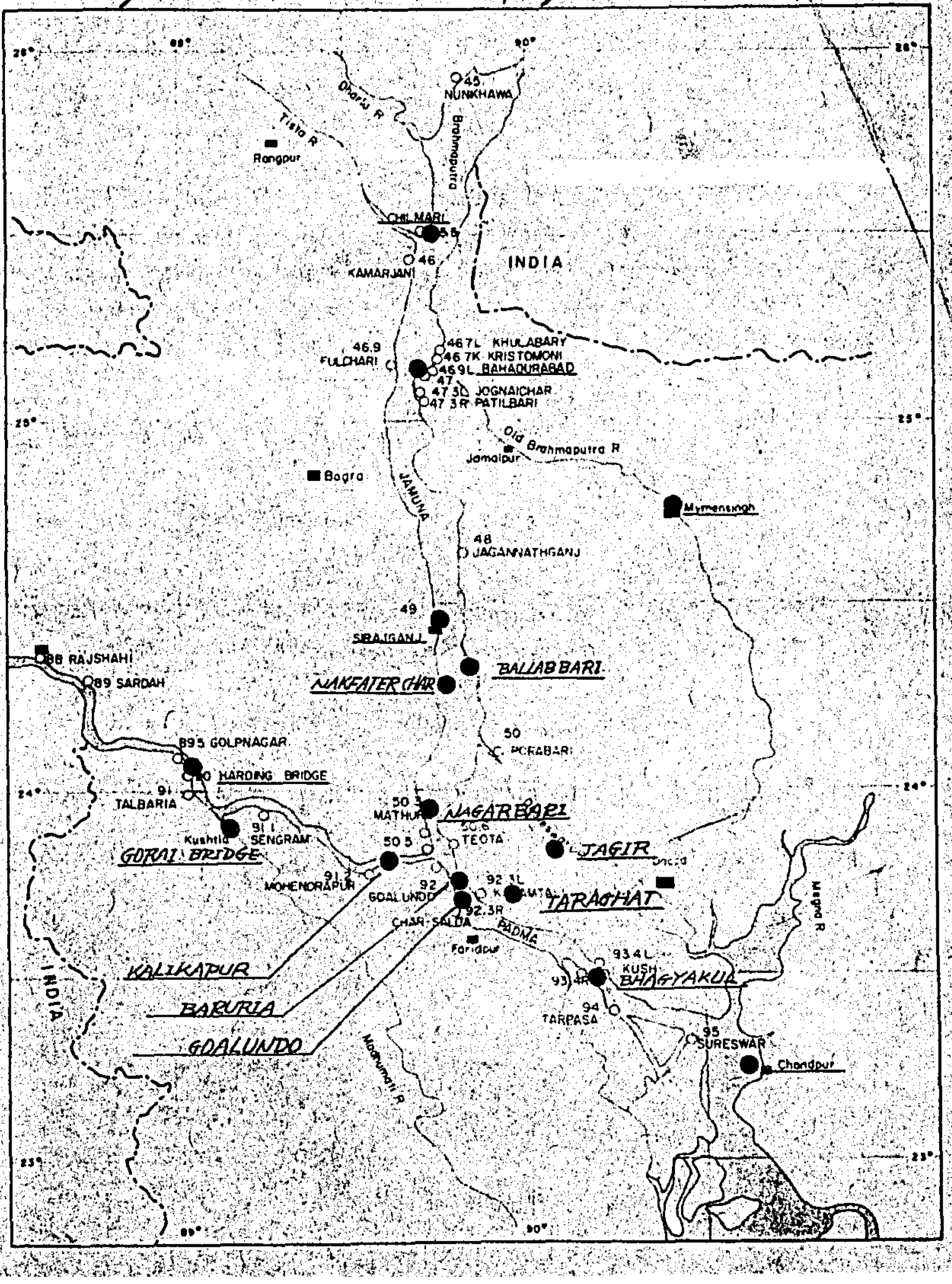


Fig. 2-16 Location of Sampling of Bed Materials



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. 2-17. This figure shows that the grain size is almost constant on the same cross section.

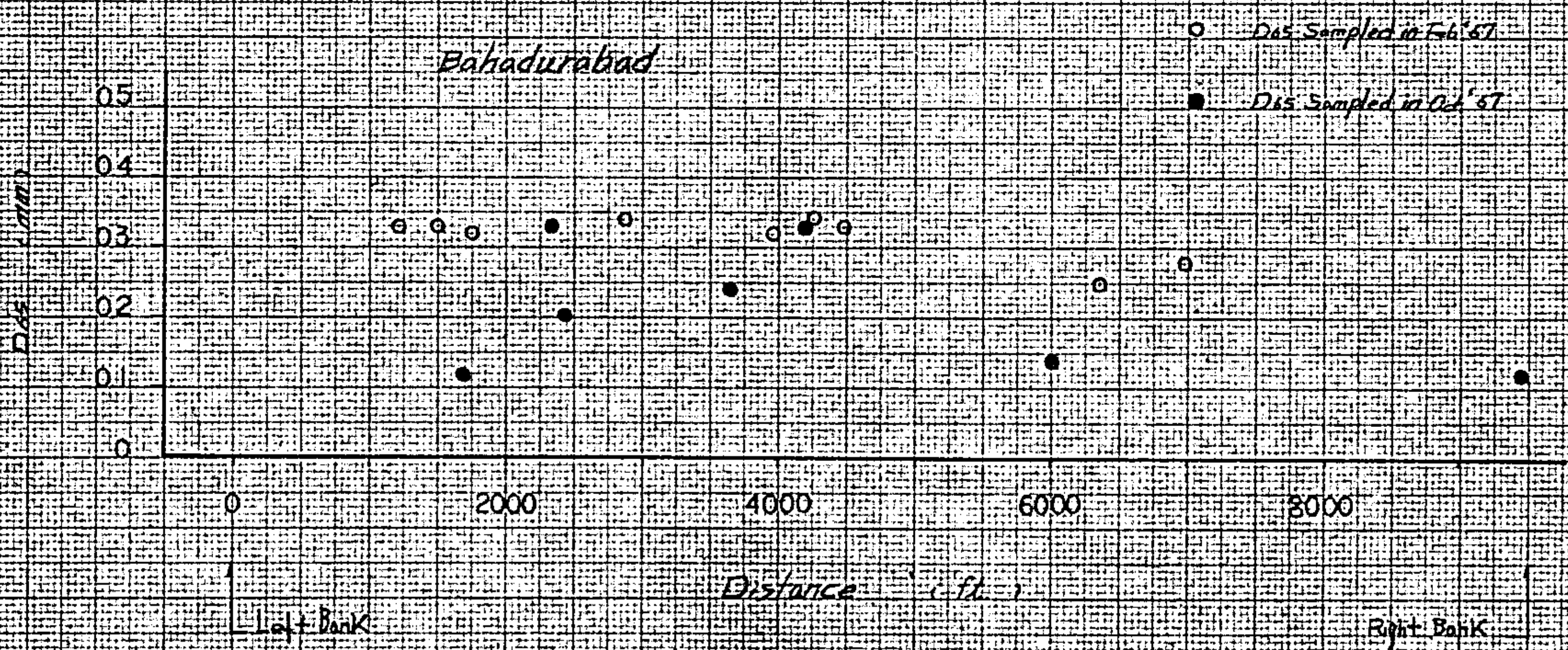
Next, in order to study the seasonal variation of grain size, two sites of Nakfater char and Nagarbari were selected because of availability of data. Grain size D_{65} was plotted against months in the years of 1968 and 1969, which is shown in Fig. 2-18. According to this figure, grain size of bed material 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 2-3.

Table 2-3 Grain Size of Bed Materials

	PLACE	D_{65}	D_{60}	D_{mean}	U.C
BRAHMAPUTRA	CHILMARI	0.266	0.249	0.261	1.9
-JAMUNA	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. 2-17 Cross Sectional Variation of D65



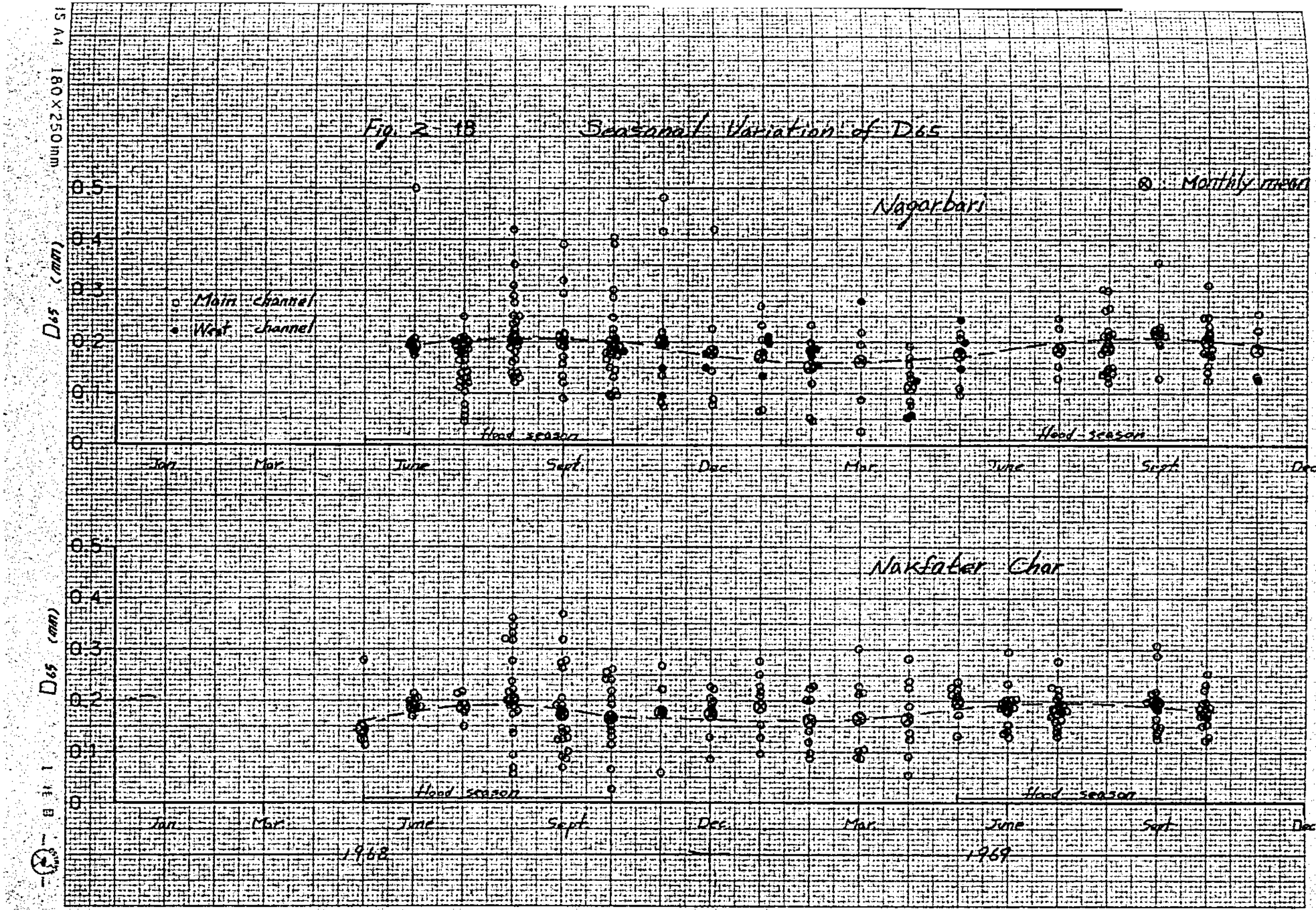


Fig. 2. 18 Seasonal Variation of D65
⊗ : Monthly mean
Nagarbari
○ Main channel
● West channel
D65 (mm)
0.5
0.4
0.3
0.2
0.1
0
Flood season
Flood season
Jan
Mar
June
Sept
Dec
Mar
June
Sept
Dec.
Nakfatar Char
D65 (mm)
0.5
0.4
0.3
0.2
0.1
0
Flood season
Flood season
Jan
Mar
June
Sept
Dec
Mar
June
Sept
Dec.
1968
1969

Fig. 2-19 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. 2-20 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.

5. Suspended Load.

(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 2-4. Samplings were made with Binkley Suspended Sediment Sampler which is shown in Fig. 2-21.

Table 2-4 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. & Ganges-Padma R.	Hardinge Br.		A	A	A	A	A
	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.

Fig. 2-19 Relation between Grain Sizes

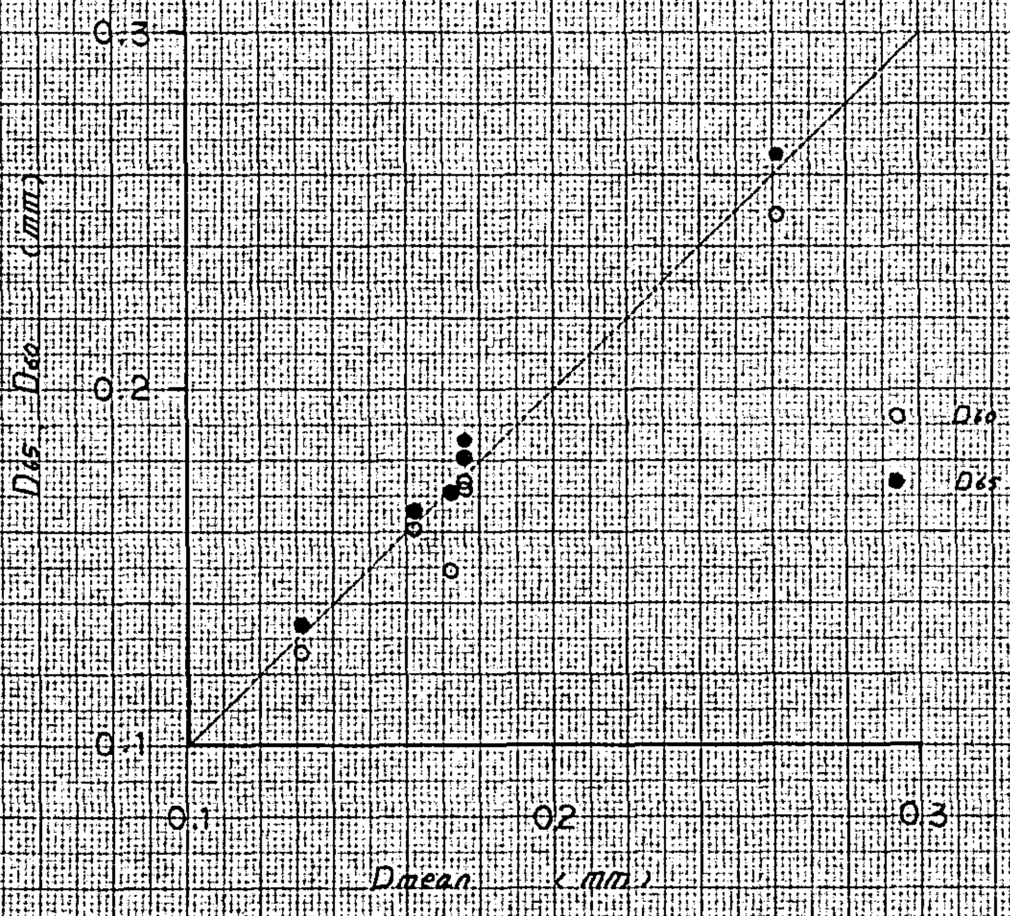


Fig. 2-20 Longitudinal Variation of Bed Materials

(D65 , Uniformity coefficient)

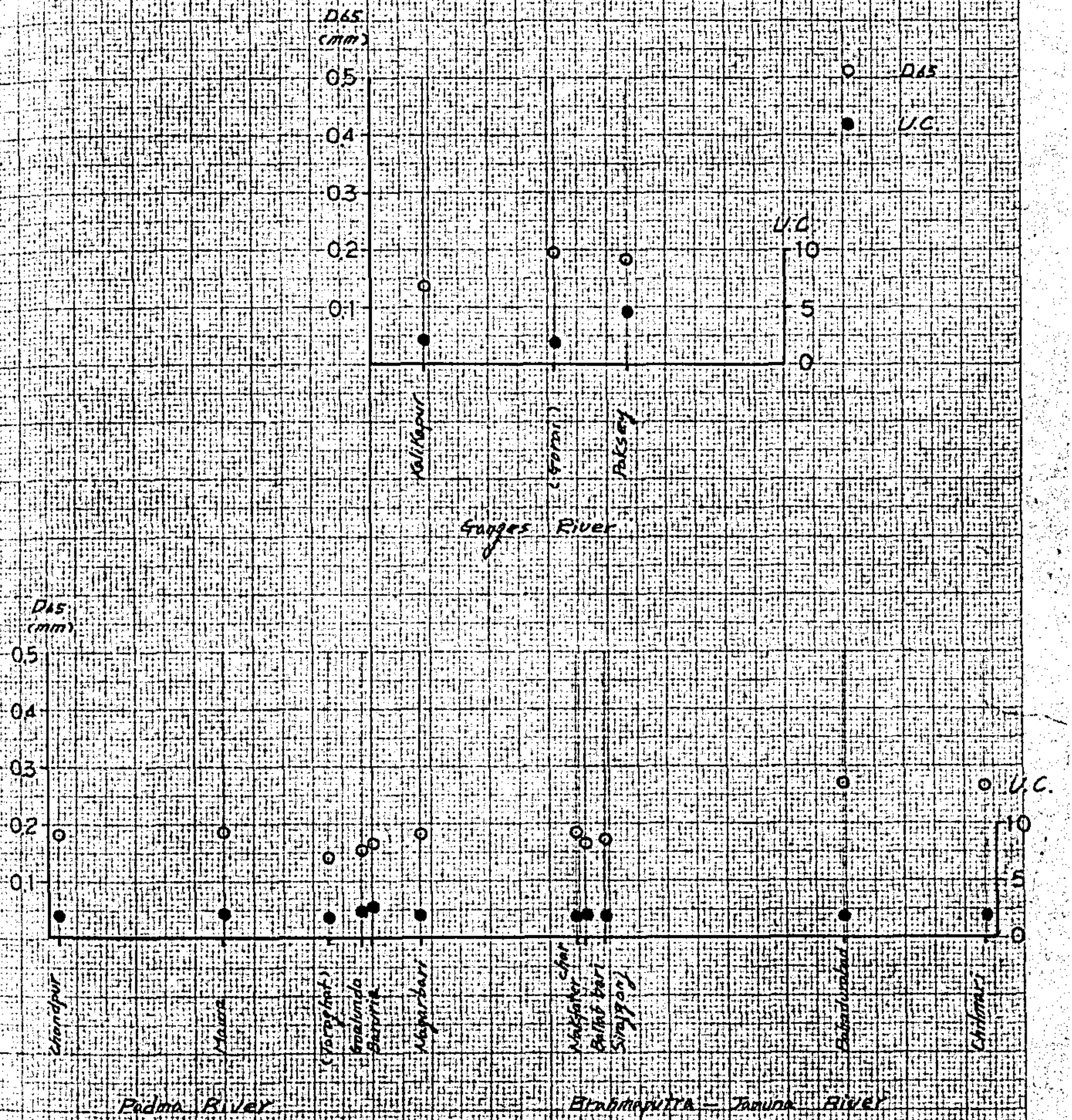
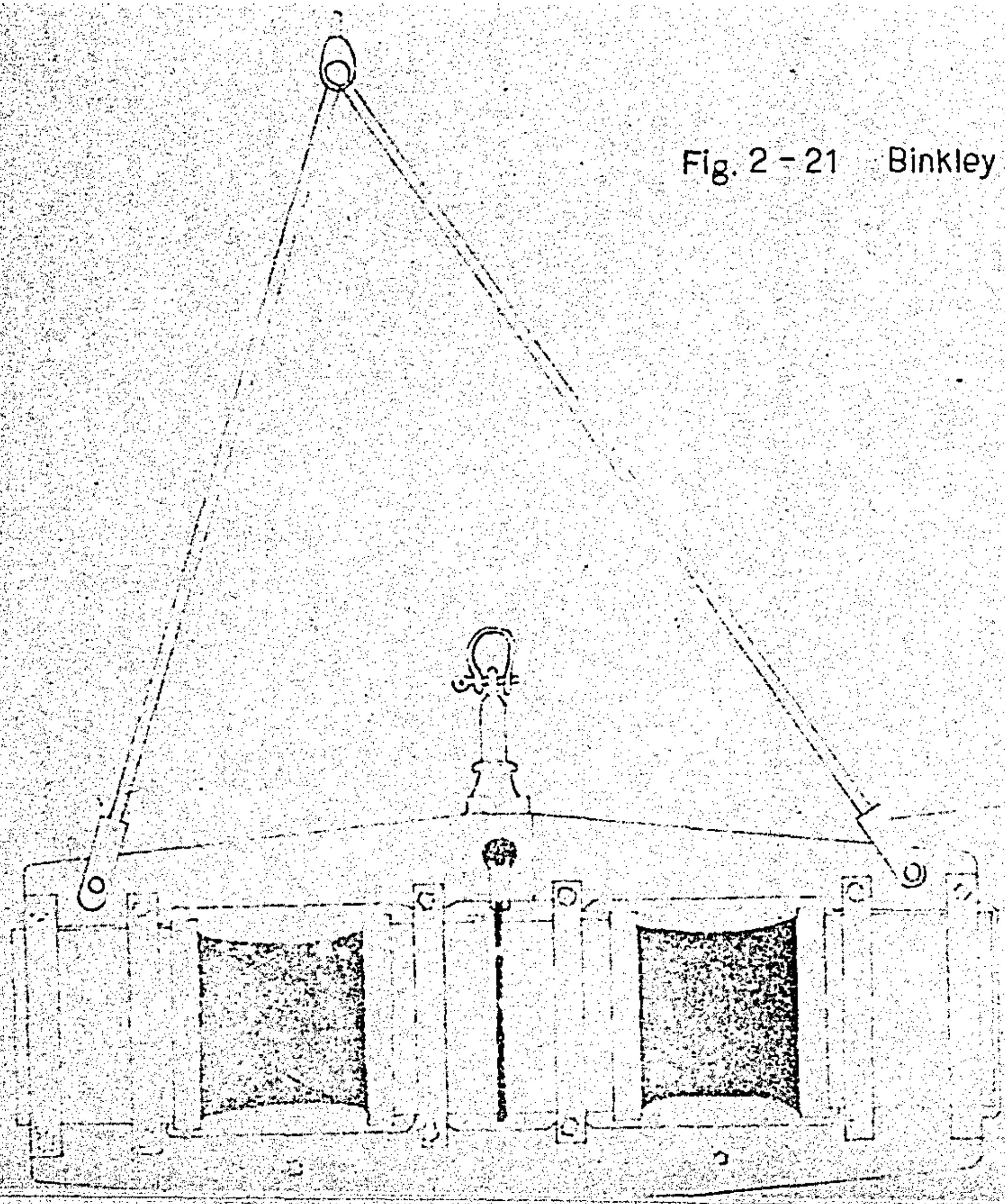


Fig. 2 - 21 Binkley Suspended Sediment Sampler



Note: The sampler is a simple rugged device consisting of a straight-through bronze tube devided into three parts each separated by rubber sleeves and the whole is supported in a metal frame. By pulling on an operating cable the center section of the tube can be rotated, thus twisting the rubber sleeves and trapping a sample of the water within the center section of the tube at the depth where the instrument is operated.

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. 2-22.

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

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. 2-22 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. 2-22 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.

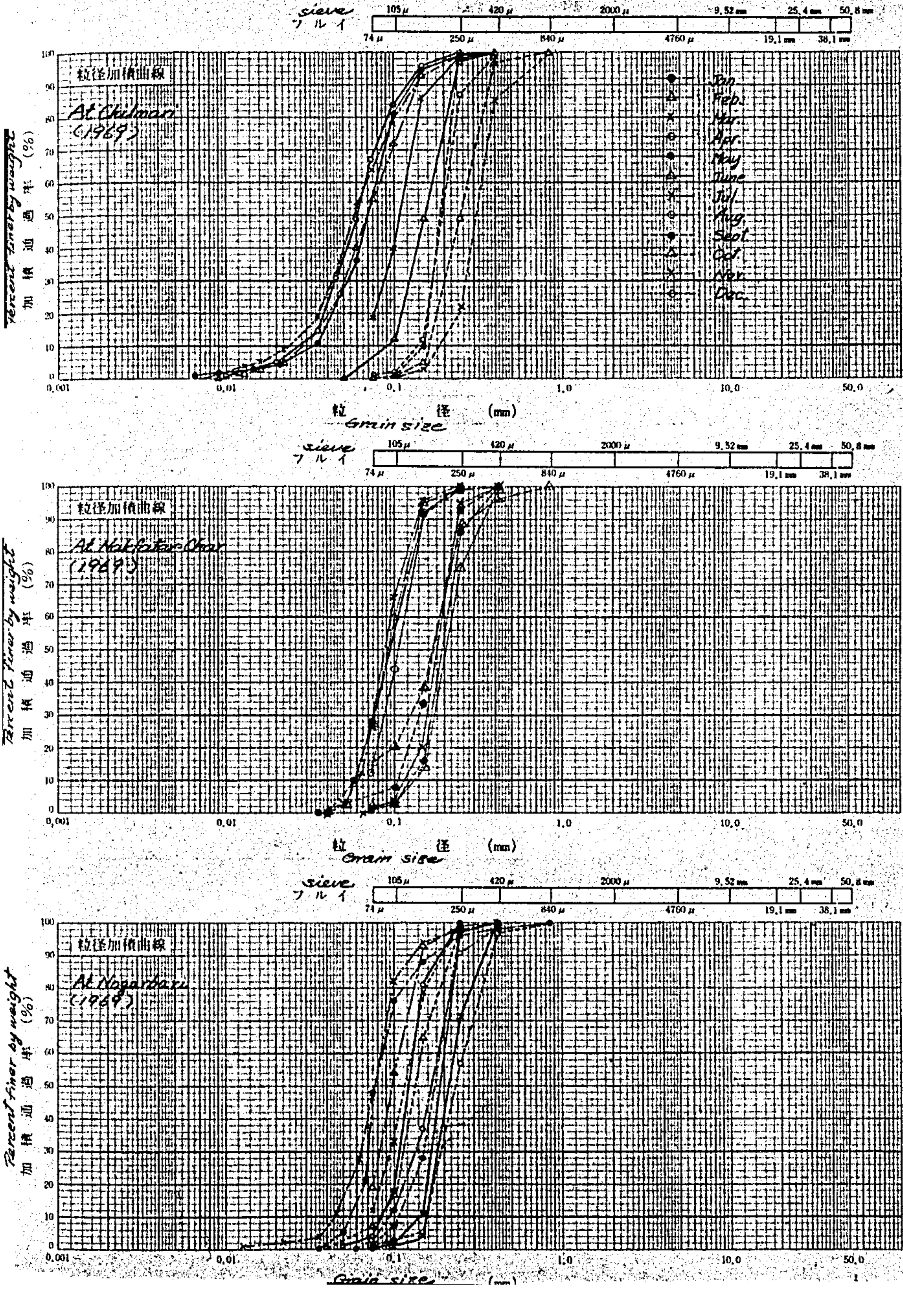
(2) Some considerations on suspended load.

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. 2-23 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.

Fig. 2-22 Grading Curves of Bed Materials (Jamuna River : 1969)



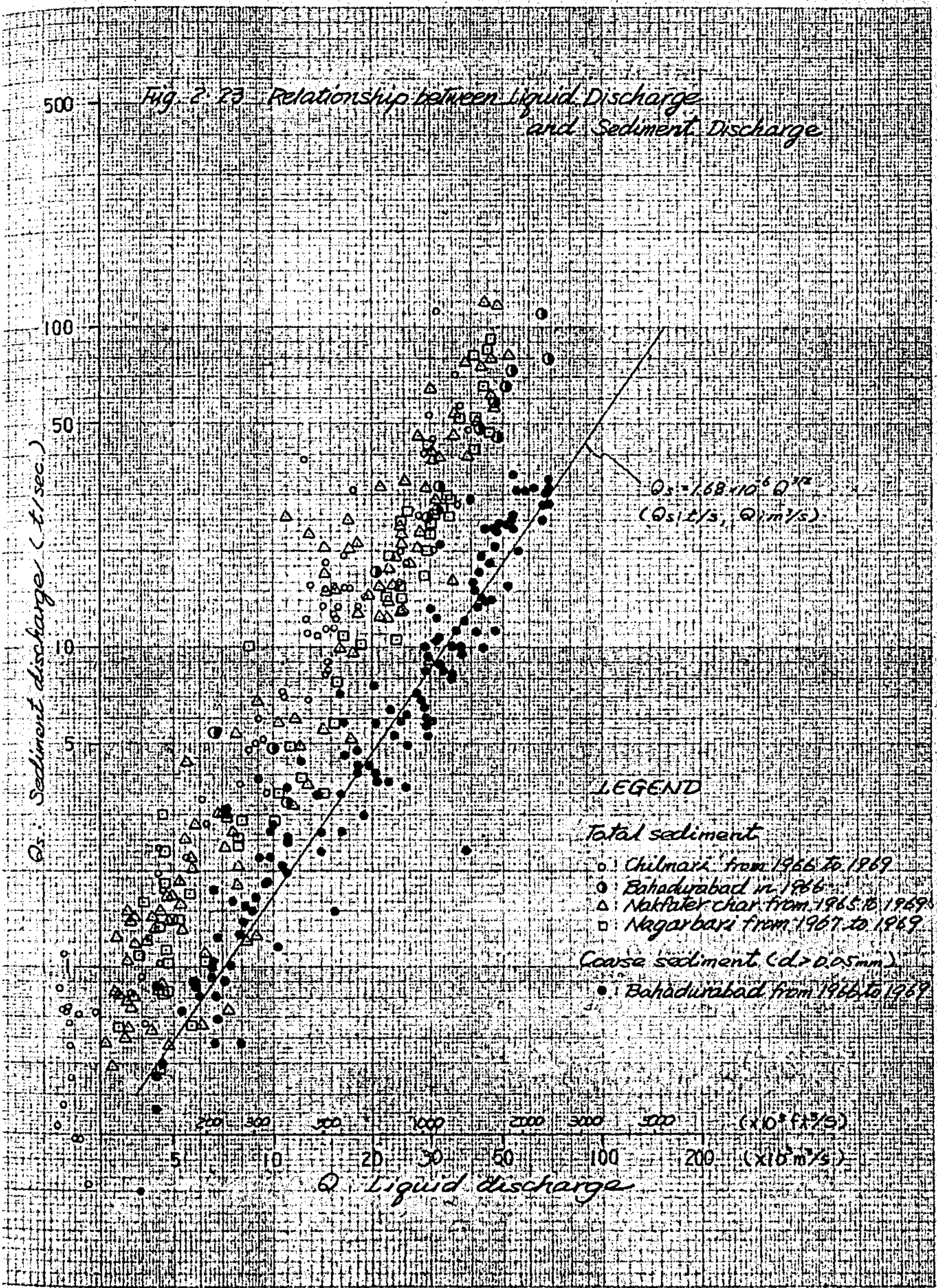


Fig. 2.23 Relationship between Liquid Discharge and Sediment Discharge
500
100
50
10
5
1
Qs : Sediment discharge (t/sec)
Qs = 1.68×10⁻⁶ Q^{3/2}
(Qs: t/s, Q: m³/s)
LEGEND
Total sediment
○ : Chilmari from 1966 to 1969
◐ : Bahadurabad in 1966
△ : Nakfater char from 1965 to 1969
□ : Nagarbari from 1967 to 1969
Coarse sediment (d > 0.05mm)
● : Bahadurabad from 1966 to 1969
200 300 500 1000 2000 3000 5000 (×10³ ft³/s)
5 10 20 30 50 100 200 (×10³ m³/s)
Q Liquid discharge

$$Q_s = KQ^n \qquad (1)$$

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)

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

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 is shown in the following equation (132 GB)

$$Q_b = K'Q^{0.9} \qquad (3)$$

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

Therefore, bed-material load Q_t can be expressed by

$$Q_t = Q_b + Q_s = K'Q^{0.9} + KQ^2/A. \qquad (4)$$

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.

$$q_t/u_*d = 10u_*^4/(\sigma/\rho - 1)^2(gd)^2 \qquad (5)$$

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

$$v = (1/n)R^{2/3}I^{1/2} \qquad (6)$$

$$Q = Av \qquad (7)$$

$$u_* = (gRI)^{1/2}. \qquad (8)$$

Applying the equations (6), (7) and (8) to the equation (5), we get

$$Q_t = aQ^{2.25}/A^{5/4} \qquad (9)$$

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

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

and the equation (9) can be rewritten as

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

The equation (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

$$Q_s = KQ^n / A \qquad (11)$$

with regard to the case of the Jamuna River where its discharge exceeds about 5,000 m^3/s. For this prupose, 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. 2-24.

Using this curve, the constants in the equation (11) were examined and also shown in Fig. 2-24. The suspended-load formula for the Jamuna River can thus be expressed by the following equation.

$$Q_s = 2.80 \times 10^{-5} Q^{2.19} / A \qquad (12)$$

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

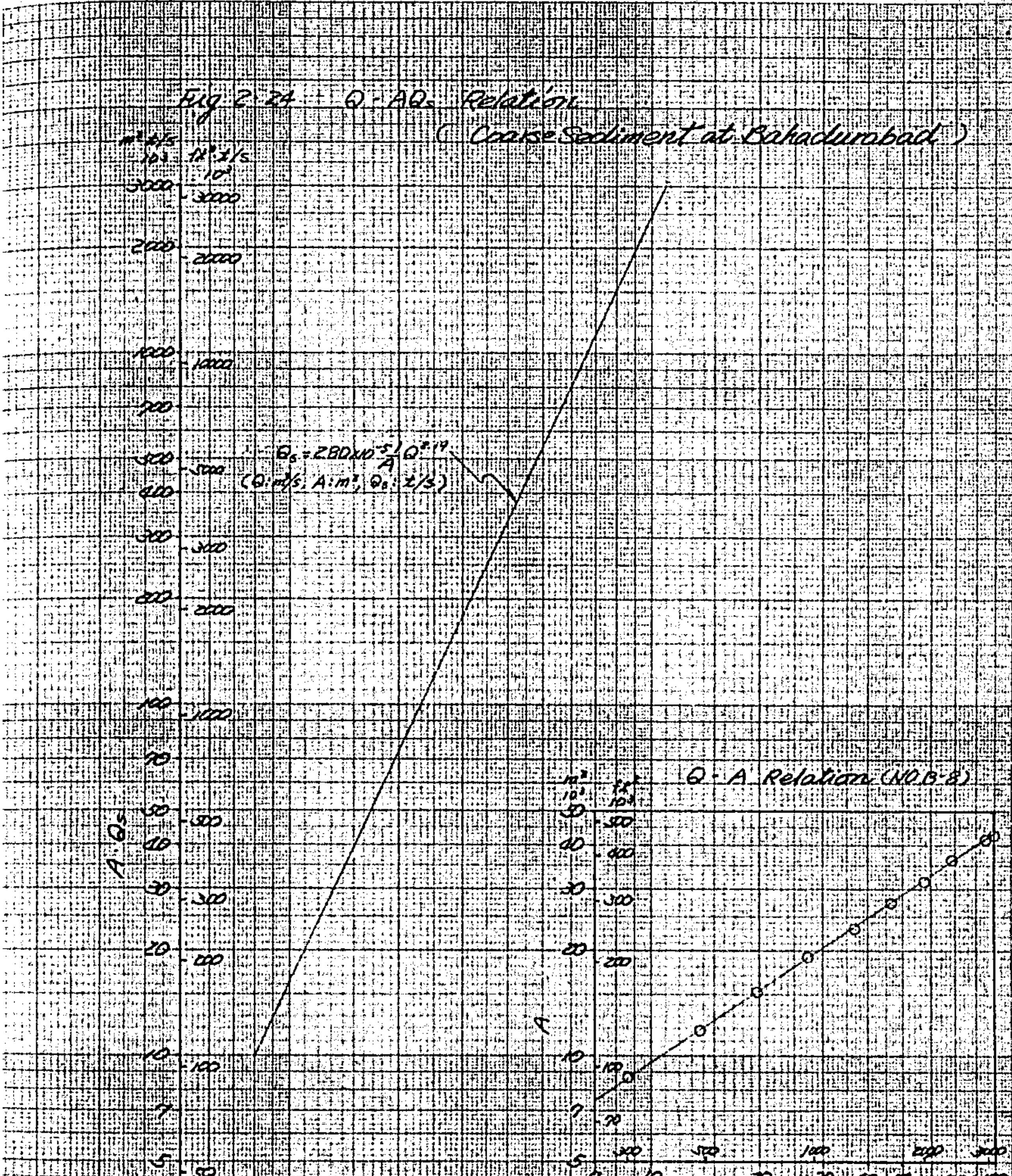


Fig 2.24 Q-AQs Relation (Coarse Sediment at Bahadurabad)

CHAPTER III

PROPOSED BRIDGE SITES

As is mentioned in Chapter II, studies were made of natural features of the river from the both viewpoints of geomorphology and river-morphology with respect to the four sites proposed by the Prefeasibility Study Team as bridge crossing points.

From the studies, it has been found that every one of the four sites is surely located at nodes of braiding, which suggest that any of them is favorable for spanning a bridge across the river. It can be concluded, however, that, from the geomorphological point of view, the Sirajganj narrow is most stable among the four, the Gabargaon site comes nearest after this, the Bahadurabad site compares unfavorably with the former two and the Nagarbari site falls behind any of the others and that, from the river-morphological point of view, 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 bank lines 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 the river-morphological points of view, there is nothing to choose between the two sites, Sirajganj and Gabargaon.

At the Sirajganj site, bridge axis has been chosen a little downstream of Sirajganj narrow. This site lies under the protection of the narrow as well as the Sirajganj bank-protection works and has only one main stream with chars on its both sides. This means that the site is very favorable for spanning a bridge. However, this site has also an unfavorable point that the left approach must cross one of the offtakes of the Dhaleswari. This offtake must be crossed over by a bridge or by a causeway. Fortunately, the entrances of the two offtakes lie with the bridge axis between. Therefore, it will be the best way for the bridge if the upper offtake may be closed and the lower one may be kept as the main to the Dhaleswari.

CHAPTER IV
DESIGN DISCHARGE

Discharge measurement has been made at Bahadurabad Station since 1956 and the station has the longest record among all the stations on the Jamuna River. In studying design discharge for bridge construction, return period of flood discharges at Bahadurabad was first examined and then the design discharge allocation on the Jamuna was determined in consideration of diversion to the Old Brahmaputra and the Dhaleswari Rivers on the basis of the master plans for flood control in Bangladesh (87 GN).

1. River System and Major Stream Gaging Stations.

(1) Data on water level and discharge.

River system around the Jamuna is shown in Fig. 4-1. BWDB has two systems of stream-gaging network, one of which is controled 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. 4-2 and availability of data at these stations are listed in Table 4-1. As seen in Table 4-1, 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.

(2) Preliminary study on water level and discharge data.

Preliminary study on water level and discharge was made in order to obtain an outline of their charateristics. Data on water level since 1964 have already been arranged by BWDB in every Water Year begining in April and ending in the next March, which were used also 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 examined 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 Fig. 4-3 and 4-4.

Fig. 4 - 1 River System around The Jamuna River

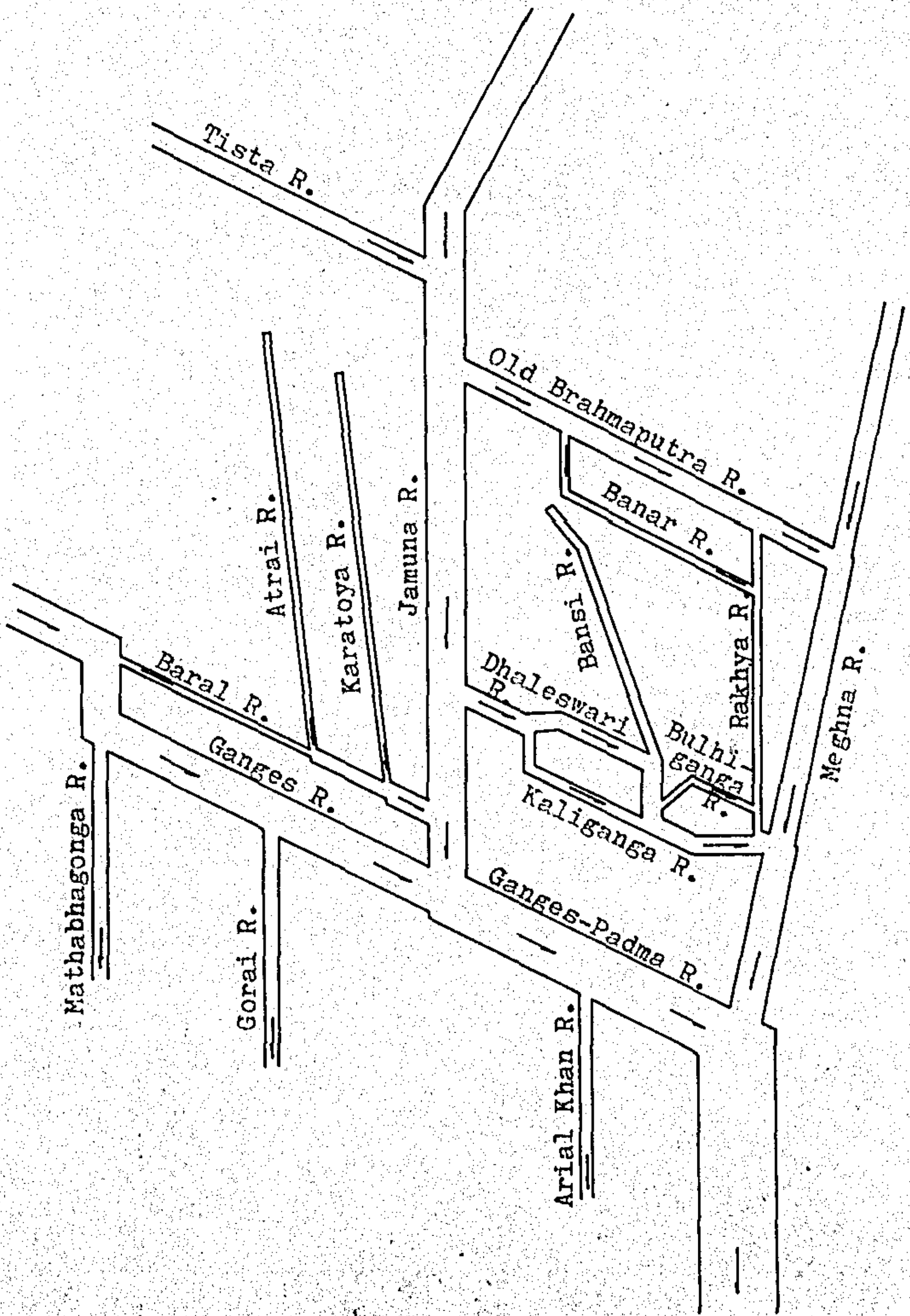


Fig. 4-2 Location of Gauging Stations

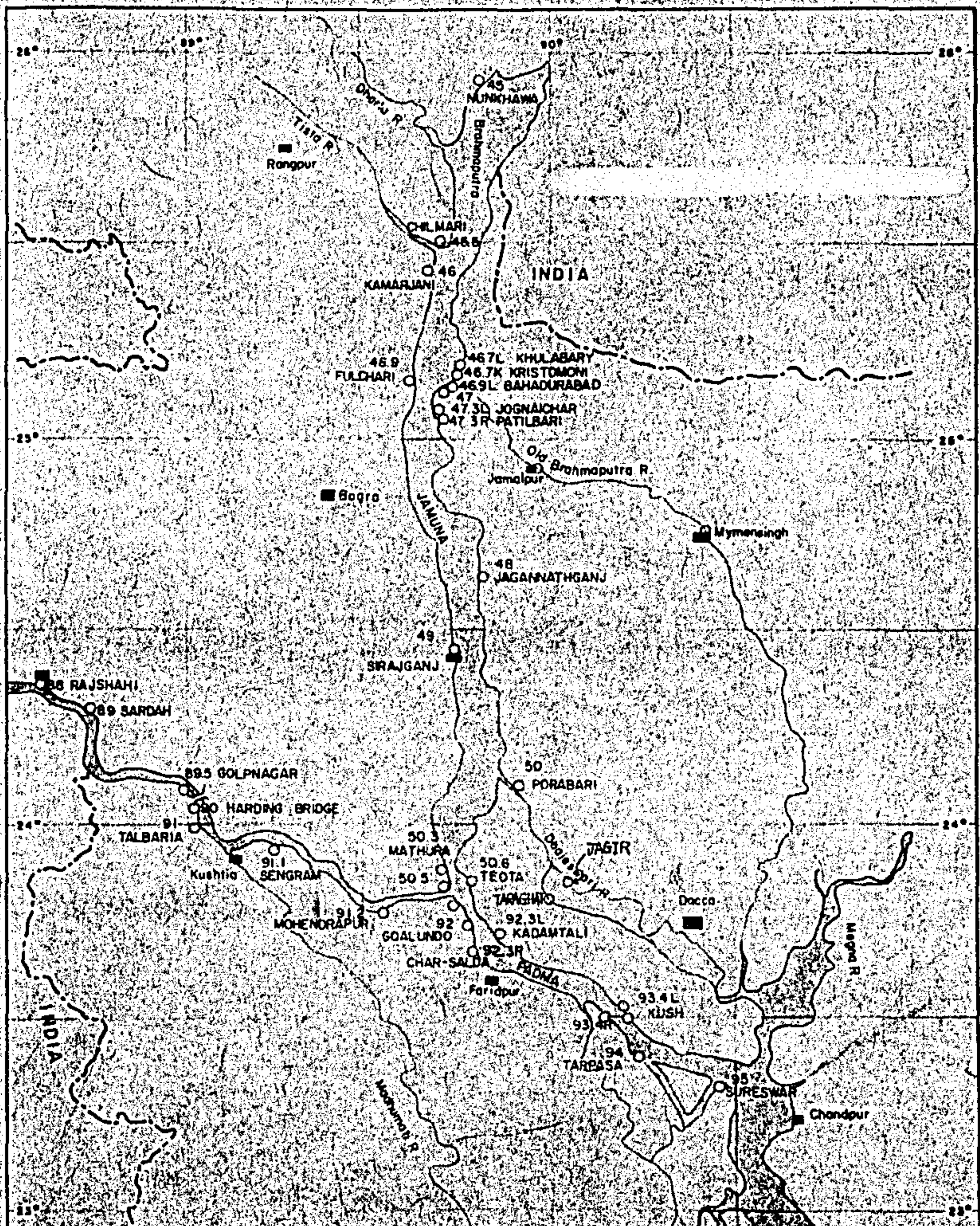


Table 4 - 1 List of Available Data on Water Level & Discharge

ITEM	River	Station \ Year		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.
		Porabari				○	○	○	○	⊖	○	○	○	○	○	○				'63 '64 Jan.-Mar.
		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.													○					"
	Dhalleswari	Jagir									○	○	○		○					1964 & '68 Jan.-Mar.
	Kaliganga	Taraghat									○	○	○		○		←			1964 & '68 Jan.-Mar.; 1965 Feb.-Mar.

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

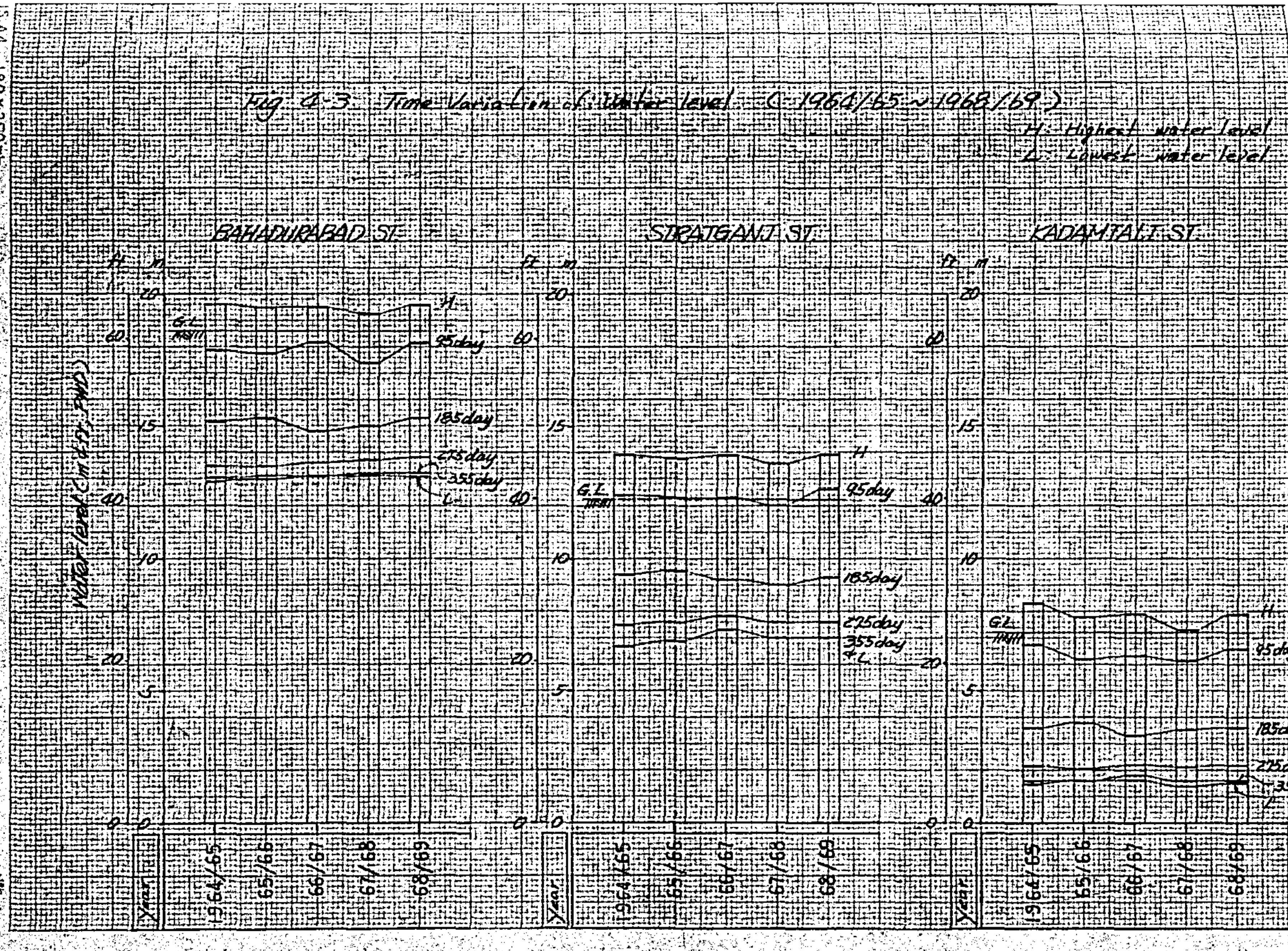


Fig 4-3 Time Variation of Water level (1964/65 ~ 1968/69)

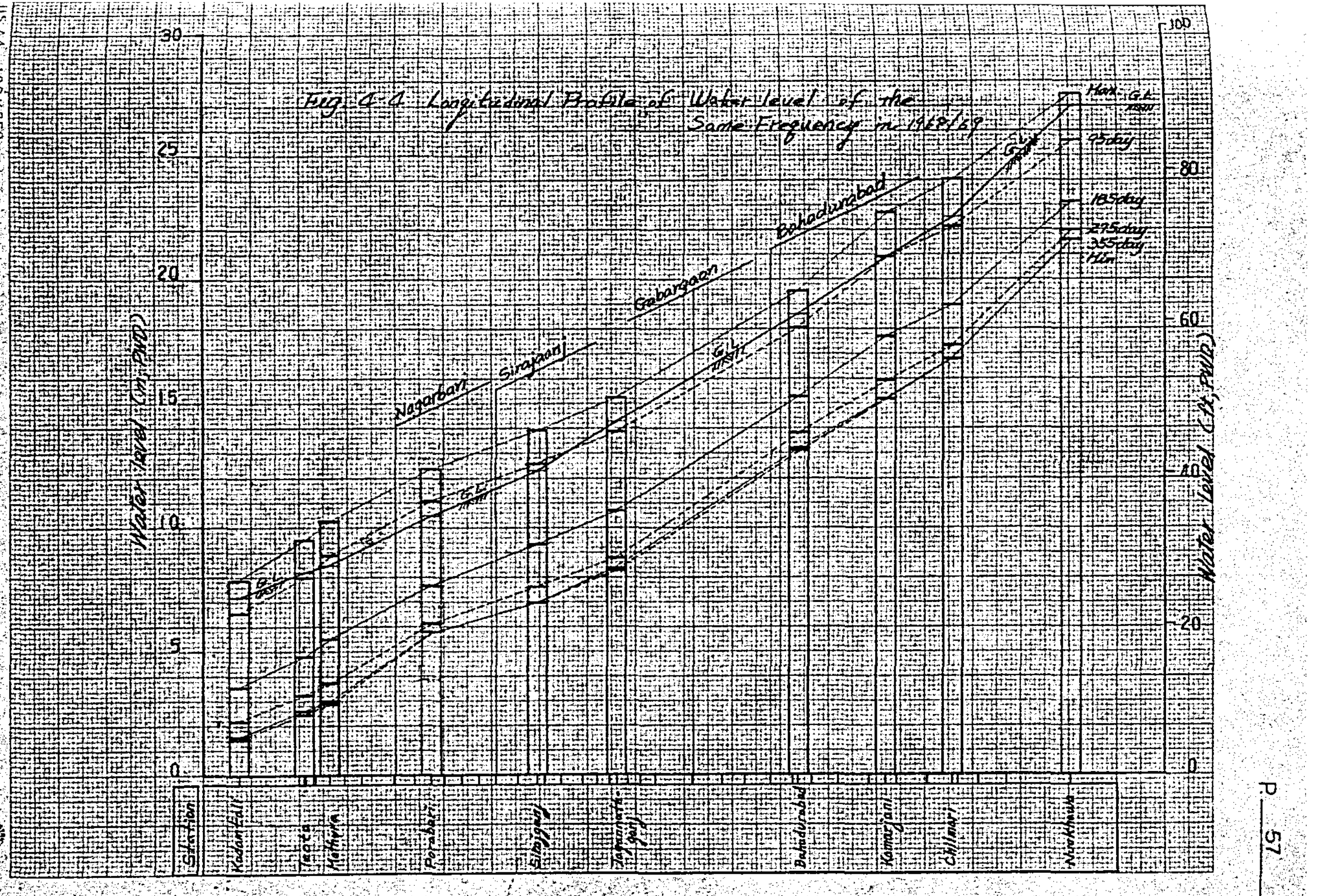


Fig. 4.4 Longitudinal Profile of Water level of the Same Frequency in 1968/69

It is supposed that the daily discharges given in Water Supply paper and Hydrological Year Book were computed on the strength of 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. 4-5. This figure indicates that the relationship between them is fairly stable, notwithstanding the conditions of river channel were largely varied.'

2. Return Period of Discharge at Bahadurabad.

Data on annual maximum discharges at Bahadurabad are available for the fifteen years from 1956 to 1970, while water level at Bahadurabad has already 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.

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 Habadurabad Station were obtained. Numerical data are shown in Table 4-2 and the four series are briefly de scribed in the following.

(a) Series 1: All annual masimum 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 Seifies 1; twenty-one samples from 1950 to 1970.

(c) Series 3: Annual maximum discharges from 1950 to 1955 estimated by the average rating curve shown in Fig. 4-5 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,

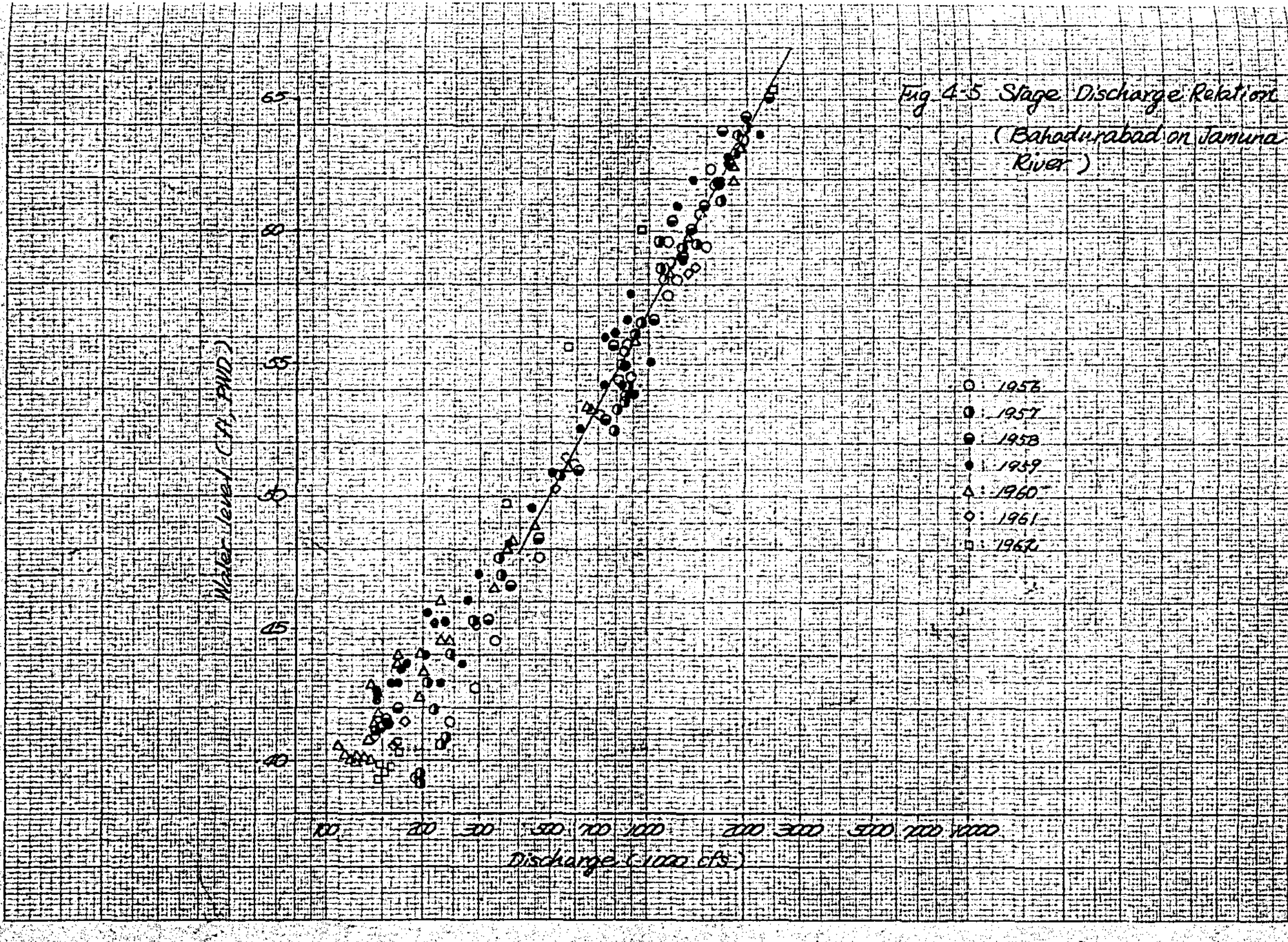


Fig. 4-5 Stage Discharge Relation (Bahadurabad on Jamuna River)

and these data were added to those of Series-1; twenty-one samples from 1950 to 1970.

Table 4-2 Annual Maximum Discharges at Bahadurabad Station

date		water level	Discharge (10^3cfs)			
		(ft, PWD)	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. 4-6 and Table 4-3.

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. 4-7.

Fig. 4-6-1 Return Period of Discharge at Bahadurabad (by Thomas method)

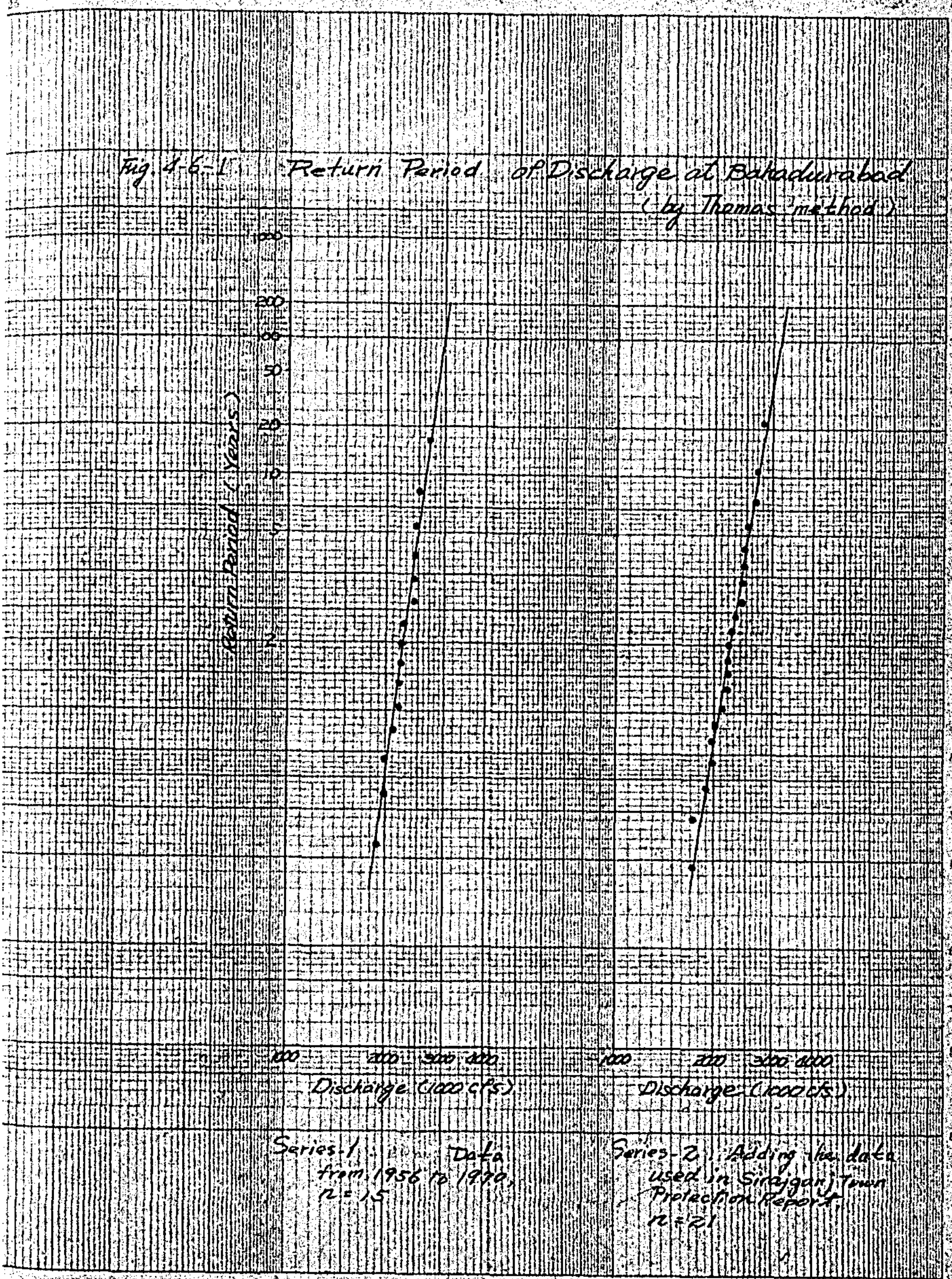
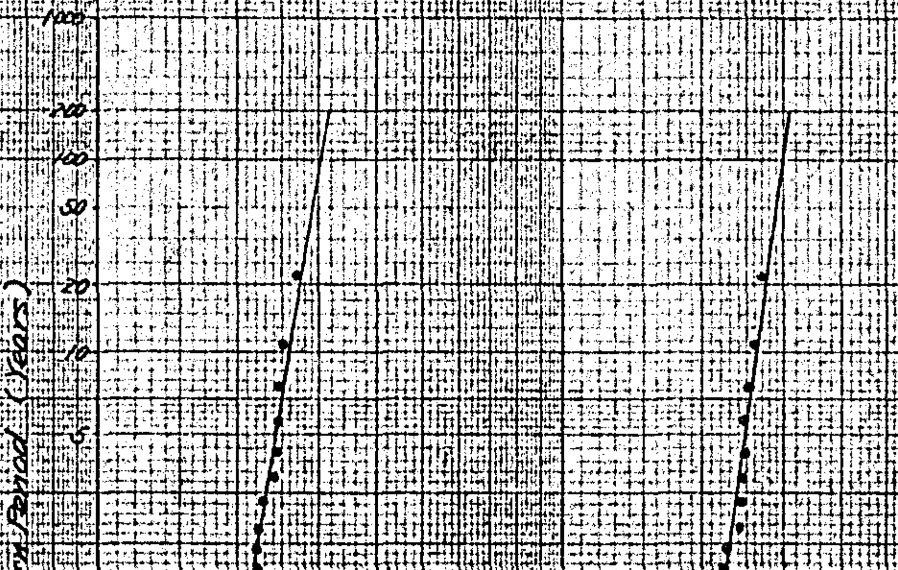


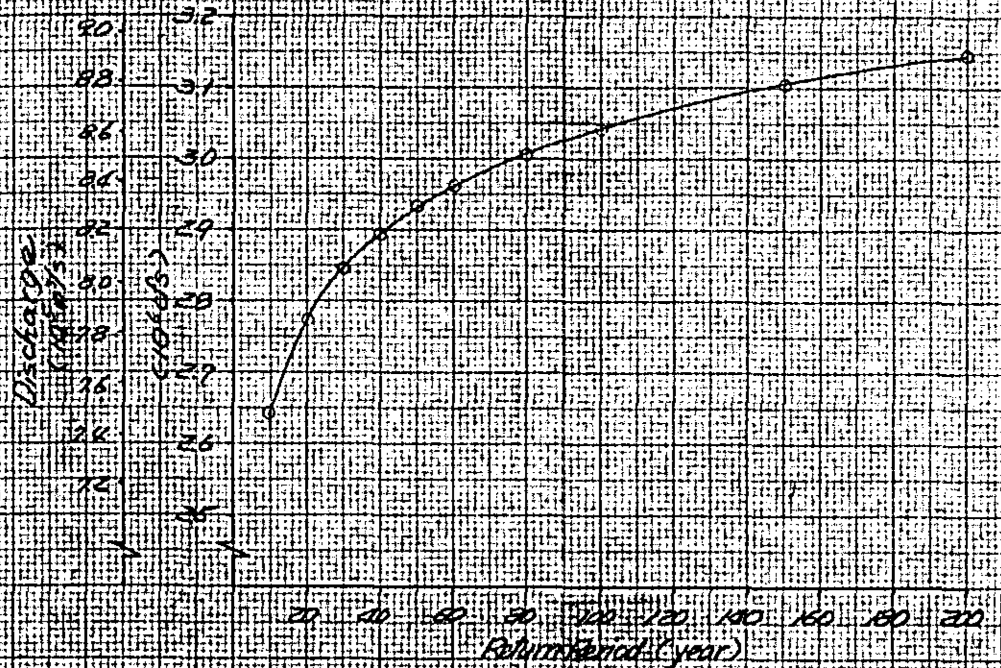
Fig. 4-6-2 Return Period of Discharge at Bahadurabad
(by Thomas method)



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 by BWDB was applied for estimation of discharges from 1950 to 1955.
n = 21

Fig. 4 - 7 Return Period of Discharge at Bahadurabad



Return period (year)	Discharge (10^3 cfs)	Discharge ($10^3 m^3/s$)	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	

Table 4-3 Return Period of Discharge at Bahadurabad (by Thomas plotting)

return period (year)	discharge (10^3cfs)				
	series-1	series-2	series-3	series-4	average
10	2624	2717	2604	2618	2641
20	2738	2871	2748	2739	2774
30	2798	2955	2826	2804	2846
40	2840	3013	2880	2848	2895
50	2871	3056	2920	2881	2932
60	2896	3091	2952	2908	2962
80	2934	3114	3002	2949	3007
100	2963	3185	3041	2980	3042
150	3014	3258	3108	3036	3104
200	3050	3309	3155	3074	3147

3. Basic Design Discharge.

Bahadurabad Station is a basic site for all plannings of the Jamuna River. In this meaning, we call the design discharge at the station the basic design discharge of the Jamuna River. In planning on the Jamuna River, the basic design discharge must be first determined and then the allocation of the design discharge on the whole Jamuna River must be determined on the basis of the basic design discharge and in consideration of branching of distributaries and confluence of tributaries.

In case of bridge construction on this river, at least, 100-year flood discharge must be taken into consideration. This discharge is 3,042,000 cfs (86,090 m^3/s) according to the previous section. If 150-year flood is taken, the discharge will be 3,104,000 cfs (87,840 m^3/s). This means and increment of only 2%.

If we use Manning's formula for mean velocity, discharge Q is given by

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

where W = River width
H = Mean water depth = A/W
A = Water area
n = Coefficient of roughness
I = 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, coefficeint of roughness n and water surface slope I were assumed unchanged.

If we express the increased water depth by

$$H' = H + yH,$$

we get from the above two equations

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

or approximately

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

If we take 150-year flood for 100-year, the ratio of the increment of discharge x is 2%, accordingly the increment ratio of water depth y will be 1.2% by the above equation. If we assume that the 100-year flood discharge is confined by embankments on both sides of the river, the mean water depth is estimated at about 18 m. Threfore, the increment of water depth when the 150-year flood was confined by both banks will be 0.2 m.

The magnitude of this increment is within mesurement error due to wind wave and variation of river bed, etc. and eventually will be covered by safety of free board. From this viewpoint, we decided to take the basic design discharge at 3,042,000 cfs, 100-year flood.

4. Allocation of Design Discharge on the Jamuna.

The principal tributary of the Jamuna is, within the river stretch to be considered, the Hurasagar River which joins the Jamuna upstream of Nagarbari, and the main distributaries are the Old Brahmaputra River which takes off upstream of Bahadurabad and the Dhaleswari River which takes off on the opposite side of Sirajganj.

The allocation of the design discharge on the Jamuna was made on the basis of the above-mentioned basic design discharge and the following.

a. Decrease of discharge due to diversion to the Old Brahamputra and the Dhaleswari is taken into consideration, but decrease due to channel storage and spill is not considered assuming that embankments will be built also on the left side of the river in the future (87 GN).

b. Joining discharge of the Hurasagar River is disregarded because the discharge is perhaps stopped due to the high water level of the Jamuna.

c. Diversion discharge to the Old Brahmaputra River will be controled at 30,000 cfs by an expected barrage which may be built on the Old Barahmaputra in the future (87 GN).

d. Diversion to the Dhaleswari River was assumed to follow the present rule of nature even when the left embankments were constructed.

(1) Diversion to the Old Brahmaputra River.

Correlation of discharges on the same day between the Jamuna and the Old Brahmaputra was studied on the basis of data at Bahadurabad Station on the Jamuna (Q_B), and those at Mymensingh on the Old Brahmaputra (Q_M), which is shown in Fig. 4-8. This figure shows a 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) Present diversion discharge to the Dhaleswari River.

The Dhaleswari River is devided into two channels, the Dhaleswari River and the Kaliganga River, after taking off from the Jamuna. Therefore, the discharge of the Dhaleswari River is the sum of the two discharges at Jagir Station on the Dhaleswari and Taraghat 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, relationship between discharge data at Bahadurabad and those at the two stations on the Dhaleswari was studied.

Since Jagir and Taraghat Stations are as far as 150 km from Bahadurabad Station, time lag in the correlation must be considered. After some trials, it was found that the most natural time lag was one day. Fig. 4-9 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} = Discharge of the Dhaleswari (discharge at Jagir plus that at Taraghat)

Q_B = Discharge at Bahadurabad.

(3) Allocation of design discharge on the Jamuna.

On the basis of the above-mentioned studies, the allocation of the design discharge of 100-year return period was determined, which is shown in Fig. 4-10. For reference, the allocation for 150-year return period is also shown in the same figure.

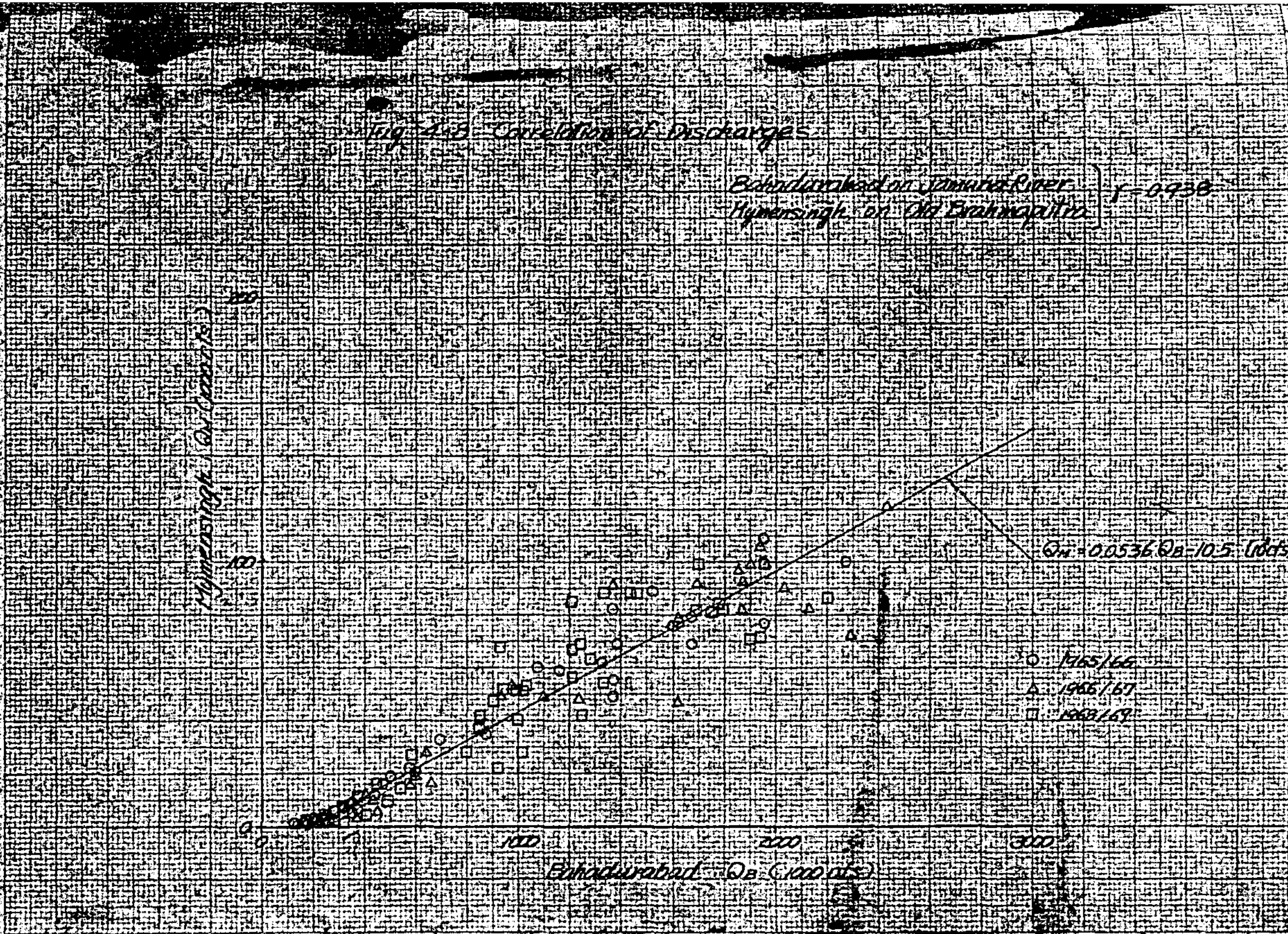


Fig 4.5 Correlation of Discharges
Bahadurabad on Jamuna River
Mymensingh on Old Brahmaputra
r = 0.938
$Q_M = 0.0536\,Q_B - 10.5$ (1000 cfs)
1965/66
1966/67
1968/69
Mymensingh : Q_M (1000 cfs)
Bahadurabad : Q_B (1000 cfs)
0
100
200
1000
2000
3000

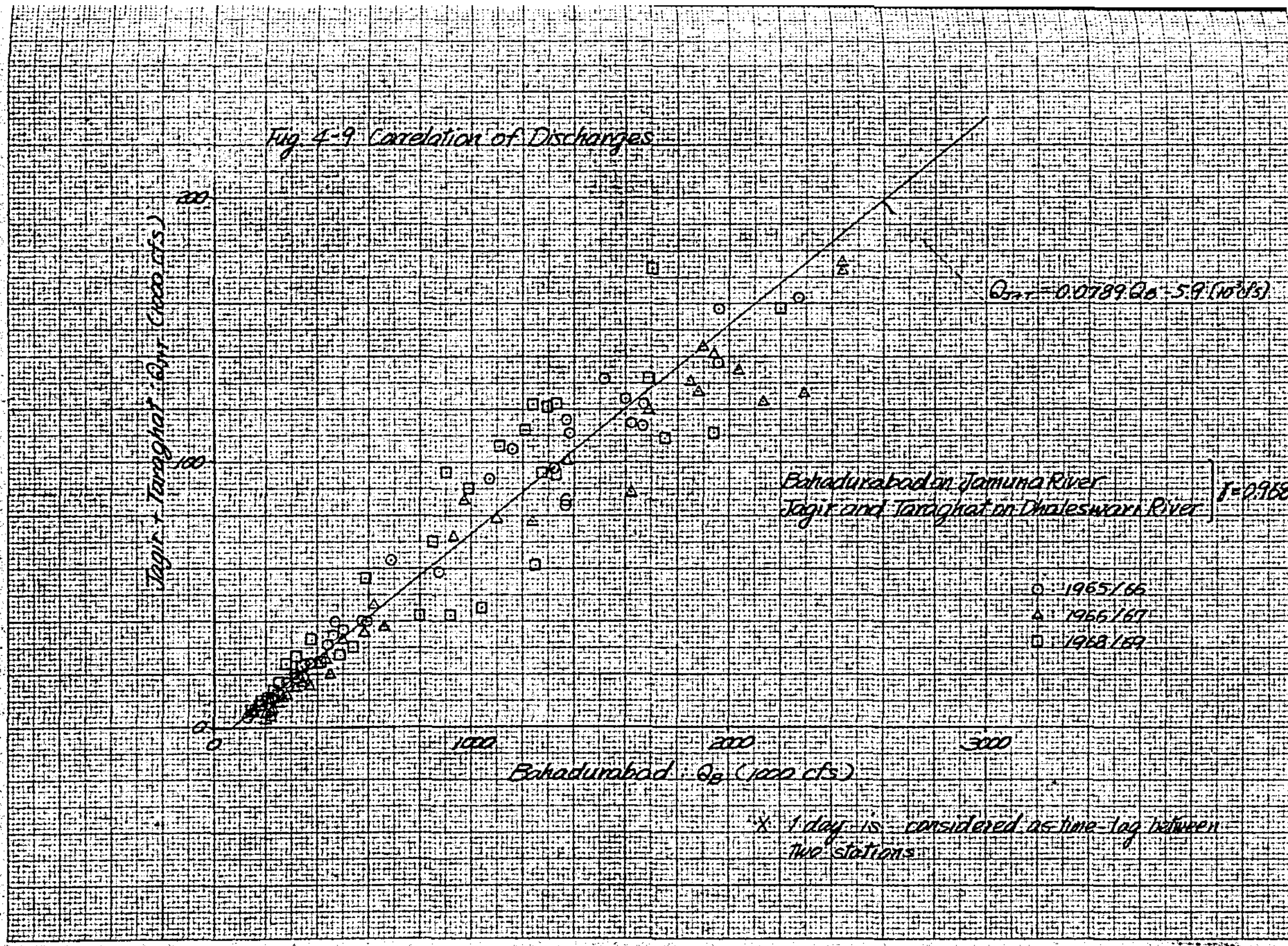
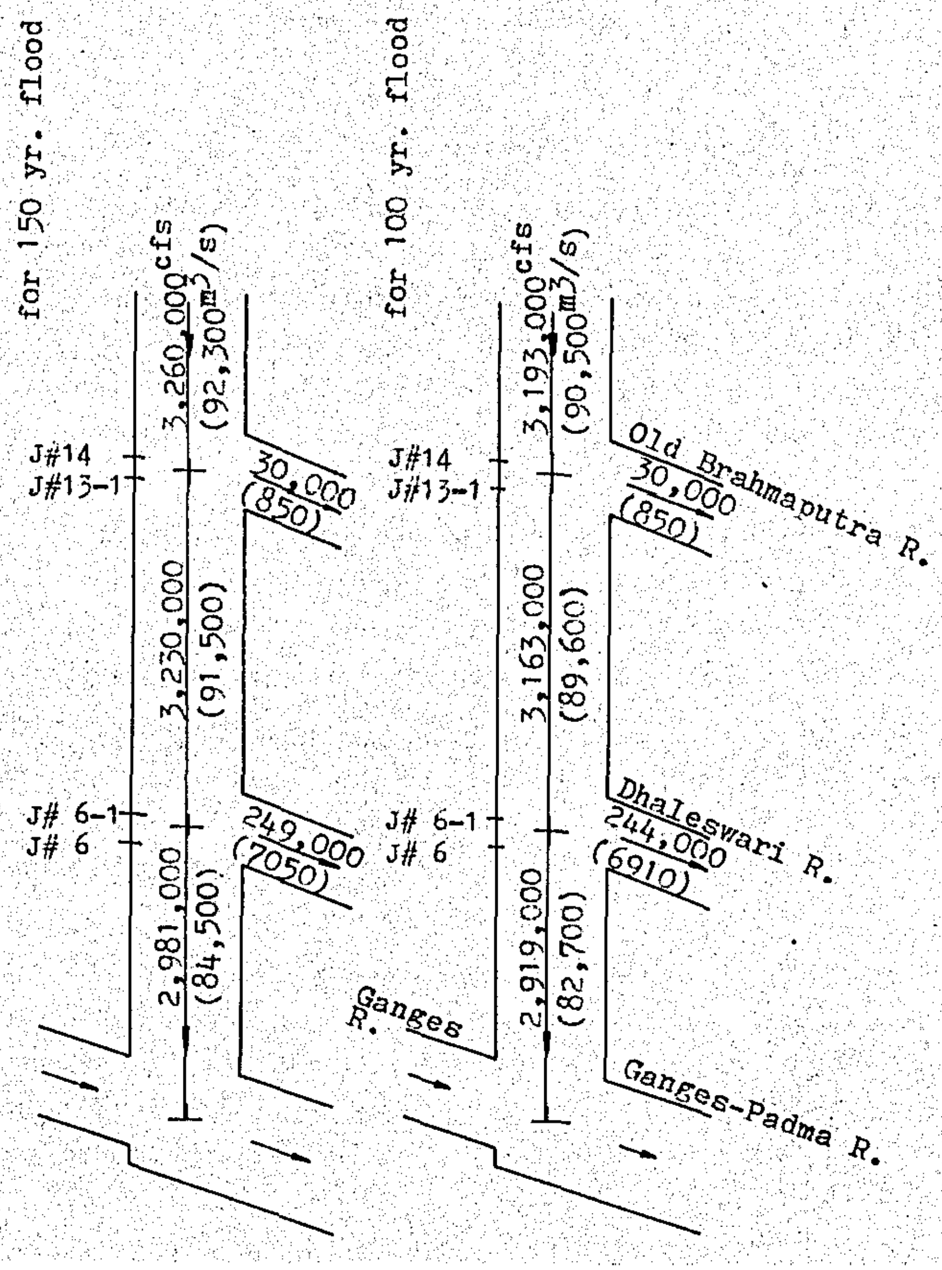


Fig. 4-9 Correlation of Discharges

Fig. 4 - 10 Dischrge Allocation of Jamuna River



CHAPTER V
COEFFICIENT OF ROUGHNESS

1. Discharge Measurements at the Proposed Four 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 Sirajaganj 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 determinig 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. 5-1 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 respective water stage at each measurement site on each measurement day.

Velocity measurements were made at every 1 m downwards from the water surface on seven or eleven verticals on each section of the proposed sites by using an electric current meter.

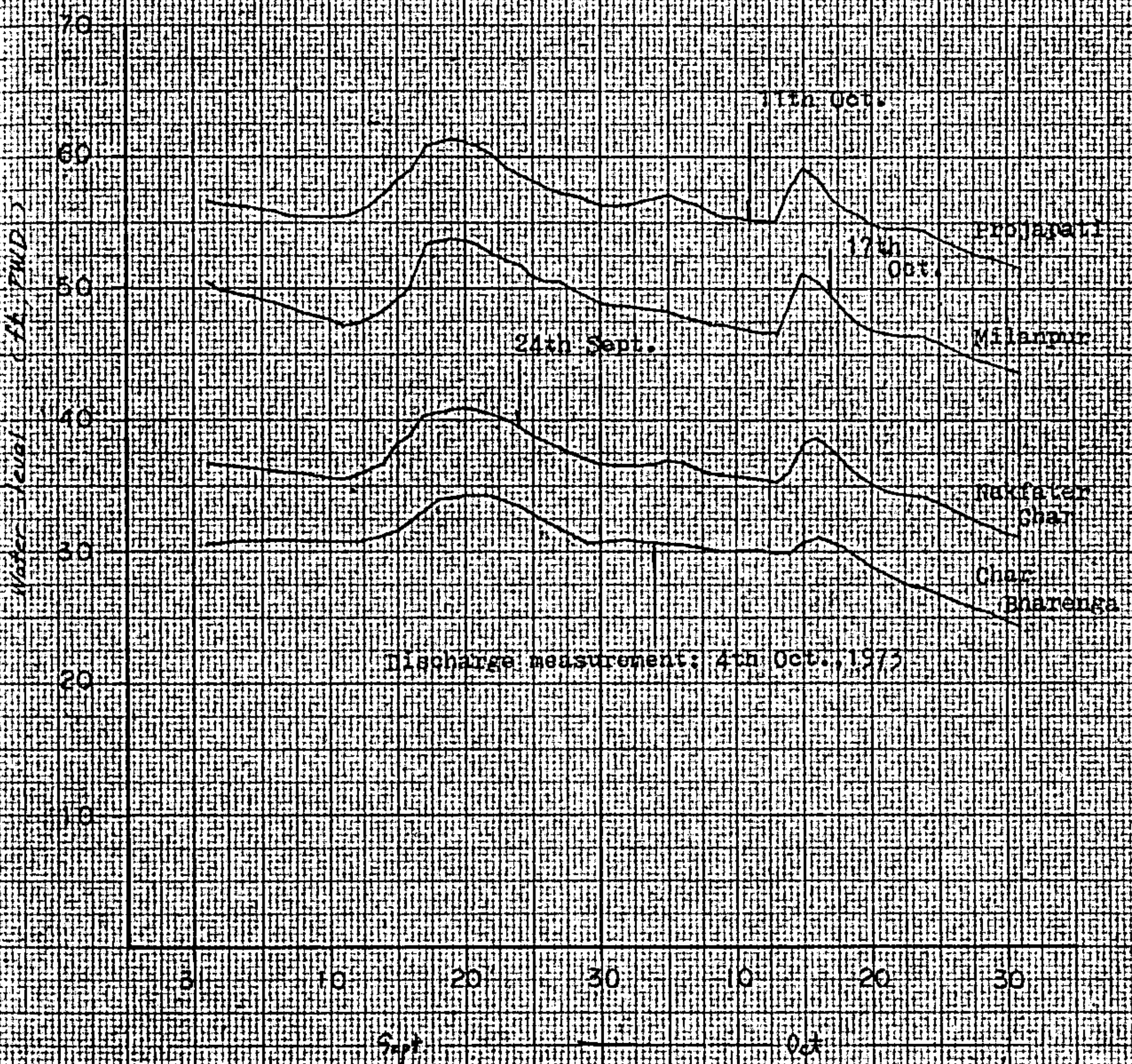
Figs. 5-2, 1 and 2 show vertical distribution of velocity on each cross section, Figs. 5-3, 1 and 2 show distribution of mean velocities on verticals on each cross section and Figs. 5-4, 1 and 2 show segment areas alotted to respective mean velocities on the verticals of each cross section. Computation of discharges are shown in Table 5-1 and thus the measured discharges at the four sites are as follows.

Site	Discharge	
Nagarbari	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

2. Mean Velocity and Surface Velocity.

Correlation between mean velocity and surface velocity is studied

Fig. 5-1 Stage Hydrograph from Sept. to Oct., 1973



JIS A4 180×250mm

Fig. 5 - 2 - 1 Vertical Distribution of Velocity

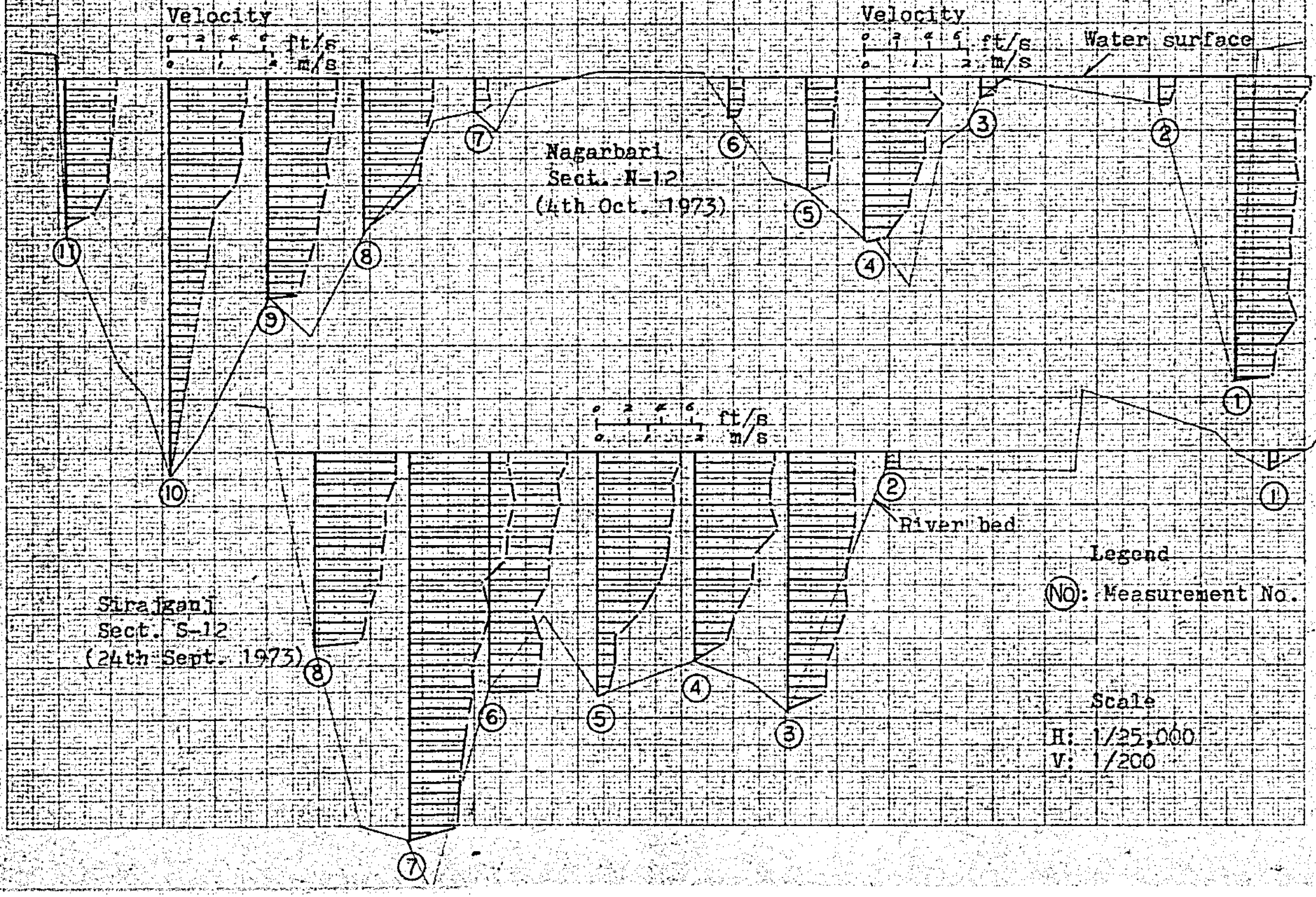


Fig. 5-2-2-2 Vertical Distribution of Velocity

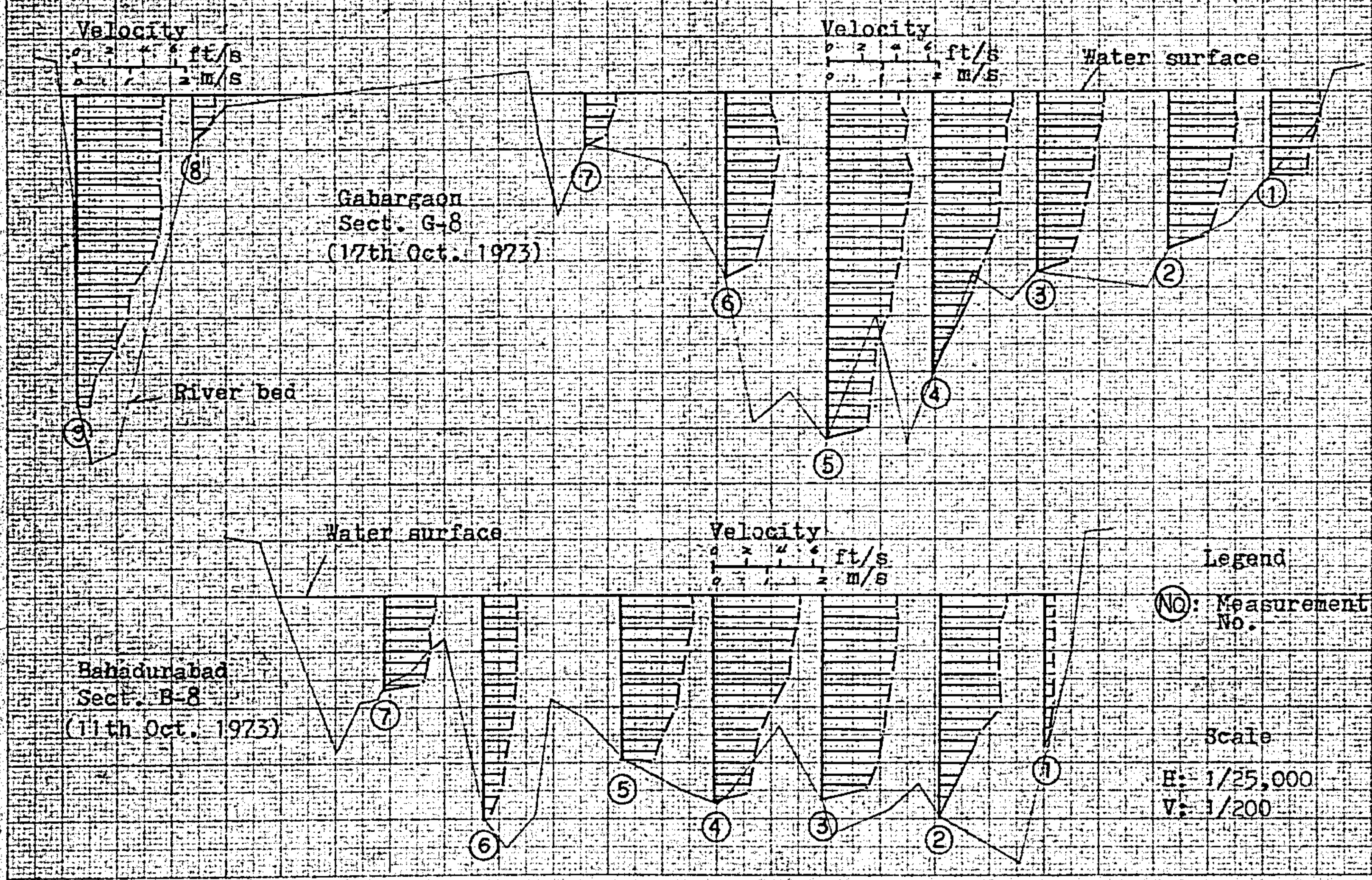
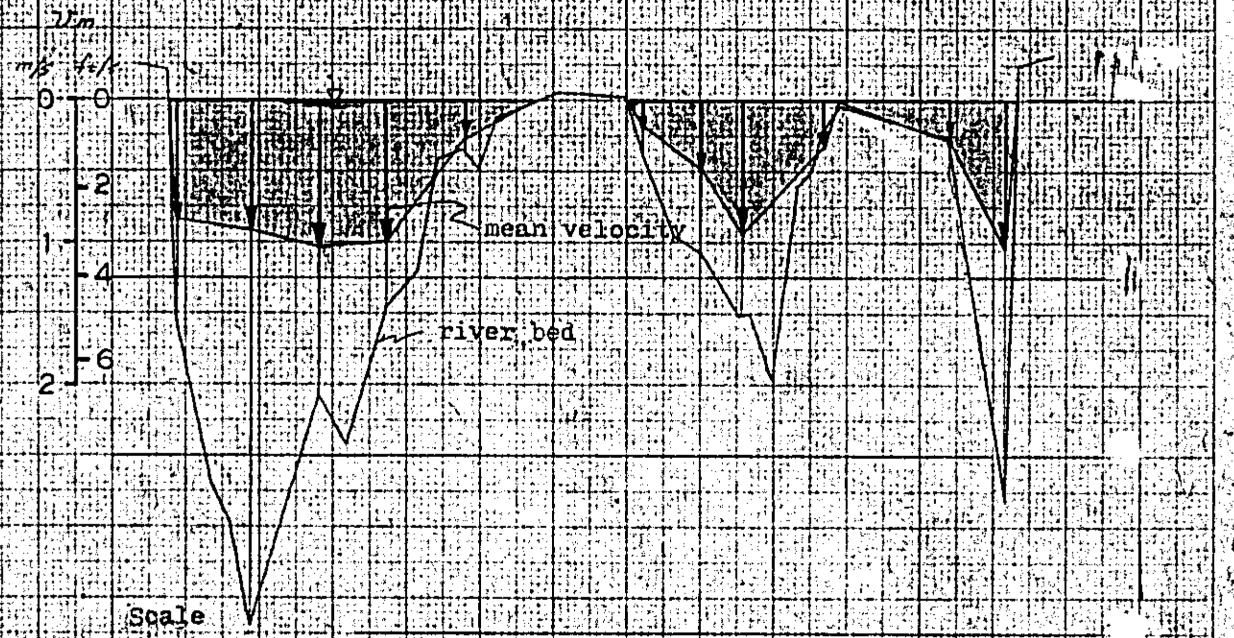


Fig. 5-3-1 Lateral Distribution of Mean Velocity ; v_m

Nagarbari (N-12) (measured on 4th Oct., 1973)



Scale
H=1/50,000
V=1/200

Sirajganj (S-12) (measured on 24th Sept., 1973)

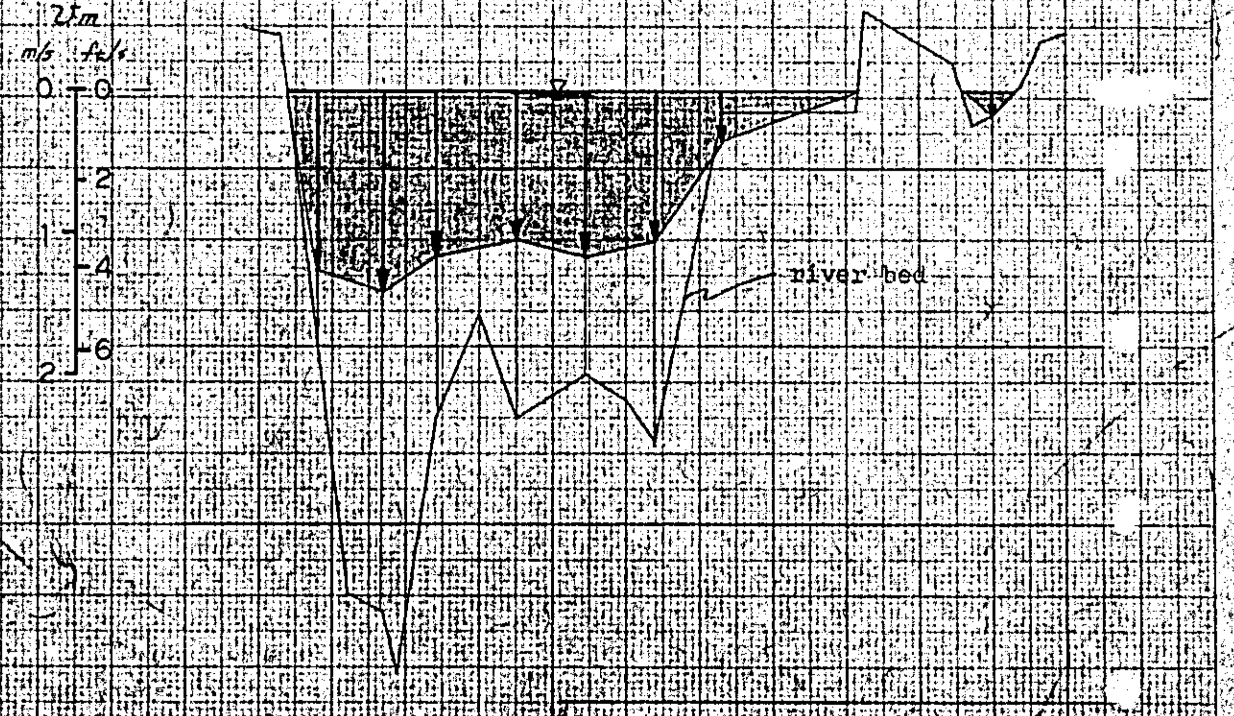
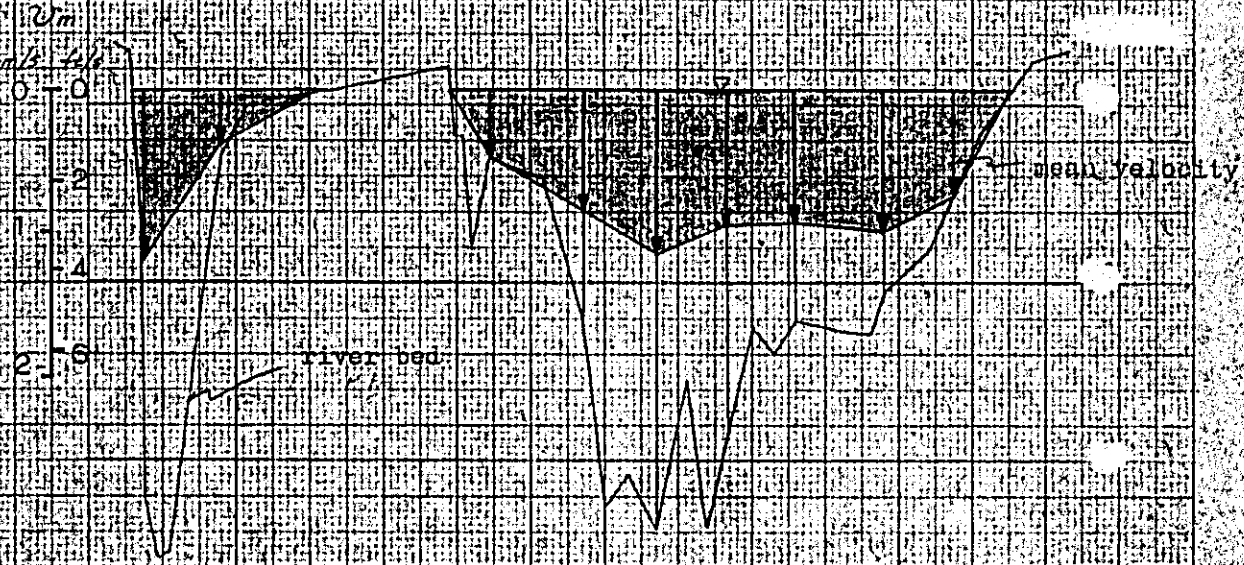


Fig.5-5-2 Lateral Distribution of Mean Velocity ; Vm

Gabargaon (G-8) (measured on 17th Oct.,1973)



Scale
H=1/50,000
V=1/200

Bahadurabad (B-8) (measured on 11th Oct.,1973)

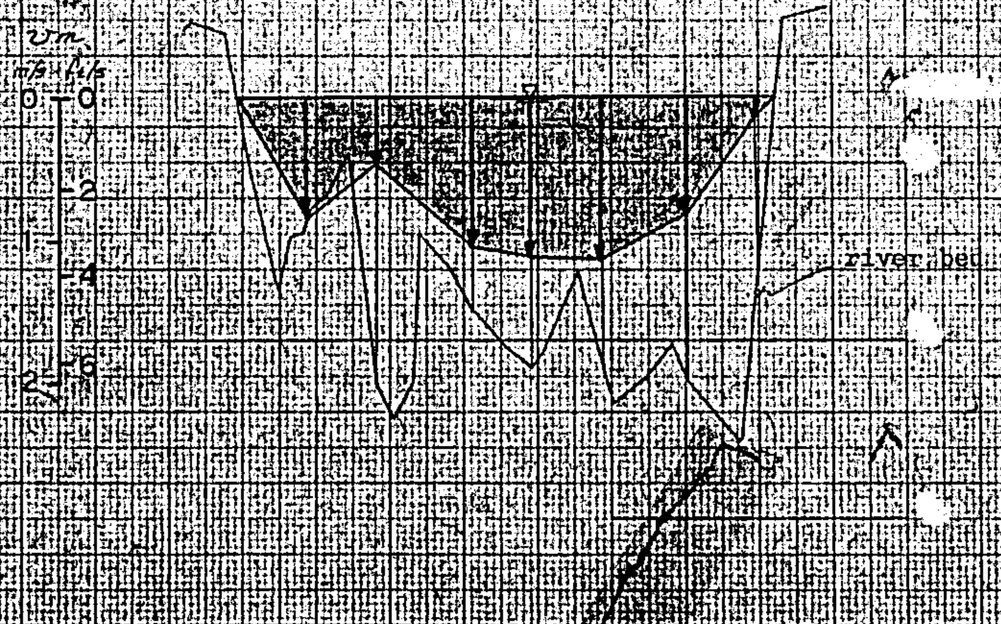


Fig. 5-4-1 Segment Area for Mean Velocity v_m on a Vertical

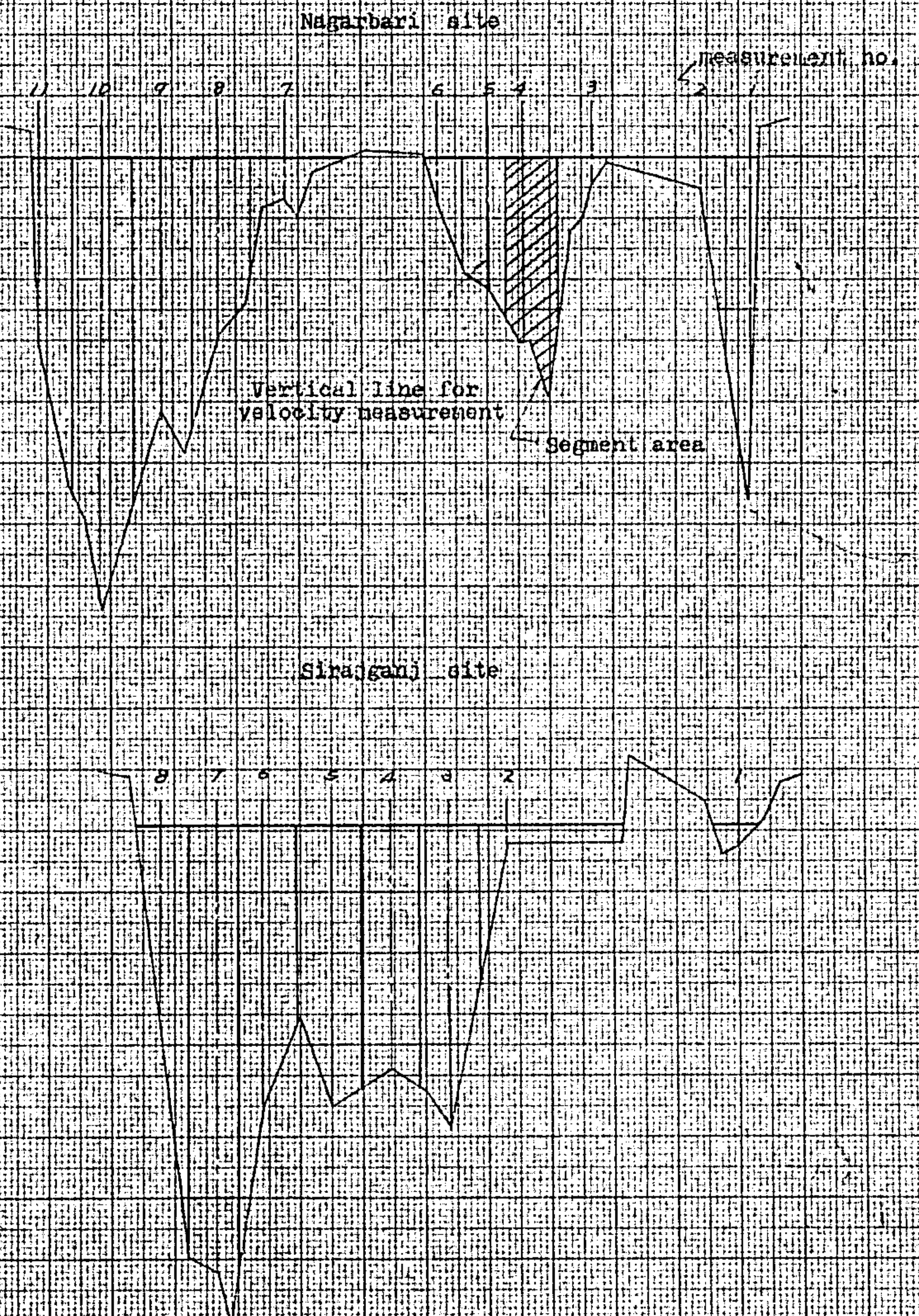


Fig. 5-4-2 Segment Area for Mean Velocity v_m on a Vertical

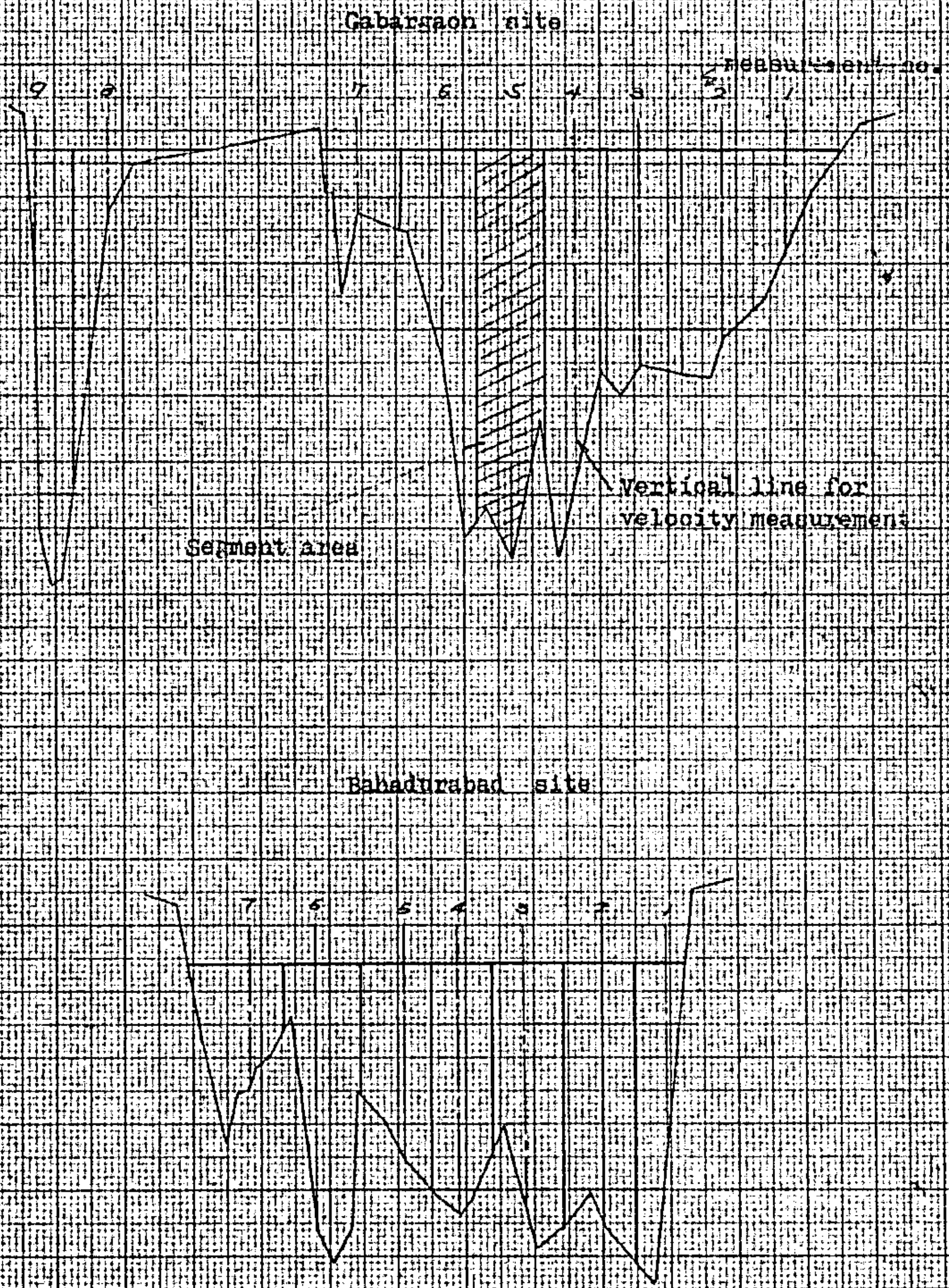


Table 5 - 1 Discharge at Proposed Sites

Nagarbari on 4th Oct.1973

Measurement No.	Mean velocity (m/s)	Segment area (m²)	Discharge (m³/s)	Remark
1	1.08	2164	2337	Mean velocity = 0.858 m/s; Q=21,566 m³/s = 761,500 cfs
2	0.28	1020	287	
3	0.35	733	257	
4	0.97	2665	2585	
5	0.50	1364	682	
6	0.22	568	125	
7	0.26	829	216	
8	1.01	2966	2966	
9	1.04	4617	4802	
10	0.91	5936	5402	
11	0.83	2261	1877	
Total		25,127	21,566	

Gabargaon on 17th Oct.1973.

Measurement No.	Mean velocity (m/s)	Segment area (m²)	Discharge (m³/s)	Remark
1	0.78	1337	1074	Mean velocity = 1.178 m/s; Q = 26,733 m³/s = 943,940 cfs
2	0.99	3238	3206	
3	0.94	3639	3421	
4	0.95	4378	4159	
5	1.17	5001	5851	
6	0.86	3761	3234	
7	0.47	1293	608	
8	0.40	2036	814	
9	1.19	3669	4366	
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 m³/s = 1,101,508 cfs
2	0.36	1182	426	
3	1.06	3865	4097	
4	1.16	3752	4352	
5	1.05	4031	4233	
6	1.16	4264	4946	
7	1.42	6387	9070	
8	1.28	3166	4052	
Total		26,766	31,195	

Bahadurabad on 11th Oct.1973

Measurement No.	Mean velocity	Segment area	Discharge	Remark
1	0.13	2486	323	Mean velocity = 0.831 m/s; Q = 18,236 m³/s = 643,910 cfs
2	0.83	4192	3479	
3	1.16	3648	4232	
4	1.14	3075	3506	
5	1.05	2826	2967	
6	0.49	3416	1674	
7	0.89	2309	2055	
Total		21,952	18,236	

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. 5-5 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. 5-6 shows the correlation between v_m and v_s measured at Hardinge Bridge, as given in Table 5-2 (refer to Prefeasibility Report).

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

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

the ratio of the mean velocity to the surface velocity is

$$v_m / v_s = 0.78$$

on the Jamuna River and the same 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 discharges, 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.

Table 5-2 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

Fig. 5-5 Relation between Velocities

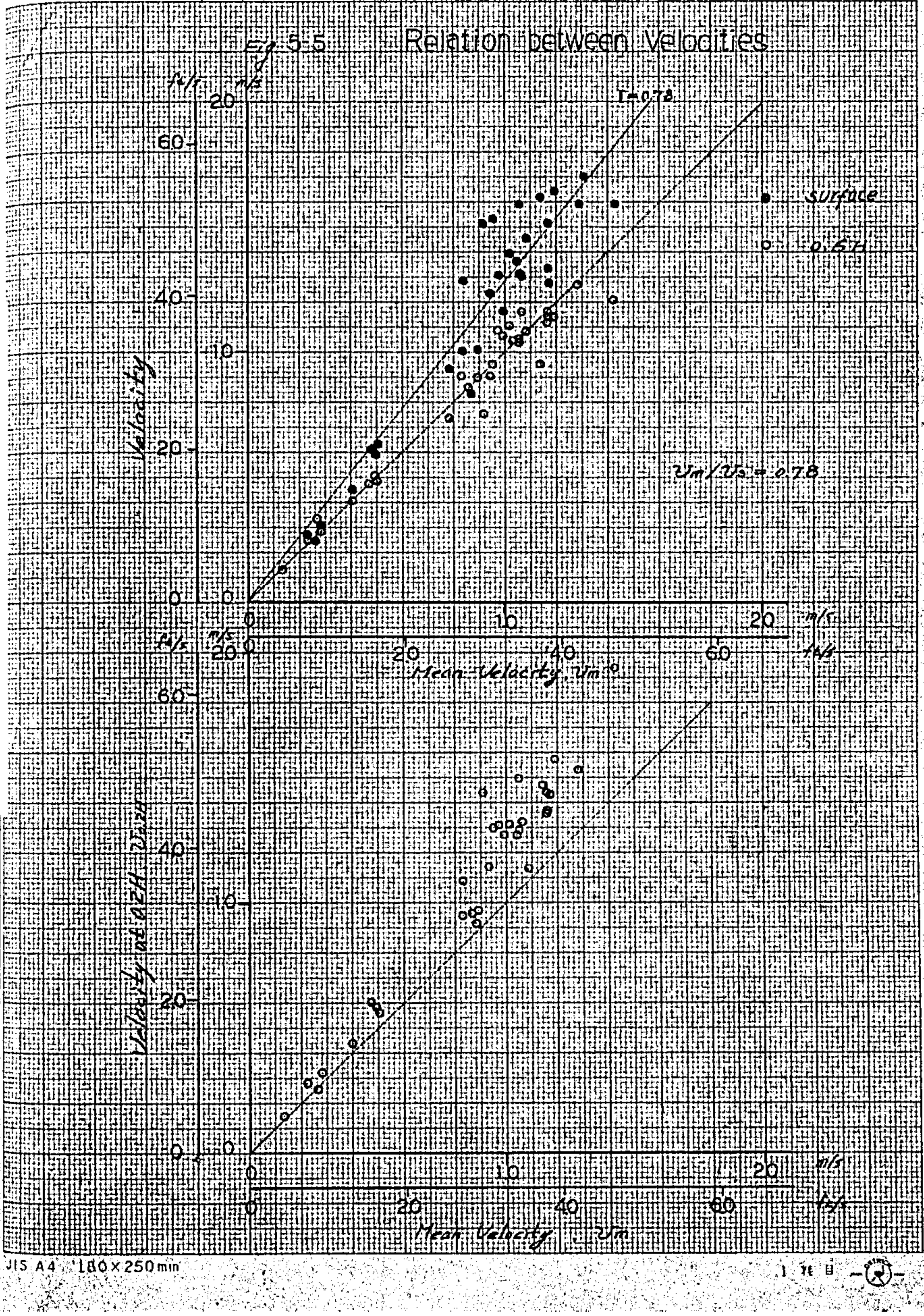
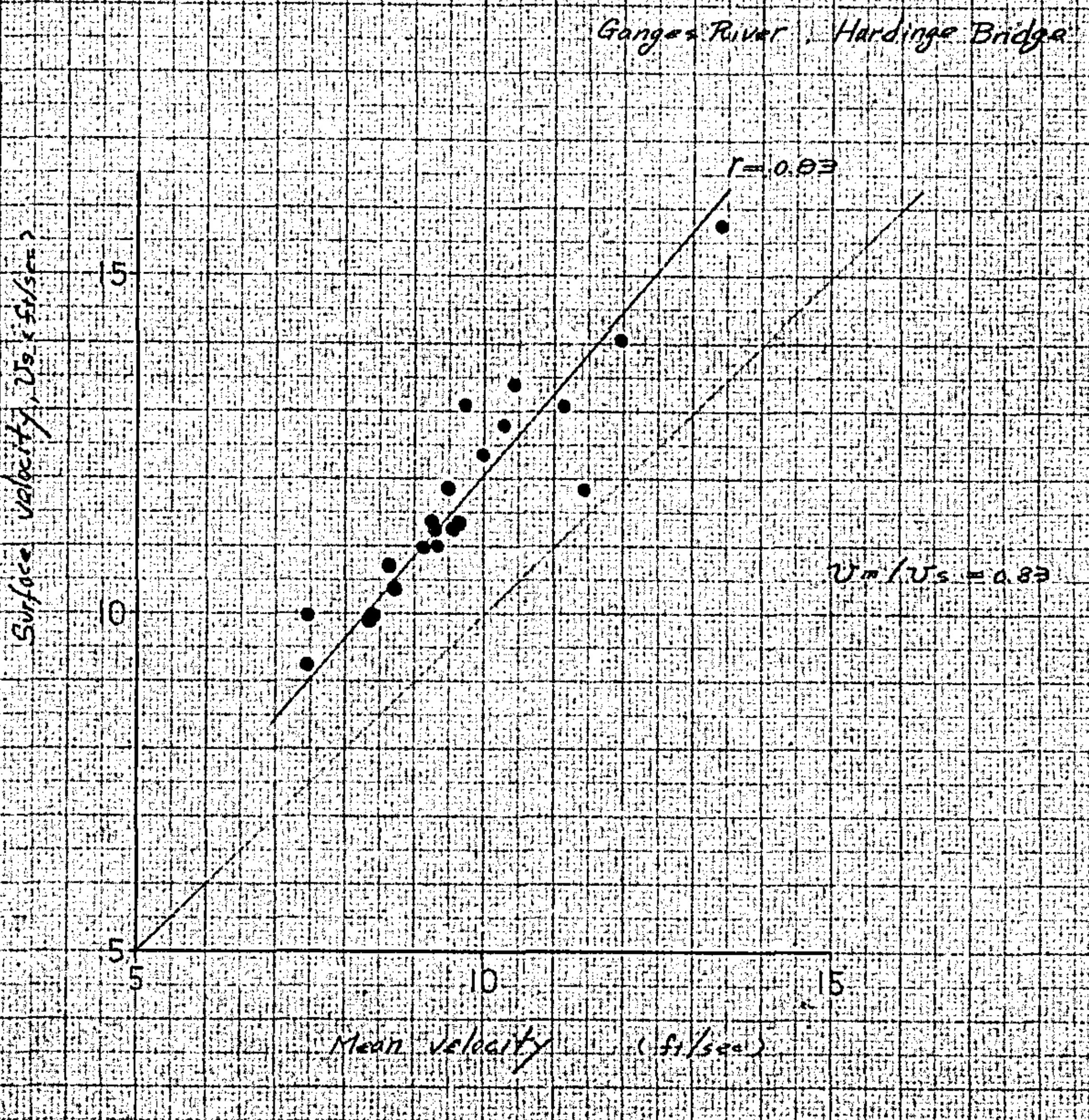


Fig. 5-6 Relation between Velocities



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 and were selected, from Table 5-2, 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 discharge are shown in Table 5-3.

Table 5-3 Discharge and Mean Velocity at Hardinge Bridge

Date	R.L. (ft)	A ($10^3 ft^2$)	Q ($10^3 cfs$)	v_M (ft/s)	v_M (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 5-2 and 5-3, 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. 5-7.

Fig. 5-7

Hardinge Bridge

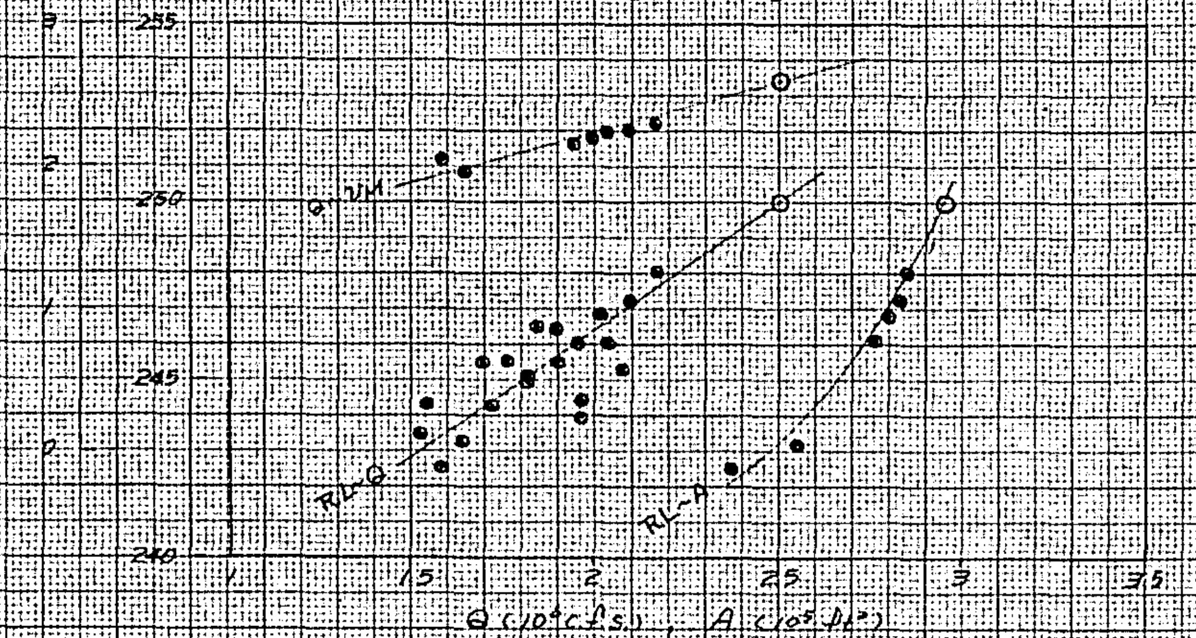


Fig. 5-8

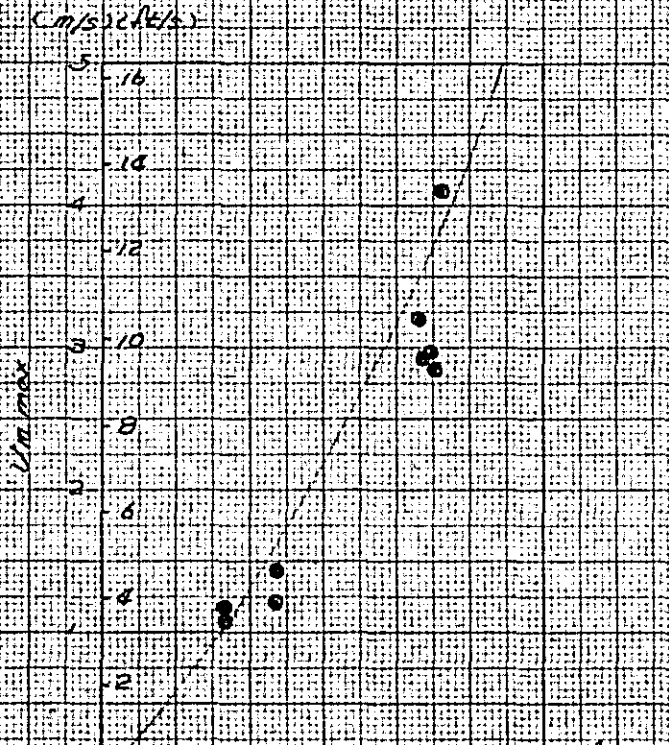


Table 5-4 v_M and $v_{m\ max}$ of the Jamuna and the Ganges

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 5-1
Sept.24, 1973	Sirajganj	1.17 (3.84)	1.42 (4.66)	"
Oct. 11, 1973	Gabargaon	1.18 (3.87)	1.19 (3.90)	"
Oct. 11, 1973	Bahadurabad	0.83 (2.72)	1.16 (3.80)	"
Aug. 26, 1969	Hardinge	2.31 (7.57)	4.08 (13.38)	Table 5-2
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 5-4 gives the data obtained in the Jamuna River by the Japanese Survey Team (Table 5-1) and the data obtained in the Ganges (Table 5-3 and 5-2) on the values of v_M and $v_{m\ max}$. Using these data, the correlations between v_M and $v_{m\ max}$ were studied, which are shown in Fig. 5-8.

3. Coefficient of Roughness.

(1) Coefficient of roughness n derived from the discharge measurement in1973.

In computing n value in the Manning's formula,

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

v = mean velocity (m/s)

I = water surface slope

R = mean water depth (m)

n = coefficient of roughness,

the values given in Table 5-1 were used for , A (v = , /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. 5-9, made by data of water stages measured at twenty-five gaging stations of BWDB during the discharge-measurement period.

Table 5-5 shows the computation of n values at the four proposed bridge sites and Fig. 5-10 gives the distribution of n values on the Jamuna River. The average value of n along the river course is 0.02 on the whole stretch except Bahadurabad. The value of 0.02 was used in this study.

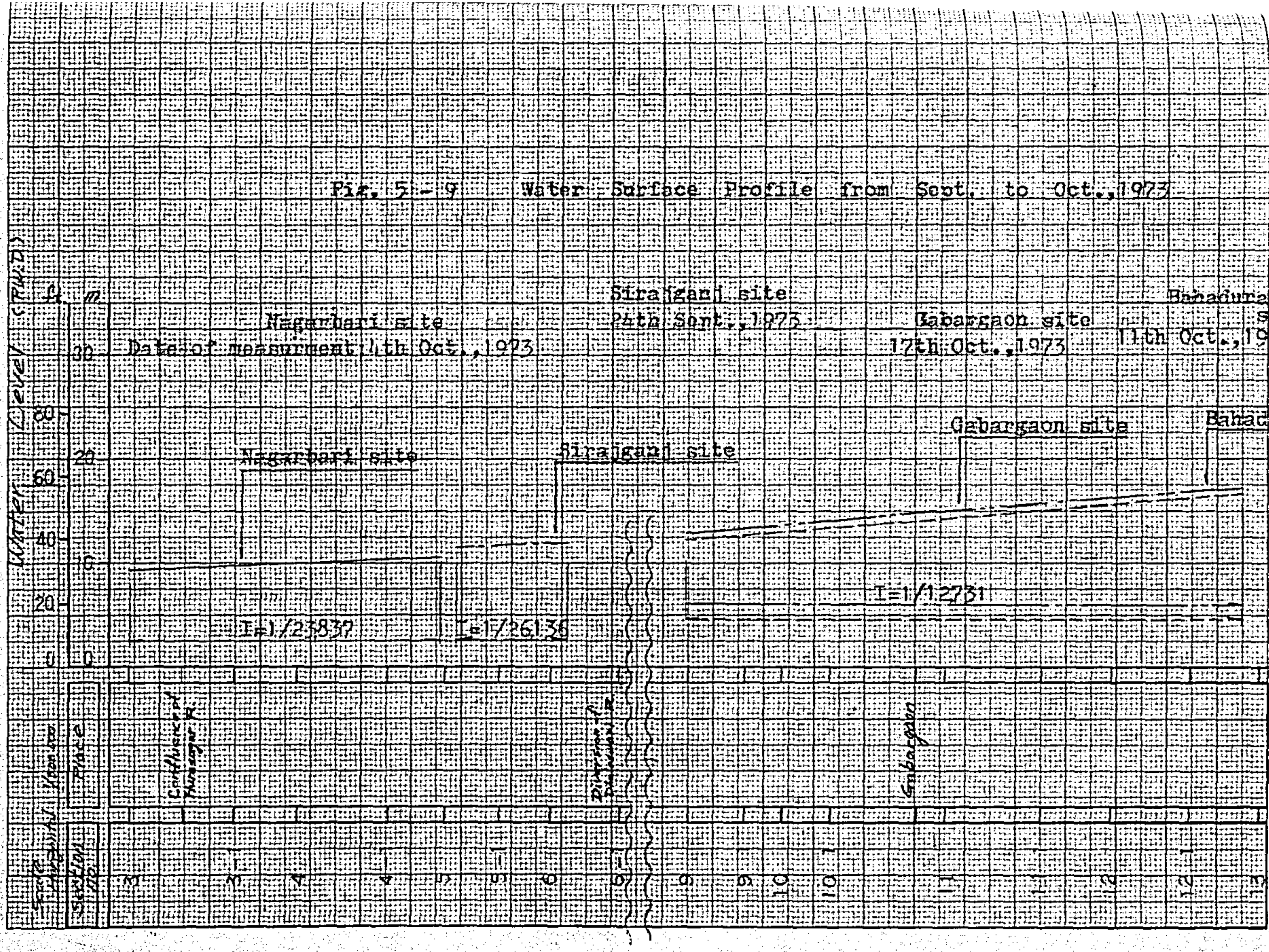
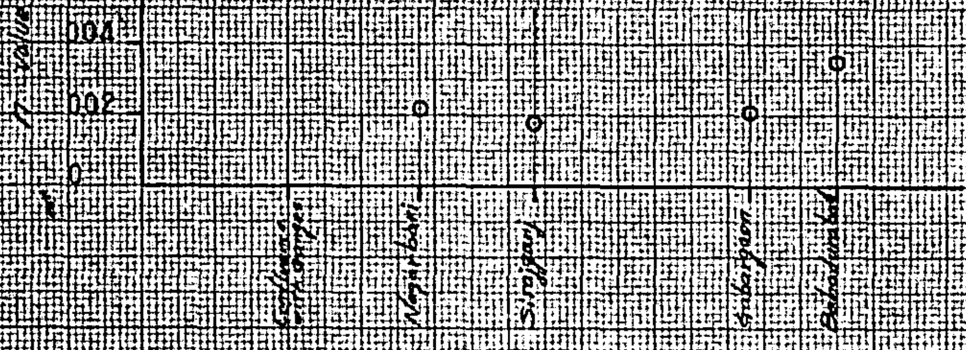


Fig. 5 - 9 Water Surface Profile from Sept. to Oct., 1973

Fig. 5 - 10 Values of n Calculated from Discharge Measurements

Longitudinal variation of value ; n



Brahmaputra-Jamuna River

Table 5 - 5 Calculation of value ; n

	site	Nagarbari	Sirajganj	Gabargaon	Bahadurabad	remarks
Measured	Q/A	0.853 m/s	1.166 m/s	1.178 m/s	0.831 m/s	
	I	1/23,840	1/26,140	1/12,730	1/12,730	
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	
$R^{\frac{2}{3}}$		2.875	3.426	2.750	3.291	
n		0.022	0.018	0.021	0.035	

(2) Coefficient of roughness n derived from the cross sections surveyed in the dry season.

In order to obtain the value of coefficient of roughness for the cross sections surveyed in the dry season, assuming the values of n at 0.02, 0.018 and 0.015, water profiles when the maximum flood discharge in 1970 (2,700,000 cfs at Bahadurabad Station on Jul. 28, 1970) was assumed to flow through the cross sections measured in 1969/70 dry season were calculated on a stretch up-and-downstream of Bahadurabad where discharge records are regarded to correspond with those of water level. The results are shown in Fig. 5-11.

This figure indicates that the most reasonable value lies between 0.015 and 0.018. According to the study described in Flood Control Plan for East Pakistan, First stage (113 GN), n value for the Jamuna River was estimated at 0.017 on the average. Therefore, 0.017 can be taken as a reasonable value for n derived from cross sections in the dry season.

(3) Some considerations.

As mentioned above, n value derived from flood discharge and cross sections at the same flood time is 0.02, while that derived from flood discharge and cross sections measured in a dry season nearest the flood time is 0.017. From these results, the value of n during flood is likely to be 0.02. The cause may be sought in the fact that the river depth may possibly be shallowed to a certain degree owing to sedimentation at the end of the flood. It is necessary, however, to make further study before we determine whether the coefficient of roughness is 0.02 or 0.017.

At the present study, 0.02 was used because the cross sections measured during flood were used for c alcutation of water levels.

Fig 5-1 Comparison of Calculated Water Level with Measured Water Level