CRITICAL REVIEW OF SEDIMENT TRANSPORT STUDIES OF JAMUNA RIVER

Submitted by

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CERTIFICATE

This is to certify that this project work has been done by me and neither this project nor any part thereof has been submitted elsewhere for the award of any degree or diploma.

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WE HEREBY RECOMMEND THAT THE PROJECT PREPARED BY NILUFER SULTANA ENTITLED " CRITICAL REVIEW OF SEDIMENT TRANSPORT STUDIES OF JAMUNA RIVER " BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (WATER RESOURCES).

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ABSTRACT

This study is concerned with the review of sediment transport studies of the river Jamuna.

Bangladesh Water Development Board has been collecting sediment data on the river Jamuna at Chilmari, Nakfatarchar, Nagarbari and Bahadurabad for several years. The collected data consists of suspended sediment load and measurements are taken by Binkley Sediment Samplers.

The first part of the study involves review of the past investigations undertaken on the data related to sediment transport studies of the Jamuna. The study also includes the application of these data to two transport equations with a view to determining the annual sediment transport through the Jamuna using the data of 1982-1988.

Sediment related data were collected by the author from BWDB covering the period from 1982 to 1988 at Bahadurabad Gauging station. These data were utilised to have a quantitative evaluation of the transport rate of the Jamuna river.

The sediment transport formulae selected in the present analysis were based on a prior comparison by, Bari (1978), Hossain and Barr (1988) and Alam and Hossain (1988).

The performance of these transport equations against the data collected has also been discussed.

Rating curves were developed and power law relationships have been established between Q_T , Q_S , and Q_W , and V .

Finally suggestions have been made to modify the existing data collection procedure of Bangladesh Water Development Board.

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LIST OF SYMBOLS

Symbol	Definition
A	Cross sectional area, m^2
a'	Distance from the stream bed to the sample inlet tube, m
B	Water surface width, m
C_a	Concentration of Sediment with fall velocity w at level y = a above the bed, ppm.
C_b	Concentration of the same size of bed material at the bed, ppm.
C_t	Total sediment concentration, ppm
C'_s	Mean sediment concentration, ppm
C	Sediment concentration at y, ppm
D	Median sieve diameter, m
D_{50}, D_m	Median sediment size, m
d	Stream depth at the vertical, m
g	Acceleration due to gravity, m/sec^2
H	Mean depth, m
Q_w	Total water discharge, m^3/sec
Q_{sobs}	Observed Suspended sediment discharge, tons/day
Q_{sY}	Total sediment calculated by Yang, tons/day
Q_{sH}	Total sediment calculated by Hossain, tons/day
Q_c	Assessed discharge, tons/day
q	Water discharge for a sub-section
Q_W	Summation of all q
r	Coefficient of correlation

Symbol	Definition
S	Average water surface slope
S	Specific gravity
u	Water velocity at a distance y above the bed, m/sec
U	Shear velocity , m/sec
VS	Velocity Slope product
V_{cr}	Critical average flow velocity, m/sec
V	Mean velocity, m/sec
w_r	Settling velocity for a representative sediment size for which D_{50} = 0.15mm at ambient temperature.
w	Fall velocity, m/sec
ρ_s	Density of a solid mass, kg-sec^2/m^4 or tons-sec /m
ρ	Density of water, kg-sec /m
γ_s	Specific weight, kg/m^3, tons/m^3
ν	Kinematic viscosity, m /sec

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Knowledge of water and sediment discharge and sediment characteristics in a stream is essential in the solution of majority of the problems associated with the folw in alluvial channels.

The mechanism of sediment transport has been a subject of study for decades due to its imporatnce in river regulation as well as design and operation of canal systems. Researchers/engineers have been engaged in the study of sediment transport in rivers and estuaries for their control and training. Alluvial streams carry not only water but also sediment and the sediment transport rate is closely linked with the stability of the streams. Alluvial channels, therefore must be designed to carry definite water and sediment discharges, in other words, the rate of total load transport must be treated as a variable affecting the design of the channel.

Hydraulic engineers may often be bewildered by the large number of relationships available in the literature regarding the sediment discharge. The very number of such formulae is itself an indication of the incomplete understanding of sediment transport phenomenon.

The estimated sediment load from various equations often differ drastically from each other for a given set of observed data. This is due to inclusion of so many variables like the size of sediment, the fall velocity, specific weight, cohesion, porosity of particles etc that influence the sediment transport. Some of these interrelated and interdependent variable play a dominating role.

It is therefore desirable to provide an assessment of the present state of art as it affects practical applications. Most of the sediment transport formulae have been derived, essentially from laboratory experiments. Thus it is necessary to know whether application of these formulae gives reasonable result in field situations. With such purpose in mind, there had been several comprehensive studies to evaluate the performance of diverse formulae over a wide range of field and laboratory data. Notable among these are studies by White et al. (1973), by the Task Committee of the American Society of Civil Engineers (1971), Yang (1977), by Gole, Tarapore and Dixit (1973), by Amin and Murphy (1981), by Hossain (1985) and by Hossain and Barr (1988).

The ASCE Task Committee have studied 13 formulae and found that Colby (1964), Tofaletti (1969) and Engelund-Hansen (1967) formulae gave consistently better result than others.

On the other hand, 19 transport formulae against about 1000 laboratory and 270 field measurements have been tested at Hydraulic Research Station, Wallingford, U.K. It was found that out of 19 theories the Ackers-White (1973), Engelund-Hansen

(1967) total load and Rottner (1959) bed load formulae are the most reliable.

In this study a comprehensive study of the efficacy of two sediment transport equations is provided. It also makes an attempt to analyse the data collected by Bangladesh Water Development Board for various stations namely, Chilmari, Sirajganj, Bahadurabad and Nagarbari of the river Jamuna. The applicability of two recent transport formulae are tested. The selected formulae are those developed by Hossain (1985, 1987) and Yang (1973). Efforts have also been made to compute the transport rate at various times of the year.

1.2 Importance of the study

Most of the river courses in Bangladesh being alluvial in nature, erosion, deposition and changes in channel profile have been a big problem since time immemorial. For planning and design of water development projects it is often required to estimate the possible future changes in river geometry. Sediment plays a dominant role in changing the morphology of a river. According to Bogardi (1978) in terms of sediment load, Jamuna is the third amongst the rivers of the world. The large discharge and heavy sediment load cause the river to be extremely unstable and the channels are constantly migrating laterally.

Without studying the sediment aspect of the river, successful planning and design of flood control, navigation, channel rectification, etc is not possible. Realising this fact the Directorate of River Morphology, Research and Training of the BWDB has been collecting sediment data since 1965. The data are collected for selected rivers at a number of stations and the sediment concentration in the form of parts per million is being published by the Hydraulic Research Laboratory of BWDB in the past. Later, the Hydraulic Research Laboratory has been renamed as River Research Institute, (RRI). The measured data are mostly to the suspended sediment; and bed-load, though important, is not measured by the Hydrology Directorate of BWDB for two reasons; first, a really reliable method of measurement has not yet been devised and secondly, the problems involved in large rivers as those of Bangladesh are probably unsurmountable.

Furthermore informations related to sediment transport formulae available in literature have been derived primarily based on laboratory, flume and natural channel data collecetd in USA, UK, Canada and other countries besides Bangladesh. Evaluation of any of the formulae have rarely been done using the data of the Jamuna.

The present study utilising the field data of few selected stations of the river Jamuna, as mentioned above may help in understanding of the limitations of the formulae on a more wider horizon.

1.3 Objectives of the study

The objective of the present study are as follows:

i) Critical review of data collection, processing, and publication procedure.

ii) Comparison of sediment load estimated by Yang and Hossain formulae.

CHAPTER TWO

SEDIMENT PROPERTIES

2.1 Introduction

This chapter deals with the basic terms, definitions, properties, source and characteristics of sediment as relevant to the present study.

2.2 Terminology

Sediment: Fragmental material that originates from weathering of rocks and is transported by, suspended in, or deposited by water.

Fine Sediment: Those sediments, mainly comprising silts and clays or a grain size smaller than about 0.05mm in diameter.

Coarse Sediment: Those sediments, mainly sand,of a grain size greater than about 0.05 mm in diameter.

Bed load: That material forming the bed of a river which is in motion but not lifted into suspension.

Suspended bed load: That portion of the bed material which is lifted into suspension and which plays dominant role in river pattern and channel formation.This is mostly of a grain size greater than 0.05 mm in diameter.

Wash load: The finer sediments, mainly silts and clays which are carried in suspension. They are mainly carried out to sea or deposited on the seaward edge of the delta.

Total suspended load: Composed of wash load plus the suspended bed load.

Total sediment load: It is the sum of the total suspended load and the bed load.

Sediment Concentration: The quantity of sediment relative to the quantity of transporting or suspending fluid, or fluid-sediment mixture. The quantity may be expressed by weight or by volume.

Unsampled zone and Sampled zone: The suspended load samples give the mean measured sediment concentration C's at each or at least several, of the vertical in which mean velocity is measured. The concentration C's includes all grain sizes, wash load as well as bed material load and is defined by

$$C's \int_{a'}^{d} u \, dy = \int_{a'}^{d} cu \, dy$$

in which a'is the distance from the stream bed to the sampler inlet tube when the sample is in its lowest position in the vertical; d is the stream depth at the vertical; u is the water velocity at a distance y above the bed; and c is the sediment concentration at this same point. The region of the cross section below a' forms what is called the unsampled zone of the cross section and the part of the cross section above a' is called the sampled zone.

Measured suspended sediment load: That part of the suspended sediment which is measured with suspended load samplers or the portion of the suspended sediment load which passes through the sampled part of the stream section.

Unmeasured sediment load: The suspended sediment measurements do not sample the sediment load in the unsampled zone, which may include the bed load and part of the suspended load. This is known as unmeasured sediment load.

Density: The density ρ_s (in lb- sec^2/ft^4 , $slugs / ft^3$, or $kg\text{-}sec^2/m^4$, $tons\text{-}sec^2/m^4$) of a solid is the mass which it possesses per unit volume. The density of water is denoted by ρ. The dimensionless expression $(\rho_s - \rho) / \rho$ involving both the density of water and sediment is used frequently in sediment transport formulas. It is sometimes called the relative density.

Specific weight: The specific weight γ_s (in lb/ft^3 or kg/m^3 or $tons/m^3$) is the weight per unit volume. The specific weight of a submerged, solid particle is = $\gamma'_s = \gamma_s - \gamma$.
Where, γ is the specific weight of water.

Specific gravity : The specific gravity S is the ratio of the sp. wt. of a solid or a fluid to the sp. wt, of the water at $4^{\circ}C$ or $39^{\circ}.2$ F.

Fall velocity: The fall velocity is the average terminal settling velocity of a particle falling alone in quiescent, distilled water of infinite extent.

Nominal Diameter: The nominal diameter is the diameter of a sphere having the same volume as the particle.

Sieve Diameter: The sieve diameter is the diameter of a sphere equal to the length of the side of a square sieve opening through which measured quantities (by wt.) of the sample will just pass. As an approximation, the sieve diameter is equal to the nominal diameter.

Fall Diameter or Standard fall Diameter: The fall diameter is the diameter of a sphere that has a specific gravity of 2.65 and has the same terminal uniform settling velocity as the particle when each is allowed to settle alone in quiescent, distilled water of infinite extent at a temperature of 24°C.

2.3 Physical Properties of Sediment

Sediments are broadly classified as cohesive and non-cohesive. With cohesive sediment the resistance to erosion depends on the strength of the cohesive bond binding the particles. Cohesion may far outweigh the influence of the physical characteristics of the individual particles. However, once erosion has taken place, cohesive material may become non-cohesive with respect to transport. Also, sediment characteristics may change through chemical or physical reactions. On the other hand the non-cohesive sediments generally consist of larger descrete particles than the coheseve soils. Non-cohesive sediment particles react to fluid forces and their movement is affected by the physical properties of the particles such as size, shape and density.

2.3.1 Size

Of the various sediment properties, size has the greatest significance to the hydraulic engineer, not only because size is important and the most readily measured property, but also because other properties such as shape and specific gravity tend to vary with particle size. Particle size may be defined by volume, diameter, weight, fall velocity, seive size and by intercepts through the particle.

The size of an individual particle is not a primary importance in seive mechanics or sedimentation studies but the size distribution of the sediment that forms the bed and banks of a stream or resevoir are of great importance.

Size may be measured by calipers, by optical methods, by photographic methods, by seiving or by sedimentation methods. A size classification recommended by the sub-committe on Sediment Terminology of the Committee on Dynamic of streams of the American Geophysical Union (Lane and others, 1947), contains consecutive size classes; boulders, cobbles, gravel, sand, silt and clay as given in Table 2.1.

2.3.2 Shape

Generally speaking, shape refers to the overall geometric form of a particle regardless of size or composition. Two particles have the same shape if the ratio of their intercepts and the angles between the intercepts are the same for the both particles. Particles of very different geometrical shape, but of the same volume and density, may behave the same in fluids. Hence the shape may be defined in terms of dynamic behaviour.

In sediment analysis one of the most pertinent shape parameters is sphericity which was defined by Wadell (1932) as the ratio of the surface area of a sphere of the same volume as the particle to the actual surface area of the particle. The primary role of sphericity is to help describe the relative motion between the falling particle and the fluid.

2.3.3 Density

The density of a solid is the mass which it possesses per unit volume. Again the density of a sediment is a function of its mineral composition. Water borne sediments are mainly quartz and felspathic minerals with specific gravity of 2.65. For this reason the specific gravity of water borne sediments is often assumed to be 2.65.

2.3.4 Size frequency distribution

The most commonly used method to determine size frequency is mechanical or seive analysis. In general, the results are presented as cumulative size frequency curves. The fraction or percentage by weight of a sediment that is smaller or larger than a given size is plotted against particle size. From the size frequency curve it is possible to obtain representative grain size of sediment mixture. Physical evidence does not conclusively fix the size that represents a given sediment mixture. The choice is rather arbitrary. For usual practice D_{35}, D_{50}, D_{65}, D_{85}, D_{90}, are commonly used. D_{35} indicates the size of sediment for which 35 percent of the sample is finer. D_{50} represents median diameter of the sediment mixture and indicates 50 percent sample is finer. In the same way D_{65}, D_{85} , D_{90} represents that 65 percent, 85 percent and 90 percent sample is finer respectively. D_m, the mean diameter is given by $D_m = \Delta_i D_i / 100$ where i represents any portion of the percentages shown on the y axis of Fig 2.1 and D_i represents the mean value of the sizes established by the extreme values of the interval i. According to Fig 2.1 D_m is computed as follows:

$$D_m = \frac{(\Delta 1D1 + \Delta 2D2 + \Delta 3D3 + \dots\dots\dots\dots + \Delta 6D6)}{100}$$

and D_m represents the mean size of the sample. It should not be assumed that the particle measure D_m represents the hydraulic properties of the sediment mixture.

2.4 Sources of Sediment

The following are the principal sources of stream borne sediment.

i) Sheet erosion by surface run off from precepitation on agricultural, forest and waste land-sheet erosion being defined by soil conservationists as the removal of surface soil by overland flow without the formation of channels of sufficient depth to present cultivation or crossing by farm machinery.

ii) Stream channel erosion, including bank cutting and degradation of formerly well defined channels.

iii) Mass movements of soil land slides, slumps and soil creep.

iv) Gullying, or the cutting of channel in soil or unconsolidated geologic formations by concentrated runoff.

v) Flood erosion, or the removal of surface soil by flood flows sweeping across flood plains.

vi) Mining, industrial, and sewage wastes discharged into stream.

vii) Erosion due to cultural developments, including roads, rail roads, power lines and industrial projects.

Of these, the first two are by far the most important, quantitatively, in all large drainage areas, although in small local areas other sources may be of major importance.

2.5 Modes of Sediment Transport

Sediment particles are transported by flow in one or a combination of the following way:

1) Rolling or sliding on the bed, surface creep.

2) Jumping into the flow and then resting on the bed, saltation;

3) Supported by the surrounding fluid during its entire motion i.e. in suspension.

There is no sharp line of demarcation between saltation and suspension. However, this distinction is important as it serves to delimit two methods of hydraulic transportation which follow different laws i.e. traction and suspension. Of course, sediments may be transported partially as saltation and then suddenly be caught by the flow turbulence and transported in suspension.

2.6 Factors affecting Sediment Transportation

The large number of variables which affect the sediment transportation are interdependent. Some of the variables change with the flow conditions and alter their roles from dependent to independent variables. It is difficult, especially in field studies, to differenciate between independent and dependent variables. Variables which are responsible in sediment trasporation are as follows:

1) Geometric properties of stream channel, depth, width , form and alignment.

2) Hydraulic properties of stream channel, slope, roughness, hydraulic radius, discharge, velocity, turbulence, tractive force, fluid properties and uniformity of discharge.

CHAPTER THREE

THE RIVER JAMUNA - ITS BEHAVIOUR AND CHARACTERISTICS

3.1 Introduction

Bangladesh is a great delta. The greatest part of Bangladesh is floored with quarternary sediments deposited by the mighty rivers like the Ganges, the Jamuna and the Meghna. These rivers carry huge quantity of sediments both in suspension and as bed load and the problem of siltation and bank erosion in almost all the rivers of Bangladesh is very acute. These river system occupied and abandoned numerous river courses, leaving behind a large, lowlying, flood plain of alluvium. The delta system of the Ganges Brahmaputra is the largest in the world, comprising some 59,600 sq.km.(23,000 sq.miles) (Habibullah, 1987).

3.2 The Jamuna and its drainage basin

The Jamuna river is the name given to the Brahmaputra river in Bangladesh and is the country's largest river.The Brahmaputra originates from the famous Manas-Sarowar in Chemayungdang glacier as Tsangpo which flows eastward for about 775 miles (1248 km) in a constricted valley through Tibet. The river Tsangpo takes a sharp bend southward before meeting Dihang,enters Assam from the north and meets with the Dihang and Luhit some 30 miles (48 km) north-east of Dibrugarh. This combined flow assumes the name Brahmaputra and continues to flow through Assam towards south-east before entering Bangladesh from the north.

In Bangladesh the river flows south and takes on the flows of the Teesta just south of Chilmari and the Hurasagar in between Porabari and Nagarbari and then joins the mighty Ganges near Goalando. Within Bangladesh important distributaries of the Brahmaputra are the Old Brahmaputra leaving the left bank south of Bahadurabad and the Dhaleswari also leaving the left bank just below Sirajganj. The combined flow of the Brahmaputra and Ganges, with the name Padma flows towards south-east before meeting another big river - the Meghna at Chandpur. From Chandpur the combined flow, one of the largest in the world - only exceeded by the Amazon and Congo, flows southward with the name Meghna and falls into the Bay of Bengal.

The course of the river Brahmaputra is shown in Fig 3.1. The total length of the Tsangpo-Brahmaputra-Jamuna river upto Goalundo is 1,600 miles (2575 sq.km) (Latif, 1969). The total drainage area down to Aricha is 2,24,000 sq.miles (5,80,455 sq.km) of which 1,13,000 sq.miles (2,92,819 sq.km) are in Tibet, 93,000 sq.miles (2,40,992 sq.km) in India and only 18,000 sq.miles (46,644 sq.km) in Bangladesh. (Rashid,1977). Although the Brahmaputra has a much smaller total length and drainage area than other major rivers of the world, its discharge is one of the highest, only exceeded by the Amazon, Congo and Yangtze. Average annual discharge, based on the data of the period 1965-1984 at Bahadurabad is approximately 6,85,000 cusecs (19,412 m^3/sec) (Habibullah,1987). The maximum and the minimum discharge recorded at Bahadurabad in between 1965 and 1984 are respectively 32,14,696 cusecs (91,100 m^3/s) (in 1974- 1975) and

1,00,922 cusecs (2,860 m^3/s) (in 1970-1971). However, it is estimated that the highest recorded discharge of the Jamuna at Bahadurabad during the flood of 1988 was of the order of 100,000 cubic meter per second. The average slope of the Brahmaputra river in Bangladesh varies from 0.5 ft per mile (9.5 cm/km) near Nunkhawa to 0.14 ft per mile (2.65 cm/km) near Chandpur. (Habibullah, 1987). Fig 3.1 shows the Jamuna and its drainage basin.

3.3 Data Observation Stations

Bangladesh Water Development Board has been collecting suspended sediment and bed material samples from the Jamuna since 1965. The present study concentrates on the analysis of data collected from Bahadurabad, Chilmari, Sirajganj (Nakfatarchar) and Nagarbari Stations of the Jamuna.

The Bahadurabad measurement station is located at a distance of 328 ft upstream of Transit Line Gauge. The section is marked with permanent monument markers. The river as already mentioned drains the high rainfall of Assam Valley and Bangladesh. The drainage area upto Bahadurabad is 5,36,077 sq.km out of which 259 sq.km lie in Bangladesh.

The Sirajganj Gauging Station is located at about 10 miles down of Sirajganj town. Here, the river is branched into three channels, namely, Dhaleswari channel at the east, Main channel at the middle and West channel at the west. The sites on the channels are Ballab Bari, Nakfatarchar and Randhunibari low flow conditions. Considering the sinuousity of the channels, it is probable that the water level slope along the Jamuna River decreases in the downstream direction, although the figures in Table 3.2 suggest the opposite. (UNDP,1986).

b) Planform Characteristics

The Jamuna River is a braiding stream with chars and deeper channels in between. The braiding character is most prominent in the upstream reaches, as observed on a number of satelite imageries taken during low flow conditions. The deepwater channel changes frequently and the banks are susceptible to heavy erosion and deposition, indicating a very unstable nature of the channel. However the channel between the "Khadirs" is maintaining the present course for quite a number of years.

c) Cross-section Characteristics

Characteristics of the cross-sections of the Jamuna were analysed from the BWDB soundings (UNDP,1986). Location of cross-sections at different stations from Ganges Jamuna confluence to India Bangladesh border is shown in Fig 3.2. Typical cross-sections of the selected stations are shown on Fig 3.3 to Fig 3.5. The mean annual flood level is also indicated, corresponding to the average annual flood of 65000 m^3/sec for the Jamuna. Most Cross-sections can be characterised as a flat sand bed with an elevation some metres below the annual flood level in which deep channels are carved. These deep channels are clearly composed of several smaller ones. Typical bend profiles seem to be present in the river. The following characteristics were determined by cross-section and year.

- total river width, defined as the width between the edges of
- the deeper channels.
- the number of main channels.
- the combined width of channels.
- the total wet area of the main channels below the mean
- annual flood level.
- the maximum depth.

The average depths were computed from the total wetted area and the combined widths of the main channels.

Mean values for the different parameters were derived by averaging the data of the available years.

d) Bed Material

Data on bed material of the Jamuna river are available in a number of RRI reports. All data have been arranged systematically and brought into proper form. The bed material data are shown in Table 3.3 and Table 3.4 for the selected four stations. A preliminary review on the available reports results in the following conclusions :

- there is only a small variation in grain size in one sample.
- the variations in average grain size of the bed material are appreciable for various dates and depths.

To arrive at a fair estimate of the bed material size and its gradation, the D_{35} and D_{65} values were analysed by stations and by year. Considering the large variation in D_m are shown in Fig 3.6 the standard deviation can be considered as an estimate of the bed material. The average bed material sizes were also computed and are presented in Fig 3.7 together with the standard deviations and the approximate gradations. The following results are obtained for the Jamuna river (UNDP,1986).

Station	D_{50} (mm)	Standard deviation (mm)
Chilmari	0.235	1.30
Bahadurabad	0.215	1.30
Sirajganj	0.190	1.30
Nagarbari	0.165	1.30

In the bed samples of the Jamuna very fine sand (down to 0.0120 mm) was found. This would imply that the distinction between wash load and bed material load would be slightly different from the assumptions usually made during the analysis of the sediment transport.

e) Resistance to flow

Resistance to flow data of the Jamuna river has been analysed by Nazim (1985) and indicate generally low flow values. There are indications that during floods, dunes are washed out and possibly even flat bed conditions may occur.

f) Sediment Transport

Measured monthly sediment transport rates in the Jamuna river vary between less than one million tons/month during low-flow season and more than two fifty million tons/month in the floods season (UNDP,1986).Concentrations of over 4000 ppm have been reported by the BWDB which has later been quoted by UNDP. The value seems to be highly suspicious and needs further investigation. The average annual suspended sediment transport (1957-1975) was found to be in the order of 600 million tons. (UNDP,1986). Goswami (1984) estimated the annual sediment transport in the Brahmaputra river to be about 400 million m^3, which corresponds well with the IECO (1980) figures- 600 million ton, when it is assumed that 1 m^3 sediment (pores included) corresponds to about 1.6 tons.

CHAPTER FOUR

DATA COLLECTION PROCESSING AND COMPILATION

4.1 Introduction

The basic data have been collected from different sections of the Bangladesh Water Development Board (BWDB). Suspended sediment concentration and bed material size have been obtained from the River Research Institute (RRI) BWDB, Dhaka, while the water discharge and other associated flow measurement data have been obtained from the Directorate of River Morphology, Research and Training, BWDB, Dhaka. A considerable amount of time had to be spent in the assimilation and compilation of the data scattered in different sections of BWDB. Moreover, sediment concentration data were not collected by BWDB on a regular basis and were often not in a usable form. All data have been arranged systematically and brought into proper form for the purpose of analysis. The information and data collected do not appear to be complete but are sufficiently representative. Preference was given to more recent information that might be more appropriate for studying present conditions.

4.2 Equipment used for sampling of suspended load

For the measurement of suspended sediment load in streams, it is essential that samples taken by any sampler, truly represent the concentration of the stream at the period of measurement. In order to fulfil this requirement, the velocity within the outting circle of the intake of a sampler should be equal to the stream velocity. The intake should be pointed in to the approaching flow and should protrude up stream from the zone of disturbance caused by the presence of samples. Besides, the sampler container should be removable and suitable for transportation to the labóratories without loss or spoilage of contents.

Considering the above factors BWDB uses an instrument called ''Binkley" Sedimemt Sampler as shown in Fig 4.1 for collection of sediment.

4.2.1 Procedure of Measurement

Special attention should be given to the following prior to any measurement programme:

1) Sampling of suspended sediment should be carried out along the verticals where velocity measurements (or along at least three verticals) are taken.

A depth integrating sample will give the mean value of the sediment load along the vertical. If point integrating samplers are used, measurements should be taken for at least three points, i.e. 1 ft below the water surface, 1 ft above the inner bed and at mid-depth.

2) If only one sample is to be taken along a vertical or in the whole cross-section, the position of sampling should be decided by detailed measurements, which will correspond to the value of sediment distribution.

3) Sediment load should be measured twice every week during low flow and mean water and daily during floods. In tidal rivers measurements is to be taken three hours before the high tide. Except, where the depth of the river is too high, the drifting method of sampling is used.

It is assumed that a liquid discharge measurement will have just been completed and is being followed immediately by the sediment sampling operation. The current meter assembly will have been dismantled, cleaned and towed away.

The width of the river section is divided into a number of subsections by means of verticals so that the discharge between any two adjacent verticals does not exceed 10 percent and preferably 5 percent of the total discharge. Samples are collected at each vertical. Before commencing the sampling it is convenient to work out the 0.2 and 0.8 depths at each vertical so that the operation may be concluded easily and in the minimum of time.

The sample collected is transferred from the container to a numbered plastic transport container. A measured quantity of distilled water (50cc) is used to rinse the sampler and added to the sample as wash water. The quantity of wash water is recorded in the data sheet for use in determining the sediment concentration. The suspended sediment concentration has been taken by BWDB at 0.2 and 0.8 depths of each sub-section and average of the two is the mean concentration for each sub-section. The average sediment concentration for a section is then calculated by summing up all the concentrations.

4.2.2 Calculation of Discharge, Sediment Concentration etc.

The procedures employed in the calculation of the water discharge, mean velocity, water surface width, etc. and sediment concentration from the measured data are as follows:

1) Water discharge, q, for each sub-section delineated by adjacent verticals is obtained as the product of the average of velocities at the two verticals and the area of the sub-section, determined from the measured water surface elevation and plotted transverse bed profile. The total flow discharge for the entire section, Q is obtained by summing the discharges for all the sub-sections.

2) Water surface width (B). It is the sum of the widths of all the sub-sections.

3) Cross sectional area (A) : From the measured depth at the verticals, the distance between verticals and water surface elevation, the tranverse bed profile is plotted, keeping the left bank at the left edge of the paper. The top boundary of the cross section is the horizontal line forming the water surface width while the rest of it is the river bed profile. The cross

sectional area is then calculated by summing up the areas of all the sub-sections.

4) Mean Velocity (V) : Mean velocity has been obtained dividing the water discharge by cross sectional area.

5) Mean depth (H) : Mean depth of flow has been determined from equivalent rectangular channel section whose top lateral dimension equals the water surface width. Thus the water section area divided by the water surface width gives the mean depth.

6) The sediment samples collected by the Directorate of Hydrology BWDB,Dhaka, are analysed in the River Research Institute ,BWDB, Dhaka.Either immediately following or along with the liquid discharge measurement, sediment samples were collected from depths of 0.2 and 0.8 of the total depth of flow on every alternate vertical used for liquid measurement. These samples after removal from the Binkley sampler, were elutriated by means of an elutriator Fig 4.2 and the sand fraction stored in glass tube in racks. The sediment samples are analysed to determine the concentration and the results are expressed in parts per million (PPM) by weight after making necessary correction for the added water. Precision balances weighing to an accuracy of 0.005 gram are used throughout. After determining the concentration, all the sediment are washed individually with silt free water to remove silt and clay. After washing only traces of fine sand are found in some cases and most of the samples are found to be composed of silt and clay only. So the suspended sediment samples would not be analysed for their size distribution except a few cases by means of the visual accumulation tube (VA) method.

4.3 Sampling of Bed Material

Althouth it has not been possible to make a detailed study of the bed materials in the rivers in Bangladesh it was decided in 1966 to collect some samples in the vicinities of selected gauging stations. Accordingly, during 1967 at both the begining and end of the year surveys were carried out to achieve this. Because of the difficulties involved in transporting large number of bed samples from up country stations, and the impossibility of analysing such samples for given size with resources both human and material available, it was decided that only five or six samples should be collected from each station rather more at Bahadurabad where the large mumber of channels during low flow period made it desirable to obtain at least one sample from each. The samples were to be more or less equally spaced across the river with the stipulation that the first and last should be near to but not necessarily at the water edge. These samples were taken with a Kolb bed sampler. This is essentially made up of two spring operated jaw which when lowered to the bed are closed by sending a messenger down the suspension cable which releases the tension on the spring allowing the jaws to snap shut and at the same time picking up a sample of bed material (UNDP, Report 1986).

The samples were stored in plastic bags and transported to Dhaka where they were analysed for grain size. Bed material samples are analysed for size distribution by means of seive and hydrometer methods.

4.4. Data processing :

Four number of stations are selected for sediment investigations. These stations are 1) Bahadurabad 2) Chilmari 3) Sirajganj (Nakfatarchar) and 4) Nagarbari. Sediment samples are collected at the time of discharge measurements at the above stations.

Samples of water with sediment in suspension are normally taken by Binkley Sampler from a number of verticals at the gauging section and from several points on each vertical. The stages in the treatment of the samples are as follows:

1) Concentration of sand fraction.
2) Disposal of the silt and clay fractions.
3) Determenation of the dry weight of the sand fraction.
4) Determination of the concentration of the silt and clay fractions.

4.4.1 Concentration of Sand Fraction :

The elutriator or sand concentrating device evolved and in use is shown in Fig 4.3. The sample collected from a position is quickly transferred to this Elutriator. The coarse fraction settles in water filled glass tube fitted at the bottom of the device in 100 seconds. The glass tube is detached from the elutriator and the water contained in the funnel of the elutriator is transferred to a container for determination of clay fraction.

The above process is repeated for each sample collected. The glass tube with sand fraction is preserved carefully for determination of the concentration of the sand fraction in the field office.

4.4.2.Disposal of Silt and Clay Fractions :

At the end of 100 seconds, sand concentrates in the glass tube and the silt and clay fractions remain in the funnel, the bottom of which has been plugged. The rate of settlements of the silts and clays is so slow that in a river, it can be assumed that they will be fairly evenly distributed by turbulence through out the cross section. They will move substantially at the same speed as the water as they are virtually floating in it. Thus, for purposes of analysis and measurement of concentration, it is permissible to bulk the samples in order to obtain a large representative sample for any one day.

4.4.3 Determination of Dry weight of Sand Fraction :

The weight of the sand fraction in the tube is determined by direct weighing. The tube with sand sample and water is weighed first. Then throwing the sample and water the tube is filled with silt free water again and weighed.. The difference in weight gives the weight of the sand fraction. Now the dry weight of the sample is determined as below.

Let, V = Volume of tube

$V1$ = Volume of sand

Therefore, $V - V1$ = Volume of clear water above sand.

Let S = Specific gravity of water.

$S1$ = Specific gravity of sand.

1st weight = Wt of tube + wt of water above sand + Wt.of sand.

2nd weight = Wt. of tube + Wt. of water in the entire tube.

Difference in Wt.= Wt. of sand + Wt. of water above sand - Wt.of water in the entire tube.

$$= V1S1 + (V - V1)S - VS$$

$$= V1S1 + VS - V1S - VS$$

$$= V1S1 - V1 \qquad (S = 1 \text{ for water})$$

$$= V1S1\ (1 - 1/S1)$$

$$= V1S1\ [(S1 - 1)/S1]$$

$$= V1S1\ [(2.65 - 1)/2.65] \qquad \text{Sp. gr.of Sand} = 2.65.$$

$$= V1S1 \times (1.65/2.65)$$

$$V1S1 = \text{Diff. in Wt.} \times 1.61$$

That is Dry wt. of sand = Diff. in wt. x 1.61

4.4.4 Determination of the Concentration of the silt and Clay Fractions :

Not much attention has been given to this matter, partly because its importance was considered small in relation to the sand fraction and partly on account of logistical and other difficulties. Bulked samples were generally sent to Hydraulic Research Laboratory, Dhaka by the field hydrometric teams and were analysed for total solids and for grading, where possible, at the convenience of the BWDB. The Hydraulic Research Laboratory determines concentration and publish periodic report for future use.

4.5 Concluding Remarks:

The sampler adopted by Bangladesh Water Development Board for sediment sampling is Binkley suspended sediment sampler. This type of sampler is suitable where the channel gradient and the velocity is low. It cannot be used very effectively where slope and velocity of flow is very high during flood season like the Teesta, Monu, Khowai etc.Sampling is done by Point - Integrating method. The advantage of using this method is , since we get the value of concentrations at several points in a vertical we can easily draw sediment concentration profile. That is why it is used in most of the rivers in Bangladesh.

The main disadvantage of the instrument is, when it is used for collecting samples in a stream of very high current, extra weight needs to be attached to keep the sampler in position, which is quite difficult. The person handling the instrument should be efficient, since due to improper handling of instrument large error may be introduced in the measurement.

Depth integrating technique is not practiced in general since by this method we cannot get the concentration profile. But for obtaining an average sediment concentration in a stream's vertical this method is very suitable.

The samples of sediment are collected occasionally during discharge measurements at some sites of major rivers. Coarse portion of the samples are measured at Hydrological Section Offices and fine composites are sent to the River Research

Institute of BWDB in Dhaka for analysis, to determine the concentration of silt and clay. The results of analysis are synthesized with results of water discharge computation and suspended sediment discharge is computed. Data are stored at the River Research Institute of BWDB in Dhaka.

CHAPTER FIVE

DATA ANALYSIS, RESULTS AND DISCUSSION

5.1 Introduction

The present study includes critical review on past studies based on data from the main channels at Sirajganj (Nakfatarchar) for the years 1969 and 1970, and for the years 1970 and 1972 at Nagarbari. This study also includes estimation of sediment transportation on the basis of data from 1982 to 1988 at the station of Bahadurabad. Sediment data for the Chilmari station was also available but it was incomplete in nature and hence could not be analysed for study.

These data are collected by the BWDB as a routine work. The hydrological and geometric data were obtained from Hydrology Directorate, whereas, sediment related data were obtained from River Research Institute. Data of 1969 to 1972 for above mentioned stations were analysed by Bari (1978). Alam and Hossain (1988) reanalysed the data from a different approach. They computed overloading factor and discrepancy ratio for preparing the merit table through systematic comparison of few wellknown transport equations including the one developed recently by Hossain (1985, 1987).

These investigators found the data in an unsystematic form and they were arranged properly to bring to usable form for analysis. The data of 1982 to 1988 were also brought to proper format for the purpose of analysis in the present study.

The collected data, however, are not complete as far as the bed load is concerned. The collected data report only the suspended sediment concentration and grain size analysis of the bed material.

5.2 Review of sediment transport studies

Suspended sediment discharge observations were introduced in BWDB in 1966 and 1967 during the FAO Hydrological Survey Project in the then East Pakistan. Data of suspended sediment discharge of some selected rivers such as the Ganges, the Brahmaputra, the Old Brahmaputra, the Gorai, the Padma (after junction of the Ganges and the Brahmaputra) were published in 1969 in the report entitled "FAO- SECOND Hydrological Survey in East Pakistan", Sediment Investigations, 1966 and 1976. Next publication of sediment data was issued by BWDB Hydrology Directorate (Surface Water) in December 1972. The format and contents of this publication in general repeats the same of the previous publication by FAO. The publication contains sediment investigations in various rivers of Bangladesh. The findings consist of yearly sediment discharge, liquid discharge, and concentrations collected from various stations.

Very few of the data from the main rivers of Bangladesh like the Ganges, the Jamuna and the Meghna have been employed to test the applicability of the sediment transport formulae available in the literature. Chang (1980) selected Duboys (1979), Einstein - Brown (1950) and Engelund - Hansen (1967) formula for verification with field data. He found that Engelund - Hansen formula produced the best results when tested against Indian and American canal data. No mention was given as to the name of Indian river in the analysis.

Bari (1978) applied five sediment transport formulae namely Colby (1964), Engelund - Hansen, (1967) Ackers White (1973), Inglis - Lacey (1968) and Yang (1976) against the data of the Ganges and the Jamuna. He compared the sediment load predicted by these equations with the measured suspended sediment and suggested that Colby and Engelund - Hansen formula give better prediction.

Yang (1977) compared ten sediment transport equations against 154 sets of field and 1093 sets of laboratory data. He found that Yang's (1973) equation is superior to others. It may be pointed out that Yang's equation is based on stream power concept. According to his evaluation his equation was followed by Shen-Hung, Ackers-White, Engelund-Hansen and the others.

Hossain and Barr (1988) compared eight well known transport equations against the data collected from various sources throughout the world. They considered Yang, Colby, Engelund-Hansen, Toffaletti, Holtorff, Ackers-White, Einstein-Brown and Hossains equations through systematic comparison against 3480 laboratory data and about 800 field data. They concluded that Hossain's equation was superior to others from all criteria of testing the efficacy of selected formulae against these large number of independent data sets.

Alam and Hossain (1988) has made an attempt to analyse the available data of the Jamuna to have a quantitative evaluation of the transport rate of the river. Their analysis was based on the measured data during the period 1969 - 1972. The analysis contained the testing of efficiency of the formulas selected by Bari and also Hossains Equation (1985,1987). It appeared from their analysis that Colby's and Hossains's formula display maximum confidence in predicting the sediment load transport capacity of the Jamuna.

Waliuzzaman (1986) selected five equations namely, Yang (1973), Ackers-White (1973), Engelund-Hansen (1967), Hossain (1985, 1987), and Mantz (1983) for analysing the sediment transport in the river Gorai- Modhumati. He also prepared a merit table on the basis of the efficacy of the prediction of the selected equations against the measured data. He concluded from the analysis that Hossain and Engelund-Hansen equation produced better prediction followed by Mantz and Yang equation. Ackers-White produced the poorest prediction.

The UNDP Report (1986) " JAMUNA BRIDGE APPRAISAL STUDY " also include some investigations regarding sediment transport in the Jamuna, but the estimation is mainly in respect of morphological study.

In a recent study conducted by BUET - BWDB(1988) on the sediment transport characteristics of the river Teesta, in connecetion with the Design of the Teesta Barrage project, the experts of BUET selected Yang, Engelund-Hansen and Colby's equations. They found Yang's equation to be superior to others.

5.3 Selection of transport equations for computing the sediment load of the Jamuna

For the purpose of present analysis, the selected formulas are those of Yang (1973) and Hossain (1985,1987). It has already been stated that the present selection was largely guided by the investigations carried out for testing the efficacy of various transport equations against the data collected from various rivers of Bangladesh. In the following sections the equations selected are discussed briefly.

5.3.1 Yang Formula (1973)

The approach proposed by Yang (1973) has provided one of the most recent formula for evaluating the total sediment transport rate. He approached the total transport from the energy expenditure point of view and related the transport rate to stream power. By using available data, most of which is of laboratory origin and with the help of multiple regression techniques, the following expression was obtained.

$$\begin{aligned}\log C_t = {} & 5.453 - 0.286 \log (wD/\nu) - 0.457 \log (U*/w) \\ & + (1.799 - 0.409 \log (wD/\nu) - 0.314 \log (U*/w)) \\ & \times \log ((VS/w) - (V_{cr} S/w))\end{aligned}$$

Where $V_{cr}/w = \dfrac{2.5}{\log(U_*D/\nu) - 0.06} + 0.66$

when $1.2 < U_*D/\nu < 70$

and $V_{cr}/w = 2.05$ when $70 < U_*D/\nu$

in which, C_t = total sediment concentration in ppm by weight.

D = median sieve diameter (m)

U_* = shear velocity (m/sec)

ν = kinematic viscosity (m^2/sec)

V_{cr} = critical average flow velocity (m/sec)

w = fall velocity (m/sec)

VS = velocity slope product (m/sec)

g = acceleration due to gravity (m/sec^2)

The equation is dimensionally homogeneous and any consistent set of units can be used.

5.3.2 Hossain's Formula (1985)

It was found that a good correlation could be obtained for different channels, between sediment concentration C and other parameters influencing sediment transport in an alluvial channel by introducing a non-dimensional term $VS/(gH)^{1/2}$ (Hossain,1985).

Based on the concept of dimensional analysis and similitude argument, it has been proposed that the sediment concentration in a stream of steady water and sediment flow is a power function of: (i) the product of Froude number and slope, (ii) the settling velocity ratio and (iii) the discharge ratio. The form of the equation could be written as;

$$C_t = A [X^a Y^b Z^c]$$

where, C_t = Sediment concentration in parts per million

$A = 0.845 \times 10^5$ for $Q < 1.0\ m^3/sec$

$= 6.946 \times 10^5$ for $Q > 1.0\ m^3/sec$ and $B/H < 100$

$= 6.946 \times 10^6$ for $Q > 1.0\ m^3/sec$ and $100 < B/H < 500$

$X = VS/(gH)^{1/2}$ and, $a = 0.745$

$Y = w_r / w$ $b = 0.633$

$Z = Q/Q_c$ $c = 0.500$

w_r = Settling velocity for a representative sediment size for which $D_{50} = 0.15$ mm at ambient temperature

w = Settling velocity of the particles

Q_c = assessed discharge from equation

$$Q_c = [(2.15 + 0.205\ B/H)\ H\ (gS)^{1/5}]^{5/2}$$

where the notations have their meaning as follows:

B average width of the channel

H average depth of flow

S average water surface slope

g acceleration due to gravity

The settling velocity has been calculated using Rubey's (1933) equation.

When $B/H > 500$, Z was suggested to be replaced by KZ, where, " K " is a coefficient which ranges from about 17 to 40. For the present analysis K was assumed to be 30. (Hossain 1989).

It should be noted here that sediment transport function developed represents a median condition of correlation.

5.4 Water Sediment Hydrographs

a) Bahadurabad

A typical Water-Sediment Flow Hydrograph has been drawn for the year 1982 using the measured data. The water hydrograph have two peaks where as the sediment hydrograph have one major and two minor peaks.

In Fig 5.1 it may be seen that the highest peak in water discharge occured in mid-July while the highest peak for the sediment discharge occurred in early August. In water discharge hydrograph, another peak is observed in early September. Sediment flow is found to be low, during the lean period. The maximum and the minimum flow is found to be 46,700 m^3/s and 5540 m^3/s for monsoon and the lean period respectively. In sediment discharge hydrograph the second and the third peak occurred in early September and early November. The major peak of 3.5 m tons occurred in early August. During October to December the daily maximum and the minimum sediment flow is found to be .98 m tons and .14 m tons respectively. The total sediment flow for the year 1982 is found to be 244 million tons per year.

b) Nagarbari

Fig 5.2 and Fig 5.3 show the water-sediment flow hydrographs at Nagarbari station for the years 1970 and 1972 respectively. Fig 5.2 shows that there are three peaks for both water and sediment discharges. The highest peak in water discharge occurred in mid- August while the highest peak for the sediment discharge occurred in early October. Possibly the local erosion during the falling stage of the river caused this rise of sediment flow. Sediment flow was low during the lean period. The daily rate of sediment movement during this period varied between .048 m tons to 0.252 m tons. The total sediment flow were 23 and 283 million tons during the lean and monsoon period respectively. This is presented in a summerized form in Table 5.1 A.

In the year 1972 Fig 5.3 there was one major peak for water and sediment discharge during first half of August. There was another very minor peak during October. During May to October the minimum and the maximum daily sediment flow was about 0.250 m tons and 2.7 million tons respectively. The total sediment flow was about 953 million tons. During the lean period (November to April) the maximum and the minimum daily sediment flow are 0.10 and .021 m tons respectively. The total sediment discharge was about 4.8 m tons. Table 5.1 A.

c) Nakfatarchar

Fig 5.4 and Fig 5.5 show water-sediment flow hydrographs for the station Nakfatarchar for the years 1969 and 1970. Both the water and sedimennt hydrographs have two peaks and occurred simultaneously. The first peak was observed around mid-June and the second peak which was the major peak occurred around late July. During the monsoon (May to October), the river stage was high, the maximum sediment movement was found to occur and the amount of suspended sediment discharge was about 17 million tons in 1969 and 95.3 million tons in 1970 as shown in Table 5.1 B. The Table also shows the daily maximum and minimum rate which varied between 6.3 million tons and .203 million tons in 1969 and 3.6 to .305 million tons in 1970. Data for the lean period (November to April) was available only for the year 1970 and during this period sediment passing the station amounted to about 17.6 million tons. The daily sediment flow varied between

5.5 Comparison of the Estimated Sediment load

The formulae selected for evaluation of total load as mentioned earlier are those of Yang (1973) and Hossain (1985, 1987) formulae. These two formulae have been tested against broad spectrum of world wide data and have been identified to provide the estimate transport rate of the river with a fair degree of accuracy. (Hossain and Barr, 1988, Alam and Hossain, 1988, BWDB - BUET 1988).

Table 5.2 shows the sediment discharge calculated by the two formulae for the river Jamuna, at station Bahadurabad. It may be seen from the Table that the total sediment discharge obtained by Yang's equation is low compared to sediment load estimated by Hossain's formula and the measured data. The annual sediment load estimated by Yang formulae varies from about 15 million tons to about 40 million tons. The formula as mentioned before has been derived for total load transport on the basis of energy expenditure point of view. It relates the transport rate to stream power. It may be noted that the river Jamuna is not a stable one.

The values obtained for total load estimated by Hossain's equation are found to be quite high in magnitude. The annual sediment load varies from about 400 million tons to about 815 million tons during the period from 1982 to 1988. The annual average total sediment flow of the Jamuna computed by Hossain's formula during this period may be taken as 643 million tons. From the analysed data it may also be noted that more than 80% of the sediment load flows during the flood season.

It was the intention of the author to develop a graphical relation between the total sediment discharge and water discharge for practical use. With this view in mind, total sediment load estimated by both Hossain and Yang equations were plotted against water discharge on log-log paper.

Best fit line was drawn using regression technique and a power type equation was developed which are discussed in the following article.

The Regression equations developed for the observed data, Hossain's and Yang's equations using all the individual data for the above mentioned period are shown in Table 5.3.

Table 5.4 shows the power law relationships which are developed for Hossain, Yang and for the measured data for the years from 1982 to 1988.

5.6 Power Relationships

Simple power law relations have been developed relating sediment transport (Q_s) with water discharge (Q_w) and velocity of flow (V), employing regression technique. Fig 5.6 , Fig 5.7 , Fig 5.8 , shows the water discharge relations for the data of the years 1982 to 1988. The regression equations may be written as follows :

$$Q_{sobs} = .4829\ Q_w^{1.45} \qquad (r^2 = .7437)\ldots\ldots 5.1$$

$$Q_{sY} = .01144\ Q_w^{1.576} \qquad (r^2 = .908)\ldots\ldots 5.2$$

$$Q_{sH} = 57.70\ Q_w^{1.050} \qquad (r^2 = .9647)\ldots\ldots 5.3$$

Where,

Q_{sobs} = observed suspended sediment discharge, (Tons/day)

Q_{sY} = total sediment calculated by Yang, (Tons/day)

Q_{sH} = total sediment calculated by Hossain, (Tons/day)

Q_w = water flow in meter cube per second.

r^2 = coefficient of correlation.

Fig 5.9 shows the sediment and water discharge relation for the data covering period 1969 to 1972 for the station Nagarbari and Nakfatarchar. (After Alam and Hossain, 1988). The regression equation of which is given by :

$$Q_s = 4.06 \times 10^{-4}\ Q_w^{1.609} \qquad (r^2 = .672)\ldots\ldots\ldots 5.4$$

Where, Q_s = suspended sediment discharge, in tons per day.

Q_s = water flow in cubic feet per second.

r^2 = the coefficient of correlation.

Similar type of equation has also been developed relating sediment transport and velocity. Fig 5.10 and Fig 5.11 shows the velocity sediment discharge graph for the station Bahadurabad for the observed data of 1982-1986 and for the data of both Nagarbari and Nakfatarchar covering period 1969 to 1972. (after Alam and Hossain,1988).

The Regression equation for the station Bahadurabad may be written as follows:

$$Q_{sobs} = 91.545 \times 10^{4} V^{3.767} \qquad (r^2 = .538) ....5.5$$

and the Regression equation for Nagarbari and Nakfatarchar (after Alam and Hossain, 1988) is given by :

$$Q_s = 22.811 \times 10^{-4} V^{2.95} \qquad (r^2 = .770) ....5.6$$

Where,

V is in meter per second for equation 5.5 and

V is in feet per second for equation 5.6.

Meaning for Q_s , Q_{sobs} and r^2 has been explained before.

It may be noticed from the above equations that sediment discharge may satisfactorily be expressed as a function of water discharge and flow velocity.

5.7 Discussion

In the present analysis, the median size of bed material ranges from about .053 mm to .24 mm, mean depth between 2.12 m to 10 m and the discharge between 3500 m^3/sec and 75,700 m^3/sec.

The formulas namely of Yang and Hossain, studied herein lack confidence in varying degrees. However, the performance of Hossain formulae seems to be more acceptable.

Performance of the Yang's formulae against the present sets of data is not very encouraging. This is due to the fact that, the river Jamuna has a large fluctuation of discharge throughout the year which led the river to be extremely unstable, in which the Yang's formulae is not very suitable. Thus the formulae appears to be doubtful as observed from its performance in the present case.

Data for the year 1985 was found to yield erratic prediction when used against the equations selected for the present analysis. For this reason the data of 1985 was not used for the present analysis.

It would be worth mentioning that majority of the sediment load whether suspended or total is transported during the flood season i.e, (May - October). In the present analysis data for the year 1988 is found only from January to July and the value for total load by Hossain's equation is found to be about 400 million tons. If complete set of data for that year were available it could be anticipated that sediment flow would have been higher than that of 1987.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The following conclusions may be drawn from the present study :

1) The sediment transport equations selected to predict sediment flow through the Brahmaputra river predicts transport rates which vary quite significantly.

2) The Hossain formulae yields higher magnitude of sediment movement. The formulae has been developed using sands of median sizes 0.15mm to 0.30mm and taking into account the influence of settling velocity.

3) The estimation by Yang shows very low value compared to the observed data, hence casts doubt about its applicability in the present case.

4) The data collection procedure by Bangladesh Water Development Board needs modification. Valuable data have been collected but many of them are not in usable form for rational analysis due to lack of one or more simple data.

5) The analysis would have been easier and simpler if the geometric and hydraulic data were found in the same data sheet.

6) Bed load discharge is required to be measured in addition to suspended sediment discharge.

7) At least five measurements at different depths should be taken at a particular vertical, so that concentraion profile can be obtained.

8) The relationship between observed and computed sediment discharge of the river Jamuna may be correlated to give simple power equations (eqn, 5.1, 5.2, 5.3). The relationship between sediment discharge and mean velocity for the Jamuna river at the Nagarbari, Nakfatarchar and Bahadurabad station may be correlated to give simple rating curves. (Fig 5.10 and 5.11).

9) It is revealed from this study that about 643 million tons of total load passes annually through the Bahadurabad in the river Jamuna.

10) The annual suspended load may be taken to be about 435 million tons as revealed from this study.

6.2 Limitations of Present Study

The collection and analysis of data should be based on recent standard practices. The necessary data like sediment concentration, water/sediment discharge, depth, width, velocity of flow, sediment size, temperature, etc, for this study were not available throught the year and hence detail investigation pertaining to sediment movement could not be done properly. Moreover, due to lack of water temperature data, evaluation of computed sediment rates of the river Jamuna was dependent on standard value of temperature. Thus systematic approach and methodology should be developed for the collection of various geometric and hydraulic parameters and published as data bank in accordance with some standard format like the one prepared by Brownlie (1981).

6.3 Recommendations for future study

The following suggestions are made for further study :

1) Data should be collected and compiled spreading over a large number of years.

2) Study of bed load should be undertaken. However, bed load sampling data are not available at this moment. Possibility of determination of bed load by tracer tecniques may be explored.

3) Evaluation of the actual transport capacity of the Jamuna has not been possible due to lack of large volume of data. Moreover, greater number of sediment transport formulae should be selected for predicting the quantum of sediment transported through the Jamuna.

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APPENDIX - A (TABLES)

TABLE 2.1

Sediment Grade Scale

(Subcommittee on Sediment Terminology, A. G. U.)

Size	Microns	Inches	Class
4000-2000		160-80	Very large boulder
2000-1000		80-40	Large boulder
1000-500		40-20	Medium boulder
500-250		20-10	Small boulder
250-130		10-5	Large cobbles
130-64		5-2.5	Small cobbles
64-32		2.5-1.3	Very coarse gravel
32-16		1.3-0.6	Coarse gravel
16-8		0.6-0.3	Medium gravel
8-4		0.3-0.16	Fine gravel
4-2		0.16-0.08	Very fine gravel
2-1	2000-1000		Very coarse sand
1-0.5	1000-500		Coarse sand
0.5-0.25	500-250		Medium sand
0.25-0.125	250-125		Fine sand
0.125-0.062	125-62		Very fine sand
0.062-0.031	62-31		Coarse silt
0.031-0.016	31-16		Medium silt
0.016-0.008	16-8		Fine silt
0.008-0.004	8-4		Very fine silt
0.004-0.002	4-2		Coarse clay
0.002-0.001	2-1		Medium clay
0.001-0.0005	1-0.5		Fine clay
0.0005-0.00024	0.5-0.24		Very fine clay

TABLE 3.1 FLOOD DISCHARGES AND SLOPES ALONG THE JAMUNA RIVER

Station	Average yearly flood		1 in 100 year flood	
	Discharge	Stage **	Discharge	Stage **
	Q (m /sec)	h(m)+PWD	Q (m /sec)	h(m)+PWD
Bahadurabad	65.000	19.70	91.000	20.2
Sirajganj	65.000	13.70	88.000	14.4
Nagarbari	65.000	9.50	81.000	10.3
Goalando	88.000	8.20	134.000	9.1

Source: BWDB DATA, UNDP (1986)

** w.r.t PWD Datum

TABLE 3.2 VALLEY SLOPES ALONG THE JAMUNA RIVER

Station	Valley slope (Slope $\times 10^{-5}$)	
	Average yearly flood (cm/km)	1 in 100 year flood
Bahadurabad		
Sirajganj	6.8	7.3
Nagarbari	7.1	7.4

TABLE 3.3

GRAIN SIZE OF BED MATERIAL (mm) STATION: NAGARBARI

Serial Number	Date	D	D	D
1	23-Sep-65	0.168	0.143	0.153
2	06-Feb-67	0.182	0.149	0.154
3	06-Mar-67	0.118	0.088	0.1
4	04-Apr-67	0.139	0.115	0.15
5	24-Jun-67	0.172	0.122	0.15
6	12-Jul-67	0.105	0.09	0.095
7	12-Jul-67	0.102	0.085	0.095
8	05-Sep-67	0.220	0.17	0.202
9	10-Oct-67	0.162	0.123	0.145
10	03-Dec-67	0.205	0.175	0.199
11	08-Jan-68	0.220	0.168	0.198
12	06-Feb-68	0.270	0.188	0.233
13	07-Mar-68	0.064	0.047	0.068
14	06-Jan-69	0.200	0.148	0.187
15	26-Aug-70	0.149	0.11	0.138
16	15-Jul-72	0.18	0.142	0.163
17	17-Jul-74	0.197	0.152	0.174
18	11-Jun-75	0.22	0.178	0.199
19	02-Jun-76	0.22	0.175	0.197
20	15-May-77	0.11	0.081	0.096

GRAIN SIZE OF COARSE SUSPENDED MATERIAL (mm) STATION: BAHADURABAD

Serial Number	Date	D	D	D
1	1/6/83 to 29/2/84	0.165	0.116	0.145
2	Year 1985	0.059	0.025	0.053
3	April '86 to Mar '87	0.215	0.174	0.195
4	12/4/87 to 9/2/88			0.21

TABLE 3.4

GRAIN SIZE OF BED MATERIAL (mm) STATION: CHILMARI

Serial Number	Date	D	D	D
1	08-Aug-66	0.208	0.19	0.2
2	19-Jul-67	0.115	0.08	0.103
3	29-Sep-67	0.138	0.1	0.143
4	16-May-68	0.224	0.185	0.209
5	16-Feb-69	0.092	0.055	0.087
6	13-Mar-69	0.298	0.198	0.27
7	04-Apr-69	0.074	0.048	0.073
8	04-May-69	0.085	0.06	0.074
9	01-Jun-69	0.182	0.13	0.173
10	16-Jun-69	0.302	0.22	0.282
11	15-Jun-70	0.177	0.128	0.168
12	09-Jun-75	0.2	0.165	0.184
13	21-Jul-76	0.2	0.17	0.185
14	14-Apr-77	0.315	0.25	0.298

GRAIN SIZE OF BED MATERIAL (mm) STATION : NAKFATARCHAR

Serial Number	Date	D	D	D
1	01-Nov-65	0.155	0.14	0.15
2	04-Dec-65	0.2	0.225	0.25
3	06-Jan-66	0.217	0.189	0.2
4	04-Feb-66	0.23	0.185	0.21
5	03-Mar-66	0.255	0.225	0.24
6	08-Apr-66	0.26	0.225	0.245
7	15-May-66	0.17	0.149	0.153
8	04-Jun-66	0.115	0.098	0.1
9	12-Jul-66	0.095	0.089	0.087
10	20-Aug-66	0.215	0.233	0.2
11	02-Feb-67	0.15	0.11	0.135
12	02-Mar-67	0.18	0.118	0.165
13	02-Apr-67	0.234	0.17	0.155
14	02-May-76	0.3	0.25	0.28
15	07-Jun-67	0.195	0.16	0.155
16	14-Jul-67	0.248	0.182	0.22
17	05-Aug-67	0.166	0.115	0.153
18	04-Sep-67	0.208	0.17	0.191
19	02-Oct-67	0.22	0.19	0.208
20	06-Nov-67	0.22	0.17	0.207
21	05-Dec-67	0.165	0.115	0.148
22	15-Jan-68	0.21	0.165	0.192
23	12-Feb-68	0.205	0.173	0.199
24	05-Apr-68	0.035	0.02	0.038
25	04-May-68	0.175	0.137	0.165
26	03-Feb-69	0.225	0.18	0.216
27	16-Jun-70	0.203	0.18	0.22
28	16-Sep-75	0.25	0.195	0.236
29	07-Jul-76	0.227	0.18	0.218
30	05-Jun-77	0.142	0.12	0.141

TABLE : 5.1 A

TOTAL SEDIMENT FLOW AT NAGARBARI (CALCULATED BY HOSSAIN'S EQUATION)

YEAR	PERIOD	LOWEST DAILY (million Tons)	HIGHEST DAILY (million Tons)	TOTAL FOR THE PERIOD (million Tons)
1970	Nov--Apr	.048	.252	23
	May--Oct	.893	3.45	283
1972	Nov--Apr	.021	.10	4.8
	May--Oct	.25	2.7	953

TABLE : 5.1 B

TOTAL SEDIMENT FLOW AT NAKFATARCHAR (CALCULATED BY HOSSAIN'S EQUATION)

YEAR	PERIOD	LOWEST DAILY (million Tons)	HIGHEST DAILY (million Tons)	TOTAL FOR THE PERIOD (million Tons)
1969	Nov--Apr	-------	-------	
	May--Oct	0.203	6.3	17
1970	Nov--Apr	.028	0.320	17.6
	May--Aug	.305	3.60	95.3

TABLE : 5.2

YEARLY SEDIMENT DISCHARGE CALCULATED BY SELECTED FORMULAE

RIVER : JAMUNA

STATION : BAHADURABAD

Suspended sediment discharge Qs (Tons/yr)		Total Sediment discharge calculated by Qs (Tons/yr)	
YEAR	OBSERVED DATA	HOSSAIN formula	YANG formula
1,982	244,918,498	732,798,778	38,428,482
1,983	279,740,243	753,832,747	34,914,761
1,984	641,397,926	747,027,151	39,366,160
1,985	297,311,446	----------	----------
1,986	708,530,218	403,173,009	17,409,414
1,987		814,924,615	35,594,448
1,988		406,703,622	15,335,388

TABLE : 5.3

REGRESSION EQUATIONS FOR OBS DATA, YANG AND HOSSAIN'S EQUATION

RIVER : JAMUNA STATION : BAHADURABAD

	Year	Regression Equation	Coefficient of co-relation	Standard error of Y estimate	Standard error of Co-efficient
	1982	$QsOBS = .3604\ Qw^{1.478}$	0.973931	0.116996	0.13018
	1983	$QsOBS = .8940\ Qw^{1.343}$	0.945018	0.188701	0.124234
(FOR OBS DATA)	1984	$QsOBS = .1678\ Qw^{1.558}$	0.838424	0.438398	0.270754
	1985	$QsOBS = .5288\ Qw^{1.391}$	0.956241	0.197378	0.128279
	1986	$QsOBS = .2427\ Qw^{1.573}$	0.846574	0.366062	0.239824
	1982	$QsH = 71.20\ Qw^{1.051}$	0.981737	0.0721	0.044452
	1983	$QsH = 272.94\ Qw^{.908}$	0.99133	0.046669	0.020343
	1984	$QsH = 309.58\ Qw^{.883}$	0.98202	0.075141	0.029119
(HOSSAIN)	1985	$QsH = 650.95\ Qw^{.918}$	0.9806	0.072197	0.033496
	1986	$QsH = 13.75\ Qw^{1.159}$	0.98985	0.058076	0.027348
	1987	$QsH = 10.31\ Qw^{1.228}$	0.98476	0.089437	0.038935
	1988	$QsH = 19.17\ Qw^{1.181}$	0.98404	0.090316	0.057069
	1982	$QsY = .0159\ Qw^{1.565}$	0.99333	0.06463	0.040626
	1983	$QsY = .0405\ Qw^{1.466}$	0.99819	0.014927	0.014927
	1984	$QsY = .0561\ Qw^{1.416}$	0.99628	0.021022	0.021022
(YANG)	1985	$QsY = .0783\ Qw^{1.570}$	0.99127	0.038125	0.038125
	1986	$QsY = .0021\ Qw^{1.717}$	0.99715	0.021376	0.021376
	1987	$QsY = .0031\ Qw^{1.704}$	0.99572	0.028405	0.028405
	1988	$QsY = .0046\ Qw^{1.675}$	0.99506	0.044645	0.044645

TABLE: 5.4

POWER LAW RELATIONSHIPS

UTILIZING SEDIMENT DATA OF (1982-1988) FOR THE JAMUNA

River: JAMUNA | Station: BAHADURABAD

OBS DATA (1982-1986)	HOSSAIN (1982-1988)	YANG (1982-1988)
$Q_{sobs} = 0.4829\ Q_w^{1.45}$	$Q_{sH} = 57.70\ Q_w^{1.0507}$	$Q_{sY} = 0.01144\ Q_w^{1.576}$
($r^2 = 0.7437$)	($r^2 = 0.908$)	($r^2 = 0.9647$)

APPENDIX - B (FIGURES)

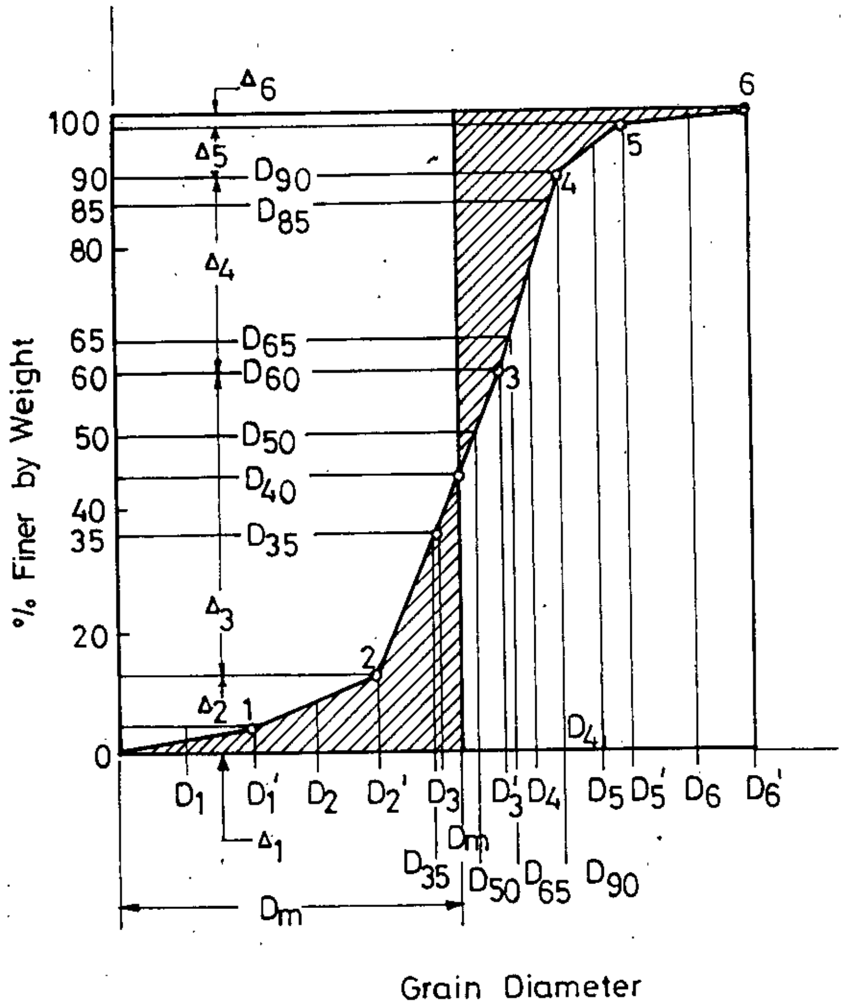


FIG. 2.1 SIZE FREQUENCY DISTRIBUTION CURVE SHOWING D_m, D_{35}, D_{50}, D_{65}, D_{85} AND D_{90}

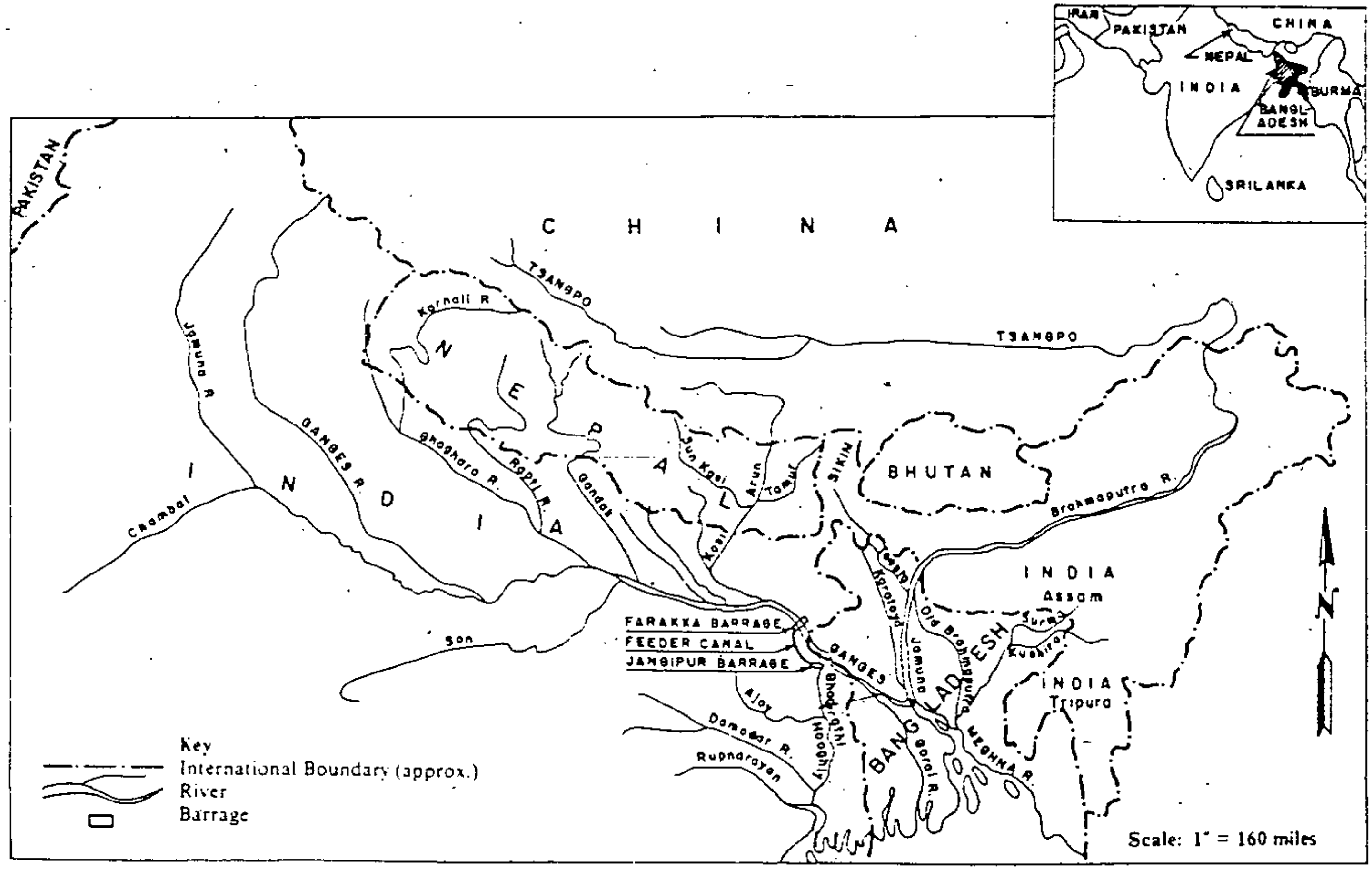


FIG. 3.1 THE JAMUNA RIVER BASIN

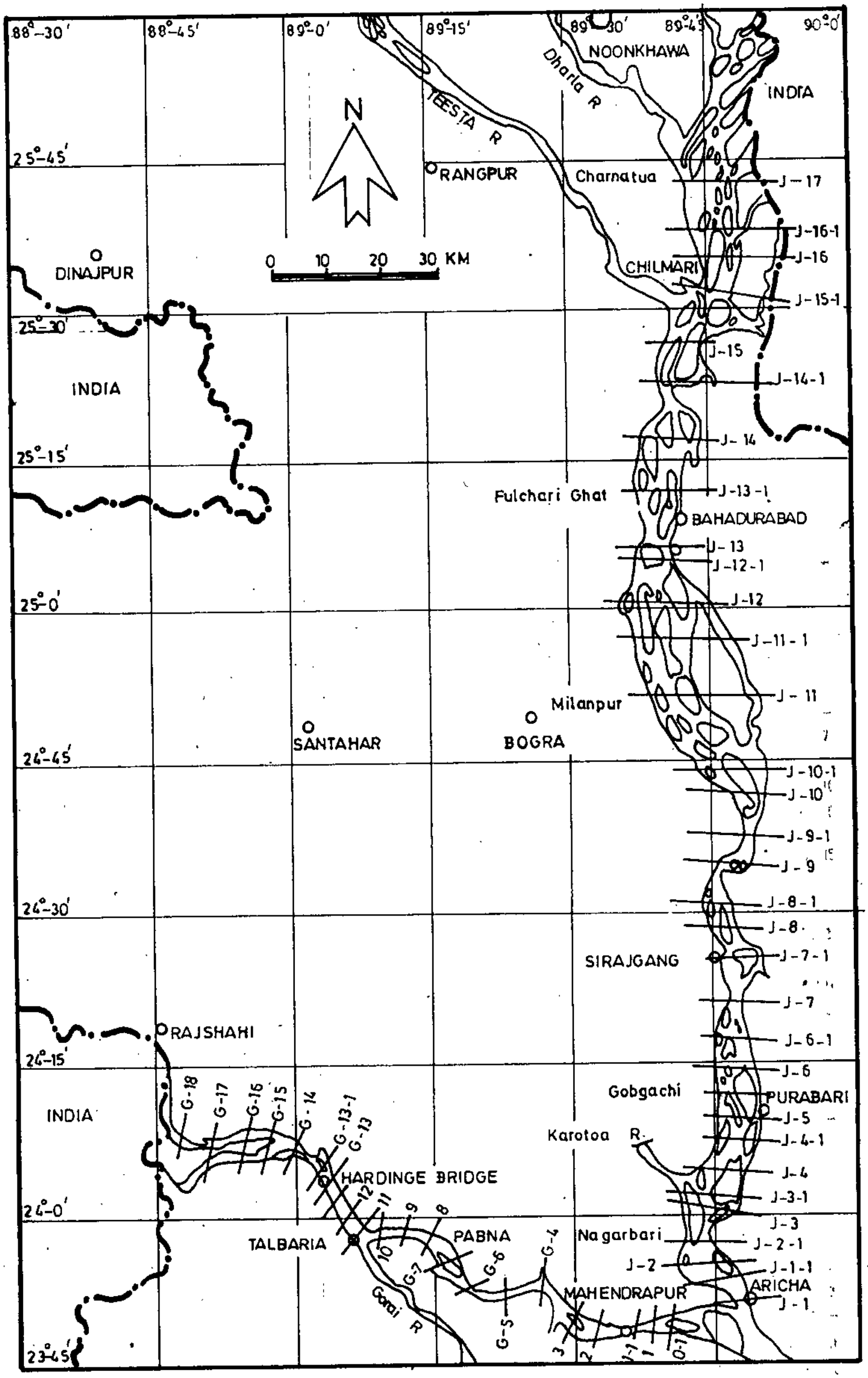


FIG. 3.2 LOCATION OF CROSS-SECTIONS FROM GANGES - JAMUNA CONFLUENCE TO INDIA BANGLADESH BORDER AND SEDIMENT GAGING STATIONS

BAHADURABAD

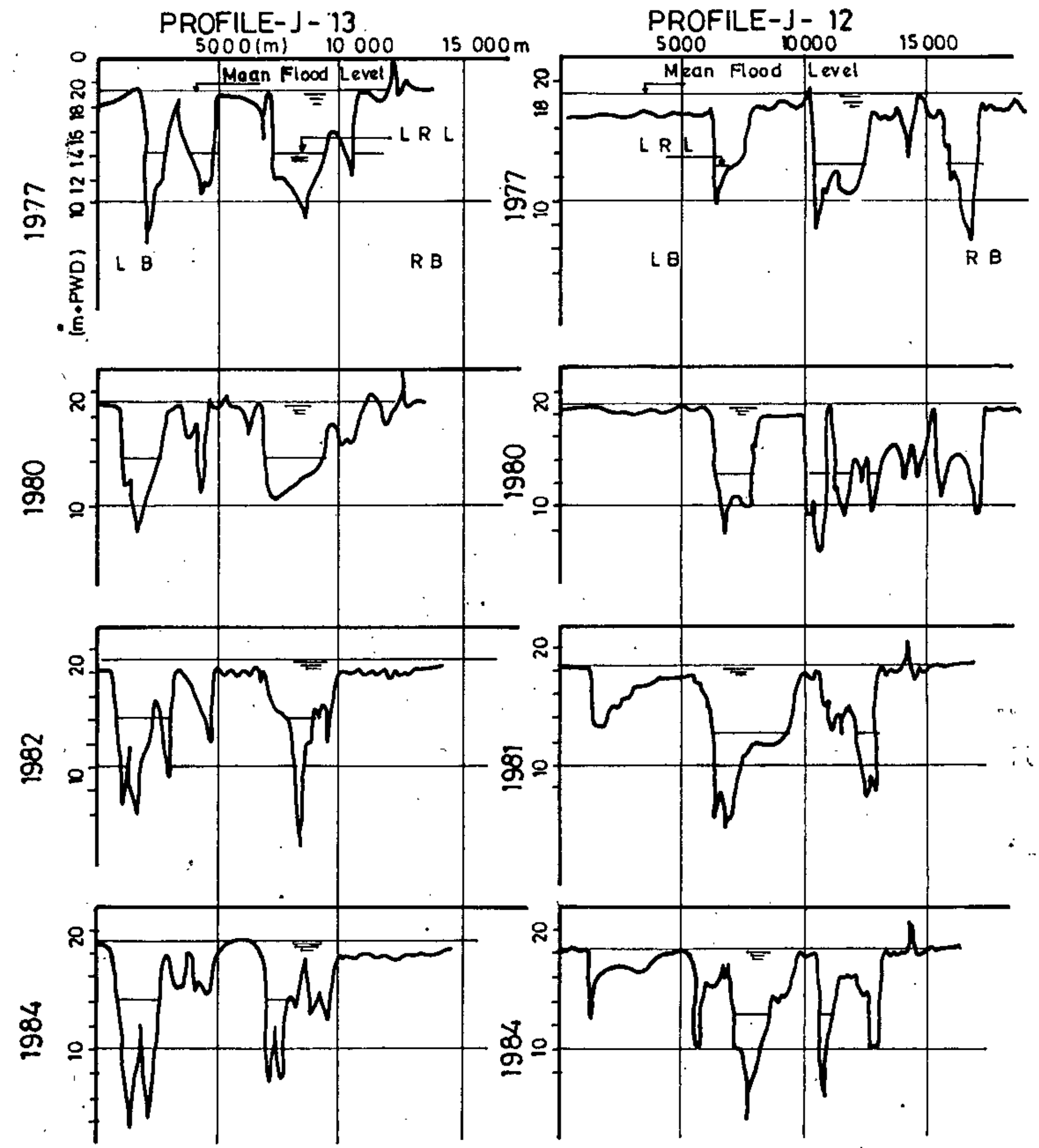


FIG. 3.3 MEASURED CROSS-SECTIONS AT BAHADURABAD - JAMUNA RIVER

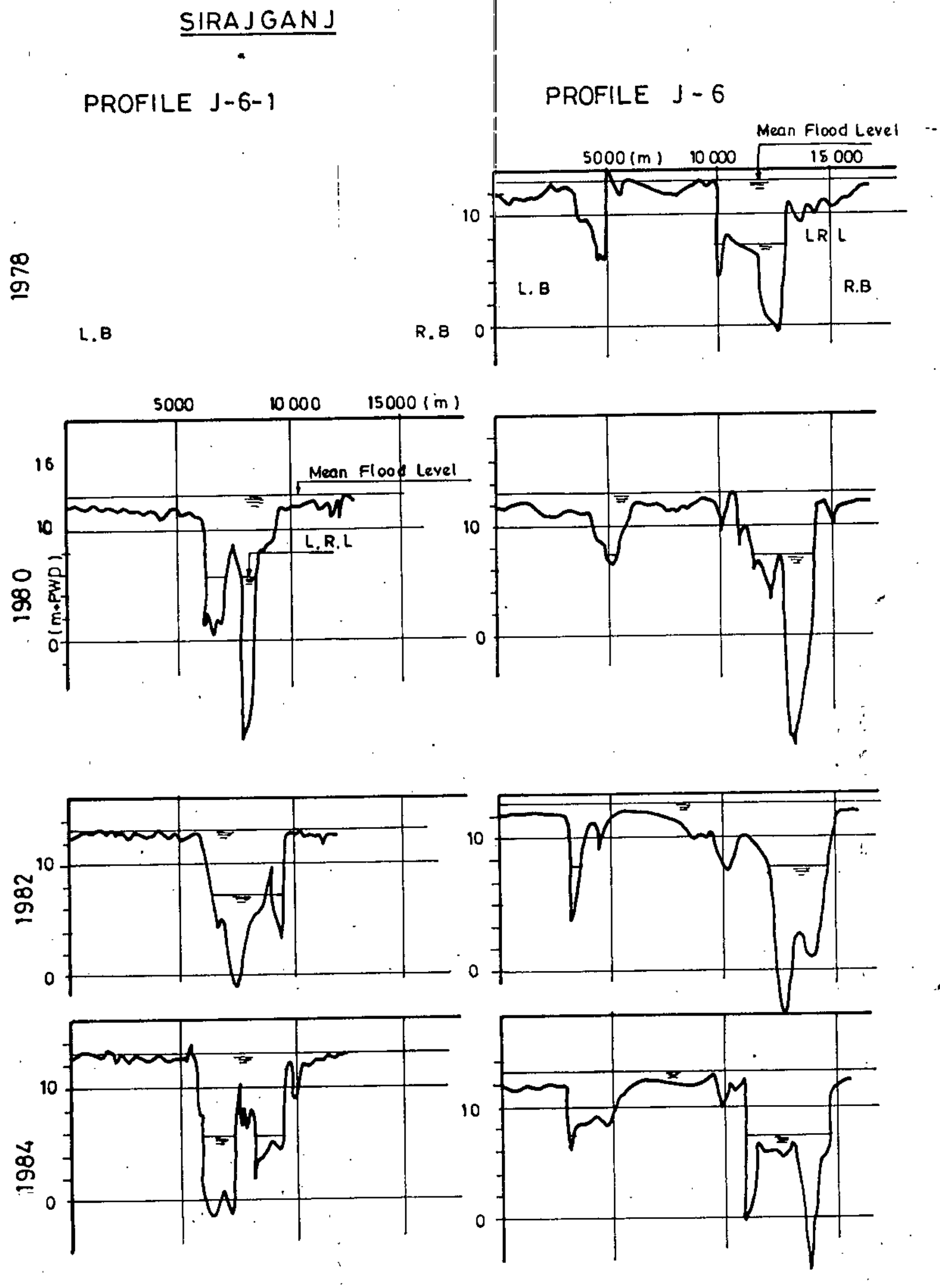


FIG. 3.4 MEASURED CROSS-SECTIONS AT SIRAJGANJ, JAMUNA RIVER

NAGARBARI

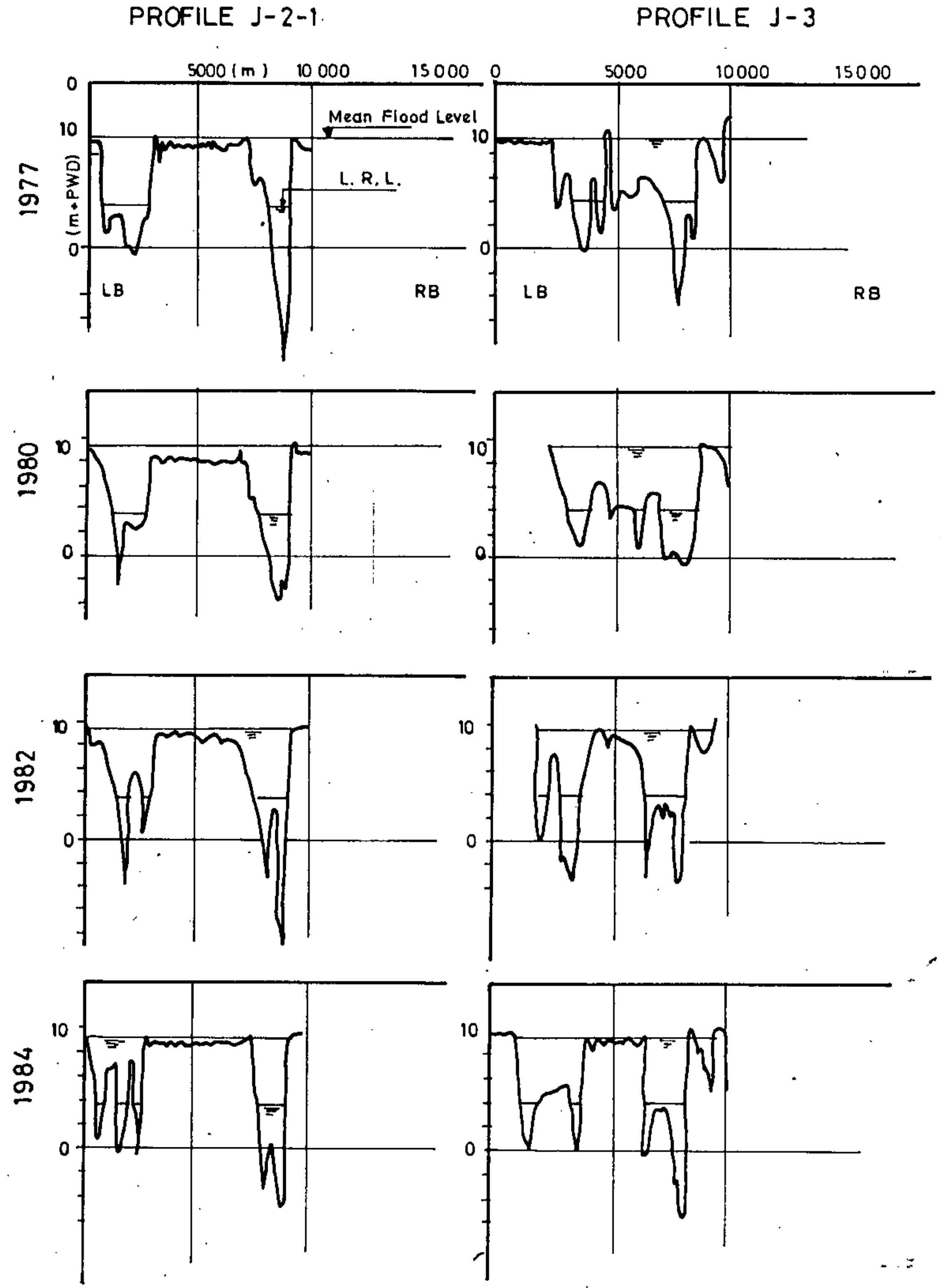


FIG. 3.5 MEASURED CROSS-SECTIONS AT NAGARBARI, JAMUNA RIVER

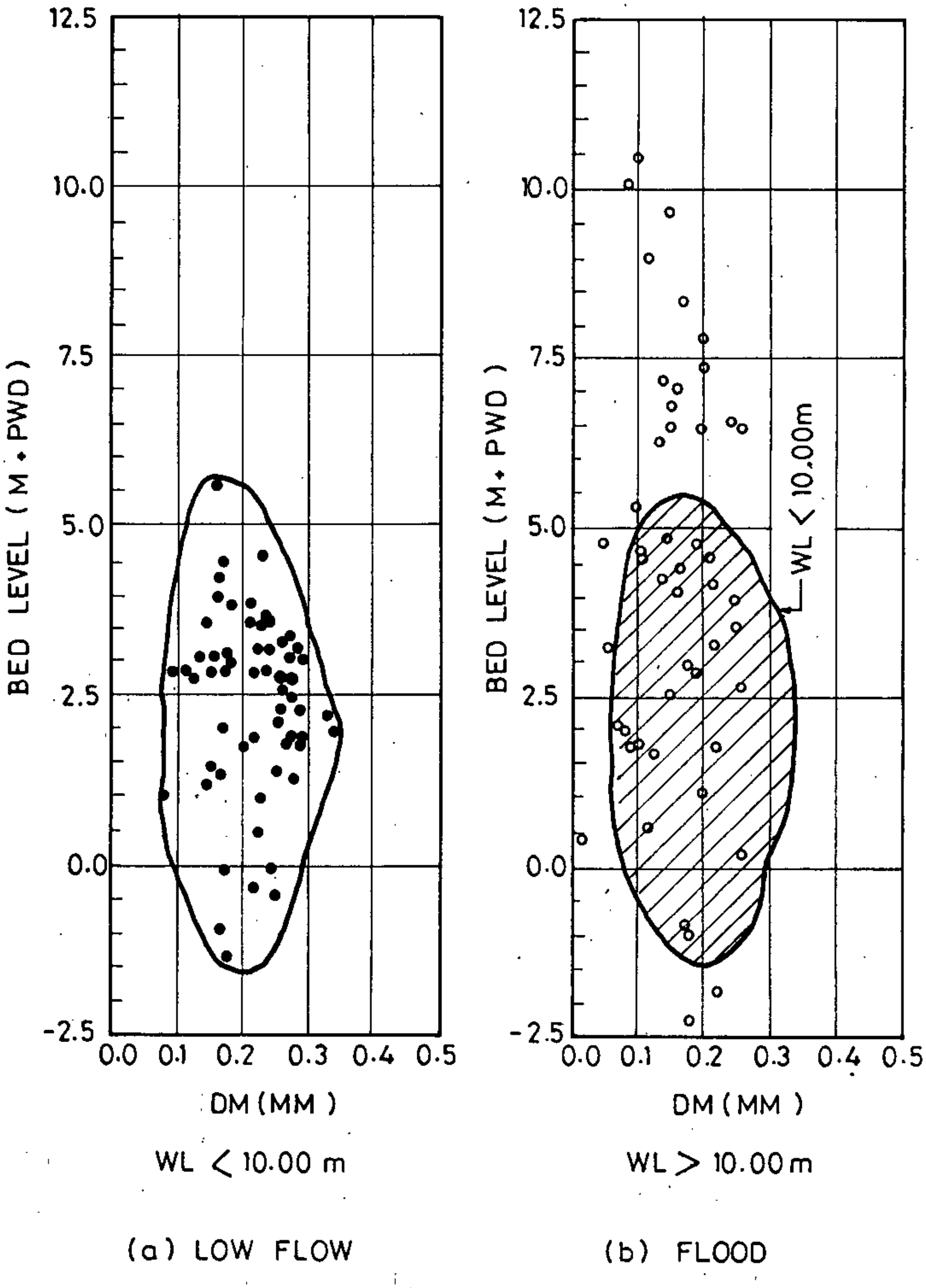
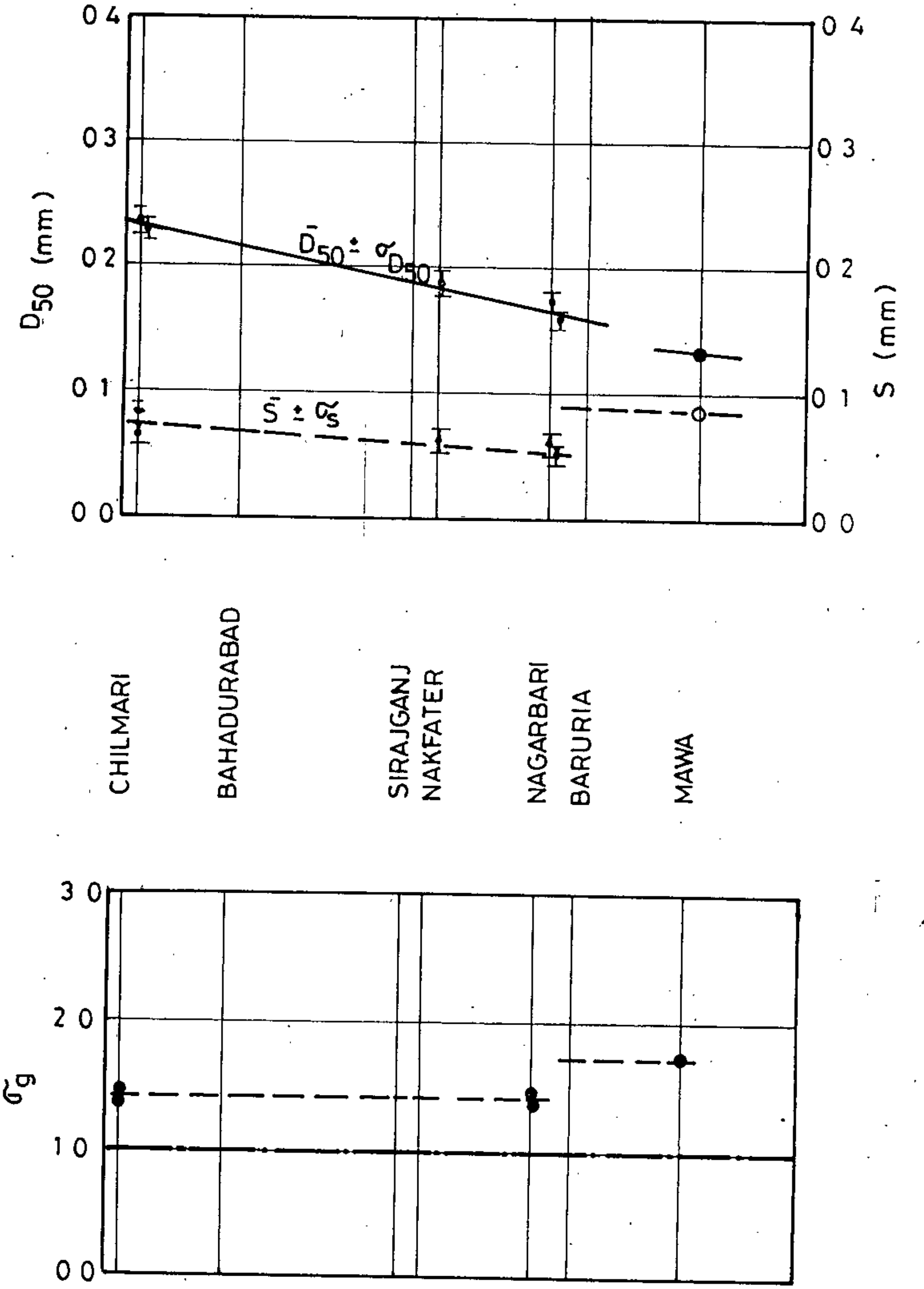


FIG. 3.6 PARTICLE SIZE VERSUS DEPTH AT SIRAJGANJ FOR LOW FLOW AND FLOOD CONDITIONS (UNDP, 1986)



$D_{16} = D_{50} - \sigma$

$D_{84} = D_{50} \cdot \sigma$

$\sigma = 1/2\left(\frac{D_{84}}{D_{50}} + \frac{D_{50}}{D_{16}}\right)$

FIG. 3.7 AVERAGE BED MATERIAL SIZE AND GRADATION JAMUNA AND PADMA RIVER (UNDP, 1986)

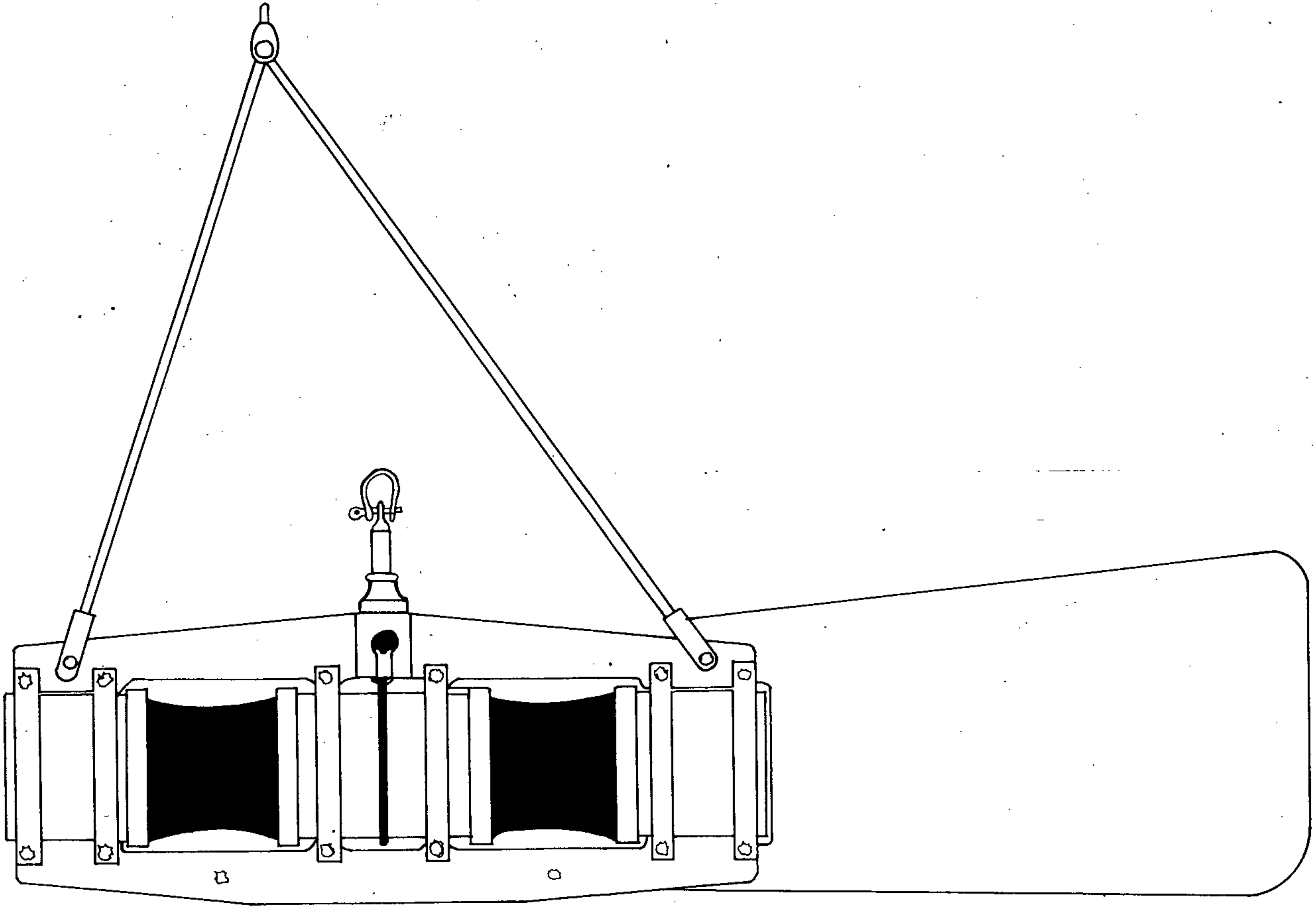


FIG. 4.1 THE BINKLEY SEDIMENT SAMPLER

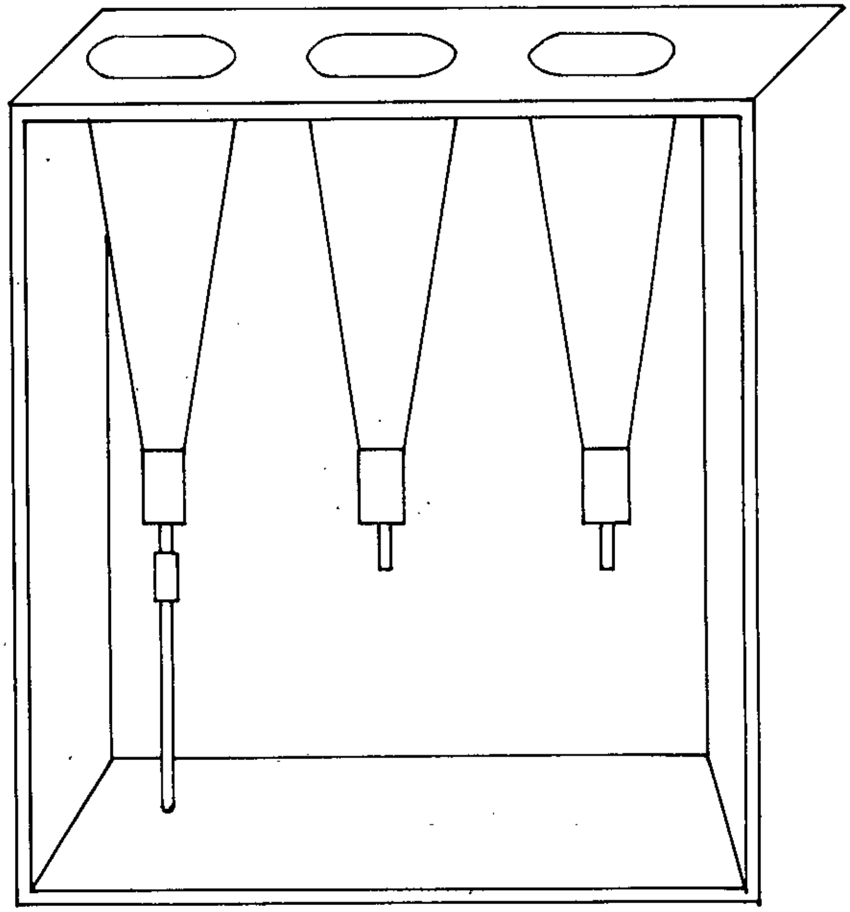


FIG. 4.2 FUNNEL ELUTRIATOR

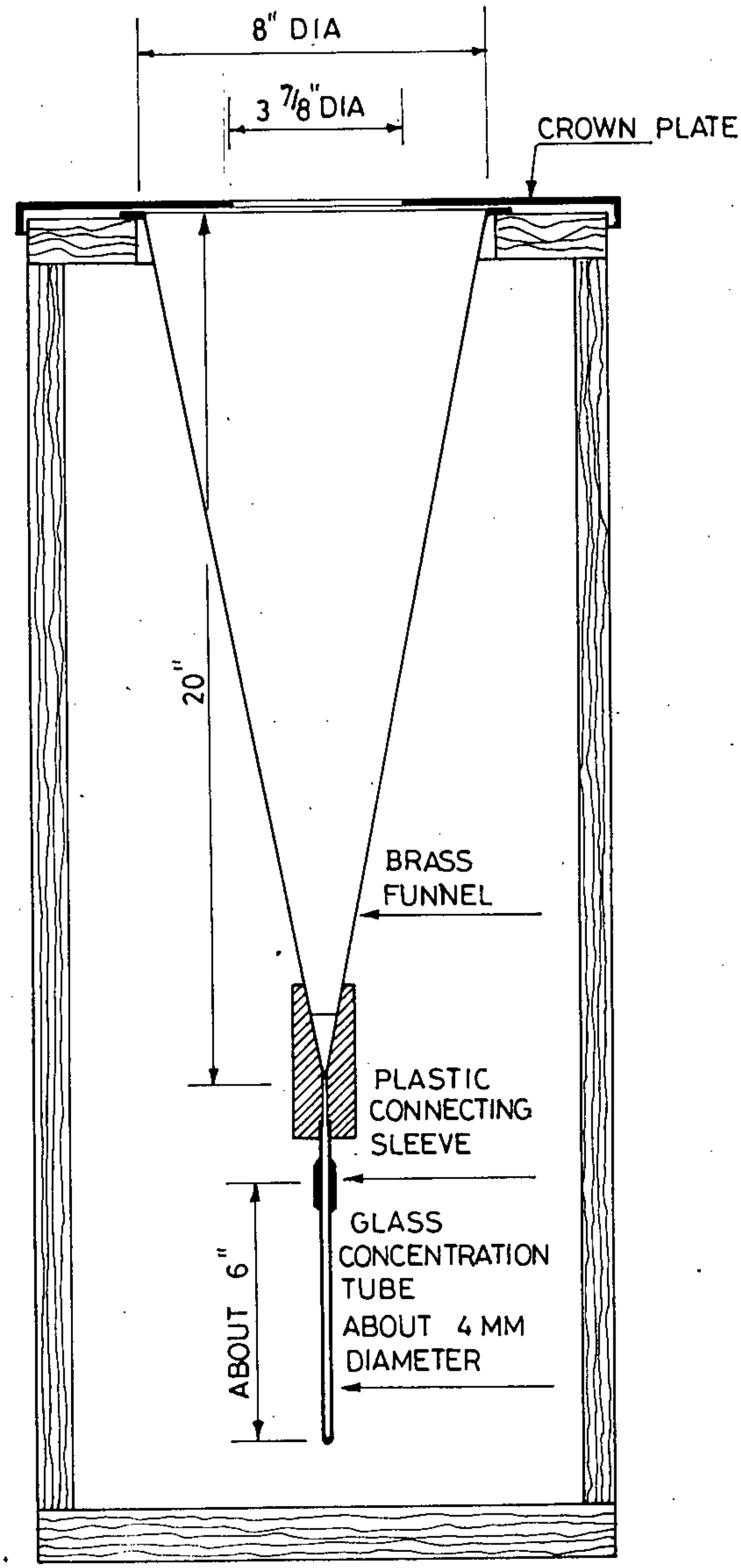


FIG. 4.3 SAND CONCENTRATING DEVICE

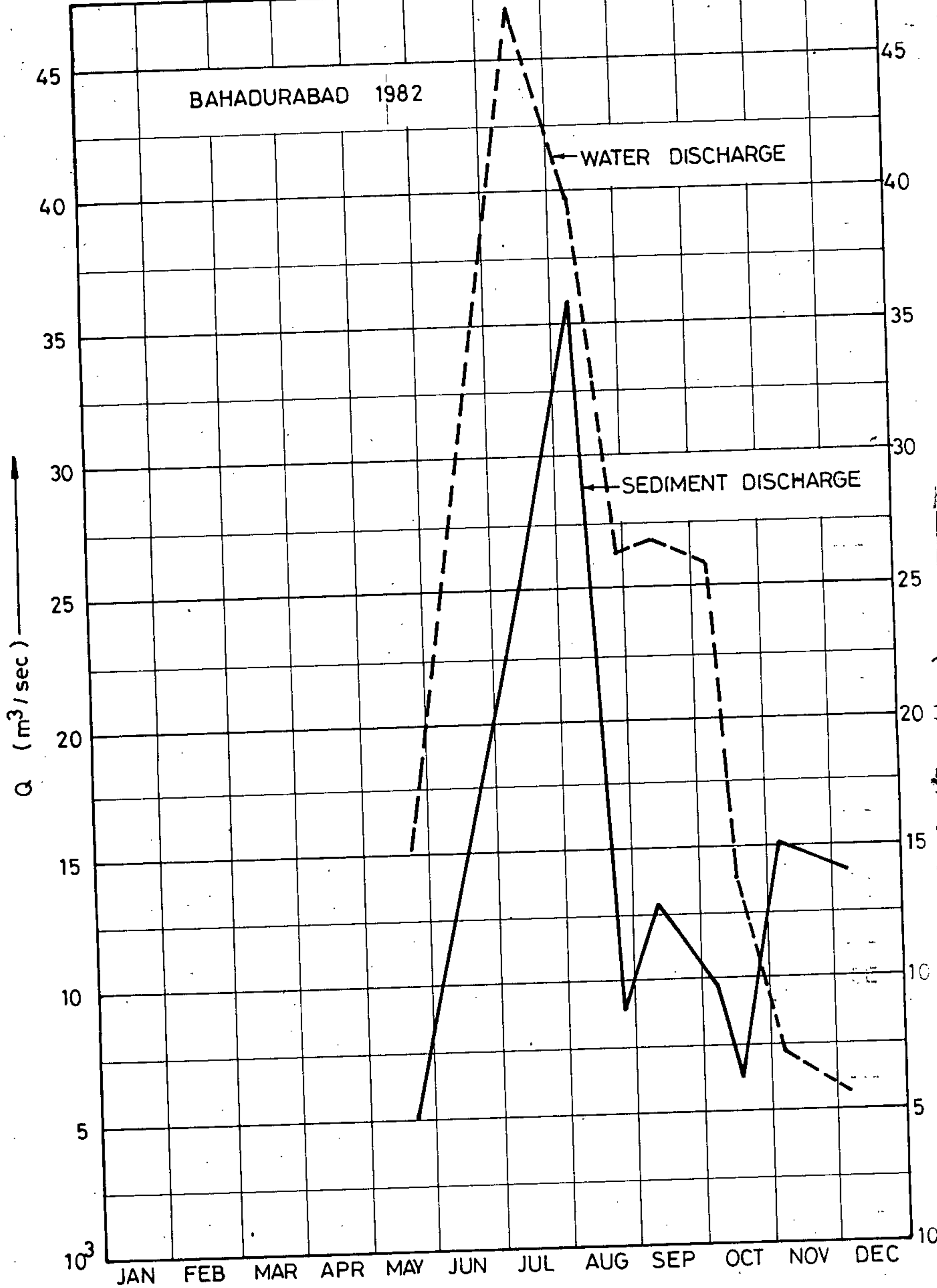


FIG. 5.1 WATER-SEDIMENT DISCHARGE HYDROGRAPH AT BAHADURABAD, 1982

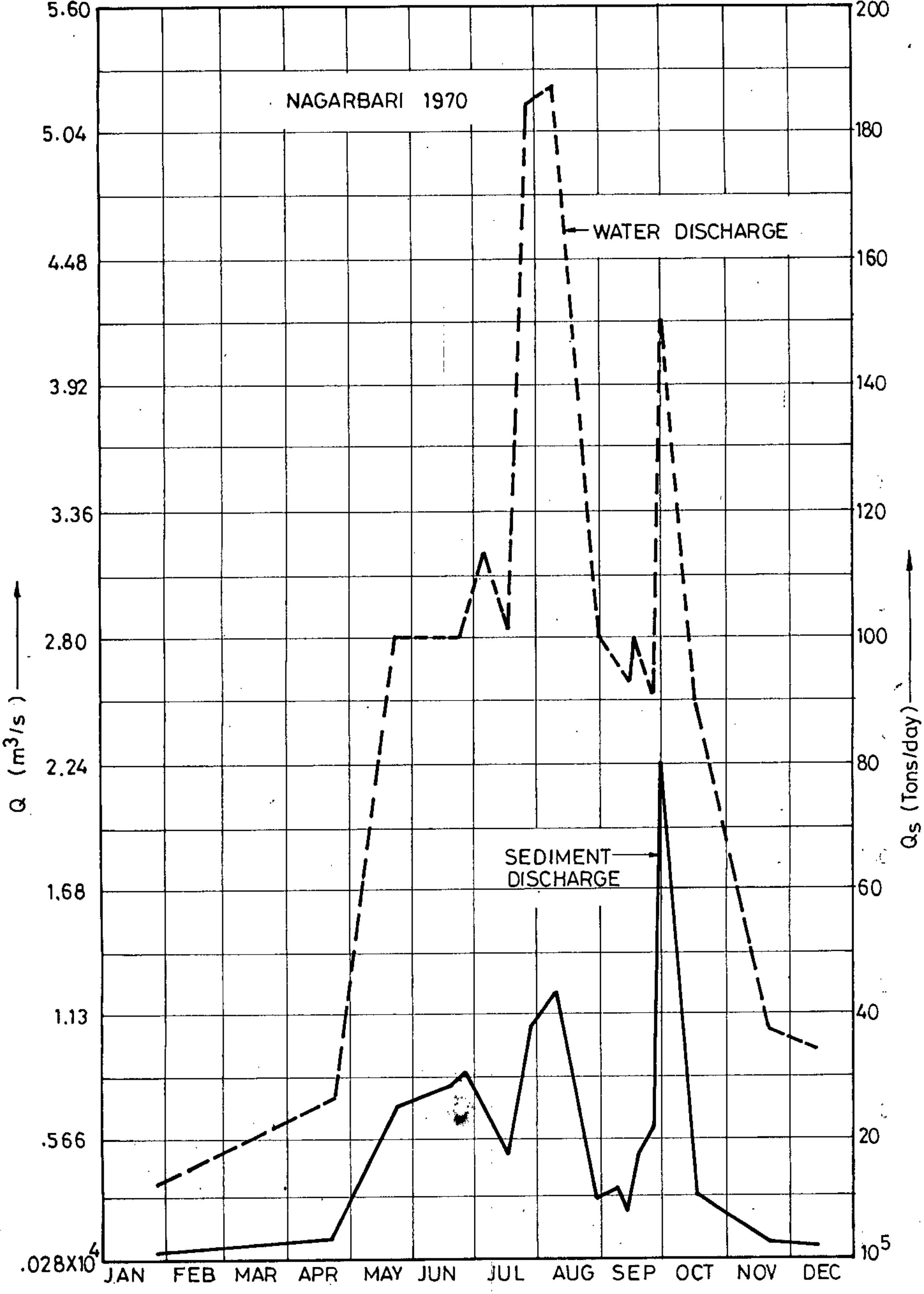


FIG. 5.2 WATER SEDIMENT DISCHARGE HYDROGRAPH AT NAGARBARI 1970

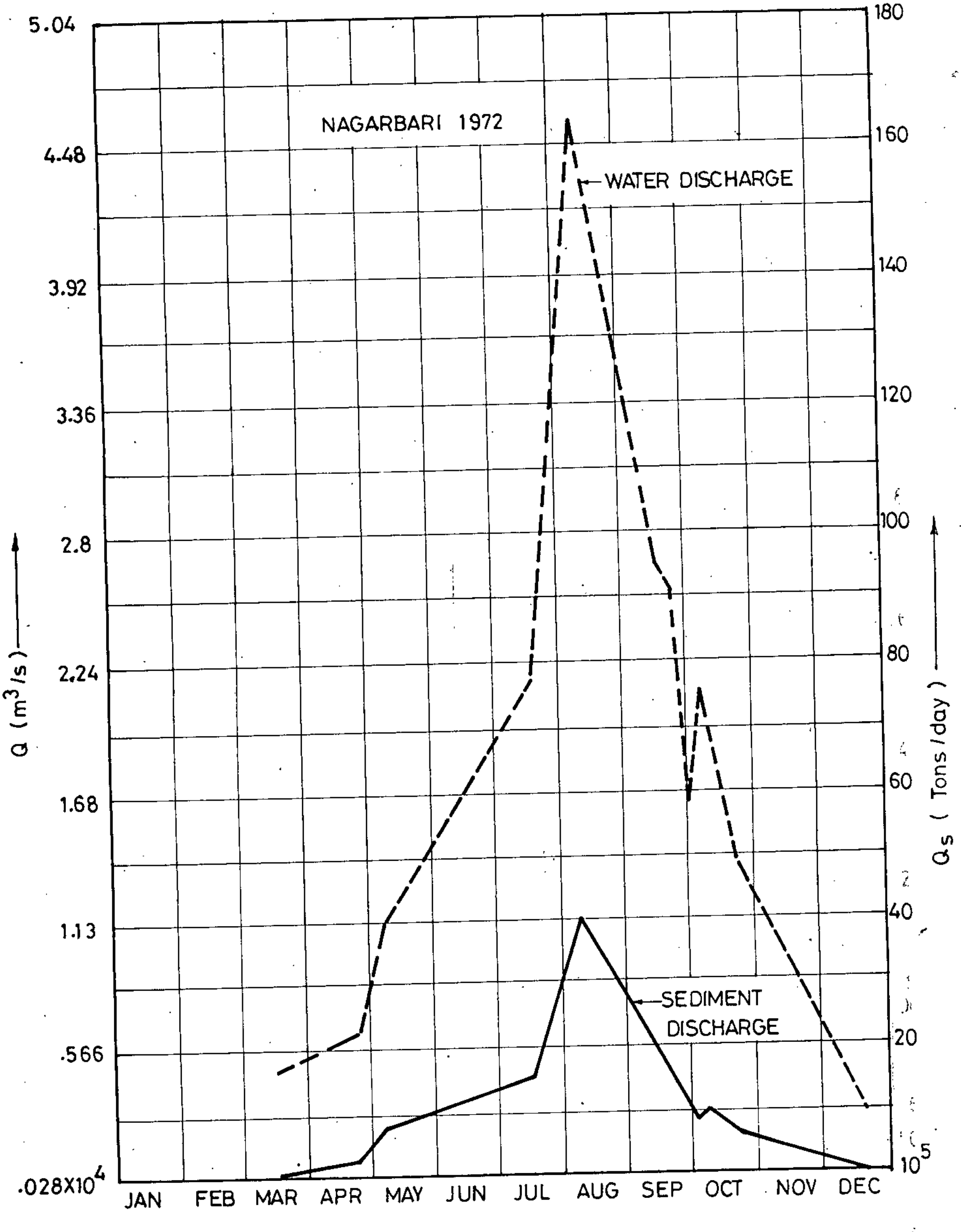


FIG. 5.3 WATER-SEDIMENT DISCHARGE HYDROGRAPH AT NAGARBARI, 1972

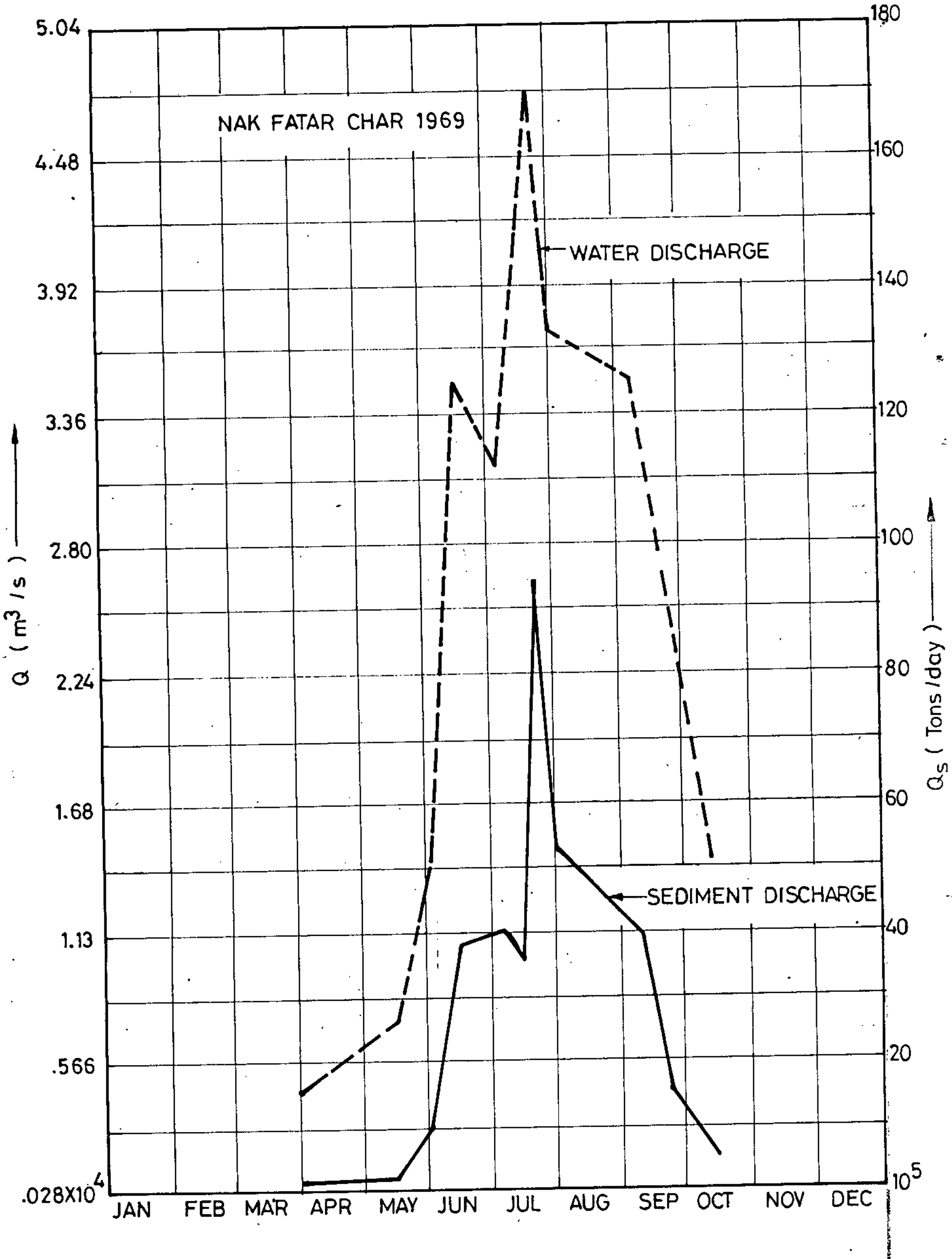


FIG. 5.4 WATER-SEDIMENT DISCHARGE HYDROGRAPH AT NAK FATAR CHAR 1969

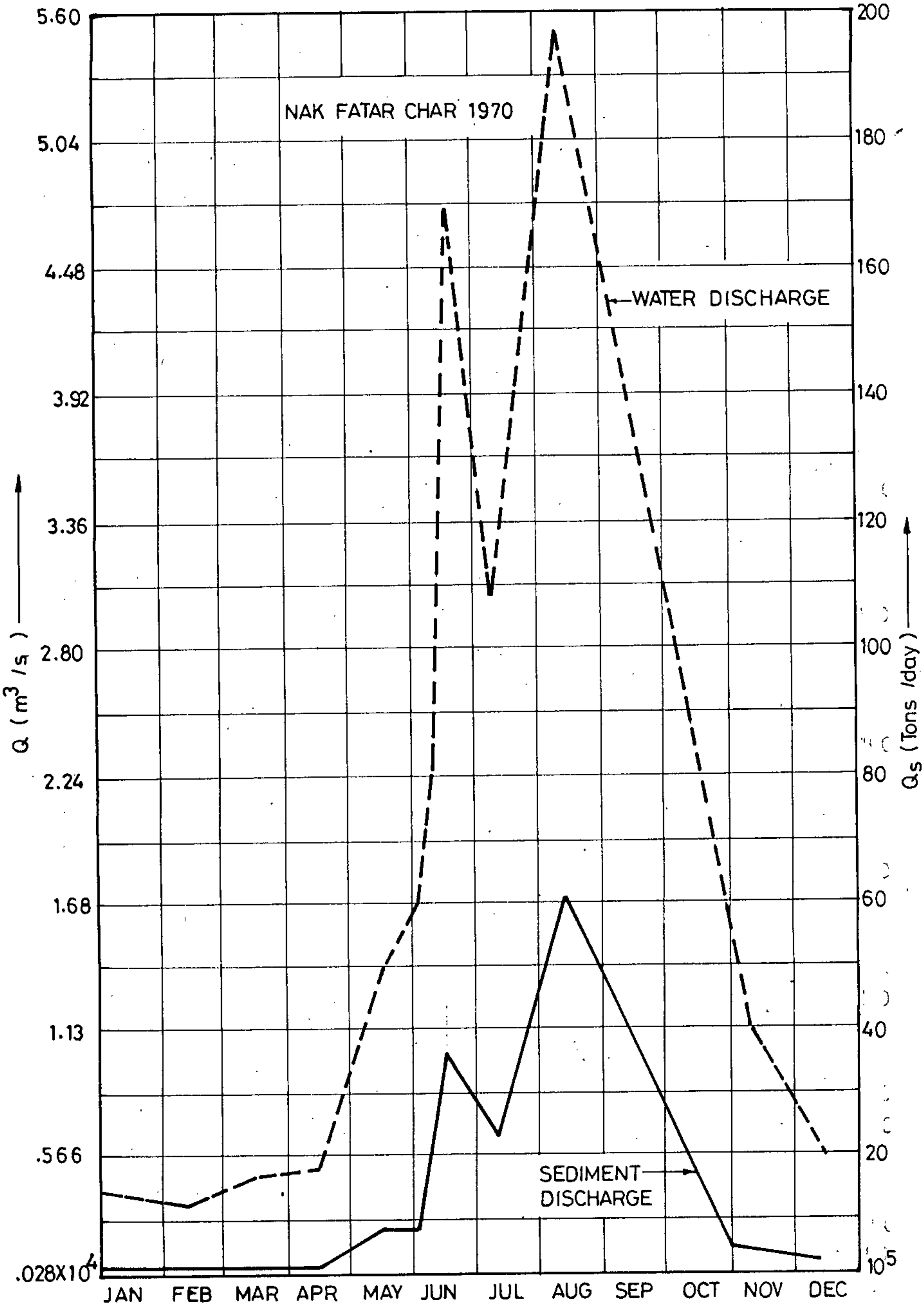


FIG. 5.5 WATER–SEDIMENT DISCHARGE HYDROGRAPH AT NAK FATAR CHAR 1970

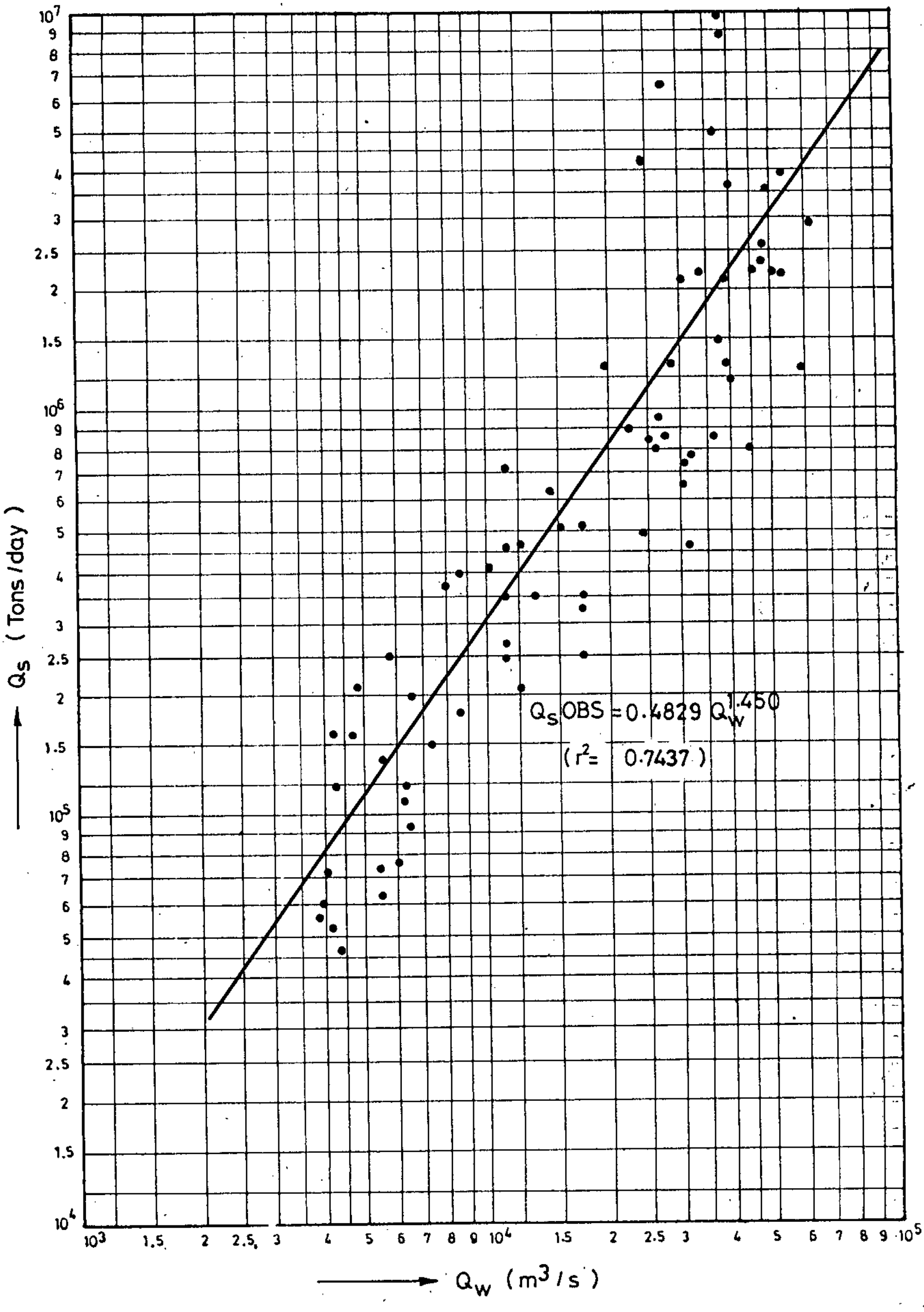


FIG. 5.6 WATER SEDIMENT DISCHARGE RELATIONSHIP FOR THE RIVER JAMUNA AT BAHADURABAD FOR OBS DATA OF 1982 - 1986

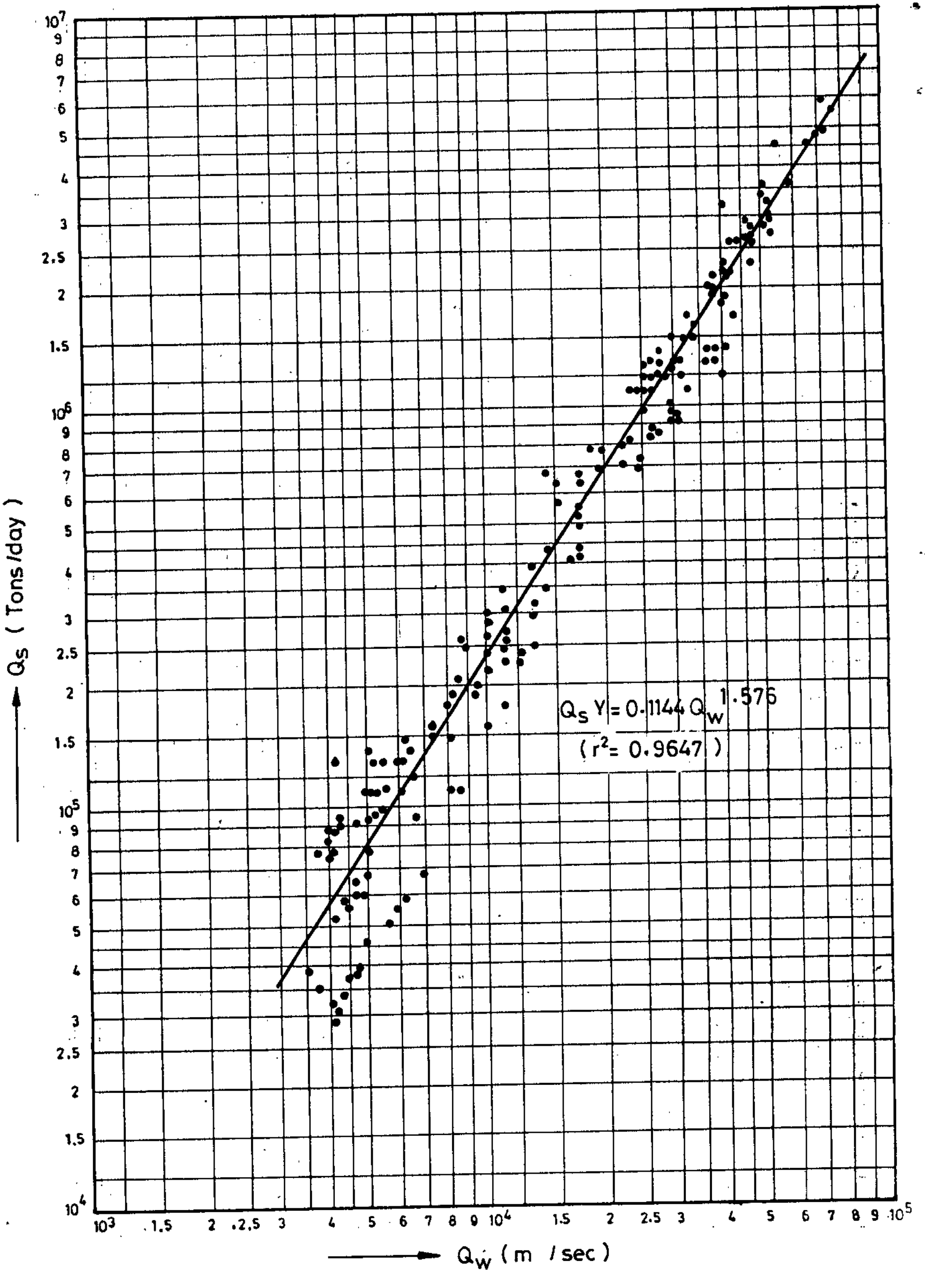


FIG. 5.7 WATER SEDIMENT DISCHARGE RELATIONSHIP USING YANG'S FORMULAE FOR THE RIVER JAMUNA AT BAHADURABAD (1982 - 1988)

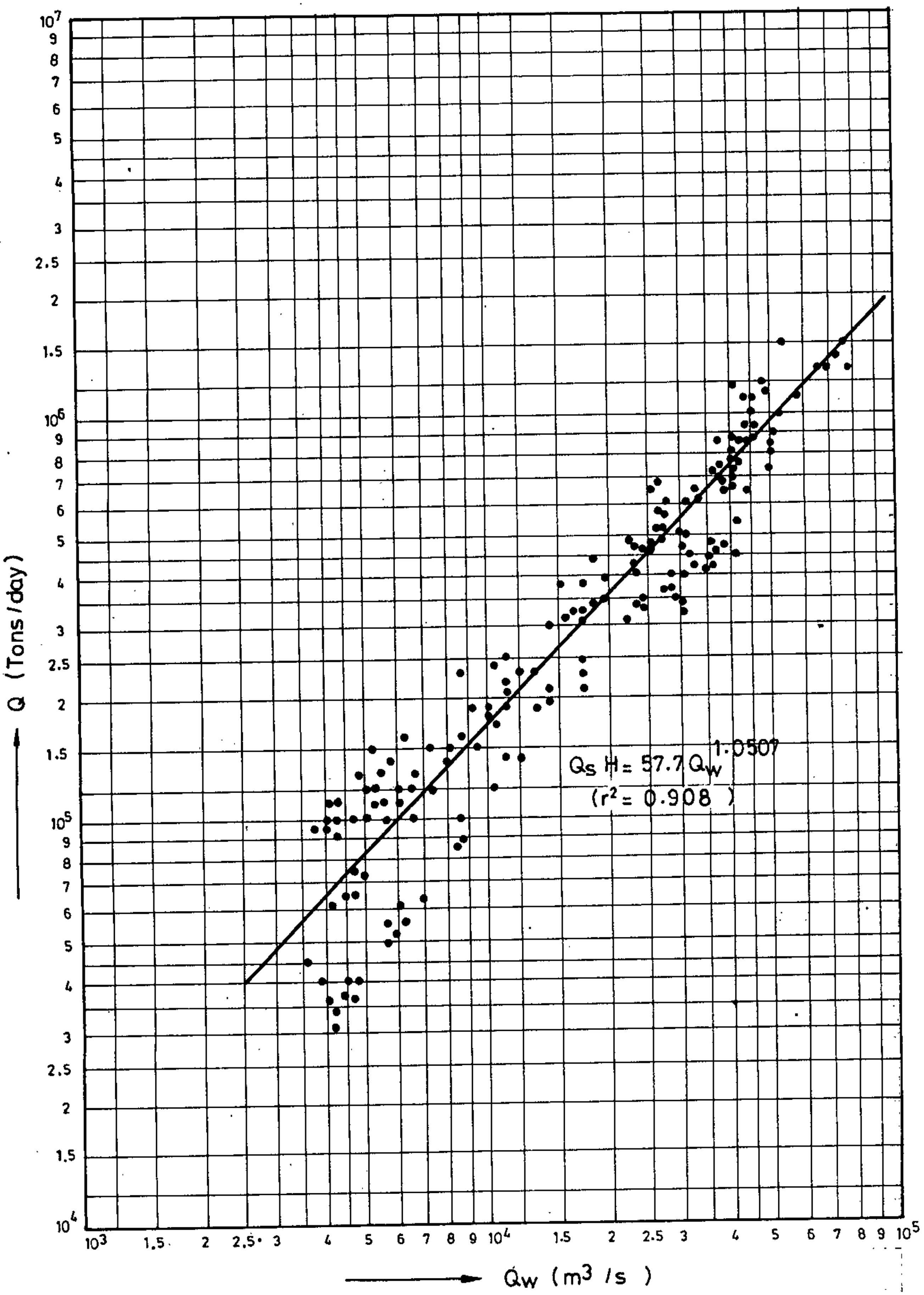


FIG. 5.8 WATER SEDIMENT DISCHARGE RELATIONSHIP USING HOSSAIN'S FORMULA FOR THE RIVER JAMUNA AT BAHADURABAD (1982 - 1988)

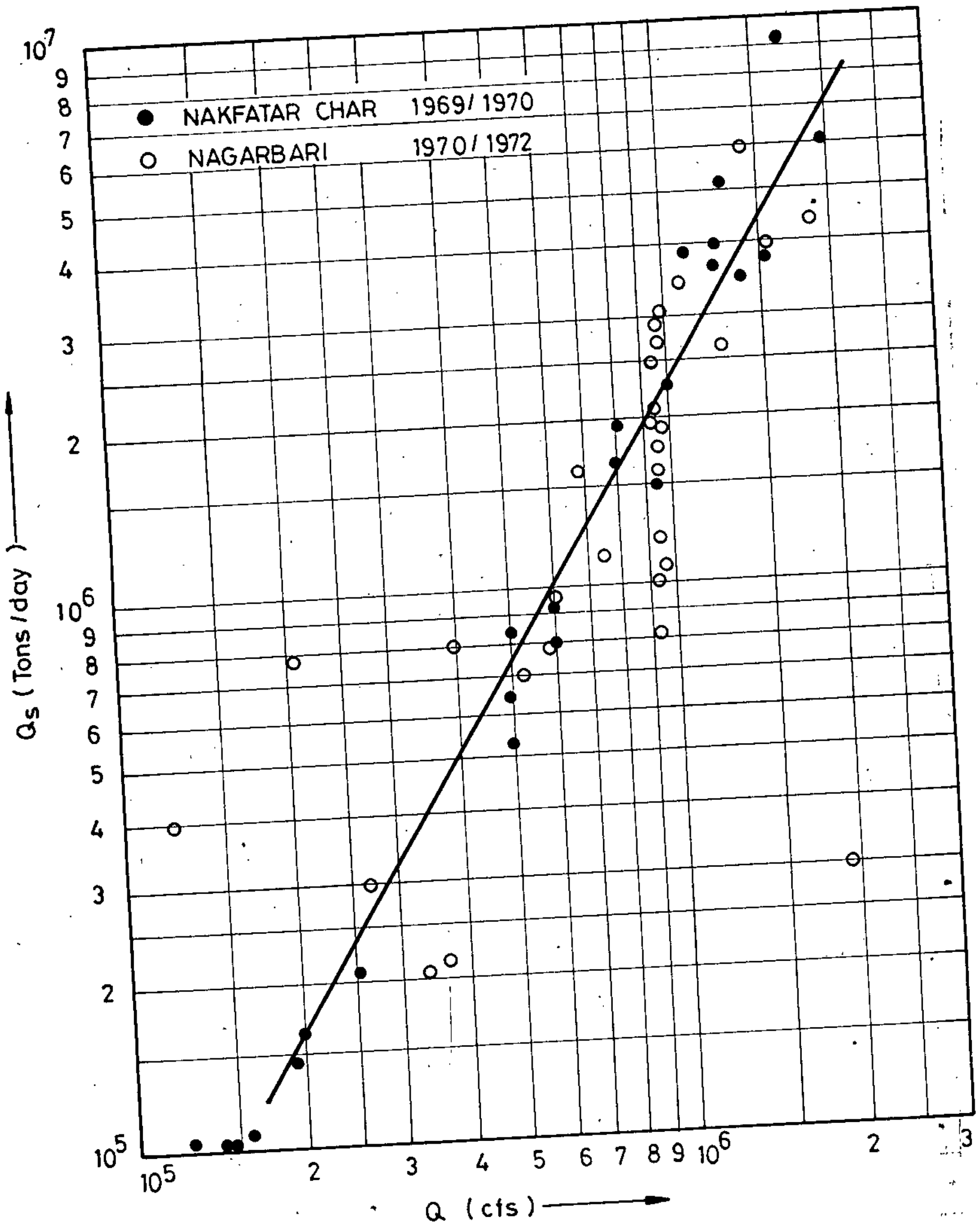


FIG. 5.9 WATER SEDIMENT DISCHARGE RELATIONSHIP FOR THE JAMUNA (AFTER ALAM & HOSSAIN 1988)

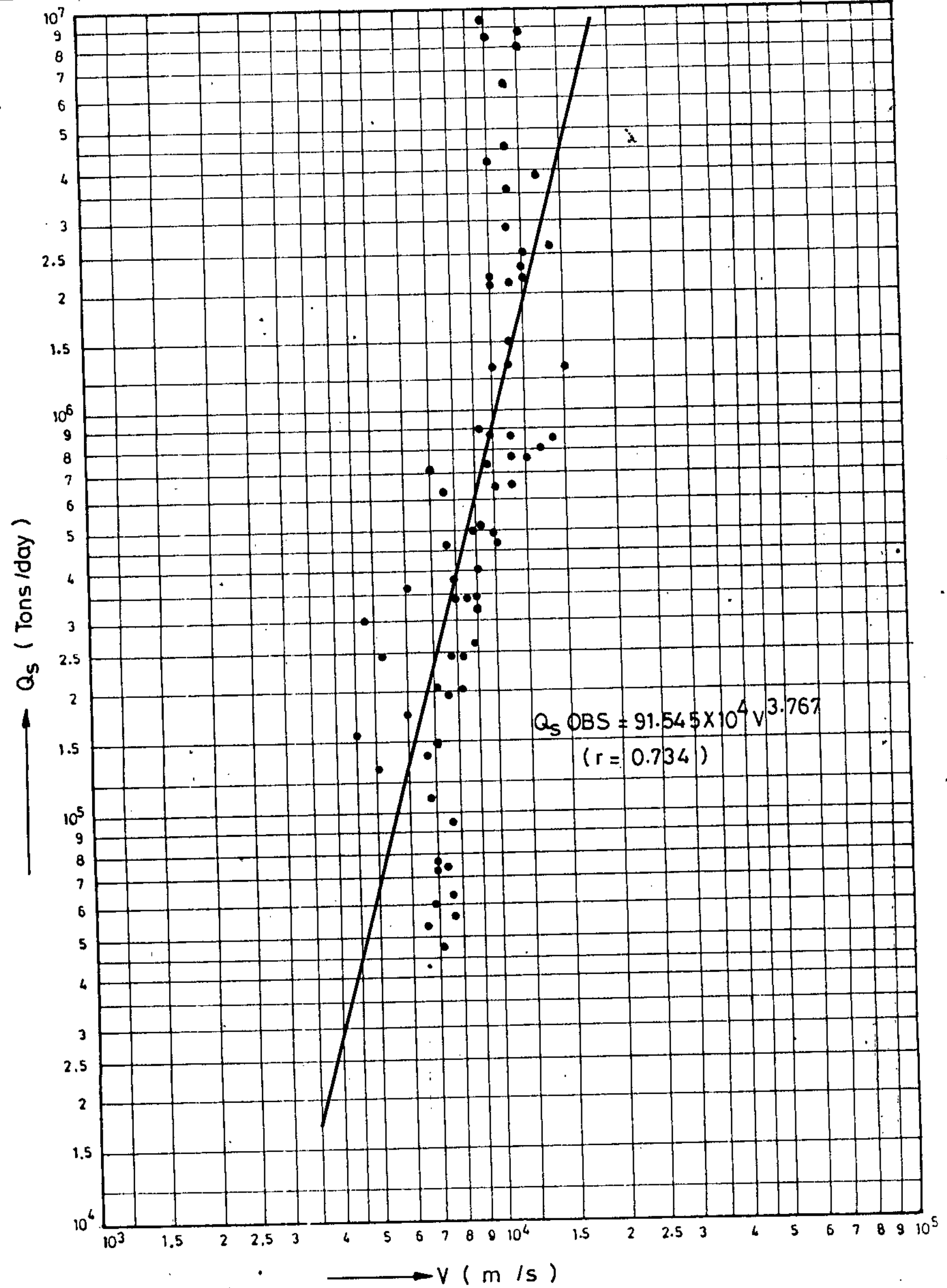


FIG. 5.10 VELOCITY-SEDIMENT DISCHARGE RELATIONSHIP FOR THE RIVER JAMUNA AT BAHADURABAD FOR OBS DATA OF 1982-1986

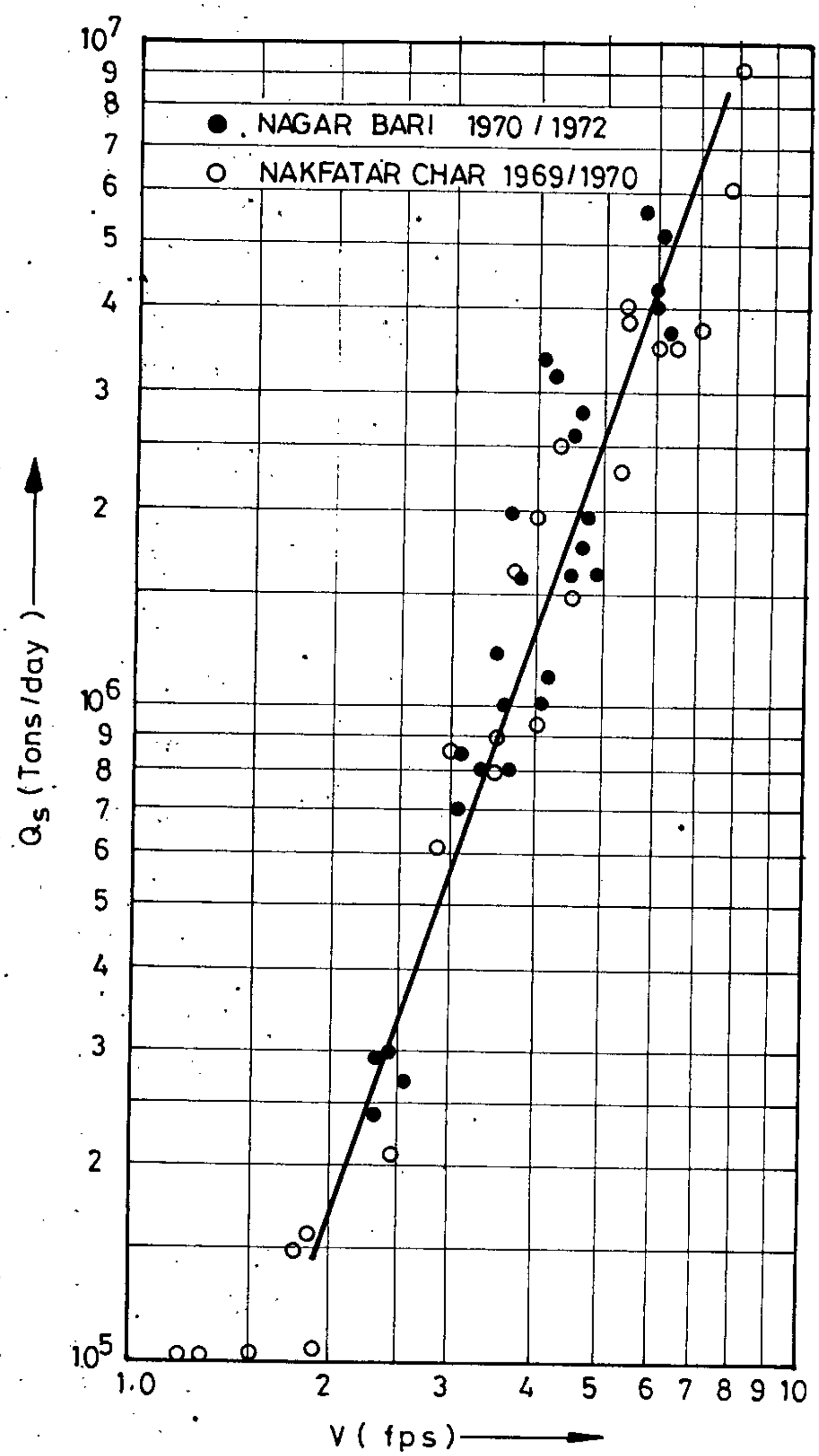


FIG. 5.11 VELOCITY - SEDIMENT DISCHARGE RELATIONSHIP FOR THE JAMUNA (AFTER ALAM & HOSSAIN 1988)