A STUDY ON STAGE-DISCHARGE RELATIONSHIP OF ATRAI RIVER

By

Md. Fazlul Quader

In partial fulfillment of the requirement for the degree of
Master of Science in Engineering (Water Resources)

Department of Water Resources Engineering, Bangladesh University
of Engineering and Technology, Dhaka, Bangladesh
February, 1995

CERTIFICATE

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

Countersigned

(Dr. Ainun Nishat)

Signature

Quader

(Md. Fazlul Quader)

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

February 6,1995

We hereby recommend that the thesis prepared by

MD. FAZLUL QUADER

entitled **A STUDY ON STAGE-DISCHARGE RELATIONSHIP OF ATRAI RIVER** be accepted as fulfilling this part of the requirements for the degree of Master of Science in Engineering (Water Resources).

Chairman of the Committee
(Supervisor)

(Dr. Ainun Nishat)

M. Fazlul Bari

(Co-supervisor and
Head of the Department)

(Dr.Muhammad F. Bari)

Member

(Dr. Monowar Hossain)

Member
(External)

(Mr. Alam Miah)

ABSTRACT

Bangladesh University of Engineering and Technology
Department of Water Resources Engineering
M.Sc. Engineering

A STUDY ON STAGE-DISCHARGE RELATIONSHIP OF ATRAI RIVER

The present study investigated the stage-discharge relationship of the Atrai river. The analysis of stage-discharge relations for four stations: Panchagarh, Bushirbandar, Mohadebpur and Atrai were carried out. Both power type and parabolic equations were selected for establishing stage-discharge relations. Annual rating curves were established for each station. It was found that no substantial shifting control had occurred. Stage-discharge curves of different stations for the same year were investigated so as to establish a correlation between them ; however no correlationship could be established.

Test for bias and goodness of fit were also applied to investigate the reliability of both power type and parabolic stage-discharge relations. All the equations were found to be free from bias and most cases dispersion of the measured data about the fitted rating curve were found to be even and within five percents of significant level. In most cases parabolic equations fitted well than the power type equations. For extrapolation purpose parabolic equations were found better than that of power type equations. For small range of gauge height, power type equations gave better results than parabolic equations.

Mean depth discharge relations were also established using both for power type and parabolic equations. But power type and parabolic equations of stage-discharge relation fitted better compared to those of mean depth-discharge relationship.

ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to **Dr. Ainun Nishat**, Professor, Department of Water Resources Engineering, who supervised this thesis work through continuous guidance and encouragement throughout the course of this research.The author is grateful to **Dr. M. Fazlul Bari**, Professor and Head of the Department of Water Resources Engineering, who was co-supervisor of this thesis. His valuable advice and guidance during the course of study has helped completion of this study.

The author wishes to thank Dr. Abdul Hannan, Professor, Department of Water Resources Engineering, BUET, for the encouragements extended by him.

Thanks are due to the employer of Bangladesh Water Development Board specially Mr. Alam Miah, Director of Surface Water Hydrology-2, for their co-operation in supplying data.

The author gratefully acknowledges his parents, wife, relatives and friends particularly Mr. Md.Imdadul Haq for their continuous encouragement.

Finally, the author wishes to thank Mr. Md. Bahauddin Bhuiyan for his co-operation and to Mr. Abdul Mannan Khan for neat typing.

Table of Contents

List of Tables

List of Figures

APPENDIX A

APPENDIX B

Chapter 1

INTRODUCTION

1.1 Introduction

For planning, design and operation of water resources projects hydrological data are very important. Analysis of hydrologic data constitutes the first step for projects dealing with irrigation, water supply, flood control, water power, water control structure and navigation etc. Basic data required for the analysis and design of these projects include such data as: climatological, hydro-meteological, soil type, cropping type and pattern, consumptive use and geo-morphologic information of the basin such as area, slope, elevation etc.

Streamflow data take an important dimension in flood management and irrigation. For environmental pollution control streamflow data is also very important. Streamflow data include mainly stage and discharge. Both stage and discharge of a river vary with time. Discharge measurements are difficult, expensive and time consuming, and require qualified technical personnel. In general it is not practicable to measure the discharge continuously. To obtain a continuous record of the stage at a site is relatively simple. An observed record of stage can easily be converted into a record of discharge using a stage-discharge relation or rating curve developed earlier for any given gauging station. Measurements at higher stages are difficult and may take time. Thus at a majority of gauging stations, discharge measurements are not available for high flood stages. In that case, stage-discharge relation is extrapolated beyond the available discharge measurements. So stage-discharge relation need to be representative and as accurate as possible.

Stage-discharge relations vary from time to time. Measurement of discharge involves many uncertainties, such as in measuring width, velocity, depth etc. So the reliability of the stage-discharge relation needs to be investigated. Stage-discharge relations also vary from station to station. Generally at an upstream location, the stage-discharge curve may have steeper slope due to steeper slope of the river, while at a downstream point the curve is expected to have a flatter slope. So comparison of stage-discharge relations at different stations may also be instructive.

In Bangladesh stage-discharge relations are generally established by power type equations. But no tests for absence of bias and goodness of fit are generally done.

In major rivers like the Jamuna, Brahmaputtra and Ganges a number of studies were undertaken which investigated stage-discharge relationships of these rivers. But limited studies have so far been undertaken on minor or medium rivers. It was felt necessary to undertake such study for a medium size river like Atrai. Other reasons for choosing the river for this study are that a relatively long record of discharge measurement is available from a number of gauging stations, as many as four discharge measurement stations are maintained and operated along the river by the Bangladesh Water Development Board (BWDB).

1.2 Measurement of Stage and Discharge

The stage of a stream is the height of water surface above an established datum plane. The water surface elevation with reference to some arbitrary or predetermined gauge datum is called the gauge height.

The datum of gauge may be a recognized datum, such as mean sea level or an arbitrary datum plane chosen for convenience. An arbitrary datum plane is selected for the convenience of using relatively low gauge height. To eliminate the possibility of negative values of gauge height, the datum selected for operating purpose is usually below the elevation of zero flow on the control for all conditions. A permanent datum need to be maintained so that only one datum for the gauge height record is used for the life of the station. Gauge height is often used interchangeably with the more general term stage, although gauge height is more appropriate when used with a reading on a gauge.

Gauge height records may be obtained by a water stage recorder, by systematic observation of a non-recording gauge, or by noting only peak stages with a crest-stage gauge. Telemetering systems are used to transmit gauge height information to points distant from the gauging station.

Streamflow flow, or discharge, is defined as the volume rate of flow of the water, including any sediment or other solids that may be dissolved or mixed with water. Various methods used in measuring discharge are area-velocity method, moving boat method, slope-area method, portable weirs and flumes, etc. The basic instrument most commonly used in making the measurement is the current meter. Echo sounder is used in some limited large river of the country. For other stations sounding lead, gauging reel, sounding rod etc. are used for depth measurement.

A current meter measurement is the summation of the products of the partial areas of the stream cross-section and their respective average velocities. The formula $Q = \Sigma\ (av)$ represents the computation, where Q is total discharge, a is an individual partial cross-sectional area, and v is the corresponding mean velocity of the flow normal to the partial area. In the mid-section method of making a current meter measurement it is assumed that the velocity sample at each location represents the mean velocity in a partial rectangular area. The area extends laterally from half the distance from the preceding meter location to half the distance to the next and vertically, from the water surface to the sounding depth. Mean section method also used for discharge measurement. Mid-section method is generally used. Mid-section method is simpler to compute and is a slightly more accurate procedure than mean section method.

Current meters, timers and counting equipment are used when making conventional types of measurements. Use of additional equipment used depends on the type of measurements being made. Instruments and equipment used in making current meter measurements are current meters, sounding equipment, width-measuring equipment, equipment assemblies etc.

1.3 Rating Curve

A rating curve is a graph that shows the relation between the water level elevation or stage of a river channel at a certain cross-section and the corresponding discharge at that section. If the measured discharge is plotted against the corresponding stage, the data will normally define a curve which is approximately parabolic, as shown in Fig. 1.1. Such a curve is generally satisfactory for a good majority of rivers where the discharge station has been selected with due regard to the essential requirements of a good gauging site and the stream is not subjected to too rapid fluctuations of the stage. If a station possesses a permanent control, the rating curve is essentially permanent, but it should be confirmed by periodic observations. Some stations have two or more controls each serving for a different range of stage. This condition can result in a rather abrupt break in the rating curve at the stage corresponding to a change in the control.

The discharge measured for a particular stage may be different under shifting control. The stage of a river may be rising or falling or remain constant. During rising stage of the river the measured discharge is more than that during a falling stage for the same stage. Thus the plot of discharge measurements for a rising stage fall to the right side and that for a falling stage to the left side of the mean rating curve. Such type of rating curve is called a looped rating curve as shown in Fig. 1.2. On same river shape of the rating curve may vary with water surface slope, change in co-efficient of roughness due to scour and deposition in bed and bank, growth of vegetation, and variable inflow in the downstream direction from station to station etc. The river Atrai provide with an opportunity to investigate these aspects in the present study.

1.4 Atrai River

The Atrai originates in a beel or depressed area of Baikunthapur in India. As shown in Fig. 1.3, the river initially enters into Bangladesh territory with the name Koratoya at Bardeshwari of Panchagarh district. At downstream it is renamed as Atrai near Khanshama Thana of Dinajpur. It runs upto Sahamjhiaghat before entering India again.

The Atrai runs about 50 km long in India. The river re-enters in Bangladesh at Naogaon and flows southward and ultimately falls at Hurasagar. The total length of the river is about 340 km. The river is non-tidal.

Atrai river may be considered into two parts namely upper and lower Atrai. The upper reach may be considered from Panchagarh to Dinajpur and the lower reach from Naogaon to Atrai Railway Bridge. There are nine water level and four discharge measurement stations on this river. Water level measuring stations are located at Bardeswari, Panchagarh, Debiganj, Khansama, Bushirbandar, Sahamjhiaghat, Chakhariharpur, Mohadebpur and Atrai Railway Bridge. Discharge stations are at Panchagarh, Bushirbandar, Mohadebpur and Atrai.

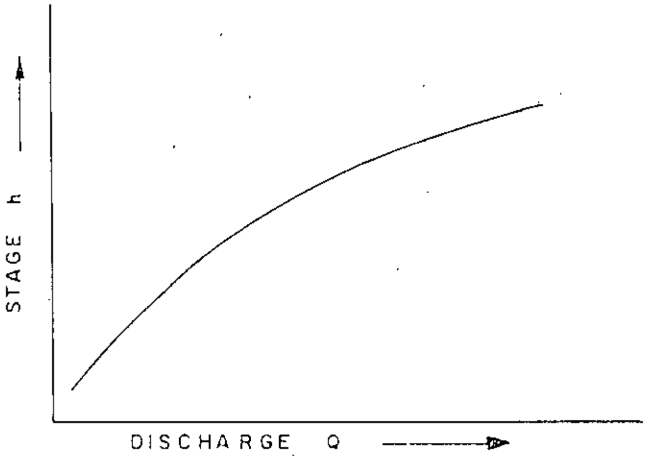


Fig. 1.1 Parabolic stage-discharge curve
Source: Mutreja K.N, Applied Hydrology, 1986.

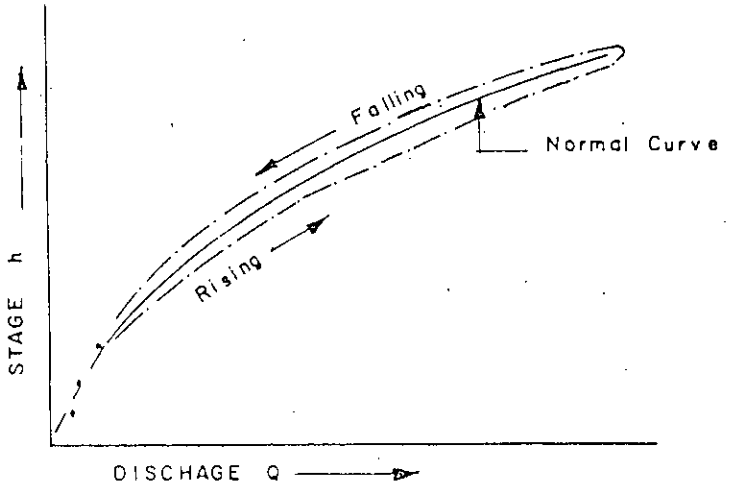


Fig. 1.2 Looped rating curve
Source: Wilson E.M, Engineering Hydrology, 1983

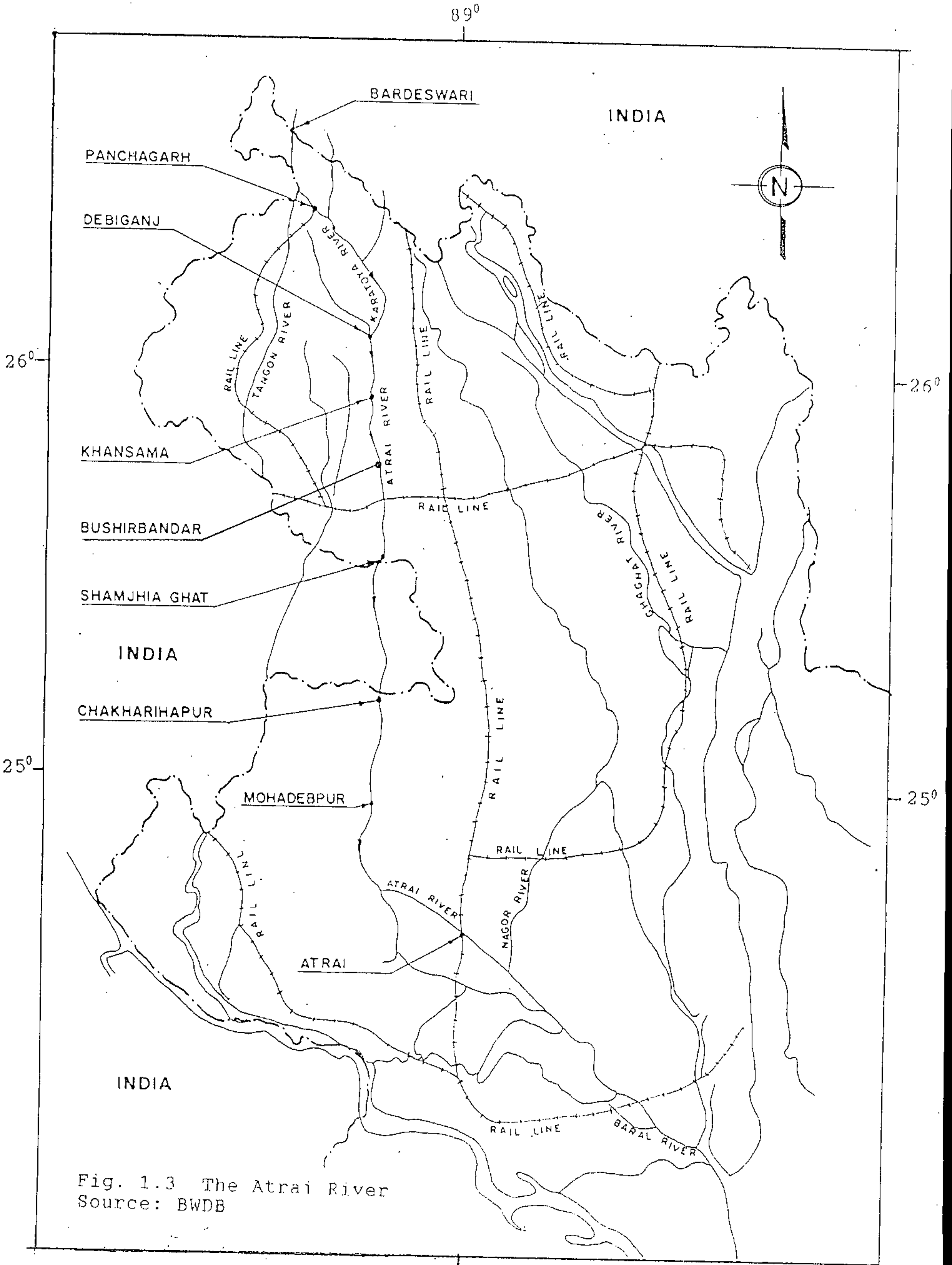


Fig. 1.3 The Atrai River
Source: BWDB

1.5 Objective of the Study

The objective of this research is to investigate stage-discharge relationship of the Atrai river at several selected stations by analytical approach. The main emphasis is on statistical analyses. The specific objectives are as follows:

1. Stage-discharge (h-Q) relation or rating curve will be established at selected stations of the Atrai river;
2. Stage-discharge relation at different stations will be compared to investigate, at least qualitatively, how they change along the river reach;
3. Statistical analysis of the uncertainties involved in the stage-discharge relation will be performed and reliability of h-Q relations will be investigated, and
4. As an alternative to h-Q relation, efforts will also be made to correlate Q with appropriate cross-sectional parameters, such as mean depth.

Chapter 2

STAGE-DISCHARGE RELATIONSHIP

2.1 Introduction

The conversion of a record of stage in a record of discharge is done using a stage-discharge relationship. Continuous records of discharge at gauging stations are computed by applying the discharge rating for the stream. The terms rating, rating curve, station rating and stage-discharge relation are synonymous.

2.2 Control

The stage-discharge relation is defined by the complex interaction of channel characteristics, including cross-sectional area, shape, water surface slope, sinuosity, roughness of stream bed and bank and vegetal cover. Among these elements, which control the stage-discharge relationship either individually or in a combination with other known as control.

Knowledge of the channel features that control the stage-discharge relationship is important. If the control is stable the stage-discharge relation will be stable. If the control is subjected to change then frequent discharge measurements are required for the continual recalibration of the stage-discharge relation which increases the operating cost of the gauging station and results in impairment of the accuracy of the streamflow record.

Classification of control

According to one classification the control can be divided as section control and channel control. Another classification divides them as permanent control and shifting control. Third classification calls them natural and artificial control. Fourth classification may be complete, compound, and partial control (WMO 1980).

Section control. In term of open channel hydraulics, critical depth control is generally termed section control, if a critical flow section exists a short distance downstream of the gauging station. Section control exists when the geometry of a single cross-section is such as to constrict the channel, or when a downward break in bed slope occurs at a cross-section. A section control may be natural or manmade. It may be a ledge of rock across the channel, a boulder covered riffle, an overflow dam or any other physical feature capable of maintaining a fairly stable relation between stage and discharge (WMO 1980).

Channel control. Channel control exists when the geometry and roughness of a long reach of channel downstream from the gauging station are the elements that control the relation between stage and discharge. Channel control consists of all the physical features of the channel which determine the stage of the river at a given point for a given rate of flow. These features include the size, slope, roughness, alignment, constrictions and expansions, and shape of the channel. The length of channel that is effective as a control increases with discharge. Generally speaking, the flatter the stream gradient, the longer the reach of channel control (WMO 1980).

Permanent control and shifting control. A control is permanent if the stage-discharge relation it defines does not change with time; otherwise it is impermanent and generally called a shifting control (WMO 1980). A shifting control exit where the stage-discharge relation changes in the physical features that form the station control.

Natural control. Natural control is not man made but it is made naturally. Natural controls vary widely in geometry and stability. The primary cause of changes in natural controls is the high velocity associated with high discharge.

Artificial control. Artificial controls are structures built for the specific purpose of controlling the stage-discharge relation. A highway bridge, or paved floodway channel that serves incidentally as a control is not classed as an artificial control.

Complete control. A complete control is one that governs the stage-discharge relation throughout the entire range of stage experienced at the gauging station. A complete control is independent of all downstream conditions at all stages such as a rock ledge crossing the channel at the crest of a rapid or a waterfall.

Compound control. Generally a single control is not effective for the entire range of stage experienced at the gauging station. For that case the gauging station have a compound control station. The compound control sometimes includes two section controls, as well as channel control. A common example of compound control is the situation where section control is the control for low stages and channel control is effective at high stages.

Partial control. A partial control is a control that acts in concert with another control in stage whenever a compound control is present. Generally section control is effective during low stages and channel control is effective during high stages. At intermediate stages a transition from one control to the other. During this transition period the two controls act in concert, each as a partial control.

2.3 Types of Stage-Discharge Relation

According to the shape and form of stage-discharge relationship it can be classified as below :

1. Simple stage-discharge relation.
2. Looped stage-discharge relation or looped Rating curve.
3. Component stage-discharge relation.

2.3.1 Simple Stage-Discharge Relation

It implies definite discharge value correspond to definite water level whatever changes of discharge may take place. Directly proportional relationship between gauge height and discharge values normally is observed during a limited period of time. Sometimes it is observed during a several years period, in that case it is temporarily disturbed by seasonal phenomena such as variable back-water from tributary streams or from the return of overbank storage, by aquatic vegetation which grows seasonally in the channel or by artificial control etc. But in this case the directly proportional relationship is observed after the disturbing phenomenon expires. Directly proportional stage-discharge relationship is graphically expressed by one curve.

According to the duration of validity of directly proportional stage-discharge relationship it can be divided into two types:

a. Temporary stage-discharge relation

b. Long-term stage-discharge relation

Temporary stage-discharge relation is one which valid not more than 1½ to 2 years. Long-term stage-discharge relation valid for longer period.

2.3.2 Looped Rating Curve

During flood stage-discharge relation curve is established, by one for the rise and another for the recession of the flood. Then these two curves togetherly form a curve which is called loop curve.

If discharge versus water level plotted in normal scale the curve shows rise of the flood on the right part of the flood loop and fall of the flood on the left part of the loop and in most cases depth sounding data show no bottom deformations. In other words it means that cross-section areas data versus water level plotting show directly proportional relationship.

Flood loops are characteristic for long stretches of rivers having no considerable tributaries. Considerable quantity of tributary water eliminates flood loop existence. Another condition for flood loop existence is a small water slope. That is why loops are never observed in mountainous rivers and in minor plain rivers. The rate of water level variations (i.e. rise and fall) is also of importance for flood loop existence. When rate of water level change is great, a flood loop may appear even in medium size of rivers.

Generally in a single peak flood, the loop would be of the shape shown in Fig. 2.1. In the lower part of the loop the two branches join together and form one curve which is the lower part of the steady flow regime curve (directly proportional relationship). Steady flow regime is such that the discharge and water level changes gradually that would not cause the difference of water slope during the rise and the fall of the flood. Relationship of such regime is shown in Fig. 2.1 by dotted line.

The point of departure from the stability regime curve indicates the starting of rise of the flood and the point of departure from the recession curve indicates the end of recession flood. In upper part of the rising and falling curve should be joined by smoothly rounding off. The highest point of the loop, the point of conjugation is situated on the steady flow regime curve, which is important for extrapolation of loop rating curve. The point of maximum discharge should be situated on the rising curve, a little lower from the highest water level. The time of maximum discharge occurs before the time of attaining maximum water level. When the loop is not wide then maximum discharge may coincide with the highest water level.

Each separate flood or each wave of multi-peak flood is correspond to its own independent loop like rating curve as shown in Fig. 2.2.

The deviation of the rising curve towards the abscissa from the steady flow regime curve would generally depend on the intensity of change of water level with time i.e. h/t. The value of h/t, can be estimated by the inclination angle of the line of rise or fall on the hydrograph. The steeper the line of the hydrograph, the more the loop curve deviates from the steady flow regime curve as shown in Fig. 2.2. With the consideration of the range of water level for flood I, the rise of flood I is more intensive than the rise of flood II, and the fall is less intensive. Accordingly the branches of the loop of flood I are situated more to the right from the branches of the loop of flood II.

When channel deformation or backwater takes place, the curves of steady flow regime for different floods may have different positions and the positions of the loop branches may not be depend on the change of water level intensity. Fig. 2.2 shows flood loop for different floods.

2.3.3 Component Rating Curve

One part of rating curve constituting a single variable directly proportional relationship and another part constituting an unstable relationship are called component rating curve.

2.4 Factors Affecting Stage-Discharge Relation

The stability or lack of stability of stage-discharge relation at the site of a gauge station is mainly related to the natural configuration of river, vegetal cover of river bed and bank and overflow area at upstream and downstream from the gauge. These characteristics collectively constitute the factors which determine the stage-discharge relation. The principal features which control the stage-discharge relation are: (a) scour and fill in unstable channel,(b) changing channel configuration,(c) aquatic vegetation, (d) back-water, (e) rapidly changing discharge,(f) variable channel storage and (g) ice.

(a). Scour and fill in unstable channel. In fixed channel well-defined stage-discharge relationship can be developed that shows minor shifting. An alluvial channel is one where the bed is composed of unconsolidated silts, sands and gravels. So instability mainly occurs

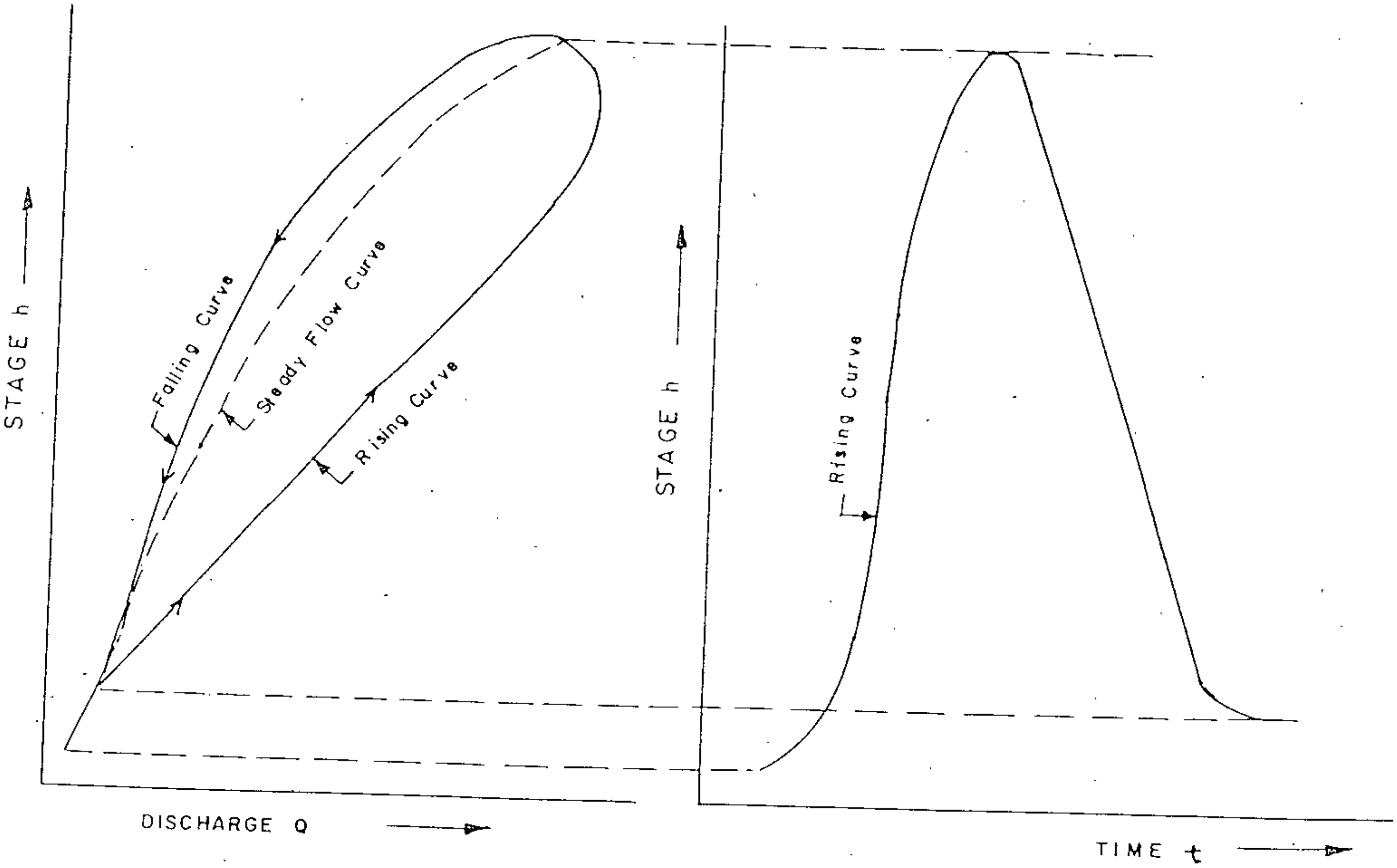


Fig. 2.1 Scheme of a single peak flood
Source: UNDP Hydrological Survey Project,UN-DTCD
BGD 72/008 Manual of data processing,1982.

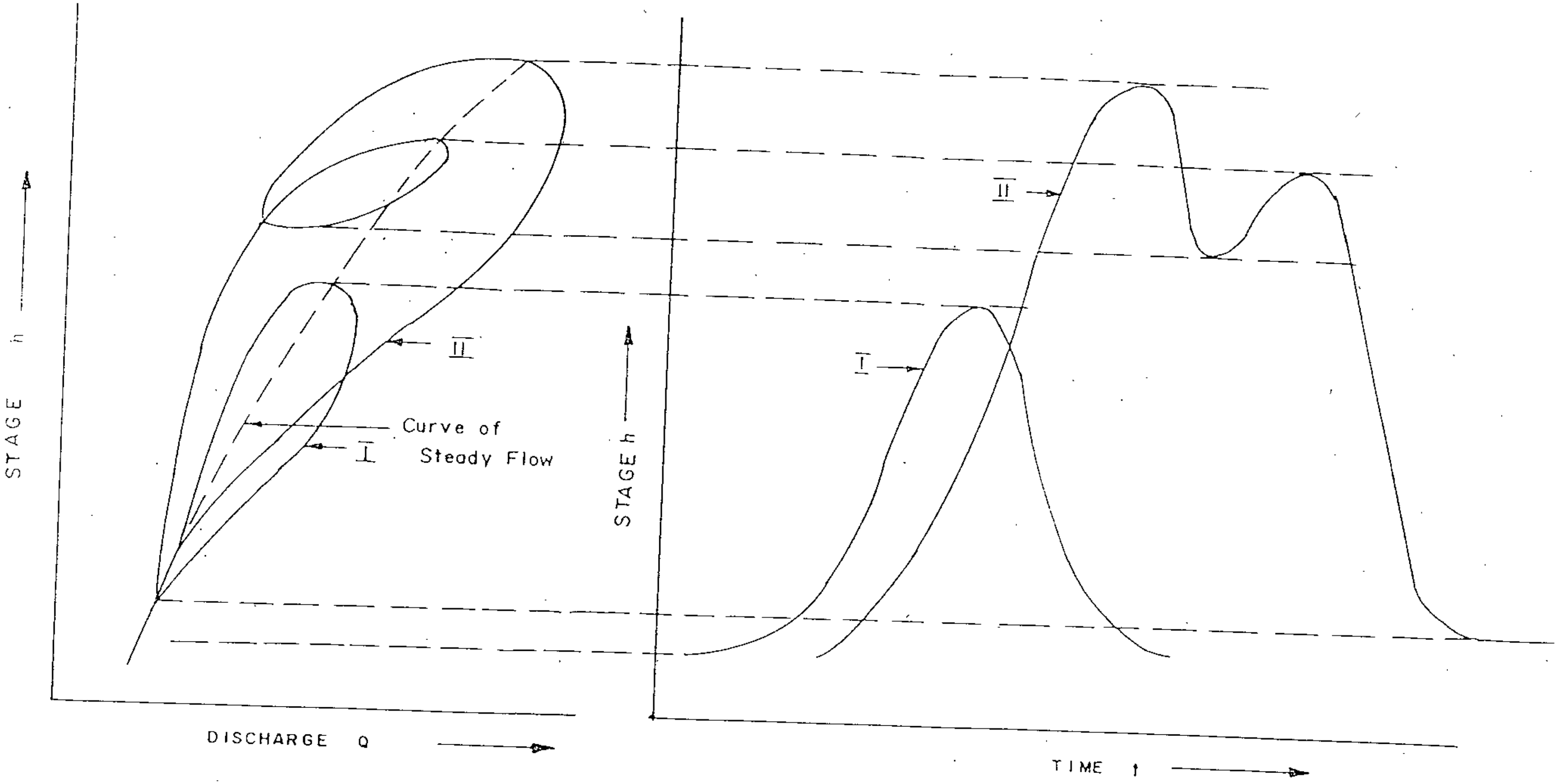


Fig. 2.2 Flood loop for multi peak
Source: UNDP Hydrological Survey Project,UN-DTCD
BGD 72/008 Manual of data processing,1982.

in alluvial channel. Because of changing configuration of the channel bed, stage-discharge relations in alluvial channels are continually changing with time. These changes cause the change of shape and position of stage-discharge relation from time to time and from flood to flood. Fig. 2.3(a) shows the stage-discharge relation for an alluvial channel for North Platte river Torrington Wyo. Two curves have been drawn to define the limits of the stage-discharge relation as determined by measurements made over a period of approximately ten years.

The manner in which the stage-discharge relation for an alluvial stream varies is not completely understood. It is assumed that it shifts between two limiting curves which converge at high stage.

(b). Changing channel configuration. Channel configuration may change as the result of its modification by dredging, the construction of bridges, or the encroachment of phreatic vegetation. Fig. 2.3(b) shows an example of the effects of channel dredging. This channel was cleaned in 1949, at which time the stage-discharge relation moved from curve 1 to curve 2. Following this work, the channel began to fill and to become obstructed by the regrowth of vegetation along its banks. The relation has been moving progressively back toward the original condition, having reached curve 3 by 1960. The dashed curve 4 represents a temporary condition, when ice jams downstream from the hygrometric station caused backwater.

(c). Aquatic vegetation. The effect of the growth of aquatic vegetation is to reduce the channel cross-section and increase the roughness, so it decreases the conveyance, thereby increasing the stage from vegetation free condition for a given discharge. Under vegetation condition, stage-discharge curve deflects to the left of the stage-discharge relation curve of vegetation free condition. When vegetation dies, the curve moves to the right of vegetation growth curve. It should be mentioned that with the increases of discharge, influences of aquatic vegetation will be less . So in large rivers it is negligible.

(d). Backwater. If variable backwater or highly unsteady flow occurs at a gauging station, a single-valued stage-discharge relation does not exist. A third variable, fall or rate of change of stage (also slope, or rate of change of discharge may be used) will have to be included in order to define the discharge rating. This condition is produced when the normal water surface slope is decreased as the result of the normal stage being increased at some point downstream. Backwater is caused by constriction such as narrow reaches of a stream channel or artificial structures such as dams or bridges. If the backwater from fixed obstructions is always the same at a given stage, the discharge rating is a function of stage only.

The effect of backwater is determined by introducing the fall through a reach of channel downstream from the hydrometric station as a third variable. This is graphically incorporated into a three dimensional stage-fall-discharge relation. Stage-fall-discharge rating is established from observation of (a) stage at a base gauge, (b) the fall of water surface between the base gauge and an auxiliary gauge downstream and (c) the discharge.

If stage-fall-discharge is affected by the variable backwater in all stages then correction is applied by constant-fall method. When the relation is affected only when the stage rises above a particular value the normal-fall method is applied.

The effect of stage-discharge relation by variable backwater nearly uniform channel, it is seen that with the increase of fall the curve is shifted toward right.

At some stations a simple single-gauge rating is applicable at low discharge when the surface slope is comparatively steep, while at higher discharges when the slope becomes more flat the discharge is affected by variable backwater. Critical values of the fall dividing these two regions are termed the normal-fall. When the points at which backwater has no effect will group to the extreme right.

(e). Rapidly changing discharge. If the discharge changes rapidly during a measurement, the slope of the water surface will be either greater or less than that for a constant stage, depending on whether the discharge is increasing or decreasing. Where slope is very flat the stage-discharge relation is frequently affected by the superimposed slope of the rising and falling limb of a passing flood wave. During the rising stage the discharge is greater than that for the same stage at steady flow conditions. Similarly for any given gauge height discharge is less than that for the steady flow conditions. So stage-discharge relation form a loop.

(f). Variable channel storage. Some streams occupy relatively small channels during low flows, but overflow onto wide flood plains during high discharges. On the rising stage the flow away from the stream causes a steeper slope than that for a constant discharge and produces a highly variable discharges with distance along the channel. After passage of the flood crest, the water reenters the stream and again causes an unsteady flow, together with a stream slope less than that for constant discharge. The effect on the stage-discharge relation is to produce what is called a loop rating for each flood. This is illustrated by Fig. 2.3(c).

(g). Ice. Ice in a stream cross-section increases wetted perimeter greatly and the resistance to flow also increases and the reduces cross-sectional area, thus the stage for a given discharge is increased. The effect of ice formation and thawing is very complex and the temporal stage-discharge relation can only be determined by a series of discharge measurements, using stage, temperature and precipitation records as a guide for interpolation between measurements.

2.5 Theory of the Logarithmic Rating Curve

The Chezy uniform flow formula is

$$V=C\sqrt{RS}$$

in Which V is the mean velocity, C is a factor of flow resistance, R the hydraulic radius and S the slope of the energy line.

Discharge is given by

$$Q=AV=AC\sqrt{RS}=AC\left[\frac{AS}{P}\right]^{\frac{1}{2}}$$

in which Q is the discharge, A the cross-sectional area and P is the wetted perimeter.

For rectangular cross-section

$$A=WD,\quad P=W+2D,\quad R=\frac{WD}{W+2D},$$

or $$Q=CWD\left[\frac{WDS}{W+2D}\right]^{\frac{1}{2}}=CWS^{\frac{1}{2}}D^{\frac{3}{2}}\left[\frac{W}{W+2D}\right]^{\frac{1}{2}}$$

in which W is the width and D the water depth.

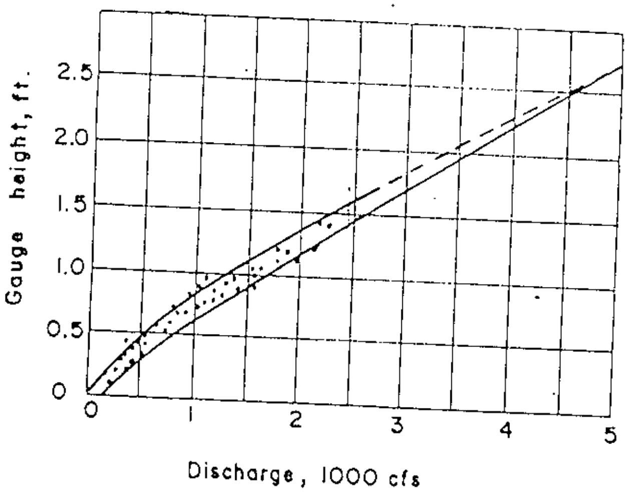


Fig. 2.3(a) Stage-discharge relation for an alluvial channel for North Platte River at Toorrington, Wyo(U.S. Geological Survey.)

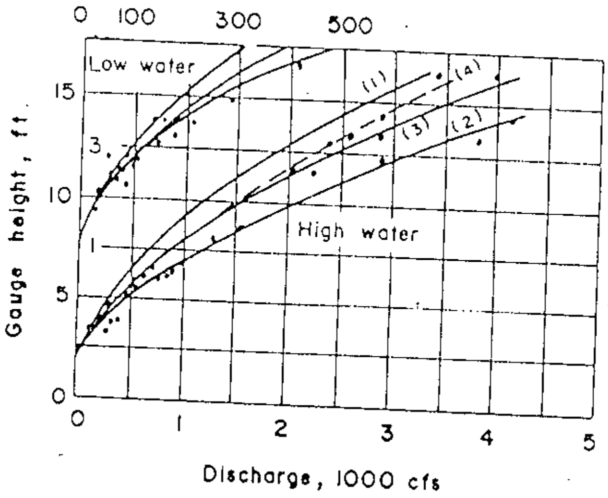


Fig. 2.3(b) Shifting of stage-discharge relation caused by dredging for little Wabash River near Huntington,Ind. (U.S.Geological Survey.)

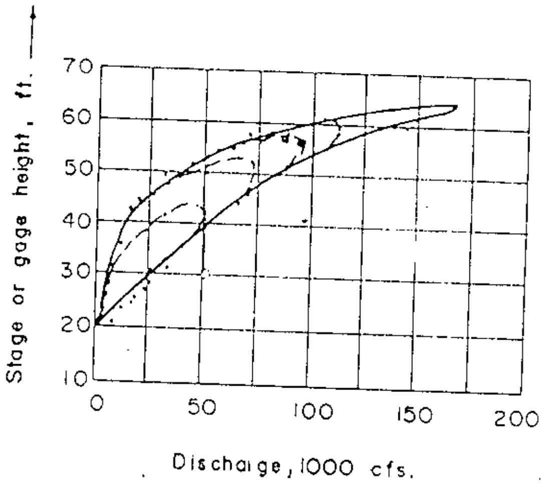


Fig. 2.3(c) Stage-discharge relation for variable channel storage Black Warrior River at Tuscaloosa Ala.(U.S. Geological Survey.)

Source: Chow,V.T,Hand book of Hydrology,1964.

For a very wide channel, $(W+2D)$ is approximately equal to W. Hence the equation becomes

$$Q = CWS^{1/2}\, D^{3/2}$$

$$= KD^{3/2} \tag{2.1}$$

where $K = CWS^{1/2}$ is a constant.

D = effective head or depth to zero flow.

For gauge height h and for gauge reading at zero flow a. eqn (2.1) can be written as

$$Q = K\,(h-a)^{3/2} \tag{2.2}$$

Similarly it can be shown for section of other shapes

$$Q = K(h-a)^{(2m+1)/2}$$

where m = 1 for rectangular section

= 3/2 for a concave section of parabolic shape

= 2 for a triangular section

The general equation relating stage with discharge is therefore as follows:

$$Q = K\,(h-a)^{n} \tag{2.3}$$

For very wide streams where $W = W+2D$, eqn (2.1) is valid and exponent n is equal to 3/2. For deep narrow streams, where $W << (W+2D)$, effect of increasing exponent in eqn (2.1), changes in the factor of flow resistance C and slope S with stage will also affect the exponent. The net result of all of these factors is that the exponent in eqn (2.3) for relatively wide rivers with channel control will generally vary from 1.3 to 1.8. For relatively deep narrow rivers with section control, the exponent n will almost always be greater than 2.0 and may often exceed a value of 3.0.

For very irregular channels or for non uniform flow, eqn (2.3) cannot be expected to apply throughout the whole range of stage. Sometimes the curve changes from a parabolic to complex curve or vice versa. Sometimes the constants and exponents vary throughout the range.

The logarithmic rating equation is rarely a straight line or a gentle curve for the entire range in stage at a gauging station. Even if the same channel cross-section is the control for all stages, a sharp break in the contour of the cross-section causes a break in the slope of the rating curve. The constants in eqn (2.3) are related to the physical characteristics of the contour of channel section.

If the control section changes at various stages, it may be necessary to fit two or more equations each corresponding to the portion of the range over which the control is applicable.

If, however, too many changes in the parameters are necessary in order to define the relation, then discharge eqn (2.3) may not be suitable and for that case a curve fitted by visual estimation would be better.

The first derivative of the eqn (2.3) is a measure of the change in discharge resulting from a corresponding changing in stage.

The first derivative is

$$\mathrm{d}Q/\mathrm{d}h = Kn\ (h-a)^{n-1}$$

The second-order differences are obtained by differentiating again.The second derivative is

$$\mathrm{d}^2Q/\mathrm{d}h^2 = Kn\ (n-1)\ (h-a)^{n-2}$$

An examination of the second derivative shows that the second-order differences increase with stage when n is greater than 2 i.e. for section control and decrease with stage when n is less than 2.0 i.e. for channel control.

2.6 Determination of Stage-Discharge Relationship

Power type equation expressing stage-discharge relation, as given by eqn (2.3) is as follows:

$$Q = C(h-a)^n \tag{2.3}$$

Alternatively stage-discharge relation may also be expressed by parabolic functions of the form :

$$Q = a_1 + b_1(h-a) + c_1(h-a)^2 \tag{2.4}$$

The relation between stage and discharge is determined by correlating measurements of discharge with corresponding observations of stage. This correlation may conveniently be done using least-squares procedure after determining gauge height of effective zero flow. The steps for determine the gauge height of effective zero flow are described below:

2.6.1 Determination of gauge height of effective zero flow

The gauge height of effective zero flow can be determined by (i) trial and error procedure or by (ii) graphical procedure.

(i) Trial and error procedure. All measured discharges are plotted against corresponding stage on log-log paper and a median line is drawn through the scatter data points. Usually this line will be a curved line. Various trial values of a are assumed,one value for each trial is subtracted or added to the gauge heights of the measurement to obtain values of $(h-a)$. Discharge Q versus $(h-a)$ are then plotted on log-log scale until the plot obtained form a straight line. The trial value forming a straight line is the required value of a, which is the gauge height of effective zero flow. All the plotted data points may be used in the trial operation. However it is better to use only a few points selected from the median line first fitted to the points.

(ii) Graphical procedure.

(a) A more direct graphical solution for gauge height of zero flow as described by Johnson (1952) is illustrated in Fig. 2.4(a). Measured discharges are plotted against corresponding stages on arithmetic paper. A smooth curve is drawn through the scatter data points by visual estimation. Three values of discharge Q_1, Q_2 and Q_3 are selected on geometric progression such that $Q_3^2 = Q_1\ Q_2$. Let h_1, h_2 and h_3 be the gauge heights read from the curve corresponding to the values of Q_1, Q_2 and Q_3 respectively. In accordance with the properties of a straight line on logarithmic plotted paper.

$$(h_3-a)^2 = (h_1-a)\ (h_2-a) \tag{2.5}$$

Expansion of term in eqn (2.4) leads to eqn (2.5) which provides a direct solution for a

$$a=\frac{h_1h_2-h_3^2}{h_1+h_2-2h_3} \tag{2.6}$$

(b) This method developed by Prof. Running. The method is based on the assumption that lower portion of the discharge curve containing three points (a, b and c), all lie on a parabola shown in Fig. 2.4(b).

All discharge measurements are plotted on arithmetical graph paper. An average line is drawn through the scatter points has resulted in the solid curved line. Three values of discharge are selected from known portion of the curve, one of these values should be near the lower end of the curve and the other value should be near the upper end of the curve. Then the third intermediate value should be so chosen that all the three values are in geometrical progression. Let these three values are represented by a, b and c in Fig 2.4(b) respectively. Vertical lines are drawn through a and b and horizontal lines are drawn through b and c. So as to intersects the vertical at d and e respectively as shown in Fig 2.4(b). A straight line is drawn through e and d. Another line is also drawn through a and b (join of a and b), these two lines intersects at f. This point f represents the elevation of the gauge height at zero flow. Hence the elevation of the point f is the value of *a*, the gauge height of effective zero flow.

Effect of gauge height of effective zero flow on the shape of rating curve. We assumed a value of gauge height at zero flow *a*, by which the established rating curve in logarithmic paper is linear. If the control is in scour then the value of *a* decreases, for a given gauge height (h), the depth ($h-a$) increases the new rating curve moves to the right will no longer be a straight line but will be a curve that is concave downward. If the control becomes built up by deposition the value of *a* increases and for a given gauge height, the depth ($h-a$) decreases and the new rating curve moves to the left and is no longer linear but is a curve that is concave upward.

2.6.2 Determination of Exponent and Co-efficient of Stage-discharge Equation

There are a number of methods available to determine the coefficient and exponent of power function of the form $Q=C(h-a)^n$ and parabolic of the form $Q= a_1+ b_1(h-a)+ c_1(h-a)^2$ Method of least squares widely used is described below:

Method of Least Squares. This method is consists of estimation of parameters by fitting a theoretical function to an empirical distribution, or any other empirical curve. The

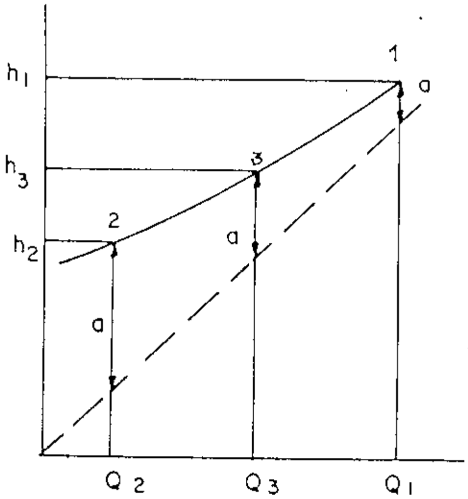


Fig. 2.4(a) Schematic representation of the linearization of a curve on logarithmic paper.
Source: WMO, Operational Hydrology,1980.

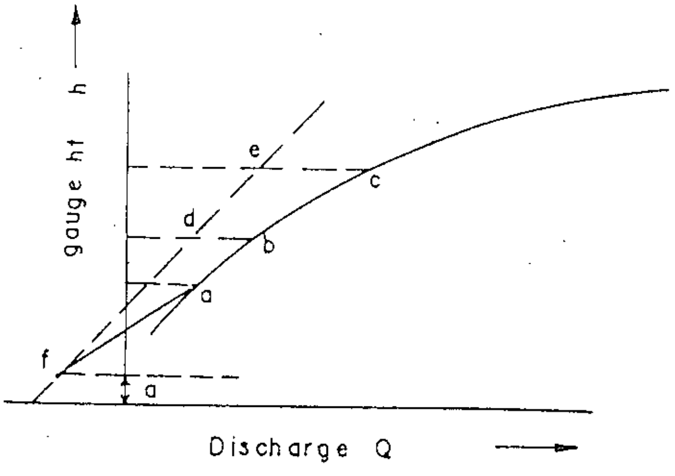


Fig. 2.4(b) Running method for determination of elevation of zero flow. Source: Garg.S.K, Irrigation and hydraulic Structures,1981.

sum of square of all deviations of observed points from the fitted function is then minimized to produce least square.

A function Y = f (X; α, β, γ ......) is to be fitted to data by determining the best estimates a, b, c, ..., of α, β, γ ..., the analytical method of least squares minimizes the sum

$$S = \Sigma\, e_j^2 = \Sigma\,(Y_j - Y)^2 = \Sigma\,[\, Y_j - f\,(X;\, \alpha,\, \beta,\, \gamma\, ...)]^2 \qquad (2.6)$$

in which X_j, and Y_j are coordinates of observed points, α, β and γ are replaced by their estimates *a*, *b* and *c*, *N* is the sample size. To obtain the minimum sum of square of eqn (2.6), all partial derivatives of this sum with respect to parameters a, b, c, ... should be zero, so that

$$\frac{\partial S}{\partial a} = \frac{\partial \sum (y_i - y)^2}{\partial a} = 0, \qquad \frac{\partial S}{\partial b} = \frac{\partial \sum (y_i - y)^2}{\partial b} = 0 \qquad (2.7)$$

These partial derivatives give m equations for the determination of m parameters.

(a) Power Type Stage-discharge Equation. Power type stage-discharge relation is $Q = C(h-a)^n$.The value of *a* which yields a perfect linear fit is taken as the gauge reading at effective zero flow . This *a* value and corresponding *C* and *n* values define the rating equation. The values of *C* and *n* is determined by the method of least squares.

Power type stage-discharge relation $Q = C(h-a)^n$ can be written as $Q = CH^n$ where $H = (h-a)$. This equation can simply be transformed to a linear function by taking logarithms so that $\log Q = \log C + b \log H_j$ Then from eqn (2.6) we can write

$$S = \Sigma e_j^2 = \Sigma(\log Q_j - \log Q)^2 = \Sigma\,[\log Q_j - (\log C + n \log H_j)]^2$$
$$= \Sigma(\log Q_j - \log C - n \log H_j)^2$$

According to the basic condition of the method of least squares from eqn (2.7)

$$\frac{\partial S}{\partial \log C} = -2\sum (\log Q_i - \log C - n\log H_i) = 0$$

$$\frac{\partial S}{\partial n} = -2\sum \log H_i (\log Q_i - \log C - N\log H_i) = 0$$

These equations can then be written in the following form.

$$\Sigma \log Q_i = N \log C + \Sigma \log H_i$$

and $\Sigma \log H_i \log Q_i = \log C \, \Sigma \log H_i + n \, \Sigma \log H_i^2$

The solution of these equations gives the estimates log a and b which are as follows:

$$n = \frac{N\, \Sigma \log H \, \log Q - \Sigma \log H \, \Sigma \log Q}{N\, \Sigma (\log H)^2 - (\Sigma \log H)^2}$$

and $\log C = (\Sigma \log Q - n\, \Sigma \log H_i)/N$

$= \log Q - N \log H_i = \mathrm{K}$ (say)

$\therefore \ \log C = \mathrm{K}$ so $C = 10^{\mathrm{K}}$

Parabolic Stage–Discharge Equation. Parabolic stage–discharge equation $Q = a_1 + b_1(h-a) + c_1(h-a)^2$ can be written as $Q = a_1 + b_1 H + c_1 H^2$, where $(h-a) = H$. From the eqn (3.1) we can write

$$S = \Sigma e_i^2 = \Sigma (Q_i - Q)^2 = \Sigma [Q_i - (a_1 + b_1 H_i + c_1 H_i^2)]^2$$
$$= \Sigma (Q_i - a_1 - b_1 H_i - c_1 H_i^2)^2$$

These sum can be minimized with respect to a_1, b_1 and c_1 by taking the partial derivatives of S with respect to a_1, b_1, and c_1 and setting the resultant equation to zero.

$$\frac{\partial S}{\partial a_1} = -2\Sigma (Q_i - a_1 - b_1 H_i - c_1 H_i^2) = 0 \qquad \frac{\partial S}{\partial b_1} = -2\Sigma H_i (Q_i - a_1 - b_1 H_i - c_1 H_i^2) = 0$$

$$\frac{\partial S}{\partial c_1} = -2\Sigma H_i^2 (Q_i - a_1 - b_1 H_i - c_1 H_i^2) = 0$$

These equations can then be written in the following form known as normal equations.

$$\Sigma Q_i = N a_1 + \Sigma H_i + c_1 \, \Sigma H_i^2$$
$$\Sigma H_i Q_i = a_1 \, \Sigma H_i + b_1 \, \Sigma H_i^2 + c_1 \, \Sigma H_i^3$$
$$\Sigma H_i^2 H_i = a_1 \, \Sigma H_i^2 + b_1 \, \Sigma H_i^3 + c_1 \, \Sigma H_i^4$$

By solving above three equations the estimates of a_1, b_1 and c_1 can be determined.

2.7 Uncertainty in the Stage–Discharge Relation

Populations are rarely known in sciences like hydrology, the population properties of random variables must be estimated from the available data. Inaccurate, deficient or biased data are usually always available and population properties must be estimated from these data by some techniques, various errors and information losses are represented as uncertainty are decreased or optimized by obtaining better data and by using better statistical technique.

2.7.1 Sources of Uncertainties

The sources of uncertainties may be identified by considering a generalized form of the working equation used for gauging by the velocity area method:

$$Q = \Sigma\ b_i\ d_i\ .\ \overline{V}_1$$

where Q is the total discharge; b_i, d_i and v_i are the width, depth and mean velocity of the water in the ith of the m verticals or segments into which the cross-section is divided. The overall uncertainty in the discharge is then composed of:

a). Uncertainties in widths;
b). Uncertainties in depths;
c). Uncertainties in determination of local point velocities;
d). Uncertainties in the use of the velocity area method.

(a) Uncertainties in Width. The measurement of the width between verticals is normally based on distance measurements from a reference point on the bank. If the determination is based on the use of a tag line or measurement of the movement of the wire in the case of a trolley suspension, then the uncertainty in the distance measurement is usually negligible. Where optical means are used to determine the distances, the uncertainty will depend on the measured distance.

(b) Uncertainties in Depth. The uncertainties in depth shall be determined by the user, based on the particular method which has been adopted, with due regard to variations in water level during the measurement.

(c) Uncertainties in Determination of Local Point Velocities. These will depend on the accuracy of the apparatus and the technique employed, and on the irregularity of the velocity distribution in time and space.

Random uncertainties in determination of the mean velocity. It is not possible to predict accurately the uncertainties which may arise, but there are four main sources, the first arising from the limited time of exposure of the current meter, the second arising from the use of a limited number of points in a vertical, the third arising from the uncertainty in the current meter rating, and the fourth arising from the use of a limited number of verticals.

(i) Time of Exposure. The velocity of any point in the cross-section is continuously and randomly fluctuating with time. Hence a single measurement over a period of say 60 sec is one sample which may differ from that found over a very long period. In practice it is found that time of exposure decreases with an increase in velocity.

(ii) Number of Points in a Vertical. As a general rule, the uncertainty decreases as the number of points per vertical increases. It should be noted that, in the case of the integration method, the measurement is continuous and the two sources of uncertainty, i.e. for the number of points and the determination of local point velocities, cannot be separated. The integration method is therefore subjected to a single source of uncertainty only on this account.

(iii) Current Meter Rating. A small uncertainty will arise in the calibration of the current meter. This will have both a random component and a systematic component, the former arising from the spread of the calibration points about the line of best fit and the latter from any systematic shift of that line or systematic error in the rating tank.

(iv) Number of Vertical. The value of the uncertainty depends not only on the number of vertical but also on the size and shape of the channel, the variations in the bed profile and the horizontal distribution of the velocity profile. It follows that the value in any particular channel will be peculiar to that channel alone. It can only be determined precisely if the discharge can be measured separately by some more accurate method or if an extensive investigation of the flow at the cross-section of the channel has already been made (Herechy 1978). The uncertainty from this cause decreases with an increase in the number of vertical.

(d) Uncertainties in the Use of the Velocity-Area Method. Particularly those concerned with the number of vertical and the number of points in each vertical. These uncertainties will also depend on the width of the channel, the ratio of width to depth, and the method of computation used.

2.7.2 Measurement of Uncertainty

Uncertainty can be measured by the standard error. If we let $\hat{Y}$ represent the value of Y for a given values of X as estimated from the equation Y = a+bX. Then a measure of the scatter about the regression line of Y on X is

$$S_{y.x}=\sqrt{\frac{\sum (Y-\hat{Y})^2}{N}}$$

which is called the standard error of estimated of Y on X. Standard error of estimate can be determined in various way are as follows:

(a) The values of Y as estimated from the regression line are given by $\hat{Y}$ = a+bX. Then

$$S^2_{y.x}=\frac{\sum (Y-\hat{Y})^2}{N}=\frac{\sum (Y-a-bX)^2}{N}$$

$$=\frac{\sum Y(Y-a-bX)-a\sum (Y-a-bX)-b\sum x(Y-a-bX)}{N}$$

We know Y = a+bX From which we get the normal equations

$\Sigma Y = aN+b\Sigma X$ or, $\Sigma Y-aN-b\Sigma X = 0$

$\Sigma XY = a\Sigma X+b\Sigma X^2$ or, $\Sigma XY - a\Sigma X - b\Sigma X^2 = 0$

But $\Sigma(Y-a-bX) = \Sigma Y-aN-b\Sigma X = 0$

$\Sigma X (Y-a-bX) = \Sigma XY - a\Sigma X - b\Sigma X^2 = 0$

So we get

$$S^2_{y.x}=\frac{\sum Y(Y-a-bX)}{N}=\frac{\sum Y^2-a\sum Y-b\sum XY}{N}$$

(b) We know equation of linear regression line is

$$Y = a+bX \tag{2.8}$$

Since regression line always pass through the centroid $(\overline{X},\overline{Y})$, So Eqn (2.8) can be written as

$$\overline{Y}=a+b\overline{X} \tag{2.9}$$

Eqn (2.8) - eqn (2.9) gives

$$(\hat{Y}-\overline{Y}) = b(X-\overline{X})$$

$$\sum (\hat{Y}-\overline{Y})^2 = b^2 \sum (X-\overline{X})^2$$

We know

$$N\ S_X^2 = \sum (X-\overline{X})^2, \qquad N\ S_Y^2 = \sum (Y-\overline{Y})^2$$

So Standard error of estimate of Y on X is

$$S_{Y.X} = \sqrt{\frac{\sum (Y-Y)^2}{N}}, \qquad N\ S_{YX}^2 = \sum (Y-Y)^2$$

We know

Total Variation = Unexplained Variation + Explained Variation

$$\sum (Y-\overline{Y})^2 = \sum (Y-\hat{Y})^2 + \sum (\hat{Y}-\overline{Y})^2$$

$$N\ S_Y^2 = N\ S_{Y.X}^2 + b^2 \sum (X-\overline{X})^2 \quad N\ S_Y^2 = N\ S_{Y.X}^2 + b_2 N S_X^2 \quad S_{Y.X}^2 = (S_Y^2 - b^2 S_X^2)$$

The standard error of estimate has properties analogous to those of standard deviation. If we construct lines parallel to the regression line of Y on X at respective vertical distances $S_{Y.X}$, $2S_{Y.X}$ and $3S_{Y.X}$ from it, then we can find if N is large enough, about 68%, 95% and 99.7% of the sample points will be lied between the lines respectively.

We know linear regression line of Y = a + bx must pass through the centriodal point $(\overline{X}, \overline{Y})$ it intersects the Y axis at a distance "a" from the origin, and has a slope b. In other words, there are three known parameters two of which are sufficient to draw the regression line. With two constraints the number of degrees of freedom lost is two. Therefore if N is the number of pairs (X_i, Y_i), the number of degrees of freedom = N-2

For degree of freedom $\nu = N - 2$. Standard error of estimate of Y, (S_e) on X can be written as

(a) $$S_e=\sqrt{\frac{\sum (Y-\hat{Y})^2}{N-2}}$$

(b) $$S_e=\frac{\sum Y^2-a\sum Y-b\sum XY}{N-2}$$

(c) $$S_e=\frac{(S_Y^2-b^2S_X^2)^{1/2}}{N-2}$$

Modified standard deviation is $\hat{S} = \sqrt{\frac{N}{N-1}S}$ for small sample, similarly modified standard error of estimate can be written $S_{Y.X}=\sqrt{\frac{N-1}{N-2}}S_{Y.X}$. So modified form of derived last standard error of estimate can be written as

$$S_e=[(\frac{N-1}{N-2})(S_Y^2-b^2S_X^2)]^{1/2}$$

Power type equation of stage-discharge relation is $Q = C(h-a)^n$. To linearize this taking logarithm on both sides gives, $\log Q = \log C + n \log (h-a)$ which is similar to the equation, $Y = A+BX$ where $Y = \log Q$, $A = \log C$ and $X = \log (h-a)$.

For power type equation standard errors of estimate derived before can be written as follows:

(a) $$S_e(\log_e Q)=\sqrt{\frac{(\log Q-\log\hat{Q}_c)}{N-2}}$$

(b) $$S_e(\log_e Q)=\frac{\sum(\log Q)^2-\log c\sum\log Q-b\sum\log(h-a)\log Q}{N-1}$$

(c) $$S_e(\log_e Q)=[\frac{(N-1)}{(N-2)}(S^2_{\log Q}-b\ S^2_{\log(h-a)}]^{1/2}$$

Above equations contain natural logarithmic and gives the standard errors in absolute terms. To get standard error as a percentage, $S_e(\log_e Q)$ to be multiplied by 2.30 and by 100 if the calculation is carried out using logarithms to the base 10.

Standard error of estimate $S_e(Q)$ as percentage can be determined provided a logarithmic distribution is used to establish the rating equation as follows:

$$S_e(Q) = \pm\left[\frac{\Sigma\left(\frac{Q-Q_c}{Q_c}\times 100\right)^2}{N-2}\right]^{\frac{1}{2}}$$

where Q_c, the calculated discharge from rating curve.

2.8 Reliability of the Stage-Discharge Curve

The stage-discharge curve obtained from the observed stages and discharges gives the mean relationship between stage and discharge. Thus, the deviation of a measured discharges from the stage-discharge curve, within the limits of reliability of the curve gives (or signify) an estimate of the observational error.

The reliability of the stage-discharge curve generally be assessed by one or more of concepts:

1. Acceptance limits for the discharge observations
2. Confidence limits of the stage-discharge curve.

2.8.1 Acceptance limits for the stage-discharge observations.

The standard deviation is the square root of the mean of squares deviation from the mean and is a measure of the degree of scatter or dispersion of observed values around their arithmetic mean. It is one of the important statistical measures. The basic assumptions for a valid estimation of the standard deviation (i.e. the standard deviation of the error of the observation) are that the error of the observation be normally distributed and independent. Usually sufficient number of observations are not available for making valid estimates of the standard deviation over the range of stage. As the errors are known to be proportional to discharge over a range having same control, a pooled estimate of the percentage of standard deviation is used.

Percentage of standard deviation may be calculated from the percentage deviations of discharge taking all the observations together are as follows.

$$P = \frac{(Q_{obs} - Q_c) \times 100}{Q_c} \%$$

$$S_D = \sqrt{\frac{(P - \overline{P})^2}{N-1}}$$

Where, P = percentage deviation

$\overline{P}$ = mean percentage deviation

Q_{obs} = observed discharge

Q_c = discharge estimated by rating curve

S_D = percentage standard deviation

N = number of discharge measurements.

A pair of curves, one each sides at a distance of twice the standard deviation form the stage-discharge curve is called the control curves and defines the 95% acceptance limits of the discharges at the corresponding stages. On an average, in 19 out of every 20 measurements, results should be within these limits. Any point lying beyond the limit of 3 times the standard deviation can be regarded as the result of faulty measurement. In those cases where more than one consecutive point, either chronologically or over a range of stage, appear to be well on one side of one of the limits, of two standard deviation where this occurs, a change of the stage-discharge curve is probable. Which means that the calibration of the station has to be repeated, or a different stage-discharge curve is required due to a shift in control.

2.8.2 Ninety five percent confidence limits of stage-discharge Curve

The standard error of estimate $S_e(Q)$ of the stage-discharge relation may be determined by the article 2.7.2. The uncertainty in Q in power type equation like $Q = (h-a)^B$ with N number of observations is expressed as a percentage is given by

$$X_Q = tS_e(Q) \left[\frac{1}{N} + \frac{(\log_e(h-a) - \overline{\log_e(h-a)})^2}{\Sigma(\log_e(h-a) - \overline{\log_e(h-a)})^2}\right]^{\frac{1}{2}} x100$$

where t = student "t" correction at the 95 percent confidence level for N gauging X_Q is also referred to as 95% confidence limit of Q or as standard error of the mean relation S_{mr}, S_{mr}

at each observation of $(h-a)$ is calculated and the limit will be curve one each side of the stage discharge relation and shall be minimum at the mean i.e. at $\overline{\log(h-a)}$. Standard error of mean relation at the mean is calculated by $S_{mr} = \dfrac{t\ S_e(Q)}{\sqrt{N}}$

Points at a distance of twice the standard error (S_e) on either side of the stage-discharge curve, the pair of curves are called the 95% confidence limits. These limit define the band-width for which there is a probability of 95% that the true curve lies within these limit.

2.8.3 Tests for absence from bias and goodness of fit

The tests enumerated below may be applied to portions of curves, each individual portion being tested for bias separately.

Absence from Bias (signs). The number of positive and negative deviations of the observed values from the stage-discharge curve drawn by visual estimation shall be evenly distributed, i.e. the difference in number between the two shall not be more than can be explained by chance fluctuations.

The test is applied to find out if the curve has been drawn in a sufficiently balanced manner so that the two sets of discharge values, observed and estimated (from the curve), may be reasonably supposed to represent the same population. This is a very simple test and can be performed by counting the observed points falling on either side of the curve. If Q_i is the observed value and Q_c the estimated value, then $Q_i - Q_c$ should have an equal chance of being positive or negative. In other words, the probability of $Q_i - Q_c$ being positive is 1/2. Hence, assuming the successive signs to be independent of each other, the sequence of the differences may be considered as distributed according to the binomial law $(p + q)^N$, where N is the number of observations, and p and q, the probabilities of occurrence of positive and negative values, are 1/2 each. The statistic t

$$t=\frac{|n-Np|-0.5^{*}}{\sqrt{Npq}}$$

Where

N = Number of observations
n = Number of positive signs
p = Probability of sign being positive
q = Probability of sign being negative
Np = Expected number of positive signs
* continuity correction.

This value of t is tested with the percentage of significant level.

Absence from Bias (values). This test is carried out to determine whether a particular stage-discharge curve, on average, yields significant under-estimates or over-estimates as compared to the actual observations on which it is based. The percentage differences,

$$\frac{(Q_i-Q_c)\times 100}{Q_c}=P$$

are worked out and averaged $(\overline{P})$. If there are N observations and P_1, $P_2 \ldots P_i \ldots P_N$ are the percentage differences, and if $\overline{P}$ is the average of these differences, the standard error S_e of $\overline{P}$ is given by:

$$S_e=\sqrt{\frac{\sum (P_i-\overline{P})^2}{N(N-1)}}$$

The average percentage $\overline{P}$ is tested against its standard error to see if it is significantly different from zero.

The percentage differences have been taken as they are somewhat independent of the discharge volume and are approximately normally distributed about a zero mean value for an unbiased curve. The statistic t

$$t = \frac{\overline{P}}{S_e}$$

Where

$\overline{P}$ = Average of percentage differences

S_e = Standard error of $\overline{P}$

This value of t is tested with the percentage of significant level.

Goodness of Fit. This test is carried out for long runs of positive and negative deviations of the observed values from the stage-discharge curve. This test is designed to ensure a balanced fit in reference to the deviations over different stages.

This test is based on the number of changes of sign in the series of deviations (observed value minus expected value). Write down the signs of deviations in discharge measurements in ascending order of stage, and, starting from the second sign of the series, write under each *0* of the sign agrees or *1* if it does not agree with the sign immediately preceding. For example:

$$\begin{array}{ccccccccc} + & - & + & + & + & - & - & + & + \\ & 1 & 1 & 0 & 0 & 1 & 0 & 1 & 0 \end{array}$$

if there are N observations in the original series, there will be $(N - 1)$ numbers in the derived series *11001010*.......

If the observed values could be regarded as arising from random fluctuations about the values estimated from the curve, the probability of a change in sign could be taken to be 1/2. It should be noted that this assumes that the estimated value is a median rather than a mean. If N is fairly large (say 25 or more) a practical criterion may be obtained by assuming successive signs to be independent (i.e. by assuming that they arise only from random fluctuations), so that the number of "*1*" (or "*0*" s) in the derived sequence of

$(N-1)$ members may be judged as a binomial variable with parameters $(N-1)$ and 1/2. The statistic t

$$t=\frac{|n-(N-1)p|-0.5}{\sqrt{(N-1)pq}}$$

Where

N = Number of observations

n = Number of changes in signs

p = Probability of changes in sign

q = Probability no changes in sign

$(N-1)\,p$ = Expected number of changes in sign.

This value of t is tested with the percentage of significant level.

Further, for goodness of fit, the standard deviation of the percentage deviations should be as low as possible, consistent with the smoothness of curve. No simple test is possible to check the smoothness of curve. As a rule, this should not be greater than the percentage standard deviation of the error of discharge measurements by the method used.

2.9 Shifting Control

The term shifting control as ordinarily used in connection with measurement of flow in open channel refers to that condition where stage-discharge relation don't remain permanent but vary from time to time,either gradually or abruptly, because of changes in the physical features that form the control for the station.

Shifts in control features occurs especially in alluvial sand bed streams. The primary cause of changes in natural section controls is the high velocity associated with high discharge.Stream channel shift will also occurs at low flow because of aquatic and vegetal growth in the channel or due to debris caught in the control section.

The stage-discharge relation usually changes with time either gradually or abruptly due to scour and silting. Once a gauging station has been calibrated and the stage-discharge curve has been drawn it is required to keep a careful watch to ascertain weather subsequent check gauging indicate any departure from the established relationship.

Changes in bed conditions over a long time may be detected from a study of the specific stage-discharge curves. In this method the observed stages with respect to specific discharges are plotted against time for a number of years. If the stage for the same discharge plot more or less horizontally with reasonable degree of scatter, then the channel may be taken as fairly stable, and it may be assumed that there no significant changes with time in the bed condition on account of erosion or silting action. For making adjustment for shifting control the Stout Method is commonly used.

The Stout Method. In this method, the gauge height corresponding to discharge measurements taken at intervals are corrected so that the discharge values obtained from the established rating curve may be same as the measured values. From the plot of these corrections against the chronological dates of measurements, a gauge height correction curve is made. Corrections from this curve are applied to the recorded gauge heights for the intervening days between the discharge measurements.

A staff gauge is established at the best available site on the river and reading taken at appropriate intervals say once a day. Discharge measurements are made as often as once or twice a week

The measured discharge are plotted against observed gauge height on ordinary scale and a median curve is fitted to the points. Most of the subsequent discharge measurements will deviate from the established curve. For points lying above the curve,a small height Δ h,is subtracted from the observed gauge height in order to make these points lie on the curve.That is, minus corrections are applied to all points above the curve, plus corrections are applied to points lying below the curve (Fig.2.5).

Next, a correction graph is made as shown in Fig.2.5, the plus and minus corrections are plotted on the date of measurements and the points connected by straight lines or a smooth curve. Gauge height corrections for each day are obtained directly from this

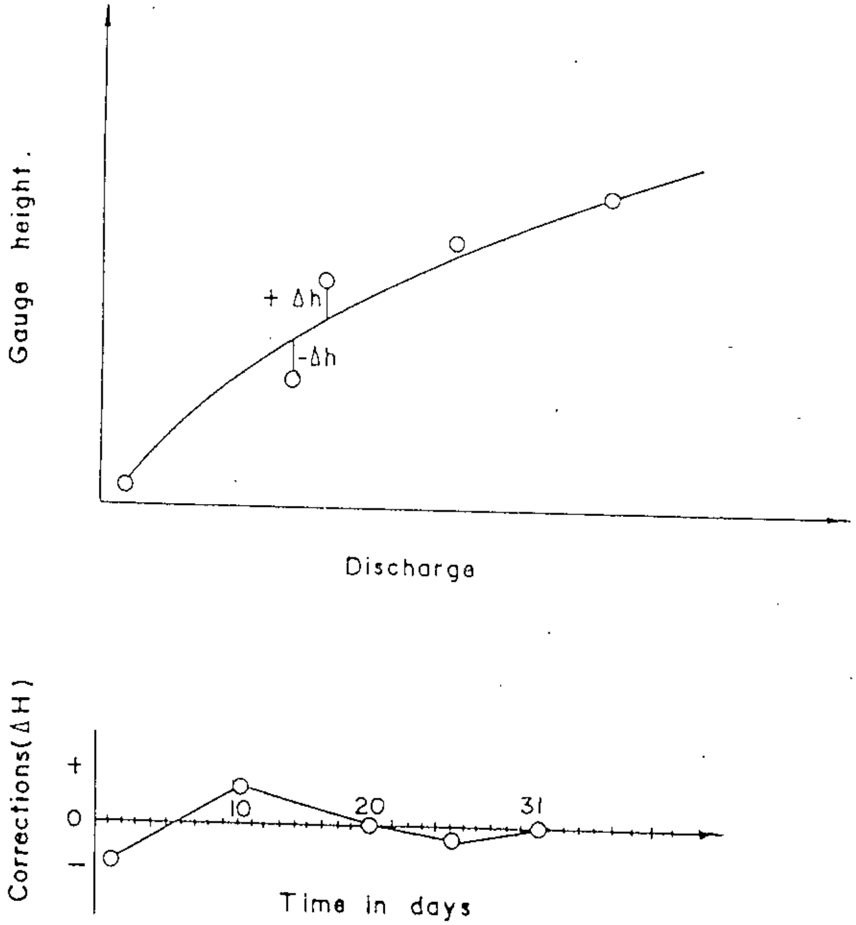


Fig. 2.5 The Stout method for correcting stage reading when control is shifting.
Source: Herschy W.Reginal,Stream flow Measurement,1985.

corrections graph. The parts of the graph below the abscissa axis give minus corrections and the parts above give plus corrections.

2.10 Discharge Rating in Sandy-streams

In alluvial sand-bed streams, the stage-discharge relation usually changes with time, either gradually or abruptly, due to scour and silting in the channel and because of moving sand dunes and bars. These variations cause the change the shape and position of stage-discharge relation with both time and magnitude of flow and also from flood to flood.

2.10.1 Mean depth-discharge Relations

A plot of stage against discharge in sandy stream often gives indistinct hydraulic relationship. Thus hydraulic relation between stage discharge is indeterminate. This is because neither the bottom nor the sides of these streams are fixed. Plot of stage against discharge relation for Huerfano River near Undercliffe, Colorado for 1941 and 1942 is shown in Fig. 2.6. The relation between stage and discharge is indeterminate.

The effect of variation in bottom elevation is eliminated by replacing stage by hydraulic radius or mean depth for wide channel. Determination of the elevation of zero flow is difficult. So determination of the elevation of zero flow can be avoided if one use hydraulic radius or mean depth in case of wide channel instead of stage. So attempted can be made to correlate hydraulic radius or mean depth with discharge.

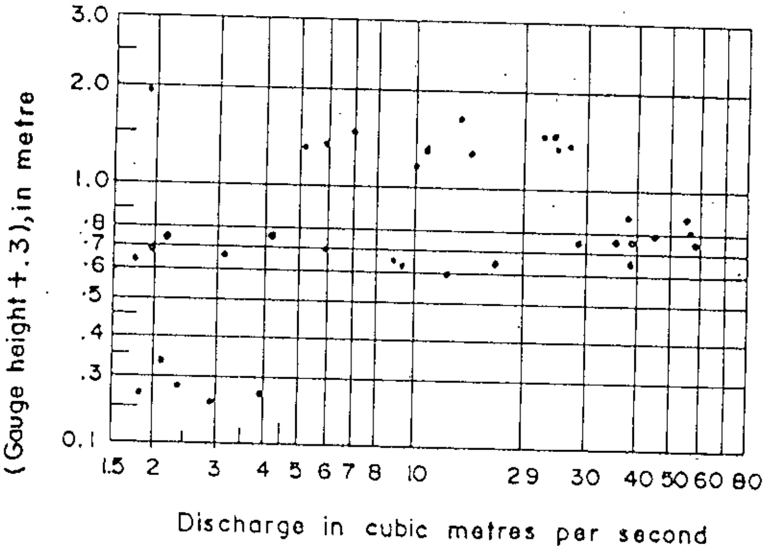


Fig. 2.6 Stage-discharge relation for Huerfano River near Undercliffe, Colo. from Dawdy(1961).
Source: WMO,Operational Hydrology,1980.

Chapter 3

STAGE-DISCHARGE MEASUREMENT IN BANGLADESH

3.1 General

The Directorate of Surface Water Hydrology-1 of Bangladesh Water Development Board (BWDB) is the primary organization which collects stage and discharge data. Bangladesh Inland Water Transport Authority (BIWTA) also collects stage. Besides SWMC (Surface Water Modelling Center), RRI (River Research Institute), FAP-3 (Flood Action Plan) are collecting stage and discharge data through BWDB in the recent years.

3.2 Stage Measurement

The stage of a stream is the height of the water surface above an established datum plane. Stages are measured by systematic observations of non-recording and recording gauge. Generally non-recording gauges are used. Most gauges are vertical wooden staff graduated meter and centimeters. For recording gauges Steven's auto water level recorders of float type whose tape is graduated in centimeter and meter and water level recorded on a continuous trip chart are used. For nontidal, flushy and hilly river mean daily water level obtained by averaging the water levels at 0600, 0900, 1200, 1500 and 1800 hrs. For tidal stations time and heights of high and low water levels are measured. All water levels are made with the reference from P.W.D. datum.

Gauges are secured to bridges, piers or any other fixed structures where available. On account of shoaling on unstable bank the gauges are fixed with a temporary pile driven in the bed of the river to ensure a good stability. In these case gauge is shifted with the rise and fall of water levels which required resurvey of the gauge zero. Normal procedure is to survey gauge zero at every month or immediately after shifting or any disturbance. In some river where a good number water level stations are available, consistency of upstream and downstream data are tested. All collected water levels are send to the surface water Hydrology-II, where data are scrutinized, analyzed, complied and finally stored for future requirements when necessary.

3.3 Discharge Measurement

Discharge measurement requires the determination of the cross-sectional area of a stream and a sufficient number of velocity measurements across the section to permit the determination of the average velocity. BWDB uses velocity area method to determine discharge and cross-section measured by mean-depths method.

To measure velocity two types of current meters are used. The WATT bucket type and the AOTT's propeller type. WATT's bucket type current meter are used in small rivers and AOTTs propeller type are used in major rivers. Launches and catamarans are used as a gauging crafts on major rivers. These are specially equipped with hydrological winches, ECO-sounders etc. On small river observations are taken from bridges, country boats. Number of pockets depends on the width of the river. In flow measurement the width of the stream is generally divided into twenty of more segments of approximately equal cross-sectional area, such that discharge passing through any two vertical doesn't exceeds 10% of the total flow. Sometimes more than 100 verticals are taken for discharge measurement in large river. Water Depth at each vertical is taken with the help of wading rod, gauging real or by sounding. Two points method is used to calculate velocity, one at 0.2 and other at 0.8 of water depth. Where single observation is made, 0.6 of water depth is considered.

Discharges are measured seasonally or continuously and generally weakly or fortnightly. Discharge stations under tidal influence (during dry period) are generally gauged during monsoon only when their effects are completely subdued by the fresh water floods. In spite of considerable tidal influence discharge measurement in some stations are taken round all the year e.g. Bhagyakul.

3.4 Stage Discharge Relationship

Bangladesh Water Development Board (BWDB) follows hydrological year starting from 1st April to 31st March of the next calendar year. Stage-discharge relationship is developed in each year at each station. Stage-discharge relation is expressed by power relation of the form $Q = C\ (h-a)^n$. The gauge height corresponding to zero flow a is determined graphically by plotting log Q and log $(h-a)$ for different assumed values of a, till a straight line is obtained. After determining gauge height of effective zero flow, regression analysis is done to relate stage with discharge by the method of least squares. Usually co-efficient of correlation and percentage of errors of rating are determined. One curve is generally developed for the whole range of water levels, two curves where necessary. Stage-discharge relation is developed in each year at each station. Stage and discharge measurements are plotted on a log-log paper with stage along ordinate and discharge along abscissa.

All the discharge and water level measurements carried out from 1966 to 1990 at Bahadurabad and Hardange Bridge leading to a rating curves plotted during a study carried under the Flood Action Plan (FAP 25 ,1993) which is shown in Fig. 3.1. They observed a considerable scatter. This scatter may be partly due to change in the physical systems such as erosion, aggravation and moving bed forms and partly as a result of random or systematic errors in discharge measurement. They found looped effects due to varying water surface slopes during rising and receding part of the flood are not significant.

The study also developed a set of new annual rating curves for Bahadurabad. Hardinge Bridge and Baruria from 1985 to 1989 (FAP 25,1993). Each annual rating curve has fitted with two or three-steps power function of equation $Q = C\,(h-a)^{n}$. They found extrapolation at Hardinage Bridge is easy most of the time because highest discharge measurement is close to the highest observed water level in a particular year. At Bahadurabad and Baruia extrapolation are done by considering rating curve slopes. Rating curves are shown in Fig. 3.2, 3.3 and 3.4 for Bahadurabad, Hardinage Bridge and Baruria respectively for the 1985 to 1989. In general the new rating curves are not much more different from BWDB derived rating curves.

Rating curve on secondary stations such as Kanaighat, Jaria Jhangail, Kaunia and Mohadebpur has also been computed (FAP 25,1993). They compute rating curves on Atrai river for the station Mohadebpur from 1965 to 1973 and 1975, and found one step function.

3.5 Discussion

Generally BWDB developed rating curve yearly, based on the total number of discharge measurements at each station in the hydrologic year and also includes some values from the previous and the following year for consistency purposes. Sometimes a few discharge measurements are omitted without having any reasonable justification, for getting better correlation between stage and discharge. Usually co-efficient of correlations and percentage of errors of rating are determined. No test for absence of bias and goodness of fit of stage-discharge relationship is done for checking reliability.

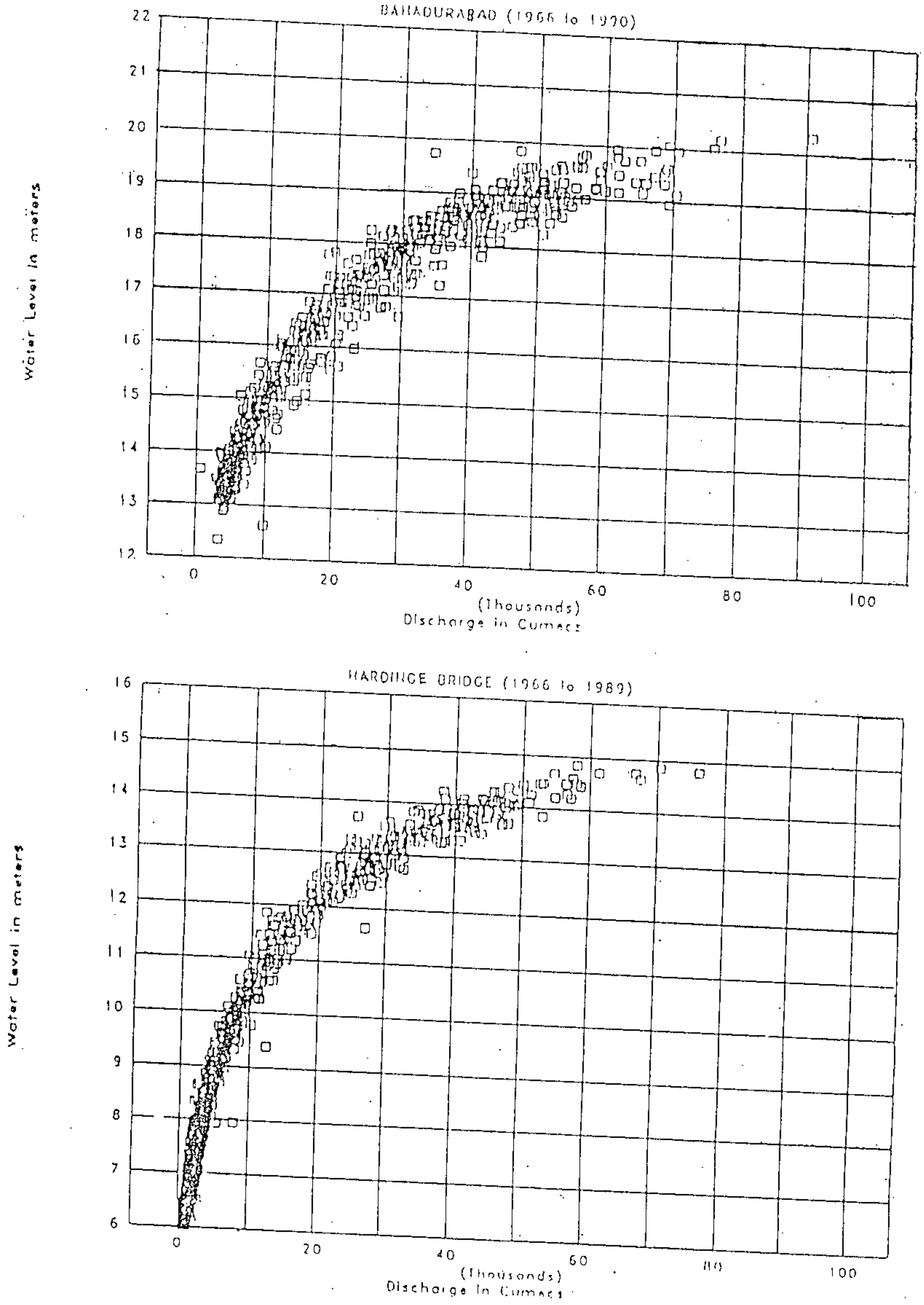


Fig. 3.1 Rating curves of Bahadurabad and Hardinge Bridge.
Source: FAP-25, Flood Modelling and Management, 1992.

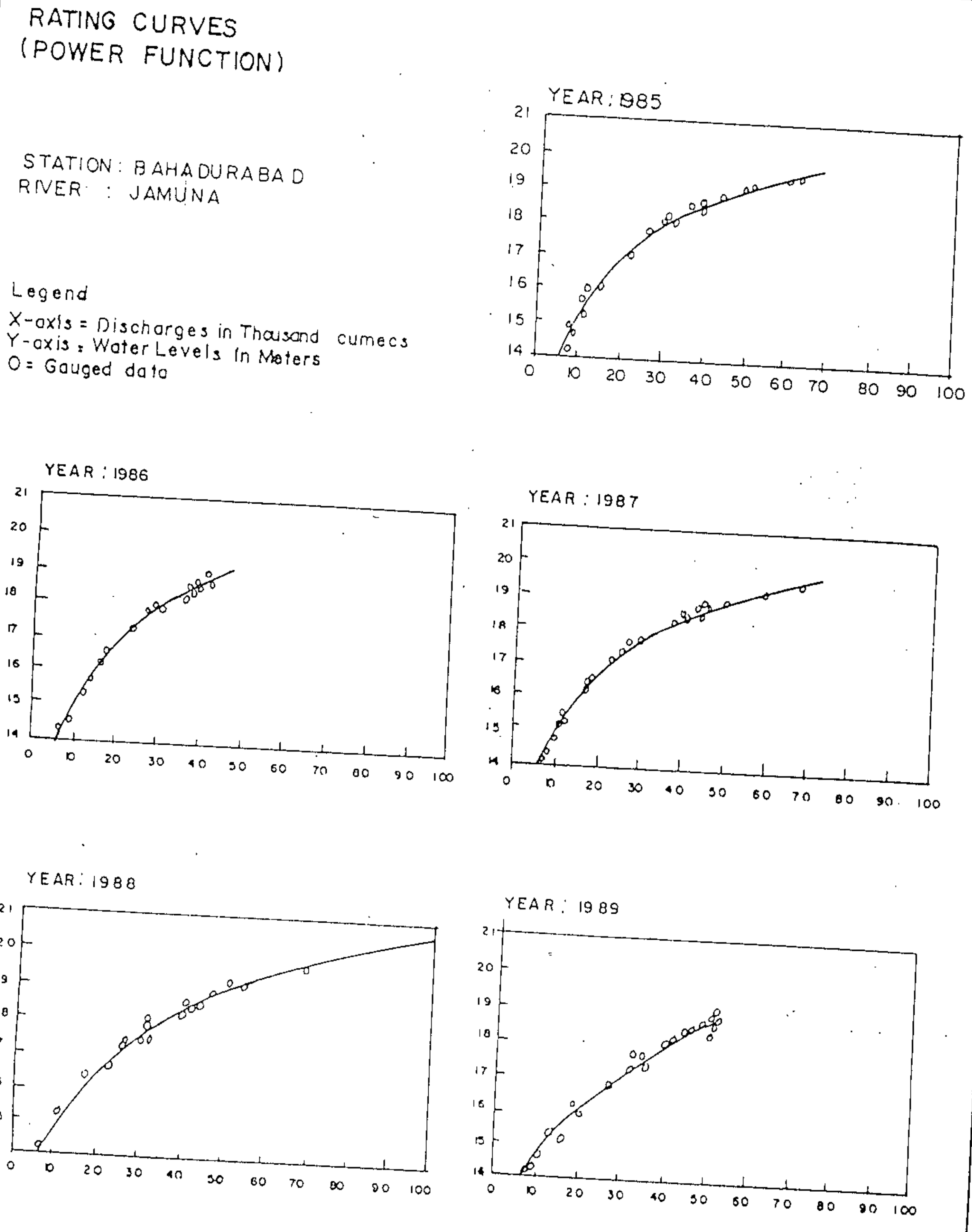
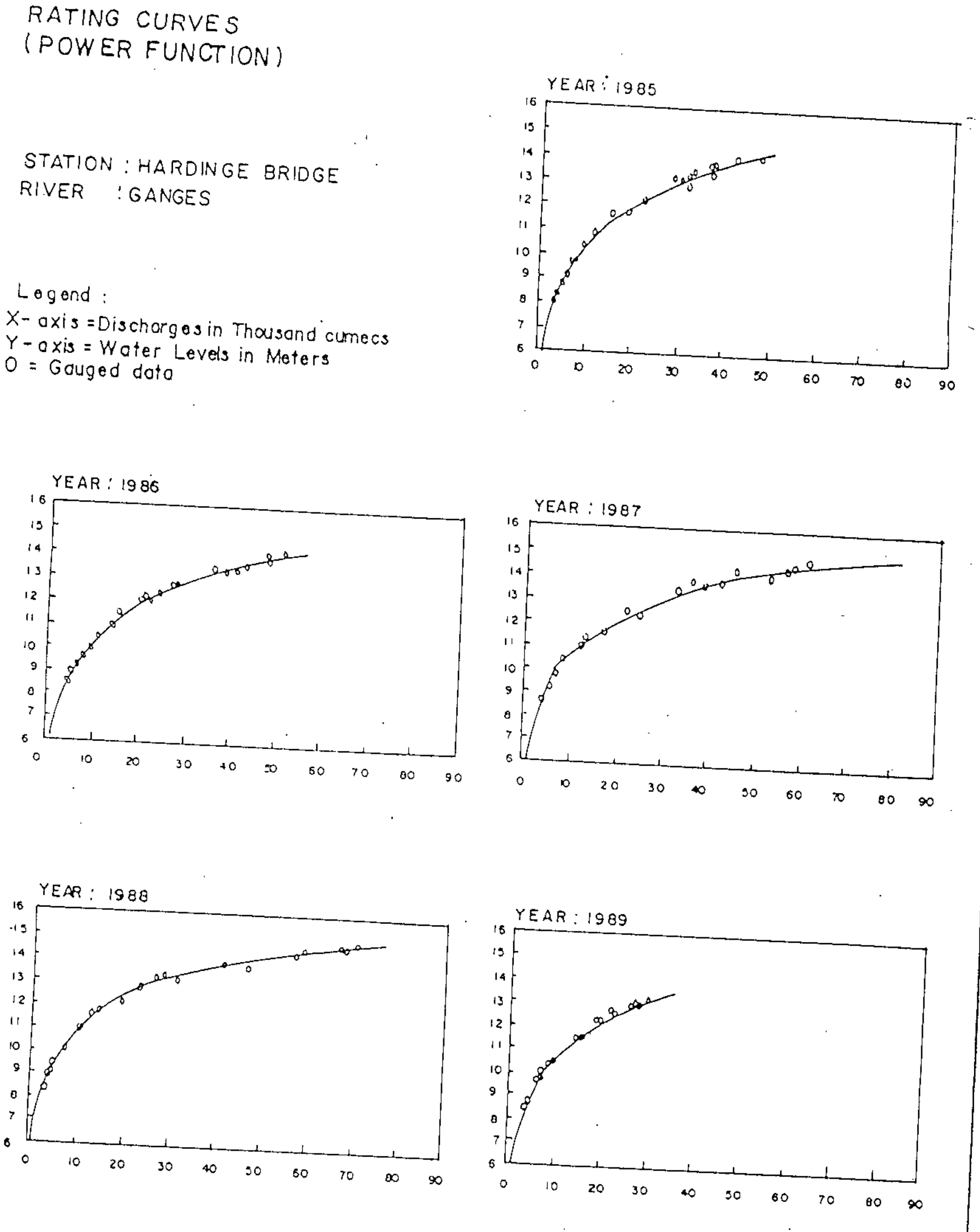


Fig. 3.2 Annual mean rating curves at Bahadurabad for 1985-89
Source: FAP-25,Flood Modelling and Management,1992.



RATING CURVES
(POWER FUNCTION)

STATION : HARDINGE BRIDGE
RIVER : GANGES

Legend :
X- axis =Discharges in Thousand cumecs
Y - axis = Water Levels in Meters
O = Gauged data

Fig 3.3 Annual mean rating curves at Hardinge Bridge for 1985-89.
Source: FAP-25,Flood Modelling and Management,1992.

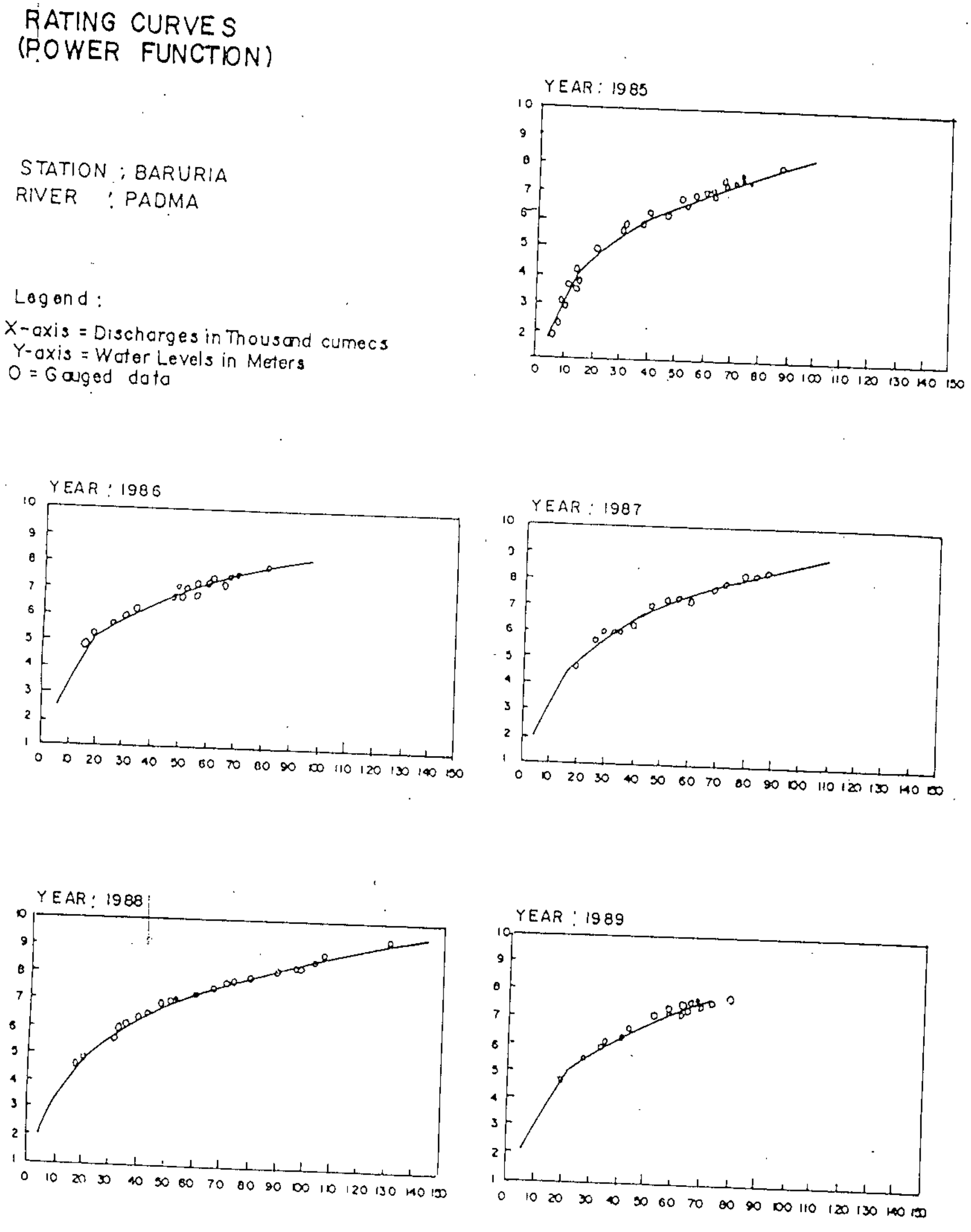


Fig 3.4 Annual mean rating curves at Baruria for 1985-86.
Source: FAP-25, Flood Modelling and Management, 1992.

Chapter 4

DATA COLLECTION AND ANALYSIS

The objective of this study is to investigate the stage-discharge relationship of Atrai river.This is a long river and it initially enters into the territory of Bangladesh at Panchagarh with the name Koratoya and at further downstream it is renamed as Atrai near Khanshama Thana of Dinajpur. For the present analysis, the river has been divided into two reaches viz. upper and lower Atrai. The upper Atrai is considered to extend from Panchagarh to Dinajpur before entering into India. The lower Atrai is considered where it reenters into Bangladesh from Naogaon, upto its outfalls at Hurasagar.Two gauge and discharge stations were selected in each of the upper and lower reaches. The names of the gauging stations are Panchagarh and Bushirbandar in the upper reach and Mohadebpur and Atrai on the lower reach. Data for the 1981-90 period for each of the four gauging stations were used in this study.

4.1 Source of Data

For the analysis of stage-discharge relationship four discharge stations of Atrai river were selected. As mentioned before these gauging stations are located at Panchagarh, Bushirbandar, Mohadebpur and Atrai. All informations such as date, mean velocity, width and discharge were collected from the Directorate of Surface Water Hydrology-2 under Bangladesh Water Development Board.

4.2 Choice of Time Period

Hydrological year in Bangladesh is considered from 1st April to 31st March of the next calendar year. This is probably done to ensure continuous record through both monsoon and dry season. All analyses of this study were performed on the basis of hydrological year.

4.3 Choice of Data

Stage-discharge data for the period from 1981 to 1990 were collected from BWDB. Data were compiled and consistency was checked. As mentioned in Section 2.8.1 , any data point lying beyond the limit three times the standard deviation was not taken into consideration in the development of stage-discharge relations.

4.4 Method of Analysis

Steps of analysis performed in this study are succinctly described below:

The analysis consists of two parts: (i) development of rating curve for each year of record and each of four selected stations, and (ii) tests for absence from bias and goodness of fit.

As an alternative to stage-discharge relations, mean depth-discharge relationship were also developed. As discussed mentioned in Section 2.10 mean depth-discharge relations are sometimes used for sandy streams. The purpose of this part of analysis was to see whether depth-discharge relationship is more suitable than stage-discharge relation.

4.4.1 Development of stage-discharge and mean depth-discharge relationship

Two types of rating curves were developed by fitting (i) power type functions and (ii) parabolic functions to the observed stage-discharge data for each of the selected stations by least square method as explained in Section 2.6.2. Similarly, power type and parabolic relations were developed.

4.4.2 Tests for absence from bias and goodness of fit

Two tests for absence from bias as described in Section 2.8.3 were employed here. Goodness of fit of the rating curves were examined by the method as described in Section 2.8.3

4.5 Comparison between Stage-discharge Power Type and Parabolic Relationship

Power type and parabolic stage-discharge relationship were compared using the co-efficient of correlations and standard deviations.

4.6 Graphical Comparison of the Stage-discharge Curves of Different Stations

Stage-discharge curves of different stations for the same year were compared graphically to study, if there is any systematic trend in its shape .

4.7 Graphical Comparisons of the Stage-discharge curves by Years

Stage-discharge curves of different years on each station were investigated graphically to study the stability of the relationship.

4.8 Comparison of Rating curve between Established curves and BWDB Curves.

For comparing stage-discharge relationships with BWDB, the coefficients of correlation and standard errors of mean relation at mean were compared.

4.9 .Comparison of Stage-discharge with Mean Depth-discharge Relationships

Power type and parabolic relationships of stage-discharge were compared with mean depth-discharge relation to see whether mean depth-discharge relation is more suitable than stage-discharge relation.

Chapter 5

RESULTS AND DISCUSSIONS

A succession of analysis, as outlined in Chapter 4 was performed using spread sheet on micro-computer. In this chapter the results are presented and discussed.

5.1 Stage-discharge Relationship of Atrai River

Two types of equations were selected for establishing stage-discharge relation (i) Power type and (ii) Parabolic.

5.1.1 Power type and parabolic stage-discharge relations

Power type and parabolic stage-discharge relationships were separately developed using methods of least squares for each year of record and for four selected stations. Summary of these rating curves are presented in Table 5.1. Power type stage-discharge relations are given detailed in Appendix A in Table 1 to 4. Similarly parabolic relationships are given in Appendix A, Table 5 to 8.

5.1.2 Tests for absence from bias and goodness of fit

Two types of tests were performed to judge the suitability of each rating curve developed above. These are (i) test for absence from bias (signs), (ii) test for absence from bias (values) and (iii) test for goodness of fit. Summary of these tests are presented in Table 5.2. The detail test results are given in Appendix A, Table 9 to 32.

5.2 Selection of Type of Relation

Comparison of power type and parabolic stage-discharge relationships are presented in Table 5.3(a) to 5.3(d) for Panchagarh, Bushirbandar, Mohadebpur and Atrai respectively.

Suitability of the relation depends on tests of bias and goodness of fit. In most cases both the power and parabolic relation, tests of bias and goodness of fit were found acceptable. So they cannot be compared.

Co-efficients of correlation and standard errors of estimate are another criterion for comparing the suitability of the different type of equations. In most cases, co-efficients of correlation were found nearly equal in both the relations. So correlation co-efficients are not strictly comparable.

Table 5.1 Summary of Power and Parabolic Stage-discharge Relations of Atrai River at different stations.

Power Equation $Q = C(h-a)^n$, Parabolic Equation $Q = a_1 + b_1(h-a) + c_1(h-a)^2$

Station	Year	Power Equation			Parabolic Equation			
		C	n	Coefficient of correlation	a_1	b_1	c_1	Coefficient of correlation
Panchagar	1981-82	23.5698	2.9200	0.9861	75.1855	-167.156	111.4455	0.9647
	82-83	18.8212	2.2113	0.7829	80.4262	-162.143	97.0834	0.9801
	83-84	0.4277	4.7846	0.9432	135.222	-152.928	45.6048	0.9434
	84-85	54.5965	1.1733	0.9449	10.6757	-9.1584	55.6853	0.9411
	86-87	32.7867	1.3569	0.9760	5.0222	36.0859	3.2853	0.9872
	87-88	5.8364	3.7535	0.9849	96.8560	-171.752	82.2177	0.9811
	88-89	30.1003	2.5987	0.9892	6.8212	-33.515	59.6251	0.9986
	89-90	29.3599	2.3271	0.979	9.5773	-31.765	51.1971	0.9853
Bushirbandar	1982-83	10.0308	3.0446	0.9368	18.7864	-54.2705	45.2997	0.9767
	83-84	15.7207	2.9665	0.9907	4.4524	-41.8829	58.4267	0.9891
	84-85	39.4685	2.3439	0.9868	6.4469	-25.9803	62.5247	0.9822
	85-86	52.7252	2.0302	0.9909	31.9526	56.0885	36.5842	0.9961
	86-87	14.2364	3.0441	0.9941	37.9169	-89.8718	65.8994	0.9889
	87-88	24.0262	2.6068	0.9902	2.3564	35.1549	57.5796	0.9955
	88-89	54.5144	2.3446	0.9846	38.9335	38.9335	51.9875	0.9979
	89-90	69.9727	2.0459	0.9941	14.6833	32.6343	83.7219	0.9946
Mohadebpur	1981-82	30.4554	1.8626	0.9923	12.2412	24.7407	19.5676	0.9990
	82-83	9.5583	2.3843	0.9802	32.7524	19.3297	31.9983	0.9940
	83-84	6.3598	2.5808	0.9927	17.1382	-4.5009	17.4720	0.9947
	84-85	5.2459	2.6898	0.9717	13.0106	-26.7716	20.2471	0.9919
	85-86	25.6218	1.9885	0.9919	9.2574	11.7084	23.2012	0.9935
	86-87	14.7546	2.3661	0.9984	9.8945	-3.4949	25.6454	0.9969
	87-88	4.2281	2.7348	0.9801	115.803	-117.079	34.3420	0.9935
	88-89	22.7397	2.0536	0.9981	21.6203	26.8731	19.8730	0.9989
	89-90(a)	37.0787	1.7314	0.998	11.6201	45.251	14.8263	0.984
	89-90(b)	13.7817	2.5458	0.998	38.9886	-65.7629	43.1821	0.997
Atrai	1981-82	9.3157	2.3052	0.9878	57.5794	-69.0794	27.6624	0.9874
	82-83	0.0909	4.3016	0.9742	206.644	137.717	23.4515	0.9929
	83-84	0.3117	3.6525	0.9814	218.2011	-144.63	24.3641	0.9881
	84-85	0.1359	4.0984	0.9940	272.645	-176.561	28.0266	0.9591
	85-86	0.3542	3.6434	0.9896	229.2407	-158.414	27.1339	0.9324
	87-88	3.0419	2.8821	0.9801	90.869	-91.7635	27.6701	0.9944
	89-90	0.6489	3.4679	0.988	89.7271	-85.5197	21.1358	0.9751

Table 5.2 Summary of Test Results of Bias and Goodness of Fit of Power and Parabolic Stage-discharge Relations of Atrai River.

Station	Year	Power Equation			Parabolic Equation		
		Test of Bias		Test of Goodness of Fit	Test of Bias		Test of Goodness of Fit
		Signs	Values		Signs	Values	
Panchagar	1981-82	+	+		+	+	
	82-83	+	+		+	+	
	83-84	+	+		+	+	
	84-85	+	+		+	+	
	86-87	+	+	+	+	+	+
	87-88	+	+	+	+	+	-
	88-89	+	+	+	+	+	+
	89-90	+	+	+	+	+	+
Bushirbandar	1982-83	+	+		+	+	
	83-84	+	+		+	+	
	84-85	+	+		+	+	
	85-86	+	+		+	+	
	86-87	+	+		+	+	
	87-88	+	+	+	+	+	+
	88-89	+	+	+	+	+	+
	89-90	+	+	+	+	+	+
Mohadebpur	1981-82	+	+				
	82-83	+	+				
	83-84	+	+				
	84-85	+	+				
	85-86	+	+				
	86-87	+	+				
	87-88	+	+	+			
	88-89	+	+	+			
	89-90(a)	+	+				
	89-90(b)	+	+				
Atrai	1981-82	+	+		+	+	
	82-83	+	+		+	+	
	83-84	+	+		+	+	
	84-85	+	+		+	+	
	85-86	+	+	-	+	+	-
	87-88	+	+		+	+	
	89-90	+	+		+	+	

Note: + Accepted at 5% significance level
- Rejected at 5% significance level

Table 5.3(a) Comparison of Stage-discharge of Power and Parabolic Relations of Atrai river at Panchagarh

Year	Coefficient of correlation		Standard deviation (S_Q)	
	Power	Parabolic	Power	Parabolic
1981-82	0.9861	0.9647	19.512	19.621
82-83	0.7829	0.9801	17.594	6.858
83-84	0.9432	0.9434	13.263	14.551
84-85	0.9449	0.9411	16.251	11.242
86-87	0.976	0.9872	4.207	3.711
87-88	0.9849	0.9811	7.7258	8.169
88-89	0.9892	0.9986	7.0308	3.569
89-90	0.979	0.9853	8.65	8.660

S_Q = Standard deviation of Q values around established rating curve.

Table 5.3(b) Comparison of Stage-Discharge of Power and Parabolic Relations of Atrai River at Bushirbandar

Year	Coefficient of correlation		Standard deviation (S_Q)	
	Power	Parabolic	Power	Parabolic
1982-83	0.9368	0.9767	15.980	15.340
83-84	0.9907	0.9891	36.649	24.336
84-85	0.9868	0.9822	36.900	33.782
85-86	0.9909	0.9961	31.452	17.261
86-87	0.9941	0.9889	11.510	10.985
87-88	0.9902	0.9955	34.194	18.654
88-89	0.9846	0.9979	32.103	9.909
89-90	0.9941	0.9946	22.894	22.286

S_Q = Standard deviation of Q values around established rating curve.

Table 5.3(c) Comparison of Stage-Discharge of Power and Parabolic Relations of Atrai River at Mohadebpur

Year	Coefficient of Correlation		Standard deviation (S_Q)	
	Power	Parabolic	Power	Parabolic
1981-82	0.9923	0.9990	7.037	6.606
82-83	0.9802	0.9940	33.498	17.226
83-84	0.9927	0.9947	41.121	20.365
84-85	0.9717	0.9919	39.119	25.912
85-86	0.9919	0.9935	23.319	22.878
86-87	0.9984	0.9969	21.736	13.488
87-88	0.9801	0.9935	48.160	30.870
88-89	0.9981	0.9989	17.023	9.028
89-90(a)	0.998	0.984	30.364	28.026
89-90(b)	0.998	0.997	9.933	10.098

S_Q = Standard deviation of Q values around established rating curve.

Table 5.3(d) Comparison of Stage-Discharge of Power and Parabolic Relations of Atrai River at Atrai.

Year	Coefficient of Correlation		Standard deviation (S_Q)	
	Power	Parabolic	Power	Parabolic
1981-82	0.9878	0.9874	33.958	28.882
82-83	0.9742	0.9929	17.844	17.752
83-84	0.9814	0.9881	24.269	25.494
84-85	0.9940	0.9591	52.678	54.422
85-86	0.9896	0.9324	72.365	74.683
87-88	0.9801	0.9944	21.974	25.151
89-90	0.988	0.9751	44.9251	39.397

S_Q = Standard deviation of Q values around established rating curve.

The standard errors of estimate cannot be compared with each other since they are in different units. For parabolic equation the standard error of estimate is always same whether in positive or negative direction from the established curve. But when logarithmic estimating equation is used, the standard error of estimate is always in percentage. So it will be different in positive or negative direction with respect to the established curve. Generally at higher discharge standard error of estimate in power type equation gives higher value than that of parabolic equation, since its unit is in percentage.

Water levels for two standard errors of estimate, one for negative error and other for positive error were determined where power type and parabolic relations are equal, and are presented in Table 5.4(a) to 5.4(d). It were found that water level of negative direction standard error of estimate were greater than that of positive direction standard errors. So for comparing purpose water level of negative direction standard errors of estimate were used. Because, water level above these parabolic relations are better than powers relations. From the Table 5.4(a) to 5.4(d), the maximum value of X, the ratio of the difference between negative direction two standard errors water level and lowest water level (L.W.L) and difference between highest and lowest water level (H), among the years, for Panchagarh, BushirBandar, Mohadebpur and Atrai is 0.740, 0.912 and 0.62 respectively. So parabolic relation is better than that of power type above the water level (0.740 H + L.W.L), (0.623 H+L.W.L), (0.912H+L.W.L) and (0.62H+L.W.L) for Panchagarh, BushirBandar, Mohadebpur and Atrai respectively. So it can be concluded that water level (0.912H+L.W.L) to above, parabolic relation is better than the power type for four stations.

Another criterion is used for comparing the suitability of power type and parabolic equation is $S_Q=\sqrt{\frac{\sum(Q-Q_c)^2}{N}}$, Where Q_c the discharge from the curve, Q the observed discharge values correspond to the gauge height and S_Q the standard deviation of the Q values around the established rating curve. Smaller value of the S_Q is the better one. By comparing S_Q values, parabolic relations were found better than that of power types.

But it was found that parabolic relationships yield negative values for low water level in most cases. But power type relations never give negative values of discharge. To avoid negative values of discharge at low water level power relations are better than that of parabolic relations. But parabolic relationships yielded positive values for high water level.

Table 5.4(a) Water levels of Panchagarh where two standard errors of estimate of power type and parabolic relations are equal.

Year	Highest Water Level (H.W.L) (m)	Lowest Water Level (L.W.L) (m)	Standard Error of estimate		Water level (m)		X
			Power Type	Parabolic	h_1	h_2	
81-82	69.113	67.666	19.79 %	21.838	68.736	68.508	0.740
82-83	69.075	67.681	47.34 %	7.513	68.127	67.734	0.320
83-84	69.610	67.425	36.78 %	15.718	68.802	68.401	0.630
84-85	69.370	67.83	30.40 %	12.194	68.698	68.300	0.564
86-87	70.03	67.63	19.96 %	3.956	68.175	67.972	0.227
87-88	68.99	67.53	19.56 %	8.646	68.4	68.222	0.596
88-89	69.56	67.445	19.09 %	3.795	67.956	67.831	0.241
89-90	69.175	67.38	27.03 %	9.208	68.243	67.994	0.481

Table 5.4(b) Water levels of Bushirbandar where two standard errors of estimate of power type and parabolic relations are equal.

Year	Highest Water Level (H.W.L) (m)	Lowest Water Level (L.W.L) (m)	Standard Error of estimate		Water level (m)		X
			Power Type	Parabolic	h_1	h_2	
82-83	37.79	35.975	40.05 %	16.805	36.766	36.347	0.436
83-84	38.65	35.975	15.92 %	26.397	37.458	37.221	0.554
84-85	38.92	35.967	22.64 %	36.814	37.431	37.078	0.496
85-86	39.18	35.967	17.81 %	18.909	37.025	36.778	0.329
86-87	37.66	35.964	12.02 %	11.865	37.020	36.871	0.622
87-88	39.44	35.964	18.13 %	19.885	37.173	36.924	0.347
88-89	38.755	36.133	22.67 %	10.486	36.650	36.470	0.197
89-90	38.95	36.11	17.02 %	23.695	37.291	37.059	0.416

Note: h_1 and h_2 are the water levels of two standard errors of estimate at negative and positive direction respectively, where power and parabolic relations are equal.

X= the ratio of the difference between negative direction of two standard errors water level and lowest water level and difference between highest and lowest water level.

Table 5.4(c) Water levels of Mohadebpur where two standard errors of estimate of power type and parabolic relations are equal.

Year	Highest Water Level (H.W.L) (m)	Lowest Water Level (L.W.L) (m)	Standard Error of estimate		Water level (m)		X
			Power Type	Parabolic	h_1	h_2	
81-82	17.968	13.442	16.03 %	7.280	14.256	14.043	0.179
82-83	18.401	13.31	26.30 %	18.771	14.937	14.426	0.319
83-84	18.62	13.31	17.29 %	22.090	15.553	15.124	0.422
84-85	18.88	13.37	37.71 %	28.106	15.327	14.578	0.355
85-86	18.815	13.64	20.46 %	24.815	15.531	15.082	0.365
86-87	18.02	13.64	8.17 %	14.465	15.768	15.571	0.486
87-88	18.82	13.18	30.45 %	32.742	15.578	14.853	0.425
88-89	18.0	13.18	8.46 %	9.624	14.854	14.673	0.347
(89-90).a	18.21	13.08	11.53 %	33.498	16.264	15.827	0.621
(89-90).b	16.38	13.36	6.71 %	11.128	15.088	14.948	0.572

Table 5.4(d) Water levels of Atrai where two standard errors of estimate of power type and parabolic relations are equal.

Year	Highest Water Level (H.W.L) (m)	Lowest Water Level (L.W.L) (m)	Standard Error of estimate		Water level (m)		X
			Power Type	Parabolic	h_1	h_2	
81-82	13.451	8.803	25.39 %	31.474	11.454	10.779	0.570
82-83	13.370	7.830	39.86 %	19.345	10.494	9.699	0.781
83-84	13.485	7.830	33.46 %	27.652	11.039	10.197	0.567
84-85	13.250	7.870	21.24 %	59.029	12.730	12.065	0.903
85-86	13.615	7.870	27.10 %	81.005	13.111	12.167	0.912
87-88	14.025	8.43	34.684 %	26.618	10.714	9.979	0.408
89-90	13.330	9.050	16.53 %	42.393	11.973	11.438	0.683

Note: h_1 and h_2 are the water levels of two standard errors of estimate at negative and positive direction respectively, where power and parabolic relations are equal.

X= the ratio of the difference between negative direction of two standard errors water level and lowest water level and difference between highest and lowest water level.

Water level (0.91H+L.W.L) and above, two standard errors of estimate of parabolic relations were found smaller than power types. For this reason it can be concluded that for extrapolation purpose at high water level parabolic relations were found better than that of power type relations.

5.3 Graphical Comparison of Stage-Discharge Curves of Different Stations

Only power type stage-discharge relations of 1981-1990 were plotted on a rectangular co-ordinate for the stations namely Panchagarh, Bushirbandar, Mohadebpur and Atrai. Generally upstream stage-discharge curve is stepper than the down-stream curve. Such type of relations are not found significantly. This is due to fluctuation of water levels among the reach, which causes changing of water surface slope from station to station and also year to year. Also changes of water surface slopes and cross-sectional areas between the gauging stations are not proportional for each year may be another cause behind this. Discharge at downstream section is higher than that of upstream section. But most of the years discharges at station Atrai were less than upstream station Mohadebpur. Because at the upstream some discharges were diverted from Atrai river to Fakirni river. So most of the years length of the rating curves of Atrai found shorter than that of the Mohadebpur. Stage-discharge relation of different stations are shown in Fig. 5.1(a) to 5.1(i).

5.4 Graphical Comparisons of Stage-discharge Curves by Years

For comparing stage-discharge relationships water level versus discharge were plotted by years in each station namely Panchagarh, Bushirbandar, Mohadebpur and Atrai.

Panchagarh Station. Water level versus discharge for various years were plotted as shown in Fig.5.2(a). Among the minimum water levels, minimum was in the year 1989-90 and maximum in 1983-84. Among the maximum water levels, minimum was in the year 1987-88 and maximum in 1986-87.

Among the maximum water levels, the curve 1986-87 was higher than that of 1988-89. But, the curve of 1988-89 produced maximum discharge. This may mainly happened due to approach velocity and other responsible factors were area, slope or their combinations. On the other hand water level of 1983-84 is higher than that of 1988-89. But discharge of 1988-89 is higher than 1983-84. The curves of 1983-84 and 1988-89 are not comparable due to non-availability of data for the curve of 1983-84. The shape of all the curves depend on the magnitude of the exponents.

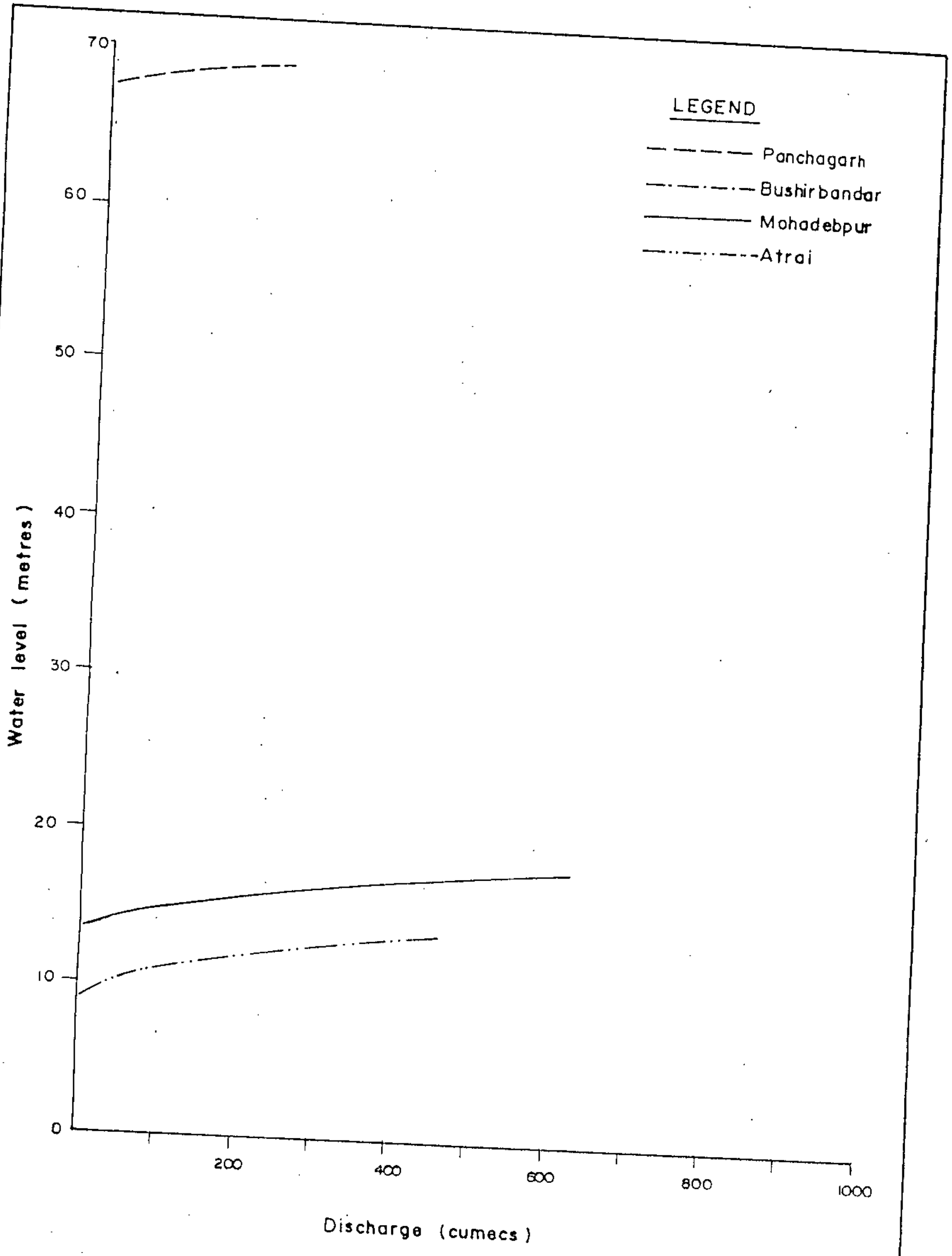


Fig. 5.1 (a). Comparison of rating curves of different stations in 1981-82

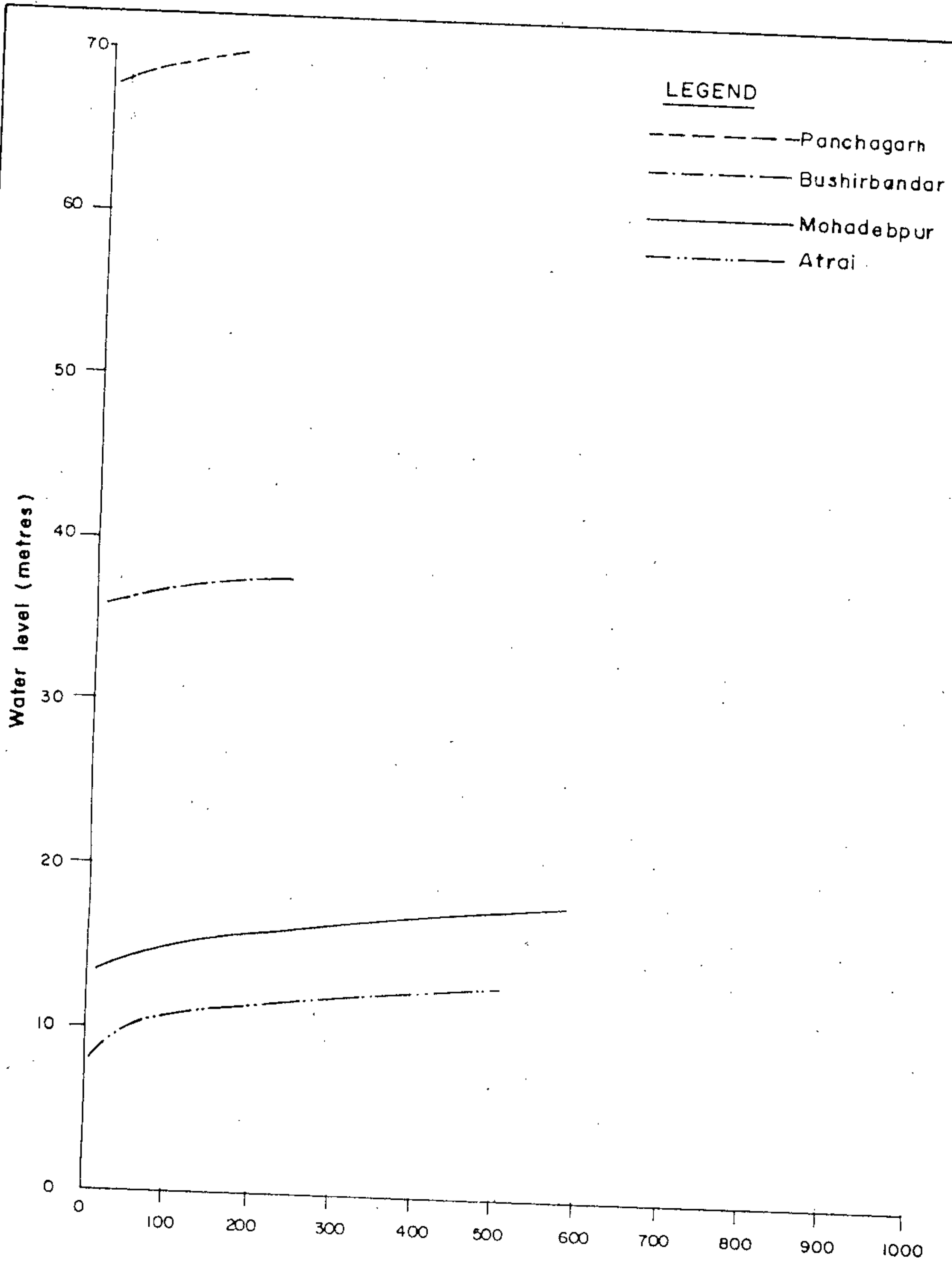


Fig. 5.1 (b). Comparison of rating curves of different stations in 1982 – 83

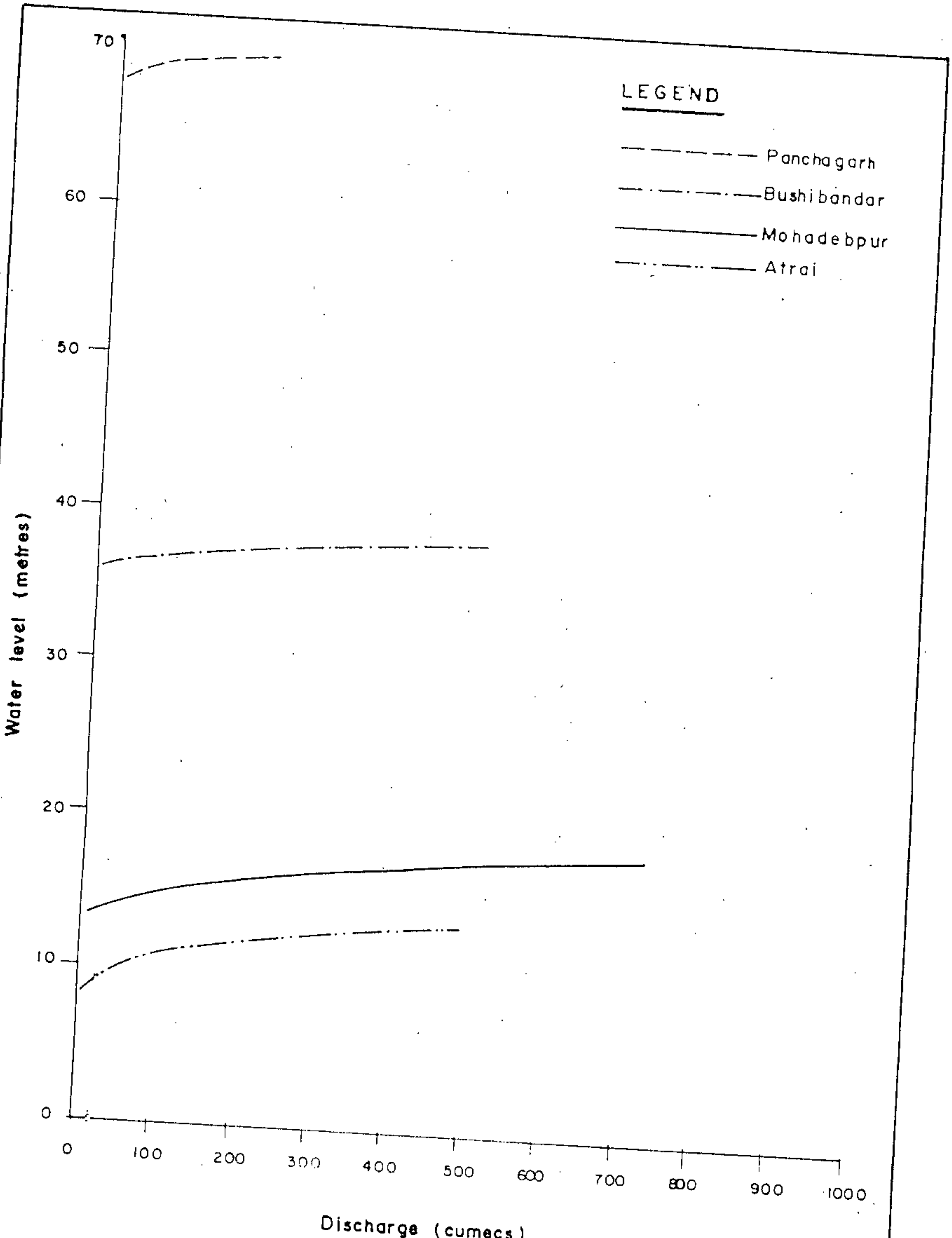


Fig. 5.1 (c). Comparison of rating curves of different stations in 1983–84

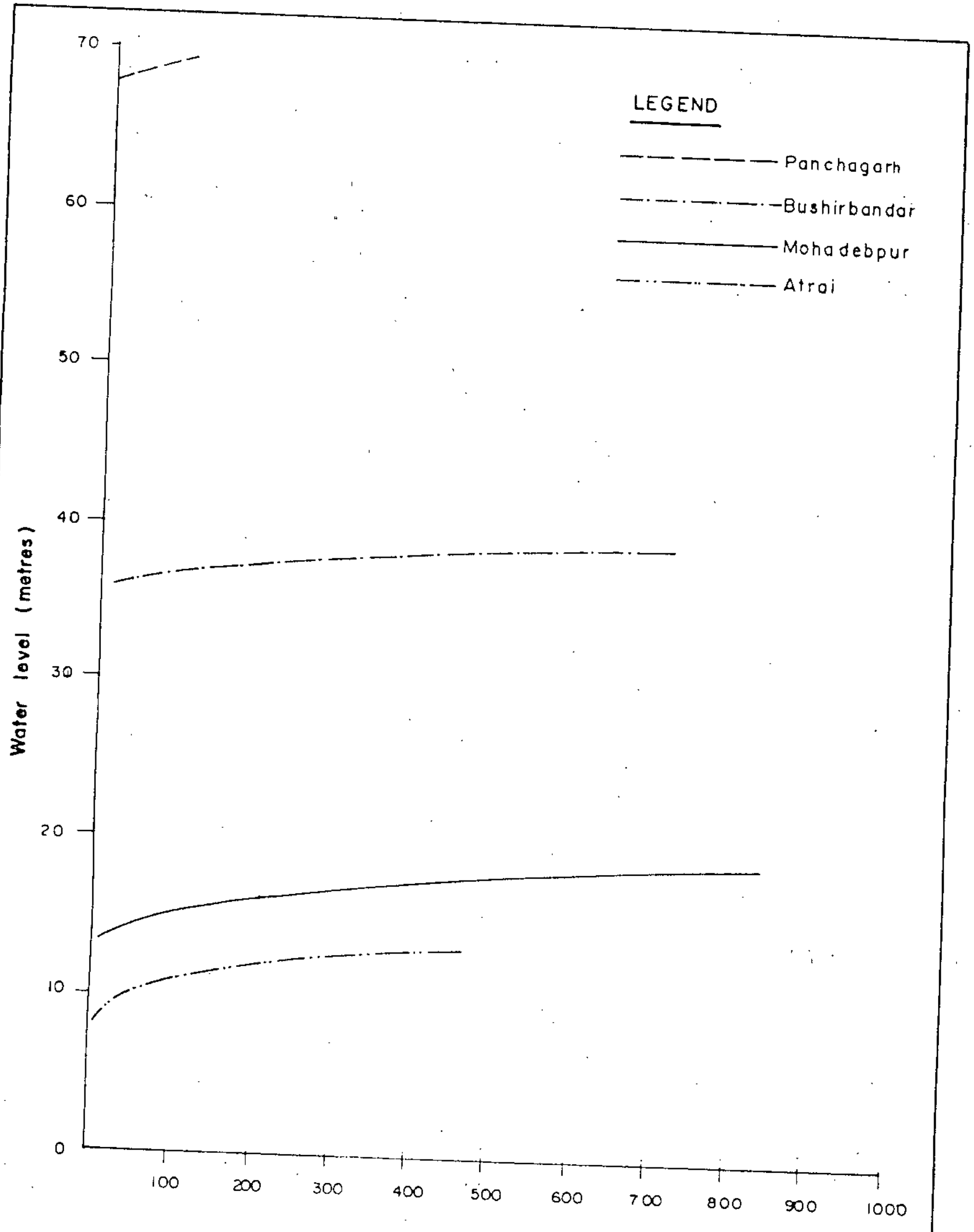


Fig. 5.1 (d). Comparison of rating curves of different stations in 1984-85

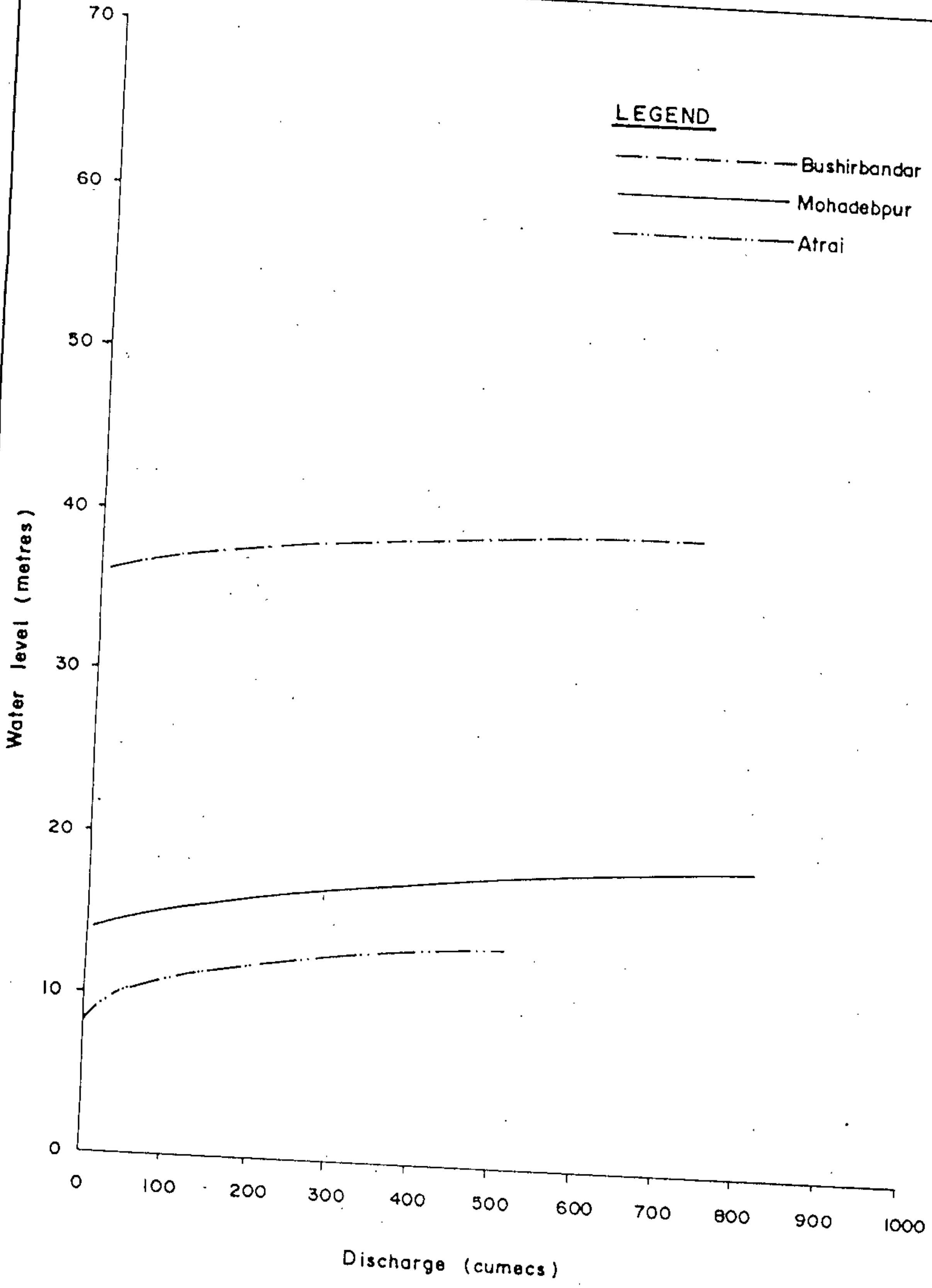


Fig. 5.1 (e). Comparison of rating curves of different stations in 1985 - 86

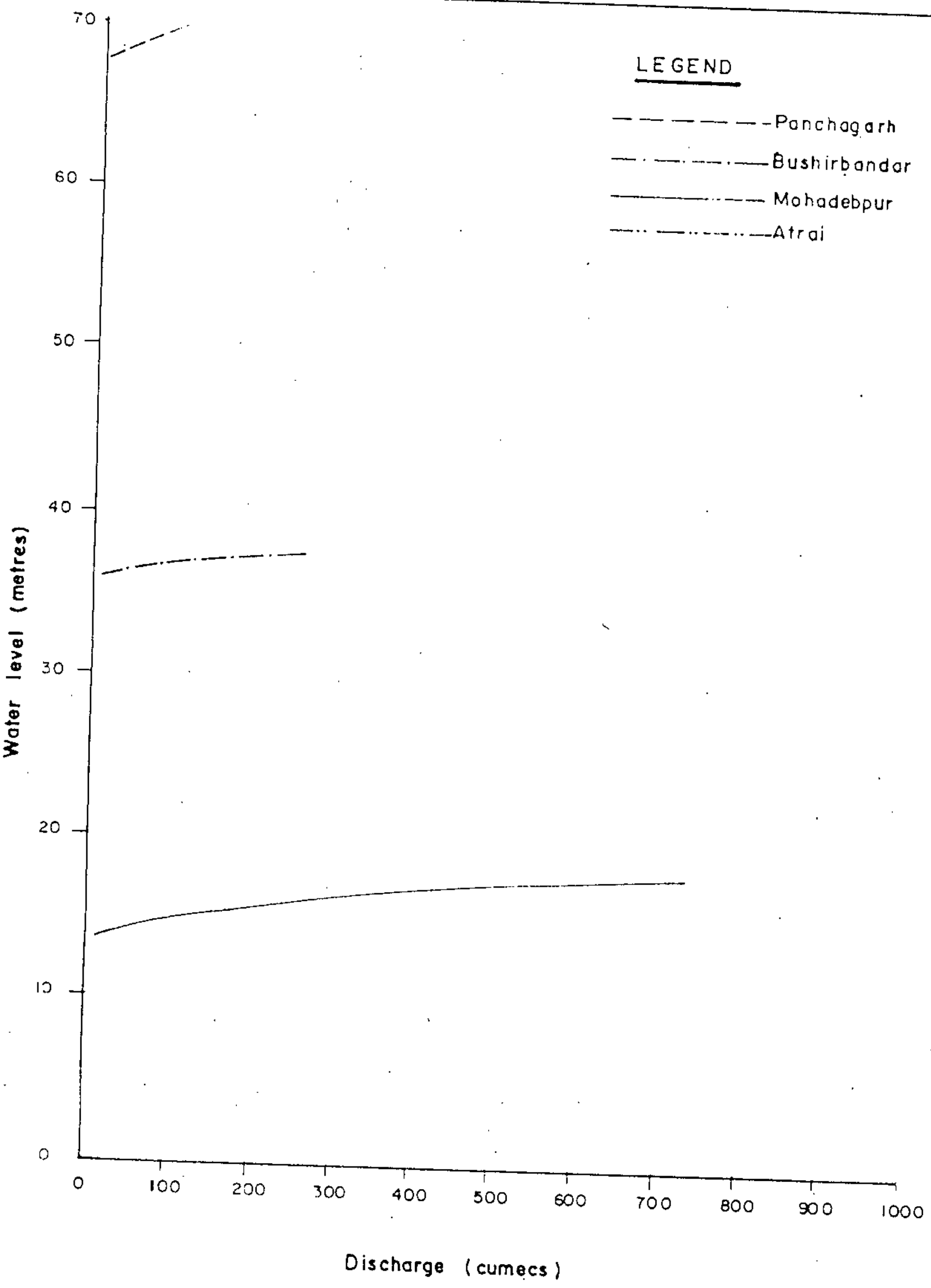


Fig.5.1 (f). Comparison of rating curves of different stations in 1986-87

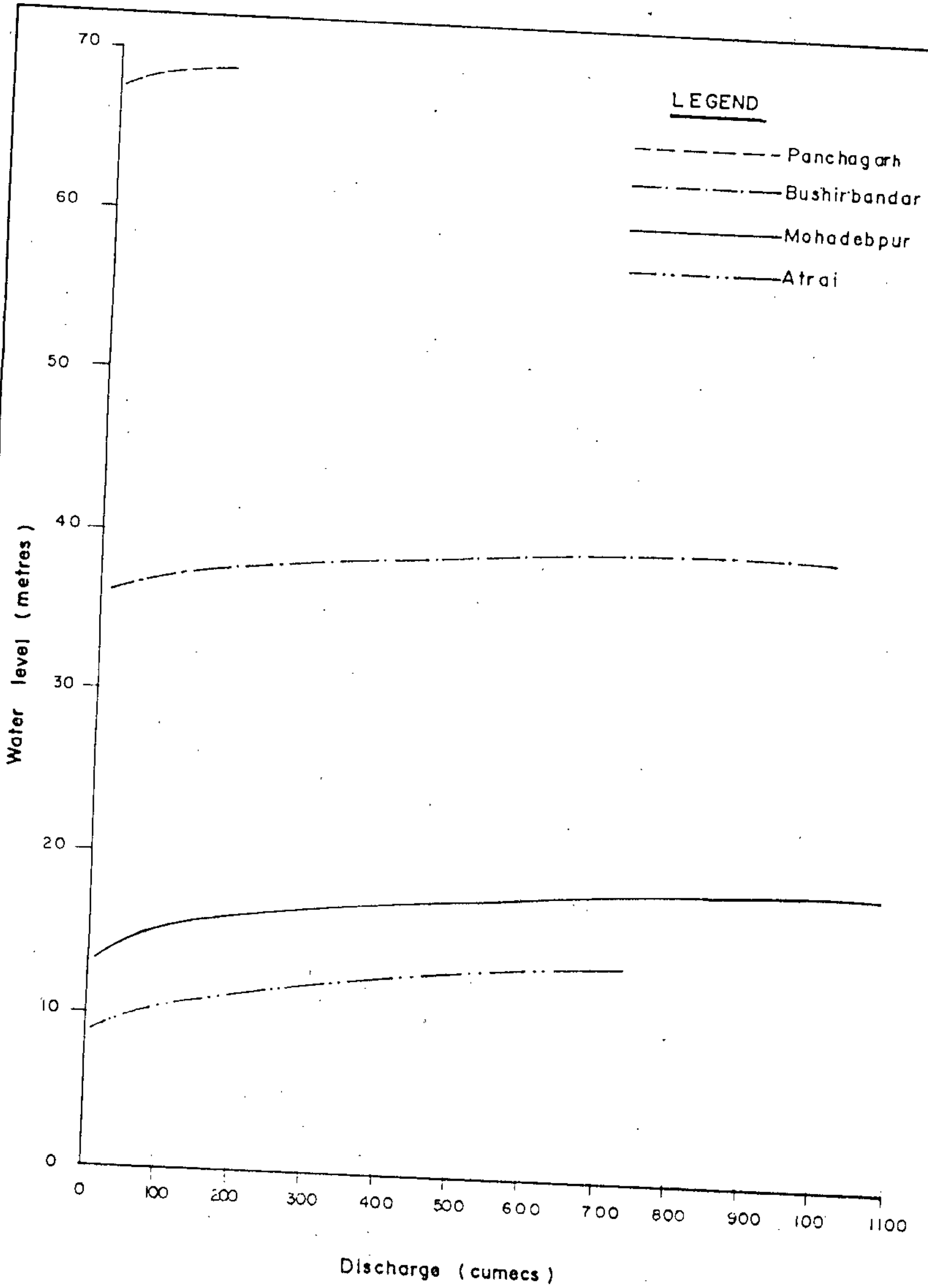


Fig. 5.1 (g). Comparision of rating curves of different stations in 1987–88

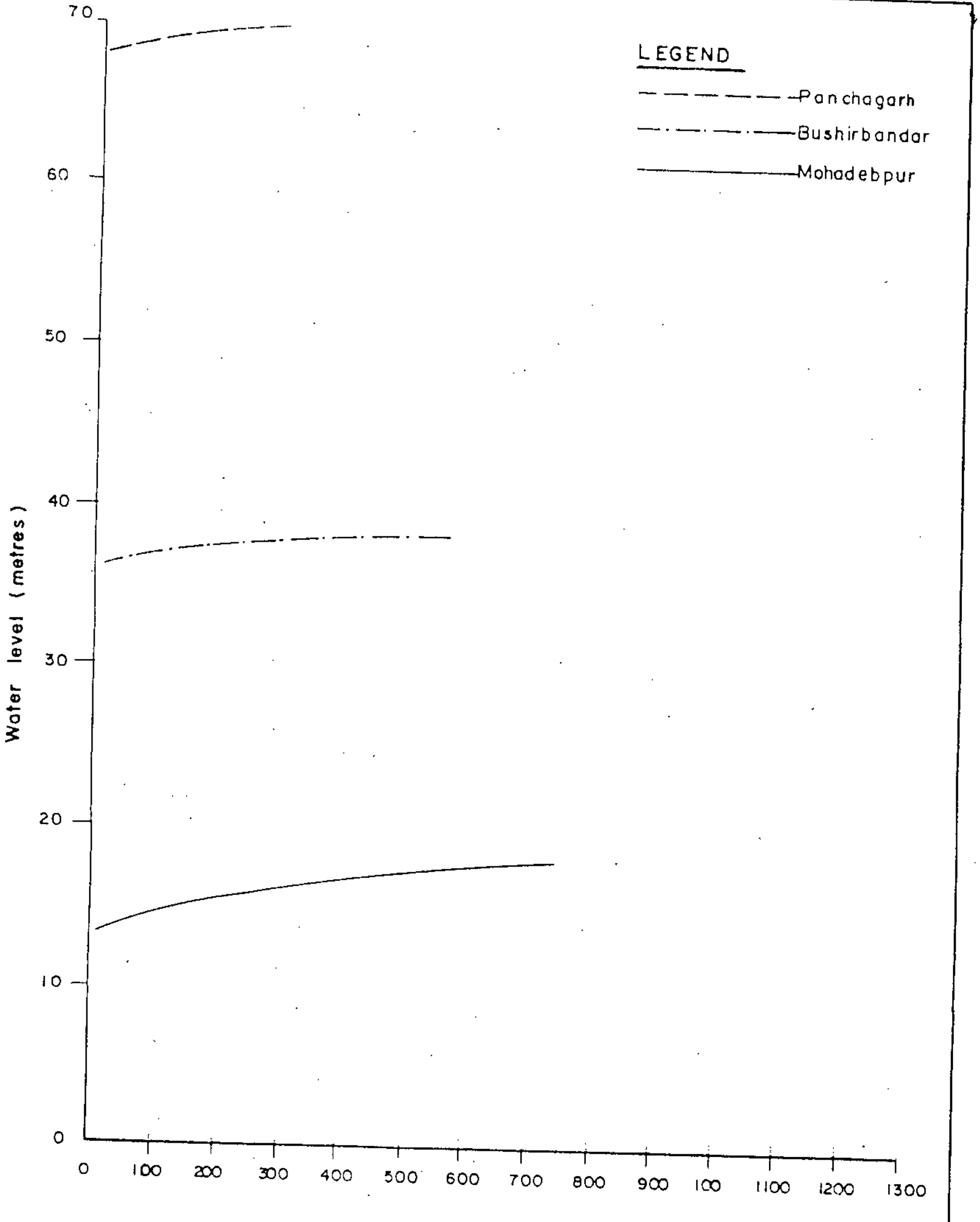


Fig. 5.1 (h). Comparison of rating curves of different stations in 1988 - 89

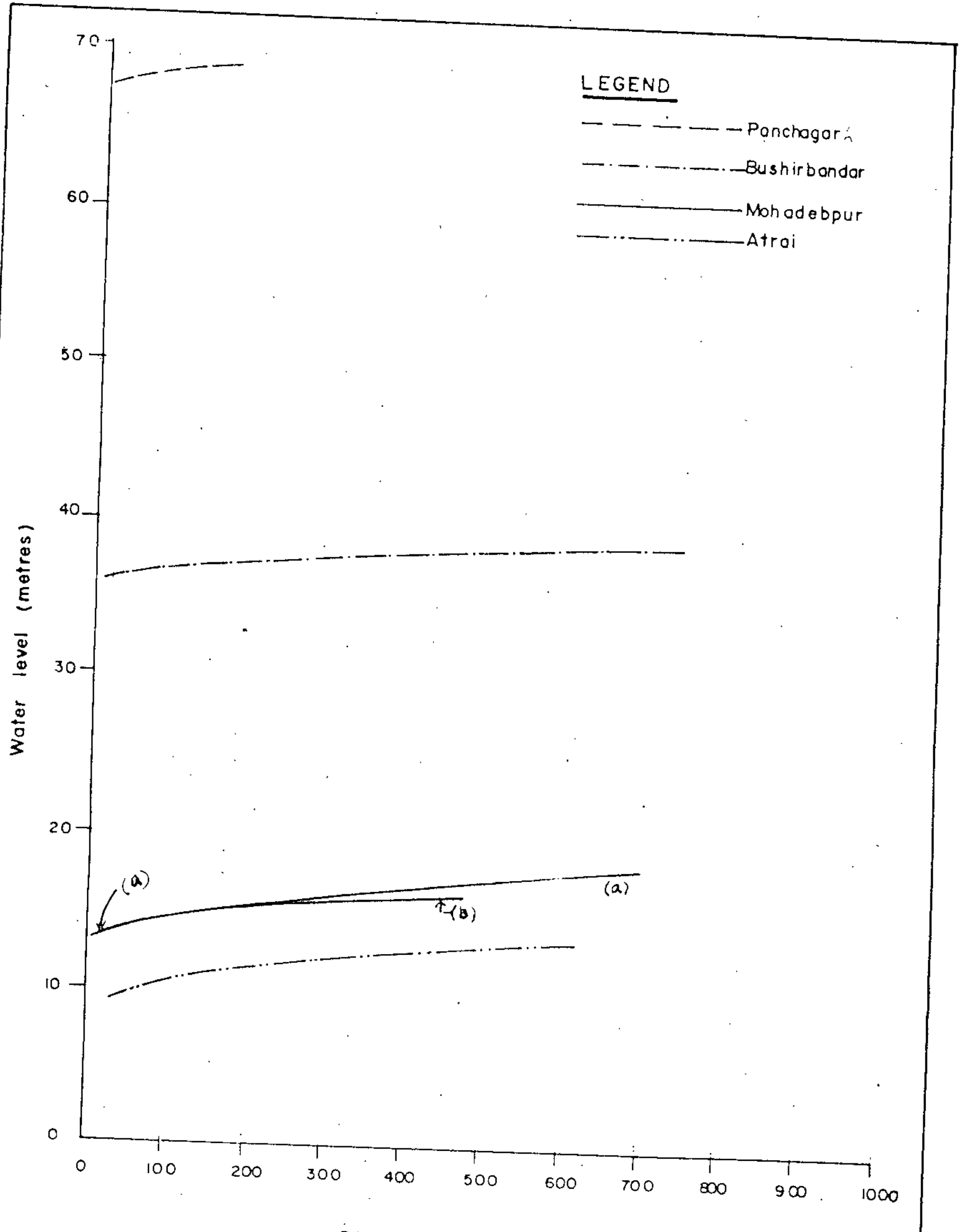


Fig. 5.1 (i) Comparison of rating curves of different stations in 1989-90

Bushirbandar Station. Discharge mainly depends on approach velocity, as approach velocity is the function of area, width, roughness co-efficient, perimeter and slope.

Among the minimum water levels in different years the lowest was in the years 1986-87 and 1987-88 and highest was in the year 1988-89 as shown in Fig. 5.2(b). Among the maximum water levels, the curve of 1987-88 was the highest and lowest in 1986-87. Approach velocity of 1989-90 was the greatest among all the years. But approach velocity of 1987-88 was nearly equal to that of 1989-90. As the area of 1987-88 was much greater than that of 1989-90, so curve of 1987-88 produced maximum discharge. The shape of the curves depend on the magnitude of their exponents.

Mohadebpur station. Shift in control was found in the year 1989-90. So two rating curves have developed in the year 1989-90. as shown in Fig 5.2(c).

Among the minimum water levels in different years the lowest was in the year 1989-90(a) and the highest was in the years 1985-86 and 1986-87. Among the maximum water levels minimum was in the year 1989-90(b) and maximum was the year 1987-88.

Maximum approach velocity occurred in the year 1987-88 and minimum in 1989-90. Area was also maximum in the year 1987-88. Probably due to maximum approach velocity maximum discharge occurs in 1987-88. But water level maximum was maximum in the year 1984-85. Water level of 1987-88 was nearly equal to the water level of 1987-88. Rating curve drawn on the basis of stage-discharge equation shows discharge of 1984-85 is slightly larger than that of the curve 1987-88. The shape of the curves depend on the magnitude of their exponents. Magnitude of the exponent in the year 1987-88 is the maximum and minimum in 1989-90(a).

Atrai Station. From the analysis of established rating curves no substantial shift in control was found. Water levels versus discharges were plotted for different years as shown in Fig 5.2(d). Among the minimum water levels, water level was 1982-83 and 1983-84 was the lowest and 1989-90 was the highest. Among the maximum water levels, the year 1987-88 was maximum and 1984-85 was the minimum. Among the different years maximum water level occurred in 1987-88 and approach velocity of this year also maximum. So rating curve of 1987-88 produced maximum discharge. Approach velocity may be the major reason behind this.

Mainly the magnitude of the exponent indicates the curvature of the rating curve . Magnitude of the exponents in the year 1982-83 is the maximum and 1981-82 is the minimum. Thus curvature for the year 1982-83 is steeper than that of 1981-82.

For a given discharge there was a considerable water level difference for each station namely Panchagar, Bushirbandar, Mohadebpur and Atrai. These may be due to temporary shifting of stations towards upstream. At Panchagar the station may be reshifted to original position at 1987-88, this possibility was investigated and no record of station shifting existed.

At Panchagar there is a systematic development in the slope of the rating curve, if 1981-82 is taken as a base year then the rating curve gets steeper till 1986-87, then trend in the slope of the curve is reversed and 1988-89 curve becomes almost similar to 1981-82. This phenomenon is also observed at Atrai and Mohadebpur though it is not as pronounced as shown at Panchagar. One possible reason could be that there was a built up on river bed or the river aggradation during 1981-82 to 1986-87 season.Then the river could be adjusting back to the original profile. A study in the changes of longitudinal profile of the river could confirm this assumption. However statistical analysis showed that no shift in control occurred.

5.5 Comparison of Rating curve between Established curves and BWDB curves

For comparing established stage-discharge relationships with BWDB, the coefficients of correlation and standard errors of mean relation at mean were compared and are presented in Table 5.5(a) to 5.5(d). Standard errors of mean relation at mean of BWDB curves were calculated from the stage-discharge relations. No significant difference between of the coefficients of correlation were found. Most of the years standard errors of mean relation at mean of BWDB curves are slightly greater than that of established curves. In establishing BWDB curves sometimes a few discharges are omitted without any reasonable justification, for getting better correlation between stages and discharges. Established rating curves of different stations are shown in Fig. 5.3(a) to 5.6(a) and BWDB curves are presented in Fig. 5.3(b) to 5.6(b).

5.6 Comparison of Stage-Discharge with Mean Depth-discharge Relationship

Power type and parabolic mean depth-discharge relationships were separately developed using methods of least squares for each year of record and for four selected stations. Summary of these rating curves are presented in Table 5.6. Power type stage-

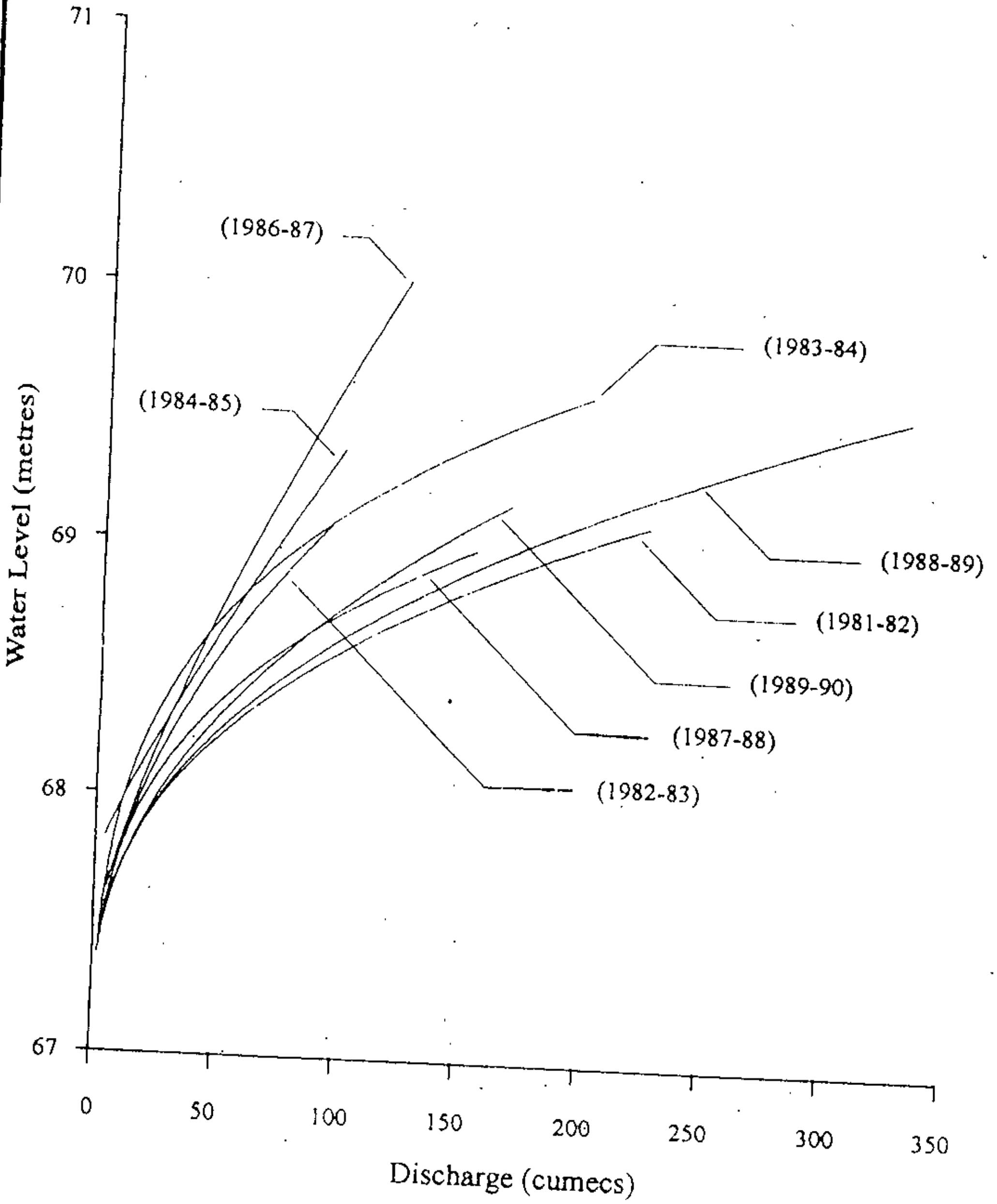


Fig. 5.2(a). Comparison of stage-discharge curves of Atrai river at Panchgarh by years.

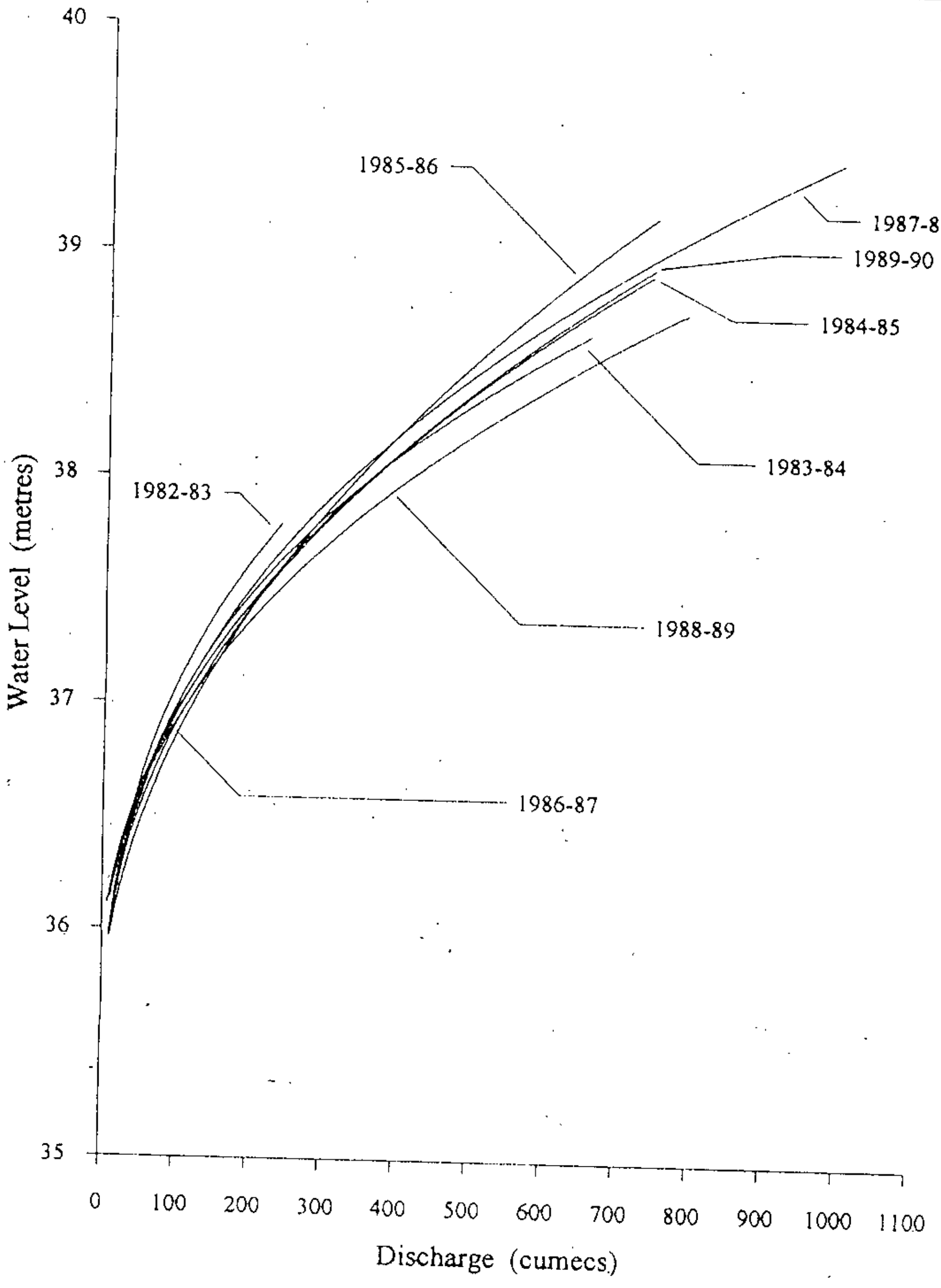


Fig. 5.2(b). Comparison of stage-discharge curves of Atrai river at Bushirbandar by years.

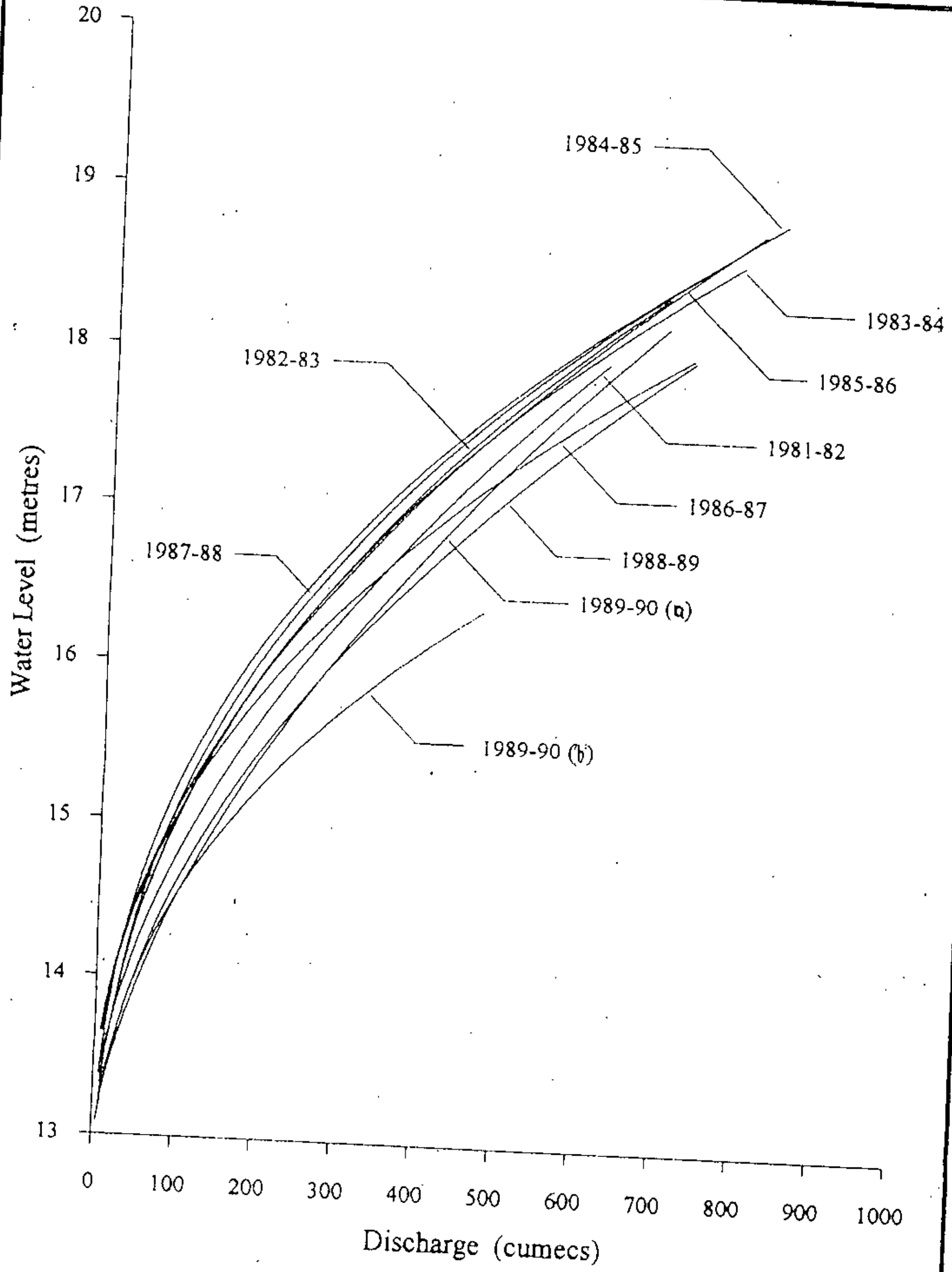


Fig. 5.2(c). Comparison of stage-discharge curves of Atrai river at Mohadebpur by years.

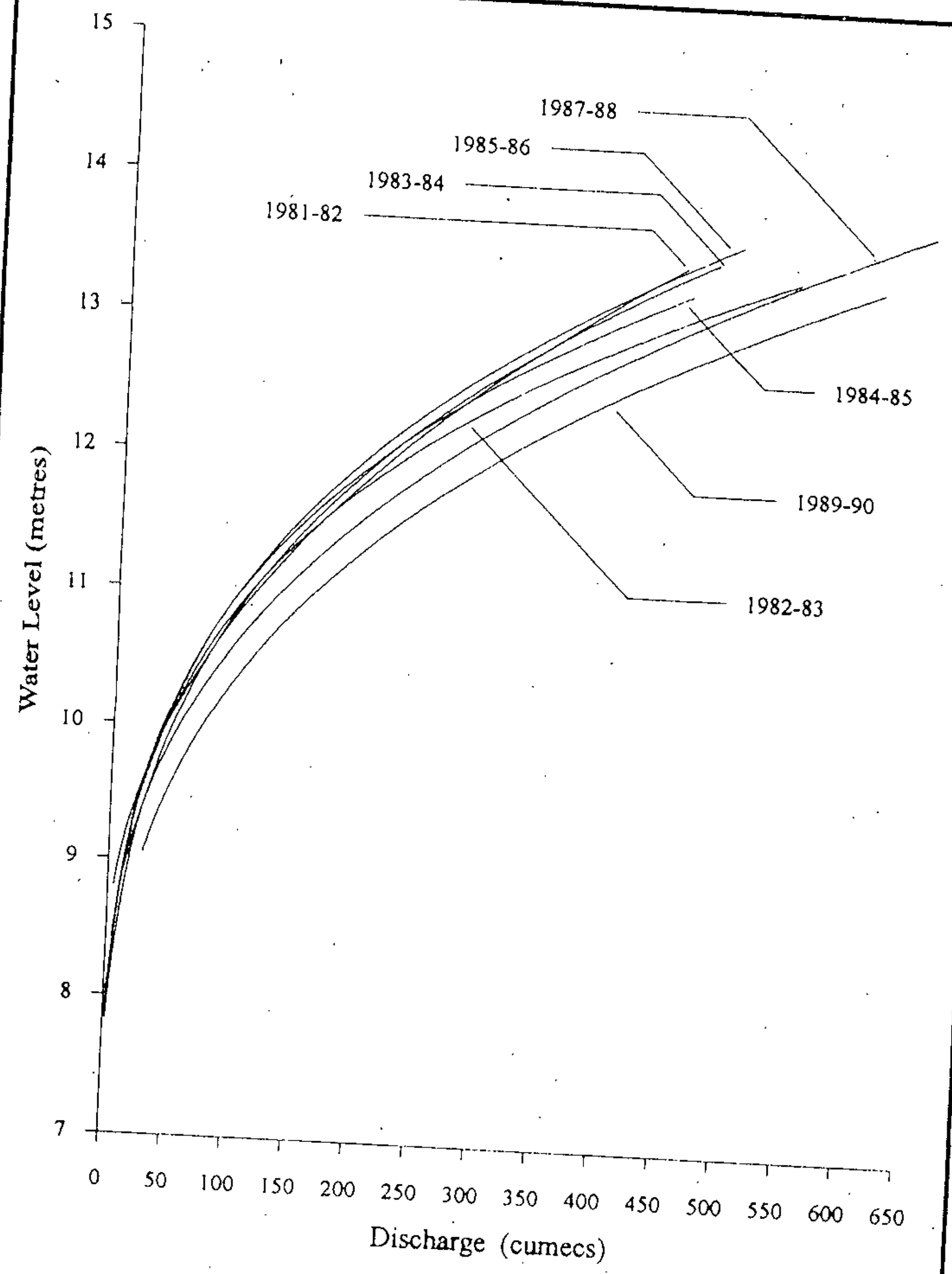


Fig. 5.2(d). Comparison of stage-discharge curves of Atrai river at Atrai by years.

Table 5.5(a) Comparison of Power Type Established Curves with BWDB Curves at Panchagarh

Year	Established Curve			BWDB Curve		
	No. Obs. (N)	Coefficiants of Correlation	2 S_{mr} (+ %)	No. Obs. (N)	Coefficiants of Correlation	2 S_{mr} (+ %)
82-83	18	0.782	26.87	18	0.784	28.08
83-84	21	0.943	18.96	21	0.943	18.92
84-85	20	0.944	16.16	20	0.932	18.51
87-88	28	0.985	7.01	11	0.994	11.69
				18	0.997	4.30
88-89	26	0.989	7.13	11	0.998	7.13
			4.72	13	0.999	4.72

Table 5.5(b) Comparison of Power Type Established Curves with BWDB Curves at Bushirbandar.

Year	Established Curve			BWDB Curve		
	No. Obs. (N)	Co-efficiants of Correlation	2 S_{mr} (+ %)	No. Obs. (N)	Co-efficiants of Correlation	2 S_{mr} (+ %)
82-83	18	0.937	19.07	7	0.999	5.0
				12	0.983	11.55
83-84	20	0.991	6.68	20	0.994	6.83
84-85	19	0.987	10.99	18	0.983	12.68
85-86	18	0.991	8.96	19	0.989	10.43
86-87	21	0.994	5.45	20	0.996	5.80
87-88	25	0.990	7.43	25	0.990	7.52
88-89	28	0.985	9.01	9	0.988	8.42
				9	0.993	7.14
				11	0.985	5.09
89-90	26	0.994	6.61	11	0.992	9.33
				11	0.992	5.23

Note: S_{mr}= Percentage of standard error of the mean relation at 95% confidence limits

Table 5.5(c) Comparison of Power Type Established Curves with BWDB Curves at Mohadebpur.

Year	Established Curve			BWDB Curve		
	No. Obs. (N)	Coefficiants of Correlation	$2\ S_{mr}$ (+ %)	No. Obs. (N)	Coefficiants of Correlation	$2\ S_{mr}$ (+ %)
82-83	19	0.980	12.31	17	0.978	16.22
85-86	20	0.992	9.48	12	0.998	8.77
				10	0.999	5.02
86-87	23	0.998	3.49	23	0.998	3.87
87-88	27	0.980	11.75	19	0.997	5.63
				8	0.972	4.97
88-89	25	0.998	3.62	23	0.997	5.18
(89-90).A	10	0.998	9.13	8	0.988	19.01
(89-90).B	17	0.998	3.30	18	0.995	3.89

Table 5.5(d) Comparison of Power Type Established Curves with BWDB Curves at Atrai.

Year	Established Curve			BWDB Curve		
	No. Obs. (N)	Coefficiants of Correlation	$2\ S_{mr}$ (+ %)	No. Obs. (N)	Coefficiants of Correlation	$2\ S_{mr}$ (+ %)
82-83	19	0.974	17.72	19	0.961	23.34
83-84	20	0.981	15.34	19	0.971	17.61
85-86	20	0.989	12.30	11	0.823	19.60
				14	0.984	15.45
87-88	28	0.980	11.60	28	0.980	11.59
89-90	22	0.988	7.33	21	0.994	5.93

Note: S_{mr}= Percentage of standard error of the mean relation at 95% confidence limits

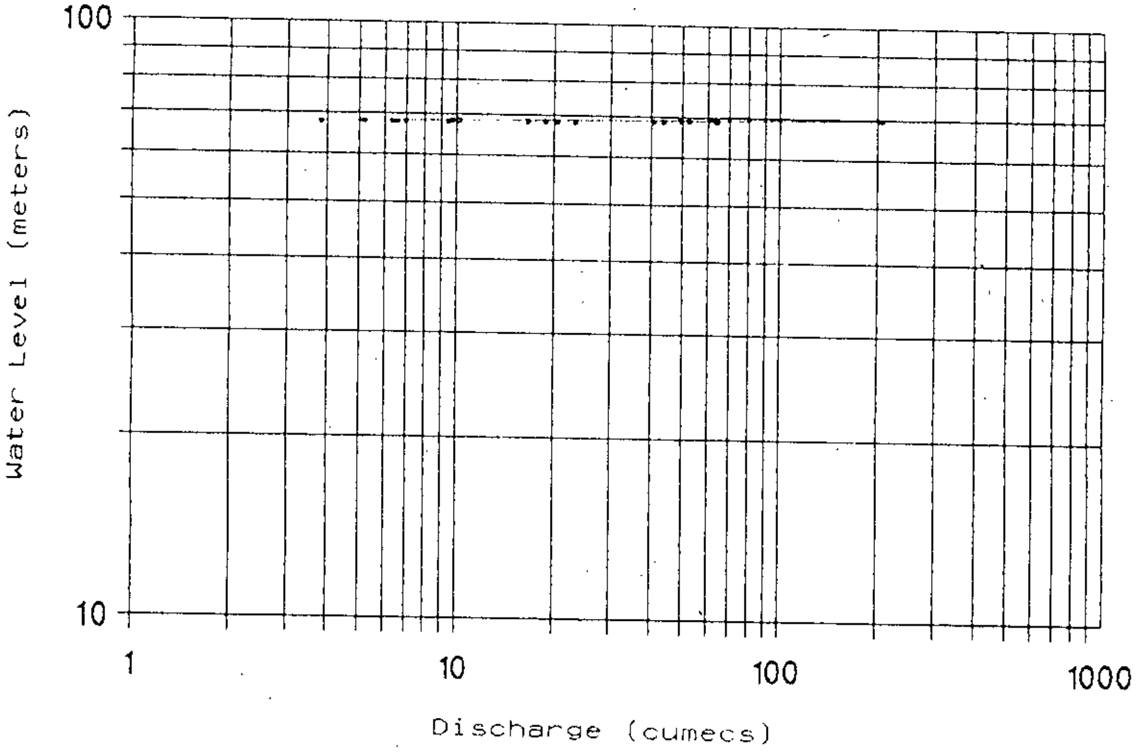


Fig. 5.3(a) Rating curve of Panchagarh for 1983-84

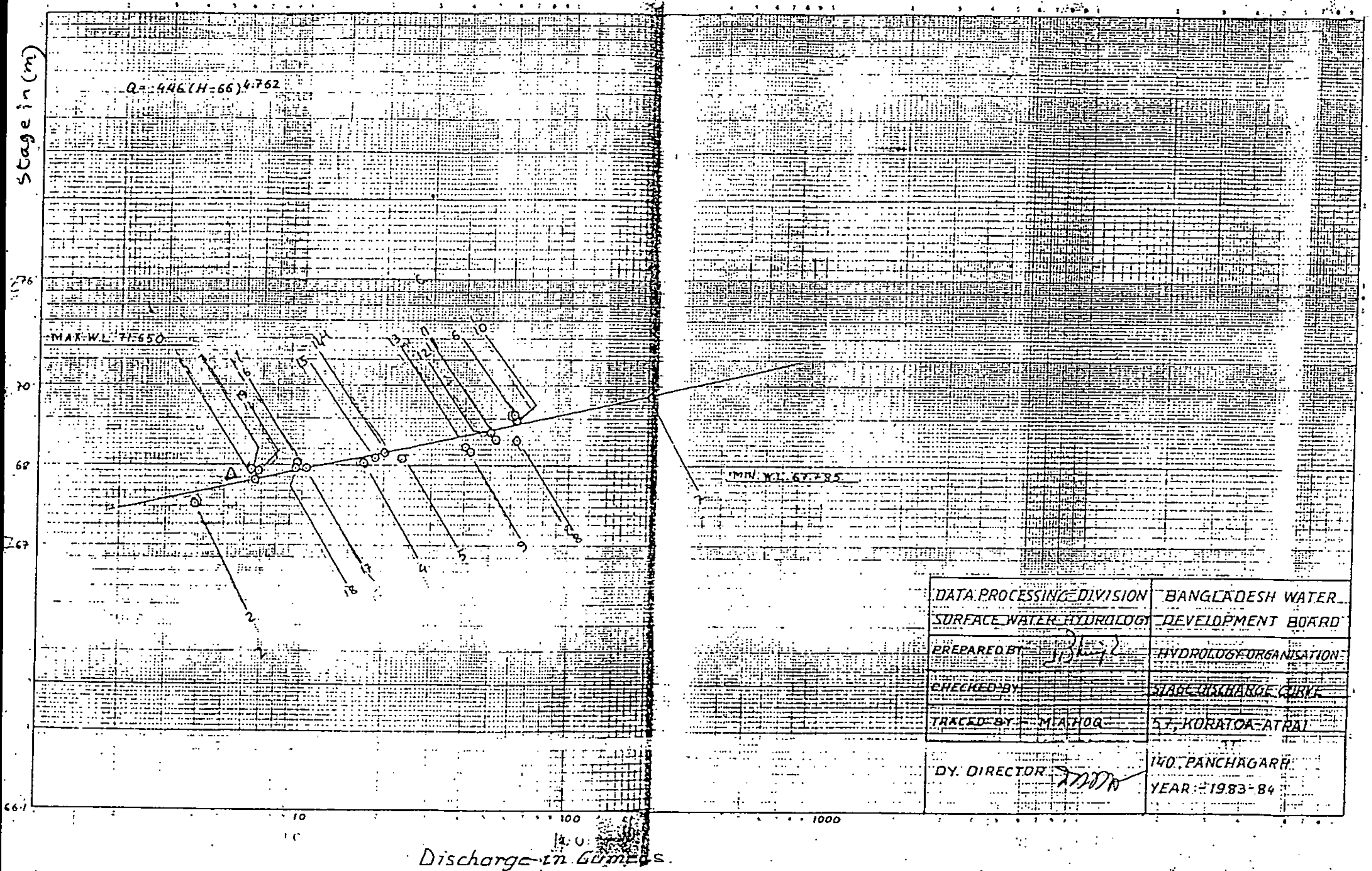


Fig. 5.3(b) BWDB rating curve of Panchagarch for 1983-84.

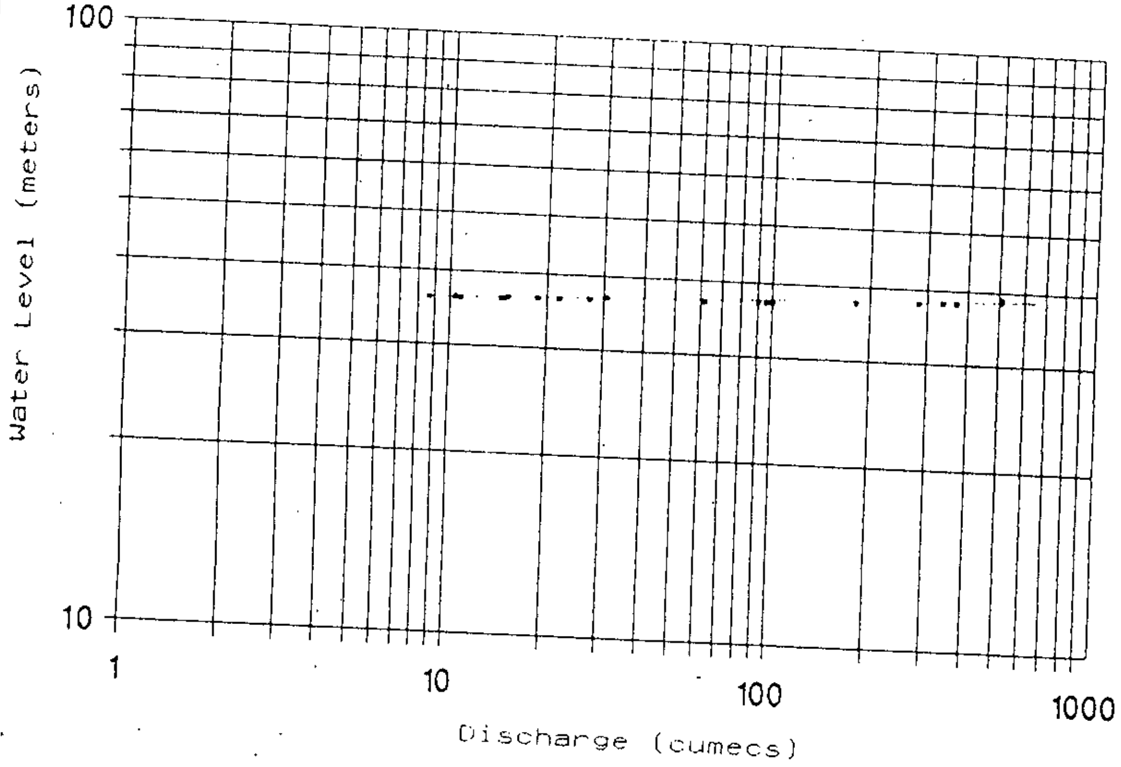
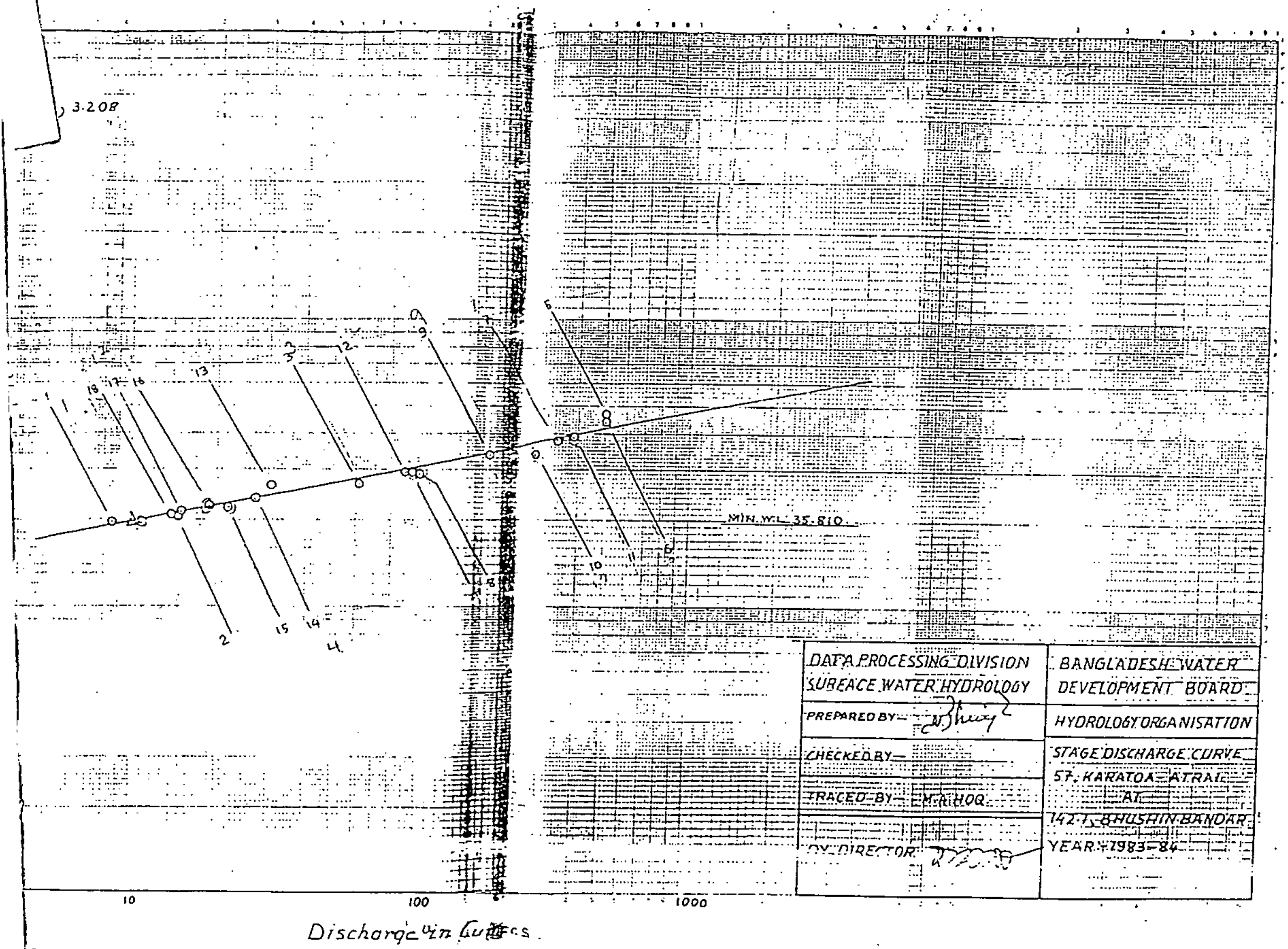


Fig. 5.4(a) Rating curve of Bushirbandar for 1983-84



DB rating curve of Bushirbandar for 1983-84.

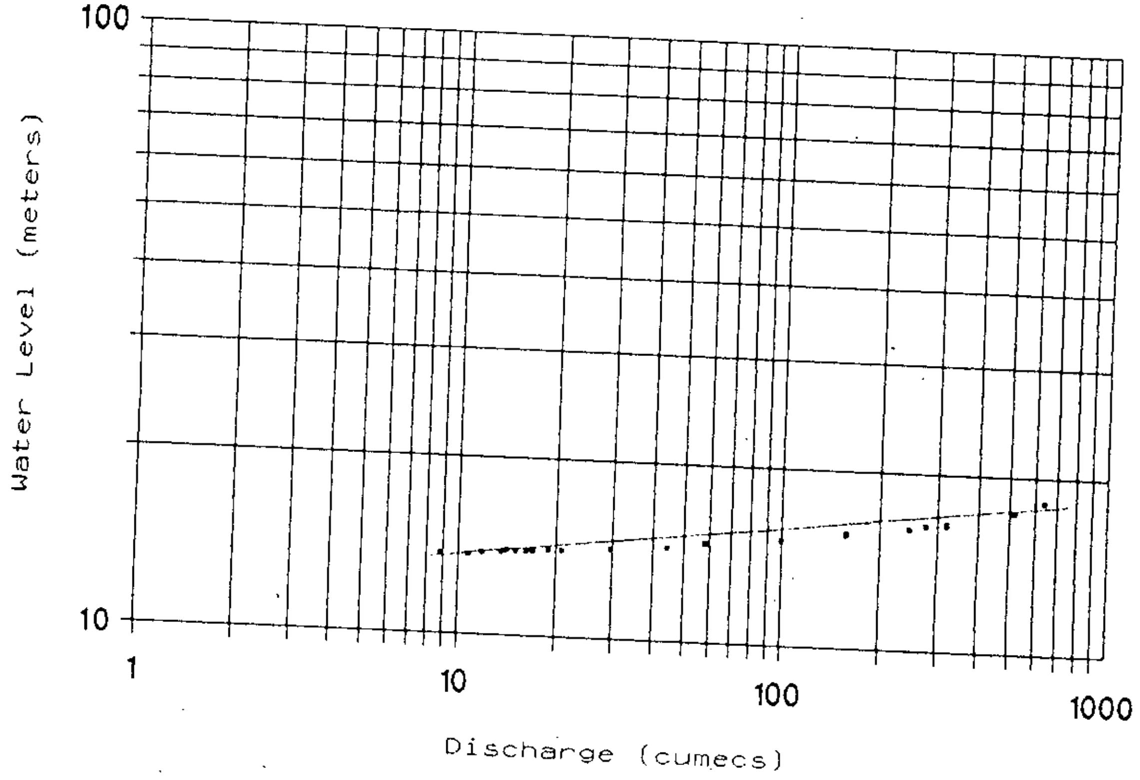
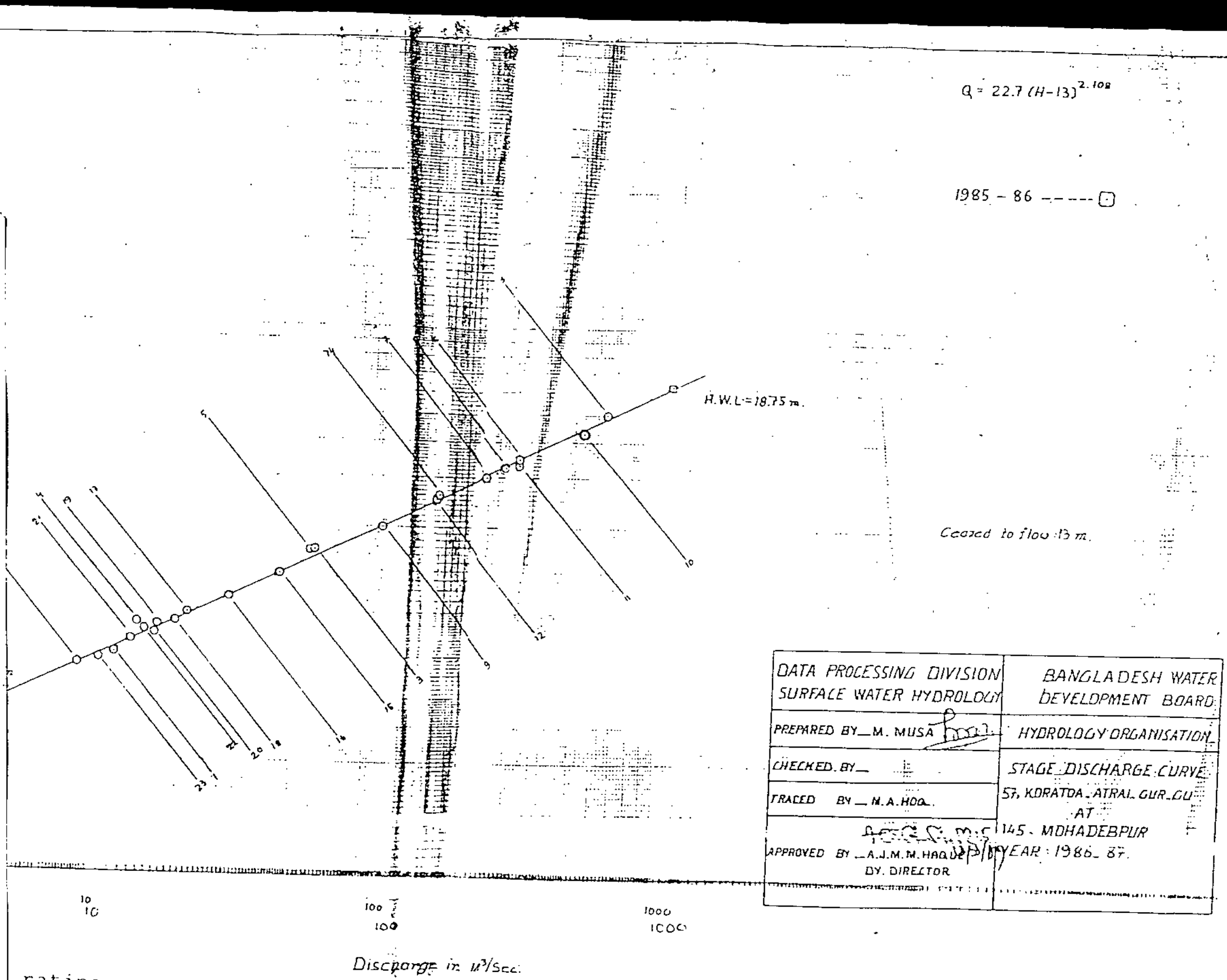


Fig. 5.5(a) Rating curve of Mohadebpur for 1986-87



DATA PROCESSING DIVISION
SURFACE WATER HYDROLOGY

BANGLADESH WATER
DEVELOPMENT BOARD

PREPARED BY _ M. MUSA

HYDROLOGY ORGANISATION

CHECKED. BY _

STAGE DISCHARGE CURVE
57, KORATOA - ATRAI - GUR - GU
AT
145 - MOHADEBPUR
YEAR : 1986 - 87.

TRACED BY _ M. A. HOQ.

APPROVED BY _ A.J.M.M. HAQUE
DY. DIRECTOR

rating curve of Mohadebpur for 1986-87.

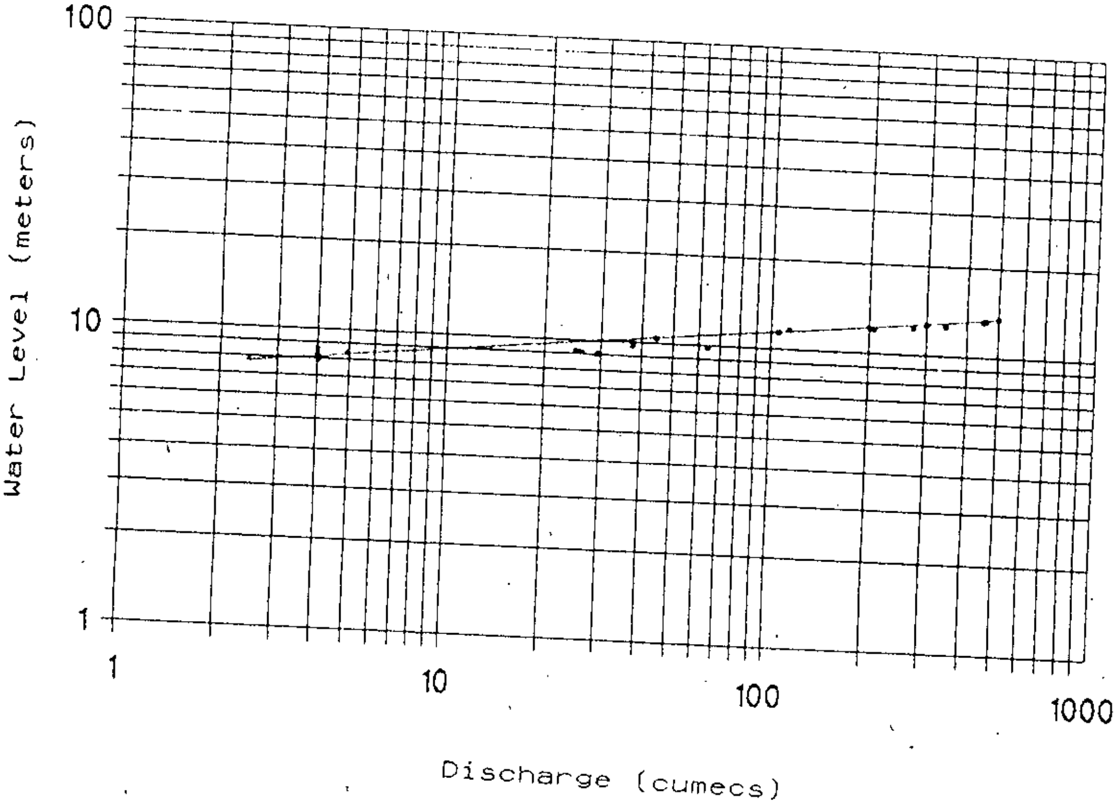
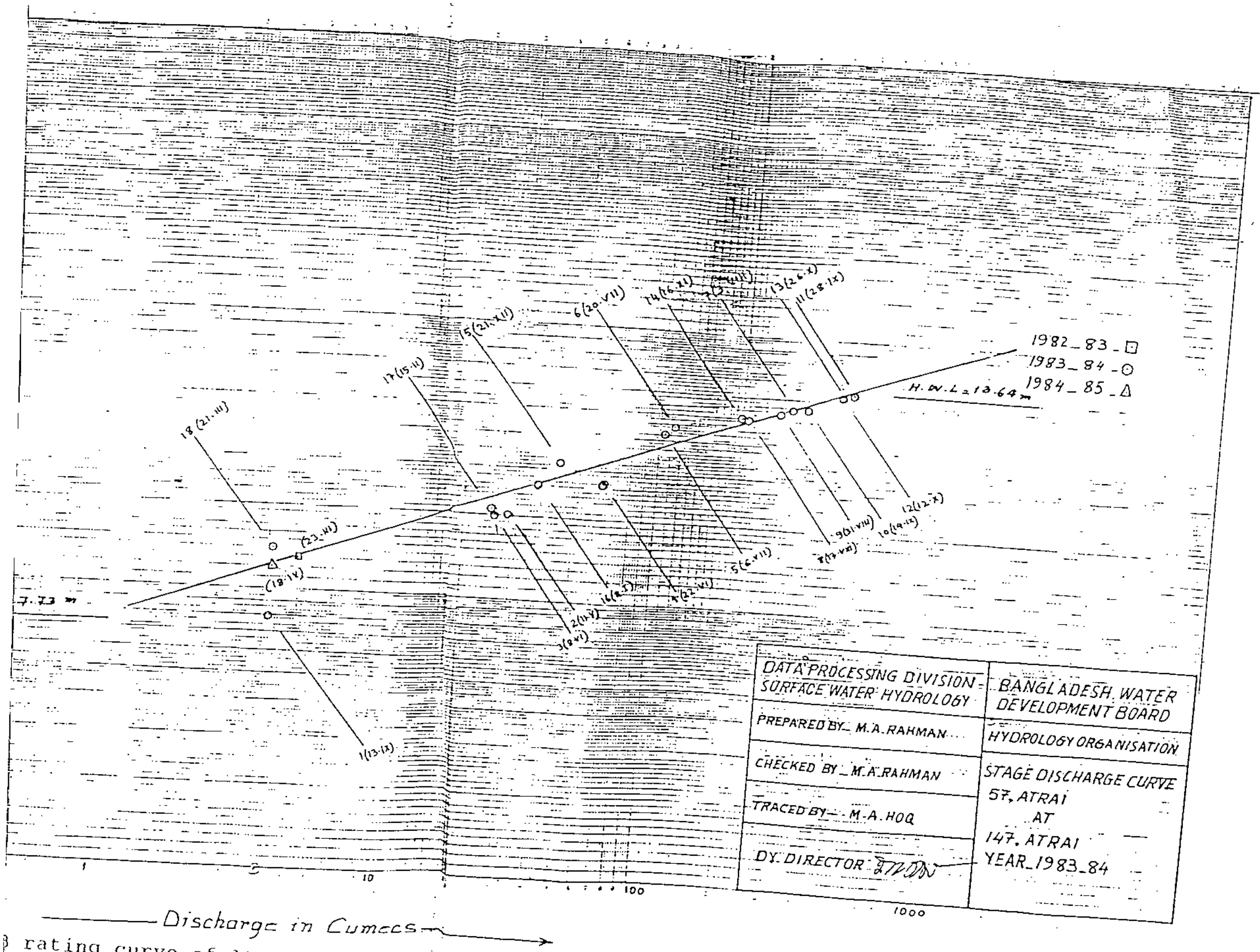


Fig. 5.6(a) Rating curve of Atrai for 1983-84



rating curve of Atrai for 1983-84

Table 5.6 Summary of Power and Parabolic Mean Depth-discharge Relations of Atrai River.

Station	Year	Power Equation			Parabolic Equation			
		K	n	Coefficient of Correlation	a	b	c	Coefficient of Correlation
Panchagarh	1981-82 82-83 86-87 87-88 88-89 89-90	124.9548 51.5457 26.4667 44.1122 65.5345 53.4973	1.5455 0.9641 1.3531 1.5686 2.2662 2.0445	0.9642 0.6842 0.7812 0.9127 0.941 0.9060	-13.531 19.842 -15.664 -19.027 88.483 -55.392	105.6769 -51.3194 62.7106 90.1198 -362.004 196.1799	39.421 110.7707 -11.6545 -10.8459 346.68 -64.7344	0.997 0.9752 0.6370 0.7704 0.9238 0.6982
Bushirbandar	1982-83 86-87 87-88 88-89 89-90	80.3822 167.6053 103.3589 139.0377 85.6384	1.8798 3.0537 2.5029 1.6619 1.2684	0.8576 0.8339 0.9778 0.9226 0.6951	-41.280 -163.674 -141.124 -26.890 89.879	127.0969 397.3259 284.7748 117.2991 -221.342	18.0872 -54.6952 19.001 82.1567 203.6954	0.789 0.9287 0.9825 0.9844 0.8803
Mohadebpur	1981-82 82-83 83-84 84-85 86-87 87-88 88-89 89-90.a 89-90.b	16.7456 14.5491 16.1403 90.1156 14.2281 12.9279 9.8774 7.8794 14.1576	2.3225 2.3581 2.2856 2.2095 2.4866 2.5444 2.647 2.8708 2.5932	0.9897 0.9815 0.9957 0.9952 0.995 0.9924 0.9923 0.996 0.996	39.552 30.976 103.635 8.134 20.620 36.957 -60.801 26.424 -54.826	-58.533 -51.6147 -141.018 -16.6355 -44.0893 -67.2187 39.8052 6.1177 31.4451	38.3555 -36.2522 56.4196 28.8926 37.3468 43.4882 17.821 27.1367 24.6460	0.9979 0.9858 0.9922 0.9572 0.9964 0.9936 0.9920 0.9555 0.9960
Atrai	1981-82 82-83 83-84 87-88 89-90	0.0514 0.3253 0.2389 0.00343 0.01189	5.3131 3.8708 4.2256 6.4736 5.72058	0.966 0.8725 0.9764 0.8572 0.969	427.236 315.555 277.578 826.127 200.492	294.047 152.865 -211.892 -477.492 -182.94	52.7455 -8.4805 40.8798 68.8814 34.6618	0.9924 0.7563 0.9740 0.9856 0.973

discharge relations are given detailed in Appendix A in Table 33 to 36. Similarly parabolic relationships are given in Appendix A, Table 37 to 40.

For comparing relationship of power type and parabolic equations of stage-discharge with mean depth-discharge for Panchagarh, Bushirbandar, Mohadebpur, and Atrai are presented in table 5.7(a) to 5.7(d) and 5.8(a) to 5.8(d) respectively.

In the above mentioned stations, both the power and parabolic equations of stage-discharge relation were better fitted than that of mean depth-discharge relations.

Table 5.7(a) Comparison of Power Type Equations Between Stage-Discharge and Mean-Depth Discharge Relations of The Atrai at Panchagarh

Year	Coefficient of Correlation		% Standard Error of Estimate of Q	
	H Vs Q	M Vs Q	H Vs Q	M Vs Q
1981-82	0.9861	0.9642	19.79	31.64
82-83	0.7829	0.6842	47.34	55.50
86-87	0.9760	0.7812	19.96	57.22
87-88	0.9849	0.9127	19.55	46.12
88-89	0.9892	0.9410	19.09	44.08
89-90	0.9790	0.9060	27.30	56.69

H Vs Q = Stage-discharge relation

M Vs Q = Mean depth-discharge relation

Table 5.7(b) Comparison of Power Type Equation Between Stage-Discharge and Mean-Depth Discharge Relation of Bushirbandar

Year	Coefficient of correlation		% Standard Error of Estamate of Q	
	H Vs Q	M Vs Q	H Vs Q	M Vs Q
1982-83	0.9907	0.8576	40.05	58.91
86-87	0.9942	0.8339	12.02	61.46
87-88	0.9902	0.9778	18.13	27.23
88-89	0.9715	0.9226	30.74	50.04
89-90	0.9941	0.6951	17.02	112.69

H Vs Q = Stage-discharge relation

M Vs Q = Mean depth discharge relation

Table 5.7(c) Comparison of Power Type Equation Between Stage-Discharge and Mean-Depth Discharge Relations of The Atrai at Mohadebpur

Year	Coefficient of correlation		% Standard Error of Estimate of Q	
	H Vs Q	M Vs Q	H Vs Q	M Vs Q
1981-82	0.9923	0.9897	16.03	18.52
82-83	0.9802	0.9815	26.30	25.47
83-84	0.9927	0.9957	17.29	13.25
84-85	0.9717	0.9952	37.71	15.54
86-87	0.9984	0.9950	8.17	14.22
87-88	0.9866	0.9924	25.09	18.92
88-89	0.997	0.9925	10.8	17.09
89-90	0.9935	0.9867	17.77	25.62

H Vs Q = Stage-discharge relation

M Vs Q = Mean depth discharge relation

Table 5.7(d) Comparison of Power Type Equation Between Stage-Discharge and Mean Depth-Discharge Relations of Atrai River at Atrai

Year	Coefficient of Correlation		% Standard Error of Estimate of Q	
	H Vs Q	M Vs Q	H Vs Q	M Vs Q
1981-82	0.9878	0.9660	25.39	42.24
82-83	0.9765	0.8725	38.10	86.4
83-84	0.9814	0.9764	33.46	33.18
87-88	0.9179	0.8572	85.52	110.78

H Vs Q = Stage-discharge relation

M Vs Q = Mean depth discharge relation

Table 5.8(a) Comparison of Parabolic Type Equation Between Stage-Discharge and Mean-Depth Discharge Relations of The Atrai at Panchagar

Year	Coefficient of Correlation		Standard Error of Estimate of Q	
	H Vs Q	M Vs Q	H Vs Q	M Vs Q
1981-82	0.9647	0.9970	21.382	6.178
82-83	0.9801	0.9752	7.513	8.365
86-87	0.9872	0.6370	3.951	19.149
87-88	0.9811	0.7704	8.645	28.475
88-89	0.9986	0.9238	3.795	27.054
89-90	0.9853	0.6982	9.207	38.639

H Vs Q = Stage-discharge relation

M Vs Q = Mean depth-discharge relation

Table 5.8(b) Comparison of Parabolic Type Equation Between Stage-Discharge and Mean Depth-Discharge Relations of The Atrai at Bushirbandar

Year	Coefficient of Correlation		Standard Error of Estimate of Q	
	H Vs Q	M Vs Q	H Vs Q	M Vs Q
1982-83	0.9767	0.7890	16.804	48.077
86-87	0.9889	0.9287	11.865	29.658
87-88	0.9955	0.9825	19.885	38.896
88-89	0.9979	0.9844	10.487	28.676
89-90	0.9946	0.8803	23.695	108.349

H Vs Q = Stage-discharge relation

M Vs Q = Mean depth discharge relation

Table 5.8(c) Comparison of Parabolic Type Equation Between Stage-Discharge and Mean Depth-Discharge Relations of The Atrai at Mohadebpur

Year	Coefficiant of Correlation		Standard Error of EStimate of Q	
	H Vs Q	M Vs Q	H Vs Q	M Vs Q
1981-82	0.9990	0.9979	7.279	10.923
82-83	0.9940	0.9858	18.771	28.718
83-84	0.9947	0.9922	22.089	26.775
84-85	0.9919	0.9572	28.106	64.003
86-87	0.9969	0.9964	14.464	16.663
87-88	0.9935	0.9936	32.742	32.309
88-89	0.9989	0.992	9.624	25.307
89-90(a)	0.984	0.9555	33.498	85.526
89-90(b)	0.997	0.966	11.127	13.9922

H Vs Q = Stage-discharge relation
M Vs Q = Mean depth-discharge relation

Table 5.8(d) Comparison of Parabolic Type Equation Between Stage-Discharge and Mean Depth-Discharge Relations of Atrai River at Atrai.

Year	Coefficiant of Correlation		Standard Error of Estimate of Q	
	H Vs Q	M Vs Q	H Vs Q	M Vs Q
1981-82	0.9874	0.9924	31.47	24.789
82-83	0.9929	0.7563	19.34	110.708
83-84	0.9881	0.9740	27.65	41.177
87-88	0.9944	0.9856	25.617	42.730
89-90	0.9751	0.973	42.393	44.145

H Vs Q = Stage-discharge relation

M Vs Q = Mean depth-discharge relation

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

The present study was aimed at establishing stage-discharge relationship of Atrai river at some selected stations analytically. Stage-discharge relationships of different stations were investigated by establishing Power type and Parabolic equations. The reliability of stage-discharge relationships were also investigated. As an alternative to stage-discharge relationship, mean depth was correlated to discharge.

On the basis of this study the following conclusions can be drawn:

1. All the equations are free from bias.
2. Both power type and parabolic equations on average do not significantly under-estimates or over-estimate discharge as compared to actual observations on which it is based.
3. No shifting control is found.
4. For low water level, power type relation is better than parabolic type relation. While for higher water level (0.912H+L.W.L), H the difference of highest and lowest water level, parabolic equation is better than that of power type equation.
5. Stage-discharge curves for different stations are not significantly comparable.
6. Power and Parabolic stage-discharge equations are better fitted than that of Mean depth discharge relations.

Recommendation for Further Study

1. Similar type of study may conducted for other rivers in Bangladesh.
2. To determine shift control in stage-discharge relation (h-Q), sediment transported by the river may be correlated with (h-Q).

REFERENCES

BWDB WATER SUPPLY PAPER-392 (1976), "Hydrological Year book of Bangladesh", 1973-74 water year, Volume II ; part-A Water level, Bangladesh water Development Board, Dhaka.

BWDB WATER SUPPLY PAPER-393 (1977), "Hydrological Year book of Bangladesh", 1973-74 water year, Volume III; part-A Discharges, Bangladesh water Development Board, Dhaka.

Chow, V.T. (1964), " Handbook of Applied Hydrology" Mc-Grow Hill Book Co, New York, Toronto, London.

Chow, V. T, Maidment, D and Mays, (1988), "Applied hydrology", Mc-Graw Hill International Edition.

CROXTON, F. E, COWDEN D. J. AND KLEIN S.(1979), "Applied General Statistics", Prentice-Hall of India Private limited, New Delhi, India.

GARG, S.K. (1981). " Irrigation Engineering and Hydraulic Structures", 3rd edition, Khanna publishers, Delhi, India.

GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH, Flood Coordination Organization (1992), FAP-25, Flood, Modelling and Plan Management, Flood Hydrology Study, Main Report.

GROVER N. C, HARRINGTON, A, W, (1943),"Stream Flow", John Wiley & Sons,Inc. New York.

HAAN, C.T.(1977), "Statistical Method in Hydrology", The Lows State University Press/Ames.

HERSCHY W. REGINALD (1985), "Streamflow Measurement" Elseyier Applied Publisher, London and Newyork.

INDIAN STANDARD (1965), "Recommendations for Estimation of Discharges by Establishing Stage-Discharge Relation in Open Channel Flow", Indian Standards Institution, New Delhi, India.

ISO, International ORGANIZATION FOR STANDARDIZATION, DRAFT ISO RECOMMENDATION NO- 1071, " Establishment and Operation Of a Gauging Station and Determination of The Stage-Discharge Relation.

MINISTRY OF WATER ENERGY AND MINERALS, Tanzania, "A Manual On Procedures In Operational Hydrology", Vol. 4. Stage-Discharge Relations At Stream Gauging Station.

MUTREJA K. N. (1986)," Applied Hydrology", Tata Mcgraw-Hill Publishing Company Limited, New Delhi.

PAULHUS.J.L.H, KOHLER. MAX A. AND JR.K.LINSLEY (1979), "Applied Hydrology", McGraw-Hill Publishing Company Limited, New Delhi.

RAGUNATH, H.M. (1986), "Hydrology, Principle, Analysis and Design", WILEY Eastern Limited", India.

SHAHIN, M. A. (1980), "Statistical Analysis in Hydrology", Vol.1, International institute for Hydraulic and Environmental Engineering, Delft, Netherlands.

SPIEGEL, M. R. (1962), "Schaum's Outline of Theory and Problems of Statistic", Schaum Publishing company, New york.

SUBRAMANYA K.,(1990), "Engineering Hydrology",Mcgraw-Hill Publishing Company Limited, New Delhi.

TECHNIQUE OF WATER RESOURCES INVESTIGATIONS OF THE UNITED STATES GEOLOGICAL SURVEY, (1974), "Stage Measurement at Gaging Stations", Chapter A7, United States Government Printing Office, Washington, 1968.

TECHNIQUE OF WATER RESOURCES INVESTIGATIONS OF THE UNITED STATES GEOLOGICAL SURVEY,(1980), "Discharge Measurements at Gaging stations", Chapter A8, United States Government Printing Office, Washington, 1969.

UNITED NATION DEVELOPMENT PROGRAMME HYDROLOGICAL SURVEY PROJECT UN-DTCD BGD 72/008, (1982), "Manual On Data Processing", Stream Flow, Dhaka, Bangladesh.

WAZED ABDUL (1991), " BANGLADESH NODIMALA, WORDINI PRINTING AND PUBLICATION,DHAKA BANGLADESH

WILSON E.M.(1983), "Engineering Hydrology",3rd Edition, English Language Book Society/Macmillan.

WORLD METROLOGICAL ORGANIZATION, (WMO), (1980), Operational Hydrology Report No.-13, WMO No- 519

YEVJEVICH, V. (1972), "Probability and Statistics in Hydrology", Water Resources, Publications, Fort Collins, Colorado, U.S.A.

APPENDIX A

Table-1 Power Type Stage-Discharge Relations of the Atrai at Panchagarh

Year	No. Obs. (N)	$Q = C\ (h-a)^n$
81-82	19	$Q = 23.5698\ (h-66.9382)^{2.9200}$
82-83	18	$Q = 18.8212\ (h-67.00)^{2.2113}$
83-84	21	$Q = 0.4277\ (h-65.9891)^{4.7846}$
84-85	20	$Q = 54.5965\ (h-67.7152)^{1.1733}$
86-87	25	$Q = 32.7867\ (h-67.3802)^{1.3569}$
87-88	28	$Q = 5.8364\ (h-66.5968)^{3.7535}$
88-89	26	$Q = 30.1003\ (h-67.0407)^{2.5987}$
89-90	26	$Q = 29.35997\ (h-67.0558)^{2.3271}$

Table-2 Power Type Stage-Discharge Relations of the Atrai at Bushirbandar

Year	No. Obs. (N)	$Q = C(h-a)^n$
82-83	18	$Q=10.0308(h-34.9569)^{3.0446}$
83-84	20	$Q=15.7207(h-35.1274)^{2.9665}$
84-85	19	$Q=39.4685(h-35.4244)^{2.3439}$
85-86	18	$Q=52.7252(h-35.4891)^{2.0302}$
86-87	21	$Q=14.2364(h-35.0567)^{3.0441}$
87-88	25	$Q=24.0262(h-35.2578)^{2.6068}$
88-89	28	$Q=54.5144(h-35.6275)^{2.3446}$
89-90	26	$Q=69.9727(h-35.7745)^{2.0459}$

Table-3 Power Type Stage-Discharge Relations of the Atrai at Mohadebpur

Year	No.Obs. (N)	$Q = c(h-a)^n$
81-82	17	$Q=30.4554(h-12.9033)^{1.8626}$
82-83	19	$Q=9.5583(h-12.3557)^{2.3843}$
83-84	20	$Q=6.3598(h-12.1415)^{2.5808}$
84-85	20	$Q=5.2459(h-12.2688)^{2.6898}$
85-86	20	$Q=25.6218(h-13.1186)^{1.9885}$
86-87	23	$Q=14.7546(h-12.8125)^{2.3661}$
87-88	27	$Q=4.2281(h-11.95)^{2.7348}$
88-89	25	$Q=22.7397(h-12.574)^{2.0536}$
(89-90).A	10	$Q=37.0787(h-12.761)^{1.7314}$
(89-90).B	17	$Q=13.7817(h-12.3622)^{2.5458}$

Table-4 Power Type Stage-Discharge Relations of Atrai river at Atrai

Year	No. Obs. (N)	$Q = c(h-a)^n$
81-82	19	$Q=9.3157(h-8.0401)^{2.3052}$
82-83	19	$Q=0.090918(h-5.8)^{4.301836}$
83-84	20	$Q=0.3117(h-6.0156)^{3.6525}$
84-85	20	$Q=0.1359(h-5.9785)^{4.0984}$
85-86	20	$Q=0.3542(h-6.2885)^{3.64345}$
87-88	28	$Q=3.0419(h-7.282)^{2.88215}$
89-90	22	$Q=0.648948(h-6.10)^{3.4679}$

Table-5 Parabolic Stage-Discharge Relations of the Atrai at Panchagarh

Year	No. of Obs. (N)	$Q = a_1 + b_1 (h-a) + c_1 (h-a)^2$
81-82	19	$Q=75.1855-167.156(h-66.9382)+111.4455(h-66.9382)^2$
82-83	18	$Q=80.4262-162.143(h-67.00)+97.08396(h-67.00)^2$
83-84	21	$Q=135.222-152.928(h-65.9891)+45.6048(h-65.9891)^2$
84-85	20	$Q=10.6757-9.1584(h-67.7152)+55.6853(h-67.7152)^2$
86-87	25	$Q=5.0222+36.0859(h-67.3809)+3.2853(h-67.3809)^2$
87-88	28	$Q=96.8560-171.752(h-66.5968)+82.2177(h-66.5968)^2$
88-89	26	$Q=6.8212-33.515(h-67.0407)+59.6251(h-67.0407)^2$
89-90	26	$Q=9.5773-31.765(h-67.0558)+51.1971(h-67.0558)^2$

Table-6 Parabolic Equation of Stage-Discharge Relation of the Atrai at Bushirbandar

Year	No.of Obs (N)	$Q = a_1 + b_1 (h-a) + c_1 (h-a)^2$
82-83	18	$Q=18.7864-54.2705(h-34.9569)+45.2997(h-34.9569)^2$
83-84	20	$Q=-4.4524-41.8829(h-35.1274)+58.4267(h-35.1274)^2$
84-85	19	$Q=6.4469-25.9803(h-35.4244)+62.52468(h-35.4244)^2$
85-86	18	$Q=-31.9526+56.0885(h-35.4891)+36.5842(h-35.4891)^2$
86-87	21	$Q=37.9169-89.8718(h-35.0561)+65.8994(h-35.0561)^2$
87-88	25	$Q=2.3564-35.1549(h-35.2578)+57.5796(h-35.2578)^2$
88-89	28	$Q=38.9335-38.9335(h-35.6275)+51.9875(h-35.6275)^2$
89-90	26	$Q=14.6833-32.6343(h-35.7745)+83.7219(h-35.7745)^2$

Table-7 Parabolic Equation of Stage-Discharge Relations of the Atrai at Mohadebpur

Year	No.of Obs. (N)	$Q = a_1+b_1(h-a)+c_1(h-a)^2$
81-82	17	$Q=-12.2412+24.7407(h-12.9093)+19.5676(h-12.9093)^2$
82-83	19	$Q=-32.7524+19.3297(h-12.3557)+13.9983(h-12.3557)^2$
83-84	20	$Q=-17.1382-4.5009(h-12.1415)+17.4720(h-12.1415)^2$
84-85	20	$Q=-13.0106-26.7716(h-12.2688)+20.2471(h-12.2688)^2$
85-86	20	$Q=-9.2574+11.7084(h-13.1186)+23.2012(h-13.1186)^2$
86-87	23	$Q=-9.8945-3.4949(h-12.8125)+25.6454(h-12.8125)^2$
87-88	27	$Q=115.803-117.079(h-11.95)+34.3420(h-11.95)^2$
88-89	26	$Q=-21.6203+26.87306(h12.5746)+19.873068(h12.574)^2$
(89-90)a	28	$Q=-11.6201+45.251(h-12.761)+14.8263(h-12.761)^2$
(89-90)b	17	$Q=-38.9886-65.7629(h-12.3622)+43.18214(h-12.3622)^2$

Table-8 Parabolic Stage-Discharge Relations of Atrai River at Atrai.

Year	No.of Obs. (N)	$Q = a_1+b_1(h-a)+c_1(h-a)^2$
81-82	19	$Q=57.5794-69.0794(h-8.0401)+27.6624(h-8.0401)^2$
82-83	19	$Q=206.644+137.717(h-5.8)+23.45154(h-5.8)^2$
83-84	20	$Q=218.2011-144.63(h-6.0156)+24.3641(h-6.0156)^2$
84-85	20	$Q=272.645-176.561(h-5.9785)+28.0266(h-5.9785)^2$
85-86	20	$Q=229.2407-158.414(h-6.2885)+27.1339(h-6.2885)^2$
87-88	28	$Q=90.869-91.7635(h-7.282)+27.6701(h-7.282)^2$
89-90	22	$Q=89.72711-85.5197(h-6.1)+21.13578(h-6.1)^2$

Table-9 Test for absence from Bias (Signs) of Power Type Stage-discharge Relations of the Atrai at Panchagar

Year	No. Obs. (N)	D.O.F	No.of +ve signs (n)	"t" Statistic	t at 5% of significance level	Remarks
81-82	19	17	9	0.0	2.11	Accepted
82-83	18	16	8	0.236	2.12	Accepted
83-84	21	21	11	0	2.08	Accepted
84-85	20	18	7	1.118	2.09	Accepted
86-87	25	23	12	0	2.06	Accepted
87-88	28	26	17	0.945	2.05	Accepted
88-89	26	24	11	0.588	2.06	Accepted
89-90	26	24	14	0.196	2.06	Accepted

Table-10 Test for absence from Bias (signs) of Power Type Stage-discharge Relations of the Atrai at Bushirbandar

Year	No. obs. (N)	D.O.F (N-2)	No.of +ve signs (n)	"t" statistics	t at 5% of significance level	Remarks
82-83	18	16	10	0.236	2.12	Accepted
83-84	20	18	12	0.671	2.10	Accepted
84-85	19	17	10	0.0	2.09	Accepted
85-86	18	16	9	-0.236	2.12	Accepted
86-87	21	19	9	0.436	2.09	Accepted
87-88	25	23	14	0.40	2.07	Accepted
88-89	28	26	16	0.567	2.06	Accepted
89-90	26	24	13	0.588	2.06	Accepted

Note: D.O.F=Degrees of freedom

Table-11 Test Result for absence from Bias (signs) of Power Type Stage-discharge Relations of Atrai at Mohadebpur

Year	No. Obs. (N)	D.O.F (N-2)	No. of +ve signs (n)	"t" statistics	t at 5% of significance Level	Remarks
81-82	17	15	9	0.0	2.13	Accepted
82-83	19	17	10	0.0	2.11	Accepted
83-84	20	18	11	0.224	2.10	Accepted
84-85	20	18	9	0.224	2.10	Accepted
85-86	20	18	11	0.224	2.10	Accepted
86-87	23	21	14	0.834	2.08	Accepted
87-88	27	25	16	0.770	2.06	Accepted
88-89	25	23	12	0.0	2.07	Accepted
(89-90).a	10	8	4	0.326	2.31	Accepted
(89-90).b	17	15	13	0.194	2.13	Accepted

Table-12 Test Result for absence from Bias (signs) of Power Type Stage-discharge relations of Atrai river at Atrai.

Year	No.Obs (N)	D.O.F (N-2)	No. of +ve signs (n)	"t" statistics	t at 5% of significance Level	Remarks
81-82	19	17	10	0.0	2.09	Accepted
82-83	19	17	11	0.459	2.09	Accepted
83-84	20	18	12	0.67	2.10	Accepted
84-85	20	18	9	0.224	2.10	Accepted
85-86	20	18	10	-0.222	2.10	Accepted
87-88	28	26	16	0.567	2.05	Accepted
89-90	22	20	10	0.213	2.07	Accepted

Note: D.O.F=Degrees of freedom

Table-13 Test Result for absence from Bias (Values) of Power Type Stage-discharge relations of Artrai at Panchagarh.

Year	No. of obs. (N)	D.O.F (N-2)	Mean of percentage difference $\overline{P}$	Standard error of $\overline{P}$ (s_e)	"t" statistics	"t" at 5% significance level	Remarks
81-82	19	17	1.771	4.39	0.40	2.11	Accepted
82-83	18	16	10.478	12.150	0.862	2.12	Accepted
83-84	21	19	6.450	8.685	0.743	2.09	Accepted
84-85	20	18	4.454	7.421	0.6	2.10	Accepted
86-87	25	23	1.843	4.069	0.453	2.07	Accepted
87-88	28	26	1.706	3.426	0.498	2.06	Accepted
88-89	26	24	1.706	3.756	0.4541	2.06	Accepted
89-90	26	24	3.302	5.051	0.654	2.06	Accepted

Table-14 Test Result for Absence from Bias (Values) of Power Type Stage-discharge Relations of Atrai at Bushirbandar.

Year	No. of Obs. (N)	D.O.F	Mean of percentage difference $\overline{P}$	Standard error of $\overline{P}$ (s_e)	"t" statistics	t at 5% of significance level	Remarks
82-83	18	16	6.767	8.565	0.7816	2.12	Accepted
83-84	20	18	1.056	3.10	0.34	2.10	Accepted
84-85	19	17	2.311	5.054	0.457	2.11	Accepted
85-86	18	16	1.435	4.126	0.3477	2.12	Accepted
86-87	21	19	0.668	2.6504	0.2606	2.09	Accepted
87-88	25	23	1.50	3.515	0.4265	2.07	Accepted
88-89	28	26	2.443	5.845	0.754	2.06	Accepted
89-90	26	24	1.318	3.225	0.408	2.06	Accepted

Note: D.O.F=Degrees of freedom

Table-15 Test Result for absence from Bias (Values) of Power Type Stage-discharge relations of Atrai at Mohadebpur

Year	No. of Obs (N)	D.O.F. (N-2)	Mean of percentage difference $\overline{P}$	Standard error of $\overline{P}$ (S_e)	"t" statistics	"t" at 5% of significance level	Remakrs
81-82	17	15	1.129	3.751	0.301	2.13	Accepted
82-83	19	17	3.001	5.653	0.531	2.11	Accepted
83-84	20	18	1.335	3.745	0.356	2.10	Accepted
84-85	20	18	6.279	8.397	0.748	2.10	Accepted
85-86	20	18	1.855	4.372	0.424	2.10	Accepted
86-87	23	21	0.302	1.636	0.184	2.08	Accepted
87-88	27	25	4.157	5.533	0.751	2.06	Accepted
88-89	25	23	0.337	1.712	0.197	2.07	Accepted
(89-90).a	10	8	0.587	3.815	0.156	2.31	Accepted
(89-90).b	17	15	0.209	1.499	0.139	2.13	Accepted

Table-16 Test Result for absence from Bias (Values) of Power Type Stage-discharge relations of Atrai river at Atrai.

Year	No. of Obs (N)	D.O.F. (N-2)	Mean of percentage difference $\overline{P}$	Standard error of $\overline{P}$ (S_e)	"t" statistics	"t" at 5% of significance level	Remakrs
81-82	19	17	2.839	5.642	0.503	2.11	Accepted
82-83	19	17	6.621	8.465	0.801	2.11	Accepted
83-84	20	18	4.991	7.378	0.676	2.10	Accepted
84-85	20	18	2.092	4.872	0.429	2.10	Accepted
85-86	20	18	3.209	5.767	0.556	2.10	Accepted
87-88	28	26	4.816	5.479	0.879	2.05	Accepted
(89-90)	22	20	1.234	3.429	0.360	2.09	Accepted

Note: D.O.F=Degrees of freedom

Table-17 Test Result for Goodness of Fit of Power Type Stage-discharge Relations of Atrai river at Panchagarh

Year	No. of obs. (N)	D.O.F (N-2)	No.of changes of sign (n).	"t" statistics	"t" at 5% of significance level	Remarks
86-87	25	23	15	1.021	2.07	Accepted
87-88	28	26	9	1.54	2.06	Accepted
88-89	26	24	13	0.00	2.06	Accepted
89-90	26	24	12	0.00	2.06	Accepted

Table-18 Test Result for Goodness of Fit of Power Type Stage-discharge Relations of the Atrai at Bushirbandar

Year	No. of obs. (N)	D.O.F (N-2)	No.of changes of sign (n)	"t" statistics	"t" at 5% of significance level	Remarks
87-88	25	23	7	1.837	2.06	Accepted
88-89	28	26	9	1.54	2.06	Accepted
89-90	26	24	12	0.00	2.06	Accepted
89-90	26	24	12	0.00	2.06	Accepted

Table-19 Test Result for Goodness of Fit of Power Type Stage-discharge relations of Atrai at Mohadebpur

Year	No. of obs. (N)	D.O.F (N-2)	No.of changes of sign (n)	"t" statistics	"t" at 5% of significance level	Remarks
87-88	27	25	8	1.765	2.06	Accepted
88-89	25	23	11	0.0	2.06	Accepted

Note: D.O.F=Degrees of freedom

Table-20 Test Result for Goodness of Fit of Power Type Stage-discharge Relations of Atrai river at Atrai

Year	No. of obs. (N)	D.O.F (N-2)	No.of changes of sign (n)	"t" statistics	"t" at 5% of significance level	Remarks
87-88	27	25	8	1.765	2.06	Accepted

Table-21 Test for absence from Bias (Signs) of Parabolic Stage-discharge Relations of the Atrai at Panchagar

Year	No. Obs. (N).	D.O.F (N-3)	No.of +ve signs (n)	"t" Statistic	t at 5% of significance level	Remarks
81-82	19	16	7	0.918	2.09	Accepted
82-83	18	15	8	0.236	2.13	Accepted
83-84	21	18	8	0.873	2.10	Accepted
84-85	20	17	6	1.565	2.11	Accepted
86-87	25	22	13	0	2.07	Accepted
87-88	28	25	13	0.189	2.06	Accepted
88-89	26	23	12	0.196	2.07	Accepted
89-90	26	23	11	0.588	2.07	Accepted

Table-22 Test for absence from Bias (signs) of Parabolic Stage-discharge Relations of the Atrai at Bushirbandar

Year	No. obs. (N)	D.O.F (N-3)	No.of +ve signs (n)	"t" statistics	t at 5% of significance level	Remarks
82-83	18	15	10	0.236	2.13	Accepted
83-84	20	17	11	0.224	2.11	Accepted
84-85	19	16	8	0.459	2.12	Accepted
85-86	18	15	10	0.236	2.13	Accepted
86-87	21	18	10	0.0	2.10	Accepted
87-88	25	22	11	0.40	2.07	Accepted
88-89	28	25	13	0.189	2.05	Accepted
89-90	26	23	11	0.588	2.07	Accepted

Note: D.O.F=Degree of freedom

Table-23 Test Result for absence from Bias (signs) of Parabolic Stage-discharge Relations of Atrai at Mohadebpur

Year	No. Obs. (N)	D.O.F (N-3)	No. of +ve signs (n)	"t" statistics	t at 5% of significance Level	Remarks
81-82	17	14	8	0.0	2.11	Accepted
82-83	19	16	8	0.459	2.12	Accepted
83-84	20	17	10	0.224	2.11	Accepted
84-85	20	17	8	0.671	2.11	Accepted
85-86	20	17	12	0.671	2.11	Accepted
86-87	23	20	14	0.834	2.09	Accepted
87-88	27	24	12	0.385	2.06	Accepted
88-89	25	22	11	0.400	2.06	Accepted
(89-90).a	10	7	3	0.949	2.23	Accepted
(89-90).b	17	14	10	0.485	2.11	Accepted

Table-24 Test Result for absence from Bias (signs) of Parabolic stage-discharge relations of Atrai river at Atrai.

Year	No. Obs. (N)	D.O.F (N-3)	No. of +ve signs (n)	"t" statistics	t at 5% of significance Level	Remarks
81-82	19	16	10	0.0	2.12	Accepted
82-83	19	16	9	0.0	2.12	Accepted
83-84	20	17	9	0.224	2.09	Accepted
84-85	20	17	6	1.565	2.09	Accepted
85-86	20	17	6	1.565	2.09	Accepted
87-88	28	25	15	0.189	2.05	Accepted
89-90	22	19	9	0.64	2.09	Accepted

Note: D.O.F=Degree of freedom

Table-25 Test Result for absence from Bias (Values) of Parabolic Stage-discharge relations of Atrai at Panchagarh.

Year	No. of obs. (N)	D.O.F (N-3)	Mean of percentage difference $\overline{P}$	Standard error of $\overline{P}$ (s_p)	"t" statistics	"t" at 5% significance level	Remarks
81-82	19	16	-1.90	5.735	-0.331	2.12	Accepted
82-83	18	15	1.456	10.696	0.136	2.13	Accepted
83-84	21	18	-3.113	8.091	-0.385	2.10	Accepted
84-85	20	17	-0.967	9.186	-0.105	2.11	Accepted
86-87	25	22	2.121	4.468	0.475	2.07	Accepted
87-88	28	25	0.329	5.052	0.065	2.05	Accepted
88-89	26	23	-0.629	3.539	-0.178	2.07	Accepted
89-90	26	23	-3.536	5.975	-0.592	2.07	Accepted

Table-26 Test Result for Absence from Bias (Values) of Parabolic Stage-discharge Relations of Atrai at Bushirbandar.

Year	No. of Obs. (N)	D.O.F (N-3)	Mean of percentage difference $\overline{P}$	Standard error of $\overline{P}$ (s_p)	"t" statistics	t at 5% of significance level	Remarks
82-83	18	15	0.117	7.731	0.015	2.13	Accepted
83-84	20	17	52.471	27.842	1.885	2.11	Accepted
84-85	19	16	-3.524	4.704	-0.749	2.12	Accepted
85-86	18	15	33.592	21.913	1.532	2.13	Accepted
86-87	21	18	0.061	2.463	0.034	2.10	Accepted
87-88	25	22	4.066	5.424	0.750	2.07	Accepted
88-89	28	25	38.679	23.319	1.658	2.06	Accepted
89-90	26	23	-5.278	4.268	-1.237	2.07	Accepted

Note: D.O.F=Degree of freedom

Table-27 Test Result for absence from Bias (Values) of Parabolic Stage-discharge relations of Atrai at Mohadebpur

Year	No. of Obs (N)	D.O.F. (N-3)	Mean of percentage difference $\overline{P}$	Standard error of $\overline{P}$ (S_e)	"t" statistics	"t" at 5% of significance level	Remakrs
81-82	17	14	5.393	5.229	1.031	2.14	Accepted
82-83	19	16	-10.232	48.117	-0.213	2.12	Accepted
83-84	20	17	53.583	31.902	1.68	2.11	Accepted
84-85	20	17	-3.655	7.042	-0.519	2.11	Accepted
85-86	20	17	18.788	11.014	1.706	2.11	Accepted
86-87	23	20	12.826	7.133	1.798	2.09	Accepted
87-88	27	24	-0.705	4.311	0.385	2.06	Accepted
88-89	25	22	32.666	19.996	1.634	2.07	Accepted
(89-90).a	10	7	-4.398	6.238	-0.705	2.36	Accepted
(89-90).b	17	14	-8.842	1.843	-0.282	2.14	Accepted

Table-28 Test Result for absence from Bias (Values) of Parabolic Stage-discharge relations of Atrai river at Atrai.

Year	No. of Obs (N)	D.O.F. (N-3)	Mean of percentage difference $\overline{P}$	Standard error of $\overline{P}$ (S_e)	"t" statistics	"t" at 5% of significance level	Remakrs
81-82	19	16	0.961	8.623	0.111	2.12	Accepted
82-83	19	16	18.441	14.559	1.267	2.12	Accepted
83-84	20	17	92.523	52.827	1.751	2.11	Accepted
84-85	20	17	-55.039	51.236	-1.074	2.11	Accepted
85-86	20	17	-165.842	100.703	-1.647	2.11	Accepted
87-88	28	25	0.905	8.25	0.11	2.06	Accepted
(89-90)	22	19	3.896	4.86	0.802	2.09	Accepted

Note: D.O.F=Degree of freedom

Table-29 Test Result for Goodness of Fit of Parabolic Stage-discharge Relations of the Atrai at Panchagarh

Year	No. of obs. (N)	D.O.F (N-3)	No.of changes of sign (n)	"t" statistics	"t" at 5% of significance level	Remarks
86-87	25	22	15	1.021	2.07	Accepted
87-88	28	25	5	3.079	2.06	Rejected
88-89	26	23	14	0.40	2.07	Accepted
89-90	26	23	11	0.40	2.07	Accepted

Table-30 Test Result for Goodness of Fit of Parabolic Stage-discharge Relations of the Atrai at Bushirbandar

Year	No. of obs. (N)	D.O.F (N-3)	No.of changes of sign (n)	"t" statistics	"t" at 5% of significance level	Remarks
87-88	25	22	8	1.429	2.07	Accepted
88-89	28	25	11	0.77	2.06	Accepted
89-90	26	23	9	1.20	2.07	Accepted
89-90	26	24	12	0.00	2.06	Accepted

Table-31 Test Result for Goodness of Fit of Parabolic Stage-discharge relations of the Atrai at Mohadebpur

Year	No. of obs. (N)	D.O.F (N-3)	No.of changes of sign (n)	"t" statistics	"t" at 5% of significance level	Remarks
87-88	27	24	9	1.373	2.06	Accepted
88-89	25	22	5	3.062	2.07	Rejected

Table-32 Test Result for Goodness of Fit of Parabolic Stage-discharge Relations of Atrai river at Atrai

Year	No. of obs. (N)	D.O.F (N-3)	No.of changes of sign (n)	"t" statistics	"t" at 5% of significance level	Remarks
87-88	28	25	7	2.309	2.06	Rejected

Note: D.O.F=Degree of freedom

Table-33 Power Type Mean Depth-discharge Relations of the Atrai at Panchagarh

Year	No.of Obs. (N)	$Q = K D^n$
81-82	19	$Q = 124.9548 D^{1.5455}$
82-83	18	$Q = 51.5457 D^{0.9641}$
86-87	25	$Q = 26.4667 D^{1.3531}$
87-88	28	$Q = 44.1122 D^{1.5686}$
88-89	26	$Q = 65.5345 D^{2.2662}$
89-90	26	$Q = 53.4973 D^{2.0445}$

Table-34 Power Type Mean Depth-discharge Relations of The Atrai At Bushirbandar

Year	No.of Obs. (N)	$Q = K D^n$
82-83	18	$Q = 80.3822 D^{1.87982}$
86-87	21	$Q = 167.6053 D^{3.035779}$
87-88	25	$Q = 103.3589 D^{2.5029}$
88-89	28	$Q = 139.0377 D^{1.6619}$
89-90	26	$Q = 85.6384 D^{1.2684}$

Table-35 Power Type Mean Depth-discharge Relations of The Atrai at Mohadebpur

Year	No.of Obs. (N)	$Q = K\ D^{n}$
81-82	17	$Q = 16.7456\ D^{2.3225}$
82-83	19	$Q = 14.5491\ D^{2.3581}$
83-84	20	$Q = 16.1403\ D^{2.2856}$
84-85	20	$Q = 19.1156\ D^{2.2095}$
86-87	18	$Q = 14.2281\ D^{2.4866}$
87-88	27	$Q = 12.9279\ D^{2.5444}$
88-89	25	$Q = 9.8774\ D^{2.647}$
(89-90).a	10	$Q = 7.8794\ D^{2.8708}$
(89-90).b	17	$Q = 14.1576\ D^{2.5932}$

Table-36 Power Type Mean Depth-discharge Relations of Atrai river at Atrai

Year	No.of Obs. (N)	$Q = K\ D^{n}$
81-82	18	$Q = 0.0514\ D^{5.3131}$
82-83	19	$Q = 0.3253\ D^{3.8708}$
83-84	18	$Q = 0.2389\ D^{4.2256}$
87-88	28	$Q = 0.003434\ D^{6.4736}$
89-90	22	$Q = 0.011885\ D^{5.72058}$

Table-37 Parabolic Mean Depth-discharge Relations of the Atrai at Panchagar

Year	No.of Obs. (N)	$Q = a+b\ D+c\ D^2$
81-82	19	$Q = -13.5310 + 105.6769\ D + 39.4210\ D^2$
82-83	18	$Q = 19.84148 - 51.3194\ D + 110.7707\ D^2$
86-87	25	$Q = -15.6635 + 62.7106\ D - 11.6545\ D^2$
87-88	28	$Q = -19.0272 + 90.1198\ D - 10.8459\ D^2$
88-89	26	$Q = 88.4826 - 362.004\ D + 346.68\ D^2$
89-90	26	$Q = -55.3921 +196.1799\ D - 64.7344\ D^2$

Table-38 Parabolic Mean Depth-discharge Relations of the Atrai at Bushirbandar

Year	No. of Obs. (N)	$Q = a+b\ D+c\ D^2$
82-83	18	$Q = -41.2795 + 127.0969\ D + 18.0872\ D^2$
86-87	21	$Q = -163.674 + 397.3259\ D - 54.6952\ D^2$
87-88	25	$Q = -141.124 + 284.7748\ D + 19.001\ D^2$
88-89	28	$Q = -26.8892 + 117.2991\ D + 82.1567\ D^2$
89-90	26	$Q = 89.8788 - 221.342\ D + 203.6954\ D^2$

Table-39 Parabolic Mean Depth Discharge Relations of the Atrai at Mohadebpur

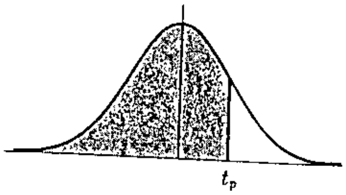
Year	No.of Obs. (N)	$Q = a+b\ D+c\ D^2$
81-82	17	$Q = 39.5522 - 58.533\ D + 38.3553\ D^2$
82-83	19	$Q = 30.9758 - 51.6147\ D - 36.2522\ D^2$
83-84	20	$Q = 103.6353 - 141.018\ D + 56.4196\ D^2$
84-85	20	$Q = 8.1335 - 16.6355\ D + 28.8926\ D^2$
86-87	18	$Q = 20.6203 - 44.0893\ D + 37.3468\ D^2$
87-88	27	$Q = 36.9570 - 67.2187\ D + 43.4882\ D^2$
88-89	25	$Q = -60.80 + 39.80516\ D - 17.821\ D^2$
89-90(A)	10	$Q = -26.4237 + 6.11774 + 27.13672\ D^2$
89-90(B)	17	$Q = -54.8259 + 31.4451\ D + 24.64601\ D^2$

Table-40 Parabolic Mean Depth-discharge Relations of Atrai river at Atrai.

Year	No.of Obs. (N)	$Q = a+b\ D+c\ D^2$
81-82	18	$Q = 427.2359 - 294.047\ D + 52.7455\ D^2$
82-83	19	$Q = 315.555 + 152.8651\ D - 8.4805\ D^2$
83-84	18	$Q = 277.5775 - 211.892\ D + 40.8798\ D^2$
87-88	28	$Q = 826.1265 - 477.492\ D + 68.8814\ D^2$
89-90	22	$Q = 200.4924 - 182.94\ D + 34.66179\ D^2$

APPENDIX B

PERCENTILE VALUES (t_p)
for
STUDENT'S t DISTRIBUTION
with ν degrees of freedom
(shaded area $= p$)



ν	$t_{.995}$	$t_{.99}$	$t_{.975}$	$t_{.95}$	$t_{.90}$	$t_{.80}$	$t_{.75}$	$t_{.70}$	$t_{.60}$	$t_{.55}$
1	63.66	31.82	12.71	6.31	3.08	1.376	1.000	.727	.325	.158
2	9.92	6.96	4.30	2.92	1.89	1.061	.816	.617	.289	.142
3	5.84	4.54	3.18	2.35	1.64	.978	.765	.584	.277	.137
4	4.60	3.75	2.78	2.13	1.53	.941	.741	.569	.271	.134
5	4.03	3.36	2.57	2.02	1.48	.920	.727	.559	.267	.132
6	3.71	3.14	2.45	1.94	1.44	.906	.718	.553	.265	.131
7	3.50	3.00	2.36	1.90	1.42	.896	.711	.549	.263	.130
8	3.36	2.90	2.31	1.86	1.40	.889	.706	.546	.262	.130
9	3.25	2.82	2.26	1.83	1.38	.883	.703	.543	.261	.129
10	3.17	2.76	2.23	1.81	1.37	.879	.700	.542	.260	.129
11	3.11	2.72	2.20	1.80	1.36	.876	.697	.540	.260	.129
12	3.06	2.68	2.18	1.78	1.36	.873	.695	.539	.259	.128
13	3.01	2.65	2.16	1.77	1.35	.870	.694	.538	.259	.128
14	2.98	2.62	2.14	1.76	1.34	.868	.692	.537	.258	.128
15	2.95	2.60	2.13	1.75	1.34	.866	.691	.536	.258	.128
16	2.92	2.58	2.12	1.75	1.34	.865	.690	.535	.258	.128
17	2.90	2.57	2.11	1.74	1.33	.863	.689	.534	.257	.128
18	2.88	2.55	2.10	1.73	1.33	.862	.688	.534	.257	.127
19	2.86	2.54	2.09	1.73	1.33	.861	.688	.533	.257	.127
20	2.84	2.53	2.09	1.72	1.32	.860	.687	.533	.257	.127
21	2.83	2.52	2.08	1.72	1.32	.859	.686	.532	.257	.127
22	2.82	2.51	2.07	1.72	1.32	.858	.686	.532	.256	.127
23	2.81	2.50	2.07	1.71	1.32	.858	.685	.532	.256	.127
24	2.80	2.49	2.06	1.71	1.32	.857	.685	.531	.256	.127
25	2.79	2.48	2.06	1.71	1.32	.856	.684	.531	.256	.127
26	2.78	2.48	2.06	1.71	1.32	.856	.684	.531	.256	.127
27	2.77	2.47	2.05	1.70	1.31	.855	.684	.531	.256	.127
28	2.76	2.47	2.05	1.70	1.31	.855	.683	.530	.256	.127
29	2.76	2.46	2.04	1.70	1.31	.854	.683	.530	.256	.127
30	2.75	2.46	2.04	1.70	1.31	.854	.683	.530	.256	.127
40	2.70	2.42	2.02	1.68	1.30	.851	.681	.529	.255	.126
60	2.66	2.39	2.00	1.67	1.30	.848	.679	.527	.254	.126
120	2.62	2.36	1.98	1.66	1.29	.845	.677	.526	.254	.126
∞	2.58	2.33	1.96	1.645	1.28	.842	.674	.524	.253	.126

Source: R. A. Fisher and F. Yates, *Statistical Tables for Biological, Agricultural and Medical Research* (5th edition), Table III, Oliver and Boyd Ltd., Edinburgh, by permission of the authors and publishers.