

Low-Flow Criteria for Water Quality Standards for Selected Rivers.

A Thesis
By

MD MATIUR RAHMAN

In partial fulfillment of the requirements for the degree
Of
MASTER OF ENGINEERING (WATER RESOURCES)



#94589#

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

OCTOBER, 2000

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. M. Fazlul Bari)
Supervisor

Signature



(Md Matnur Rahman)

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF WATER RESOURCES ENGINEERING

We hereby recommend that the thesis prepared by

MD MATIUR RAHMAN

Entitled **Low-Flow Criteria for Water Quality Standards for Selected Rivers** be accepted as fulfilling this part of the requirements for the degree of Master of Engineering (Water Resources).

Chairman of the Committee
(Supervisor)



.....
(Professor Dr. Muhammad F. Bari)

Member



.....
(Professor Dr. Md. Abdul Matin)

Member
(Head of the Department)



.....
(Professor Dr. Md. Monowar Hossain)

October 17, 2000

ABSTRACT

Low flow quantiles are commonly used to describe stream characteristics and are used for establishing water quality standards. The objective of this study is to investigate the surface water quality in terms of parameter concentrations and specified standards as well as to develop low flow criteria for water quality standards. Water quality and stream flow data for Brahmaputra at Bahdurabad, Surma at Sylhet and Karotoa at Panchagahr were collected and analyzed. The Department of Environment collects surface water quality samples without any information and reference to the water discharge values at the time of sampling.

Analyses performed in this study began with obtaining concurrent discharge values from BWDB database for the dates on which water quality data were available. To gain an insight of the discharge-water quality relationships, first the variation of water quality parameter concentrations with discharge was investigated by visual inspection of plots and linear regression. For comparison, water quality standards for irrigation use, fish culture and drinking water were superimposed on these plots. In case of Brahmaputra river measured BOD concentrations exceeded both the drinking water and fish culture standard, whereas for Surma river about a half of the measured values exceeded the standard, and for Karotoa river concentrations were found to be below the standards for all uses. Plots for DO and pH showed that their amounts were well above the standard values for all of the three rivers. All measured concentrations of coliform in Brahmaputra exceeded the drinking water standard, several values exceeded irrigation standard, and fish standard was generally met. It is seen that the discharge water-quality plots showed substantial scatter although a decreasing trend in parameter is expected with increasing discharge. It may be due to the fact that all the available water might not serve to dilute the polluting substances. In rivers it is not uncommon for waste effluents to remain segregated along a shore line for many miles below the outfall. Regression equations relating water quality with discharge were not found to be useful in predicting parameter concentration as a function of discharge in term of such criteria as correlation coefficients and other test statistics.

One of the critical elements of any water quality standard is the low-flow criterion to be applied. Usually low flows corresponding to 7-day, 10-year return period or 10-day, 25-year return is used. These flow values were computed using best-fit probability distributions. Then to assess the exceedence probabilities of 7Q10 and 10Q25 flow values, flow duration curves were obtained for each of 7-day and 10-day annual low flow series. Computed 7Q10 and 10Q25 flows were found to exceed 99.99 percent of the time. Estimates of such exceedence probabilities provide guidance in setting level of effluent treatment required for protection of water quality. For example if the 7-day, 10-yr flow is equalled or exceeded 99% of the time on a given river, it would be required to provide effluent treatment which should be adequate 99% of the time.

ACKNOWLEDGEMENT

I express my deepest gratitude and profound respect to my thesis supervisor Dr. M. Fazlul Bari, Professor, Department of Water Resources Engineering, BUET for his valuable guidance, constant encouragement and keen interest at every stage of this study, without which this would have been extremely difficult to accomplish. I consider it as a great opportunity to have a share of some of his knowledge and expertise and find myself proud to work with him

I am also grateful to Dr. M. Monowar Hossain, Professor, and Head, Department of Water Resources Engineering, BUET, for his constant cooperation and providing every facility to work. I express my sincere thanks to him for his valuable suggestions.

My sincerest gratitude to Dr. Md. Abdul Matin, Professor, Department of Water Resources Engineering, BUET, for his valuable comments and suggestions.

My gratefulness is to Bangladesh Water Development Board for providing me deputation for pursuing the Master of Engineering Degree in Water Resources Engineering. Special gratitude is to Mr Sharif Rafiqul Islam, Director, PMU-CAD Project, BWDB, Dhaka for providing me official logistic support and personal encouragement for carrying out this work.

I would like to give my heartiest thanks to BWDB and DOE officials for their extended cooperation during data collection.

I am Thankful to BUET-DUT Linkage Project for providing me scholarship to carry out this research. I am also thankful to the project officials for their cooperation during this work.

I am indebted to WRE department officials and staff for their all time cooperation during this work.

Thank is to Mr. Farooque Iftekhar, Senior Consultant, SWMS for providing suggestion and support for using SWMC computing facilities during analysis phase.

I acknowledge with sympathy, the sacrifice made by my wife Ms Shohana Parveen and son Md Farhan Hasin Rahman providing me with time to carry out this work.

TABLE OF CONTENTS

	Page
ABSTRACT	
ACKNOWLEDGEMENT	iv
TABLE OF CONTENTS	vi
LIST OF FIGURES	vii
LIST OF ABBREVIATIONS	viii
I. INTRODUCTION	ix
1.1 Importance of the Study	1
1.2 Objective of the Study	4
1.3 Approach and Methodology	5
II. LITERATURE REVIEW	
2.1 Introduction	7
2.2 Review of Previous Studies	7
2.3 Frequency Studies and Flow-Duration Analysis	7
2.4 Surface Water Quality Parameters	10
2.5 Water Quality Standards	14
	18
III. DATA COLLECTION	
3.1 Criteria for Selection of Study Stations	20
3.2 Sources of Data	20
3.3 Water Quality Parameters	20
3.4 Surface Water Quality Criteria	24
3.5 Data Collection and Organization	25
3.6 Extraction of Low-flow Series	25
3.7 Data Screening	26
	27
IV. RESULTS AND DISCUSSION	
4.1 Introduction	29
4.2 Discharge-Water Quality Relationships	29
4.3 Low Flow Criteria	29
4.4 Flow Variability	30
4.5 Discussion	33
	33
V. CONCLUSION AND RECOMMENDATIONS	
5.1 Conclusion	35
5.2 Recommendations	35
	35
REFERENCES	
	37

APPENDIX	A	FIGURES	A-1
APPENDIX	B	TABLES	B-1
APPENDIX	C	FORTRAN PROGRAMS	C-1

LIST OF TABLES

Table 3.1	DOE Data Collection Stations on Different Rivers
Table 3.2	Inland Surface Water Quality Standards
Table 3.3	Selected Discharge Gauging and Water Quality Data Stations
Table 3.4	Data Length of Low Flow Series of Specified Duration after removal of Outliers
Table 5.1	Low flow values in m^3/s of various duration for indicated return period
Table 5.2(a)	Seven-day, ten-year low flow (7Q10) values for selected stations
Table 5.2(b)	Ten-day, twenty five-year low flow (10Q25) values for selected stations
Table 5.3	Percent of time the stream flow was equal to or greater than 7-day, 10-year flow
Table 5.4	Flow duration parameter and Variability ratio
Table B.1	Water Quality Parameter Concentration for Selected Rivers
Table B.2	Low-flow Series of different averaging period on selected Rivers
Table B.3	Basic Statistics of Selected Data Series
Table B.4	Result of Regression Analysis of Water Quality vs Discharge
Table B.5	Result of Frequency Analysis
Table B.6	Result of Kolmogorov-Smirnov Tests

LIST OF FIGURES

- Figure 1.1 Flow Chart Showing Steps of Analysis
- Figure 3.1 Index Map Showing the selected Data Stations
- Figure 3.2 A Typical Box Plot
- Figure A.1 Flow Duration Curves
- Figure A.2 Plot of Water Quality against Discharge

LIST OF ABBREVIATIONS

BOD	Biological Oxygen Demand
BWDB	Bangladesh Water Development Board
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DOE	Department of Environment
DQT	D-day average low flow with T -year return period
EV I	Extreme Value Type -I
EV II	Extreme Value Type -II
LG	Log Gumbel
LP3	Log-Pearson Type 3 Distribution
JICA	Japan International Cooperation Agency
MIKE 11	Hydrodynamic Model
P3	Pearson Type 3 Distribution
pH	Acid-Base Index
P-Alkalinity	Phosphate Alkalinity
T-Alkalinity	Total Alkalinity
TDVS	Total Dissolved Volatile Solid
TS	Total Solid
TVS	Total Volatile Solid
7Q10	7-day average low flow with 10 -year return period
10Q25	10-day average low flow with 25 -year return period

CHAPTER ONE INTRODUCTION



1.1 Importance of the Study

Knowledge of a stream's water quality plays an important role in developing effective water quality planning and management. This information is extremely desirable due to extensive use of the streams and due to the growing water pollution problems.

Pollution growth has resulted in increased water demand and greater contamination of water from the disposal of wastes. Water quality is important not only because of its linkage to the availability of water for various uses and its impact on public health, but also because water quality has an intrinsic value. The quality of life is often judged on the availability of pristine waters. Contamination of water deprives present and future generations of a birthright. There is also need to preserve the aquatic habitats of fish, birds, and mammals. Preservation of habitats is rarely viewed in terms of simple economics but is often taken to be as important as ensuring the public health.

Urban and industrial areas continue to expand and consequently, to create serious water pollution problems to natural streams. It is attributed that surface water in natural rivers and streams are being polluted by pollutant discharges from point source, such as industrial plants and municipal waste discharges as well as non-point sources such as, pollutant discharge corresponding to storm water run-off and other discharges that carry sediment and pollutants from various distributed sources as well as run-off from agricultural watersheds due to increased chemical fertilizer and pesticides usage. The quality of the water is influenced by the type and concentration of the pollutants.

The pollutant loading from point source and non-point source on receiving streams often do not occur at the same time. Pollution from point source is usually less variable, and frequently have severe impacts during periods of low stream flow. Nonpoint sources on the other hand often occur only during runoff-producing storm events, which is when nonpoint discharges generally have their most severe effect on water quality.

During the periods of high runoff, most rivers exhibit their most favorable chemical water-quality characteristics. Although the water may contain extremely large amounts of suspended matter, the concentrations of dissolved substances are low, often only a fraction of that found during dry-weather periods. There are some instances where high runoff may cause deterioration in water quality.

Because of an inherent capacity to assimilate wastes, surface waters and ground waters are capable of natural purification. There are limits to the degree of purification that can be effected by nature, however, and excessive water-quality deterioration may result if the amounts of wastes discharged are too great. Federal, state, and interstate pollution-control agencies regulate the discharge of waste products to prevent water-quality degradation which affects the other beneficial uses of water. The greatest attention has generally been given to the ability of surface waters to assimilate wastes. Some study has been devoted to the assimilative capacity of groundwaters, however, and a brief mention of this should be made here.

The waste-assimilative capacity of surface waters is generally considered to be the amount of waste which will not cause water-quality deterioration beyond the limits required for other beneficial uses of the supply. Because oxygen-demanding wastes are more frequently encountered, this capacity is commonly given in terms of the biochemical oxygen demand (BOD) of the waste. Other wastes are very important in determining the assimilative capacity, however, and BOD should not be assumed the only criterion.

The greatest single factor controlling the overall waste-assimilative capacity of surface waters is the amount of dilution that is provided. With fixed limits on the degree of water-quality deterioration that may be tolerated, the waste-assimilative capacity increases as the amount of dilution water increases. It cannot be assumed, however, that all the available water will serve to dilute the polluting substances. In rivers it is not uncommon for waste effluents to remain segregated along a shore line for many miles below the outfall. This effect is in addition to the normal variations in streamflow. The dilution in tidal estuaries is exceedingly complex, and special techniques must be applied to determine the degree of dispersion which will actually take place. In all studies of assimilative capacity it must be remembered that the amount of dilution water available at any time is a primary concern.

The waste-assimilative capacity in terms of polluting substances which exert high oxygen demands depends not only on the available dilution, but also on the factors which control the oxygen resources in the water body.

Discharging industrial and municipal wastes into natural streams requires using the assimilative capacity of the receiving stream water. Dilution of the river is considered to be the primary self-purification factor (Prati and Richardson, 1971), which means "the natural purification capacity of a stream is dependent in part on the quantity of water passing through its channels. One of the critical elements of any water quality standard is the low-flow criterion to be applied" (Ray and Walker, 1968).

The most critical impact of pollution loadings on receiving water quality does not necessarily occur under low flow conditions; often the shock loads associated with intermittent urban storm-water runoff are more critical. Nevertheless, water-quality standards are usually stated in terms of a maximum allowable d-day average concentration. Aquatic life protection involves survival, propagation, and growth of aquatic life forms. The survival of all species in its food chain. Thus a toxic threat to any aquatic species within the food web should be only infrequent and produce less than 100% mortality. It is essential that the affected species recover quickly from an acutely toxic exposure. Water-quality standards are usually stated in terms of a maximum allowable d-day average concentration (Rodriguez-Iturbe, 1987). The most common type of design event for the protection of aquatic life is based on the one in T-year d-day average annual low stream flow, which is often expressed as dQT flow (Box and Cox, 1964).

The usual minimum flow of the receiving stream to be used in the evaluation of a pollution control case is the average of the lowest 7 consecutive days' flows that is equaled or exceeded 90 percent of the time (Ray and Walker, 1968). Stated another way, this is the minimum flow that may be expected to recur in every 10 years; that is it has a 10-year "return frequency". This is also written as 7Q10 flow.

This study is concerned with the establishing of 7Q10 design flow and to investigate whether the present pollution level is exceeded in some of the selected rivers in Bangladesh. By examining the stream flow data for a gaging station, it is possible to determine the percentage of time a particular design flow is equaled or exceeded at specific location. If the 7-day, 10-year (7Q10)

flow is equalled or exceeded 99% of the time on one stream, but only 95% of the time on the other, the degree of treatment required could be economically significant. One plant could be required to provide treatment which was adequate 99% of the time, while the other firm's disposal system would need to be satisfactory only 95% of the time. This condition appears to be less than equitable for the former industry unless the higher standard is required in the public interest.

Inquiring so far it is known that some study regarding low-flow have been performed (Chowdhury, 1989; Ahmed, 1982; Ullah, 1989). Rahman (1998) studied Instream Flow Requirement for the Ganges River. The instream flow requirements are defined as those flows which remain in the stream channel after diversions for off-stream uses such as urban and irrigation needs and in some configurations, hydropower, are approximately catered for (Maidment, 1992). These flows are essential within a stream to maintain its natural resources at a desired or specified levels. Knowledge of the instream flow requirements assists in planning for new projects and in evaluating existing projects and it is needed for proper understanding of the issue relating to the natural environment of stream. Sadek (1999) studied Regional low flow frequency relationship for North-Western Bangladesh. The research was done to extend regional frequency analysis technique for low flow studies. In regionalization technique spatial information is employed to make up for the paucity of temporal information with the assumption that the region is homogeneous. The outcome of that study would enable to obtain estimates of low flows at ungauged sites and also improved estimates of low flows at gauged sites by using information at other gauged sites. But none of this study made any attempt to correlate low flow with water quality.

1.2 Objective of the study

The objective of the research is to determine the low-flow criteria that may be used to define permissible concentration of various pollution parameters in rivers.

The specific objectives of the present study are as follows:

- (1) To establish the design flow for waste load allocation based on 7Q10 low flow criteria for some of the selected rivers of Bangladesh.
- (2) To determine the percentage of time, the reference low-flow, 7Q10 is equalled or exceeded in a given year in various streams/rivers, and thus assess the

assimilative capacity of selected streams. This can serve as a qualitative index of assimilative capacity of those selected rivers.

- (3) To examine the present status of the pollution level with respect to the 7Q10 flow magnitude.

1.3 Approach and Methodology

With the above mentioned objectives, the steps of work may be divided into three steps: (1) Analysis of low flow selecting an appropriate distribution, (2) Computation of 7Q10-flow magnitudes, (3) Comparison of water-quality parameter concentration at 7Q10 with Water Quality standards. The methodology and the steps of analysis can be described by following flowchart (Figure 1.1).

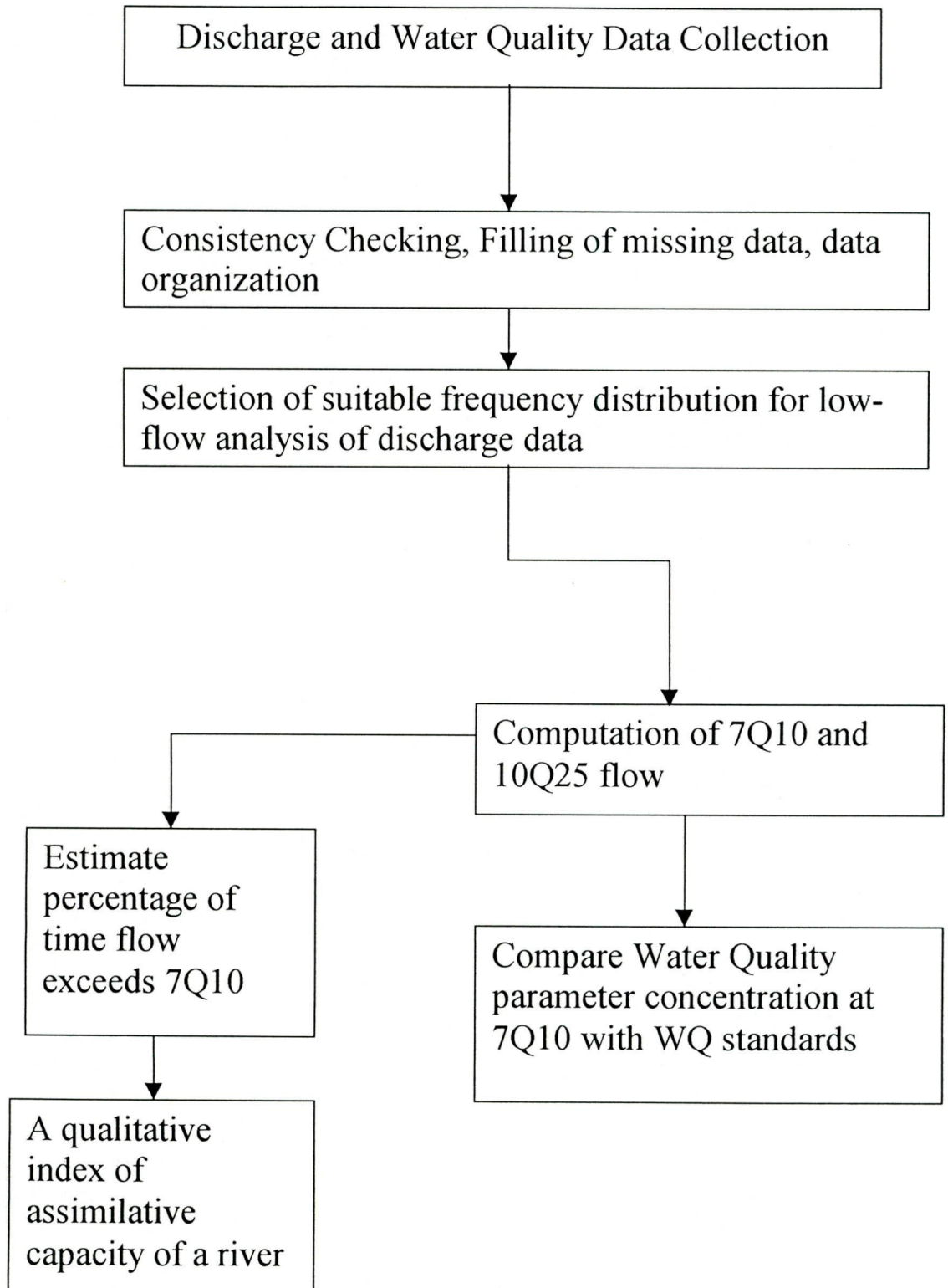


Figure 1.1 Flowchart Showing Steps of Analysis

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Statistical behaviour of floods and low-flows have been well-studied both locally and globally. Though the water quality criteria for streams or rivers have already been established in all of the developed countries well before, unfortunately we are lagging behind in this regard. Low-flow frequency analysis techniques together with Duration curve study can help in establishing stream standards. To correlate the low-flow studies with assimilative capacity or to verify the stream's present quality, the relevant available literature collected for this study were reviewed and summarised in the following sections.

2.2 Review of Previous Studies

In this section a review is made of water quality studies and related low flow criteria. Prati and Richardson (1971) studied the Po River to determine the degree of pollution and self-purification capacity of the river by collecting samples from a 30 km stretch of the river from May to August 1969. It was found that the river below Ferrara was lightly polluted by organic substances. The deoxygenation rate has been determined by the Isaac and Gaudy method and the atmospheric reaeration rate according to the equations of O'Connor and Dobbins. The atmospheric reaeration capacity was found to be very low, resulting in a low self-purification capacity for the river. The dissolved oxygen averaged 80 percent of the saturation value; this value is attributed to the low organic load of the river and the high dilution ratio. Dilution of the river is considered to be the primary self-purification factor.

Abouel Nour (1972) carried out a research, the first objective of which was to set a guidelines for dividing a natural stream into more or less independent reaches based on some criteria and the second objective was to obtain the predicting equations of the water pollutants in a selected stream. The preliminary phase of this research evaluated water quality data sampled from the Pearl River which flows southwest and then turns south through the states of Mississippi and

Louisiana. This evaluation served as guidelines to divide the total river basin into reaches (subsystems) appropriate to the objective of that research. Subsequent to this subsystem assignment, a stepwise multiple regression FORTRAN program was used to regress the pollutants (dependent variables) for both time and space on their water characteristics (independent variables). Based on the results obtained, the proposed statistical approach provides a practical tool for developing regression equations for the purpose of water pollutants' prediction. Biswas and Bell (1984) carried out a research to obtain a method for establishing site-specific stream design flows for wasteload allocations. He made a review of existing state practices for developing wasteload allocations and found that a majority of states used the chronic level water quality criteria and the 7-day, 10-year low flow (7Q10) as the stream design flow. Within each state the stream design flow was generally the same for all pollutants and all streams. However the stream design flow used by adjacent states for the same stream could be quite different. This review of the literature did not reveal a strict water quality basis for establishing 7Q10 as the stream design flow. While the 7Q10 flow is considered to protect water quality, many water quality scientists and engineers have long felt the need for a technical method to estimate appropriate stream design flows. Also, to implement two-number water quality criteria, i.e., the final chronic value (FCV) and the final acute value (FAV) of any pollutant, various states at the United States would need to establish two design flows of appropriate flow averaging periods and return period intervals. The major objective of this study was to develop a scientific method for establishing the stream design flow for use in steady-state water quality modeling. The result predicts an optimum design flow for the FCV of any pollutant. The allocated wasteload based on this design flow and the FCV of the pollutant should meet the requirements of the two-number water quality criteria now used. Another objective was to illustrate the uses and limitations of the method.

Walker and Ray (1968) carried out a study regarding low-flow criteria for stream standards. In that study, Virginia's 7-day, 10-year low flow criterion for determining stream's capacity for waste assimilation was evaluated, study consisted of selection of gaging stations and period of record to be investigated, obtaining low-flow summaries and daily discharge data, preparation of frequency curves, preparation of duration curves by digital computer from daily discharge data, and evaluation of 7-day, 10-yr standard based on percent of time that resulting design flow was equaled or exceeded during period studied. Bernier (1971) studied Mathematical river pollution models. The principal mathematical models used for single space dimensional investigation of

pollution processes are described, especially models of self-purification processes describing the behaviour of dissolved oxygen and the BOD, which distinguish between the mechanical aspect of pollutant transport and the physical and chemical aspects of pollutant reoxygenation and breakdown. Purdy (1968) studied the natural purification capacity of a river by identifying the physical characteristics of the river channel and the time flow or time of passage for a segment of water to move downstream to a predetermined point. Grossman (1968) studied the surface water quality standards in which multipurpose water uses are recognized in the five classes established for fresh surface waters. Standards of water quality include such basic parameters as aesthetic, toxic and deleterious effects, oxygen requirements and pH. Anderson and McCall (1968) studied the effect of drought on stream quality in New Jersey. The 5-year of drought have had a pronounced effect on the quality of New Jersey's streams.

In Bangladesh, water quality studies conducted so far focused mainly on pollutant loads from point sources in terms of BOD and concomitant effect on the dissolved oxygen in Buriganga River. Department of Environment (1992) analyzed total solids, dissolved oxygen (DO), biological oxygen demand (BOD) for the period from 1984 to 1992 and deterioration of water quality was indicated. Browder (1992) selected seven monitoring locations along Buriganga from Mirpur to Pagla Sewage Treatment Plant and plotted DO profiles for the month of May (low flow period) and July (high flow period) in 1991. In lean period DO was found to be below the minimum requirement of 4.0 mg/l. Other studies on DO and BOD in Buriganga around Dhaka city include Ahmed (1988, 1993), Mohammed (1988), Azim (1992), JICA (1987), Karim (1992). Using Streeter-Phelps equation, Rahman and Rana (1994) investigated the impact of BOD load on DO concentration in a 15-km reach of Buriganga from Hazaribag up to the Daleswari confluence. They estimated the maximum amount pollutant loads that can be discharged to Buriganga through Hazaribag and Pagla outfall by a linear programming model. A one-dimensional hydrodynamic model MIKE 11 was used for calculating the necessary hydraulic parameters including the cumulative frequency curve of water discharge. Kamal (1996) also studied the impact of a range of pollutant loading on the DO level in Buriganga at Dhaka and at its confluences with Turag and Dhaleswari using BOD/DO module of MIKE11. Surface Water Modelling Centre (1996) also applied MIKE 11 BOD/DO module and conducted some preliminary studies in Halda-Karnafuli River System and in Buriganga near Dhaka. Rahman (1998) performed a study on hydrologic determination of instream flow of the Ganages. Instream flow specifies the amount of flow that is essential within a stream to maintain its natural

resources and aquatic environment at a desired level. None of these studies dealt with low-flow criteria for specifying permissible pollutant concentration.

As far as low flow studies are concerned, Rahman and Ahmed (1986) performed regional flood frequency analysis of Bangladesh dividing entire Bangladesh into four distinct homogeneous regions and developed regional frequency curves for each region showing relationship between flood ratios and return periods. They used Gumbel distribution as a suitable one. They established a simplified power-law relationship between watershed area and mean annual flood. Ahmed (1982) analyzed the annual minimum daily discharge of the Ganges at Hardinge Bridge by Gumbel, Pearson type 3, log Pearson type 3, and lognormal distributions. Sadek (1999) studied the regional low flow frequency relationships for north-western Bangladesh. Her study enabled to obtain improved estimates of low flows at gauged sites by using information at other gauged sites. This also permitted estimation of low flows for ungauged sites as well. Ullah (1989) studied the low flow characteristics of three rivers of the north-east region of Bangladesh. The rivers are Manu, Khawai and Ghagot. He developed frequency-volume-duration curves for the rivers mentioned above taking the duration as parameter. He also developed some curves using synthetic data generated by Thomas-Fiering model to examine the effect of record lengths on low flow-frequency-duration relationships.

In Bangladesh, the Department of Environment (DOE) has collected limited surface water quality data on 29 streams at 60 locations. But there has been no attempt yet to suggest low flow criteria to specify critical concentration of pollutants for any river. The present study has been undertaken to determine the low-flow criteria that may be used to define permissible concentration of various pollution parameters in rivers.

2.3 Frequency Studies and Flow-Duration Analysis

For low -flow criteria related to water quality, 7-day low-flow with 10 year return period (7Q10) or 10-day low-flow with 25 year return period (10Q25) have been used as suggested by Ray and Walker (1968). They suggested the use of the Velz and Gannon (1960) adaptation of Gumbel's theory of extreme values for drought flows. For the present study frequency analysis will be done analytically using suitable probability distributions. From previous studies it is seen that Weibull,

Log-Pearson Type 3, EV-I, Log-Gumbel distributions exhibited better fit for low-flow series of rivers of Bangladesh (Sadek, 1999; Ahmed, 1982).

Weibull Distribution

The Extreme Value Type 3 or Weibull distribution arises when the extreme is from a parent distribution that is limited in the direction of interest. This distribution has found its greatest use in hydrology as the distribution of low stream flows. Naturally low flows are bounded by zero on the left. The type 3 for minimum values is also known as the Weibull distribution.

Log Pearson Type 3 (LP3) Distribution

The Pearson type 3 (P3) distribution is a member of the Pearson system of frequency distributions, derived by Karl Pearson in 1895. If the logarithms of a random variable X are distributed as Pearson type 3 distribution, then the variable X is distributed as Log Pearson type 3 distribution. If the kurtosis of the logarithms of data is equivalent to $K_s = 1.5C_s + 3.0$, where C_s is the skewness of the logarithmically transformed data, then the LP3 distribution can be used.

Extreme Value Type I or Gumbel's Extreme Value Distribution

The type I extreme value has been referred to as Gumbel's extreme value distribution, the extreme value (EV) distribution, the Fisher-Tippett type I distribution, and the double exponential distribution. The type I asymptotic distribution for maximum (minimum) values is the limiting model as n approaches infinity for the distribution of maximum (minimum) of n independent values from an initial distribution whose right (left) tail is unbounded and which is an exponential type; that is the initial cumulative distribution approaches unity (zero) with increasing (decreasing) values of the random variable at least as fast as the exponential distribution approaches unity. The skewness coefficient is

$$\gamma = 1.1396 \text{ (maximum)}$$

$$= -1.1396 \text{ (minimum)}$$

Thus the type I has a constant coefficient of skewness. The kurtosis of Gumbel distribution is 5.4 (Shahin et. Al., 1993). Thus a sample of low flow series with skewness = -1.1396 and kurtosis = 5.4 is expected to fit EV I distribution

Log-Gumbel Distribution

The log Gumbel variate x is such that $z = \ln x$ is a gumbel or EV I variate and it is equivalent to a Frechet or EV2 distribution. Since the Gumbel variate depends on two parameters this is a two parameter distribution. A third parameter x_0 may be introduced by specifying that $z = \ln(x-x_0)$ is a Gumbel variate. The statistics in the log-domain can be used to find its applicability just same as EV I distribution.

Frequency Analysis of Data Series Containing Zero Elements

Low-flow series often contain years with zero values. In some arid areas, zero flows are recorded more often than nonzero flows. Stream flows recorded as zero imply either that the stream was completely dry or that the actual stream flow was below a recording limit. At most U.S. Geological Survey gauges there is a lower stream flow level of $0.0015 \text{ m}^3/\text{s}$ below which any measurements is reported as zero. This implies that low-flow series are censored data sets. Low-flow values which are rounded to or reported as zero are said to be censored samples because it is as if the values of observations in a complete sample that fell above or below some level were removed, or censored.

Low-flow data values are bounded on the left-hand side by zero, so that the probability of a negative discharge on a stream is zero. Theoretically speaking, the probability of a zero discharge on a given stream would have to be greater than zero. In a real-life situation, this probability could be so small that it might be neglected. However, in the case of an ephemeral stream, the probability of a zero discharge can be significantly large. As a consequence, the data series corresponding to these streams have to be treated separately.

Another problem in the treatment of ephemeral streams arises in the case of log distributions. The logarithm of zero is not defined. Therefore, the transformation of elements equal to zero is not possible. There are three basic ways to treat zero elements (Haan, 1977). One approach is to add a small constant to all observations. This cannot be used in low-flow frequency analysis, however, because it leads to a probability of zero discharge, on an ephemeral stream, equal to zero. Another method is to ignore the zero values, which is also unacceptable in case of low-flow data series due to the fact mentioned above. A third method, theoretically the most sound one, uses the theorem of total probability. In this study, the non-zero part of the data series are

modeled by the Weibull, EV - I for the smallest values, Log-Gumbel distribution and LP3 distributions as selected for the study.

Goodness-of-Fit Tests

The above distributions are subjected to quantitative statistical tests for further screening. Kolmogorov-Smirnov test, a non-parametric test, will be applied here. Kolmogorov-Smirnov test is a quantitative statistical test to judge whether or not a particular distribution adequately describes a set of observations.

Flow-Duration Studies

Stream flow varies over a water year and one of the popular methods of studying this stream flow variability is through flow-duration curves. A flow-duration curve of a stream is a plot of discharge against the per cent of time the flow was equaled or exceeded. This curve is also known as discharge-frequency curve.

Flow-duration curves which display the flow characteristics of a river for its entire range of discharge were developed for each of the stations of record. The slope of the duration curve measures this variation in flow throughout the entire range of discharge. The slope may vary over the range of discharge. The variation is caused by maximum and minimum stream-flow values that are extremes and do not blend smoothly with the normal or central range of stream flow. In 1920, the U.S. Geological Survey adopted a *flow duration parameter* to indicate this slope and defined it as the ratio of the flow available 90% of the time divided by the flow available 50% of the time. The 50% and 90% flow values are far enough from the extremes to yield a stable measurement of the slope of the central portion of the duration curve.

The flow characteristics of river basins can be compared with an index called *variability ratio*. Variability ratio is defined by Velz and Gannon as the ratio of the once-in-10-year drought to the most probable drought. The most probable drought is the drought flow having a return period of 1.575 year. The latter is useful in defining the variation that can be expected in drought flows from year to year. A high number would indicate a stable stream while an extremely small number would indicate a stream with large flow variations.

2.4 Surface Water Quality Parameters

Surface water usually contains a lot of impurities, which pollutes the water and bring it in an unusable state for common usage. Common constituents of natural and polluted waters usually encountered are described in this chapter in the following sections.

Dissolved Oxygen

Dissolved oxygen (DO) content is a measure of the ability of surface waters to support aquatic life. Oxygen is poorly soluble in water, and the oxygen saturation concentration is dependent on three primary parameters, such as temperature, atmospheric pressure, and dissolved solids. At 1 atmosphere of pressure, the solubility of oxygen in fresh water ranges from 14.6 mg/l at 0°C to 6.4 mg/l at 40°C.

The low solubility of oxygen in water is the primary factor that requires treatment of liquid wastes before discharge to a receiving water. The presence of dissolved oxygen determines whether waste material is degraded by aerobic (with oxygen) or anaerobic (without oxygen) processes. Aerobic processes use oxygen for the oxidation of organic matter in wastes and produce relatively innocuous end products. Anaerobic processes degrade wastes without oxygen in a slower process and the degradation products, such as hydrogen sulfide and methane, are often obnoxious. The critical conditions for dissolved oxygen deficiency typically occur during the late summer months when temperatures are high, saturation concentrations are low, biological processes are enhanced, and stream flow is low.

Biochemical Oxygen Demand (BOD)

BOD is the amount of oxygen consumed by microorganisms while stabilizing or degrading carbonaceous and nitrogenous compounds under aerobic conditions. The BOD test is widely used as an indicator of the strength of municipal and industrial wastes and is an important test used in protecting aquatic life from oxygen deficiency. It is the primary regulatory tool used in

limiting discharge of these wastes to water; and the BOD test is a key in defining the technology-based waste treatment requirements (e.g., secondary treatment or equivalent).

Chemical Oxygen Demand (COD)

The COD test measures the total quantity of oxygen required for oxidation of a waste to carbon dioxide and water. It is sometimes used as an approximate substitute for BOD as the COD test can be performed in 3 h instead of 5-day period required for the BOD test. During the COD test, all organic matter is converted to CO_2 and water in contrast to BOD test, in which only biologically reactive carbon is oxidized. As a result, COD values are greater than BOD values. The primary limitation of the COD test is the inability to distinguish between biologically degradable and biologically refractory material (nonbiodegradable material).

Hydrogen-ion Concentration (pH)

The negative logarithm to the base 10 of the hydrogen-ion concentration of an aqueous solution is termed the pH value. A pH of 7.0 denotes a neutral water, or one in which there is a balance between dissociated hydrogen and hydroxyl ions. An excess of hydrogen ions indicates an acid solution with a corresponding pH value less than 7.0. Conversely, an excess of hydroxyl ions indicates a basic solution which has a pH value greater than 7.0. The full pH scale is from 0 to 14. Most natural waters are within one or two units of neutrality. Surface water usually show a basic characteristic with pH greater than 7.0.

Microorganisms

Microorganisms are present in all surface waters. The significant microorganisms in water quality studies are viruses, bacteria, fungi, algae, and protozoa. Standard Methods includes a number of tests for microbial examination of water samples. These tests include the coliform test, which is generally accepted as the principal microbiological indicator of human contamination. Decades of experience have established the significance of the coliform group density as measure of the degree of pollution from sewage because *Escherichia Coliform* (*E. coli*) is an abundant bacterial species in the human intestine. Coliform bacteria are present in the intestines of all warm-blooded animals and are excreted with feces. Their presence is an indication that other pathogenic(disease-causing) bacteria are present. Tests are available to differentiate the Fecal coliform (*F. coli*) bacteria from the larger coliform group (total coliforms)

as a more specific indicator of warm-blooded animal contamination. This test is useful because the nonfecal members of the coliform group, which may have originated in soils, can be expected to live longer in the relatively unfavourable environment of surface waters. Fecal streptococci is also used as an indicator of fecal contamination.

Other indicator organisms used in the examination of recreational waters (swimming pools, whirlpools, and naturally occurring waters) include *Pseudomonas*, *Streptococcus*, *Staphylococcus*, and in rare cases, *Legionella*. Viruses may also be examined, as well as some spore- and cyst-producing bacteria. Routine testing for enteric viruses is usually not recommended in Standard Methods, but special circumstances such as disease outbreaks or wastewater reclamation may dictate testing for these microorganisms. Iron and sulfur bacteria are of concern in surface water, and water treatment and distribution systems, especially those for industrial use. Actinomycetes can cause difficult-to-remove earthy-musty odors in municipal water supplies. Though originally considered to be fungi, they have been identified as filamentous, branching bacteria. Traces of these microorganisms can be a problem in water supplies since certain of their metabolites can be detected by humans at concentrations below 20 ng/l and massive outbreaks can disrupt wastewater treatment processes.

Fungi, including yeasts and filamentous species or molds, may be found wherever nonliving organic matter occurs, but some species are pathogenic. Their water quality significance is that they can survive without sunlight and thus persist in water distribution systems where they can cause taste and odor problems at low densities and can clog systems at high densities.

Algae, or phytoplankton, are free-floating one-celled organisms that are ubiquitous in surface waters. Many are a primary food source for higher organisms. Most algae are photosynthetic, and the concentration of the photosynthetic pigment chlorophylla, which constitutes 1 to 2 percent of their dry weight, is often used to estimate algal biomass. Algae have long been used as indicators of water quality. Some species flourish in highly eutrophic waters and develop noxious blooms, causing offensive tastes and odors. Excessive algal growth depletes dissolved oxygen and causes toxic conditions, resulting in fish kills, animal deaths, human illness. Because of their short life cycle, algae respond rapidly to changing water quality. However, their usefulness as a indicator of water quality is limited by their transient nature and patchy

distribution. In addition, algal response to pollution may occur at some distance from pollution sources.

Periphyton are a community of microscopic plants and animals that live on submerged surfaces. Unlike phytoplankton, which do not respond immediately to pollution sources, there are often dramatic changes in the periphyton community immediately downstream of waste sources. However, like phytoplankton, their patchy nature limits their use as a quantitative indicator.

Pathogenic protozoa of concern in drinking water supplies and wastewater are *Giardia lamblia*, *Entamoeba histolytica*, and *Cryptosporidium*. These organisms can cause diarrhea or gastroenteritis. *Giardia* is the most frequently identified agent in waterborne outbreaks. *E. histolytica* causes amoebic dysentery, resulting in even human deaths. *Cryptosporidium* can cause a cholera-like diarrhea and is of increasing concern as a human pathogen. Schistosomiasis, found in stream banks in Africa, Asia, and South America is a major cause of water-borne disease in the tropics.

Dissolved Solids

Total Dissolved Solids (TDS) is determined by evaporation of a filtered sample to obtain a residue whose weight divided by the sample volume is the total dissolved solids concentration. The TDS concentration of surface waters varies widely. Runoff from wet, well-drained regions can have a TDS concentration as little as 25 mg/l.

There are several reasons why TDS is an important indicator of water quality. Dissolved solids affect ionic strength, which has an impact on the mobility and transformation of metals and ionizable chemicals. In addition, TDS is a major determinant of aquatic habitat that affects both aquatic biota and irrigated plants. Many aquatic plants and animals are adapted to fresh waters or to salt waters and cannot survive when dissolved solids concentrations are too high or too low. Only a few of the higher-order animals can migrate between oceans and freshwater rivers. Some bacteria and other simple organisms survive in both fresh and brackish waters, but their metabolism is affected when moving from one to the other. Monitoring of dissolved solids provides a gross measure of geochemical conditions and the load of constituents in rivers.

TDS is an important indicator of the suitability of water for drinking, irrigation, and industrial use. Dissolved solids increase as waters move over the land surface. Use of water for human consumption, industrial activities, and farming further increases TDS as the water is returned to surface waters. TDS affects saturation concentrations of dissolved oxygen and influences the ability of a water body to assimilate wastes. The rate of degradation of organic wastes is lower in salt waters than in fresh waters. Also eutrophication (the growth of algae in water) rates depend on total dissolved solids.

2.5 Water Quality Standards

Water is a limited resource subject to many demands. As the population and technology expands, the demands on available water resources increases as does the complexity of environmental issues. The intended use of water may be limited by both its quality and its quantity. Poor water quality can affect aquatic life as well as human beings as is used for drinking, recreational, agricultural, and industrial purpose. Water quality is regulated by the development of criteria and standards.

A *water quality criteria* is that concentration, quality, or intensive measure (e.g., temperature) that, if achieved or maintained, will allow or make possible a specific water use. A criterion may be a concentration that, if not exceeded, will protect an organism, aquatic community, or designated use with an adequate degree of safety. A criterion may also be a narrative statement concerning some desirable condition. While water quality criteria are often the starting point in deriving standards, criteria do not have a direct regulatory impact because they relate to the effects of pollution rather than its causes.

A *water quality standard* is the translation of a water quality criterion into legally enforceable ambient concentration, mass discharge or effluent limitation expressed as a definite rule, measure, or limit for a particular water quality parameter. A standard may or may not be based on a criterion.

Standards may differ from *criteria* because of prevailing local quality conditions such as natural impairment of water quality. For example, some natural waters may exceed some water quality criteria even in the absence of anthropogenic pollution. Standards and criteria may also differ

from one place to another owing to economic considerations, the perceived importance of a particular ecosystem, or the degree of safety required for a particular water.

Historically, the first effects of poor water quality that were the subject of criteria and standards were those affecting human health. For example, the control of infectious disease was the first goal of water quality regulations, followed by regulation of *toxic chemicals*, i.e., chemicals which, through their chemical or physical action, produce a harmful biological effect, the by regulation of those conditions that impact the convenience of use or aesthetics of water. For example, the quality of drinking water is impacted by its taste and odor, even though this taste or odor may not have serious health effects. The effect of water quality on the health of aquatic ecosystems is also an important consideration.

Water Quality Standards are the implementation of water quality criteria in an enforceable regulatory framework. Standards may deviate from water criteria since they may consider factors other than health considerations. Water quality standards are typically established on the basis of one or more of the following factors:

1. Established and ongoing practice or experience
2. Existing criteria
3. Bioassays to establish new criteria
4. Ability to measure parameters reliably and other technical factors
5. Evidence derived from accidental human exposure
6. Epidemiological studies
7. Educated guess based on available information and judgement
8. Application of mathematical models (e.g., those that simulate health risks)
9. Economic attainability and impact on specific industries
10. Legal enforceability

For the protection of environment water quality standards were established in Bangladesh in 1997 and these are given in Chapter Three.

CHAPTER THREE

DATA COLLECTION

3.1 Criteria for Selection of Study Stations

Considering the availability of simultaneous water quality data and discharge data, three rivers have been selected for this study. These are Brahmaputra-Jamuna at Bahadurabad, Surma at Sylhet, Jamuneswari-Karotoa at Bogra and Karotoa-Atrai-Gur-Kumari-Hurasagar at Panchagahr. The Brahmaputra-Jamuna is the international drainage course passing through India and then through Bangladesh. Many important industrial installations are situated on the bank of this international drainage course. Bahadurabad being below a long length inside Bangladesh and just a few kilometer above Jamuna Fertilizer Factory is an important location to see the water quality of transboundary flow. Surma is a river in the south-eastern region of Bangladesh, where the Divisional city of Sylhet is located on the bank of this river. The Karotoa-Atrai is the main system draining a large part of the north-west region containing important district city of Panchagahr. Municipal and industrial wastes are disposed in these rivers. The stations selected for present study are shown in Figure 3.1.

3.2 Sources of Data

Surface Water Hydrology Directorate of Bangladesh Water Development Board (BWDB) has a hydrological network to collect hydrological and hydrometeorological data. Generally mean daily discharge is measured fortnightly. Using the collected data, rating curve of each station is prepared for each water year. A year is the time interval starting in April 1 of one calendar year and ending in March 31 of the next calendar year. Mean daily discharge is obtained from the rating curve using observed daily water level. A computer-based data bank is available at BWDB. Data is stored in a text format. The unit of daily discharge data is cubic meter per second.

In Bangladesh, the Department of Environment (DOE) has collected limited surface water quality data on 29 streams at 60 locations as shown in Table 3.1. Water quality data are being

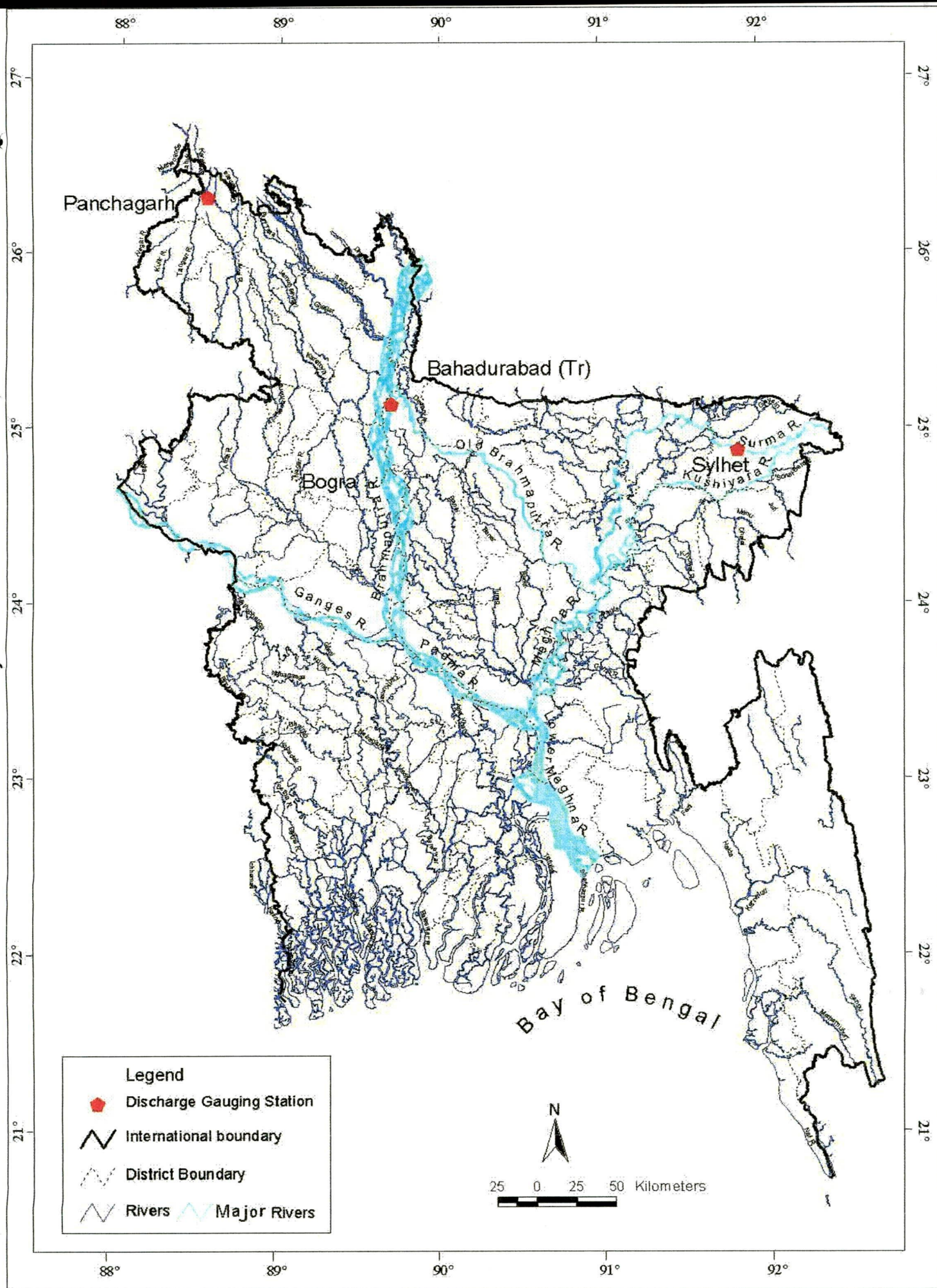


Figure 3.1 : Index Map Showing Locations of Selected Gauging Stations

collected by DOE since 1980 at selected locations on a number of rivers. The average length of record is about 10 years. However, for a number of rivers, concurrent discharge data are not available. For the present study water quality and discharge data have been collected from DOE and BWDB respectively for three stations, Bahadurabad on Brahmaputra river, Sylhet on Surma river and Panchagahr on Korotoa river.

Table 3.1: DOE Data Collection Stations on Different Rivers.

Dhaka Division

Sl No.	River	Station	Data Length
1	Balu River	Tongi	1980 - 93
2	Brahmaputra River	Jamalpur	1980 - 93
3	Brahmaputra River	Kishoreganj	1980 - 93
4	Brahmaputra River	Mymensingh	1980 - 93
5	Brahmaputra River	Nanghal Banda	1980 - 93
6	Brahmaputra River	Netrakona	1980 - 93
7	Buriganga	Chandighat Water Works	1980 - 93
8	Buriganga	Demra Ferry Ghat	1980 - 93
9	Buriganga	Dhaka City	1980 - 93
10	Buriganga	Dolaikhal	1980 - 93
11	Buriganga	Farashgonj	1980 - 93
12	Buriganga	Gab tali Bridge	1980 - 93
13	Buriganga	Islambagh	1980 - 93
14	Buriganga	Kamrangir Char	1980 - 93
15	Buriganga	Mirpur	1980 - 93
16	Buriganga	Narinda	1980 - 93
17	Buriganga	Near Hazaribagh Tanneries	1980 - 93
18	Buriganga	Pagla	1980 - 93
19	Buriganga	Sadarghat	1980 - 93
20	Buriganga	Savar	1980 - 93
21	Buriganga	Tejgaon	1980 - 93

Chittagong Division

Sl No.	River	Station	Data Length
1	Dakatia River		1980 - 93
2	Halda River	Chandragona	1980 - 93
3	Halda River	Madhunath Ghat	1980 - 93
4	Halda River	Mohra	1980 - 93
5	Halda River	Near Halda River	1980 - 93
6	Karnaphuli	At 7 locations	1980 - 93
7	Kushiara River	Jakigonj	1980 - 93
8	Meghna River	Chandpur	1980 - 93
9	Surma River	Chatak	1980 - 93
10	Surma River	SPPM	1980 - 93
11	Surma River	Sunamganj	1980 - 93
12	Surma River	Sylhet	1980 - 93
13	Kaptai Lake	Kaptai	1980 - 93

Rajshahi Division

Sl No.	River	Station	Data Length
1	Isamoti River		1980 - 93
2	Jamuna River		1980 - 93
3	Korotoa River	Bogra	1980 - 93
4	Korotoa River	Panchagahr	1980 - 93
5	Padma River	Pakshi Paper Mills	1980 - 93
6	Padma River	Rajshahi	1980 - 93
7	Tangs River	Tangs River Bridge	1980 - 93
8	Tista River	Lalmonirhat	1980 - 93
9	Tista River	Rangpur	1980 - 93
10	Tista River	Teesta Bridge	1980 - 93

Khulna Division

Sl No.	River	Station	Data Length
1	Bagerhat River	Bagerhat	1980 - 93
2	Balesher River	Perojpur	1980 - 93
3	Bhoirab River	Chorerhat	1980 - 93
4	Bhoirab River	Fultala Bazar Ghat	1980 - 93
5	Bhoirab River	Gilatola	1980 - 93
6	Bhoirab River	Ggilatola Ghat	1980 - 93
7	Bhoirab River	Goalpara	1980 - 93
8	Bhoirab River	Goalpara Ghat	1980 - 93
9	Bhoirab River	Noapara	1980 - 93
10	Bil Dakatia	Bil Dakatia	1980 - 93
11	Doratana River	Bagerhat	1980 - 93
12	Gabkhan River	Gabkhan	1980 - 93
13	Kakshiraly River	Khaligonj	1980 - 93
14	Kakshiraly River	Satkhira	1980 - 93
15	Kitankhola River	Barisal	1980 - 93
16	Kumar River	Madaripur	1980 - 93
17	Kumar River	Mostafapur	1980 - 93
18	Modhumoti River	Mollarhat	1980 - 93
19	Padma River	Kushtia	1980 - 93
20	Padma River	Maowa Ferry Ghat	1980 - 93
21	Pashur River	Mongla Port	1980 - 93
22	Rupsha River	Goalpara	1980 - 93
23	Rupsha River	Khulna	1980 - 93
24	Rupsha River	Rupsha Ghat	1980 - 93
25	Shugandha River	Jhalkathi	1980 - 93

3.3 Water Quality Parameters

DOE collects surface water sample and measures temperature, pH, BOD, COD, DO, Electrical Conductivity, Chloride, Turbidity, T-Alkalinity, P-Alkalinity, TS, TDVS, TVS, Ammonia,

Nitrate/Nitrite, Coliform colonies etc. Though this long list of parameters describe the quality of water, a very few number of parameters such as pH, BOD, DO, and Total Coliform are used to describe the surface water quality to be used for various purposes as given in the Environmental Protection Regulation, 1997.

3.4 Surface Water Quality Criteria

The surface water quality criteria was promulgated in the Environmental Protection Regulations, 1997 as published in Bangladesh Gazette, 28 August 1997 issue, which is given in Table 3.3.

Table 3.3: Inland Surface Water Quality Standards

Sl No.	Best uses Class	Criteria			
		pH	BOD (mg/l)	DO(mg/l)	Overall Coliform No./100 ml
A	Drinking Water Source used only after disinfection	6.5 - 8.5	2 or below	6 or above	50 or below
B	Recreational uses	6.5 - 8.5	3 or below	5 or above	200 or below
C	Drinking water source for common processing	6.5 - 8.5	3 or below	6 or above	5000 or below
D	Fish culture	6.5 - 8.5	6 or below	5 or above	5000 or below
E	Source of water used for different processing and cooling industries	6.5 - 8.5	10 or below	5 or above	
F	Irrigation water source	6.5 - 8.5	10 or below	5 or above	1000 or below

3.5 Data Collection and Organization

For the present study, surface water quality data for selected rivers were collected from DOE. For surface water quality measured parameters include pH, BOD, DO, and total coliforms. Data for these parameters were collected from DOE and given in Appendix B (Table B.1). Steamflow data together with an index map showing the gauging stations is collected from Surface Water Hydrology Directorate of BWDB. Considering the availability of water quality and discharge data, four rivers have been selected for this study as shown below.

Table 3.4 Selected Discharge Gauging and Water Quality Data Stations

River	Gauging Station No. and Location	Period of Record	
		Discharge	Water Quality
Bhrahmaputra-Jamuna	46.9L: Bahadurabad	1964-1993	1980 – 1990
Surma	267: Sylhet	1964-1993	1980 – 1993
Jamuneswari-Korotoa	65: Bogra	1964-1993	1980 – 1993
Karatoa-Atrai-Gur-Kumari-Hurasagar	140: Panchagarh	1964-1993	1980 – 1993

It is seen from the Table 3.4 that for the discharge data the smallest record length is 26 and the largest is 39 years, the average record length is 29.5 years. A further effort was given to collect current data. But from the concerned authorities it was known that data beyond those collected are yet to be processed and there is no provision of supplying row data. The data were converted from BWDB format to required format using a computer program written in FORTRAN 77. Discharge data of each station was checked year-wise for consistency. If there were missing values, those were filled up by reasonable values.

A field visit was made to Bahadurabad to be familiar with the process of sampling for surface water quality data collection system. Surface water sampling are usually done by a junior level Chemist or Technician. Water sample is collected in the river about 15 meters away from the bank and 0.3 meter below water surface using winlker bottle. The observer needs to use an engine boat for collection of sample. The BOD bottle and DO bottle are made of glass of 300 ml size with a glass stopper, while sampling bottle for other parameters are just plastic bottles of 750 ml size. The sampled bottles are tied up tightly by wrapping with rope. Some reagents are added to DO bottle if tests are to be done in a laboratory later.

3.6 Extraction of Low-flow series

Using the daily flow data, low-flow of specified duration, such as 7-day and 10-day for each water year has been calculated by means of running average technique (Hudson and Hazen, 1964). By definition the d-day low-flow in any water year is the minimum of the averages of discharges over d consecutive days. At gauging stations, values of annual minimum d-day average flows have been determined by selecting the smallest of the (366 - d) values obtained as

running averages over all consecutive d-day periods within a year. As mentioned before, the year begins on April 1 and ends on March 31. Low-flow series of specified duration for each station were extracted by writing a computer program in FORTRAN 77.

3.7 Data Screening

After developing the low-flow series for each of the site, these have been subjected to various tests to verify whether the samples are suitable for frequency analysis. The four basic statistical criteria that a data sample must satisfy are randomness, stationarity, independence and homogeneity. There are several wellknown tests for these criteria, but most of them cannot be applied to low-flow data (Loucks, Stedinger and Haith, 1981). The main obstacle to the usage of those tests is the assumption that the data come from a normal distribution. The assumption is almost always invalid in the case of low-flow data. As such the tests used in this research are of the non-parametric type which avoids hypothesis regarding the underlying distribution.

Test of Outliers

A visual inspection of the plots of the data series for the selected stations suggested that over 70% of the data series contain high outliers. High outliers, when not identified and removed, can yield erroneous results in low-flow frequency analysis. On the other hand, low outliers, once detected and interpreted, can yield more accurate results in low-flow frequency analysis.

For the present study, outliers have been detected by providing box plot method (Hirsch et al., 1993). A box plot is a concise graphical display for summarizing the distributions of a data set. Box plot provides visual summaries that provide at a glance an idea of the central tendency of the data, the variability, the symmetry and the presence of outliers.

The box plot of each station is performed using Microsoft Excel spreadsheet software. After performing box plot it is revealed that 3 data series contain high outliers. The number of outliers in each data series is listed in Table 3.5. Outliers, which are detected, are removed from the data series.

Table 3.5 Data Length of Low-flow Series of specified duration after removal of outliers

River	Station Name	Data series	Original Record Length	No. of Outliers	Record Length after Outlier Removal
Brahmmaaputra	Bahadurabad	1-day	39	2	37
		7-day	39	2	37
		10-day	39	2	37
Surma	Sylhet	1-day	25	0	25
		7-day	25	0	25
		10-day	25	0	25
Karatoa-Atrai-Gur- Kumari-Hurasagar	Panchagahr	1-day	28	0	28
		7-day	28	0	28
		10-day	28	0	28

Test of Randomness

In hydrologic context, randomness essentially means, that the data arise from natural causes. In many cases, low-flow data series are not random. For instance, if discharge on a stream is controlled by a reservoir upstream from the gauging station, the corresponding low-flow data series may not be random. Non-randomness may caused by human influences, such as the construction of dams, diversions, etc. Unfortunately, there are no suitable randomness tests for short data series (Bobee and Ashkar, 1991). The only practical ways to identify potential non-randomness are to plot the data series and to look at the history of the data series. Both of these tests require subjective judgement and should be used in conjunction with other tests.

A plot of each of the data series has been made in order to perform a visual inspection. However, the data series, from which outliers have been removed, are plotted again. In particular, the plots are examined for instability in mean low-flow value. The data series under study were not found to show any instability.

Low-flow data of 1-day, 7-day and 10-day averaging period selected for frequency analysis are given in Appendix B, Table B.2.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

Results of analysis of available water quality data and low flow criteria are presented in this chapter. First, variation of surface water quality parameter concentrations with discharge is looked into to gain an insight of discharge-water quality relationships in terms of measured parameter concentrations. Water quality data for Brahmaputra at Bahadurabad, Surma at Sylhet, and Karotoa at Panchagar were used. This is followed by analysis to establish low flow criteria at each of the selected locations of these rivers.

4.2 Discharge-Water Quality Relationships

During the periods of high runoff, most rivers exhibit their most favourable chemical water-quality characteristics. Although the water may contain extremely large amounts of suspended matter, the concentrations of dissolved substances are low, often only a fraction of that found during dry-weather periods. Because of an inherent capacity to assimilate wastes, surface waters are capable of natural purification. Excessive water-quality deterioration may result if the amounts of wastes discharged are too high. Pollution control agencies need to regulate the discharge of waste products to prevent water-quality degradation, which affects the beneficial uses of water. The greatest attention has generally been given to the ability of surface waters to assimilate wastes.

The waste-assimilative capacity of surface waters is generally considered to be the amount of waste which will not cause water-quality deterioration beyond the limits required for other beneficial uses of the supply. The greatest single factor controlling the overall waste-assimilative capacity of surface waters is the amount of dilution that is provided. With fixed limits on the degree of water-quality deterioration that may be tolerated, the waste-assimilative capacity increases as the amount of dilution water increases. In all studies of assimilative capacity it must be remembered that the amount of dilution water available at any time is a primary concern.

In the present study analysis began with obtaining concurrent discharge values from the BWDB database for the dates on which surface water quality parameter concentration data were available from DOE. Such plots for BOD, DO, and pH against discharge for Brahmaputra at Bahadurabad, Surma at Sylhet and Karotoa at Pachagar are shown in Figures A.2(i) through A.2(ix) in Appendix A. Data on total coliform were available only for Brahmaputra and plotted in Figure A.2(x) of Appendix A. For comparison water quality standards for irrigation use, fish culture and drinking water are superimposed on these plots. In case of Brahmaputra measured BOD concentrations exceed both the drinking water and fish culture standard, whereas for Surma about a half of the measured values exceed the standard and for Karotoa concentrations are seen to be below the standards for all uses. Plots for DO and pH show that their amounts are well above the standard values for all of the three rivers. All measured concentrations of coliform in Brahmaputra exceed the drinking water standard, several values exceed irrigation standard and fish standard is generally met. It is seen that the discharge water-quality plots show substantial scatter although a decreasing trend in parameter is expected with increasing discharge. It may be due to the fact that all the available water might not serve to dilute the polluting substances. In rivers it is not uncommon for waste effluents to remain segregated along a shore line for many miles below the outfall.

Next linear regression analysis was performed to relate water quality with discharge. The regression equation was not found to be useful in predicting parameter concentration as a function of discharge from consideration of correlation coefficients and other test statistics. Results of regression analysis for BOD, DO, pH and coliform for Brahmaputra at Bahadurabad are given in Table B.8. Regression results were similar for other rivers.

4.3 Low Flow Criteria

One of the critical elements of any water quality standard is the low-flow criteria to be applied. Results of analysis for determination of 7Q10 and 10Q25 are presented in this section. Table B.2 shows the 7-day and 10-day annual low flow series together with 1-day series. Gumbel (EV-1), log-Gumbel, LP3 and Weibull distributions were selected for frequency analysis. Low flow values for 1-day, 7-day and 10-day durations are presented in Table B.5. Next goodness-of-fit was tested by Kolmogorov-Smirnov (K-S) test and low flow values for 1-day, 7-day and 10-day durations at 10% level of significance are summarized in Table 4.1. Detailed results of K-S tests for various distributions are given in Table B.6 of Appendix B.

Table 4.1: Low flow values in m³/s of various duration for indicated return periods

River	Low flow series	Best-fit Distribution	Return Period (years)		
			1.575	10	25
Brahmmaputra at Bahadurabad	1-day	Gumbel	4036	3245	2913
		Log-Gumbel	4018	3258	29832
		LP3	3996	2978	2868
		Weibull	3995	3221	3014
	7-day	Gumbel	4095	3330	3008
		Log-Gumbel	4078	3345	3078
		LP3	4048	3102	2999
		Weibull	4050	3327	3143
	10-day	Gumbel	4122	3349	3024
		Log-Gumbel	4104	3364	3095
		LP3	4076	3117	3013
		Weibull	4078	3344	3156
Surma at Sylhet	1-day	Gumbel	5.0	2.7	1.8
		Log-Gumbel	4.9	2.9	2.3
		LP3	4.8	2.4	2.2
		Weibull	4.9	2.8	2.3
	7-day	LP3	5.0	2.6	2.4
		10-day	Gumbel	5.6	2.8
	Log-Gumbel		5.4	3.1	2.5
	LP3		5.2	2.8	2.6
	Weibull		5.2	3.0	2.7
	Korotoa at Panchagahr	1-day	Weibull	3.8	1.2
Log-Gumbel			3.9	1.6	1.1
7-day		Weibull	4.0	1.3	0.4
		Log-Gumbel	4.1	1.8	1.2
10-day		Gumbel	4.1	1.3	0.4
		Log-Gumbel	4.2	1.8	1.3

It may be noted here that both skewness and kurtosis of Gumbel distribution are constant which are -1.136 and 5.4, respectively. Based on computed skewness and kurtosis, Gumbel distribution was not acceptable for all three rivers whereas log-Gumbel distribution was found to be acceptable for Karotoa river only.

In summary Weibull distribution showed good fit to all three rivers, LP3 for Brhmaputra and Surma, and log-Gumbel for Korotoa river only. Finally calculated 7Q10 and 10Q25 flow values using good-fit distributions are given in Table 4.2(a) and 4.2(b).

Next flow duration curves were obtained using low flow series of 1-day, 3-day and 7-day durations to assess the exceedence probabilities associated with the computed 7Q10 and 10Q25 flow values. The flow durations curves are given in Figure A.1(i) through A.1(ix) and using these curves exceedence probabilities of 7-day, 10-year flows are computed and presented in Table 4.3. It is seen that 7Q10 and 10Q25 flows are exceeded 99.99 percent of the time.

Estimates of such exceedence probabilities provide guidance in setting level of effluent treatment required for protection of water quality. For example if the 7-day, 10-year flow is equaled or exceeded 99% of the time on a given river, it would be required to provide effluent treatment which should be adequate 99% of the time.

Table 4.2(a) : Seven-day, ten-year low flow (7Q10) values for selected stations

River	Station Name	Station No.	7Q10 (m ³ /s)	Best-fit Distribution
Brahmaputra	Bahadurabad	46.9L	3102	LP3
			3327	Weibull
Surma	Sylhet	267	2.60	LP3
Korotoa	Panchagahr	140	1.75	LG
			1.30	Weibull

Table 4.2(b) : Ten-day, twenty five-year (10Q25) values for selected stations

River	Station Name	Station No.	10Q25 (m ³ /s)	Best-fit Distribution
Brahmaputra	Bahadurabad	46.9L	3013	LP3
			3156	Weibull
Surma	Sylhet	267	2.62	LP3
			2.7	Weibull
Korotoa	Panchagahr	140	1.29	LG
			0.4	Weibull

Table 4.3: Percent of Time the Stream Flow was equal to or greater than 7 day, 10-yr Flow

Station	7-day, 10-yr flow (m ³ /sec)	Duration as percentage		
		From 7-day duration curve	From 3-day duration curve	From 1-day duration curve
Bahadurabad	3102	99.99	99.99	99.99
Sylhet	2.98	99.99	99.99	99.99
Panchagahr	1.75	99.99	99.99	99.99

4.4 Flow Variability

The average discharge, variability ratio and flow-duration parameters are calculated and given in Table 4.4. A high number of variability index would indicate a stable stream while extremely low numbers would indicate a stream with large flow variations. Inspection of variability ratio shows that Brahmaputra is the most stable and Karotoa is the least stable among the three rivers.

Table 4.4 : Flow duration parameter and variability ratio

River	Average Daily Discharge; m ³ /sec	Variability ratio (1-day value)	Flow-duration parameter (1-day value)
Brahmaputra at Bahadurabad	20129	0.745	0.367
Suma at Sylhet	567	0.506	0.036
Korotoa at Panchagahr	42	0.327	0.262

4.5 Discussion

From the plots of discharge-water quality parameter data, it can be seen that in respect of BOD content the water at Bahadurabad cannot be used as a drinking water source without chemical treatment to reduce BOD. For fish culture also, this BOD level is out of acceptable limit. Only this water can be used as irrigation water source. Dissolved Oxygen (DO) content is found to be above required lower limit of standards for drinking water use, fish culture and irrigation. Coliform colonies are present in a hazardously higher number than the tolerable limit for water supply for drinking purpose. For Surma about a half of the measured BOD values exceed the standard and for Karotoa BOD concentrations are seen to be below the standards for all uses. Plots for DO and pH show that their amounts are well above the standard values for all of the three rivers. It is seen that the discharge water-quality plots exhibit substantial scatter although a decreasing trend in parameter is expected with increasing discharge. It may be due to the fact that all the available water might not serve to dilute the polluting substances. In rivers it is not uncommon for waste effluents to remain segregated along a shore line for many miles below the outfall.

Kolmogorov-Smirnov test shows that the selected low flow data series can be fitted with Weibull distribution. EV I for smallest or Gumbel distribution can be fitted to all data series of Bahadurabad station with 90% confidence limit (10% significance level). Data series of Surma river at Sylhet station can be fitted with Gumbel distribution only at 90% confidence limit except

the 7-day series. The data series of Karotoa river at Panchagahr station does not follow Gumbel distribution. All data series except 7-day series of Sylhet station can be fitted to Log-Gumbell distribution at 10% significance level (90% confidence limit). At 10% significance level all data series of Bahadurabad can be fitted with Log-Gumbell distribution.

LP3 distribution can be used to fit all the data series of Bahadurabad and Sylhet at 10% significance level.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Results obtained and presented herein were based on a very limited water quality data that were available from the Department of Environment. For example, 31 samples were collected from Brahmaputra at Bahaduarbad over a period of 11 years (1980 to 1990), 23 samples from Surma at Syhet in years (1985 to 1993), and 10 samples for Korotoa at Panchagahr in 6 years (1988-1993). Comparison of measured concentrations for selected parameters showed that water quality in Brahmaputra has deteriorated most compared to Surma and Korotoa.

Variation of water quality with quantity did not show any trend although a decrease in concentration is expected with increase in discharge. This is likely due to the fact that water samples are not collected and analyzed systematically in terms of regularity and continuity. Also water sample collected from one point may not be adequate for multi-channel rivers like Brahmaputra.

The 7Q10 flow was found to be 3102 cubic meter per second for Brahmaputra at Bahadurabad, 2.98 cubic meter per second in Surma river at Sylhet and 1.75 cubic meter per second in Korotoa river at Panchagahr. As a guideline these values may be used as the reference design flow in any pollution abatement case.

5.2 Recommendations

Currently water quality and discharge are not measured concurrently. This poses a serious limitation on water quality studies, especially the variation of water quality with amount of discharge. Data collection efforts by concerned agencies should be coordinated for obtaining data in a meaningful way.

Water quality data should be collected systematically on a regular basis at several locations along a river. This is necessary to investigate dilution characteristics and assimilative capacity of rivers. Water quality data should be collected at the waste disposal points as well as at some

distant locations. For example, in case of Brahmaputra river, water quality data may be collected just at the downstream of the Jamuna Fertilizer Factory and at points further downstream for studying the effect of waste disposal. It may be worthwhile to determine the 7Q10 flows of other rivers at important locations using appropriate frequency distribution.

Reference:

- Abouel Nour, A-Razek A., 1972. Water Resources Bulletin. Journal of the American Water Resources Association 8-1:15-23.
- Ahmed, S.M.U., 1982. The Return Period of Ganges' Droughts. Journal of the IEB 10(2): 1-6.
- Anderson, Peter W. and John E. McCall, 1968. Effect of Drought on Stream Quality in New Jersey, Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 94, No. SA 5, October, 1968.
- Azim, Zahurul, 1992. Buriganga River Water Quality Monitoring, The Telegraph, Dhaka, July 7, 1992.
- Biswas, H. and B. A. Bell, 1984. A Method for Establishing of Site-specific Stream Design Flows for Waste Load Allocation, journal of the Water Pollution Control Federation, Vol 50, No 10: 1123-1130.
- Browder, Greg J. , 1992. Final Report for Water Quality Management Task, Dhaka, July, 1992.
- Box, G.E.P., and D. R. Cox, 1964. Handbook of Hydrology, Maidment, Editor-in-chief, Chapt. 18, An Analysis of Transformations, J. Royal State. Soc., Series B, Vol 26, pp. 211 - 252, 1964 in Hand Book of Hydrology.
- Chow, V.T. (ed.), 1964. Handbook of Applied Hydrology, Chap. 11 & 12, McGraw Hill Book Co., New York.
- Chowdhury, J.U., 1979. A Probabilistic Approach for Forecasting Low Flow of the Gumti River. Journal of IEB 7 (1).
- Dalrymple, T., 1960. Flood Frequency Analyses. U.S. Geological Survey Water Supply Paper 1543-A.
- Department of Environment, 1992. Report on Water Quality of Selected Rivers in Bangladesh for 1990-91 and Pollution Trend Since 1984, Dhaka, October, 1992.
- Dingman, S. L., 1978. Synthesis of Flow Duration Curves for Unregulated Streams in New Hampshire. Water Resources Bulletin 14:1481-1502.
- Environment Protection Rules, 1997. Bangladesh Gazette, 28 August, 1997.
- Grossman, Irving, 1968. Experiences with Surface Water Quality Standards. Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 94. No. SA 1, February, 1968.
- Hirsch, R. M., D. R. Helsel, T. A. Cohn and E. J. Gilroy, 1990. Handbook of Hydrology, Maidment, Editor-in-chief, Chapt. 17, Statistical Analysis of Hydrologic Data: 17.1-17.54.

- Hudson H.E. and Hazen R., 1964. Droughts and Low Streamflow, in Handbook of Applied Hydrology, Chapt. 18, Editor-in-chief V.T. Chow, McGraw-Hill, New York.
- JICA, 1987. Study on Storm Water Drainage System Improvement Project in Dhaka City, Dhaka, October, 1987.
- Kamal, Mir Mostafa, 1996. Assessment of Impact of Pollutants in the River Buriganga Using a Water Quality Model, M. Sc. Engg. thesis, Department of Civil Engineering, BUET, Dhaka.
- Karim, Md. Abdul, 1992. Impact of Greater Dhaka City Flood Protection Works on the Environment with Specific Reference to Industrial Waste Disposal, M. Sc. Thesis, Department of Civil Engr. , BUET, Dhaka, November, 1992.
- McCuen, R.H., 1985. Statistical Methods for Engineers. Prentice hall, Englewood Cliffs, New Jersey.
- McCutcheon, S. C., J. I. Martin and T. O. Barnwell, Jr., 1987. Handbook of Hydrology, Maidment, Editor-in-chief, Chapt. 11: 11.1-11.11.73.
- Mohammed, Kazi Noor, 1988. Characterization, Treatment and Disposal of Sewage of Dhaka City, M. Sc. Thesis, Department of Civil Engr. , BUET, Dhaka, November, 1988.
- Prati, L. and Q. B. Richardson, 1971. Water Pollution and Self-Purification Study on the Po River below Ferrara, Water Research, Vol 5, No 5: 203-212.
- Rahman, M. R. and S. M. U. Ahmed, 1986. Regional Flood Frequency Analysis of Bangladesh. Bangladesh Journal of Water Resources Research, 6(1):1-9.
- Rahman, Md Ataur, 1998. A Hydrologic Determination of Instream Flow Requirement for the River Ganges, Master of Engineering thesis, Department of Water Resources Engineering, BUET, Dhaka.
- Rahman, R and Yunus Rana, 1994. Management of Buriganga river Water Quality Under Alternative Scenarios. Final Report, IFCDR (Institute of Flood Control and Drainage Research), Bangladesh University of Engineering and Technology, Dhaka.
- Purdy, Ralph W., 1966. What Do We Know About Natural Purification. Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 94. No. SA 1, February, 1968.
- Rodriguez-Iturbe, I., B. Ferber de Power, and J. B. Valdes, 1987. Rectangular Pulses Point Process Models for Rainfall: Analysis of Empirical Data. J. Geophys. Res., Vol. 92, no. D8, pp. 9645-9656, 1987.
- Sadek, Sabina, 1999. Regional Low Flow Frequency Relationships for North-western Bangladesh, M. Sc. Engg. Thesis, Department of WRE, BUET, Dhaka, 1999.

- Sala, J. D., 1990. Handbook of Hydrology, Maidment, Editor-in-chief, Chapt. 19: Analysis and Modeling of Hydrologic Time Series: 19.1-19.70.
- Shahin, M., Oorschot H. J. L. V. and Lange S. J. O., 1993. Statistical Analysis in Water Resources Engineering, A.A. Balkema Publishers, Holland, 208 pp.
- Singh, K. P., 1971. Model Flow Duration and Stream Flow Variability. Water Resources Research 7:1031-1036.
- Stedinger, J. R., R. M. Vogel and E. F. Georgiou. Handbook of Hydrology, Maidment, Editor-in-chief, Chapt. 18: Frequency Analysis of Extream Events: 18.1-18.66.
- Surface Water Modelling Centre (SWMC), 1996. Water Quality Modelling of theKarnafuli-Halda River System, Calibration Report, July, 1996, Surface Water Simulation Modelling Programme Phase III, Surface Water Modelling Centre, River Research Institute, Ministry of Water Resources, Government of The People's Republic of Bangladesh in Cooperation With DANIDA.
- Ullah, M.R., 1989. Statistical Characteristics of Low Flows of Three Rivers in Bangladesh. M. Engg. Thesis, Dept. of Water Resources Engg., BUET.
- Velz, C. J., and J. T. Gannon, 1960. Drought Flow Characteristics of Michigan Streams. Water Resources Commission, State of Michigan, Lansing, 1960.
- Vogel, R.M. and C. N. Kroll, 1990. Generalized Low-Flow Frequency Relationships for Ungauged Sites in Massachusetts. Water RESources Bulletin 26:241-253.

APPENDIX A

FIGURES

- Figure A.1 Flow-Duration Curves of 1-, 7- and 10-day Average Flow
Figure A.2 Plot of Water Quality Parameters, i.e., BOD, DO, pH and Coliform Colonies

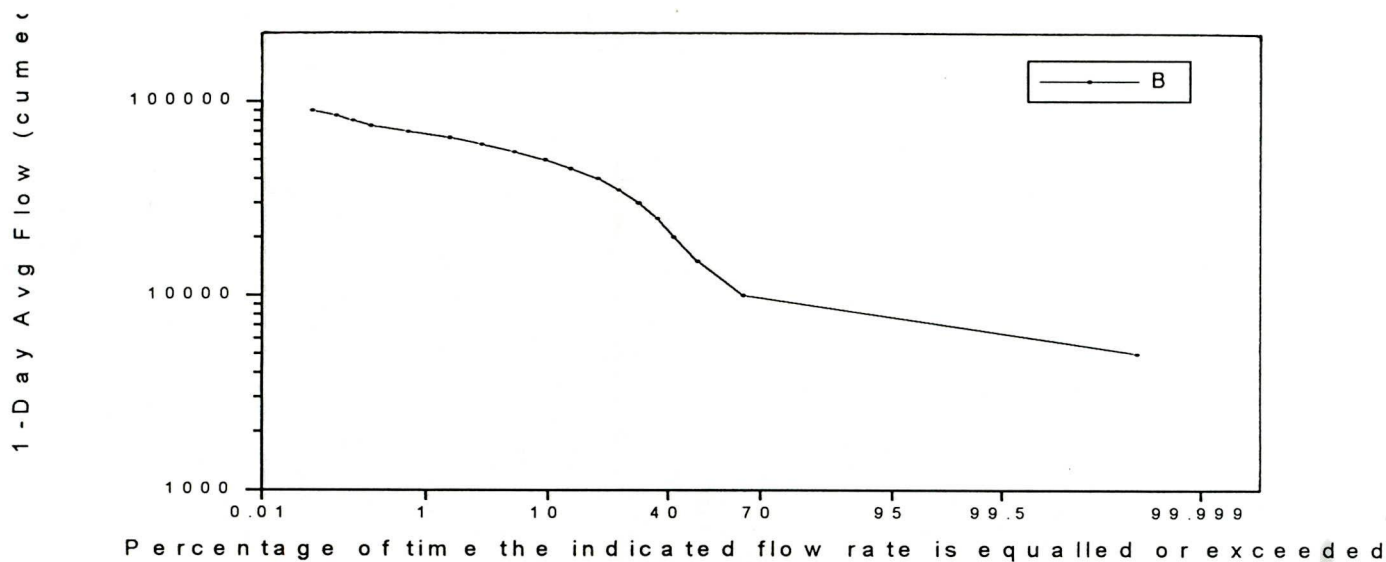


Figure A.1(i): 1-Day Average Flow -Duration curve of Brahmaputra River at station Bahadurabad

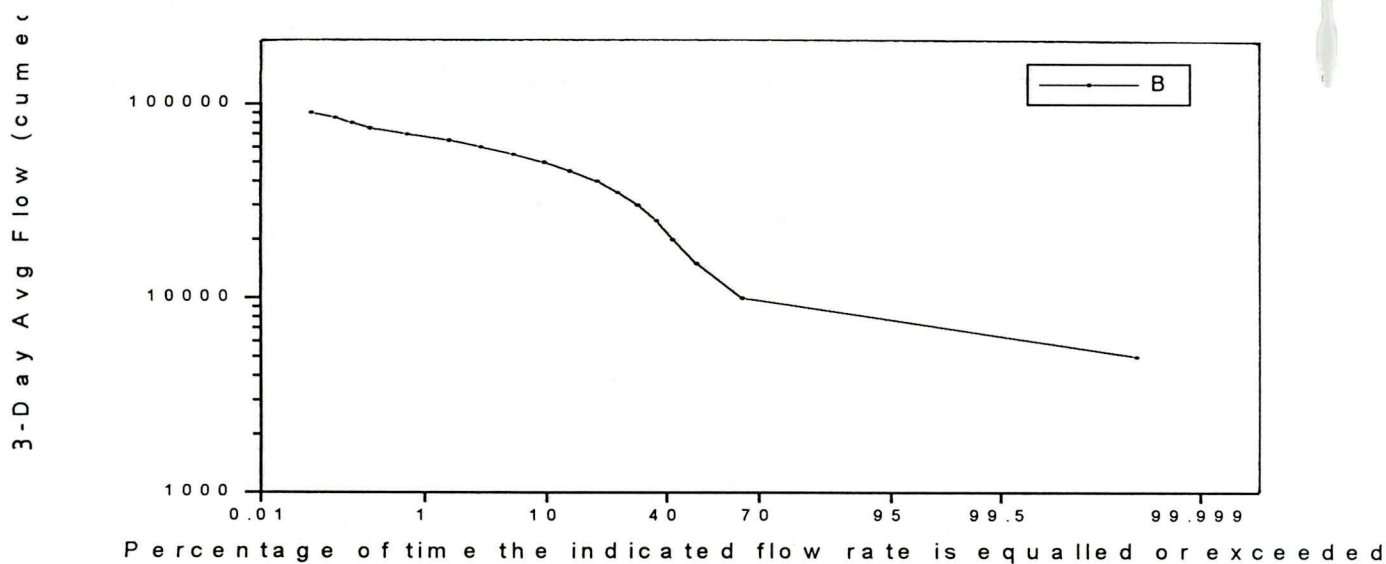


Figure A.1(ii): 3-Day Average Flow -Duration curve of Brahmaputra River at station Bahadurabad

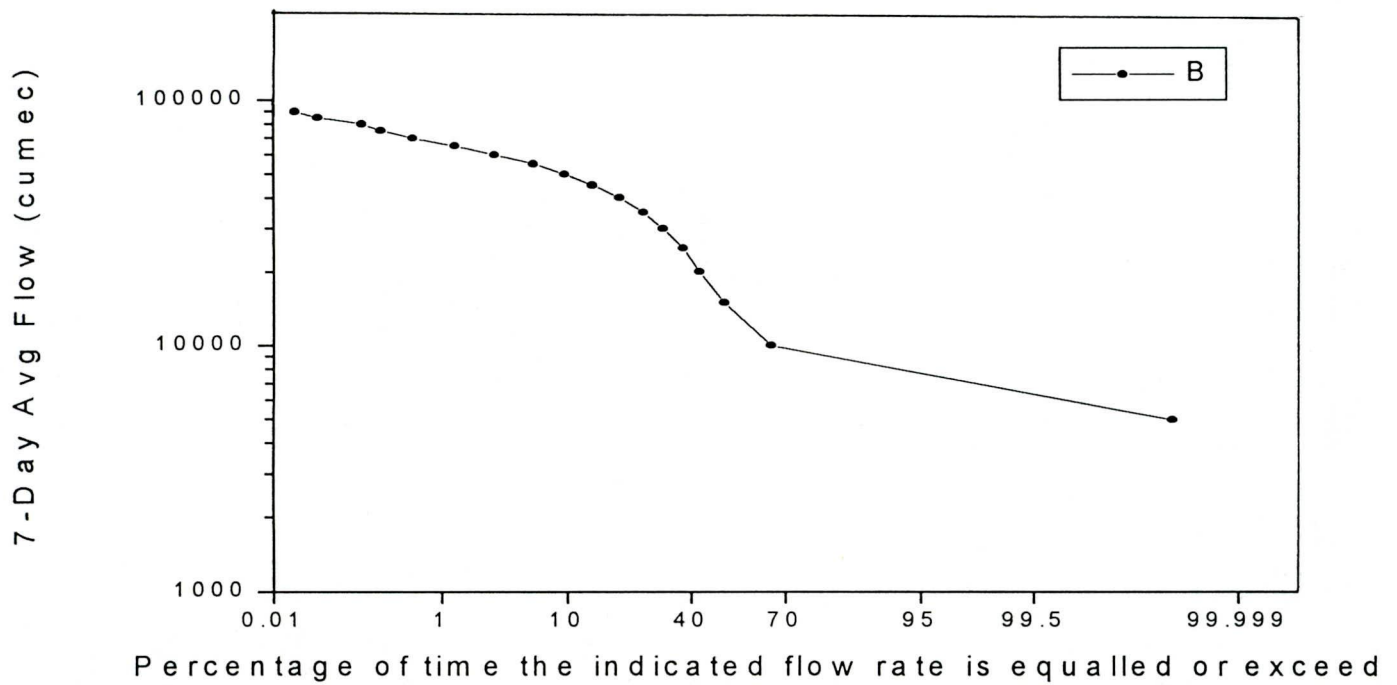


Figure A.1(iii): 7-Day Average Flow -Duration curve of Brahmaputra River at station Bahadurabad

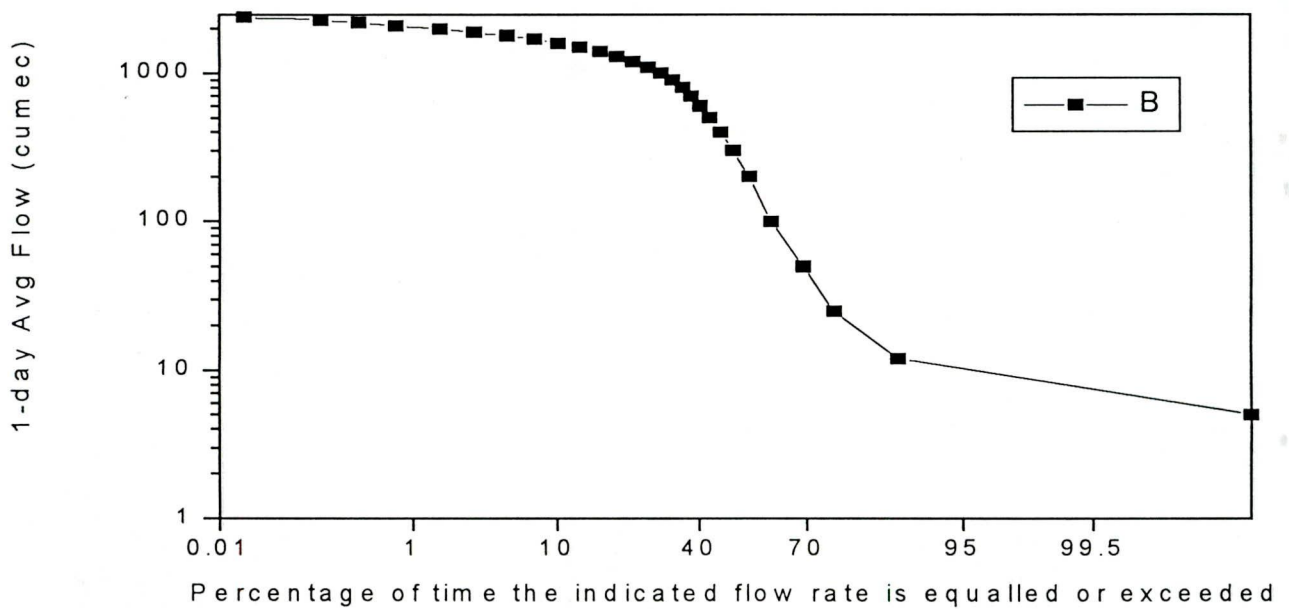


Figure A.1(iv): 1-Day Average Flow -Duration curve of Surma River at station Sylhet

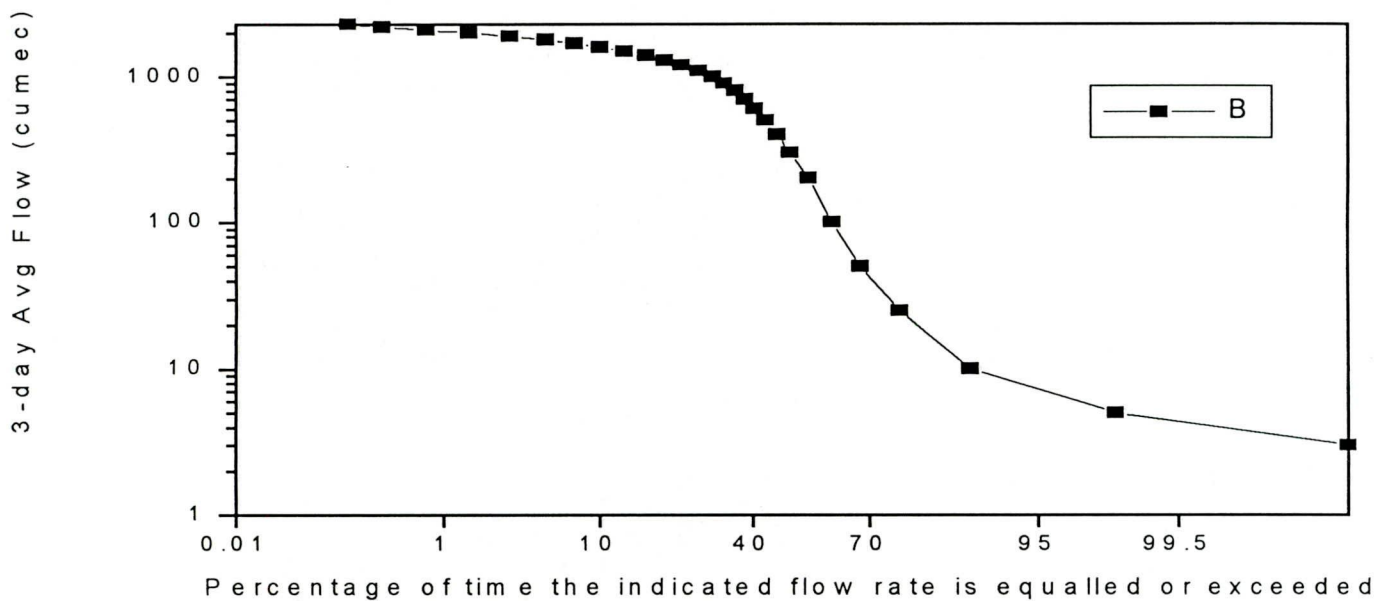


Figure A.1(v): 3-Day Average Flow -Duration curve of Surma River at station Sylhet

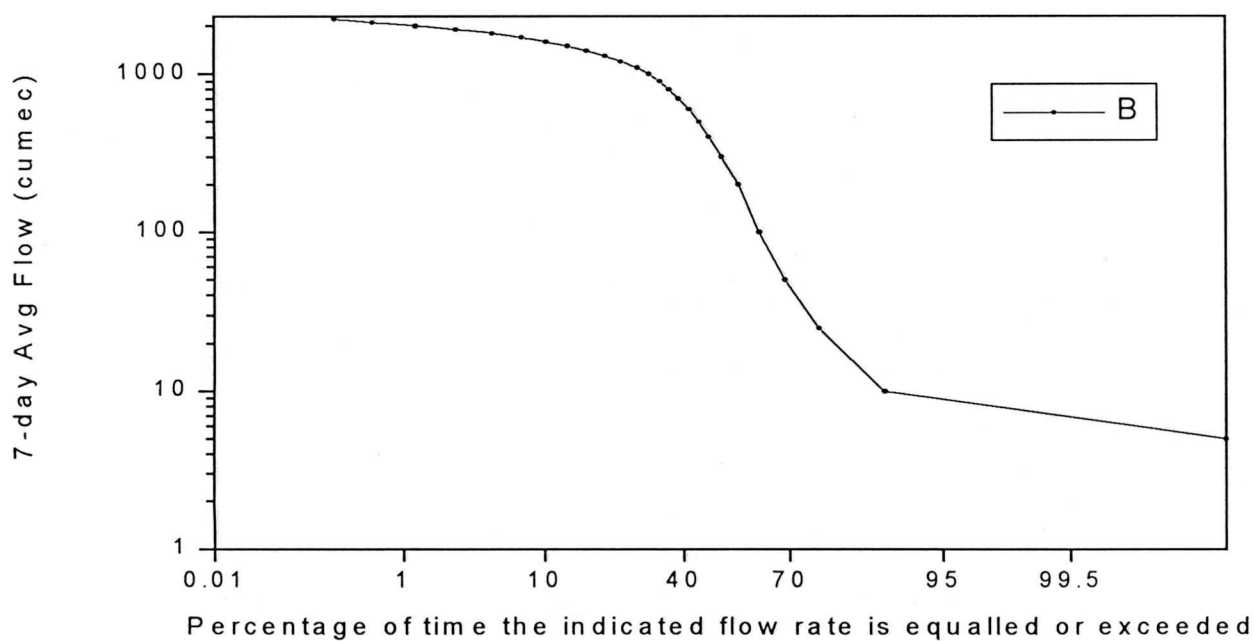


Figure A.1(vi): 7-Day Average Flow -Duration curve of Surma River at station Sylhet

1-day Avg Flow (cumec)

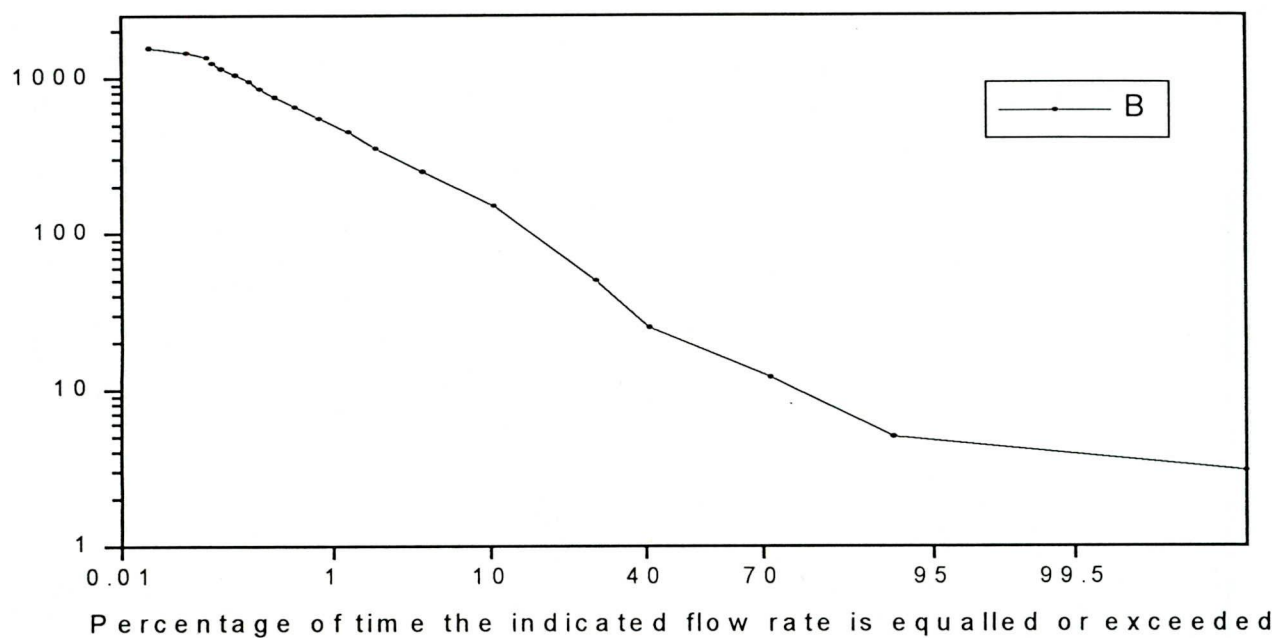


Figure A.1(vii): 1-Day Average Flow -Duration curve of Karotoa River at station Panchagahr

3-day Avg Flow (cumec)

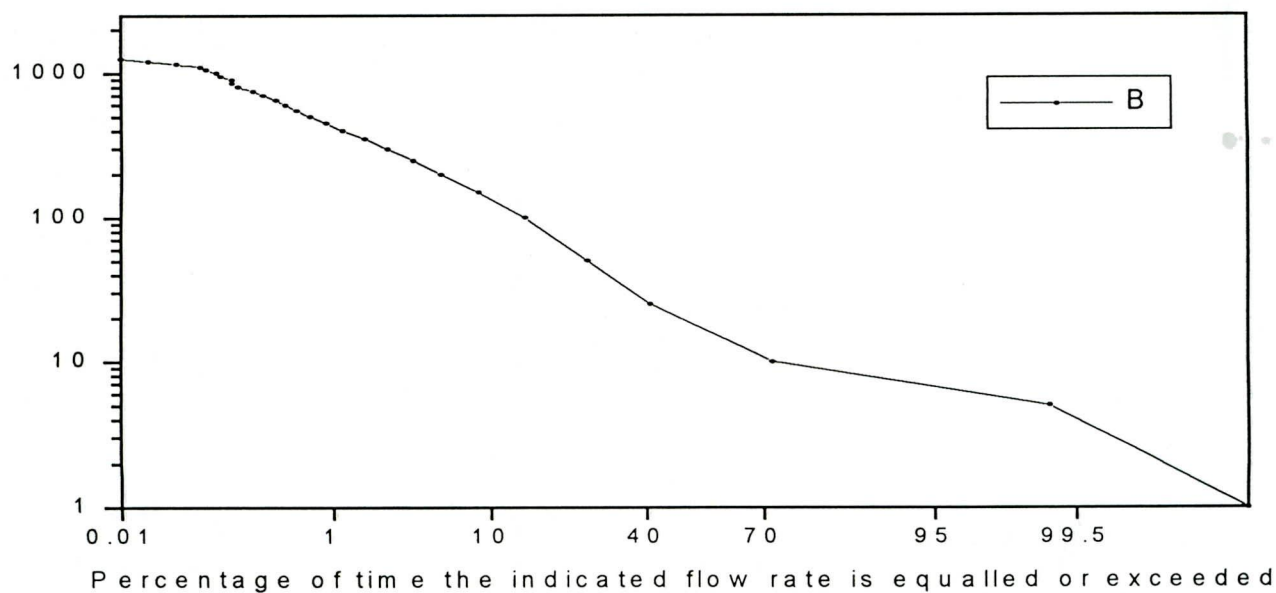


Figure A.1(viii): 3-Day Average Flow -Duration curve of Karotoa River at station Panchagahr

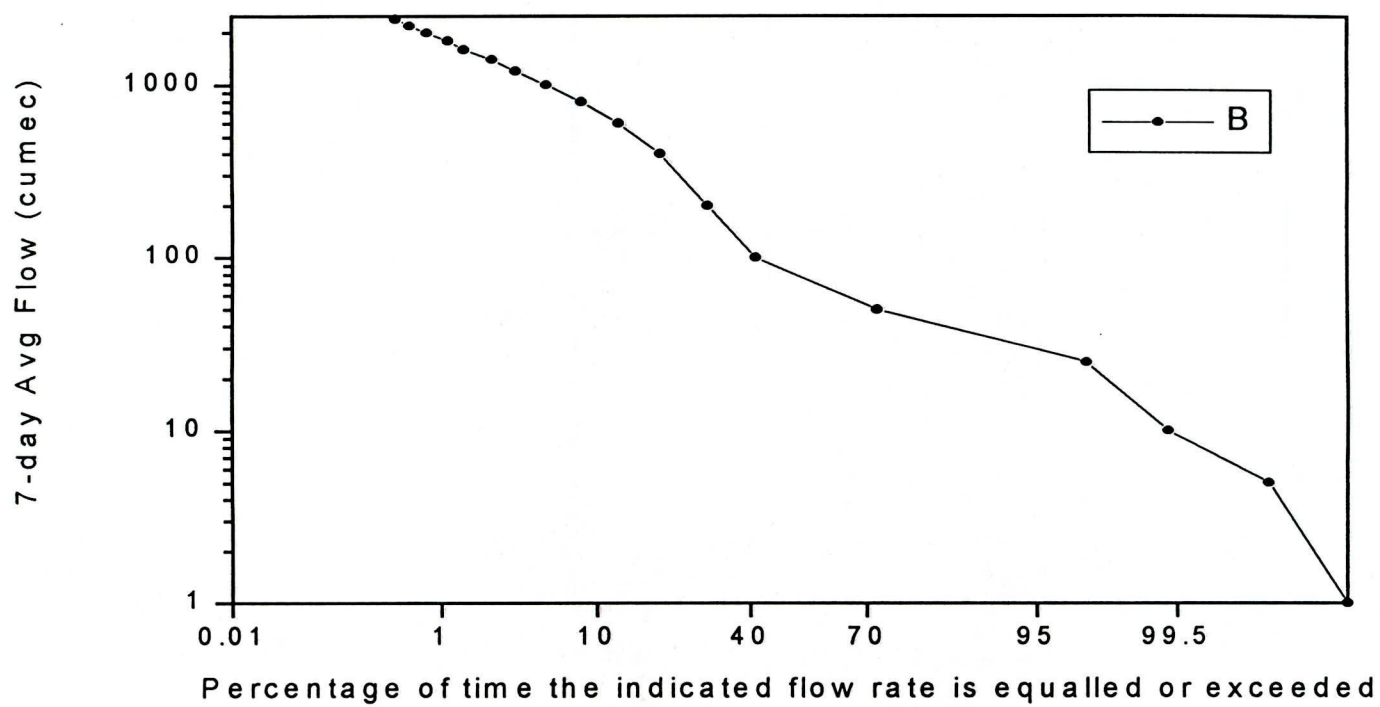


Figure A.1(ix): 7-Day Average Flow -Duration curve of Karotoa River at station Panchagahr

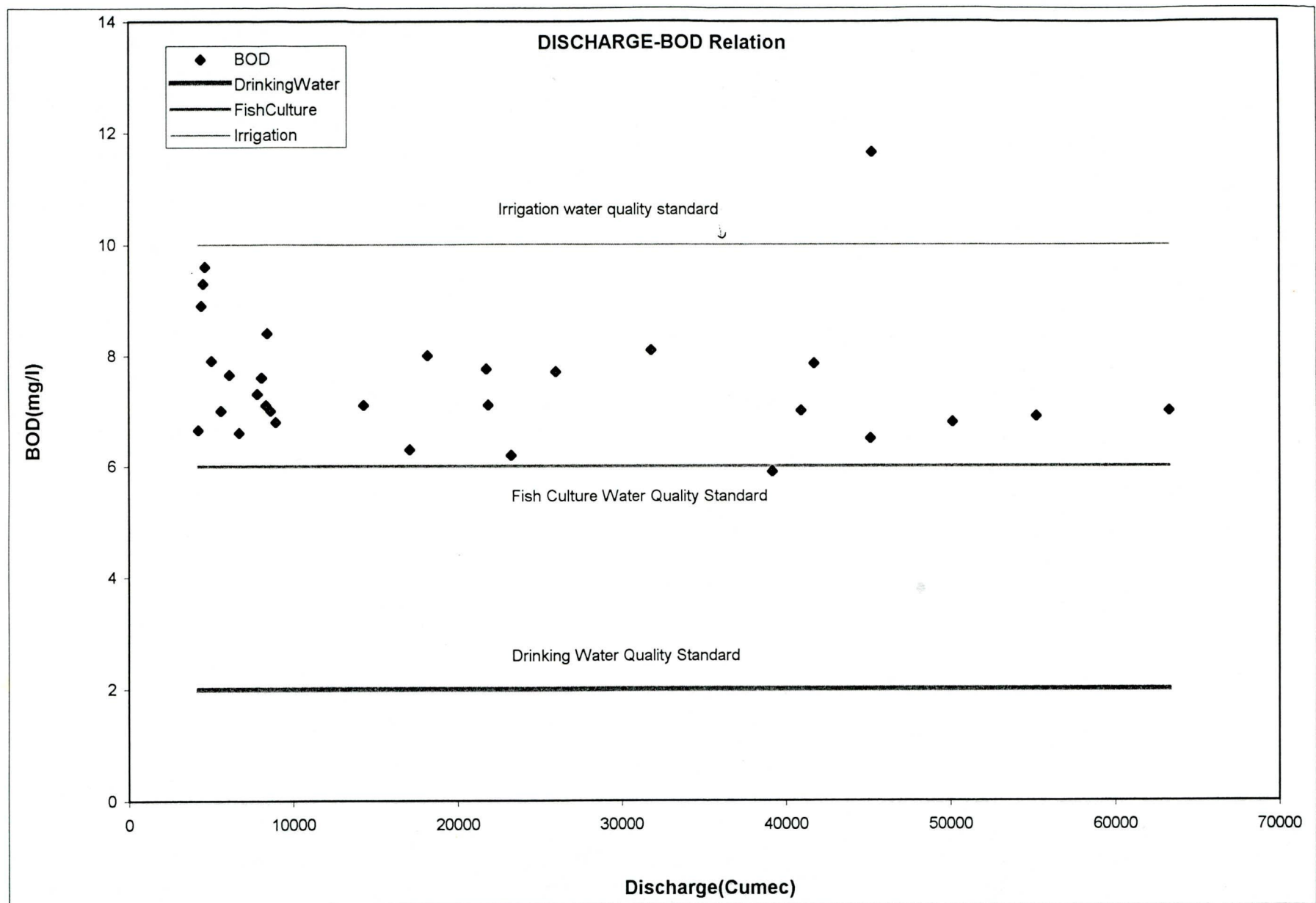


Figure A.2(i): Plot of BOD vs Discharge of Brahmaputra River at Bahadurabad

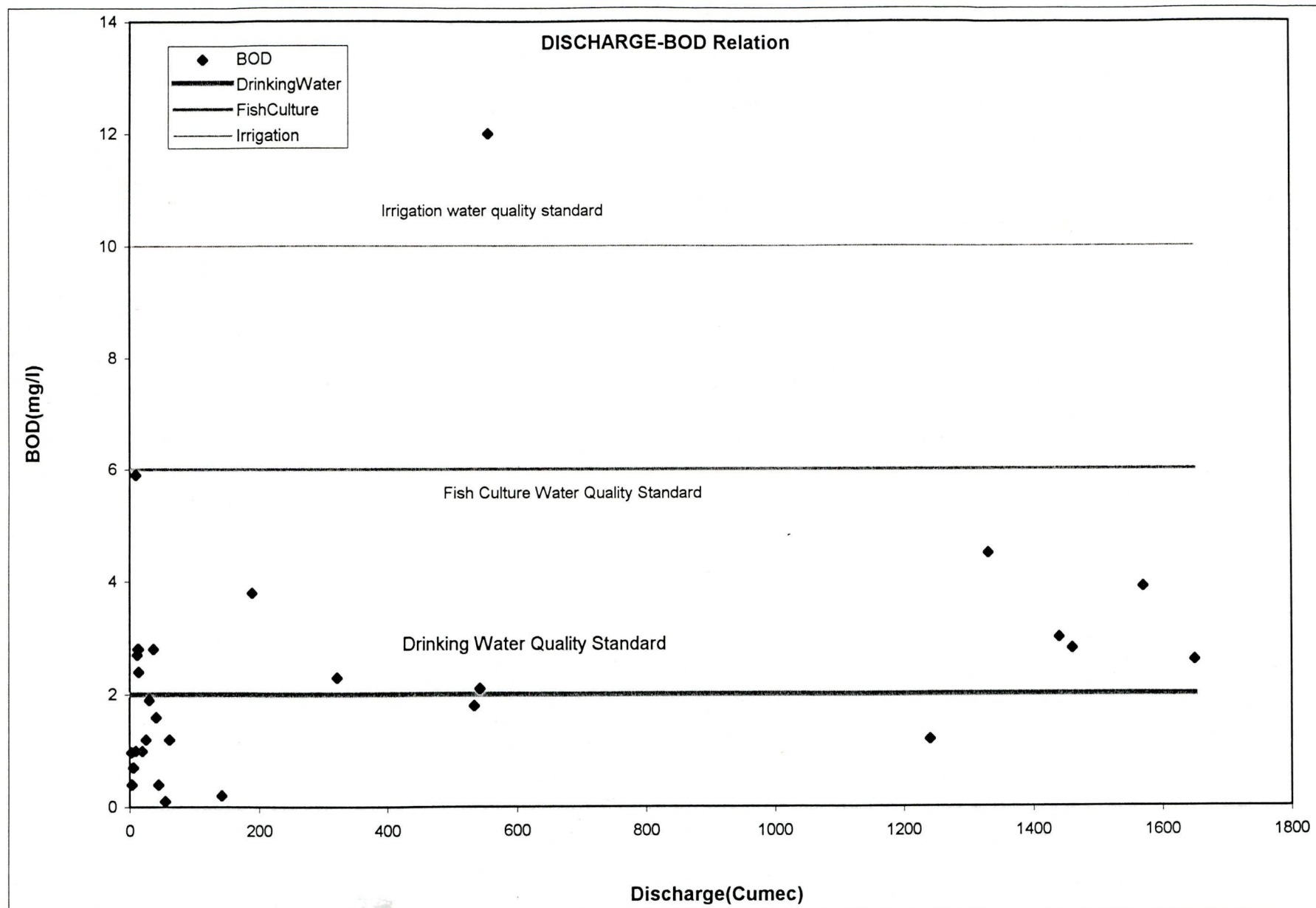


Figure A.2(ii): Plot of BOD vs Discharge of Surma River at Sylhet

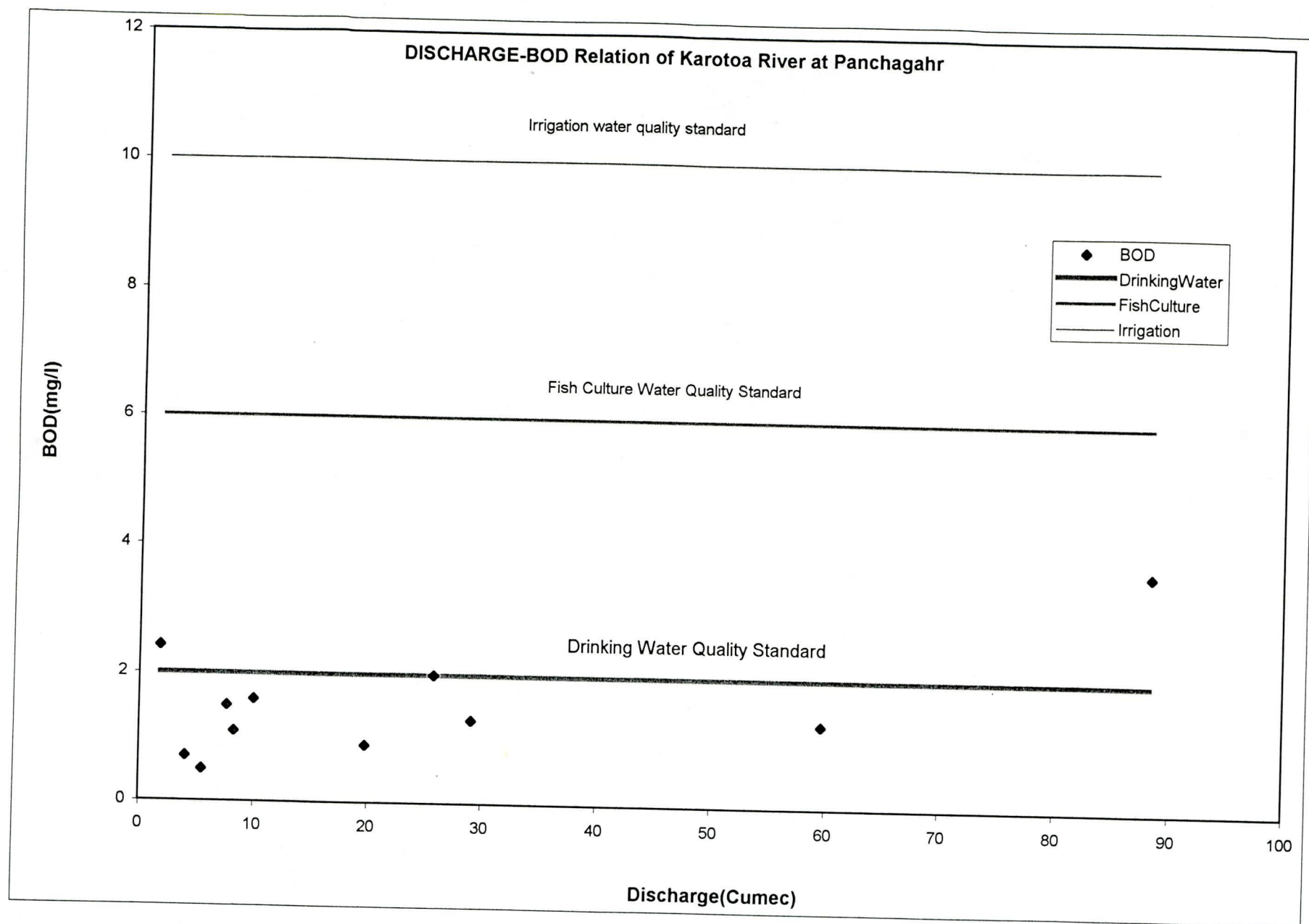


Figure A.2(iii): Plot of BOD vs Discharge of Korotoa River at Panchagahr

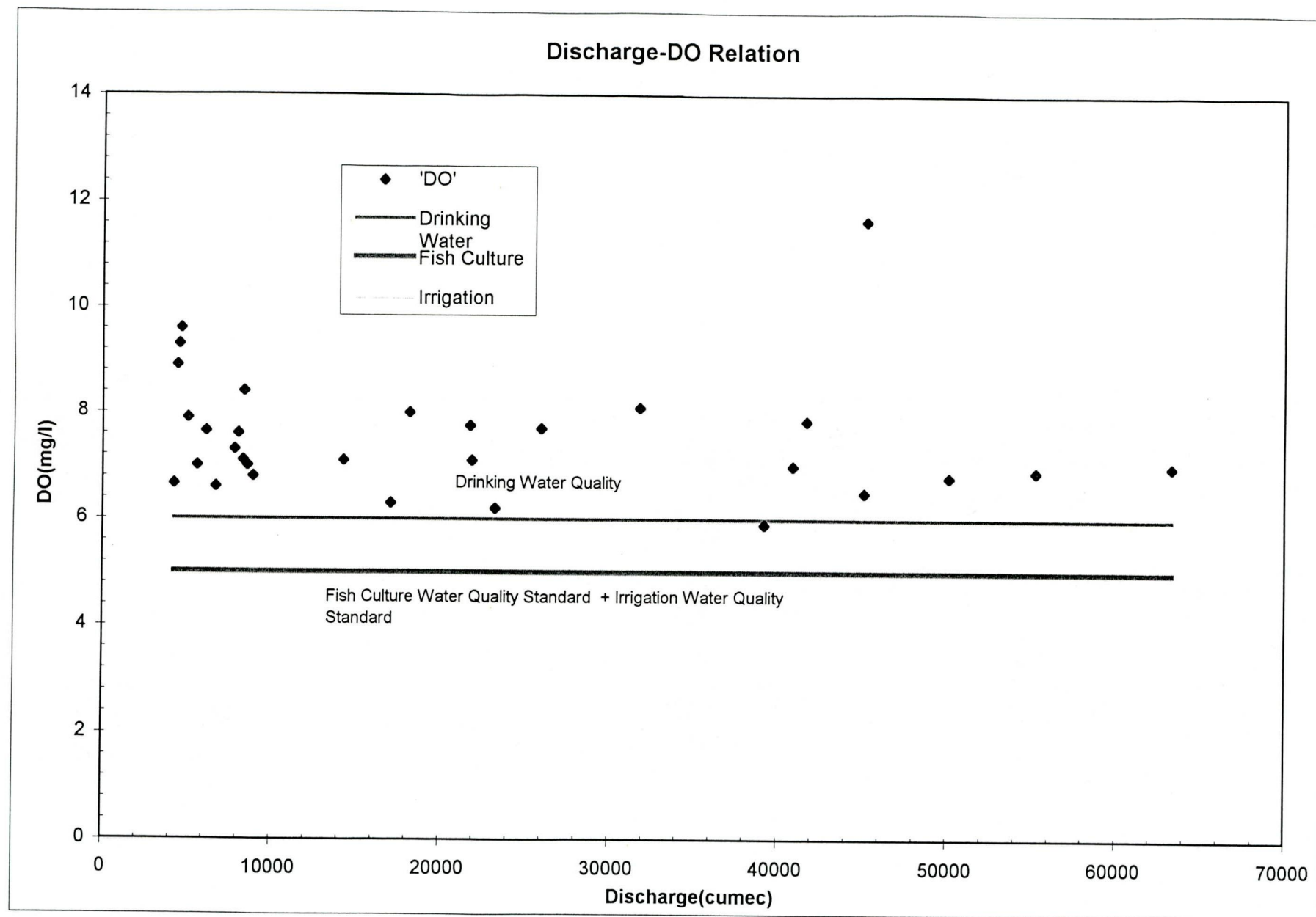


Figure A.2(iv): Plot of DO vs Discharge of Brahmaputra River at Bahadurabad

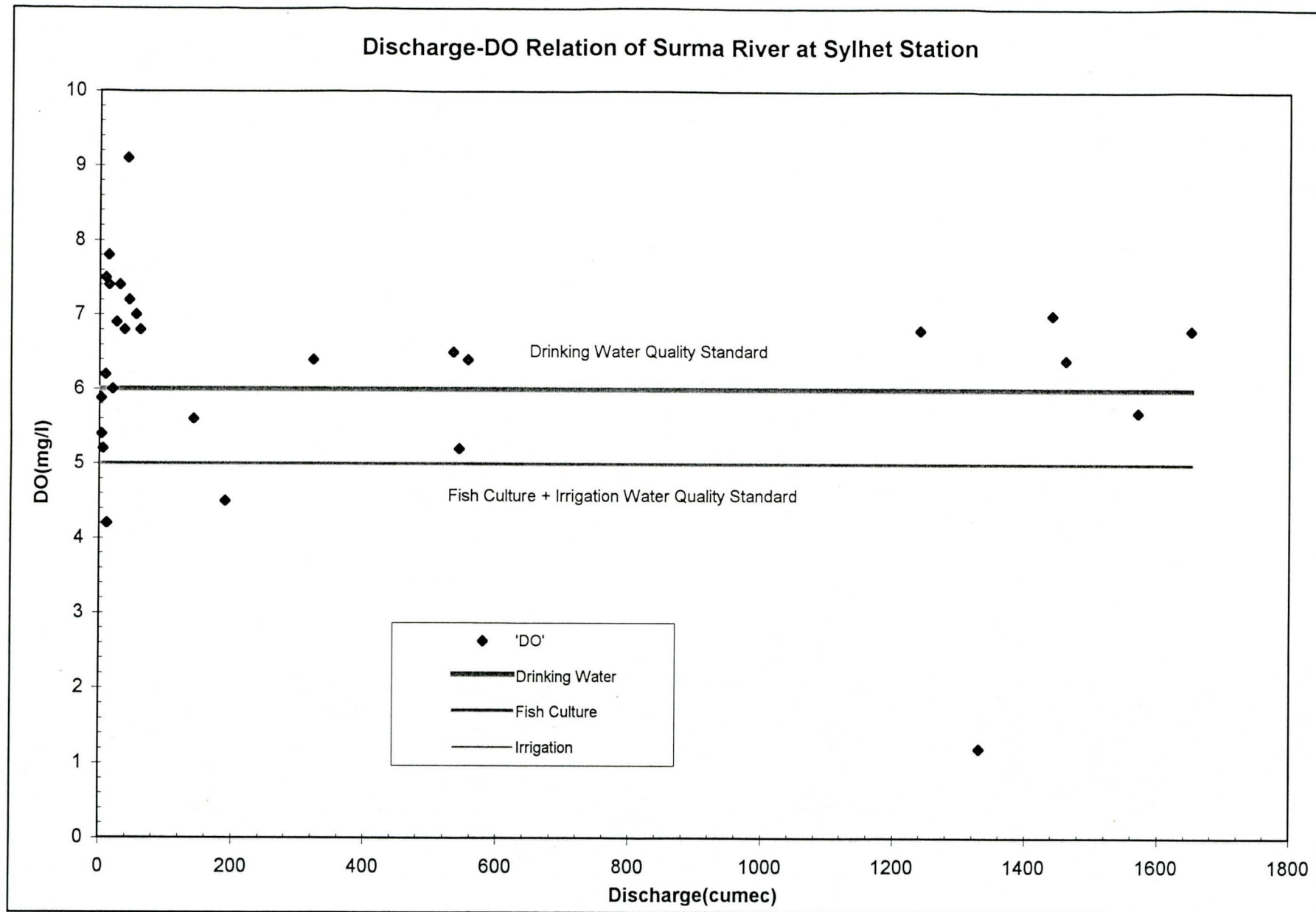


Figure A.2(v): Plot of DO vs Discharge of Surma River at Sylhet

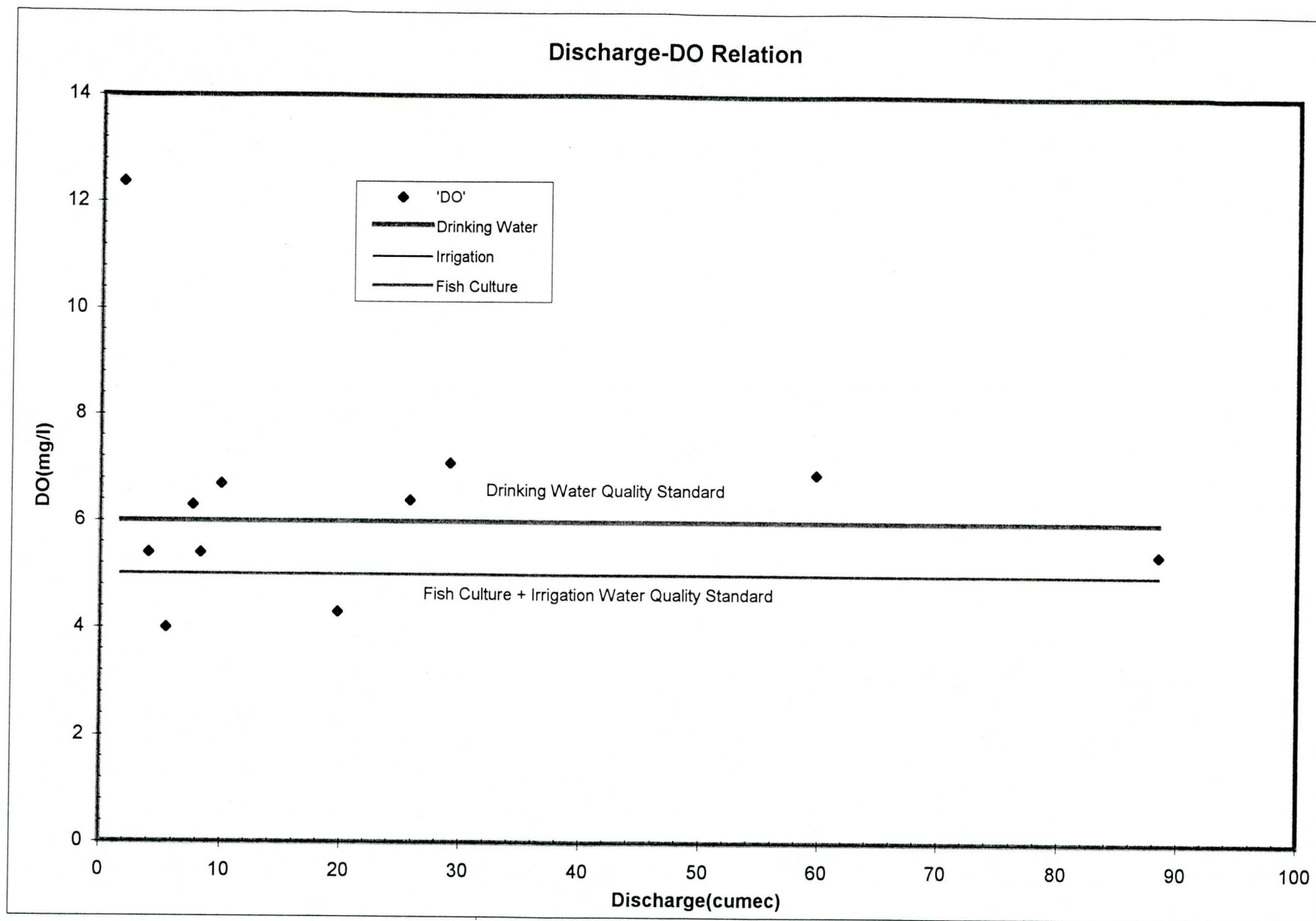


Figure A.2(vi): Plot of DO vs Discharge of Korotoa River at Panchagahr

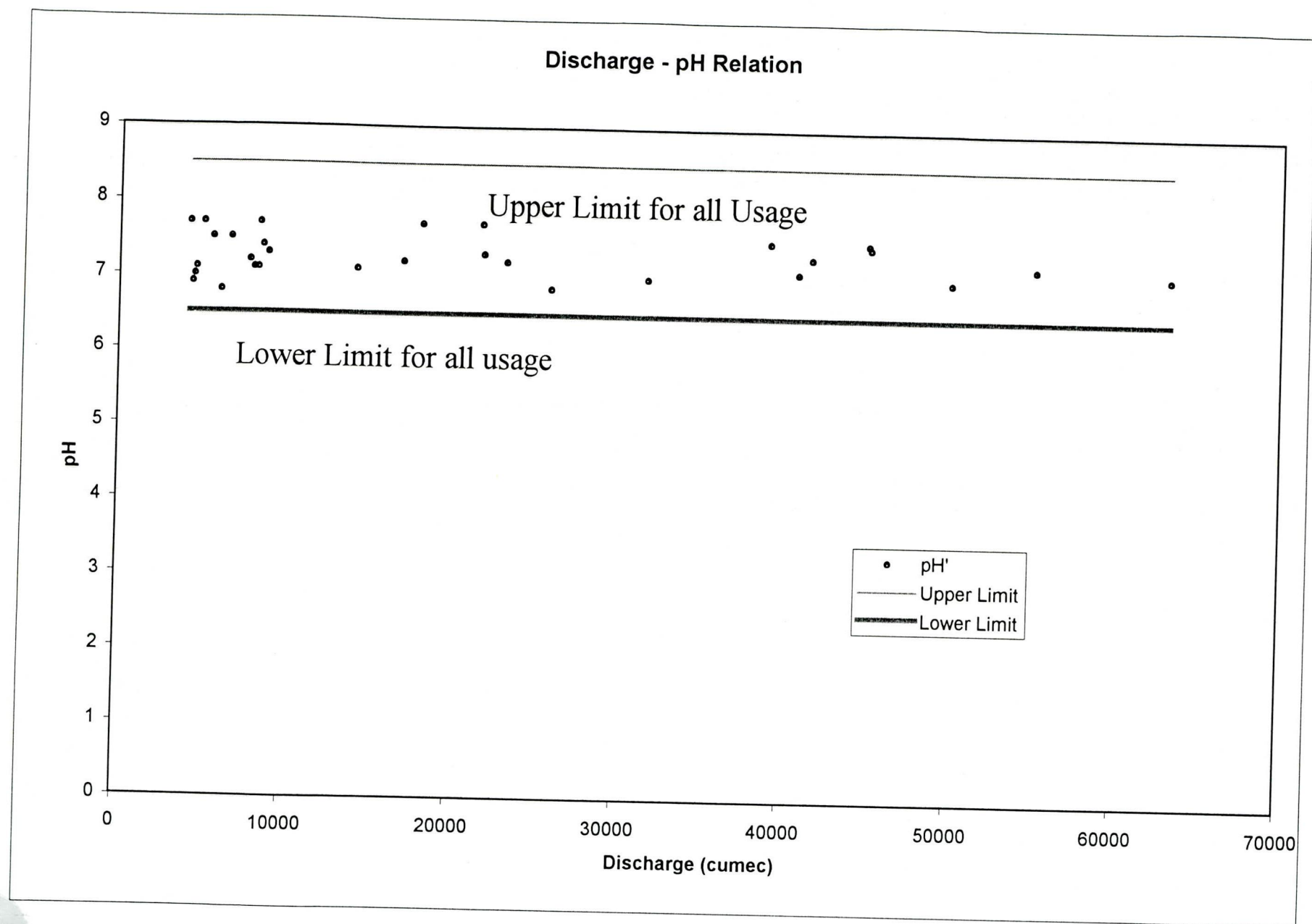


Figure A.2(vii): Plot of pH vs Discharge of Brahmaputra River at Bahadurabad

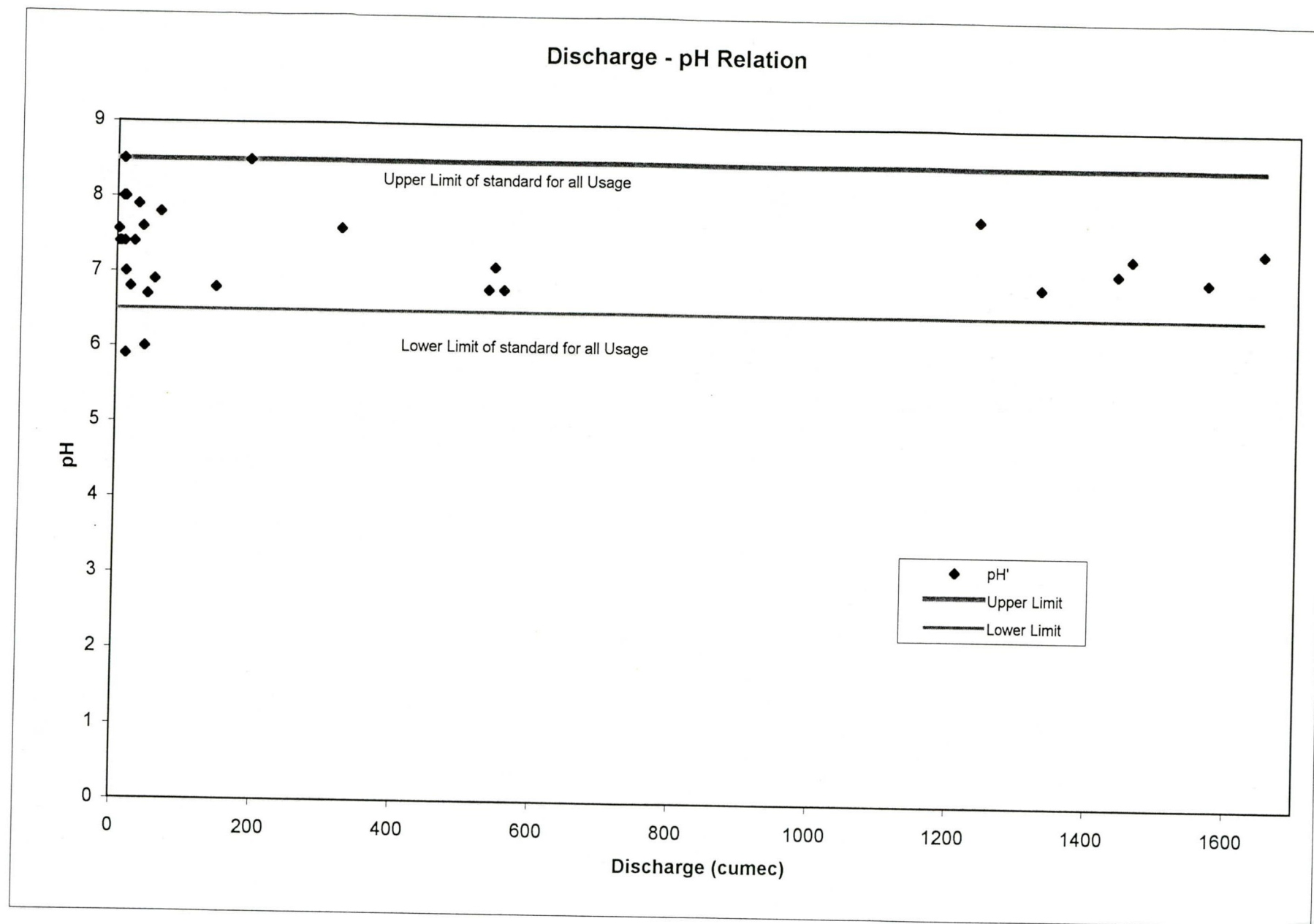


Figure A.2(viii): Plot of pH vs Discharge of Surma River at Sylhet

Discharge - pH Relation

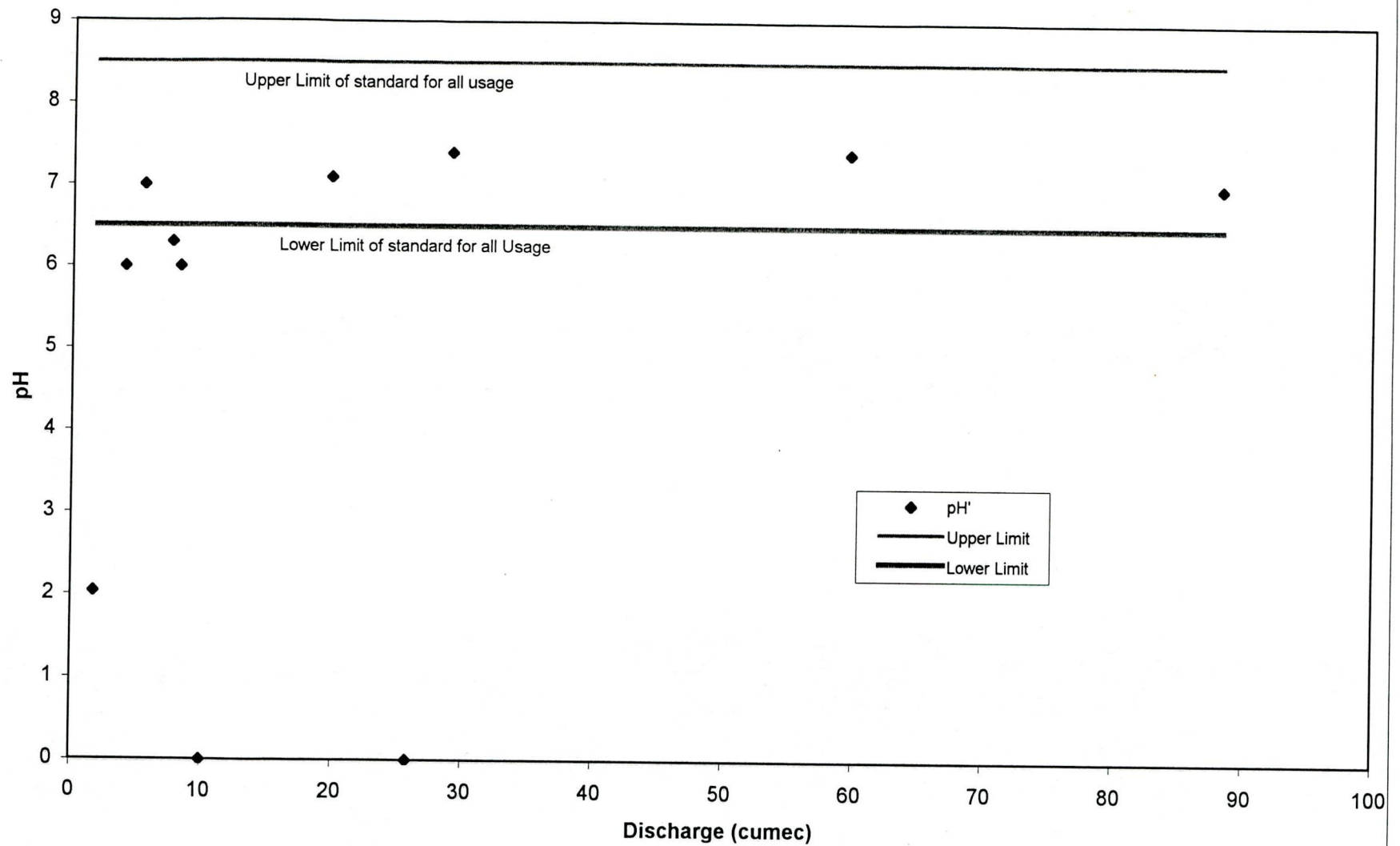


Figure A.2(ix): Plot of pH vs Discharge of Korotoa River at Panchagahr

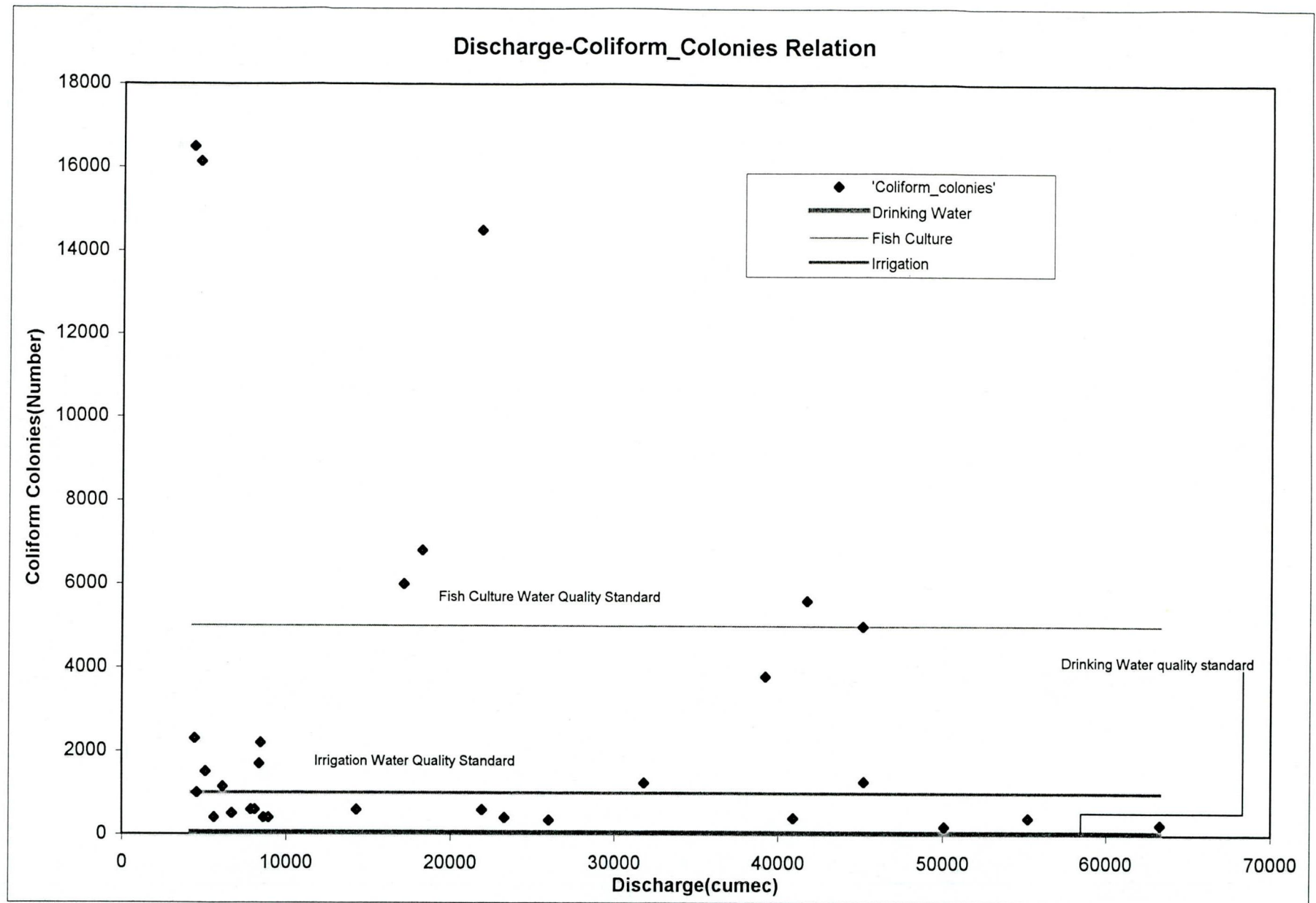


Figure A.2(x): Plot of Total Coliform Colonies Vs Discharge of Brahmaputra River at Bahadurabad

APPENDIX B

TABLES

Table B.1	Water Quality Parameter Concentration for Selected Rivers
Table B.2	Low-flow Series of 1-day, 7-day, and 10-day series on selected Rivers
Table B.3	Basic Statistics of Selected Data Series
Table B.4	Result of Regression Analysis of WQ vs Discharge
Table B.5	Result of Frequency Analysis
Table B.6	Result of Kolmogorov-Smirnov Tests

Table B.1(a): Water Quality Parameter Concentration of Brahmaputra River at Bahadurabad

Date	River flow, m ³ /s	Temp (field), °C	pH (Field)	DO, mg/l	BOD, mg/l	Coli. Colonies, No.
23-Feb-83	4250	24.5	7.7	7.5	1.1	16500
26-Feb-80	4440	74	6.9	8.9	1.8	2300
26-Jan-80	4560	69	7	9.7	2.4	1200
24-Jan-83	4660	30	7.1	9.65	3.85	16500
14-Mar-83	5070	28	7.7	7.9	1.1	1500
23-Feb-89	5620	23	7.5	7	2.5	400
26-Jan-89	6100	25	7.6	7.5	3.1	400
20-Dec-83	6140	21.5	6.9	7.75	1.35	1100
23-Mar-89	6720	27	7.5	6.9	2	600
21-Dec-88	7850	30	7.1	7.3	2.9	600
21-Nov-83	8090	27.5	7.1	7.6	4.35	600
18-Apr-80	8350	82	7.1	7.1	1.5	1700
26-Apr-83	8420	28	7.7	8.4	1.8	2200
27-Dec-90	8620	22	7.5	7.1	1.5	400
16-Apr-89	8950	33	7.4	7	2.2	600
30-Nov-88	14300	25	7.2	7.3	3	600
26-May-80	17100	83.5	7.2	6.3	4.3	6000
06-Jun-83	18200	28	7.7	8	6.1	6800
30-May-83	21800	28	7.7	8.15	2.3	15200
06-Nov-89	21900	27	7.4	7.4	2.5	600
28-May-89	23300	32	7.3	6.4	1.2	400
24-Oct-83	26000	29.5	6.85	7.7	5.2	350
23-Aug-83	31800	29.5	7	8.1	2.35	1250
28-Sep-80	39200	84	7.4	6.5	4.2	3800
25-Jun-89	40900	31	7.3	7.3	1.5	400
26-Jul-83	41700	29	7.3	7.85	3	5600
27-Jul-80	45100	86	7.5	6.4	2.6	4400
26-Sep-83	45200	28.5	7.45	11.65	5.2	1285
19-Aug-90	50100	32	7	7.1	1.6	200
27-Sep-90	55200	31	7.3	7.1	2	400
20-Jul-89	63300	30	7	7.1	1.3	250

Table B.1(b): Water Quality Parameter Concentration of Surma at Sylhet

Date	Flow, m ³ /sec	Temperature °C	PH	DO, mg/l	BOD, mg/l
20-Feb-93	3.88	22	7.3	5.8	1
22-Dec-92	5.96	18	7.5	5.4	1.2
30-Jan-85	9.29	29	6.9	7.5	5.9
17-Nov-92	9.4	20	7.2	7.4	1.4
30-Jan-92	11.6	40	7.6	2.3	85
30-Nov-93	12	28	7.9	4.2	2.8
23-Jan-89	13.5	20	0	7.8	2.4
23-Jan-89	14	20	0	1.9	104
24-Dec-91	19.7	14	7.1	7.2	2.1
19-Oct-92	25.4	32	7.7	6.4	1
21-Mar-92	30.3	28	7.9	7.4	1.9
20-Sep-92	37.3	32	7.9	1.8	16
22-Dec-88	41.5	23	0	9.1	1.6
27-Nov-88	44.8	27	0	7.2	0.4
29-Mar-89	54.9	28	0	7	0.1
27-Jul-92	61.7	29	7.4	7.2	2
26-Apr-92	142	30	7.6	7.6	1.4
29-Mar-85	189	30	0	7.5	4.9
16-Oct-93	322	27	7.1	6.4	2.3
14-Jun-89	534	34	0	0.4	111
30-May-89	543	33	0	0.6	30
25-Oct-91	556	0	6.3	0	140
23-Jul-92	1240	29	7.4	7.2	2
22-Aug-89	1330	37	6.8	0	90
21-Aug-93	1440	28	7.1	7	3
20-Aug-91	1460	35	7.5	1.3	627
27-Aug-93	1570	27	7	5.7	3.9
26-Sep-91	1650	32	7.3	6.8	2.6

Table B.1(c): Water Parameter Concentration of Korotoa River at Panchagahr

Date	River flow, m ³ /s	Temp (field), °C	PH		
			(Field)	DO, mg/l	BOD, mg/l
05-Mar-89	4.04	27.00	7.00	0.60	1.00
15-Jun-88	5.49	27.00	7.00	5.00	0.50
26-May-88	7.67	27.00	7.20	6.50	1.00
20-Apr-88	8.32	25.00	7.30	6.80	1.30
16-Dec-93	10.00	25.00	0.00	6.70	1.60
23-Oct-88	19.80	31.00	7.20	4.50	0.30
06-Oct-93	25.80	29.00	0.00	6.80	1.80
04-Jun-91	29.10	29.00	7.30	7.00	1.20
20-Aug-91	59.70	29.00	7.20	7.10	1.00
08-Aug-88	88.40	32.00	7.00	5.40	1.10

Table B.2 (a): Low-flow (m^3/sec) Data Series of Brahmaputra River at Bahadurabad Station
for Different Averaging Period.

Year\Day	1-day	7-day	10-day
1956	4750.00	4797.14	4816.00
1957	4050.00	4077.14	4077.00
1958	4020.00	4050.00	4062.00
1959	3280.00	3327.14	3349.00
1960	3790.00	3862.86	3862.00
1961	3990.00	4041.43	4041.00
1962	3540.00	3557.14	3561.00
1963	3770.00	3865.71	3876.00
1964	3170.00	3170.00	3173.00
1965	3500.00	3580.00	3580.00
1966	3950.00	4124.29	4285.00
1967	3620.00	3680.00	3698.00
1968	3880.00	3902.86	3911.00
1969	4020.00	4041.43	4053.00
1970	2860.00	3294.29	3317.00
1972	3140.00	3182.86	3199.00
1973	3280.00	3347.14	3415.00
1974	3200.00	3200.00	3211.00
1975	4050.00	4068.57	4084.00
1976	3990.00	4022.86	4040.00
1977	4530.00	4565.71	4590.00
1978	4050.00	4100.00	4152.00
1979	4330.00	4398.57	4429.00
1980	4020.00	4085.71	4114.00
1981	3500.00	3541.43	3564.00
1982	3980.00	4201.43	4214.00
1983	3530.00	3624.29	3674.00
1984	3840.00	3911.43	3932.00
1985	3660.00	3695.71	3732.00
1986	3370.00	3420.00	3439.00
1987	3990.00	4042.86	4084.00
1988	5280.00	5411.43	5495.00
1989	5090.00	5188.57	5284.00
1990	3930.00	4031.43	4089.00
1991	4630.00	4651.43	4670.00
1992	4440.00	4497.14	4555.00
1993	4510.00	4561.43	4581.00
1994	4190.00	4200.00	4208.00
1995	3410.00	3462.86	3478.00

Table B.2 (b): Low-flow (m³/sec) Data Series of Surma River at Station Sylhet
for Different Averaging Period

Year\day	1-day	7-day	10-day
1964	5.60	5.73	5.76
1965	7.08	7.20	7.28
1966	5.21	5.46	5.82
1967	5.21	5.46	5.82
1969	3.20	3.23	3.29
1970	4.05	4.12	4.14
1972	2.77	3.17	3.30
1973	3.06	3.18	3.41
1974	4.22	4.35	4.56
1975	2.63	2.72	3.20
1976	4.22	4.37	4.50
1977	3.40	3.55	3.60
1981	3.50	3.56	3.61
1982	4.27	4.34	4.37
1983	4.22	4.31	4.32
1984	5.37	8.62	8.81
1985	3.53	3.65	3.69
1986	2.68	3.04	3.27
1987	5.35	5.50	5.54
1988	6.23	6.60	6.78
1989	5.79	5.99	6.09
1990	6.43	6.78	6.88
1991	6.06	6.50	6.73
1992	3.57	3.65	3.72
1993	3.11	3.32	3.46

Table B.2 (c): Low-flow (m^3/sec) Data Series of Korotoa River at Station Panchagarh for Different Averaging Period.

Year\day	1-day	7-day	10-day
1964	0.54	0.68	0.71
1965	2.49	2.73	2.83
1966	2.18	2.32	2.39
1967	2.58	2.58	2.74
1968	2.18	2.50	2.54
1969	2.07	2.58	2.70
1970	2.83	3.24	3.26
1972	4.19	4.42	4.52
1973	2.83	2.94	3.02
1974	3.68	3.84	3.96
1975	4.92	4.96	4.99
1976	5.94	6.31	6.45
1977	0.00	0.00	0.00
1978	1.50	1.57	1.65
1979	4.64	5.04	5.13
1980	4.62	4.73	4.78
1981	2.69	2.99	3.16
1982	5.19	5.28	5.31
1983	6.16	6.26	6.31
1984	6.32	6.54	6.62
1986	4.40	4.56	4.62
1987	4.20	4.36	4.39
1988	3.09	3.13	3.23
1989	2.48	2.55	2.57
1990	2.72	3.11	3.23
1991	2.33	2.50	2.59
1992	2.27	2.44	2.52
1993	3.02	3.10	3.12

Table B.3: Summary Statistics of the selected data series

River	Station	Day	year	Statistics for normal data				Statistics for log-domain			
				mean (m ³ /s)	Std Dev. (m ³ /s)	Skewness	Kurtosis	mean (m ³ /s)	Std Dev. (m ³ /s)	Skewness	Kurtosis
Brahmmaputra	Bahadurabad (46_9L)	1-day	37	3831.35	449.78	-0.01	2.79	8.24	0.12	-0.29	2.89
		7-day	37	3896.87	435.01	0.07	2.53	8.26	0.11	-0.14	2.45
		10-day	37	3922.03	439.54	0.06	2.49	8.27	0.11	-0.14	2.43
Surma	Sylhet (267)	1-day	25	4.43	1.31	0.36	2.28	1.45	0.3	-0.01	2.11
		7-day	25	4.74	1.56	0.78	3.14	1.4	0.27	1.29	4.79
		10-day	25	4.88	1.56	0.82	3.13	1.54	0.31	0.43	2.23
Korotoa	Panchagahr (140)	1-day	27	3.41	1.48	0.43	2.82	1.12	0.51	-1.3	6.87
		7-day	27	3.6	1.48	0.42	2.91	1.19	0.48	-1.2	6.41
		10-day	27	3.68	1.48	0.41	2.98	1.21	0.47	-1.23	6.58

Table B.4(a): Summary Output of Regression Analysis of BOD on Flow Of Brahmaputra River at Bahadurabad

Regression Statistics	
Multiple R	0.061
R Square	0.004
Adjusted R Square	-0.031
Standard Error	1.352
Observations	31

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.200	0.200	0.109	0.743
Residual	29	52.974	1.827		
Total	30	53.174			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	2.54229	0.37942	6.70037	0.00000	1.76627	3.31830	1.76627	3.31830
River flow cumec	0.00000	0.00001	0.33066	0.74328	-0.00002	0.00003	-0.00002	0.00003

$m=1$; $n=31(1+1)=29$. $F_{1,29,0.95}=4.2=F_{critical}$

$R=0.061 < 1.0$. $F_{observed}=0.109 < F_{critical}$. So the regression eqn is not useful in predicting BOD

Table B.4(b): Summary Output of Regression Analysis of DO on Flow Of Brahmaputra River at Bahadurabad

<i>Regression Statistics</i>	
Multiple R	0.094
R Square	0.009
Adjusted R Square	-0.025
Standard Error	1.120
Observations	31

ANOVA

	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	0.327	0.327	0.261	0.613
Residual	29	36.350	1.253		
Total	30	36.677			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	7.78954	0.31430	24.78368	0.00000	7.14672	8.43236	7.14672	8.43236
River flow cumec	-0.00001	0.00001	-0.51088	0.61330	-0.00003	0.00002	-0.00003	0.00002

$m=1; n=31(1+1)=29. F_{1,29,0.95}=4.2=F_{critical}$

$R=0.094 \ll 1.0. F_{observed}=0.261 < F_{critical}$. So the regression eqn is not useful in predicting DO

Table B.4(d): Summary Output of Regression Analysis of Total Coliform on Flow of Brahmaputra River at Bahadurabad

Regression Statistics	
Multiple R	0.16127885
R Square	0.02601087
Adjusted R Square	-0.007575
Standard Error	4713.73355
Observations	31

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	17207935.22	17207935	0.774459	0.3860758
Residual	29	644359234.1	22219284		
Total	30	661567169.4			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	3931.64562	1323.3022	2.971087	0.00591	1225.187255	6638.104	1225.18726	6638.10398
River flow cumec	-0.042494	0.04828675	-0.88003	0.386076	-0.14125152	0.056264	-0.14125152	0.05626357

$m=1; n=31(1+1)=29. F_{1,29,0.95}=4.2=F_{critical}$

$R=0.61 < 1.0. F_{observed}=0.774 < F_{critical}$. So the regression eqn is not useful in predicting Total Coliforms

Table B.4(c): Summary Output of Regression Analysis of pH on Flow Of Brahmaputra River at Bahadurabad

Regression Statistics	
Multiple R	0.139
R Square	0.019
Adjusted R Squar	-0.014
Standard Error	0.271
Observations	31

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	0.042	0.042	0.572	0.456
Residual	29	2.123	0.073		
Total	30	2.165			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	pper 95%	Lower 95.0%	Upper 95.0%
Intercept	7.3473713	0.075954076	96.73439	5.9E-38	7.192027688	7.502715	7.19202769	7.502714914
River flow cumec	-2.096E-06	2.77153E-06	-0.75623	0.45561	-7.7643E-06	3.57E-06	-7.7643E-06	3.5725E-06

$m=1$; $n=31-(1+1)=29$. $F_{1,29,0.95}=4.2 = F_{\text{critical}}$

$R=0.139 < 1.0$. $F_{\text{observed}} = 0.572 < F_{\text{critical}}$. So the regression eqn is not useful in pridicting pH.

Table B.5(a): Computed Low Flow Values in m³/sec Using Gumbel Distribution

River and Station	Low-flow series	Return period (Year)		
		1.575	10	25
Brahmmaputra at Bahadurabad	1-day	4036	3245	2912
	7-day	4095	3330	3008
	10-day	4122	3349	3024
Surma at Sylhet	1-day	5.03	2.72	1.76
	7-day	5.45	2.70	1.55
	10-day	5.59	2.84	1.68
Korotoa at Panchagahr	1-day	4.04	1.00	0
	7-day	4.23	1.18	0
	10-day	4.31	1.26	0

Table B.5(b): Computed Low Flow Values in m³/sec Using Log-Gumbel Distribution

River and Station	Low-flow series	Return period (Year)		
		1.575	10	25
Brahmmaputra at Bahadurabad	1-day	4018	3258	2983
	7-day	4077	3345	3078
	10-day	4104	3364	3095
Surma at Sylhet	1-day	4.87	2.88	2.31
	7-day	5.21	2.98	2.36
	10-day	5.35	3.13	2.50
Korotoa at Panchagahr	1-day	3.87	1.56	1.07
	7-day	4.07	1.75	1.23
	10-day	4.16	1.82	1.29

Table B.5(c): Computed Low Flow Values in m³/sec Using LP3 Distribution

River and Station	Low-flow series	Return period (Year)		
		1.575	10	25
Brahmmaputra at Bahadurabad	1-day	3996	2978	2868
	7-day	4048	3102	2999
	10-day	4076	3117	3013
Surma at Sylhet	1-day	4.76	2.41	2.21
	7-day	5.02	2.61	2.41
	10-day	5.15	2.81	2.61
Korotoa at Panchagahr	1-day	3.89	0.72	0.69
	7-day	4.08	0.87	0.71
	10-day	4.17	0.91	0.74

Table B.5(d): Computed Low Flow Values in m³/sec Using Weibull Distribution

River and Station	Low-flow series	Return period (Year)		
		1.575	10	25
Brahmmaputra at Bahadurabad	1-day	3995	3221	3014
	7-day	4050	3327	3143
	10-day	4078	3344	3156
Surma at Sylhet	1-day	4.83	2.77	2.33
	7-day	5.09	2.88	2.52
	10-day	5.22	3.04	2.69
Korotoa at Panchagahr	1-day	3.78	1.22	0.38
	7-day	3.98	1.30	0.41
	10-day	4.05	1.34	0.42

Table B.6(a): Kolmogorov-Smirnov Test Result Using Gumbel Distribution

River and Station	Low-flow series	$D_{\max}$	D_{critical}	Accepted at Sig level 0.1
Brahmaputra at Bahadurabad	1-day	0.14	0.20	Yes
	7-day	0.10	0.20	Yes
	10-day	0.10	0.20	Yes
Surma at Sylhet	1-day	0.20	0.24	Yes
	7-day	0.43	0.24	No
	10-day	0.23	0.24	Yes
Korotoa at Panchagahr	1-day	0.23	0.23	Yes
	7-day	0.24	0.23	No
	10-day	0.25	0.23	No

Table B.6(b): Kolmogorov-Smirnov Test Result Using Log-Gumbel Distribution

River and Station	Low-flow series	$D_{\max}$	D_{critical}	Accepted at Sig level 0.1
Brahmaputra at Bahadurabad	1-day	0.12	0.20	Yes
	7-day	0.9	0.20	Yes
	10-day	0.10	0.20	Yes
Surma at Sylhet	1-day	0.15	0.24	Yes
	7-day	0.29	0.24	No
	10-day	0.19	0.24	Yes
Korotoa at Panchagahr	1-day	0.13	0.23	Yes
	7-day	0.15	0.23	Yes
	10-day	0.17	0.23	Yes

Table B.6(c): Kolmogorov-Smirnov Test Result Using LP3 Distribution

River and Station	Low-flow series	$D_{\max}$	D_{critical}	Accepted at Sig level 0.1
Brahmaputra at Bahadurabad	1-day	0.13	0.20	Yes
	7-day	0.11	0.20	Yes
	10-day	0.10	0.20	Yes
Surma at Sylhet	1-day	0.13	0.24	Yes
	7-day	0.15	0.24	No
	10-day	0.17	0.24	Yes
Korotoa at Panchagahr	1-day	0.25	0.23	No
	7-day	0.26	0.23	No
	10-day	0.26	0.23	No

Table B.6(d): Kolmogorov-Smirnov Test Result Using Weibull Distribution

River and Station	Low-flow series	$D_{\max}$	D_{critical}	Accepted at Sig level 0.1
Brahmaputra at Bahadurabad	1-day	0.11	0.20	Yes
	7-day	0.11	0.20	Yes
	10-day	0.10	0.20	Yes
Surma at Sylhet	1-day	0.11	0.24	Yes
	7-day	0.30	0.24	No
	10-day	0.12	0.24	Yes
Korotoa at Panchagahr	1-day	0.12	0.23	Yes
	7-day	0.13	0.23	Yes
	10-day	0.13	0.23	Yes

