ANALYSIS OF DAILY RAINFALL AND RUNOFF DATA OF SERANG RIVER BASIN, INDONESIA

A DISSERTATION

Submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
HYDROLOGY

By

SUTJIPTO

UNESCO SPONSORED
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DECEMBER, 1993

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled "ANALYSIS OF DAILY RAINFALL AND RUNOFF DATA OF SERANG RIVER BASIN, INDONESIA" in partial fulfilment of the requirement for the award of the Degree of Master of Engineering in Hydrology, submitted in the Department of Hydrology, University of Roorkee, is an authentic record of my work carried out during a period from July 17, 1993 to December 14, 1993 under the supervision of Dr. N.K. Goel, Reader Department of Hydrology University of Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

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Candidate's Signature

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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(Sutjipto)

Roorkee, December 14, 1993

SYNOPSIS

Linear Perturbation Model (LPM) is a simple and versatile technique used to extend the runoff record using rainfall data.

Model developed by Nash and Barsi (1983) for flow forecasting on larger catchment considering the relatively regular seasonal variation of potential evaporation has been studied in detail utilizing the daily rainfall runoff data of 10 raingauge stations and 3 discharge sites of Serang river basin, Indonesia.

The specific objectives of the study are as follow :

1. Processing of the daily rainfall and runoff data of Serang basin, Indonesia.
2. To develop/understand the methodology of linear perturbation model.
3. To evaluate the performance of linear perturbation model and compare it with the performance of single input total response linear model in calibration and validation mode.
4. To study the effect of number of error terms on efficiency of the model
5. To study the periodic structure of the daily time series of rainfall and runoff data using harmonic analysis.
6. And finally to suggest the rainfall runoff model parameters which can be used to extend the runoff records of three sites of Serang basin.

Based on the analysis of data and application of models, the following conclusions can be drawn.

1. The increase in memory length, increases the efficiency of linear perturbation model. For the three sites the following memory lengths may be taken.

   a. Lusi at Kunduran 3 days

   b. Lusi at Menduran 4 days

   c. Serang at Tongpait 5 days

2. For the three sites, two number of error terms in error model are significant. The increase in number of term will, though increase the efficiency, yet increase is not significant.

3. The number of significant harmonics to smoothen the mean daily discharge and rainfall series are (runoff = 17 and rainfall = 63) for Lusi at Kunduran, (runoff = 8 an rainfall = 38) for Lusi at Menduran, and (runoff = 2 and rainfall = 36) for Serang at Tongpait.

4. The linear perturbation model may be applied to other sites of other river basins on the similar lines. The performance of linear perturbation model is quite satisfactory for a basin, where seasonality is not very strong and drainage areas are also relatively small.

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CHAPTER - I

INTRODUCTION

1.1 General

Water Resources Projects are of major importance due to great demand of power, irrigation needs, and flood control. To design and plan these projects, emphasis is being given on proper collection of hydrologic data. Nevertheless due to different considerations governing the location of discharge gauging station and projects sites, it is seldom that the information on runoff data is available at the point of interest for a good length of time. Thus quite often one is confronted with the problem of analysing and designing water resource projects with inadequate data. Under the circumstances, planners and engineers have to rely on tools such as synthesis and simulation of runoff data with the help of long term rainfall data. Simulation techniques use rainfall runoff models of varying degrees of complexity to generate synthetic discharges.

In literature, many rainfall-runoff models have been proposed. In the present work hybrid model (Linear Perturbation Model) proposed by Nash and Barsi (1983) has been studied in detail utilizing the daily rainfall data of 10 raingauge stationsand 3 discharge sites of Serang river basin, Indonesia.

1.2 Chapterization of the Dissertation

A brief review of rainfall runoff models is presented in Chapter II. Chapter III gives the details of study area, availability of data and statement of the problem.

Chapter IV of the dissertation presents the methodology of linear perturbation model in detail. Application of linear perturbation model and evaluation of its performance is presented in Chapter V. Chapter VI gives the conclusions of the study.

CHAPTER II

REVIEW OF LITERATURE

2.1 Rainfall-Runoff Process and Models

The origin of rainfall-runoff modeling, in the broad sense, can be found in the second half of 19th Century when the engineers were confronted with the problems relating to urban areas, drainage of basins and river training works. According to Dooge (1957, 1973), during the last part of 19th Century and earlier part of 20th Century, most of the engineers used the empirical formulae or rational method. These approaches were mainly confined to small and mountainous watersheds and during 1920s, however, these were attemptedly extended to larger catchments.

As a modification to it, the concept of isochrones (i.e. lines of equal travel time) was developed. It can be seen as the first rainfall-runoff model based on a transfer function.

The nature of engineering problems being tackled continued to be the same during 1930's, however, the Task Committee, set up by the Boston Society of Civil Engineers (1930) realized that it is not the peak discharge, but rather estimation of a time distribution of the runoff that should be the prime concern of hydrologists. It was Sherman (1932) who introduced the concept of Unit Hydrograph based on the principle of superposition. In spite of its limitations, it proved to be a powerful tool in predicting the overall shape of hydrographs due to complex rainfall functions. As a refinement to it, subsequently,the mathematical concept of Instantaneous Unit Hydrograph (IUH) was propounded. With the advent of computers in 1950's, various hypothetical/mathematical functions which were known earlier but could not be applied, were introduced.Many of such techniques, though satisfactory from the mathematical and philosophical point of view, lost more and more of their connection with the real world hydrological problems, and became more or less mathematical games played by mathematicians concerned only to prove the generality of their approach.

The subsequent era saw the development of so many hydrological models that it became increasingly difficult to keep a track on them. This necessitated the need to develop some broad classifications in order to find a path among the plethora of different rainfall-runoff models available today. Some such attempts have been made by Amorocho and Hart (1964), Dooge (1973), Todini (1988), Franchini and Pacciani (1991) and others.

2.1.1 Classification of Rainfall-Runoff Models

Rainfall runoff models can broadly be classified into two main categories viz. the deterministic models and the stochastic models. The stochastic models are generally avoided for rainfall-runoff modeling, or used only when dealing with time increments longer than the system dynamics (for instance monthly time increments, Todini,1988). A broad classification of deterministic models can be as under (Todini, 1988).

(i) Lumped integral models.

(ii) Distributed integral models.

(iii) Distributed differential models.

A model is said to be lumped if spatial variation in parameter values is not considered. In case of distributed models, the transfer function and parameters vary with respect to space.

(a) Lumped integral models

Most of the purpose oriented, event based models,belong to the category of lumped integral models. Generally, these are linear and make use of the principle of superposition. Hydrologic models proposed by Clark (1945), Nash (1957), Dooge (1959), Singh (1962) and Kulandaiswamy (1964), etc. belong to this category.

The objective of these models remained primarily to develop an Instantaneous Unit Hydrograph (IUH) or a Unit Hydrograph (UH).

(b) Distributed integral models

In lumped integral models, the system dynamics is represented in integral form and is related to a catchment or sub catchment as a whole, by considering its overall behavior.

In this category, various hydrologic simulation models of continuous category are included.A continuous watershed model is one that operates over an extended period of time, determining flow rates and conditions during both runoff periods and periods of no surface runoff. Thus, the model keeps a continuous account of the basin moisture condition and, therefore, determines the initial conditions applicable to runoff events. Thus, the continuous watershed models represent a major part of the hydrologic cycle to account for the surface as well as sub-surface flows of a watershed.

(c) Distributed differential models

In this category, models represent the catchment behavior in terms of all the differential equations discretised in time and space, expressing mass and momentum balance for each sub-system and linking together the sub-systems by matching at each step in time their mutual boundary conditions. One typical example of such type of model is the SHE-Model.

General applicability of such models gets considerably reduced due to large data requirement and difficulties being faced in integration of various links.

Following other criteria, the models may also be classified as (i) linear models or nonlinear models, (ii) time invariant or time variant models and (iii) event based models or continuous models.

Keeping in view scope of the present study, brief description of available models, which will be of interest, is presented in the following section.

2.2 Available Models

Different models belonging to the above-mentioned categorization, which may be of utility for the present study,are described under the following two heads.

(i) Event based simulation models.

(ii) Continuous simulation models.

2.2.1 Event based simulation models

Event based models may further be classified as lumped models and distributed parameters model, depending upon neither spatial distribution of parameters is neglected or taken into account. Some of the widely used models in each category is listed below.

Lumped Models Linear

1. Single, reservoir model
2. Nash model (1957)
3. Clark's model (1945)
4. Dooge's model (1959)
5. Kulandai Swamy's model (1964)

Distributed Models

1. Linear reservoir and Linear channel models
2. Kinematic wave theory based models.

Details of these model can be found in Singh (1989) and Mathur et al (1989).

2.2.2 Continuous simulation models

As discussed earlier, watershed models belonging to this category simulate a large part of hydrologic cycle. Some of the popular and well known watershed models of this category are as under :

(i) Stanford Watershed Model (SWM) and its modified versions such as Kentucky watershed model (KWM) and Optimal Set (OPSET) Parameter Models.

(ii) USDA HL-series Watershed Hydrology models

(iii) SCS - 20 Watershed Model

(iv) Stream-flow Synthesis and Reservoir Regulation (SSARR) Model.

(v) Hydrologic Engineering Centre (HEC) Models.

(vi) U.S.National Weather Service Hydrologic Model (NWSH).

(vii) Sacramento River Forecast Centre Hydrologic Model (SRFCH).

(viii) Texas Watershed Model.

(ix) Swedish Models - SHE Model (Systeme Hydrologique European).

Clarke(1973), Fleming(1975) and Singh(1989) have presented excellent reviews of different stream flow simulation models.

2.3 Brief about adopted model

Nash and Barsi(1983) developed a hybrid model (linear perturbation model) for flow forecasting on large catchments.

The hybrid model or linear perturbation model is simply a transfer function between perturbations/deviations of rainfall and perturbations/deviation of runoff on continuous time basis. The model avoids seperation of baseflow and excess rainfall. The model inputs are only rainfall and runoff data. This model has been applied on some of the data of W.M.O. Intercomparision, and has given better results than other models such as SSARR model. Permana (1989) also used this model for forecasting of stream flow on Negara River Basin (Indonesia) with a high degree of performance.

Hydrologic modelling is quite complex and models which require different kind of data in large quantity are difficult to apply in developing countries where these data are generally not available. Therefore, in this dissertation the hybrid model (linear perturbation model) has been used, due to following considerations.

i) The model structure is simple.

ii) Input data of only rainfall and runoff is needed.

iii) The model has given good performance for larger catchments.

iv) The required data for the model was readily available.

The linear perturbation model is explained in detail in chapter IV.

In next chapter, details of study area, data used and objectives of the study are explained.

CHAPTER - III

STUDY AREA AND DATA USED

3.1 Study Area

The study area (Serang Basin) is situated in the north-east part of the Central Java Province - Indonesia. It extends from $6^{o}42'$ to $7^{o}29'$ South latitude and from $110^{o}26'$ to $111^{o}32'$ East longitude. It occupies four districts namely Kabupaten Kudus in the north, Kabupaten Grobogan in the middle part, Kabupaten Boyolali in the South part, and Kabupaten Blora in the east part. It is about 50 km eastern Semarang, the capital city of Central Java Province.

The catchment area of Serang basin is about 3,350.2 km^2 in the Central Java Province-Republic of Indonesia. In this dissertation only a part of the catchment, consisting of 2,531.6 km^2 is considered. The map of the catchment area upto Tongpait gauging site is shown in Fig.3.1.

3.1.1 Topography

The study area consist of coastal area, alluvial plain, and the hilly and mountainous area. The Serang basin consists of two sub basins, that is Serang sub basin in the south west part, and Lusi sub basin in east part. The average slope of Serang sub basin is steeper than Lusi sub basin. The maximum elevation of Serang sub basin in about 3000 m(Merbabu

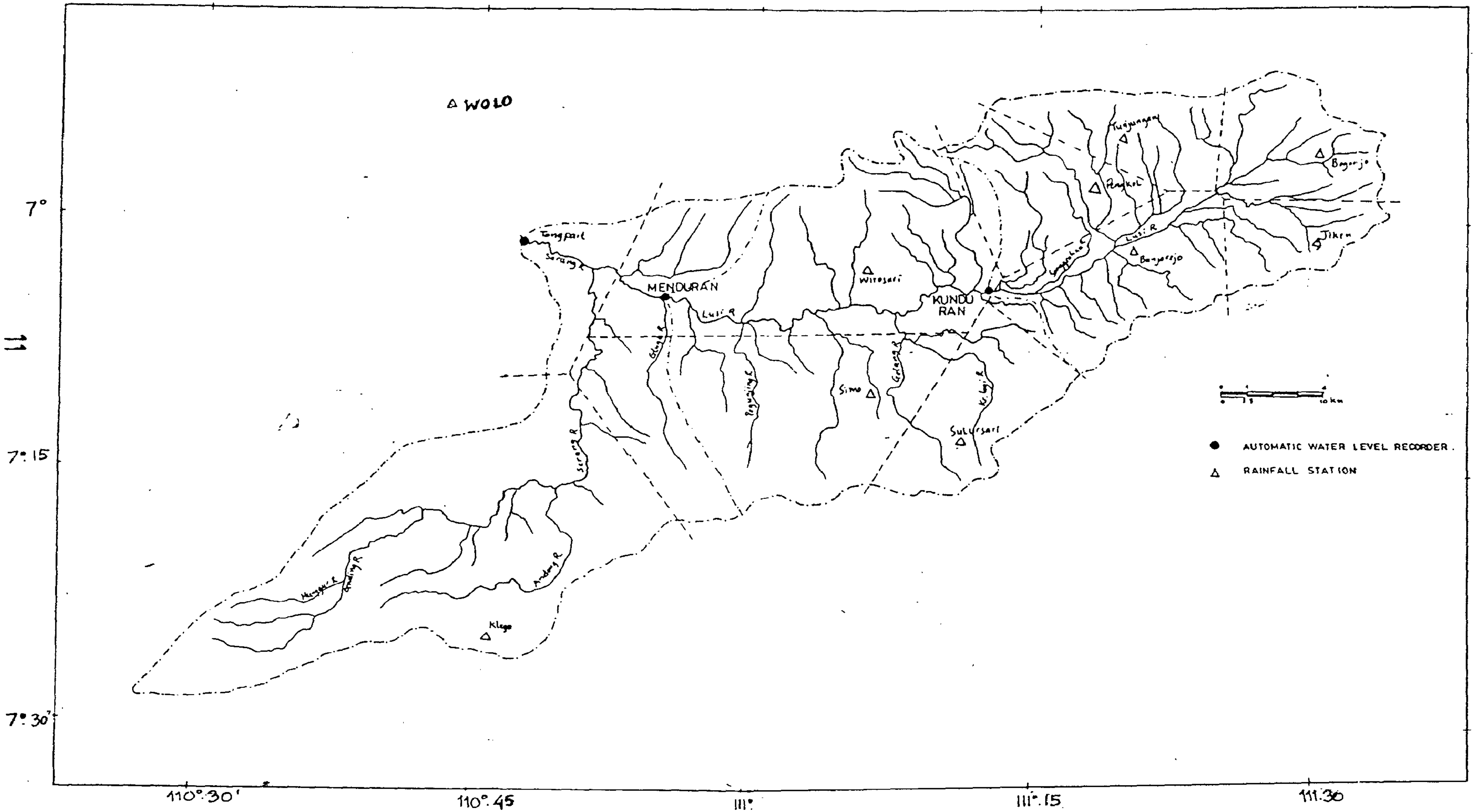

Fig. 3.1. Map of catchment and Thiessen Polygon

mountain), while the maximum elevation of Lusi sub basin is only about 400 m.

3.1.2 Climate

The climate of the Serang sub basin is characterized by typical monsoon climate. Heavy rainfall occurs during the north west monsoon (November to May). June to October is dry season, however some rainfall occurs due to south east monsoon during this period.

Rainfall : Average annual rainfall (10 stations) in the study area varies from 3000 to 4000 mm in the mountainous area (Merbabu and Muria mountain). The rainfall in large part (85 %) of the study area (plain area) varies from 1500 to 2000 mm.

Temperature : The monthly mean air temperature of Serang basin also varies from 15-20^{o}C in mountainous area and 25-30^{o}C in plain area.

Evaporation : The monthly mean evaporation measured by class A pan at 3 stations (Rembang, Semarang, and Blora) varies from 2.65 to 5.42 mm/day and the annual mean evaporation is 3.95 mm/day. The monthly evaporation data for the three stations are given in Table 3.1.

3.2.2 Daily runoff data

The research Institute for Water Resources Development also provided daily runoff data for Serang basin. This data is available at 3 gauging sites. The fluctuation of water level at each gauging site has been monitored and recorded by installing the automatic water level recorder. Digitizer is used to calculate the mean daily water level from the water level charts. Discharge measurements were done regularly to prepare the rating curves for the whole year. The availability of the runoff data for the 3 stations is given in Table 3.3.

Table 3.3 : The length of record for 3 stream flow gauging stations.

S.No.	Name of stream and flow gauging station	Catchment Area (km^2)	Years of Record
1.	Lusi-Kunduran	734.5	1979-1984, 1990
2.	Lusi-Menduran	1830.8	1975-1977, 1980-1986, 1990
3.	Serang-Tongpait	2531.6	1973-1982, 1989-1990

Same computer programme as used for rainfall data has been used to read and write the runoff data.

3.3 Processing of Rainfall and Runoff Data

3.3.1 Processing of Rainfall Data

Processing of rainfall data mainly included the following

(i) rewriting the data in desired format

(ii) gap filling

(iii) Computation of mean areal rainfall

Rewriting the data in desired format :

As already explained in previous section, programme rainfall.f was developed and used for this purpose.

Gap filling :

The rainfall data had many gaps. Using distance power method these gaps were filled up. The computer programme power. f was developed for this purpose. The same is given in Appendix-II.

Computation of mean areal rainfall

Rainfall observation from gauge are point measurements. It is well known fact that the rainfall process exhibits appreciable spatial and temporal variation. For the proper representation of spatial and temporal distribution of rainfall, there should be an adequate network of raingauge stations distributed uniformly over the whole catchment. Further, an accurate assessment of mean areal rainfall over the catchment is a prerequisite and basic input to the model selected for the study.

In this study, the mean areal rainfall is computed using Thiessen Polygon method which is one of the popular and versatile methods available for the estimation of mean areal rainfall. The Thiessen polygon map prepared for the study area based on the ten raingauge stations is shown in Fig.3.1.

A computer programme (rbar.f) is developed for computing the mean areal rainfall using Thiessen polygon method. The same is given in Appendix-III.

Using this programme basin average rainfall (daily) were computed for Lusi sub basin upto Kundurun, Lusi sub basin upto Mendurun and Serang basin upto Tongpait.

3.3.2 Processing of runoff data

Stream flow data form one of the important inputs to the model for its calibration and validation. In this study the availability of data is given in Table 3.3. All these data are observed and processed by Experimental station for Hydrology, Research Institute for Water Resources Development Bandung-Indonesia.

During that period, the data were missing for few days. In order to fill up the missing flow values, the hydrograph of average daily flow is plotted along with average daily rainfall. Then the missing flow values are interpolated from the hydrograph maintaining the consistency in the rainfall runoff observed in the previous and following years for the respective days, even though there are always errors associated with interpolated flow values affecting the calibration and validation of the model. More over the number of missing data mountain), while the maximum elevation of Lusi sub basin is only about 400 m.

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The climate of the Serang sub basin is characterized by typical monsoon climate. Heavy rainfall occurs during the north west monsoon (November to May). June to October is dry season, however some rainfall occurs due to south east monsoon during this period.

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Table 3.1 : Monthly Evaporation Data for Rembang, Semarang and Blora.

Month	Monthly Evaporation in mm for :		
	Rembang	Semarang	Blora
January	4.50	3.59	3.51
February	3.76	3.59	3.63
March	2.82	3.46	4.06
April	2.65	3.49	4.03
May	3.49	3.67	3.76
June	3.09	3.67	3.23
July	3.47	4.14	4.88
August	4.17	4.67	5.42
September	4.35	4.92	5.99
October	6.41	4.85	5.41
November	6.37	4.44	4.75
December	3.53	3.11	3.77

3.2 Data Availability

3.2.1 Rainfall data

The meteorological and Geophysical Agency, Ministry of Transportation, Indonesia and the Research Institute of Water Resources Development (Ministry of Public Works), Bandung, West Java, Indonesia has installed a number of standard and recording type raingauges in the study area. 10 stations daily rainfall data have been used in this study. The length of record for 10 stations is given in Table 3.2.

The rainfall data were made available on floppies by the above agencies. The data were in a particular format giving various details and statistics.

A computer programme rainfall. f was developed to read the data from this agency format and to write the same in desired format. This was necessary as good amount of data had to be handled. This programme alongwith some necessary portion of input file and output file is given in Appendix I.

Table 3.2 : The length of record for 10 raingauge stations.

S.No.	Name of Raingauge station	Length of Record (Years)	Years
1.	Bogorejo (ST1)	28	1960-1987
2.	Jiken (ST2)	28	1960-1987
3.	Banjarejo (ST3)	28	1960-1987
4.	Pengkol (ST4)	26	1960-1985
5.	Tunjungan (ST5)	28	1960-1987
6.	Sulursari (ST6)	28	1960-1987
7.	Simo (ST7)	28	1960-1987
8.	Wirosari (ST8)	28	1960-1987
9.	Klego (ST9)	28	1960-1987
10.	Wolo (ST 10)	28	1960-1987

3.2.2 Daily runoff data

The research Institute for Water Resources Development also provided daily runoff data for Serang basin. This data is available at 3 gauging sites. The fluctuation of water level at each gauging site has been monitored and recorded by installing the automatic water level recorder. Digitizer is used to calculate the mean daily water level from the water level charts. Discharge measurements were done regularly to prepare the rating curves for the whole year. The availability of the runoff data for the 3 stations is given in Table 3.3.

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3.3.2 Processing of runoff data

Stream flow data form one of the important inputs to the model for its calibration and validation. In this study the availability of data is given in Table 3.3. All these data are observed and processed by Experimental station for Hydrology, Research Institute for Water Resources Development Bandung-Indonesia.

During that period, the data were missing for few days. In order to fill up the missing flow values, the hydrograph of average daily flow is plotted along with average daily rainfall. Then the missing flow values are interpolated from the hydrograph maintaining the consistency in the rainfall runoff observed in the previous and following years for the respective days, even though there are always errors associated with interpolated flow values affecting the calibration and validation of the model. More over the number of missing data are not much. Therefore the flow records including interpolated values may be used for model calibration and validation without much loss of accuracy.

3.4 Statement of the Problem

The problem, precisely, is the extension of runoff records using rainfall data. For this purpose, it was decided to use the linear perturbation model for the reasons given in chapter II.

The specific objectives of the study are as follows :

1. Processing of the daily rainfall and runoff data of Serang basin, Indonesia.
2. To develop/understand the methodology of linear perturbation model.
3. To evaluate the performance of linear perturbation model and compare it with the performance of single input total response linear model in calibration and validation mode.
4. To study the effect of number of error terms on efficiency of the model.
5. To study the periodic structure of the daily time series of rainfall and runoff data using harmonic analysis.

6. And finally to suggest the rainfall runoff model parameters which can be used to extend the runoff records of three sites of Serang basin.

The methodology for linear perturbation model is described in next chapter.

CHAPTER IV

DEVELOPMENT OF THE METHODOLOGY

4.1 The Hybrid Model

Nash and Barsi (1983) developed a model for flow forecasting on larger catchments considering the relatively regular seasonal variation of potential evaporation. In the model it was assumed that in a year in which the rainfall on each day is the exactly the seasonal mean for that date i(d), the corresponding discharges would also agree with their seasonal means q(d) hence :

$$i(d) \longrightarrow q(d) \qquad (4.1)$$

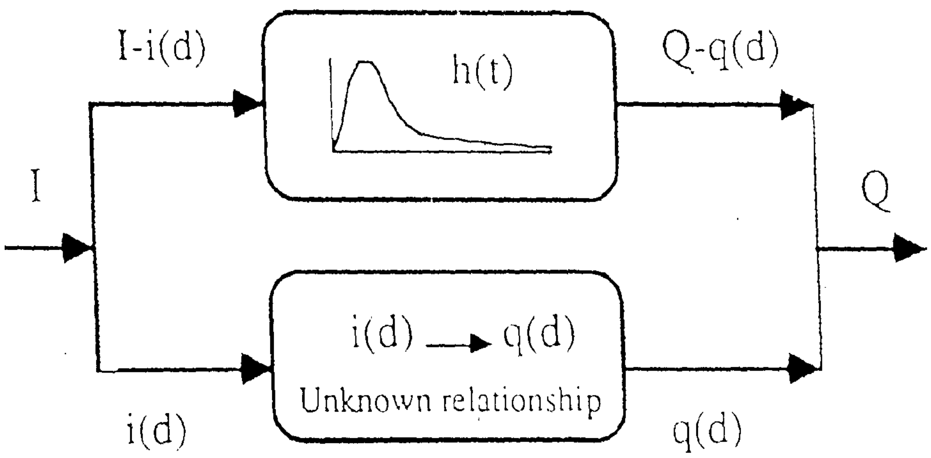
No assumption is made concerning the nature of this relationship (linear or non-linear, time invariant or not), but it would seem an attractive hypothesis that, in any particular year, the departures of the rainfall and the discharge from these seasonal means might be linearly related(shown next page)

where :

$$x = I - i(d) \qquad (4.2)$$

$$y = Q - q(d) \qquad (4.3)$$

For testing the hypothesis of linearity in the relationship of eq.(4.3) the values of i(d) and q(d) can be obtained by averaging the rainfall and the discharge records for each date d, over the years in the period of calibration, and



Linear Perturbation Model

smoothing by Fourier analysis. The seasonal values of i(d) and q(d) may be subtracted from the actual values of I and Q on each day in order to obtain the departures x and y. Thus, the input and output series x and y of length equal to the number of days in the calibration period are obtained.

Assuming that a general linear relationship with a memory length m exists between x and y series, as obtained, it may be expressed as a linear multiple regression of y on the m previous X values as independent variables.

$$y_i = h_1 x_i + h_2 x_{i-1} + \;.....h_m\, x_{i-m+1} + u_i \qquad (4.4)$$

where, h = the vector of regression coefficients or the discrete series of pulse response and u_i is the disturbance term. Eq.(4.4) may be solved to obtain h using method of least square

Eq.(4.4) can also be expressed as :

$$y_i = \sum_{j=1}^{m} h_j\, x_{i-j+1} + u_i \qquad (4.5)$$

In the matrix form the above equation is written as :

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \\ \\ \\ \\ \\ \\ y_n \end{bmatrix} = \begin{bmatrix} x_1 & 0 & 0 & 0 & & \\ x_2 & x_1 & 0 & 0 & & \\ x_3 & x_2 & x_1 & 0 & & \\ \cdot & x_3 & x_2 & x_1 & & \\ \cdot & & x_3 & x_2 & & \\ \cdot & & \cdot & \cdot & & \\ x_m & & \cdot & \cdot & x_2 & x_1 \\ \cdot & & & \cdot & & x_2 \\ \cdot & & & \cdot & & \cdot \\ x_n & x_{n-1} & & \cdot & & x_{n-m+1} \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \\ \\ \\ \\ \\ h_m \\ \\ \\ h_n \end{bmatrix} + \begin{bmatrix} u_1 \\ u_2 \\ \\ \\ \\ \\ \\ \\ \\ u_n \end{bmatrix}$$

or

$$Y = XH + U \qquad (4.6)$$

Where : Y is a vector of y values in the calibration period

X is a matrix of size (n x n - m + 1) having the elements of x values in the calibration period.

H is a vector of h values; and

U is a vector of disturbance term

4.1.1 Parameter estimation using least square approach

Let $\hat{H}$ be the least square estimate of H then :

$$Y = X\hat{H} + e \qquad (4.7)$$

where e is the column vector of the residuals

$$e = Y - \hat{Y} \; ; \quad e = Y - X\hat{H}$$

$$e^T e = (Y - X\hat{H})^T (Y - X\hat{H})$$

$$= Y^T Y - 2\hat{H}^T X^T Y + H^T X^T X \hat{H}$$

$$\frac{\delta}{\delta H} (e^T e) = -2 X^T Y + 2 X^T X H = 0$$

$$(X^T X)\hat{H} = X^T Y \qquad (4.8)$$

and hence

$$\hat{H} = (X^T X)^{-1} X^T Y \qquad (4.9)$$

4.1.2 Computation of Standard Errors

The variance of the estimates of h (or standard errors of estimates of h) can also be obtained using following equation

: (Johnston, 1972)

$$\text{Var (H)} = V^{-1} \sigma^2 \qquad (4.10)$$

where $V = [X^T X]$

Under the usual assumptions of a linear regression model, σ^2 is the variance of the disturbance term e_i, and unbiased estimator of σ^2 is given by :

$$S^2 = (n - m)^{-1} \sum_{i=1}^{n} e_i^2 \quad . \qquad (4.11)$$

The variance of h_i may be obtained by taking the i^{th} term of the principal diagonal of V^{-1} and multiplying by S^2. The standard error of h_i is the square root of its variance. It generally indicates the firmness in the estimation of H.

4.1.3 Smoothing of daily mean series of rainfall and runoff

In linear perturbation model, the deviations/ perturbation from seasonal mean of rainfall and runoff are required. The daily seasonal mean of rainfall and runoff are periodic in nature but because of short length of data and natural characteristics of variables involved had fluctuations.

The smoothening of daily mean series is done with the help of harmonic analysis. The details are as follows :

Let X_τ is the parameter for the τ^{th} day.

$X_{S\tau}$ is the smoothed parameter for τ^{th} day

$$X_{S\tau} = \nu_x + \sum_{j=1}^{m} A_j \cos \frac{2\pi j\tau}{\omega} + B_j \sin \frac{2\pi j\tau}{\omega} \qquad (4.12)$$

where :

ω is number of seasons in a year for daily data, ω=365.

m is number of harmonics to be fitted to data

ν_x overall mean

$$A_j = \frac{2}{\omega} \sum_{\tau=1}^{\omega} X_\tau \cos \frac{2\pi j\tau}{\omega} \qquad (4.13)$$

$$B_j = \frac{2}{\omega} \sum_{\tau=1}^{\omega} X_\tau \sin \frac{2\pi j\tau}{\omega} \qquad (4.14)$$

$$\text{Variance } (h_j) = \frac{A_j^2 + B_j^2}{2} = C_j^2 \qquad (4.15)$$

Fraction of variance explained by $h_j = \Delta P_j$

$$\Delta P_j = \frac{\text{Var } (h_j)}{S^2 (X_\tau)} \qquad (4.16)$$

$$P_{min} = a \sqrt{\frac{\omega}{cn}} \qquad (4.17)$$

Where : a = 0.033

C = 1 for mean and C = 2 for s.d.

n = number of years of data

$$P_{max} = 1 - P_{min} \qquad (4.18)$$

$$P_1 = \Delta P_1$$

$$P_2 = \Delta P_1 + \Delta P_2$$

$$\vdots$$

$$P_{w/2} = \Delta P_1 + \Delta P_2 + \Delta P_3 + \ldots \Delta P_{w/2}$$

Selection of the significant harmonic

If $P_{w/2} < P_{min}$ then no harmonic is significant

If $P_{w/2} > P_{max}$ then only some of the w/2 harmonics are significant

If $P_{min} < P_{w/2} < P_{max}$, then all w/2harmonics are significant

4.2 Model Updating Procedure

Having obtained the pulse response or regression coefficients h, the y values can be obtained using the following matrix equation

$$Y = XH \qquad (4.19)$$

Finally the mean q(d) is added with y values to give the estimates for Q values. The residual errors are obtained after subtracting the computed Q values from the corresponding observed Q values. The residual errors (e_i) thus obtained are analysed to identify the following persistence structure :

$$e_i = b_1 e_{i-1} + b_2 e_{i-2} + b_3 e_{i-3} + \ldots + b_n e_{i-n} + E_i \qquad \ldots(4.20)$$

where, b_1, b_2, b_3 etc. are the regression coefficients to be obtained from least square analysis and E_i is the random component of mean zero.

The model results during the calibration period are updated the error model (4.20) after identifying the persistence structure i.e. number of error terms to be included to improve the estimates of discharge.

Thus the discharge at any day t will be given by following equation

$$Q_t = q\ (d_t) + h_1\ (I_t - i(d_t)) + h_2\ (I_{t-1} - i(d_{t-1})) + \ldots + h_m\ (I_{t-m+1} - i\ (d_{t-m+1}) + b_1\ e_{t-1} + b_2 e_{t-2} + \ldots + b_n\ e_{t-n} \qquad (4.21)$$

where,

Q_t	runoff for the day t
$q(d_t)$	seasonal mean of runoff for day t
$i(d_t)$	seasonal mean of rainfall for day t
I_t	rainfall for day t
$h_1, h_2, ..h_m$	regression coefficients
m	memory length to be decided by trial and error
$b_1, b_2..b_n$ etc.	coefficients of error terms to be evaluated during calibration period
e_{t-1}	error for the (t-1) day.

4.3 Computation of Model Efficiency

The efficiency of the model is computed by

$$\text{Efficiency} = \left[1 - \frac{RV}{IV} \right] * 100 \qquad (4.22)$$

where

RV = remaining variance

$$= \sum_{i=1}^{n} (Q_i - \hat{Q}_i)^2$$

Q_i = Observed discharge for the i^{th} day

$\hat{Q}_i$ = computed discharge using the model for the i^{th} day

n = total no. of observations

IV = Initial variance

$$= \sum_{i=1}^{n} (Q_i - \bar{Q})^2$$

$\bar{Q}$ = overall mean daily discharge

The efficiency is computed by eq.(4.22) during calibration period and testing period.

The computer programme lpm. f was developed in FORTRAN-77 language for the linear perturbation model. The programme is interactive in nature and is given in Appendix-IV along with are input file and output file.

CHAPTER V

MODEL APPLICATION AND RESULTS

5.1 Model Application

5.1.1 Calibration and validation period

The linear perturbation model has been applied to the following three sub-basins

(i) Lusi at Kundurun (C.A = 734.5 km^2)

(ii) Lusi at Mendurun (C.A. = 1830.8 km^2)

(iii) Serang at Tongpait (C.A. = 2531.6 km^2)

For computing the mean areal rainfall upto Kundurun rain gauge station (ST1 to ST5) were considered. For mean areal rainfall upto Mendurun (ST1 to ST8) and upto Tongpait (ST1 to ST10) were used. Thus the data used for further analysis is given below :

Site	Runoff	average rainfall over the basin
Kundurun	1979-84, 1990	(1960-1987)
Mendurun	1975-77, 1980-86, 1990	(1960-87)
Tongpait	1973-1982, 1989-1990	(1960-87)

The selection of calibration and validation periods are as follows

Site	Calibration	Testing
Kundurun	1979-81	1983-84
Mendurun	1975-77	1980-81
Tongpait	1979-82	1976-78

5.1.2 Models Applied

The following models have been applied

(i) Single input total response linear model (TRL)

(ii) Linear perturbation model with observed daily means of rainfall (amr) and runoff (amdis) (LPM 1)

(iii) Linear perturbation model with smoothened/harmonic daily means of rainfall (hmr) and runoff (hmdis) (LPM2)

In single input and total response model (TRL) the total rainfall at any day t and total runoff at any day t are used. In LPM (both the options) perturbations are used.

5.1.3 Memory Length (m)

In all the three models (TRL, LPM1, LPM2) the effect of memory lengths (1 to 10) have been studied in calibration mode. For the three sites, depending upon the efficiencies one memory length for each site has been selected.

5.1.4 Number of Error Terms

All the three models have been studied with following error terms in error model during calibration mode and testing mode.

(i) no error model i.e. no error term

(ii) one error term

(iii) two error terms

(iv) three error terms

(v) four error terms

5.1.5 Selection of Number of Harmonic in LPM2

The number of harmonics for smoothening the observed mean daily rainfall and runoff series have been selected on the basis of P_{max} and P_{min} test.

5.2 Results

5.2.1 Lusi at Kundurun

For Kundurun, the number of significant harmonics are 17 for mean daily discharges and 63 for mean daily rainfall series. The observed and smoothened mean daily rainfall and runoff are plotted in Fig.5.1 and 5.2. The observed and computed discharges in calibration mode are plotted in Fig.5.3-5.5 and in validation mode (1983-84) in Fig.5.6-5.7.

The efficiency of different models with memory lengths (1-10) and no. of error terms 0 to 4 in calibration and validation modes are shown in Table 5.1 to 5.3.

It may be seen from Table 5.1 to 5.3 that

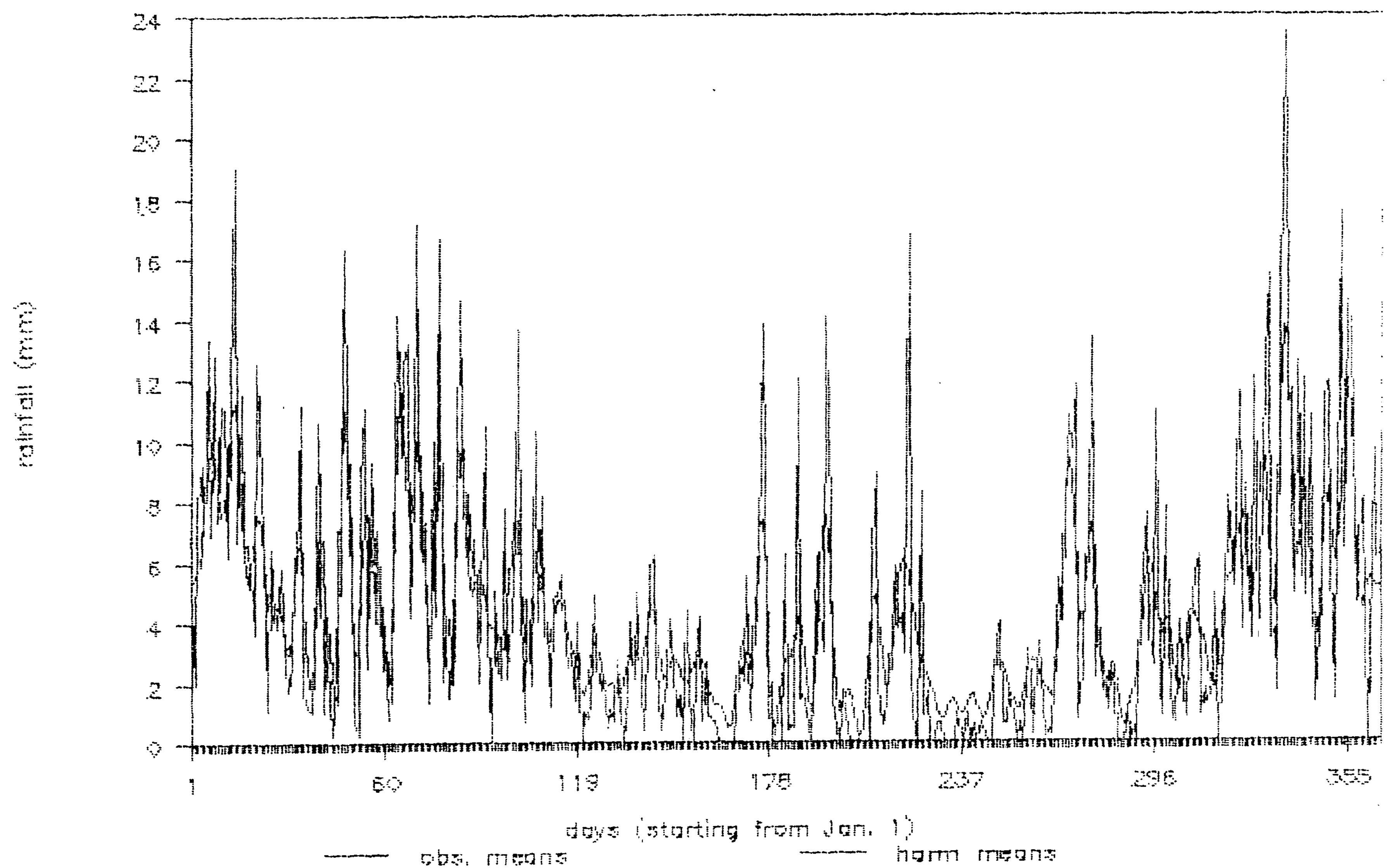


Fig.5.1 : Observed mean rainfall and harmonic mean rainfall of Lusi at Kunduran

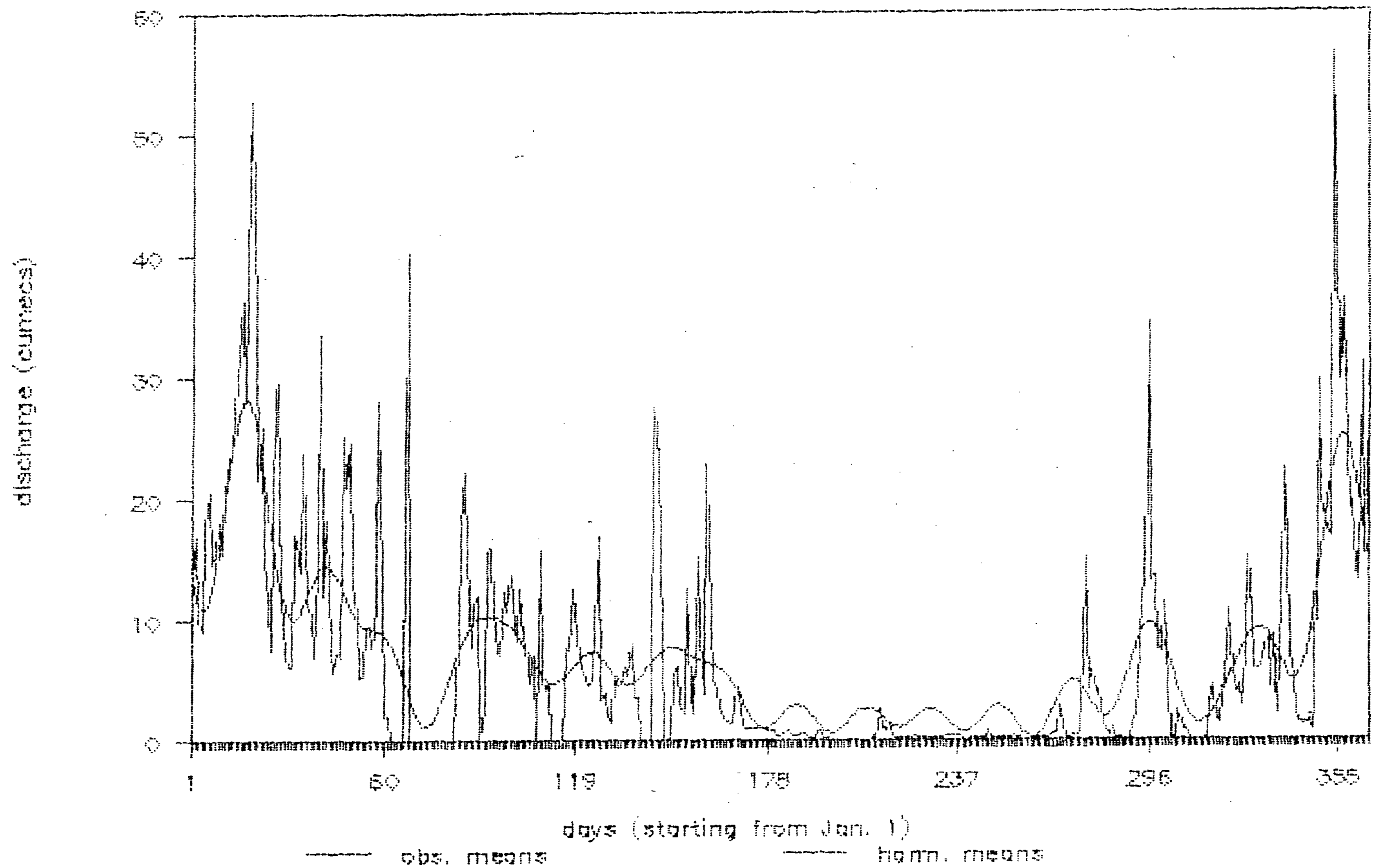


Fig. 5.2 : Observed mean discharge and harmonic mean discharge of Lusi at Kunduran.

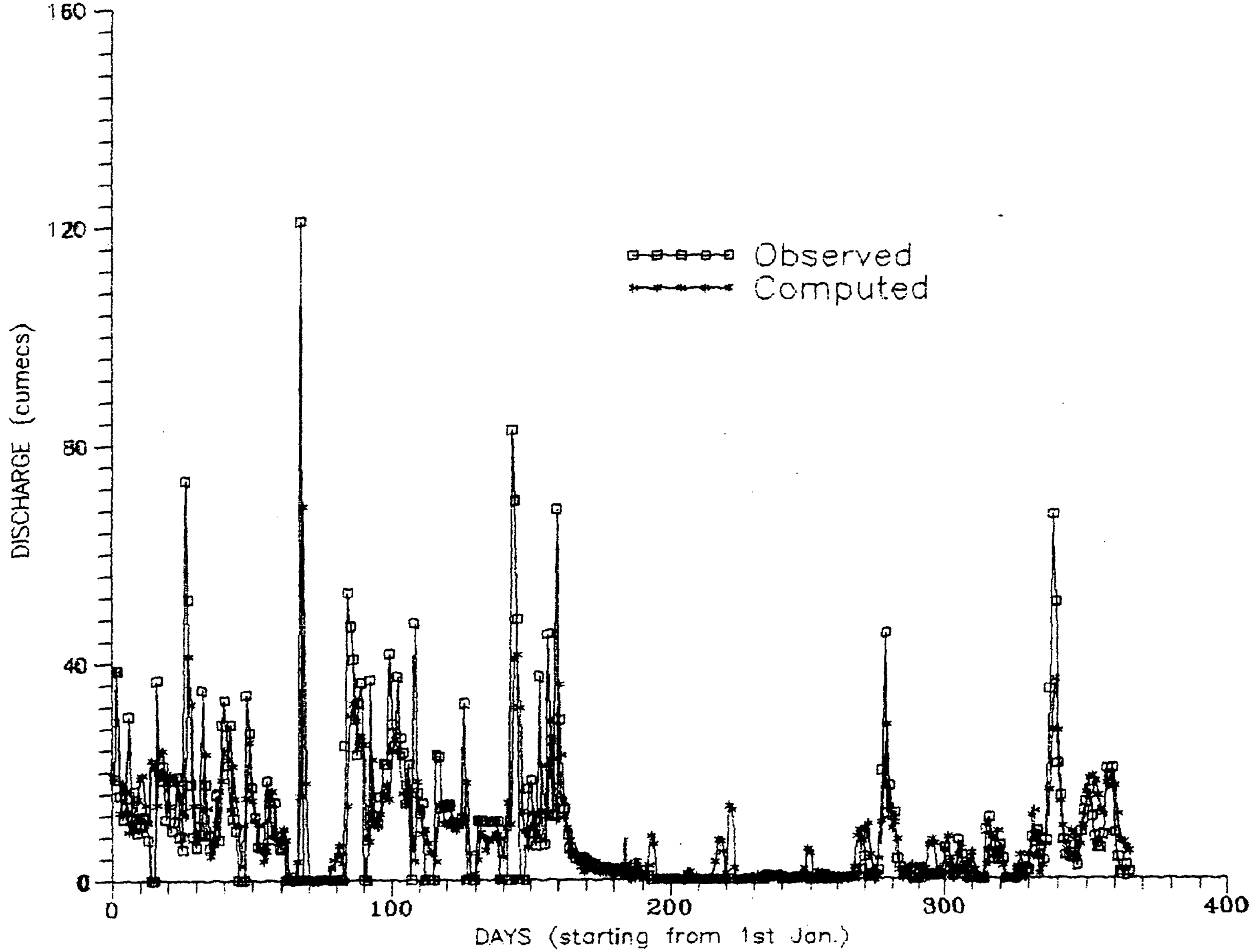


Fig. 5.3: Observed and computed discharges of Lusi at Kunduran (1979).

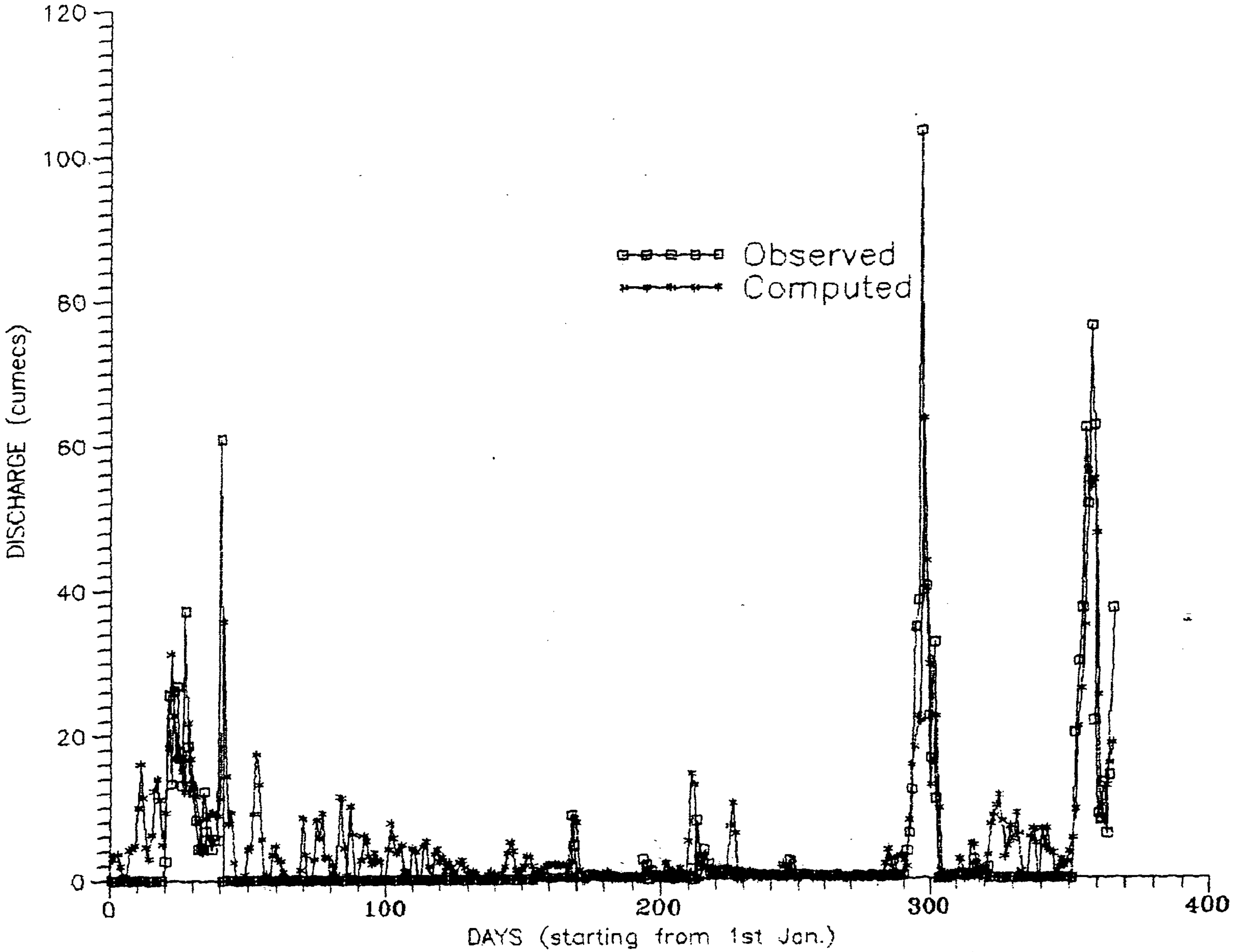


Fig.5.4: Observed and computed discharges of Lusi at Kunduran (1980).

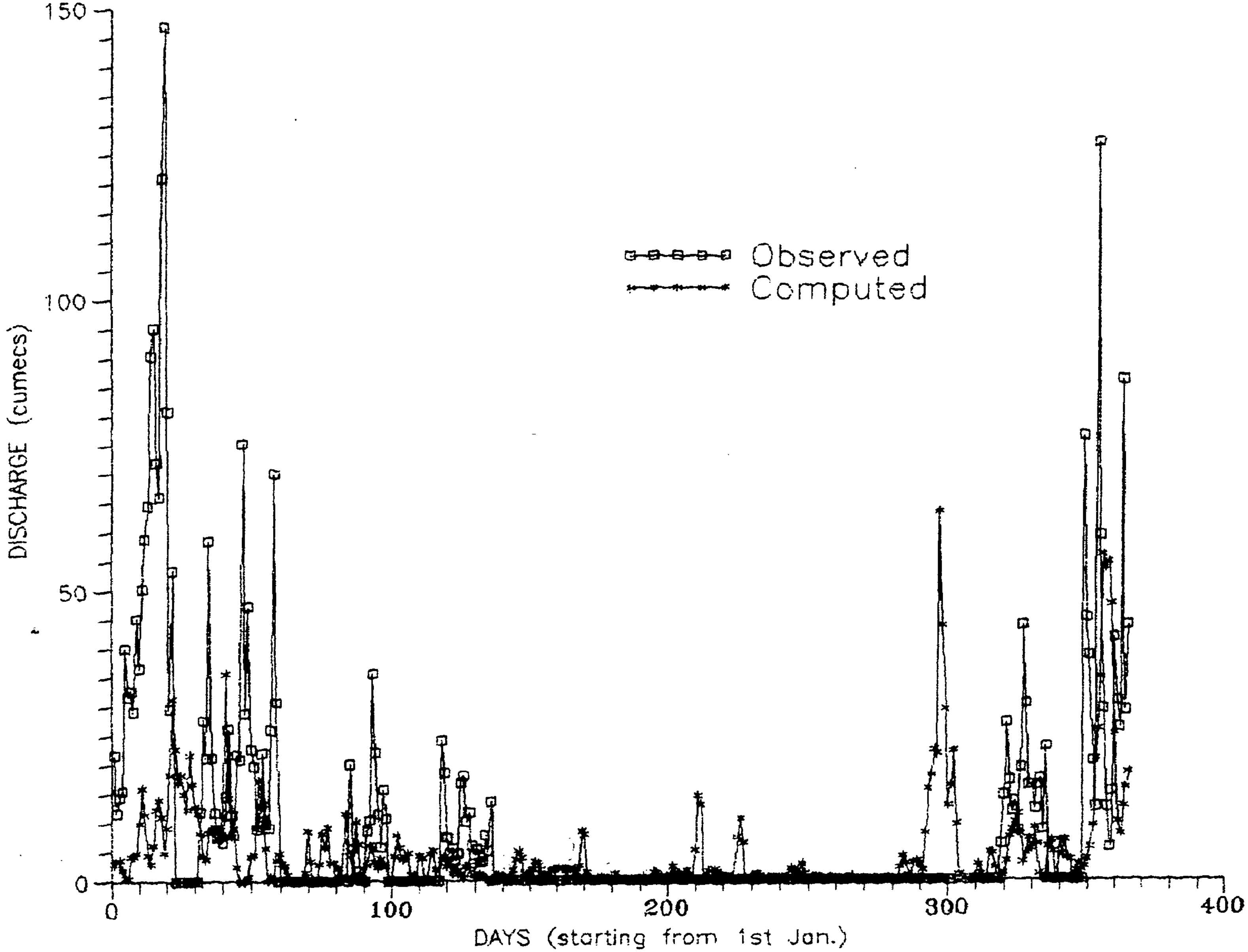


Fig.5.5: Observed and computed discharges of Lusi at Kunduran (1981).

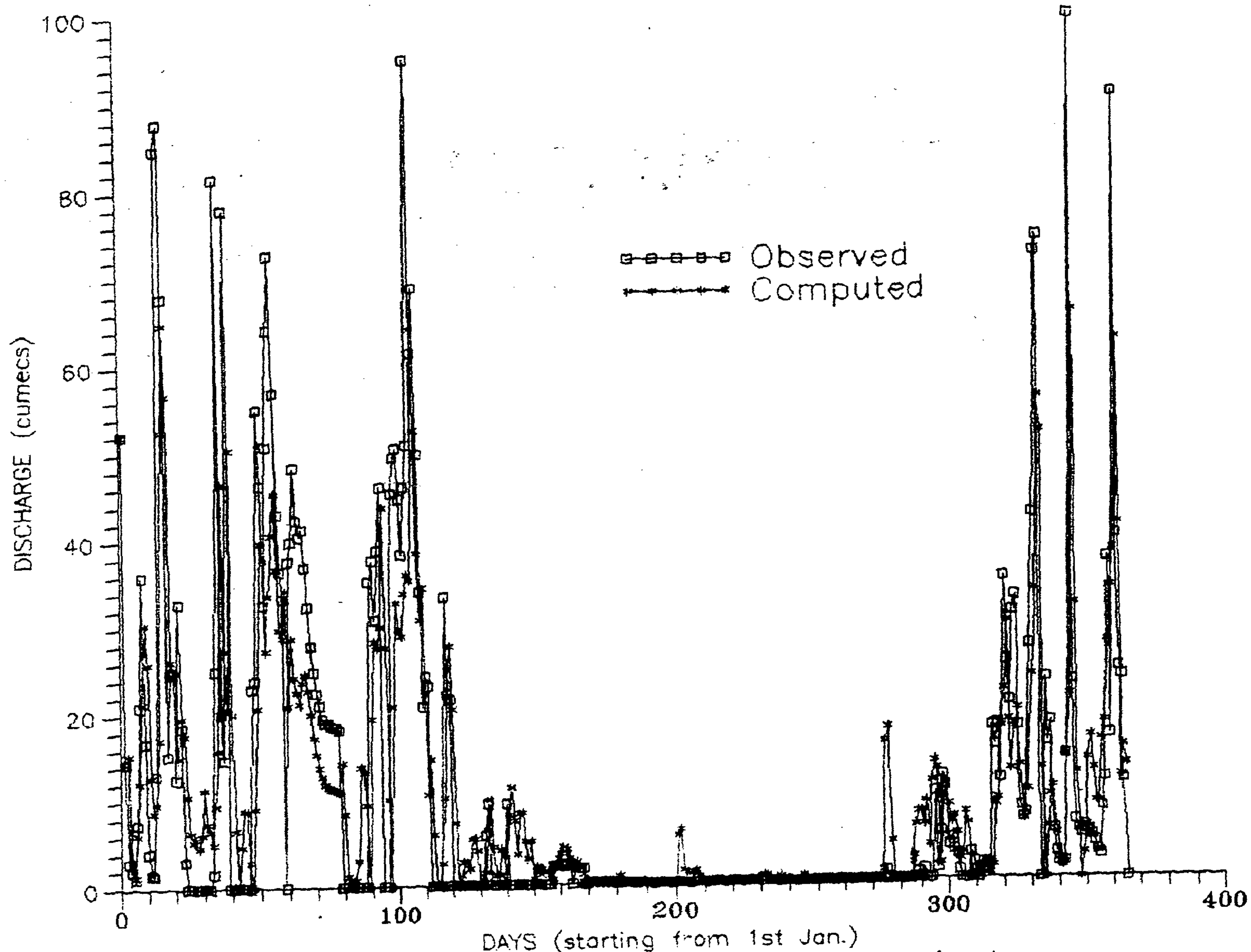


Fig.5.6: Observed and computed discharges of Lusi at Kunduran (1983).

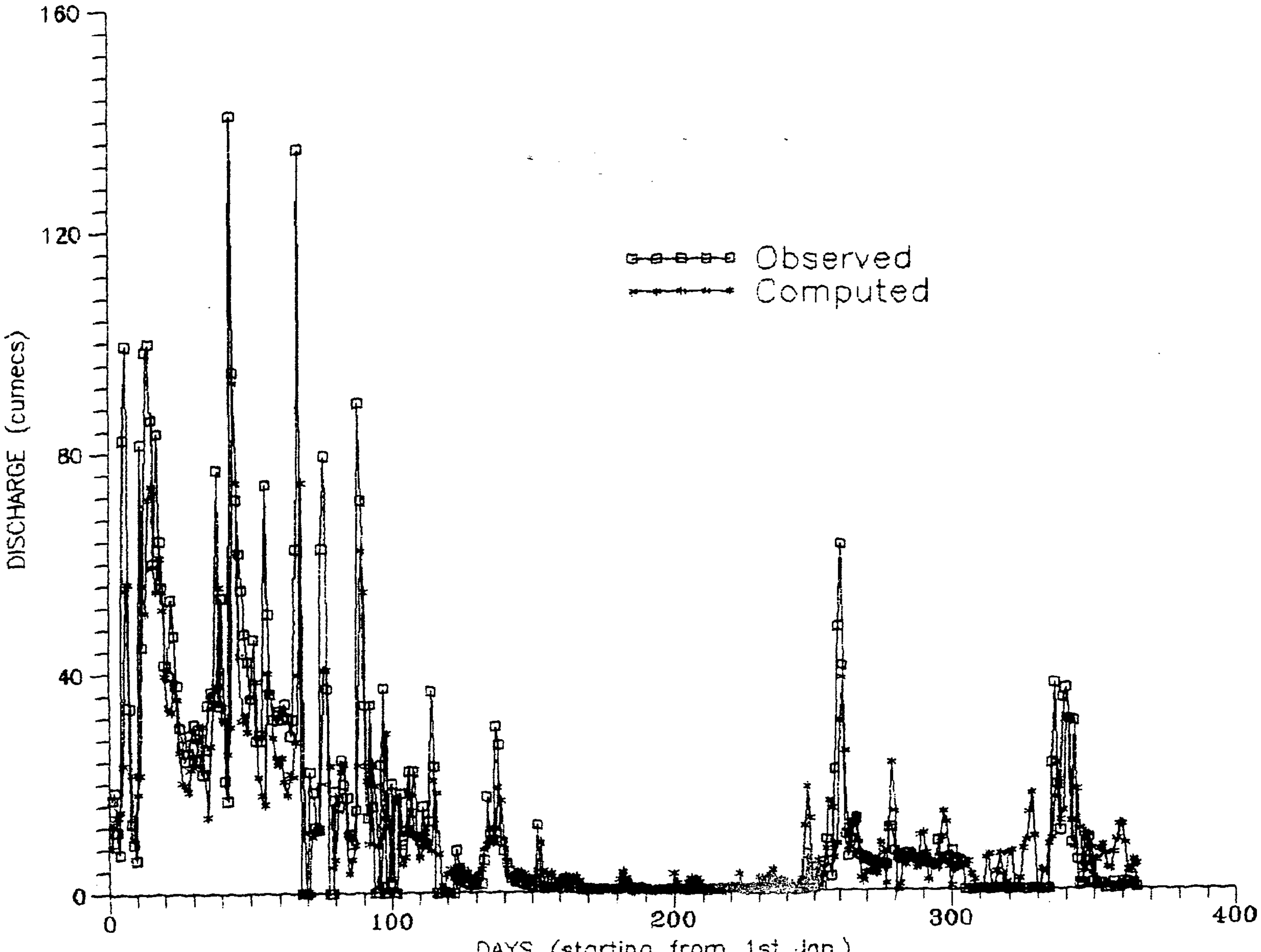


Fig. 5.7: Observed and computed discharges of Lusi at Kunduran (1984).

Table 5.1 : Efficiency of TRL model in calibration and validation mode for Lusi at Kunduran.

Calibration

Memory Length	Efficiency with no. of error terms				
	0	1	2	3	4
1	3.59	39.17	40.55	41.36	41.67
2	15.14	48.53	49.82	50.41	50.56
3	19.65	50.47	52.21	52.88	52.96
4	21.09	51.32	52.82	53.49	53.58
5	21.57	51.35	52.74	53.34	53.47
6	22.00	51.37	52.75	53.35	53.47
7	22.60	51.66	53.04	53.67	53.75
8	22.98	51.93	53.33	53.91	53.99
9	23.14	52.04	53.39	53.97	54.04
10	23.16	51.97	53.32	53.89	53.97

Validation with memory length 3

3	21.43	55.08	55.48	56.28	56.45

Table 5.2 : Efficiency of LPM1 model in calibration and validation mode for Lusi at Kunduran.

Calibration

Memory Length	Efficiency with no. of error terms				
	0	1	2	3	4
1	41.51	64.02	65.00	65.25	65.34
2	46.84	67.64	68.68	69.00	69.08
3	48.64	68.19	69.31	69.74	69.77
4	49.50	68.51	69.52	69.92	69.98
5	49.96	68.57	69.50	69.84	69.94
6	50.33	68.58	69.46	69.83	69.91
7	51.08	68.88	69.81	70.19	70.24
8	51.74	69.26	70.20	70.53	70.57
9	51.89	69.29	70.20	70.54	70.58
10	51.89	69.24	70.15	70.49	70.52

Validation with memory length 3

3	17.48	54.77	55.26	56.16	56.35

Table 5.3 : Efficiency of LPM2 model in calibration and validation mode for Lusi at Kunduran.

Calibration

Memory Length	Efficiency with no. of error terms				
	0	1	2	3	4
1	26.11	48.52	49.13	49.44	49.54
2	31.85	52.29	53.02	53.32	53.35
3	34.68	53.62	54.58	54.92	54.93
4	35.65	54.13	54.93	55.26	55.28
5	35.98	54.14	54.89	55.17	55.2
6	36.33	54.16	54.85	55.14	55.17
7	36.99	54.45	55.12	55.43	55.44
8	37.57	54.78	55.50	55.77	55.78
9	37.84	54.95	55.65	55.93	55.93
10	37.86	54.91	55.61	55.87	55.88

Validation with memory length 3

3	24.54	54.54	54.91	55.53	55.62

(i) Performance of TRL model is comparable with linear perturbation model in validation mode. However LPM models give better performance in calibration mode.

(ii) Performance of LPM1 is better than LPM2 model.

(iii) In case of LPM1 and LPM2, as the memory length increases, the efficiency also increases. This increase is significant upto memory length 3. Hence memory length of 3 may be selected.

(iv) The incorporation of error model in LPM1 and LPM2 significantly improves the performance. As the number of error terms increases there is improvement in efficiency. However this increase in efficiency is not significant after two error terms.

Through the performance of LPM2 is inferior to that of LPM1, yet it is recommended to be selected as it uses smoothened means. Finally for Lusi at Kundurun, LPM2 model with memory length of three days and two error terms is recommended.

5.2.2 Lusi at Mendurun

For Menduran, the number of significant harmonics are 8 for mean daily discharges and 38 for mean daily rainfall series. The observed and smoothened mean daily rainfall and run off are plotted in Fig.5.8 and 5.9. The observed and computed

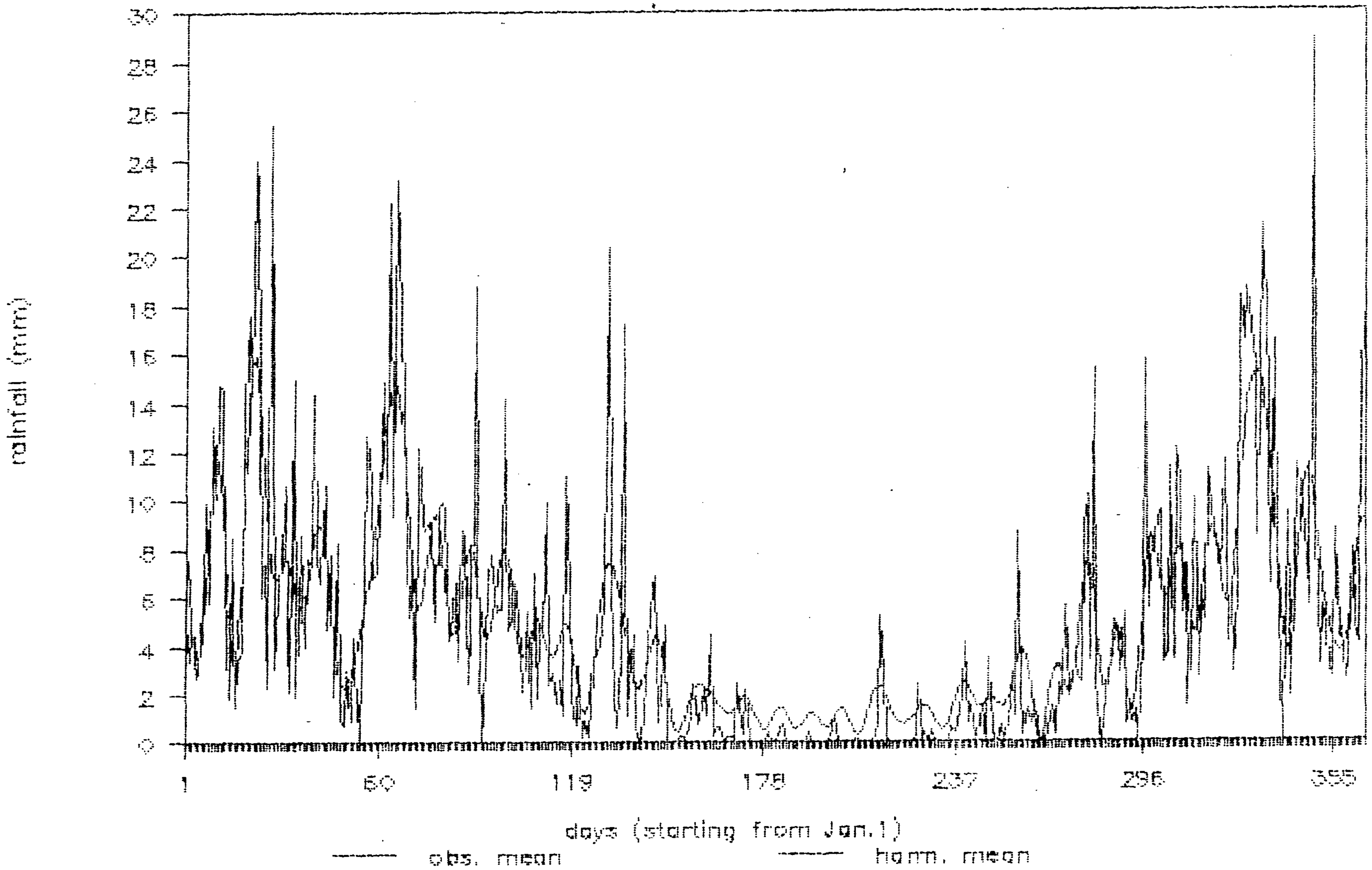


Fig. 5.8 : Observed mean rainfall and harmonic mean rainfall of Lusi at Menduran.

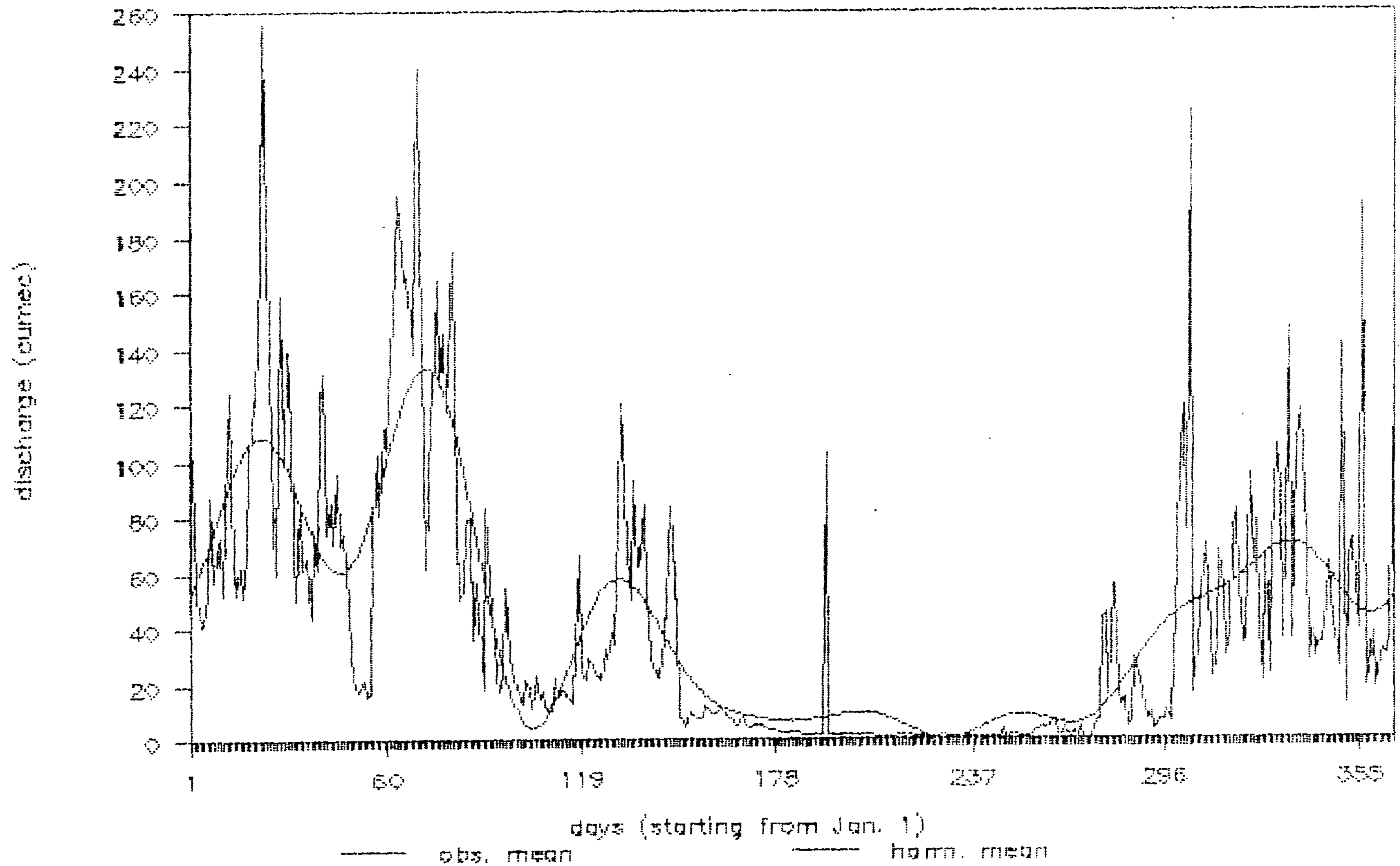


Fig. 5.9 : Observed mean discharge and harmonic mean discharge of Lusi at Menduran

discharges in calibration mode (1975-77) are plotted in Fig.5.10 to 5.11 and validation mode (1980-81) in Fig.5.12-5.13.

The efficiency of different models with memory length (1-10) and no. of error terms 0 to 4 in calibration and validation modes are shown in Table 5.4 to 5.6.

It may be seen from Table 5.4 to 5.6 that

(i) Performance of TRL model is comparable with linear perturbation model in validation mode. However LPM models give better performance in calibration mode without incorporating any error model and after incorporating error models.

(ii) Perfromance of LPM1 is better than LPM2 model

(iii) In case of LPM1 and LPM2, as the memory length increases, the efficiency also increases. This increase is significant upto memory length 4. Hence memory length of 4 may be selected.

(iv) The incorporation of error model in LPM1 and LPM2 significantly improves the performance. As the number of error terms increases there is improvement in efficiency. However this increase in efficiency is not significant after two error terms. Finally for Lusi at Menduran, LPM2 model with memory length of four days and two error terms is recommended.

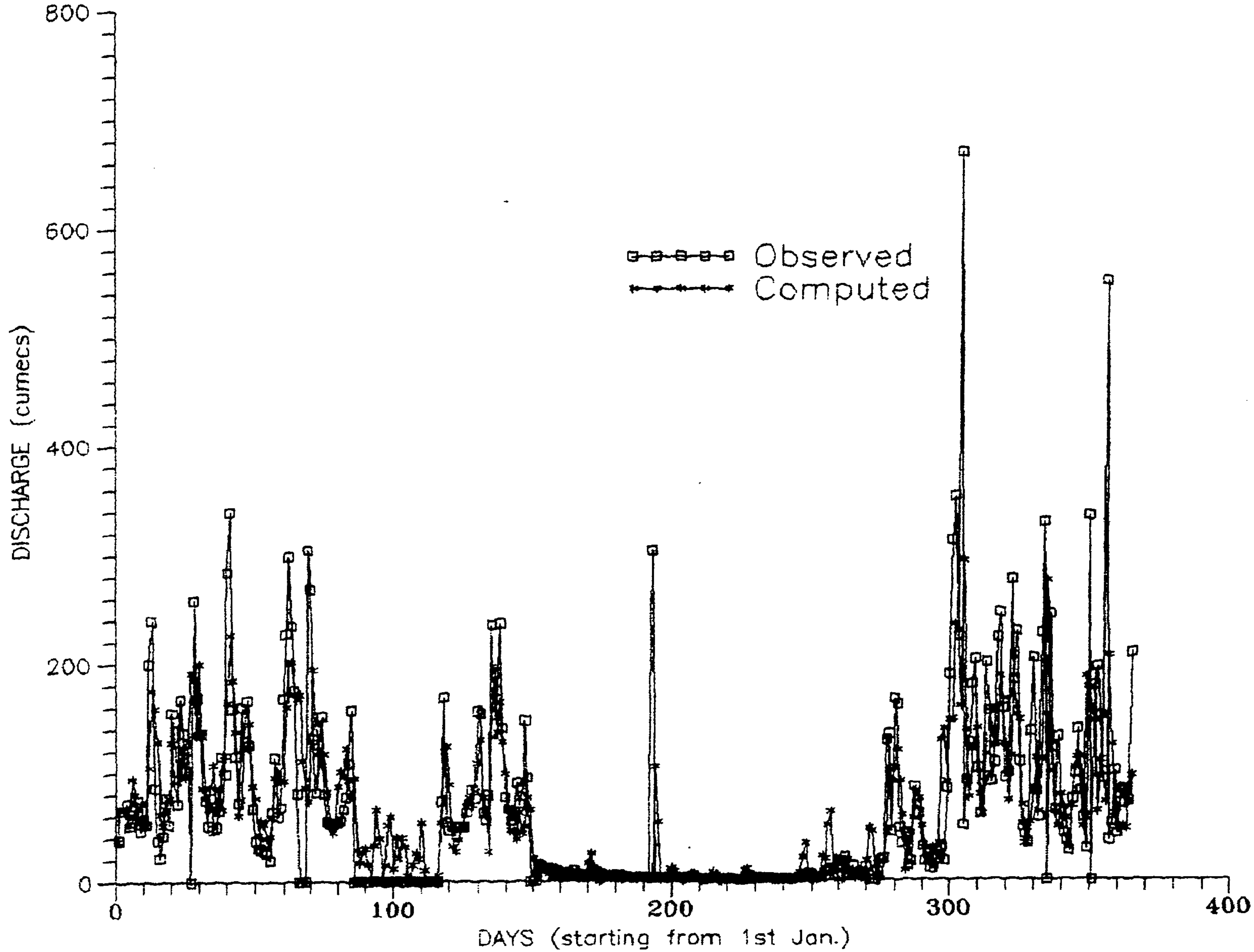


Fig.5.10: Observed and computed discharges of Lusi at Menduran (1975).

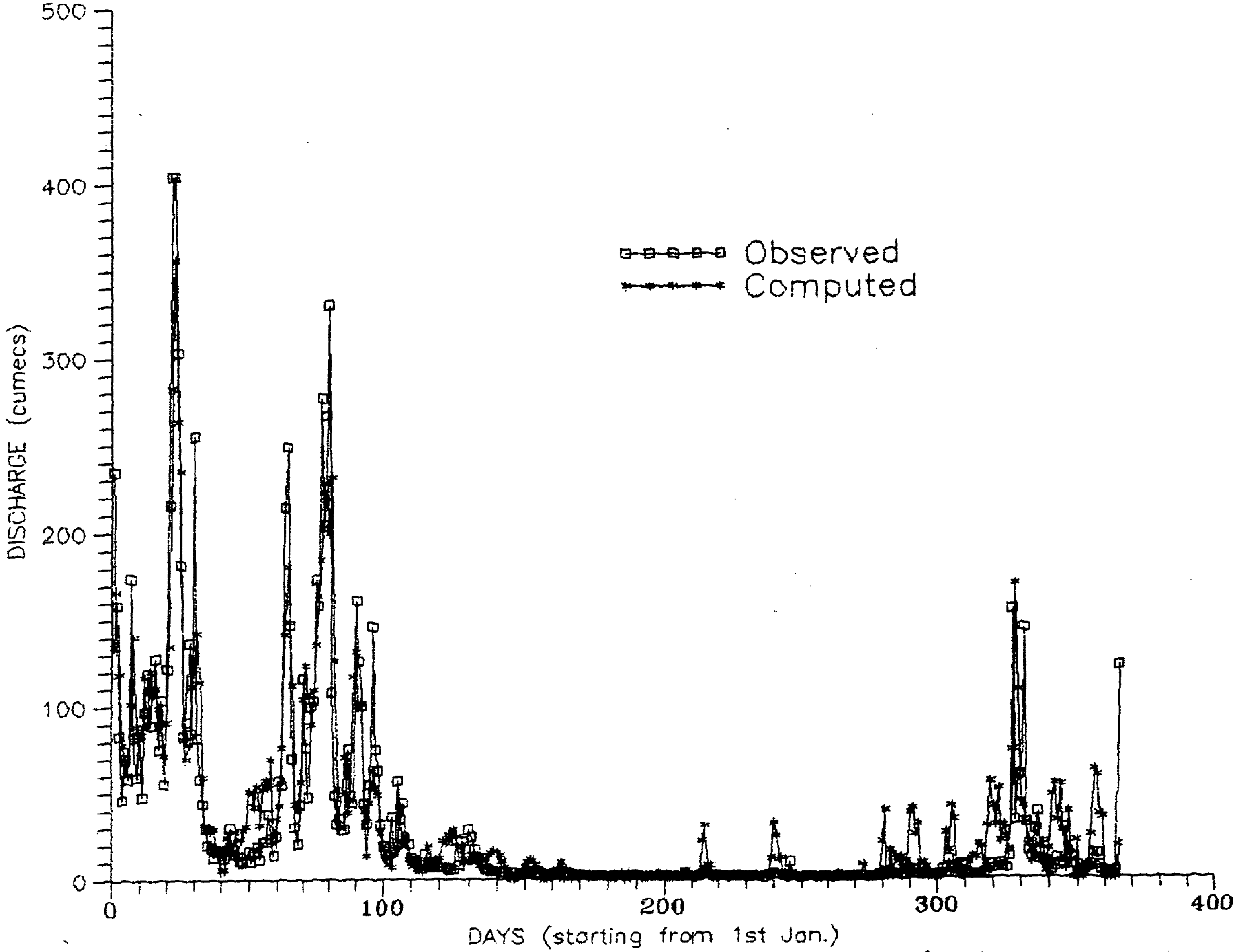


Fig.5.11a: Observed and computed discharges of Lusi at Menduran (1976).

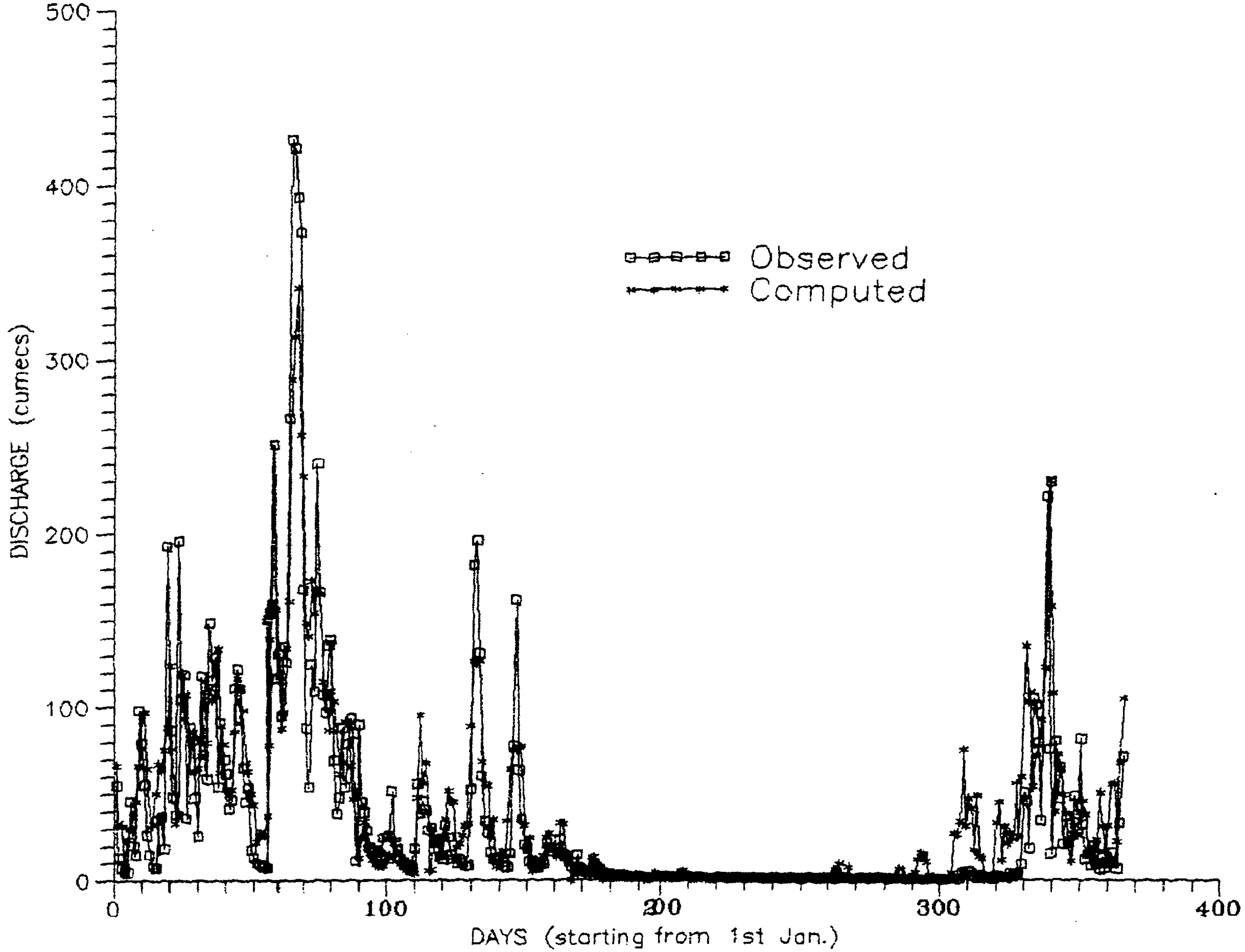


Fig.5.11b: Observed and computed discharges of Lusi at Menduran (1977).

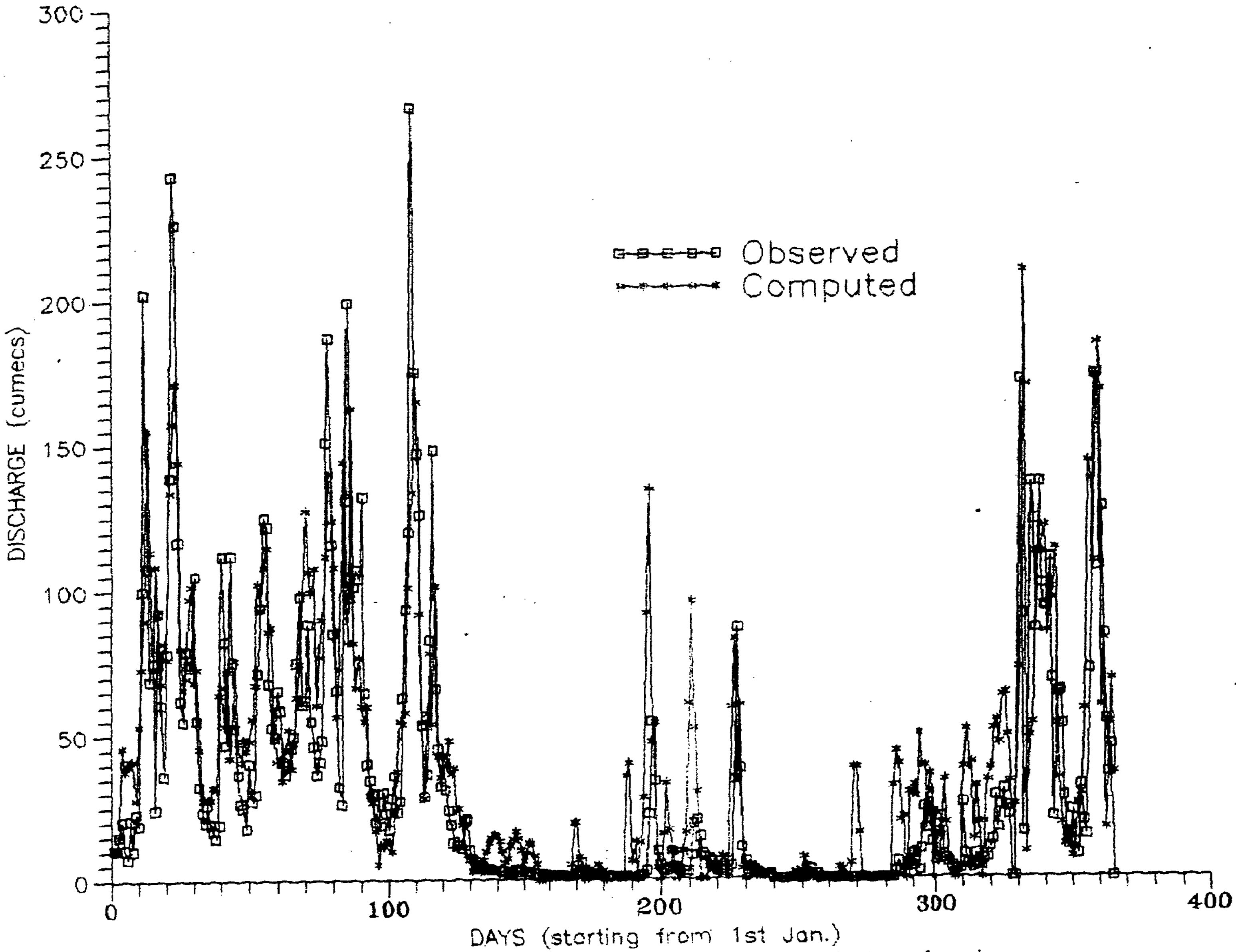


Fig.5.12: Observed and computed discharges of Lusi at Menduran (1980).

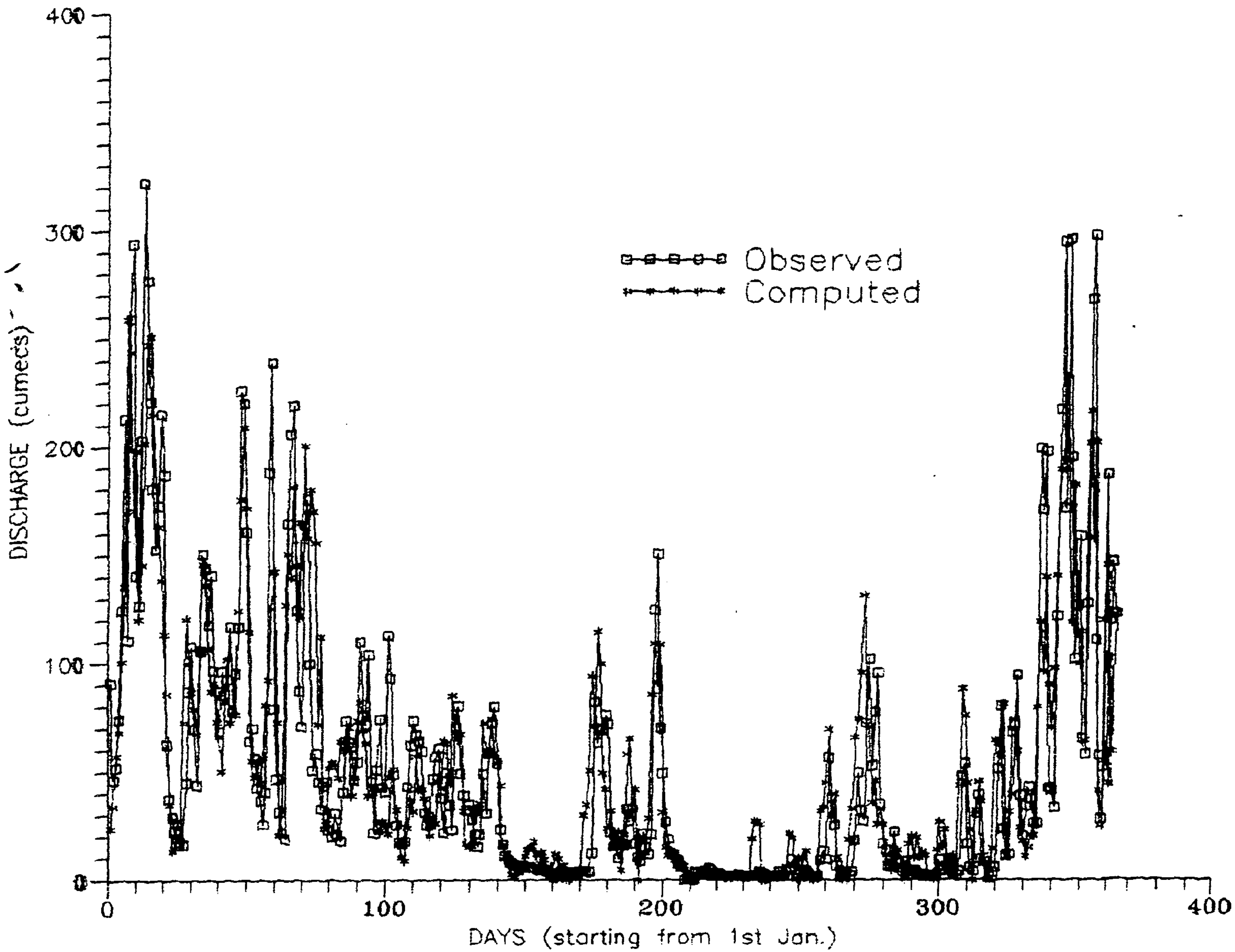


Fig.5.13: Observed and computed discharges of Lusi at Menduran (1981).

Table 5.4 : Efficiency of TRL model in calibration and validation mode for Lusi at Menduran.

Calibration

Memory Length	Efficiency with no. of error terms				
	0	1	2	3	4
1	17.03	39.95	39.95	40.00	40.16
2	38.53	54.33	55.38	55.56	55.69
3	44.48	56.97	58.37	58.90	58.93
4	48.68	59.88	61.55	61.92	61.92
5	49.89	60.78	62.37	62.55	62.55
6	50.15	60.82	62.24	62.46	62.49
7	50.45	60.60	62.14	62.37	62.40
8	51.76	61.79	63.34	63.55	63.55
9	51.88	61.88	63.41	63.62	63.64
10	51.91	61.87	63.41	63.60	63.63

Validation with memory length 4

4	54.48	67.59	66.91	67.81	67.81

Table 5.5 : Efficiency of LPM1 model in calibration and validation mode for Lusi at Menduran.

Calibration

Memory Length	Efficiency with no. of error terms				
	0	1	2	3	4
1	53.86	67.71	68.81	68.83	68.86
2	62.13	72.47	73.50	73.58	73.60
3	65.06	73.48	74.60	74.80	74.81
4	67.25	74.93	76.00	76.13	76.14
5	67.90	75.31	76.27	76.33	76.33
6	68.28	75.44	76.26	76.33	76.33
7	68.58	75.36	76.19	76.26	76.26
8	69.43	75.77	76.66	76.71	76.71
9	69.93	76.27	77.04	77.08	77.08
10	70.02	76.19	76.98	77.02	77.02

Validation with memory length 4

4	55.74	68.70	67.83	68.53	68.54

Table 5.6 : Efficiency of LPM2 model in calibration and validation mode for Lusi at Menduran.

Calibration

Memory Length	Efficiency with no. of error terms				
	0	1	2	3	4
1	39.52	52.62	53.61	53.60	53.60
2	49.61	59.33	60.24	60.30	60.31
3	53.59	60.30	61.26	61.44	61.44
4	55.37	62.29	63.31	63.44	63.44
5	56.16	62.90	63.85	63.89	63.89
6	56.26	62.90	63.76	63.81	63.81
7	56.45	62.76	63.65	63.70	63.70
8	57.84	63.91	64.78	64.81	64.82
9	58.08	64.03	64.87	64.90	64.92
10	58.18	64.06	64.89	64.91	64.94

Validation with memory length 4

4	48.58	64.62	64.30	64.68	64.67

5.2.3 Serang at Tongpait

For Serang river at Tongpait, the number of significant harmonics are 2 for mean daily discharges and 36 for mean daily rainfall series. The observed and smoothened mean daily rainfall and runoff are plotted in Fig.5.14 and 5.15. The observed and computed discharges in Fig.5.16 to 5.19 for calibration mode and in Fig.5.20 to Fig.5.22 for validation mode (1976-78).

The efficiency of different models with memory lengths (1-10) and no. of error terms 0 to 4 in calibration and validation models are shown in table 5.7 to 5.9.

It may be seen from Table 5.7 to 5.9 that

(i) Performance of TRL model is comparable with linear perturbation model in validation mode. However LPM models give better performance in calibration mode.

(ii) Perfromance of LPM1 is better than LPM2 model

(iii) In case of LPM1 and LPM2, as the memory length increases, the efficiency also increases. This increase is significant upto memory length 5. Hence memory length of 5 may be selected.

(iv) The incorporation of error model in LPM1 and LPM2 significantly improves the performance. As the number of error terms increases there is improvement in efficiency. However this increase in efficiency is not significant after two error terms.

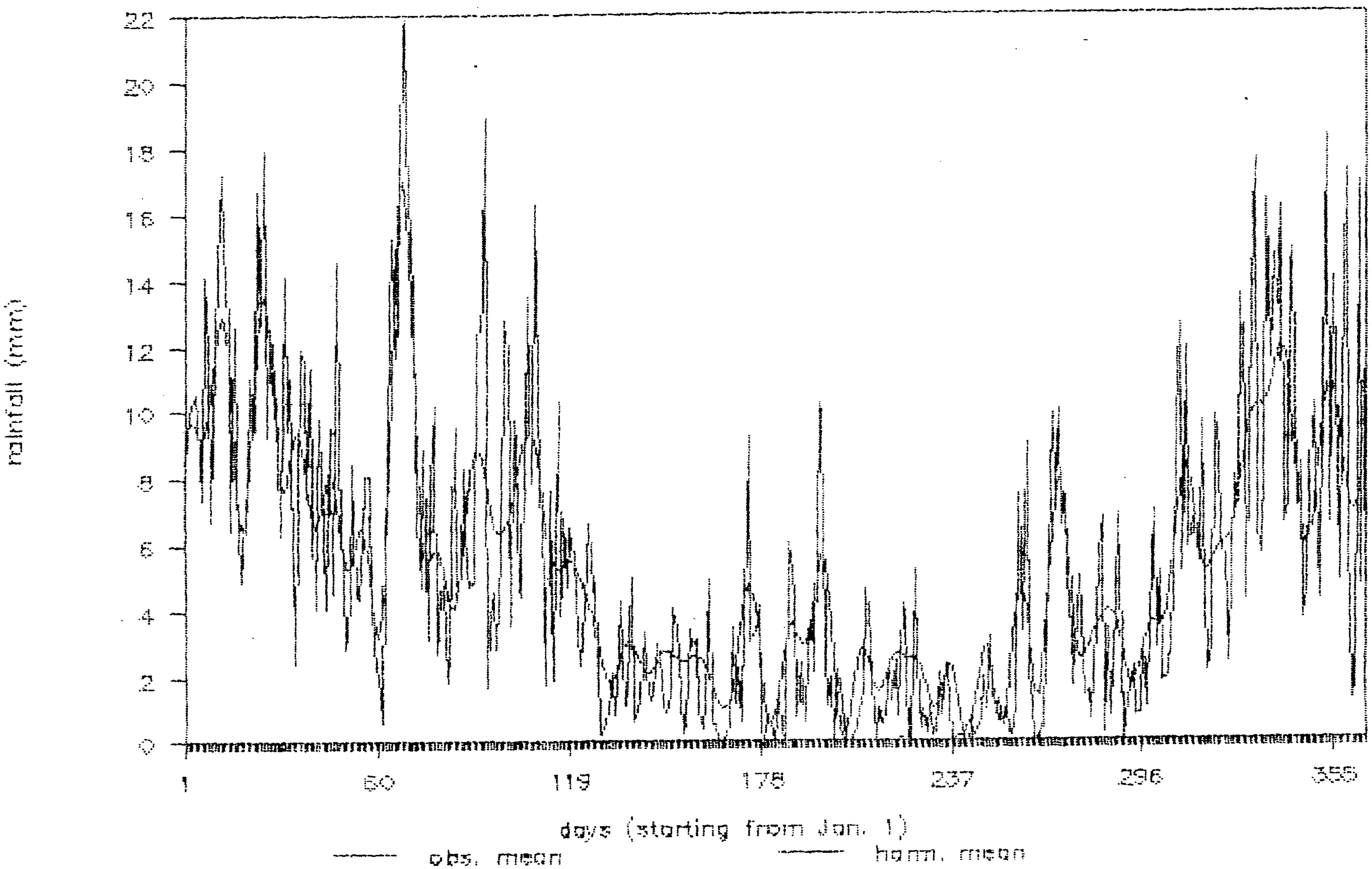


Fig.5.14 : Observed mean rainfall and harmonic mean rainfall of Serang at Tongpait.

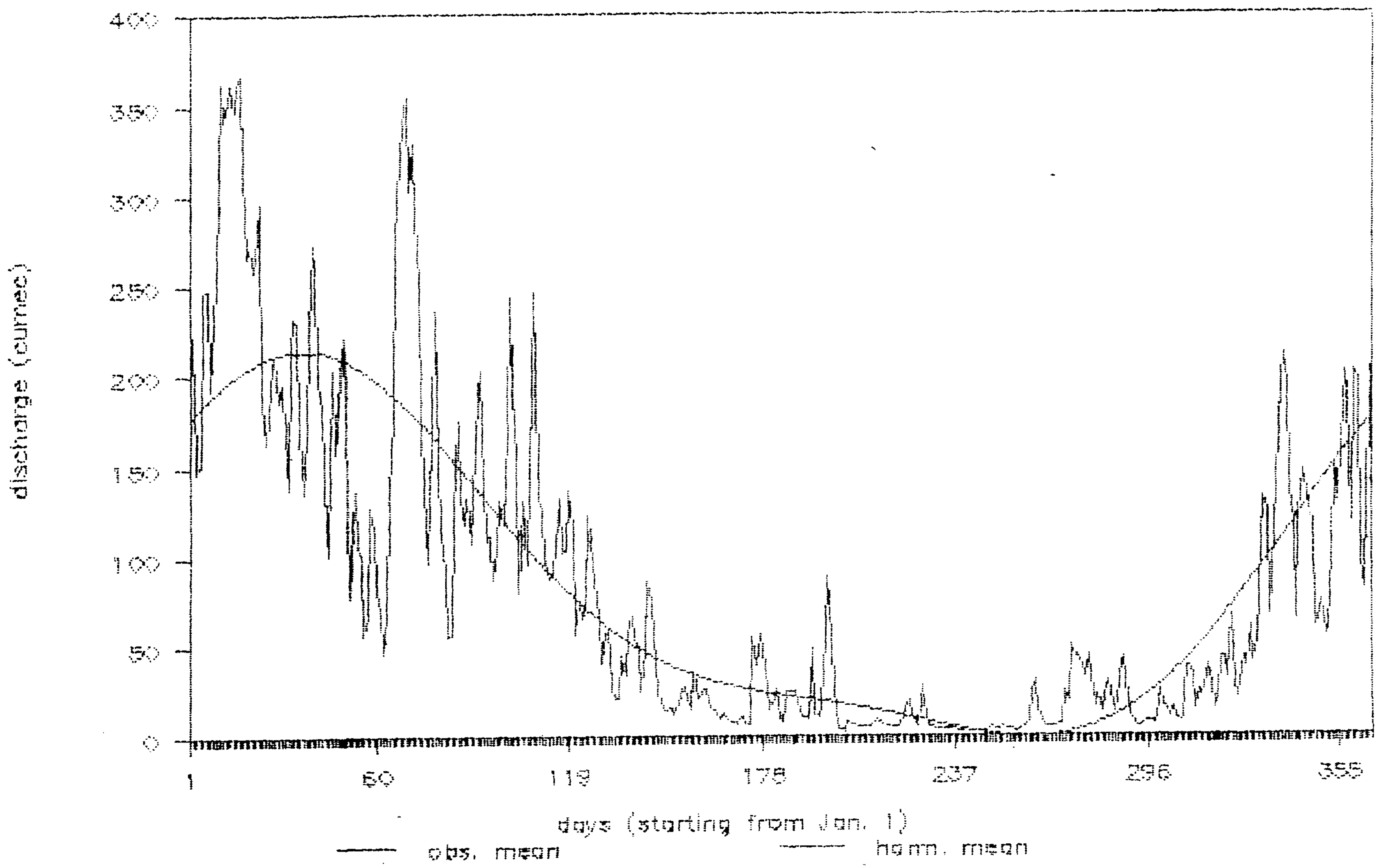


Fig. 5.15 : Observed mean discharge and harmonic mean discharge of Serang at Tongpait.

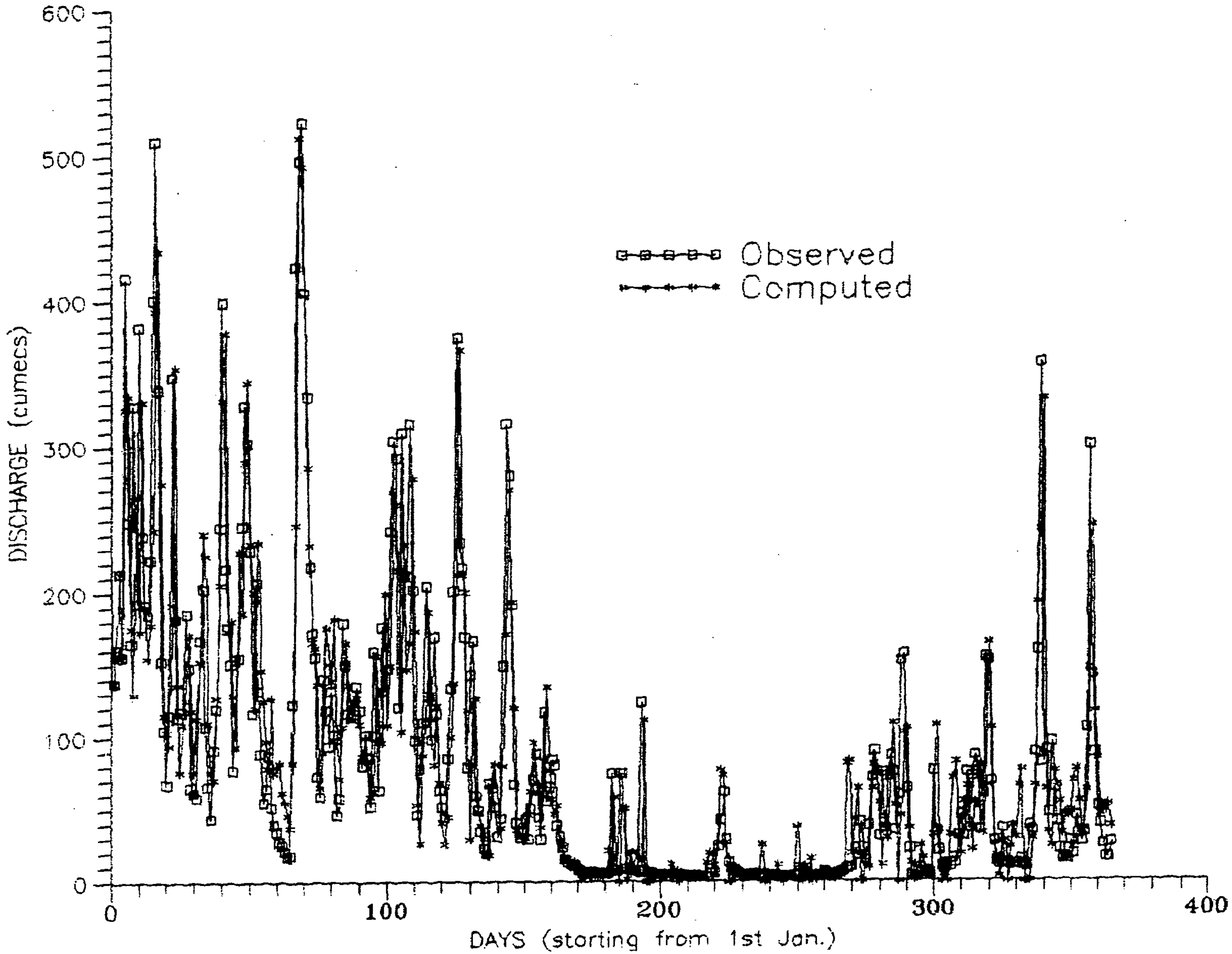


Fig.5.16: Observed and computed discharges of Serang at Tongpait (1979).

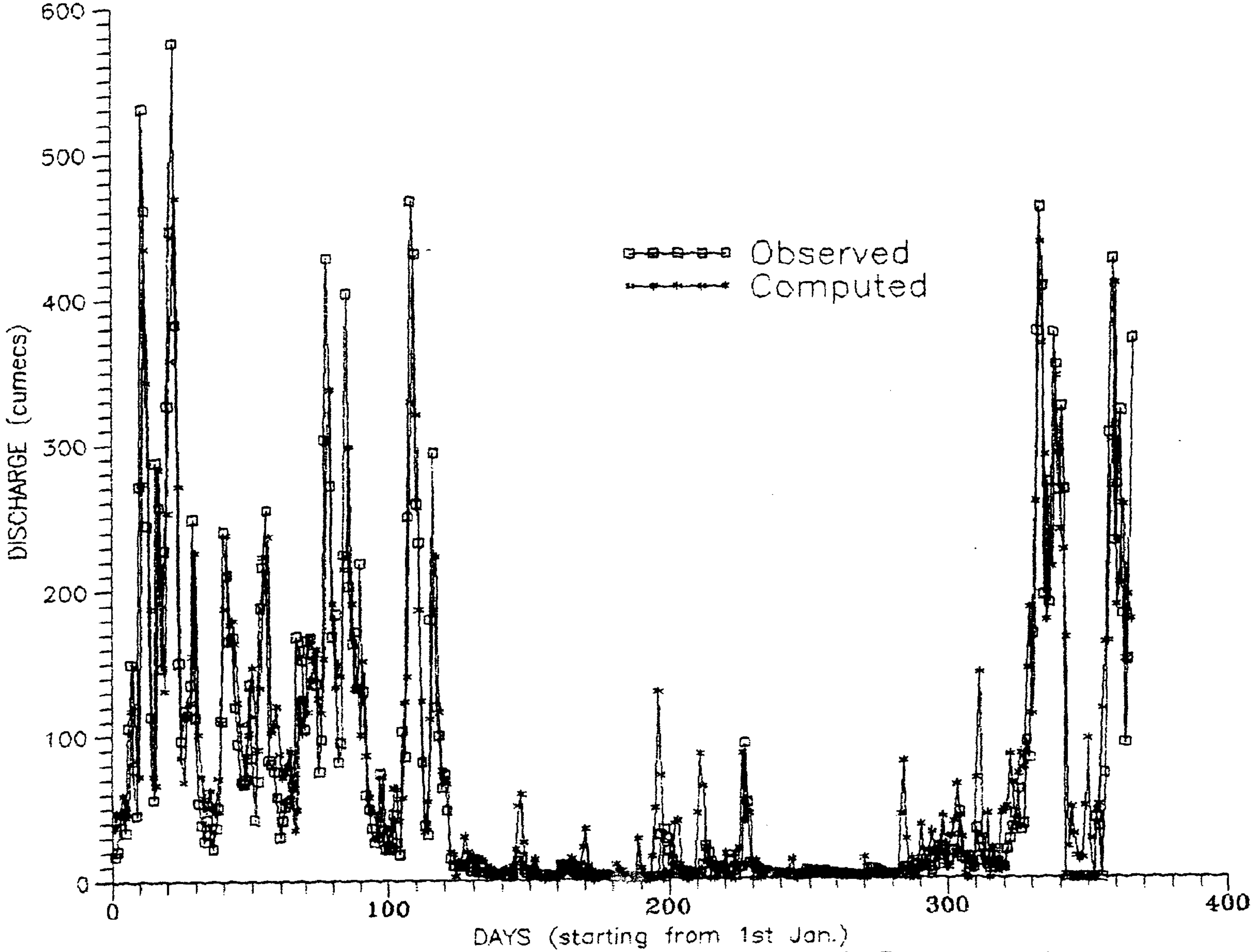


Fig. 5.17: Observed and computed discharges of Serong at Tongpait (1980).

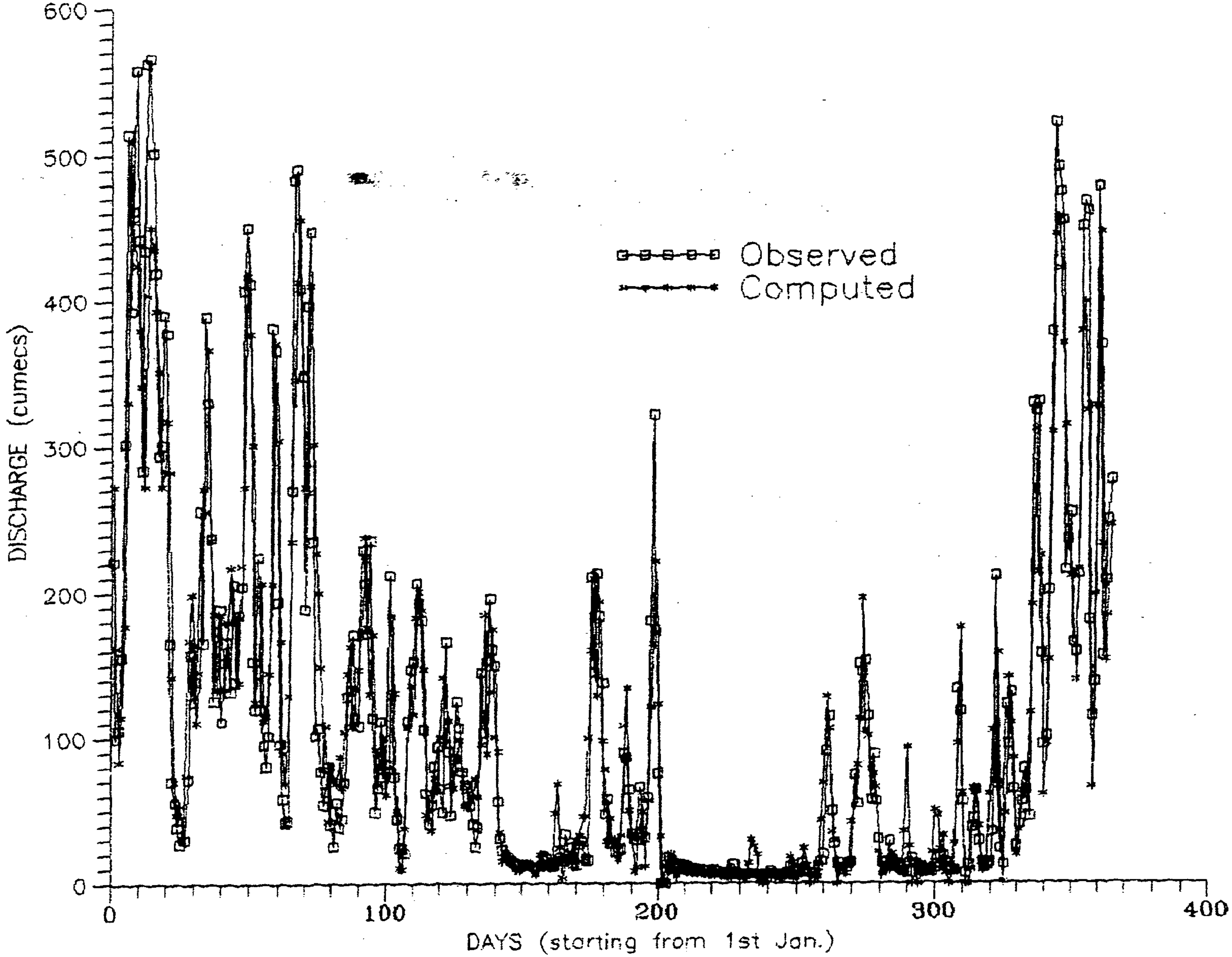


Fig.5.18 Observed and computed discharges of Serang at Tongpait (1981).

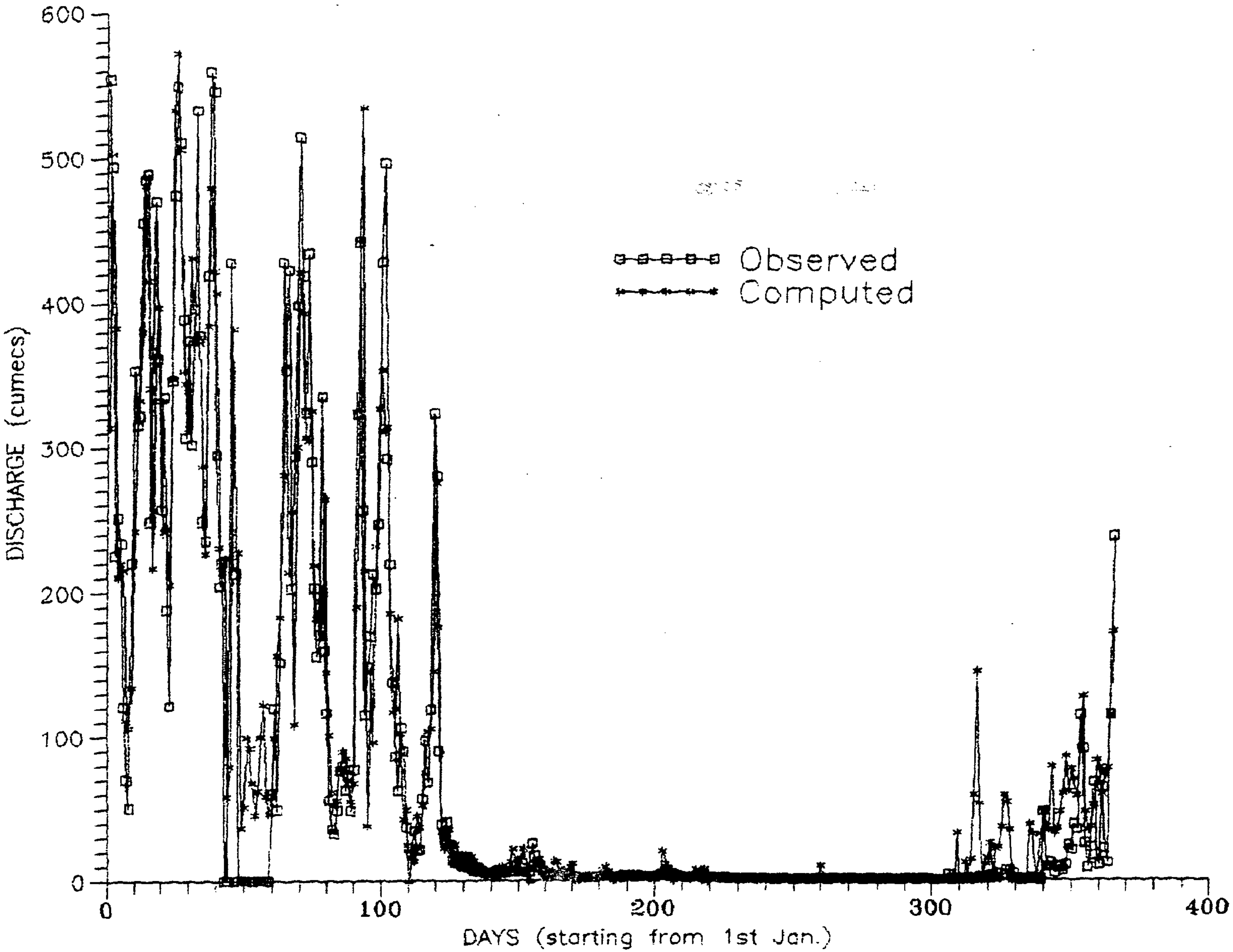


Fig.5.19 Observed and computed discharges of Serang at Tongpait (1982).

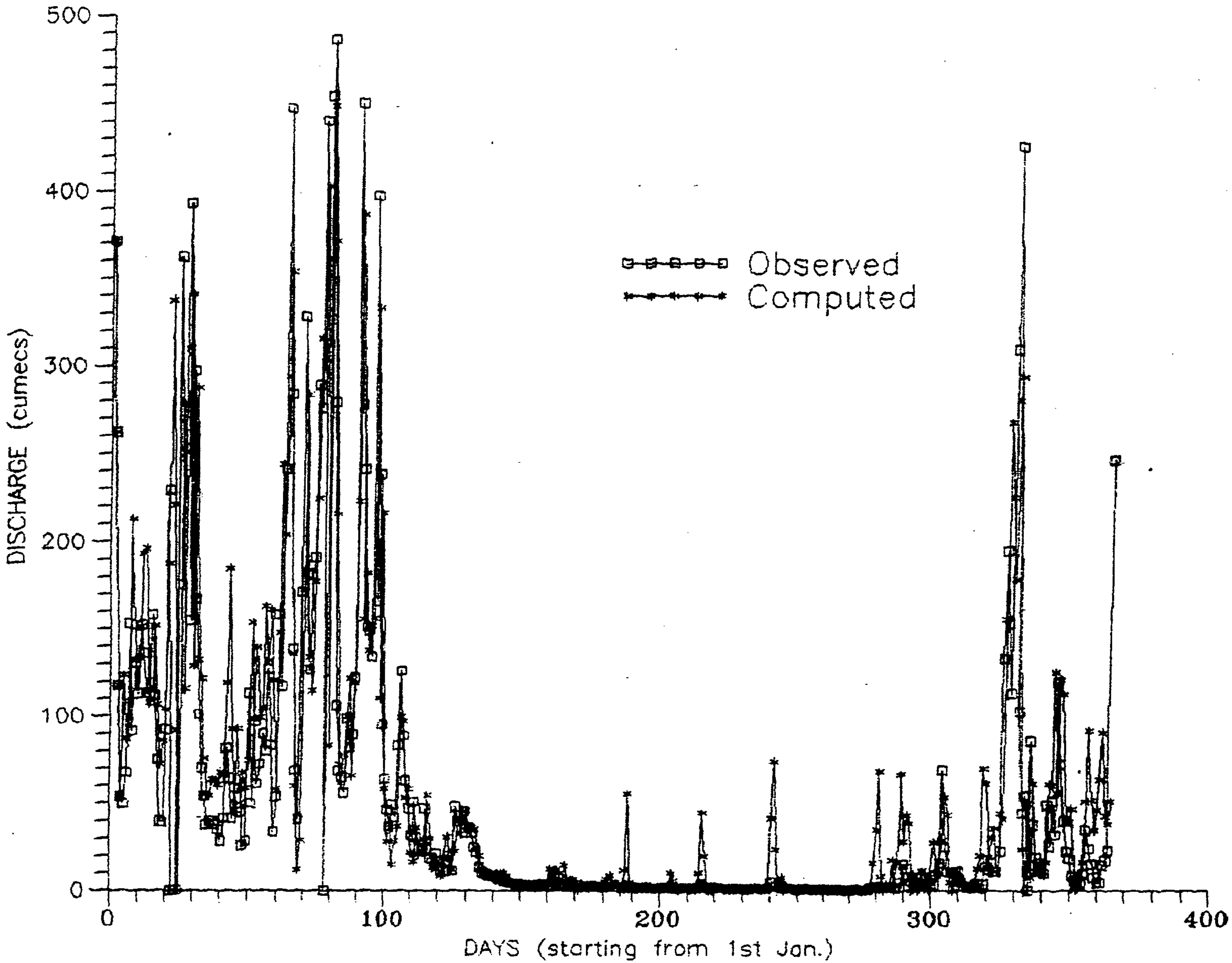


Fig.5.20 Observed and computed discharges of Serang at Tongpait (1976).

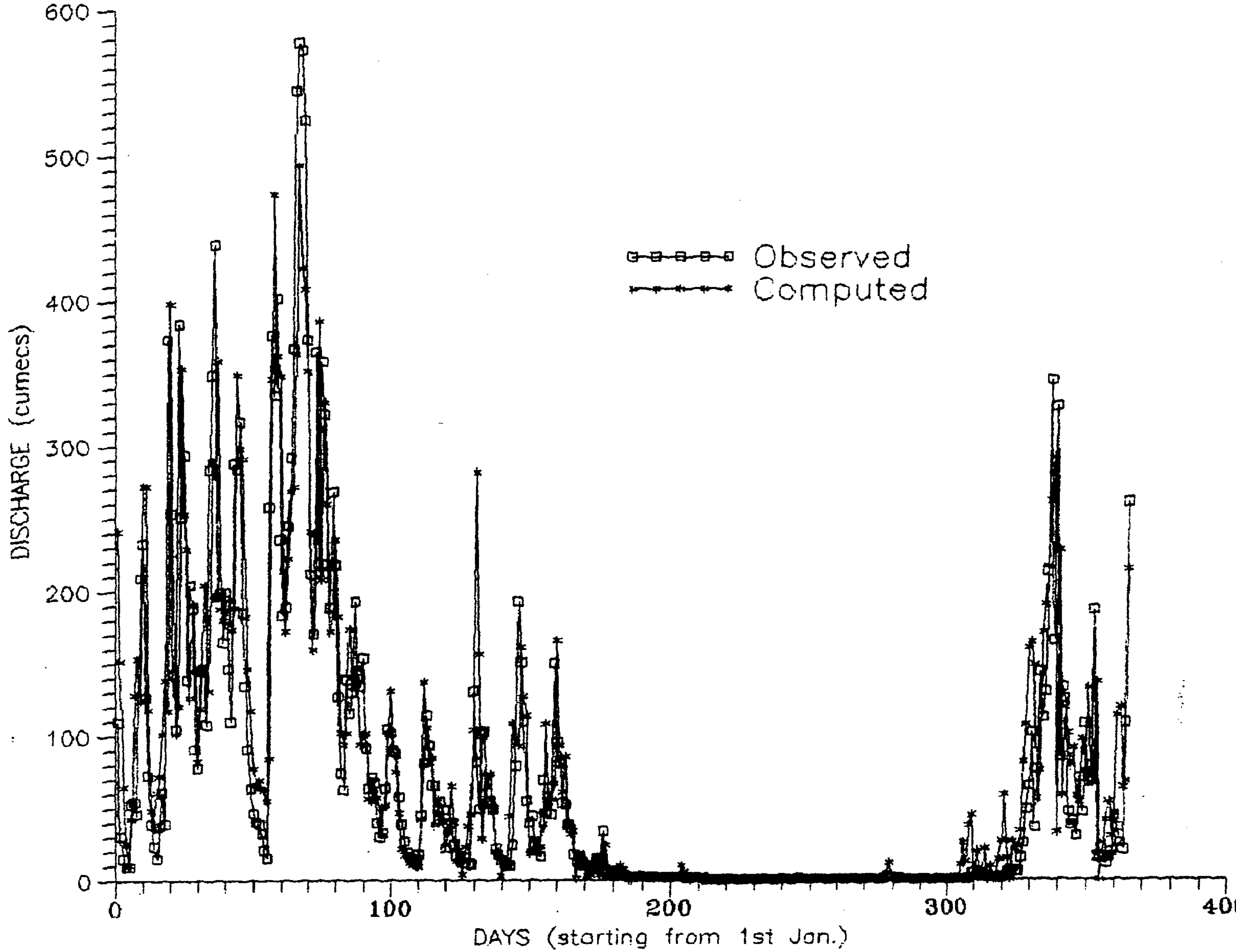


Fig.5.21: Observed and computed discharges of Serong at Tongpait (1977).

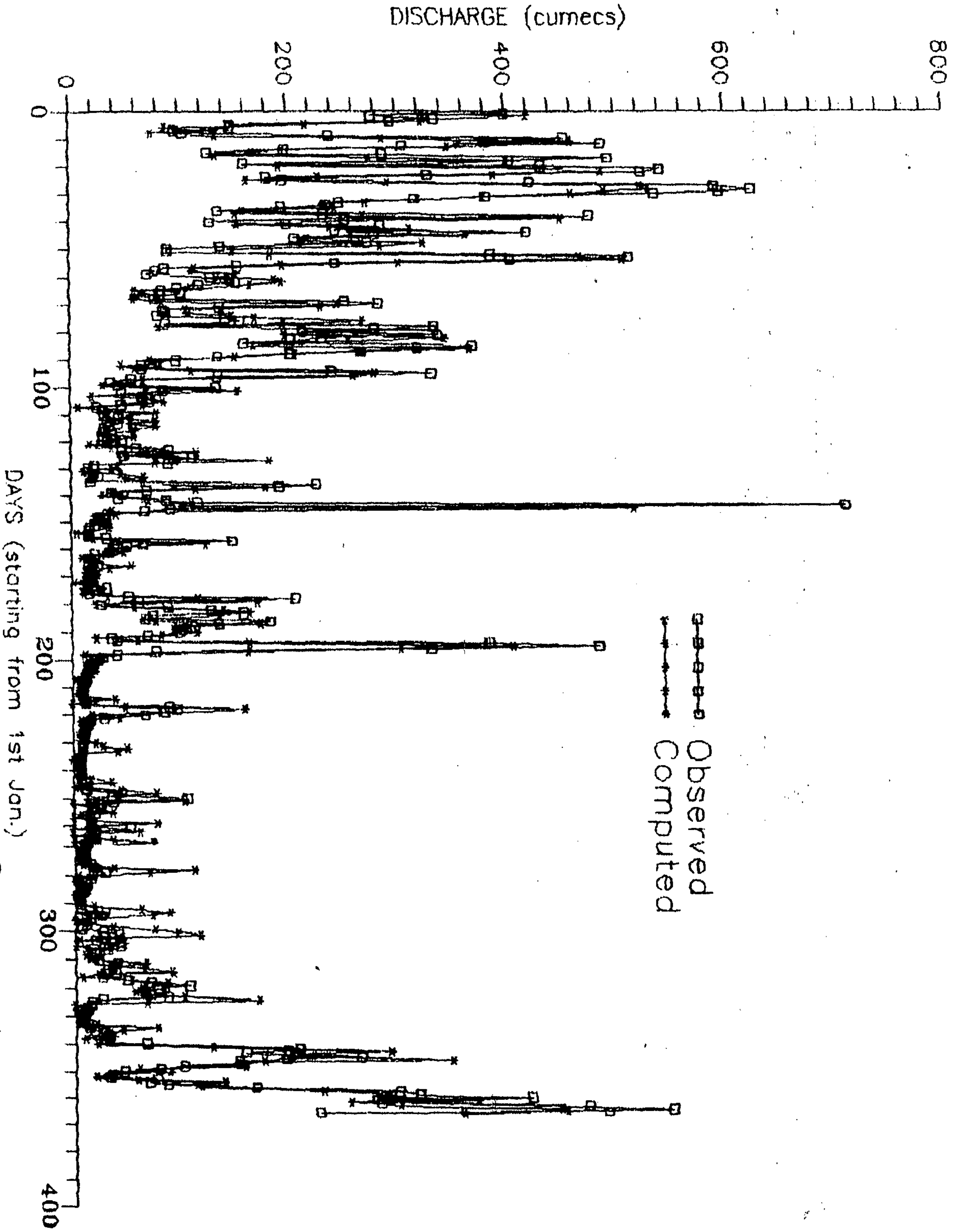


Fig.5.22: Observed and computed discharges of Serang at Tongpait (1978).

Table 5.7: Efficiency of TRL model in calibration and validation mode for Serang at Tongpait.

Calibration

Memory Length	Efficiency with no. of error terms				
	0	1	2	3	4
1	8.87	41.89	41.79	42.64	43.26
2	39.75	65.89	65.80	66.66	67.03
3	54.90	78.34	78.32	78.41	78.82
4	58.50	79.82	79.82	80.28	80.38
5	60.15	80.77	80.79	81.19	81.44
6	61.04	81.32	81.35	81.71	81.94
7	61.48	81.41	81.44	81.78	82.00
8	61.87	81.57	81.60	81.95	82.18
9	62.29	81.78	81.84	82.28	82.50
10	62.54	81.79	81.84	82.30	82.49

Validation with memory length 5

5	51.35	70.328	69.97	69.95	70.48

Table 5.8 : Efficiency of LPM1 model in calibration and validation mode for Serang at Tongpait.

Calibration

Memory Length	Efficiency with no. of error terms				
	0	1	2	3	4
1	58.26	74.42	74.57	74.83	74.91
2	70.80	81.01	81.01	81.06	81.15
3	77.44	86.50	86.51	86.58	86.67
4	78.50	86.80	86.82	86.94	86.98
5	79.16	87.19	87.22	87.32	87.40
6	79.45	87.40	87.45	87.55	87.61
7	79.58	87.40	87.44	87.51	87.58
8	79.71	87.54	87.59	87.67	87.74
9	79.85	87.65	87.72	87.83	87.89
10	79.92	87.69	87.74	87.86	87.92

Validation with memory length 5

5	49.38	69.85	69.27	69.63	70.11

Table 5.9 : Efficiency of LPM2 model in calibration and validation mode for Serang at Tongpait.

Calibration

Memory Length	Efficiency with no. of error terms				
	0	1	2	3	4
1	41.54	68.19	68.51	68.94	69.03
2	54.75	74.11	74.12	74.27	74.41
3	63.01	80.72	80.74	80.87	80.95
4	64.70	81.26	81.29	81.54	81.55
5	65.46	81.76	81.82	82.06	82.15
6	65.78	81.97	82.05	82.25	82.35
7	65.90	81.98	82.06	82.25	82.34
8	66.00	82.06	82.15	82.35	82.44
9	66.17	82.21	82.32	82.58	82.66
10	66.29	82.29	82.29	82.55	82.62

Validation with memory length 5

5	55.75	70.86	70.34	67.54	70.51

Finally for Serang at Tongpait, LPM2 model with memory length of five days and two error terms is recommended.

5.3 Discussion of Results

The results of application of LPM model and TRL model have been discussed in the previous section for individual sites. Keeping in view all the results, the following observations can be made.

1. For Serang river basin, there is no strong seasonality in rainfall and runoff. At the most the hydrological year can be divided in two parts i.e. dry season (June to Oct.) and wet season (Nov. to May). Within wet season or dry season the variation is not much.

   It is because of this reason that LPM models are not giving significantly better performance than TRL model.

2. In general, LPM models are better than TRL model.

3. LPM1 model is better than LPM2 model. However due to smoothening of means. The determination in efficiency is not significant.

4. As the catchment area increases, the performance of linear perturbation model improves. For Serang at Tongpait the efficiency in calibration and validation mode are 81.8% and 70.34% which are quite satisfactory.

5. The incorporation of error model improves the efficiency significantly. For all the three sites the error model with two error terms are sufficient.

The incorporation of error model, in forecasting the flows in real time will be quite useful. However for extending the stream flow records with the help of long term rainfall records, the error model can not be incorporated, as we will not have the observed runoff values.

6. As the catchment area increases, we require much lesser no. of harmonics to smoothen the mean daily discharge and rainfall series.

CHAPTER VI

CONCLUSIONS

Linear perturbation model and single input total response linear model have been applied to three sites of Serang river basin of Indonesia. The effect of memory length and no. of error terms in error model have been studied. Based on the analysis of data and application of models, the following conclusions can be drawn.

1. The increase in memory length, increases the efficiency of linear perturbation model. For the three sites the following memory lengths may be taken
   a. Lusi at Kundurun - 3 days
   b. Lusi at Memdurun - 4 days
   c. Serang at Tonfpait - 5 days

2. For the three sites, two number of error terms in error model are sufficient. The increase in number of error term will, through increase the efficiency, yet increase is not significant.

3. For the three sites, the significant harmonics to smoothen the mean daily discharge and rainfall series are as given under

Site	No. of significant harmonics	
	Runoff	rainfall
a. Lusi at Kundurun	17	63
b. Lusi at Mendurun	8	38
c. Serang at Tongpait	2	36

4. For the three sites the coefficients of equation (4.21) are as follows

Site	Coefficients								
	h_1	h_2	h_3	h_4	h_5	b_1	b_2	b_3	b_4
Lusi at Kundurun	0.35	0.54	0.41	0	0	0.47	0.13	0	0
Lusi at Mendurun	2.11	3.00	1.47	1.84	0	0.35	0.17	0	0
Serang at Tonfpait	1.53	4.93	4.33	1.76	1.37	0.73	-0.07	0	0

For extension of runoff records, error model can not be used. Hence b_1, b_2 will be zero for all three sites.

For forecasting of flows, the error model should be incorporated and b_1, b_2 are given above should be used.

5. The conclusions drawn in the study are site specific. The linear perturbation model may be applied to other sites of other river basins on the similar lines. The performance of perturbation model is quite satisfactory for a basin, where seasonality is not very strong as drainage are also relatively small.

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RAINFALL.F

```
C       ***********************************************************
C       *                                                         *
C       *  DISSERTATION WORK OF SUTJIPTO                          *
C       *  GUIDED BY DR. NK. GOEL                                 *
C       *  PROGRAMME FOR PLOTTING AND CHANGING THE FORMAT OF RAIN- *
C       *  FALL/RUNOFF DATA                                       *
C       *  DEPARTMENT OF HYDROLOGY UNIVERSITY OF ROORKEE INDIA    *
C       *                                                         *
C       ***********************************************************
 DIMENSION RAIN(12,32),NDAY(12),ARAIN(50,12,31),XX1(366)
        INTEGER YEAR
        CHARACTER *200 NAME
        CHARACTER *20 FILE1,FILE2
        DATA NDAY/31,28,31,30,31,30,31,31,30,31,30,31/
        WRITE(*,*) ' INPUT FILE NAME  = '
        READ(*,'(A)')FILE1
        WRITE(*,*) ' OUTPUT FILE NAME = '
        READ(*,'(A)')FILE2
 OPEN(UNIT=1,FILE=FILE1)
        OPEN(UNIT=2,FILE=FILE2)
 OPEN(UNIT=3,FILE='PLOT')
 READ(1,*)IT1,IT2,IT3
 DO 30 I=1,2
 30 READ(1,200)NAME
 WRITE(2,31)NAME
 31 FORMAT(2X,A160)
 REWIND1
        READ(1,*) IT1, IT2, IT3
 WRITE(2,20) IT1, IT2, IT3
        DO 10 I1=1,IT1
 DO 1 I=1,2
 1 READ(1,200) NAME
 200    FORMAT(A200)
 READ(1,*)YEAR
        WRITE(*,*)YEAR
 DO 2 I=1,2
```

```
2 READ(1,200)NAME
K1 = 28
A=YEAR-1900
IF(MOD(A,4).EQ.0)THEN
K1=29
      ENDIF
DO 3 J=1,K1
3 READ (1,*) IDAY,(RAIN(I,J), I=1,12)
DO 4 J=K1+1,30
4 READ(1,*) IDAY,RAIN(1,J),(RAIN(I,J),I=3,12)
READ(1,*) IDAY,RAIN(1,31),RAIN(3,31),RAIN(5,31),RAIN(7,31),
   1  RAIN(8,31),RAIN(10,31),RAIN(12,31)
DO 5 I=1,8
5 READ(1,200)NAME
C       WRITE(2,21)YEAR
21      FORMAT(2X,F10.0)
20 FORMAT(2X,6I8)
J=1
J1=31
WRITE(2,23)YEAR,J,J1
23  FORMAT(2X,6I6)
WRITE(2,22)(RAIN(1,J),J=1,31)
J=2
J1=K1
WRITE(2,23)YEAR,J,J1
WRITE(2,22)(RAIN(2,J),J=1,K1)
J=3
J1=31
WRITE(2,23)YEAR,J,J1
WRITE(2,22)(RAIN(3,J),J=1,31)
J=4
J1=30
WRITE(2,23)YEAR,J,J1
WRITE(2,22)(RAIN(4,J),J=1,30)
J=5
J1=31
```

```
WRITE(2,23)YEAR,J,J1
WRITE(2,22)(RAIN(5,J),J=1,31)
J=6
J1=30
      WRITE(2,23)YEAR,J,J1
WRITE(2,22)(RAIN(6,J),J=1,30)
J=7
J1=31
WRITE(2,23)YEAR,J,J1
WRITE(2,22)(RAIN(7,J),J=1,31)
J=8
J1=31
WRITE(2,23)YEAR,J,J1
WRITE(2,22)(RAIN(8,J),J=1,31)
J=9
J1=30
WRITE(2,23)YEAR,J,J1
WRITE(2,22)(RAIN(9,J),J=1,30)
J=10
J1=31
WRITE(2,23)YEAR,J,J1
WRITE(2,22)(RAIN(10,J),J=1,31)
J=11
J1=30
WRITE(2,23)YEAR,J,J1
WRITE(2,22)(RAIN(11,J),J=1,30)
J=12
J1=31
WRITE(2,23)YEAR,J,J1
WRITE(2,22)(RAIN(12,J),J=1,31)
22      FORMAT(1X,10F7.2)
10 CONTINUE
REWIND 2
READ(2,31)NAME
READ(2,20)IT1,IT2,IT3
DO 100 I=1,IT1
```

```
 ILAST=0
 ISTART=1
 DO 500 K=1,12
 READ(2,*)YEAR1,MONTH,NDAY1
 ILAST=ILAST+NDAY1
 READ(2,*)(XX1(J),J=ISTART,ILAST)
 ISTART=ILAST+1
 500 CONTINUE
 CALL PLOT(XX1,365,1,YEAR1)
 100 CONTINUE
 STOP
       END
```

```
C******L*************************************************************
       SUBROUTINE PLOT (X1,N,OPTION,Y1)
       DIMENSION X1(1),A(101)
       DATA CHAR,GRID,BLANK,ZERO,ANEG/1H*,1H+,1H ,1H0,1H-/
       IF(OPTION.EQ.0) GO TO 71
 WRITE(3,100)Y1
 100 FORMAT(//10X,'HYETOGRAPH FOR THE YEAR = ',2F8.0)
       X1MAX=X1(1)
       DO 51 I=1,N
       IF(X1MAX-X1(I))52,51,51
52     X1MAX=X1(I)
51     CONTINUE
       SF1=X1MAX/100.
       SF2=SF1
       WRITE(3,1)X1MAX
1      FORMAT(20X,'MAX. VALUE OF X1 IS',F10.1)
       WRITE(3,2)SF1
2      FORMAT(20X,'ONE SQUARE IS EQUAL TO'F10.2)
3      FORMAT(16X,101A1)
       DO 55 I=1,101
```

```
55        A(I)=GRID
          WRITE(3,4)(J,J=1,101,10)
4         FORMAT(/2X,'NUM.','    X1',5X,I2,10(6X,I4))
          I=1
          IF(X1(1).GT.0.0)GO TO 60
          NA=1
          A(NA)=ANEG
          GO TO 61
60        NA=X1(1)/SF1+1.5
          A(NA)=CHAR
61        WRITE(3,5)I,X1(I),(A(J),J=1,101)
5         FORMAT(1X,I5,F10.1,101A1)
          DO 56 I=1,101
56        A(I)=BLANK
          DO 57 I=2,N
          IF(X1(I).GT.0.0)GO TO 62
          NA=1
          A(NA)=ANEG
          GO TO 63
62        AA=X1(I)/SF1+1.5
          NA=AA
          A(NA)=CHAR
63        WRITE(3,5)I,X1(I),(A(J),J=1,101)
          DO 58 J=1,101
58        A(J)=BLANK
57        CONTINUE
          DO 59 J=1,101
59        A(J)=GRID
          WRITE(3,3)(A(JJ),JJ=1,101)
          WRITE(3,4)(J,J=1,101,10)
71          RETURN
          END
C.............................................................
```

1 1979 1979

1 MEAN DAILY DISCHARGE DATA OF LUSI AT KUNDURAN YEAR 1979

(FOR INPUT FILE OF RAINFALL.F)

1979

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	10.9	35.1	5.9	.0	13.9	6.3	.9	.0	.2	.9	7.2	[illegible]
2	30.8	17.8	6.1	36.9	10.5	37.6	1.6	.0	.2	1.7	4.5	7.0
3	15.0	8.5	.0	11.9	10.3	12.3	2.3	.0	.2	20.1	2.3	35.1
4	11.5	6.1	.0	10.5	10.3	6.5	1.5	.0	.2	45.3	1.6	67.2
5	13.7	7.0	.0	10.5	11.5	45.3	1.2	.0	.2	12.0	.0	51.1
6	30.2	15.8	.0	15.3	32.6	25.7	1.2	.0	.2	17.2	.0	21.4
7	11.8	7.6	.0	21.5	.0	11.8	1.3	.0	.0	11.5	.0	15.3
8	16.6	28.7	121.0	21.3	.0	68.3	1.6	.0	.0	12.3	.0	7.2
9	8.9	33.3	.0	41.7	.0	29.6	1.7	.0	.0	3.8	.0	4.3
10	10.1	21.3	.0	28.7	.0	14.5	.7	.0	.0	2.1	.0	3.9
11	11.8	28.7	.0	24.8	11.0	13.1	.7	.0	.0	1.3	9.1	4.1
12	11.5	11.5	.0	37.6	11.0	8.3	.0	.0	.8	.9	11.3	4.7
13	7.6	9.1	.0	26.3	10.8	5.9	.0	.0	.5	.7	4.5	2.4
14	.0	.0	.0	23.6	10.8	4.8	.0	.0	.4	.5	3.4	0.7
15	.0	.0	.0	14.2	10.8	3.9	.0	.0	.0	.0	3.8	12.6
16	36.9	.0	.0	21.3	10.8	3.9	.0	.0	.0	.0	6.1	14.2
17	18.4	34.2	.0	.0	10.8	4.1	.0	.0	.0	.0	3.7	16.4
18	21.0	27.2	.0	47.3	10.8	3.9	.0	.0	.3	.0	.0	11.5
19	11.3	17.2	.0	16.1	.0	3.6	.0	.0	.3	.7	.0	7.0
20	18.6	11.7	.0	12.3	.0	3.1	.0	.0	.3	.8	.0	5.7
21	9.3	6.3	.0	14.2	.0	3.0	.0	.0	.4	.7	.0	5.7
22	11.0	6.3	.0	.0	.0	2.8	.0	.6	.4	.5	1.6	8.1
23	19.2	6.3	.0	.0	82.7	2.4	.0	.8	.3	.7	1.6	20.4
24	8.1	18.4	24.8	.0	69.8	2.3	.0	.7	1.5	.7	1.7	19.2
25	5.7	14.2	52.9	.0	48.0	2.3	.0	.7	1.8	.5	1.7	20.4
26	73.5	7.6	46.8	23.0	.0	2.3	.0	.6	8.1	.5	1.6	8.5
27	51.8	14.5	40.7	22.7	.0	2.1	.0	.5	4.2	5.7	7.6	3.9
28	17.8	8.3	23.0	13.4	.0	2.0	.0	.0	.3	2.0	6.8	1.2
29	8.1		32.6	13.4	16.9	2.1	.0	.0	.4	1.5	0.9	.7
30	6.1	—	36.4	13.7	18.4	.9	.0	.2	.9	.7	4.3	2.6
31	10.1		.0		8.5		.0	.2		.9		1.5
TOTAL	534.1	402.7	390.2	522.2	420.2	334.7	14.7	4.3	22.1	146.2	93.3	395.9
MEAN	17.2	14.4	12.6	17.4	13.6	11.2	.5	.1	.7	4.7	3.1	12.8
MAXI	73.5	35.1	121.0	47.3	82.7	68.3	2.3	.8	8.1	45.3	11.3	67.2
MINI	.0	.0	.0	.0	.0	.9	.0	.0	.0	.0	.0	.7

MEAN 9.0 MAXIMUM 121.0 MINIMUM .0 VOLUME 283.4 MILLION M3 ANNUAL RUNOFF 385.9 MM

```
1 MEAN DAILY DISCHARGE DATA OF LUSI AT KUNDURAN YEAR 1979
                (FOR OUTPUT FILE  OF RAINFALL.F)
      1    1979    1979
  1979     1    31
 18.90  38.80  15.80  11.50  13.70  30.20  11.80  16.60   8.90  10.10
 11.80  11.50   7.60   0.00   0.00  36.90  18.40  21.00  11.30  18.60
  9.30  11.00  19.20   8.10   5.70  73.50  51.80  17.80   8.10   6.10
 10.10
  1979     2    28
 35.10  17.80   8.50   6.10   7.00  15.80   7.60  28.70  33.30  21.30
 28.70  11.50   9.10   0.00   0.00   0.00  34.20  27.20  17.20  11.70
  6.30   6.30   6.30  18.40  14.20   7.60  14.50   8.30
  1979     3    31
  5.90   6.10   0.00   0.00   0.00   0.00   0.00 121.00   0.00   0.00
  0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  0.00   0.00   0.00  24.80  52.90  46.80  40.70  23.00  32.60  36.40
  0.00
  1979     4    30
  0.00  36.90  11.90  10.50  10.50  15.30  21.50  21.30  41.70  28.70
 24.80  37.60  26.30  23.60  14.20  21.30   0.00  47.30  16.10  12.30
 14.20   0.00   0.00   0.00   0.00  23.00  22.70  13.40  13.40  13.70
  1979     5    31
 13.90  10.50  10.30  10.30  11.50  32.60   0.00   0.00   0.00   0.00
 11.00  11.00  10.80  10.80  10.80  10.80  10.80  10.80   0.00   0.00
  0.00   0.00  82.70  69.80  48.00   0.00   0.00   0.00  16.90  18.40
  8.50
  1979     6    30
  6.30  37.60  12.30   6.50  45.30  25.70  11.80  68.30  29.60  14.50
 13.10   8.30   5.90   4.80   3.90   3.90   4.10   3.90   3.60   3.10
  3.00   2.80   2.40   2.30   2.30   2.30   2.10   2.00   2.10   0.90
  1979     7    31
  0.90   1.60   2.30   1.50   1.20   1.20   1.30   1.60   1.70   0.70
  0.70   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
  0.00
  1979     8    31
```

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.60	0.80	0.70	0.70	0.60	0.50	0.00	0.00	0.20
0.20									
1979	9	30							
0.20	0.20	0.20	0.20	0.20	0.20	0.00	0.00	0.00	0.00
0.00	0.80	0.50	0.40	0.00	0.00	0.00	0.30	0.30	0.30
0.40	0.40	0.30	1.50	1.80	8.10	4.20	0.30	0.40	0.90
1979	10	31							
0.90	1.70	20.10	45.30	12.00	17.20	11.50	12.30	3.80	2.10
1.30	0.90	0.70	0.50	0.00	0.00	0.00	0.00	0.70	0.80
0.70	0.50	0.70	0.70	0.50	0.50	5.70	2.00	1.50	0.70
0.90									
1979	11	30							
7.20	4.50	2.30	1.60	0.00	0.00	0.00	0.00	0.00	0.00
9.10	11.30	4.50	3.40	3.80	6.10	3.70	0.00	0.00	0.00
0.00	1.60	1.60	1.70	1.70	1.60	7.60	6.80	8.90	4.30
1979	12	31							
3.40	7.00	35.10	67.20	51.10	21.30	15.30	7.20	4.30	3.90
4.10	4.70	2.40	8.70	12.60	14.20	16.40	11.50	7.80	5.70
5.70	8.10	20.40	19.20	20.40	8.50	3.90	1.20	0.70	2.60
1.30									

POWER.F

```
C       ***************************************************************
C       *                                                             *
C       *   DISSERTATION WORK OF SUTJIPTO                             *
C       *   GUIDED BY DR.NK.GOEL                                      *
C       *   MASTER PROGRAMME FOR FILLING THE MISSING DATA USING       *
C       *   POWER DISTANCE METHOD                                     *
C       *   DEPARTMENT OF HYDROLOGY UNIVERSITY OF ROORKEE INDIA       *
C       *                                                             *
C       ***************************************************************
 DIMENSION RAIN1(31),RAIN2(31),CALRAIN(31)
        CHARACTER*200 TITLE1
 CHARACTER*80 FN1
 CHARACTER*80 FN2
 CHARACTER*80 FN3
 WRITE (*,*) 'INPUT FILE NAME OF RAINFALL STATION1 ?'
 READ (*,'(A)')FN1
 WRITE (*,*) 'INPUT FILE NAME OF RAINFALL STATION2 ?'
 READ (*,'(A)')FN2
        WRITE (*,*) 'OUTPUT FILE NAME ?'
 READ(*,'(A)')FN3
 OPEN(UNIT=1,FILE=FN1,STATUS='OLD')
 OPEN(UNIT=2,FILE=FN2,STATUS='OLD')
 OPEN(UNIT=3,FILE=FN3)
        READ(1,9999) TITLE1
        READ(1,*)TT1,TT2,TT3
 9999   FORMAT(200A)
 READ(2,9999)TITLE1
 READ(2,*)TT1,TT2,TT3
 WRITE(3,5)
5 FORMAT(' RAINFALL DATA FROM THE CALCULATION')
 WRITE(3,10)TT1,TT2,TT3
10 FORMAT(3F7.0)
 D1=6.5
 D2=9.0
 DO I=1,100
 DO  J=1,12
```

```
 READ (1,*,END=99) NYEAR1,MON1,MONDAY
 READ(2,*,END=99)NYEAR2,MON2,MONDAY
 IF (NYEAR1.NE.NYEAR2)THEN
 TYPE 2,NYEAR1
 GO TO 99
 END IF
 IF (MON1.NE.MON2)THEN
 TYPE 4,MON1
 GO TO 99
 END IF
2 FORMAT('YEAR NO.' I5' NOT MATCHING')
4 FORMAT('MONTH NO.' I5 'NOT MATCHING')
 READ (1,*)(RAIN1(J1),J1=1,MONDAY)
 READ(2,*)(RAIN2(J1),J1=1,MONDAY)
 WRITE(3,1)NYEAR1,MON1,MONDAY
1 FORMAT(3I5)
 DO J1=1,MONDAY
 CALRAIN(J1)=((RAIN1(J1)/D1**2)+(RAIN2(J1)/D2**2))
     1  /((1/D1**2)+(1/D2**2))
 END DO
 WRITE(3,6)(CALRAIN(J1),J1=1,MONDAY)
6 FORMAT(10F7.2)
 END DO
 END DO
99 STOP
 END
```

RBAR.F

```
C        ***************************************************************
C        *                                                             *
C        *  DISSERTATION WORK OF SUTJIPTO                              *
C        *  GUIDED BY DR.NK. GOEL                                      *
C        *  MASTER PROGRAMME FOR COMPUTATION OF AVERAGE RAINFALL       *
C        *  OF SERANG RIVER BASIN, INDONESIA USING THIESEN POLYGON     *
C        *  METHOD                                                     *
C        *  DEPARTMENT OF HYDOLOGY UNIVERSITY OF ROORKEE, INDIA        *
C        *                                                             *
C        ***************************************************************
         DIMENSION RAIN1(31),RAIN2(31),RAIN3(31),RAIN4(31),
     1   RAIN5(31),RAIN6(31),RAIN7(31),RAIN8(31),RAIN9(31),
     1   RAIN10(31),AVERAIN(31)
         CHARACTER*200 TITLE1
         CHARACTER*80 FN1,FN2,FN3,FN4,FN5,FN6,FN7,FN8,FN9,
     1   FN10,FN11
         WRITE (*,*) 'INPUT FILE NAME OF RAINFALL STATION1 ?'
         READ (*,'(A)')FN1
         WRITE (*,*) 'INPUT FILE NAME OF RAINFALL STATION2 ?'
         READ (*,'(A)')FN2
         WRITE (*,*)'INPUT FILE NAME OF RAINFALL STATION3 ?'
         READ (*,'(A)')FN3
         WRITE (*,*) 'INPUT FILE NAME OF RAINFALL STATION4 ?'
         READ (*,'(A)')FN4
         WRITE (*,*) 'INPUT FILE NAME OF RAINFALL STATION5 ?'
         READ (*,'(A)')FN5
         WRITE (*,*) 'INPUT FILE NAME OF RAINFALL STATION6 ?'
         READ (*,'(A)')FN6
         WRITE (*,*) 'INPUT FILE NAME OF RAINFALL STATION7 ?'
         READ (*,'(A)')FN7
         WRITE (*,*) 'INPUT FILE NAME OF RAINFALL STATION8 ?'
         READ (*,'(A)')FN8
         WRITE (*,*) 'INPUT FILE NAME OF RAINFALL STATION9 ?'
         READ (*,'(A)')FN9
         WRITE (*,*) 'INPUT FILE NAME OF RAINFALL STATION10 ?'
         READ (*,'(A)')FN10
         WRITE (*,*) 'OUTPUT FILE NAME ?'
         READ(*,'(A)')FN11
         OPEN(UNIT=1,FILE=FN1,STATUS='OLD')
         OPEN(UNIT=2,FILE=FN2,STATUS='OLD')
         OPEN(UNIT=3,FILE=FN3,STATUS='OLD')
         OPEN(UNIT=4,FILE=FN4,STATUS='OLD')
         OPEN(UNIT=5,FILE=FN5,STATUS='OLD')
         OPEN(UNIT=6,FILE=FN6,STATUS='OLD')
         OPEN(UNIT=7,FILE=FN7,STATUS='OLD')
         OPEN(UNIT=8,FILE=FN8,STATUS='OLD')
         OPEN(UNIT=9,FILE=FN9,STATUS='OLD')
         OPEN(UNIT=10,FILE=FN10,STATUS='OLD')
         OPEN(UNIT=11,FILE=FN11)
         READ(1,9999) TITLE1
         READ(1,*)TT1,TT2,TT3
 9999    FORMAT(200A)
         READ(2,9999)TITLE1
         READ(2,*)TT1,TT2,TT3
```

```
      READ(3,9999)TITLE1
      READ(3,*)TT1,TT2,TT3
      READ(4,9999)TITLE1
      READ(4,*)TT1,TT2,TT3
      READ(5,9999)TITLE1
      READ(5,*)TT1,TT2,TT3
      READ(6,9999)TITLE1
      READ(6,*)TT1,TT2,TT3
      READ(7,9999)TITLE1
      READ(7,*)TT1,TT2,TT3
      READ(8,9999)TITLE1
      READ(8,*)TT1,TT2,TT3
      READ(9,9999)TITLE1
      READ(9,*)TT1,TT2,TT3
      READ(10,9999)TITLE1
      READ(10,*)TT1,TT2,TT3
      WRITE(11,5)
5     FORMAT(' AVERAGE RAINFALL OF THE BASIN')
      WRITE(11,10)TT1,TT2,TT3
10    FORMAT(3F7.0)
      A1=0.053
      A2=0.037
      A3=0.082
      A4=0.064
      A5=0.05
      A6=0.061
      A7=0.176
      A8=0.188
      A9=0.260
      A10=0.029
      DO I=1,100
      DO  J=1,12
      READ (1,*,END=99) NYEAR1,MON1,MONDAY
      READ(2,*,END=99)NYEAR2,MON2,MONDAY
      READ(3,*,END=99)NYEAR3,MON3,MONDAY
      READ(4,*,END=99)NYEAR4,MON4,MONDAY
      READ(5,*,END=99)NYEAR5,MON5,MONDAY
      READ(6,*,END=99)NYEAR6,MON6,MONDAY
      READ(7,*,END=99)NYEAR7,MON7,MONDAY
      READ(8,*,END=99)NYEAR8,MON8,MONDAY
      READ(9,*,END=99)NYEAR9,MON9,MONDAY
      READ(10,*,END=99)NYEAR10,MON10,MONDAY
      IF (NYEAR1.NE.NYEAR2.OR.NYEAR1.NE.NYEAR3.OR.NYEAR1.NE.
     1 NYEAR4.OR.NYEAR1.NE.NYEAR5.OR.NYEAR1.NE.NYEAR6.OR.NYEAR1
     1 .NE.NYEAR7.OR.NYEAR1.NE.NYEAR8.OR.NYEAR1.NE.NYEAR9.OR.
     1 NYEAR1.NE.NYEAR10)THEN
      WRITE(11,2)NYEAR1
      GO TO 99
      END IF
      IF (MON1.NE.MON2.OR.MON1.NE.MON3.OR.MON1.NE.MON4
     1 .OR.MON1.NE.MON5.OR.MON1.NE.MON6.OR.MON1.NE.MON7
     1 .OR.MON1.NE.MON8.OR.MON1.NE.MON9.OR.MON1.NE.MON10
     1 )THEN
      WRITE(11,4)MON1
```

```
      GO TO 99
      END IF
2     FORMAT('YEAR NO.' I5' NOT MATCHING')
4     FORMAT('MONTH NO.' I5 'NOT MATCHING')
      READ (1,*)(RAIN1(J1),J1=1,MONDAY)
      READ (2,*)(RAIN2(J1),J1=1,MONDAY)
      READ (3,*)(RAIN3(J1),J1=1,MONDAY)
      READ (4,*)(RAIN4(J1),J1=1,MONDAY)
      READ (5,*)(RAIN5(J1),J1=1,MONDAY)
      READ (6,*)(RAIN6(J1),J1=1,MONDAY)
      READ (7,*)(RAIN7(J1),J1=1,MONDAY)
      READ (8,*)(RAIN8(J1),J1=1,MONDAY)
      READ (9,*)(RAIN9(J1),J1=1,MONDAY)
      READ (10,*)(RAIN10(J1),J1=1,MONDAY)
      WRITE(11,1)NYEAR1,MON1,MONDAY
1     FORMAT(3I5)
      DO J1=1,MONDAY
      AVERAIN(J1)=A1*RAIN1(J1)+A2*RAIN2(J1)+A3*RAIN3(J1)+
     1 A4*RAIN4(J1)+A5*RAIN5(J1)+A6*RAIN6(J1)+A7*RAIN7(J1)+
     1 A8*RAIN8(J1)+A9*RAIN9(J1)+A10*RAIN10(J1)
      END DO
      WRITE(11,6)(AVERAIN(J1),J1=1,MONDAY)
6     FORMAT(10F7.2)
      END DO
      END DO
99    STOP
      END
```

TESTING.F

```
C *************************************************************
C       *                                                         *
C       *  DISSERTATION WORK OF SUTJIPTO                          *
C       *  GUIDED BY DR.N.K.GOEL                                  *
C       *  HYBRID MODEL FOR DAILY RUNOFF ANALYSIS,MEAN DAILY RUNOFF *
C       *  AND MEAN DAILY RAINFALL ARE SMOOTHENED USING HARMONICS  *
C       *  FITTING AND MODEL PARAMETERS ARE UPTODATED             *
C       *  DEPARTMENT OF HYDROLOGY UNIVERSITY OF ROORKEE, INDIA    *
C       *                                                         *
C       ***********************************************************
 DIMENSION SUMD(365),SUMR(365),NYEAR(50),NDAY(12),DIS(31)
 DIMENSION DISCHARG(1500),AMDIS(365),DIFFQ(1500),R(31)
 DIMENSION RF(1500),AMR(365),DIFFR(1500),Y(1500),A(2500)
 DIMENSION X(1500,30),XT(30,1500),XTX(30,30),XTY(30)
 DIMENSION XINV(30,30),COEF(30),LMN(1500),MNO(1500)
 DIMENSION CDIS(1500),CDIFFQ(1500),SS1(12)
 DIMENSION ERR(1500),ERH(30)
 DIMENSION Y1(1500),A1(2500),CERR(1500)
 DIMENSION X1(1500,30),XT1(30,1500),XTX1(30,30),XTY1(30)
 DIMENSION XINV1(30,30),COEF1(30),LMN1(1500),MNO1(1500)
 DIMENSION HMDIS(365),HMR(365),T(30)
        CHARACTER*200 TITLE1
 CHARACTER*80 FN1
 CHARACTER*80 FN2
 CHARACTER*80 FN3
 OPEN(UNIT=7,FILE='TESTING.DAT',STATUS='OLD')
 OPEN(UNIT=8,FILE='COEF1.DAT')
 WRITE (*,*) 'INPUT FILE NAME OF RUNOFF ?'
 READ (7,'(A)')FN1
 WRITE (*,*) 'INPUT FILE NAME OF RAINFALL ?'
 READ (7,'(A)')FN2
        WRITE (*,*) 'OUTPUT FILE NAME ?'
 READ(7,'(A)')FN3
 WRITE(*,*) 'DO YOU WANT TO CALIBRATE THE MODEL?'
 READ(7,334)IANS
 334 FORMAT(A4)
```

```
DATA NDAY/31,28,31,30,31,30,31,31,30,31,30,31/
DATA IYES/'YES'/
OPEN(UNIT=1,FILE=FN1,STATUS='OLD')
OPEN(UNIT=2,FILE=FN2,STATUS='OLD')
OPEN(UNIT=3,FILE=FN3)
DO 1 I=1,365
SUMD(I)=0.0
SUMR(I)=0.0
1 CONTINUE
WRITE(*,*)'BEGINING YEAR'
READ(7,*)NBYEAR
WRITE(*,*)'ENDING YEAR'
READ(7,*)NEYEAR
NYR=NEYEAR-NBYEAR+1
K2=0
K1=0
SUMD1=0
       READ(1,9999) TITLE1
       READ(1,*)TT1,TT2,TT3
9999   FORMAT(200A)
       DO 2 I=1,NYR
K=0
DO 3 J=1,12
READ (1,*) NYEAR(I),MON,MONDAY
READ (1,*)(DIS(J1),J1=1,MONDAY)
IF(J.EQ.2.AND.MONDAY.EQ.29)THEN
DIS(28)=(DIS(28)+DIS(29))/2.
END IF
DO 4 J1=1,NDAY(J)
K=K+1
SUMD(K)=SUMD(K)+DIS(J1)
K2=K2+1
DISCHARG(K2)=DIS(J1)
4 CONTINUE
3 CONTINUE
2 CONTINUE
```

```
IF(IANS.NE.IYES)THEN
OPEN(UNIT=4,FILE='COEF.DAT',STATUS='OLD')
READ(4,*)(HMDIS(I),I=1,365)
GO TO 742
END IF
DO 5 I=1,K
AMDIS(I)=SUMD(I)/NYR
5 CONTINUE
CALL HARM(AMDIS,HMDIS,NYR,20,365,2,1,1.)
742 WRITE(3,951)
951 FORMAT(5X'MEAN VALUES OF AMDIS')
WRITE(3,452)(AMDIS(I),I=1,K)
        GO TO 666
666 WRITE(3,451)
451 FORMAT(10X,'SMOOTHENED MEAN VALUES OF DISCHARGE HMDIS')
WRITE(3,452)(HMDIS(I),I=1,K)
WRITE(8,452)(HMDIS(I),I=1,K)
DO I=1,K
HMDIS(I)=AMDIS(I)
END DO
452 FORMAT(10F7.2)
NB=1
DO 6 II=1,NYR
NE=NB+364
K=0
DO 7 I=NB,NE
K=K+1
DIFFQ(I)=DISCHARG(I)-HMDIS(K)
7 CONTINUE
NB=NE+1
6 CONTINUE
NDQ=K2
K2=0
K1=0
SUMR1=0.0
        READ(2,9999)TITLE1
```

```
      READ(2,*)TT1,TT2,TT3
DO 10 II=1,NYR
K=0
DO 11 J=1,12
READ (2,*) NYEAR(II),MON,MONDAY
READ (2,*) (R(J1),J1=1,MONDAY)
IF(J.EQ.2.AND.MONDAY.EQ.29)THEN
R(28)=(R(28)+R(29))/2.
END IF
DO 12 J1=1,NDAY(J)
K=K+1
SUMR(K)=SUMR(K)+R(J1)
K2=K2+1
RF(K2)=R(J1)
12 CONTINUE
11 CONTINUE
10 CONTINUE
IF(IANS.NE.IYES)THEN
READ(4,*)(HMR(I),I=1,365)
GO TO 743
END IF
DO 14 I=1,K
AMR(I)=SUMR(I)/NYR
14 CONTINUE
CALL HARM(AMR,HMR,NYR,100,365,36,1,1.)
J1=365
743 WRITE(3,954)
954 FORMAT(5X'MEAN VALUES OF AVERAGE RAINFALL AMR')
WRITE(3,452)(AMR(I),I=1,K)
      GO TO 888
888 WRITE(3,454)
454 FORMAT(10X,'SMOOTHENED MEAN VALUES OF AVERAGE RAINFALL HMR')
WRITE(3,452)(HMR(I),I=1,K)
WRITE(8,452)(HMR(I),I=1,K)
DO I=1,K
      HMR(I)=AMR(I)
```

```
END DO
NB=1
DO 15 II=1,NYR
NE=NB+364
K=0
DO 16 I=NB,NE
K=K+1
    DIFFR(I)=RF(I)-HMR(K)
16 CONTINUE
NB=NE+1
15 CONTINUE
WRITE(*,*)'SUPPLY MEMORY LENGTH'
READ(*,*)ML
K=O
DO 19 I=ML,NDQ
K=K+1
Y(K)=DIFFQ(I)
19  CONTINUE
DO 20 I=1,ML
K=0
DO 21 J=ML+1-I,NDQ-I+1
K=K+1
X(K,I)=DIFFR(J)
21 CONTINUE
20 CONTINUE
N=NDQ-ML+1
M=ML
IF(IANS.NE.IYES)THEN
READ(4,*)(COEF(I),I=1,M)
READ(4,*)(COEF1(I),I=1,4)
CLOSE(UNIT=4)
GO TO 338
END IF
DO 22 I=1,N
DO 23 J=1,M
XT(J,I)=X(I,J)
```

```
 23 CONTINUE
 22 CONTINUE
 DO 24 I=1,M
 DO 25 J=1,M
 XTX(I,J)=0.0
 DO 26 K=1,N
 XTX(I,J)=XTX(I,J)+XT(I,K)*X(K,J)
 26 CONTINUE
 25 CONTINUE
 24 CONTINUE
 DO 27 I=1,M
 XTY(I)=0.0
 DO 28 J=1,N
 XTY(I)=XTY(I)+XT(I,J)*Y(J)
 28 CONTINUE
 27 CONTINUE
 K=0
 DO 29 I=1,M
 DO 30 J=1,M
 K=K+1
 A(K)=XTX(I,J)
 30 CONTINUE
C WRITE (*,*)'I=',I,(XTX(I,J),J=1,M)
 29 CONTINUE
 CALL MINV(A,M,D,LMN,MNO)
 K=0
 DO 31 I=1,M
 DO 32 J=1,M
 K=K+1
 XINV(I,J)=A(K)
 32 CONTINUE
 31 CONTINUE
 DO 33 I=1,M
 COEF(I)=0.0
 DO 34 J=1,M
 34 COEF(I)=COEF(I)+XINV(I,J)*XTY(J)
```

```
33 CONTINUE
338 WRITE(3,740)ML
740 FORMAT(6X,'MEMORY LENGTH=',I3,' DAYS')
WRITE (3,540)
WRITE(*,540)
540 FORMAT(10X,'REGRESSION COEFFICIENTS')
WRITE(3,541)(COEF(I),I=1,M)
WRITE(8,541)(COEF(I),I=1,M)
WRITE(*,541)(COEF(I),I=1,M)
541 FORMAT(10F9.5)
DO 35 I=1,ML-1
CDIFFQ(I)=DIFFQ(I)
35 CONTINUE
K=0
DO 36 I=ML,NDQ
K=K+1
CDIFFQ(I)=0.0
DO 37 J=1,M
CDIFFQ(I)=CDIFFQ(I)+X(K,J)*COEF(J)
37 CONTINUE
36 CONTINUE
NB=1
DO 38 II=1,NYR
NE=NB+364
K=0
DO 39 I=NB,NE
K=K+1
CDIS(I)=CDIFFQ(I)+HMDIS(K)
IF(CDIS(I).LT.0.0)CDIS(I)=0.0
39 CONTINUE
NB=NE+1
38 CONTINUE
SSM=0.0
DO 42 I=1,NDQ
ERR(I)=DISCHARG(I)-CDIS(I)
SSM=SSM+ERR(I)*ERR(I)
```

```
42 CONTINUE
VARE=SSM/(NDQ-M)
IF(IANS.NE.IYES) GO TO 777
DO 99 I=1,M
VARH=XINV(I,I)*VARE
ERH(I)=SQRT(VARH)
99 CONTINUE
912     FORMAT(10F9.3)
WRITE(3,542)
WRITE(*,542)
542 FORMAT(10X,'STANDARD ERROR OF REGRESSION COEFFICIENTS')
WRITE(3,541)(ERH(I),I=1,M)
WRITE(*,541)(ERH(I),I=1,M)
DO I=1,M
T(I)=(COEF(I)/ERH(I))
END DO
WRITE(3,911)
WRITE(*,911)
911 FORMAT(10X,'T VALUES OF COEFFICIENTS')
WRITE(3,912)(T(I),I=1,M)
WRITE(*,912)(T(I),I=1,M)
777 WRITE(*,*)'DO YOU WANT TO INCORPORATE ERROR MODEL ?'
READ(*,334)IANS1
       IF(IANS1.NE.IYES)GO TO 999
       WRITE (*,*)'SUPPLY LEAD TIME FOR UPDATING'
READ (*,*) NP
K=0
DO 44 I=NP+ML,NDQ
K=K+1
Y1(K)=ERR(I)
44 CONTINUE
KKK=4
DO 45 I=1,KKK
K=0
DO 46 J=ML+1-I,NDQ-NP+1-I
K=K+1
```

```
X1(K,I)=ERR(J)
46 CONTINUE
45 CONTINUE
IF(IANS.NE.IYES)GO TO 744
NN=NDQ-NP-ML+1
MM=KKK
DO 47 I=1,NN
DO 48 J=1,MM
XT1(J,I)=X1(I,J)
48 CONTINUE
47 CONTINUE
       DO 49 I=1,MM
DO 50 J=1,MM
XTX1(I,J)=0.0
DO 51 K=1,NN
XTX1(I,J)=XTX1(I,J)+XT1(I,K)*X1(K,J)
51 CONTINUE
50 CONTINUE
49 CONTINUE
DO 52 I=1,MM
XTY1(I)=0.0
DO 53 J=1,NN
XTY1(I)=XTY1(I)+XT1(I,J)*Y1(J)
53 CONTINUE
52 CONTINUE
K=0
DO 54 I=1,MM
DO 55 J=1,MM
K=K+1
A1(K)=XTX1(I,J)
55 CONTINUE
54 CONTINUE
CALL MINV(A1,MM,D,LMN1,MNO1)
K=0
DO 56 I=1,MM
DO 57 J=1,MM
```

```
K=K+1
       XINV1(I,J)=A1(K)
57 CONTINUE
56  CONTINUE
DO 58 I=1,MM
COEF1(I)=0.0
DO 59 J=1,MM
COEF1(I)=COEF1(I)+XINV1(I,J)*XTY1(J)
59 CONTINUE
58 CONTINUE
WRITE(8,541)(COEF1(I),I=1,MM)
744 K=0
MM=KKK
DO 60 I=ML,NDQ
IF(I.GE.NP+ML)THEN
K=K+1
CERR(I)=0.0
DO 61 J=1,MM
CERR(I)=CERR(I)+X1(K,J)*COEF1(J)
61 CONTINUE
CDIS(I)=CDIS(I)+CERR(I)
       IF(CDIS(I).LT.0.0)CDIS(I)=0.0
END IF
60 CONTINUE
WRITE(3,643)NP
643 FORMAT(4X,'LEAD TIME USED IN UPDATING-',I3,'DAYS')
WRITE(3,642)
642 FORMAT(10X,'REGRESSION COEFFICIENTS IN UPDATING EQUATION')
WRITE(3,541)(COEF1(J),J=1,MM)
999    CONTINUE
NB=1
NE=0
WRITE(3,747)
747 FORMAT(10X,'COMPUTED DISCHARGE ORDINATES')
DO 62 II=1,NYR
DO 63 J=1,12
```

```
NE=NE+NDAY(J)
WRITE(3,745)NYEAR(II),J
WRITE(3,746)(CDIS(I),I=NB,NE)
NB=NE+1
63 CONTINUE
62 CONTINUE
745 FORMAT(2I5)
746 FORMAT(10F7.2)
NB=1
SS2=0
DO 64 I=1,NDQ
SS2=SS2+DISCHARG(I)
64 CONTINUE
AMEAN=SS2/NDQ
SS2=0.0
SS3=0.0
DO 65 I=1,NYR
 WRITE(3,235)NYEAR(I)
235 FORMAT(1X,'YEAR:--',I4)
SS=0.0
DO 66 J=1,12
IF(I.EQ.1.AND.J.EQ.1)THEN
NE=NDAY(J)
ELSE
NE=NE+NDAY(J)
END IF
SS1(J)=0.0
DO 67 K=NB,NE
SS1(J)=SS1(J)+(CDIS(K)-DISCHARG(K))**2
SS2=SS2+(DISCHARG(K)-AMEAN)**2
67 CONTINUE
NB=NE+1
66 CONTINUE
WRITE(3,236)
236 FORMAT(10X,'MONTHLY VARIANCES')
WRITE(3,237)(SS1(J),J=1,12)
```

```
 237 FORMAT(4X,6F9.1)
 DO 68 J=1,12
 SS=SS+SS1(J)
 68 CONTINUE
 WRITE(3,238)
 238 FORMAT(10X,'ANNUAL VARIANCE')
 WRITE(3,237)SS
 SS3=SS3+SS
 65 CONTINUE
 EFF=(SS2-SS3)/SS2
 EFF=EFF*100
 WRITE(3,438)EFF
 WRITE(*,438)EFF
 438 FORMAT(4X,'OVERALL EFFICIENCY (%)= ',F10.3)
C TESTING OF THE MODEL IN TESTING MODEL
1000 STOP
 END
C
C
 SUBROUTINE MINV(A,N,D,L,M)
 DIMENSION A(1),L(1),M(1)
C SEARCH FOR LARGEST ELEMENT
 D=1.0
 NK=-N
 DO 80 K=1,N
 NK=NK+N
 L(K)=K
 M(K)=K
 KK=NK+K
 BIGA=A(KK)
 DO 20 J=K,N
 IZ=N*(J-1)
 DO 20 I=K,N
 IJ=IZ+I
 10 IF(ABS(BIGA)-ABS(A(IJ))) 15,20,20
 15 BIGA=A(IJ)
```

```
 L(K)=I
 M(K)=J
 20 CONTINUE
C INTERCHANGE ROWS
 J=L(K)
 IF(J-K) 35,35,25
 25 KI=K-N
 DO 30 I=1,N
 KI=KI+N
 HOLD=-A(KI)
 JI=KI-K+J
 A(KI)=A(JI)
 30 A(JI)=HOLD
C INTERCHANGE COLUMNS
 35 I=M(K)
 IF(I-K)45,45,38
 38 JP=N*(I-1)
 DO 40 J=1,N
 JK=NK+J
 JI=JP+J
 HOLD=-A(JK)
 A(JK)=A(JI)
 40 A(JI)=HOLD
C DIVIDE COLUMNS BY MINUS PIVOT
 45 IF(BIGA)48,46,48
 46 D=0.0
 RETURN
 48 DO 55 I=1,N
 IF(I-K)50,55,50
 50 IK=NK+I
 A(IK)=A(IK)/(-BIGA)
 55 CONTINUE
C REDUCE MATRIX
 DO 65 I=1,N
 IK=NK+I
 HOLD=A(IK)
```

```
52        X(I)=X(I)+A(J)*COS(THETA)+B(J)*SIN(THETA)
51        X(I)=X(I)+XBAR
C         CHECK IF THERE ARE NEGATIVE ORDINATES
          DO 53 I=1,W
          IF(X(I).LT.0.0)GO TO 54
53        CONTINUE
          GO TO 55
C         CALCULATE THE TOTAL NEGATIVE VOLUME
54        IF(KMAX.EQ.0)GO TO 56
          GO TO 57
56        SVOL=0.0
          DO 58 I=1,W
          IF(X(I).LT.0.0)SVOL=SVOL+(X(I)*(-1.0))
58        CONTINUE
          TVOL=(SVOL/(XBAR*W))*100.0
57        CONTINUE
C         CHECK THE OPTIONS
          IF(NOPT.EQ.0)GO TO 55
C         CARRY OUT THE CORRECTIONS
          KMAX=KMAX+KDEL
          DO 59 J=1,N
          IF(NOPT.EQ.1)AK(J)=KMAX
          IF(NOPT.EQ.2)AK(J)=(FLOAT(J)/FLOAT(N))*KMAX
59        CONTINUE
C         CALCULATE CONSTRAINED COEFFICIENTS
          DO 60 J=1,N
          A(J)=((W/2.)*A(J))/((W/2.)+AK(J))
          B(J)=((W/2.)*B(J))/((W/2.)+AK(J))
60        CONTINUE
          GO TO 61
55        CONTINUE
          WRITE(3,2)
2         FORMAT(/6X'A(J)'5X'B(J)'1X'C(J)**2/2'3X'VAR'
       13X'VARH(J)'2X'CUM. SUM')
          SUM=0.0
          DO 62 J=1,N
```

```
L(K)=I
M(K)=J
20 CONTINUE
C INTERCHANGE ROWS
J=L(K)
IF(J-K) 35,35,25
25 KI=K-N
DO 30 I=1,N
KI=KI+N
HOLD=-A(KI)
JI=KI-K+J
A(KI)=A(JI)
30 A(JI)=HOLD
C INTERCHANGE COLUMNS
35 I=M(K)
IF(I-K)45,45,38
38 JP=N*(I-1)
DO 40 J=1,N
JK=NK+J
JI=JP+J
HOLD=-A(JK)
A(JK)=A(JI)
40 A(JI)=HOLD
C DIVIDE COLUMNS BY MINUS PIVOT
45 IF(BIGA)48,46,48
46 D=0.0
RETURN
48 DO 55 I=1,N
IF(I-K)50,55,50
50 IK=NK+I
A(IK)=A(IK)/(-BIGA)
55 CONTINUE
C REDUCE MATRIX
DO 65 I=1,N
IK=NK+I
HOLD=A(IK)
```

```
 IJ=I-N
 DO 65 J=1,N
 IJ=IJ+N
 IF(I-K)60,65,60
 60 IF(J-K)62,65,62
 62 KJ=IJ-I+K
 A(IJ)=HOLD*A(KJ)+A(IJ)
 65 CONTINUE
C DIVIDE ROW BY PIVOT
 KJ=K-N
 DO 75 J=1,N
 KJ=KJ+N
 IF(J-K)70,75,70
 70 A(KJ)=A(KJ)/BIGA
 75 CONTINUE
C PRODUCT OF PIVOTS
 D=D*BIGA
C REPLACE PIVOT BY RECIPROCAL
 A(KK)=1.0/BIGA
 80 CONTINUE
C FINAL ROW AND COLUMN INTERCHANGE
 K=N
 100 K=(K-1)
 IF(K)150,150,105
 105 I=L(K)
 IF(I-K)120,120,108
 108 JQ=N*(K-1)
 JR=N*(I-1)
 DO 110 J=1,N
        JK=JQ+J
 HOLD=A(JK)
 JI=JR+J
 A(JK)=-A(JI)
 110 A(JI)=HOLD
 120 J=M(K)
 IF(J-K)100,100,125
```

```
 125 KI=K-N
 DO 130 I=1,N
 KI=KI+N
 HOLD=A(KI)
 JI=KI-K+J
 A(KI)=-A(JI)
 130 A(JI)=HOLD
 GO TO 100
 150 RETURN
 END
C
C
 SUBROUTINE LEAP(NY,ND)
 IF(MOD(NY,4).EQ.0) THEN
 ND=29
 ELSE
 ND=28
 END IF
 RETURN
 END
C...........................................................
       SUBROUTINE CONS(X,XBAR,VARX,A,B,N,W,NOPT)
       DIMENSION X(1),A(1),B(1),AK(100),VARH(100),C(100)
       INTEGER W
C      A AND B ARE COEFFICIENTS
C      N IS NO. OF HARMONICS TO BE FITTED
C      W IS NO. OF SEASONS IN A YEAR. HERE W=365
C      SET THE MAXIMUM SMOOTHING PARAMETER
C      INCREMENT OF KMAX =1% OF MAXIMUM POSSIBLE HARMONICS
       KMAX=0
       KDEL=0.01*(W/2.)
       PAI=3.141592654
61     DO 51 I=1,W
       X(I)=0.0
       DO 52 J=1,N
       THETA=2.*PAI*J*I/W
```

```
52      X(I)=X(I)+A(J)*COS(THETA)+B(J)*SIN(THETA)
51      X(I)=X(I)+XBAR
C       CHECK IF THERE ARE NEGATIVE ORDINATES
        DO 53 I=1,W
        IF(X(I).LT.0.0)GO TO 54
53      CONTINUE
        GO TO 55
C       CALCULATE THE TOTAL NEGATIVE VOLUME
54      IF(KMAX.EQ.0)GO TO 56
        GO TO 57
56      SVOL=0.0
        DO 58 I=1,W
        IF(X(I).LT.0.0)SVOL=SVOL+(X(I)*(-1.0))
58      CONTINUE
        TVOL=(SVOL/(XBAR*W))*100.0
57      CONTINUE
C       CHECK THE OPTIONS
        IF(NOPT.EQ.0)GO TO 55
C       CARRY OUT THE CORRECTIONS
        KMAX=KMAX+KDEL
        DO 59 J=1,N
        IF(NOPT.EQ.1)AK(J)=KMAX
        IF(NOPT.EQ.2)AK(J)=(FLOAT(J)/FLOAT(N))*KMAX
59      CONTINUE
C       CALCULATE CONSTRAINED COEFFICIENTS
        DO 60 J=1,N
        A(J)=((W/2.)*A(J))/((W/2.)+AK(J))
        B(J)=((W/2.)*B(J))/((W/2.)+AK(J))
60      CONTINUE
        GO TO 61
55      CONTINUE
        WRITE(3,2)
2       FORMAT(/6X'A(J)'5X'B(J)'1X'C(J)**2/2'3X'VAR'
     13X'VARH(J)'2X'CUM. SUM')
        SUM=0.0
        DO 62 J=1,N
```

```
      C(J)=(A(J)**2.+B(J)**2.)/2.
      VARH(J)=C(J)/VARX
      SUM=SUM+VARH(J)
      WRITE(3,3)A(J),B(J),C(J),VARX,VARH(J),SUM
62    CONTINUE
3     FORMAT(4F9.1,F9.4,F9.4)
      WRITE(3,4)KMAX,KDEL
4     FORMAT(' KMAX='I5,'KDEL='I5)
      WRITE(3,5)TVOL
5     FORMAT(5X,'NEGATIVE VOLUME='F7.3'%')
C     WRITE(3,1)(X(I),I=1,W)
1     FORMAT(3X'SMOOTHENED SERIES'/(10F9.1))
      RETURN
      END
C*****************************************************************
C     SUBROUTINE FOR HARMONIC ANALYSIS
      SUBROUTINE HARM(X,XH,N,NH,NS,NH1,NOPT,A1)
C     X:SERIES FOR HARMONIC ANALYSIS
C     XH:SMOOTHEND SERIES
C     N:NO OF YEARS FOR WHICH DATA ARE AVAILABLE.
C     NS:NO. OF SEASONS IN A YEAR
C     NH:MAXIMUM  NO. OF HARMONICS TO BE FITTED TO DATA.
C     NH1:NO OF DESIRED HARMONICS FOR THE DATA.
C     NOPT:OPTION CODE FOR SUBROUTINE FOR HARMONIC ANALYSIS
C     WITH NON NEGATIVITY CONSTRAINT.
C     A1:CONSTANT USED IN PMIN AND PMAX TEST.
C     A1=1 FOR MEAN
C     A1=2 FOR STANDARD DEVIATION.
      DIMENSION X(1),XH(365),A(100),B(100)
      PAI=3.141592654
      DO 50 J=1,NH
      A(J)=0.0
      B(J)=0.0
      DO 51 I=1,NS
      A(J)=A(J)+X(I)*COS(2.*PAI*J*I/NS)
51    B(J)=B(J)+X(I)*SIN(2.*PAI*J*I/NS)
```

```
      A(J)=2.*A(J)/NS
      B(J)=2.*B(J)/NS
50    CONTINUE
C     PMAX AND PMIN TEST
      ANS=NS
      PMIN=0.033*SQRT(ANS/(A1*N))
      PMAX=1.-PMIN
      WRITE(3,1)
1     FORMAT(10X'HARMONIC ANALYSIS')
      WRITE(3,2)
2     FORMAT(/2X'J'6X'A(J)'5X'B(J)'1X'C(J)**2/2'3X'VARX'2X'VARH(J)'
     11X'CUM. SUM'5X'PMIN'5X'PMAX')
      SUM1=0.0
      DO 52 I=1,NS
52    SUM1=SUM1+X(I)
      XBAR=SUM1/NS
      SUM2=0.0
      DO 53 I=1,NS
      SUM2=SUM2+(X(I)-XBAR)**2.
53    CONTINUE
      VARX=SUM2/(NS-1.)
      SUM3=0.0
      DO 54 J=1,NH
      CJ=(A(J)**2.+B(J)**2.)/2.
      VARHJ=CJ/VARX
      SUM3=SUM3+VARHJ
      WRITE(3,3)J,A(J),B(J),CJ,VARX,VARHJ,SUM3,PMIN,PMAX
54    CONTINUE
3     FORMAT(I3,4F9.1,4F9.3)
      WRITE(3,4)NH1
4     FORMAT(2X'SELECTED HARMONICS ARE'I5)
C     CALCULATE HARMONIC SERIES
      DO 55 I=1,NS
      XH(I)=0.0
      DO 56 J=1,NH1
      THETA=2.*PAI*J*I/NS
```

```
56        XH(I)=XH(I)+A(J)*COS(THETA)+B(J)*SIN(THETA)
55        XH(I)=XBAR+XH(I)
C         CALCULATE HARMONIC SERIES WITH NON NEGATIVITY CONSTRAINT
          CALL CONS(XH,XBAR,VARX,A,B,NH1,NS,1)
          RETURN
 END
```

HARMONIC ANALYSIS

J	A(J)	B(J)	C(J)**2/2	VARX	VARH(J)	CUM. SUM	PMIN	PMAX
1	7.0	3.4	30.3	92.7	0.326	0.326	0.364	0.636
2	3.6	0.1	6.6	92.7	0.071	0.397	0.364	0.636
3	2.8	2.0	6.1	92.7	0.065	0.463	0.364	0.636
4	1.4	1.5	2.1	92.7	0.023	0.486	0.364	0.636
5	1.1	1.0	1.1	92.7	0.012	0.498	0.364	0.636
6	-0.4	-0.8	0.4	92.7	0.004	0.502	0.364	0.636
7	0.6	-0.9	0.6	92.7	0.006	0.508	0.364	0.636
8	0.1	0.6	0.2	92.7	0.002	0.510	0.364	0.636
9	-0.4	0.6	0.3	92.7	0.003	0.513	0.364	0.636
10	-1.0	-0.1	0.5	92.7	0.005	0.518	0.364	0.636
11	-0.6	-1.9	2.0	92.7	0.022	0.540	0.364	0.636
12	-0.2	-1.8	1.6	92.7	0.018	0.558	0.364	0.636
13	-1.6	-1.7	2.7	92.7	0.029	0.587	0.364	0.636
14	-1.7	-1.3	2.3	92.7	0.025	0.612	0.364	0.636
15	-0.8	-1.0	0.8	92.7	0.009	0.621	0.364	0.636
16	0.0	-1.0	0.5	92.7	0.005	0.626	0.364	0.636
17	0.0	-1.6	1.3	92.7	0.014	0.640	0.364	0.636
18	-0.3	-1.0	0.6	92.7	0.006	0.647	0.364	0.636
19	-1.4	0.3	1.0	92.7	0.010	0.657	0.364	0.636
20	-0.4	-0.1	0.1	92.7	0.001	0.658	0.364	0.636

SELECTED HARMONICS ARE 17

A(J)	B(J)	C(J)**2/2	VAR	VARH(J)	CUM. SUM
5.5	2.6	18.6	92.7	0.2011	0.2011
2.8	0.1	4.1	92.7	0.0437	0.2447
2.2	1.6	3.7	92.7	0.0402	0.2849
1.1	1.2	1.3	92.7	0.0142	0.2991
0.9	0.8	0.7	92.7	0.0072	0.3064
-0.3	-0.6	0.3	92.7	0.0028	0.3091
0.5	-0.7	0.3	92.7	0.0037	0.3129
0.1	0.5	0.1	92.7	0.0013	0.3141
-0.3	0.5	0.2	92.7	0.0018	0.3160
-0.8	-0.1	0.3	92.7	0.0031	0.3191

-0.4	-1.5	1.3	92.7	0.0136	0.3327
-0.2	-1.4	1.0	92.7	0.0109	0.3436
-1.2	-1.4	1.7	92.7	0.0181	0.3617
-1.3	-1.0	1.4	92.7	0.0152	0.3770
-0.7	-0.8	0.5	92.7	0.0055	0.3825
0.0	-0.8	0.3	92.7	0.0032	0.3857
0.0	-1.3	0.8	92.7	0.0087	0.3943

KMAX= 9KDEL= 1

NEGATIVE VOLUME= 1.046%

MEAN VALUES OF AMDIS

13.57	16.87	10.10	9.03	17.93	20.63	14.90	15.30	18.07	15.60
20.73	23.50	24.07	30.17	31.77	36.30	28.17	47.33	52.77	34.07
21.60	26.00	15.17	11.67	7.53	28.87	29.70	12.13	7.07	6.13
6.13	17.13	16.70	14.03	23.87	11.23	10.63	6.93	14.07	33.67
12.00	18.33	7.67	5.73	7.27	7.00	25.10	21.07	24.83	13.30
10.50	5.13	5.60	9.47	9.40	7.77	11.20	28.20	13.03	1.97
2.03	0.00	0.00	0.00	0.00	0.00	40.33	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	8.27	17.63	22.30	15.43	7.80	11.40	12.13	0.00
2.90	15.80	15.87	10.87	7.33	7.07	12.43	10.70	13.90	9.57
8.27	12.53	8.77	7.87	4.73	7.10	0.00	15.77	5.37	4.10
4.73	0.00	0.00	0.00	0.00	7.67	7.57	12.53	10.67	7.03
6.23	5.40	4.63	5.00	9.47	16.90	3.37	3.93	2.03	1.50
5.47	4.70	4.73	6.20	5.33	8.17	3.60	3.60	0.00	0.00
0.00	0.00	27.57	23.27	16.00	0.00	0.00	0.00	5.63	6.13
2.83	2.37	12.53	4.10	2.33	15.23	8.70	4.07	22.87	9.97
4.93	4.47	2.87	2.07	1.70	1.40	1.40	4.33	2.87	1.30
1.13	1.10	1.10	1.00	1.00	0.97	0.93	0.87	0.80	0.83
0.43	0.43	0.67	0.87	0.60	0.50	0.50	0.53	0.63	0.67
0.33	0.33	0.10	0.93	0.63	0.00	0.37	0.17	0.10	0.13
0.13	0.10	0.07	0.07	0.07	0.10	0.10	0.10	0.07	0.10
0.50	0.00	2.70	0.97	0.87	1.37	0.70	0.37	0.30	0.27
0.27	0.30	0.37	0.43	0.30	0.30	0.30	0.30	0.23	0.23
0.23	0.23	0.23	0.40	0.47	0.43	0.43	0.40	0.37	0.17
0.17	0.23	0.23	0.20	0.20	0.20	0.93	0.30	0.30	0.23
0.23	0.20	0.20	0.17	0.43	0.33	0.30	0.13	0.13	0.13

0.23	0.23	0.27	0.30	0.23	0.20	0.60	0.70	2.80	1.50
0.20	0.27	0.43	0.40	0.67	6.80	15.20	4.13	5.83	3.93
4.20	1.40	0.80	0.53	1.07	0.33	0.27	0.13	0.13	0.13
1.27	2.33	4.37	11.83	13.00	34.57	13.50	13.63	7.63	7.43
11.53	4.17	0.23	0.30	2.50	1.60	0.87	0.70	0.13	0.10
0.10	0.10	0.13	0.20	3.13	4.63	1.70	1.40	3.67	7.30
10.80	5.73	3.93	4.57	2.83	7.03	15.20	10.73	6.03	6.00
6.63	7.73	8.80	4.33	8.80	2.33	11.70	22.40	17.03	7.10
5.10	2.40	1.43	1.30	1.37	1.57	0.80	2.90	29.67	19.83
18.40	17.43	16.77	56.67	42.37	29.73	36.37	29.10	19.17	19.70
14.27	13.53	30.97	15.37	27.53					

SMOOTHENED MEAN VALUES OF DISCHARGE HMDIS

13.36	12.13	11.30	10.93	11.05	11.66	12.73	14.21	16.00	18.01
20.11	22.18	24.10	25.75	27.04	27.89	28.26	28.12	27.50	26.43
24.98	23.23	21.28	19.25	17.24	15.35	13.67	12.27	11.19	10.47
10.10	10.06	10.30	10.76	11.39	12.10	12.82	13.48	14.03	14.42
14.62	14.63	14.45	14.10	13.61	13.03	12.39	11.75	11.14	10.60
10.15	9.80	9.55	9.39	9.29	9.24	9.19	9.11	8.96	8.73
8.38	7.92	7.35	6.66	5.90	5.09	4.27	3.47	2.75	2.13
1.66	1.35	1.23	1.30	1.55	1.97	2.54	3.22	4.00	4.82
5.65	6.46	7.23	7.93	8.54	9.06	9.49	9.82	10.06	10.22
10.32	10.36	10.36	10.31	10.22	10.09	9.93	9.72	9.47	9.18
8.83	8.44	8.02	7.56	7.08	6.60	6.15	5.73	5.37	5.09
4.90	4.80	4.81	4.92	5.12	5.39	5.71	6.07	6.42	6.74
7.02	7.22	7.33	7.34	7.26	7.08	6.83	6.51	6.16	5.79
5.45	5.15	4.91	4.76	4.70	4.74	4.88	5.10	5.40	5.74
6.11	6.48	6.83	7.14	7.40	7.59	7.70	7.75	7.72	7.65
7.53	7.39	7.23	7.08	6.94	6.81	6.70	6.61	6.53	6.44
6.34	6.20	6.03	5.80	5.51	5.15	4.74	4.28	3.79	3.28
2.78	2.31	1.89	1.55	1.29	1.13	1.08	1.12	1.26	1.46
1.72	2.01	2.29	2.55	2.76	2.90	2.96	2.93	2.81	2.62
2.36	2.06	1.74	1.44	1.16	0.94	0.79	0.72	0.75	0.85
1.03	1.27	1.55	1.84	2.13	2.37	2.57	2.69	2.74	2.70
2.59	2.42	2.20	1.96	1.71	1.49	1.30	1.18	1.12	1.14
1.24	1.39	1.59	1.82	2.06	2.28	2.47	2.59	2.64	2.62
2.51	2.34	2.11	1.84	1.56	1.29	1.05	0.87	0.77	0.76

0.84	1.00	1.24	1.53	1.85	2.17	2.47	2.70	2.86	2.93
2.88	2.74	2.49	2.17	1.79	1.39	1.00	0.66	0.41	0.25
0.23	0.34	0.60	0.98	1.46	2.03	2.63	3.24	3.80	4.29
4.67	4.91	5.00	4.94	4.73	4.41	3.99	3.52	3.05	2.62
2.27	2.04	1.97	2.07	2.35	2.81	3.44	4.19	5.04	5.94
6.84	7.68	8.43	9.03	9.46	9.69	9.71	9.53	9.15	8.60
7.91	7.12	6.27	5.40	4.56	3.77	3.07	2.49	2.03	1.71
1.54	1.50	1.59	1.80	2.11	2.51	2.97	3.50	4.07	4.67
5.29	5.92	6.54	7.14	7.70	8.20	8.64	8.98	9.21	9.31
9.28	9.12	8.82	8.39	7.87	7.28	6.67	6.09	5.58	5.21
5.04	5.10	5.45	6.10	7.08	8.37	9.94	11.74	13.72	15.79
17.87	19.84	21.63	23.13	24.28	25.00	25.27	25.07	24.42	23.35
21.94	20.28	18.47	16.64	14.89					

HARMONIC ANALYSIS

J	A(J)	B(J)	C(J)**2/2	VARX	VARH(J)	CUM. SUM	PMIN	PMAX
1	2.7	0.9	4.1	18.3	0.225	0.225	0.364	0.636
2	0.6	0.1	0.2	18.3	0.009	0.234	0.364	0.636
3	-0.1	-0.9	0.4	18.3	0.023	0.257	0.364	0.636
4	0.8	-0.5	0.4	18.3	0.024	0.281	0.364	0.636
5	0.2	-0.5	0.1	18.3	0.008	0.289	0.364	0.636
6	-0.4	0.3	0.1	18.3	0.008	0.297	0.364	0.636
7	-0.1	0.9	0.4	18.3	0.020	0.317	0.364	0.636
8	0.1	0.4	0.1	18.3	0.004	0.322	0.364	0.636
9	-0.7	0.2	0.2	18.3	0.013	0.334	0.364	0.636
10	0.2	0.3	0.1	18.3	0.005	0.339	0.364	0.636
11	-0.1	0.5	0.1	18.3	0.006	0.345	0.364	0.636
12	0.0	0.0	0.0	18.3	0.000	0.345	0.364	0.636
13	-0.2	-0.6	0.2	18.3	0.011	0.357	0.364	0.636
14	-1.0	0.0	0.5	18.3	0.025	0.382	0.364	0.636
15	0.2	0.2	0.0	18.3	0.002	0.384	0.364	0.636
16	-0.1	-0.4	0.1	18.3	0.006	0.390	0.364	0.636
17	0.0	0.0	0.0	18.3	0.000	0.390	0.364	0.636
18	-0.8	-0.1	0.3	18.3	0.018	0.408	0.364	0.636
19	-0.5	0.4	0.2	18.3	0.010	0.419	0.364	0.636
20	-0.4	-0.4	0.2	18.3	0.010	0.429	0.364	0.636

21	0.2	-0.1	0.0	18.3	0.001	0.430	0.364	0.636
22	-0.2	0.3	0.1	18.3	0.003	0.433	0.364	0.636
23	0.0	0.5	0.1	18.3	0.008	0.441	0.364	0.636
24	-0.3	0.4	0.1	18.3	0.007	0.448	0.364	0.636
25	0.0	0.2	0.0	18.3	0.001	0.449	0.364	0.636
26	0.4	0.1	0.1	18.3	0.005	0.454	0.364	0.636
27	0.1	-0.1	0.0	18.3	0.000	0.454	0.364	0.636
28	0.1	-0.1	0.0	18.3	0.001	0.455	0.364	0.636
29	-0.2	-0.2	0.0	18.3	0.003	0.458	0.364	0.636
30	0.0	0.5	0.1	18.3	0.007	0.465	0.364	0.636
31	0.2	-0.3	0.1	18.3	0.003	0.468	0.364	0.636
32	0.1	0.0	0.0	18.3	0.000	0.468	0.364	0.636
33	0.2	-0.1	0.0	18.3	0.002	0.470	0.364	0.636
34	0.0	0.4	0.1	18.3	0.005	0.475	0.364	0.636
35	0.1	0.0	0.0	18.3	0.000	0.476	0.364	0.636
36	-0.5	0.2	0.2	18.3	0.008	0.484	0.364	0.636
37	0.0	0.0	0.0	18.3	0.000	0.484	0.364	0.636
38	0.3	0.0	0.1	18.3	0.003	0.487	0.364	0.636
39	0.3	-0.2	0.1	18.3	0.003	0.490	0.364	0.636
40	0.0	0.4	0.1	18.3	0.004	0.494	0.364	0.636
41	0.1	-0.1	0.0	18.3	0.001	0.494	0.364	0.636
42	-0.3	-0.1	0.1	18.3	0.004	0.498	0.364	0.636
43	-0.1	-0.9	0.4	18.3	0.021	0.519	0.364	0.636
44	-0.2	-0.2	0.0	18.3	0.002	0.521	0.364	0.636
45	0.2	-0.1	0.0	18.3	0.001	0.522	0.364	0.636
46	0.0	-0.4	0.1	18.3	0.004	0.526	0.364	0.636
47	0.4	-0.1	0.1	18.3	0.004	0.530	0.364	0.636
48	0.1	0.2	0.0	18.3	0.001	0.532	0.364	0.636
49	-0.3	0.6	0.2	18.3	0.010	0.542	0.364	0.636
50	0.1	-0.3	0.0	18.3	0.002	0.544	0.364	0.636
51	0.0	-0.6	0.2	18.3	0.010	0.555	0.364	0.636
52	0.5	-0.3	0.2	18.3	0.008	0.563	0.364	0.636
53	0.0	-0.2	0.0	18.3	0.001	0.564	0.364	0.636
54	0.4	-0.3	0.1	18.3	0.006	0.570	0.364	0.636
55	-0.3	-0.2	0.1	18.3	0.004	0.574	0.364	0.636
56	0.0	0.0	0.0	18.3	0.000	0.574	0.364	0.636

57	-0.2	0.5	0.1	18.3	0.007	0.581	0.364	0.636
58	-0.2	0.6	0.2	18.3	0.010	0.591	0.364	0.636
59	-0.7	0.4	0.3	18.3	0.019	0.609	0.364	0.636
60	-0.6	0.0	0.2	18.3	0.008	0.618	0.364	0.636
61	0.1	-0.1	0.0	18.3	0.000	0.618	0.364	0.636
62	0.7	0.2	0.3	18.3	0.015	0.633	0.364	0.636
63	0.1	0.3	0.0	18.3	0.003	0.636	0.364	0.636
64	0.3	-0.4	0.1	18.3	0.006	0.642	0.364	0.636
65	0.3	0.2	0.1	18.3	0.004	0.645	0.364	0.636
66	0.4	-0.6	0.2	18.3	0.012	0.658	0.364	0.636
67	0.1	-0.7	0.2	18.3	0.013	0.670	0.364	0.636
68	0.0	-0.3	0.0	18.3	0.002	0.672	0.364	0.636
69	-0.1	0.0	0.0	18.3	0.000	0.672	0.364	0.636
70	-0.2	0.2	0.0	18.3	0.002	0.674	0.364	0.636
71	0.0	0.1	0.0	18.3	0.000	0.674	0.364	0.636
72	-0.1	-0.3	0.0	18.3	0.002	0.676	0.364	0.636
73	0.0	0.5	0.1	18.3	0.006	0.682	0.364	0.636
74	0.1	-0.5	0.1	18.3	0.008	0.690	0.364	0.636
75	0.1	-0.2	0.0	18.3	0.001	0.690	0.364	0.636
76	0.4	-0.4	0.2	18.3	0.008	0.699	0.364	0.636
77	-0.1	0.0	0.0	18.3	0.000	0.699	0.364	0.636
78	0.2	0.1	0.0	18.3	0.001	0.701	0.364	0.636
79	-0.2	-0.5	0.2	18.3	0.009	0.709	0.364	0.636
80	-0.3	0.2	0.1	18.3	0.003	0.712	0.364	0.636
81	-0.4	-0.1	0.1	18.3	0.004	0.717	0.364	0.636
82	-0.3	-0.2	0.1	18.3	0.004	0.720	0.364	0.636
83	0.0	0.0	0.0	18.3	0.000	0.720	0.364	0.636
84	0.3	0.5	0.2	18.3	0.009	0.729	0.364	0.636
85	0.3	0.3	0.1	18.3	0.005	0.734	0.364	0.636
86	0.5	0.2	0.1	18.3	0.007	0.741	0.364	0.636
87	0.4	-0.2	0.1	18.3	0.005	0.746	0.364	0.636
88	0.0	0.2	0.0	18.3	0.001	0.747	0.364	0.636
89	-0.1	-0.2	0.0	18.3	0.002	0.748	0.364	0.636
90	-0.2	-0.1	0.0	18.3	0.002	0.750	0.364	0.636
91	0.1	-0.4	0.1	18.3	0.005	0.755	0.364	0.636
92	-0.1	-0.3	0.1	18.3	0.003	0.758	0.364	0.636

93	-0.3	-0.1	0.0	18.3	0.002	0.760	0.364	0.636
94	-0.1	0.1	0.0	18.3	0.001	0.761	0.364	0.636
95	-0.4	-0.2	0.1	18.3	0.004	0.766	0.364	0.636
96	-0.1	-0.1	0.0	18.3	0.000	0.766	0.364	0.636
97	-0.1	-0.5	0.1	18.3	0.006	0.772	0.364	0.636
98	-0.2	-0.1	0.0	18.3	0.001	0.774	0.364	0.636
99	-0.2	-0.2	0.0	18.3	0.002	0.776	0.364	0.636
100	-0.1	-0.2	0.0	18.3	0.001	0.777	0.364	0.636

SELECTED HARMONICS ARE 63

A(J)	B(J)	C(J)**2/2	VAR	VARH(J)	CUM. SUM
2.1	0.7	2.5	18.3	0.1385	0.1385
0.4	0.0	0.1	18.3	0.0055	0.1440
-0.1	-0.7	0.3	18.3	0.0144	0.1585
0.6	-0.4	0.3	18.3	0.0145	0.1729
0.2	-0.4	0.1	18.3	0.0049	0.1778
-0.3	0.3	0.1	18.3	0.0049	0.1828
-0.1	0.7	0.2	18.3	0.0126	0.1954
0.1	0.3	0.0	18.3	0.0027	0.1980
-0.5	0.1	0.1	18.3	0.0079	0.2059
0.2	0.3	0.1	18.3	0.0028	0.2087
-0.1	0.4	0.1	18.3	0.0040	0.2127
0.0	0.0	0.0	18.3	0.0000	0.2127
-0.2	-0.5	0.1	18.3	0.0068	0.2196
-0.8	0.0	0.3	18.3	0.0157	0.2352
0.1	0.2	0.0	18.3	0.0013	0.2365
-0.1	-0.4	0.1	18.3	0.0035	0.2401
0.0	0.0	0.0	18.3	0.0000	0.2401
-0.6	-0.1	0.2	18.3	0.0114	0.2514
-0.4	0.3	0.1	18.3	0.0064	0.2579
-0.3	-0.3	0.1	18.3	0.0061	0.2640
0.2	-0.1	0.0	18.3	0.0009	0.2648
-0.1	0.2	0.0	18.3	0.0020	0.2668
0.0	0.4	0.1	18.3	0.0050	0.2718
-0.2	0.3	0.1	18.3	0.0043	0.2761
0.0	0.1	0.0	18.3	0.0004	0.2765

0.3	0.1	0.1	18.3	0.0030	0.2796
0.1	-0.1	0.0	18.3	0.0002	0.2797
0.1	-0.1	0.0	18.3	0.0007	0.2804
-0.2	-0.2	0.0	18.3	0.0016	0.2820
0.0	0.4	0.1	18.3	0.0045	0.2866
0.1	-0.2	0.0	18.3	0.0018	0.2884
0.1	0.0	0.0	18.3	0.0001	0.2884
0.2	-0.1	0.0	18.3	0.0012	0.2896
0.0	0.3	0.1	18.3	0.0030	0.2927
0.1	0.0	0.0	18.3	0.0002	0.2929
-0.4	0.1	0.1	18.3	0.0051	0.2980
0.0	0.0	0.0	18.3	0.0001	0.2981
0.3	0.0	0.0	18.3	0.0018	0.2998
0.2	-0.2	0.0	18.3	0.0021	0.3020
0.0	0.3	0.0	18.3	0.0022	0.3041
0.1	-0.1	0.0	18.3	0.0003	0.3045
-0.3	-0.1	0.0	18.3	0.0022	0.3066
-0.1	-0.7	0.2	18.3	0.0127	0.3193
-0.1	-0.2	0.0	18.3	0.0014	0.3207
0.1	0.0	0.0	18.3	0.0006	0.3213
0.0	-0.3	0.0	18.3	0.0026	0.3240
0.3	-0.1	0.0	18.3	0.0026	0.3266
0.1	0.2	0.0	18.3	0.0009	0.3275
-0.2	0.4	0.1	18.3	0.0065	0.3340
0.0	-0.2	0.0	18.3	0.0013	0.3353
0.0	-0.5	0.1	18.3	0.0064	0.3417
0.4	-0.2	0.1	18.3	0.0052	0.3469
0.0	-0.1	0.0	18.3	0.0006	0.3475
0.3	-0.2	0.1	18.3	0.0037	0.3512
-0.2	-0.2	0.0	18.3	0.0022	0.3534
0.0	0.0	0.0	18.3	0.0000	0.3534
-0.2	0.4	0.1	18.3	0.0044	0.3578
-0.1	0.4	0.1	18.3	0.0059	0.3637
-0.6	0.3	0.2	18.3	0.0116	0.3753
-0.4	0.0	0.1	18.3	0.0051	0.3804
0.1	0.0	0.0	18.3	0.0003	0.3807

0.6	0.1	0.2	18.3	0.0093	0.3900
0.1	0.2	0.0	18.3	0.0016	0.3916

KMAX= 9KDEL= 1

NEGATIVE VOLUME= 0.378%

MEAN VALUES OF AVERAGE RAINFALL AMR

4.70	2.00	8.02	9.23	7.01	13.39	6.97	12.84	7.39	11.21
11.09	6.26	11.22	18.99	6.73	11.56	6.63	6.62	5.72	3.65
12.61	8.59	6.77	1.16	6.45	4.30	3.90	5.86	2.89	1.73
2.66	6.21	5.78	11.18	1.64	1.17	1.08	2.60	10.61	7.45
1.04	4.30	2.30	1.72	1.38	8.52	16.37	10.24	6.67	0.70
0.37	8.70	11.08	2.51	9.28	7.92	4.12	7.11	2.49	3.97
0.84	1.76	9.79	14.13	9.53	12.48	13.23	4.19	8.46	17.10
6.40	8.36	4.34	1.38	9.98	4.28	16.68	2.03	4.03	4.21
2.01	3.39	14.60	11.02	6.22	8.24	5.87	6.81	1.98	4.63
10.47	3.89	0.01	5.07	2.52	2.20	7.77	2.23	4.22	6.94
13.70	4.57	0.71	4.80	1.90	10.30	4.03	8.22	3.54	4.00
1.23	4.82	4.93	5.58	4.02	2.57	3.05	1.45	4.06	0.01
1.07	0.78	1.40	4.92	2.57	1.75	2.20	0.47	1.11	0.74
2.77	1.18	0.01	1.50	4.01	2.14	5.02	2.00	0.40	2.90
5.87	6.23	2.74	0.46	1.04	2.06	4.10	2.63	0.95	1.60
0.12	4.40	1.63	0.00	2.62	4.15	0.73	2.73	0.97	0.71
0.74	0.03	0.00	0.00	0.00	0.00	0.00	2.16	2.57	2.10
5.56	0.70	2.80	4.35	6.27	13.87	3.42	1.63	0.00	0.02
0.02	0.00	6.22	0.43	0.57	0.47	12.03	1.46	1.63	1.09
0.01	1.87	6.13	4.36	3.03	14.05	7.00	1.47	0.42	0.01
1.78	1.00	0.01	0.00	0.00	0.00	0.00	0.00	0.03	6.56
8.96	1.90	0.60	0.71	2.27	3.67	5.86	3.77	4.27	2.93
16.72	2.03	0.26	0.00	8.27	0.99	1.64	0.00	0.00	0.68
0.68	0.00	0.05	0.03	0.00	0.94	0.28	0.00	0.96	0.02
0.56	0.01	0.68	0.51	0.02	0.00	1.52	3.52	4.00	0.69
0.65	1.59	0.98	0.02	0.66	0.00	1.83	3.11	0.36	2.33
3.35	1.23	0.21	0.45	0.32	1.94	5.46	4.03	7.98	10.82
9.68	11.77	0.72	2.28	6.18	5.95	13.35	2.22	3.86	1.79
2.63	1.04	2.46	1.85	0.01	0.03	0.03	1.18	0.01	0.54
0.00	4.42	5.81	7.58	3.60	2.56	10.95	1.76	0.87	7.77
2.85	0.81	0.69	4.06	2.74	0.83	3.13	4.53	5.64	6.19

1.01	1.72	1.29	2.02	4.91	0.00	2.31	4.27	8.13	6.12
5.09	11.57	3.73	8.51	6.65	3.50	12.01	3.39	4.70	12.58
15.37	3.45	3.70	1.66	14.48	23.46	14.70	7.80	4.91	12.55
5.42	11.98	4.83	10.80	1.26	2.52	4.57	11.30	11.93	6.03
1.38	8.08	17.54	6.37	14.52	13.55	7.01	4.56	7.96	8.04
0.00	2.92	9.58	6.11	6.24					

SMOOTHENED MEAN VALUES OF AVERAGE RAINFALL HMR

5.36	5.49	5.72	6.44	7.75	9.17	9.89	9.48	8.36	7.55
7.89	9.29	10.81	11.29	10.25	8.19	6.25	5.41	5.85	6.91
7.60	7.27	6.09	4.81	4.17	4.28	4.56	4.33	3.56	2.99
3.47	5.01	6.49	6.52	4.75	2.47	1.65	3.22	5.99	7.52
6.19	2.84	0.31	1.04	4.94	9.31	11.02	9.09	5.38	2.87
3.15	5.34	7.29	7.60	6.67	5.80	5.59	5.40	4.34	2.69
1.98	3.62	7.22	10.63	11.68	10.17	8.00	7.36	8.62	10.01
9.45	6.74	3.92	3.40	5.63	8.50	9.24	6.93	3.41	1.63
3.09	6.61	9.47	9.82	7.99	5.84	4.92	5.26	5.77	5.56
4.75	4.07	3.90	3.92	3.62	3.12	3.20	4.43	6.36	7.64
7.24	5.40	3.58	3.19	4.42	6.07	6.69	5.84	4.29	3.29
3.39	4.17	4.75	4.69	4.17	3.64	3.27	2.87	2.28	1.71
1.58	2.07	2.85	3.33	3.20	2.65	2.14	1.96	1.97	1.89
1.70	1.67	2.05	2.74	3.28	3.33	2.97	2.73	3.03	3.78
4.40	4.34	3.59	2.66	2.15	2.27	2.69	2.94	2.79	2.39
2.06	2.02	2.24	2.58	2.86	2.96	2.79	2.38	1.86	1.45
1.30	1.30	1.20	0.87	0.53	0.64	1.43	2.58	3.39	3.36
2.75	2.50	3.39	5.29	7.06	7.37	5.78	3.13	0.94	0.27
0.99	2.12	2.76	2.82	2.87	3.38	4.13	4.38	3.60	2.13
1.08	1.47	3.42	5.94	7.62	7.55	5.87	3.57	1.75	1.02
1.20	1.67	1.79	1.34	0.60	0.14	0.48	1.69	3.33	4.62
4.93	4.18	2.90	1.94	1.89	2.81	4.21	5.43	6.07	6.06
5.58	4.86	4.08	3.34	2.75	2.36	2.13	1.90	1.55	1.12
0.81	0.80	1.06	1.35	1.42	1.23	0.99	0.98	1.24	1.54
1.58	1.27	0.86	0.74	1.13	1.87	2.58	2.93	2.86	2.54
2.14	1.75	1.39	1.14	1.16	1.52	2.11	2.61	2.77	2.59
2.27	2.01	1.81	1.60	1.50	1.93	3.37	5.72	8.12	9.33
8.64	6.54	4.47	3.83	4.86	6.49	7.21	6.25	4.19	2.36
1.70	2.11	2.66	2.56	1.76	0.91	0.59	0.86	1.36	1.81

2.36	3.30	4.61	5.73	6.04	5.42	4.44	3.85	3.90	4.13
3.89	3.02	2.05	1.75	2.37	3.45	4.27	4.46	4.21	3.90
3.63	3.20	2.50	1.86	1.85	2.71	4.01	5.04	5.45	5.62
6.13	7.02	7.60	7.09	5.67	4.55	5.01	7.06	9.13	9.39
7.45	5.01	4.53	7.05	11.09	13.79	13.27	10.18	7.09	6.12
7.24	8.49	8.01	5.81	3.72	3.57	5.45	7.66	8.37	7.32
6.02	6.25	8.35	10.90	11.94	10.65	7.93	5.50	4.46	4.68
5.24	5.43	5.25	5.09	5.17					

MEMORY LENGTH= 3 DAYS

REGRESSION COEFFICIENTS

0.34880 0.53826 0.40646

STANDARD ERROR OF REGRESSION COEFFICIENTS

0.06637 0.06789 0.06638

T VALUES OF COEFFICIENTS

5.256 7.928 6.124

LEAD TIME USED IN UPDATING- 1DAYS

REGRESSION COEFFICIENTS IN UPDATING EQUATION

0.46629 0.13256

OBSERVED AND COMPUTED DISCHARGE ORDINATES

1979 1

1	18.90	18.90
2	38.80	38.80
3	15.80	12.71
4	11.50	18.03
5	13.70	16.48
6	30.20	9.01
7	11.80	12.27
8	16.60	9.45
9	8.90	15.11
10	10.10	18.82
11	11.80	19.38
12	11.50	13.91
13	7.60	10.87
14	0.00	22.22
15	0.00	20.82
16	36.90	13.97

1063	17.50	16.81
1064	8.70	13.58
1981	12	
1065	23.00	13.55
1066	0.00	22.74
1067	0.00	8.13
1068	0.00	0.00
1069	0.00	0.00
1070	0.00	2.64
1071	0.00	9.38
1072	0.00	8.37
1073	0.00	1.52
1074	0.00	4.21
1075	0.00	5.81
1076	0.00	6.32
1077	0.00	5.67
1078	0.00	15.43
1079	76.40	21.86
1080	45.30	51.41
1081	38.80	33.66
1082	20.70	26.32
1083	12.60	33.39
1084	127.00	30.34
1085	59.40	69.94
1086	29.60	42.60
1087	12.60	23.36
1088	5.70	16.74
1089	15.30	18.60
1090	41.70	29.45
1091	30.80	37.11
1092	26.30	23.79
1093	86.10	20.23
1094	29.30	51.66
1095	44.00	30.68

MONTHLY VARIANCES

6753.0	2115.4	19662.2	5033.1	8910.1	5651.1
130.3	496.5	297.7	1124.7	282.5	2785.9

ANNUAL VARIANCE

53242.6

YEAR:--1980

MONTHLY VARIANCES

2359.8	4891.4	768.4	411.5	107.3	162.1
380.7	249.9	12.8	8315.7	686.4	3281.0

ANNUAL VARIANCE

21627.2

YEAR:--1981

MONTHLY VARIANCES

15101.3	8389.4	1654.8	1960.1	503.7	633.4
745.3	10.4	322.3	113.8	1104.2	19787.1

ANNUAL VARIANCE

50325.8

OVERALL EFFICIENCY (%)= 54.582