CS-8

APPLICATION OF THOMAS FIERING MODEL FOR MONTHLY STREAMFLOW GENERATION IN CHALIYAR RIVER BASIN

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The Thomas Fiering model is a well known model for hydrologic time series modelling of monthly flows based on nonstationarity of time series. The main objective of the present study is to apply Thomas Fiering model for generation of monthly streamflow data for Chaliyar basin. Four cases using first order Thomas Fiering model i.e.(i) without any transformation(including negative flows) (ii) with square root transformation (iii) with logarithmic transformation and (iv) without any transformation but excluding negative flows, have been studied. Monthly streamflows from 1965 to1978 for eight sites on Chaliyar river, one of the major rivers of Western Ghats, and its tributaries have been used. The performance of each of the four cases of the model has been judged by comparing means and standard deviations of historical data with that of 100 years generated data.

Thomas Fiering model with square root transformation is able to reproduce monthly means in a better way for most of the sites of Chaliyar river basin. The 8 sites have been grouped under three typical categories (Category 'A' sites, Category 'B' sites and Category 'C' sites). Category 'A' sites include the sites on tributaries which directly join the main river. For Category 'A' sites (5 sites) Thomas Fiering model with square root transformation is either best or second best. Category 'B' sites (one site) include sites on the tributaries which do not join main river directly. Thomas Fiering model in its original form reproduces monthly means in a better way for Category 'B'

sites. Sites on main river have been kept in Category 'C' sites. For sites on main river(Category 'C' sites), on an average, Thomas Fiering model excluding negative flows gives better results.

It is seen that Thomas Fiering model with square root transformation is able to reproduce monthly means in a better way for most of the sites of Chaliyar river basin (Kerala).

1.0 INTRODUCTION

Sequential generation of hydrologic phenomena is a statistical process to produce a random sequence of hydrologic data on the basis of a stochastic model for the hydrologic process. In several water resources projects it is required to predict the characteristics and quantity of streamflow to derive critical flow sequences of their associated return period. Most of the existing flow records are very short, generally less than 25 years. The exact pattern of the flows during that historical period is extremely unlikely to recur during the economic life of the project . By generating several streamflow sequences all with the same statistical characteristics and all assumed to be equally likely to occur the designer is able to decide the basis of expected behaviour of the system.

Data generation procedure is used to provide equally likely flow sequences to the historical one in capacity yield analysis. The synthetic sequences give the designer a qualitative picture of the probability of failure-storage yield relation in simulation studies.

The design of water resources projects is commonly based on assumed recurrence of past hydrological extents. By generating a number of hydrological sequences each of a specified desired length, it is possible to create a much broader base for hydrologic design. While it is not possible to create information that is not already in the record, it is possible to use the information more systematicaly and more effectively (Beard,1972).

Such studies involving monthly generation of streamflows are in vogue in India for the last 10-15 years. Several investigators have attempted (Seth et.al.1976, Shankar et.al 1979) to generate monthly flows for some of the Indian rivers and tributaries.

In the present study, first order Thomas Fiering model under four alternative cases of transformation and consideration of negative generated flows, has been applied on monthly stream-

2.0 REVIEW

Various Generating Models

Hazen (1974) is considered to be the first to recognise the desirability of extending hydrologic data. Hazen combined standardized annual flows for forteen streams in the north west of U.S.A. to produce a synthesized record of 300 years. Sudler(1927) utilized historical and representative annual flows which were entered on 50 cards. Barnes(1954) used a Monte Carlo approach to generate 10,000 years of data of annual flow for upper Yarra Dam in Australia. From 1936 to 1960 Hurst studied the River Nile and developed various card sampling techniques to generate annual flows which were used in simulated operational studies of the Aswan High Dam. For generating annual volumes of discharge when persistence is present, models based on the principle of Markov process are available. This includes auto-regressive models, moving average models, fractional Gaussian noise models and autoregressive integrated moving average models(Box and Jenkins,1970) . For the generation of monthly flow sequences (univariate), Thomas Fiering model (1962) and periodic model are available. To generate synthetic sequences of several hydrological variables multivariate Thomas Fiering Model (Clarke,1973), multivariate Matalas model(Matalas,1967 and Young,1968) and multivariate fractional Gaussian noise models (Metalas and Wallis, 1971) are available.

The Thomas Fiering model is restricted to normally distributed flows. To cater for nonnormal monthly stream flows either t_j is modified by an appropriate transformation (Thomas and Burden,1963) or normally distributed flows are generated and inverse normalizing equations are applied. The procedure for the later was proposed by Beard and has been adopted by U.S.Army Corps of Engineers(Beard,1972). This is only for annual flows. To deal with nonnormally distributed monthly flows the mean, standard deviation and coefficient of skewness need to be modified (Beard, 1972).

3.0 STATEMENT OF THE PROBLEM

The main objective of the study is to apply Thomas Fiering model for generation of monthly streamflow data for different sites in Chaliyar river basin (Kerala).

Four cases of first order Thomas Fiering model i.e.(i) without any transformation (including negative flows) (ii) with squareroot transformation (iii) with logarithmic transformation and (iv) without any transformation excluding negative flows, have been studied. Monthly streamflows from 1965 to 1978 for eight sites of Chaliyar river and its tributaries have been used. The objective is also to study the comparative performance of four cases of Thomas Fiering model for each of 8 sites with respect to reproduction of means and standard deviations on annual and monsoon basis.

4.0 STUDY AREA

Western Ghats nurse some of the major river systems of the peninsular India. Chaliyar river basin is one of them. The physiography, geomorphology, land use and water use aspects in the basin have been presented by Bhatia et.al.(1982). The Chaliyar river basin has been chosen for this study as this basin represents the general topography of Kerala and the river and its tributaries traverse all the three physiographic terrains i.e. the high lands, the mid land and the coastal low lands. Chaliyar river basin is situated between $11^\circ 5'$ and $11^\circ 37'$ North latitude; $75^\circ 48'$ and $76^\circ 35'$ East latitude in Wynad,Kozhikode and Malappuram districts of Kerala and some portion of Gudalur districts of Tamil Nadu state. The basin extends from north to south over a distance of 60 km, from east to west over a distance of about 90 km and alongwith tributaries it drains an area of 2952.87 km^2. It is bounded in the east and north by east flowing river basins Kabbani and Bhavani respectively,south by Kadalundi river and west by Arabian sea. Chaliyar river originates on the eastern slope of Elamaleri hills at an elevation of 2068 meters above mean sea level and joins the Arabian sea near Byporeport. The length of Chaliyar river is 169 km. The Chaliyar river is the third largest river of Kerala state and it is known near the mouth as Beypore river. The main tributaries of the Chaliyar river are Karimpuzha, Kuthirpuzha, Kanjirpuzha, Cherupuzha, Punnarpuzha, Mukkom, Koodathai etc.(Figure 1). The eight sites, for which monthly flow data have been used and their catchment areas are given in Table 1.

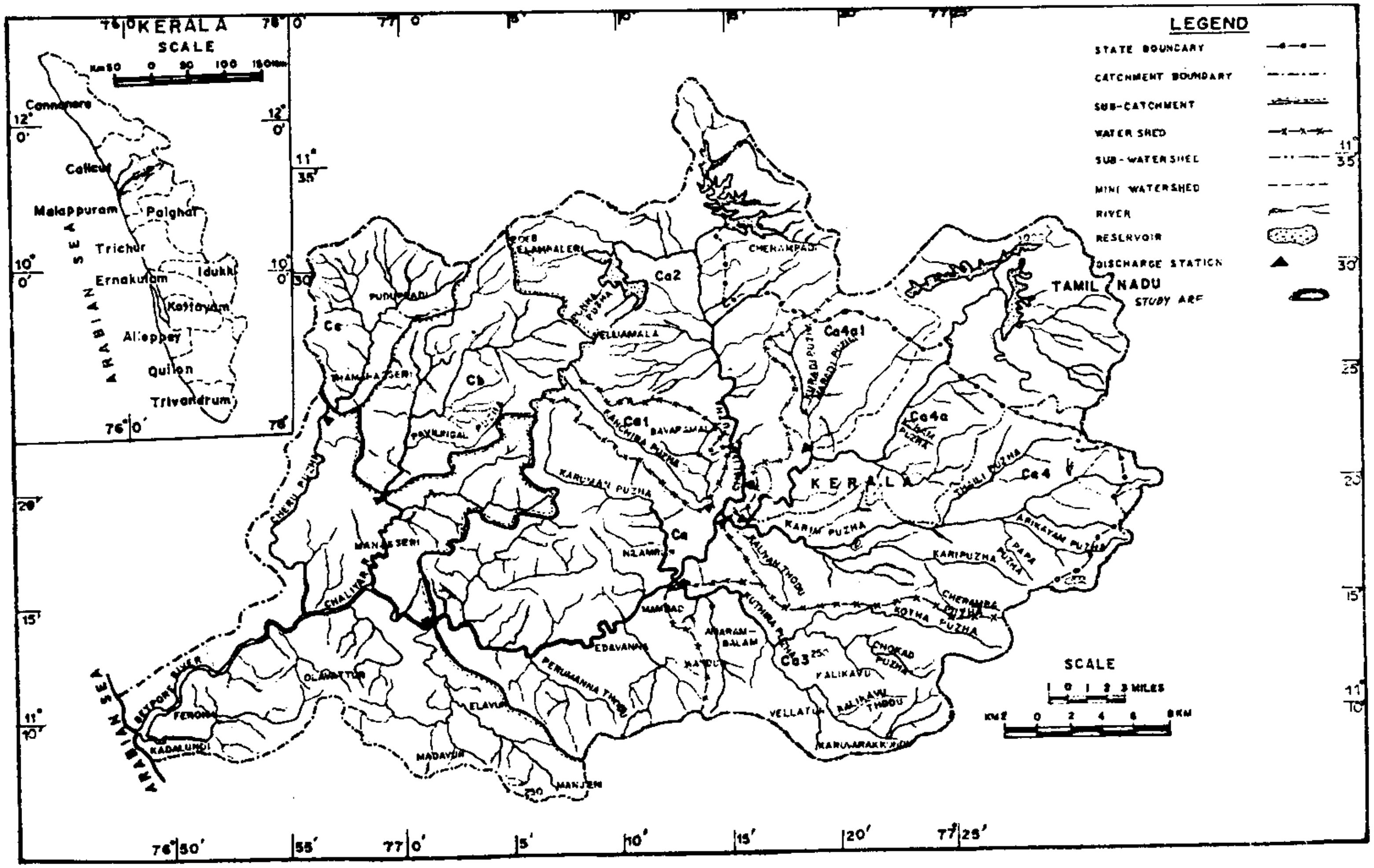


Fig.1.Chaliyar river catchment

TABLE- 1

TRIBUTARIES AND THEIR CATCHMENT AREAS

Sr.No.	Name of the tributary	(Area Km^2)
1.	Kuthirpuzha	259.22
2.	Kanjirpuzha	71.77
3.	Koodathai	121.25
4.	Mukkom	208.10
5.	Karimpuzha	804.76
6.	Punnarpuzha	468.96
7.	Chaliyar	448.15
8.	Areakode	2049.52

5.0 AVAILABILITY OF DATA

Chaliyar river, though one of the largest rivers of Kerala state, has not been exploited for its water resources. The river does not have any irrigation or power projects on it. Many futuristic schemes are in the pipeline and hence the hydrologic data of Chaliyar river and its tributaries have been collected by the State irrigation department. Hydrological data collection system on various tributaries was started in 1965. The daily discharge is being measured three times a day by either stages, current meters or structures. Central Water Commission is also maintaining a site in the basin.

There are eight gauging sites in the basin. For this study the daily discharge data were available in cumecs from 1965to 1978(14 years),except Karimpuzha which is having 13 years data. This data were checked (for any spurious value), processed and were converted into monthly values for the eight discharge sites for use in the present study.

6.0 METHODOLOGY

The algorithm for the Thomas Fiering(1862) seasonal model is as follows:

$$X_{i+1} = \overline{X}_{j+1} + b_j (X_i - \overline{X}_j) + t_i \; S_{j+1} (1 - r_j^2)^{1/2} \qquad \ldots(1)$$

where:

X_{i+1}, X_i Generated flows during the (i+1)th and ith seasons reckoned from the start of the synthesized sequence.

$\overline{X}_{j+1}$, $\overline{X}_j$ Mean flows during (j+1)th and jth seasons within a respective annual cycle of seasons(if months are being used then $1 \leq j \leq 12$)

b_j Least square regression coefficientfor estimating (j + 1)th season's flow from the jth season's flow

$$b_j = r_j \frac{S_{j+1}}{S_j} \qquad \ldots(2)$$

t_j Normal random variate with zero mean and unit variance

S_{j+1}, S_j Standard deviations of flows during (j+1)th and jth seasons

r_j Correlation coefficient between flows of jth and (j+1)th seasons

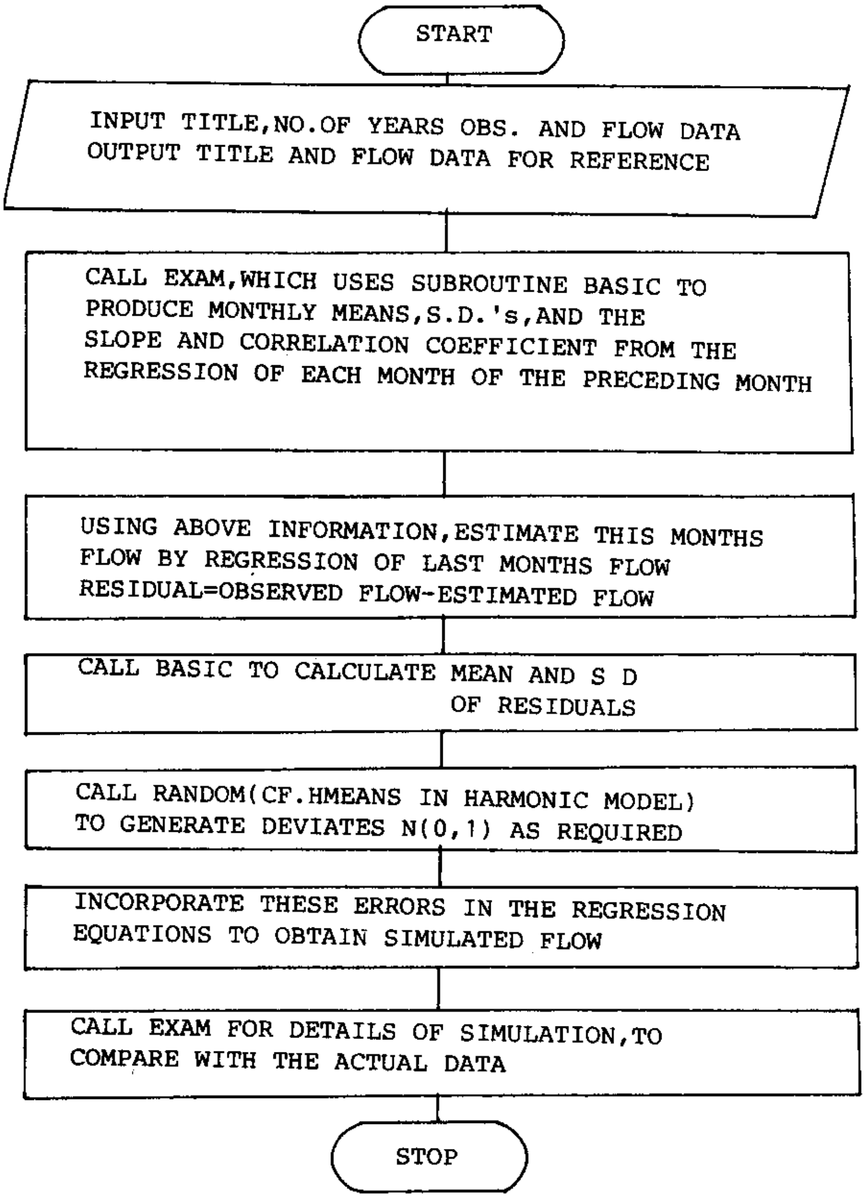
The flow chart of Thomas Fiering model has been given in Flow Chart 1.

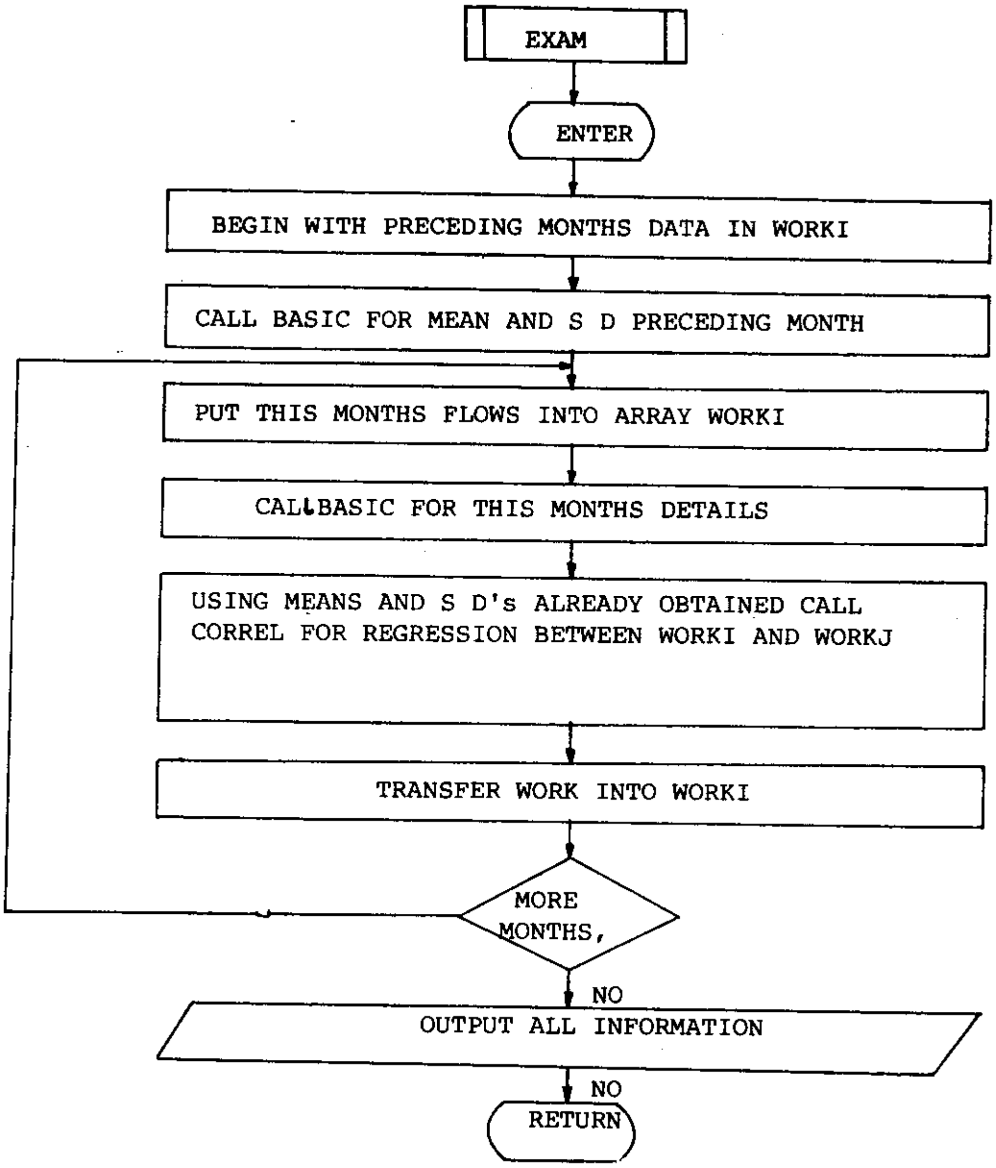
To use the model to generate monthly flows at a site 36 parameters i.e. monthly means, standard deviations and lag one serial correlations are reqired. These are obtained from the analysis of monthly historical flows.

The statistical characteristics of monthly flows were computed for all the 8 sites. Though in some months, the monthly

FLOW CHART - I

THOMAS FIERING MODEL





SUBROUTINES BASIC AND CORREL ARE STRAIGHTFORWARD, INVOLVING SUMMATION OF ITEMS, THEIR SQUARES OR CROSS-PRODUCTS, FOLLOWED BY EVALUATION OF THE NECESSARY EQUATIONS TO GIVE MEANS, STANDARD DEVIATIONS, REGRESSION SLOPES AND CORRELATION COEFFICIENTS.

flows are non-normal, in general normality assumption could be reasonable as far as application of Thomas Fiering model is concerned.

7.0 ANALYSIS

Monthly streamflows (cumecs) for 8 tributaries and their statistical parameters (mean,standard deviation and correlation with previous month)are given in Table 2to Table 9. The mean, standard deviation and correlation with previous months have been calculated using the following equations:

$$\overline{X}_j = \frac{\sum_{i=1}^{N} X_{i,j}}{N} \qquad ...(3)$$

$$S_j = \left[\frac{\sum_{i=1}^{N} (X_{i,j} - \overline{X}_j)^2}{N-1} \right]^{1/2} \qquad ...(4)$$

$$r_j = \frac{\sum_{i=1}^{N} (X_{i+1} - \overline{X}_{j+1}) (X_i - \overline{X}_j)}{[\sum_{i=1}^{N} (X_{i,j} - \overline{X}_j)^2]^{1/2} [\sum_{i=1}^{N} (X_{i+1} - \overline{X}_{j+1})^2]^{1/2}} \qquad ...(5)$$

Data sets of 100 years period were generated using Thomas Fiering model. To avoid negative flows in the generated data following three alternatives were attempted which take care of the negative flows:

a. Square root transformation

b. Logarithmic transformation

c. Replacing negative flows in the generated flows by zeros.

In the square root transformation case the square root of flow sequence was taken and the flows were generated. Where negative values were encountered they were retained and used to

TABLE - 2

MONTHLY STREAMFLOWS AND STATISTICAL PARAMETERS FOR KUTHIRPUZHA

MONTHLY FLOWS OF KUTHIRPUZHA TRIBUTARY IN CUMECS FROM 1965 TO 1978

FLOWS

7.7	5.0	4.2	4.5	11.4	40.4	127.6	64.8	53.6	90.6	36.7	20.6
6.8	2.2	0.4	1.2	10.6	66.0	244.0	125.3	29.8	30.7	21.7	8.2
4.2	2.2	3.9	5.7	13.0	41.0	175.0	100.6	42.2	45.0	21.0	6.7
3.2	2.7	2.7	19.3	20.0	2.3	214.6	77.0	51.2	57.4	351.2	28.6
6.3	1.8	0.5	3.1	28.7	59.5	234.2	257.3	94.5	102.7	40.4	7.7
23.0	17.1	15.8	14.3	49.4	274.7	218.9	179.1	106.6	132.4	56.2	39.0
21.6	17.8	17.1	16.7	30.3	39.3	142.8	61.3	40.6	56.8	35.6	30.2
32.1	23.4	22.3	21.8	22.6	108.6	182.4	144.6	61.8	58.5	48.8	36.9
13.4	7.5	6.4	14.8	24.8	28.9	482.1	408.4	148.7	106.0	33.9	20.1
16.8	14.1	15.4	11.8	19.0	194.9	144.7	322.6	133.8	102.1	81.3	19.7
13.7	10.4	9.1	9.5	9.6	15.7	145.4	174.2	90.4	36.0	53.6	20.3
3.8	1.3	1.1	1.1	14.2	122.2	262.8	97.2	99.9	91.9	67.0	18.6
8.0	2.7	2.0	2.1	6.7	121.4	253.7	255.9	62.4	36.4	124.0	14.7
6.9	2.6	1.9	1.0	6.3	66.5	191.0	336.1	40.1	27.5	27.8	12.3

MEANS

11.96	7.90	7.35	9.07	19.06	84.37	215.65	186.03	75.39	69.58	71.37	20.28

STANDARD DEVIATIONS

9.63	7.36	7.32	7.32	11.71	75.18	98.67	112.15	37.20	33.87	85.03	10.31

SLOPES

0.351	0.836	0.985	0.762	0.885	3.203	-0.086	0.679	0.200	0.675	-0.180	0.032

CORRELATION WITH PREVIOUS MONTH

0.413	0.980	0.991	0.762	0.553	0.499	-0.073	0.537	0.602	0.741	-0.072	0.266

TABLE - 3

MONTHLY STREAMFLOWS AND STATISTICAL PARAMETERS FOR KANJIRPUZHA

MONTHLY FLOWS OF KANHIRPUZHA TRIBUTARY IN CUMECS FROM 1965 TO 1978

FLOWS

2.3	1.1	0.8	0.4	2.0	4.6	46.2	15.9	10.7	34.3	14.5	4.4
7.0	4.4	3.0	2.2	4.1	16.7	97.5	53.3	27.1	23.4	17.2	13.3
13.0	8.1	7.4	7.2	7.8	26.2	187.5	129.5	84.7	39.1	25.1	17.2
5.6	4.0	3.0	4.1	5.0	16.9	95.1	51.2	43.3	8.9	8.0	7.7
3.9	3.1	3.2	3.1	5.7	16.1	35.2	48.5	13.5	16.9	6.4	5.1
1.2	0.7	0.5	0.5	1.1	157.3	73.4	66.8	44.6	35.5	15.0	8.7
8.5	6.0	4.8	3.8	3.4	7.1	42.5	12.7	5.0	14.0	9.7	3.0
0.7	0.6	0.3	0.3	0.7	37.3	53.6	33.1	8.0	4.0	2.3	1.0
0.9	0.5	0.3	0.1	0.4	1.8	64.5	79.9	24.6	19.1	2.7	0.1
2.2	1.6	1.6	1.0	1.1	80.2	58.1	86.9	26.3	23.3	18.0	4.7
1.7	1.0	0.7	0.6	0.5	0.8	27.9	30.9	11.4	4.5	9.4	3.0
1.1	0.7	0.4	0.3	1.2	18.8	54.8	18.5	21.3	15.0	15.6	4.3
2.3	1.7	1.2	0.7	0.9	32.2	71.6	79.4	19.7	7.5	29.6	3.1
4.2	1.8	1.1	1.1	1.1	26.2	86.0	146.9	20.2	10.7	10.1	7.2

MEANS

3.91	2.52	2.02	1.82	2.51	31.58	70.99	60.97	25.75	18.30	13.13	5.91

STANDARD DEVIATIONS

3.56	2.32	2.07	2.05	2.32	41.38	39.64	40.81	20.68	11.52	7.84	4.66

SLOPES

0.511	0.643	0.881	0.963	1.054	-3.643	0.079	0.676	0.292	0.330	0.262	0.298

CORRELATION WITH PREVIOUS MONTH

0.672	0.986	0.987	0.973	0.932	-0.204	0.082	0.657	0.576	0.592	0.385	0.502

TABLE - 4

MONTHLY STREAMFLOWS AND STATISTICAL PARAMETERS FOR KOODATHAI

MONTHLY FLOWS OF KOODATHAI TRIBUTARY FROM 1965 TO 1978

FLOWS

2.6	2.4	2.6	3.3	15.5	9.1	132.0	139.3	26.1	40.2	21.3	5.9
5.2	3.1	3.5	3.5	7.5	33.3	335.7	216.1	28.0	37.1	21.2	11.2
3.8	1.6	1.3	1.8	3.9	46.3	451.0	107.3	2.6	7.7	5.3	3.7
2.2	1.4	1.2	2.2	18.4	67.0	231.1	164.3	94.7	32.0	19.5	13.8
17.2	9.8	6.8	5.5	29.4	82.5	196.6	184.4	46.7	57.6	20.7	16.5
6.9	5.3	3.5	3.5	19.8	144.8	91.8	37.6	30.5	51.4	28.9	16.6
5.1	3.4	2.6	10.9	2.8	22.4	126.4	66.0	21.7	36.3	23.7	7.9
4.9	3.2	2.4	2.6	3.1	90.2	123.1	107.3	24.4	13.1	14.6	6.0
2.7	1.8	1.1	3.6	4.6	11.1	195.5	116.1	95.3	41.7	6.8	6.6
6.7	5.5	5.4	3.3	6.7	120.0	134.5	170.4	87.4	91.1	65.4	20.4
9.8	3.6	1.9	2.4	1.3	2.8	60.4	70.0	36.1	27.0	32.5	12.6
3.6	3.8	4.3	5.3	17.3	82.1	148.0	64.3	77.3	75.1	63.4	24.3
25.2	17.7	13.5	7.9	12.4	216.8	310.9	281.4	92.0	43.3	16.3	83.2
15.8	7.9	4.0	6.2	45.7	178.1	351.7	321.5	99.5	110.1	95.7	37.9

MEANS

7.90	5.05	3.87	4.43	13.46	79.04	206.34	146.15	53.73	46.69	31.10	19.04

STANDARD DEVIATIONS

6.79	4.35	3.22	2.54	12.39	56.09	114.78	83.67	33.69	27.30	25.78	20.56

SLOPES

0.167	0.617	0.705	0.392	0.987	2.831	0.432	0.446	0.210	0.531	0.845	0.204

CORRELATION WITH PREVIOUS MONTH

0.500	0.963	0.959	0.493	0.182	0.531	0.249	0.611	0.521	0.656	0.894	0.256

TABLE - 5

MONTHLY STREAMFLOWS AND STATISTICAL PARAMETERS FOR MUKKOM

MONTHLY FLOWS OF MUKKOM TRIBUTARY IN CUMECS FROM 1965 TO 1978

FLOWS

7.0	1.9	0.0	0.0	19.7	139.7	397.6	217.5	93.3	140.8	42.3	17.9
10.9	4.3	0.8	0.4	55.1	400.9	606.8	548.9	60.5	61.6	14.9	5.3
3.3	1.3	2.8	2.5	2.9	315.5	923.8	234.2	197.1	133.5	48.1	10.4
2.7	1.1	0.4	0.6	1.7	325.3	819.7	300.0	248.1	102.1	52.7	40.5
7.1	2.8	1.6	4.0	56.2	206.8	416.8	416.6	137.7	150.6	51.4	19.5
2.2	2.5	2.6	3.0	26.7	366.5	366.9	235.9	160.2	133.1	35.0	15.0
8.6	5.9	5.0	5.2	25.9	80.6	428.8	166.3	50.6	94.7	48.6	19.8
8.6	4.1	2.3	3.2	4.3	249.8	371.5	289.0	64.3	40.8	38.9	10.4
18.7	13.5	12.6	16.6	29.9	65.3	618.8	439.7	225.6	128.5	49.9	25.0
4.3	2.4	3.6	2.5	7.5	405.8	318.0	478.5	202.8	143.4	118.9	19.5
4.7	2.0	1.5	3.4	2.1	13.3	189.1	172.6	71.5	30.4	47.3	18.8
10.8	5.8	4.3	6.0	36.3	196.9	362.2	168.1	147.8	151.1	119.7	41.1
8.4	2.2	1.8	1.7	8.9	229.3	409.8	300.4	77.6	43.1	94.8	14.2
3.8	1.1	11.3	16.1	34.1	221.4	517.4	650.7	68.9	50.0	47.2	17.7

MEANS

7.21	3.64	3.60	4.66	22.24	229.78	481.93	329.89	129.00	100.26	57.83	19.55

STANDARD DEVIATIONS

4.40	3.26	3.80	5.24	18.78	124.60	199.36	152.99	68.42	45.86	30.92	10.26

SLOPES

0.004	0.675	0.701	1.346	0.946	0.244	0.527	0.140	0.007	0.432	0.202	0.153

CORRELATION WITH PREVIOUS MONTH

0.010	0.911	0.601	0.976	0.264	0.037	0.329	0.193	0.015	0.644	0.300	0.492

TABLE - 6

MONTHLY STREAMFLOWS AND STATISTICAL PARAMETERS FOR KARIMPUZHA

MONTHLY FLOWS OF KARIMPUZHA TRIBUTARY IN CUMECS FROM 1965 TO 1978

FLOWS												
	23.7	19.0	19.8	21.4	31.9	99.2	218.3	222.2	138.4	196.4	184.8	63.8
	43.2	18.6	24.6	12.7	26.7	466.7	666.8	615.2	190.0	41.9	26.0	14.4
	14.0	18.5	14.7	18.2	24.0	98.2	397.0	56.0	339.8	199.4	167.9	145.1
	122.7	37.7	27.2	22.8	20.0	25.2	69.3	282.8	120.1	87.4	49.1	34.1
	23.5	4.2	2.8	2.2	2.4	11.3	74.4	201.2	220.6	110.8	103.8	48.7
	20.6	69.1	58.8	53.7	53.0	96.0	334.2	205.3	263.9	185.0	202.5	113.9
	103.0	44.6	33.8	27.9	19.9	52.1	79.8	211.5	139.6	82.3	114.3	85.9
	87.0	22.9	9.9	5.4	4.1	9.1	334.5	519.9	431.1	169.4	85.2	61.8
	29.5	9.9	4.4	1.2	21.0	10.6	32.4	501.8	455.0	12.4	127.2	28.1
	1.2	3.1	1.3	1.1	0.4	1.9	260.2	212.9	541.6	154.0	127.6	89.1
	16.5	10.8	5.3	1.2	2.7	0.4	12.4	137.7	245.0	146.8	52.7	68.9
	26.5	10.5	5.9	3.0	3.4	19.8	174.5	353.3	163.4	170.4	135.0	99.3
	34.5	37.0	19.3	6.4	5.6	19.6	270.3	458.6	508.1	206.1	135.9	279.5
MEANS												
	42.01	23.54	17.52	13.64	16.54	70.01	224.16	306.03	288.98	135.53	116.31	87.13
STANDARD DEVIATIONS												
	37.57	18.88	16.15	15.27	15.45	124.91	182.92	168.90	149.58	63.06	52.92	68.21
SLOPES												
	0.687	0.203	0.809	0.905	0.886	3.497	1.166	0.352	0.208	0.073	0.481	0.585
CORRELATION WITH PREVIOUS MONTH												
	0.732	0.403	0.946	0.957	0.876	0.432	0.796	0.382	0.235	0.172	0.574	0.454

TABLE-7

MONTHLY STREAMFLOWS AND STATISTICAL PARAMETERS FOR PUNNARPUZHA

MONTHLY FLOWS OF PUNNARPUZHA TRIBUTARY IN CUMECS FROM 1965 TO 1978

FLOWS

9.9	5.6	4.2	3.1	16.7	14.0	29.0	26.3	20.0	69.7	49.2	18.4
11.7	7.2	5.4	5.1	10.4	40.4	79.4	70.5	20.1	22.8	14.0	10.2
4.1	4.2	4.9	3.9	5.0	76.4	641.0	266.4	160.9	108.6	68.0	92.0
26.5	8.9	1.7	2.4	3.5	14.3	18.0	432.9	465.1	72.1	74.9	52.5
31.0	15.6	6.0	2.8	6.3	20.8	47.5	138.4	167.5	91.2	116.0	58.1
36.8	35.7	25.5	21.2	17.1	29.6	126.5	141.5	146.5	105.7	144.1	71.3
53.2	26.4	17.1	11.8	10.7	88.0	37.2	91.4	69.3	39.7	57.2	39.5
29.9	13.7	8.7	5.7	5.2	7.3	63.8	127.7	115.0	64.9	39.4	27.2
17.9	10.3	6.5	4.6	25.3	12.6	18.3	158.3	161.5	102.7	83.9	34.8
18.6	17.2	12.7	12.1	8.4	13.3	62.4	95.6	156.5	88.2	78.2	50.0
28.3	19.0	12.4	7.9	10.1	5.7	11.6	65.1	99.3	88.7	41.4	50.7
26.6	10.5	7.5	6.3	5.8	14.5	61.9	146.4	120.8	128.5	110.3	74.5
31.6	15.5	8.1	5.6	8.1	7.6	56.5	145.9	192.2	83.9	53.3	124.6
30.7	17.0	9.6	6.5	5.2	5.9	50.4	128.7	218.2	67.2	38.3	47.9

MEANS

25.48	14.76	9.31	7.05	9.85	25.03	93.03	145.36	150.92	90.98	69.09	53.70

STANDARD DEVIATIONS

12.45	8.47	6.13	5.03	6.08	26.14	160.46	99.89	107.86	27.82	35.43	30.02

SLOPES

0.234	0.530	0.685	0.795	0.325	-0.167	3.542	0.194	0.961	0.054	0.911	0.321

CORRELATION WITH PREVIOUS MONTH

0.602	0.779	0.947	0.969	0.269	-0.039	0.577	0.312	0.890	0.210	0.715	0.379

TABLE - 8

MONTHLY STREAMFLOWS AND STATISTICAL PARAMETERS FOR CHALIYAR

MONTHLY FLOWS OF CHALIYAR TRIBUTARY IN CUMECS FROM 1965 TO 1978

FLOWS

14.5	9.9	9.6	6.6	18.5	35.8	209.5	122.3	80.9	140.1	81.8	33.8
14.8	9.8	9.2	9.0	13.8	98.7	400.6	254.8	64.8	52.7	27.9	27.8
30.0	30.0	29.6	28.4	30.7	160.8	658.1	391.6	213.3	100.0	83.9	87.8
51.0	40.4	39.3	40.0	44.2	118.0	451.3	298.6	321.5	100.0	148.8	109.9
79.6	59.1	54.4	57.3	91.8	138.2	217.8	194.8	68.8	68.2	61.9	62.6
5.1	3.3	2.9	3.4	11.2	371.3	140.1	135.6	45.8	67.2	16.2	6.8
9.9	4.6	4.0	10.9	3.4	85.2	195.5	46.4	20.8	37.4	25.6	12.7
12.6	8.4	7.0	6.6	7.9	267.8	513.5	372.5	97.2	43.2	33.4	17.6
9.4	6.3	5.1	6.2	8.2	17.5	394.5	381.9	145.8	98.5	27.5	15.4
6.8	4.2	7.1	3.5	5.0	77.6	155.6	311.3	131.7	96.9	65.4	17.6
14.0	8.9	7.0	7.9	4.8	9.7	245.3	327.2	127.3	37.2	54.4	18.2
9.1	6.1	4.8	5.1	11.1	155.2	274.5	144.2	133.5	126.6	91.5	39.3
79.0	54.4	44.3	54.0	54.0	254.6	311.8	344.9	174.6	127.3	175.1	94.7
90.8	70.4	52.3	54.5	52.8	192.6	431.5	596.3	203.7	154.2	145.6	108.8

MEANS

30.47	22.55	19.75	20.94	25.52	141.69	327.82	280.16	130.68	89.25	74.23	46.64

STANDARD DEVIATIONS

30.94	23.68	19.63	21.24	26.13	103.14	152.04	143.00	79.33	39.03	50.86	38.12

SLOPES

0.676	0.760	0.819	1.069	1.149	0.796	0.129	0.597	0.336	0.245	0.938	0.662

CORRELATION WITH PREVIOUS MONTH

0.750	0.993	0.988	0.988	0.934	0.202	0.088	0.635	0.606	0.499	0.720	0.883

TABLE - 9

MONTHLY STREAMFLOWS AND STATISTICAL PARAMETERS FOR AREAKODE

MONTHLY FLOWS OF AREAKOD TRIBUTARY IN CUMECS FROM 1965 TO 1978

FLOWS

24.9	12.8	9.6	3.1	26.5	99.9	688.6	368.6	327.7	534.6	211.2	73.3
46.9	18.2	7.4	5.4	38.2	285.4	1373.4	927.5	230.2	207.4	123.4	817.9
51.2	26.5	20.7	27.3	46.9	313.6	1770.8	1018.7	423.3	267.8	183.3	92.9
50.3	29.8	17.6	20.5	44.3	327.5	274.9	970.4	548.5	376.2	213.7	152.0
77.9	52.6	43.2	52.9	141.6	80.7	1559.1	1667.5	464.4	585.5	218.9	101.8
41.7	24.6	18.3	19.5	83.4	1069.2	813.1	636.8	386.1	427.9	148.5	91.5
44.2	27.3	17.3	15.4	85.5	163.4	969.0	404.9	164.9	304.5	171.4	107.3
46.5	22.2	14.4	13.0	19.6	447.4	887.9	711.2	230.7	155.7	122.8	61.1
33.0	16.5	9.2	13.9	28.8	83.0	1251.3	1130.5	537.9	367.0	109.9	59.9
25.2	18.0	19.3	13.9	21.0	757.8	646.0	1157.5	541.5	401.1	309.5	54.8
51.6	31.5	21.6	28.6	15.4	40.8	609.8	743.8	507.4	162.7	234.2	83.0
43.1	25.5	19.0	19.5	72.5	526.2	1131.8	565.1	525.3	546.9	346.6	140.7
33.4	11.5	5.9	4.2	11.5	572.5	1147.6	1316.1	368.6	149.1	466.5	62.1
33.2	13.3	6.8	5.5	35.7	363.5	1052.3	1526.9	243.1	150.5	170.8	63.5

MEANS

43.09	23.60	16.46	17.33	47.92	366.49	1012.54	938.97	392.83	331.21	216.50	140.12

STANDARD DEVIATIONS

13.53	10.55	9.50	13.04	36.21	292.57	401.71	396.36	134.77	155.72	98.87	197.35

SLOPES

0.015	0.718	0.853	1.318	1.955	-0.183	-0.256	0.382	0.074	0.510	0.046	-0.515

CORRELATION WITH PREVIOUS MONTH

0.234	0.921	0.948	0.960	0.704	-0.023	-0.187	0.387	0.217	0.441	0.073	-0.258

derive the subsequent value in the sequence, however, after generating complete record the flows were squared. The statistics of these flows were computed.

In the logarithmic transformation case the logarithmic of flow sequence was first taken and the flows were generated. The antilogarithmic of these flows was taken and the statistical parameters were determined.

The efficiency of all the four cases i.e.(i) Thomas Fiering model without any transformation, (ii) with square root transformation,(iii) with logarithmic transformation and (iv) replacing negative values by zeros, was compared on the basis of residual sum of squares of mean and standard deviation of historical data and of generated data.

The residual sum of squares of mean (R_m) is given by

$$R_m = \sum_{j=1}^{n} (M_{h,j} - M_{g,j})^2 \qquad ...(6)$$

where:

R_m : Residual sum of squares of mean

n : number of months

$M_{h,j}$: mean of jth month's flows (historical)

$M_{g,j}$: mean of jth month's flows (generated)

Similarly residual sum of squares of standard deviation (R_s) is given by:

$$R_s = \sum_{j=1}^{n} (S_{h,j} - S_{g,j})^2 \qquad ...(7)$$

where:

R_s Residual sum of squares of standard deviations

$S_{h,j}$ Standard deviation of jth month's flows(historical)

$S_{g,j}$ Standard deviation of jth month's flows (generated)

The listing of source file (Thomas Fiering model) has been given in Appendix I. Data file (Areakode flows) and output file are in Appendix II and III respectively.

8.0 RESULTS

The studies have been carried out on monsoon(June to October) and annual (June to May) basis. There are eight discharge measuring sites in Chaliyar river basin. These sites have been divided into following three groups:

(i) Categorv 'A' sites

(ii) Cateaory 'B' sites

(iii) Category 'C' sites

Category 'A' sites include Kuthirpuzha, Kanjirpuzha, Koodathai, Mukkom and Karimuzha. All these sites are on tributaries which are directly joining to the main river.

The sites which are on tributaries which are not joining to the main river directly but join to some other tributary, have been named as Category'B' sites. Only Punnarpuzha falls in this group.

Category 'C' sites include discharge measuring sites on main river. Chaliyar and Areakode sites fall in this group.

The mean monthly flows per unit area (cumecs per km^2) and coefficients of variation for various sites are given in Table 10 and 11 respectively.

The suitability and applicability of four cases of Thomas Fiering model have been discussed in subsequent sections in the light of reproduction of means and standard deviations in the 100 year generated data. The efficiency of four cases of Thomas Fiering model is given in Table 12. In the foregoing discussion the following notations have been used.

TABLE - 10

MEAN MONTHLY FLOWS PER UNIT AREA FOR DIFFERENT SITES

TRIBUTARY	MEAN MONTHLY FLOW PER UNIT AREA (CUMECS PER KM^2) FOR THE MONTH											
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
a. Category'A'Sites												
(i) Kuthirpuzha	0.046	0.030	0.028	0.035	0.073	0.325	0.831	0.717	0.290	0.268	0.275	0.078
(ii) Kanjirpuzha	0.054	0.035	0.028	0.025	0.034	0.440	0.989	0.849	0.358	0.254	0.182	0.823
(iii)Koodathai	0.065	0.041	0.031	0.036	0.111	0.651	1.701	1.205	0.443	0.385	0.256	0.157
(iv) Mukkom	0.034	0.017	0.017	0.022	0.106	1.104	2.315	1.585	0.619	0.481	0.277	0.093
(v) Karimpuzha	0.052	0.029	0.021	0.016	0.020	0.087	0.278	0.380	0.359	0.168	0.144	0.108
b.Category'B'Sites												
(i)Punnarpuzha	0.054	0.031	0.019	0.015	0.021	0.053	0.198	0.310	0.321	0.172	0.147	0.114
c. Category'C'Sites												
(i)Chaliyar	0.068	0.050	0.044	0.046	0.057	0.316	0.731	0.625	0.291	0.199	0.165	0.104
(ii) Areakode	0.021	0.011	0.008	0.008	0.023	0.178	0.494	0.458	0.191	0.161	0.105	0.068

TABLE - 11

COEFFICIENTS OF VARIATION FOR DIFFERENT SITES

TRIBUTARY	COEFFICIENT OF VARIATION FOR THE MONTH											
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
a. Category A sites												
(i) Kuthirpuzha	0.72	0.93	0.99	0.80	0.61	0.89	0.41	0.60	0.49	0.48	1.19	0.50
(ii) Kanjirpuzha	0.91	0.92	1.02	1.12	0.92	1.31	0.55	0.66	0.80	0.62	0.59	0.78
(iii) Koodathai	0.85	0.86	0.83	0.57	0.92	0.83	0.55	0.57	0.62	0.58	0.82	1.07
(iv) Mukkom	0.71	0.89	1.05	1.12	0.844	0.54	0.41	0.46	0.53	0.45	0.53	0.52
(v) Karimpuzha	0.89	0.80	0.92	1.11	0.93	1.78	0.81	0.55	0.51	0.46	0.45	0.78
b.Category'B'sites												
(i) Punnarpuzha	0.48	0.57	0.65	0.71	0.61	1.04	1.72	0.68	0.71	0.34	0.51	0.55
c.Category 'C'sites												
(i) Chaliyar	1.01	1.05	0.99	1.01	1.02	0.72	0.46	0.51	0.60	0.43	0.68	0.81
(ii) Areakode	0.31	0.44	0.57	0.75	0.75	0.79	0.39	0.42	0.34	0.47	0.45	1.40

TABLE - 12

EFFICIENCY OF THE MODEL ON THE BASIS OF FUNCTION R_m and R_s ON (i) ANNUAL BASIS (ii) MONSOON BASIS FOR FOUR CASES

TRIBUTARY	BASIS	VALUE OF FUNCTION R_m * for MODEL				VALUE OF FUNCTION R_s ** for MODEL			
		TFM[1]	STFM[2]	LTFM[3]	ZTFM[4]	TFM	STFM	LTFM	ZTFM
a.Category'a' sites									
(i) KUTHIR-PUZHA	ANNUAL	109.5	(128.3)	158.3	389.4	180.7	748.6	2749.1	(274.7)
	MONSOON	50.6	(63.6)	134.0	76.4	128.3	386.8	2157.8	(177.2)
(ii)KANJIRPUZHA	ANNUAL	(16.4)	12.5	50.2	33.8	14.7	220.9	736.0	(99.1)
	MONSOON	(16.2)	11.9	27.0	33.0	14.2	220.1	374.4	(98.8)
(iii)KOODATHAI	ANNUAL	(51.8)	50.6	380.9	79.3	99.7	151.1	4558.3	(117.5)
	MONSOON	(50.3)	49.1	366.3	72.3	96.0	122.5	4455.1	(103.0)
(iv) MUKKOM	ANNUAL	188.4	155.1	471.6	(176.5)	520.5	370.3	12616.9	(458.3)
	MONSOON	182.6	142.8	392.0	(162.3)	512.2	367.1	11924.7	(455.8)
(v)KARIMPUZHA	ANNUAL	403.4	(587.9)	4016.4	1419.5	1374.6	4313.6	35343.0	(2712.8)
	MONSOON	375.0	(501.5)	2585.0	1295.9	923.2	4017.0	20226.0	(2566.8)
b. Category'b' sites									
(i)PUNNARPUZHA	ANNUAL	45.2	(84.7)	937.2	1098.9	326.5	4848.4	11729.6	(1702.2)
	MONSOON	40.10	(82.7)	928.5	1095.5	322.8	4841.6	11429.9	(1699.4)
c.Category'c'sites									
(i)CHALIYAR	ANNUAL	172.9	219.9	938.6	(196.1)	(258.7)	393.4	10446.9	251.4
	MOONSOON	169.2	210.5	849.6	(172.9)	209.7	385.2	8934.9	((243.4)
(ii)AREAKODE	ANNUAL	(1639.1)	1511.8	3385.3	1961.7	2762.6	9713.6	32148.5	(5571.3)
		1546.6	(1422.2)	2987.7	1206.6	2394.5	3170.5	20417.0	(3610.1)

REMARKS FOR TABLES 10,11,12

$$*R_m = \sum_{j=k}^{n} (\text{Mean of historical flows-mean of generated flows})^2$$

$$**R_s = \sum_{j=k}^{n} (\text{Standard deviation of historical flows-standard deviation of generated flows})^2$$

for monsoon k = 6, n=10 (June to October)

for annual k = 1, n=12 (January to December)

1 TFM : First order Thomas Fiering Model

2 STFM : First order Thomas Fiering Model with square root transformation.

3 LTFM : First order Thomas Fiering Model with Logarithmic transformation

4 ZTFM : First order Thomas Fiering Model in which negative generated flows are replaced by zeros.

Minimum (Best) values of function R_m and R_s are underlined and second best values are bracketed.

(i) TFM for first order Thomas Fiering model

(ii) STFM for first order Thomas Fiering model with square root transformation to avoid negative flows in the generated data.

(iii) LTFM for first order Thomas Fiering model with logarithmic transformation to avoid negative flows in the generated data.

(iv) ZTFM for first order Thomas Fiering model in which negative flows in the generated data are replaced by zeros.

The observed and generated means and standard deviation for one site(Areakode, the main site on Chaliyar river) for all the four cases have been plotted in figures 2a to 5 b.

8.1 Category 'A' sites

8.1.1 Kuthirpuzha

Thomas Fiering model in its original form (TFM) gives better reproduction of means and standard deviations on annual and monsoon basis while STFM is second best in reproducing monthly means. STFM is not able to reproduce standard deviations correctly. Mean monthly flows per unit area for Kuthirpuzha vary between .0305 cumecs per km^2 to 0.8319 cumecs per km^2.

8.1.2 Kanjirpuzha

STFM is better in reproducing monthly means on monsoon and annual basis while TFM is better in reproducing standard deviations. Kanjirpuzha is a small tributary having drainage area of 71.77 km^2. The mean monthly flows per unit area as calculated for Kanjirpuzha are a bit

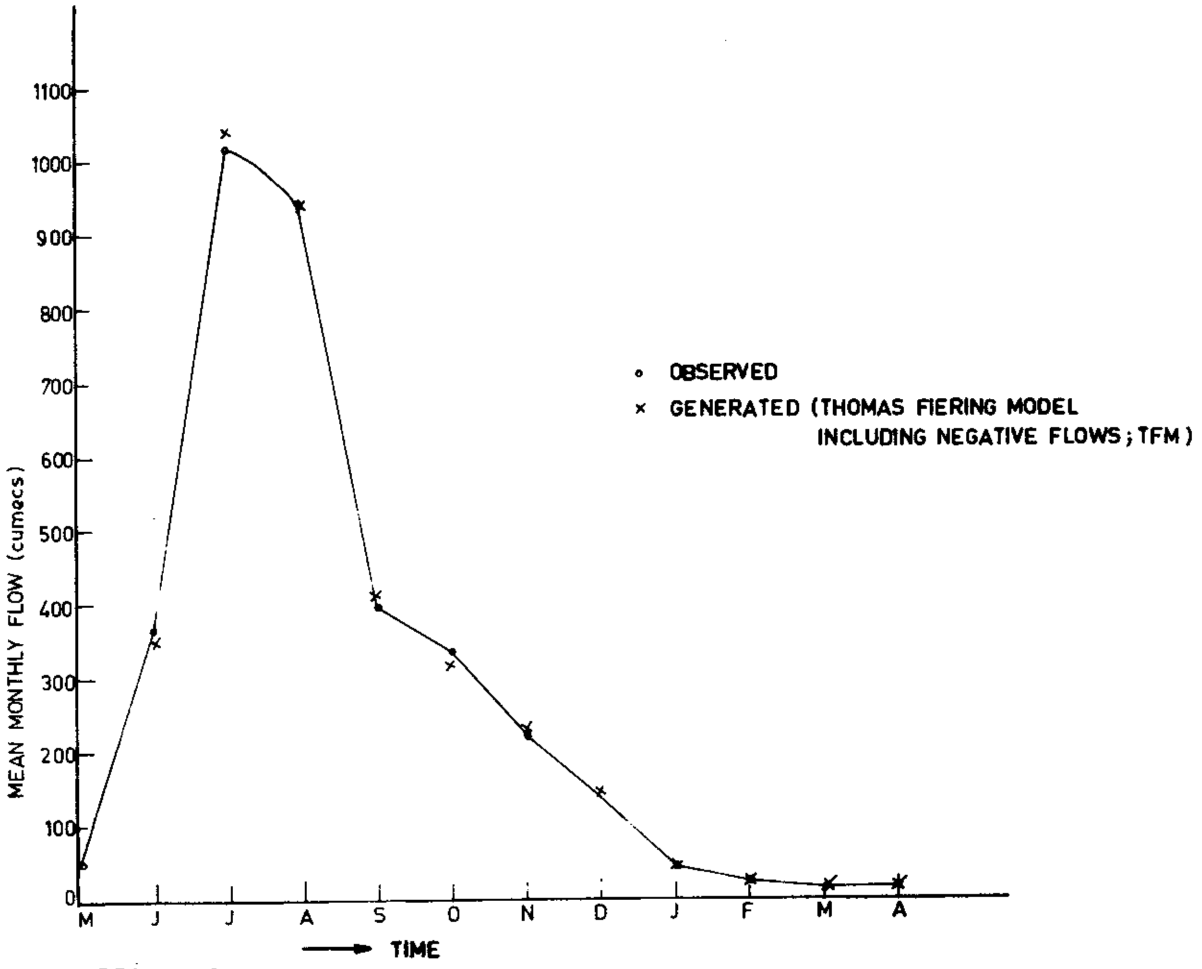


FIGURE 2a - THOMAS FIERING MODEL, MONTHLY MEANS OF OBSERVED AND GENERATED FLOWS FOR AREAKODE (TFM)

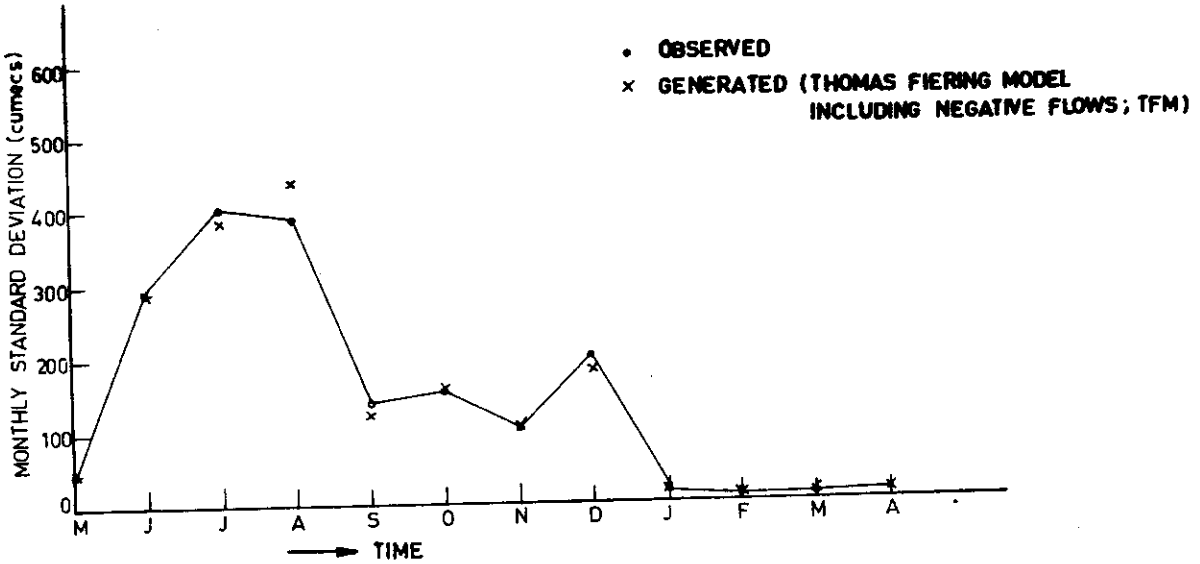


FIGURE 2 b- THOMAS FIERING MODEL, MONTHLY STANDARD DEVIATION OF OBSERVED AND GENERATED FLOWS FOR AREAKODE (TFM)

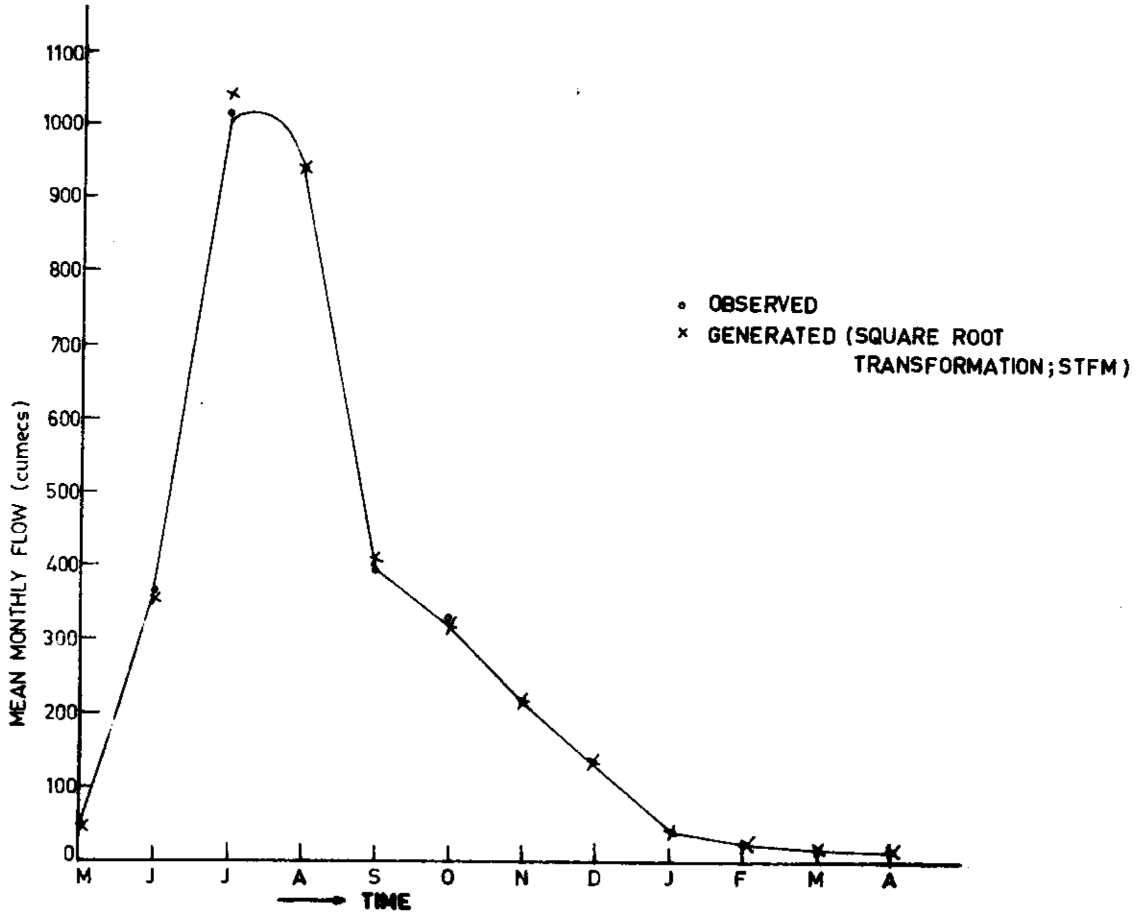


FIGURE 3a - THOMAS FIERING MODEL, MONTHLY MEANS OF OBSERVED AND GENERATED FLOWS FOR AREAKODE (STFM)

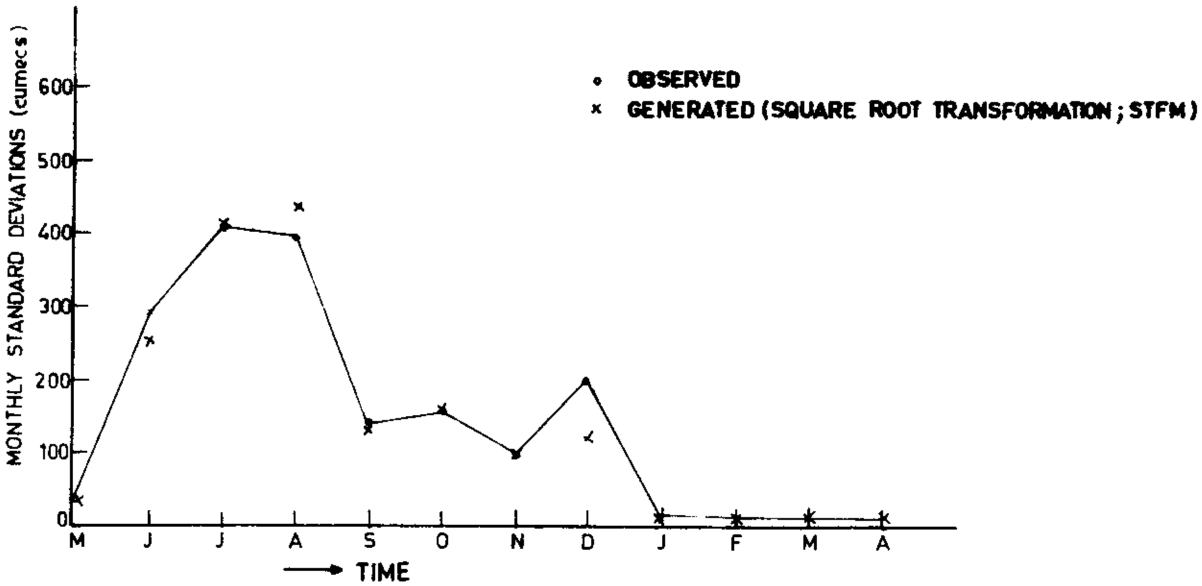


FIGURE 3b- THOMAS FIERING MODEL, MONTHLY STANDARD DEVIATIONS OF OBSERVED AND GENERATED FLOWS FOR AREAKODE (STFM)

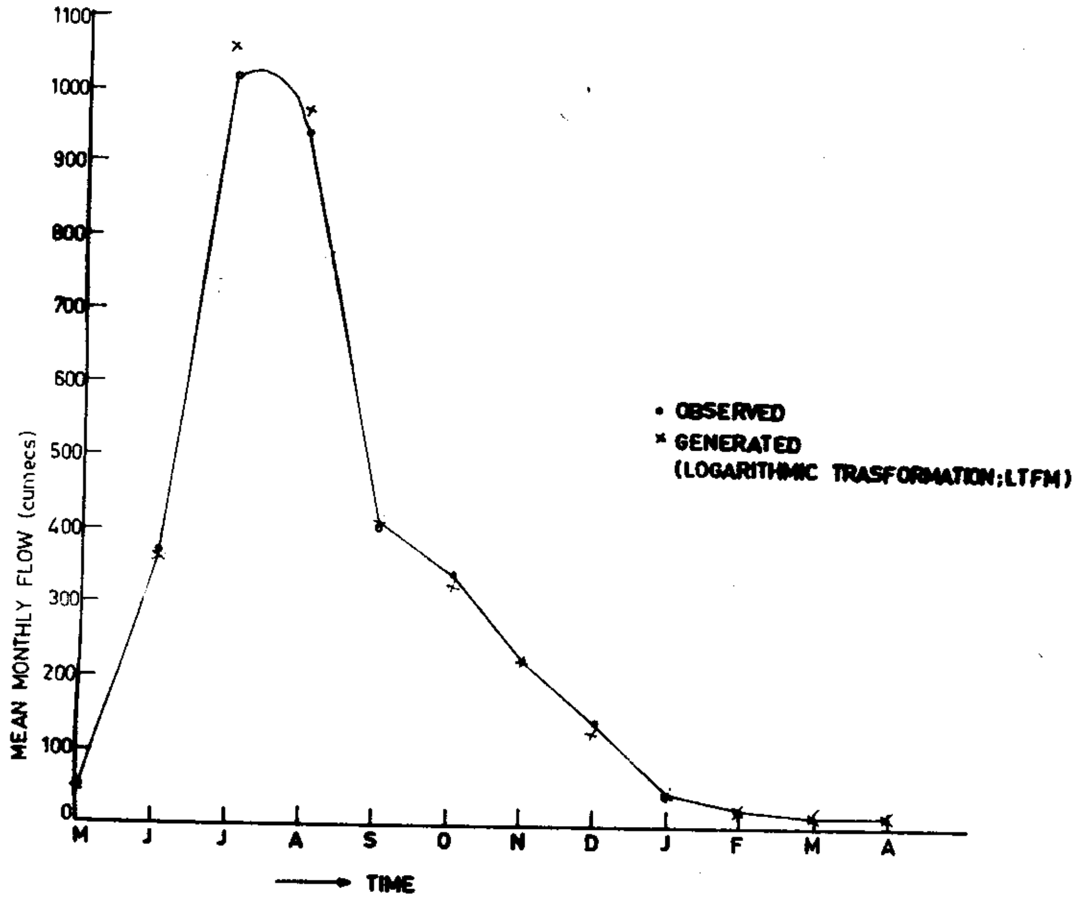


FIGURE 4a- THOMAS FIERING MODEL,MONTHLY MEANS OF OBSERVED AND GENERATED FLOWS FOR AREAKODE (LTFM)

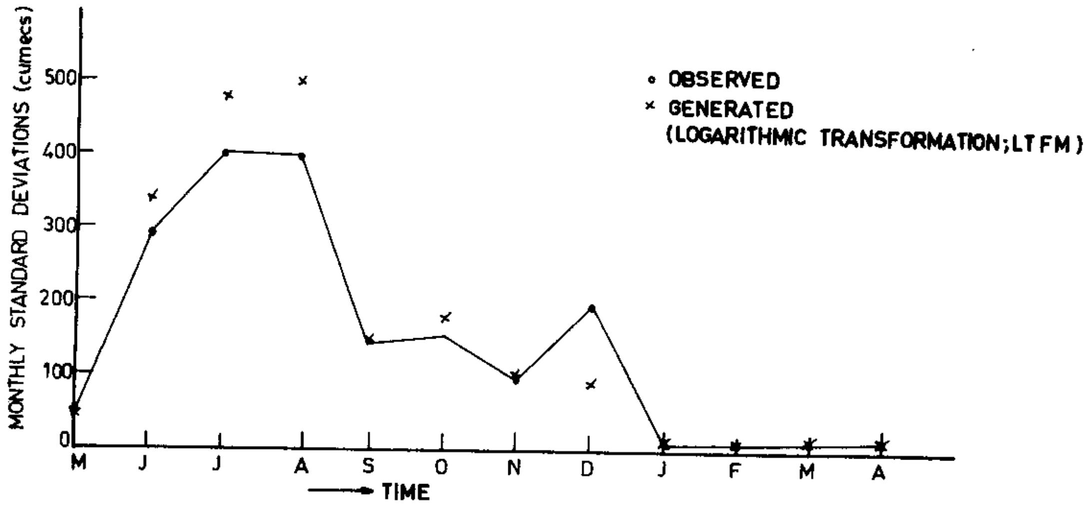


FIGURE 4 b - THOMAS FIERING MODEL,MONTHLY STANDARD DEVIATIONS OF OBSERVED AND GENERATED FLOWS FOR AREAKODE (L

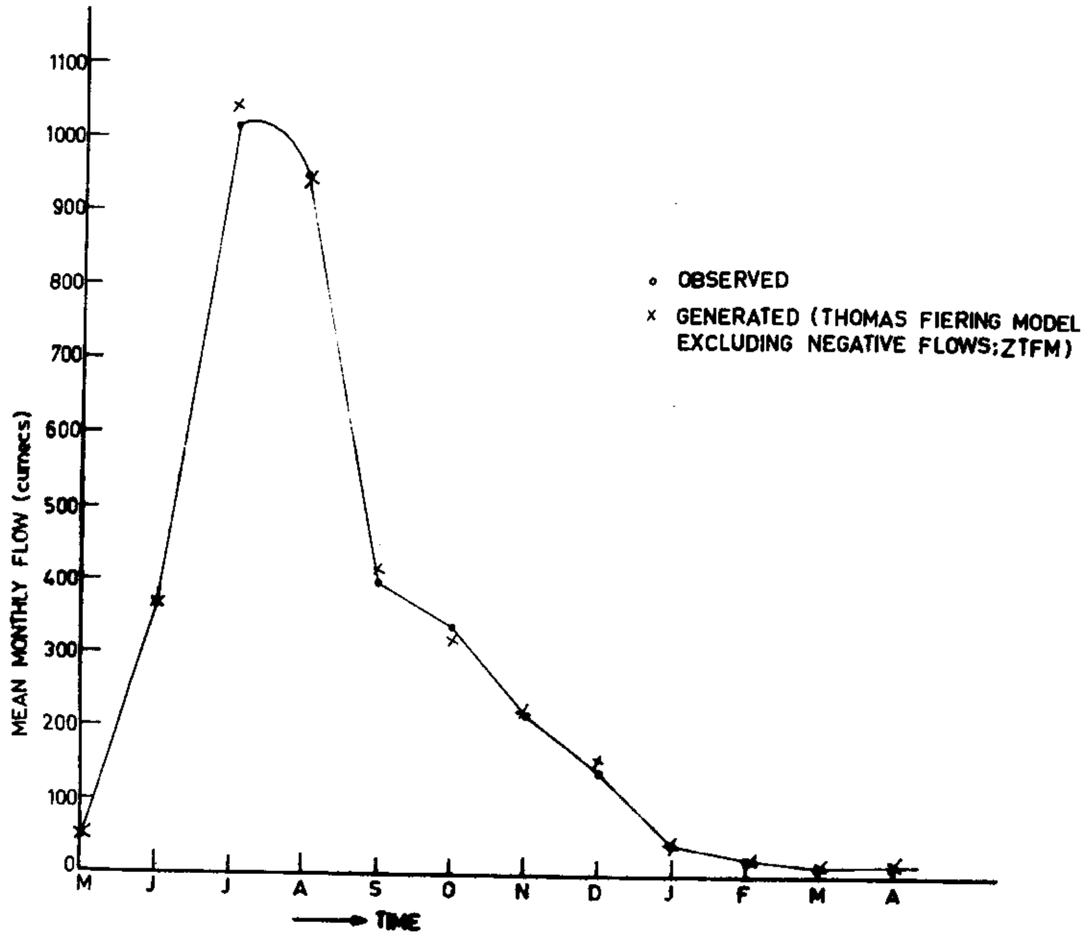


FIGURE 5a- THOMAS FIERING MODEL, MONTHLY MEANS OF OBSERVED AND GENERATED FLOWS FOR AREAKODE (ZTFM)

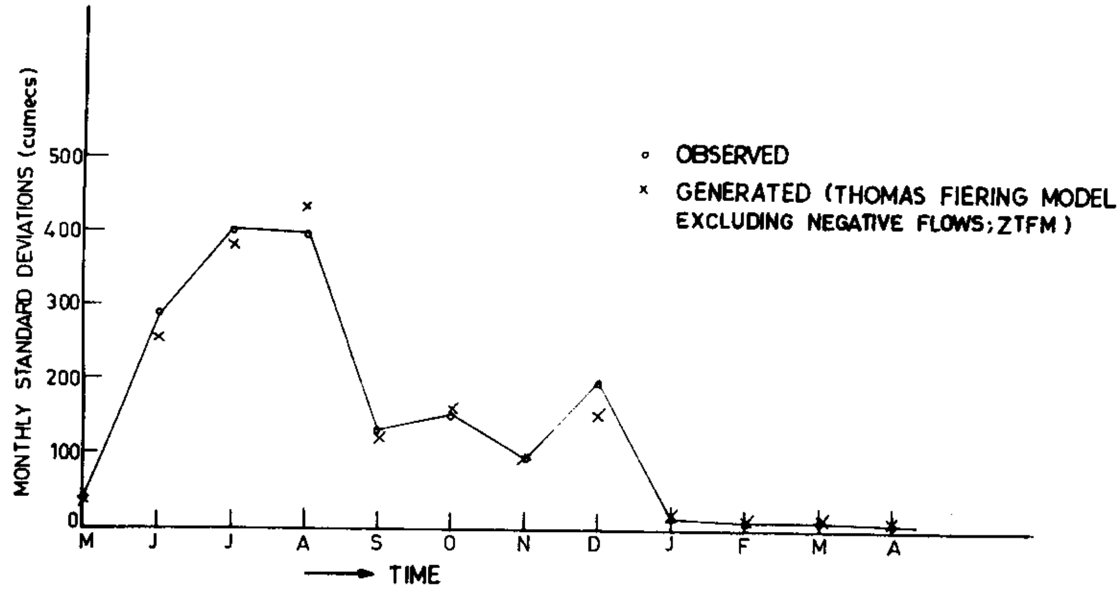


FIGURE 5b - THOMAS FIERING MODEL, MONTHLY STANDARD DEVIATIONS OF OBSERVED AND GENERATED FLOWS FOR AREAKODE (ZTFM) higher than Kuthirpuzha. STFM can be considerea appropriate for monthlystreamflow generation for Kanjirpuzha.

8.1.3 Koodathai

On monsoon and annual basis, monthly means are reproduced in a better way in STFM. TFM is better in reproducing monthly standard deviations. Mean monthly flows per unit area are very high in Koodathai. These vary from 0.416 cumecs per km^2 to 1.7018 cumecs per km^2. Coefficients of variation for different months are comparable with other tributaries.

8.1.4 Mukkom

On monsoon and annual basis STFM is better in reproducing means and standard deviations. Mean monthly flows per unit area are very high (highest) in Mukkom. This may probably be due to high rainfall in the catchment.

8.1.5 Karimpuzha

Thomas Fiering model in its original form gives better reproduction of means and standard deviations on monsoon and annual basis. STFM is second best in reproducing monthly means. Mean monthly flows per unit area are bit lower in Punnarpuzha.

For Category 'A'sites STFM is either best or second best in all the five cases. In two cases(Kuthirpuzha and Karimpuzha) Thomas Fiering model in its original form gives better reproduction of monthly means.

STFM can be considered appropriate for monthly stream flow generation for Category 'A' sites.

8.2 Category 'B' sites

8.2.1 Punnarpuzha

The Thomas Fiering model in its original form gives better reproduction of means and standard deviations on monsoon and annual basis. STFM is second best in reproducing means of monthly flows on annual and monsoon basis. Mean monthly flows per unit area are very low in Punnarpuzha. This may be due to lesser rainfall in the catchment.

Keeping in view the negative flows in generated data STFM can be considered appropriate for monthly stream flow generation for Punnarpuzha.

8.3 Category 'C' sites

8.3.1 Chaliyar

Thomas Fiering model in its original form gives better reproduction of means on monsoon and annual basis. This is better in reproducing standard deviations on monsoon basis but not on annual basis. STFM is better on annual basis.

8.3.2 Areakode

ZTFM is better in reproducing monthly means on monsoon basis. On annual basis STFM is better. TFM gives better reproduction of standard deviations on monsoon and annual basis.

For sites on main river (Category 'C' sites) ZTFM is giving better results than STFM. Flow is always here in the main river, so putting negative flows in the generated data as zeros will not be appropriate. Hence STFM is suitable for monthly stream flow generation for Category 'C' sites on main river.

9.0 CONCLUSION

The study provides some indications of the applicability of Thomas Fiering model for monthly streamflow generation for Chaliyar river basin. It is seen that first order Thomas Fiering model with square root transformation would be able to adequately represent monthly means for Chaliyar river basin.

If reproduction of monthly standard deviations is the criterion, the Thomas Fiering model in its original form provides good reproduction of standard deviations. The ZTFM is second best in reproducing monthly standard deviations. In view of the negative flows in the generated data application of first order, Thomas Fiering model is not appropriate as the flow is always positive in the river and its tributaries. In view of this, first order Thomas Fiering model with square root transformation to avoid negative flows in the generated data can be used for the synthetic generation of monthly streamflow data for Chaliyar river basin.

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APPENDIX - I

SOURCE PROGRAMME - THOMAS FIERING MODEL

```
C       MASTER THOMAS FIERING MODEL
C       A ROUTINE TO FIT  THOMAS-FIERING MODEL MONTHLY FLOWS
        CHARACTER*10 FILEI,FILEO
        COMMON B(12),R(12)
        DIMENSION Q(480),WQ(480),MONS(12),RES(480),TITLE(80),
        1SYNQ(1200),E(1200),AVEMON(12),SDMON(12),GAVEMON(12),GSDMON(12)
        DIMENSION OAVEMON(12),OSDMON(12)
        REAL MONSUM1,MONSUM2
C       B & R ARE THE SLOPE OF THE REGRESSION LINE &CORR. COEFF. RESPECTIVELY
C       AVEMON,SDMON,ARE MONTHLY MEANS AND STANDARD DEVIATIONS
C       SYNQ ARE THE GENERATED SERIES
        WRITE(5,89)
89      FORMAT(4X,'NAME OF THE INPUT FILE?'$)
        READ(5,90)FILEI
90      FORMAT(A)
        WRITE(5,91)
91      FORMAT(4X,'NAME OF THE OUTPUT FILE?'$)
        READ(5,90)FILEO
        OPEN(UNIT=1,FILE=FILEI,STATUS='OLD')
        OPEN(UNIT=2,FILE=FILEO,STATUS='NEW')
        READ(1,1150)TITLE
 1150   FORMAT(80A1)
        WRITE(2,1150)TITLE
        READ(1,*) NYEARS
        N=NYEARS*12
        NA=N-1
        READ(1,*) (Q(I),I=1,N)
C       OUTPUT TITLE AND INPUT SERIES FOR CHECKING
        WRITE(2,105)( Q(I),I=1,N)
 104    FORMAT(//12(3X,A4,2X))
 105    FORMAT(//' FLOWS'/(12F9.1))
        CALL EXAM(Q,NYEARS,OAVEMON,OSDMON)
        DO 300 I=1,12
        AVEMON(I)=OAVEMON(I)
300     SDMON(I)=OSDMON(I)
        DO 7 I=1,N
        J=MOD(I,12)
        IF (J.EQ.0) J=12
 7      WQ(I)=Q(I)-AVEMON(J)
        DO 8 I=2,N
        J=I-1
        K=MOD(I,12)
        IF (K.EQ.0) K=12
        A=B(K)*WQ(J)
        RES(J)=WQ(I)-A
 8      CONTINUE
        WRITE(2,109) (RES(I),I=1,NA)
 109    FORMAT(//' RESIDUALS OF FIT'/9X,11F9.1/(12F9.1))
C       EXAMIN RESIDUALS
        CALL BASIC(RES,AVER,SD,NA)
```

```
      WRITE(2,110) AVER,SD
      TYPE 110,AVER,SD
 110  FORMAT(//' MEAN OF RESIDUALS IS',3X,F9.4,' AND VARIANCE IS'
      1,3X,F9.4)
C     DATA GENERATION. USE RANDOM NUMBER GENERATOR TO GET
C     1200 ELEMENTS N(0,1)
      CALL RANDOM(E,1200)
      DO 10 I=1,12
      COR=R(I)
 10   TITLE(I)=SDMON(I)*SQRT(1-COR*COR)
      SYNQ(1)=B(1)*WQ(N)+E(1)*TITLE(1)
      DO 9 I=2,1200
      J=I-1
      K=MOD(I,12)
      IF(K.EQ.0)K=12
 9    SYNQ(I)=B(K)*SYNQ(J)+E(I)*TITLE(K)
CI    INSERT MONTHLY MEANS
      DO 31 I=1,1200
      J=MOD(I,12)
      IF(J.EQ.0)J=12
 31   SYNQ(I)=SYNQ(I)+AVEMON(J)
C     EXAMIN GENERATED DATA
      WRITE(2,106) SYNQ
      I100=100
      CALL EXAM(SYNQ,I100,GAVEMON,GSDMON)
      ANSUM1=0.0
      ANSUM2=0.0
      DO 2000 I=1,12
      A1=(OAVEMON(I)-GAVEMON(I))**2
      A2=(OSDMON(I)-GSDMON(I))**2
      ANSUM1=ANSUM1+A1
2000  ANSUM2=ANSUM2+A2
      MONSUM1=0.0
      MONSUM2=0.0
      DO 3000 I=6,10
      A1=(OAVEMON(I)-GAVEMON(I))**2
      A2=(OSDMON(I)-GSDMON(I))**2
      MONSUM1=MONSUM1+A1
      MONSUM2=MONSUM2+A2
3000  CONTINUE
      WRITE(2,2010)ANSUM1,ANSUM2,MONSUM1,MONSUM2
2010  FORMAT(1X,'ANNUAL SUM OF SQUARESOF ERROR IN MEAN'F13.2/
     1 1X,'ANNUAL SUM OF SQUARES IN ERROR IN S.D.'F13.2/
     2 1X,'MOSOON SUM OF SQUARES OF ERROR IN MEAN'F13.2/
     3 1X,'MONSOON SUM OF SQUARES OF ERROR IN S.D.'F13.2)
 106  FORMAT(///,' GENERATED FLOWS'/(12F9.1))
      TYPE 2222
 2222 FORMAT(5X,'THE PROGRAM THOMAS FIERRING MODEL HAS BEEN RUN'
      15X,'SUCCESSFULLY BY NK GOEL ON VAX 11')
      STOP
```

```
      END
      SUBROUTINE EXAM(Q,NYEARS,AVEMON,SDMON)
C     A SUBROUTINE TO CALCULATE MONTHLY MEANS,SD,SLOPES
C     AND CORRELATIONS START CYCLE BY LOADING 12TH MONTH
      COMMON B(12),R(12)
      DIMENSION Q(1),WORKI(100),WORKJ(100),AVEMON(12),SDMON(12)
      N=NYEARS*12
      DO 20 I=12,N,12
      J=I/12
 20   WORKI(J)=Q(I)
      CALL BASIC(WORKI,AVEMON(12),SDMON(12),NYEARS)
      DO 21 I=1,12
      M=I-1
      IF (M.EQ.0) M=12
      DO 22 J=I,N,12
      K=(J+11)/12
 22   WORKJ(K)=Q(J)
      CALL BASIC (WORKJ,AVEMON(I),SDMON(I),NYEARS)
      IF (I-1) 24,25,24
 25   NYEARS=NYEARS-1
      A=WORKJ(1)
      DO 26 IJ=1,NYEARS
 26   WORKJ(IJ)=WORKJ(IJ+1)
 24   CALL CORREL(WORKI,WORKJ,AVEMON(M),AVEMON(I),SDMON(M),
     1SDMON(I),B(I),R(I),NYEARS)
      IF (I-1) 27,28,27
 28   NYEARS=NYEARS+1
      DO 29 IJ=1,NYEARS-1
      IK=NYEARS-IJ
 29   WORKJ(IK)=WORKJ(IK-1)
      WORKJ(1)=A
 27   DO 23 K=1,NYEARS
 23   WORKI(K)=WORKJ(K)
 21   CONTINUE
C     OUTPUT THIS INFORMATION FOR CHECKING
      WRITE(2,106) AVEMON
      WRITE(2,114) SDMON
      WRITE(2,107) B
      WRITE(2,115) R
 106  FORMAT(//' MEANS'/12F9.2)
 114  FORMAT(//' STANDARD DEVIATIONS'/12F9.2)
 107  FORMAT(//' SLOPES'/12F9.3)
 115  FORMAT(//' CORRELATION WITH PREVIOUS MONTH'/12F9.3)
      RETURN
      END
      SUBROUTINE BASIC(X,AVER,SD,N)
      DIMENSION X(1)
C     THIS SUBROUTINE EVALUATES THE MEAN AND STANDARD DEVIATIN
C     OF AN INPUT SERIES X,LENGTH N)
      SX=0.0
```

```
      SSX=0.0
      RN=1.0/FLOAT(N)
      DO 1 I=1,N
      A=X(I)
      SX=SX+A
 1    SSX=SSX+A*A
      AVER=SX*RN
      SD=SSX-SX*AVER
      SD=SQRT(SD/FLOAT(N-1))
      RETURN
      END
      SUBROUTINE CORREL (X,Y,XMEAN,YMEAN,SDX,SDY,SLOPE,R,N)
      DIMENSION X(1),Y(1),WX(100),WY(100)
C     THIS SUBROUTINE GIVES THE SLOPE OF THE FIT WHEN Y IS
C     REGRESSED ON X,ALSO R,THE CORRELATION COFFICIENT BETWEEN
C     X AND Y.
C     MEANS AND SD'S ASSUMED FROM EARLIAR WORK
      DO 1 I=1,N
      WX(I)=X(I)-XMEAN
 1    WY(I)=Y(I)-YMEAN
      SSX=0.0
      SXY=0.0
      SSY=0.0
      DO 2 I=1,N
      A=WX(I)
      B=WY(I)
      SXY=SXY+A*B
      SSX=SSX+A*A
 2    SSY=SSY+B*B
      SSX=SQRT(SSX)
      SSY=SQRT(SSY)
      R=SXY/(SSX*SSY)
      SLOPE=R*SSY/SSX
      RETURN
      END

      SUBROUTINE RANDOM(E,N)
      DIMENSION E(N)
      IX=1073741823
      DO 20 I=1,N
      CALL GAUSS (IX,1.0,0.,V)
 20   E(I)=V
      RETURN
      END
      SUBROUTINE GAUSS (IX,S,AM,V)
      A=0.0
      DO 50 I=1,12
      Y=RAN(IX)
```

```
50    A=A+Y
      V=(A-6.0)*S+AM
      RETURN
      END
```

APPENDIX-II

DATA FILE

MONTHLY FLOWS OF AREAKOD TRIBUTARY IN CUMECS FROM 1965 TO 1978
14

24.9	12.8	9.6	3.1	26.5	99.9	688.6	368.6	327.7	534.6	211.2	73.3
46.9	18.2	7.4	5.4	38.2	285.4	1373.4	927.5	230.2	207.4	123.4	817.9
51.2	26.5	20.7	27.3	46.9	313.6	1770.8	1018.7	423.3	267.8	183.3	92.9
50.3	29.8	17.6	20.5	44.3	327.5	274.9	970.4	548.5	376.2	213.7	152.0
77.9	52.6	43.2	52.9	141.6	80.7	1559.1	1667.5	464.4	585.5	218.9	101.8
41.7	24.6	18.3	19.5	83.4	1069.2	813.1	636.8	386.1	427.9	148.5	91.5
44.2	27.3	17.3	15.4	85.5	163.4	969.0	404.9	164.9	304.5	171.4	107.3
46.5	22.2	14.4	13.0	19.6	447.4	887.9	711.2	230.7	155.7	122.8	61.1
33.0	16.5	9.2	13.9	28.8	83.0	1251.3	1130.5	537.9	367.0	109.9	59.9
25.2	18.0	19.3	13.9	21.0	757.8	646.0	1157.5	541.5	401.1	309.5	54.8
51.6	31.5	21.6	28.6	15.4	40.8	609.8	743.8	507.4	162.7	234.2	83.0
43.1	25.5	19.0	19.5	72.5	526.2	1131.8	565.1	525.3	546.9	346.6	140.7
33.4	11.5	5.9	4.2	11.5	572.5	1147.6	1316.1	368.6	149.1	466.5	62.1
33.2	13.3	6.8	5.5	35.7	363.5	1052.3	1526.9	243.1	150.5	170.8	63.5

APPENDIX - III

OUTPUT FILE

MONTHLY FLOWS OF AREAKOD TRIBUTARY IN CUMECS FROM 1965 TO 1978

FLOWS

24.9	12.8	9.6	3.1	26.5	99.9	688.6	368.6	327.7	534.6	211.2	73.3
46.9	18.2	7.4	5.4	38.2	285.4	1373.4	927.5	230.2	207.4	123.4	817.9
51.2	26.5	20.7	27.3	46.9	313.6	1770.8	1018.7	423.3	267.8	183.3	92.9
50.3	29.8	17.6	20.5	44.3	327.5	274.9	970.4	548.5	376.2	213.7	152.0
77.9	52.6	43.2	52.9	141.6	80.7	1559.1	1667.5	464.4	585.5	218.9	101.8
41.7	24.6	18.3	19.5	83.4	1069.2	813.1	636.8	386.1	427.9	148.5	91.5
44.2	27.3	17.3	15.4	85.5	163.4	969.0	404.9	164.9	304.5	171.4	107.3
46.5	22.2	14.4	13.0	19.6	447.4	887.9	711.2	230.7	155.7	122.8	61.1
33.0	16.5	9.2	13.9	28.8	83.0	1251.3	1130.5	537.9	367.0	109.9	59.9
25.2	18.0	19.3	13.9	21.0	757.8	646.0	1157.5	541.5	401.1	309.5	54.8
51.6	31.5	21.6	28.6	15.4	40.8	609.8	743.8	507.4	162.7	234.2	83.0
43.1	25.5	19.0	19.5	72.5	526.2	1131.8	565.1	525.3	546.9	346.6	140.7
33.4	11.5	5.9	4.2	11.5	572.5	1147.6	1316.1	368.6	149.1	466.5	62.1
33.2	13.3	6.8	5.5	35.7	363.5	1052.3	1526.9	243.1	150.5	170.8	63.5

MEANS

43.09	23.60	16.46	17.33	47.92	366.49	1012.54	938.97	392.83	331.21	216.50	140.12

STANDARD DEVIATIONS

13.53	10.55	9.50	13.04	36.21	292.57	401.71	396.36	134.77	155.72	98.87	197.35

SLOPES

0.015	0.718	0.853	1.318	1.955	-0.183	-0.256	0.382	0.074	0.510	0.046	-0.515

CORRELATION WITH PREVIOUS MONTH

0.234	0.921	0.948	0.960	0.704	-0.023	-0.187	0.387	0.217	0.441	0.073	-0.258

RESIDUALS OF FIT

	2.3	2.3	-5.1	6.3	-270.5	-392.3	-446.5	-23.2	236.6	-14.7	-69.5
4.8	-8.1	-4.5	0.0	13.6	-82.8	340.1	-149.4	-161.8	-40.8	-87.3	629.9
-2.0	-2.9	1.7	4.4	20.6	-53.1	744.8	-210.2	24.6	-79.0	-30.2	-64.3
7.9	1.0	-4.1	1.6	-9.9	-39.7	-747.7	313.5	153.4	-34.4	-4.9	10.4
34.7	4.0	2.1	0.2	24.2	-268.7	473.3	519.6	17.9	217.8	-9.4	-37.0
-0.8	2.0	1.0	-0.3	31.3	709.2	-19.4	-225.9	15.5	100.1	-72.5	-83.6
1.9	2.9	-2.4	-3.0	41.4	-196.2	-95.6	-517.4	-188.5	89.5	-43.9	-56.1
3.9	-3.9	-0.8	-1.7	-19.9	75.7	-103.9	-180.1	-145.3	-92.9	-85.5	-127.3
-9.0	0.1	-1.2	6.1	-12.3	-287.0	166.2	100.3	131.0	-38.2	-108.2	-135.1
-16.7	7.3	7.6	7.2	-20.1	386.4	-266.3	358.7	132.6	-5.9	89.8	-37.4
9.8	1.8	-1.6	4.4	-54.5	-331.6	-486.1	-41.2	128.9	-226.9	25.5	-48.0
0.9	1.9	0.9	-1.2	20.4	164.2	160.2	-419.5	160.0	148.2	120.1	67.5
-9.7	-5.1	-0.2	0.8	-10.8	199.3	187.8	325.5	-52.0	-169.8	258.5	50.7

-8.7	-3.2	-0.9	0.9	10.9	-5.3	39.0	572.8	-193.1	-104.3	-37.3	-100.2

MEAN OF RESIDUALS IS 0.1021 AND VARIANCE IS 189.5106

GENERATED FLOWS

43.9	16.6	9.8	2.8	-2.0	-236.5	924.5	113.8	296.2	547.2	290.0	171.2
34.4	17.4	14.0	17.3	68.9	253.8	1524.1	711.4	491.4	505.2	159.0	291.5
32.8	11.8	6.9	3.8	23.5	-156.3	698.7	1223.1	440.1	438.1	149.4	-170.4
3.1	-5.9	-8.8	-14.4	19.0	239.4	503.7	1245.7	438.1	182.1	235.7	-69.3
33.1	24.4	21.6	26.8	25.8	168.1	1690.0	1639.8	464.4	243.1	227.3	122.9
43.2	23.1	12.8	4.9	-5.9	-45.1	854.7	426.5	504.5	389.7	270.8	-81.8
30.9	19.0	17.9	16.4	22.6	540.8	1644.2	632.6	437.1	538.2	273.7	205.0
23.0	7.3	-0.2	-1.9	-2.3	550.9	1199.2	997.8	369.3	51.0	242.6	-24.2
62.2	41.8	27.4	25.1	118.5	804.9	344.9	510.1	280.2	313.7	377.7	616.5
57.8	27.9	13.5	11.8	22.4	601.8	1287.8	1087.6	316.7	380.5	155.7	228.9
26.6	13.6	10.9	13.2	11.5	55.0	603.6	422.1	234.0	146.1	129.1	474.7
33.6	18.6	14.3	11.2	35.5	204.6	555.2	598.8	523.3	607.6	335.4	101.3
39.6	22.7	9.9	11.0	55.4	245.8	1021.4	900.5	402.0	288.6	107.2	330.1
31.2	20.7	15.7	21.3	48.5	87.4	1110.9	1256.2	403.3	158.3	247.2	-123.4
47.8	29.0	19.8	22.1	68.3	-25.1	1133.3	710.7	256.3	279.6	284.8	127.7
45.9	23.4	14.4	12.9	23.3	-127.2	1475.0	1288.5	585.7	361.6	153.4	36.1
42.6	33.6	29.8	31.2	92.9	193.4	1524.2	914.4	383.4	251.9	89.5	128.8
27.8	20.9	11.9	14.9	66.1	381.5	329.6	150.9	367.0	356.3	233.5	186.0
44.3	26.0	19.6	22.3	21.6	765.0	1552.8	1077.2	363.6	270.5	147.1	13.9
38.8	18.9	14.3	18.9	60.2	482.5	1271.6	1073.3	530.5	344.9	143.0	47.3
37.9	20.7	18.0	19.3	112.2	371.1	954.6	246.5	421.4	475.8	316.8	84.3
34.4	21.1	14.1	21.5	110.2	228.9	959.8	1047.4	372.4	357.0	238.2	-30.6
46.5	19.2	16.0	19.0	85.3	479.1	1193.6	756.6	653.3	689.5	362.9	-36.6
28.2	12.2	3.7	-2.4	-26.5	377.5	1471.5	1397.5	453.4	254.3	393.1	204.6
41.8	15.4	10.9	12.2	67.3	489.2	390.4	809.2	481.4	416.0	250.6	160.3
36.3	12.5	2.9	-0.5	1.1	168.6	1400.3	1453.7	685.9	433.1	229.0	26.5
48.9	26.1	20.2	21.0	94.7	458.0	1307.7	814.2	304.8	522.0	322.5	72.0
47.5	19.2	12.8	18.4	44.1	158.9	1444.3	688.4	622.5	433.3	233.5	205.6
12.6	2.9	-5.9	-9.9	7.4	-52.1	1778.1	461.7	362.3	281.7	77.1	328.6
32.0	20.8	6.3	6.1	35.1	360.0	1331.3	1194.8	559.9	480.3	254.4	161.5
31.0	20.6	15.6	18.5	28.2	553.6	766.2	1039.5	508.9	476.9	284.8	178.7
33.9	15.0	13.1	7.8	17.1	233.3	1398.8	982.7	255.8	271.0	133.3	115.1
32.4	20.5	12.2	11.6	32.1	478.3	547.3	418.8	504.4	469.4	189.0	73.6
65.2	38.4	33.0	44.4	68.0	750.8	1276.5	1148.8	377.5	271.9	61.8	143.3
50.8	28.8	14.6	22.1	58.7	-2.6	1361.4	1608.2	379.7	65.0	256.0	252.8
32.0	19.4	13.8	11.0	49.6	54.3	604.0	1034.7	435.1	246.1	316.0	124.1
80.0	51.9	43.2	57.7	115.3	32.0	1383.6	1048.6	364.9	315.1	239.1	-167.5
49.5	25.5	22.1	25.2	109.7	675.2	1522.0	276.1	380.0	487.3	229.1	266.5
29.3	19.7	14.4	11.1	40.8	711.4	644.7	1805.4	544.5	546.5	224.8	81.8
57.2	31.1	24.7	30.3	85.9	284.4	781.6	1266.9	391.2	453.1	297.3	-165.2
20.0	7.0	5.1	5.4	26.9	400.3	885.3	723.7	175.0	-30.8	312.6	10.5
42.3	29.5	23.2	23.3	79.7	-223.3	1485.6	1224.5	422.8	490.9	386.1	-20.8

46.2	26.7	24.7	24.8	75.3	770.3	704.9	824.0	439.6	199.1	534.7	224.2
44.5	23.7	18.9	23.4	34.9	130.4	1264.0	458.0	549.7	477.1	259.3	-159.4
21.5	2.0	-2.3	-10.5	15.7	362.0	763.3	867.6	653.6	668.6	347.8	135.2
61.9	36.8	24.7	33.0	99.5	294.2	1498.5	1144.6	351.1	480.7	299.6	-6.6
41.7	12.1	0.5	-1.7	6.9	343.0	726.3	1496.5	690.4	421.9	194.9	-172.3
39.2	25.7	28.2	29.1	92.6	501.3	947.2	1604.3	462.5	157.1	198.9	68.3
59.2	29.9	22.2	21.8	38.3	796.8	1401.2	1300.0	428.2	208.7	123.5	388.1
70.4	42.7	32.0	34.5	31.6	418.9	1350.4	1364.9	317.6	112.5	303.1	-32.9
46.0	27.0	18.2	18.9	4.6	416.7	473.1	665.4	297.1	-31.3	162.3	469.4
44.2	26.6	21.3	24.5	51.2	624.9	736.7	431.6	199.0	294.1	157.3	39.7
62.3	38.9	26.1	29.0	65.0	-342.9	775.4	189.7	504.3	531.8	103.8	598.2
37.8	23.5	18.9	24.4	80.1	327.3	717.1	612.4	283.7	202.3	192.0	406.8
49.0	28.5	19.3	21.6	67.5	547.0	1260.0	881.6	259.2	289.5	336.1	267.2
23.5	13.0	15.6	18.4	73.8	538.9	935.7	1205.2	457.0	193.1	402.5	304.6
54.6	28.4	22.0	23.4	53.5	162.2	248.5	-76.8	224.5	77.3	195.9	309.0
48.4	29.3	19.2	17.0	19.2	859.2	1077.8	861.3	318.0	363.2	199.2	259.5
57.1	29.9	20.7	19.1	12.9	30.4	1705.5	1107.3	390.5	273.9	299.1	-20.0
20.4	11.6	8.2	7.6	42.6	332.2	650.4	790.1	468.6	228.6	68.6	280.0
42.6	30.7	23.1	25.7	55.1	-42.9	1427.7	1518.8	541.2	201.2	245.0	239.9
19.8	-1.1	-4.2	-16.4	-22.0	742.4	505.9	226.1	336.9	130.6	258.2	342.3
25.3	4.4	1.7	-3.6	40.7	140.8	710.9	413.0	118.7	11.3	281.5	224.6
49.5	33.1	25.0	26.3	67.5	637.1	821.2	406.5	312.9	88.7	32.8	201.8
45.2	29.7	25.5	34.0	102.3	492.6	998.2	1189.9	342.3	229.3	298.0	-137.4
21.8	0.9	-1.6	-11.6	8.6	1058.2	813.5	808.3	418.4	-39.2	443.5	-125.8
56.2	34.4	29.2	39.3	110.7	-143.7	1712.3	1795.1	475.7	269.8	-46.4	380.5
67.8	42.0	34.5	37.2	67.0	366.0	855.6	1053.9	315.8	286.2	224.5	412.6
43.4	26.9	22.6	24.2	107.4	316.6	1124.9	1264.5	282.0	247.6	42.8	168.2
55.1	37.7	29.2	36.2	47.9	569.6	1643.6	2053.4	445.1	489.8	49.4	1.2
43.9	24.7	18.1	18.7	19.9	524.3	1224.1	123.0	448.1	215.6	291.4	108.3
62.3	25.2	21.0	27.1	83.8	748.4	1146.3	819.9	588.9	526.0	239.9	-99.1
37.6	21.5	11.4	10.1	56.7	303.4	1008.8	1475.5	428.4	43.6	336.5	211.4
65.0	34.9	30.9	39.6	31.8	379.3	1250.9	683.3	362.2	429.4	450.1	36.1
66.0	39.9	29.2	30.5	56.4	477.8	1663.7	926.8	465.2	169.5	254.3	106.9
49.0	35.0	24.6	31.3	75.6	104.5	1647.2	1278.5	447.9	107.0	-48.0	182.2
39.3	24.9	11.6	9.9	22.3	726.5	794.2	89.7	215.5	339.2	206.1	179.3
26.9	18.1	10.2	12.9	44.5	393.2	959.0	1170.8	159.3	330.5	147.1	7.7
26.5	12.0	6.7	6.3	-18.3	778.5	802.7	1018.0	577.5	259.4	172.7	-12.1
14.6	4.2	1.9	3.7	20.9	553.1	549.8	1502.8	339.9	442.4	121.0	218.1
22.2	12.8	9.4	8.6	37.1	696.7	1712.4	1270.3	564.1	378.4	385.0	-47.1
56.4	31.0	28.9	32.7	85.4	532.4	903.7	1322.5	519.4	678.3	301.1	292.0
58.1	37.4	29.2	29.0	84.3	-240.9	1058.6	80.5	388.9	385.5	169.6	423.2
53.4	29.4	21.6	28.1	23.4	95.3	1441.9	1167.1	361.9	251.1	198.5	-165.9
12.1	2.7	-0.5	-1.4	45.5	511.0	1139.0	1494.8	513.1	402.0	173.6	150.7
43.2	25.2	18.6	21.8	59.5	443.1	896.7	1379.0	594.2	338.9	222.7	119.8
26.6	20.6	17.6	14.0	42.3	543.9	858.5	1388.3	426.0	499.1	173.0	468.8
51.6	32.7	28.2	31.6	60.9	-27.7	766.3	137.8	361.5	361.3	227.2	458.5
59.0	37.7	28.5	37.2	118.7	443.2	402.3	944.1	427.0	209.0	232.6	119.1
55.3	31.1	17.3	21.7	26.5	327.9	1001.6	946.4	541.2	368.0	113.2	170.6
29.9	20.4	15.6	16.3	38.4	22.7	621.6	937.9	415.9	143.9	190.5	474.7
46.3	24.2	16.8	11.7	-8.6	570.3	1105.3	993.4	386.3	305.3	189.7	-72.4

40.5	24.6	21.0	20.8	65.0	522.5	498.1	1133.6	110.6	151.0	163.3	131.2
43.3	27.3	19.2	23.1	75.7	384.3	494.2	791.4	340.2	333.4	-92.8	116.4
58.7	35.4	21.1	20.0	65.1	384.9	987.9	657.0	391.1	416.7	302.0	181.4
39.0	21.6	13.0	17.4	81.7	445.1	1168.2	812.7	78.8	107.7	288.6	159.3
40.2	18.2	6.3	5.7	31.1	131.5	1404.5	1362.7	257.9	195.1	239.7	-77.0
15.1	1.2	-1.7	-5.7	-31.3	-8.1	833.0	687.7	424.4	173.8	148.7	269.7
47.4	27.6	16.4	17.6	79.8	608.7	1052.2	1151.4	418.4	335.8	392.3	383.6
60.4	30.1	17.1	16.4	54.9	300.0	693.3	1087.2	459.0	495.5	167.4	308.6

MEANS

41.77	23.15	16.42	17.51	48.96	348.97	1040.73	937.20	406.41	315.16	224.26	145.52

STANDARD DEVIATIONS

14.67	10.80	9.78	13.21	35.05	283.38	383.91	439.22	123.58	161.30	107.24	180.17

SLOPES

0.020	0.672	0.850	1.305	1.807	-0.017	-0.188	0.396	0.081	0.634	0.057	-0.302

CORRELATION WITH PREVIOUS MONTH

0.239	0.914	0.939	0.966	0.681	-0.002	-0.139	0.346	0.288	0.486	0.085	-0.180

ANNUAL SUM OF SQUARESOF ERROR IN MEAN 1639.11

ANNUAL SUM OF SQUARES IN ERROR IN S.D. 2762.64

MOSOON SUM OF SQUARES OF ERROR IN MEAN 1546.60

MONSOON SUM OF SQUARES OF ERROR IN S.D. 2394.55