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ANALYSIS OF SURFACE RUNOFF AND BASEFLOW AT ARIYANAYAKIPURAM ANICUT, TAMBRAPARANI BASIN, TAMILNADU

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LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The hydrological behaviour of catchments is a very complex phenomenon which is controlled by a large number of climatic and physiographic factors that vary in time and space. The analysis of surface runoff and baseflow has been carried out at Ariyanayakipuram Anicut, Tambaraparani basin, Tamilnadu for a period of 13 years (1983-95). The analysis shows that the contribution of baseflow at Ariyanayakipuram anicut was observed to be more. Further the annual catchment water balance model has been applied to simulate annual surface runoff and baseflow at the anicut. The model has been calibrated for a period of eight years (1983-90) and validated for five years(1991-95). The model is able to simulate surface runoff more accurately than baseflow. The model has also established the relation between precipitation and surface runoff, and runoff and baseflow coefficient functions at Ariyanayakipuram anicut and these functions may be useful to water management departments to understand the surface runoff and baseflow runoff processes at the anicut. The study recommends to carry out further detailed investigations to find out the possible reasons for high flows at the anicut.

1.0 INTRODUCTION

The distribution of rainfall over a region is of fundamental importance in the study of its hydrology. However, since the advent of water balance techniques, particularly that of Thornth waite (1948) and later of Thornth waite and Mather (1995), efforts have been directed at knowing the distribution of the water budget elements, obtained therefrom, for studying the regional water balances towards development of water resources and agricultural potential of the region. Water yield is the continuous surface and sub surface responses of a catchment area at its outlet or at some point on the channel section within the catchment. The size, length, shape and relief of the drainage basin affect the rate and volume of the water yield. The estimation of water balance components will help in assessing the system performance and maximum utilization of available resources in the basin. Water balance techniques are a way of solving important theoretical and practical hydrological problems. Using the water balance approach it is possible to make a quantitative evaluation of water resources and to assess any changes that might occur through the influence of man's activity. The study of the water balance structure of regulated river basins permits the rational use, control and redistribution of water resources in time and space. Water balance studies can also provide an indirect evaluation of any unknown water balance components. For example, long term evaporation from a river basin may be computed by the difference between precipitation and runoff. The detailed water balance studies in the Tambraparani river basin showed that the return flows at Ariyanayakipuram anicut was more (IIT Madras, 1994). Therefore the available data of precipitation and runoff at the anicut for a period of thirteen years (1983-95) are analysed using conceptual catchment water balance model (Ponce and Shetty, 1995). The study will give the information about rainfall and surface runoff relationships and runoff and baseflow coefficient functions at the upstream of the Ariyanayakipuram anicut. An attempt has also been made to simulate annual surface runoff and baseflow at the anicut.

2.0 PURPOSE OF THE STUDY

The river "Tambraparani" serves one of the oldest irrigation systems in Tamil Nadu, located in Tirunelveli - Kattabomman and Chindhambaranar district. The system consists of three reservoirs, eight anicuts and eleven channels. The present operation rules for the anicuts and the channels in the system were framed long before the construction of the Servallar reservoir. These rules have not been designed to take advantage of the information on various important variables viz. rainfall in the catchment and command areas, storage levels in tanks and reservoirs, inflows into reservoirs and tanks. In order to utilize the available water resources in a more efficient manner by evolving an integrated operation of the reservoirs in the system, a computer aided simulation model has been developed by IIT Madras, 1994, in which the detailed water balance study has been conducted reach wise in the basin (River module). A close observation shows that the reach between Kannadiyan and Ariyanayakipuram anicut, which flows in a steep slope always gains water due to possible return flows and regenerated flows from the upper channels. Keeping in view the high return flows at Ariyanayakipuram anicut, this study was taken up to analyse surface runoff and baseflow at the anicut using conceptual catchment water balance model for a period of thirteen years (1983- 95).

3.0 STUDY AREA

The river Tambaraparani is one of the major rivers in Tamil Nadu and it originates from Pothigai hills in the western ghats and after traversing a distance of 125 kms., it confluences in the Bay of Bengal at Gulf of Mannar. It traverses through two districts namely, Tirunelveli-Kattabomman and Chidambaranar. More than 12 tributaries join the main river during its course of flow, out of which Servallar, Manimuthar, Gadana, Chittar and Uppodai are the major tributaries. River Tambaraparani after traversing a distance of 22 kms. from its origin in western ghats is joined by its tributary Servallar. Similarly, Manimuthar river joins at its 36th km., Gadana joins on its left at 43rd km., Pachayar river joins on its right at 61st km. and Chittar , the largest tributary joins at the 73rd km.

The Tambaraparani basin lies between 8^0 6' and 9^0 12' North latitudes and between 77^0 9' and 78^0 8' East longitudes. The total area of the basin is 5969 sq.kms. It is bounded on the north by Vaipparu basin , on the south by Nambiyaru basin, on the west by the eastern ridges of the western ghats and the Gulf of Mannar forms the eastern boundary of the basin.

The Tambraparani river system consists of three reservoirs namely, Papanasanam, Servallar and Manimuthar. Papanasanam reservoir or Tambaraparani reservoir is constructed across R.Tambraparani, mainly with the purpose to impound flood flows and to utilise it for both irrigation and power. Manimuthar reservoir was constructed across R.Manimuthar which is a tributary of Tambaraparani with an objective to stabilise the Tambaraparani command area as well as to divert the surplus water through the Manimuthar main canal to the tanks lying in the arid region. Servallar river was constructed across Servallar river to meet the irrigation and power demands. The average annual surface water potential of the river system is 1873 MCM.

Apart from these three reservoirs, there are 8 major anicuts on the river and about 87 other anicuts on its tributaries. The eight anicuts across the river are namely, Kodaimelalagian anicut, Nadhiyunni anicut, Kannadian anicut, Ariyanayakipuram anicut, Palavur anicut, Suthimalli anicut, Marudur anicut and Srivaikundam anicut (Fig. 1). The gradient of the basin is 4.5 m/km. sloping from north-west side to south-east side. For the present study, the study area has been limited upto the Ariyanayakipuram anicut. The area of the present study is about 1450.7 sq. kms. The line diagram of the study area is shown Fig. 2.

Cropping pattern

The main crop in the study area is paddy which is cultivated regularly both during south-west and north-east monsoon seasons. The crop grown during the south-west monsoon season is called `Kar' and its duration extends from June to September, whereas the crop cultivated during the nort-east monsoon season from October to February is called as `Pishanam'.

Geology and hydrogeology

Tambaraparani river basin is built of crystalline rocks of Archean age comprising of gneisses and charnockites on the western portion and sedimentary formation of tertiary and quarternary age on the eastern coastal area. The transmissivity in the hard rock area ranges from 3 to 56 sq.m./day whereas in sedimentary formation it is 100 to 800 sq.m/day. Sandy loam soils are encountered in the study area which is a very heavy textured soil. The pH value of the soil ranges from 7.5 to 8.1 and the electrical conductivity (EC) values range between 0.80 to 2.00 mmhos/cm.

Climate

The climate of the study area is of tropical monsoonic type. The mean monthly values of humidity vary from 50% to 80% and the temperature varies from 24^0 C to 34^0C. Strong winds are experienced during June, July and August. The average wind speed

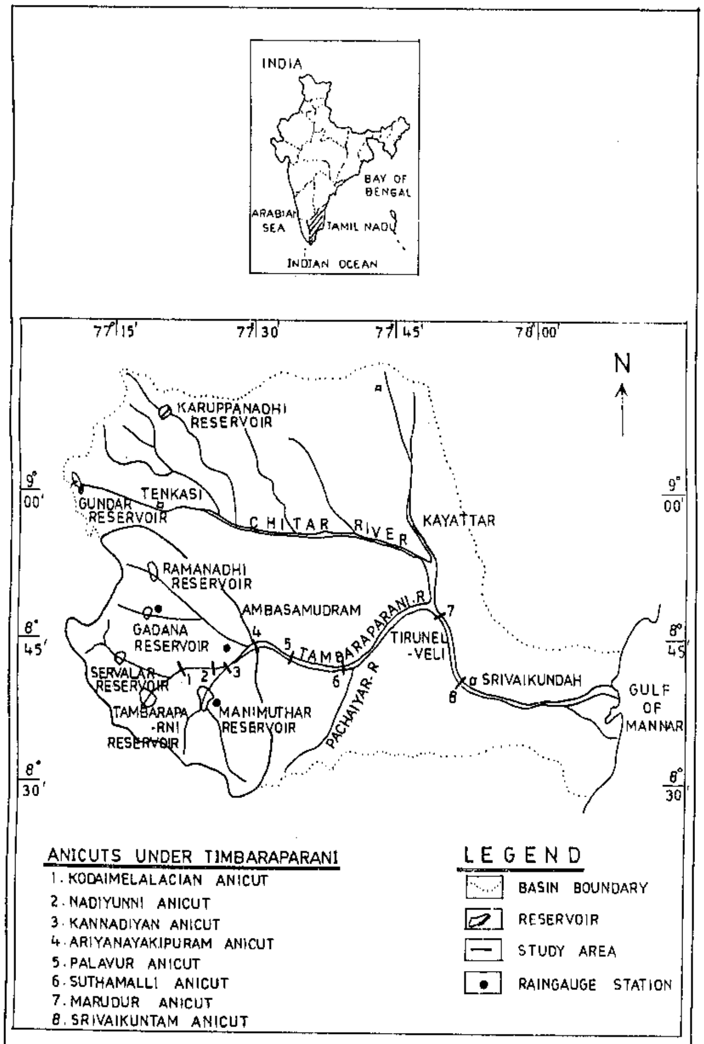

Fig. 1 Location map of Tambraparani basin

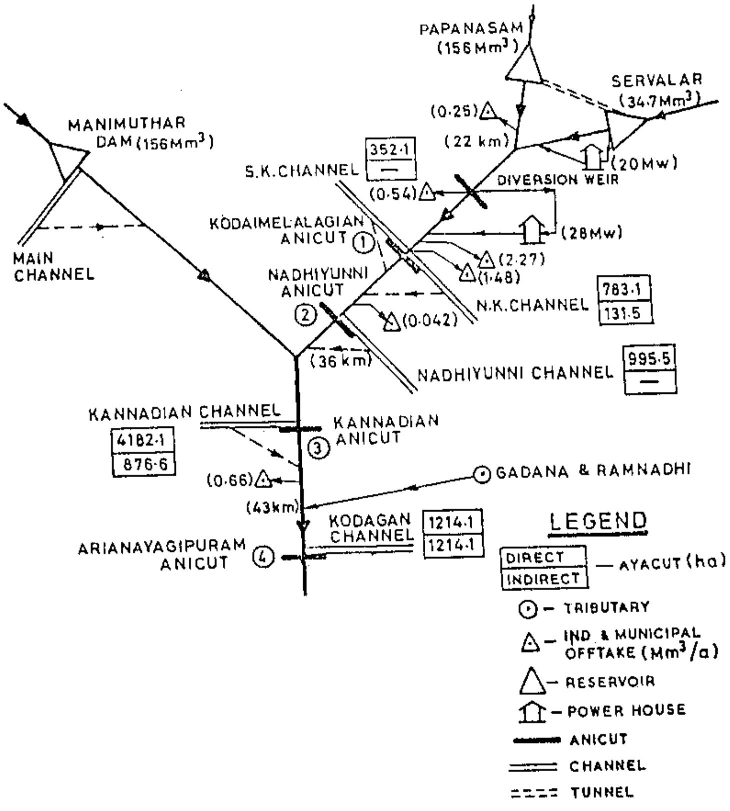

Fig. 2 Line diagram of catchment area up to Ariyanayakipuram anicut

varies 4.0 to 14.9 kms/hr. The evaporation is considerable in June, July and August and the evaporation values range from 100 mm to 450 mm during the whole year. Evapotranspiration rates are less than potential evapotranspiration rates by 20 to 50%.

The annual rainfall in the basin is 1626 mm. The annual rainfall is very high on the western ghats with over 4000 mm and it is less than 1000 mm on the plains. However, very heavy rainfall in the study area is limited only upto the head reaches of Tambraparani and Manimuthar. During the south-west monsoon the raingauge station in western ghats receive rainfall of around 2000 mm whereas the plains get less than 100 mm and during north-east monsoon the ghats receive more than 1000 mm rainfall whereas it is about 500 mm in the plains. There is no significant rainfall during winter and summer months.

4.0 METHODOLOGY

Rainfall-runoff records for the 1983-95 period are used to estimate conceptual water balance components at the upstream of the Ariyanayakipuram anicut, Tambaraparani basin, Tamil Nadu. Monthly rainfall data at Ambasamudram, Manimuttar and Gadana (Fig.1) were used to calculate the annual precipitation at each station, from which the spatially-averaged annual precipitation (P) was calculated using the Thiessen polygon method. Daily discharge data at Ariyanayakipuram anicut were used to calculate the annual runoff (R). The daily inflows to the Ariyanayakipuram anicut is taken as outflows from the Ariyanayakipuram anicut plus inflows to the Kodagan Channel (Fig. 2). Annual runoff has been calculated by integrating the daily hydrograph over a year. Annual runoff was separated into surface runoff (S) and baseflow (U) using the straight line separation technique.

Conceptual Model

The conceptual catchment water balance model separates the annual precipitation into two components (Ponce and Shetty, 1995).

$$P = S + W \tag{1}$$

where,

P = annual precipitation, S = Surface runoff and W = Catchment wetting. In turn, wetting is separated into two components:

$$W = U + V \tag{2}$$

where,

U = baseflow, defined as the fraction of wetting which exfiltrates as the dry weather flow of rivers, and V = Vaporization, the fraction of wetting returned to the atmosphere as water vapor (Lee, 1970).

Runoff consists of surface runoff and baseflow:

$$R = S + U \tag{3}$$

Precipitation consists of runoff and vaporization:

$$P = R + V \tag{4}$$

Combining Eqs. 3 and 4

$$P = S + U + V \tag{5}$$

Equations 1 to 4 constitute a set of water balance equations.

The runoff coefficient is:

$$K_r = \frac{R}{P} \tag{6}$$

The runoff gain is

$$K_r' = \frac{dK_r}{dp} \tag{7}$$

The base flow coefficient is:

$$K_u = \frac{U}{W} \tag{8}$$

The baseflow gain is

$$K_u' = \frac{dK_u}{dp} \tag{9}$$

Ponce and Shetty (1995) have used this proportional concept to formulate the equations of their water balance model. The surface runoff submodel is:

$$S = \frac{(P - \lambda_S W_p)^2}{P + (1 - 2\lambda_s) W_p} \tag{10}$$

Subject to P > λ_s W_p and S = 0 otherwise, with λ_s = surface-runoff initial abstraction ratio(dimension less), and W_p = wetting potential, in cm or mm.

The baseflow submodel is :

$$U = \frac{(W - \lambda_u V_p)^2}{W + (1 - 2\lambda_u)V_p} \qquad (11)$$

Subject to W > λ_u V_p and U = 0 otherwise, with λ_u = baseflow initial abstraction ratio (dimensionless) and V_p = vaporization potential in cm or mm.

Model Application

The annual runoff measured for a period of thirteen years (1983-95) has been divided into surface runoff and baseflow. Using Eqns. 1,2 and 3 the water balance components were estimated. Due to the presence of reservoirs at the upstream of the anicut, the catchment water balance model has been applied on annual time interval. The reservoir operations are assumed to be constant on an annual time scale. The model has been calibrated for eight years (1983 -90) and validated for the remaining five years (1991-95).

Methodology

The calibration proceedure sought to minimise the root mean square (RMS) of the difference between calculated and measured values of surface runoff (Eq.10) and baseflow (Eq. 11). For this purpose, λ_s was varied at 0.01 intevals in the range $0 \leq \lambda_s \leq 1$ and W_p was varied at 1 cm intervals in the range $0 \leq W_p \leq 1200$ cm. The selected surface-runoff submodel parameters (λ_s ,W_p) were those corresponding to the minimum root mean square of the difference between calculated (Eq. 10) and measured runoff (Table 2). Likewise, λ_u was varied at 0.01 intervals in the range of 1, and V_p was varied at 1cm intervals in the range $0 \leq V_p \leq 1200$ cm. The selected baseflow submodel parameters (λ_u, V_p) were those corresponding to the minimum root mean square of the difference between calculated (Eq. 11) and seperated baseflow (Table 2). The high upper limit on

W_p and V_p (1,200 cm) was necessarry to guarantee attainment of the stated objective (minimum RMS). The computer programme has been developed to attain minimum RMS value to find the corresponding (λ_S , W_p) and (λ_u , V_p) values.

The methodology adopted was as follows:

1. use the root mean square minimization procedure to calculate λ_s and W_p.
2. use the root mean square minimization procedure to calculate λ_u and V_p.
3. use Eq. 10 to calculate a set of surface runoff values corresponding to precipitation values in the range of $1 \leq P \leq 200$ cm, at 1 cm intervals.
4. use Eq.11 to calculate a set of baseflow values corresponding to wetting values in the range $1 \leq W \leq 200$ cm, at 1 cm intervals.
5. use Eq. 1 and the S-P data calculated in step 3 to determine a set of corresponding wetting (W) values.
6. use Eq.11 with the wetting values calculated in step 5 to determine a set of corresponding baseflow (U) values.
7. use Eq.3 to calculate a set of corresponding runoff (R) values, based on S values (step 3) and U values (step 6).
8. use Eq.6 to calculate a set of runoff coefficients (K_r), based on corresponding runoff (step 7) and precipitation (step 3) values.
9. use Eq.8 to calculate a set of baseflow coefficients (K_u), based on corresponding baseflow (step 6) and wetting (step 5) values.
10. use Eq.7 to calculate a set of runoff gains (K_r'), based on the runoff coefficients Vs. precipitation relation developed in step 8.
11. use Eq.9 to calculate a set of baseflow gains (K_u'), based on the baseflow coefficients Vs. precipitation relation developed in step 9.

The average baseflow index has been established at Ariyanayakipuram anicut using the following equation.

$$BFI = \frac{V_B}{V_A}$$

Where, V_B is the volume beneath the baseflow separation

V_A represents the mean flow beneath the hydrograph

5.0 RESULTS AND DISCUSSIONS

The spatial average annual precipitation at the upstream of Ariyanayakipuram anicut, Tambraparani basin for a period of thirteen years (1983 - 95) are given in Table 1. The data on daily inflows was integrated over a year to obtain the annual runoff at the anicut. The annual runoff (R) has been separated into the baseflow (U) and surface runoff (S) using straight line separation method. For example daily runoff hydrograph for the year 1991 with base flow separation is shown in Fig. 3 . The measured runoff, surface runoff, baseflow and base flow index for a period of thirteen years are given in Table 2. Using the measured precipitation, runoff; and baseflow, the catchment wetting and vaporization have been calculated, using water balance equations. These water balance components are given in Table 3. Using the precipitation (P) and surface runoff (S), and wetting (W) and baseflow (U) data sets the model parameters are calibrated using root mean square minimisation technique. The calibrated parameters viz. surface runoff initial abstraction coefficient (λ_s) , wetting potential (W_p), baseflow abstraction coefficient (λ_u) and vaporization potential (V_p) are given in Table 4.

With calibrated model parameters, the surface runoff submodel (Eq. 10) and baseflow submodel (Eq. 11) are rewritten as the following:

Surface runoff submodel :

$$S = \frac{(P - 1.09)^2}{(P + 106.82)} \tag{12}$$

Baseflow submodel :

$$U = \frac{(W - 0.61)^2}{(W + 59.78)} \tag{13}$$

Using the Eq.12. a relation between surface runoff and precipitation has been developed for a valid range of precipitation (0-200 cm) and it is shown in Fig. 4. Similarly using

TABLE 1. SPATIAL AVERAGE ANNUAL PRECIPITATION DURING THE YEARS (1983-95)

YEAR	AMBASAMUDRAM	MANIMUTTAR	GADANA	AVERAGE ANNUAL RAINFALL
THEISSEN WEIGHTING FACTOR	0.222	0.177	0.601	
1983	66.4	60.1	94.5	82.1
1984	181.4	123.7	146.6	150.1
1985	137.8	67.3	113.9	110.8
1986	63.8	60.1	91.3	79.6
1987	140.3	68.7	130.8	121.8
1988	110.4	85.5	114.6	108.4
1989	95.8	87.1	107.1	101.2
1990	137.3	106.3	124.0	123.7
1991	117.7	109.5	115.7	115.0
1992	130.4	136.5	125.1	128.3
1993	144.7	137.3	134.6	137.3
1994	116.8	112.0	137.9	128.6
1995	94.8	78.9	115.7	104.5

All units are in cm/yr

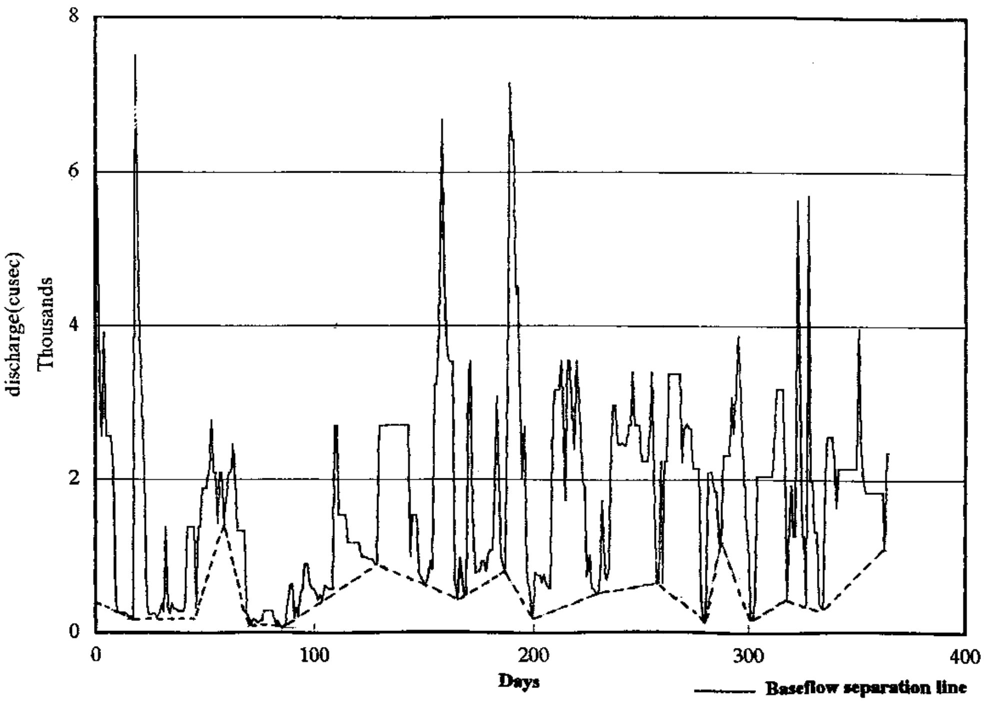

Fig. 3 Daily Hydrograph for the year 1991

TABLE 2. MEASURED RUNOFF ANALYSIS

YEAR	MEASURED RUNOFF (R)	SURFACE RUNOFF (S)	BASEFLOW (U)	BASEFLOW INDEX (BFI)
1983	51.56	38.23	13.33	0.26
1984	127.46	91.79	35.67	0.28
1985	83.63	56.02	27.61	0.33
1986	64.14	47.51	16.63	0.26
1987	68.74	41.43	27.31	0.40
1988	103.34	57.11	46.23	0.45
1989	91.08	62.96	28.12	0.31
1990	80.27	53.14	27.13	0.34
1991	107.27	62.41	45.56	0.42
1992	126.59	67.03	59.56	0.47
1993	111.83	76.26	35.57	0.32
1994	144.22	74.65	69.57	0.48
1995	90.44	51.15	39.29	0.43

All units are in cm/yr

TABLE 3. WATER BALANCE COMPONENTS (1983-90)

YEAR	S	U	R	P	W	V	BFI
1983	38.23	13.33	51.56	82.10	43.87	30.54	0.26
1984	91.79	35.67	127.46	150.10	58.31	22.64	0.28
1985	56.02	27.61	83.63	110.80	54.78	27.17	0.33
1986	47.51	16.63	64.14	79.60	32.09	15.46	0.26
1987	41.43	27.31	68.74	121.80	80.37	53.06	0.40
1988	57.11	46.23	103.84	108.40	51.29	5.06	0.45
1989	62.96	28.12	91.08	101.20	38.24	10.12	0.31
1990	53.14	27.13	80.27	123.70	70.56	43.43	0.34

All units are in cm/yr
BFI : Base flow index.

TABLE 4. **CALIBRATED MODEL PARAMETERS (1983-90)**

P_a (cm)	λ_s	W_p (cm)	RMS_{min} (cm)	P_{rt} (cm)	P_{rt} / P_a	K_{rp} (cm^{-1})
109.71	0.01	109	11.858	3	0.0273	0.02161
P_a (cm)	λ_u	V_p (cm)	RMS_{min} (cm)	P_{ut} (cm)	P_{ut} / P_a	K_{up} (cm^{-1})
109.71	0.01	61	11.239	2	0.0182	0.01431

TABLE 5. **COMPARISON OF MEASURED AND SIMULATED RUNOFF, SURFACE RUNOFF AND BASEFLOW**

YEAR	SURFACE RUNOFF (S)		BASEFLOW (U)		RUNOFF (R)		BASEFLOW INDEX	
	OBSERVED	FROM MODEL	OBSERVED	FROM MODEL	OBSERVED	FROM MODEL	CALIBRATED	MODELLED
1991	62.41	58.50	45.56	24.04	107.97	82.54	0.42	0.29
1992	67.03	70.10	59.56	31.68	126.59	101.78	0.47	0.31
1993	76.26	75.92	35.57	30.15	111.83	106.07	0.32	0.28
1994	74.65	69.00	69.57	25.00	144.22	94.00	0.48	0.26
1995	51.15	50.60	39.29	24.60	90.44	75.20	0.43	0.33

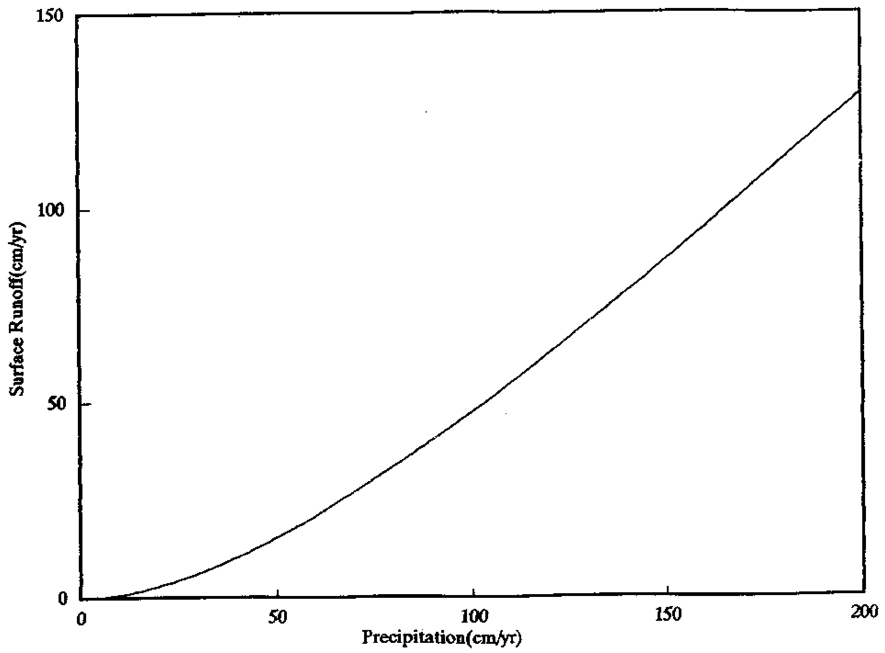

Fig. 4 Precipitation and Surface runoff function

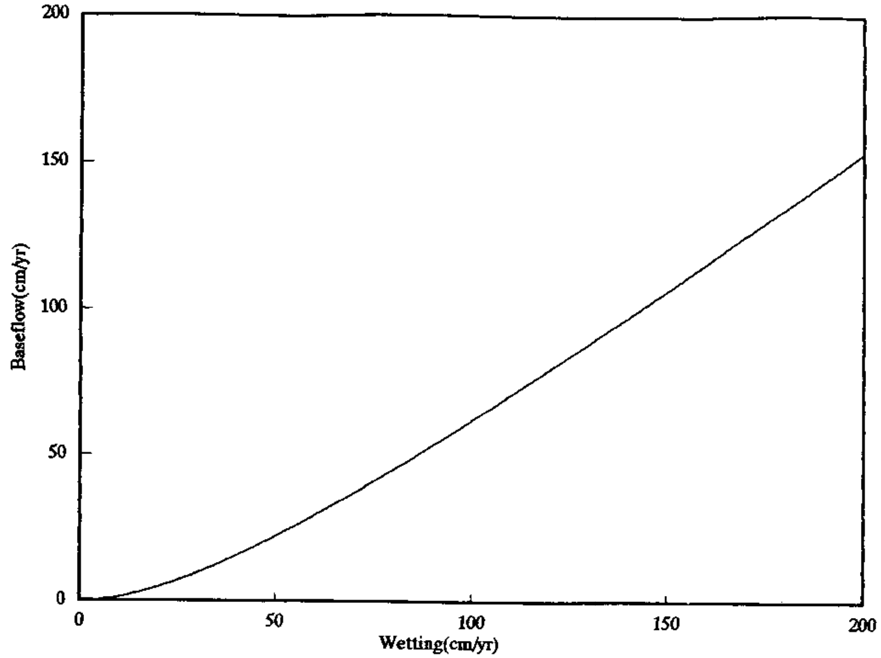

Fig. 5 Baseflow and Wetting function

Eq. 13, a relation between catchment wetting and baseflow has been developed for a valid range of catchment wetting (W) and it is shown in Fig. 5. Eqs. 6 and 8 are used in establishing runoff and baseflow coefficient functions and are shown in Fig. 6 and 7 respectively. Runoff and baseflow gain functions have been established using Eqs. 7 and 9, and are shown in Fig. 8 and 9 respectively.

The runoff threshold precipitation P_{rt} and maximum runoff gain K_{rp}' are obtained from Fig. 8 and are given in Table 4. Similarly the baseflow threshold precipitation P_{ut} and maximum baseflow gain K_{up}' are obtained from Fig. 9 and given in Table 4.

The initial abstraction coefficient of surface runoff (λ_s) and base flow abstraction coefficient (λ_u) are observed to be same as 0.01 (Table 4), which is not the case generally in most of the basins. The application of model for various basins (Ponce and Shetty, 1995) shows that λ_S is always less than λ_u . Thus, it indicates that the surface runoff response is more quicker than baseflow response at the basin outlet. But in the study area the surface runoff and baseflows are competitive to each other. The high values of RMS_{min} (11.853 and 11.239) indicates the variation between P and S, and W and U data sets in the basin. The ratio between P_{rt}/P_a represents the climatic setting of the basin. In seasonally humid, humid and subaratic regions, P_{rt}/P_a has low values, generally less than 0.3. The catchment data shows that runoff and baseflow gains are always positive. Runoff gain (Fig.8) reaches a peak for a runoff threshold precipitation(3cm) and baseflow gain(Fig.9) reaches a peak for a baseflow threshold precipitation (2cm). The water balance components in Table 3 shows that catchment wetting is higher than the surface runoff which may due to the many reservoirs located on the upstream side of the anicut. The comparison of precipitation and runoff shows that the runoff observed at Ariyanayakipuram anicut varies between 57% to 95% of precipitation in the basin, which indicates that apart from the precipitation, the inter basin transfer of water as well as the possible return flows and regenerated flows are contributing to the runoff observed at the anicut. Therefore, it is necessary to investigate more about the topography, geology and groundwater table conditions at the upstream of the anicut. The groundwater table

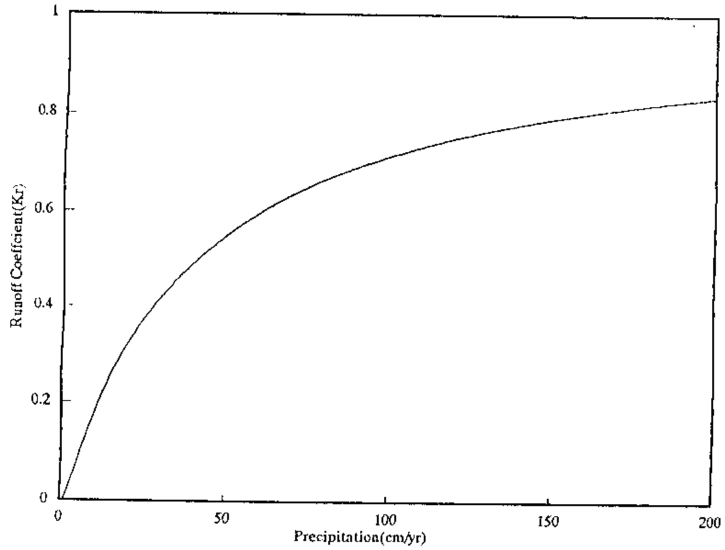

Fig. 6 Runoff coefficient function

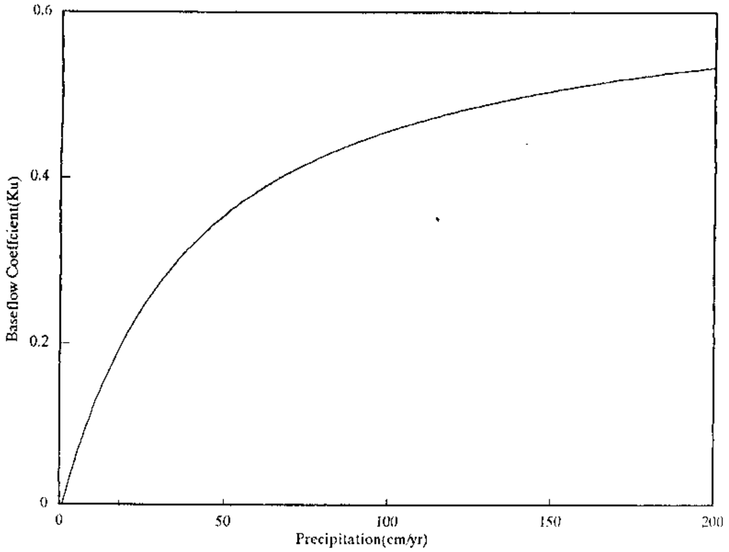

Fig. 7 Baseflow coefficient function

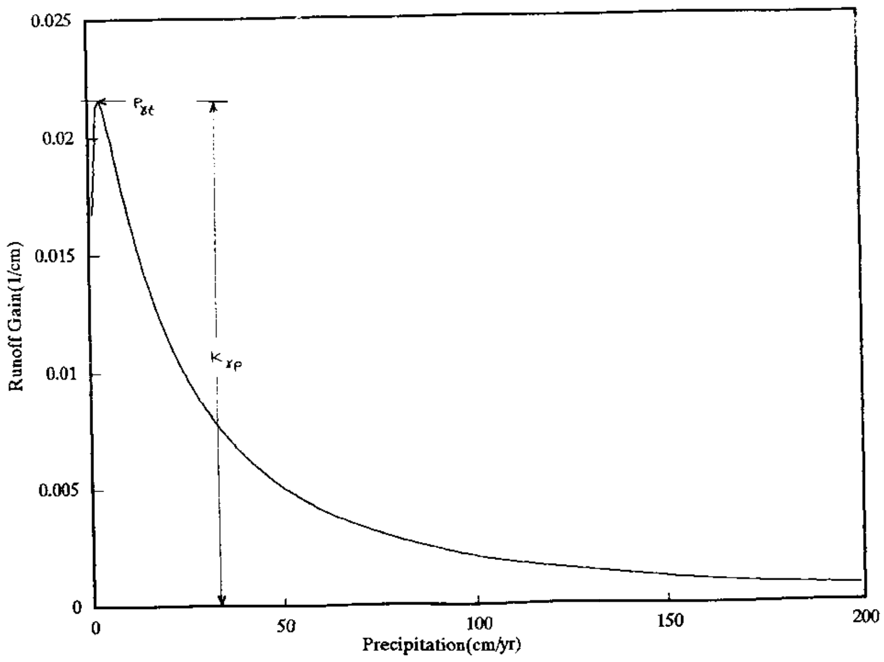

Fig. 8 Runoff gain function

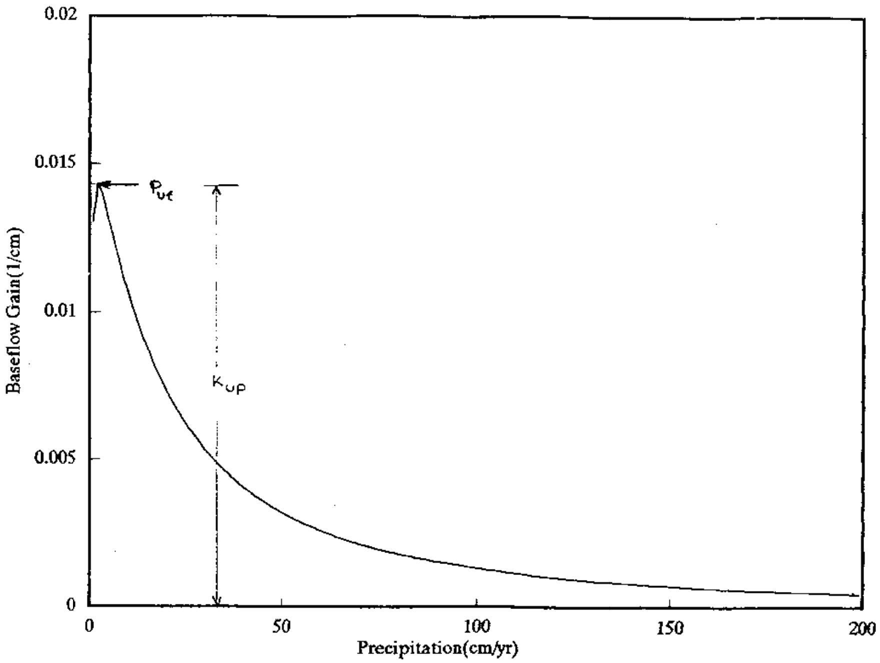

Fig. 9 Baseflow gain function

contours for the month of July 85 (Premonsoon) and January 86 (Postmonsoon) are shown in Fig. 10 and 11 respectively. The general groundwater flow direction is towards the Ariyanayakipuram anicut from both sides. The anicut is located on the steep slope of Tambraparani river. The flow duration curve for each year during the study period (1983-95) were plotted and it is found that the uniform portion on the curve indicates that the flows are controlled by the upstream reservoirs. For an example the flow duration curve for the year 1991 is shown in Fig.12.

Further the annual catchment water balance model has been applied to simulate the surface runoff and baseflow at the Ariyanayakipuram anicut. The model has been calibrated for a period of eight years (1983- 90) and validated for the remaining five years (1991-95). The comparison of the modelled surface runoff and baseflow with the corresponding observed values are given in Table 5. The model application shows that model has simulated surface runoff more accurately than baseflow. The comparison of surface runoff, baseflow and runoff obtained from model and observed values are shown in the form of bar charts in Fig. 13 , 14 and 15 respectively. The high variation in baseflow for the years 1992 and 1994 may require further detailed study in the catchment. During the study period the average base flow index(BFI) had been established in the basin as 0.35, which is representative of basin characteristics and may be useful for carrying out low flow studies in the basin.

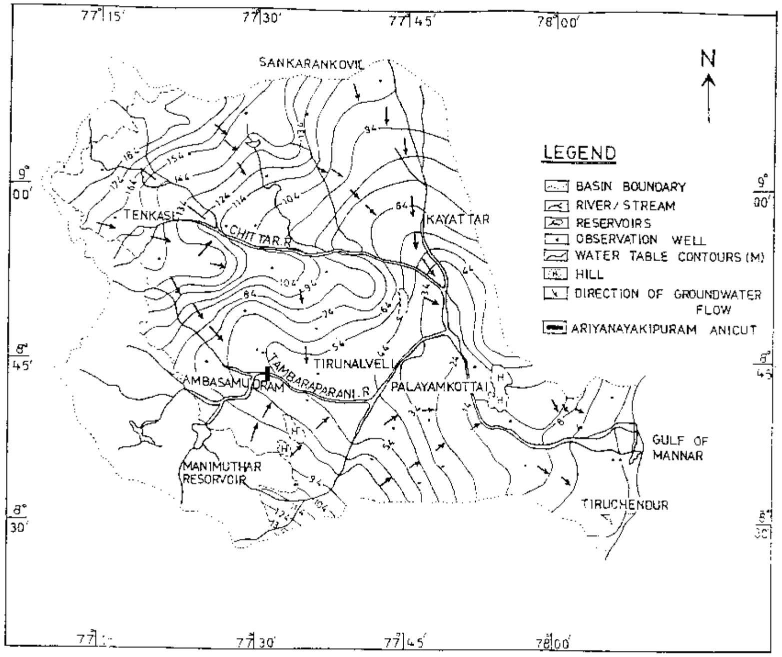

Fig. 10 Groundwater table contours during premonsoon period
(JULY 1985)

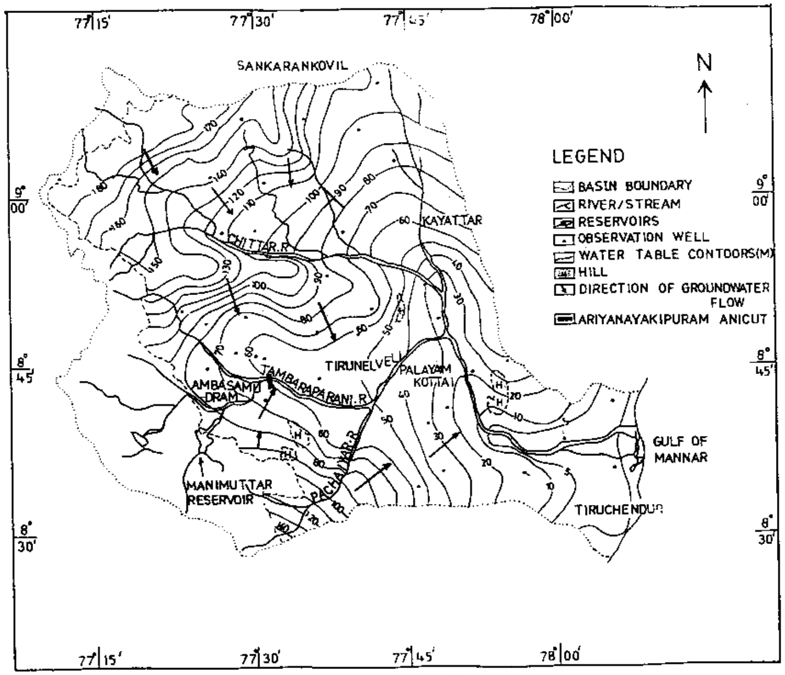

Fig. 11 Groundwater table contours during post monsoon period
(JANUARY 1986)

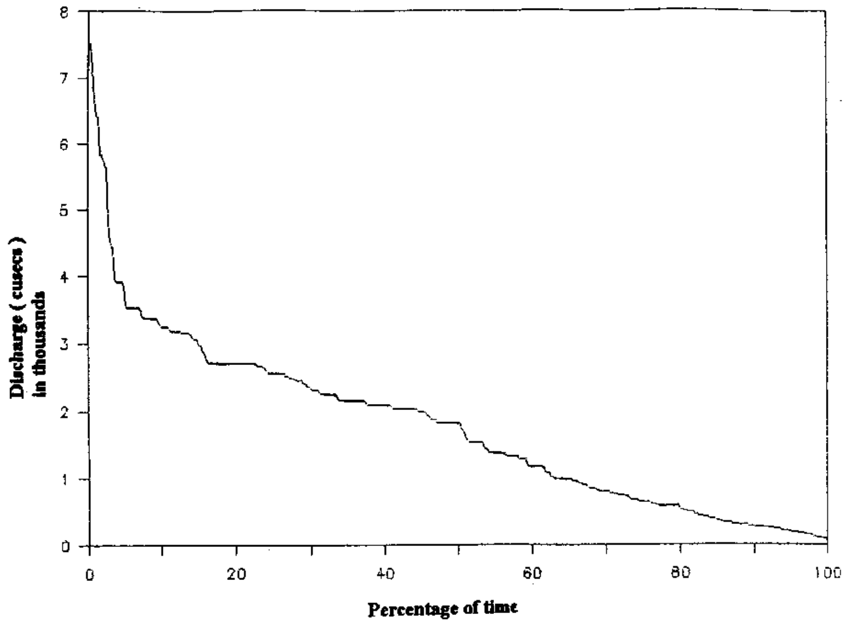

Fig. 12 Flow duration curve at Ariyanayakipuram anicut for the year 1991

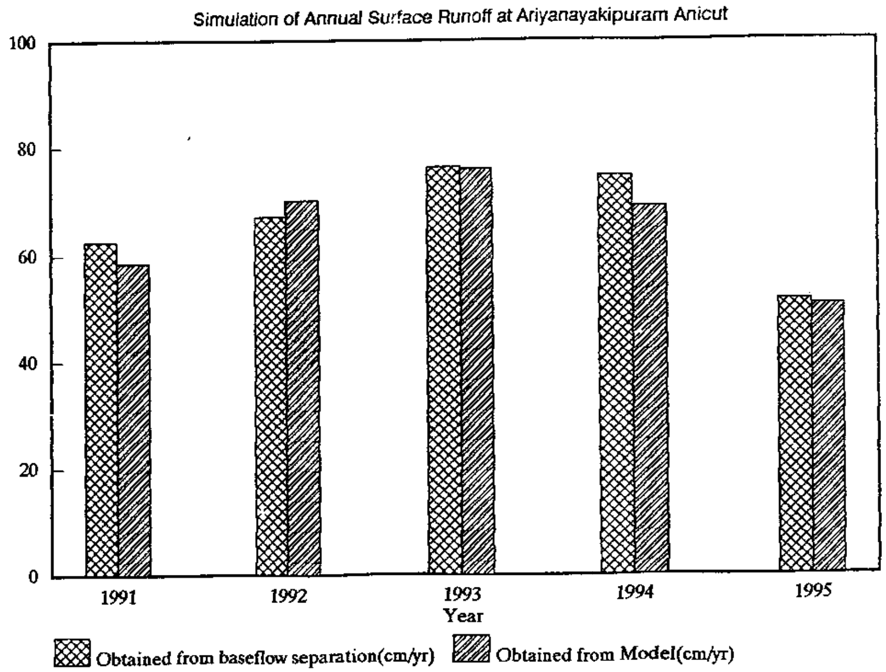

Fig. 13 Bar chart showing calculated and simulated Surface runoff

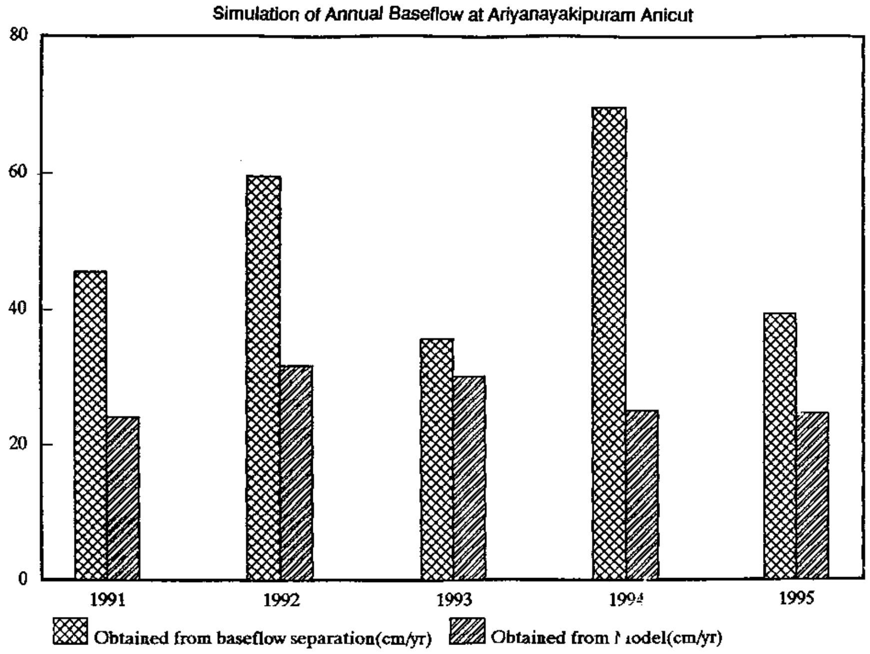

Fig. 14 Bar chart showing calculated and simulated baseflow

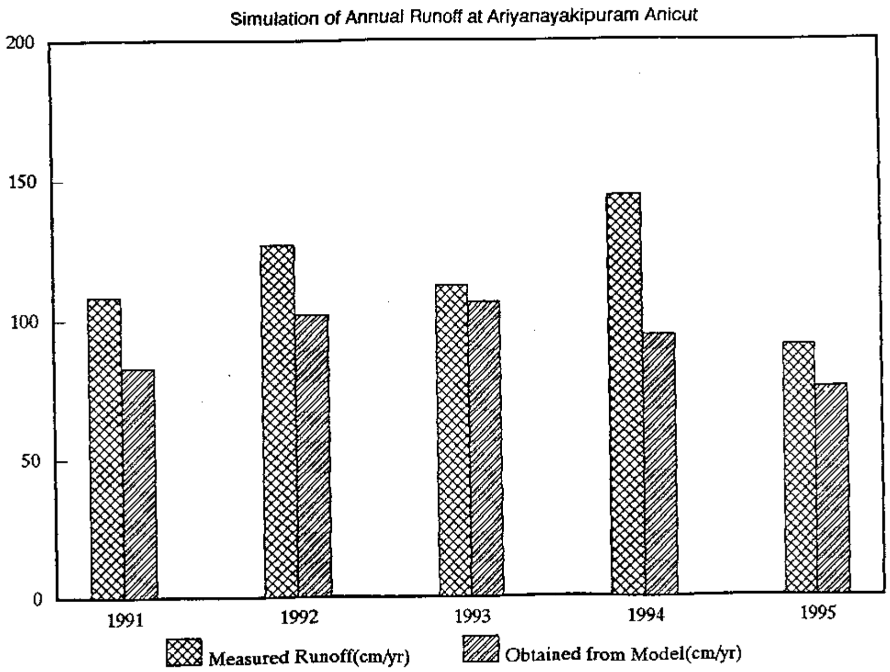

Fig. 15 Bar chart showing measured and simulated runoff.

6.0 CONCLUSIONS

1. The surface runoff and baseflow have been analysed for a period of thirteen years (1983-1995) at Ariyanayakipuram anicut, Tambraparani basin.

2. The comparison of precipitation and runoff shows that the runoff observed at the anicut was not only from precipitation, but it may also be due to the high baseflow, inter basin transfer of water etc.

3. The groundwater flow direction, the steep river reach at the anicut and geology of the area may be possible reasons for the high runoff response at the anicut.

4. Detailed investigations are necessary to understand the influence of upstream reservoirs on the anicut and, runoff and baseflow process in the catchment of the anicut.

5. The annual catchment water balance model had been applied for simulating the surface runoff and baseflow at Ariyanayakipuram anicut.

6. The model parameters have been calibrated using eight years data (1983-1990) of precipitation- surface runoff and catchment wetting - baseflow.

7. The calibrated model has been applied for its validation for a period of five years (1990-95). The application of model shows that the model has simulated surface runoff more accurately than baseflow.

8. The model application also confirms that the runoff observed at the anicut is not only from the precipitation in the basin. The high values of catchment wetting indicates that the subflow contribution is dominating at the anicut.

9. The study highlights the high flows observed at the anicut and its requires further investigations to understand the runoff and baseflow processes at the upstream of the Ariyanayakipuram anicut.

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REFERENCES

I I T Madras, 1994, 'Computer Aided Simulation study of Tambraparani river system' Final report submitted to PWD, National Water Management Project, Govt. of Tamilnadu.

Lee, R. 1970. Theoretical estimates versus forest water yield. Water Resources Research, 6(5), 1327 - 1324.

Ponce, V.M., and Shetty, A.V. (1995). A conceptual model of catchment water balance 1. Formulation and calibration; 2. Application to runoff and baseflow modeling, Journal of Hydrology, Vol. 173, pp 27-40.

Thornthwaite, C.W. (1948). An approach toward a rational classification of climate, Geogr. Rev., Vol. 39, NO.1, pp 55-94.

Thornthwaite, C.W and Mather, J.R. (1995). The water balance, Publ. in Climatol., lab. of Climatol. (Centerton, NJ), Vol. 8, No. 1, PP. 104.

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