CS(AR)-15/98-99

BASE FLOW STUDIES FOR THREE RIVERS BETWEEN MAHANADI AND GODAVARI DELTAS IN THE SUB-ZONE 4(A)

आपो हि ष्ठा मयोभुव

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE - 247 667 (INDIA)
1998-99

PREFACE

Rainfall – runoff process is an important part of land phase of hydrological cycle. Runoff is defined as the portion of the precipitation flowing off from a catchment through surface channels as surface or sub-surface flow. Depending upon the catchment geomorphology, surface runoff, interflow, sub-surface runoff or baseflow combine to form total runoff. The amount of baseflow increases after the recharge of ground water and it gradually diminishes during periods of no recharge. Fluctuations of baseflow contribution to a stream mainly depend on fluctuations of water levels in the stream during and after a storm.

A number of regional low flow studies have highlighted the importance of indexing hydrogeology of catchment if flows are successfully to be predicted at the ungauged site. In order to avoid a profusion of relationship between low flow indices and catchment characteristics the low flow studies report of Institute of Hydrology, Wallingford, U.K., recommended using the proportion of base flow in a river defined by an index called Base Flow Index (BFI), for indexing the geology on the low flows.

In this study a procedure as suggested in the low flow studies report is employed for three rivers of Zone 4(A) and baseflow indices are developed for three east flowing rivers namely the Rishikulya at Purushottampur in Orissa, the Nagavali at Narayanapuram Anicut and the Sarada at Anakapalli in Andhra Pradesh using the daily flows over a period of 4 to 6 years. A computer program in FORTRAN 77 is written for the procedure to estimate BFI. The BFI's thus arrived at are varying from 0.23 at the Sarada (PWD site) to 0.42 for the Nagavali.

As part of work plan of Deltaic Regional Centre of NIH, Kakinada, this study was carried out by Sri S.V.Vijaya Kumar, Scientist 'C', with the support of Sri Y.R.Satyaji Rao, Scientist 'C' and Sri U.V.N.Rao, SRA., with the encouragement by Sri J.V.Tyagi, Scientist 'C'. This report was reviewed by Sh R D Singh, Scientist 'F'.

(S M Seth)

Director

CONTENTS

List of Tables

List of Figures

ABSTRACT

Baseflows or low flows form an important part of available waters, especially towards the lower reaches of watershed, as they are the flows sustaining over a prolonged period of time. Any water resources development of available surface water must consider the contribution of these low flows. As the low flows are the contributions from the discharges of the aquifers to the rivers, they depend on the drainage and the geotechnical properties of the formations of river basin. Low flows are important as the quality of the environment depends on the quantity of low flows occurring particularly in areas of urban living and having check on pollution.

Base flow studies can be undertaken by a number of techniques. The purpose for which the study is being undertaken mainly determines the particular procedure to be adopted. In this study a procedure as suggested in the low flow studies report of by Gustard et.al, 1992 to estimate the Base flow Index using the mean daily discharge data is employed for three rivers of Zone 4(A) and baseflow indices are developed for three east flowing rivers namely the Rishikulya at Purushottampur in Orissa, the Nagavali at Narayanapuram Wier and the Sarada at Anakapalli in Andhra Pradesh using the daily flows over a period of 4 to 6 years. The indices indicate the contribution of the baseflow to the total available flows on these streams.

A computer program in FORTRAN 77 is written for the procedure to estimate BFI's as recommended in the Low flows studies report of Institute of Hydrology, UK. The BFI's thus arrived at are varying from 0.23 at the Sarada (PWD site) to 0.42 for the Nagavali. Among the three streams studied it is observed that Nagavali has good baseflow contribution.

INTRODUCTION

Rainfall-runoff process is an important part of land phase of hydrological cycle. Runoff is defined as the portion of the precipitation flowing off from a catchment through surface channels as surface or sub-surface flow. Depending upon the catchment geomorphology, surface runoff, interflow, sub-surface runoff or baseflow combine to form total runoff. However, while dealing with small catchments baseflow is dealt exclusively from other flows.

Baseflow or base runoff is defined as the sustained or fair weather runoff in a stream. Since baseflow represents the discharge of aquifers, changes occur slowly and there is a lag between cause and effect, which may extend to period of days and weeks. The amount of baseflow increases after the recharge of ground water and it gradually diminishes during periods of no recharge. Fluctuations of baseflow contribution to a stream mainly depend on fluctuations of water levels in the stream during and after a storm. Thus contribution of baseflow to the stream runoff depends on the stream whether it is influent or effluent. An influent stream is one where the baseflow is negative i.e., stream feeds the aquifer and the effluent stream is fed by aquifer and acts as a drain. An intermittent stream is one, which acts as both influent and effluent within a single reach at different times or different reaches at any time. There are three different patterns of hydrographs like hydrographs of ephemeral streams, hydrographs of intermittent streams and hydrographs of perennial streams depending on whether the region is arid, semi arid or humid (Balek, 1989).

As the low flows are the contributions from the discharges of the aquifers to the rivers, they depend on the drainage and the geotechnical properties of the formations of river basin. Low flows are important as the quality of the environment depends on the quantity of low flows occurring particularly in areas of urban living and having check on pollution. According to Raju et.al(1995), the period of low flow which may occur once or several times of a year is virtually constant for any basin or sub-basin and base flow index (BFI) can be treated as catchment characteristic. The important factors apart from man's influence that make low flow characteristic for a basin are climatic-rainfall, its occurrence, distribution and intensity; watershed-land use, soil, relief, depression storages & releases, lakes, swamps, evaporation and evapotranspiration etc; Geomorphologic-area, mean altitude, slope, drainage, channel embodiment etc.,

Baseflows or low flows form an important part of available waters, especially towards the lower reaches of watershed, as they are the flows sustaining over a prolonged period of time. Any water resources development of available surface water must consider the contribution of these low flows. In this study various baseflow techniques are discussed and baseflow indices are developed for three east flowing rivers namely the Rishikulya at Purushottampur in Orissa, the Nagavali at Narayanapuram Wier and the Sarada at Anakapalli in Andhra Pradesh using the daily flows over along term. The indices indicate the contribution of the baseflow to the total available flows on these streams. The higher the BFI the contribution of baseflows to the river discharges is more and vice-versa. The estimated baseflow index may be used to assess the baseflow component in any conceptual water balance models.

2.0 REVIEW

Base flow studies can be undertaken by a number of techniques. The purpose for which the study is being undertaken mainly determines the particular procedure to be adopted. Raju et.al., (1995) reviewed at length in their report on long term base flow studies on parameters affecting the base flow. They also presented some techniques of estimating base flow parameters undertaking while conducting base flow studies. In this study a procedure as suggested in the low flow studies report (Gustard et. al., 1992) to estimate the Base Flow Index using the mean daily discharge data is employed. The procedure is discussed in detail here.

Base Flow Index:

A number of regional low flow studies (Wright, 1974, Klaassen and Pilgrim 1975; Institute of Hydrology 1980, Pirt and Douglas 1982) have highlighted the importance of indexing hydrogeology of catchment if flows are successfully to be predicted at the ungauged site. In order to avoid a profusion of relationship between lowflow indices and catchment characteristics the low flow studies report (Institute of Hydrology, 1980) recommended using the proportion of base flow in a river defined by an index called Base Flow Index (BFI), for indexing the geology on the low flows. Values of BFI range from 0.1, for a very flashy river to nearly unity for a very stable river with high base flow contribution.

Although BFI was originally reluted to geology and lake storages in the U.K., a wider use of the index by Pilon and Condie (1986) in Canada; Green (1986) in Fijji, Meigh(1987) in Zimbabwe, NWSCA (1984) in New Zealand, Tallaksen (1986) in Norway; Nathan and McMohan(1990) in Australia have shown it to have been useful in regional flood and low flow studies.

BFI can be used as key variable in describing the hydrological response of catchments in order to develop the Hydrology of Soil Type (HOST) classification scheme (Boorman and Hollis, 1990 and Boorman et. Al 1991). BFI can also be used directly as a key variable linking low flow statistics (IH,1980). Accordingly BFI can be used for estimation of key low flow statistics where short period of low flow data are available.

Also BFI may be used as a catchment characteristic and relationship between lowflow indices such as Q95 (10) i.e, 95 percentile ten day discharge. Raju et. Al (1995) describe about the following regression equation based on the lowflow studies, report (IH 1980) of Institute of Hydrology, Wallingford.

Q95 (10)=8.6 BFI + 0.00377 Area + 0.0414 SAAR - 3.22 ------(1)
MAM (10) = 9.39 BFI +0.00199 Area + 0.0144 SAAR - 2.98 ----- (2)

Where MAM (10) = Mean annual 10 day minimum flow
SAAR = Average annual rainfall in a standard period
Area = Catchment area in Sq.km.

The latest report on low flow studies (Gustard et.al; 1992) supplemented the earlier findings and procedures of low flow study of Institute of Hydrology. Relationships are developed between catchment characteristics and low flow statistics, specially the mean flow and two key low flow statistics, Q95 (1), the 95 percentile from the 1 day flow discharge and MAM (7), the mean annual 7 day minimum, representing the flow duration and low flow frequency respectively. The use of HOST (Hydrology of Soil Types) classifications was the principal development in their study. Their study conducted on 865 gauged catchments in the U.K. has enabled parameter estimates for Q95 (1) and MAM (7) for 12 low flow HOST groups. They proposed regression equations using short period of continuous local flow data to find Q95 (1) and MAM (7), wherein BFI alongwith other catchment characteristic has been employed as below.

$$Q95\,(1) = 44.BFI^{1.43}.\,SAAR^{-0.0330}.AREA^{0.0342} \qquad \text{----------- (3)}$$

$$MAM\,(7) = 190.99\,BFI^{1.52}.\,SAAR^{-0.199} \qquad \text{----------- (4)}$$

3.0 METHODOLOGY

In this study a procedure as suggested in the low flow studies report (Gustard et. Al, 1992) to estimate the Base Flow Index using the mean daily discharge data is employed. The procedure is discussed in detail here.

The BFI can be thought of as measuring the proportion of the rivers runoff that derives from stored sources. A computer program is applied to smooth and to separate the recorded or observed flow hydrograph from which the index is calculated as the ratio of the flow under the separated hydrograph to the flow under the total hydrograph.

The program written in FORTRAN 77 calculates the minimum of five-day non-overlapping consecutive periods and subsequently searches for turning points in this sequence of minima. The turning points are then connected to obtain the base flows hydrographs, which is constrained to equal the observed hydrograph ordinate on any day when separated hydrograph exceeds the observed. The procedure for calculating the BFI is as follows:

1. Divide the mean daily flow data into non-overlapping blocks of five days and calculate the minimum for each of the blocks and they may be called as Q1,Q2,Q3,....., Qn.

2. Consider in turn (Q1, Q2, Q3), (Q2, Q3, Q4), (Qi-1, Qi, Qi+1) etc., In each case if 0.9 times central value is less than other values, then the central value is an ordinate for the base flow line. This procedure is continued till all the data are analyzed to provide a derived set of base flow ordinates QB1, QB2,QB3,....QBn which will have different time periods between them.
3. By linear interpolation between each Qbi value as found above, daily value of QB1 to QBn are estimated.
4. If Qbi is greater than Qi then Qbi is made equal to Qi.
5. The volume beneath the base flow line thus separated VB is calculated between the first and last points QB1 to QBn.
6. The volume beneath the recorded mean daily flow Qi and Qn is calculated as VA for the period QB1 to QBn.
7. The base flow index is derived as the ratio of VB and VA.

Base flow separation can not start on the first day of the data record and similarly will not finish on the last day of the record. It is important to recognize that when the dates of the beginning and end of base flow line have been established, then these same dates must be used in calculating the total volume of flow beneath the hydrograph as well as in calculating the volume of flow beneath the baseflow line.

Calculation of annual BFI:

There are two alternative methods for calculating the annual BFI's. The first is to compute the separation for the entire record and the estimation of BFI for each year. The second is to run the separation program yearwise and finding the BFI's for each year of analysis. The two approaches differ slightly and for calculating the annual BFI, the first procedure is recommended.

Calculation of BFI for full period:

A mean value of BFI can be calculated from a series annual BFI's as mentioned above. But the average BFI obtained thus, will be different from a single value obtained for the whole period. The recommended procedure is to calculate one value of BFI based on separation of the entire record.

Studies have shown that annual value of BFI were more stable than other low flow variables. The BFI value are sensitive to the missing data because several days of data are omitted from the base flow separation as a result of only 1 missing day of gauged data. Interpolation of missing data may be done only upto 5 days.

BFI values are to be used with caution if the recorded contains several gaps. Coming to sensitivity of BFI to hydrometric errors, it was stated that the percentage error in BFI was less than a given percentage of error in flow data. The error was largest for catchments with low BFI values. Gustard et. Al. (1992) mentioned that a 10% error in high flows (Q5) or low flows(Q95) resulted in a 7% error in BFI for low BFI catchments(0.2) and less than 1% error in BFI for high BFI (0.9) catchments.

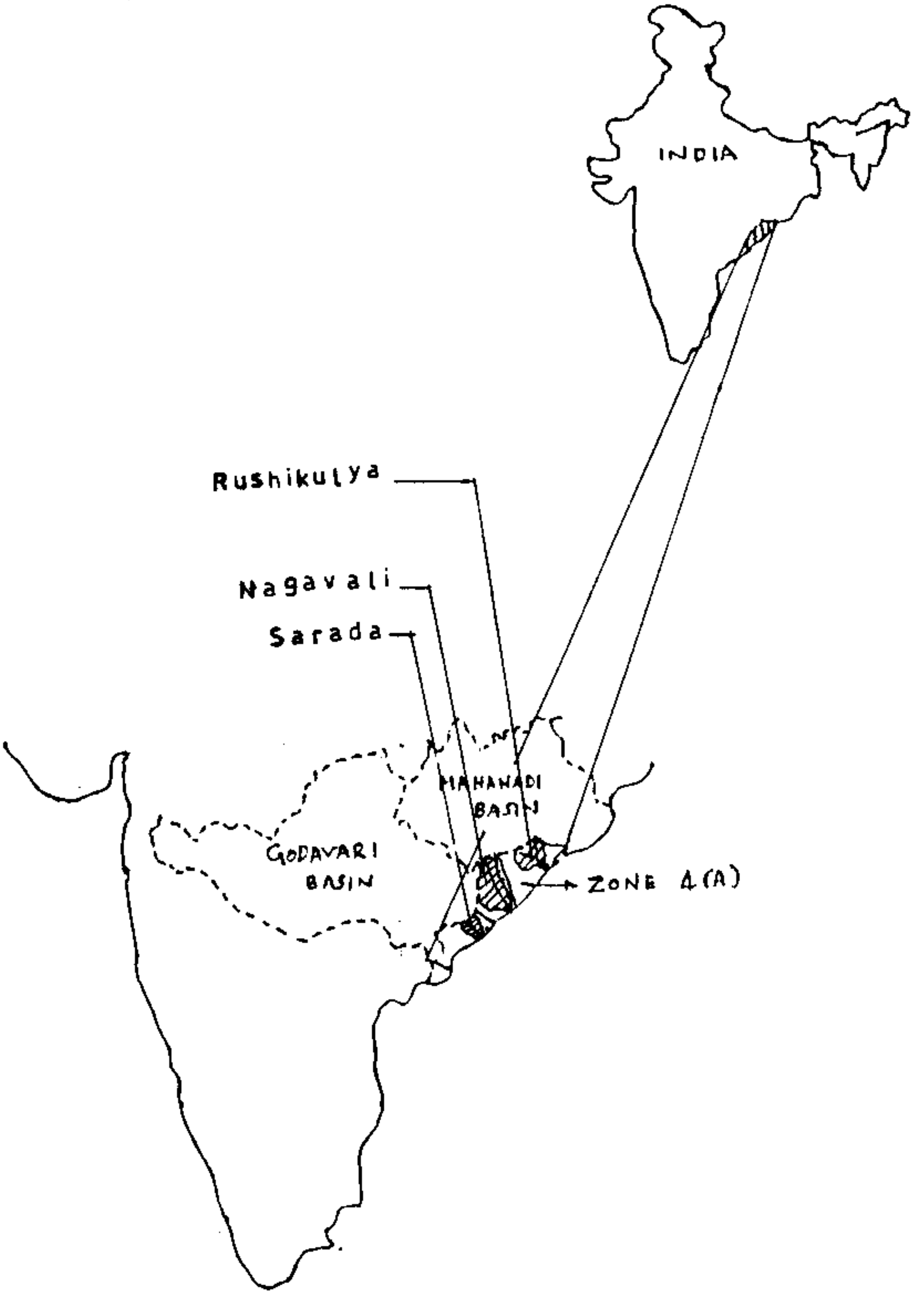
4.0 STUDY AREA AND DATA :

In this study three rivers along the east coast falling in sub-zone 4(a) of CWC classification, namely the Rishikulya in Orissa; the Nagavali and the Sarada in Andhra Pradesh are studied. The location map of the study area is at fig 1. The detailed description of the basins is as below.

Rishikulya:

The Rishikulya drains most of the Ganjam district. The basin is covered by the SOI toposheets 73-D/8,12,16; 74-A/1,2,5 to 11, 13 to 15; 74-E/1 to 3 and lies between $19^0 10'$N to $20^0 20'$N latitude and $84^0 0'$E to $85^0 5'$ E longitude (fig.2). The Rishikulya originates near Kilabarthi in the Pondakhol reserved forest area at an elevation of about 1300 m on the ridges that separate Ganjam and Phulbani district of Orissa. It traverses rapidly and is joined on the right side by Pathma Nadi at the confluence of which Sarada reservoir was formed. It traverses further and is joined on the left by Burtha Nadi, which drains whole of northern region of Ganjam district. It flows south-east and is joined on the right by

Fig.1 Location map of study area



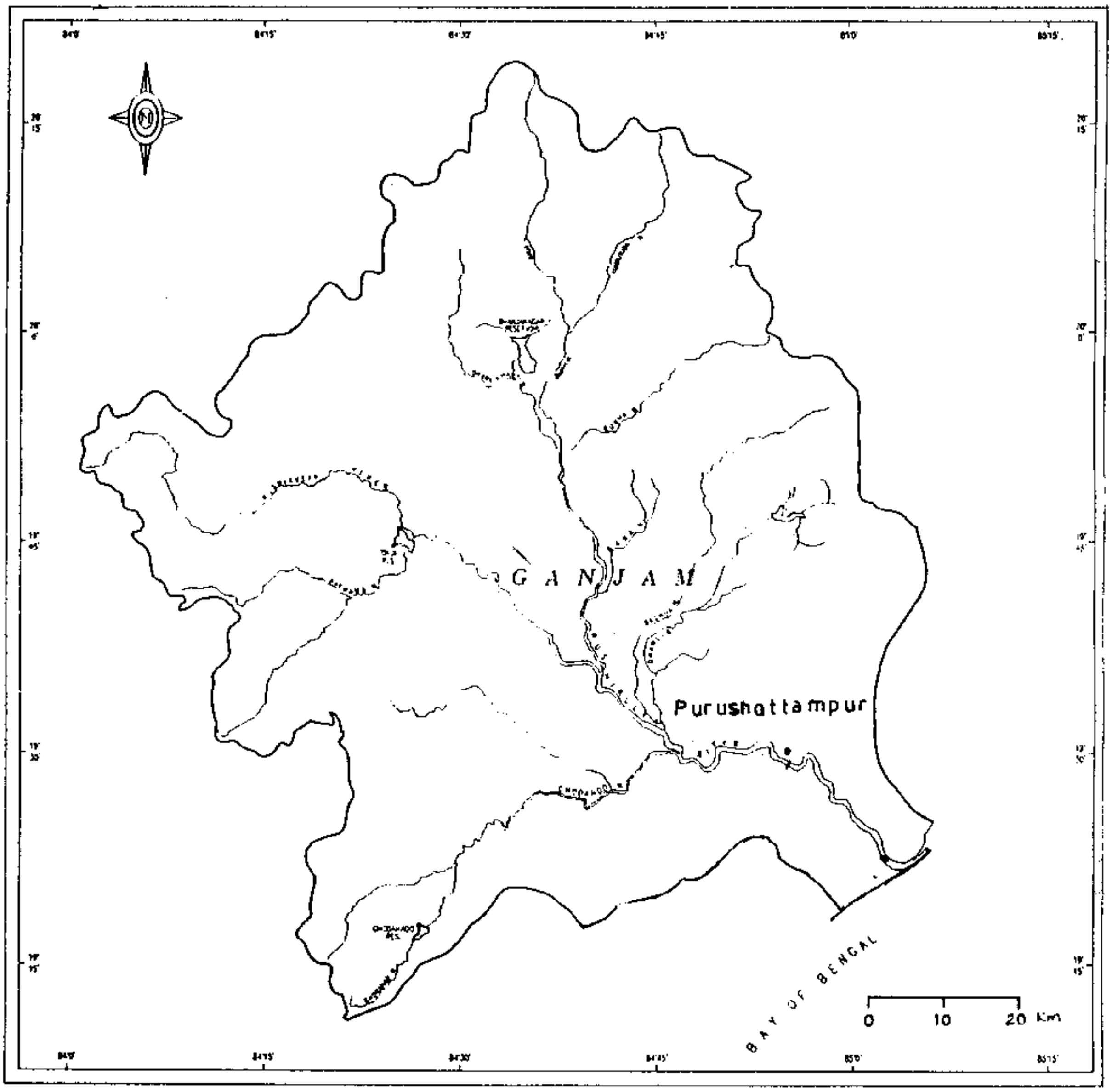


Fig.2 Rushikulya river basin

Gorhanarh river after the confluence of which it travels eastwards upto Purushottampur, where the catchment area is 7112 sq.km. Flowing further south-east Rishikulya is met on the left by Kharkhari nala and joins the Bay of Bengal about 10 km eat of Ganjam Railway station with a total drainage area of 8200 sq.km.

Daily flow data at Purushottampur CWC site on the Rishikulya for about 4 years from June, 1992 to May, 1996 is used in the study.

Nagavali:

Nagavali river basin lies between latitudes $18^0 11$'N to $19^0 45$'N and longitudes $82^0 53$'E to $84^0 02$'E and falls in the SOI toposheets 65 M and N. The total catchment area of the basin is 8845 sq.km. and almost equally shared by the states of Orissa and Andhra Pradesh.
Nagavali rises in the Eastern Ghats in Orissa and flows southeast for about 40 km and then takes a turn towards south and flows for another 67 km and enters Andhra Pradesh State limits at a point 6 km south of Jimidipeta R.S. Then the river takes a south-easterly course and continue to flow in this direction till it joins Bay of Bengal about 10 km south-east of Srikakulam town near Dibbalapalem village. The major tributaries of the Nagavali are Janjhavati, Vottigedda, Vegavathi and Suvarnamukhi. The catchment area upto Narayanapuram anicut is about 8526 sq.km. (Fig.3).
Daily flow data at Narayanapuaram Anicut site on the Nagavali for about 6 years from January 1987 to December 1992 is used in the study.

Sarada:

Sarada river basin forms part of SOI toposheets 65 O/1,2,3 and 6 and 65 K/13 to 15 and extends geographically from latitudes $17^0 25$'N to $18^0 17$'N and longitudes $82^0 30$'E to $83^0 37$'E and drains most of the Visakhapatnam district of Andhra Pradesh. It is one of east flowing streams which gathers its headwaters in the high mountains of the Eastern Ghats and flows from north to south over a length of 140 km and empties into Bay of Bengal 60 km south of Visakhapatnam. The main tributaries of the basin, whose maximum relief is

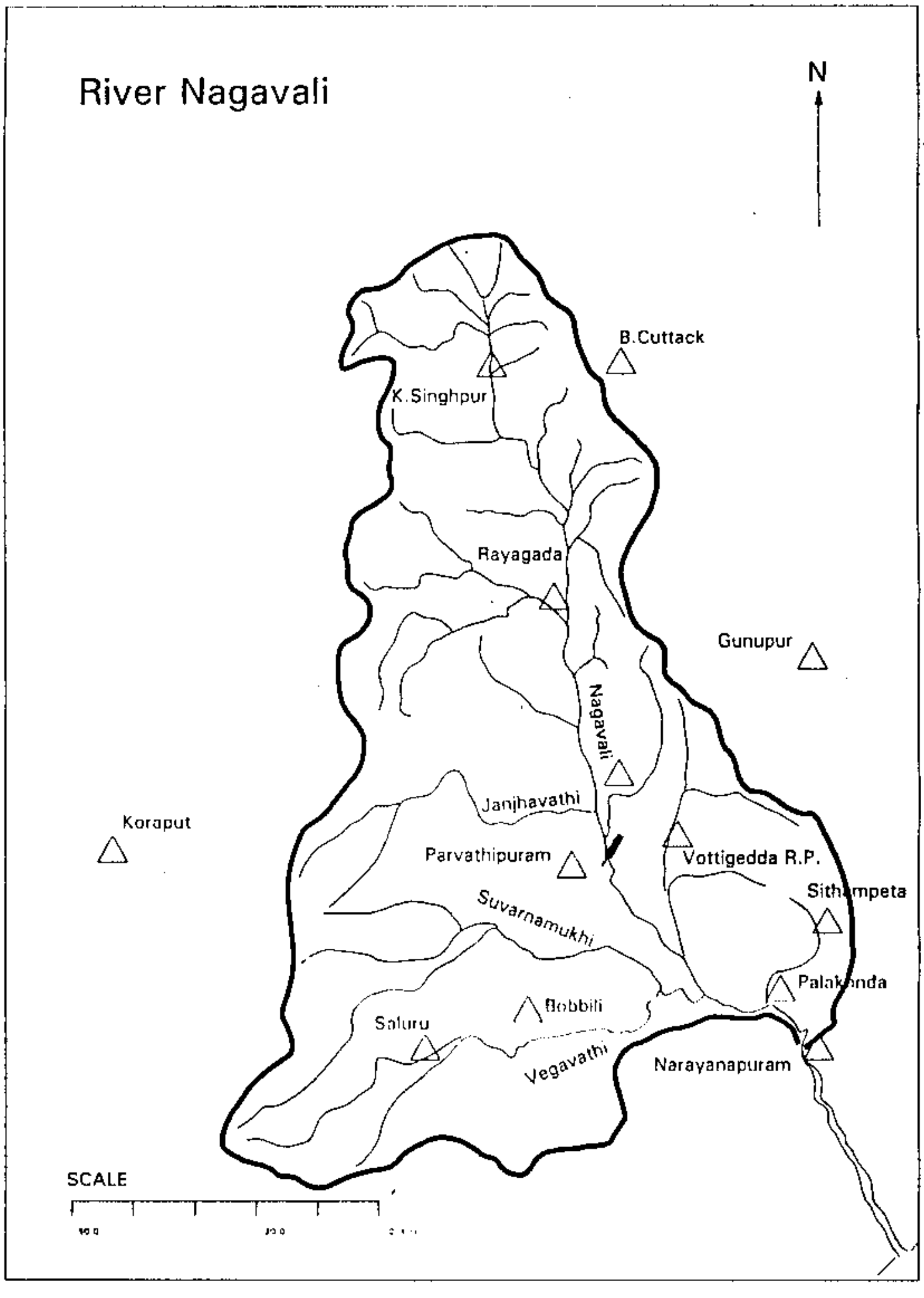


Fig.3 Nagavali river basin

1620 m, are Bodderu, Tacheru, Pedderu and Vedurlagedda. The catchment area of the Sarada river basin upto Anakapalli is about 1980 sq.km. (fig.4.).

Daily flow data at Gudari Anicut PWD site at Anakapalli for about 6 years from January 1981 to December 1986 and at CWC site at Anakapalli for about 5 years from June 1990 to May 1995 on the Sarada is used in the study. The PWD data are very significant at 99% significance level as the resulting modulus t value was 18.5353 with the CWC data for the means from the students-t test results. This may be due to change in regime of the catchment due to construction of reservoir towards the end of '80s. The measurement technique of flow over weir by PWD and of current metering by CWC may also be additional reason. In the study both data sets are analyzed separately.

5.0 ANALYSIS & RESULTS

Flow duration curves are plotted for the data used in the study for each site, as they indicate to some extent the baseflow regime of the basin. The respective standardized flow-duration curves for the 4 sites are shown at fig.5 to fig.8. The plots are standardized by mean flow to facilitate comparisons between catchments because it reduces the differences in the location of flow-duration curve which are caused by mean annual runoff. This standardization may also reduce the bias of estimated percentiles caused by above or below average flows during the period of record. According to Gustard et. al. (1992), the slope of the flow duration curve indicates the geotechnical properties of the formations of the basin. Flatter the slope baseflow contribution is good and lowflow variability is low. If slope of flow-duration line is steep the formations are likely to be impermeable and the stream will be a flashy one.

From the plots drawn it can be observed that the slopes of the flow duration curves at the 4 sites tend to be neither steep not flat and lie in a range comparable to one another. This indicates that the formations of the region have average baseflow contributions and must have similarities in their permeability characteristics at a regional level as per the criteria of Gustard et.al referred above.

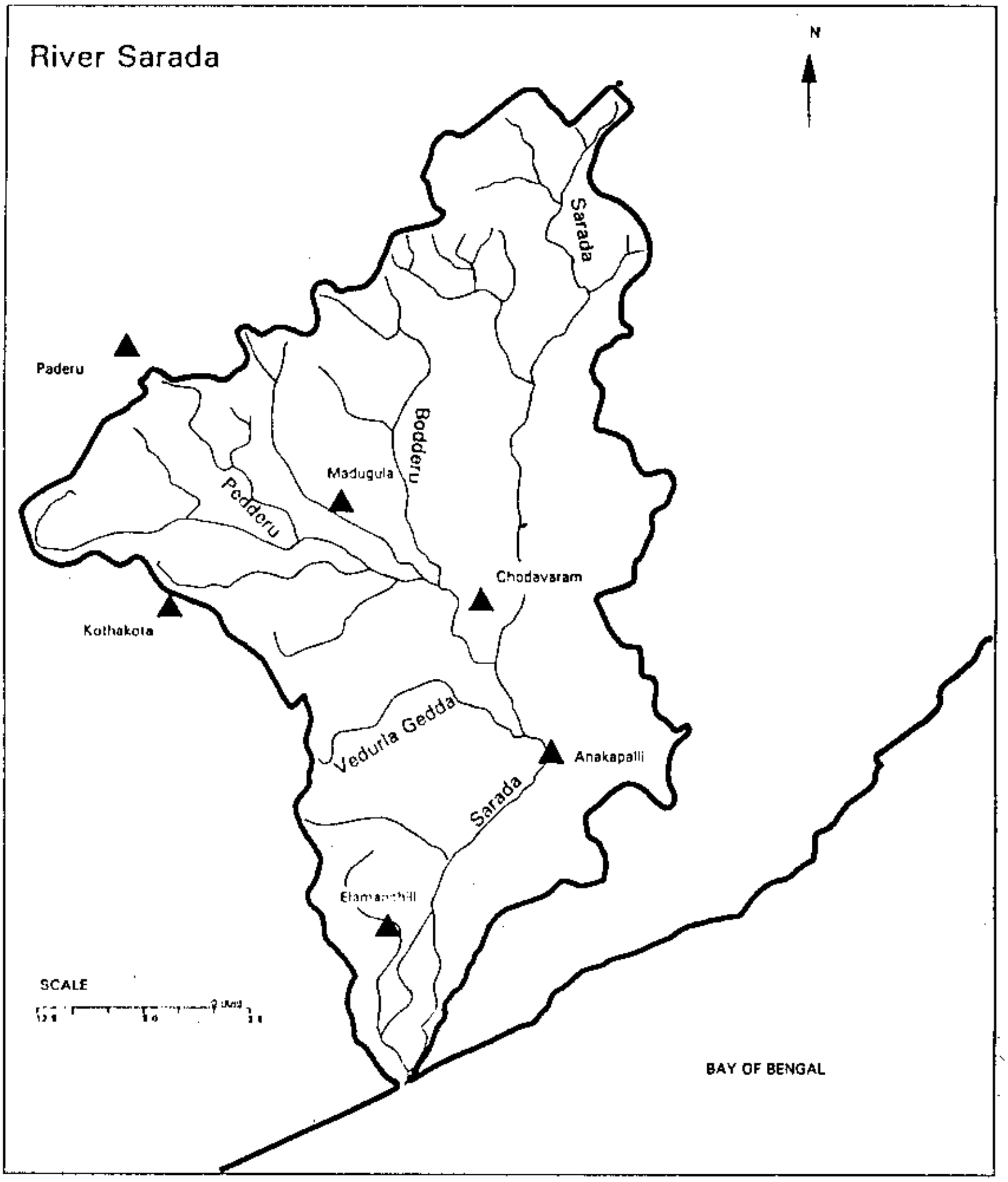


Fig.4 Sarada river basin

Fig.5 Flow duration curve of Rishikulya at Purushottampur

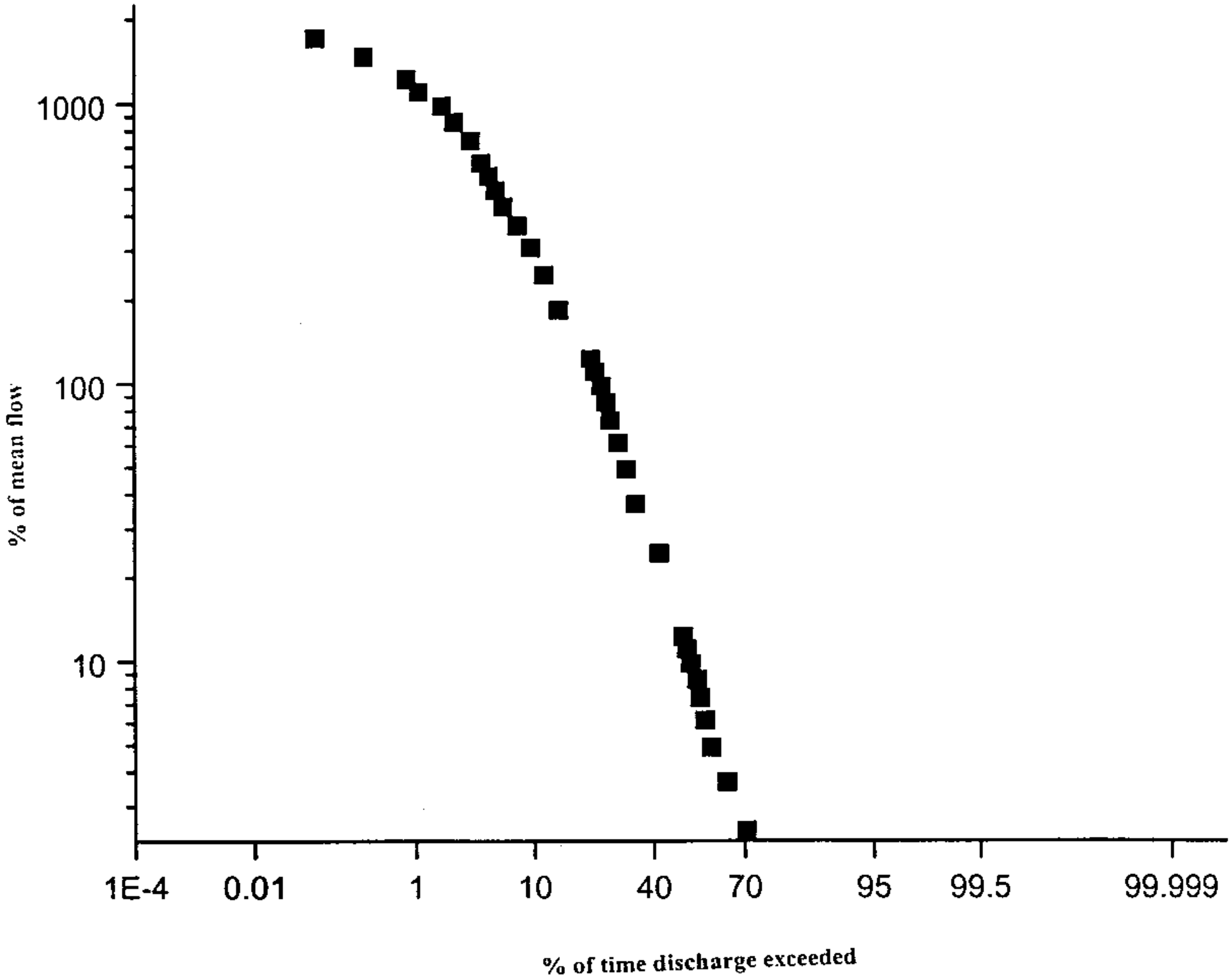


Fig.7 Flow duration curve of Sarada at Gudari Anicut

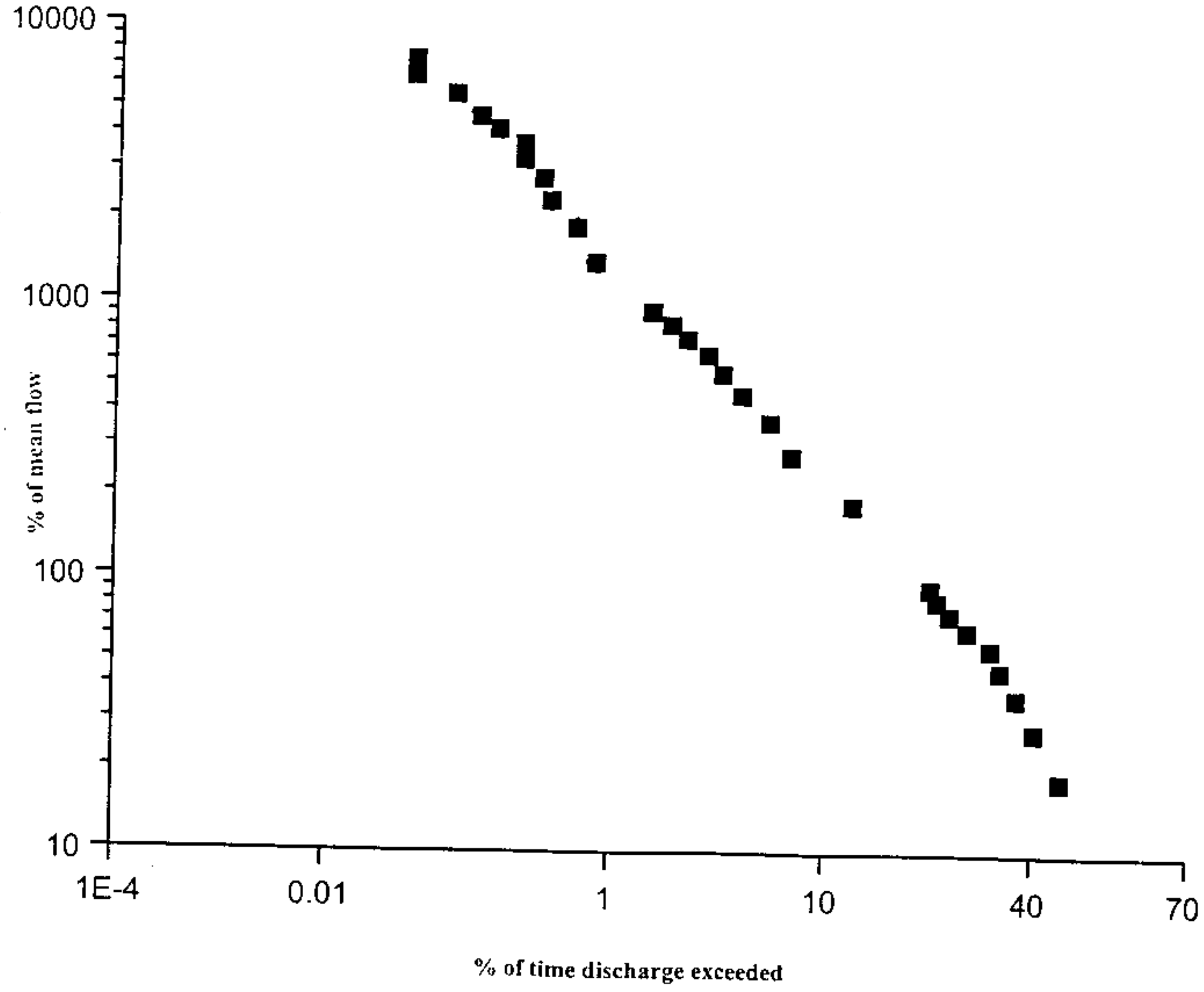


Fig.6 Flow duration curve of Nagavali at Narayanapuram Anicut

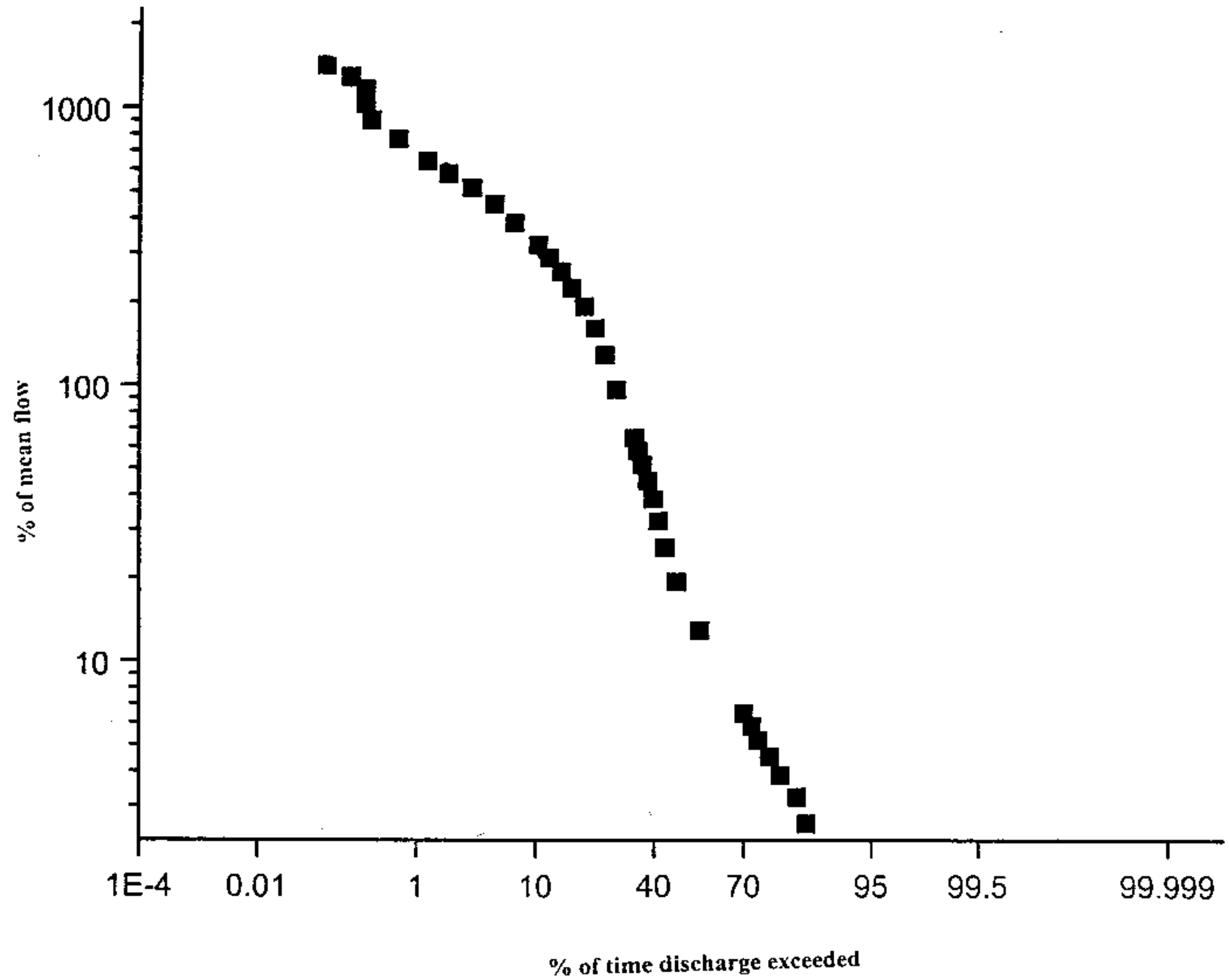
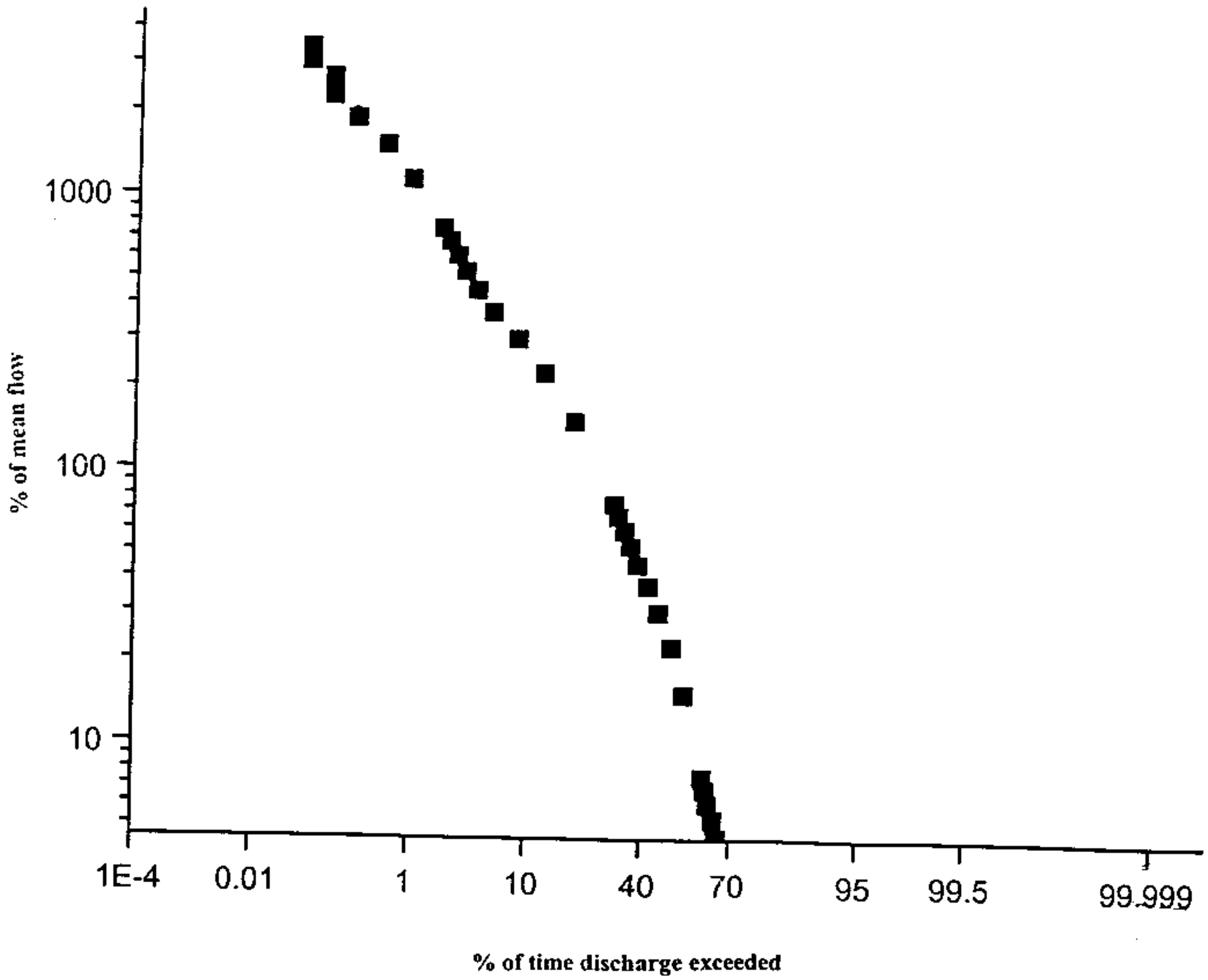


Fig.8 Flow duration curve of Sarada at Anakapalli



As mentioned earlier a program in FORTRAN 77 is written for the base flow index methodology recommended in the low flows studies report (Gustard et. al. 1992) to assess the BFI of the river basins under study. The daily discharge data available at the four sites on the three river basins namely, the Rishikulya, the Nagavali and the Sarada are used as input data to the Program and respective Base Flow Indices (BFI's) are estimated and are shown at table 1.

Table 1: Base flow indices for Subzone 4(a)

No	SITE	RIVER	BFI
1.	Purushottampur CWC site	Rishikulya	0.23
2.	Narayanapuram anicut PWD site	Nagavali	0.42
3.	Anakapalli Gudari anicut PWD site	Sarada	0.28
4.	Anakapalli CWC site	Sarada	0.33

The separated baseflow from the above procedure along with hydrograph at individual sites is presented as hydrograph plots from fig.9 to fig.16. The flow hydrograph with separated baseflow for the Rishikulya at Purushottampur is shown at fig.9 and a close-up view is presented in fig.10. The baseflow index arrived at for this site is 0.23 for the period of study. In the same way fig.11 and fig.12, fig.13 and 14 and fig. 15 and 16 present the details for the Nagavali site and the two Sarada sites at Anakapalli respectively. The BFI's at these sites are found as 0.42, 0.28 and 0.33 respectively for their corresponding period of study. From the figures it can be observed that base flow feature is striking in the streams which maintain flows throughout the year as in Nagavali and Rishikulya.

As per the procedure followed the separated baseflow is supposed to depend on the observed daily flows. To understand this relationship, scatter diagrams are plotted for the observed daily flow and separated baseflow for all 4 sites and the plots are shown at fig.17. To get an idea of the flow regimes in convenient way X and Y-axes are plotted on the same scale for all 4 sites. Linear equations are arrived at considering the baseflow as

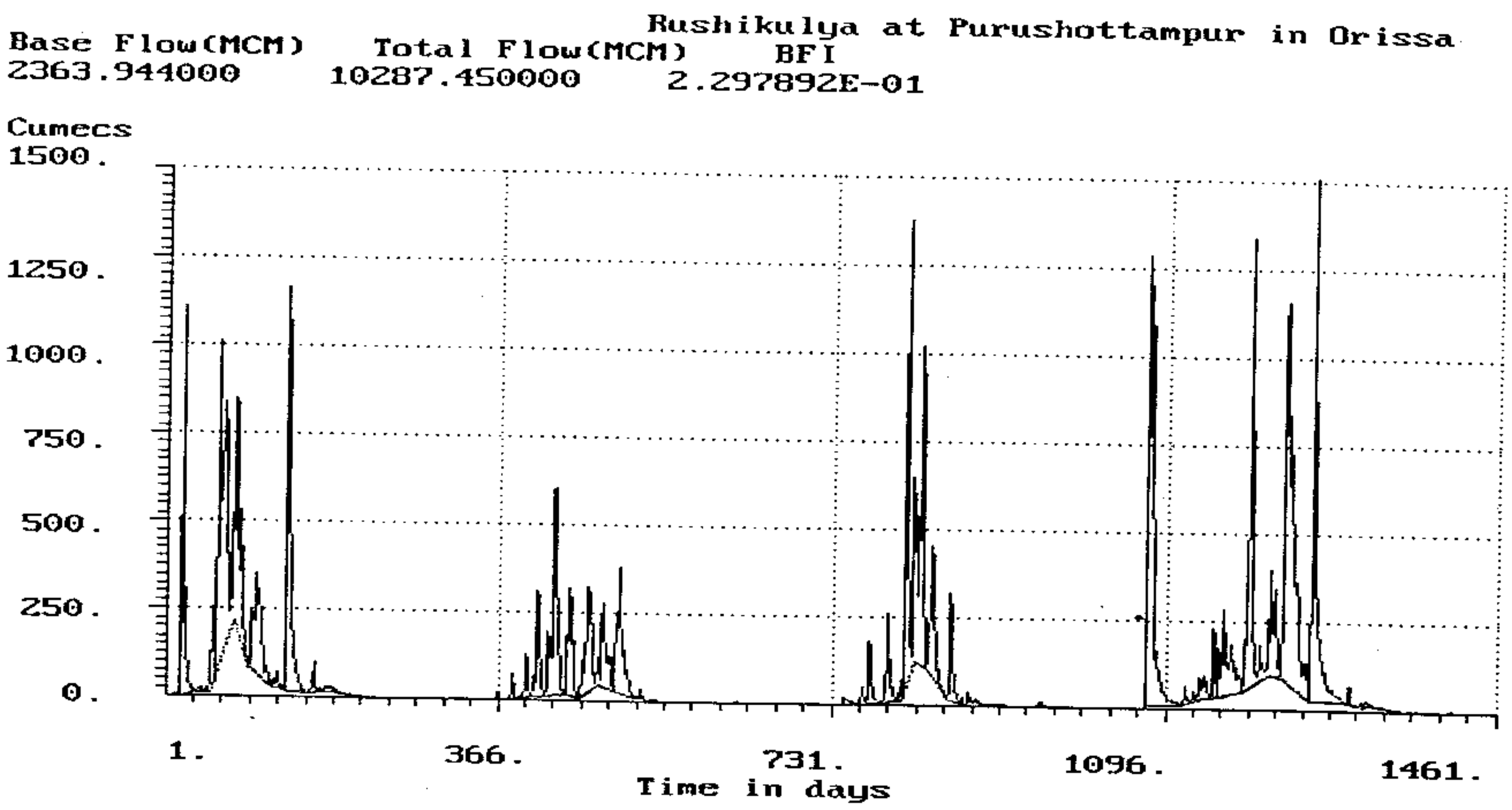


Fig.9 Hydrograph of daily flow and separated base flow for Rushikulya

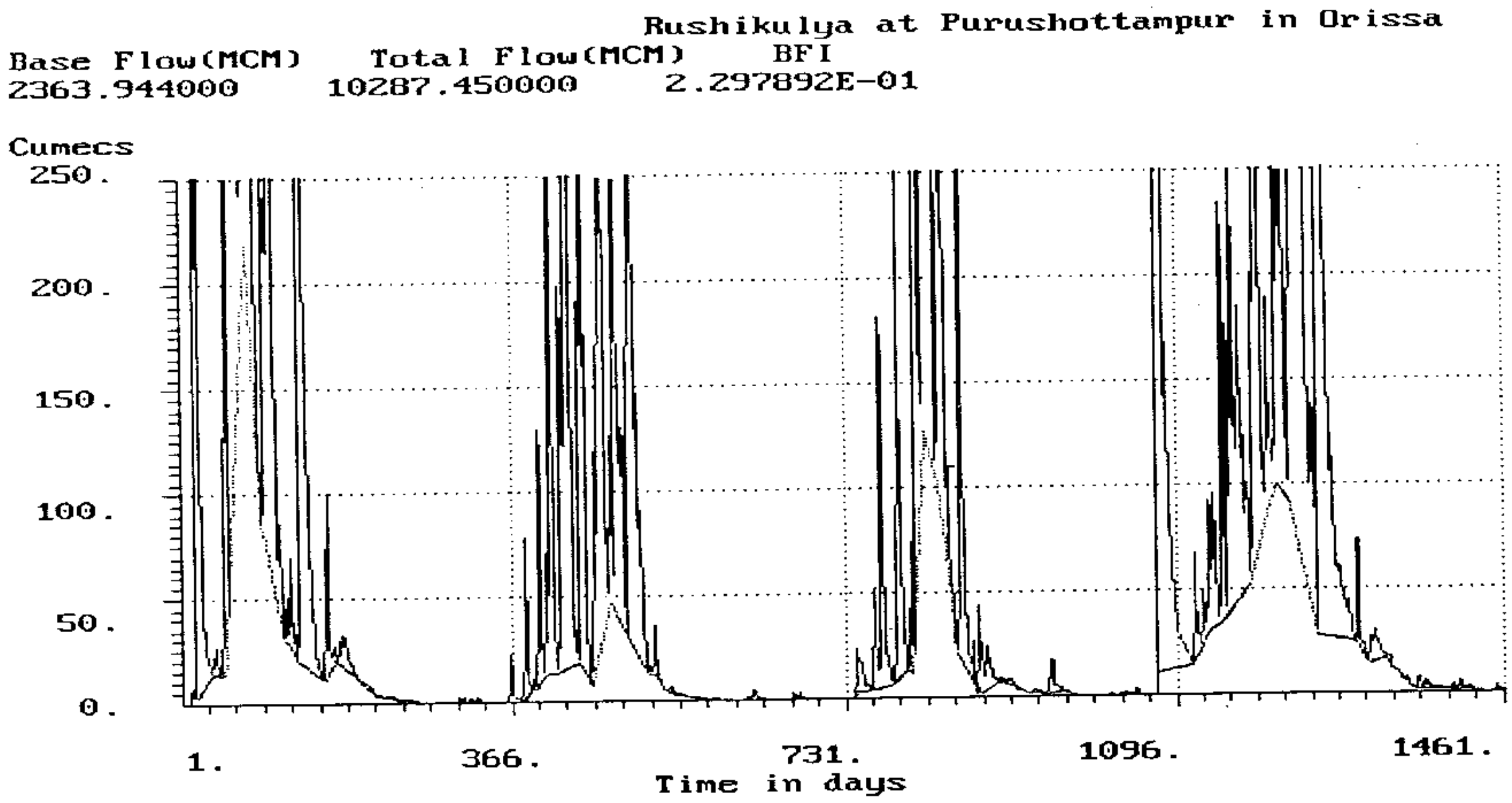


Fig.10 Hydrograph of separated base flow for Rushikulya

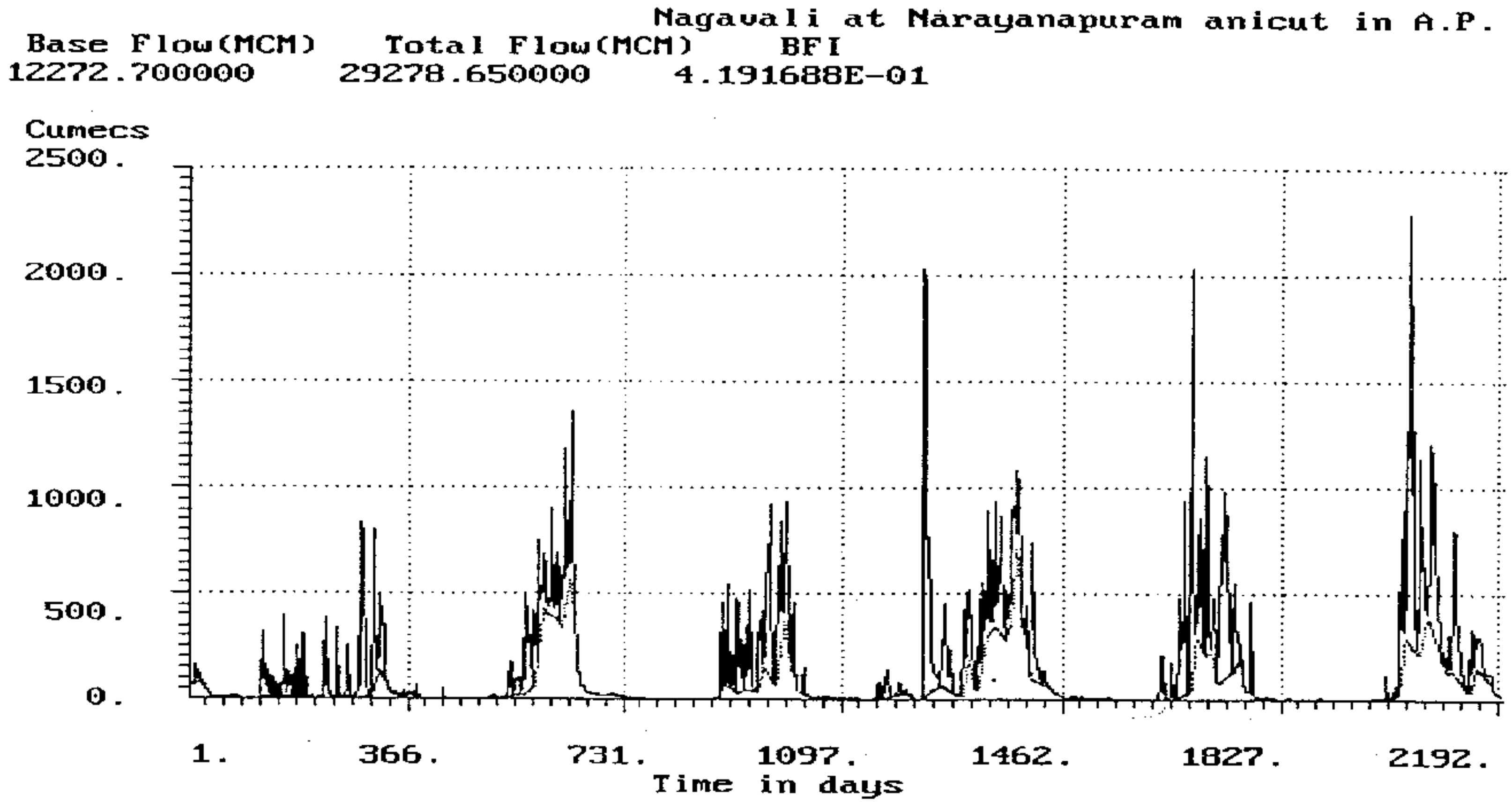


Fig.11 Hydrograph of daily flow and separated base flow for Nagavali

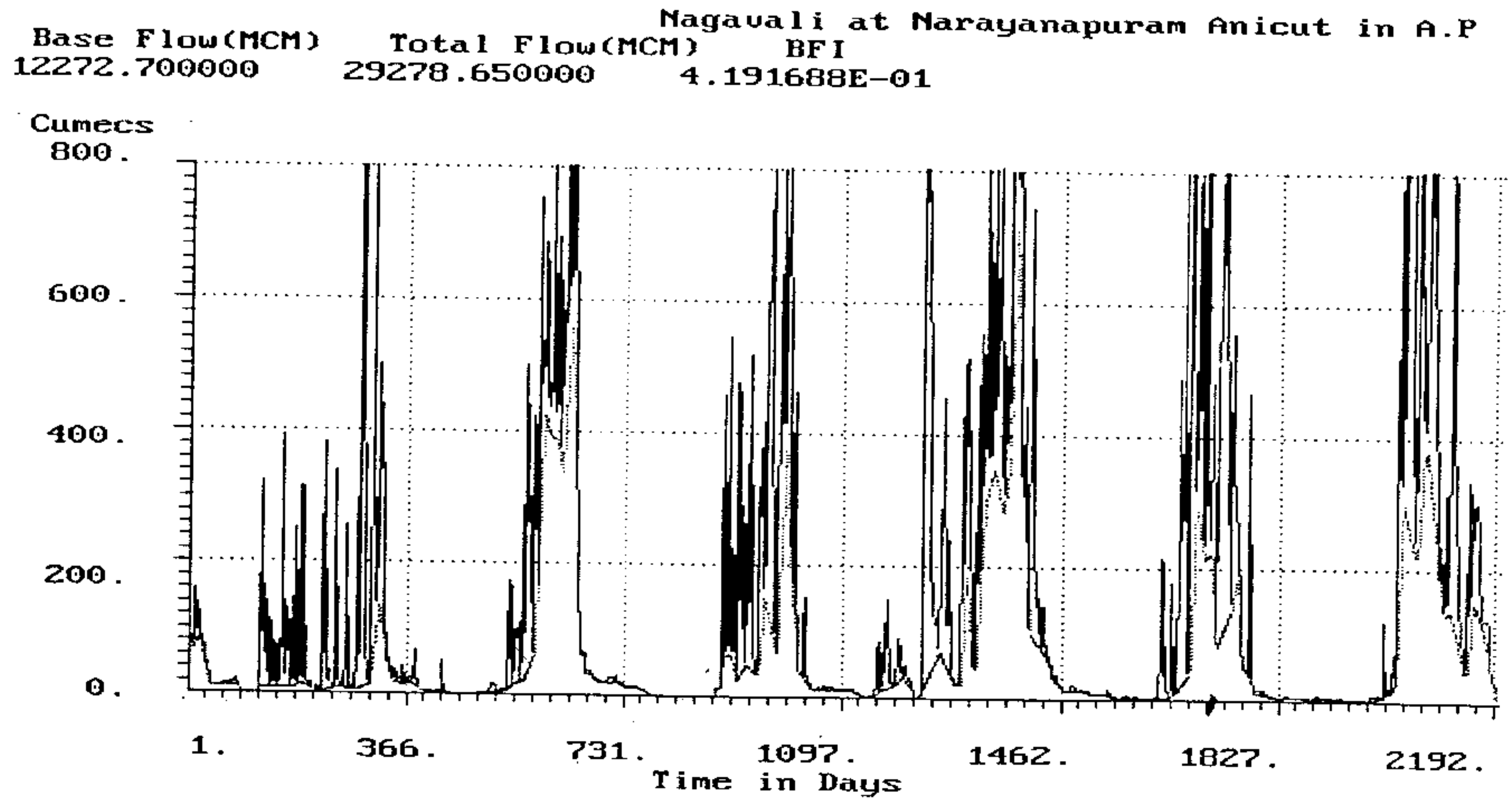


Fig.12 Hydrograph of separated base flow for Nagavali

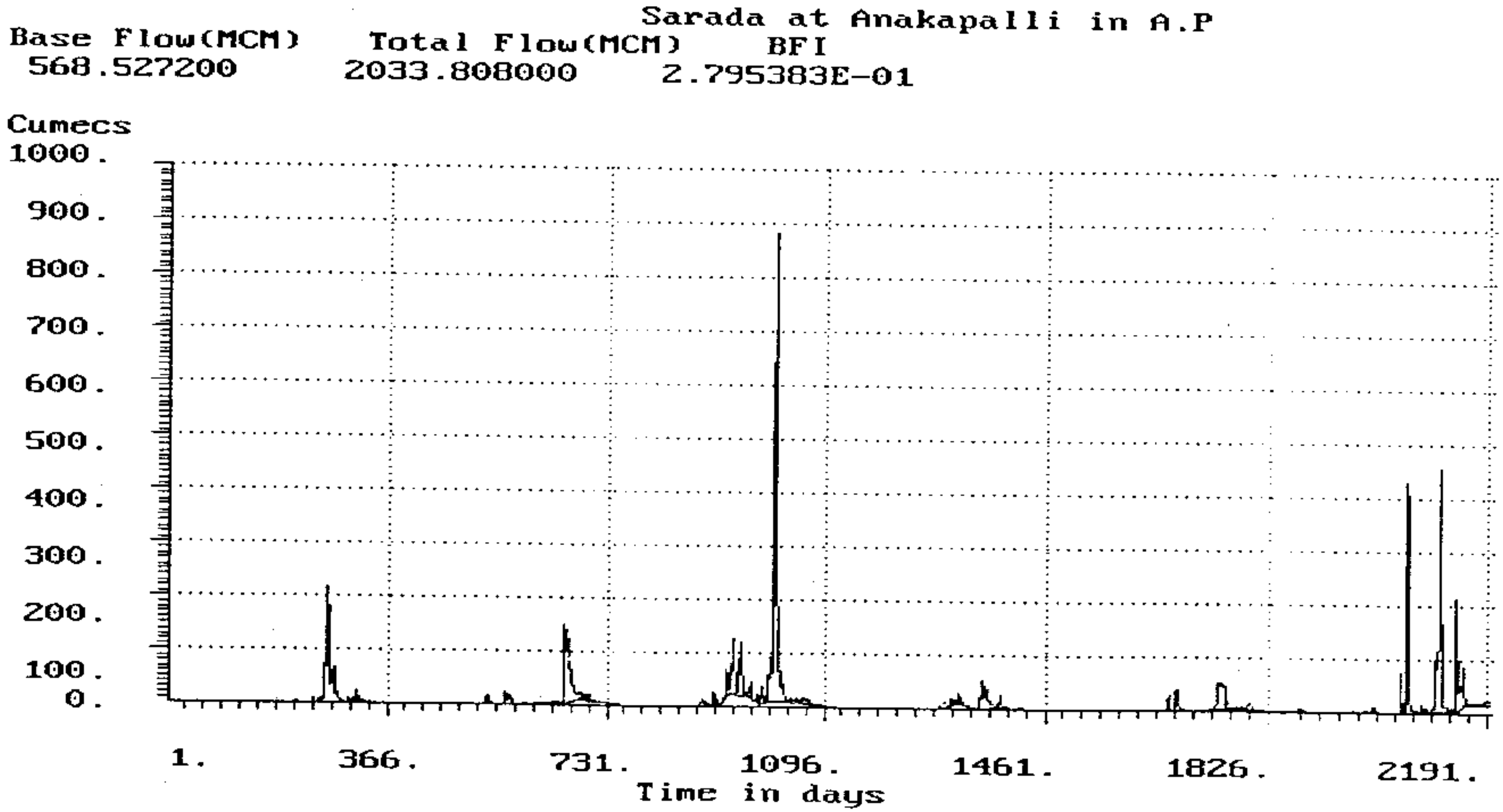


Fig.13 Hydrograph of daily flow and separated base flow for Sarada at Gudari Anicut

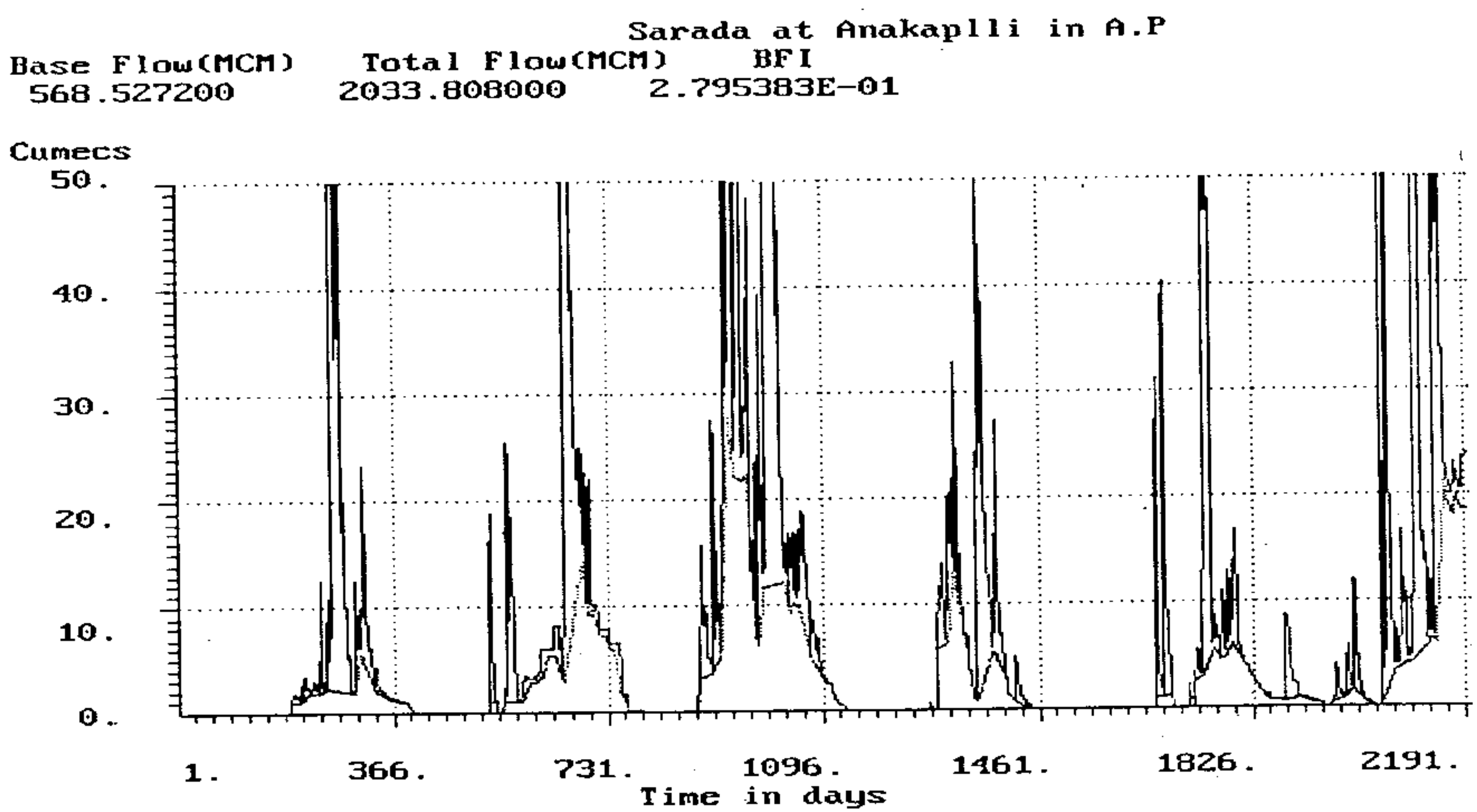


Fig.14 Hydrograph of separated base flow for Sarada at Gudari Anicut

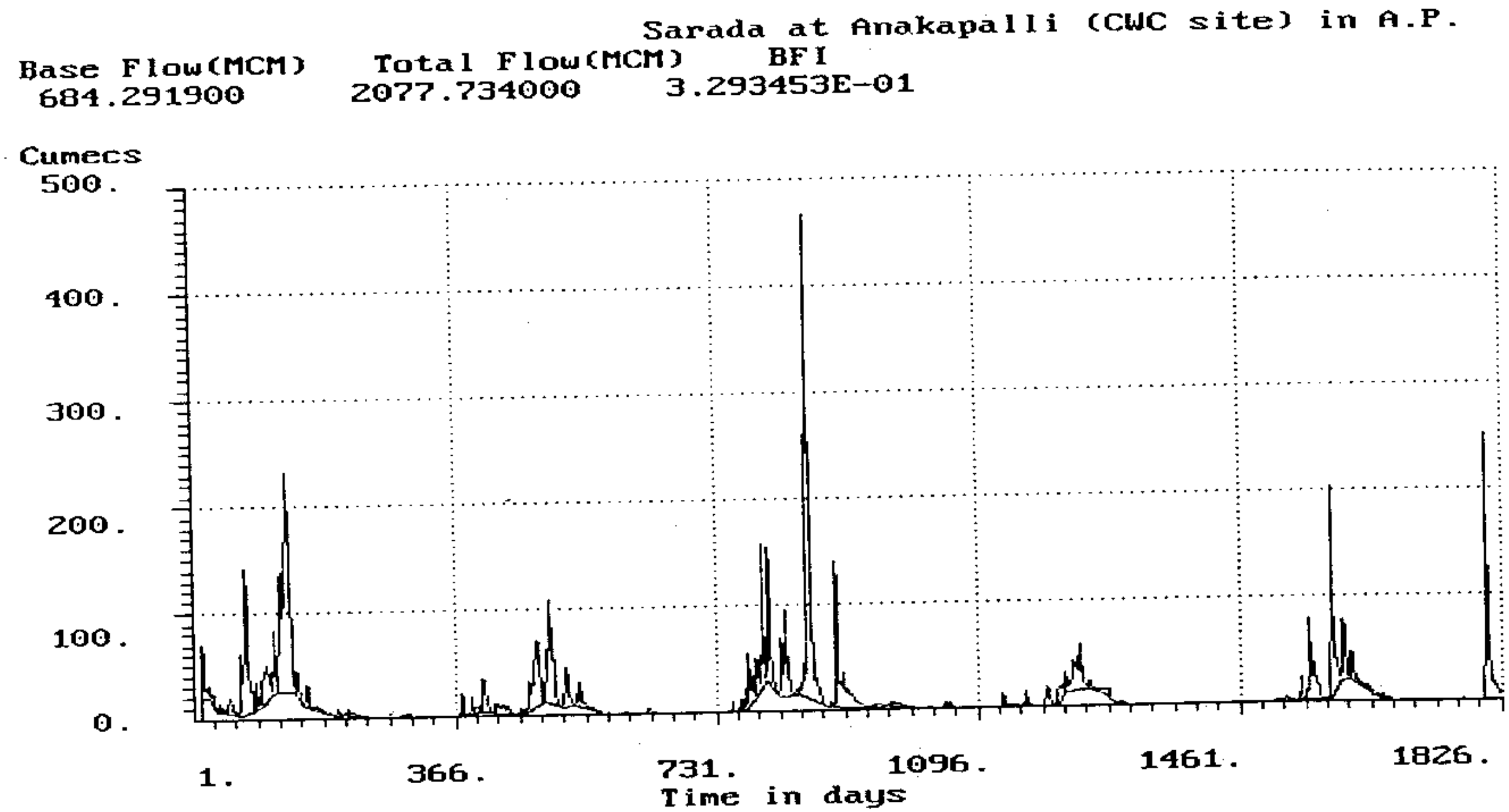


Fig.15 Hydrograph of daily flow and separated base flow for Sarada at CWC site

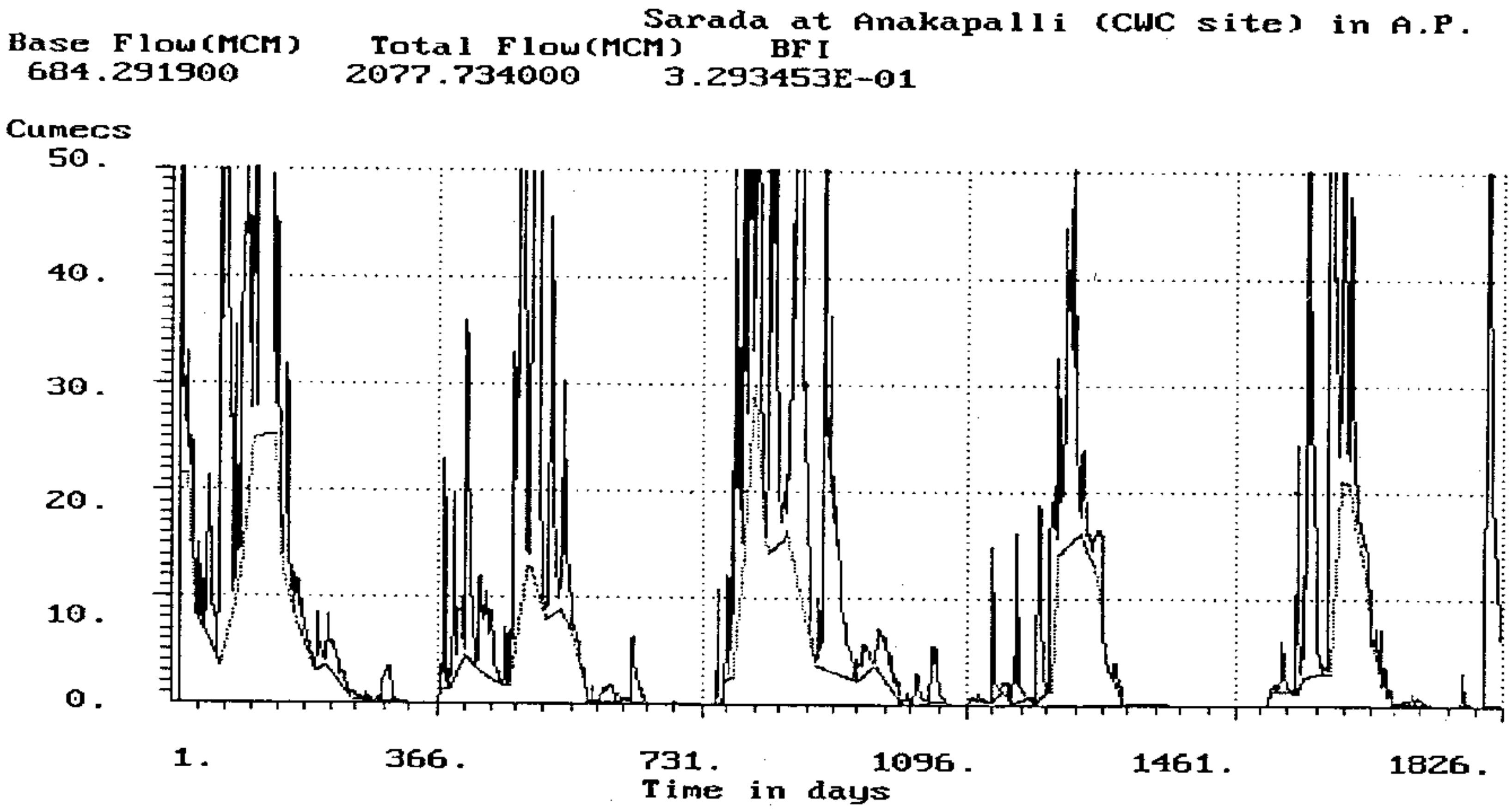


Fig.16 Hydrograph of separated base flow for Sarada at CWC site

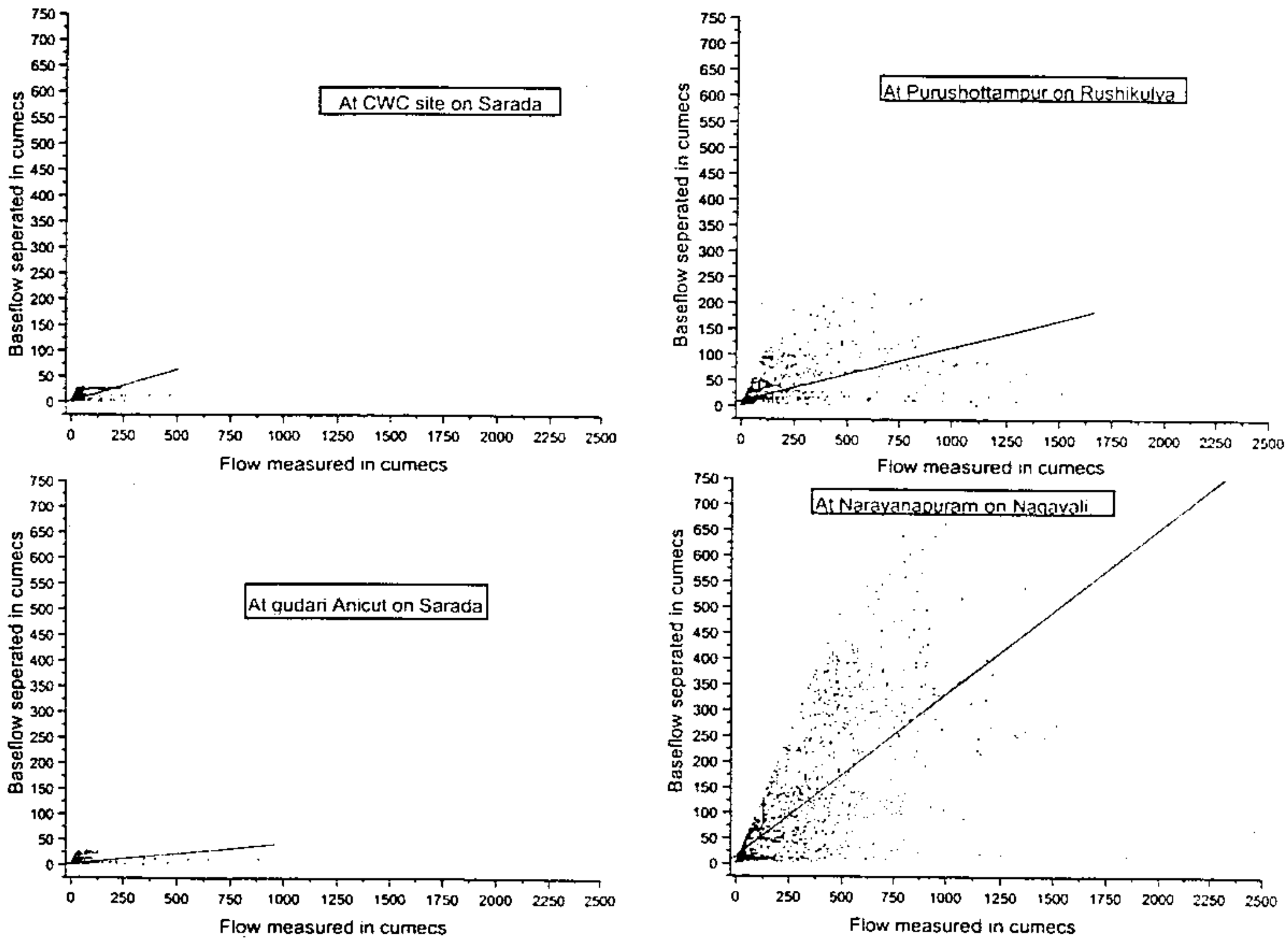
independent variable and daily discharge as dependent as variable. The developed relationships are not intended for comparison with each other. The relationships are developed with the intention of finding the baseflow directly from observed daily discharges at individual sites. The non-dimensionalised analysis is already undertaken in earlier section to compare the baseflow regimes at the four sites. The statistics of the fitted linear equations are presented in Table 2. From the plots it can be observed that among the 4 sites at the Narayanapuram anicut site on Nagavali the contribution of the base flow is predominant. Base flow is also appreciable at Anakapalli on the Sarada and at Purushottampur on the Rishikulya . The Base Flow Indices arrived from the study do also confirm this trend.

Table 2: Linear Fits (Y=A+Bx) for the Baseflow separated (Y) vs Daily stream discharge (X) & coefficient of regression (R)

S.NO.	SITE	DATA POINTS	A	B	R	|t|
1.	Purushottampur (Rishikulya)	1460	10.18245	0.10493	0.60	0.00981
2.	Narayanapuram (Nagavali)	2191	15.62727	0.31819	0.74	0.00721
3.	Anakapalli PWD (Sarada)	2190	2.55747	0.04123	0.32	4.229837
4.	Anakapalli CWC (Sarada)	1825	2.77136	0.11904	0.56	1.17474

To judge the significance of the fitted lines, both separated series and fitted series have been subjected to students t-test at each site for their means, the values of which are presented in Table-2. From the results it can be observed that the fitted line is not significant even at 50% level of significance for Rishikulya and Nagavali sites. At CWC site on Sarada river the fitted line is significant at 50% level of significance but not

Fig.17 Scattered diagrams for the observed daily flow and separated base flow for the 4 sites



significant at 90% level of significance. The fitted line for PWD site on the Sarada is not significant even at 99% level of significance and hence may not be useful.

6.0 CONCLUSIONS AND RECOMMENDATIONS

In this study the daily discharge data of 4 sites on three east flowing rivers of Zone 4(a), namely the Rishikulya at Purushottampur, the Nagavali at Narayanapuram and the Sarada near Anakapalli at Gudari (PWD) site and at CWC site for 4 to 6 years are used to understand the baseflow regime by estimating the Base Flow Indices (BFI's) at these sites. BFI gives an indication of the geotechnical properties of the formations drained by the streams. BFI may be used to estimate other low flow characteristics like flow duration and flow frequency of the basin namely Q95 (1) i.e., 95 percentile 1 day low flow discharge and MAM (7) i.e., 7 day minimum low flow. BFI can also be used to classify hydrology of soil types.

A computer program in FORTRAN 77 is written for the procedure to estimate BFI's as recommended in the Low flows studies report of Institute of Hydrology, U.K. The BFI's thus arrived at are varying from 0.23 at the Sarada (PWD site) to 0.42 for the Nagavali. Among the three streams studied it is observed that Nagavali has good baseflow contribution.

This study initiated to understand the baseflow regime of the Zone 4(a) may be extended to other zones along the east coast. It is recommended to use the whole daily discharge series in such studies to arrive at dependable baseflow indices. It is also suggested that the monitoring agencies take extra care to measure the low flows during the lean season as well. It will make estimated BFI's to be more realistic and hence the base flow characteristics more reliable.

Acknowledgments:

1. Irrigation & Command Area Development Department, Andhra Pradesh.
2. Central Water Commission, Eastern rivers circle, Bhubaneswar, Orissa.

References

Balek, J., 1989: 'Groundwater resources assessment', Developments in Water Sciences, No.38; Elsevier, Amsterdam.

Boorman, D.B. and Hollis, 1990: ' Hydrology of soil types (HOST): a hydrologically based classification of the soils of England and Wales', MAFF conf. on river and coastal engrs., Loughborough University, U.K.

Boorman, D.B., J.M.Hollis and A.Lilly, 1991 : 'The production of the hydrology of soil types (HOST) dataset, BHS 3rd national symp., Southampton, U.K.

Green, C.S., 1986 : 'Preliminary notes on the processing and analysis of hydrological data for groundwater assessment', Dept., of mineral res. Internal document, Govt. of Fiji.

Gustard, A., A. Bullock and J.M. Dixon 1992: ' Low flow estimation in the United Kingdom; Rep. No.108, Institute of Hydrology, Wallingford, U.K.

IH; 1980 : ' Low flow studies report', Institute of Hydrology, Wallingford, U.K.

Klaassen, B.E. and D.H. Pilgrim, 1975: ' Hydrograph recession constants for New South Wales streams, Civil Engineering Trans., Institute of Engineers, Australia, 43-39.

Meigh, J.R., 1987: ' Low flow analysis of selected catchments in Malawi and Zimbabwe', Preliminary rep. On the basement aquifer project, Institute of Hydrology, Wallingford, U.K.

Nathan, R.J. and T.A. Mc Mahon, 1990 : 'Evaluation of automated techniques for baseflow and regression analyses', Wat. Res. Res. Vol.: 26, no.: 7, 1465-1473.

NWSCA, 1984: 'An index for baseflow' National Water and Soil Conservation Authority, Streamland, 24 Water and soil directorate, Ministry of works and dvpt., Wellington, Newzealand.

Pilon, P.J., and R.Condie, 1986: 'Median drought flows at ungauged sites in southern Ontario', Canadian Hydrology Symp. (CHS 86), National Res. Cou. Of Canada, Regina, Canada.

Pirt, J and R. Douglas, 1982: 'A study of low flows using data from the Severn and Trent catchments', Instn. Water Engrs. Scient., vol. 36, No.4 299-309.

Raju, T.S., G.C.Misra, A.G.Chachadi, 1995 : 'Long term baseflow studies', No.INCOH/SAR-1/95 ; Indian National Committee on Hydrology, Roorkee.

Tallaksen, L., 1986 : 'An evaluation of baseflow index (BFI)', Dept., of Geography, University of Oslo, Norway.

Wright, C.E., 1974 : 'The influence of catchment characteristics upon low flows in South East England', Water Services, July 1974, 227-230.

Director	:	**S.M.Seth**
Co-ordinator	:	**K.S.Ramasastri**
Head	:	**S.V.N.Rao**

STUDY GROUP

S.V.Vijayakumar, Scientist 'C'

Y.R.Satyaji Rao, Scientist 'C'

U.V.N.Rao, Senior Research Assistant