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AN ALTERNATIVE STATISTICAL REGIONAL APPROACH FOR ESTIMATING DESIGN FLOOD PEAK

S Thirumalai* and P B Sinha**

ABSTRACT

Regional flood frequency studies are often made following traditional approach viz, a formula for mean annual flood and growth factors for higher return periods based on individual station values. This approach necessitates data generation and individual station studies introduce jerks in growth factor values. The pooled regional growth curve approach provides better prediction values and permits utilisation of all available data from different stations. The values of $Q/\bar{Q}$ and Y of all samples computed, grouped, averaged and then a combined growth curve for the region is obtained. This method is illustrated with details of studies and results for Mahanadi river basin (Subzone 3 'd').

Annual peak flood data of 16 sites (16 to 28 years) are considered and the efficacy of the pooled curve is tested.

1.0 INTRODUCTION

Design flood peaks were estimated even in the recent past using empirical formulae such as Dickens, Ryve's, Inglis etc. Since these formulae included a term of a constant or coefficient, the magnitude of this term was quite often fixed arbitrarily based on subjective considerations. Further the results obtained by these formulae were magnitudes with no indication about their frequency or chances or occurance.

The Khosla Committee of Engineers appointed by Government of India in 1957 recommended that the design flood peak for the waterway of bridges should be maximum value on record if data availability extends over a period of 50 years or the 50 year flood computed by statistical method or unit hydrograph method if the data availability is less or very much less than 50 years. The implementation agency of the Khosla Committee recommendations known as ''Planning and Coordination Committee" (PCC) represented by four Central Ministries viz. Railways(RDSO), Irrigation (CWC), Science and Technology (IMD) and Transport (Roads Wing) decided to develop Flood Estimation method based on regional/ subzonals synthetic unit hydrograph approach at the first instance since adequate data was not available to develop statistical methods. For the purpose of subzonal synthetic unit

*Deputy Director, Standards, Bridges and Floods, R.D.S.O., Lucknow-226011

**Chief Research Assistant, Bridges and Floods, R.D.S.O., Lucknow-226011.

hydrograph studies, the country was divided into 7 zones and 26 subzones by the P.C.C. on meteorological and hydrological homogenity considerations. Flood Estimation reports covering the subzonal synthetic unit hydrograph equations, design loss rate, design storm duration, storm values of specified return periods, point to areal relationship, time distribution of storms, base flow etc. have so far been prepared for 16 subzones covering almost 80% of our country's total area. Reports for six other subzones are expected to be ready in the next 3 years or so. The data collected at 13 to 20 railway and 2 to 3 Road bridge sites and catchments in each subzone over a period of about 5 years formed the basis for preparation of subzonal flood estimation reports. After collecting required volume of data for the above purpose, the P.C.C. felt the need to continue collection of flood peaks data at all the representative sties with the help of crest gauges to facilitate studies based on statistical approaches and thus considerable data has now become available for flood frequency studies. Keeping the preference indicated by Khosla Committee of Engineers for statistical approaches and the claim of the Institution of Engineers Australia that statistical methods are superior to single storm methods in view, flood frequency studies are now being made by Railways for different subzones despite the fact flood estimation reports based on S.U.H. approach are already available. The data collected at various sites in Mahanadi River basin, which as a whole is labelled as one subzone No.3D - by P.C.C. forms the basis for preparation of this paper. The same data have already been used for preparation of Synthetic Unit Hydrograph equations by the P.C.C. (Report No.M/5/1981) published by HSC Directorate of C.W.C., Sewa Bhawan, R.K.Puram, New Delhi) and regional flood frequency studies based on (i) Tate Dlrymple approach by Gupta and (ii) by Wakeby five parameter distribution by Singh and Seth of NIH. The studies and conclusions reported in this paper are confined to an alternative statistical approach with the concept of regional pooled curve as mentioned in the U.K. Flood studies report. This approach aims at providing a regional growth curve which will reflect the mean distribution of all recorded floods scaled by a single parameter viz. $Q/\bar{Q}$ values. This curve together with an equation provided to estimate mean annual flood can be used to estimate flood of 50 year return period from any other ungauged catchment in the subzone.

2.0 POOLED REGIONAL CURVE

A pooled regional curve, which provides the growth factor values to compute flood of higher return periods from base flood, essentially follows the concept of analysis of station year records. The curve represents the mean distribution of all recorded floods through the parameter $Q/\bar{Q}$ from a homogeneous region. The mean values of the relationship between 'T' or 'Y' and $Q/\bar{Q}$ are depicted by this curve. The curve is obtained following the steps given below:

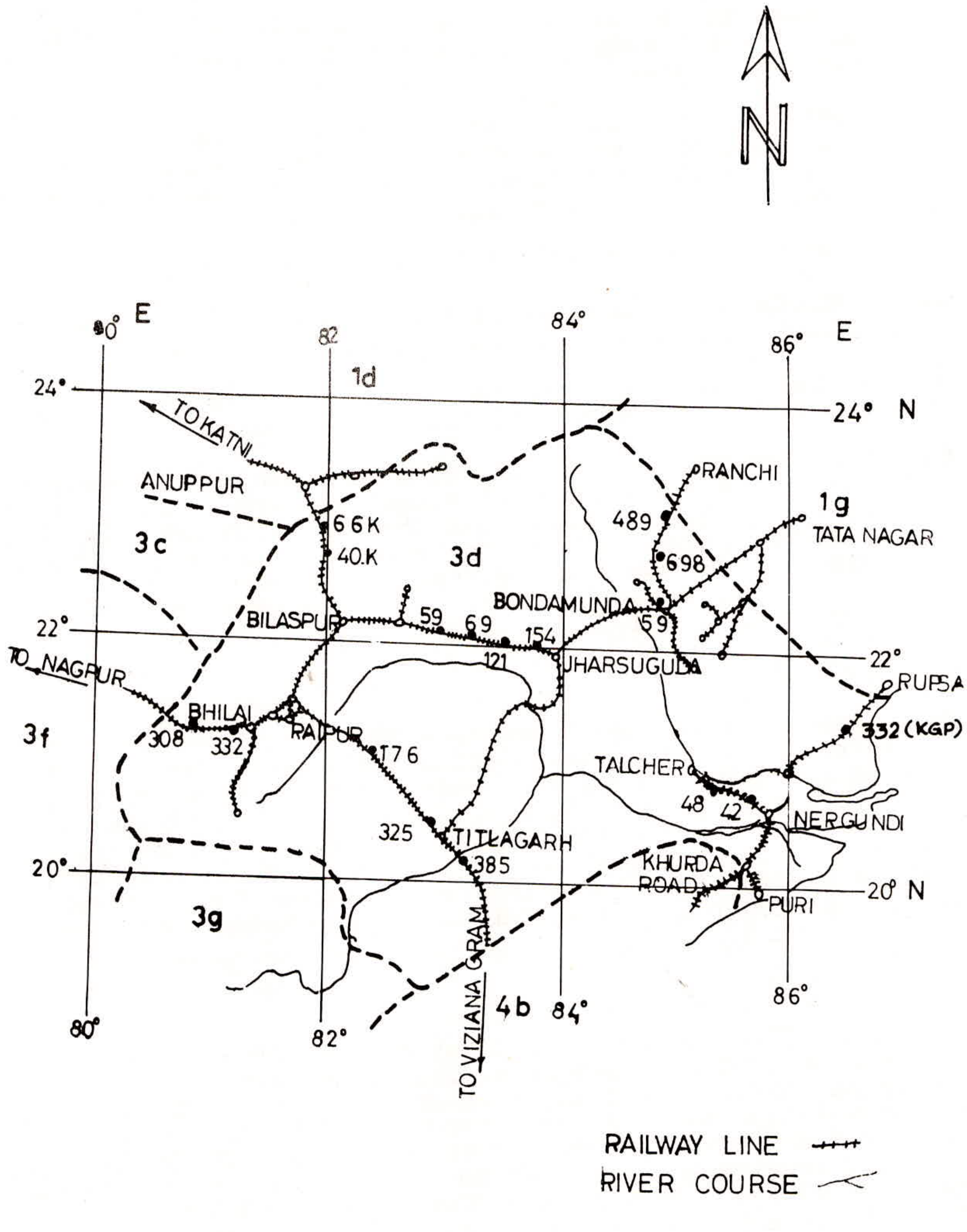

FIGURE-1 : MAHANADI BASIN SHOWING LOCATION OF REPRESENTATIVE BRIDGE SITES

1. Compute the values of Gumbel's reduced variate 'Y' for each one of samples viz. annual flood peaks taking one site at a time.

2. Pool the 'Y' values of all sites considered for the study and group them in specified class intervals, say- 1.5 to -1.0, -1.0 to -0.5, -0.5 to 0, 0 to +0.5 etc. The total no. of intervals may be 10 to 12.

3. Obtain the mean value of Y for each class interval.

4. Compute the $Q/\bar{Q}$ ratios for each one of the samples viz. annual flood peaks, taking one site at a time.

5. Compute the 'mean' and 'standard deviation' values of $Q/\bar{Q}$ ratios for corresponding class intervals.

6. Plot the class interval average, values of $Q/\bar{Q}$ against corresponding average 'Y' values and draw a best fit line by eye judgement. Also mark the standard deviation limits (67% confidence limit) for each class interval. The best fit line becomes the regional pooled curve.

3.0 DATA USED FOR ANALYSIS

3.1 Study Region

Mahanadi River Basin -subzone 3(d) - treated as a homogeneous region by the Planning and Coordination Committee is considered for this study. The basin covers an area of 1,95,000 sq.kms. and is located between longitudes 80°25'E and 87°0'E and latitudes 19°15'N and 23°35'N. It comprises parts of M.P., Orissa and Bihar States and is traversed by South Eastern Railway System Fig.1 shows the region under study alongwith railway lines and location of railway bridge catchments considered for this study.

3.2 Data Availability

Data collected from 17 railway bridge sites during the period 1958 to 1985 has been used. The actual length of data for different sites vary from 16 years to 28 years. These include the annual peak flood values extracted from regular gauging data over a period of about five years and crest gauging data for the remaining years. For the sake of uniformity and consistancy, a combined mean stage curve prepared on the basis of regular gauging data (i.e. 5 years) for each site has been used for converting the annual flood peak stage values into discharge values. The particulars of annual peaks data are given in Table I alongwith C.A. and mean values of samples. Though, the length and period of collection of data had differed, the samples were available without any break.

4. TEST FOR HOMOGENITY

As mentioned earlier, the region under study has already been treated as hydrometeorologically homogeneous by P.C.C.

Table I - Annual Peaks, Mean and Catchment Area of Mahanadi Basin Sub Zone 3(d)

Sr. No.	Br.No.	YEARS 1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
1	12											150	220	380	375	410
2	48											13	300	143	130	310
3	59(KGF)											-	24	50	37	33
4	66 K											320	128	90	770	640
5	176	47	34	55	58	20	28	100	4	16	140	30	29	55	29.75	63
6	308	-	-	-	-	-	75	65	32	28	24	17	30	12	22	93
7	325	-	-	-	-	-	-	-	-	-	-	-	-	78	36	51
8	332(NGF)	-	-	-	-	-	-	-	75	342	260	170	171	180	380	70
9	698	-	-	-	-	-	-	-	100	225	425	185	76	85	220	18
10	40 K	-	-	-	-	-	-	-	-	145	132	104	162	135	475	108
11	121									540	1600	94	1490	940	920	470
12	385									85	157	48	9	85	68	98
13	332(KGP)									46	53	47	52	23	127	14
14	59(BSP)										330	6	80	650	270	139
15	489										700	370	400	290	780	520
16	154											45	50	40	53	82
17	69													235	240	75

Contd....

Table I - Annual Peaks, Mean and Catchment Area of Mahanadi Basin Sub Zone 3(d)

Sr. No.	Br.No.	YEARS 1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	m^3/s	A (Km^2)
1	12	780	500	310	308	408	320	320	710	885	200	375	440	350	413.89	665.37
2	48	90	150	100	160	93	650	100	360	85	95	120	298	12	183.68	108.52
3	59(KGP)	54	73	66	64	62	170	38	100	69	120	80	60	150	64.00	49.08
4	66 K	325	530	148	130	638	170	305	800	152	160	176	300	290	387.33	154.10
5	176	240	14	11	90	60	44	101	96	25	93	15	50	52	57.35	65.78
6	308	44	33	56	9	15	23	45	68	50	38	62	66	92	45.48	17.48
7	325	31	2	24	28	88	50	110	17	30	40	15	6	120	45.38	26.77
8	332(NGP)	780	40	160	110	500	340	196	220	178	265	210	310	105	241.05	234.39
9	698	375	202	95	530	77	180	50	115	80	63	390	242	378	216.76	112.66
10	40 K	925	34	380	150	450	340	54	650	175	280	270	381	500	292.45	115.41
11	121	1860	1500	1700	460	1480	400	385	54	880	560	440	910	565	952.00	1149.95
12	385	62	17	44	230	160	120	165	152	99	110	64	195	115	102.75	194.25
13	332(KGP)	151	30	75	42	32	67	65	54	55	31	29	63	56	60.45	175.16
14	59(BSP)	500	220	460	130	200	28	390	100	120	140	141	155	165	222.37	135.69
15	489	1000	616	820	3000	805	1200	415	821	385	230	260	18.50	300	776.89	828.5
16	154	170	90	91	75	105	48	32	52	28	88	240	80	94	81.22	58.09
17	69	450	160	135	189	400	95	230	108	112	500	245	155	260	223.75	172.72

However, as per the standard practice, homogenity test is carried out adopting following steps:

1. Consider the annual peak flood data of any one site at a time. Compute the return period value (T) for each of the annual peaks using Gringorten plotting position formula.

   $Fi = (i - 0.44)/(N+0.12)$

   where, $Yi = -\ln - \ln Fi$

   $= -\ln - \ln \frac{T-1}{T}$

2. Plot the annual peak values against corresponding Y values separately for each site.

3. Read Q_{10} and $Q_{2.33}$ values from each graph and compute the ratio $\frac{Q_{10}}{Q_{2.33}}$

4. Compute the average of above ratios for all sites.

5. Compute adjusted Q values as a product of $Q_{2.33}$ (for the particular site) and average ratio and read T values for each value of adjusted Q from corresponding graphs.

6. Plot the T values thus obtained against actual length of record for each site, on the standard test curve.

7. All points if plotted within the curve proves the homogenity.

5.0 PROCEDURE ADOPTED FOR ANALYSIS

The steps followed are as under :

5.1 The mean of the annual maximum peaks were obtained using the equation

$$\bar{Q} = \sum_{i=1}^{N} Q_i/N$$

5.2 Values of $\bar{Q}$ were plotted against catchment area A as shown in Fig.2.

5.3 Values of $\bar{Q}$ and CAs were transformed into log form and then regressed to obtain a linear correlation. The equation obtained is

$$\bar{Q} = 4.444\ A^{0.734}$$

(Coefficient of correlation is 0.865)

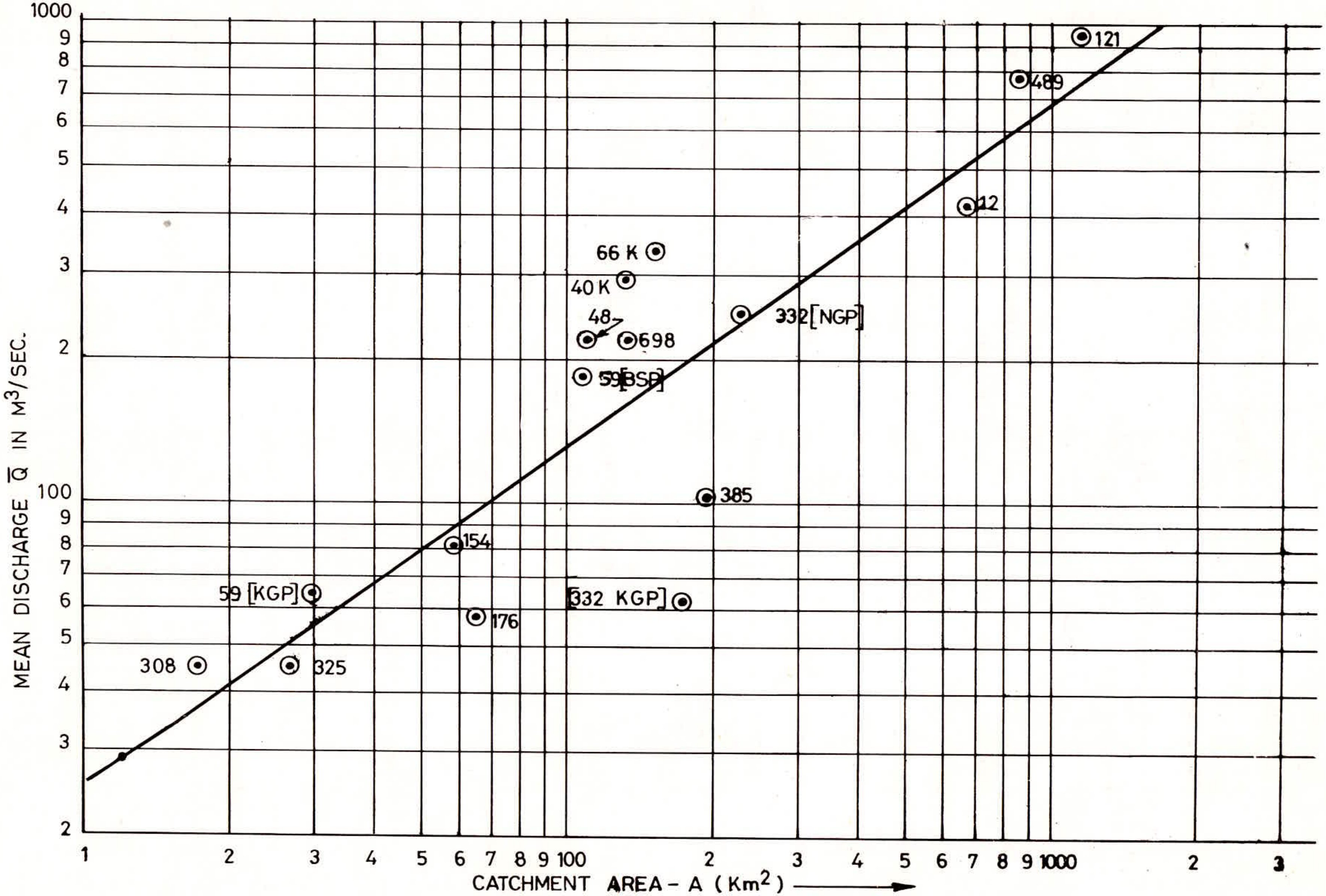

Fig. 2 MEAN DISCHARGE $\overline{Q}$ VS CATCHMENT AREA

5.4 The $Q/\bar{Q}$ values and corresponding reduced variate (Y) values were obtained and tabulated in descending order.

5.5 Values obtained in the preceding step have been plotted on a linear graph for all the 16 sites. In addition to 'Y' values on obscissa side, the return period 'T' values have also been indicated. After plotting, it was seen that for eleven out of sixteen sites the fit was very close to EVI distribution, though in the remaining five cases, the fit was tending towards EV II. A close study for the variation revealed that type of soil may be the prime cause as it was seen that for the eleven catchments the soil was of moorum type while for the other five catchments, it was of sandy type.

5.6 The ratio of $Q/\bar{Q}$ values were posted against chosen class intervals of -- 'Y'. The mean values of range of 'Y' and range of $Q/\bar{Q}$ were then obtained for each class interval.

5.7 The mean values of Y and $Q/\bar{Q}$ obtained as above were then plotted on a graph and a mean line has been drawn (Fig.3) The standard $\bar{Q}$ deviations of $Q/\bar{Q}$ for each class interval have also been marked on the same graph. It is seen from this graph that the standard deviation of $Q/\bar{Q}$ is about 10% for return periods upto 15 years and about 25% for return periods upto 50 years. This goes to prove that even with limitations in data availability, 50 year flood can be estimated with fair reliability using this pooled growth curve alongwith the equation for mean annual flood. Based on soil considerations as mentioned earlier, the estimated values can further be modified if required considering the standard deviation. The growth factor values obtained from the pooled curve alongwith standard deviations for the mean values are given below :

$$\frac{Q_{50}}{\bar{Q}} = 2.95 \pm 0.76$$

$$\frac{Q_{25}}{\bar{Q}} = 2.50 \pm 0.52$$

$$\frac{Q_{10}}{\bar{Q}} = 1.93 \pm 0.26$$

$$\frac{Q_{5}}{\bar{Q}} = 1.45 \pm 0.25$$

6.0 VALIDATION OF RESULTS

The annual flood peak data appearing against S.No.17 of Table No.1 pertaining to Bridge No.69 is used for testing the results. This data has been treated independantly using graphical approach with Gingorten plotting position. Values of $Q/\bar{Q}$ and Y have been plotted as shown in Fig.4.

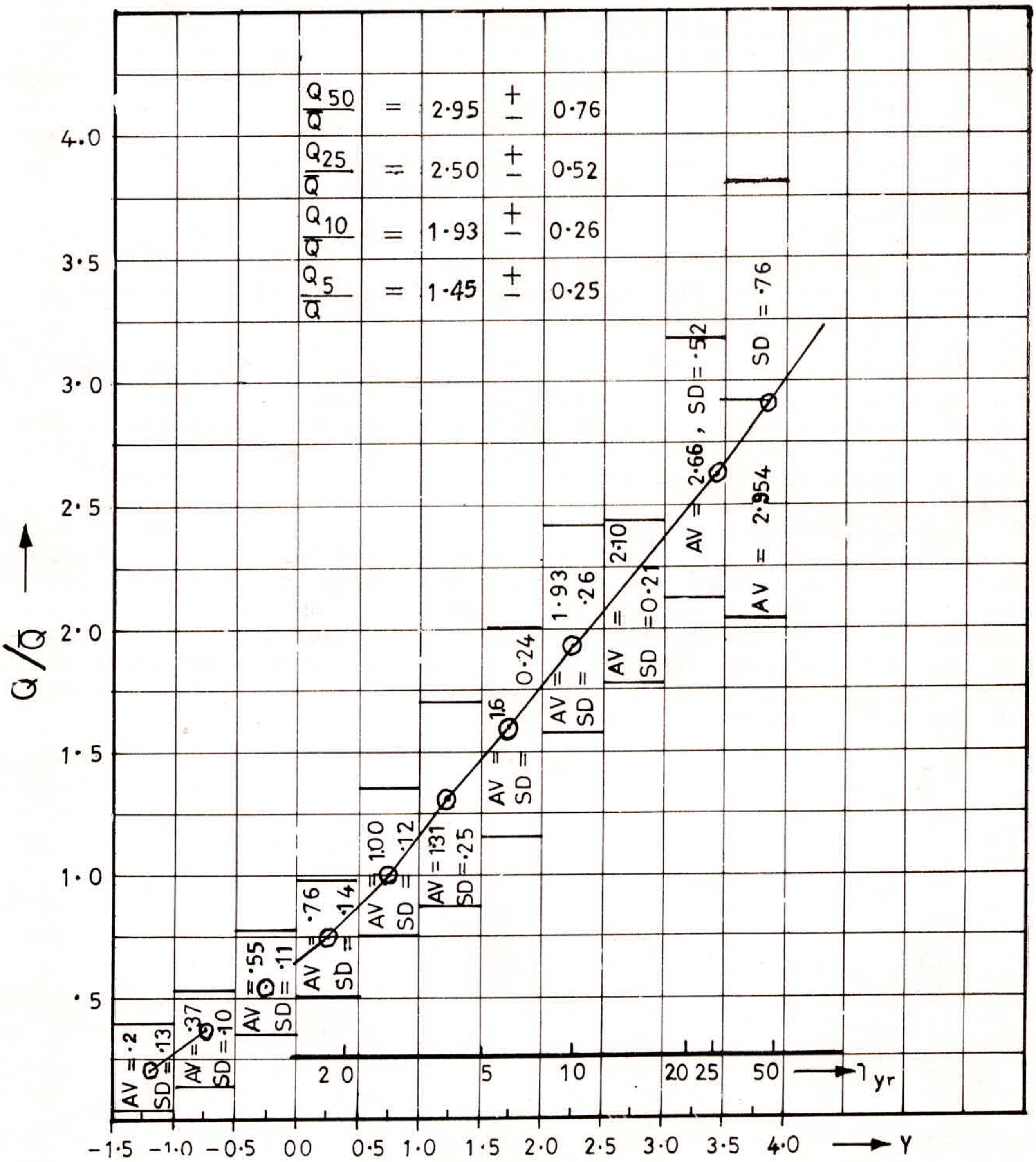

Fig. 3 GROWTH CURVE

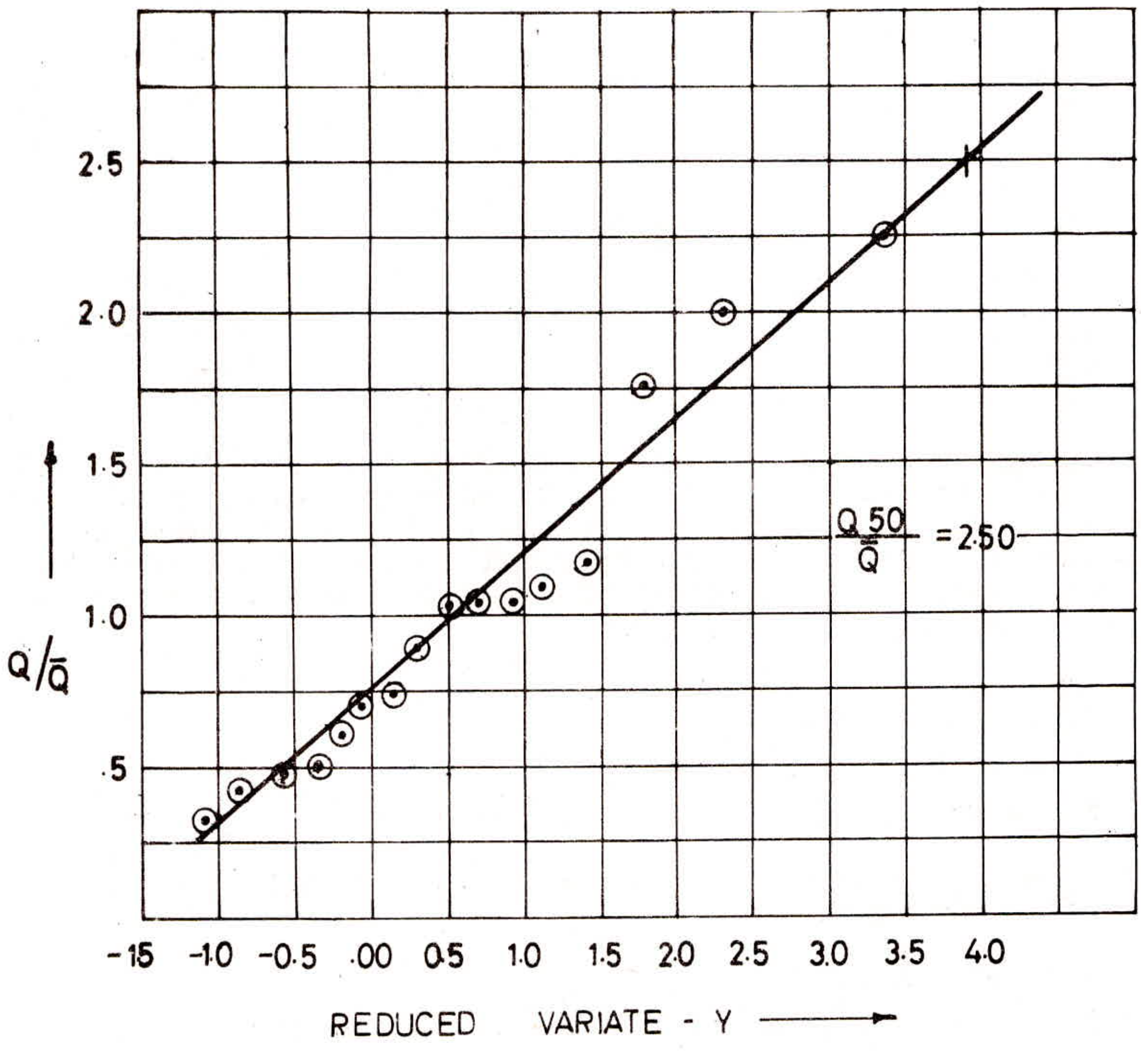

Fig - 4 : Q/$\bar{Q}$ Vs Y For Br NO. 69

The growth factor values obtained from the individual site based graph (Fig. 3) are as under :

Comparison level of return period	Ratio site based	Ratio pooled curve based
$\frac{Q_{50}}{\bar{Q}}$	2.5	2.95
$\frac{Q_{25}}{\bar{Q}}$	2.15	2.50
$\frac{Q_{10}}{\bar{Q}}$	1.75	1.93
$\frac{Q_{5}}{\bar{Q}}$	1.4	1.45

Though the above comparison of growth factors apparently indicates variation of about 18% at 50 year return period level comparison of actual 50 year return period flood peak values from the site based data and regional pooled data prove that the variation is of the order of about 3% only as per details given below :

Br. No.69
C.A. 172.77 km^2

From regional study

$\bar{Q} = 4.444\ A^{.734}$ $= 195.02\ m^3/sec$

$Q_{50} = 2.95 \times 195.02$ (pooled curve) $= 575.31\ m^3/sec$

From actual data

$\bar{Q} = 223.75\ m^3/sec$ (Table I)

$\frac{Q_{50}}{\bar{Q}} = 2.5$ (Fig.4)

$Q_{50} = 2.5 \times 223.75 = 559.37\ m^3/sec.$

$$\text{Variation} = \frac{575 - 559}{559} \times 100 = 2.85 \text{ or say } 3\%$$

7.0 COMPARISON OF RESULTS

The 50years return period peak flood values for 16 railway bridge catchments considered for this study have earlier been computed following the results of studies carried out by P.N.Gupta on the basis of the traditional method indicated by Tate Dalrymple. The values for the same site and return period have now been computed on the basis of the methodology given

Table II - Comparison of Q_{50} values by Different Approaches

Sr. No.	Br.No.	CA - (Km^2)	Computed Q_{50} values by			
			the regional Pooled Curve method	By Tate Dalrymple method	Wakeby Distributor	By SUH method
1	12	665.37	1547.83	1579	1516	2685
2	48	108.52	408.94	363	506	550
3	59(KGP)	49.18	228.75	190	224	217
4	66K	154.10	528.98	476.8	1016	-
5	176	65.78	283.19	246.7	190	-
6	308	17.48	107.05	88.45	141	-
7	325	26.77	146.42	123.00	121	-
8.	332(NGP)	234.39	719.66	639	532	658
9	698	112.66	420.33	374	713	463
10	40K	115.41	427.84	381	878	-
11.	121	1149.95	2312.78	2259	2173	3596
12	385	194.25	626.98	570	402	794
13	382(KGP)	175.16	581.13	526.5	232	-
14	59(BSP)	135.69	481.82	432	715	773
15	489	828.5	1818.12	1744	3118	2237
16	154	58.09	258.49	224	340	301
		Ungauged	Catchment			
17	69	172.77	575.31	521	566	-

in this paper. Besides the above, the Q_{50} values have also been computed for ten bridge catchments (out of the same sixteen) following the subzonal synthetic unit hydrograph based flood estimation report (No.M/5/81). Tabulation and comparison of the above values, (Table II) reveal that generally, the variation between the results obtained by SUH approach and regional flood frequency approach reduce when regional pooled growth curve is used. To facilitate an appreciation regarding the results obtained by Wakeby distribution, the values are given in the same table.

8.0 APPLICATION

The regression equation for $\bar{Q}$ and the growth factor (pooled) curve given in this report can be combinedly used for estimating flood of any return period upto 50 years, for any ungauged catchments ranging in size from 15 to 1200 km^2 if the catchments lie in Mahanadi river basin. The input data required is only the catchment area. With this known value of C.A., the mean annual flood can first be computed using the equation $\bar{Q}=4.444\ A^{.734}$

and then multiply this with the growth factor depending upon the choice of return period viz. 2.95 for estimating 50 year return period.

9.0 ADVANTAGES

The approach given in this paper eliminates the need for any data generation and permits utilisation of data of varying lengths from diffrent stations. Further this approach accommodates outliers at the same time avoiding jerks in results as a result of the effect of the outliers. Further this method facilitates improved estimation of flood values on the basis of standard deviation and the causative significant parameter.

10.0 LIMITATION

Since the analysis is based on limited data, extension of the mean line of the growth curve beyond Y = 3.9 or T = 50 is not recommended. With accumulation of more data, the accuracy of the results can further be improved since sample size, especially in the range of value of Y beyond 3 will increase.

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