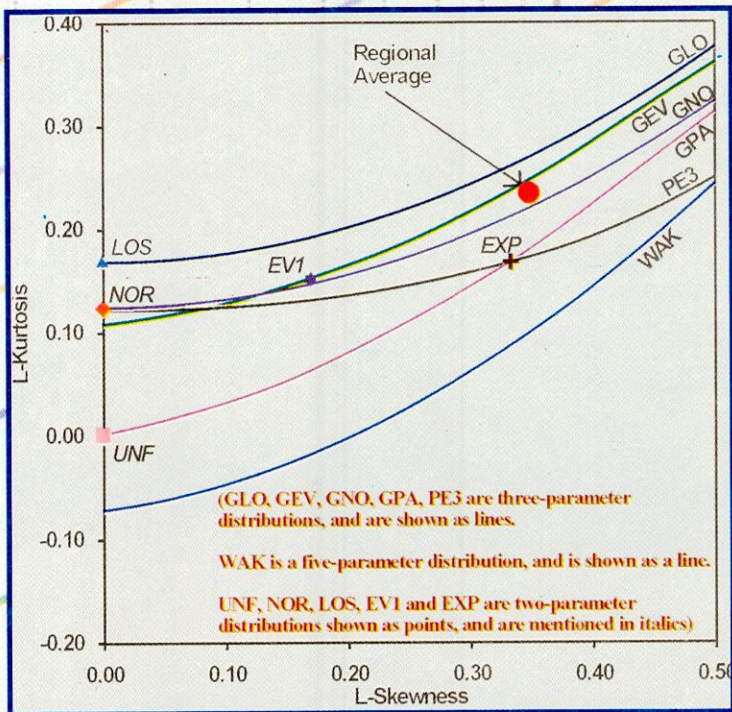


Regional Flood Formulae for Seven Subzones of Zone 3 of India

- Mahi and Sabarmati Subzone 3(a)
- Lower Narmada and Tapi Subzone 3(b)
- Upper Narmada and Tapi Subzone 3(c)
- Mahanadi Subzone 3(d)
- Upper Godavari Subzone 3(e)
- Lower Godavari Subzone 3(f)
- Krishna and Penner Subzone 3(h)



National Institute of Hydrology
Jalvigyan Bhawan
Roorkee - 247 667

A
BROCHURE ON
REGIONAL FLOOD FORMULAE
FOR SEVEN SUBZONES OF ZONE 3 OF INDIA



आपो हि स्था मयोनुव

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MARCH 2001

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PREFACE

Estimates of flood magnitudes and their frequencies are required for design of different types of hydraulic structures. At site flood frequency analysis provides such estimates for those gauging sites where adequate records are available for carrying out such analysis. However, for those sites where either limited data are available or the catchment upto the sites are ungauged, it is not possible to carry out flood frequency analysis using at site data for reliable and consistent flood frequency estimates. For such sites regional flood frequency analysis approach provides the flood frequency estimates within the desirable accuracy.

In this brochure, regional flood frequency formulae developed for seven sub-zones of zone 3 of India are presented. Step by step procedure for application of the developed regional flood formula is described for the computation of frequency floods. Some illustrative examples are included in order to demonstrate the applicability of the regional flood formula. This brochure has been prepared by Sri R D Singh, Sc. F and Sri Rakesh Kumar, Sc. E1 of National Institute of Hydrology, Roorkee. I hope that the practising field engineers will find this brochure very much useful for the computation of flood frequency estimates for the ungauged catchments or catchments having limited data located in various subzones of zone 3 of India.

1.0 INTRODUCTION

Estimation of flood magnitudes and their frequencies has been engaging attention of the engineers the world over since time immemorial, as this information is needed for design of different types of hydraulic structures. Methods of flood estimation may be broadly divided into five categories viz. (i) flood formulae and envelope curves, (ii) rational formula, (iii) flood frequency analysis, (iv) unit hydrograph techniques and (v) watershed models. The choice of method depends on the design criteria applicable to the structure and availability of data. As per Indian design criteria, frequency based floods find their applications in estimation of design floods for almost all the types of hydraulic structures viz. small size dams, barrages, weirs, road and railway bridges, cross drainage structures, flood control structures, large and intermediate size dams, etc.

Whenever, rainfall or river flow records are not available at or near the site of interest, it is difficult for hydrologists or engineers to derive reliable flood estimates directly. In such a situation, flood formulae developed for the region are one of the alternative methods for estimation of design floods, especially for small to medium size catchments. The conventional flood formulae developed for different regions of India are empirical in nature and do not provide flood estimates for desired return periods. A number of studies have been carried out for estimation of design floods for various structures by different Indian organizations. Prominent among these include the studies carried out jointly by Central Water Commission (CWC), Research Designs and Standards Organization (RDSO) and India Meteorological Department (IMD) using the methods based on synthetic unit hydrograph and design rainfall considering physiographic and meteorological characteristics for estimation of design floods (e.g. CWC, 1983), and regional flood frequency studies carried out by RDSO using the USGS

and pooled curve methods (e.g. RDSO, 1991) for various hydro-meteorological subzones of India. Besides these, regional flood frequency studies have also been carried out at some of the academic and research Institutions.

Considering the wide applicability of the frequency based flood estimation approach and need for development of regional flood formulae for estimation of floods of various return periods for the ungauged catchments, regional flood formulae have been developed using the L-moment based General Extreme Value distribution at the National Institute of Hydrology (NIH, 1997-98 and Kumar et al., 1999) for seven subzones of Zone-3 of India. These seven subzones cover an areal extent of about 10,41,661 square kilometers, which forms nearly one-third part of geographical area of the country. Following two types of approaches are presented for estimation of floods of various return periods for small to medium size gauged and ungauged catchments lying in the seven subzones of Zone-3 of India.

- (i) **Regional flood frequency relationships for estimation of floods of various return periods for gauged catchments, and**
- (ii) **Regional flood formulae for estimation of floods of various return periods for ungauged catchments.**

2.0 ABOUT SEVEN SUBZONES OF ZONE-3

India has been divided into seven major hydrometeorological zones, which are in turn sub-divided into twenty-six hydrometeorologically homogeneous subzones. A brief description of the Zone-3 and its following seven subzones is given below.

- (i) Mahi and Sabarmati subzone 3(a),
- (ii) Lower Narmada and Tapi subzone 3(b),
- (iii) Upper Narmada and Tapi subzone 3(c),
- (iv) Mahanadi subzone 3(d),
- (v) Upper Godavari subzone 3(e),
- (vi) Lower Godavari subzone 3(f), and
- (vii) Krishna and Penner subzone 3(h)

The regional flood formulae could not be developed for the Indravati subzone 3(g) and Cauveri subzone 3(i) as data for these subzones were not available.

The Zone-3 lies roughly between 13°7' to 25° north latitudes and 69° to 87° east longitudes. Location map of Zone-3 of India and its subzones are shown in Fig.1. All these seven subzones receive about 75% to 80% of their annual rainfall from south west monsoon during the period of June to October. The normal annual rainfall varies from 400 mm to 2000 mm in their different parts. A brief description of these subzones is given below.

Mahi and Sabarmati subzone 3(a) is traversed by the rivers Mahi, Sabarmati, Saraswati and a large number of coastal streams. This subzone lies in semi-arid zone. The general elevation of

this subzone varies from 0 to 600 meters above mean sea level. Lower Narmada and Tapi subzone 3(b) is covered by the lower reaches of river Narmada and Tapi and their tributaries. It is a semi-arid region with elevation varying from 300 meters to 900 meters in its various parts. Upper Narmada and Tapi subzone 3(c) comprises of upper portions of Narmada and Tapi basins. Areas varying in height from 150 meters to 900 meters lie in its various portions. Mahanadi subzone 3(d) comprises of Mahanadi, Brahmani and Baitarani basins. About 50% of the area of this subzone are hilly varying from 300 meters to 1350 meters. Rest of the area lies in the elevation range of 0 to 300 meters. The Upper Godavari subzone 3(e) is traversed by the Upper Godavari and its tributaries. The elevation range of various portions of this subzone varies from 300 meters to 1350 meters. Lower Godavari subzone 3(f) is a sub-humid region with elevation varying from 150 meters to 1350 meters in its various portions. Krishna and Penner subzone 3(h) is traversed by the Krishna and Penner rivers excluding their deltaic strip along the eastern coast. The elevation range of its various parts varies from 150 meters to 600 meters.

3.0 DATA AVAILABILITY

The annual peak flood series data varying over the period 1957 to 1989 for 115 bridge sites of the seven hydrometeorologically homogeneous subzones of the Zone-3 were available for the

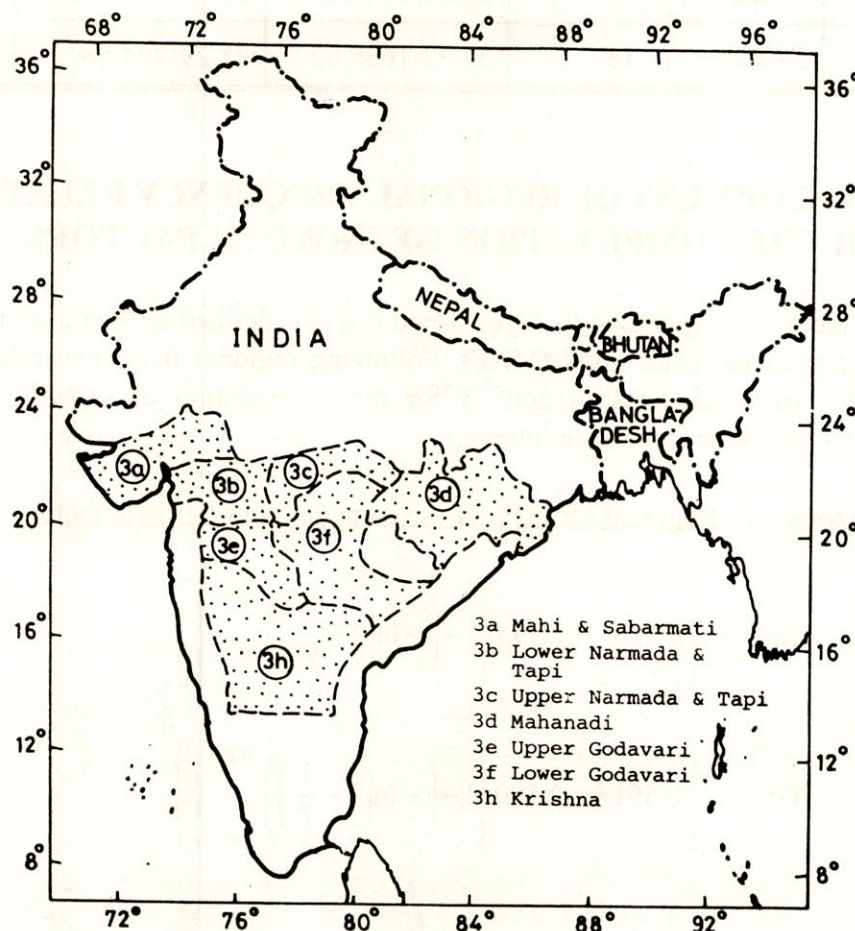


FIG.1 LOCATION MAP OF HYDROMETEOROLOGICAL ZONE 3 OF INDIA AND ITS SUBZONES

study (RDSO, 1991). The salient features of the seven subzones of Zones-3 viz. area of each subzone, number of bridge sites for which data are available, range of catchment area of the various bridge sites, range of mean annual peak flood and record length are summarised in Table 1.

Table 1. Salient Features of Various Catchments of the Seven Subzones of Zone-3

Subzone	Area of Subzone (km ²)	No. of bridge sites in a subzone	Range of catchment area of bridge sites (km ²)	Range of mean annual peak flood (m ³ /s)	Range of record length (Years)
3(a)	138400	10	18.44-1094.00	74.00-448.65	14-25
3(b)	77700	19	17.22-1017.00	34.95-558.29	12-28
3(c)	86353	15	41.80-2110.85	111.95-1730.53	14-30
3(d)	195256	22	19.00-1150.00	25.09-1071.95	11-31
3(e)	88870	12	31.31-2227.39	60.13-868.88	14-32
3(f)	174201	19	35.00-824.00	77.75-1212.83	14-29
3(h)	280881	18	31.72-1689.92	28.29-794.88	14-33

4.0 DEVELOPMENT OF REGIONAL FREQUENCY RELATIONSHIPS FOR THE COMPUTATION OF GRWOTH FACTORS

The growth factor corresponding to T-year flood (GF_T) is defined as the ratio of T-year flood (Q_T) and mean annual peak flood (MAF). Following regional frequency relationships are developed for each subzones of zone 3 for the computation of growth factors (GF_T) corresponding to T-year recurrence interval:

Sub-zone Regional formula for the computation of growth factor

$$3(a), \quad GF_T = \left[0.558 - 1.995 \left\{ 1 - \left(-\ln \left(1 - \frac{1}{T} \right) \right)^{-0.247} \right\} \right] \quad (1)$$

$$3(b), \quad GF_T = \left[0.591 - 2.500 \left\{ 1 - \left(-\ln \left(1 - \frac{1}{T} \right) \right)^{-0.200} \right\} \right] \quad (2)$$

$$3(c), \quad GF_T = \left[0.665 - 4.413 \left\{ 1 - \left(-\ln \left(1 - \frac{1}{T} \right) \right)^{-0.109} \right\} \right] \quad (3)$$

$$3(d) \quad GF_T = \left[0.649 - 2.461 \left\{ 1 - \left(-\ln \left(1 - \frac{1}{T} \right) \right)^{-0.180} \right\} \right] \quad (4)$$

$$3(e) \quad GF_T = \left[0.563 - 2.778 \left\{ 1 - \left(-\ln \left(1 - \frac{1}{T} \right) \right)^{-0.194} \right\} \right] \quad (5)$$

$$3(f) \quad GF_T = \left[0.704 - 11.357 \left\{ 1 - \left(-\ln \left(1 - \frac{1}{T} \right) \right)^{-0.042} \right\} \right] \quad (6)$$

$$3(h) \quad GF_T = \left[0.597 - 3.580 \left\{ 1 - \left(-\ln \left(1 - \frac{1}{T} \right) \right)^{-0.150} \right\} \right] \quad (7)$$

The computed values of growth factors for some of the commonly adopted return periods viz. 2, 10, 20, 50, 100 and 200 years are given in Appendix I.

5.0 DEVELOPMENT OF REGIONAL FLOOD FREQUENCY FORMULA

Following regional flood frequency formulae are developed for each sub-zone of zone 3 for the computation of floods for T-year recurrence interval for the catchments of respective subzones.

$$\text{Subzone 3(a), } Q_T = [41.7(-\ln(1 - \frac{1}{T}))^{-0.247} - 30.1] A^{0.46} \quad (8)$$

$$\text{Subzone 3(b), } Q_T = [61.3(-\ln(1 - \frac{1}{T}))^{-0.200} - 46.9] A^{0.46} \quad (9)$$

$$\text{Subzone 3(c), } Q_T = [52.2(-\ln(1 - \frac{1}{T}))^{-0.109} - 44.3] A^{0.67} \quad (10)$$

$$\text{Subzone 3(d), } Q_T = [8.1(-\ln(1 - \frac{1}{T}))^{-0.180} - 6.0] A^{0.79} \quad (11)$$

$$\text{Subzone 3(e), } Q_T = [23.1(-\ln(1 - \frac{1}{T}))^{-0.194} - 18.5] A^{0.61} \quad (12)$$

$$\text{Subzone 3(f), } Q_T = [82.3(-\ln(1 - \frac{1}{T}))^{-0.042} - 77.1] A^{0.73} \quad (13)$$

$$\text{Subzone 3(h), } Q_T = [12.9(-\ln(1 - \frac{1}{T}))^{-0.150} - 10.7] A^{0.68} \quad (14)$$

(Here, Q_T is flood in cubic meter per second for T year return period, T is return period in years,

and A is the catchment area in square kilometers).

Floods of some of the commonly adopted return periods viz. 2, 10, 20, 50, 100 and 200 years corresponding to different areas of the catchments of the seven sub-zones are tabulated in Appendix II. The graphical representation of the regional flood formulae for some of the commonly adopted return periods, viz. 2, 10, 20, 50, 100 and 200 years are illustrated in Appendix III for the respective subzones for the catchment area varying from 10 sq. km. to 2500 sq. km.

6.0 COMPUTATION OF T-YEAR FLOODS

6.1 Computation of T-year floods for gauged catchments having limited at site data

Step by step procedure for estimation of floods of various return periods for the gauged catchments having limited at site data of annual maximum peak floods in various subzones of zone 3 is given below:

Step 1: Compute the mean annual peak flood (MAF) in cubic meter per second for the gauged catchment by taking the mean of the annual maximum peak flood (QAM) values observed at the gauging site of the catchment for different years.

Step 2: Compute the growth factors (GF) using one of the equations (1) to (7) for the respective subzone wherein the catchment is located corresponding to T -year return period. In case the growth factors are required for 2, 10, 20, 50, 100 and 200 years return periods, these may be directly taken from the tabulated values of growth factors for the seven subzones of zone 3 in Appendix I.

Step 3: Compute the flood of desired return period (T) by multiplying the value of mean annual peak flood (MAF) for the catchment computed in step 1, with the corresponding value of the growth factor of the respective subzone obtained in step 2.

Example 1:

Annual maximum peak flood (QAM) values observed at the gauging site of a catchment lying in subzone 3 (d) are available for a period of ten years from 1981 to 1990, as given below, in cubic meter per second. Area of the catchment is 615 sq. km. Find out the floods of (a) 5 year, and (b) 50 year return periods at the gauging site of the catchment:

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
QAM (m ³ /s)	320	785	788	571	690	1080	1065	850	1550	1290

Solution:

Step 1: Compute the mean annual peak flood (MAF) for the catchment by taking the arithmetic mean of the annual maximum peak floods (QAM) values observed at the gauging site of the catchment during ten years.

$$\begin{aligned}
 \text{MAF} &= (320+785+788+571+690+1080+1065+850+1550+1290)/10 \\
 &= 8989/10 \\
 &= 898.9 \text{ m}^3/\text{s}
 \end{aligned}$$

Step 2:

(a) Computation of growth factor corresponding to 5 year return period

Since the catchment is located in subzone (3d), therefore equation (4) may be used to compute the growth factor corresponding to 5-year return period. Thus:

$$\begin{aligned}
 GF_5 &= \left[0.649 - 2.461 \left\{ 1 - \left(-\ln \left(1 - \frac{1}{5} \right) \right)^{-0.180} \right\} \right] \\
 &= 1.412
 \end{aligned}$$

(Note that the growth factor for 5-year return period are not tabulated in Appendix I. Therefore its value cannot be directly taken from the tabulated values)

(b) Computation of growth factor corresponding to 50 year return period (GF_{50}):

$$GF_{50} = \left[0.649 - 2.461 \left\{ 1 - \left(-\ln \left(1 - \frac{1}{50} \right) \right)^{-0.180} \right\} \right]$$

$$= 3.155$$

Alternatively, the growth factor for 50 year return period (GF_{50}) may be directly taken from the tabulated values of growth factors for the seven sub-zones in Appendix I. The GF_{50} value from the table is also 3.155 for sub-zone 3(d).

Step 3:

(a) Computation of the flood corresponding to 5-year return period

Multiply the value of mean annual peak flood (MAF) of the catchment, computed in step 1, i.e. $MAF = 898.9 \text{ m}^3/\text{s}$ with the value of the growth factor corresponding to 5 year return period ($GF_5 = 1.412$) for computing the flood for 5 year return period (Q_5) as:

$$\begin{aligned} Q_5 &= GF_5 * MAF \\ &= 1.412 * 898.9 \text{ m}^3/\text{s} \\ &= 1268.68 \text{ m}^3/\text{s} \end{aligned}$$

(b) Computation of the flood corresponding to 50 year return period

Multiply the value of mean annual peak flood (MAF) of the catchment, computed in step 1, i.e. $MAF = 898.9 \text{ m}^3/\text{s}$ with the value of the growth factor corresponding to 50 year return period ($GF_{50} = 3.155$) for computing the flood for 50 year return period (Q_{50}) as:

$$\begin{aligned} Q_{50} &= GF_{50} * MAF \\ &= 3.155 * 898.9 \text{ m}^3/\text{s} \\ &= 2836.03 \text{ m}^3/\text{s} \end{aligned}$$

Thus, for the gauged catchment considered in Example 1, floods for (a) 5 year and (b) 50 year return periods are computed as $1268.68 \text{ m}^3/\text{s}$ and $2836.03 \text{ m}^3/\text{s}$ respectively.

6.2 Computation of T year floods for ungauged catchments

Step by step procedure for the estimation of floods of various return periods using the developed regional flood formulae (as discussed in section 5.0) for small to moderate size catchments lying in the various sub-zones of zone 3 is given below:

Step1: Find out the area of the ungauged catchment (A) in square kilometers

Step 2: Substitute the value of the catchment area (A) mentioned at step 1 and the value of the desired return period (T) in the regional flood formula of the respective subzone given as

equations (8) to (14) and compute the flood of desired return period (Q_T). In case the catchment area of the ungauged catchment matches with the given catchment areas tabulated in Appendix II and also the desired return periods are 2, 10, 20, 50, 100 and 200, then the T year return period (Q_T) may be directly taken from the Appendix II utilising the table of the respective subzone.

Alternatively, the floods for the desired return period may also be computed using the graphical form of the regional flood formulae given in Appendix III provided the return periods are 2, 10, 20, 50, 100 and 200 years and catchment area lies between 10 to 2000 square kilometers.

Example 2:

An ungauged catchment lies in subzone 3 (b). Area of this catchment is 400 square kilometers. Find out the flood of 100 year return period for the catchment.

Solution:

Step 1: Area of the ungauged catchment (A) is given as 400 square kilometers.

Step 2: Substitute the value of catchment area (A) = 400 sq. km. and value of return period (T) = 100 years in the regional flood formula of subzone 3 (b) given as equation (9) and compute the flood of 100 year return period as shown below:

$$Q_{100} = [61.3(-\ln(1 - \frac{1}{100}))^{0.200} - 46.9](400)^{0.46}$$

$$= 1683 \text{ m}^3/\text{s}$$

Note that the catchment area (A) = 400 sq. km. and return period T = 100 year match with the given catchment area and return period in table B of Appendix II for subzone 3(b). Thus, alternatively, the flood of 100 years return period may be directly taken from this table and the above computation may be avoided for the given catchment. From table B of Appendix II, for a catchment area of 400 sq. km. the value of flood for the return period (T) = 100 years for the ungauged catchment lying in subzone 3 (b) is obtained as 1683 m³/s.

Since the catchment area (A) = 400 sq. km. lies between 10 to 2000 sq. km. and desired return period T=100 year matches with the return periods given in Appendix III, therefore, another alternative approach for the computation of flood of 100 year return period (Q_{100}) may be utilising Figure B of Appendix III for subzone 3 (b). Thus, from figure B of Appendix III, for a catchment area of 400 sq. km. located in subzone 3(b), the value of the flood for the return period (T) = 100 years is obtained as 1683 m³/s.

For the ungauged catchment having catchment area of 400 sq. km. considered in Example 2, flood for return period of 100 years is computed as 1683 cubic meter per second.

Example 3:

An ungauged catchment lies in subzone 3 (e). Area of this catchment is 168 sq. km. Find out the flood of 25 year return period for the catchment.

Solution:

Step 1: Area of the ungauged catchment (A) is given as 168 sq. km.

Step 2: Substitute the value of catchment area (A) = 168 sq. km. and value of return period (T)=25 years in the regional flood formula of sub-zone 3 (e) given as equation (12) and compute the flood of 25 year return period as follows:

$$Q_{25} = [23.1(-\ln(1 - \frac{1}{25}))^{0.194} - 18.5](168)^{0.61}$$
$$= 557.13 \text{ m}^3/\text{s}$$

Note that the catchment area (A) = 168 sq. km. and return period (T) = 25 years do not match with the given catchment area and return period given in Table E of Appendix II for subzone 3 (e). Thus, for the catchment, the flood of 25 years return period cannot be directly taken from this table. Also the return period (T) = 25 years does not match with the given return period in Figure E of Appendix III although catchment area (A) = 168 sq. km. lies between 10 to 2000 sq. km. Hence the Q_{25} for the catchment cannot be computed using Figure E of Appendix III.

Thus for the catchment of example 3, the flood of 25 year return period (Q_{25}) may be computed using the regional flood formula for subzone 3 (e). Q_{25} values cannot be derived either from the tabulated values of Appendix II or utilising the figure of Appendix III for subzone 3 (e).

Hence, for the ungauged catchment having catchment area of 168 sq. km. considered in example 3, flood for return period of 25 years is computed as 557.13 cubic meter per second.

7.0 REMARKS

- (i) For estimation of floods of different return periods for gauged catchments having limited data and lying in the various subzones of Zone-3, the regional flood frequency relationships developed for the respective subzones together with the at-site mean annual peak floods may be used. However, alternatively the growth factors for 2, 10, 20, 50, 100 and 200 years return period may be directly taken from the tabulated values in Appendix I for the respective subzones of zone 3 in order to compute the floods for these return periods by multiplying the growth factors with the at-site mean annual peak flood.
- (ii) For estimation of floods of different return periods for ungauged catchments lying in the seven subzones of Zone-3, the regional flood formulae developed for the respective subzones may be adopted. However, for those catchments whose catchment area matches with the given catchment areas tabulated in Appendix II and also the desired return periods are 2, 10, 20, 50, 100 and 200 years, the T year flood may be directly taken from the tabulated values in Appendix II for the respective subzone wherein the catchment is located. Furthermore, the graphical form of the regional flood formula

given in Appendix III may be utilised alternatively provided the catchment area lies between 10 to 2000 sq. km. and the desired return periods are among 2, 10, 20, 50, 100 and 200 years.

- (iii) The conventional empirical flood formulae do not provide floods of desired return periods. However, the flood formulae presented here are capable of providing flood estimates for different return periods.
- (iv) The flood estimates computed using the regional flood formulae are subject to errors associated with the input data, its record length, regional heterogeneity in development of the regional flood frequency curves as well as the relationship between mean annual peak flood and catchment area. These formulae may be revised by utilising additional observed peak flood data and catchment area as well as other physiographic and climatic characteristics of the various catchments, which govern the process of runoff generation from a catchment.
- (v) As these flood formulae have been developed using the data of maximum period of 33 years, for small to moderate size catchments upto 2227 square kilometers in size; therefore, these formulae are expected to provide reliable flood estimates of return periods upto 50 years, for the catchments of about 2500 square kilometers in areal extent.
- (vi) The form of the developed regional flood formulae is very simple; as for estimation of flood of desired return period for an ungauged catchment, it requires only catchment area, which is readily available. Hence, these formula may be easily used by the field engineers for estimation of floods of desired return periods.

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APPENDIX -I

Growth Factors for the Seven Subzones of Zone-3

S. No.	Subzone	Return Period (Years)					
		2	10	20	50	100	200
1.	3(a)	0.747	2.042	2.719	3.793	4.780	5.946
2.	3(b)	0.780	2.009	2.615	3.547	4.335	5.289
3.	3(c)	0.844	1.892	2.352	3.004	3.538	4.112
4.	3(d)	0.817	1.879	2.391	3.155	3.826	4.578
5.	3(e)	0.767	2.082	2.726	3.707	4.563	5.543
6.	3(f)	0.880	1.830	2.213	2.726	3.124	3.533
7.	3(h)	0.780	2.035	2.608	3.445	4.157	4.942

Table A Variation of floods of various return periods with catchment area for subzone 3(a)

Sl. No.	Catchment Area (km ²)	Return Period (Years)					
		2	10	20	50	100	200
1	10	45	123	164	229	288	359
2	20	62	169	226	315	396	493
3	30	75	204	272	379	478	594
4	40	85	233	310	433	545	678
5	50	94	258	344	480	604	752
6	60	103	281	374	522	657	818
7	70	110	301	401	560	706	878
8	80	117	320	427	596	750	933
9	90	124	338	450	629	792	985
10	100	130	355	473	660	831	1034
11	200	179	488	650	908	1143	1422
12	300	215	589	784	1094	1378	1714
13	400	246	672	895	1249	1573	1957
14	500	272	745	991	1384	1743	2168
15	600	296	810	1078	1505	1895	2358
16	700	318	869	1157	1615	2035	2531
17	800	338	924	1231	1718	2164	2691
18	900	357	976	1299	1813	2284	2841
19	1000	375	1024	1364	1903	2398	2982
20	1100	392	1070	1425	1989	2505	3116
21	1200	408	1114	1483	2070	2607	3243
22	1300	423	1155	1539	2148	2705	3365
23	1400	437	1196	1592	2222	2799	3482
24	1500	452	1234	1643	2294	2889	3594
25	1600	465	1271	1693	2363	2976	3702
26	1700	478	1307	1741	2430	3060	3807
27	1800	491	1342	1787	2494	3142	3908
28	1900	503	1376	1832	2557	3221	4007
29	2000	515	1409	1876	2618	3298	4102

**Table B Variation of floods of various return periods with catchment area
for subzone 3(b)**

Sl. No.	Catchment Area (km ²)	Return Period (Years)					
		2	10	20	50	100	200
1	10	55	142	185	251	309	375
2	20	76	196	255	345	425	516
3	30	92	236	307	416	512	622
4	40	105	269	351	475	584	710
5	50	116	298	389	526	647	786
6	60	126	325	422	572	704	855
7	70	135	348	454	614	756	918
8	80	144	370	482	653	804	976
9	90	152	391	509	689	848	1030
10	100	159	411	534	724	890	1082
11	200	219	565	735	995	1225	1488
12	300	264	680	886	1200	1476	1793
13	400	302	777	1011	1369	1683	2046
14	500	334	861	1120	1517	1867	2268
15	600	363	936	1218	1650	2030	2466
16	700	390	1005	1308	1771	2180	2647
17	800	415	1068	1391	1883	2318	2815
18	900	438	1128	1468	1988	2447	2972
19	1000	460	1184	1541	2087	2568	3119
20	1100	480	1237	1610	2181	2683	3259
21	1200	500	1288	1676	2270	2793	3392
22	1300	519	1336	1739	2355	2898	3519
23	1400	537	1382	1799	2436	2998	3641
24	1500	554	1427	1857	2515	3095	3759
25	1600	571	1470	1913	2591	3188	3872
26	1700	587	1511	1967	2664	3278	3982
27	1800	602	1552	2020	2735	3365	4088
28	1900	618	1591	2071	2804	3450	4191
29	2000	632	1629	2120	2871	3533	4291

**Table C Variation of floods of various return periods with catchment area
for subzone 3(c)**

Sl. No.	Catchment Area (km ²)	Return Period (Years)					
		2	10	20	50	100	200
1	10	47	105	130	166	196	227
2	20	74	166	207	264	311	362
3	30	98	218	271	347	408	475
4	40	118	265	329	420	495	576
5	50	137	307	382	488	575	668
6	60	155	347	432	552	650	755
7	70	172	385	479	612	720	837
8	80	188	421	524	669	788	916
9	90	204	456	567	724	853	991
10	100	218	489	608	777	915	1063
11	200	348	778	968	1236	1456	1692
12	300	456	1021	1270	1622	1910	2220
13	400	553	1238	1540	1967	2316	2692
14	500	642	1438	1788	2284	2690	3126
15	600	726	1625	2020	2580	3039	3532
16	700	805	1802	2240	2861	3370	3916
17	800	880	1970	2450	3129	3685	4283
18	900	952	2132	2651	3386	3988	4635
19	1000	1022	2288	2845	3634	4279	4974
20	1100	1089	2439	3032	3873	4562	5302
21	1200	1155	2585	3215	4106	4835	5620
22	1300	1218	2728	3392	4332	5102	5929
23	1400	1280	2867	3564	4552	5361	6231
24	1500	1341	3002	3733	4768	5615	6526
25	1600	1400	3135	3898	4978	5863	6814
26	1700	1458	3265	4059	5185	6106	7097
27	1800	1515	3392	4218	5387	6345	7374
28	1900	1571	3518	4373	5586	6579	7646
29	2000	1626	3641	4526	5781	6809	7913

**Table D Variation of floods of various return periods with catchment area
for subzone 3(d)**

Sl. No.	Catchment Area (km ²)	Return Period (Years)					
		2	10	20	50	100	200
1	10	17	38	48	64	78	93
2	20	29	66	84	111	134	160
3	30	39	91	115	152	185	221
4	40	50	114	145	191	232	277
5	50	59	136	173	228	276	331
6	60	68	157	200	264	319	382
7	70	77	177	225	298	361	431
8	80	86	197	250	331	401	479
9	90	94	216	275	363	440	526
10	100	102	235	299	395	478	572
11	200	177	406	517	682	826	989
12	300	243	560	712	940	1138	1362
13	400	305	702	893	1180	1429	1710
14	500	364	838	1065	1408	1704	2039
15	600	421	967	1230	1626	1968	2355
16	700	475	1093	1390	1836	2223	2660
17	800	528	1214	1544	2040	2471	2956
18	900	580	1333	1695	2239	2712	3245
19	1000	630	1448	1842	2434	2947	3526
20	1100	679	1562	1986	2624	3177	3802
21	1200	728	1673	2128	2811	3403	4073
22	1300	775	1782	2266	2994	3626	4339
23	1400	822	1890	2403	3175	3844	4600
24	1500	868	1995	2538	3353	4059	4858
25	1600	913	2100	2670	3528	4272	5112
26	1700	958	2203	2801	3701	4481	5363
27	1800	1002	2304	2931	3872	4688	5610
28	1900	1046	2405	3059	4041	4893	5855
29	2000	1089	2505	3185	4208	5095	6097

**Table E Variation of floods of various return periods with catchment area
for subzone 3(e)**

Sl. No.	Catchment Area (km ²)	Return Period (Years)					
		2	10	20	50	100	200
1	10	26	71	93	126	155	188
2	20	40	108	141	192	237	287
3	30	51	138	181	246	303	368
4	40	61	165	216	293	361	438
5	50	70	189	247	336	414	502
6	60	78	211	276	375	462	562
7	70	85	232	303	412	508	617
8	80	93	251	329	447	551	669
9	90	100	270	354	481	592	719
10	100	106	288	377	513	631	767
11	200	162	440	576	782	964	1170
12	300	207	563	737	1002	1234	1499
13	400	247	671	879	1194	1471	1786
14	500	283	769	1007	1368	1685	2047
15	600	317	859	1125	1529	1883	2287
16	700	348	944	1236	1680	2069	2513
17	800	377	1024	1341	1822	2245	2726
18	900	405	1101	1441	1958	2412	2929
19	1000	432	1174	1536	2088	2572	3124
20	1100	458	1244	1628	2213	2726	3311
21	1200	483	1312	1717	2334	2874	3491
22	1300	507	1377	1803	2450	3018	3666
23	1400	531	1441	1886	2564	3158	3835
24	1500	554	1503	1968	2674	3294	4000
25	1600	576	1563	2047	2781	3426	4161
26	1700	598	1622	2124	2886	3555	4318
27	1800	619	1680	2199	2989	3681	4471
28	1900	640	1736	2273	3089	3804	4621
29	2000	660	1791	2345	3187	3925	4768

**Table F Variation of floods of various return periods with catchment area
for subzone 3(f)**

Sl. No.	Catchment Area (km ²)	Return Period (Years)					
		2	10	20	50	100	200
1	10	34	71	86	106	121	137
2	20	57	118	143	176	202	228
3	30	76	159	192	236	271	306
4	40	94	196	237	292	334	378
5	50	111	230	279	343	393	445
6	60	127	263	318	392	449	508
7	70	142	294	356	439	503	569
8	80	156	325	393	484	554	627
9	90	170	354	428	527	604	683
10	100	184	382	462	569	652	738
11	200	305	634	766	944	1082	1224
12	300	410	852	1030	1269	1455	1645
13	400	506	1051	1271	1566	1795	2030
14	500	595	1237	1496	1843	2112	2389
15	600	680	1413	1709	2106	2413	2729
16	700	761	1581	1913	2356	2701	3054
17	800	839	1743	2108	2598	2977	3366
18	900	914	1900	2298	2831	3244	3669
19	1000	987	2052	2481	3057	3504	3962
20	1100	1058	2200	2660	3278	3756	4247
21	1200	1127	2344	2835	3492	4003	4526
22	1300	1195	2485	3005	3703	4243	4798
23	1400	1262	2623	3172	3908	4479	5065
24	1500	1327	2759	3336	4110	4711	5326
25	1600	1391	2892	3497	4309	4938	5583
26	1700	1454	3023	3655	4504	5161	5836
27	1800	1516	3151	3811	4695	5381	6085
28	1900	1577	3278	3965	4885	5598	6330
29	2000	1637	3403	4116	5071	5811	6571

Table G Variation of floods of various return periods with catchment area for subzone 3(h)

Sl. No.	Catchment Area (km ²)	Return Period (Years)					
		2	10	20	50	100	200
1	10	14	35	45	59	72	85
2	20	22	56	72	95	115	136
3	30	29	74	95	125	151	180
4	40	35	90	115	152	184	218
5	50	41	105	134	177	214	254
6	60	47	119	152	201	242	288
7	70	52	132	169	223	269	320
8	80	57	144	185	244	294	350
9	90	61	156	200	264	319	379
10	100	66	168	215	284	343	407
11	200	106	269	344	455	549	653
12	300	139	354	454	600	723	860
13	400	169	431	552	729	880	1046
14	500	197	501	642	849	1024	1217
15	600	223	567	727	961	1159	1378
16	700	248	630	807	1067	1287	1530
17	800	271	690	884	1168	1409	1675
18	900	294	748	958	1266	1527	1815
19	1000	316	803	1029	1360	1640	1950
20	1100	337	857	1098	1451	1750	2080
21	1200	357	909	1165	1539	1856	2207
22	1300	377	960	1230	1625	1960	2331
23	1400	397	1010	1293	1709	2062	2451
24	1500	416	1058	1356	1792	2161	2569
25	1600	434	1105	1416	1872	2258	2684
26	1700	453	1152	1476	1951	2353	2797
27	1800	471	1198	1534	2028	2446	2908
28	1900	488	1243	1592	2104	2537	3017
29	2000	506	1287	1648	2179	2627	3124

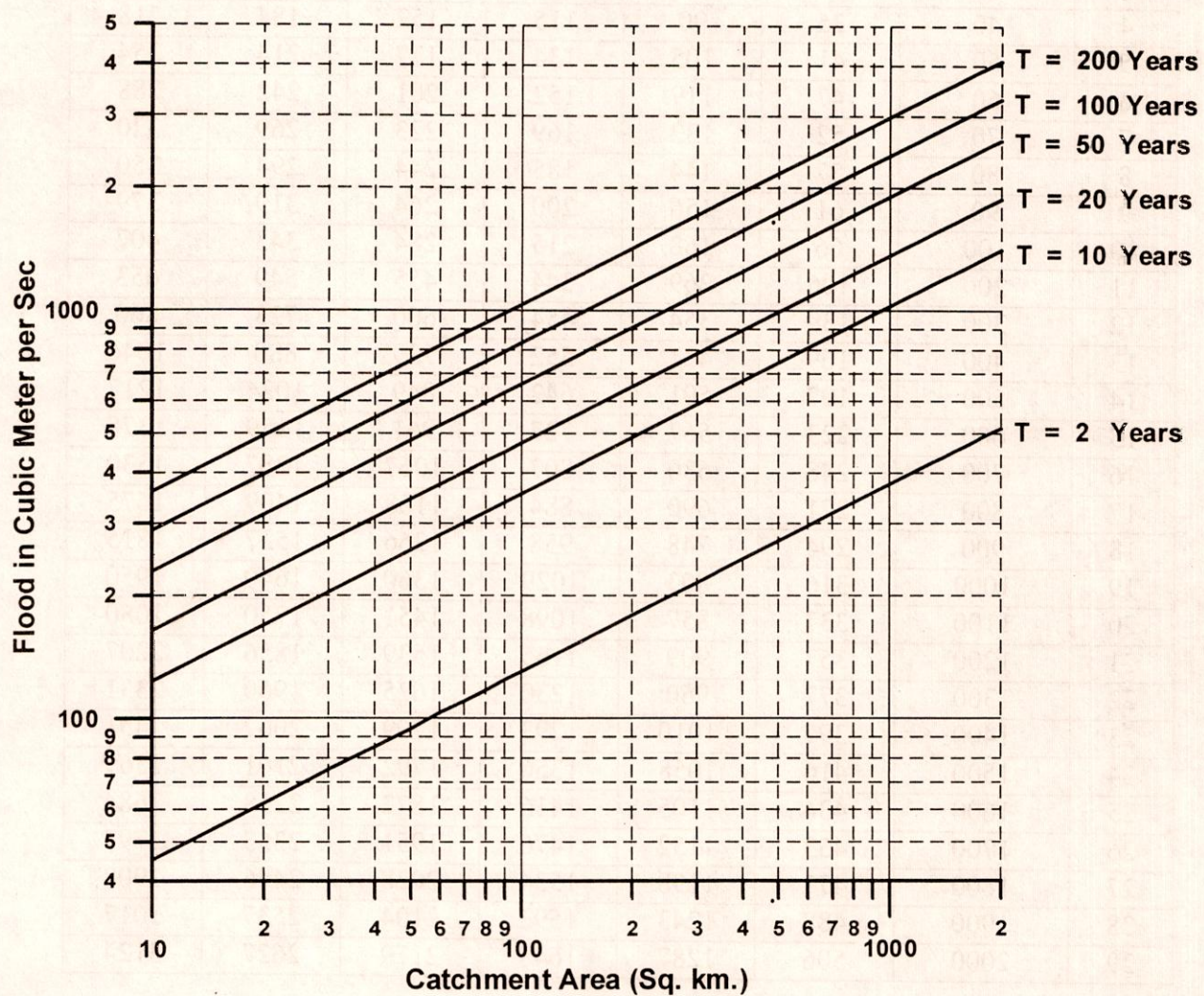


Fig.A Variation of floods of various return periods with catchment area for Subzone 3 (a)

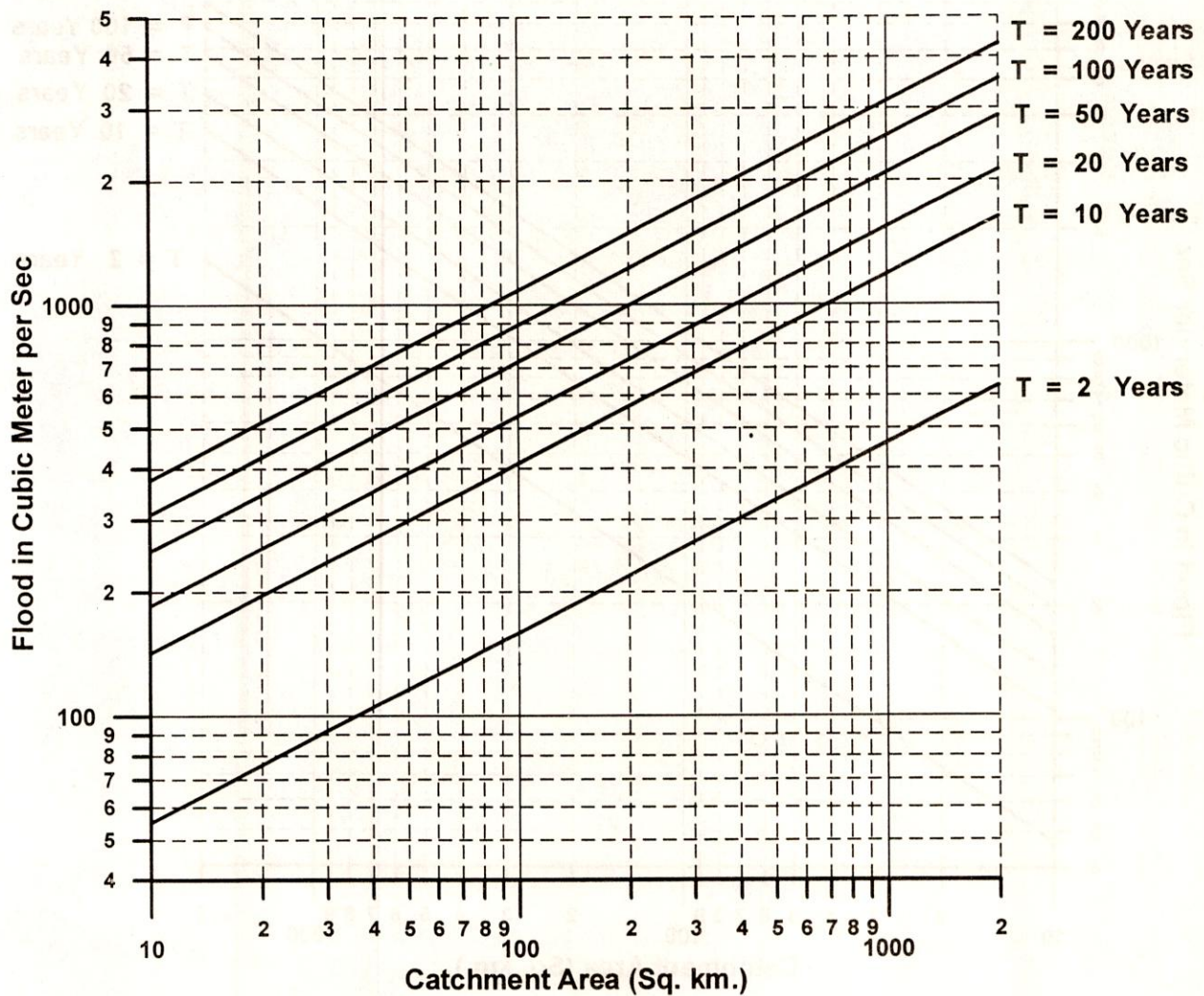


Fig.B Variation of floods of various return periods with catchment area for Subzone 3 (b)

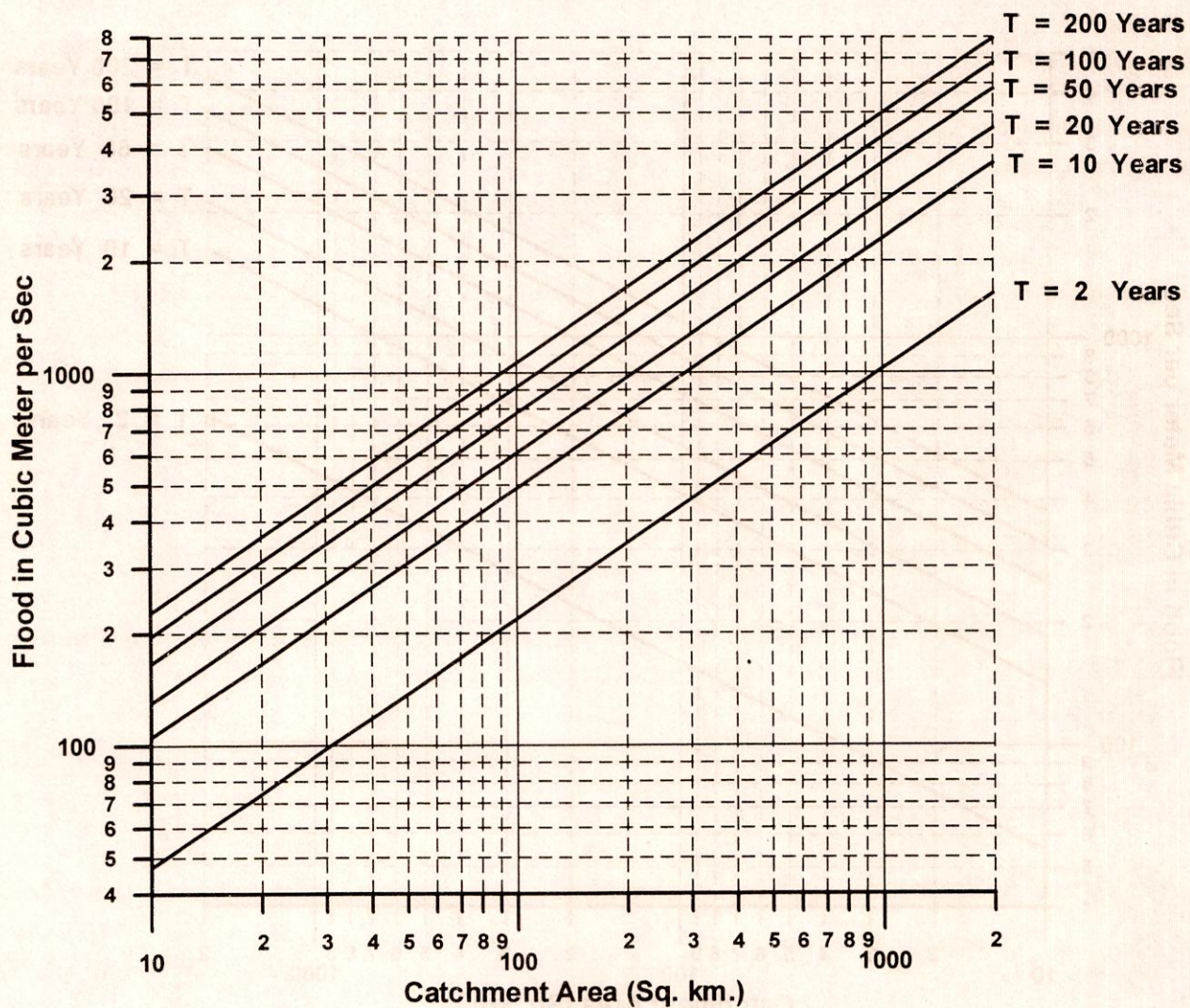


Fig.C Variation of floods of various return periods with catchment area for Subzone 3 (c)

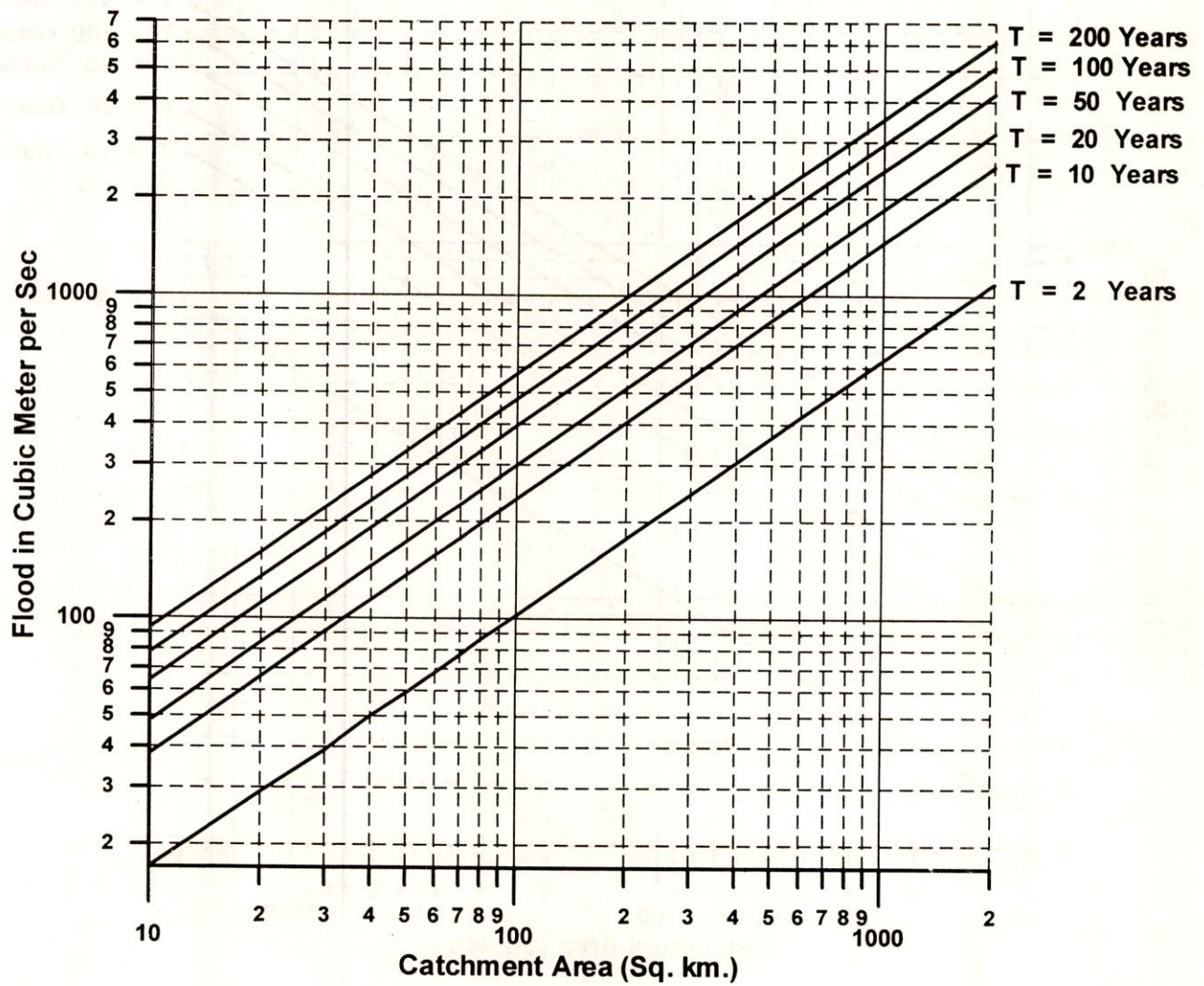


Fig.D Variation of floods of various return periods with catchment area for Subzone 3 (d)

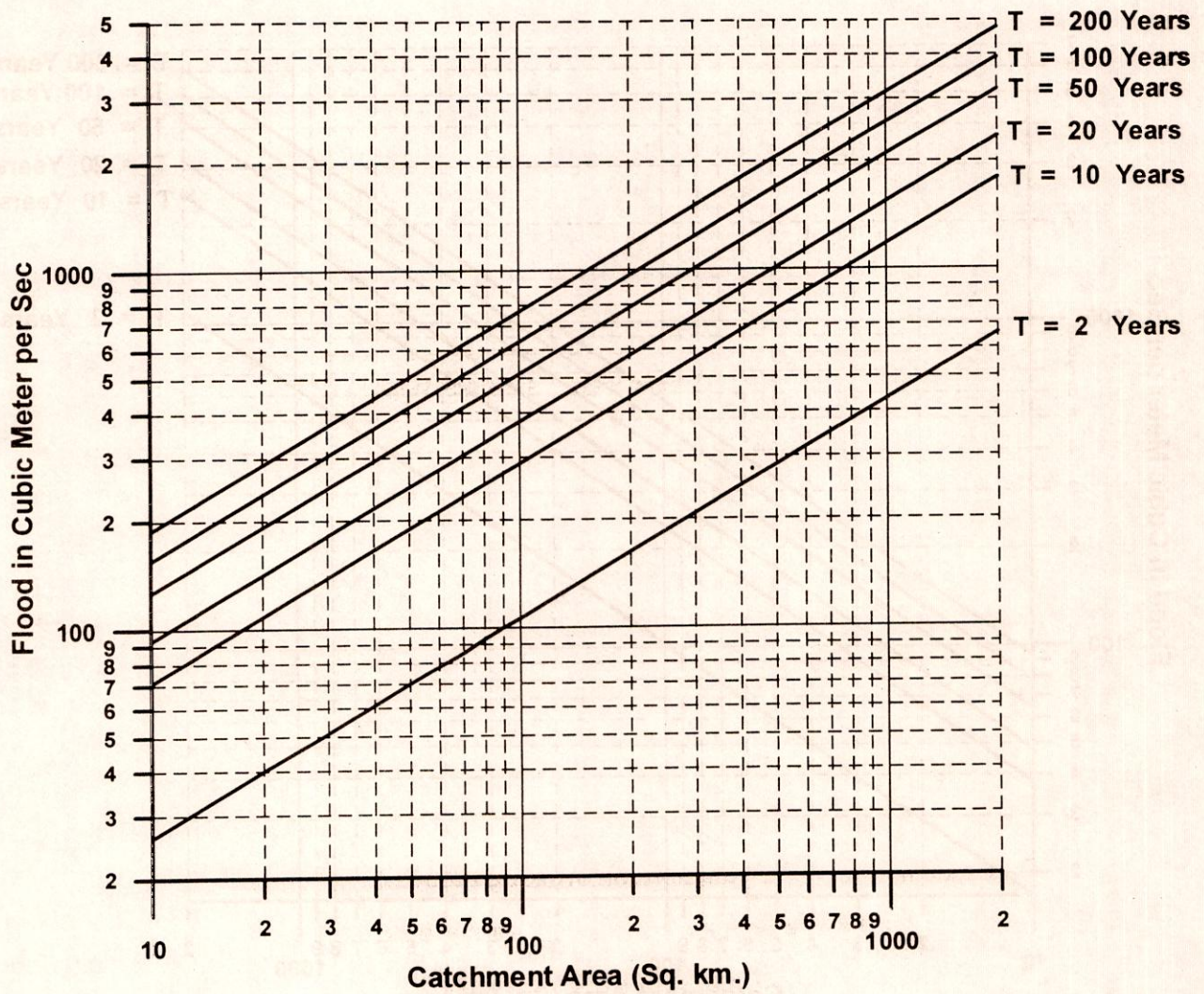


Fig. E Variation of floods of various return periods with catchment area for Subzone 3 (e)

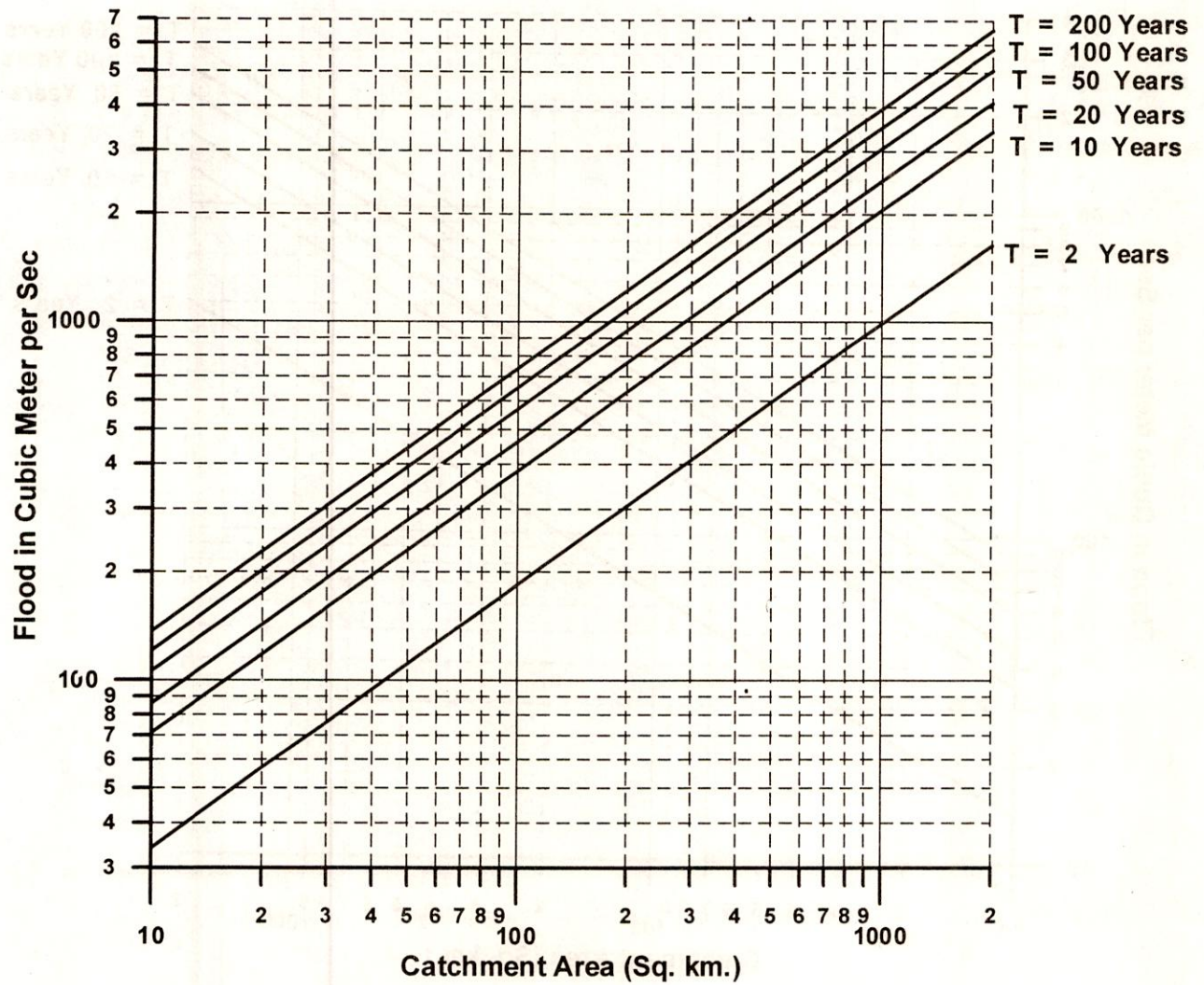


Fig.F Variation of floods of various return periods with catchment area for Subzone 3 (f)

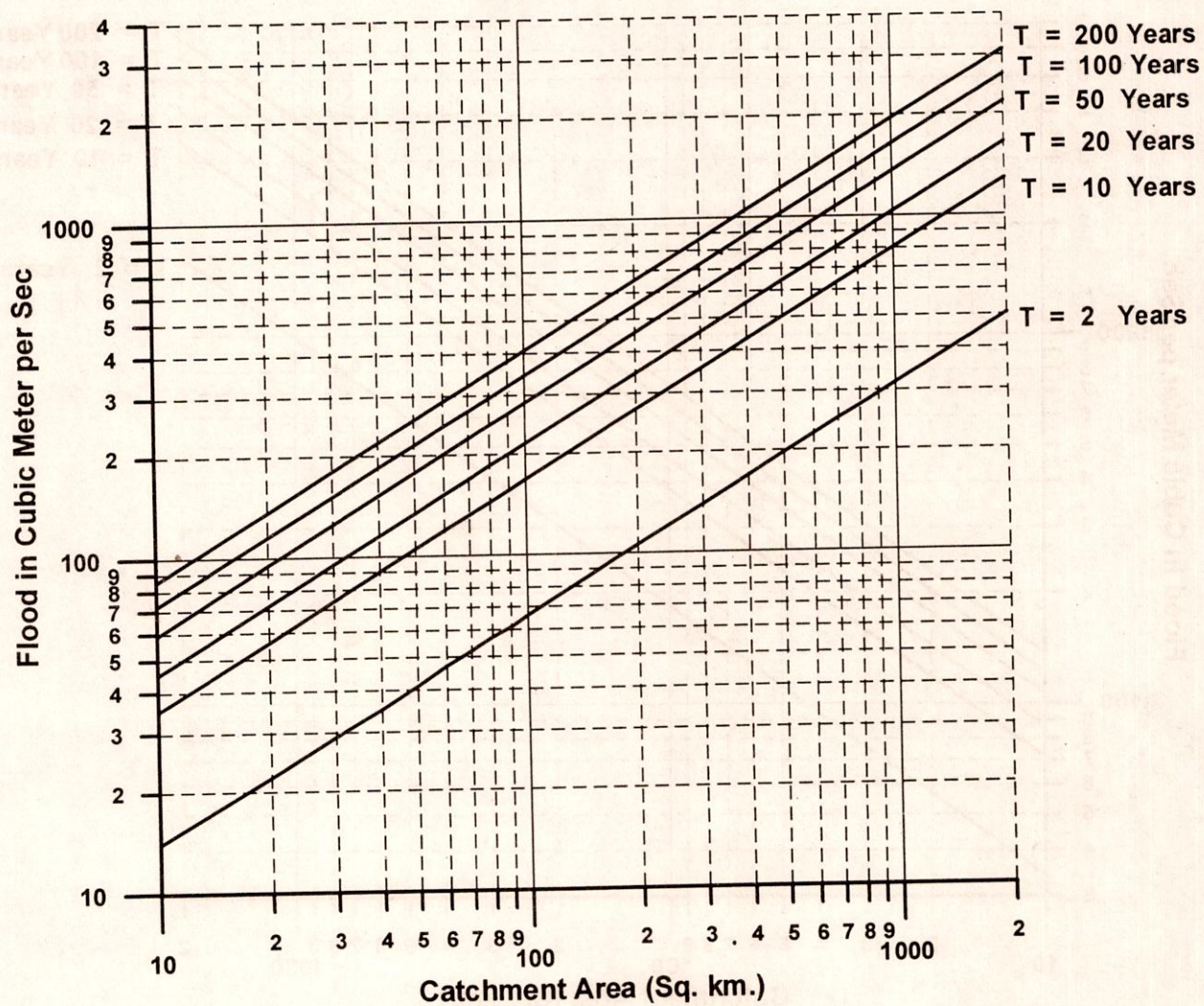


Fig.G Variation of floods of various return periods with catchment area for Subzone 3 (h)

