REGIONAL UNIT HYDROGRAPH ANALYSIS

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OBJECTIVES

This lecture would provide an understanding of the various steps involved in developing the regional unit hydrograph relationships. The participants would also be introduced with some of the regional unit hydrograph relationships (synthetic unit hydrographs) developed for specific regions in India.

INRODUCTION

Whenever sufficient and reliable records on stream flow and rainfall are available the unit hydrograph for those catchments can be derived from the rainfall-runoff data of storm events using one of the techniques. However, most of the small catchments are generally not gauged and many water resources projects are being planned in those catchments. Therefore, it becomes necessary to have the estimates of floods at the proposed sites in small ungauged catchments. As we know, the unit hydrograph technique is one of the simple and most powerful techniques among other for the estimation of design flood. Therefore, the unit hydrographs for such catchments have to be estimated by using data on climatological, physiographic and other factors of these catchments.

The main purpose of the regional unit hydrograph study is to estimate the unit hydrograph ordinates or the unit hydrograph parameters for basins for which no gauge discharge data are available. The procedure involved in regional unit hydrograph analysis requires the evaluation of representative unit hydrograph parameters and pertinent physical characteristics for the gauged catchments in the region. Then multiple linear regression analysis is performed, considering one of the unit hydrograph parameters at a time as a dependent variable and various catchment characteristics as independent variables, in order to develop the regional relationship for the unit hydrograph derivation. Further, knowing the catchment characteristic for an ungauged catchment in the region from the available toposheet and climatological data the unit hydrograph for that catchment can be derived using the relationships developed for the region.

In this lecture, the various steps involved in developing the regional unit hydrograph relationships for a hydrometeorologically homogeneous region are described and discussed. Various regional unit hydrograph studies conducted in India as well as abroad are also presented to provide the proper understanding to the participants about the different forms of relationships established.

BASIC STEPS INVOLVED IN DEVELOPING THE REGIONAL UNIT HYDROGRAPH

The following steps should be followed in executing a regional study to develop regional unit hydrograph relationships for a basin.

(i) ***Choice of the catchment:*** In regional study, care should be taken to select those catchments which are indeed similar in hydro-meteorological characteristics. The catchments considered for developing the regional unit hydrograph should be able to represent the regional behavior as close as possible. Further, one should always try to include maximum no. of gauged catchments in the regional study. However, minimum eight to ten catchments are required for the regional study.

(ii) ***Split sample tests for the region:*** In order to test the performance of the developed regional relationships, the data of at least two to three catchments should be kept independent. It means, those catchments should be treated as ungauged catchments and they should not be considered while developing the regional relationship.

(iii) ***Rainfall-runoff data:*** Rainfall-runoff data of different catchments for each of the major past flood events should be considered for analysis. If the catchment underwent to some major changes due to man's influence or landuse changes, then the rainfall-runoff data of only recent past flood events should be considered for analysis.

(iv) ***Computation of excess rainfall***: A suitable technique should be adopted to separate the loss from total rainfall in order to get the excess rainfall hyetograph.

(v) ***Base flow separation:*** The base flow should be separated from the streamflow hydrograph using a consistent base flow separation technique, in order to get the direct surface runoff hydrograph.

(vi) ***Derivation of Unit Hydrograph***: The unit hydrograph should be derived by analyzing the excess rainfall-direct surface runoff data for each event of different catchment using a suitable unit hydrograph derivation technique.

(vii) ***Derivation of representative unit hydrograph***: The representative unit hydrograph for each catchment may b derived by averaging the unit hydrograph obtained from different events of the catchment using standard averaging procedure. However, if considerable variations are observed in unit hydrographs derived from different events of a catchment, then the unit hydrograph parameters of each event should be considered, along with the catchment and storm characteristics, in the regional study.

(viii) ***Split sample test for the storms:*** The performance of the representative unit hydrograph of a catchment should be tested by reproducing the two or three independent storms which are not to be used for deriving the representative unit hydrograph.

(ix) ***Development of regional unit hydrograph relationship:*** Step-wise multiple linear regression analysis can be performed, taking the unit hydrograph parameters of different catchment as dependent variables, and/or climatic characteristics as independent variables to develop the optimal regional unit hydrograph relationships.

(x) ***Representative Unit Hydrograph for ungauged catchments:*** The regional relationships developed at step (ix) are used for split sample test for the region as described in step (ii). Further the representative unit hydrograph for the ungauged catchments of the hydrometeorolgoically homogeneous region can be derived using measurable catchment and/or climatic characteristics in the generalized relationships developed in step (ix).

The basic procedure can be summarized as follows:

(i) From records of gauged catchment in a given region, derive the relations between characteristics of the unit hydrograph and the physical characteristics of the catchment. These relations depend on the method used, some of which are described as follows.

(ii) Assume that these relationships apply to the ungauged catchments in the region and use them to derive the synthetic unit hydrograph.

Nash's Approach

Nash (1959) related the first and second moments and IUH with the catchment characteristics of some English basins. He tried various forms of the relationships using different catchment characteristics. However, the following relationships were finally obtained.

$$m_1 = 27.6\ A^{0.3}\ S^{-0.3}$$
$$m_2 = 1.0\ m_1^{-0.2}\ S^{-0.2}$$

Where,

m_1 is the first moment of IUH about the origin

m_2 is the ratio of the second moment of IUH about the centroid to m_1^2

A is the catchment area (mile^2) and

S is a measure of overland slope.

For ungauged catchment Eq. (1) and (2) were used to get m_1 and m_2 which are further used to get the parameters of Nash Model, n and K, using theorem of moments.

Regional Unit Hydrograph for Narmada basin based on Clark's Approach

A regional unit hydrograph study has been conducted for Narmada basin at National Institute of Hydrology, Roorkee. In this study the parameters, T_c and R, of Clark Model have been derived for the Narmada sub-basins using HEC-1 programme package. The value of (T_c + R) and R/(T_c+R) of each of the floods analyzed in each of the sub-basins have been averaged for the respective sub-basins. The regional relationship has been presented in the graphical form where average of $(T_c + R)$ for each sub basins have been plotted against their respective catchment area as shown in Fig. 1. This plot along with the fixed value $R/(T_c+R)$ has been used to estimate the regional parameters for ungauged catchments. The fixed value of $R/(T_c+R)$ has been taken up around 0.6 for sub-basins up stream of Bermanghat site, while for sub-catchments on downstream of Bermanghat site, the average values of this ratio is around 0.45.

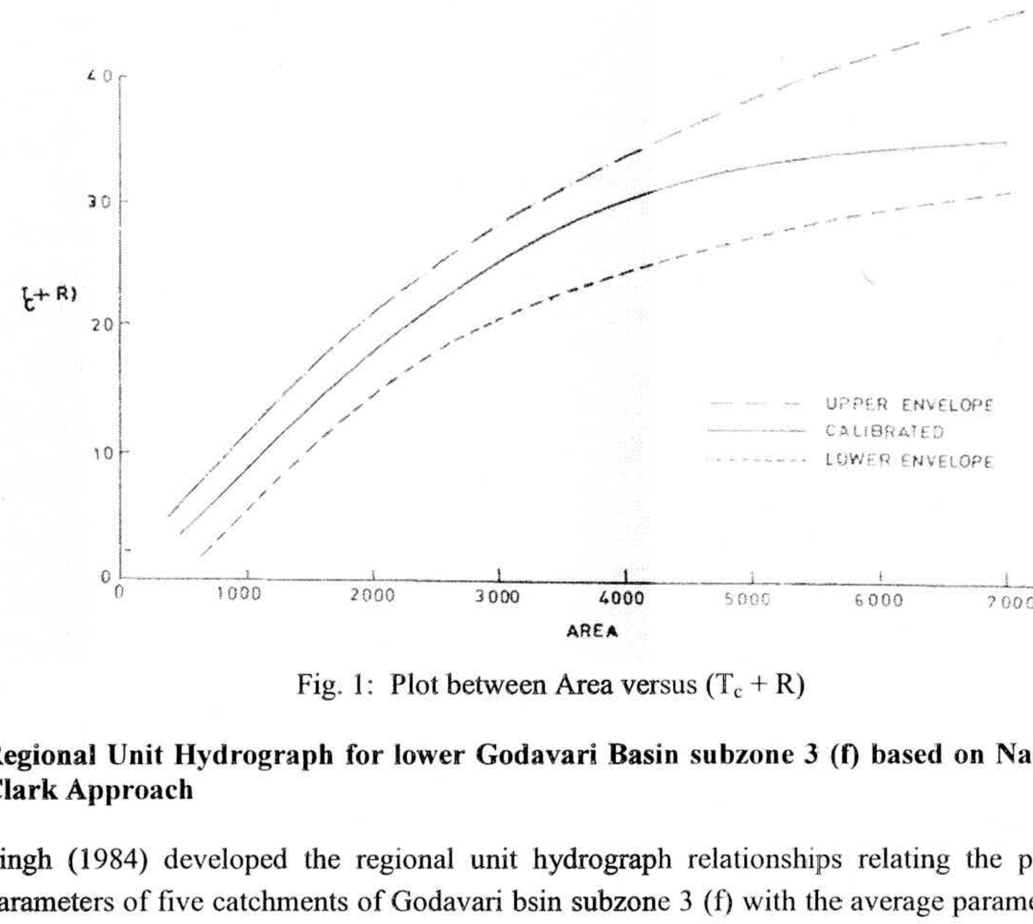

Fig. 1: Plot between Area versus $(T_c + R)$

Regional Unit Hydrograph for lower Godavari Basin subzone 3 (f) based on Nash and Clark Approach

Singh (1984) developed the regional unit hydrograph relationships relating the physical parameters of five catchments of Godavari bsin subzone 3 (f) with the average parameters of Nash Model and Clark model for those catchments. Fig. 2 and 3 illustrate the variation of n K with $(LL_{cc}/\sqrt{S})$ and K with main stream length L respectively. These two plots are used as the regional relationships based on Nash model.

The Clark model parameter T_c has been related with $(LL_{cc}/\sqrt{S})$ as shown in Fig. 4. A fixed value of the ratio $R/(T_c+R)$ along with T_c V/s $LL_c/\sqrt{S}$ plot is used to establish the regional unit hydrograph relationships based on clark model. Due to non-availability of much data for the other bridge catchments of the subzone 3 (f). Only five catchments have been considered in the regional study. Therefore the study has some what limited scope. However, it provides encouraging results for further investigation.

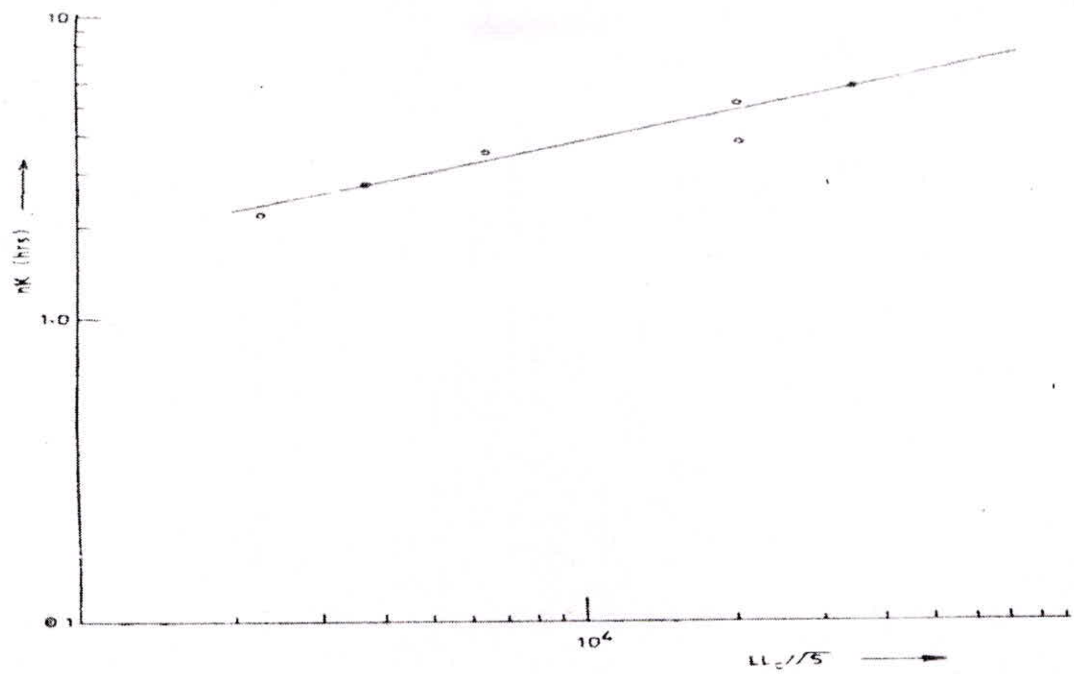

Fig. 2: Plot between nk and $LL_c/S^{0.5}$

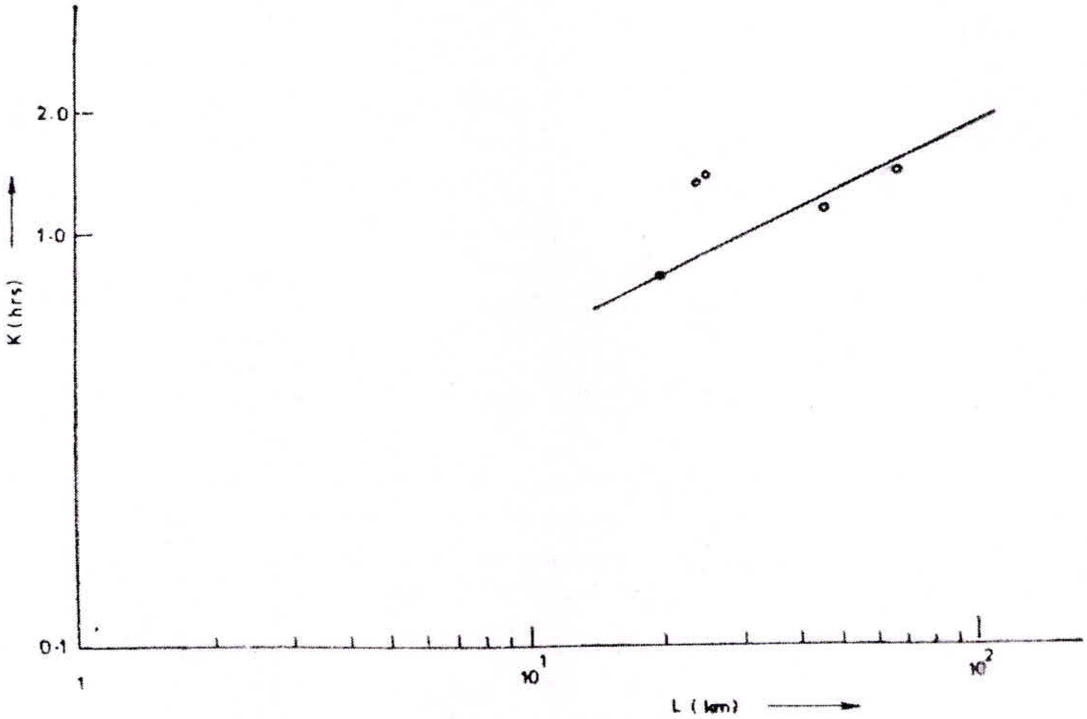

Fig. 3: Plot between K and L

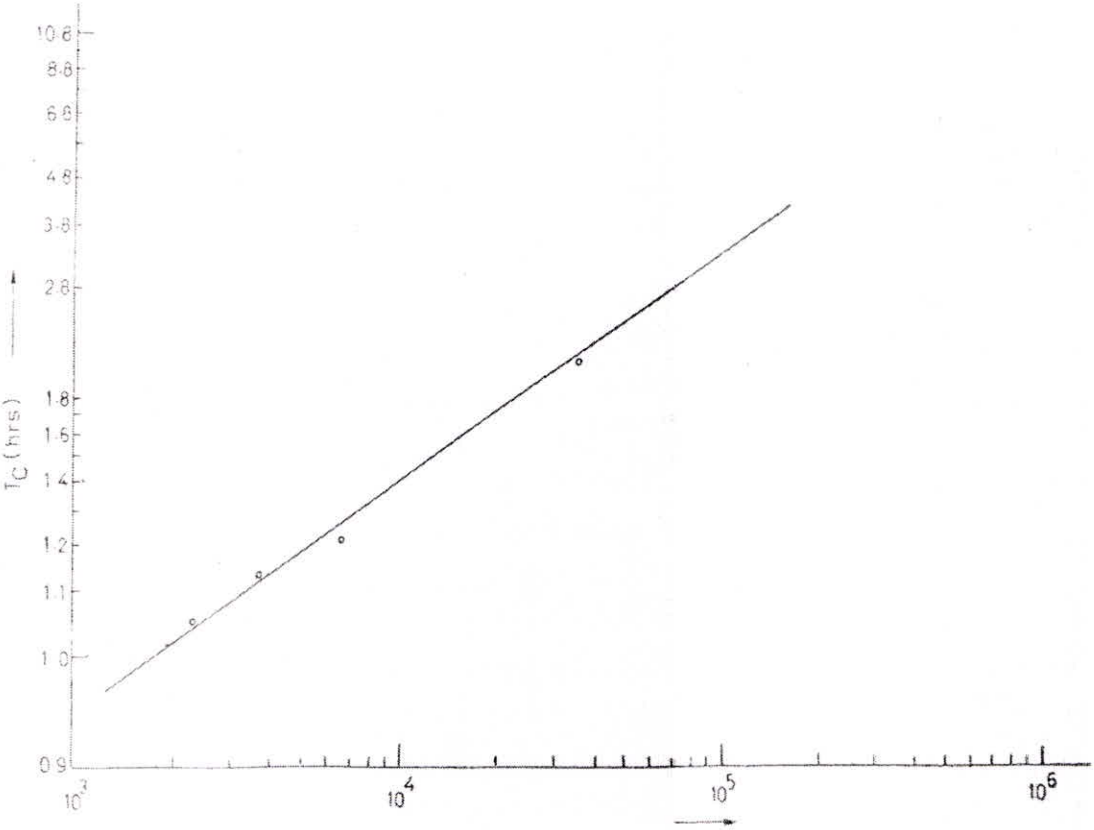

Fig 4: Plot between Tc and $LL_c/\sqrt{S}$

SUMMARY

(i) The regional unit hydrograph or synthetic unit hydrograph are a tool to overcome lack of stream flow data at the specific site under investigation.

(ii) It is assumed that the unit hydrograph represents the physiographic characteristics of a catchment.

(iii) Multiple linear regression analysis is a most powerful tool for the regional unit hydrograph analysis.

(iv) Data of unit hydrograph derived from stream flow and rainfall records in catchments adjoining the catchment under study should be used to estimate the constants for use to any regional unit hydrograph study.

(v) Estimated constants in the regional relationships are transposed to the catchment under study for the derivation of unit hydrograph parameters.

(vi) Studies conducted for some typical region in India indicate encouraging results. It demands similar studies in systematic way for different hydrometeorologically homogeneous regions in India.

Flood Estimation Using Regional Unit Hydrograph Approach (A Case Study)

Unit hydrograph approach is one of the most widely used techniques for the estimation of flood hydrograph. In this approach the excess design hyetograph of an event is converted into the direct surface runoff hydrograph using the principle of convolution, which is based on the principle of linearity. The flood hydrograph resulting due to the rainfall of desired duration and frequency is obtained using the principle of unit hydrograph. The regional equations for derivation of synthetic unit hydrograph for the Subzone 3 (d) jointly developed by CWC, IMD and RDSO (1977) and described in Design flood estimation report of the Mahanadi Subzone 3 (d) (CWC, 1997) are mentioned below.

Sl.No.	Relationship	Equation No
1	$t_p = 1.757\,(LLc/\sqrt{S})^{0.261}$	3. 4. 3. 2
2	$q_p = 1.260\,(t_p)^{-0.725}$	3. 4. 3. 3
3	$W_{50} = 1.974\,(q_p)^{-1.104}$	3. 4. 3. 4
4	$W_{75} = 0.961\,(q_p)^{-1.125}$	3. 4. 3. 5
5	$W_{R50} = 1.150\,(q_p)^{-0.829}$	3. 4 .3. 6
6	$W_{R75} = 0.527\,(q_p)^{-0.932}$	3. 4. 3. 7
7	$T_B = 5.411\,(t_p)^{0.826}$	3. 4. 3. 8
8	$T_m = t_p + t_r/2$	3. 4. 3 .9
9	$Q_p = q_p * A$	3. 4. 3. 10

The procedure for computing design flood peak and design flood hydrograph for T-year return period by the synthetic unit hydrograph as described in Design flood estimation report of the Mahanadi Subzone 3 (d) (CWC, 1997) is briefly mentioned here under.

(i) Derive the synthetic unit hydrograph for 1-cm and 1-hour.

(ii) Estimate design storm duration as, $T_D = 1.1 * tp$.

(iii) Estimate the storm rainfall for the desired return period and design storm duration.

(iv) Compute design storm rainfall hyetograph at hourly interval using the available distribution co-efficient (CWC, 1997)

(v) Adopt design loss rate as recommended. In the present study a design loss of 0.21 mm/hour has been adopted (CWC, 1997).

(vi) Obtain hourly excess rainfall hyetograph after subtracting the design loss rate from the design rainfall hyetograph.

(vii) Arrange 1-hour rainfall values against the 1-hour unit hydrograph ordinates in such a manner that the maximum value of excess rainfall lies against the maximum ordinate of unit hydrograph, the next lower value of excess rainfall against the next lower unit hydrograph ordinate and so on.

(viii) Reverse the sequence of hourly excess rainfall obtained in Step - (vii) to get the critical sequence of the rainfall units.

(ix) Compute the direct surface runoff hydrograph by convoluting the hourly excess rainfall sequence, obtained in step (viii), with the unit hydrograph.

(x) Estimate the base flow for the catchment area under study. In this study, base flow of 0.01 cumecs per sq km area of the catchment was used (CWC, 1997).

(xi) Compute the flood hydrograph by adding the constant base flow to total direct surface runoff computed in Step - (ix).

Physiographic characteristics of the four catchments and the parameters of the synthetic unit hydrographs for the four catchments, derived based on CWC (1997) are in Tables 1 and 2, respectively.

Table 1 Physiographic characteristics of the four catchments

S. No.	Catchment Characteristics	Catchment A	Catchment B	Catchment C	Catchment D
1	A (km^2)	6.07	11.24	4.13	21.45
2	L (km)	2.59	5.63	1.84	7.295
3	Lc (km)	1.76	2.32	0.83	3.53
4	S (m/km)	2.0980	0.4770	1.9187	0.2705

Where, A is catchment area in km^2, L is the length of the main channel in km, L_c is the length of the main channel from the perpendicular intercept of the center of the gravity of the catchment in km^2, and S is the slope of the main channel in m/km.

Table 2 Unit hydrograph parameters for the four catchments

S. No.	Unit Hydrograph characteristics	Catchment A	Catchment B	Catchment C	Catchment D
1	t_r (hours)	1	1	1	1
2	t_p (hours)	2.5	3.5	1.5	4.5
3	q_p ($m^3/s/km^2$)	0.65	0.50	0.90	0.42
4	W_{50} (hours)	3.2	4.2	2.1	5.10
5	W_{75} (hours)	1.5	2.1	1.0	2.53
6	W_{R50} (hours)	1.6	2.0	1.2	2.34
7	W_{R75} (hours)	0.9	1.0	0.6	1.17
8	T_B (hours)	11.5	15.2	7.6	18.74
9	T_D (hours)	2.5	3.5	1.5	4.5
10	T_m (hours)	3	4	2	5
11	Q_p (cumecs)	3.9	5.71	3.88	9.08

Where, t_r is the duration of unit hydrograph in hours, t_p is time from the centre of the unit rainfall duration to the peak of unit hydrograph in hours, Q_p is the peak discharge of the unit hydrograph in cubic meters per second (cumecs), q_p is the peak discharge of the unit hydrograph per square kilometers of the catchment in m3/s/km^2. W_{50} is the width of the unit hydrograph measure at discharge ordinate equal to 50% of the Q_p. W_{75} is the width of the unit hydrograph measured at discharge ordinate equal to 75% of the Q_p. W_{R50} is the width of the rising limb of the unit hydrograph measure at discharge ordinate equal to 50% of the Q_p. W_{R75} is the width of the of the rising limb of the unit hydrograph measured at discharge ordinate equal to 75% of the Q_p, T_D is the design storm duration computed as $T_D = 1.1 * T_P$ and T_m is the time from the beginning of the rise of the peak of the unit hydrograph. It is summation of t_p and $t_p * 0.5t_r$.

Estimation of flood hydrographs using Unit Hydrograph Approach

The values of hourly rainfall and flood hydrographs computed for the four catchments for the return periods of 25, 50 and 100 years are given in Tables 3 to Table 14. A comparison of design flood hydrographs for return periods of 25, 50 and 100 for the four catchments is shown in Figs. 1 to 4.

The flood hydrographs for probable maximum flood (PMF) for the four catchments were also computed. Value of 1-day probable maximum precipitation (PMP) was adopted as 45 cm from the PMP atlas (IMD, 1988). The distribution coefficients for converting the 1-day PMP value into 24-hour rainfall were adopted from CWC (1997). Considering two bells of the PMP convoluted the PMP values. For this purpose, the maximum 12 values of the PMP were considered as first bell and the remaining 12 values were considered as the second bells. The values of first bell were so arranged that the maximum value is placed at the 9th hour and next to maximum value is placed at 10th hour and next to its at the 8th hour and so on till all the 12 values are arranged. For the second bell highest value is placed at the 15 hour and second highest at the 14th hour and the next highest at the 16th hour and so on till all the values are arranged. The estimated PMF hydrographs and the distributed PMP values are given in Tables 15 to 18, respectively.

Table 3: Flood hydrograph for 25 year return period 3-hour rainfall for catchment A

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	25-Year Flood Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0	0.61
1	10.91	1.5	1.21
2	1.91	2.9	17.82
3	0.82	3.9	35.75
4	0	2.7	48.35
5	0	1.8	36.85
6	0	1.4	25.02
7	0	1	19.05
8	0	0.8	14.01
9	0	0.6	11.11
10	0	0.3	8.51
11	0	0	4.84
12	0	0	1.12
13	0	0	0.61

Table 4: Flood hydrograph for 50 year return period 3-hour rainfall for catchment A

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	50-Year Flood Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0	0.61
1	12.82	1.5	1.42
2	2.25	2.9	21.09
3	0.96	3.9	42.34
4	0	2.7	57.16
5	0	1.8	43.58
6	0	1.4	29.57
7	0	1	22.47
8	0	0.8	16.51
9	0	0.6	13.06
10	0	0.3	9.97
11	0	0	5.61
12	0	0	1.22
13	0	0	0.61

Table 5: Flood hydrograph for 100 year return 3-hour rainfall period for catchment A

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	100-Year Flood Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0	0.61
1	14.73	1.5	1.63
2	2.58	2.9	24.36
3	1.1	3.9	48.92
4	0	2.7	65.94
5	0	1.8	50.28
6	0	1.4	34.09
7	0	1	25.88
8	0	0.8	18.99
9	0	0.6	15
10	0	0.3	11.42
11	0	0	6.38
12	0	0	1.32
13	0	0	0.61

Table 6: Flood hydrograph for 25 year return period 4-hour rainfall for catchment B

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	25-Year Flood Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0.00	1.12
1	10.39	1.50	1.38
2	2.52	2.80	5.06
3	1.34	4.20	23.58
4	0.59	5.70	41.99
5	0.00	4.30	60.94
6	0.00	3.20	74.37
7	0.00	2.40	59.14
8	0.00	2.00	44.44
9	0.00	1.60	34.06
10	0.00	1.30	28.11
11	0.00	1.00	22.85
12	0.00	0.60	18.58
13	0.00	0.40	14.23
14	0.00	0.20	9.32
15	0.00	0.00	6.34
16	0.00	0.00	3.61
17	0.00	0.00	1.35
18	0.00	0.00	1.12

Table 7: Flood hydrograph for 50 year return period 4-hour rainfall for catchment B

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	50-Year Flood Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0	1.12
1	12.19	1.5	1.54
2	2.97	2.8	6.05
3	1.56	4.2	28
4	0.7	5.7	49.88
5	0	4.3	72.16
6	0	3.2	87.84
7	0	2.4	69.84
8	0	2	52.45
9	0	1.6	40.16
10	0	1.3	33.1
11	0	1	26.86
12	0	0.6	21.79
13	0	0.4	16.63
14	0	0.2	10.82
15	0	0	7.28
16	0	0	4.06
17	0	0	1.39
18	0	0	1.12

Table 8: Flood hydrograph for 100 year return period 4-hour rainfall for catchment B

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	100-Year Flood Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0	1.12
1	14	1.5	1.69
2	3.4	2.8	6.97
3	1.8	4.2	32.34
4	0.8	5.7	57.68
5	0	4.3	83.31
6	0	3.2	101.34
7	0	2.4	80.6
8	0	2	60.51
9	0	1.6	46.3
10	0	1.3	38.12
11	0	1	30.9

12	0	0.6	25.01
13	0	0.4	19.05
14	0	0.2	12.34
15	0	0	8.23
16	0	0	4.52
17	0	0	1.44
18	0	0	1.12

Table 9: Flood hydrograph for 25 year return period 2-hour rainfall for catchment C

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	25-Year Flood Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0	0.41
1	10.5	2.4	24.61
2	1.3	3.9	42.34
3	0	1.8	22.81
4	0	1.3	15.48
5	0	1	11.91
6	0	0.7	8.56
7	0	0.3	4.2
8	0	0	0.74

Table 10: Flood hydrograph for 50 year return period 2-hour rainfall for catchment C

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	50-Year Flood Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0	0.41
1	12.33	2.4	29
2	1.52	3.9	50.01
3	0	1.8	26.96
4	0	1.3	18.25
5	0	1	14.03
6	0	0.7	10.06
7	0	0.3	4.9
8	0	0	0.81

Table 11: Flood hydrograph for 100 year return period 2-hour rainfall for catchment C

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	100-Year Flood Hydrograph
(hours)	**(cm)**	**(cumecs)**	**(cumecs)**
0	0	0	0.41
1	14.15	2.4	33.36
2	1.75	3.9	57.66
3	0	1.8	31.13
4	0	1.3	21.03
5	0	1	16.14
6	0	0.7	11.56
7	0	0.3	5.61
8	0	0	0.88

Table 12: Flood hydrograph for 25 year return period 5-hour rainfall for catchment D

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	25-Year Flood Hydrograph
(hours)	**(cm)**	**(cumecs)**	**(cumecs)**
0	0	0	2.14
1	10.35	1.6	2.98
2	2.66	3.2	7.73
3	1.26	5.3	28.96
4	0.94	7.5	53.16
5	0.47	9.1	82.77
6	0	7.6	110.84
7	0	5.5	125.15
8	0	4.2	106.37
9	0	3.6	80.42
10	0	3.0	62.86
11	0	2.5	53.14
12	0	2.0	44.6
13	0	1.5	37.26
14	0	1.0	30.03
15	0	0.8	22.97
16	0	0.5	16.6
17	0	0.4	13.13
18	0	0.2	9.4
19	0	0	7.42
20	0	0	4.72
21	0	0	2.46
22	0	0	2.2
23	0	0	2.14

Table 13: Flood hydrograph for 50 year return period5-hour rainfall for catchment D

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	50-Year Flood Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0	2.14
1	12.15	1.6	3.25
2	3.13	3.2	9.03
3	1.47	5.3	34.25
4	1.11	7.5	63.02
5	0.55	9.1	98.18
6	0	7.6	131.28
7	0	5.5	148.04
8	0	4.2	125.86
9	0	3.6	95.23
10	0	3.0	74.39
11	0	2.5	62.78
12	0	2.0	52.61
13	0	1.5	43.87
14	0	1.0	35.26
15	0	0.8	26.9
16	0	0.5	19.34
17	0	0.4	15.2
18	0	0.2	10.77
19	0	0	8.41
20	0	0	5.21
21	0	0	2.53
22	0	0	2.21
23	0	0	2.14

Table 14: Flood hydrograph for 100 year return period 5-hour rainfall for catchment D

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	100-Year Flood Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0	2.14
1	13.95	1.6	3.51
2	3.6	3.2	10.29
3	1.7	5.3	39.48
4	1.3	7.5	72.82
5	0.6	9.1	113.53
6	0	7.6	151.69
7	0	5.5	170.94
8	0	4.2	145.40
9	0	3.6	110.08
10	0	3.0	85.94
11	0	2.5	72.43
12	0	2.0	60.63
13	0	1.5	50.50
14	0	1.0	40.52
15	0	0.8	31.83
16	0	0.5	22.08
17	0	0.4	17.28
18	0	0.2	12.14
19	0	0	9.39
20	0	0	5.69
21	0	0	2.61
22	0	0	2.23
23	0	0	2.14

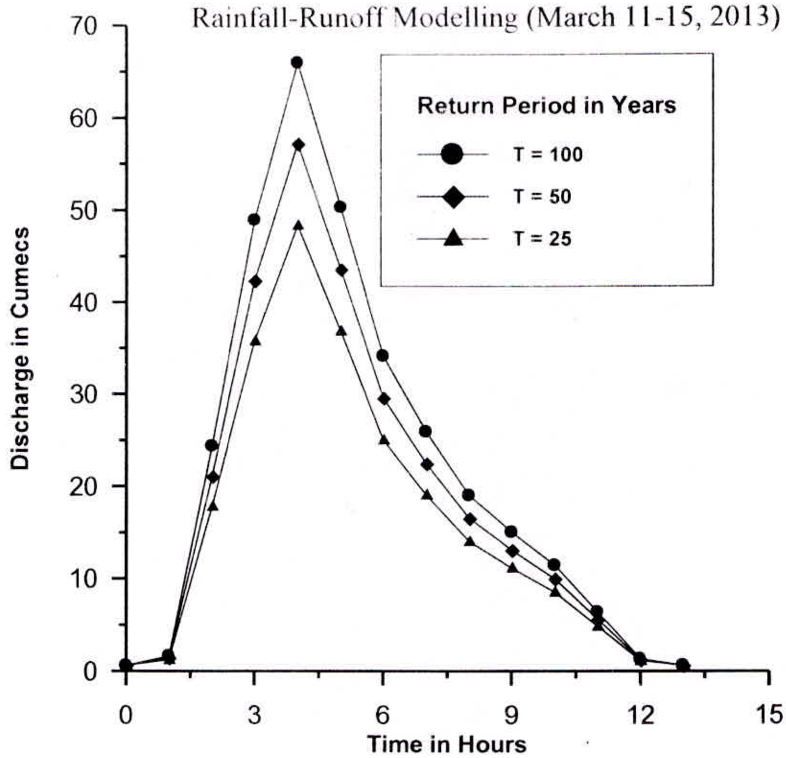

Fig. 7 Flood hydrographs for catchment A for 25, 50 and 100 year return periods

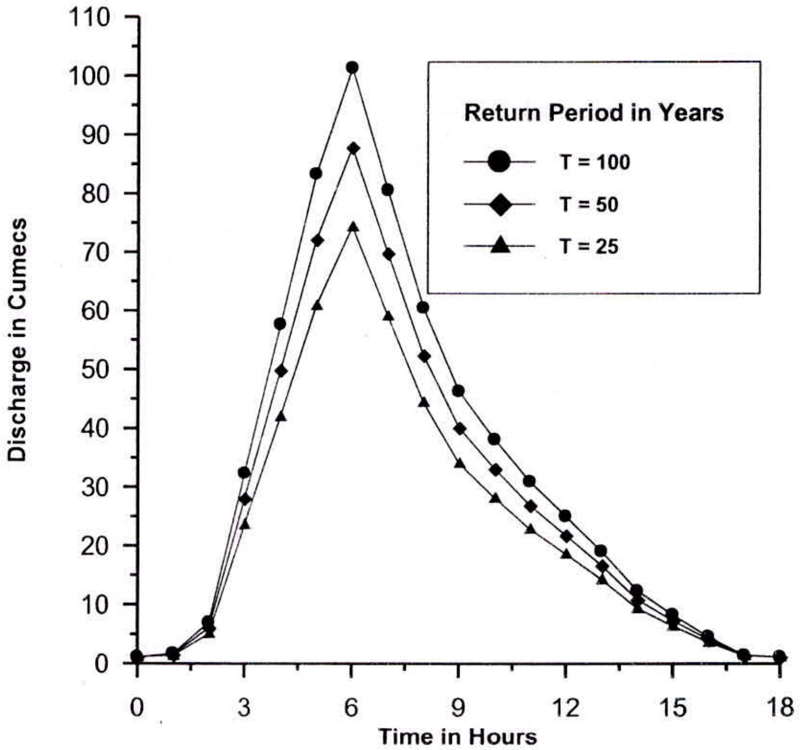

Fig. 8 Flood hydrographs for catchment B for 25, 50 and 100 year return periods

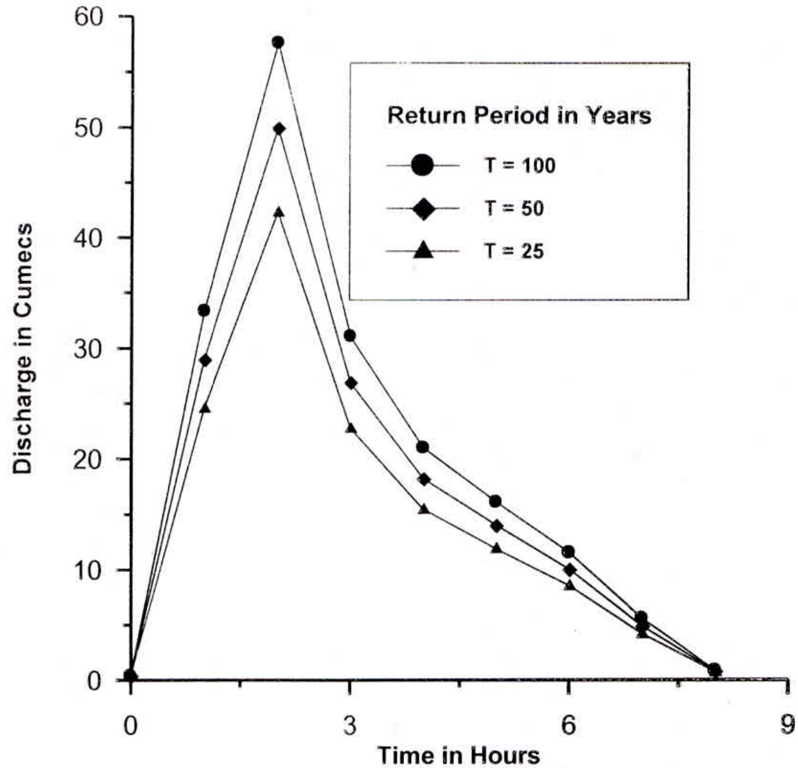

Fig. 9 Flood hydrographs for catchment C for 25, 50 and 100 year return periods

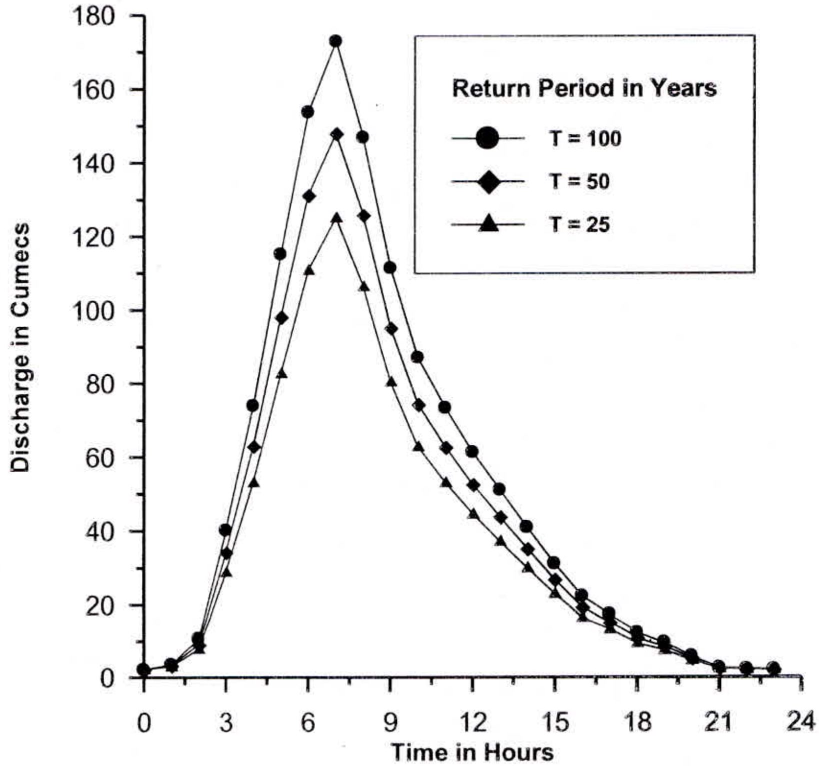

Fig. 10 Flood hydrographs for catchment D for 25, 50 and 100 year return periods

Table 15: PMF hydrograph for catchment A

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	PMF Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0	0.61
1	1.329	1.5	2.6
2	1.329	2.9	6.45
3	1.329	3.9	11.64
4	1.329	2.7	15.23
5	1.779	1.8	18.29
6	2.229	1.4	22.13
7	2.679	1	27.2
8	3.579	0.8	33.89
9	8.529	0.6	48.5
10	4.029	0.3	62.67
11	2.679	0	71.22
12	2.679	0	65.5
13	1.329	0	56.68
14	1.329		49.17
15	1.329		41.79
16	1.329		36.79
17	0.879		32.16
18	0.879		26.85
19	0.879		21.67
20	0.879		19.06
21	0.879		17.58
22	0.879		16.68
23	0.429		15.55
24	0.429		13.89
25			11.22
26			8.62
27			6.14
28			4.35
29			3.13
30			2.17
31			1.47
32			0.99
33			0.74
34			0.61

Table 16: PMF hydrograph for catchment B

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	PMF Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0.00	1.13
1	1.329	1.50	3.12
2	1.329	2.80	6.84
3	1.329	4.20	12.43
4	1.329	5.70	20
5	1.779	4.30	26.39
6	2.229	3.20	32.58
7	2.679	2.40	39.59
8	3.579	2.00	49.32
9	8.529	1.60	67.78
10	4.029	1.30	86.33
11	2.679	1.00	103.41
12	2.679	0.60	116.36
13	1.329	0.40	109.83
14	1.329	0.20	98.84
15	1.329	0.00	87.73
16	1.329	0.00	78.19
17	0.879	0.00	69.95
18	0.879	0.00	62.71
19	0.879		55.51
20	0.879		47.59
21	0.879		41.74
22	0.879		37.06
23	0.429		32.69
24	0.429		29.54
25			25.84
26			21.31
27			17.12
28			12.97
29			9.86
30			7.5
31			5.75
32			4.31
33			3.17
34			2.34
35			1.73
36			1.39
37			1.21
38			1.13

Table 17: PMF hydrograph for catchment C

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	PMF Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0	0.41
1	1.329	2.4	3.6
2	1.329	3.9	8.79
3	1.329	1.8	11.18
4	1.329	1.3	12.91
5	1.779	1	15.31
6	2.229	0.7	19.08
7	2.679	0.3	23.12
8	3.579	0	28.43
9	8.529		45.67
10	4.029		57.14
11	2.679		47.33
12	2.679		40.67
13	1.329		34.19
14	1.329		27.35
15	1.329		22.13
16	1.329		18.22
17	0.879		15.52
18	0.879		13
19	0.879		11.92
20	0.879		11.33
21	0.879		10.88
22	0.879		10.57
23	0.429		9.35
24	0.429		7.6
25			5.76
26			3.5
27			2.28
28			1.41
29			0.84
30			0.54

Table 18: PMF hydrograph for catchment D

Time	Rainfall	1-hr 1-cm Unit Hydrograph Ordinates	PMF Hydrograph
(hours)	(cm)	(cumecs)	(cumecs)
0	0	0	2.14
1	1.329	1.6	4.27
2	1.329	3.2	8.52
3	1.329	5.3	15.57
4	1.329	7.5	25.54
5	1.779	9.1	38.35
6	2.229	7.6	50.61
7	2.679	5.5	62.46
8	3.579	4.2	76.69
9	8.529	3.6	102.13
10	4.029	3	130.41
11	2.679	2.5	160.15
12	2.679	2	187.02
13	1.329	1.5	203.1
14	1.329	1	195.52
15	1.329	0.8	177.05
16	1.329	0.5	159.26
17	0.879	0.4	144.36
18	0.879	0.2	131.13
19	0.879	0	119.2
20	0.879	0	107.41
21	0.879	0	95.44
22	0.879	0	84.91
23	0.429	0	76.72
24	0.429		68.89
25			61.23
26			52.39
27			42.51
28			34.07
29			26.57
30			20.79
31			16.45
32			13.07
33			10.22
34			7.94
35			6.2
36			4.89
37			3.88
38			3.23
39			2.71
40			2.4
41			2.23
42			2.14

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