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REGIONAL FLOOD FREQUENCY STUDIES THROUGH REGIONAL UNIT HYDROGRAPH

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SYNOPSIS

The estimation of floods for small and medium catchments poses a problem due to impractiability of collecting site specific long term data to overcome this Central Water Commission has therefore been using a method which uses regional estimate of storm of the desired frequency convolated with the representive unit hydrograph. To obtain design flood hydrograph, this paper outlines the methodology and brings out the limitations.

1.0 Introduction

Design Engineers dealing with the design of road and railway bridges, cross drainage works, small dams etc are faced with the problem of design flood estimation for these structures. Design floods for these structures are decided on the basis of say 50-yrs or 100-yrs return period with a calculated risk of the flood beeing exceeded. A frequency flood is adopted depending on the functional importance with judicious combination of safety and economy. In the absence of rational methods of design flood estimation engineers had been applying the age old methods of emperical flood formulae like Dickens, Ryves, Inglis etc.

An urgent need was, therefore, felt in the country to fill up this gap and evolve a rational scientific and sound hydrologic design for estimation of frequency flood for the design of culverts, bridges cross drainage structures like aequaducts etc. minor dams and tanks on streams with small and meduim catchments.

2.0 Regional Approach to Flood Frequency Estimation

The flood frequency concept involves availability of long term peak discharges of streams under similar catchment conditions at sites for stastitical analysis to estimate the floods of different return periods say 5-yrs, 10-yrs, 25-yrs 50-yrs and 100-yrs etc. However, it is, in general not feasible to undertake hydrologic investigations at each specific site.

Flood Estimation Through Regional Unitgraph

The other approach is to evolve a regional frequency storm rainfall loss synthetic unit hydrograph model for a hydrometerologically homogeneous regions. Regional relationships are established between the physiographic and regional unit hydrograph (RUG) parameters to derive a synthetic unitgraph (SUG) with standard unit duration for ungauged small and medium catchments in the same region. Frequency point rainfall maps for different return period and duration are prepared for the region on the basis of avilable long term short duration rainfall data. Areal and time distribution factors are also evolved for obtaining rainfall units corresponding to unit duration of SUG. Modal value of constant loss rate used to conversion of design storm rainfall units to effective rainfall units (or rainfall excess). These effective rainfall units in a critical sequence are applied to SUG for obtaining the direct ruoff hydrograph. The modal base flow is added to the total direct runoff to obtain the design flood hydrograph.

3.0 Approach for Regional Estimation:-

Broadly two approach are followed for the flood estimation based on regional flood frequency studies :-

(a) Detailed Approach:-

The detailed approach consists of working out the synthetic unit graph (SUG) parameter from the recommended formulae of that sub zone, drawing and adjusting SUG, computation of design storm duration and areal rainfall, distribution of rainfall, estimation of base flow and computation of 50 yr. flood peak and 50 yr flood hydrograph.

The detailed approach gives more reliable result but takes a longer time. The detailed approach also give the complete flood hydrograph for flood routing to design a minor irrigation tank.

Data Requirements:-

For unitgraph studies the following data are required:-

(1) Hourly gauge data at the gauging site.
(2) Hourly rainfall data for raingauge stations in the catchments.
(3) Gauge and discharge data observed at the gauging site.
(4) Catchment area plan showing the river network, raingauge stations, gauge and discharge sites, contours, roads and railway network natural and manmade storages, forests, habitaions, agricultural and irrigation areas soils etc.
(5) Cross sections at the bridge site and also up and down of the bridge site.

If such data are available for a number of small and medium catchments in the sub zone, the regional unit hydrograph parameters can be decided. Once the regional study is available and is to be used no localised specific data is necessary except for the down stream cross section which would be utilised for converting discharges into flood levels.

Procedure

In the computation of design flood on regional basis the following steps are involved:-

(1) Analysis of physiographic parameters catchment area (A) lengths (L & Lc) and equivalent slope (S) in m/km ((L) longest main stream along the river course in km. Lc - length of the longest main stream from the point opposite to the centroid of the catchment area to the gauging site along the main stream in km).
(2) Scrutiny of data, finalisation of gauge and discharge curves.
(3) Selection of flood on corresponding storm events.
(4) Seperation of base flow and computation of dircet runoff.
(5) Computation of infilteration loss and effective rainfall units.
(6) Deriving unitgraphs.
(7) Drawing the RUG.
(8) Establishing relationship between physiographic and RUG parameters.
(9) Derivation of SUG for the region.

(b) Simlified Approach:-

For some one interested in 50 year flood peak only for prelimenary assement of water way of bridges and cross drainage structure a direct 50-year flood peak formulae are easy and simple one relating qp (peak discharge of unitgraph per unit area of catchment in cumecs/sq. km.) with the physiographic parameters L & S can been evolved by this methodology. In the simplified approach the 50 yr. flood peak is only estimated based on relationship of 50 yr flood peak and physiographic parameters and 50 yr TD-hr (Design storm duration in Hrs) point rainfall read from the isopluvial maps. The simplified approach by using flood frequency formulae will give only 50 yr flood peak for designing the bridge and cross drainage structures.

4.0 ASSUMPTION AND LIMITATIONS

The steps involved, main assumptions and limitations are mentioned below:

1.	Rainfall with required return period is to be estimated.	This does not pose serious problem.
2.	The distribution of rainfall for short period is to be decided.	This is some what problamatic but based on the analysis of SRRG data this is possible.
3.	The unit hydrograph for the problem catchment	This is done through regionalisation of U.G. parameters i.e. relat-

is to be decided.	ing to area, shape etc. through analysis of observed events.
4. The infilteration under design storm to be decided.	This is perhaps the weakest link, since a large storm can produce a a smaller flood with large infilteration. At present a standardised infilteration rate is beeing recommended after ensuring that its use gives results in conformity with the results of the direct flood frequency analysis for the catchment with longer data.

5.0 ILLUSTRATIVE EXAMPLE FOR APPLICATION OF THE ABOVE METHODOLOGY BY DETAILED APPROACH :-

Illustrative example for estimation of design flood for bridge no 505 of Central railway in sub zone 3(c) on river Passa.

The step by step solution of the above examples as below:-

Step-1: Preperation of Catchment area plan:

Catchment area upto the point of study was marked on the Survey of India toposheets and was traced withall details as shown in Fig. 1.

Step-2: Computation of Physiographic Parameters:

From the catchment area plan prepared, the area of the catchment (A) in sq km and the length of the longest main stream (L) in km from the farthest catchment boundary to the point of study was measured. The length of the main longest stream opposite to the centre of gravity to the point of study (Lc) was measured in km.,

Statistical stream slope (Sst) is worked out based on L-section (shown in Fig.1) of the longest main stream.

Results are given in Annexure-1. The following physiographic parameters are worked out for Br. No.505 as below:-

A = 70.18 sq.km., L = 23.10 km., Lc = 12.88 km., S = 3.19 m/km. and $LLc/\sqrt{s}$ = 166.58.

Step-3: Determination of 1-hr Synthetic Unit Graph(SUG) Parameters:

The following SUG relationships were used to compute the 1-hr U.G. parameters:

i) $t_p = 0.854 \left(\frac{LLc}{\sqrt{s}}\right)^{0.28} = 3.58$ (rounded to 3.5)

(this is rounded to nearest half hour so as to get t_m as a whole value since t_r is 1-hr)

ii) $t_m = t_p + t_r/2 = 3.5 + 0.5 = 4.0$

iii) $q_p = 2.009\,(t_p)^{-0.85} = 2.009(3.5)^{-0.85}$
$= 0.69$ cumecs/sq.km.

iv) $W_{50} = 2.259\,(q_p)^{-1.08} = 2.259(0.69)^{-1.08}$
$= 3.37$ hrs.

v) $W_{75} = 1.519\,(q_p)^{-0.99} = 1.519(0.69)^{-0.99}$
$= 2.19$ hrs.

vi) $W_{R50} = 0.844\,(q_p)^{-1.24} = 0.844(0.69)^{-1.24}$
$= 1.34$ hrs.

vii) $W_{R75} = 0.583\,(q_p)^{-1.19} = 0.583(0.69)^{-1.19}$
$= 0.91$ hrs.

viii) $T_B = 4.84(t_p)^{0.74} = 4.84(3.5)^{0.74}$
$= 12.23$ hrs. (say 12hrs)

ix) $Q_P = q_p * A = 0.69*70.18$
$= 48.42$ cumecs
(say 48.50 cumecs)

Step-4: Preparation of 1-hr Synthetic U.G.:

The above U.G. parameters were plotted on a natural graph paper and 1-hr U.G. was drawn as shown in (fig 2) and suitably adjusted to equate the volume of 1 cm depth of effective rainfall (rainfall excess) over the catchment. This is the sum of the U.G. ordinates at 1-hr intervals = area/$(0.36*t_r)$

$= 70.18/(0.36*1.0)$
$= 195.00$ cumecs

Step-5: Design Storm Duration:

Design Storm Duration $(T_D) = 1.1 *(t_p)$

=1.1*3.5
=3.85 =4.0 hrs

Step-6: 50-yr TD -hr Point Rainfall:

Catchment upto Br. No. 505 was located on 50-yr 1,3,6,9,12,15,18 and 24 hrs rainfall maps and their point rainfall values are read as given in table-1.

Table-1

Hour	Point Rainfall in mm	Rainfall read from curves in mm
1	82	
3	130	
4	-	162
6	200	
9	235	
12	280	
15	310	
18	320	
24	360	

The point rainfall values in col.(2) were plotted againest duration to get a depth duration curve. Rainfall for design storm duration of 4 hr was read from the curve which is 162 mm or 16.20 cm (fig.3).

Step:- 7 50-yr.TD-hr. Areal Rainfall:

An areal reduction factor of 0.92 (or 92 percent) correspon-ding to a catchment area of 70.18 sq.km and 4-hr.design storm duration was interpolated from Annexure-2.

so 50yr. 4hr. areal rainfall = 16.20 x 0.92
= 14.90 cm.

Step-8: Time distribution of areal rainfall:

The design storm duration is(TD) 4-hrs. Therefore, mean ave-rage time distribution curve of storm rainfall for storm duration of 4 to 6 hrs was selected(fig. 4). The 50-yr 4-hr areal rainfall was split into hourly rainfall using the above curve. The hourly rainfall increments are then worked out and given in Table-2.

Table-2

Time (hrs)	Percentage of storm duration col(1)*100 / TD	cumulative percentage of total rainfall	cumulative rainfall depth RTD*col(3) / 100 (cms)	rainfall increment (cms)
1	2	3	4	5
0	0	0	0	0
1	25	58	8.64	8.64
2	50	78	11.62	2.98
3	75	93	13.85	2.23
4	100	100	14.90	1.05

Step-9: <u>Estimation of 1-hr effective rainfall units</u>:

A constant value of 0.30 cm/hr as design loss rate (modal value) is adopted. This value is deducted from the 1-hr rainfall increments in col-5 of Table-2 in Step-8 to get 1-hr effective rainfall. The results are tabulated in Table-3 given.

Table - 3

Time hrs	Rainfall incre-ments (cms)	Design loss rate cm/hr	Effective Rainfall (cms)
1	2	3	4
1	8.64	0.30	8.34
2	2.98	0.30	2.68
3	2.23	0.30	1.93
4	1.05	0.30	0.75

Step-10: <u>Estimation of Base Flow</u>:

Design base flow adopted is 0.05 cumecs/sq km as recommended in the Flood Estimation report on the sub-zone 3(c) published by this Dte. of CWC.

Step-11: <u>Estimation of 50-yr Flood (Peak only)</u>:

There are four effective rainfall units. The SUG ordinates nearer to the peak are selected. The maximum effective rainfall was placed against the max. peak ordinate of U.G. The next max. effective rainfall was placed against the next max. value of U.G.

ordinate and so on. The product of effective rainfall and U.G. ordinate value gives the direct runoff. The sum of direct runoff gives the total direct runoff peak to which the base flow is added to get the 50-yr flood peak. Results are given in Table-7 below:

Table-7

Time (hrs)	U.G. ordinate cumecs	1-hr effec. rainfall (cms)	Direct Runoff (cumecs)
1	2	3	4
3	31.0	1.93	59.83
4	48.5	8.34	404.49
5	43.0	2.68	115.24
6	25.0	0.75	18.75
		Total	598.31
		Add Base Flow	3.51
		50-yr Flood Peak	601.82

Step-12: <u>Computation of 50-yr Flood Hydrograph</u>:

Table-8 below shows the computation of 50-yr flood hydrograph. 1-hr effective rainfall units in col(3) of Step-11 were reversed to get the critical sequence for rainfall. Each effective rainfall was multiplied with U.G. ordinates to get the direct runoff ordinates in col(3) to col(6) with a lag of 1-hr between each successive unit. The ordinates of design runoff hydrograph (DRH) were added to get total DRH ordinates. The base flow of 3.51 cumecs was added to DRH ordinates to get the total flood hydrograph ordinates with a 50-yr return period as shown in fig. 5.

6.0 CONCLUSIONS

The methodology as described above for estimating the design flood of 50-yrs return period is recommended for adoption for small and medium catchments since:-

(1) The physical constants of the catchment are taken into account directly.
(2) Rainfall values are frequency based which are more sound than using limited discharge data directly.
(3) Relations are derived from a number of samples so weightage is given for a large range of areas.

COMPUTATION OF DESIGN FLOOD HYDROGRAPH

SUB-ZONE 3(c) BRIDGE NO: 505

TIME IN HOURS	S.U.H. ORDINATES IN CUMECS	1-HOURLY RAINFALL EXCESS (CM) 0.75	2.68	8.34	1.93	TOTAL D.S.R.O. IN CUMECS	BASE FLOW IN CUMECS	TOTAL FLOOD FLOW IN CUMECS	
0	0.00	0.00				0.00	3.51	3.51	
1	4.50	3.38	0.00			3.38	3.51	6.89	
2	12.00	9.00	12.06	0.00		21.06	3.51	24.57	
3	31.00	23.25	32.16	37.53	0.00	92.94	3.51	96.45	
4	48.50	36.38	83.08	100.08	8.69	228.22	3.51	231.73	
5	43.00	32.25	129.98	258.54	23.16	443.93	3.51	447.44	
6	25.00	18.75	115.24	404.49	59.83	598.31	3.51	601.82	--->PI
7	14.00	10.50	67.00	358.62	93.61	529.73	3.51	533.24	
8	8.50	6.38	37.52	208.50	82.99	335.39	3.51	338.90	
9	5.80	4.35	22.78	116.76	48.25	192.14	3.51	195.65	
10	2.50	1.88	15.54	70.89	27.02	115.33	3.51	118.84	
11	1.00	0.75	6.70	48.37	16.41	72.23	3.51	75.74	
12	0.00	0.00	2.68	20.85	11.19	34.72	3.51	38.23	
			0.00	8.34	4.83	13.17	3.51	16.68	
				0.00	1.93	1.93	3.51	5.44	
					0.00	0.00	3.51	3.51	

7.0 References

(1) Report of the Khosla Committee of Engineers (October, 1959) Government of India, Ministry of Railways.

(2) Hand Book of Hydrolgy, Ven-Te-Chow.

(3) Guide to Hydrological Practices (Third Edition) World Metereological Organisation No. 168, 1974.

(4) Estimation of Design Flood Recommended Procedures Sept. 1972, Government of India, Central Water Commission, New Delhi.

ANNEXURE - 1

CALCULATION OF STASTICAL STREAM SLOPE

SUB-ZONE 3 (c) BRIDGE NO : 505

Sl No	Reduced Distance (km)	Reduced Level (m)	Length of reach (km)	Differance in elevation (m)	Slope col(5) / col(4)	L/_/S
1	0	315.47	0	0	0	
2	2.49	335.28	2.49	19.31	7.96	0.88
3	7.64	343.81	5.15	8.53	1.66	4.00
4	11.99	350.52	4.35	6.71	1.54	3.51
5	12.87	359.66	0.88	9.14	10.39	0.27
6	19.15	381.00	6.28	21.34	3.40	3.41
7	23.10	457.20	3.85	76.20	19.84	0.86
				TOTAL :		12.93

$$\text{Slope (S)} = \left(\frac{L}{L/\_/S}\right)^2 = \left(\frac{23.10}{12.93}\right)^2$$

$$= 3.19 \text{ m/km.}$$

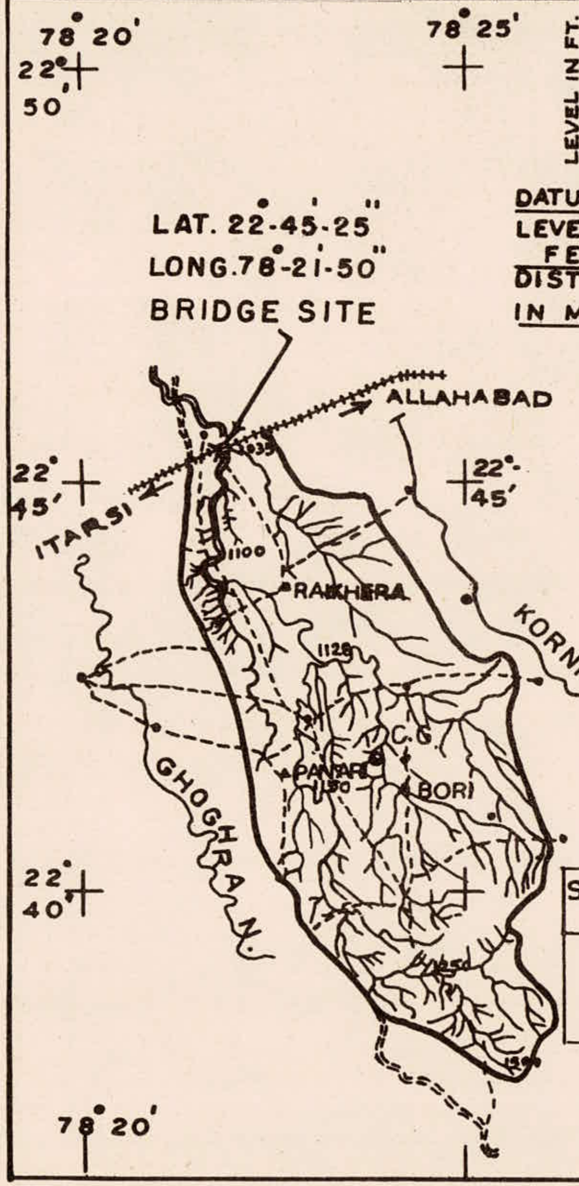
ANNEXURE - 2

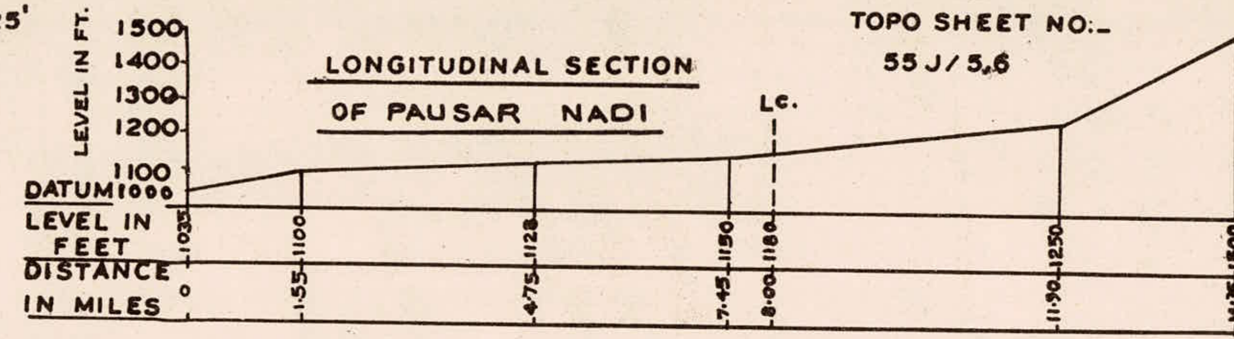
AREA REDUCTION FACTORS (ARF) FOR VARIOUS AREAS AND DURATIONS

SUB-ZONE - 3(c)

Area in sq km	1-hr	3-hr	6-hr	12-hr	24-hr
50	82	93	96	97	99
100	80	88	93	94	97
150	74	84	90	91	96
200	70	82	87	90	95
250	67	79	85	88	94
300	64	75	83	87	93
350	-	74	82	87	92
400	-	74	80	86	92
450	-	73	79	85	91
500	-	-	78	85	91
600	-	-	-	84	90
700	-	-	-	84	89
800	-	-	-	83	89
900	-	-	-	82	88
1000	-	-	-	82	87
1500	-	-	-	81	86
2000	-	-	-	80	85
2500	-	-	-	-	85
3000	-	-	-	-	84
3500	-	-	-	-	83
4000	-	-	-	-	82
5000	-	-	-	-	81

FIG. :1





TOPO SHEET NO:- 55 J/5,6

NOTES —

ALL LEVELS CORRESPOND TO G.T.S DATUM

H.F.L AT BRIDGE SITE

REFERENCES —

1. CATCHMENT BOUNDARY
2. RIVER & ITS TRIBUTARIES
3. RAILWAY LINE
4. ROADS
5. R.G. STATIONS ... ▲BORI
6. SPOT LEVEL .... •1250

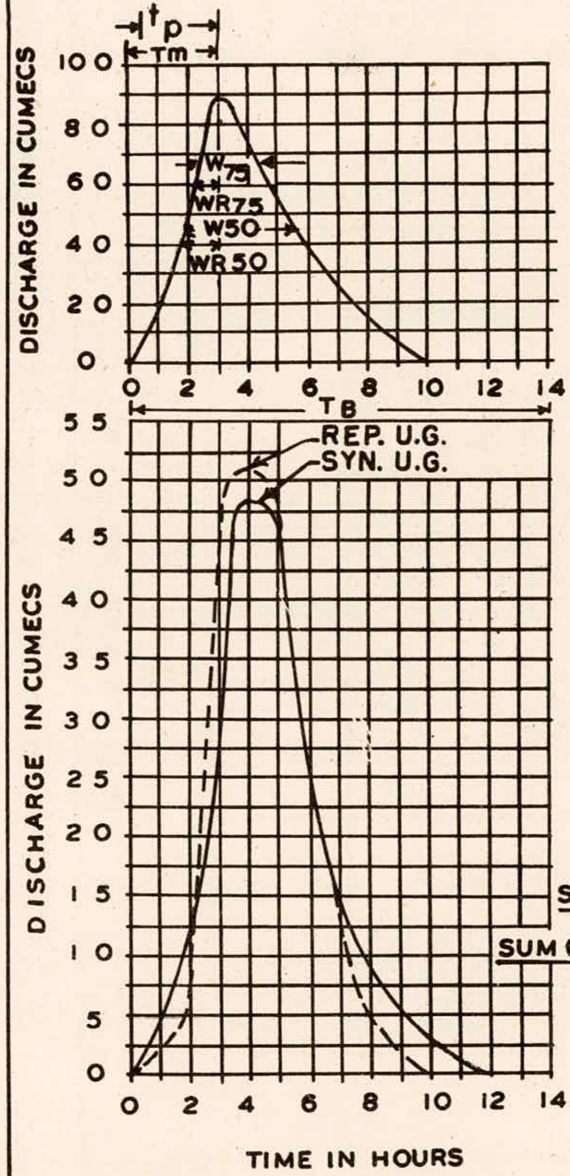
DETAILS OF CATCHMENT —

1. AREA OF CATCHMENT . . 27.1 Sq. M (70.18 Km².)
2. SHAPE OF CATCHMENT . . LEAF
3. LENGTH . . . . . . 14.35 M., (23.10 Km.)
4. Lc . . . . . . 8 M., (12.88 Km.)
5. Wc . . . . . . 3.6 M., (5.8 Km.)
6. S_{st} . . . . . . 3.18 Mt/Km.
7. S_{Lc} . . 2.21 M/Km.

S.No.	NAME OF R.G. STATION	LOCATION LONG.	LATI.	STN. Wt. 65	66	67	68	69
1	RAIKHERA	78° 22' 45"	22° 43' 50"	.31	.34	.34	.36	.36
2	PANARI	78° 22' 40"	22° 41' 30"	.52	.66	.66	—	—
3	BORI	78° 24' 15"	22° 41' 20"	.17	—	—	.64	.64

CATCHMENT AREA PLAN OF PAUSAR NADI BR. NO. 505/813/4-5 SUB ZONE 3 (C)

FIG. : 2



HOURS	SYN. U.G	REP. U.G.
0	0	0
1	4.5	2
2	12.0	8
3	31.0	41
4	48.5	51
5	43.0	49
6	25.0	28
7	14.0	11
8	8.5	4
9	5.0	1
10	2.5	0
11	1.0	-
12	0	-
TOTAL	195	195

COMPARISION OF PARAMETERS

SYMBAL	FOR SYN. U.G.	FOR REP. U.G.
Q_P	48.5 Cum.	51.0 Cum.
T_m	4 Hours	4.0 Hours
t_p	3.5 Hrs.	3.5 Hrs.
W_{50}	3.37 Hrs.	3.4 Hrs.
W_{R50}	1.34 Hrs.	1.3 Hrs.
W_{75}	2.19 Hrs.	2.75 Hrs.
W_{R75}	0.91 Hrs.	1.05 Hrs.
T_B	12.0 Hrs.	10.0 Hrs.

$$\text{SURFACE RUNOFF DEPTH} = \frac{\text{SUM OF U.G. ORD. AT 1 hr. INTERVAL} \times 0.36}{\text{CATCHMENT AREA (Sq. Km.)}}$$

$$= \frac{195 \times 0.36}{70.18} = 1.0 \text{ Cm.}$$

SYNTHETIC UNIT HYDROGRAPH

BR. NO.-505

UPPER NARMADA & TAPI BASIN.

SUB ZONE 3(C).

FIG. :3

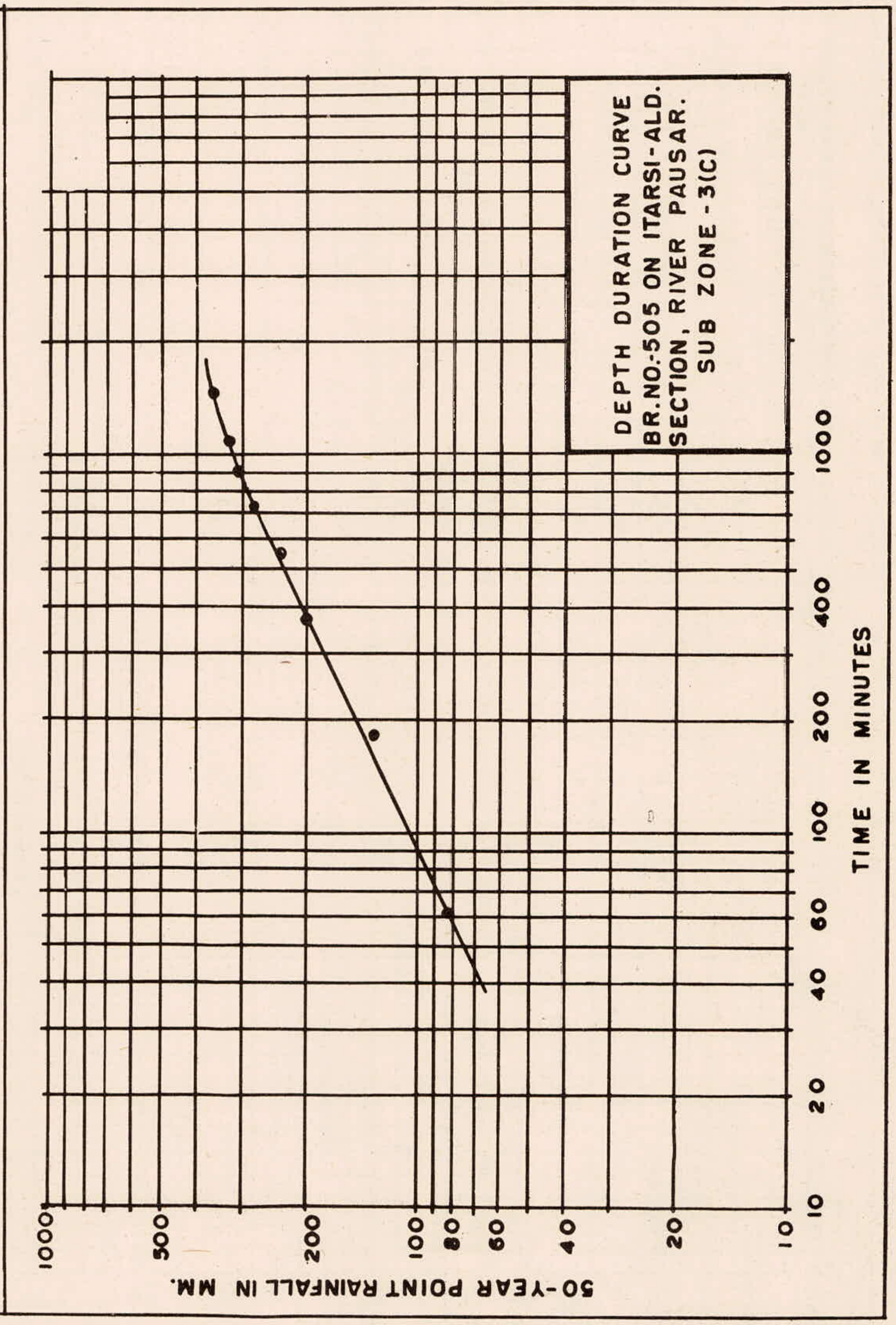
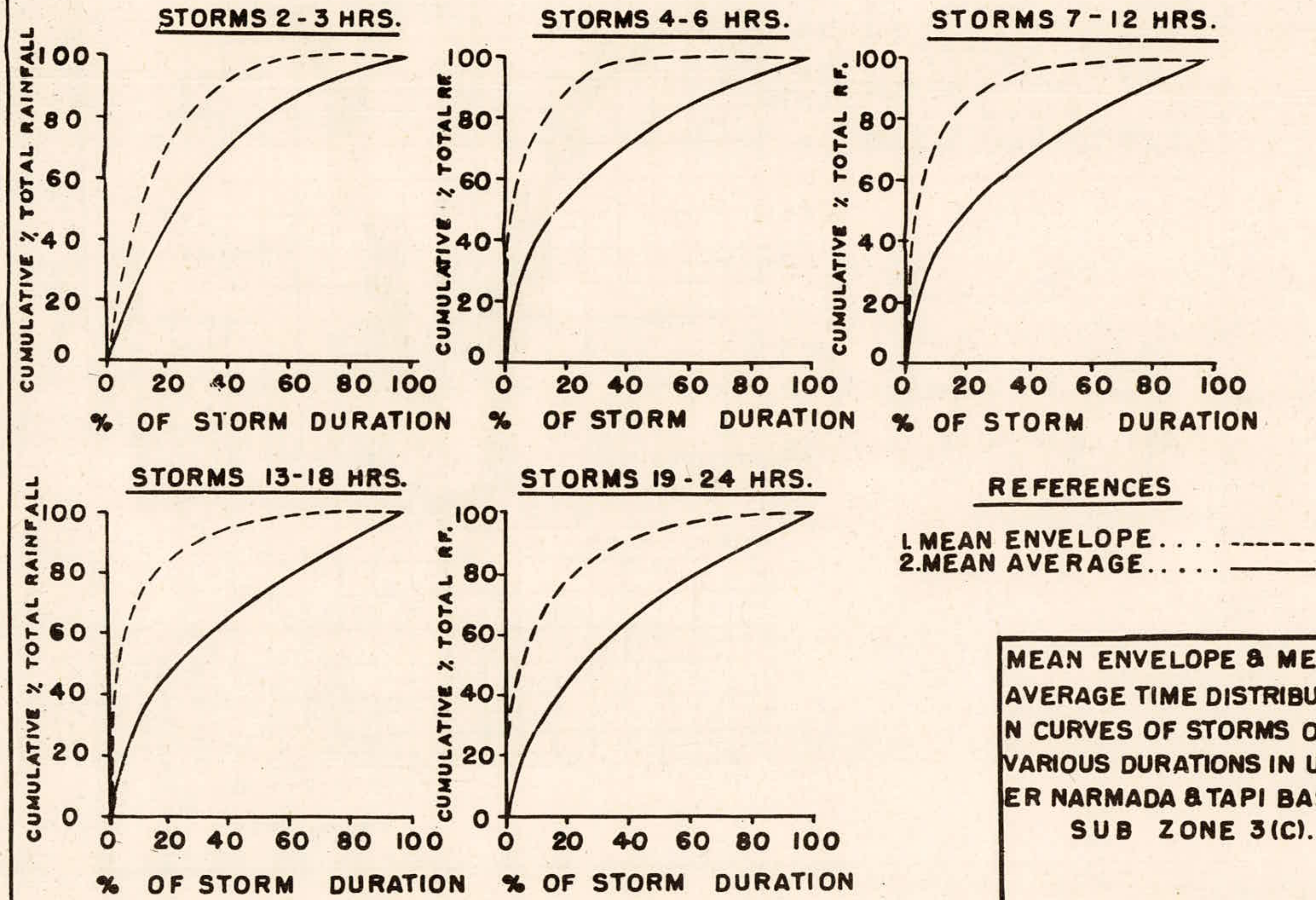
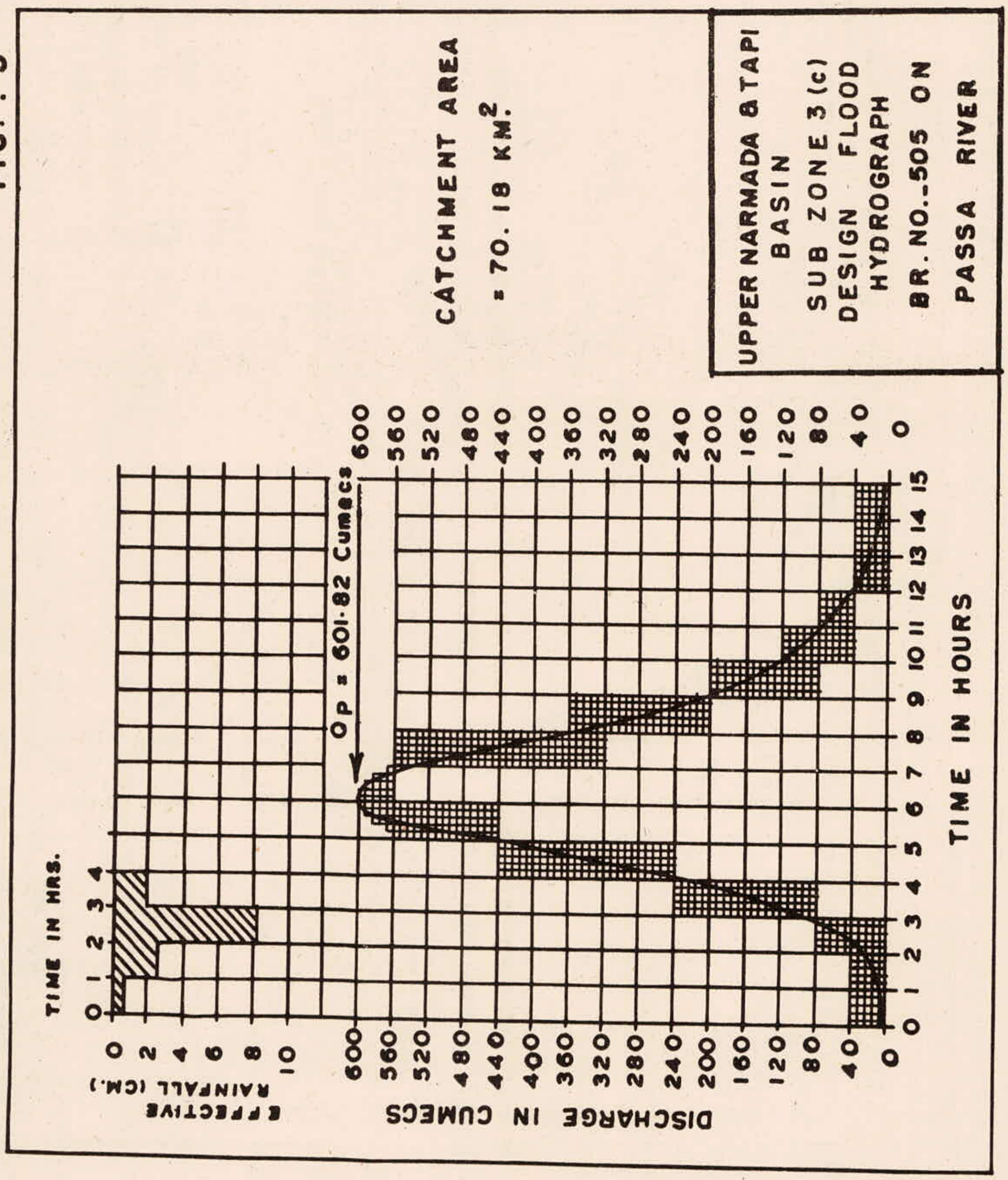

DEPTH DURATION CURVE
BR.NO:-505 ON ITARSI-ALD.
SECTION, RIVER PAUSAR.
SUB ZONE -3(C)
TIME IN MINUTES
10
20
40
60
100
200
400
1000
50-YEAR POINT RAINFALL IN MM.
1000
500
200
100
80
60
40
20
10

FIG. : 4



MEAN ENVELOPE & MEAN AVERAGE TIME DISTRIBUTION CURVES OF STORMS OF VARIOUS DURATIONS IN UPPER NARMADA & TAPI BASIN SUB ZONE 3(C).

FIG. : 5


CATCHMENT AREA
= 70. 18 KM.2
UPPER NARMADA & TAPI
BASIN
SUB ZONE 3 (c)
DESIGN FLOOD
HYDROGRAPH
BR. NO._505 ON
PASSA RIVER
TIME IN HRS.
EFFECTIVE
RAINFALL (CM.)
Qp = 601·82 Cumecs
DISCHARGE IN CUMECS
TIME IN HOURS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 2 4 6 8 10
600 560 520 480 440 400 360 320 280 240 200 160 120 80 40 0