1(e)

F O R E W O R D

The empirical approaches generally followed for estimation of design flood of bridges, culverts and cross drainage works may lead to erroneous conclusions. Studies are under way for rational and scientific estimation of floods of various return periods for safe and yet economic design of structures. Such studies for the following seven sub-zones have been published in the form of Flood Estimation Reports.

1)	Lower Gangetic Plains	-	1(g)
2)	Lower Godavari	-	3(f)
3)	Lower Narmada and Tapi	-	3(b)
4)	Upper Narmada and Tapi	-	3(c)
5)	Mahanadi	-	3(d)
6)	Krishna and Penner	-	3(h)
7)	South Brahamputra	-	2(b)

The present report presents the studies for Upper Indo-Ganga Plains sub-zone - 1 (e) The report was approved by the Planning and Co-ordination Committee in its 40th meeting held in R.D.S.O. (Railways) at Lucknow on 23rd and 24th July, 1984.

This report is a result of a joint effort by Central Water Commission, Research Designs and Standards Organisation (RDSO) of the Ministry of Railways, Roads Wing of the Ministry of Transport, and India Meteorological Department (IMD), in pursuance of the recommendations of the Khosla Committee of Engineers. The rainfall and discharge data from selected catchments was collected by Northern, North Eastern and Western Railways under the overall guidance and supervision of RDSO. The storm studies were carried out by IMD. The flood studies were carried out and the report was prepared in the Hydrology (Small Catchments) Directorate of Central Water Commission.

The studies have been based on the data specially collected for a period of 5 to 10 years by the Indian Railways. Crest gauge observations are being continued by the Railways on the bridge catchments. Also the Ministry of Shipping & Transport have organised special collection of data through CWC. When more data becomes available, further refinements will be possible.

The joint efforts of the Railways, Roads and Water Resources Engineers together with Meteorologists are a landmark in the country in the field of Hydrology of small and medium catchments.

Sd/-

(N.K. SARMA)
MEMBER (WATER RESOURCES), CWC
& EX-OFFICIO ADDITIONAL SECRETARY
TO THE GOVERNMENT OF INDIA.

P R E F A C E

The starting point for any activity dealing with a river is the study of its hydrology. The project planners and engineers have to construct safe and economic structures.

The road and railway net-work cross a number of streams with the small and medium catchments and therefore for the design discharge of these bridges the hydrology of these streams would be required. It is common knowledge that in most of the cases, any hydrological record is not available for these streams. For determining the waterway for bridges and cross drainage works, the design flood of desired frequency are required, but economic constraints do not justify detailed hydrological and meteorological investigation at every new site on a large scale and on long term basis. Waterway should be adequate to pass safely the design flood, but at the same time it should not be too wide involving higher cost. Therefore, it becomes necessary to reasonably estimate the flood discharge of the required return period of stream at the point of study with sufficient care. A casual approach can lead in extreme cases to loss and destruction of structure due to floods of magnitude higher than expected or over design of structures leading to un-economical and problematic situation.

In the early years, design discharges were calculated by well known empirical formulae viz: Dickens, Ryves, Inglis and Ali Nawaz Jung etc. In these formulae, flood discharge is related to catchment area only and all other factors are included in a constant which is to be decided by the designer from his experience. Even intensity of the storm rainfall which is a prime factor responsible for the flood and which varies substantially from place to place is not indicated in the above formulae. The need to evolve a method on estimation of design flood peak of desired frequency knowing the physical characteristics of the catchments and design rainfall has been recognised and a committee of engineers under the Chairmanship of Dr. A.N. Khosla have recommended, "---Systematic and sustained collection of hydro-meteorological data of selected catchments in different climatic zones of India for evolution of a rational approach for determination of flood discharges. The committee felt that design discharge should be maximum flood on record for a period not less than 50 years. Where adequate records are available extending over a period of not less than 50 years, the design flood should be 50 year flood determined from probability curve on the basis of recorded floods during the period. In case where the requisite data, as above are not available, the design flood should be decided based on the ground and meteorological characteristics obtained on the basis of design storm". In this report, a method has been based on unit hydrograph principle to derive the design flood.

A procedure for estimation of design flood peak with characteristics of rainfall storm and the basin characteristics as parameters has been evolved in the short term plan utilising the hydro-meteorological data that was readily available. Systematic and sustained collection of hydro-meteorological data from the representative catchments in the different sub-zones of India also have been started since 1965. For this purpose, the country has been divided into 7 major zones, which are in turn sub-divided into 26 hydro-meteorologically homogeneous sub-zones. Out of 26 sub-zones, gauging has been/ is being carried out in 22 sub-zones, and in each sub-zone 10 to 25 catchments had been selected for the collection of data. The results of the study made utilising the data of representative catchments located in Lower Gangetic Plains subzone - 1(g), Lower Godavari subzone - 3(f), Lower Narmada and Tapi subzone - 3(b), Mahanadi subzone - 3(d), Upper Narmada and Tapi subzone - 3(c) and Krishna & Penner Basins subzone - 3(h) have been brought out earlier in separate reports. In the present report on Upper Indo-Ganga Plains subzone - 1(e) studies have been made on the data collected in the subzone and the method recommended for the estimation of design flood for subzone - 1(e) is given. The gauging data of 137 bridge years collected for 23 railway bridges during the period 1961 to 1982 has been considered for analysis in this report. The gauging data was collected by Northern and North-eastern Railways under the supervision of Bridges and Flood Wing of R.D.S.O., Ministry of Railways. The Central Water Commission has collected the data of 2 road bridges in the sub-zone on behalf of Ministry of Shipping and Transport.

Hydrology (Small Catchments) Directorate of CWC has carried out the analysis of selected storm rainfall and floods for the gauged catchments to derive 2-hr. unit hydrographs on the basis of data of rainfall, gauge and discharges collected during the monsoon season. Representative 2-hr. unit hydrographs have been obtained for each of the gauged catchments. The parameters of the catchments and their respective representative unit hydrographs have been cor-related by regression analysis and the equation for synthetic unit hydrographs for the sub-zone were derived. The loss rate and base flow studies were carried out. Methodology for estimation of design flood (50 yr. flood) for ungauged/inadequately gauged catchments has been indicated.

Rainfall-Depth-Duration-Frequency studies as well as point to areal rainfall ratio studies and time distribution of storm studies have been made available by Hydromet Cell of IMD.

The present report deals with the estimation of design flood for small and medium catchments in Upper Indo-Ganga Plains subzone - 1(e) based on 50-yr. design storm rainfall and synthetic unitgraph. This report is recommended for estimation of design flood (50-yr. flood) for fixing the waterway of the bridges/culverts on streams with their catchment areas from 25 sq.km. to 2500 sq.km.

The methodology adopted and conclusions arrived at are subject to periodical review and revision in the light of further data being collected and analysed.

The views expressed in this report [redacted] represent the views of Central Water Commission.

Sd/-

(S.M. HUQ)
DIRECTOR, HYDROLOGY (SC) DTE.
CENTRAL WATER COMMISSION

New Delhi

C O N T E N T S

LIST OF TABLES, PLATES AND FIGURES

TABLES

PLATES

FIGURES

SYMBOLS AND ABBREVIATIONS

SYMBOLS

As far as possible well recognised letter symbols in the hydrological science have been used in this Report. The list of symbols adopted is given below with the units.

A	:	Catchment Area in sq.km.
C.G.	:	Centre of Gravity
L	:	Length of main stream along the river course in km.
Lc	:	Length of the main stream from a point opposite to centroid of the catchment area to the gauging site in km. along the main stream.
Li	:	Length of the ith segment of L-Section in km.
Di-1, Di	:	The depth of the river at the point of intersection of (i-1) and ith contours from the base line (datum) drawn at the level of the point of study in meters.
Q_{50}	:	Maximum flood peak with a return period of 50 years in cumecs.
q_p	:	Peak discharge of unit hydrograph per unit area in cumecs per sq.km.
Q_p	:	Peak discharge of unit hydrograph in cumecs.
S	:	Equivalent stream slope in m/km.
S.U.G.	:	Synthetic Unit Hydrograph.
T	:	Time duration of rainfall in hours.
T_B	:	Base width of unit hydrograph in hours.
T_D	:	Design storm duration in hours.
t_p	:	Time from the centre of unit rainfall duration to the peak of unit hydrograph in hours.
t_r	:	Unit rainfall duration adopted in a specific study in hours.
U.G.	:	Unit Hydrograph.
W_{50}	:	Width of the U.G. measured at 50% of maximum discharge ordinate (Q_p) in hours.

W_{75}	:	Width of the U.G. measured at 75% of maximum discharge ordinate (Q_p) in hours.
T_m	:	Time from the start of rise to the peak of Unit Hydrograph (hr).
WR_{50}	:	Width of the rising side of U.G. measured at 50% of maximum discharge ordinate (Q_p) in hours.
WR_{75}	:	Width of the rising side of U.G. measured at 75% of maximum discharge ordinate (Q_p) in hours.
ARF	:	Arial reduction factor
%	:	Percent
Σ	:	Summation

ABBREVIATIONS

Cumecs	:	Cubic metres per second
Cms	:	Centimetres
Hr.	:	Hour
M.	:	Metres
Min.	:	Minutes
Km.	:	Kilometres
Sq.Km.	:	Square Kilometres
In.	:	Inches
Sec.	:	Seconds
Sq.	:	Square
R.D.S.O.	:	Research Designs and Standards Organisation (Ministry of Railways), Lucknow.
H(SC), CWC.		Hydrology (Small Catchments) Directorate, Central Water Commission, New Delhi.
I.M.D.	:	India Meteorological Department.
C.W.C.	:	Central Water Commission.

INTRODUCTION

FLOOD ESTIMATION IN UPPER INDO-GANGA PLAINS SUBZONE 1(e)

The purpose of the report entitled "Flood Estimation Report for Upper Indo-Ganga Plains, subzone - 1 (e)", presented herein is to estimate the design flood for fixing the waterway of bridges/cross drainage structures across small and medium streams.

The report consists of two parts namely abstract part giving the application of the methodology in the report with an illustrative example and the detailed part explaining the six main sections on the methodology. The six sections of the detailed report are briefly summarised below.

Section - 1 briefly narrates the river system, topographical features, monsoon rainfall and temperature pattern, types of soil, land use, railways and road communications in the subzone. The size of the subzone is 2,26,000 sq.km. covering parts of the States of Punjab, Haryana, Uttar Pradesh, Rajasthan besides Union Territories of Delhi and Chandigarh.

Section - 2 comprises of the nature of data collected for 42 representative catchments in the subzone. Northern and North-eastern Railways had collected the data of 40 catchments under the overall supervision of Research Designs and Standards Organisation (Railways), Central Water Commission has also collected the data of two catchments on behalf of Ministry of Transport.

Section - 3 deals with the analysis of storm rainfall and floods and derivation of two hour unitgraphs (U.G.) for each of the 23 catchments found suitable out of 42 catchments to prepare their representative 2-hour U.G's. The Parameters of the representative U.G.'s were measured. The physiographic parameters of the catchments were estimated. A simple model ($Y = C\ X^P$) was adopted to establish relationship between dependent variable Y and independent variable X with constant C and an exponent 'P'. The relationships were established with this simple model based on the sets of physiographic and U.G. parameters for 23 catchments. These relations are given in the form of equations and also on log-log graph which shall be utilised to estimate the parameters of synthetic U.G. for the ungauged catchments with their known physiographic parameters. Based on the synthetic U.G. parameters, a synthetic 2-hour U.G. is drawn. Besides, model values of design loss rate and base flow have also been suggested.

Section - 4 furnishes the methodology adopted by I.M.D. for estimating the design storm point rainfall for 50-year return period for duration from 1 hour to 24 hours, conversion of point rainfall to areal rainfall and the distribution of storm rainfall for various design storm durations. These studies have been depicted in the isopluvial map of 50-year point rainfall for duration of 24 hours with duration ratio curve for conversion of 24-hour point rainfall to short duration point rainfall in the subzone.

Similarly, curves and tables for conversion of point to areal rainfall and curves for distribution of design storm rainfall for various durations have been furnished.

Section - 5 describes the procedure for estimation of design flood (50-year) of an ungauged or inadequately gauged catchment by the application of design storm rainfall to synthetic U.G.

Section - 6 deals with the assumptions made in the study along with conclusions.

The report herein recommends the estimation of design flood for small and medium catchments varying in size from 25 sq.km. to 2,500 sq.km. keeping in view the compatibility of parameters of the ungauged and gauged catchments.

The "Application" of the report has been presented after the Introduction with a worked out problem along with graphs and tables to create interest for the users.

ABSTRACT

(A) APPLICATION

The Flood Estimation Report for Upper Indo-Ganga Plains subzone-1(e) may be used for estimation of design flood (50-year flood) for ungauged and inadequately gauged catchments in the subzone. In order to elucidate the procedure, an illustrative example is given below with relevant details.

The various steps necessary to estimate the design flood/design flood hydrograph are as under:

i) Preparation of catchment area plan of the ungauged catchment in question.

ii) Determination of physiographic parameters viz; the catchment area (A), the length of the longest stream (L) and equivalent stream slope (S).

iii) Determination of 2-hr. synthetic unitgraph parameters (for the specified unit duration) i.e. the unit peak discharge (q_p), the peak discharge (Q_p), the basin lag (t_p), the period of U.G. (Tm), widths of the unitgraph at 50% and 75% of Q_p (W_{50} and W_{75}), widths of the rising limb of U.G. at 50% and 75% of Q_p (W_{R50} and W_{R75}) and time base of unitgraph (T_B).

iv) Preparation of a synthetic unitgraph.

v) Estimation of design storm duration (T_D).

vi) Estimation of point rainfall and areal rainfall for design storm duration (T_D).

vii) Distribution of areal rainfall during design storm duration (T_D) to obtain rainfall increments for unit duration intervals.

viii) Estimation of rainfall excess units after subtraction of design loss rate from rainfall increments.

ix) Estimation of base flow.

x) Computation of design flood peak.

xi) Computation of design flood hydrograph.

The step No. (xi) may not be necessary for those intending to estimate the design flood peak only.

ILLUSTRATIVE EXAMPLE

The particulars of a road bridge catchment (treated as ungauged) for illustrating the procedure are as under:

i) Subzone - 1 (e)

ii) Name of site : 2 (M.O.T.)

iii) Name of the river/tributary : Ghaggar

iv) Shape of the catchment upto the point of study : Oblong

v) Location : 30^{o}- 24' N (Latitude) and 76^{o}-44' E (Longitude)

vi) Topography : Moderate steep slope.

The procedure is explained step by step.

Step - 1: Preparation of Catchment Area Plan

The point of interest (Bridge Site in this case) was located on the Survey of India's toposheet and catchment boundary was marked using the contours along with ridge line and also from the spot levels in the plains. A catchment area plan Fig. A-1 showing the main rivers, contours and spot levels was prepared.

Step - 2: Determination of Physiographic Parameters

The following physiographic parameters were determined from the catchment area plan:

i) Area (A) = 1126.0 sq.km

ii) Length of the longest stream = 81.42 kms.

iii) Equivalent stream slope $S = \Sigma \dfrac{L_i (D_{i-1} + D_i)}{L^2} = 5.14$ m/km

Where L_i = Length of ith segment in kms.

D_i, D_{i-1} = Reduced levels of the river at (i-1) and ith location along the longest stream.

For detailed calculation of 'S', refer Table A-1.

In Table A-1, cols. (2) and (4) are the reduced distances and corresponding levels along the longest stream from the point of study to the contours across the stream or spot levels on the bank. Other columns are self-explanatory. Prepare L-Section (Fig. A-1) of the longest stream from the point of study to source based on the data in cols. (2) and (4).

iv) $L/\sqrt{S} = 81.42/\sqrt{5.14} = 35.91$ ✓

Step - 3: Determination of Synthetic Unitgraph Parameters

Two hour unit duration for the unitgraph i.e. unitgraph produced due to one cm depth of rainfall excess in two hour duration has been considered.

The two hour synthetic U.G. parameters may be found out by using one of the following approaches:

i) By using the synthetic relations

ii) By using coaxial diagram

i) By using Synthetic Relations

Calculation of parameters of synthetic U.G. are shown in Table A.2 which are briefly explained below.

Sl. No. 1 : Substitute the value of $L/\sqrt{S} = 35.91$ as found out in (iv) of Step - 2 in equation 3.9.3 to obtained the value of q_p.

Sl. No. 2 : $Q_p = q_p \times A$

Sl. No. 3,5, 6, 7 & 8 : Substitute the value of q_p in respective equations in col. (3) of Table A-2 to obtain the corresponding parameters in col. (3).

Sl. No.4 : $T_m = t_p + t_r/2 = t_p + 2/2 = t_p + 1$

The unit duration (t_r) is 2.0 hrs.

Sl. No.9 : Substitute the value of t_p in equation 3.9.8 to obtain T_B.

The values of T_B may be rounded of to nearest even number.

ii) By using Coaxial Diagram

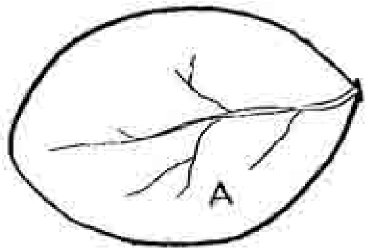
The synthetic relations have been transferred on one graph sheet in Fig. A-2 in such a way that with the known values of L, S, $L/\sqrt{S}$ the values of q_p can be found out. Similarly with the known value of q_p, the other parameters like t_p, W_{50}, W_{75}, W_{R50}, W_{R75} can be directly read from the respective relations (curves). Again with the known value of t_p, the value T_B is read from the respective relation. The values so obtained are similar to the calculated in Table A-2.

Step - 4 Preparation of 2-hr. Synthetic Unitgraph

The parameters got in Step - 3 above were plotted to scale on a graph paper as shown in Fig. A-3. The points were joined to fit a trial synthetic unitgraph. By defination, the volume of the unitgraph must be equivalent to 1.0 cm depth of direct runoff over the entire catchment (A) in sq.km.

(a) Volume of direct runoff from runoff depth (d) of 1.0 cm on the entire catchment (A) in sq.km.

= A X 1000 X 1000 X d/100 = (   ) expressed in cubicmetres
(sq.m)   (m)

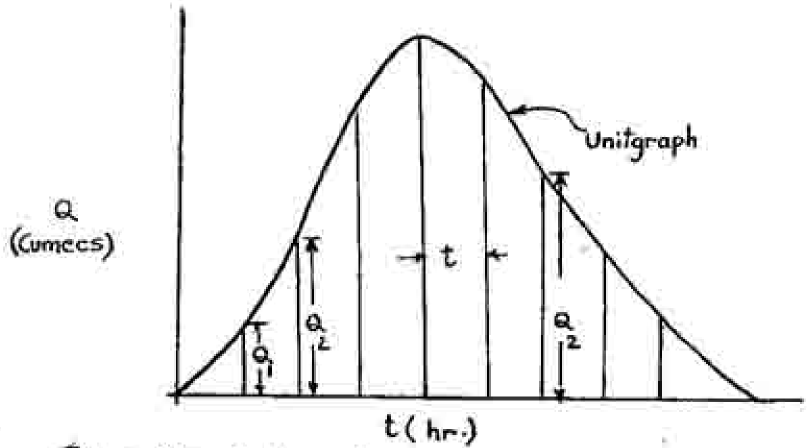


1 cm = $\frac{1}{100}$ m depth of direct runoff over the catchment area (A) in sq.km.

(b) Volume of direct runoff graph (Synthetic Unitgraph) obtained from the addition of all the unitgraph ordinates at time interval t in hrs. equal to unit duration (t_r) of U.G. = $\sum Q_i$ t

= $\sum Q_i \times t \times 3600$ = (   ) expressed in cubicmetres

(cubicmetres/sec) (sec)



$\sum Q_i$ = Sum of the ordinates of unit graph at t-hr. interval (in this case 2 hr.)

(a) should be equal to (b).

i.e $A \times 1000 \times 1000 \times d/100 = \sum Q_i \times t \times 3600$
d = 1cm

Therefore $\sum Q_i = A/0.36\ t$

All the ordinates of the synthetic U.G. so drawn with slight adjustments in Fig. A-3 were summed up at 2-hr. interval to get a total volume of 1564 cumecs which tallied with the computed value from A/0.36 t = 1126/(0.36 x 2) = 1564 cumecs. Therefore, the 2-hr. synthetic U.G. so drawn in Fig. A-3 was found to be in order.

In case, the summed up values of all the ordinates of synthetic U.G. do not tally with the computed value from A/0.36 t, then some of the ordinates in the rising and falling limbs or only in the falling limb of the U.G. may be suitably changed (slightly increased or decreased) keeping at the same time the shape of U.G. a smooth one. Normally one or two trials are carried out to adjust the volume of Synthetic U.G. so as to obtain 1.0 cm. of direct runoff over the entire catchment area (A) in sq. km.

Step - 5: Estimation of Design Storm Duration

The design storm duration is

$T_D = 1.1 \times t_p = 1.1 \times 10 \simeq 11.0$ hrs.

Adjusting the design storm duration to nearest even hour the adopted design storm duration is 12.0 hours.

Step - 6: Estimation of Point Rainfall and Areal Rainfall

The point rainfall estimated for 50-year return period for a duration of 24-hr. are first read from isopluvial map (Plate - 9 in Section 4.2). The value of 50-year, 24-hr. point rainfall = 25.0 cm.

The design storm duration (T_D) for the catchment is 12.0 hrs. The point rainfall estimate of 21.0 cm for 12.0 hrs. was obtained by multiplying the 50-yr., 24-hr. point rainfall of 25.0 cm with the value of 0.84 read from Fig. 10 in Section 4.2.

50-yr., 12-hr. point rainfall = 25 x 0.84 = 21.0 cm.

The above point rainfall estimates of 21.0 cm was multiplied by areal reduction factor of 0.765 corresponding to a catchment area of 1126.0 sq.km given in Table-6 or from Fig. 11 (a) or 11 (b) 0.765 X 21 = 16.06 cms.

Step - 7: Time Distribution of Areal Rainfall

The areal rainfall estimate for 50-year return period for a design storm duration of 12-hrs. got in Step - 6 above was distributed to give 2-hour gross rainfall units as shown in the following table by using Fig.12 in Section 4.4.

Hr.	% age of storm duration	Cumulative % of total rainfall	Cumulative rainfall col.3 x pa/ 100	2-hourly gross rainfall increments.
1	2	3	4	5
0	0	0		
2	16.66	58	9.31	9.31
4	33.33	74	11.88	2.57
6	50.00	86	13.82	1.94
8	66.66	92	14.78	0.96
10	83.33	95	15.26	0.48
12	100.00	100	16.06	0.80
			Total	16.06

Step - 8: Estimation of Rainfall Excess Units

Col.5 of the Table in Step - 7 give the 2 hourly gross rainfall units. A design value ofloss rate of 0.3 cm/hr. is subtracted from each of the units to give the rainfall excess units. For 2-hours, the loss rate is to be subtracted.

= 2 X 0.3 = 0.6 cm.

The table below illustrates the procedure for calculation of rainfall excess units:

Hr.	Gross rainfall (col.5) of Step - 7	Loss/ 2-hr. cm	Rainfall excess cm col.(2) - Col.(3)
1	2	3	4
0	0	-	-
2	9.31	0.60	8.71
4	2.57	0.60	1.97
6	1.94	0.60	1.34
8	0.96	0.60	0.36
10	0.48	0.60	-
12	0.80	0.60	0.20

Step - 9 Estimation of Base Flow

It has been shown in Section-3.12 that the model value of base flow for Upper Indo-Ganga Plains subzone - 1(e) is 0.05 cumecs/sq.km.

The total base flow for the ungauged catchment of 1126.0 sq.km. in question = 0.05 x 1126.0 = 56.3 cumecs.

Step - 10: Estimation of Design Flood (Peak only)

For estimation of the peak discharge, the rainfall excess units have to be re-arranged against the unitgraph ordinates such that maximum rainfall excess is placed against the maximum unitgraph ordinate the next lower value of rainfall excess comes against the next lower value of unitgraph ordinate and so on.

In the present case, the maximum peak discharge ordinate of U.G. was occurring at 11th hour. The U.G. ordinates at 2-hour interval from the peak hour of 11th were read from Fig. A-3 near the neighbourhood of the peak and tabulated as under. The maximum 2-hourly rainfall excess unit was placed against the peak discharge of U.G. Likewise, the next lower rainfall excess unit was placed against the next lower U.G. ordinate in the following table and so on. Summation of the products of cols (2) and (3) gives the total direct runoff to which base flow is added to get the total peak discharge.

Time hrs.	U.G. Ordinate Cumecs	2-hr. rainfall excess cm.	Direct runoff cumecs
1	2	3	4 =(2) x (3)
9	172.0	1.34	230.38
11	223.0	8.71	1942.33
13	198.0	1.97	390.06
15	167.0	0.36	60.12
17	135.0	0.20	27.00
		Total	2649.89
	Add Base Flow from Step - 9		56.30
	Total Peak Discharge		2706.19

Step - 11: Computation of Design Flood Hydrograph

The 2-hour rainfall excess sequence shown in col.3 of Table in Step-10 was reversed to obtain the critical sequence as shown below:

Time hrs. (1)	(2) Critical 2 hour rainfall excess sequence
2	0.20
4	0.36
6	1.97
8	8.71
10	1.34

For computation of design flood hydrograph, the U.G. ordinates for 2-hour interval were tabulated in col.(2) of Table A-3 against time (hrs.) in col.(1). The critical sequence of rainfall excess units as given above were entered in cols. (3) to (7) horizontally as shown in Table A-3. The direct runoff resulting from each of the rainfall excess units was obtained by multiplying the rainfall excess unit with the U.G. ordinates in col. (2) and the direct runoff values were entered in vertical columns against each unit with a successive lag of 2-hours, since the unit duration of U.G. was 2-hours. The direct runoff so obtained is shown in cols. (3) to (7). The direct runoffs were added horizontally and the total direct runoff is shown in col. (8). The total base flow of 56.3 cumecs was entered in col. (9). Col. (10) gives the addition of cols. (8) and (9) to get the design flood hydrograph ordinate.

The design flood hydrograph so obtained does not give the same value of maximum peak discharge since the peak period of the U.G. (T_m) is at odd hour (i.e. 11.00 hours). In this case the maximum peak discharge of 2706.29 cumecs computed in Step - 10 was entered in Table A-3 between the maximum discharge values of the rising and the falling limbs i.e. between 10 hrs. and 12 hrs.

The total discharge ordinate in col. (10) were plotted against time in col.(1) to get the design flood hydrograph in Fig. A-4.

TABLE-A-1: COMPUTATION OF 'S'

Sl. No.	Reduced distance starting from gauging site (Kms)	Reduced levels of River bed (m)	Length of each segment L_i (Km)	Height above datum * =Difference between the Ist & the ith R.L. D_i (m)	$(D_{i-1}+D_i)$	$L_i(D_{i-1}+D_i)$ =(4) x (6) (m.Km.)
1	2	3	4	5	6	7
1.	0	265.50	0	0	0	0
2.	17.38	281.01	17.38	15.51	15.51	269.56
3.	34.92	300.09	17.54	34.59	50.10	878.73
4.	37.01	319.72	2.09	54.22	88.81	185.61
5.	54.38	500.76	17.37	235.26	289.48	5028.27
6.	60.50	609.57	6.12	344.07	579.33	3545.50
7.	70.80	761.96	10.30	496.46	840.53	8657.46
8.	74.66	914.36	3.86	648.86	1145.32	4420.94
9.	79.16	1066.75	4.50	801.25	1450.11	6525.50
0.	79.94	1219.14	0.78	953.64	1754.89	1368.81
1.	80.77	1371.53	0.83	1106.04	2059.67	1709.53
2.	81.42	1447.73	0.65	1182.23	2288.28	1487.37

$\Sigma L_i(D_{i-1}+D_i)$

= 34077.30

$$S = \frac{\Sigma L_i (D_{i-1}+D_i)}{L^2} = \frac{34077.3}{6629.216} = 5.14 \text{ m/km.}$$

*Datum = 265.50 m (i.e. reduced level of river bed at the point of study)

TABLE-A-2: COMPUTATION OF PARAMETERS OF 2-HOUR SYNTHETIC UNITGRAPH

Sl.No.	Known Parameter	Unknown Parameter	Synthetic Relationship	Calculated value	Adopted value
1	2	3	4	5	6
1.	$L/\sqrt{s}$ =35.91	q_p (Cumec/Sq.km.)	$q_p=2.030/(L/\sqrt{s})^{0.649}$ (See eqn.3.9.3)	q_p=0.198	0.198
2.	q_p	Q_p (cumecs)	$Q_p=q_p \times A$	Q_p=222.95	223.00
3.	q_p	t_p (Hours)	$tp=1.858/(q_p)^{1.038}$ (See Eqn.3.9.4)	tp= 9.97	10.0
4.	tp	Tm (Hours)	$Tm=tp+(tr/2)$	Tm=11.0	11.0
5.	q_p	W_{50} (Hours)	$W_{50}=2.217/(q_p)^{0.990}$ (See Eqn.3.9.5)	W_{50}=11.017	11.0
6.	q_p	W_{75} (Hours)	$W_{75}=1.477/(qp)^{0.876}$ (See Eqn.3.9.6)	W_{75}= 6.10	6.10
7.	q_p	WR_{50} (Hours)	$WR_{50}=0.812/(qp)^{0.907}$ (See Eqn.3.9.7)	WR_{50}=3.53	3.53
8.	q_p	WR_{75} (Hours)	$WR_{75}=0.606/(qp)^{0.791}$ (See Eqn.3.9.8)	WR_{75}=2.18	2.18
9.	tp	T_B (Hours)	$T_B=7.744x(tp)^{0.779}$ (See Eqn.3.9.9)	T_B= 46.55	47.0

TABLE-A-3: COMPUTATION OF DESIGN FLOOD HYDROGRAPH

Time in Hours	Synthetic Unit hydrograph ordinates (Cumecs)	2-Hourly rainfall excess in cms 0.2	0.36	1.97	8.71	1.34	Total (Cumecs)	Base Flow (Cumecs)	Total (Cumecs)	Remarks
1	2	3	4	5	6	7	8	9	10	11
0	0	0					0	56.30	56.30	
2	15.00	3.00	0				3.00	56.30	59.30	
4	37.00	7.40	5.40	0			12.80	56.30	69.10	
6	70.00	14.00	13.32	29.55	0		56.87	56.30	113.10	
8	131.00	26.20	25.20	72.89	130.65	0	254.94	56.30	311.24	
10	215.00	43.00	47.16	137.90	322.27	20.10	570.43	56.30	626.73	
12	214.00	42.80	77.40	258.07	609.70	49.58	1037.55	56.30	1093.85	
14	182.00	36.40	77.04	423.55	1141.01	93.80	1771.80	56.30	1828.10	
16	151.00	30.00	65.52	421.58	1872.65	175.54	2565.29	56.30	2621.59	2706.29 (Peak)
18	120.00	24.00	54.00	358.54	1863.94	288.10	2588.58	56.30	2644.88	
20	91.00	18.20	43.20	295.50	1585.22	286.76	~~2228.08~~ 2230.85	56.30	~~2285.18~~	2287.15
22	72.00	14.40	32.76	236.40	1306.50	243.88	~~1833.94~~ 1842.65	56.30	~~1890.24~~	1898.95
24	58.50	11.70	25.92	179.27	1045.20	~~201.00~~ 202.34	~~1463.09~~ 1464.43	56.30	~~1519.39~~	1520.73
26	47.50	9.50	21.06	141.84	792.61	160.08	1125.09	56.30	1181.39	
28	39.00	7.80	17.10	115.25	627.12	121.94	889.21	56.30	945.51	
30	32.00	6.40	14.04	93.58	509.54	96.48	720.04	56.30	776.34	
32	26.50	5.30	11.52	76.83	413.73	78.39	585.77	56.30	642.07	
34	20.50	4.10	9.52	63.04	339.69	63.65	~~480.00~~ 480.02	56.30	~~536.30~~ 536.32	
36	15.50	3.10	7.38	52.29	278.72	52.26	393.75	56.30	450.05	
38	14.50	2.90	5.58	40.39	230.82	42.88	322.57	56.30	378.87	
40	8.00	1.60	5.22	30.54	178.56	35.51	251.43	56.30	307.73	
42	4.50	0.90	2.88	28.57	135.00	27.47	194.82	56.30	251.12	
44	2.50	0.50	1.62	15.76	126.30	20.77	164.95	56.30	221.25	
46	1.00	0.20	0.90	8.87	69.68	19.43	99.08	56.30	155.38	
48	0	0	0.36	4.93	39.20	10.72	55.21	56.30	111.51	
50			0	1.97	21.78	6.03	29.78	56.30	86.08	
52				0	8.71	3.35	12.06	56.30	68.36	
54					0	1.34	1.34	56.30	57.64	
56						0	0	56.30	56.30	

(B) COMPUTATION OF 50-YEAR FLOOD PEAK BY FLOOD FORMULA

I) <u>50-Year Flood Formula</u>

The magnitude of 50-year flood peak (Q_{50}) in cumec for small and medium catchments falling in the subzone-1(e) may be calculated from the following formula:

$$Q_{50} = K \times A \times R \times \frac{S^{0.324}}{L^{0.649}}$$

Where A = Catchment area in sq.km.

R = 50-year T_D hour point rainfall in cm.

S = Equivalent stream slope of the longest river in m/km.

L = Length of the longest stream in km.

K = A coefficient, the value of which is dependent on the catchment area as under:

C.A. (sq.km.)	K value
25	1.70
100	1.51
500	1.32
1000	1.15
2500	1.00

The K value corresponding to the catchment area under study falling in between the above range of catchment areas is interpolated linearly between the K values corresponding to that particular range of catchment areas.

II) <u>Application of 50-year Flood Formula</u>

The following steps may be followed for estimating the 50-year flood peak with the application of flood formula:

Step-i) Measure the catchment area 'A' in sq.km., length of the longest stream 'L' in km and equivalent slope 'S' in m/km after marking the catchment boundary on the toposheet upto the point of study.

Step-ii) Calculate design storm duration (T_D) in hours from the following formula:

$$T_D = 0.98(L/\sqrt{S})^{0.6737}$$

The value of T_D so obtained is rounded off to the nearest whole number.

Step-iii) Mark the catchment boundary on the 50-year, 24-hour isopluvial map (Plate-9 of the report) and record the 24-hour point rainfall value. Obtain the conversion ratio from the table of 24-hour to short duration ratio shown in figure-10 of the report corresponding to design storm duration (T_D) and apply the ratio to 24-hour point rainfall to get the design storm rainfall R in cm. for T_D hour duration.

Step-iv Estimate the value of K for the catchment area under study from the table of catchment areas vs values of K shown in B(I).

Step-v Then substitute the values of K,A,S,L and R in the Q_{50} formula to get 50-year flood at the point of study for the river catchment.

III) Illustrative Example

Application of 50-year flood formula to road bridge catchment No.2(MOT) for which detailed studies are shown in (A) application, is as under:

Name of river/tributary	:	Ghaggar
Location on toposheet	:	$30^{\circ}24'$ N(Latitude) $76^{\circ}44'$ E (Longitude)

Step-i The catchment boundary on the Survey of India toposheet for the Road Br. Catchment No. 2 (MOT) as shown in Figure-A 1 was marked. Following catchment parameters were estimated.

A = 1126.0 sq.km.

L = 81.42 km

S = 5.14 m/km

Step-ii The design storm duration (T_D) for the catchment was calculated from the following formula:

$$T_D = 0.98 \left(L/\sqrt{S}\right)^{0.6737}$$

$$= 0.98 \left(81.42/\sqrt{5.14}\right)^{0.6737}$$

$$= 10.94 \text{ hrs.} \qquad \text{say 11 hours.}$$

Step-iii The catchment boundary for Br. No.2(MOT) was marked on the 50-year 24-hr. isopluvial map (Plate-9 of the report) and the 24-hr. point rainfall value for the catchment was found to be 25 cm. Since the design storm duration (T_D) for the catchment under study was 11 hr., a ratio of 0.84 was obtained from Fig.10 of the report corresponding to design storm duration of 11 hrs. for conversion of 24 hrs. point rainfall to 11 hrs. design storm duration point rainfall.

Step-iv The value of constant K corresponding to catchment area of 1126.0 sq.km. was interpolated from the range of value of K for catchment areas between 1000 and 2500 sq.km. from the table given in B(I) as under:

A (sq.km.)	K
1000	1.15
2500	1.00

$$K = 1.15 - \frac{(1.15 - 1.00)}{1500} \times 1126$$

$$= 1.15 - \frac{0.15}{1500} \times 1126$$

$$= 1.15 - 0.0126 = 1.1374 \quad \text{say } 1.137$$

<u>Step-v</u> The above values of K,A,S,L and R were substituted in the flood formula as under:

$$Q_{50} = 1.137 \times 1126 \times 21 \times \frac{(5.14)^{0.324}}{(81.42)^{0.649}}$$

$$= 26885.50 \times \frac{1.70}{17.38}$$

$$= 2629.77 \quad \text{say} \quad 2630 \text{ cumec}$$

Thus 50-yr. flood peak from the flood formula works out to 2630 cumec as against 2706 cumec. from the detailed studies in (A) Application. The 50-year flood peak estimated by the flood formula is less by 2.81% as compared to the 50-year flood peak estimated from the detailed studies. This percentage difference may be considered nominal for preliminary designs.

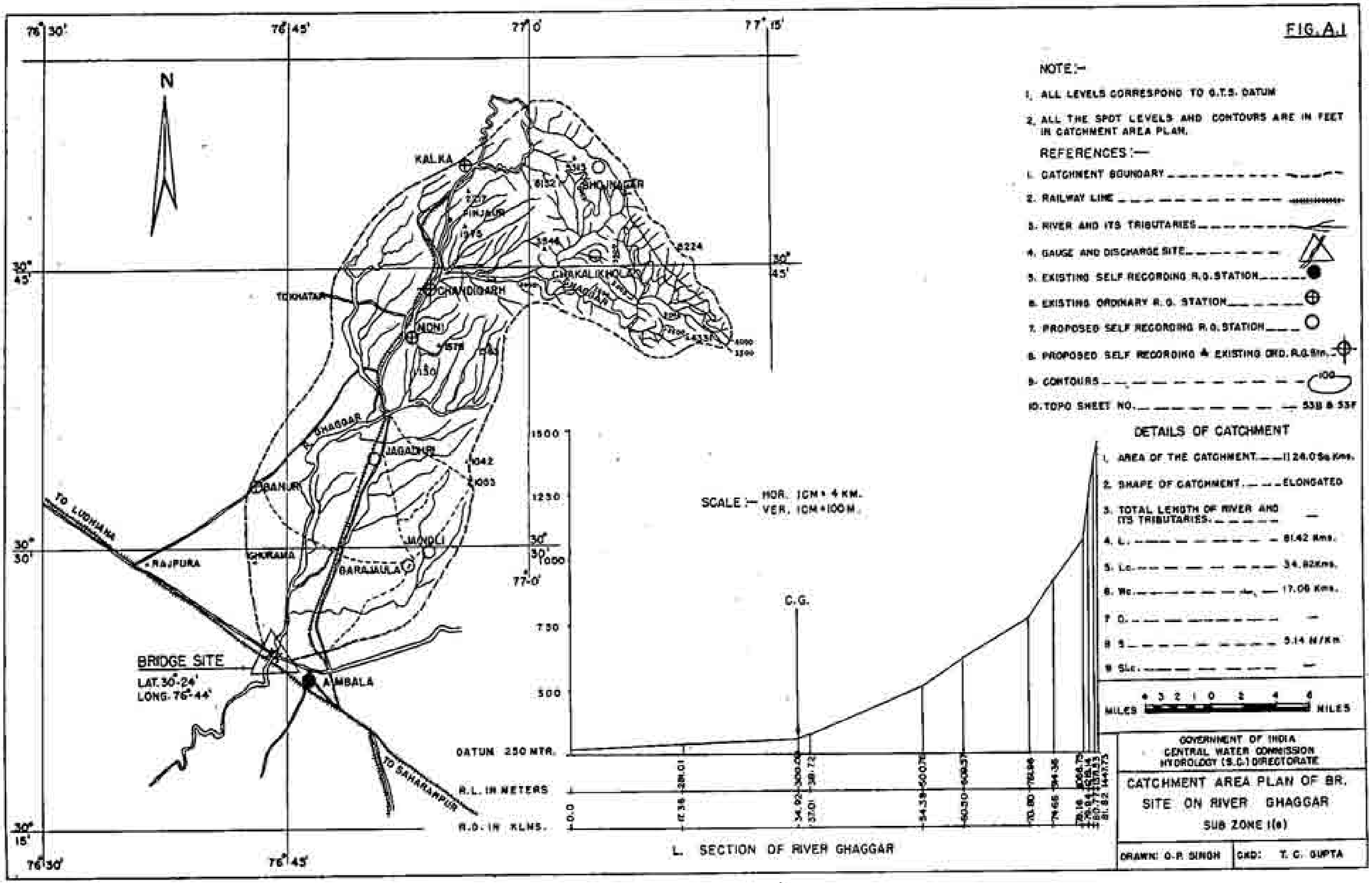
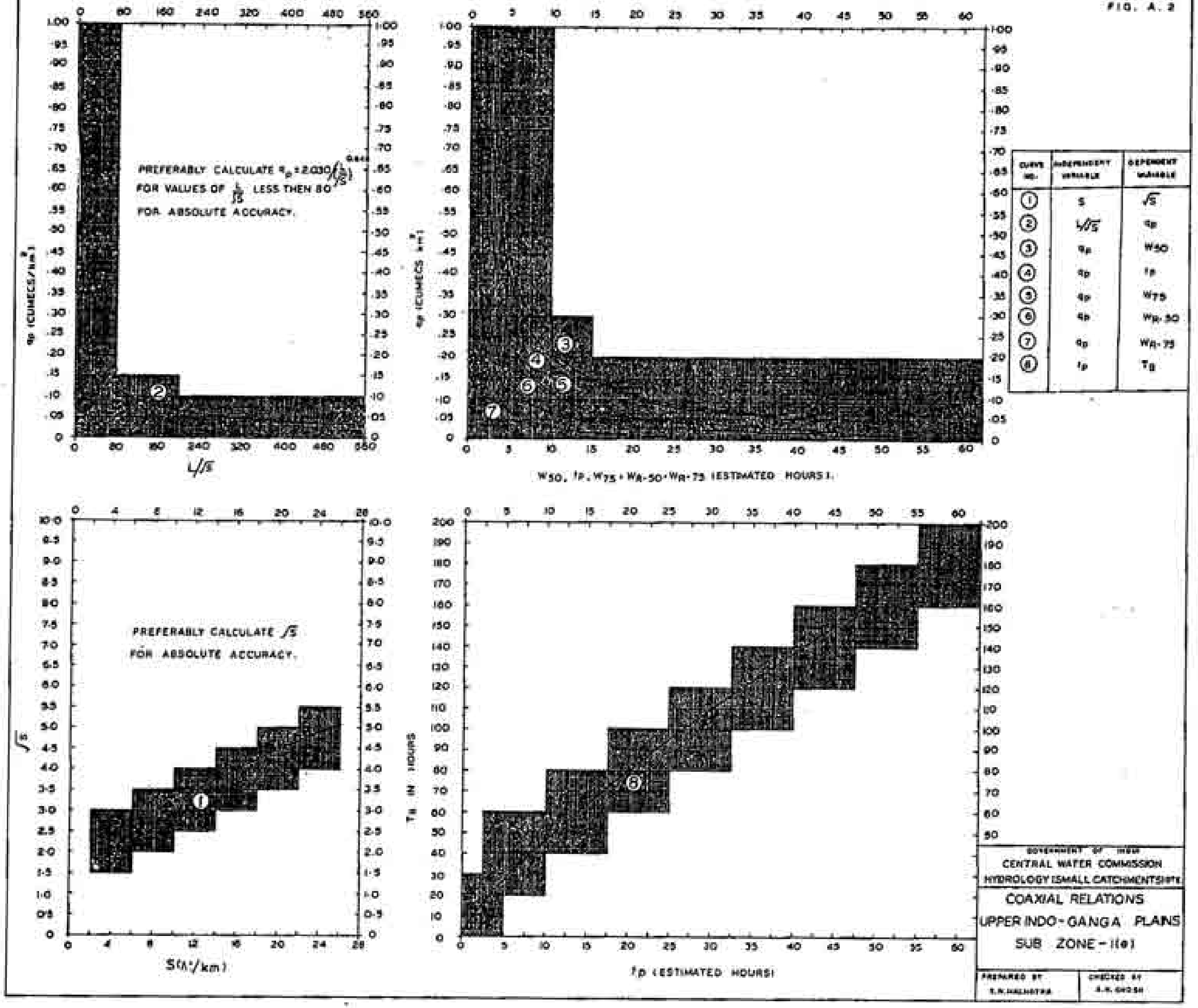


FIG. A.I
NOTE:-
1. ALL LEVELS CORRESPOND TO G.T.S. DATUM
2. ALL THE SPOT LEVELS AND CONTOURS ARE IN FEET IN CATCHMENT AREA PLAN.
REFERENCES:-
1. CATCHMENT BOUNDARY
2. RAILWAY LINE
3. RIVER AND ITS TRIBUTARIES
4. GAUGE AND DISCHARGE SITE
5. EXISTING SELF RECORDING R.G. STATION
6. EXISTING ORDINARY R.G. STATION
7. PROPOSED SELF RECORDING R.G. STATION
8. PROPOSED SELF RECORDING & EXISTING ORD. R.G.Stn.
9. CONTOURS
10. TOPO SHEET NO. 53B & 53F
DETAILS OF CATCHMENT
1. AREA OF THE CATCHMENT 1124.0 Sq Kms.
2. SHAPE OF CATCHMENT ELONGATED
3. TOTAL LENGTH OF RIVER AND ITS TRIBUTARIES —
4. L 81.42 Kms.
5. Lc 34.92 Kms.
6. Wc 17.06 Kms.
7. D —
8. S 5.14 M/Km.
9. Slc —
MILES 4 3 2 1 0 2 4 6 MILES
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S.C.) DIRECTORATE
CATCHMENT AREA PLAN OF BR. SITE ON RIVER GHAGGAR
SUB ZONE 1(a)
DRAWN: O.P. SINGH
CKD: T. C. GUPTA
N
76°30'
76°45'
77°0'
77°15'
30°45'
30°30'
30°15'
KALKA
PINJAUR
BHOJNAGAR
CHAKALI KHOLA
GHAGGAR
TOKHATAR
CHANDIGARH
MONI
JAGADHRI
BANUR
JANDLI
GHURAMA
BARAJAULA
RAJPURA
TO LUDHIANA
AMBALA
TO SAHARANPUR
BRIDGE SITE
LAT. 30°-24'
LONG. 76°-44'
SCALE:- HOR. 1CM = 4 KM.
VER. 1CM = 100 M.
C.G.
1500
1250
1000
750
500
DATUM 250 MTR.
R.L. IN METERS
R.D. IN KLMS.
L. SECTION OF RIVER GHAGGAR

FIG. A. 2



CURVE NO.	INDEPENDENT VARIABLE	DEPENDENT VARIABLE
1	S	$\sqrt{S}$
2	$L/\sqrt{S}$	q_p
3	q_p	W_{50}
4	q_p	t_p
5	q_p	W_{75}
6	q_p	W_{R-50}
7	q_p	W_{R-75}
8	t_p	T_B

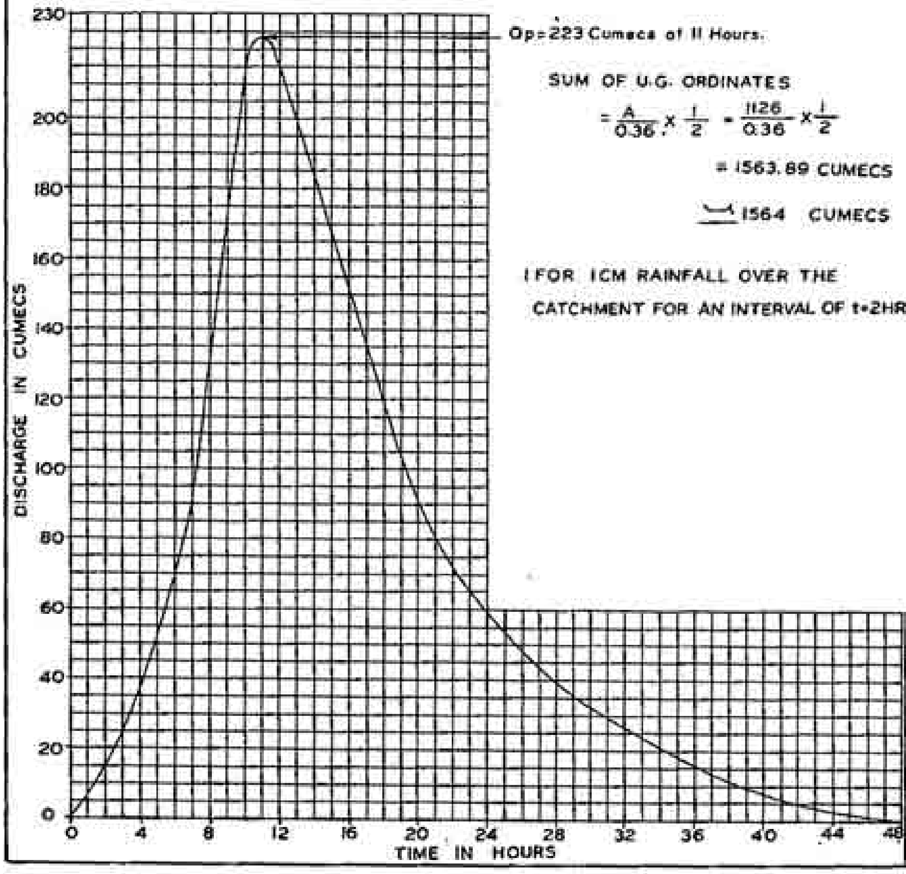
FIG. A-3

PARAMETERS OF 2HRS. U.G.

SYMBOL	FOR SYNTHETIC U.G.
Qp	223.00 CUMECS
tm	11.00 HOURS
tp	10.00 "
W_{50}	11.00 "
W_{R50}	3.50 "
W_{75}	6.10 "
W_{R75}	2.18 "
TB	48.00 "

2HRS SYNTHETIC U.G.

HOURS	ORDINATES IN CUMECS
0	0.00
2	15.00
4	37.00
6	70.00
8	131.00
10	215.00
11 Peak	223.00
12	214.00
14	182.00
16	150.00
18	120.00
20	91.00
22	72.00
24	58.50
26	47.50
28	39.00
30	32.00
32	26.50
34	20.50
36	15.50
38	11.50
40	8.50
42	4.50
44	2.50
46	1.00
48	0.00
TOTAL	1564.00



SUM OF U.G. ORDINATES

$$= \frac{A}{0.36} \times \frac{1}{2} = \frac{1126}{0.36} \times \frac{1}{2}$$

$$= 1563.89 \text{ CUMECS}$$

$$\simeq 1564 \text{ CUMECS}$$

I FOR 1CM RAINFALL OVER THE CATCHMENT FOR AN INTERVAL OF t=2HRS

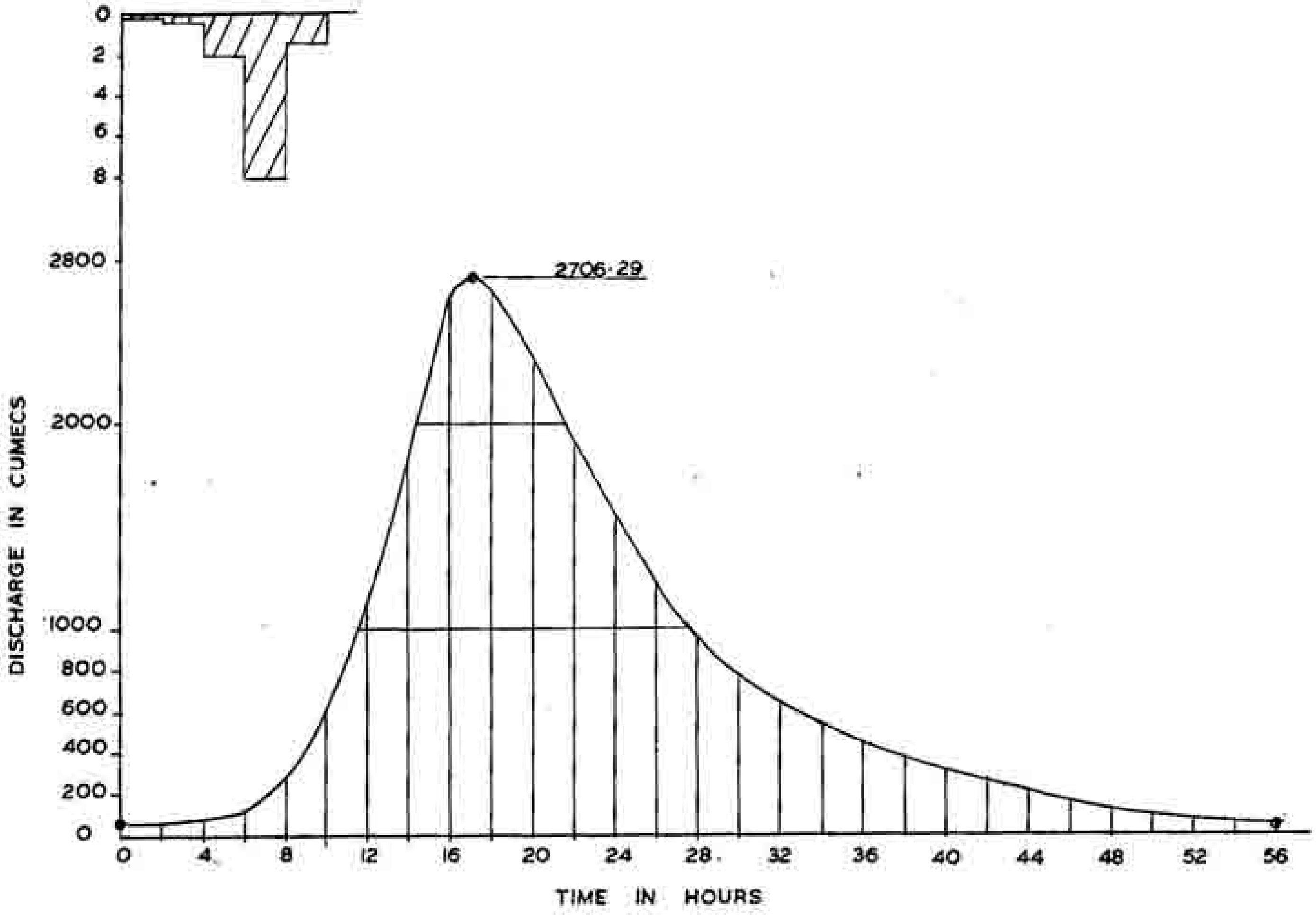
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY(SMALL CATCHMENTS)DTE

SYNTHETIC UNIT HYDROGRAPH
BR. SITE ON RIVER GHAGGAR

UPPER INDO-GANGA PLAINS
SUB-ZONE 1(e)

DRAWN	CHECKED
K.B. AHUJA	K.K. AICH

FIG. A.4



GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE

UPPER INDO-GANGA PLAINS
SUB-ZONE 1(b)
DESIGN FLOOD HYDROGRAPH
SITE NO. 2 ON RIVER GHAGGAR

DRAWN	CHECKED
R.N. SHARMA	A.K. GHOSH

1.0 GENERAL DESCRIPTION OF THE UPPER INDO-GANGA PLAINS SUB-ZONE - 1(e)

1.1 LOCATION

The subzone - 1(e) lies roughly between longitude 74° to 81° East and latitude 26° to 33° North. It covers almost entire Haryana and Punjab, Union Territories of Delhi and Chandigarh, Western Uttar Pradesh and eastern border areas of Rajasthan. The important towns and cities in the subzone are Delhi, Chandigarh, Amritsar, Ferozepur, Aligarh, Mathura, Agra, Bareilly, Etawaha, Alwar, Hissar, Rohtak, etc. The Upper Indo-Ganga Plains subzone - 1(e) is bounded on the north by J&K Kumaon Hills zone - 7, on the south by Luni basin and Thar subzone - 1(a), Chambal basin subzone - 1(b) and Betwa Basin subzone - 1(c), on the east by middle Ganga Plains subzone - 1(f) and on the west by Pakistan. Plate - 1 shows the location of subzone - 1(e).

1.2 RIVER SYSTEM

Plate - 2 shows the river system of the subzone - 1(e). The rivers flowing in this subzone are Ravi (Sakki N), Beas, Sutlej, Ghaggar, Yamuna, Ramganga, Ganga, Gomti, Sahibi and Banganga. The flat reaches of these rivers are almost covered in this subzone. The area covered by each river system is detailed as under:

Sl.No.	River	Drainage area (sq.km.)
1.	Ravi (Sakki N)	4,667
2.	Beas	5,859
3.	Sutlej	25,540
4.	Yamuna and other plain areas	82,630
5.	Ghaggar	23,637
6.	Ganga	30,748
7.	Gomti	5,007
8.	Sahibi and Banganga	19,381
9.	Ramganga	28,531
	Total	2,26,000

The total area of subzone-1(e) is 2,26,000 sq.km.

1.3 TOPOGRAPHY AND RELIEF

The Upper Indo-Ganga Plains subzone - 1(e) have been built up in the northwest by the Ravi (Sakki N), Beas, Sutlej and Ghaggar and the remaining area by the Yamuna, Ganga, Ramganga, Gomti, etc. There is a small mountainous area in the northern part of Punjab varying in elevation from 450 to 600 m.

Areas with elevations less than 150 m are located in the southeast of the subzone. The general elevation of the remaining area is between 150 m to 300 m. Sahibi, Banganga and Gambhir rivers originate from the hills in the South of the subzone. Plate-3 shows the physiography of the subzone.

The thickness of the alluvium varies greatly from area to area, and is the maximum in the Ganga plains and the minimum in the western plains. Towards the northern, there is a narrow marshy tract called Tarai, a part of which lies in this subzone. The low lying flood plains adjacent to the river banks are formed of newer alluvium. The general slopes are mainly in two directions i.e. the southeast and the southwest.

The general slopes of the rivers in the plains seldom exceed 0.38 m. per km. The rivers are of meandering type and the river courses are normally wide and shallow. The plains in the Punjab State are flat with the exception of Hoshiarpur tract where the general elevation varies between 300 m to 400 m.

1.4 RAINFALL

Plate - 4 depicts the mean annual rainfall isohyets along with the histograms showing the mean monthly rainfall for raingauge stations at Amritsar, Hissar, Delhi and Bareilly in the subzone. The mean annual rainfall in the northern areas near the hills is 100.0 cm. The middle and southern areas in the subzone experience the mean annual rainfall varying from 80.0 cm to 60.0 cm. The mean annual rainfall in the south western parts varies from 30.0 cm to 40.0 cm. The subzone lies in the semi arid zone based upon the Thornwait's moisture index classification. The major portion of rainfall comes from southwest monsoon in the subzone.

1.5 TEMPERATURE

The climate of subzone - 1(e) presents extreme of both heat and cold due to its geographical position. The temperature rise slowly till the end of March and the hot spell begins with April for the next three months. The temperature begins to fall gradually from July onwards as the hot winds receive the moisture. The minimum temperature is in January with the fall of the winter rains. Plate - 5 shows the variation in temperature in the subzone. Plate - 5 also depicts the bar graphs of temperature for Hissar, Delhi and Bareilly in the subzone showing the maximum and minimum daily mean temperature for the different months of the year. The mean annual temperature varies from 22.5°c to 25.0°c. in the plains except the northern parts adjacent to the foothills and Tarai area with mean annual temperature of below 22.5°c and south eastern areas with mean annual temperature of above 25.0°c. The maximum and minimum daily mean temperature in large parts of the plains during the monsoon season from June to September varies from 33.0°c to 40.0°c and 25.0°c to 28.0°c respectively.

1.6 SOILS

Plate - 6 shows the soil classification in subzone-1(e). The plains of Yamuna, Ganga, Ramganga, Gomti and upper parts of Ravi, Beas, Sutlej and Ghaggar are covered with recent alluvial soils. The plains in the middle reaches of Beas , Sutlej and Ghaggar are covered with calcareous soils of alluvial origin. The saline and alkaline soils are also found in some parts of the plains covered with alluvial soils old alluvial soils cover the areas lying in the northwest part of the subzone between Sutlej and Ghaggar. The areas near the southwest boundary in the subzone are covered with desert and grey brown soils. The areas adjacent to the northern boundary are covered with brown hill soils. Tarai soils are found in the Tarai area in the northern parts.

1.7 LAND USE

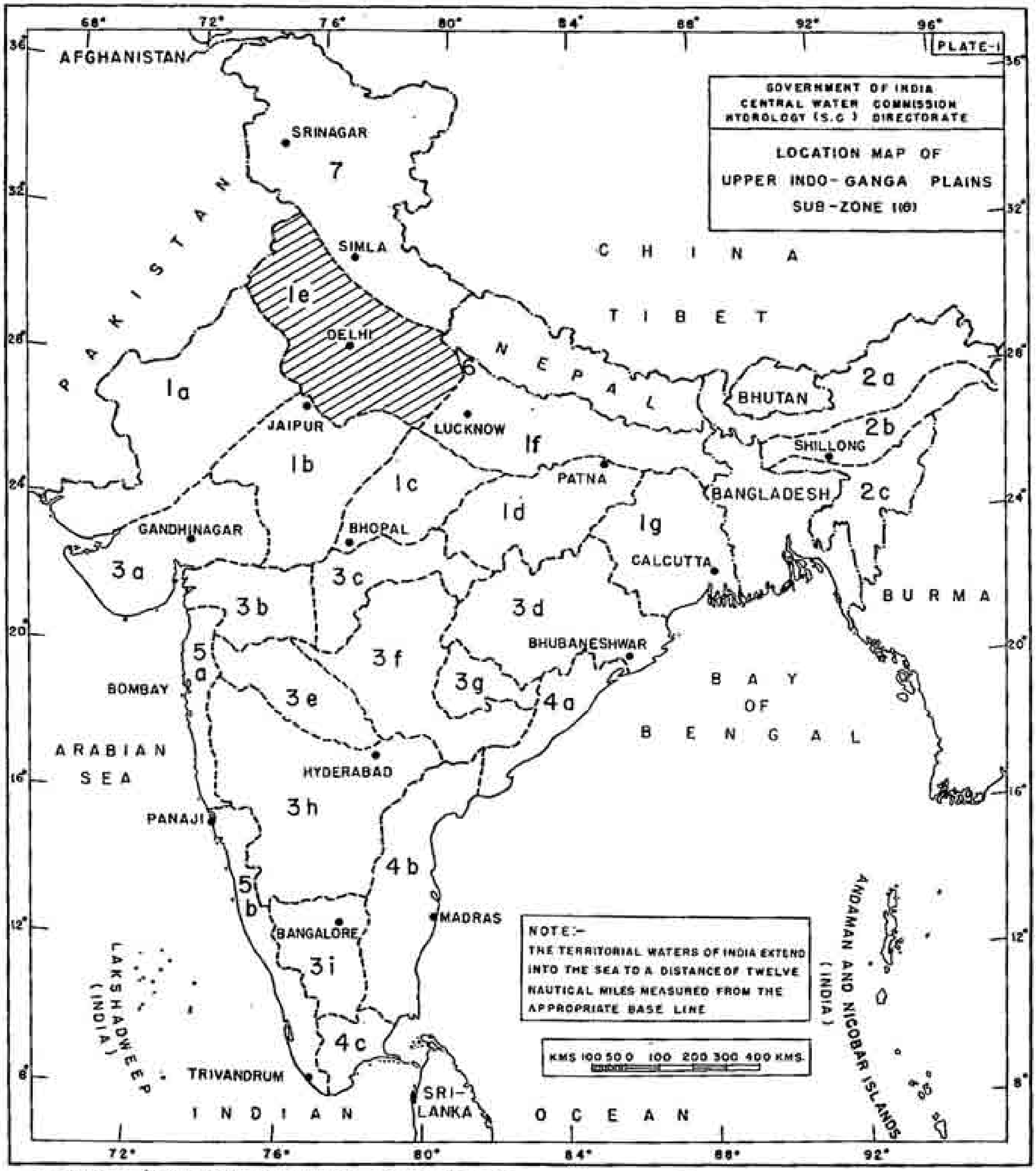
The plains of the subzone - 1(e) are fertile and cultivable. Most of these parts are also irrigated. The northwest and southwest portions comprising of 50%.of the subzone are intensely irrigated to an extent of 80%. The intensity of irrigation in 25% of the area is 20% to 60%. Forests lie in the northwestern, southern and northeastern areas. Plates - 7 & 8 show the land use in the subzone.

1.8 COMMUNICATIONS

1.8.1 The following railway sections traverse the area in the subzone - 1(e)

S.No.	Railway Sections	Railways
1.	Amritsar - Ludiana-Najibabad-Moradabad-Bareilly-Sitapur	Northern Railway (NR)
2.	Ferozepur-Bhatinda-Delhi-Ghaziabad-Moradabad	N.R.
3.	Hindumalkate-Bhatinda-Hissar-Rewari	N.R
4.	Pathankot-Jullundur-Ferozepur-Fazilka	N.R.
5.	Ludhiana-Dhuri-Jakhal-Hissar-Churu	N.R.
6.	Kalka-Ambala-Delhi-Rewari	N.R.
7.	Saharanpur-Meerut-Ghaziabad-Khurja-Hathras-Tundla-Kanpur	N.R.
8.	Meerut-Hapur-Khurja	N.R.
9.	Najibabad-Moradabad-Chandausi-Bareilly	N.R.
10.	Nangal dam - Sirhind	N.R.
11.	Dera Babananak - Amritsar-Lahore	N.R.
12.	Rajpura-Dhuri-Bhatinda - Bikaner	N.R.
13.	Pathankot-Amritsar	N.R.
14.	Ludhiana-Ferozepur	N.R.
15.	Najibabad-Gajralla	N.R.
16.	Farrukhabad-Shikahabad	N.R.
17.	Barhan - Etah	N.R.
18.	Narivana-Kurukshetra	N.R.
19.	Jind - Panipat	N.R.

1	2	3	4
3(d)	Mahanadi basin including Brahmani and Baitarani rivers	Mahanadi	Mahanadi, Baitarani and Brahmani rivers.
3(e)	Upper Godavari basin	Upper Godavari	Upper portion of Godavari basin.
3(f)	Lower Godavari basin except coastal region	Lower Godavari	Lower portion of Godavari basin.
3(g)	Indrawati basin	Indrawati	Indrawati river.
3(h)	Krishna subzone including Panner basin except coastal region	Krishna	Krishna & Panner rivers except coastal region.
3(i)	Kaveri & east flowing rivers except coastal region	Kaveri	Kaveri river(except coastal region).
4(a)	Circars including east flowing rivers between Mahanadi & Godavari	Upper Eastern Coast	East flowing coastal rivers between deltas of Mahanadi and Godavari rivers.
4(b)	Coromandal cost including east flowing rivers between Godavari & Kaveri	Lower eastern coast	East flowing coastal rivers Manimukta, South Panner, Cheyyar, Palar, North Penner, Munneru, Palleru, Cundelakama & Krishna Delta.
4(c)	Sandy Coroman belt(east flowing rivers between the Kaveri & Kanyakumari)	South Eastern Coast	East flowing coastal rivers Manimuther, Vaigai, Arjuna, Tamra - Parni.
5(a)	Konkan Coast (west flowing rivers between the Tapi & Panaji)	Konkan Coast	West flowing coastal rivers between Tapi & Mahdavi rivers.
5(b)	Malabar coast (West flowing rivers between Kanyakumari & Panaji)	Malabar coast	West flowing coastal rivers between Mahdavi & Kanyakumari .
6.	Andaman and Nicobar	Andaman & Nicobar	----
7.	J&K Kumson Hills(Indus basin)	Western Himalayas	Jhelum, Upper portion of Indus, Ravi & Beas rivers.



THE EXTERNAL BOUNDARY AND COAST LINE OF INDIA ON THE MAPS AGREE WITH THE RECORD COPY CERTIFIED BY THE SURVEY OF INDIA

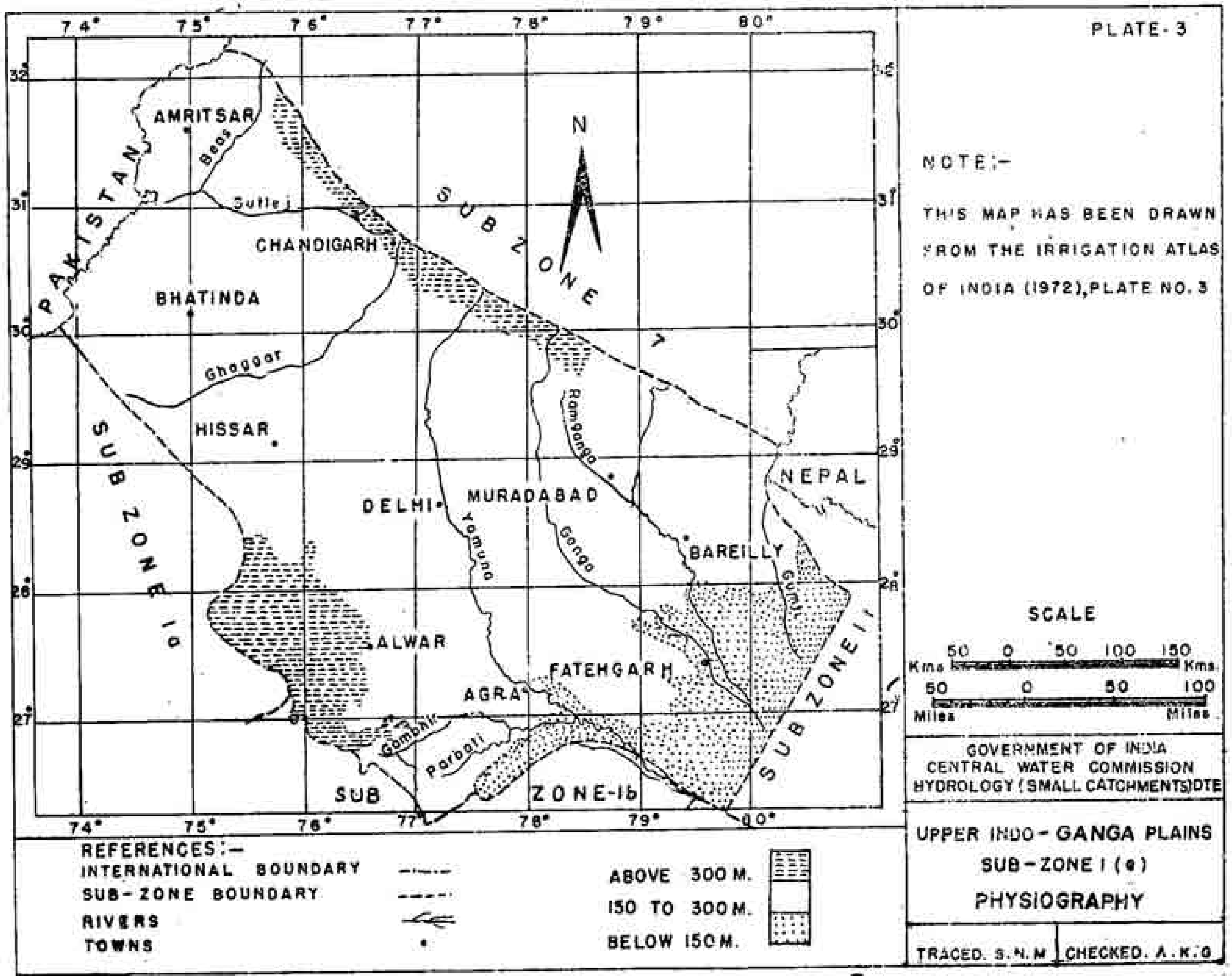
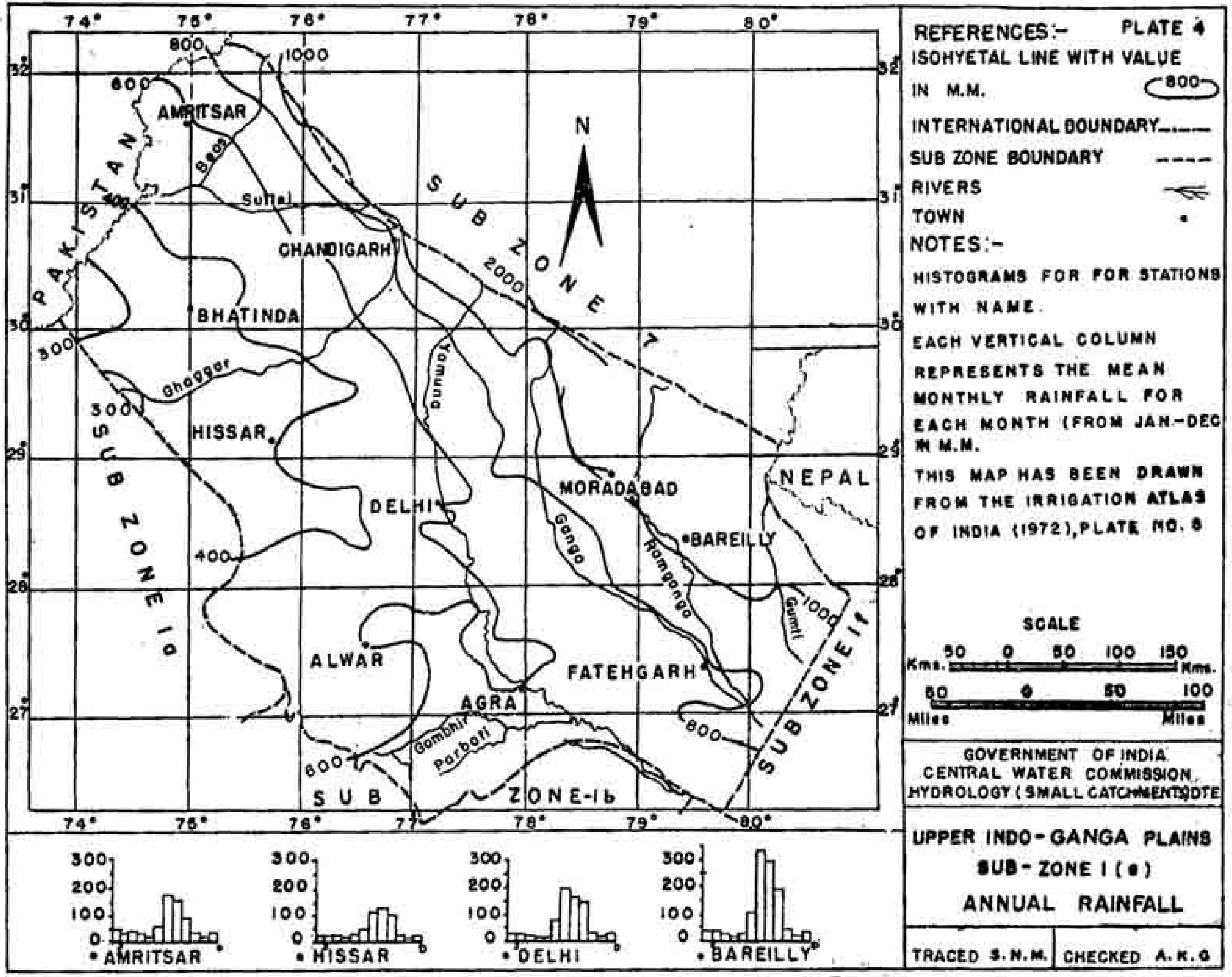
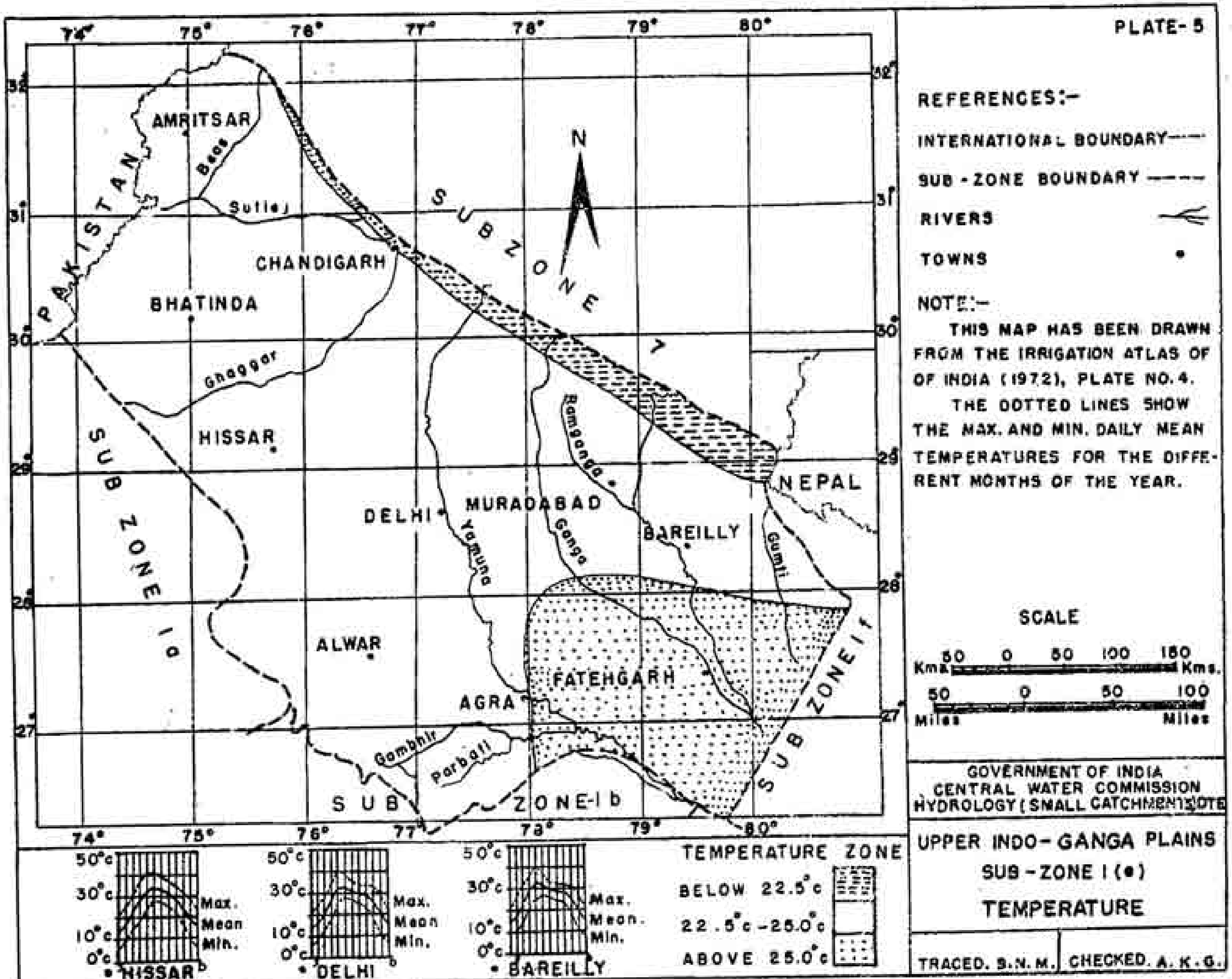


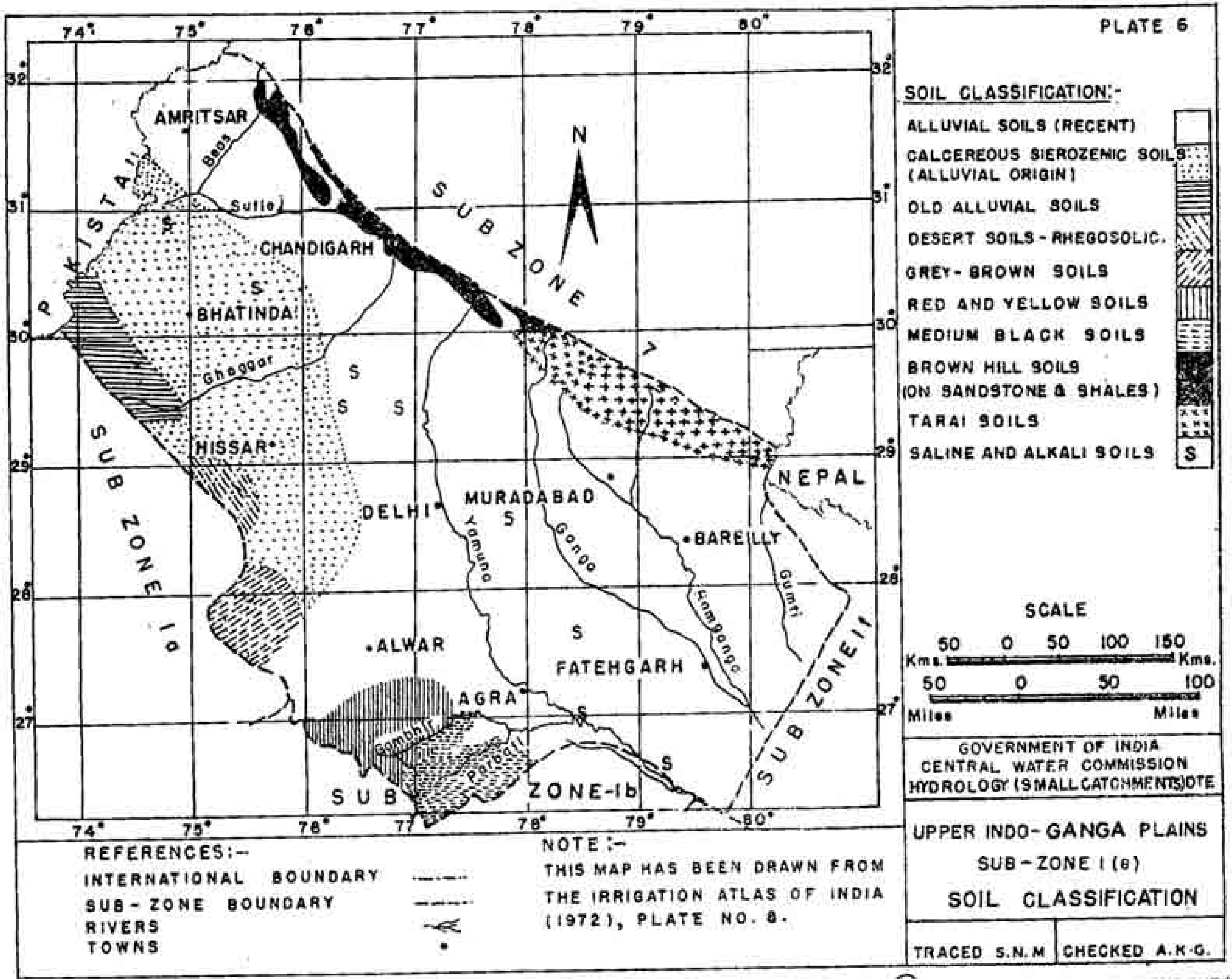
PLATE-3
NOTE:-
THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972), PLATE NO. 3
SCALE
Kms 50 0 50 100 150 Kms.
Miles 50 0 50 100 Miles
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE
UPPER INDO-GANGA PLAINS
SUB-ZONE I (e)
PHYSIOGRAPHY
TRACED. S.N.M
CHECKED. A.K.G
REFERENCES:-
INTERNATIONAL BOUNDARY
SUB-ZONE BOUNDARY
RIVERS
TOWNS
ABOVE 300 M.
150 TO 300 M.
BELOW 150 M.
N
PAKISTAN
AMRITSAR
Beas
Sutlej
CHANDIGARH
BHATINDA
Ghaggar
HISSAR
SUB ZONE 1a
SUB ZONE 1
DELHI
MURADABAD
Ramganga
Yamuna
Ganga
NEPAL
BAREILLY
Gumti
ALWAR
AGRA
FATEHGARH
Gambhir
Parbati
SUB ZONE-1b
SUB ZONE 1i
74° 75° 76° 77° 78° 79° 80°
32° 31° 30° 29° 28° 27°



BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA

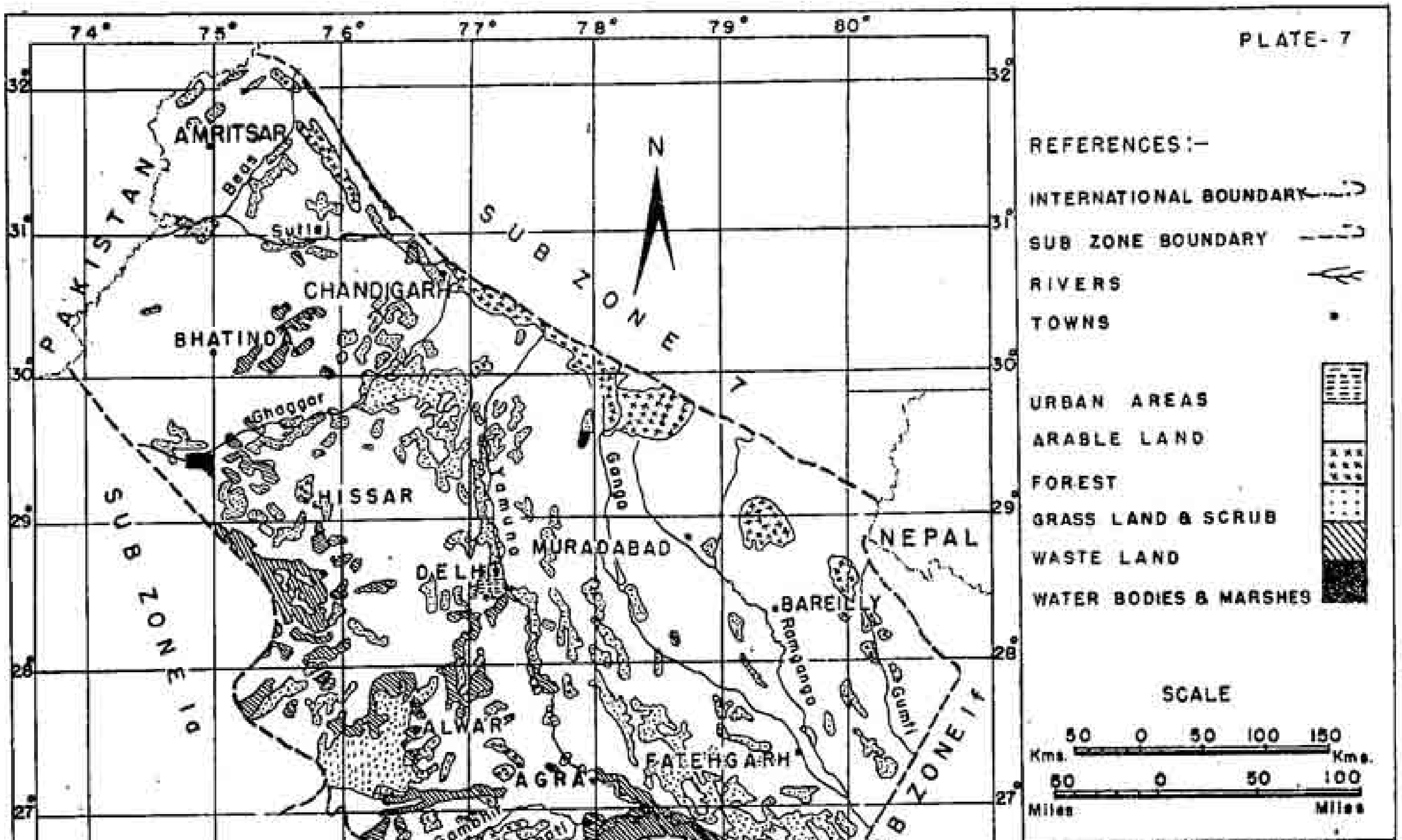


BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA



BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.

PLATE- 7



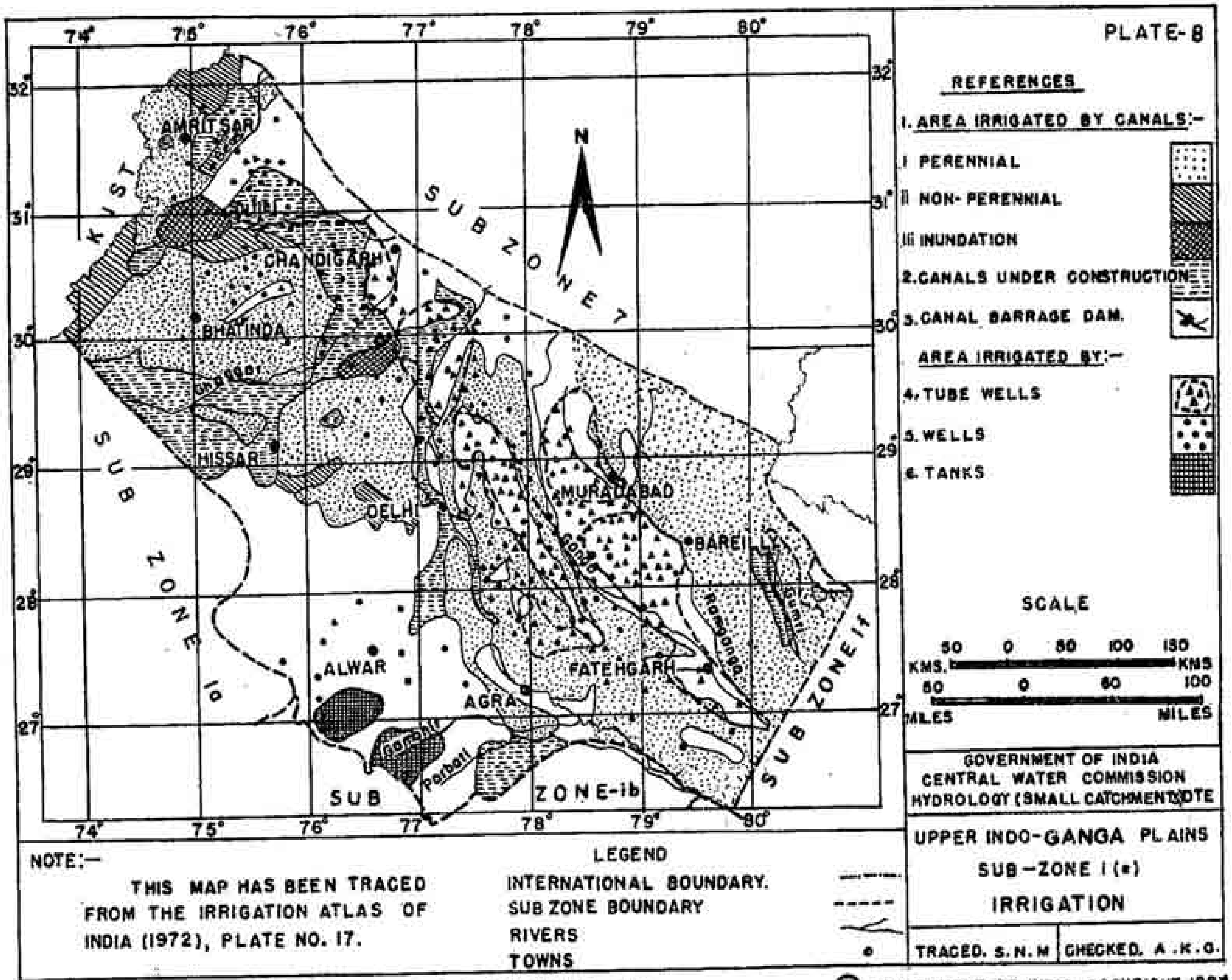
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS)DTE

UPPER INDO-GANGA PLAINS
SUB-ZONE I (a)
LAND USE

TRACED S.N.M | CHECKED A.K.O.

NOTE :-
THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972), PLATE NO. 9

BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA



BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.

2.0 DESIGN FLOOD, DATA AND THE METHOD ADOPTED FOR ANALYSIS

2.1 DESIGN FLOOD

The Khosla Committee of Engineers had recommended a design flood of 50-year return period for fixing the optimum waterway of the bridges. The design flood in other words may be defined broadly as a rational estimate of flood discharge for the design of safe and economic structure across a river. The Committee of Engineers had suggested that 50-year flood may be considered as the maximum observed discharge from the yearly peak discharge records available for not less than 50 years. Where the yearly peak discharge records are not much less than 50 years, the 50-year flood may be obtained from the probability curve of peak discharges. In the absence of adequate data of peak discharges, storm rainfall and runoff data for the selected catchments shall be collected for a required period and detailed studies carried out to derive the unitgraphs for these catchments and to prepare storm rainfall maps for different durations. In this connection, the Committee had suggested to develop a suitable rational methodology for estimation of 50-year flood, subzonewise based on application of storm rainfall to unitgraph. It has been assumed that 50-year storm rainfall applied to unit graph may produce a flood of the same return period (50-year)as that of storm rainfall.

2.2 DATA

For conducting the unitgraphs and design storm rainfall studies, the following concurrent rainfall and runoff data for a number of catchments of small and medium sizes representatively located in a subzone are required for a minimum period of 5 to 8 years during the monsoon season:

i) Hourly gauge data at the gauging site (bridge site) round the clock.

ii) Gauge and discharge data observed 2 to 3 times a day at the gauging site (bridge site).

iii) Hourly rainfall data of raingauge stations in the catchment. Raingauge stations are to be selfrecording and/or manually operated.

iv) Catchment area plans showing the river network, location of raingauge stations and gauge and discharge sites, contours, highway and railway network, natural and man made storages, habitations, forests, agricultural and irrigated areas, soils, etc.

v) Cross sections at the bridge site (gauging site) upstream and downstream of the bridge site.

vi) Longitudinal section of the river upstream and downstream of the bridge site.

In addition to the above, the data of gauged catchments, rainfall data of self-recording raingauge stations maintained by India Meteorological Department is also required.

The Northern and the North-eastern Railways under the supervision of Research and Designs Standards Organisation (RDSO) had observed and collected the required data in Section 2.2 for 40 catchments in the Upper Indo-Ganga Plains subzone - 1(e) for a period of 3 to 12 years for each of the catchments. Central Water Commission on behalf of Ministry of Transport has also observed and collected the required data since 1981 for two catchments in this subzone. The sizes of the gauged catchments varied from 25.26 sq.km. to 2425.54 sq.km. The location of gauging sites at road and railway bridges in subzone - 1(e) are shown in plate-2. IMD has collected rainfall data of additional raingauge stations maintained by IMD. CWC has also prepared the detailed plans of the gauged catchments showing the information in Section 2.2(iv). Table - 1 shows name, number of bridge, location of gauging sites, name of streams, catchments areas, number of raingauges and period of availability of data along with observational agency. R.D.S.O. has made available the data collected to CWC and IMD for carrying out the studies.

2.3 DESCRIPTION OF THE METHOD ADOPTED

In this report, Section-3 explains the procedure for obtaining the synthetic unitgraph for ungauged catchments in subzone - 1(e).

Section - 4 explains the procedure for obtaining the design storm input.

Section - 5 explains the steps to be followed for obtaining a design flood of 50-year return period.

The adoption of synthetic unitgraph is recommended for ungauged catchments or gauged catchments having inadequate data. However, for gauged catchments with adequate data, representative unitgraph based on actual data should be preferred.

3.0 DERIVATION OF SYNTHETIC UNIT HYDROGRAPHS

The Synthetic Unitgraph is a unitgraph of unit duration for a catchment under study obtained from the relations established between the physiographic and unitgraph parameters of the representative catchments in a hydrometeorologically homogenous region. In order to obtain a Synthetic Unitgraph the following steps have to be followed:

i) Analysis of physiographic parameters of the catchments.

ii) Scrutiny of data and finalisation of gauge discharge rating curves.

iii) Selection of flood and corresponding storm events.

iv) Computation of hourly catchment rainfall.

v) Separation of base flow and computation of direct runoff-depth.

vi) Computation of infiltration loss (Ø-index) and 2-hourly rainfall excess unit.

vii) Derivation of 2-hourly unitgraphs.

viii) Drawing of representative unitgraphs and measuring the parameters.

ix) Establishing relationships between physiographic and representative unitgraph parameters.

x) Derivation of 2-hour Synthetic Unitgraph for an ungauged catchment.

The above steps are briefly described as under:

3.1 ANALYSIS OF PHYSIOGRAPHIC PARAMETERS OF THE CATCHMENT

The representative catchments selected for the study were analysed for physiographic parameters. The catchment parameters shown in Fig.1 are as under:

3.1.1 Catchment Area (A)

On a reliable map, the watershed boundary is marked. The area enclosed in this boundary up to the gauging site may be referred to as the catchment area.

3.1.2 Length of the Main Stream (L)

This implies the longest length of the main river course in the catchment.

3.1.3 Equivalent Stream Slope (S)

Longitudinal section (L-section) of the main stream was prepared from the values of the contours across the stream and the spot levels near the banks with respect to their distances from the point of interest/gauging site. A line is so drawn by trials from the point of interest on the L-section such that the areas of the L-section (profile) above and below the line are equal. This line is called equivalent Stream Slope Line. Alternatively, the L-section may be broadly divided into 3 to 4 segments representing the broad ranges of the slopes of the segments and the following formulae may be used to calculate the equivalent slope (S):

$$S = \sum \frac{L_i \; (D_{i-1} + D_i)}{L^2} \qquad \text{.............(3.1)}$$

Where L_i = Length of the ith segment in km.

D_{i-1}, D_i = The depth of the river at the point of intersection of (i-1) and ith contours from the base line (datum) drawn at the level of the point of study in meters.

L = The length of the longest stream as defined in section 3.1.2 in km.

Out of 42 gauged catchments, the physiographic parameters A, L and S were estimated only for 23 catchments which were found suitable for analysis. These parameters are shown in Table - 2.

3.2 SCRUTINY OF DATA AND FINALISATION OF GAUGE DISCHARGE RATING CURVE

The data was scrutinised through arithmetical checks. The gauge (stage) vs. area curves and the stage vs. velocity curves were prepared to identify the outliers and reconcile the data in the plotted points of the stage-discharge curves. At many places, the average trend of the stage-area curve and the stage-velocity curve was used to obtain the discharges at various levels. Where wide dispersions were observed in the stage-discharge curve, log-log fitting was adopted. The stages for conceivable floods were converted into discharges initially identified with reference to rise and fall in the stages of the river.

3.3 SELECTION OF FLOOD AND CORRESPONDING STORM EVENTS

The general guidelines adopted for selection of flood events for each catchments are as under:

i) The flood should not have unduly stagnating water levels.

ii) The selected flood should result from significant rainfall excess generally not less than one cm.

iii) The runoff resulting from particular storm should not be less than about 15% of the gross rainfall.

3.4 COMPUTATION OF HOURLY CATCHMENT RAINFALL

The Theissen network was drawn for the raingauge stations on the catchment map and then Theissen Weights were computed. The hourly point rainfall at each station was multiplied with their respective Theissen Weight and added to obtain the catchment rainfall for each one hour duration during the storm period. Two hourly catchment rainfall units were estimated by adding the successive hourly rainfall units.

3.5 SEPARATION OF BASE FLOW

The selected flood events were plotted on the normal graph paper. The Base Flow was separated through the normal procedures to obtain direct surface runoff hydrographs and the direct runoff depth over the catchment was computed for each flood events.

3.6 COMPUTATION OF INFILTRATION LOSS (Ø-INDEX) AND 2-HOURLY RAINFALL EXCESS UNITS

With the known values of 2-hourly catchment rainfall in section 3.4 and the direct runoff depth in section 3.5 for each flood event, the infilteration loss (constant loss rate) by trials was estimated to obtain the direct runoff depth. The 2-hourly infiltration loss was deducted from the 2-hourly rainfall to get the 2-hourly rainfall excess units.

3.7 DERIVATION OF 2-HOUR UNITGRAPH

A unit duration of 2-hours was adopted for derivation of unitgraphs to reduce computational work as the floods from the catchments with flat slopes were of long duration. The 2-hour unitgraphs were derived from the rainfall excess hyetographs and their corresponding direct runoff hydrographs by iterative methods. The iterations were carried out till the observed and estimated direct runoff hydrographs compared favourably. Normally 5 to 15 unitgraphs are derived for each of the 23 catchments considered.

3.8 DRAWING OF REPRESENTATIVE UNITGRAPHS AND MEASURING THEIR PARAMETERS

The representative unitgraph is the unitgraph which reproduces, in reasonable limits, the direct surface runoff hydrographs corresponding to their rainfall excess of the storm from which it has been obtained. Representative 2-hour unitgraphs were drawn from a set of superimposed 2-hour unitgraphs for each of the 23 catchments and their parameters noted. The parameters of the representative unitgraph illustrated in Fig.2 were measured for each of the catchments. The parameters of the representative unitgraphs are t_r, t_p, T_m, Q_p, q_p, W_{50}, W_{75}, W_{R50}, W_{R75} and T_B. These parameters for 23 catchments are listed in Table -3.

3.9 ESTABLISHING RELATIONSHIPS BETWEEN PHYSIOGRAPHIC AND REPRESENTATIVE UNITGRAPH PARAMETERS

Physiographic parameters like L, Lc, S and A and the parameters of the 2-hour unitgraph like t_p, Q_p, T_B, W_{50}, W_{75}, W_{R50}, W_{R75}, for 23 gauged catchmets out of 42 catchments in subzone - 1(e) were estimated as shown in Tables - 2 and 3 respectively. The reasons for eliminating the 19 catchments in this study are indicated in Table - 1. Following simple model was adopted for establishing the relationships between these parameters:

$$Y = C\,X^{P} \qquad \text{.............3.9.1}$$

where

Y = Dependent variable

X = Independent variable

C = A constant

P = An exponent.

From equation 3.9.1, it follows that

$$\text{Log } Y = \text{Log } C + p \text{ Log } X \qquad \text{........................ 3.9.2}$$

Thus if Y and X are plotted on a log-log paper, one may expect a straight line relationship.

Various trials of relationship between the physiographic parameters and one of the unitgraph parameters and among the unitgraph parameters themselves were made. The relationship between the physiographic parameters ($L/\sqrt{S}$) and unit peak discharge of the U.G.(qp) was found to be significant. Similarly, the relationships between qp were individually found to be significant with the U.G. parameters of tp, W50, W75, WR50 and WR75 as dependent variables. The time base (TB) could be significantly correlated to (tp). Principle of least squares was used in the regression analysis to get the above relationship in equation 3.9.1 above to predict the parameters of the Synthetic Unitgraph in an unbiased manner.

The following relationships have been derived for estimating the 2-hour unitgraph parameters in the subzone -1(e).

Sl. No.	Relationship	Corr. Coeff.	Equ. No.	Fig. No.
1.	$q_p = 2.030/(L/\sqrt{S})^{0.649}$	0.80	3.9.3	3
2.	$t_p = 1.858/(q_p)^{1.038}$	0.90	3.9.4	4
3.	$W_{50} = 2.217/(q_p)^{0.990}$	0.99	3.9.5	5
4.	$W_{75} = 1.477/(q_p)^{0.876}$	0.98	3.9.6	6
5.	$W_{R50} = 0.812/(q_p)^{0.907}$	0.91	3.9.7	7
6.	$W_{R75} = 0.606/(q_p)^{0.791}$	0.86	3.9.8	8
7.	$T_B = 7.744\ (t_p)^{0.779}$	0.91	3.9.9	9

TABLE - I

LIST OF SELECTED RAILWAY BRIDGE CATCHMENTS IN SUBZONE 1(e) (UPPER INDO - GANGA PLAINS) AND DATA AVAILABILITY OF GAUGE, DISCHARGE AND RAINFALL

S. NO.	NAME OF STREAM	NAME OF SECTION WHERE BRIDGE IS LOCATED WITH RAILWAY ZONE/ ROAD SEC.	RAILWAY BR. NO/ SITE NO.	G & SITE LOCATION LATITUDE DEG. MIN. SEC	G & SITE LOCATION LONGITUDE DEG. MIN. S	CATCHMENT AREA (SQ. Km.)	NO. OF RAIN-GAUGE STATIONS	DATA AVAILABILITY	NO. OF YEARS	REMARKS
1	2	3	4	5	6	7	8	9	10	11
	A : BRIDGES CONSIDERED FOR REGRESSION ANALYSIS									
1.	WHITE BEIN	AMRITSAR - LUDHIANA, N.R.	20	31 15 00	75 41 00	2426	20	1962,66 76-78	8	
2.	KOSI	LALKUA - KASHI PUR, N.R.	104(I)	29 10 00	79 02 37	2072	9	1966-72	7	
3.	SOT NADI	BAREILLY - KASGANJ, N.E.R.	400	28 01 00	79 07 00	1908	9	1966-73, 75-78	12	
4.	GHAGGAR	SAHARANPUR - LUDHIANA	2 (MOT)	30 24 00	76 44 00	1126	3	1981-83	3	
5.	SUNAM CHOE	DHURI - JAKHAL, N.R.	181	30 07 30	75 48 00	912	10	1963-66	4	
6.	KALI R.	MORADABAD-GHAZIABAD, N.R.	89	28 46 30	77 49 00	815	8	1964-69, 75-78	10	
7.	QADIRABAD	KHURJA - HAPUR, N.R.	124	28 38 18	77 47 22	512	6	1962-66	5	
8.	MALIN	MORADABAD-SAHARANPUR, N.R.	1244	29 34 00	78 11 00	440	5	1975-79	5	
9.	HINDAN	SAHARANPUR-MORADABAD, N.R.	1307	29 56 00	77 38 00	322	4	1968-74	7	
10.	PATTI NALLA	JULLUNDUR - AMRITSAR, N.R.	99 (I)	31 35 00	75 02 30	297	3	1968-71	4	
11.	JAGBURA	PILIBHIT - TANKPUR, N.R.	65 (II)	28 59 48	80 03 24	190	3	1966,71-76	7	
12.	AMRI - CHOE	DELHI - AMBALA, N.R.	229	30 14 00	76 52 00	188	2	1963-67	5	
13.	KUBHRA NALLA	GHAZIABAD - SAHARANPUR, N.R.	166	29 29 30	77 43 30	166	2	1962-67	6	
14.	PANGELI	BHOJPURA - PILIBHIT, N.E.R.	288	28 33 00	79 38 00	160	3	1962,66, 68-74	9	
15.	SISWAN	SIRHIND - NANGAL DAM, N.R.	93 (II)	30 50 00	76 34 00	141	2	1967-69, 70,71	5	
16.	DEORANIAN N.	BHOJPURA - KATHGODAM, N.E.R.	2	28 30 30	79 27 05	106	3	1962-66 68,69	7	
17.	SUGHRAO	SIRHIND - NANGAL DAM, N.R.	104(II)	30 56 00	76 31 30	105	2	1962-65	4	
18.	AMRI CHOE	SAHARANPUR - AMBALA, N.R.	291	30 15 00	76 52 00	96	2	1968-73	6	
19.	NAKATIA	BHOJPURA - PILLIBHIT, N.E.R.	315	28 31 18	79 30 30	73	4	1961-67	7	
20.	KHAR	KOTPUTLI - SHAHPURA	1(MOT)	27 34 52	76 04 37	55	1	1981-82	2	
21.	GANGAN N.	SAHARANPUR - MORADABAD, N.R.	1231	29 33 50	78 22 55	49	2	1963-66	4	
22.	MOAND	REWARI - PHULERA, NER	184	27 41 00	75 44 00	36	1	1961-64, 66	4	
23.	DENI	BHOJPUR - LALKUA, N.E.R.	50	28 56 30	79 31 20	25	1	1968-73	6	
	B : BRIDGES NOT CONSIDERED FOR REGRESSION ANALYSIS									
24.	SIRSA	SHIKOHABAD - FARRUKHABAD, NR	3	27 06 00	78 37 00	3624	10	1968-72	5	FLOODS UNSUITABLE FOR U.G. ANALYSIS.
25.	KASUR - NALLA	JULLUNDUR - AMRITSAR, N.R.	120	31 35 00	74 57 00	743	3	1963,64, 66,67	4	——— DO ———
26.	TANGRI N.	AMBALA - SAHARANPUR, N.R.	294	30 17 00	76 52 30	416	2	1962-65	4	——— DO ———
27.	SARETA DRAIN	JAKHAL BHATINDA, N.R.	278	29 51 30	75 43 30	337	3	1972-73	2	——— DO ———
28.	DEORA NIAN	MORADABAD - BAREILLY, N.R.	1038	28 22 30	79 22 30	280	3	1966-72	7	——— DO ———
29.	DHANAULA DR.	RAJPURA - BHATINDA, N.R.	221	30 18 00	75 25 00	277	4	1968-74	7	NO FLOODS.
30.	QADIRABAD	MORADABAD - DELHI, N.R.	116	28 43 30	77 43 30	270	4	1962-66	5	FLOODS UNSUITABLE FOR U.G. ANALYSIS.
31.	JAMUNA SPILL	~~MATHURA - VRINDAVAN~~, N.E.R.	10	27 32 00	77 40 00	259	2	1961,64, 65	3	——— DO ———
32.	TANGURI CHOE	AMBALA - LUDHIANA, N.R.	325	30 28 30	76 37 00	255	3	1965-71	7	——— DO ———
33.	RAHI - BEAS.	JULLUNDUR - AMRITSAR, N.R.	65 (i)	31 32 30	75 17 00	232	2	1966-67	2	——— DO ———
34.	ALIGARH DR.	GHAZIABAD - TUNDLA, N.R.	146	27 56 00	78 03 00	194	3	1976-79	4	——— DO ———
35.	JASSOWAL DR.	LUDHIANA - FEROZEPUR, N.R.	68	30 49 00	75 30 00	190	3	1963, 65, 66	3	——— DO ———
36.	NASRALA CHOE	JULLUNDUR - HOSHIARPUR, N.R	70	31 29 00	75 49 00	190	3	1962, 65, 66	3	——— DO ———
37.	KINGERWALA CHOE.	JULLUNDUR - PATHANKOT, N.R.	55	31 50 00	75 36 00	187	[illegible]	1968-74	[illegible]	[illegible]
38.	PATHRIRA	LAKSAR - DEHRADUN, N.R.	6 (ii)	29 47 50	78 02 18	178	[illegible]	1966, 70, 71	[illegible]	FLOODS UNSUITABLE FOR U.G. ANALYSIS.
39.	DAGRU DR.	LUDHIANA - FEROJPUR, N.R.	93 (i)	30 49 00	75 04 00	177	3	1968-74	7	——— DO ———
40.	KAIL NALA	PHAGWARA - NAWASHAHR, N.R.	71	31 11 00	75 54 30	90	1	1964-66	3	——— DO ———
41.	BUDKI NADI	SIRHIND - NANGAL DAM, N.R.	99 (ii)	30 54 00	76 30 30	85	2	1972-73	2	——— DO ———
42.	MUDKI DRAIN	FEROZEPUR - BHATINDA, N.R.	60 A	30 44 00	74 44 00	79	2	1965	1	INADEQUATE DATA.

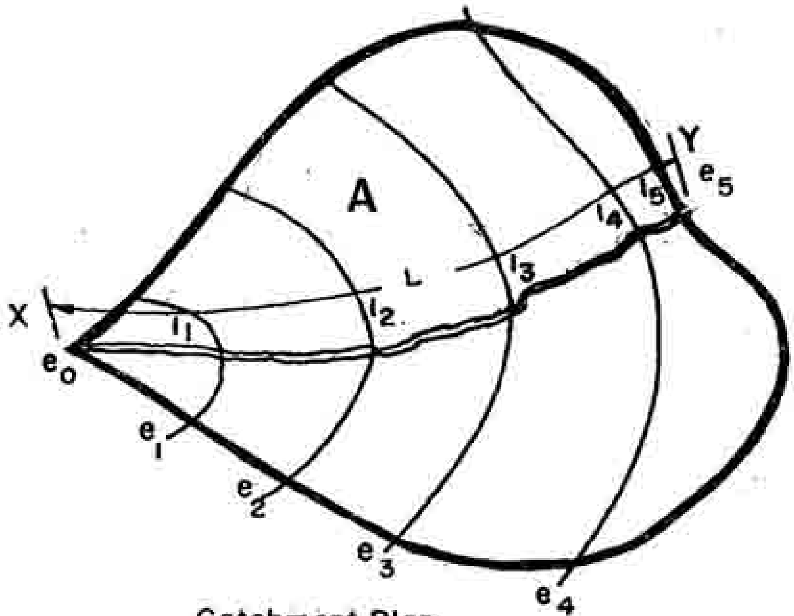
TABLE -2: BASIN CHARACTERISTICS OF SUBZONE -1(e)

Sl. No.	Br.No.	A Sq.km.	L km.	S(q) m/km	$\frac{L}{\sqrt{S}}$
1	20	2425.54	96.60	0.629	121.82
2	104 (i)	2072.0	125.19	0.870	134.21
3.	400	1908.00	200.80	0.257	396.09
4.	Ghaggar	1126.00	81.42	5.14	35.91
5.	181	911.68	144.90	0.901	152.61
6.	89	814.75	97.40	0.39	155.96
7.	124	511.53	54.74	0.465	88.23
8.	1244	440.00	64.50	6.280	25.74
9.	1307	322.20	56.32	3.65	29.48
10.	99(i)	296.61	49.88	0.422	76.78
11.	65	190.11	32.2	11.43	9.52
12.	229	187.96	47.75	0.974	48.38
13.	166	165.76	27.48	0.61	35.18
14.	288	160.06	36.70	0.492	52.32
15.	93(ii)	140.66	28.60	3.60	15.07
16.	2	106.40	61.98	0.361	183.16
17.	104 (ii)	104.58	23.90	4.363	11.44
18.	291	96.41	36.20	1.08	34.83
19.	315	73.04	28.34	0.128	79.21
20.	Khar	55.00	17.00	5.8	7.06
21.	1231	49.47	16.19	2.41	10.43
22.	184	35.87	9.45	4.37	4.53
23.	50	25.26	15.0	2.0	10.61

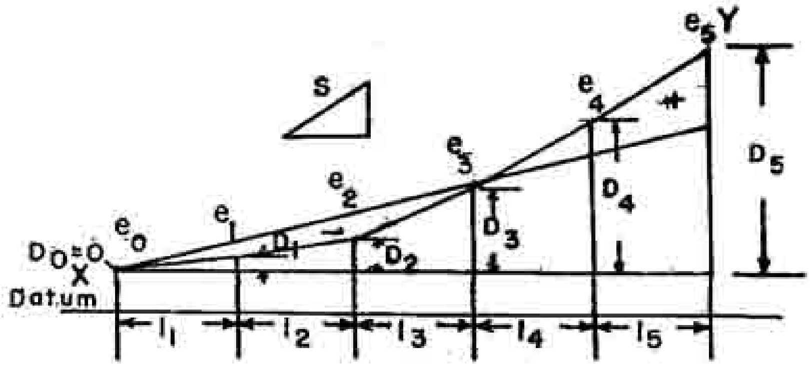
TABLE - 3: REPRESENTATIVE 2-HOUR U.G. PARAMETERS SUBZONE 1(e)

Sl. No.	Br.No.	tp hrs	Qp Cumecs	qp Cumec/ Sq.Km.	tr hr.	T_B hr.	W_{50} hr.	W_{75} hr.	WR_{50} hr.	WR_{75} hr.
1.	20	25	226.50	0.093	2	86	26.00	14.00	7.5	5.00
2.	104 (I)	23	237.00	0.114	2	80	17.60	10.80	8.80	5.60
3.	400	27	141.40	0.074	2	104	31.20	16.00	11.20	6.40
4.	Ghaggar	7	289.00	0.257	2	36	8.50	4.50	3.00	1.80
5.	181	27	37.50	0.041	2	188	53.00	23.00	13.00	5.00
6.	89	25	55.70	0.068	2	127	36.10	15.20	11.10	5.20
7.	124	27	70.20	0.137	2	74	15.00	10.00	5.00	4.00
8.	1244	13	114.50	0.260	2	40	7.70	4.10	3.20	2.10
9.	1307	7	140.45	0.436	2	24	4.30	2.70	2.20	1.50
10.	99(i)	45	24.39	0.082	2	120	26.00	12.50	8.00	4.00
11.	65	6	84.22	0.440	2	21	5.20	2.98	2.60	1.68
12.	229	6	70.00	0.372	2	28	5.80	2.90	2.20	1.30
13.	166	3	28.00	0.169	2	54	13.00	5.60	1.00	0.60
14.	288	32	10.80	0.067	2	177	27.50	13.00	7.00	4.00
15.	93(ii)	5	66.00	0.469	2	15	5.40	3.50	2.35	1.70
16.	2	39	6.50	0.061	2	144	36.50	26.50	17.00	11.55
17.	104 (II)	1	120.00	1.147	2	9	2.10	1.60	0.60	0.40
18.	291	6	53.50	0.555	2	21	3.30	1.90	1.40	1.00
19.	315	33	4.24	0.058	2	138	38.50	17.00	10.10	4.60
20.	Khar	4	16.19	0.294	2	25	7.80	5.00	2.70	2.00
21.	1231	8	14.65	0.296	2	29	7.40	3.80	2.40	1.60
22.	184	1	35.62	0.992	2	8	2.50	1.90	0.70	0.50
23.	50	9	4.5	0.178	2	58	11.20	5.60	2.00	1.20

Fig. 1



Catchment Plan



L- Section

$$S = \frac{\sum_{i=1}^{n} (D_i + D_{i-1})\, l_i}{L^2}$$

Where : S = Equivalent stream slope (m/km)

L = Length of longest stream course (km)

$l_i = l_1, l_2, l_3, \ldots\ldots l_n$ = Segment lengths (km)

$e_i = e_1, e_2, \ldots\ldots\ldots e_n$ = Contour elevations (m)

$D_i = D_0, D_1, D_2, \ldots\ldots D_n$

$= (e_0 - e_0), (e_1 - e_0), (e_2 - e_0) \ldots\ldots (e_n - e_0)$ (m)

A = Catchment area (km²)

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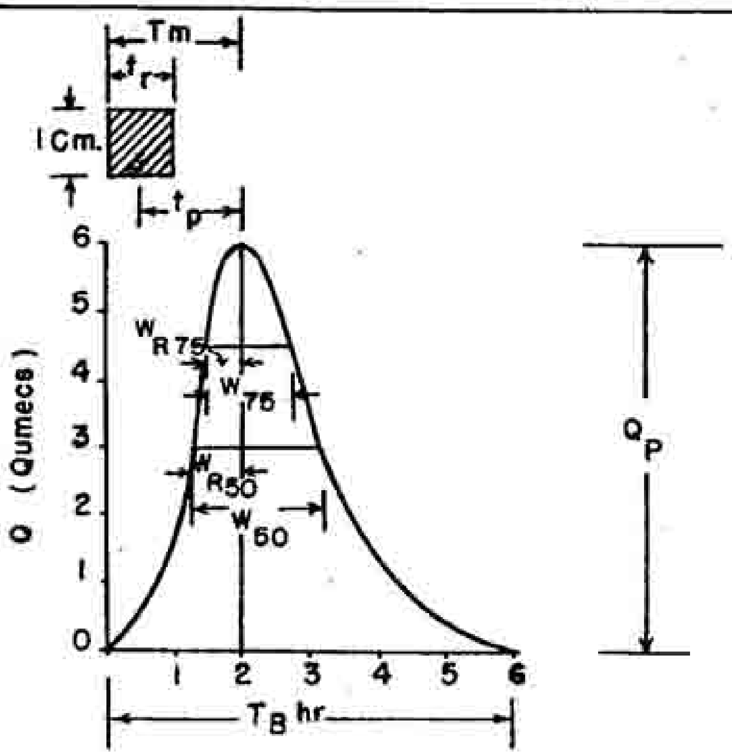
PHYSIOGRAPHIC PARAMETERS

DRAWN AVNISH | CHECKED. A.K.GHOSH

Fig: 2



U.G. = Unit Graph

t_r = Unit Rainfall Duration adopted in a specific study (hr)

T_m = Time from the start of rise to the peak of the U.G. (hr.)

Q_P = Peak Discharge of Unit Hydrograph (Cumecs)

t_p = Time from the Centre of rainfall excess duration to the U.G. Peak (hr)

W_{50} = Width of the U.G. measured at 50 % of peak discharge ordinate (hr.)

W_{75} = Width of the U.G. measured at 75 % of peak discharge ordinate (hr.)

W_{R50} = Width of the rising limb of U.G. measured at 50% of peak discharge ordinate (hr.)

W_{R75} = Width of the rising limb of U.G. measured at 75% of peak discharge ordinate (hr.)

T_B = Base width of Unit Hydrograph (hr.)

A = Catchment Area (Sq. km.)

$q_p = Q_p/A$ = Cumec per Sq. km.

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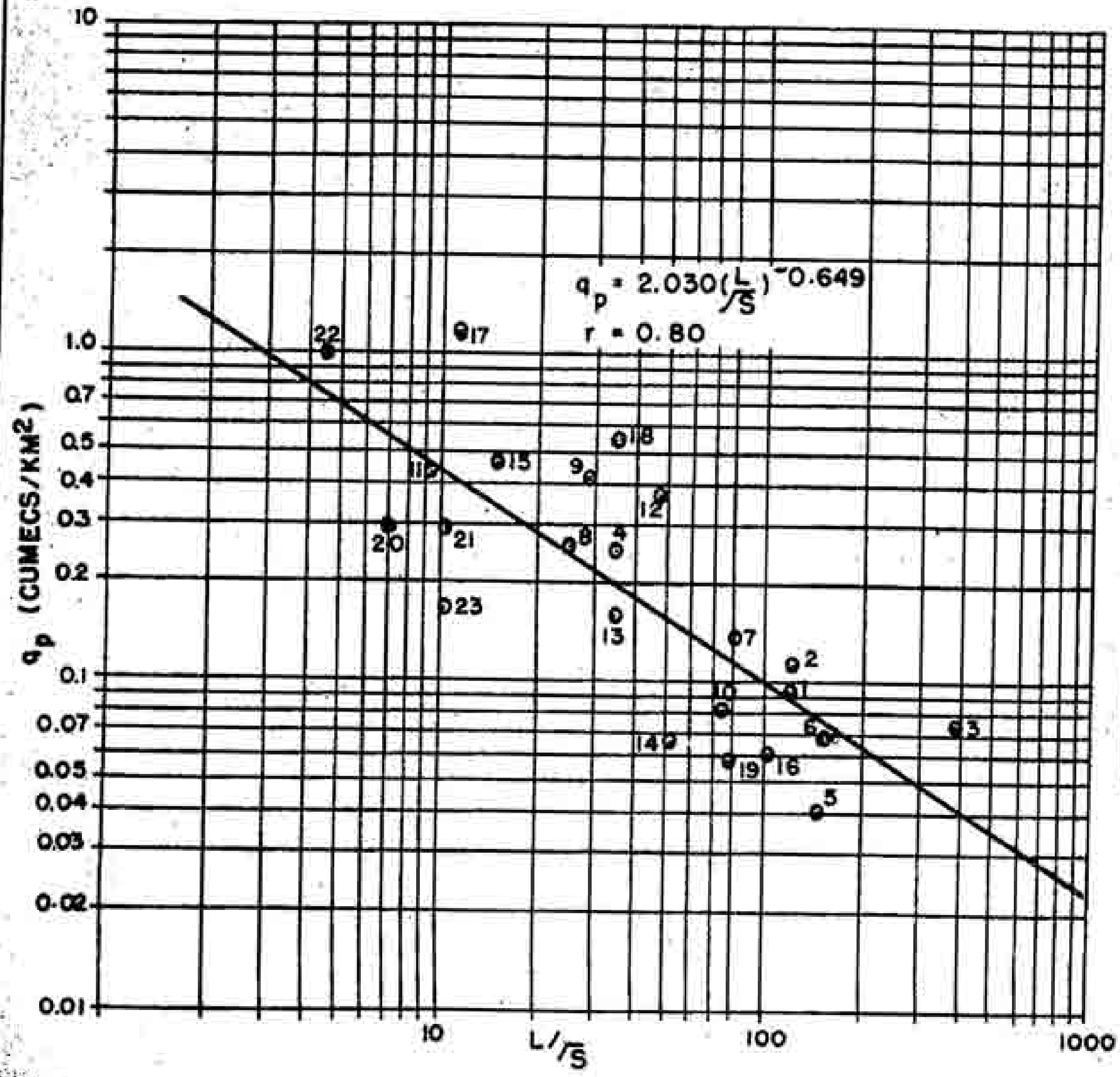
UNIT GRAPH PARAMETERS

DRAWN BY AVNISH KUMAR
CHECKED BY. A. K. GHOSH

FIG. 3



Sl. No.	BRIDGE NO.	$\frac{L}{\sqrt{S}}$	q_p
1	20	121·82	0·093
2	104	134·21	0·114
3	400	396·09	0.074
4.	Ghoggar	35·91	0.257
5	181	152.61	0.041
6	89	155.96	0.068
7	124	80.23	0.137
8	1244	25.74	0.260
9	1307	29.48	0.436
10	99(I)	76.78	0.082
11	65	9.52	0.440
12	229	48·38	0·372
13	166	35.18	0.169
14	288	52.32	0.067
15	93 (II)	15.07	0.469
16	2	103.16	0.061
17	104	11.44	1.147
18	291	34.83	0.555
19	315	79.21	0.058
20	Khar	7.06	0.294
21	1231	10.43	0.296
22	184	4.52	0.992
23	50	110.61	0.178

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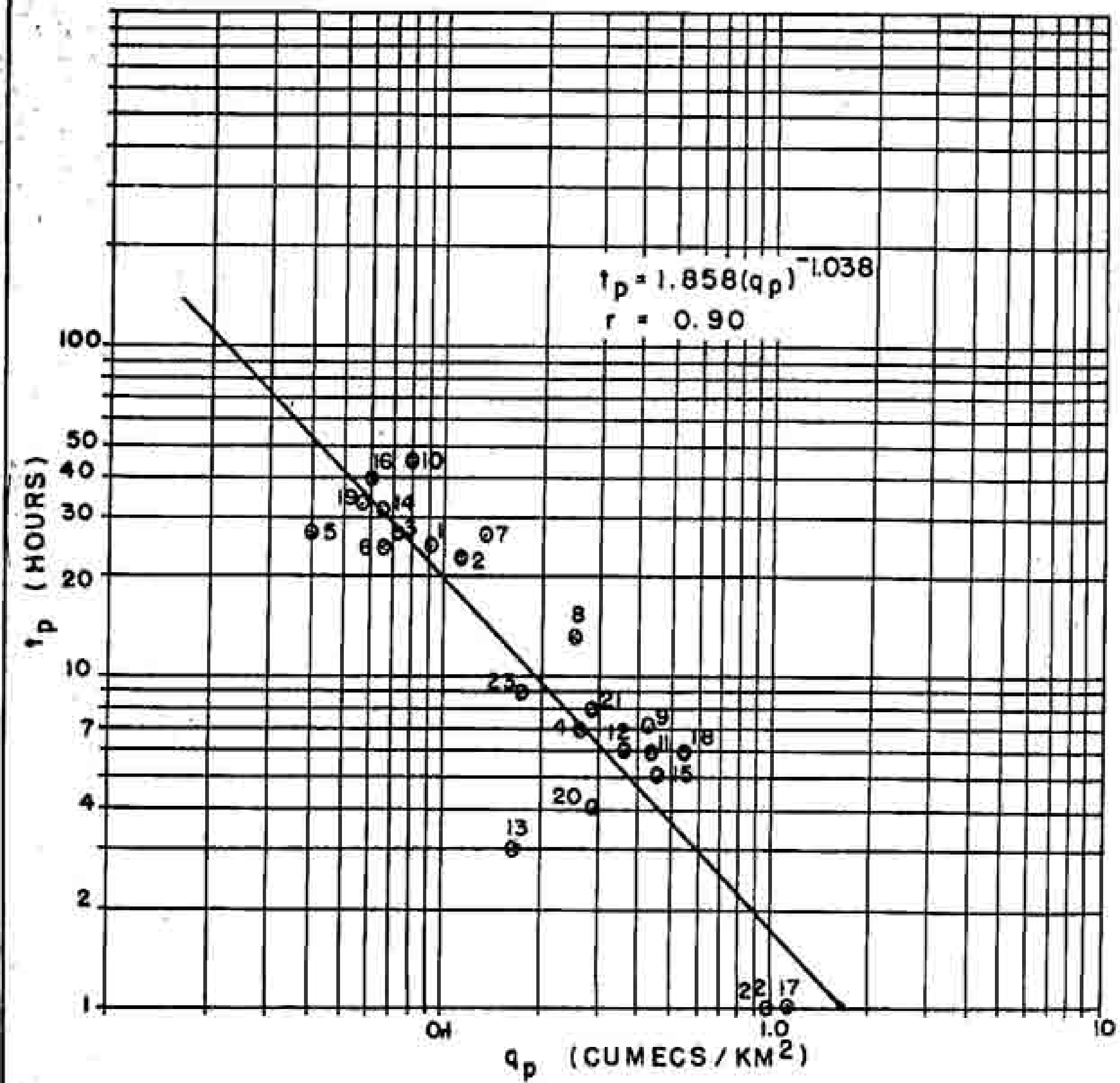
RELATION BETWEEN
L/√S AND q_p
UPPER INDO-GANGA PLAINS
SUB-ZONE I (e)

TRACED	CHECKED
S.K. BHATIA	A. P KHANNA

FIG. 4



Sl.NO	BRIDGE NO	q_p	t_p
1	20	0.093	25
2	104	0.114	23
3	400	0.074	27
4	Ghaggar	0.257	7
5	181	0.041	27
6	89	0.068	25
7	124	0.137	27
8	1244	0.260	13
9	1307	0.436	7
10	99 (I)	0.082	45
11	65	0.440	6
12	229	0.372	6
13	166	0.169	3
14	288	0.067	32
15	93 (II)	0.469	5
16	2	0.061	39
17	104	1.147	1
18	291	0.555	6
19	315	0.058	33
20	Khar	0.294	4
21	1231	0.296	8
22	184	0.992	1
23	50	0.178	9

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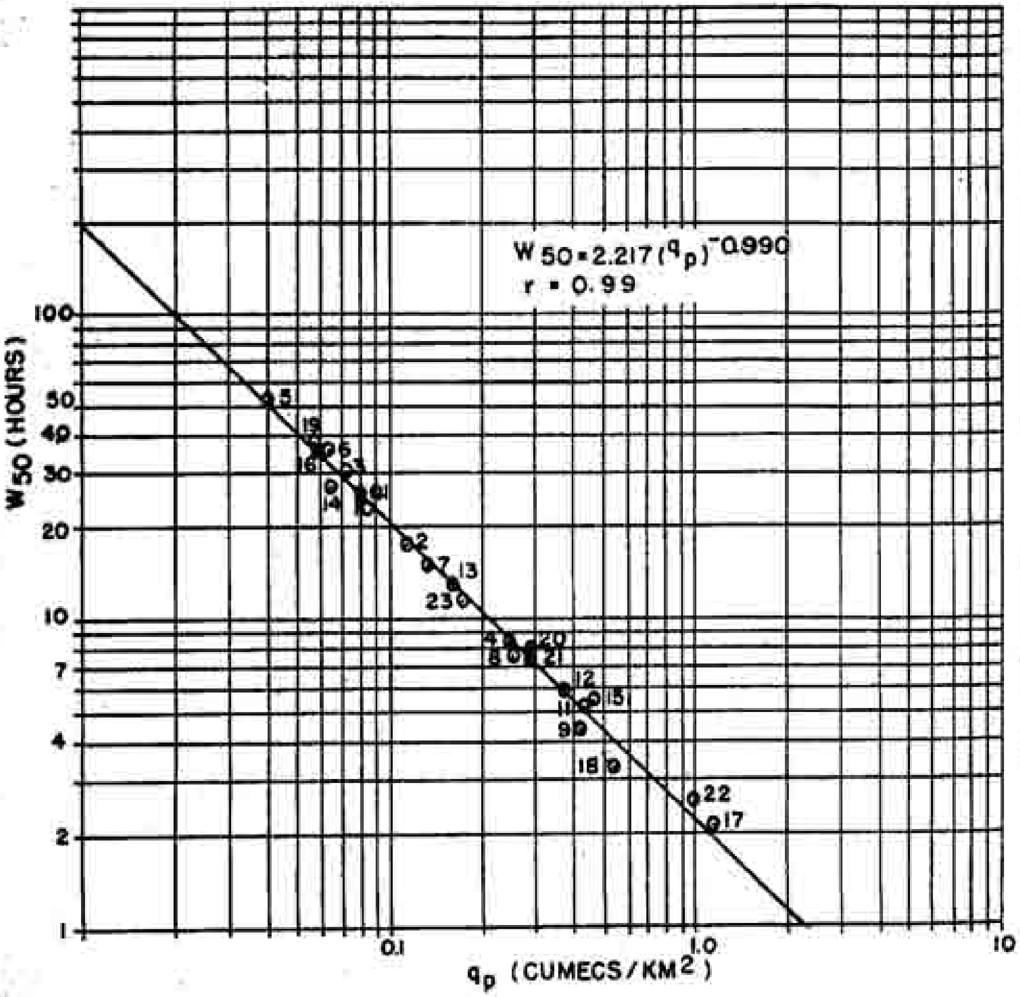
RELATION BETWEEN q_p AND t_p
UPPER INDO-GANGA PLAINS
SUB-ZONE 1 (e)

TRACED	CHECKED
AVNISH KUMAR	A. P. KHANNA

FIG.5



Sl.NO.	Br. NO.	q_p	W_{50}
1	20	0.093	26.00
2	104	0.114	17.60
3	400	0.074	31.20
4	Ghaggar	0.257	8.50
5	181	0.041	53.00
6	89	0.068	36.10
7	124	0.137	15.00
8	1244	0.260	7.70
9	1307	0.436	4.30
10	99 (I)	0.082	26.00
11	65	0.440	5.20
12	229	0.372	5.80
13	166	0.169	13.00
14	288	0.067	27.50
15	93(II)	0.469	5.40
16	2	0.061	36.50
17	104	1.147	2.10
18	291	0.555	3.30
19	315	0.058	38.50
20	Khar	0.294	7.80
21	1231	0.296	7.40
22	184	0.992	2.50
23	50	0.178	11.40

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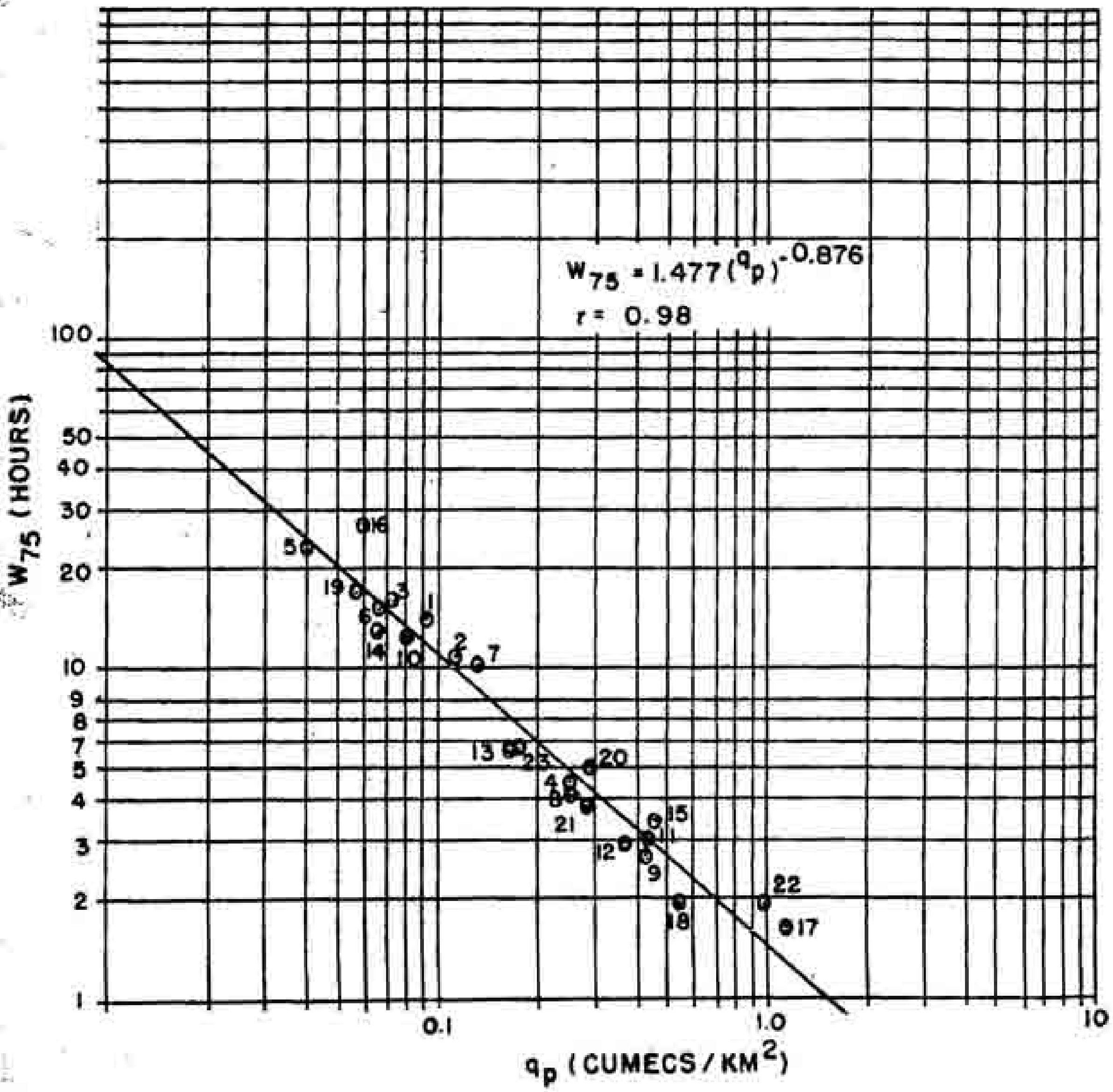
RELATION BETWEEN
q_p AND W_{50}
UPPER INDO-GANGA PLAINS
SUB-ZONE 1 (e)

TRACED	CHECKED
O. P. SINGH	A. P. KHANNA

FIG. 6



Sl.NO.	Br. NO.	q_p	W_{75}
1	20	0.093	14.00
2	104	0.114	10.80
3	400	0.074	16.00
4	Ghaggar	0.257	4.50
5	181	0.041	23.00
6	89	0.068	15.20
7	124	0.137	10.00
8	1244	0.260	4.10
9	1307	0.436	2.70
10	99 (I)	0.082	12.50
11	65	0.440	2.98
12	229	0.372	2.90
13	166	0.169	5.60
14	288	0.067	13.00
15	93 (II)	0.469	3.50
16	2	0.061	26.50
17	104	1.147	1.60
18	291	0.555	1.90
19	315	0.058	17.00
20	Khar	0.294	5.00
21	1231	0.296	3.80
22	184	0.992	1.90
23	50	0.178	5.60

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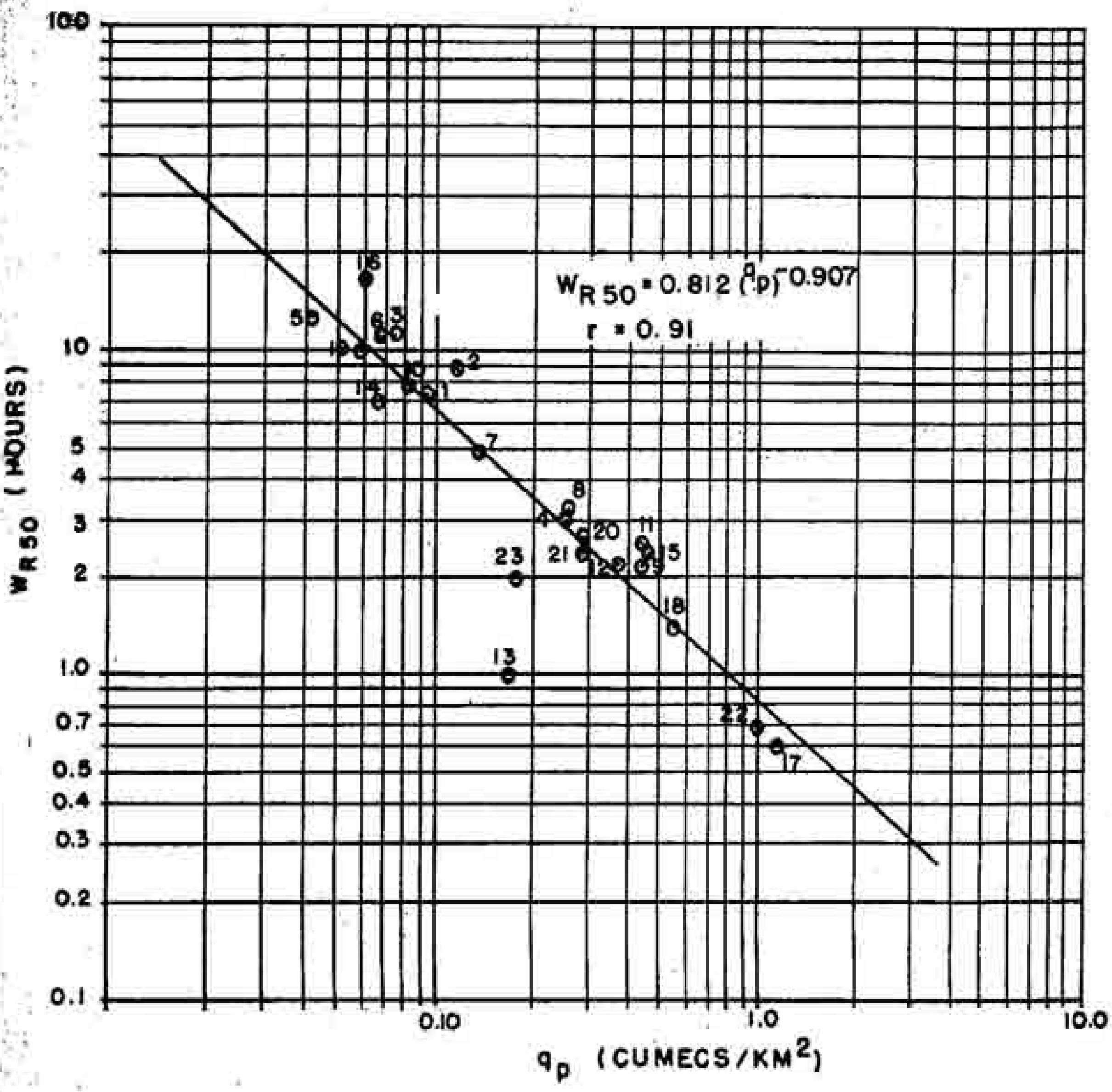
RELATION BETWEEN
q_p AND W_{75}
UPPER INDO-GANGA PLAINS
SUB-ZONE I (e)

DRAWN BY	CHECKED BY
S. K. BHATIA	A. P. KHANNA

FIG. 7



Sl NO	Br. NO.	q_p	W_{R50}
1	20	0.093	7.50
2	104	0.114	8.80
3	400	0.074	11.20
4	Ghaggar	0.257	3.00
5	181	0.041	13.00
6	89	0.068	11.10
7	124	0.137	5.00
8	1244	0.260	3.20
9	1307	0.436	2.20
10	99 (I)	0.082	8.00
11	65	0.440	2.60
12	229	0.372	2.20
13	166	0.169	1.00
14	288	0.067	7.00
15	93 (II)	0.469	2.35
16	2	0.061	17.00
17	104	1.147	0.60
18	291	0.555	1.40
19	315	0.058	10.10
20	Khar	0.294	2.70
21	1231	0.296	2.40
22	184	0.992	0.70
23	50	0.178	2.00

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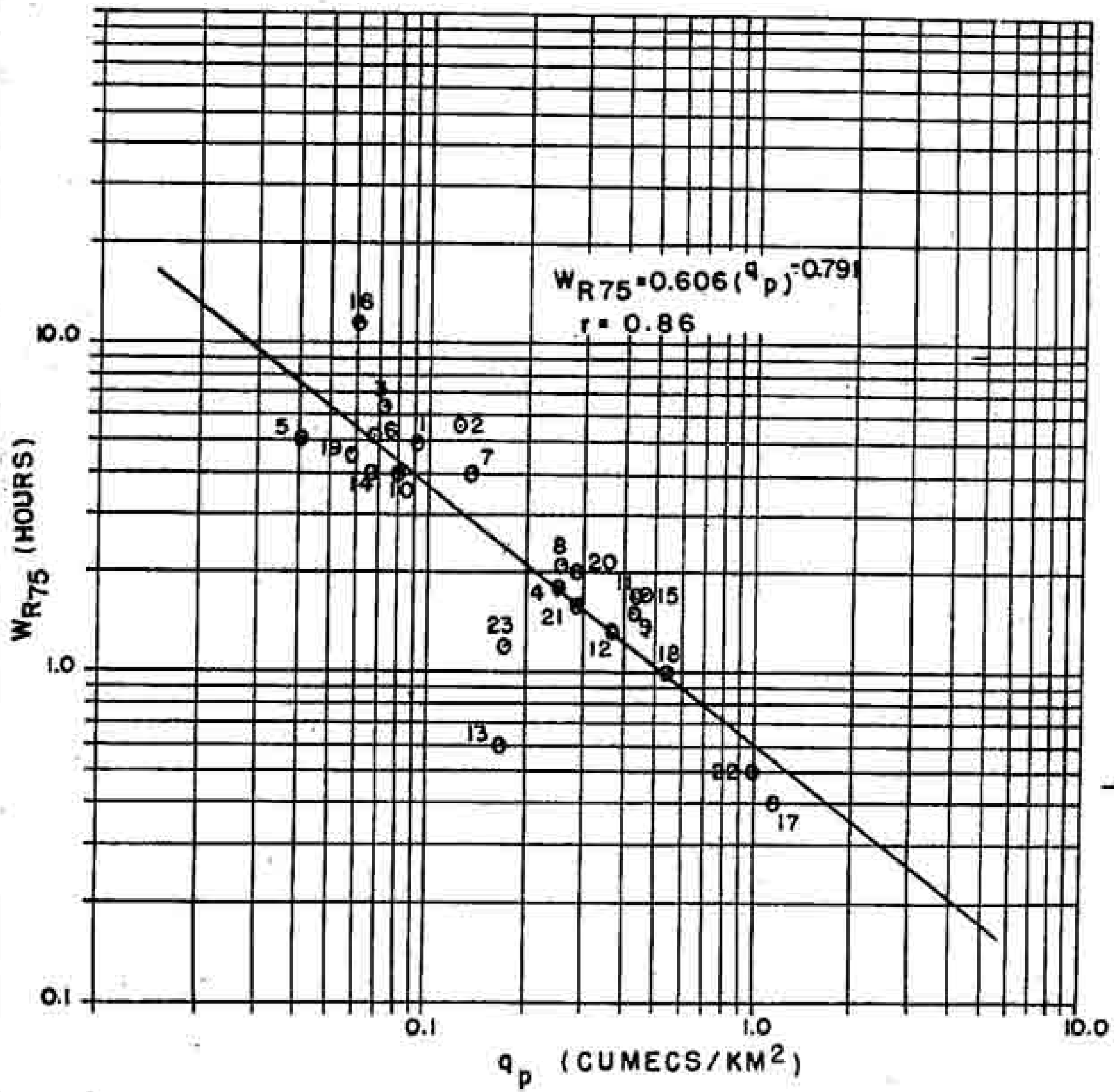
RELATION BETWEEN
q_p AND W_{R50}
UPPER INDO-GANGA PLAINS
SUB-ZONE 1 (a)

DRAWN BY T. R. ARORA
CHECKED BY A. P. KHANNA

FIG. 8



Sl.No.	BRIDGE NO.	q_p	W_{R75}
1	20	0.093	5.00
2	104	0.114	5.60
3	400	0.074	6.40
4	Ghaggar	0.257	1.80
5	181	0.041	5.00
6	89	0.068	5.20
7	124	0.137	4.00
8	1244	0.260	2.10
9	1307	0.436	1.50
10	99 (I)	0.082	4.00
11	65	0.440	1.68
12	229	0.372	1.30
13	166	0.169	0.60
14	288	0.067	4.00
15	93 (II)	0.469	1.70
16	2	0.061	11.55
17	104	1.147	0.40
18	291	0.555	1.00
19	315	0.058	4.60
20	Khar	0.294	2.00
21	123)	0.296	1.60
22	184	0.992	0.50
23	50	0.178	1.20

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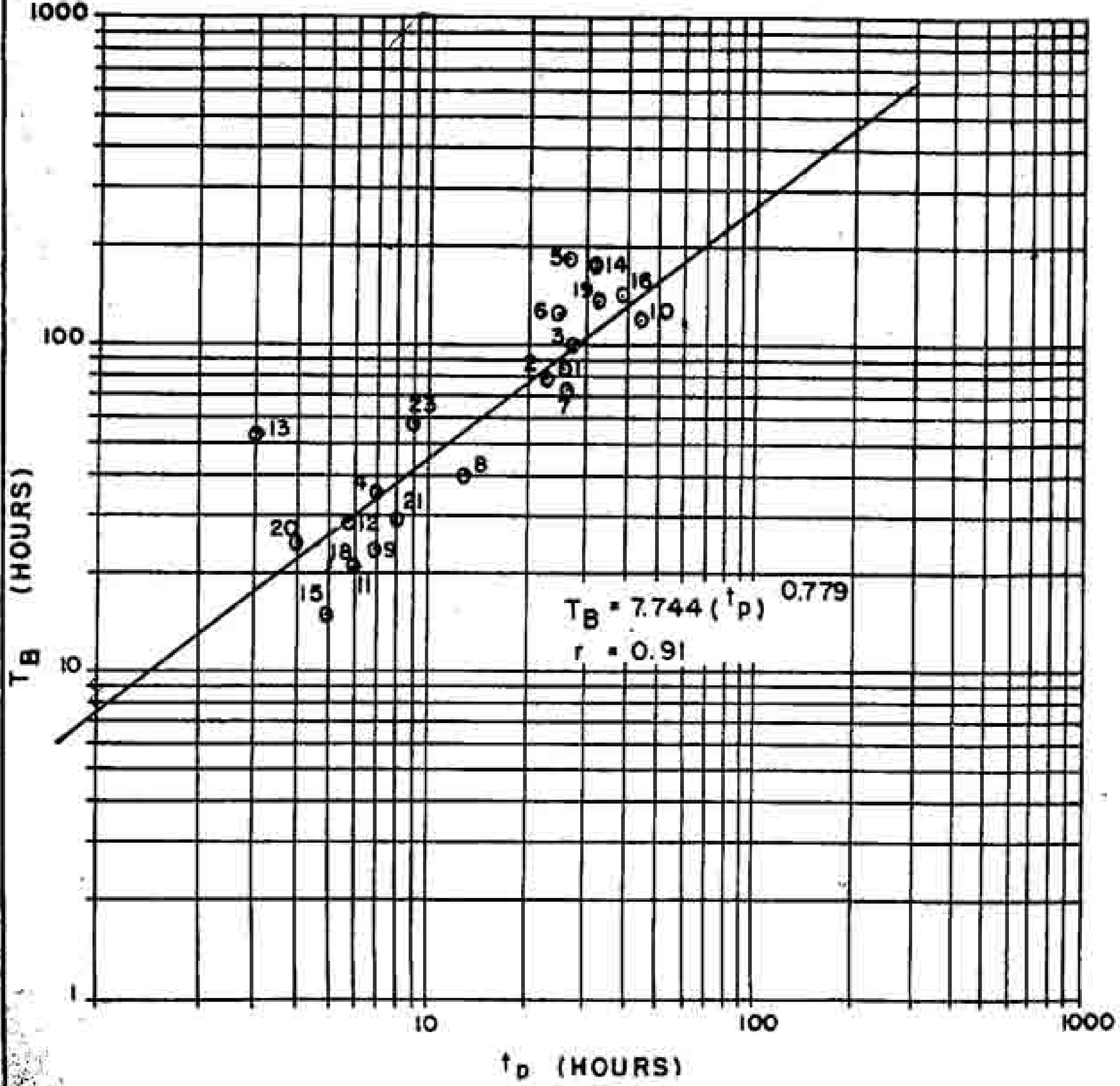
RELATION BETWEEN
q_p AND W_{R75}
UPPER INDO-GANGA PLAINS
SUB-ZONE I (e)

TRACED T. R. ARORA | CHECKED A.P. KHANNA

FIG. 9



Sl.No	BRIDGE NO	t_p	T_B
1	20	25	86
2	104	23	80
3	400	27	104
4	Ghogger	7	36
5	181	27	188
6	89	25	127
7	124	27	74
8	1244	13	40
9	1307	7	24
10	99 (I)	45	120
11	65	6	21
12	229	6	28
13	166	3	54
14	288	32	177
15	93 (II)	5	15
16	2	39	144
17	104	1	9
18	291	6	21
19	315	33	138
20	Khar	4	25
21	1231	8	29
22	184	1	8
23	50	9	58

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RELATION BETWEEN t_p AND T_B
UPPER INDO-GANGA PLAINS
SUB-ZONE 1(e)

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$$Q_p = q_p \times A$$

$$T_m = t_p + t_r/2$$

The above relationships may be utilised to estimate the parameters of 2-hour Synthetic Unitgraph for an ungauged catchment with its known physiographic parameter L, A and S.

3.10 DERIVATION OF 2-HOUR SYNTHETIC UNITGRAPH FOR AN UNGAUGED CATCHMENT

Considering the hydro-meteorological homogenity of subzone -1(e), the relations established between physiographic and unitgraph parameter in Section 3.9 for 23 representative catchments are applicable for derivation of 2-hour Synthetic Unitgraph for an ungauged catchment in the same subzone.

The steps for derivation of 2-hour unitgraph are:

i) Physiographic parameters of the ungauged catchment viz. the catchment area (A), length of the longest stream (L) and equivalent stream slope (S) are determined from the catchment area plan. $L/\sqrt{S}$ is calculated.

ii) Substitute $L/\sqrt{S}$ in the equation 3.9.3

$$q_p = 2.030/(L/\sqrt{S})^{0.649}$$

to obtain q_p in cumecs/sq.km.

Then $Q_p = q_p \times A$ in cumecs.

iii) Substitute q_p in equation 3.9.4

$$t_p = 1.858/(q_p)^{1.038}$$

to obtain t_p in hours

$$T_m = t_p + t_r/2 = (t_p + 1) \text{ hours.}$$

iv) Substitute q_p in the following equations 3.9.5 to 3.9.8 to obtain W_{50}, W_{75}, W_{R50} and W_{R75} in hours

$$W_{50} = 2.217/(q_p)^{0.990}$$

$$W_{75} = 1.477/(q_p)^{0.876}$$

$$W_{R50} = 0.812/(q_p)^{0.907}$$

$$W_{R75} = 0.606/(q_p)^{0.791}$$

v) Substitute t_p in equation 3.9.9

$$T_B = 7.744\ (t_p)^{0.779}$$

to obtain T_B in hours.

vi) Plot the parameters of 2-hour unitgraph viz: T_m, T_B, Q_p, W_{50}, W_{75}, W_{R50}, W_{R75} on a graph paper as shown in illustrative Fig.2 and sketch the unitgraph through these points. The discharge ordinates (Q_i) of the unitgraph at 2-hour (t_r) interval are summed up and the direct runoff depth (d) in cm is obtained from the following equation 3.9.10

$$d = \frac{0.36 \times Q_i \times t_r}{A} \quad \ldots\ldots 3.9.10$$

where d = depth of direct runoff in cm.

Q_i = Discharge ordinates at 2-hour interval(cumecs).

A = Catchment area in sq. km.

In case the depth of runoff (d) for the Synthetic Unitgraph drawn is not equal to 1.0 cm, then suitable modification may be made in falling limb of the unitgraph to obtain 1.0 cm depth of runoff.

3.11 DESIGN LOSS RATE

Surface runoff occurs when the gross rainfall has met with the abstractions due to infiltration, evapotranspiration, interception, filling up of surface depressions etc.. Since each and every parameter cannot be observed at various locations in the catchments, a need therefore arises to adopt an average value of design loss rate representing all the abstractions. Variations due to the soil conditions and topography along with the spatial variations in rainfall make this loss rate a complex phenomena. In this report, the loss rate study based on Ø-index approach using the actual data of flood hydrographs provide necessary guidance in arriving at the design loss rate. In Table-4 the ranges of loss rate are presented against the number of events falling in each category for each catchment. There could perhaps be two alternatives. One was to adopt the lowest value of loss rate and the second to adopt the model value of loss rate. Since this report is intended at providing 50-year estimates which may not be a very rare event when considered from design point of view, a model value of design loss rate of 3.0 mm per hour is recommended for adoption.

3.12 BASE FLOW FOR DESIGN FLOOD

The number of events with various ranges of base flow are shown in Table-5. Out of 179 number of flood events, 126 flood events fall in the range of 0.01 to 0.09 cumecs per sq. km. An average value of base flow of 0.05 cumecs per sq. km. is recommended for adoption in the subzone.

TABLE-4: LOSS RATE RANGES (mm per hour) FOR NUMBER OF FLOOD OCCASIONS OBSERVED IN SUBZONE-1(e)

Sl. No.	Br. No.	Catchment areas in Sq.km.	0 to 2	2 to 4	4 to 6	6 to 8	8 to 10	10 to 12	12 to 14	14 to 16	16 to 18	18 to 20	20 to 22	22 to 24	24 to 26	26 to 28	28 to 30	30 to 32	32 to 34	34 to 36	36 to 38	38 to 40	40 to 42	42 to 44	44 to 46	Total
1	20	2425.54	4	5	4	1	2																			16
2	104(i)	2072.00		4																						4
3	400	1908.00	4	7	2	2																				15
4	Ghaggar	1126.00		1		1	1	1																		4
5	181	911.63		3		1																				4
6	89	914.75	1	1	2	3	1																			8
7	124	511.53		1	3																					4
8	1244	400.00	4	3	2	2	1																			12
9	1307	322.20		2		2	4	2	2		1			1					1							15
10	99(i)	296.61	2	2	2	1																				7
11	65	190.11	1	1	1	3	1	1	1	2																11
12	229	157.96	1		2																					3
13	166	165.76							2	1	1															4
14	288	160.86	4	3	2	2																				11
15	93(ii)	140.65			3			1						1												5
16	2	106.40	5	3	2	2	1																		1	14
17	104(ii)	104.58													1	1										2
18	291	96.40	4	1	1	1	3	1	2	1	1															15
19	315	73.04	6	2	1		1																			10
20	Khar	55.00					1																			1
21	1231	49.47			1			1	2	1		1														6
22	184	35.87						1	1	1		1														4
23	50	25.26		2		1	1																			4
	Total:		36	41	28	22	17	8	10	6	3	2		2	1	1			1						1	179

TABLE-5: AVERAGE BASE FLOW RANGES FOR NUMBER OF FLOOD OCCASIONS SUBZONE -1(e)

Sl.No.	Bridge No.	0.001	.001 to .005	.0051 to	.01 to .09	.10 to .19	.20and above	Total
					in cumecs per sq.km.			
1	20		14	2				16
2	104(1)				4			4
3	400	1			14			15
4	Ghaggar				3	1		4
5	181		1	1	2			4
6	89		2		6			8
7	124		1		3			4
8	1244	1			11			12
9	1307			1	13	1		15
10	99(i)			1	6			7
11	65				10	1		11
12	229		1		2			3
13	166				4			4
14	288				10	1		11
15	93(ii)				4	1		5
16	2				11	3		14
17	104(ii)	1	1					2
18	291				9	4	2	15
19	315				6	3	1	10
20	Khar	1						1
21	1231				6			6
22	184				2		2	4
23	50					3	1	4
	Total	4	20	5	126	18	6	179

4.0 DESIGN STORM INPUT

The areal distribution and time distribution of the rainfall of a given duration are two main meteorological factors deciding the design flood peak and the shape of the design flood hydrograph. This input has to be converted into rainfall excess and applied to the transfer function (Synthetic Unit Hydrograph) to obtain the response (Flood Hydrograph).

4.1 DESIGN STORM DURATION

The duration of the storm rainfall which causes the maximum discharge in a drainage basin is called the design storm duration. The design storm duration (Td) for a catchment may be adopted as 1.1 times tp (basin lag time) i.e. Td = 1.1 x tp. The estimated design storm duration (T_D) exceeding 24 hours shall be limited to 24.0 hrs.

4.2 RAINFALL DEPTH DURATION FREQUENCY STUDIES

India Meteorological Department have conducted this study on the basis of 19 self recording raingauge stations and 145 ordinary raingauge stations maintained by IMD/States and 15 SRRG stations maintained by Railway in 6 bridge catchments in subzone 1(e).

The annual maximum series for all the ordinary raingauge stations in and around the subzone were computed for each station from the daily rainfall data of the stations for the period varying from 50 to 70 years of records. The annual extreme value series was subjected to Gumbel's extreme value distribution and the rainfall estimates for 50 year return periods were computed. The daily values of rainfall estimates were converted into 24 hour rainfall estimates by using the conversion factor of 1.15. These 24-hour rainfall estimates for all the stations in the subzone were plotted on a base map of the subzone and isopluvial map for 50-year return period is shown in plate-9

The hourly rainfall data recorded by SRRG stations for the period of 5 years to 38 years were processed by frequency analysis (partial duration series method) and the rainfall estimates for 50-years return period of specified duration namely 1,3,6,9,12,15,18 and 24 hours were computed.

The ratios of short duration of 1,3,6,9,12,15 and 18 hours rainfall estimates with respect to 24-hour rainfall estimates were worked out for all the SRRG's stations in the subzone. The average value of the ratio for each specified duration was computed for the basin assuming the basin as a unit.

The average ratios for durations of 1,3,6,9,12,15 and 18 hours with respect to 24-hour rainfall are as follows:

Duration	Ratio	= 50-yr. T-hr. point rainfall / 50-yr. 24-hr. point rainfall
24	1.0	
18	0.93	
15	0.89	
12	0.84	
9	0.77	
6	0.68	
3	0.56	
1	0.34	

Fig. 10 shows the ratios for short durations point rainfall with respect to 24-hour point rainfall.

The short duration rainfall estimates for various short durations (1,3,6,9,12,15 & 18 hours) can be computed by using the respective ratios. The value of 24-hr. rainfall estimates for a particular station for 50-yr. return period can be interpolated from plate 9 and the short duration rainfall estimates can be obtained by multiplying with the corresponding ratio for that particular short duration obtained from Fig.10.

4.3 CONVERSION OF POINT TO AREAL RAINFALL

The short duration rainfall data of only 6 bridge catchments were used for this study. The data of remaining bridge catchments could not be utilised as the period of data were less than 4 years and concurrent years data were not recorded over the stations in a bridge catchment. 2-yr. point rainfall values for specified duration for each station in the catchment were computed by frequency analysis. Arithmetic average of 2-yr. point rainfall of all the stations in the catchment was calculated to get the 2-yr. representative point rainfall for the catchment. Events of maximum average depth for a particular duration in each year were selected on the basis of simultaneous occurrance of rainfall at each station in the catchment. The areal rainfall series thus obtained was subjected to frequency analysis and 2-year areal rainfall depths for specified duration were computed. The percentage ratio of 2-yr. areal rainfall to 2-year representative point rainfall for the catchment was calculated and plotted against the area of the catchment for various durations. The best fit curves were drawn for specified durations on the points obtained for all the catchments. Areal to point rainfall ratios versus catchment area curves for design storm durations of 1,3 and 6 hrs. are shown in Fig.11(a) and similar curves for durations of 12 and 24 hrs. are shown in Fig.11(b). The areal to point rainfall ratios also called Areal Reduction Factors (ARF) read from the curves in Figs.11(a) and 11(b) also shown in Table-6.

4.4 TIME DISTRIBUTION OF INPUT STORMS

The study of time distribution of short duration rainfall has been carried out by IMD for the following categories of durations:

1. Rain storm of 2 to 3 hours

TABLE-6 AREAL TO POINT RAINFALL RATIOS (PERCENTAGE)

Area (Sq.Km.)	1 hr.	3 hr.	6 hr.	12 hr.	24 hr.
50	88	92	95	96	98
100	80	88	91	94	96
150	73	84	88	92	94
200	68	81	86	90	93
250	63	78	85	89	91
300	60	76	84	88	90
350	-	74	83	87	89
400	-	73	82	86	88
450	-	73	81	85	87
500	-	72	80	84	86
600	-	-	-	82	85
700	-	-	-	80	83
800	-	-	-	79	82
900	-	-	-	78	81
1000	-	-	-	77	81
1200	-	-	-	76	80
1400	-	-	-	-	79
1600	-	-	-	-	78
1800	-	-	-	-	77
2000	-	-	-	-	77
2500	-	-	-	-	77

2. Rain storm of 4 to 6 hours

3. Rain storm of 7 to 12 hours

4. Rain storm of 13 to 18 hours

5. Rain storm of 19 to 24 hours

About 5000 rain storms of various durations upto 24 hours occurring in various parts of the subzone were analysed based on 600 station year data. Rain storm selected at each stations were grouped under the above 5 categories and plotted on different graphs as dimensionless curves with cumulative percentage of storm duration along the abcissa. Thus, five different graphs were prepared for each stations corresponding to various duration and were then examined. The envelope and average time distribution curves for the various durations were drawn for each station. All the average and envelope curves for the stations thus obtained were plotted on a single graph and a single average and a single envelope curve for the subzone as a whole were drawn for storms of different durations and are shown in Fig.12.

4.5 100-YEAR 24-HOUR POINT RAINFALL MAP

Under earlier section 4.2: Rainfall Duration frequency studies, 50-yr. 24-hour point rainfall map in plate 9 and 50-year short duration point rainfall to 50-year 24-hr. point rainfall ratios for conversion of 24-hr. point rainfall to 1,3,6,9,12,15 and 18 hours were provided for estimation of 50-year flood.

However, those interested in the design flood from 100-year short duration rainfalls upto 24 hours, 100 year 24 hour point rainfall map is shown in plate-10. To obtain 1,3,6,9,12,15 and 18 hrs. from 100-year 24 hour rainfall, the ratios given in section 4.2 may be used. Similarly sections 4.3 and 4.4 may be used for conversion of point to areal rainfall and time distribution of input storm respectively.

4.6 PROCEDURE FOR ESTIMATING THE DESIGN STORM RAINFALL

The following procedure is recommended to be adopted for estimation of critical distribution of storm rainfall to cause the maximum flood due to the rainfall of a specified duration:

Step-1

Having estimated tp vide section 3.9, calculate the design storm duration T_D = 1.1 tp (hrs.)

Step - 2

Locate catchment under study on the 50-yr. 24 hr. rainfall isopluvial map (plate 9) and obtain the 50-yr. 24 hr. point rainfall value.

Step - 3

Read the conversion ratio for T_D hrs. from Fig.10 and multiply the 24 hr. rainfall in step-2 by the ratio to obtain the 50-yr. T_D-hr. point rainfall.

Step-4

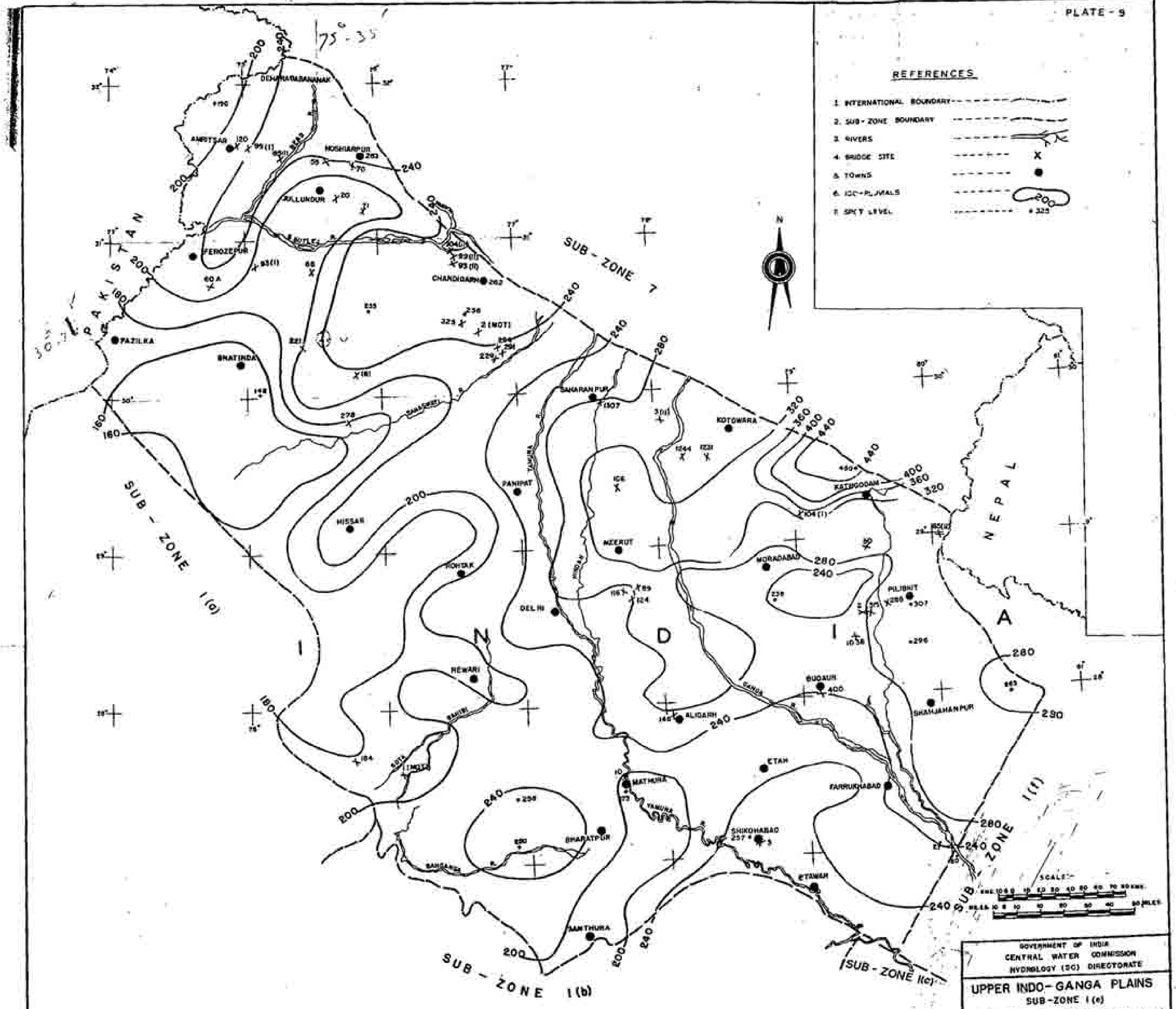
Convert the 50-yr. T_D-hr. point rainfall to 50-yr. T_D-hr. areal rainfall by multiplying with the areal reduction factor (ARF) corresponding to catchment area under study and for T_D-hr. duration from Table-6 or by interpolation from Figs. 11(a) and 11(b) in section 4.3 for the duration T_D hours and catchment area under study.

Step-5

Apply the cumulative percentage of total rainfall against the percentage of average design storm duration curve in Fig.12 corresponding to design storm duration, T_D to obtain the depth at 2-hrs. interval since the unit duration of synthetic U.G. in 2-hrs.

Step-6

Obtain the 2-hourly rainfall increments from subtraction of successive 2-hrs. cumulative value of rainfall in Step-5.



NOTE:-
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER.

BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SC) DIRECTORATE

UPPER INDO-GANGA PLAINS
SUB-ZONE I (e)
50 YEAR - 24 HOUR RAINFALL (mm)

PREPARED BY:	CHECKED BY
S.N. MALHOTRA A.K. SHARMA	S.S. SIL

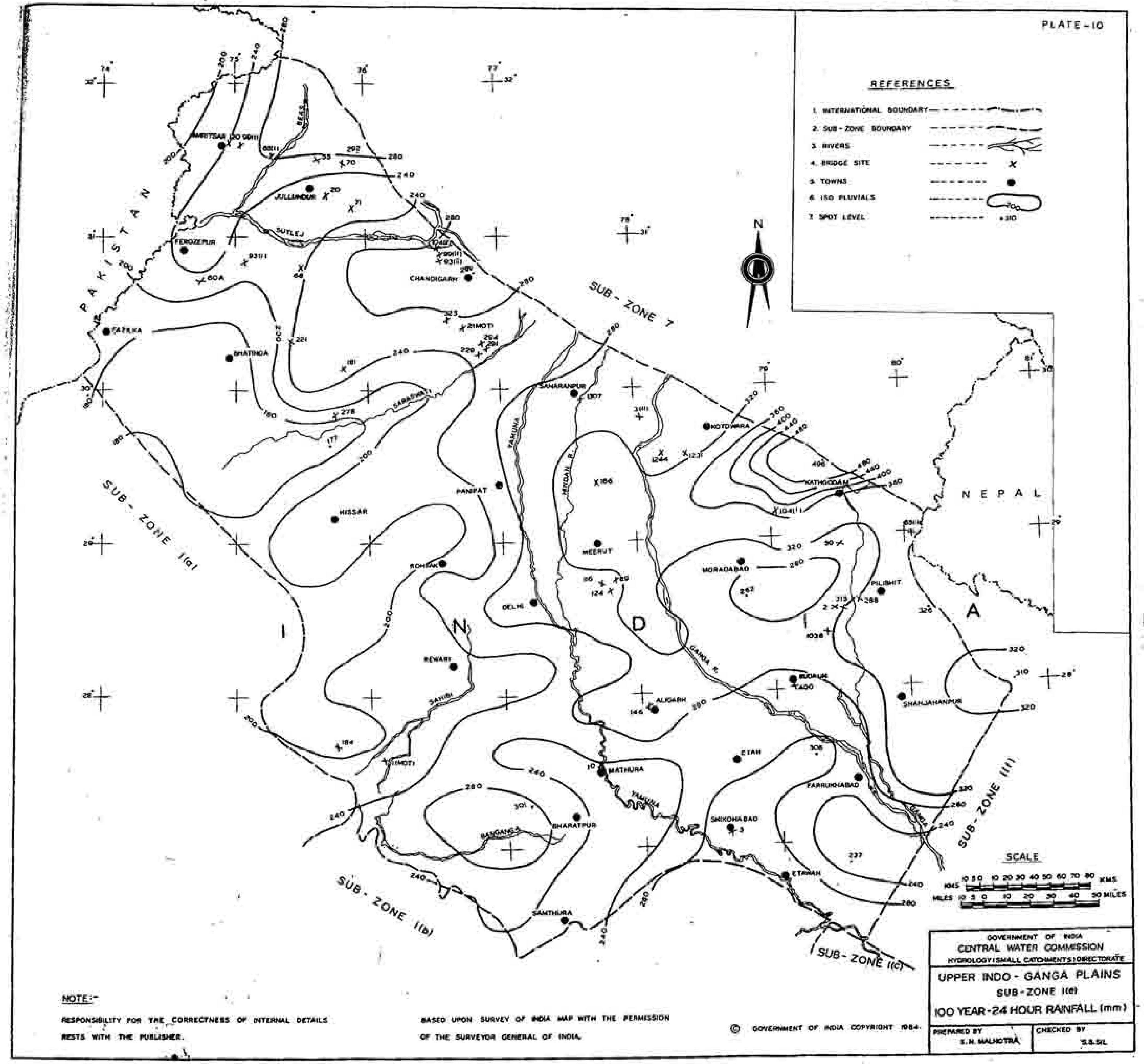


PLATE - 10
REFERENCES
1. INTERNATIONAL BOUNDARY
2. SUB - ZONE BOUNDARY
3. RIVERS
4. BRIDGE SITE
5. TOWNS
6. ISO PLUVIALS
7. SPOT LEVEL
N
PAKISTAN
NEPAL
INDIA
SUB - ZONE 7
SUB - ZONE 1(a)
SUB - ZONE 1(b)
SUB - ZONE 1(c)
SUB - ZONE 1(f)
AMRITSAR
JULLUNDUR
FEROZEPUR
SUTLEJ
BEAS
CHANDIGARH
FAZILKA
BHATINDA
SARASWATI
HISSAR
ROHTAK
PANIPAT
DELHI
REWARI
SAHIBI
SAHARANPUR
YAMUNA
HINDAN R.
MEERUT
KOTDWARA
KATHGODAM
MORADABAD
PILIBHIT
GANGA R.
BUDAUN
ALIGARH
SHAHJAHANPUR
MATHURA
ETAH
FARRUKHABAD
BHARATPUR
BANGANGA
SHIKOHABAD
ETAWAH
SAMTHURA
SCALE
KMS 10 5 0 10 20 30 40 50 60 70 80 KMS
MILES 10 5 0 10 20 30 40 50 MILES
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY(SMALL CATCHMENTS)DIRECTORATE
UPPER INDO - GANGA PLAINS
SUB - ZONE 1(e)
100 YEAR - 24 HOUR RAINFALL (mm)
PREPARED BY S.N. MALHOTRA
CHECKED BY S.S. SIL
NOTE:-
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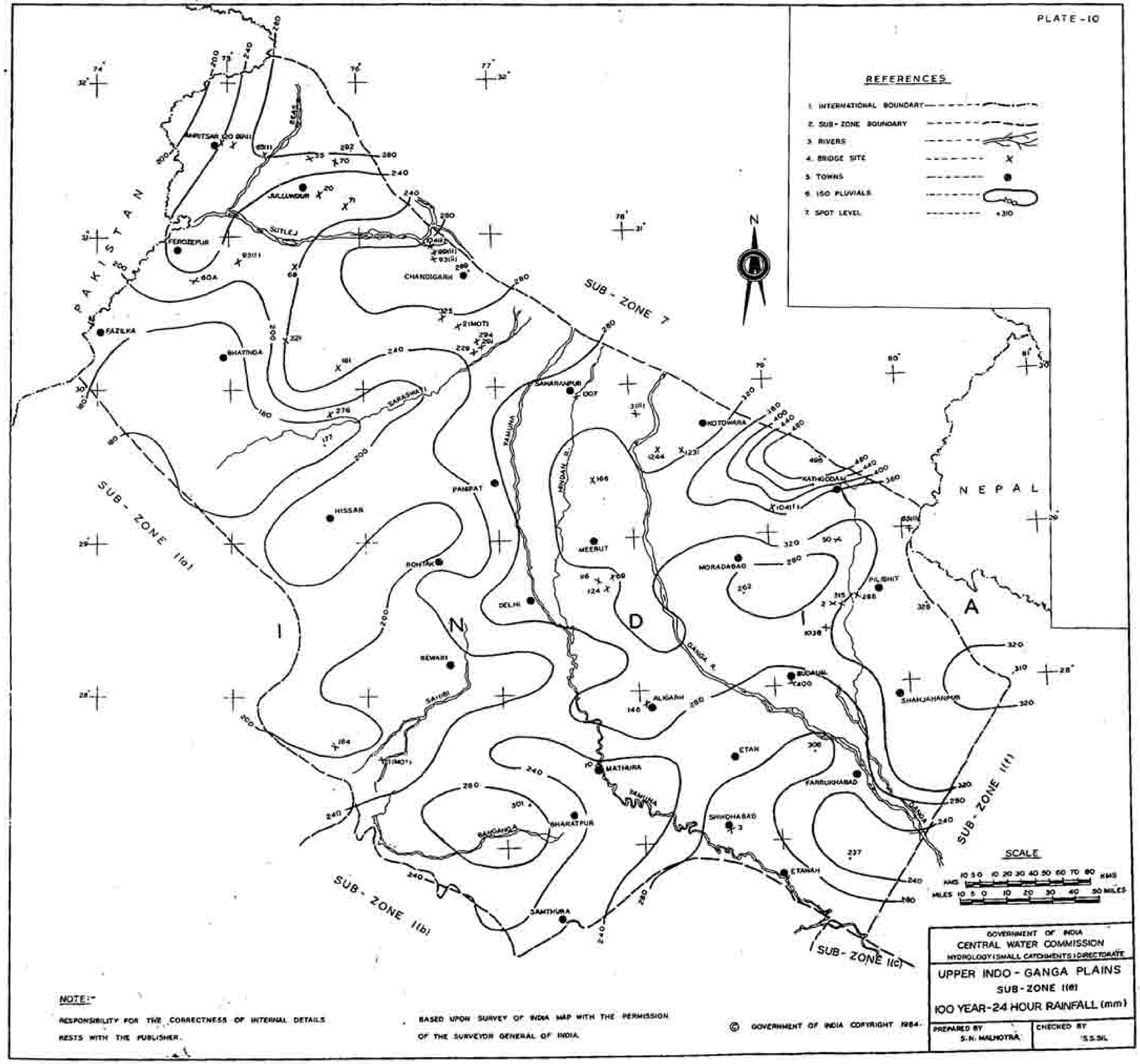

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DIRECTORATE

UPPER INDO - GANGA PLAINS
SUB - ZONE 1(e)
100 YEAR - 24 HOUR RAINFALL (mm)

PREPARED BY S. N. MALHOTRA | CHECKED BY S. S. SIL

NOTE:-
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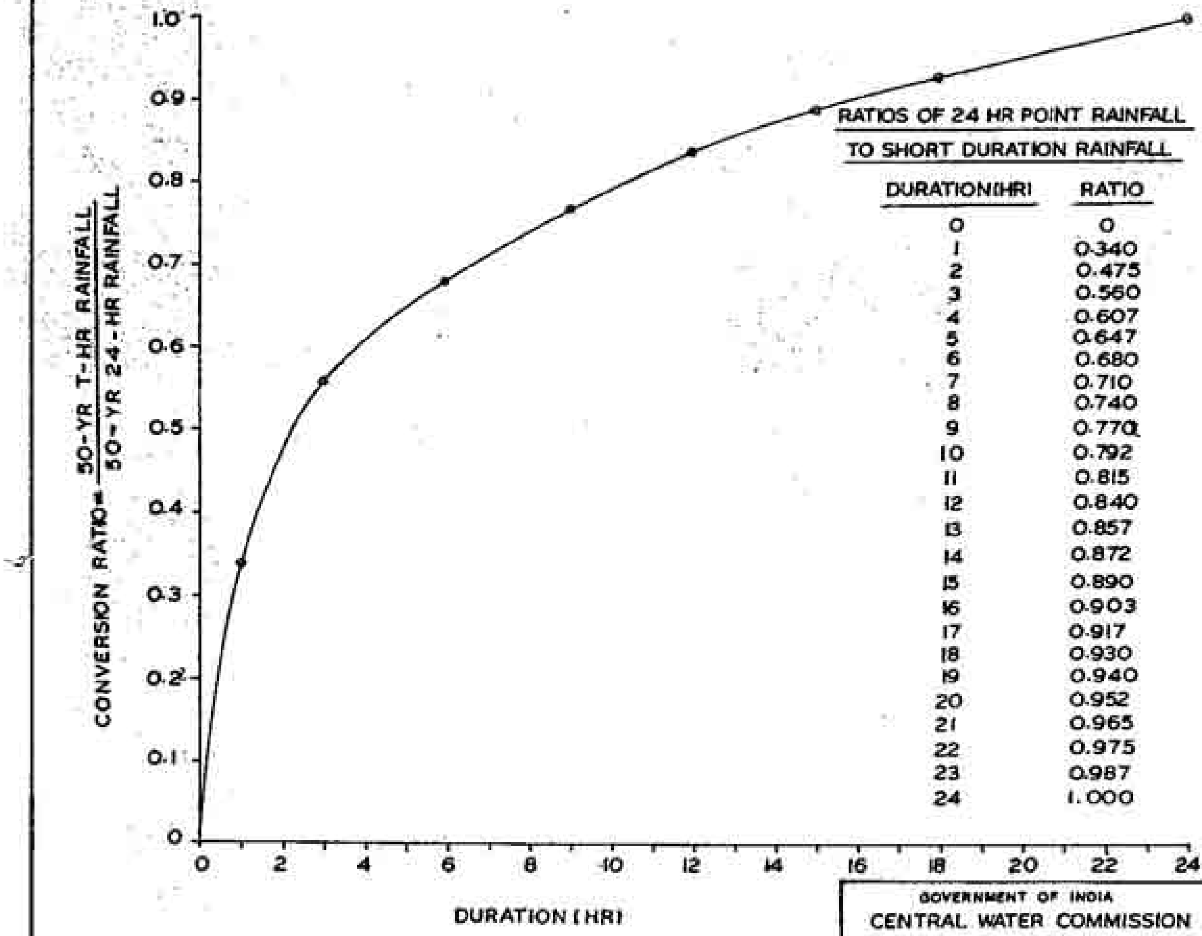
BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.

FIG. 10



RATIOS OF 24 HR POINT RAINFALL TO SHORT DURATION RAINFALL

DURATION (HR)	RATIO
0	0
1	0.340
2	0.475
3	0.560
4	0.607
5	0.647
6	0.680
7	0.710
8	0.740
9	0.770
10	0.792
11	0.815
12	0.840
13	0.857
14	0.872
15	0.890
16	0.903
17	0.917
18	0.930
19	0.940
20	0.952
21	0.965
22	0.975
23	0.987
24	1.000

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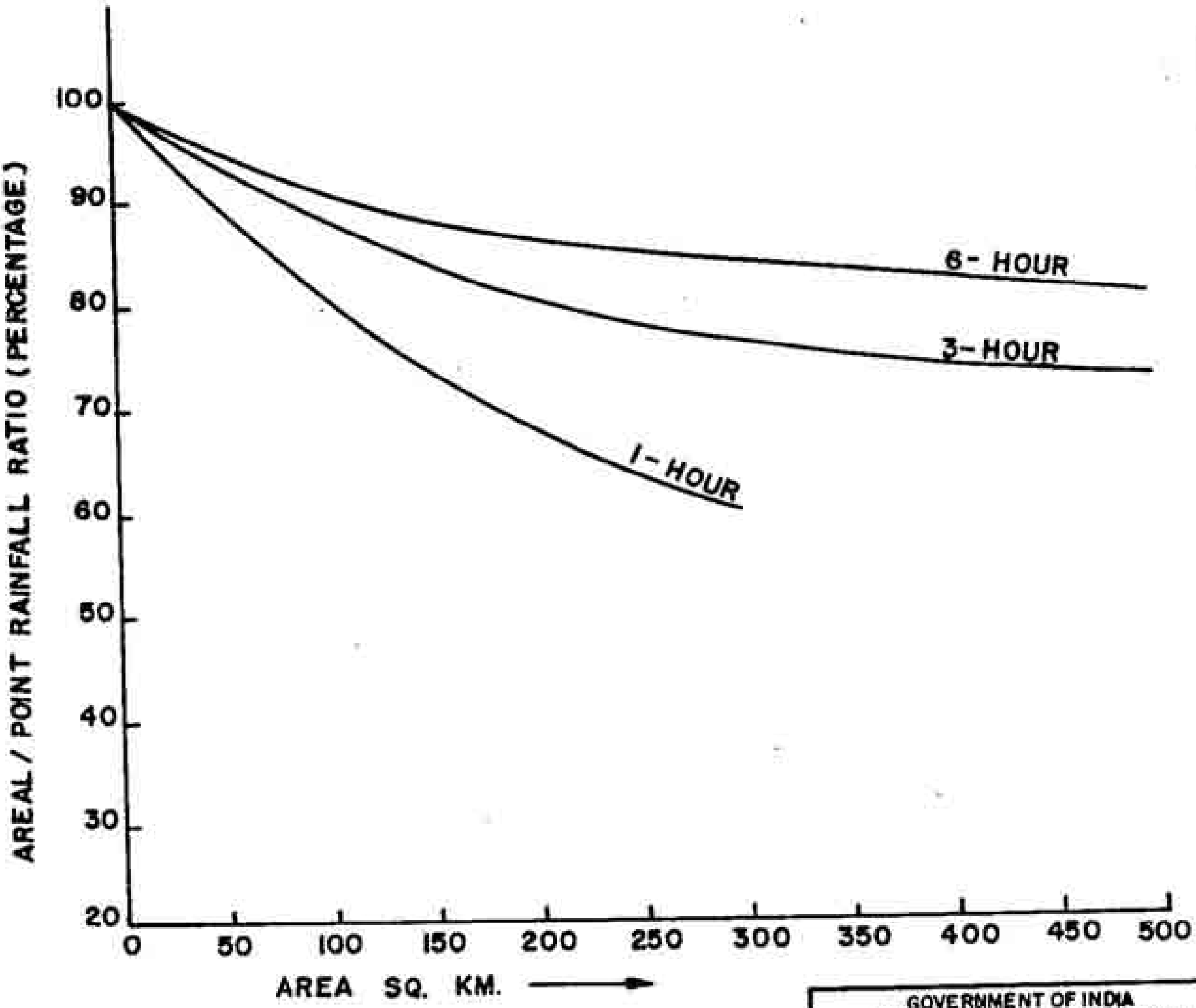
UPPER INDO-GANGA PLAINS
SUB-ZONE (1e)
DURATION Vs CONVERSION RATIO

DRAWN K.B. AHUJA | CHECKED A.P. KHANNA

Fig: 11 a



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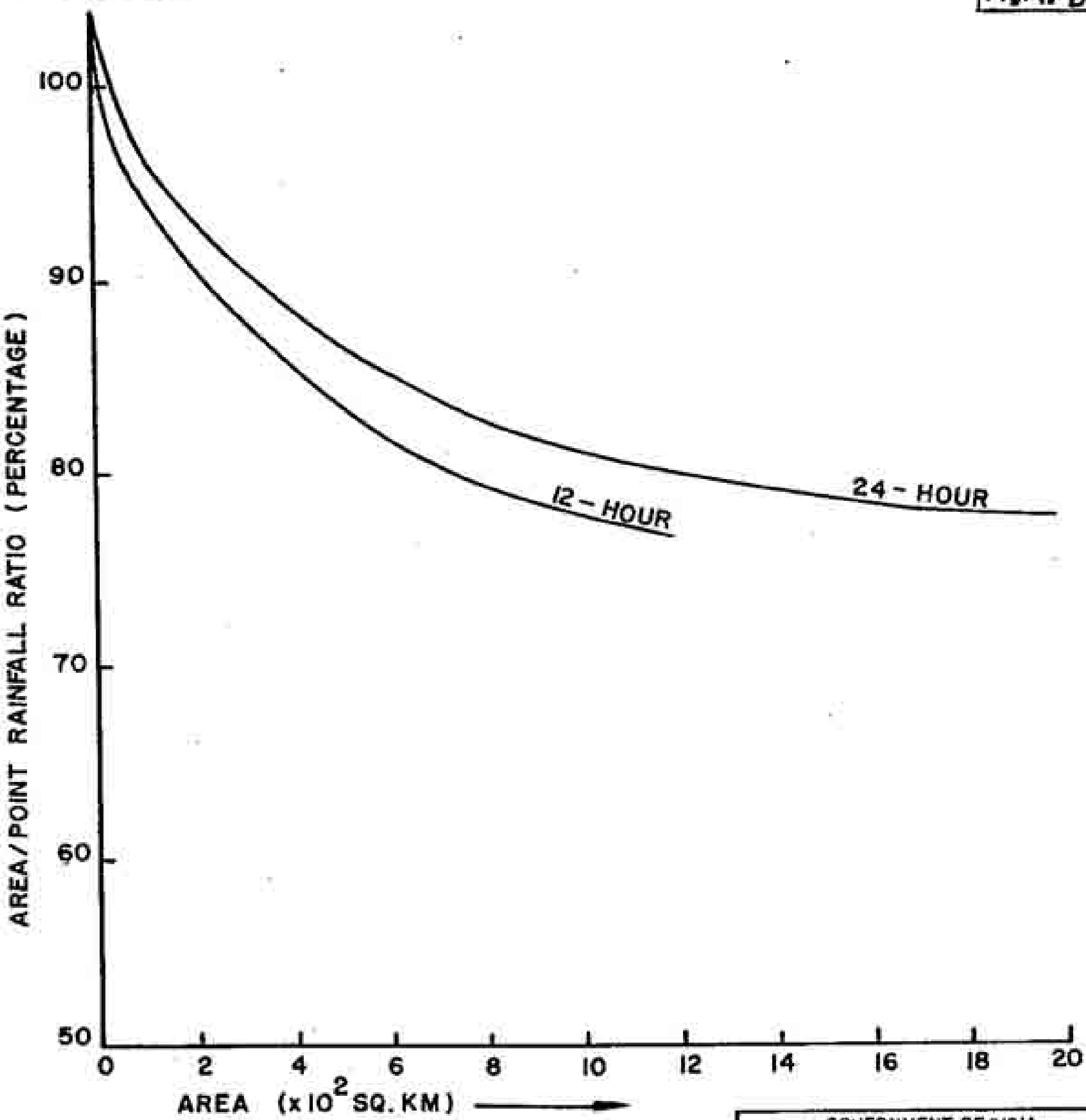
UPPER INDO-GANGA PLAINS
(SUB - ZONE 1 e)

AREAL/POINT RAINFALL RATIO(%)

DRAWN. AVNISH	CHECKED A.P.KHANNA

Fig: 11 b



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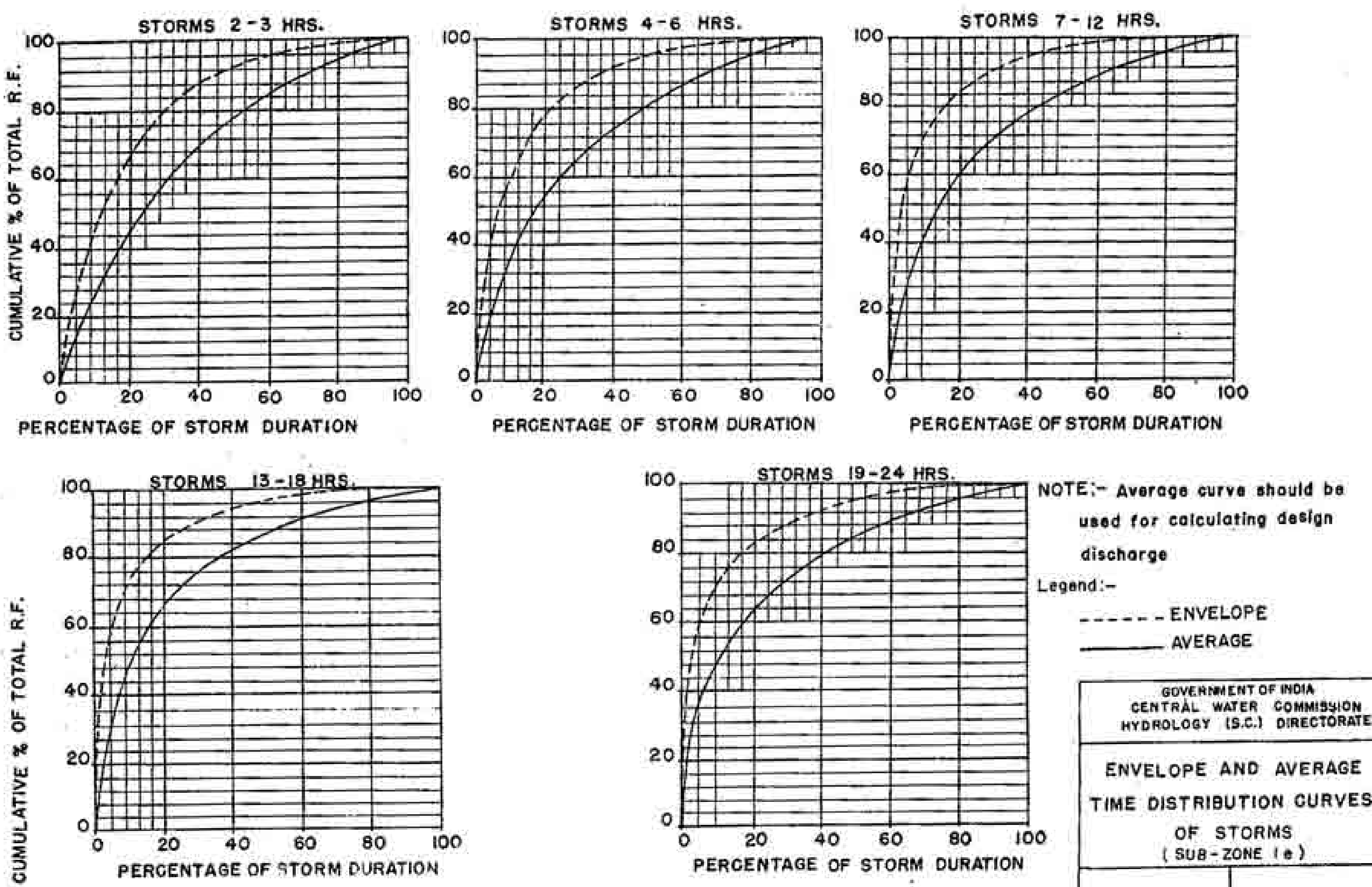
HYDROLOGY (S.C.) DIRECTORATE

UPPER INDO-GANGA PLAINS
(SUB-ZONE 1e)

AREAL/POINT RAINFALL RATIO (%)

DRAWN. AVNISH KUMAR	A.P. KHANNA. CHECKED

Fig: 12



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HYDROLOGY (S.C.) DIRECTORATE

ENVELOPE AND AVERAGE TIME DISTRIBUTION CURVES OF STORMS
(SUB-ZONE 1 e)

DRAWN: AVNISH | CHECKED: A.P. KHANNA

5.0 ESTIMATION OF DESIGN FLOOD FOR AN UNGAUGED CATCHMENT

The following procedure is recommended:

Step-1

Determine the synthetic unitgraph vide section 3.9

Step-2

Determine the design storm rainfall input vide section 4.0

Step-3

Obtain the design loss rate of 0.3 cm/hr. vide section 3.11.

Step-4

Obtain the hourly rainfall excess units upto the design storm duration T_D by subtracting the design loss rate of 0.6 cm/2-hr. from the 2-hourly rainfall increments in step-6 of section 4.6.

Step-5

(i) The peak period (Tm) value having even number (i.e. multiple of 2 since the unit duration is 2 hours)

Tabulate the U.G. discharge values obtained from Step-1 at 2-hour intervals.

Arrange the rainfall excess increments against the 2-hourly synthetic U.G. ordinates such that the maximum value of rainfall excess comes against the peak discharge of synthetic U.G., the next lower value of rainfall excess increment comes against the next lower discharge ordinate and so on upto T_D-hr. duration.

(ii) The peak period (Tm) value having odd number (i.e. not a multiple of 2 hrs. since the unit duration is 2 hrs.)

Tabulate the U.G. discharge values from the peak period of U.G. at 2 hours interval.

Arrange the rainfall excess increments against the 2-hourly, synthetic U.G. ordinates such that the maximum value of rainfall excess comes against the peak discharge of synthetic U.G., the next lower value of rainfall excess increment comes against the next lower discharge ordinate and so on upto T_D hr. duration.

Step - 6

Reverse the sequence of rainfall excess increments obtained in Step-5 (i) or (ii) as the case may be which will give the critical sequence of the rainfall excess.

Step - 7

Multiply the first 2-hour rainfall excess with the synthetic U.G. ordinates at 2-hours interval which will give the corresponding direct runoff ordinate. Likewise repeat the procedure with the rest of the 2-hourly rainfall excess increments giving a lag of 2-hours to obtain successive direct runoff ordinates.

Step - 8

Add the direct runoff ordinates at 2-hr. interval to get the direct runoff hydrograph.

Step -9

Obtain the average base flow of 0.05 cumec/sq.km. vide section 3.12. Multiply average base flow of 0.05 cumec/sq.km. with the catchment area under study to get the total base flow.

Step - 10

Add the total base flow to the direct runoff ordinates at 2-hour interval in step-8 to get the 50-year flood hydrograph. Plot the hydrograph.

Note : Where the peak period of U.G. is at odd hours.

Step-11

Tabulate the U.G. values at 2-hr. interval as explained in step-5'(ii)

Arrange the rainfall excess increments against the 2-hourly synthetic U.G. ordinates such that the maximum value of rainfall excess comes against the peak discharge of synthetic U.G., the next lower value of rainfall excess increment comes against the next lower discharge ordinate and so on upto T_D hour duration.

Step-12

Multiply the discharge ordinates of U.G. and the corresponding rainfall excess units at 2-hr. interval in step-11 to obtain the consecutive direct runoff values. Then add the direct runoff values to get the direct runoff peak. Add the total base flow obtained in Step-9 to get the total peak discharge.

Step-13

The total peak discharge obtained in step-12 should be plotted on the hydrograph in step-10 between the maximum values of the rising and recession limb of the plotted hydrograph. Then draw a smooth curve through these three points to get the complete flood hydrograph.

6.0 ASSUMPTIONS, LIMITATIONS AND CONCLUSION

6.1 ASSUMPTIONS

6.1.1 It is assumed that rainfall excess increments derived from depth duration curves obtained from the storm Isopluvial maps of a particular return period will yield the flood of the same return period.

6.1.2 A generalised conclusion regarding the base flow and loss rate are assumed to hold good during the design flood event.

6.1.3 Most of the catchments in the subzone are of elongated shape and flat. Because of the non-availability of the long term peak discharge data of undisturbed catchments, no other procedure except the unit hydrograph procedure will hold good for the catchment in question, despite the fact that due to elongated shapes of the catchments a spatial nonuniformity of rainfall may be more pronounced.

6.1.4 The hydrological data has been collected in various representative catchments for periods generally ranging from 2 to 9 years during the years 1962 to 1980. Consequent to man made changes in the catchments and river courses, the pattern of floods had changed considerably. The slope of the land is also very flat in most parts of the subzone and spilling and spreading of flood water are quite common. The results of the analysis contained in the report generally represent the above complex conditions. Due to above factors, the critical design storm duration has been judiciously limited to a maximum value of 24 hours. The data used for storm study had also indicated that the number of storms of more than 24 hours duration are negligible. Therefore, for values of estimated design storm duration (T_D) more than 24 hours, the design storm duration shall be limited to 24 hours.

6.2 LIMITATIONS

6.2.1 The data of 23 catchments has been considered for developing generalised approach for a large subzone. Due to inconsistancies of data and of non-availability of suitable floods, about 50% of the gauged catchments could not be utilised for developing the relationships. This may have introduced some limitations in the study. However, for more reliable relationships, data of more suitable catchments would be desirable.

6.2.2 The method would be applicable for reasonably free catchments with interception, if any, limited to 20% of the total catchment. For calculating the discharge, the total area of the catchment has to be considered.

6.2.3 The approach developed mostly covers the catchments with flat to moderate slopes. For foothill catchments (steep slopes) suitable increase in the calculated peak discharge should be given.

6.3 CONCLUSION

6.3.1. The methodology for estimating the design flood of 50-year return period incorporated in the body of the report is recommended for adoption.

6.3.2 The report is generally applicable for the catchment areas ranging from 25 sq.km. to 2500 sq.km. However, certain unusual site conditions may necessitate individual site study. Engineer-in-charge at site is advised to take a pragmatic view while deciding the design discharge of a bridge.