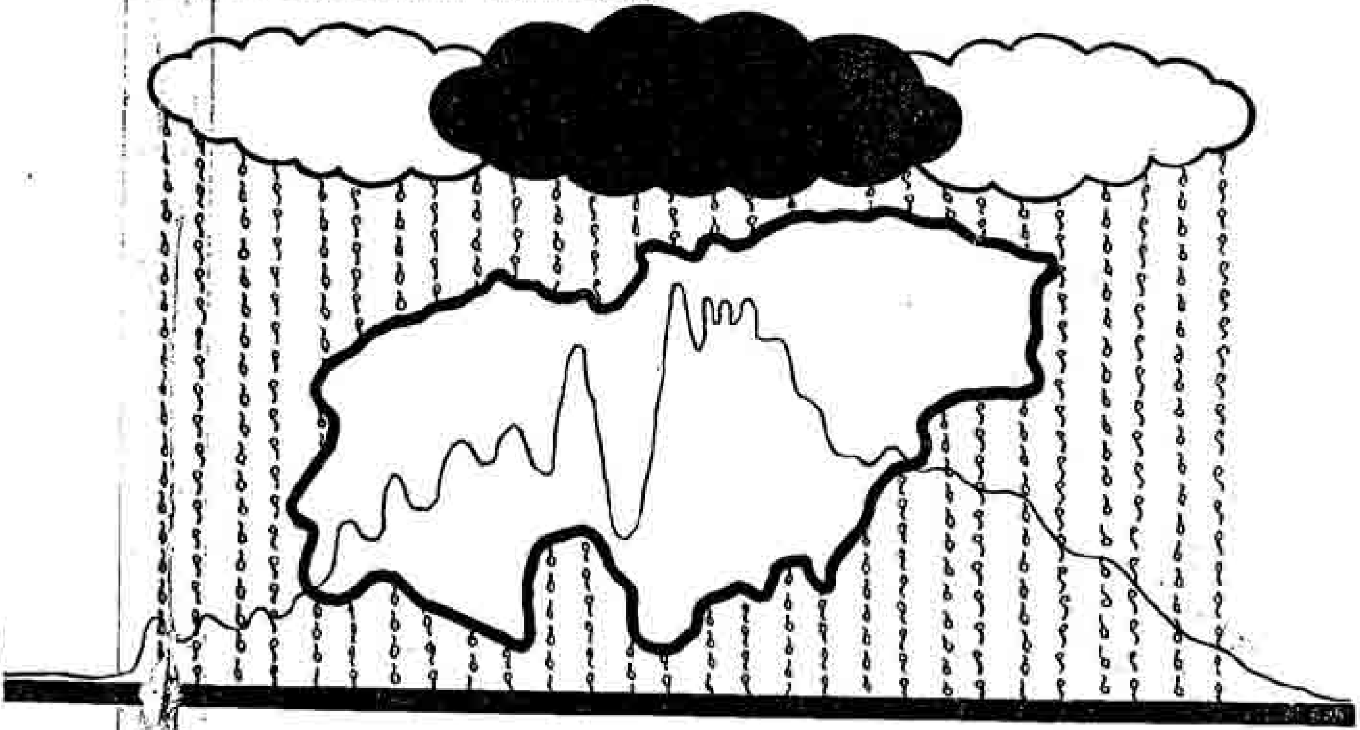
सोन उप क्षेत्र-१(डी) की बाढ़ आकलन का विवरण

यूनिट जलारेख सिद्धान्त पर आधारित एक प्रणाली

FLOOD ESTIMATION REPORT FOR SONE SUB ZONE-1 (d)

A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE



DIRECTORATE OF HYDROLOGY
(SMALL CATCHMENTS)
CENTRAL WATER COMMISSION
NEW DELHI-110066

A JOINT WORK OF
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(DEPTT. OF SCIENCE & TECHNOLOGY)

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CWC PUBLICATION NO. 33/88

FLOOD ESTIMATION REPORT FOR SONE SUBZONE - 1 (d)

A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE
DESIGN OFFICE REPORT NO. S/15/1987

HYDROLOGY (SMALL CATCHMENTS) DIRECTORATE
CENTRAL WATER COMMISSION
NEW DELHI

AUGUST 1987

FOREWORD

The Government of India set up a Committee of Engineers in March 1957 under the chairmanship of Dr. A.N. Khosla to review, inter alia, the methods for estimating maximum flood discharge to determine waterway and other parameters of the bridges which were designed and constructed in this country in the last century on the basis of technical knowledge and data then available. In their report in October 1959 this Committee recommended systematic collection of rainfall and runoff data of small and medium catchments and the use of rational methodology of unit hydrograph and design storm rainfall. As a follow up action, joint efforts are in progress since then by Railway Designs and Standards Organisation, Ministry of Transport, India Meteorological Department and Central Water Commission to collect and analyse discharge and rainfall data for a large number of bridge catchments. For this purpose, the country has been divided into 26 sub-zones. In each sub-zone, the rainfall-runoff data for bridge catchments is being collected for a period of about 5 years by the Railways and also by CWC on behalf of the Ministry of Transport. While storm analysis is done by IMD, the development of the unitgraph based methodology and preparation of flood estimation report is being done by the Hydrology (Small Catchments) Directorate of CWC.

So far flood estimation reports based on the hydrometeorological approach have been finalised for 15 subzones and published for 11 subzones. Out of 26 subzones in which the country has been divided and with the planned data collection activities, reports can be prepared for 22 sub-zones covering 81 percent of the country's geographical area. This report marks the completion of 16 subzonal reports which together cover 65 percent of geographical area. The efforts have now been directed towards reviewing and updating these reports on the one hand and ensuring the acceptability and utilisation of these methods by large number of user organisations engaged in the design and construction of railway and road bridges, cross drainage works and hydraulic structures on small and medium catchments. In order to achieve this objective, CWC has conducted two Workshops, one at Calcutta and the other at Bhubaneshwar for working engineers fo various State Organisations, to familiarise them with the regional methods as brought out in the reports. Looking to the response received for holding such Workshops, similar workshops are proposed to be conducted in other regions of the country. It is hoped that the method propagated in these reports would be applied extensively for estimating the maximum flood discharge in the coming years.

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PREFACE

Design Engineers essentially need the design flood of a specific return period for fixing the waterway vis-a-vis the design H.F.L. and foundation depths of a bridge, culvert and cross drainage structures depending on their life and importance to ensure safety as well as economy. A casual approach may lead to under-estimation or over-estimation of design flood resulting in the loss and destruction of structure or uneconomic structure with problematic situation.

The use of empirical flood formulae like Dickens, Ryves, Inglis etc., has no such frequency concept except the simplicity of relating the maximum flood discharge to the power of catchment area with constants. These formulae do not take account of the basic meteorologic factor of storm rainfall intensity besides other physiographic and hydrologic factors varying from catchment to catchment. Proper selection of constants in these empirical formulae is left to the discretion of design engineer involving subjectivity.

The need to evolve a method of 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 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 much 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".

Economic constraints do not justify detailed hydrological and meteorological investigations at every new site on a large scale and on a long term basis for estimation of design flood with a desired return period. Regional flood estimation studies become necessary for hydro-meteorologically homogeneous regions in the country. Broadly two main regional approaches are open for adoption depending on the availability of the storm rainfall and flood data. The first approach involved long term discharge observations for the representative catchments for subjecting to statistical analysis to develop a regional flood model. The other approach was to collect concurrent storm rainfall and runoff data of the representative catchments over a period of 5 to 10 years to develop a regional design storm rainfall-loss-unitgraph (runoff) model. The latter approach in line with the recommendations of the high level committee of engineers has been adopted in the preparation of flood estimation reports under short term plan and for each of the 22 subzones out of 26 subzones in the country under long term plan.

Systematic and sustained collection of Hydro-meteorological data for the representative catchments numbering 10 to 30 for a period of 5 to 10 years in each of the 22 subzones has been carried out in a phased manner by different zonal railways since 1965 under the supervision and guidance of Bridges and Flood Wing of Research Designs and Standard Organisation of the Ministry of Transport (Deptt. of Railways). Similarly the Ministry of Transport (Deptt. of Surface) has undertaken the collection of data for 45 catchments through Central Water Commission since 1979. Rainfall and runoff data was supplied to Hydrology (Small Catchments) Directorate of Central Water Commission and rainfall data to India Meteorological Department (IMD) for necessary studies.

Hydrology (Small Catchments) Directorate of CWC has carried out the analysis of selected storm rainfall and floods for the gauged catchments to derive 1-hr. unit hydrographs on the basis of data of rainfall, gauge and discharges collected during the monsoon season. Representative 1-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 correlated by regression analysis and the equations for synthetic unit hydrographs for the subzone 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.

Studies of Rainfall-Depth-Duration-Frequency, point to areal ratios and time distribution of storm rainfall are made available by Hydromet Cell of IMD to Hydrology (SC) Dte., which prepares the full report for the subzone. The report is approved by the Planning and Coordination Committee in its meetings. A "Foreword" from Member (Water Planning) of CWC recommends the extensive use of the report to design engineers for estimation of design flood for small and medium catchments. The report is published in Central Water Commission.

Flood Estimation Reports for the following subzones have been prepared, got approved in PCC meetings, published and circulated to various states and Central agencies for the use of design engineers:

A. UNDER SHORT TERM PLAN

1. Estimation of Design Flood Peak (1973)

B. UNDER LONG TERM PLAN

1. Lower Gangetic Plains subzone - 1(g) (1978)
2. Lower Godavari subzone - 3(f) (1981)
3. Lower Narmada & Tapi subzone - 3(b) (1982)
4. Mahanadi subzone - 3(d) (1982)
5. Upper Narmada & Tapi subzone - 3(c) (1983)
6. Krishna & Penner subzone - 3(h) (1983)

7. South Brahmaputra Basin subzone - 2(b) (1984)
8. Upper Indo-Ganga Plains subzone - 1(e) (1984)
9. Middle Ganga Plains subzone - 1(f) (1985)
10. Kaveri Basin subzone - 3(i) (1986)
11. Upper Godavari subzone - 3(e) (1986)
12. Mahi & Sabarmati subzone - 3(a) (1987)
13. East Coast subzone - 4(a), (b) & (c) (1987)

The present report on Sone subzone - 1(d) is based on the detailed storm rainfall and runoff studies of 15 representative catchments. The data of each of the 15 catchments collected for a period varying from 4 to 9 years by the Eastern Railways, South Eastern Railways and Central Railways under the guidance of R.D.S.O. Besides the data of 134 ordinary raingauge stations maintained by IMD/States alongwith data of 40 self-recording raingauge stations maintained by IMD/Railways has been made use of.

The Sone subzone - 1(d) report deals with the estimation of design flood of 25-yr., 50-yr and 100-yr. return periods for small and medium catchments in this subzone covering the parts of Bihar, M.P. and U.P. states based on design storm rainfall and synthetic unitgraph. Formulae for 25-yr., 50-yr. and 100-yr. flood for easy and quick application are given in the report for the preliminary designs only. Illustrative example under (i) detailed and (ii) simplified approaches are also given for application of the report. Besides a formula for fixing the waterway of bridges and cross drainage structures on subzone-1(d) has been given. The utility of the report under section-7 has been dealt with for the guidance of the design engineers.

The report on subzone-1(d) is recommended for estimation of design flood for small and medium catchments varying in areas from 25 to 1500 sq.km. This report may also be used for catchment areas upto 5000 sq.km. judiciously after comparison of available rainfall and runoff data of neighbouring catchments with similar characteristics.

This report is a joint effort of Central Water Commission of Ministry of Water Resources, R.D.S.O. of Ministry of Transport (Railways) Roads and Bridges wing of Ministry of Transport (Surface) and Hydromet Directorate of I.M.D.

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

Sd/-
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SYMBOLS AND ABBREVIATIONS

SYMBOLS

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

A	: Catchment Area in sq.km.
C.G.	: Centre of Gravity
L	: Length of longest main stream along the river course in km.
L_c	: Length of the longest main stream from a point opposite to centroid of the catchment area to the gauging site along the main stream in km.
L_i	: Length of the ith segment of L-section in km.
D_{i-1}, D_i	: Depths between the river bed bed profile (L-section) based on the levels of (i-1) and ith contours at the inter-section points and the level of the base line (datum) drawn at the point of study in metres.
S	: Equivalent stream slope in m/km
U.G.	: Unit Hydrograph
S.U.G.	: Synthetic Unit Hydrograph
t_r	: Unit Rainfall Duration adopted in a specific study in hours
t_p	: Time from the centre of Unit Rainfall Duration to the Peak of Unit Hydrograph in hours
t_m	: Time from the start of rise to the peak of Unit Hydrograph in hours
T	: Time Duration of Rainfall in hours
T_B	: Base Width of Unit Hydrograph in hours
T_D	: Design Storm Duration in hours

Min.	: Minutes
Km.	: Kilometres
Sq.km.	: Square Kilometres, Km^2
In.	: Inches
Sec.	: Seconds
Sq.	: Square
M.O.T. (DOR)	: Ministry of Transport (Deptt. of Rlys.)
R.D.S.O.	: Research Designs & Standards Organisation (Ministry of Railways), Lucknow
H(SC), CWC	: Hydrology (Small Catchments) Directorate, Central Water Commission, New Delhi.
I.M.D.	: India Meteorological Department
M.O.T.	: Ministry of Surface Transport (Roads Wing).

SUMMARY OF APPROACHES & CONTENTS OF THE APPROACHES.

APPROACHES

Estimation of design flood peak value of "T" years return period.

(a) Detailed S.U.H. approach

(b) Regression formula based on design flood computed using S.U.H. approach.

Estimation of water level corresponding to "T" year return period flood.

Estimation of approximate lineal waterway to cater to "T" year return period flood.

CONTENTS OF APPROACHES

1(a) is given in the report Page Nos.

(b) $Q_{25} = 5.613 A^{0.708} S^{0.465} R_{25}^{0.178}$

$Q_{50} = 6.214 A^{0.701} S^{0.484} R_{50}^{0.202}$

$Q_{100} = 10.437 A^{0.678} S^{0.396} R_{100}^{0.145}$

Where Q_{25}, Q_{50} and Q_{100} are the 25-yr, 50-yr and 100-yr flood in the cumecs respectively.

A is catchment area upto the point of study in sq.km.

S is the equivalent stream slope in m/km (See worked out example).

R_{25} : R_{50} and R_{100} are the design storm point rainfall values in cms. for the design storm duration $T_D = 1.1 \times tp$ in hrs. The rainfall values are found after locating the catchment on the isopluvial maps (Plates 9, 10, 11).

As given in the report 65,67,69 pages.

3. $Q_{25} = 2.83 \ Q_{2.33}$

$Q_{50} = 3.38 \ Q_{2.33}$

$Q_{100} = 3.82 \ Q_{2.33}$

Where $Q_{2.33}$ is the 2.33 yr. flood in cumecs.

A = is catchment area upto the point of study in sq.kms.

F = is shape factor of catchment.

The worked out examples of the above approaches for design flood estimation and lineal waterway are follow:

ILLUSTRATIVE EXAMPLE

A typical example with reference to Railway Bridge Catchment (treated as ungauged) is worked out for illustrating the procedure. The particulars of the catchment under study are as under:

i) Name and Number of subzone	:	Sone subzone - 1(d).
ii) Name of site (i.e. point of study)	:	Railway Bridge No. 1198
iii) Name of Railway section	:	Itarsi - Allahabad
iv) Name of Tributary	:	Simrawal Nadi
v) Shape of the catchment	:	Fan
vi) Site location	:	24° 44' 12" (Latitude)
vii) Topography	:	80° 51' 53" (Longitude) Moderately steep slope

The procedure is explained stepwise:

Step-1: Preparation of Catchment Area Plan

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

Step-2: Determination of Physiographic Parameters

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

1) Area (A) : 340.64 km^2

2) Length of the longest stream (L) : 34.94 km.

3) Equivalent stream slope (S) : 3.70 m/km.

Following methods are adopted for computation of slope (S):

(a) <u>By Graphical Method</u>

Draw a longitudinal section of the longest main stream from contours crossing the stream and the spot levels along the banks from the sources to the point of study from the catchment plan as shown in Fig. A-1. Draw a sloping line by trial on the L-section from the point of study such as that the areas between L-section and above and below the line are equal. Then compute the slope (S) of this line.

(b) <u>By Mathematical Calculation</u>

The computations of (S) shown in Table A-1 with reference to Fig. A.1 are self-explanatory.

Step-3: <u>Determination of Synthetic 1-hr. Unitgraph Parameter</u>

The following equations were used to compute the unitgraph parameters with the known values A, L and S as under:

i) $tp = 0.314 \ (L/\sqrt{S})^{1.012}$

$= 0.314 \ (34.94/\sqrt{3.70})^{1.012} = 5.90$ hrs. rounded off to 5.5. hrs.

ii) $q_p = 1.664/(tp)^{0.965}$

$= 1.664/(5.5)^{0.965} = 0.321 \ m^3 \ sec/km^2$

iii) $W_{50} = 2.534/(q_p)^{0.976}$

$= 2.354/(0.321)^{0.976} = 7.68$ hrs.

iv) $W_{75} = 1.478/(q_p)^{0.860}$

$= 1.478/(0.321)^{0.860} = 3.93$ hrs.

v) $W_{R50} = 1.091/(q_p)^{0.750}$

$= 1.091/(0.321)^{0.750} = 2.56$ hrs.

vi) $W_{R75} = 0.672/(q_p)^{0.719}$

$= 0.672(0.321)^{0.719} = 1.52$ hrs.

vii) $T_B = 5.526(tp)^{0.866}$

$= 5.526(5.5)^{0.866} = 24.19$ hrs Say 24 hrs.

viii) $Tm = tp + tr/2$

$= 5.5 + ½ = 6.0$ hrs.

ix) $Q_p = q_p \times A$

$= 0.321 \times 340.64 = 109.34$ Say 109.3 m^3/sec.

Step-4: Drawing of a Synthetic Unitgraph

Estimated parameters of unitgraph in step-3 were plotted to scale on a graph paper as shown in Fig. A-2. The plotted points were joined to draw synthetic unitgraph. The discharge ordinates (Qi) of the unitgraph at ti = tr = 1 hr. interval were summed up i.e. $\sum Qi\ ti = 946.2\ m^3/sec.$ as shown in Fig. A-2 and compared with the volume of 1.00 cm Direct Runoff Depth over the catchment with the Formula $\sum Qi\ ti = 2.78\ A.d/ti$.

Where A = Catchment area in km^2

d = 1.0 cm depth

ti = tr (the unit duration of the UG) = 1.00 hr.

$$Qi = \frac{A \times d}{0.36 \times tr} = \frac{340.64 \times 1}{0.36 \times 1} = 946.2$$

Thus the unitgraph so drawn was found to be in order.

In case the $\sum Qi\ ti$ for the unitgraph drawn is higher or lower than the volume worked out by the above formula, then the falling limb and/or rising limb may be suitably modified to get the correct volume under the hydrograph, taking care to get the smooth shape of the unitgraph.

Step-5: Estimation of Design Storm Duration

The design storm duration (T_D) = 1.1 x tp = 1.1 x 5.5 = 6.05 hrs. Adjusting the design storm duration to nearest one hour, the adopted design storm duration (T_D) is 6.0 hrs.

Step-6: Estimation of point rainfall and areal rainfall

The catchment under study was located on plate-10 showing 50-yr. 24-hr point rainfall. 50-yr. 24-hr. point rainfall = 23.0 cm. Conversion factor of 0.700 was read from Fig. 10 in section for conversion of 50-yr 24-yr point rainfall to 50-yr 16-hr point rainfall since T_D = 6 hrs. 50-yr 6-hr point rainfall = 23.0 x 0.700 = 16.10 cm.

Areal Reduction Factor of 0.78 corresponding to a catchment area of 340.64 km^2 for T_D = 6 hrs was interpolated from Table-6 or Fig. 11(a) in section for conversion of point to areal rainfall 50-yr 6-hr areal rainfall = 16.10 x 0.78 cm.

Note : When the catchment under study falls between two isohyets the point rainfall may be computed for the catchment taking into account the isohyets.

Step-7: Time Distribution of Areal Rainfall

50-yr 6-hr areal rainfall = 12.56 cm was distributed with the distribution coefficients (col.6 of Table A-2) or from mean average time distribution curve for storms of 4-6 hrs in Fig. 12(b) corresponding to 6-hrs to get 1-hr rainfall increments as follows:

Duration (hr)	Distribution co-efficients	Storm rainfall (cm)	1-hr. rainfall increments
(1)	(2)	(3)	(4)
1	0.58	7.28	7.28
2	0.77	9.67	2.39
3	0.85	10.68	1.01
4	0.92	11.55	0.87
5	0.97	12.18	0.63
6	1.00	12.56	0.38

Step-8: Estimation of Effective Rainfall Units

Design loss rate of 0.25 cm/hr under section has been adopted.

The following table shows the computation of 1-hr effective rainfall units in col. (4) by substracting the design loss rate in col.(3) from 1-hr rainfall increments in col. (2).

Duration (hr)	1-Hr. rainfall (cm)	Design loss Rate (cm/hr)	1-hr. effective rainfall (cm)
(1)	(2)	(3)	(4)
1	7.28	0.25	7.03
2	2.39	"	2.14
3	1.01	"	0.76
4	0.87	"	0.62
5	0.63	"	0.38
6	0.38	"	0.13

The column (2) in above table is taken from col. (4) of table in Step-7.

Step-9: Estimation of 50-yr. Flood (Peak only)

For the estimation of the peak discharge the effective rainfall units were re-arranged against the ordinates such that the maximum effective rainfall was placed against the maximum U.G. ordinate, the next lower value of rainfall effective against the next lower value of U.G. ordinate and so on as shown in col. (2) and (3) in the following table. Summation of the product of U.G. ordinate and the rainfall gives the total direct runoff as under:

Time	U.G. ordinate (cumecs)	1-hr. Effective (Rainfall (cm))	Direct Runoff (cumecs)
(1)	(2)	(3)	(4)
4	68.6	0.13	8.92
5	95.0	0.76	72.20
6	109.3	7.03	768.38
7	98.0	2.14	209.72
8	86.5	0.62	53.63
9	76.0	0.38	28.88
			1141.73

Time	U.G. Ordinate (cumecs)	1-hr. Effective Rainfall (cm)	Direct Runoff (cumecs)
			B.F.
		Base flow	15.33
		50-yr Flood peak	1157.06

Step-10: Computation of Design Flood Hydrograph

The 1-hr effective rainfall sequence shown in col.(3) of Table in Step-9 was reversed to obtain the critical sequence.

For computation of design flood hydrograph, the U.G. ordinates for 1-hr. interval were tabulated in col.(2) of Table-A-3 against time (hrs) in col.(1). The critical sequence of 1-hr. effective rainfall units were entered in col.3 to 8, horizontally as shown in Table A-3. The direct runoff resulting from each of the 1-hr effective rainfall units was obtained by multiplying the 1-hr effective rainfall with the synthetic 1-hr U.G. ordinates in col.(2) and direct runoff values were entered in vertical columns against each unit with a successive log of 1-hr since the unit duration of S.U.G. is 1 hr. The direct runoff so obtained are shown in col.(3) to (8). The direct runoff were added horizontally and the total direct runoff is shown in col.(9). The total base flow of 15.33 m^3/sec was entered in col.(10), col.(11) gives the addition of col.(9) and col.(10) to get the design flood hydrograph ordinates. The total discharge in col. (11) were plotted against time in col.(1) to get the design flood hydrograph in Fig. A-3.

PART - B

SIMPLIFIED APPROACH

(B) SIMPLIFIED APPROACH

1. FLOOD FORMULAE BY MULTIPLE REGRESSION ANALYSIS

In the multiple regression analysis, the peak discharge (Q_N) for a return period of N years as externally dependent variable was to be

$$Q_N = a\, A^b\, S^c\, R_N^d$$

Where A, S and R_N are same as in flood Peak formulae as independent variables, a, b, c, and d are multiple regression coefficients when a logarithemic transformation is applied to all variables. Principle of least square was used in the regression analysis to get the above relationship.

2. 25-YR. 50-YR AND 100-YR. FLOOD FORMULAE

25-yr, 50-yr and 100-yr flood values for each of the 15 gauged catchments for different sizes were computed by detailed approach. Series of Q_{25}, Q_{50} and Q_{100} for the 15 catchments as dependent variables were related by multiple regression analysis to their respective physiographic parameters A, S and meteorologic parameter of point rainfall R_{25}, R_{50} and R_{100} as independent variables applying the least square method for fitting. The derived flood formulae for Q_{25}, Q_{50} and Q_{100} with their respective coefficient of correlation (r) are as under:

$$Q_{25} = 5.613 . A^{0.708} . S^{0.485} . R_{25}^{0.178} \qquad r = 0.962$$

$$Q_{50} = 6.214 . A^{0.701} . S^{0.484} \quad R_{50}^{0.202} \qquad r = 0.960$$

$$Q_{100} = 10.437 . A^{0.678} \quad S^{0.396} \quad R_{100}^{0.145} \qquad r = 0.954$$

Where Q_{25}, Q_{50} and Q_{100} are 25-yr. 50-yr and 100-yr flood in cumecs respectively.

A is catchment area upto point of study in sq.km.

S is equivalent slope in m/km (details of estimating S are shown in step-2 of illustrative example).

R_{25}, R_{50} and R_{100} are the design storm point rainfall in cms for the design storm duration $T_D = 1.1 = t_p = 0.334 \left(\frac{L}{\sqrt{S}} \right)^{1.072}$ in hrs.

The rainfall values are found after locating the catchment on the isopluvial maps (Plates-9,10 & 11).

The coefficients of correlation for all the above relationships are extremely high and therefore the relationships derived are very reasonable. Further overall range of the + and - percentage variations in the computed flood (Q_{25}, Q_{50} and Q_{100}) by both the respective derived formulae and the detailed approach for the 15 catchments shown in the following table are within tolerable limits of $\pm$ 30%.

	Variation (+)	Range (-)
Q_{25}	0.78 to 23.39	0.15 to 27.84
Q_{50}	2.81 to 23.07	0.01 to 28.13
Q_{100}	1.60 to 28.04	4.77 to 28.71

The flood formulae for computation of 25-yr, 50-yr and 100-yr flood may be applied only for preliminary designs.

3. SOLUTION OF THE PROBLEM

Illustrative example for estimation of 25-yr, 50-yr and 100-yr flood for catchment area upto Rly. Bridge No. 1198 is considered for solution of the problem by flood formulae. The physiographic and meteorologic parameters for the catchment under study are:

A = 340.64 sq.km. S = 3.70m/km. $t_p = 0.314\ (L/\sqrt{S})^{1.012} \simeq 5.50$ hrs.

$T_D = 1.1\ t_p = 1.1 \times 5.50 = 6.00$ hrs.

R_{25} = 10.37cm, R_{50} = 12.56, R_{100} = 14.20

$$Q_{25} = 5.613\ (340.64)^{0.708}\ (3.70)^{0.483}\ (10.37)^{0.178} = 994.10 \text{ cumecs.}$$

$$Q_{50} = 6.214\ (340.64)^{0.701}\ (3.70)^{0.484}\ (12.56)^{0.202} = 1160.04 \text{ cumecs.}$$

$$Q_{100} = 10.437\ (340.64)^{0.678}\ (3.70)^{0.396}\ (14.20)^{0.145} = 1338.18 \text{ cumecs.}$$

The percentage variations in the values of Q_{25}, Q_{50} and Q_{100} by the detailed approach and the flood formulae with respect to the flood values by detailed approach for the catchment under study are -6.14, -0.01 and -9.20 respectively. Therefore, the flood values for 25-yr, 50-yr and 100-yr return periods estimated by the respective flood formulae are reasonable for adoption in preliminary designs.

TABLE - A-1: COMPUTATION OF EQUIVALENT SLOPE(S) OF BRIDGE NO. 1198

C.A...340.64. Km^2

Sl. No.	Reduced distance starting from Bridge site (K.M.)	Reduced levels of river bed	Length of each segment	Height above datum (D_i) = difference between the datum and its R.L. (M)	$(D_{i-1}+D_1)$	$L_i\ (D_i-1+D_i)$
	(K.M.)	(M)	(K.M.)	(M)	(M)	(K.M x M)
1	2	3	4	5	6	7
1.	0	*278.88	0	0	0	0
2.	13.85	323.38	13.85	44.50	44.50	616.32
3.	27.05	356.74	13.20	86.86	131.36	1733.95
4.	33.49	448.34	6.44	169.46	256.32	1650.70
5.	34.94	466.93	1.45	188.05	357.51	518.39
						4519.36

$$\text{Eq. Slope} = \frac{EL1\ (D_i-1+D_i)}{L^2} = \sqrt{\frac{4518.36}{(34.94)^2}} = 3.70 \text{ m/km}$$

*Datum = 278.88 i.e. Reduced level of river bed at the stage of study.

TABLE - A-2: TIME DISTRIBUTION COEFFICIENTS OF AREAL RAINFALL
SONE, SUB-ZONE 1(d)

TIME IN HOURS 1	DISTRIBUTION: COEFFICIENT FOR DESIGN STORM DURATION OF 2-24 HOURS 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	—	20	21	22	23	24	TIME IN HOURS 25
24																							1.00	24
23																						1.00	0.99	23
22																					1.00	0.99	0.98	22
21																				1.00	0.99	0.98	0.96	21
20																			1.00	0.99	0.97	0.96	0.95	20
19																		1.00	0.99	0.97	0.96	0.95	0.93	19
18																	1.00	0.99	0.97	0.96	0.94	0.93	0.91	18
17																1.00	0.99	0.97	0.96	0.94	0.92	0.91	0.89	17
16															1.00	0.99	0.97	0.95	0.94	0.92	0.90	0.89	0.87	16
15														1.00	0.98	0.97	0.96	0.93	0.91	0.89	0.88	0.87	0.85	15
14													1.00	0.98	0.97	0.95	0.94	0.91	0.89	0.87	0.86	0.85	0.83	14
13												1.00	0.98	0.97	0.95	0.94	0.92	0.88	0.87	0.85	0.83	0.82	0.80	13
12											1.00	0.98	0.97	0.95	0.93	0.92	0.90	0.86	0.84	0.82	0.80	0.79	0.77	12
11										1.00	0.98	0.96	0.95	0.93	0.91	0.89	0.88	0.83	0.81	0.79	0.77	0.76	0.74	11
10									1.00	0.98	0.96	0.94	0.92	0.90	0.88	0.87	0.85	0.79	0.77	0.76	0.74	0.72	0.70	10
9								1.00	0.98	0.96	0.94	0.91	0.89	0.87	0.86	0.84	0.82	0.75	0.74	0.72	0.70	0.69	0.67	9
8							1.00	0.98	0.96	0.93	0.91	0.88	0.86	0.84	0.82	0.81	0.79	0.72	0.69	0.68	0.66	0.65	0.63	8
7						1.00	0.98	0.95	0.93	0.90	0.88	0.85	0.82	0.81	0.79	0.77	0.76	0.67	0.64	0.63	0.62	0.59	0.58	7
6					1.00	0.97	0.94	0.91	0.89	0.86	0.84	0.80	0.78	0.76	0.75	0.73	0.71	0.61	0.59	0.58	0.56	0.55	0.54	6
5				1.00	0.97	0.93	0.90	0.87	0.84	0.82	0.80	0.75	0.74	0.71	0.70	0.69	0.67	0.55	0.54	0.52	0.51	0.50	0.48	5
4			1.00	0.96	0.92	0.88	0.84	0.81	0.78	0.76	0.73	0.70	0.68	0.66	0.64	0.62	0.60	0.49	0.47	0.46	0.44	0.43	0.42	4
3		1.00	0.95	0.90	0.86	0.80	0.77	0.73	0.70	0.68	0.66	0.61	0.59	0.57	0.56	0.54	0.53	0.41	0.39	0.38	0.37	0.36	0.34	3
2	1.00	0.90	0.86	0.81	0.76	0.69	0.66	0.64	0.60.	0.57	0.56	0.49	0.47	0.45	0.44	0.43	0.42	0.30	0.30	0.27	0.27	0.27	0.26	2
1	0.83	0.72	0.69	0.64	0.59	0.50	0.46	0.43	0.40	0.37	0.34	-0.32	0.30	0.28	0.27	0.26	0.25	0.18	0.18	0.18	0.16	0.14	0.14	1

NOTE: HOURLY RAINFALL DISTRIBUTION COEFFICIENTS AREA GIVEN IN THE VERTICAL COLUMNS FOUR VARIOUS DESIGN STORM DURATIONS FROM 2-24 HOURS.

TABLE - A - 3 COMPUTATION OF DESIGN FLOOD HYDROGRAPH

SUB-ZONE-1(d) RIVER-SIMRAWAL N.RAILWAY BRIDGE NO. 1198 CA 340.64 Km^2

Time (Hrs)	1-hr Synthetic Unitgraph (Cumecs)	EFFECTIVE RAINFALL UNITS (CM) 0.38	0.62	2.14	7.03	0.76	0.13	Total Direct Runoff (Cumecs)	Base Flow (Cumecs)	Flood (Cumecs)	Remarks
		DIRECT RUNOFF (CUMECS)									
1	2	3	4	5	6	7	8	9	10	11	12
0	0	0						0	15.33	15.33	
1	8.0	3.04	0					3.04	15.33	18.37	
2	19.5	7.41	4.96	0				12.37	15.33	27.70	
3	37.5	14.25	12.09	17.12	0			65.75	15.33	81.08	
4	68.6	26.07	23.25	41.73	56.24	0		147.29	15.33	162.62	
5	95.0	36.10	42.53	80.25	137.08	6.08	0	302.04	15.33	317.37	
6	109.3	41.53	58.90	146.80	263.62	14.82	1.04	526.71	15.33	542.04	
7	98.0	37.24	67.77	203.30	482.26	28.50	2.53	821.60	15.33	836.93	
8	86.5	32.87	60.76	233.90	667.85	52.14	4.87	1052.39	15.33	1067.72	
9	76.0	28.88	53.63	209.72	768.37	72.20	8.93	1141.73	15.33	1157.06	Peak
10	66.0	25.08	47.12	185.11	688.94	83.07	12.35	1041.67	15.33	1057.00	
11	55.0	20.90	40.92	162.64	608.09	74.48	14.21	921.24	15.33	936.57	
12	46.0	17.48	34.10	141.24	534.28	65.74	12.74	805.58	15.33	820.91	
13	38.5	14.63	28.52	117.70	463.98	57.76	11.24	693.83	15.33	709.16	
14	31.6	12.01	23.87	98.44	386.65	50.16	9.88	581.01	15.33	596.34	
15	26.1	9.92	19.59	82.39	323.38	41.80	8.58	485.66	15.33	500.99	
16	21.5	8.17	16.18	67.62	270.65	34.96	7.15	404.73	15.33	420.06	
17	17.3	6.57	13.33	55.85	222.15	29.26	5.98	333.14	15.33	348.47	
18	14.0	5.32	10.73	46.01	183.48	24.02	5.00	274.56	15.33	289.89	
19	11.0	4.18	8.68	37.02	151.14	19.84	4.11	224.97	15.33	240.30	
20	8.6	3.27	6.82	29.96	121.62	16.34	3.39	181.40	15.33	196.73	
21	6.2	2.36	5.33	23.54	98.42	13.15	2.79	145.59	15.33	150.92	
22	4.0	1.52	3.84	18.40	77.33	10.65	2.25	113.98	15.33	129.31	
23	2.0	0.76	2.48	13.27	60.46	8.36	1.82	87.15	15.33	102.38	
24	0	0	1.24	8.56	43.59	6.54	1.43	61.36	15.33	76.69	
			0	4.28	28.12	4.71	1.12	38.23	15.33	53.56	
				0	14.06	3.04	0.81	17.91	15.33	33.24	
					0	1.52	0.52	2.04	15.33	17.37	
						0	0.26	0.26	15.33	15.59	
							0	0	15.33	15.33	

PART-C
GENERAL DESCRIPTIONS

1.0 GENERAL DESCRIPTIONS OF SONE SUBZONE DATA, COLLECTION AND ANALYSIS

1.1 LOCATION

The Sone subzone - 1(d) lies approximately between 80° and 86° 15' longitude (East) and 22° 30' to 25° 45' latitude (North). Plate-1 shows the location of Sone subzone with the appended list of hydrometeorological subzones of India.

The Sone subzone is bounded on the north by Middle Ganga plains subzone-1(f), on the south by Mahanadi subzone - 3(d) and Upper Narmada and Tapi subzone - 3(c), on the east by Lower Ganga plains - 1(g) and on the west by Betwa subzone - 1(c). This subzone - 1(d) covers parts of Bihar, Madhya Pradesh and Uttar Pradesh. The important towns and cities in the subzone are Patna, Gaya, Palamau, Deltonganj, Bhagalpur, Shahbad in Bihar State, Rewa, Raipura, Govindgarh, Ketva, Sirsi, Sarai and Ramgarh in Madhya Pradesh State and Mughalsarai and Mirzapur in Uttar Pradesh.

1.2 RIVER SYSTEM

Plate-2 depicts the river system of Sone subzone. Sone river is the biggest river in the subzone - 1(d). Besides, there are other sizable rivers like Tons, Karmanasa, Punpun and Phalgu. Sone river, a major southern tributary of Ganga, outfalls upstream of Patna. The major tributaries of Sone river are Banas, Gopat, Rihand, Kanhar and North Koel along the right bank and Johilla, Mahanadi and Katni along the left bank. Rihand is the biggest tributary of Sone river followed by North Koel.

Sone river runs a main course of about 404 km. in Madhya Pradesh about 71 km. in Uttar Pradesh and 211 km. in Bihar State with total course of 686 km. The drainage areas of the river systems in Sone subzone are as under:

S.No.	Name of river/tributary	Drainage area (sq.km.)
1	2	3
1.	Tons	18,730
2.	Karmanasa (Ghorai)	16,025
3.	Sone Right Bank Tributaries	
	(i) Banas	3,876
	(ii) Gopat	6,230

South Bihar plains Dhadhar a tributary of phalgu with its source in the hills almost flows in the South Bihar plains.

Sone subzone has a complex relief comprising of hills, platean and plains. A chain of depressions known as Mokanah Tals falls along the southern bank of Ganga. The spill chanals of Dhadhar outfall into Mokamah.

1.4 RAINFALL

Plate - 4 shows the normal annual rainfall of the Sone subzone and the histograms of normal monthly rainfall at Rewa, Patna and Ganga. The subzone experiences heared rainfall due to South-west monsoon during June to September. The normal annual rainfall generally varies with the decrease in elevation; from 140 to 160 cm in the hills and from 100 to 120 cm in the plains. The monsoon season rainfall is about 80 to 85% of this annual rainfall mean maximum monsoon rainfall is experienced during July and August.

1.5 TEMPERATURE

Plate-5 depicts the normal annual temperatures in the subzone alongwith histograms of the minimum, maximum and mean monthly temperatures at Patna and Ganga. In line with the general physiography of the subzone, it is seen that the southern portion of the subzone has mean annual temperatures below 25^{o}c and the remaining portion mostly constituted of plains has mean annual temperature between 25^{o} to 25.7^{o} c. Mean monthly temperatures start rising from March with its peak during April and May. Again the mean monthly temperature start falling from June and reaches the minimum by December and January.

1.6 SOILS

Plate-6 shows the soil classification in the Sone subzone. It is mostly covered with red and yellow soils except the alluvial soils in the South Bihar Plains and patches of medium black soils red sandy soils and mixed red and black soils in the south west. At micro level (i.e. when small catchments are considered) the soil type may vary considerably from the above mentioned groups.

1.7 LAND USE

Plate-7 delineates the land use in the Sone subzone. Arable land mostly in the plains and also a large number of patches in the remaining part constitute about 45% of the subzone. Forests cover about 50% of the subzone, 5% of the remaining subzone is mostly grass land, scrub, wasteland morshes and water bodies.

1.8 COMMUNICATIONS

The Sone subzone has an average road and rail network.

1.8.1 Railway Lines

The following railway lines traverse the Sone subzone.

Subzone - 1(d)

S.No. (1)	Railway Section (2)	
1.	Katni to Allahabad	Central Railway
2.	Katni to Bishrampur	South Eastern Railway
3.	Katni to Garwa via Billi	Eastern Railway
4.	Garwa to Purulia	Eastern Railway
5.	Anupur to Bilaspur	South Eastern Railway
6.	Billi to Mughalsarai	Northern Railway
7.	Allahabad to Mughalsarai	Northern Railway
8.	Mughal Sarai to Kiul via Patna	Eastern Railway
9.	Mughal Sarai to Kiul via Gaya	Eastern Railway
10.	Garwa to Sone east Bank	Eastern Railway
11.	Gaya to Patna	Eastern Railway
12.	Gaya to Futwah	Eastern Railway
13.	Rajgir to Bukhtiarpur	Eastern Railway
14.	Manpur to Dhanbad	Eastern Railway

1.8.2 Roads

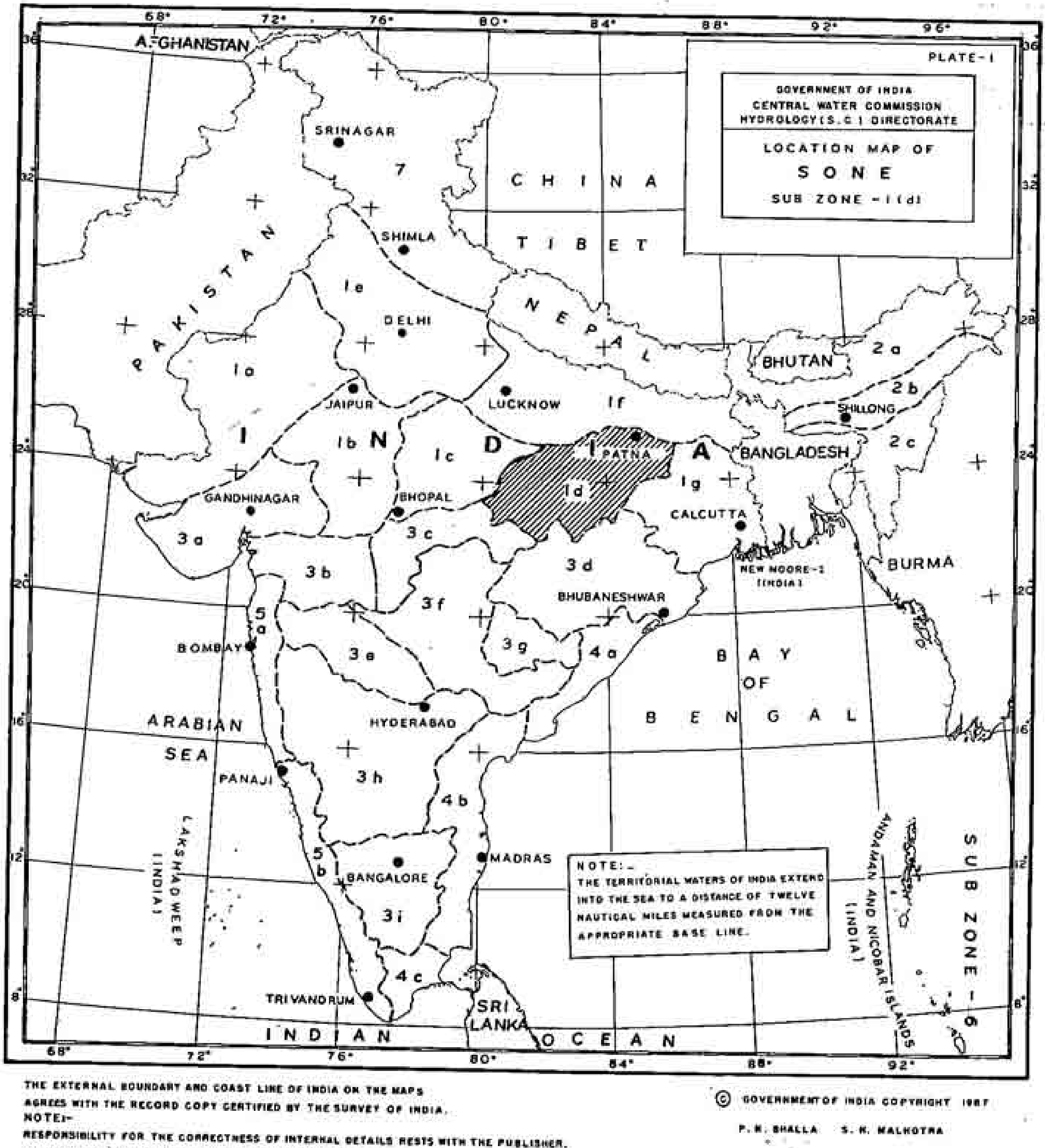
The major highways in the subzone are:

1. National Highway No. 2 (Mohania to Barhi)
2. National Highway No. 31 (Barhi to Patna)
3. National Highway No. 30 (Patna to Mahania)
4. National Highway No. 33 (Barhi to Ranchi)
5. National Highway No. 7 (Katni to Varanasi)
6. National Highway No. 27 (Mangawan to Allahabad).

LIST OF HYDRO-METEOROLOGICAL SUB-ZONES

Sub-zone	Name of subzone (designated earlier)	Name of subzone (designated now)	River Basins included in the subzone
1.	2.	3.	4.
1(a)	Luni basin & Thar (Luni & other rivers of Rajasthan and Kutch)	Luni	Luni river, Thar (Luni & other rivers of Rajasthan and Kutch, and Banas river).
1(b)	Chambal Basin	Chambal	Chambal river
1(c)	Betwa Basin & other Tributaries	Betwa	Sind, Betwa and Ken rivers and other South Tributaries of Yamuna.
1(d)	Sone Basin and Right Bank Tributaries.	Sone	Sone and Tons rivers and other South Bank Tributaries of Ganga.
1(e)	Punjab Plains including parts of Indus, Yamuna, Ganga and Ramganga Basins.	Upper Indo-Ganga Plains	Lower portion of Indus Ghaggar Sahibi Yamuna, Ganga and Upper portion of Sirsa, Ramganga, Gomti and Sai rivers.
1(f)	Gangetic Plains including Gomti, Ghagra, Gandak, Kosi and other.	Middle Ganga Plains	Middle portion of Ganga, Lower portion of Gomti, Ghagra, Gandak, Kosi and middle portion of Mahanadi Basin.
1(g)	Lower Gangetic Plains including Subarnarekha and other east-flowing rivers between Ganga and Baitarani.	Lower Ganga Plains	Lower portion of Ganga, Hoogli river system and Subarnarekha.

1.	2.	3.	4.
4(b)	Coromandal Coast including east flowing rivers between Godavari and Cauveri	Lower Eastern Coast	East flowing coastal rivers, Manimukta, South Penner, Cheyyar, Palar, North Penner, Munneru, Palleru, Gundalakama and Krishna Delta.
4(c)	Sandy Coroman Belt (east flowing rivers between Cauvery & Kanyakumari).	South Eastern Coast	East flowing coastal rivers - Manimuther, Vaigai, Arjuna, Tamraparni.
5(a)	Konkan coast (west flowing river between Tapi and Panaji).	Konkan Coast	West flowing coastal rivers between Tapi and Mandavi rivers.
5(b)	Malabar Coast (West flowing rivers between Kanyakumari and Panaji).	Malabar Coast	West flowing coastal rivers between Mandavi and Kanyakumari
6.	Andaman and Nicobar	Andaman & Nicobar	
7.	J & K Kumaon Hills (Indus Basin).	Western Himalayas	Jhelum, Upper portion of Indus, Ravi and Beas rivers.



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

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.

P. K. BHALLA S. K. MALHOTRA

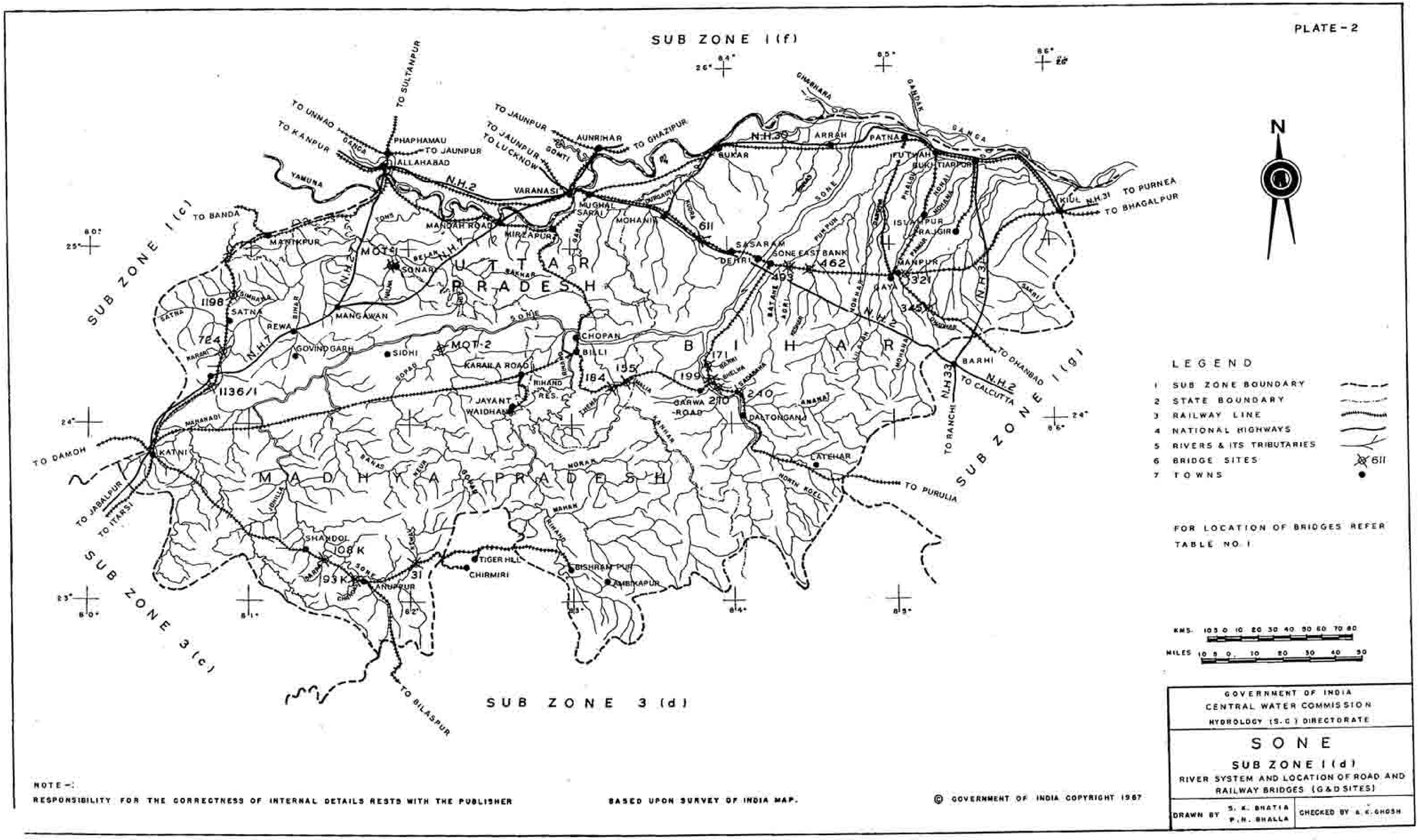


PLATE - 2
SUB ZONE I (f)
SUB ZONE I (c)
SUB ZONE I (g)
SUB ZONE 3 (c)
SUB ZONE 3 (d)
N
UTTAR PRADESH
BIHAR
MADHYA PRADESH
TO SULTANPUR
TO UNNAO
TO KANPUR
PHAPHAMAU
TO JAUNPUR
ALLAHABAD
TO JAUNPUR
TO LUCKNOW
AUNRIHAR
TO GHAZIPUR
VARANASI
MUGHAL SARAI
MIRZAPUR
MANDAH ROAD
MOHANIA
BUKAR
ARRAH
PATNA
FUTWAH
BUKHTIARPUR
ISLAMPUR
RAJGIR
KIUL
TO PURNEA
TO BHAGALPUR
SASARAM
DEHRI
SONE EAST BANK
493
462
611
GAYA
MANPUR
321
345
BARHI
TO DHANBAD
TO CALCUTTA
TO RANCHI
N.H.2
N.H.30
N.H.31
N.H.33
N.H.7
TO BANDA
MANIKPUR
MOT-1
SONARI
SATNA
1198
REWA
MANGAWAN
724
GOVINDGARH
SIDHI
MOT-2
CHOPAN
BILLI
KARAILA ROAD
RIHAND RES.
JAYANT
WAIDHAN
184
155
171
199
210
240
GARWA ROAD
DALTONGANJ
LATEHAR
TO PURULIA
1136/1
KATNI
TO DAMOH
TO JABALPUR
TO ITARSI
SHAHDOL
108 K
93 K
ANUPPUR
31
TIGER HILL
CHIRMIRI
BISHRAMPUR
AMBIKAPUR
TO BILASPUR
GANGA
YAMUNA
SONE
GOMTI
GANDAK
NORTH KOEL
LEGEND
1 SUB ZONE BOUNDARY
2 STATE BOUNDARY
3 RAILWAY LINE
4 NATIONAL HIGHWAYS
5 RIVERS & ITS TRIBUTARIES
6 BRIDGE SITES
7 TOWNS
FOR LOCATION OF BRIDGES REFER TABLE NO. I
KMS. 10 5 0 10 20 30 40 50 60 70 80
MILES 10 5 0 10 20 30 40 50
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S.C) DIRECTORATE
SONE
SUB ZONE I (d)
RIVER SYSTEM AND LOCATION OF ROAD AND RAILWAY BRIDGES (G&D SITES)
DRAWN BY S. K. BHATIA P. N. BHALLA
CHECKED BY A. K. GHOSH
NOTE -:
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER
BASED UPON SURVEY OF INDIA MAP.
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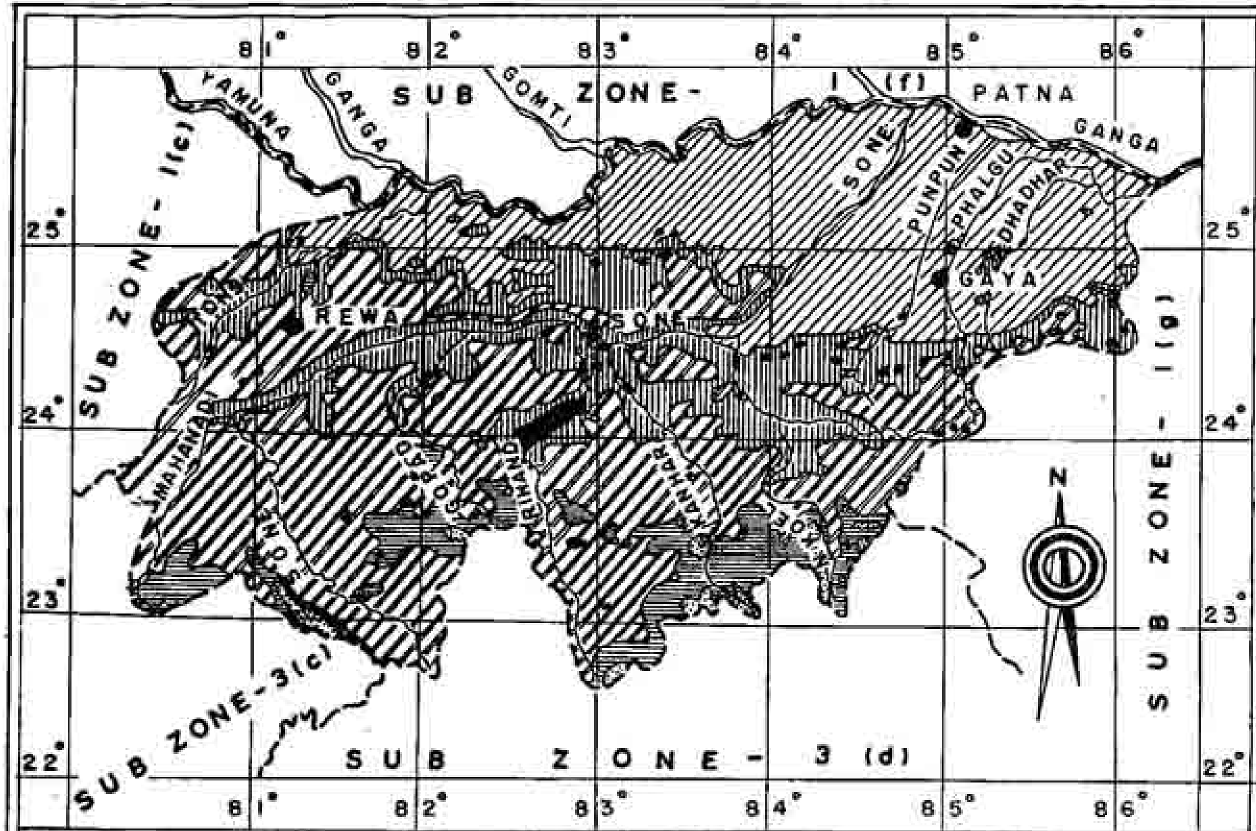
PLATE - 3



LEGEND

ALTITUDE IN METRES

< 150
150 — 300
300 — 600
600 — 900
900 — 1350
1350 — 1800

SCALE

KMS. 50 0 50 100 150

MILES. 40 20 0 40 80

REFERENCES

1. SUB ZONE BOUNDARY
2. RIVERS.
3 TOWNS.
4 WATER BODIES.

NOTE:-

THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972) PLATE NO. 3

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

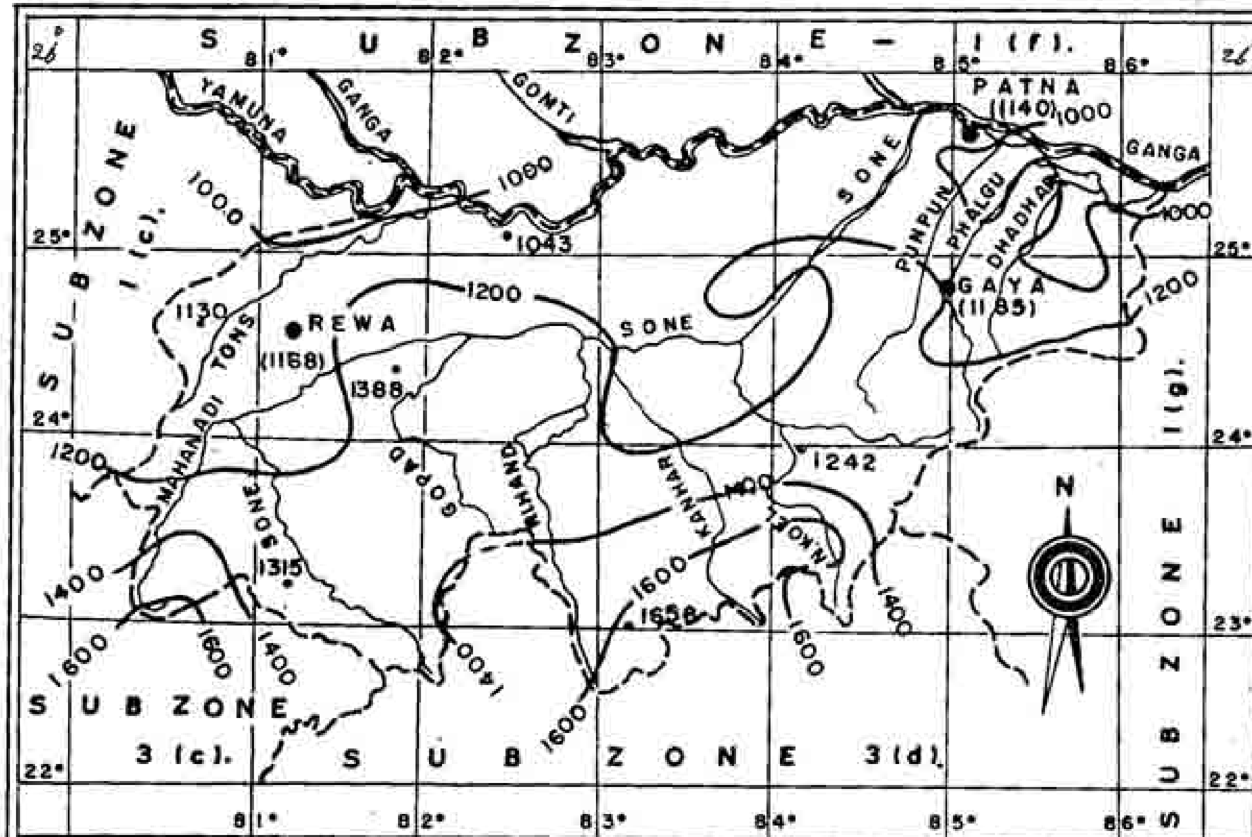
SONE

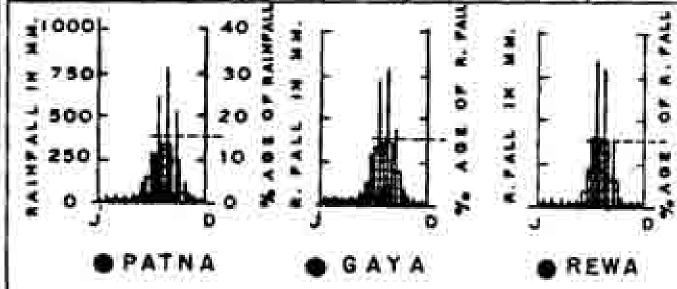
SUB ZONE I (d)

PHYSIOGRAPHY

DRAWN BY-: S. N. MALHOTRA, P. N. BHALLA.

CHECKED BY. A. K. GHOSH.





REFERENCES.

1. ISOHYETAL LINES WITH VALUE IN mm. (NORMAL ANNUAL) 1000
2. SUB ZONE BOUNDARY . . .
3. RIVERS . . . . . .
4. TOWNS . . . . ●
5. SPOT RAINFALL (mm.) . . . • 1315

PLATE - 4

NOTES:-

1 HISTOGRAMS FOR THREE STATIONS WITH NAMES.
2 EACH VERTICAL COLUMN REPRESENTS THE MEAN MONTHLY RAINFALL FOR EACH MONTH (FROM JANUARY TO DECEMBER)
3. THE THICK VERTICAL LINES AT THE CENTRE OF EACH COLUMN INDICATES THE PERCENTAGE OF RAINFALL IN THE MONTH TO THE MEAN ANNUAL TOTAL.
4 THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972) - PLATE - 6

SCALE

KMS. 50 0 50 100 150

MILES. 40 20 0 40 80

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

SONE

SUB ZONE 1 (d)

NORMAL ANNUAL RAINFALL (mm)

DRAWN BY.–	CHECKED BY.–
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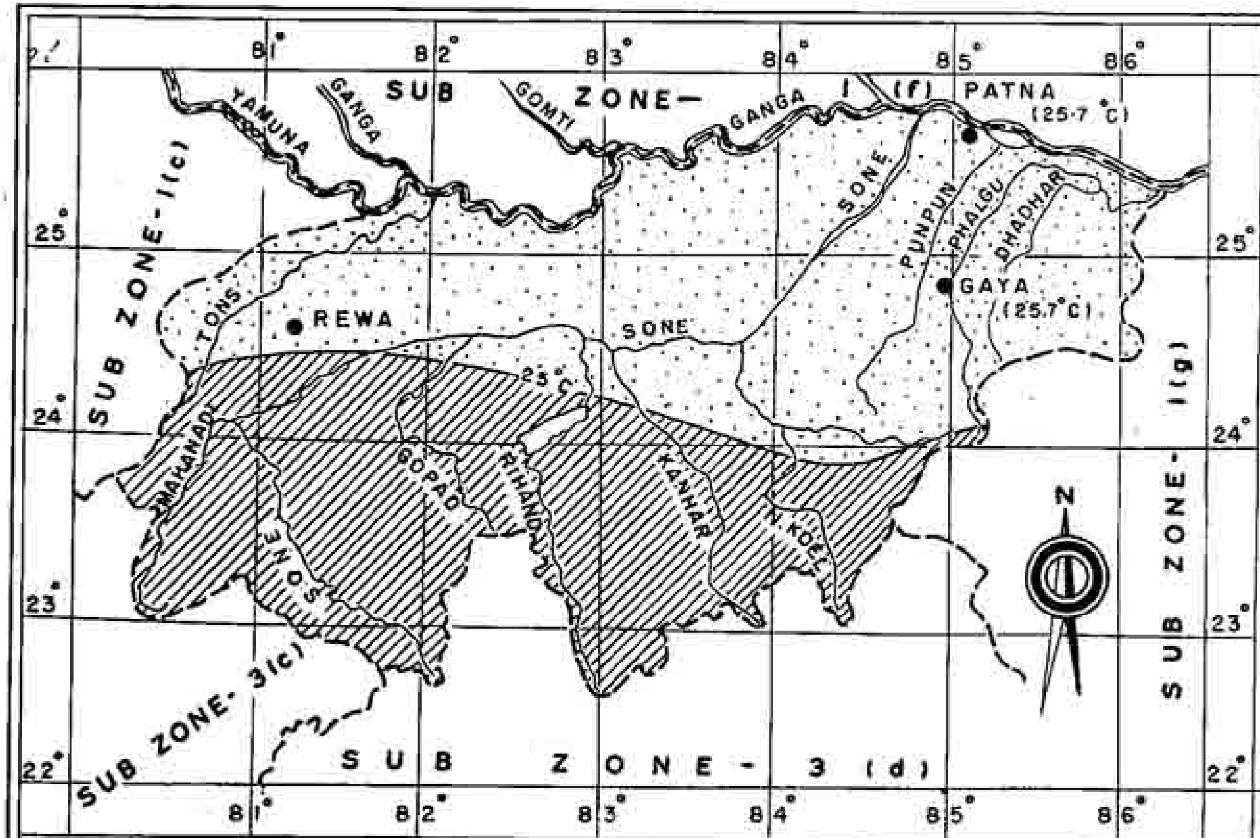
PLATE – 5



NOTE–
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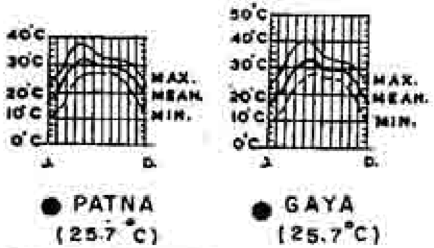
SCALE–
50 0 50 100 150 KMS.
40 20 0 40 80 MILES.

REFERENCES–



1 TEMPERATURE BETWEEN 22.5°C TO 25°C
2 " " " 25°C TO 27.5°C
3 SUB ZONE BOUNDARY
4 TOWNS
5 RIVERS
6 ISOTHERMS WITH VALUE IN °C DEGREES —25°C—

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

SONE

SUB ZONE – 1 (d)

NORMAL ANNUAL TEMPERATURE.

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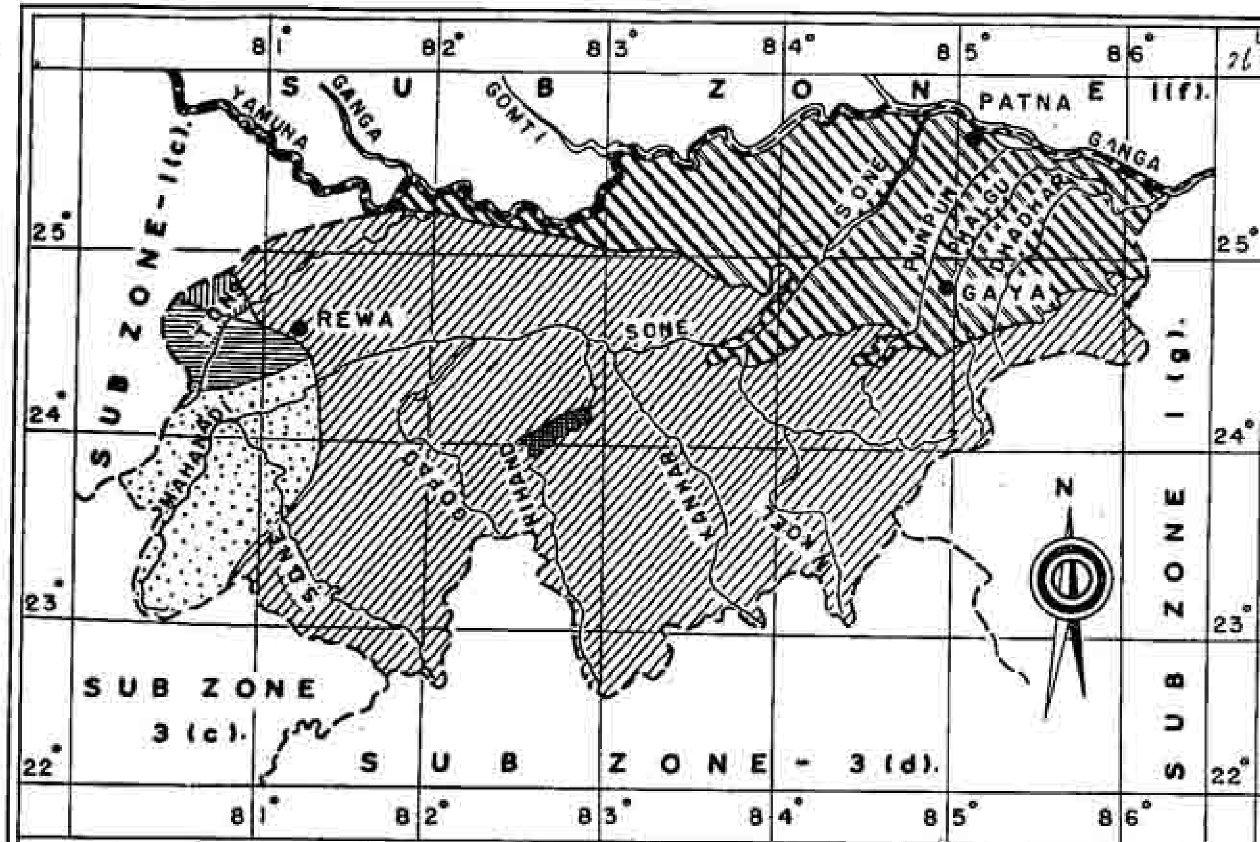
CKD.– A. K. GHOSH.

PLATE - 6



LEGEND—

1. ALLUVIAL SOILS (RECENT).
2. RED AND YELLOW SOILS.
3. RED SANDY SOILS . . .
4. MEDIUM BLACK SOILS. .
5. MIXED RED AND BLACK SOILS.
6. WATER BODIES. . . . .
7 SUB ZONE BOUNDARY. .
8 RIVERS. . . . . .
9 TOWNS. . . . . . .

SCALE

KMS. 50 0 50 100 150

MILES. 40 20 0 40 80

NOTE—

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GOVERNMENT OF INDIA
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HYDROLOGY (SMALL CATCHMENTS) DTE.

SONE
SUB ZONE 1 (d)
SOIL CLASSIFICATION

DRAWN BY.—
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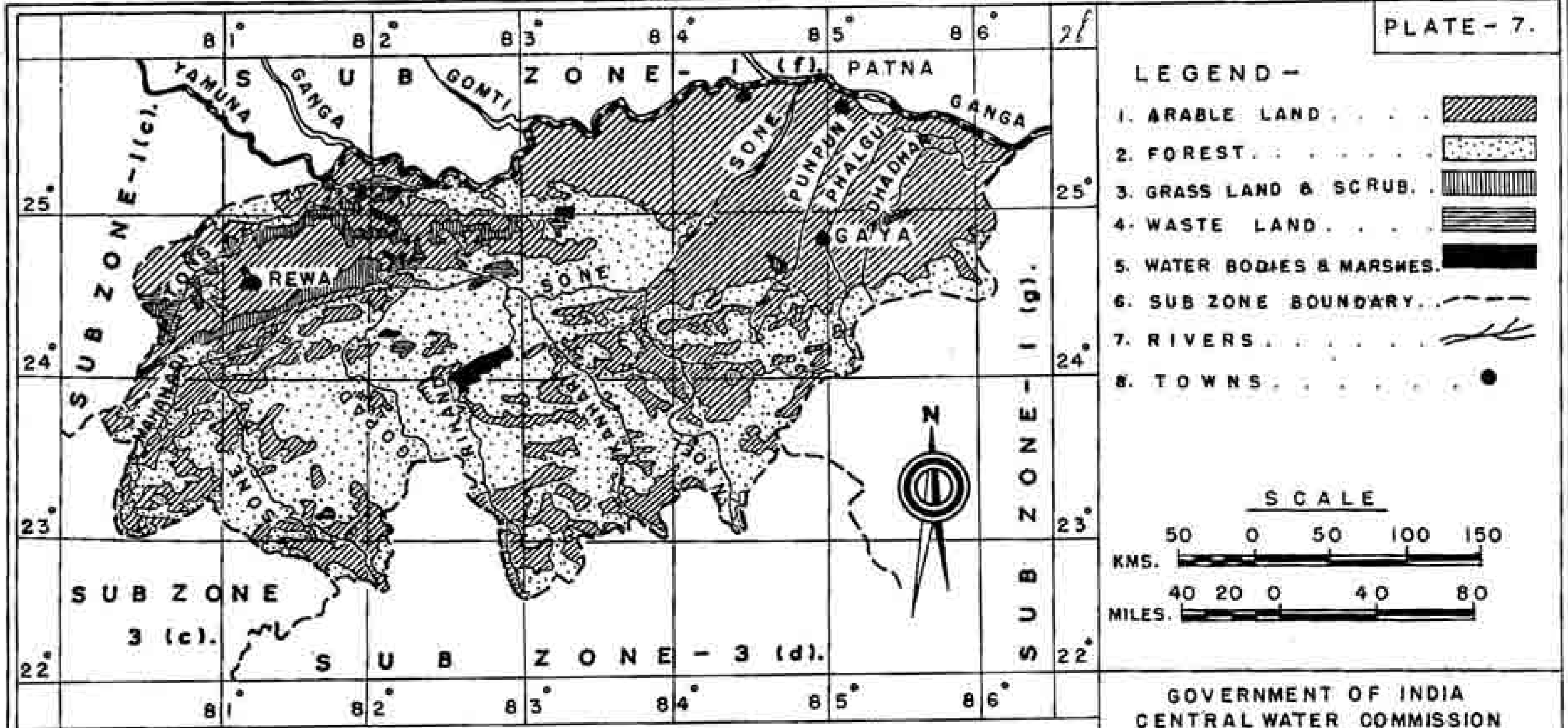
PLATE - 7.



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

SONE
SUB ZONE. 1 (d)
LAND USE

NOTE —

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P. N. BHALLA

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2.0 DESIGN FLOOD, DATA COLLECTION AND 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 structures across a river. The Committee of Engineers had suggested that the design discharge may be considered as the maximum observed discharge from the yearly peak discharge records available for over 50 years. However, the present Indian Railways substructure Code recommends that the design discharge may be computed as a 50-year flood using records of larger than/equal to/less than 50 years. In the absence of adequate data of peak discharges 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 unitgraph may produce a flood of the same return period (50-year).

2.2 DATA REQUIRED

For conducting the unitgraph 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 & 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 self-recording or manually operated.

iv) Catchment area plan showing the river network, location raingauge stations and gauge & 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.

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.

2.3 DATA COLLECTED

The Eastern South Easter and Central Railways under the supervision and guidance of Research and Designs Standard Organisation (RDSO) had observed and collected the required data in section 2.2 for 19 catchments in the Sone sub-zone-1(d) for a period ranging from 4 to 10 years. Central Water Commission on behalf of Ministry of Transport has also observed and collected the required data for 2 catchments for a period from 1980-86. The size of the gauged catchments vary from 27.51 to 5815 sq.km. concurrent rainfall, gauge and discharge data for 103 bridge catchment years from 18 catchments was available for study.

The locations of the gauging sites at round and railway bridges in the Sone subzone-1(d) are shown in Plate-2. India Meteorological Department has collected the rainfall data of additional raingauge stations maintained by IMD and States following in the Sone subzone-1(d). Central Water Commission(CWC) has also prepared the details plans of the gauged catchments showing information in section 2.2(iv). Table-1 shows the names of streams, Railway bridge numbers with Railway sections, bridge sites on behalf of Ministry of Transport their catchment areas, number of raingauge stations and the period of concurrent rainfall, gauge and discharge data, RDSO has made available the data collected to CWC and IMD for carrying out the studies.

2.4 DESCRIPTION OF THE METHOD ADOPTED

The following three main sections deal with specific studies in the report.

Section - 3 explains the procedure for obtaining the synthetic unit-graph for small and medium catchments in the Sone subzone-1(d) Design loss and base flow rate are also included in this section.

Section- 4 explains the procedure for obtaining the design storm rainfal of 50-year return period.

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

The adoption of synthetic unitgraph is recommendd for ungauged catchment to estimate the design flood.

3.0 ANALYSIS FOR OBTAINING 1-HOUR SYNTHETIC UNITGRAPH

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 homogeneous 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) Separation of base flow and computation of direct runoff.

v) Computation of infiltration loss (ϕ -index) and 1-hourly effective rainfall units.

vi) Derivation of 1-hourly unitgraphs.

vii) Drawing of representative unitgraphs and measuring the parameters.

viii) Establishing relationships between physiographic and representative unitgraph parameters.

ix) Derivation of 1-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 showing 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 upto the gauging site may be referred to as the catchment area.

3.1.2 Lengths of the Main Stream (L) and (Lc)

The L is the longest length of the main river course from the farthest watershed boundary to the point of study. Lc is the longest length of the main river course from a point opposite to the centre of gravity to the point of study.

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 drawan by trials fromthe point of interest on the L-section such that the areas enclosed between the L-section and the line so drawn (above and below) 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 formula may be used to calculate the equivalent slope (S).

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

Where L_i = Length of the ith segment in km.

D_{i-1}, D_i = Elevations of river bed at intersection points of contours reckoned from the bed elevation at point of interest considered as datum, and D(i-1) and D_i are the heights of successive bed location at contour and intersections.

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

Similarly the slope Sc for Lc may be calculated on above line. Rapids or vertical falls in the L-section shall not be considered for computation of slope.

Detailed studies were carried out for 19 gauged catchments out of which 15 catchments have been considered for the unitgraph studies. The remaining 4 catchments have been excluded due to non-availability of suitable floods for Railway Br.Nos.31 and 493 and the parameters of Rly Br.No.171 and the road bridge MOT(ii) do not fit in the regression analysis. The physiographic parameters like A,L,Lc, S and Sc for the 15 catchments are shown in Table-2.

3.2 SCRUTINY OF DATA AND FINALISATION OF GUAGE 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 1 cm.

3.4 COMPUTATION OF HOURLY CATCHMENT RAINFALL

The Theissen network was drawn for the rain gauge stations on the catchment map and then Theissen weights were computed. The hourly point rainfall at each stations was multiplied with their respective Theissen Weight and added to obtain the catchment rainfall for each 1-hour duration during the storm period.

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 event.

3.6 COMPUTATION OF INFILTRATION LOSS (Ø-index) AND 1-HOURLY EFFECTIVE RAINFALL UNITS

With the known values of 1-hourly catchment rainfall in section 3.4 and the direct runoff depth in section 3.5 for each flood event, infiltration loss (constant loss rate) by trials was estimated to obtain the direct runoff depth. The 1-hourly infiltration loss was deducted from the 1-hourly rainfall to get the 1-hourly effective rainfall units.

3.7 DERIVATION OF 1-HOUR UNITGRAPH

A unit duration of 1-hour was adopted for derivation of unitgraphs. The 1-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 hy hydrographs compared favourably. Normally 5 to 15 unitgraphs were derived for each of the 15 catchments considered.

3.8 DRAWING OF REPRESENTATIVE UNITGRAPHS AND MEASURING THEIR PARAMETERS

The representative unitgraphs 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 1-hour unitgraphs were drawn from a set of superimposed 1-hour unitgraphs for each of the 15 catchments and their parameters noted. The parameters of the representative unitgraphs illustrated in Fig.2 were measured for each of the catchments. The parameters of the representative unitgraphs are tr, tp, Tm, Q_p, q_p, W_{50}, W_{75}, WR_{50}, WR_{75} and T_B. These parameters for 15 catchments are listed in Table-3.

3.9 ESTABLISHING RELATIONSHIPS BETWEEN PHYSIOGRAPHIC AND REPRESENTATIVE UNITGRAPH PARAMETERS

Physiographic parameters like A, L, Lc, S and Sc and the parameters of 1-hour unitgraphs like tp, Q_p, T_B, W_{50}, W_{75}, WR_{50}, WR_{75} for 14 gauged catchments out of 17 catchments in subzone -(d) were estimated as shown in Tables - 2 & 3 respectively.

Following simple model was adopted for establishing the relationships between these parameters:

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

Where

Y = Dependent variable

X = Independent variable

C = A constant

P = An exponent

From equation 3.9.1, it follows that

$$\text{Log } Y = \text{Log } C + P \log X$$

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

Alternative studies were carried out for relating physiographic parameters with the corresponding parameters of the 1-hr representative unitgraphs of the 15 gauged catchments. For instance, the basin lag t_p was related to $LLc/\sqrt{S}$, $L/\sqrt{S}$, $Lc/\sqrt{S}$ and $Lc/\sqrt{Sc}$. Similarly q_p, W_{50}, W_{75}, W_{R50}, W_{R75} and T_B were related to physiographic parameters and also to other suitable unitgraph parameters.

Synthetic unitgraph relationships developed by regression analysis using least square method alongwith their coefficients of correlation (r) are listed in Annexure-1. The correlation coefficients for the relationships between tp vs. $Lc/\sqrt{S}$ and tp vs. $L/\sqrt{S}$ and tp vs. $LLc/\sqrt{S}$ are 0.934, 0.903 and 0.895 respectively as seen from Annexure-1. Out of the three relationships, the relationship for tp vs. $Lc/\sqrt{S}$ gives a highest correlation coefficients and the next higher correlation coefficient is for tp vs. $L/\sqrt{S}$. The relationship for tp vs. $L/\sqrt{S}$ is suggested because of simplicity as it excludes Lc and Sc involving the centre of gravity of the catchment. The following relationships are suggested for determining the 1-hr synthetic unitgraph parameters of ungauged catchment in Sone subzone - 1(d):

S.No.	Relationships	Eq.No.	Fig.No.	correlation Coefficient(r)
i)	$tp = 0.314(L/\sqrt{S})^{1.102}$	3.9.3	3	r = 0.903
ii)	$q_p = 1.664/(tp)^{0.965}$	3.9.4	4	r = 0.923
iii)	$W_{50} = 2.534/(q_p)^{0.976}$	3.9.5	5	r = 0.979
iv)	$W_{75} = 1.478/(q_p)^{0.860}$	3.9.6	6	r = 0.942
v)	$W_{R50} = 1.091/(q_p)^{0.750}$	3.9.7	7	r = 0.917
vi)	$W_{R75} = 0.672/(qp)^{0.719}$	3.9.8	8	r = 0.872
vii)	$T_B = 5.526\ (tp)^{0.866}$	3.9.9	9	r = 0.937

Besides the above equations, the following equations are also used to draw the synthetic unitgraph :

viii) $Tm = tp + tr/2$ 3.9.10

ix) $Q_p = q_p \times A$ 3.9.11

The above relationships may be utilised to estimate the parameters of 1-hour synthetic unitgraph for an ungauged catchment with its known physiographic characteristics like L, A and S.

3.10 DERIVATION OF 1-HOUR SYNTHETIC UNITGRAPH FOR AN UNGAUGED CATCHMENT

Considering the hydro-meteorological homogenity of subzone-1(d), the relations established between physiographic and unitgraph parameter in section 3.9 for 15 representative catchments are applicable for derivation of 1-hour synthetic unitgraph for an ungauged catchment in the same subzone.

The steps for derivation of 1-hour unitgraph are :

i) Physiographic parameters of the ungauged catchment viz. catchment area (A), L and S are determined from the catchment area plan.

ii) Substitute $\frac{\quad\quad}{\sqrt{S}}$ in the equation 3.9.3 to obtain tp in hours.

Then $Tm = tp + tr/2 = tp + \frac{1}{2}$ hours

iii) Substitute the value of tp in the equation 3.9.4 to obtain q_p in cumec /sq.km.

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

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

v) Substitute the value of tp in equation 3.9.9.

vi) Plot the parameters of 1-hr unitgraph viz. Tm, T_B, Q_p, W_{50}, W_{75}, W_{R50}, W_{R75}, on a graph paper and sketch the unitgraph through these points. The discharge ordinates(Qi) of the unitgraph at 1-hr (tr) interval are summed up and the direct runoff depth in cm. is obtained from the following equation 3.9.12.

$$d = \frac{0.36 \times \sum (Q_i \times tr)}{A} \qquad 3.9.12$$

Where d = depth of direct runoff in cm.

Q_i = discharge ordinates at 1-hour interval (cumecs)

A = Catchment area in sq.km.

LIST OF SELECTED BRIDGE CATCHMENTS IN SUBZONE 1(d)

TABLE-1

S.No.	Name of stream	Name of section bridge is located with Railway Zone/ road section	Railway bridge No./ Site No.	G.Site location Latitude Deg.Min.Sec.	Longitude Deg.Min.Sec.	Catch-ment area (Sq.Km)	No. of Rain-gauge stations	Data availability	No. of year
1	2	3	4	5	6	7	8	9	10
	Bridges considered for regression Analysis								
1.	Nalna Nadi near SONARI		MOT (I)	24-54-30	81-52-45	1040.00	8	1980-86	7
2.	Kashar Nadi	Gaya-Sone East Bank	462	24-51-00	84-31-00	516.50	5	1970-74 & 83-84	7
3.	Kudra Nala	Gaya-Mughal Sarai	611	25-01-45	83-50-30	440.30	8	1958-66	9
4.	Simrawal Nadi	Itarsi-Allahabad-C.R.	1198	24-44-12	80-51-53	340.64	11	1957-62 64-66	9
5.	Dhadhar-N	Gaya-Gomoh	345	24-36-30	85-13-40	297.85	4	1958 & 1960-66	8
6.	Paimar	Kiul-Gaya E.Rly	321	24-48-16	85-06-15	288.14	3	1960-62	5
7.	Sarpa Nadi	Anuppur-Katni S.E.	108 K	23-14-10	81-28-35	279.00	4	1965-66 1970-73	4
8.	Thams-R	Garwa-Chopan East R	184	24-11-40	83-13-30	248.00	3	1970-74	5
9.	Malia-N	Garwa-Chopan East R	155	24-14-50	83-21-30	180.00	4	1970-74	5
10.	Sadabaha	Daltonganj-Sone East Bank	240	24-09-25	84-02-40	161.7	3	1970-73	4
11.	Ghusu Nadi	Jabalpur-Allahabad-C.R.	1136	24-12-00	80-47-00	157.87	4	1972-73 75-77	5
12.	Chandas N	Katni Bilaspur	93 K	23-07-15	81.41.20	73.97	5	1961-66	6
13.	Dhamukai River	Daltonganj-Sone Bank E.	210	24-11-30	83.54.55	54.9	2	1960-66	7
14.	Badwa River	do	199	24-13-37	83-52-52	34.03	1	1960-66	7
15.	Karari-River	Itarsi-Allahabad Cent. R	724	24-26-40	80-48-45	27.51	5	1959-63	5
	Bridges not considered for Regression Analysis								
1.	Gopad	Govindgarh-Waidhon	MOT(II)	24-25-40	82-13-00	5815.00	27	1980-86	7
2.	Kowai	Anuppur-Chirimiri S.E.	31	23-13-40	82-02-00	812.00	7	1975-80	6
3.	Banki Nadi	Daltonganj-Sone East Bank	171	24-19-30	83-51-02	372.96	6	1958-67	10
4.	Adri-river	Gaya-Sone East Bank E.Rly.	493	24-51-00	84-22-00	300.43	4	1958	1

TABLE - 2

BASIN CHARACTERISTICS OF SUBZONE - 1(d)

Sl No.	Bridge No.	Area (Sq.km.)	L (km)	Lc (km)	SEQ (m/km)	$L/\sqrt{S}$
1	2	3	4	5	6	7
1.	MOT (1)	1040.00	58.57	28.96	2.38	37.97
2.	462	516.50	56.35	23.51	2.35	36.76
3.	611	440.30	42.34	25.24	0.80	47.34
4.	1198	340.64	34.94	18.35	3.70	18.16
5.	345	297.85	36.55	18.84	4.20	17.83
6.	921	288.14	49.91	23.34	1.70	38.28
7.	108 K	279.00	35.88	17.30	4.60	16.73
8.	184	248.00	34.75	18.50	3.703	18.06
9.	155	180.00	24.15	8.05	2.93	14.11
10.	240	161.70	32.98	10.06	5.105	14.60
11.	1136	157.86	34.10	19.70	4.42	16.22
12.	93K	73.97	14.97	7.89	7.62	5.42
13.	210	27.51	12.56	8.04	6.15	5.06
14.	799	34.03	15.30	7.65	5.52	6.51
15.	724	27.51	16.10	8.53	5.00	7.20

REPRESENTATIVE 1-HR. UNIT GRAPH PARAMETERS

SUB ZONE-1d

TABLE-3

SL.No.	BR.NO.	t_1 tp (HRS)	Qp (CUMECS)	qp (CUMECS/ Sq.KM)	tr (HRS)	T_B (HRS)	W_{50} (HRS)	W_{75} (HRS)	WR_{50} (HRS)	WR_{75} (HRS)
1	2	3	4	5	6	7	8	9	10	11
1.	MOT (1) (Sonauri)	13.5	140.0	0.135	1	50	18.80	9.5	4.70	2.40
2.	462	15.5	63.00	0.12	1	66.0	18.80	6.00	3.40	1.80
3.	611	21.5	24.90	0.056	1	112	44.00	21.50	11.00	6.50
4.	1198	5.5	110.00	0.323	1	23.0	7.20	3.60	1.70	1.00
5.	345	4.5	144.60	0.48	1	13.0	5.20	2.50	2.60	1.40
6.	321	7.5	40.00	0.14	1	50.0	17.20	8.70	4.90	3.50
7.	108 k	5.5	150.70	0.54	1	19.0	3.80	2.00	1.50	0.70
8.	184	5.5	108.63	0.44	1	19.0	5.40	2.80	2.10	1.20
9.	155	6.5	66.70	0.37	1	26.0	5.90	3.00	2.90	1.60
10.	240	2.5	90.00	0.56	1	15.0	4.10	2.70	1.60	1.30
11.	1136	8.5	45.2	0.286	1	23.0	9.00	4.00	4.20	2.00
12.	93 K	1.5	60.12	0.81	1	9.0	3.15	2.00	1.20	0.90
13.	210	2.5	39.00	0.71	1	13.0	6.20	4.0	2.22	1.66
14.	199	2.5	14.50	0.43	1	15.0	5.95	3.30	1.75	1.30
15.	724	1.5	40.22	1.46	1	8.0	1.50	0.80	0.60	0.30

TABLE-4

LOSS RATE RANGES (MM/HR) - NUMBER OF FLOOD OCCASIONS

SUBZONE - 1d

Sl.No.	Br. No.	Catchment Area (Sq.km.)	LOSS RATE RANGES (mm/hr) NUMBER OF FLOOD OCCASIONS 0.01 to 5.0	5.1 to 10.0	10.1 to 15.0	15.1 to 20.0	20.1 to 25.0	25.0 to 30.0	30.1 to 35.0	35.0 & Above	
1	2	3	4	5	6	7	8	9	10	11	12
1.	MOT(I)	1040	4	-	-	-	-	-	-	-	4
2.	462	516.50	5	-	-	-	-	-	-	-	5
3.	611	440.30	2	3	-	-	-	-	-	-	5
4.	1198	340.64	12	4	-	1	-	-	-	-	17
5.	345	297.85	3	2	-	-	-	-	-	-	5
6.	321	288.14	5	2	-	1	-	-	-	-	8
7.	108K	279.00	10	4	-	2	3	-	-	-	19
8.	184	248.00	1	-	3	2	-	-	-	-	6
9.	155	180.00	5	3	-	-	-	-	-	-	8
10.	240	161.70	2	-	-	-	-	-	-	-	2
11.	1136	157.86	6	1	-	-	-	-	-	-	7
12.	93K	73.97	10	5	4	-	-	-	-	-	19
13.	210	54.90	2	2	3	1	-	-	-	-	8
14.	199	34.03	2	-	-	1	-	-	-	-	3
15.	724	27.51	2	7	1	4	-	-	-	-	14
		Total	75	33	11	12	3	-	-	-	134

BASE FLOW RANGES-NUMBER OF FLOOD OCCASIONS
SUB ZONE - 1d

TABLE-5

Sl.No.	Br.No.	BASE FLOW RANGES (CUMECS PER SQUARE KILOMETER)						
		0 to 0.001	0.001 to 0.005	0.005 to 0.009	0.01 to 0.09	0.10 to 0.19	0.20& above	Total
		NUMBER OF FLOOD EVENTS						
1	2	3	4	5	6	7	8	9
1.	MOT(I)	-	2	1	1	-	-	4
2.	462	1	-	1	3	-	-	5
3.	611	-	-	2	3	-	-	5
4.	1198	-	2	4	9	2	-	17
5.	345	-	-	-	3	2	-	5
6.	321	1	-	-	7	-	-	8
7.	108 K	-	2	1	16	-	-	19
8.	184	-	3	1	2	-	-	6
9.	155	-	-	-	4	4	-	8
10.	240	-	-	-	2	-	-	2
11.	1136	-	-	-	4	2	1	7
12.	93 K	-	2	-	16	1	-	19
13.	210	-	-	1	7	-	-	8
14.	199	-	-	-	2	1	-	3
15.	724	-	-	-	10	4	-	14
	TOTAL	2	11	11	93	16	1	134

Annexure-1

LIST OF PHYSICAL AND UNIT HYDROGRAPH PARAMETERS STUDIED TO ESTABLISH RELATIONSHIPS WITH THEIR COEFFICIENTS OF CORRELATION

SUBZONE - 1(d)

Sl. No.	Independent variables Physiographic Parameters/unit graph parameters	Dependent Variables Unit graph			Coefficient of correlation
		Constant	Parameter	Exponent	
1	2	3	4	5	6
1	$L/\sqrt{S}$	0.314	tp	1.012	0.903
2	$L/\sqrt{S}$	5.737	qp	-1.020	0.870
3	$L/\sqrt{S}$	0.562	W_{50}	0.924	0.791
4	$L/\sqrt{S}$	0.437	W_{75}	0.775	0.724
5	$L/\sqrt{S}$	0.332	W_{R50}	0.721	0.752
6	$L/\sqrt{S}$	0.258	W_{R75}	0.626	0.648
7	$L/\sqrt{S}$	1.813	TB	0.917	0.885
8	$LLc/\sqrt{S}$	0.183	tp	0.612	0.895
9	$LLc/\sqrt{S}$	9.203	qp	-0.604	0.845
10	$LLc/\sqrt{S}$	0.355	W_{50}	0.553	0.775
11	$LLc/\sqrt{S}$	0.302	W_{75}	0.461	0.706
12	$LLc/\sqrt{S}$	0.234	WR_{50}	0.430	0.735
13	$LLc/\sqrt{S}$	0.199	WR_{75}	0.365	0.619
14	$LLc/\sqrt{S}$	1.240	TB	0.534	0.846
15	$Lc/\sqrt{S}$	0.634	tp	1.023	0.911
16	$Lc/\sqrt{S}$	2.825	qp	-1.031	0.878
17	$Lc/\sqrt{S}$	0.994	W_{50}	0.969	0.827
18	$Lc/\sqrt{S}$	0.694	W_{75}	0.820	0.764
19	$Lc/\sqrt{S}$	0.520	WR_{50}	0.755	0.786
20	$Lc/\sqrt{S}$	0.386	WR_{75}	0.648	0.669
21	$Lc/\sqrt{S}$	3.550	TB	0.910	0.876
22	tp	1.664	qp	-0.965	0.923
23	qp	2.534	W_{50}	-0.976	0.979
24	qp	1.478	W_{75}	-0.860	0.942
25	qp	1.091	WR_{50}	-0.750	0.917
26	qp	0.672	WR_{75}	-0.719	0.872
27	tp	5.526	TB	0.866	0.937

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 effective rainfall 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 (T_D). Alternative studies were carried out assuming $T_D = 1.1\ t_p$ and $T_D = T_B$ for estimating 25-yr, 50-yr and 100-yr flood for 15 catchments by synthetic unit hydrograph relations with loss rates of 0.25 cm/hr and 0.5 cm/hr. A comparison of the 25-yr flood, 50-yr flood and 100-yr flood with $T_D = 1.1\ t_p$ and $T_D = T_B$ showed that in 60 to 75% of the cases $T_D = 1.1\ t_p$ gives higher discharge. Therefore, the design storm duration (T_D) for a catchment is adopted = 1.1 t_p.

$$T_D = 1.1\ t_p$$

$$T_D = 0.345\ (L/\sqrt{S})^{1.012}$$

4.2 RAINFALL DEPTH DURATION FREQUENCY STUDIES

India Meteorological Department have conducted this study for Sone subzone - 1(d) utilizing the data of 14 self Recording Raingauge stations and 22 ordinary raingauge stations maintained departmentally. 112 Ordinary Raingauge Stations belonging to Bihar, Madhya Pradesh and Uttar Pradesh States and 26 self recording raingauge stations maintained by Railways in their 8 bridge catchments falling in subzone-1(d).

The annual maximum series of one-day rainfall were formed for each of 134 ordinary raingauge stations in and around the subzone using the rainfall records of 50 to 80 years. The annual extreme value series were subjected to frequency analysis by Gumbel's extreme values distributions and the rainfall estimates for one-day corresponding to 25, 50 and 100 years return period were computed. The daily values of 25-yr, 50-yr and 100-yr rainfall estimates were converted into 24-hr rainfall estimates of corresponding return periods by using the conversion factor of 1.15. These 24-hour rainfall estimates for all the stations in and around the subzone were plotted on base maps and isopluvial maps of 25-yr, 50-yr and 100-yr return period were drawn. These maps are shown in Plates 9 and 10.

The hourly rainfall data recorded at 14 self recording raingauge stations maintained by India Meteorological Department were analysed by frequency analysis (partial duration series) method and the rainfall estimates for various return periods (viz. 2,5,10,25,50 and 100 years) were computed for duration 1,3,6,9,12,15,18 and 24 hours. The rainfall estimates corresponding to durations from 1 to 18 hours for each of the 14 stations were converted into ratios with respect to 24 hours estimates for each of the above mentioned return periods. Average ratios for various durations for each return period were computed for the whole subzone. It was noticed that for a specified durations the average ratios, except for return period less than 5-year were independent of return period. The averaged ratios for various durations for converting 24-hour rainfall into short duration rainfall are given below:

Duration (hrs)	Ratio
1	0.37
3	0.58
6	0.70
9	0.80
12	0.89
15	0.94
18	0.98
24	1.00

$$\text{Ratio} = \frac{\text{50-yr T-hr point rainfall}}{\text{50-yr 24-hr point rainfall}}$$

Fig. 10 shows the ratios for short duration point rainfall with respect to 24-hr. 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 stations for 25-yr, 50-yr and 100-yr return periods can be interpolated from Plates - 9, 10 & 11 and the short duration rainfall estimates can be obtained by multiplying with the corresponding ratio for that particular short duration obtained from Fig.10.

Statement of highest ever recorded daily rainfall at selected stations in the subzone is at Annexure-II.

4.3 CONVERSION OF POINT TO AREAL RAINFALL

The short duration rainfall data of 8 bridge catchments were used for this study. The data of remaining bridge catchments could not be utilised as the period of data were either less than 4 years and/or concurrent years data were not recorded continuously for 4 years over the stations in a bridge catchment. 2-yr point rainfall values for specified duration for each station in the catchments were computed by frequency analysis. Arithematic 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 occurrence of rainfall at each stations in the catchment. The areal rainfall series thus obtained was subjected to frequency analysis of 2-yr areal rainfall depths for specified duration were computed. The percentage ratio of 2-yr areal rainfall to 2-yr 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 the catchments. Fig.11(a) and 11(b) give the curves for conversion of point rainfall into areal rainfall for 1,3,6,12 and 24 hrs. The areal reduction factor (ARF) at different intervals of catchment areas for the above durations are given in Table-6.

Data for bridge catchment is available only upto 800 sq.km. and point to areal curves have been extrapolated upto 2500 sq.km. on the basis of limited ARF's obtained from bridges having area less than 800 sq.km. Point to areal rainfall values may, therefore, be used with caution for areas more than 800 sq.km.

4.4 TIME DISTRIBUTION OF INPUT STORMS

The time distribution studies have been carried out for the following rainfall durations:

1) Rain storm of 2 to 3 hours

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

1994 rain storms of various durations upto 24 hours occurring in various parts of the subzone were analysed based on 147 stations year data. Rain storms selected at each station were grouped under the above 5 categories and plotted on different graphs as dimensionless curves with cumulative percentage of the total rainfall along the abscissa. Thus, five different graphs were prepared for each station corresponding to various durations, and were then examined. The average time distribution curves for the various durations were drawn for each station. All the average curves for the stations thus obtained were plotted on a single graph and a single average curve for the subzone as a whole was drawn for storms of different durations and are shown in Fig. 12(a) to (e).

4.5 PROCEDURE FOR ESTIMATION OF 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 rainfall of a specified duration:

<u>Step-1</u>: Estimate $T_D = 1.1\ t_p = 0.345(L/\sqrt{S})^{1.012}$ (rounded off the nearest full hour) by substituting the known values of L and S for the catchment under study.

Step - 2: Locate bridge catchment area under study on the 50-yr, 24-hour isopluvial map (plate-10) and obtain the 50-yr 24-hour point rainfall value in cms. For catchment covering more than one isohyet, compute the average point storm rainfall.

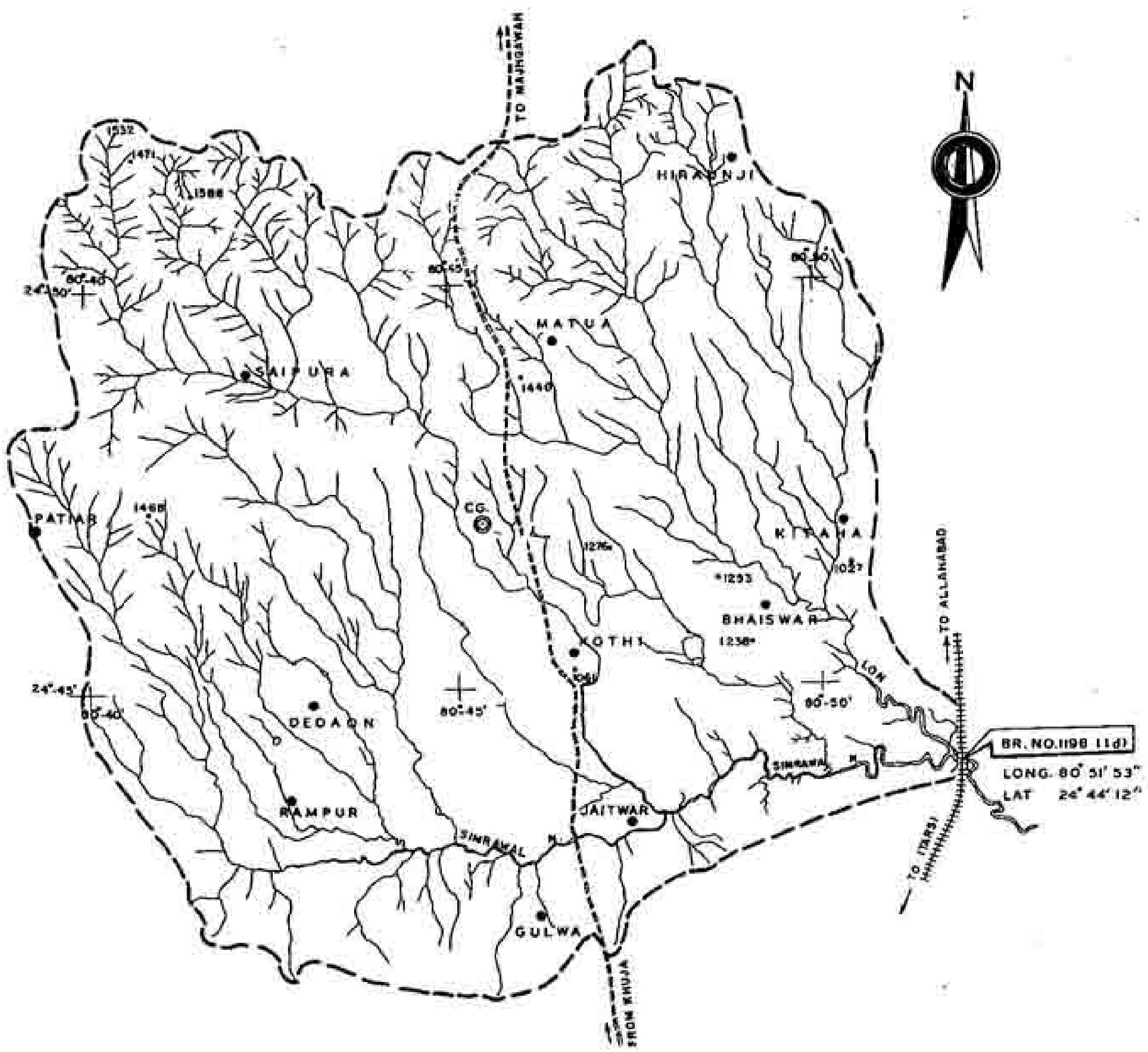
Step-3 : Read the conversion ratio for T_D hours from Fig. 10 and multiply the 50-yr 24-hr rainfall in Step-2 by the ratio to obtain 50-yr T_D-hr point rainfall.

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 and for T_D -hr duration from Table-4 or by interpolation from Fig.11(a) and 11(b) in section 4.3.

Step - 5: Apply the cumulative percentage of total rainfall against the cumulative percentage of storm duration curves in Fig. 12(a) to (e) or from Table A-2 corresponding to design storm duration T_D to obtain the depths at 1-hr interval since the unit duration of synthetic U.G. is 1-hour.

Step - 6: Obtain the 1-hourly rainfall increments from subtraction of successive 1-hour cumulative values of rainfall in step-5.

FIG. A-1



NOTES

1 ALL LEVELS CORRESPOND TO G.T.S. DATUM

REFERENCES

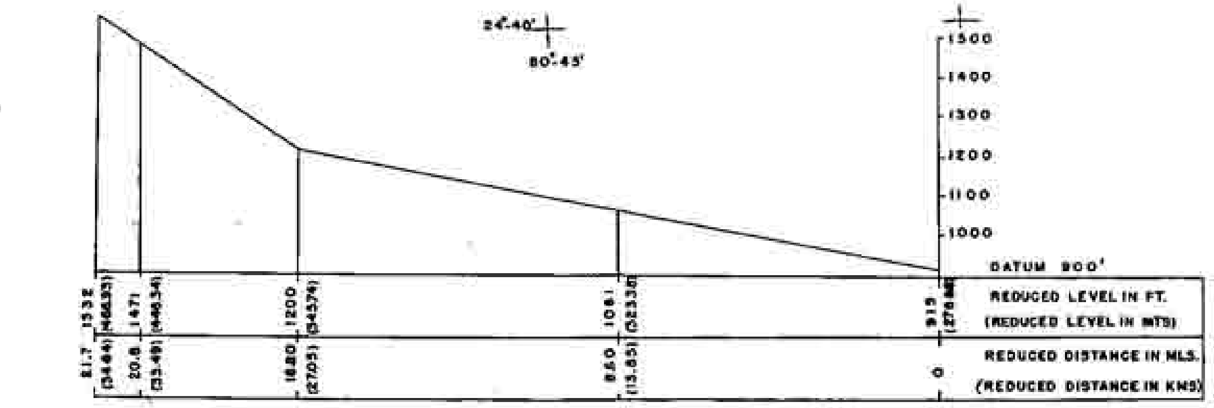
1 CATCHMENT BOUNDARY
2 RAILWAY LINE
3 RIVER AND ITS TRIBUTARIES
4 RAINGAUGE STATIONS
5 SPOT LEVELS ---- • 1238
6 ROADS
7 CENTRE OF GRAVITY
8 TOPO SHEETS (1" = 1 MILE) NO. 63 D/9, 10, 13, AND 14 (1952 EDITION)

DETAILS OF CATCHMENT AREA

1 CATCHMENT AREA ---- 340.64 Sq. km.
2 SHAPE OF THE CATCHMENT AREA ---- FAN
3 TOTAL LENGTH OF MAIN RIVER & ITS TRIBUTARIES -- 483 Km.
4 L ---- 34.94 Km.
5 Lc ---- 18.35 Km.
6 Wc ---- 19.32 Km.
7 D ---- 1.42 Km/Sq.Km.
8 Sst ---- 4.08 mt/km.
9 Seq. ---- 3.70 mt/km.
10 ORDINARY SLOPE ---- 5.38 mt/km.
11 FORM FACTOR $\frac{A}{L_B^2} = \frac{340.64}{(24.63)^2} = 0.56$

S	NAME OF R.G. STATION	LOCATION		STATION WTS				
		LONG. DEG. MIN. SEC.	LAT DEG. MIN. SEC.	1958	59	60	61-62	1965
1	PATIAR	80 39 22	24 47 15	–	0.197	0.197	0.197	–
2	SAIPURA	80 42 20	24 49 00	0.241	–	–	–	–
3	RAMPUR	80 42 45	24 43 45	0.168	–	–	–	–
4	DEDAON	80 43 00	24 44 35	–	0.251	0.269	0.251	0.435
5	HIRAUNJI	80 48 55	24 51 45	–	0.194	0.247	0.194	0.207
6	MATUA	80 46 22	24 49 20	0.173	–	–	–	–
7	GULWA	80 46 20	24 42 24	–	0.077	0.077	0.077	0.077
8	KOTHI	80 46 36	24 45 30	0.175	–	–	–	–
9	JAITWAR	80 47 28	24 43 26	0.120	0.087	0.210	0.087	0.087
10	KITAHA	80 50 20	24 47 00	0.123	–	–	–	–
11	BHAISWAR	80 49 16	24 46 00	–	0.194	–	0.194	0.194
			TOTAL	1.000	1.000	1.000	1.000	1.000

SCALE
FURLONGS 8 6 4 2 0 1 2 MILES



LONGITUDINAL SECTION OF SIMRAWAL RIVER

SCALE

FURLONGS 8 4 0 1 2 3 4 5 6 7 8 9 MILES
HORIZONTAL

FEET 200 100 0 200 400 600 800 FEET
VERTICAL

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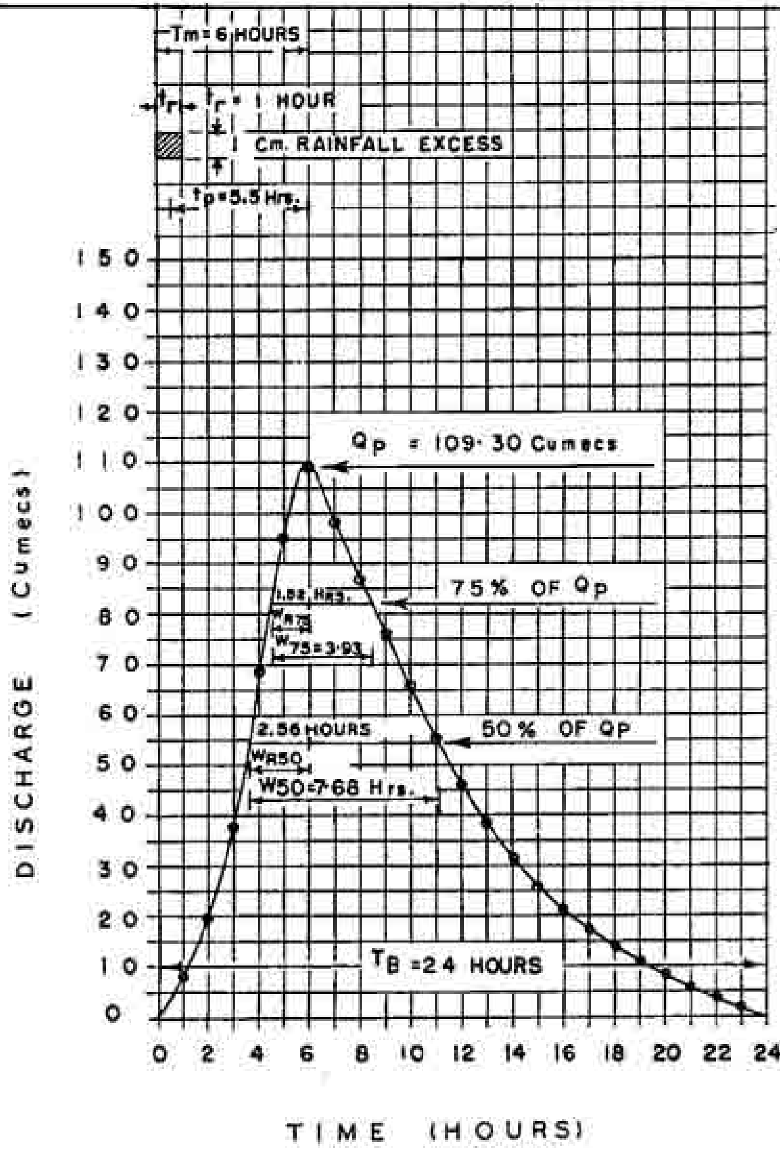
CATCHMENT AREA PLAN
FOR BR. NO. 1198 AT KM. 744/14-15
ON ITARSI - ALLAHABAD SECTION
CENTRAL RLY. SUB ZONE 1(d)

DRAWN BY:-	CHECKED BY:-
P. N. BHALLA S. H. MALHOTRA	A. K. GHOSH

FIG.- A - 2



SYNTHETIC U.G PARAMETER

C.A = 340·64 Sq. Kms.

t_p = 5.50 HOURS

T_B = 24·00 HOURS

Q_p = 109·30 CUMECS

W_{50} = 7·68 HOURS

W_{75} = 3.93 HOURS

W_{R50} = 2·56 HOURS

W_{R75} = 1.52 HOURS

q_p = 0·321 M^3/ Sq. Km.

T_m = 6.00 HOURS

$\frac{L}{\sqrt{S}}$ = 18.16

d = 1·00 Cm.

$$\Sigma Q_i = \frac{A \times d}{t_r \times 0.36}$$

$$= \frac{340{\cdot}64 \times 1{\cdot}00}{1{\cdot}00 \times 0{\cdot}36}$$

= 946·20 CUMECS

TIME IN HOURS	1-HOUR SYNTHETIC U.G ORDINATES (Cumecs)
0	0
1	8.00
2	19.50
3	37·50
4	68.60
5	95.00
6	109.30
7	98.00
8	86.50
9	76.00
10	66.00
11	55.00
12	46.00
13	38.50
14	31.60
15	26.10
16	21.50
17	17.30
18	14·00
19	11.00
20	8.60
21	6.20
22	4.00
23	2.00
24	0
	TOTAL 946.20 Cumecs

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SONE

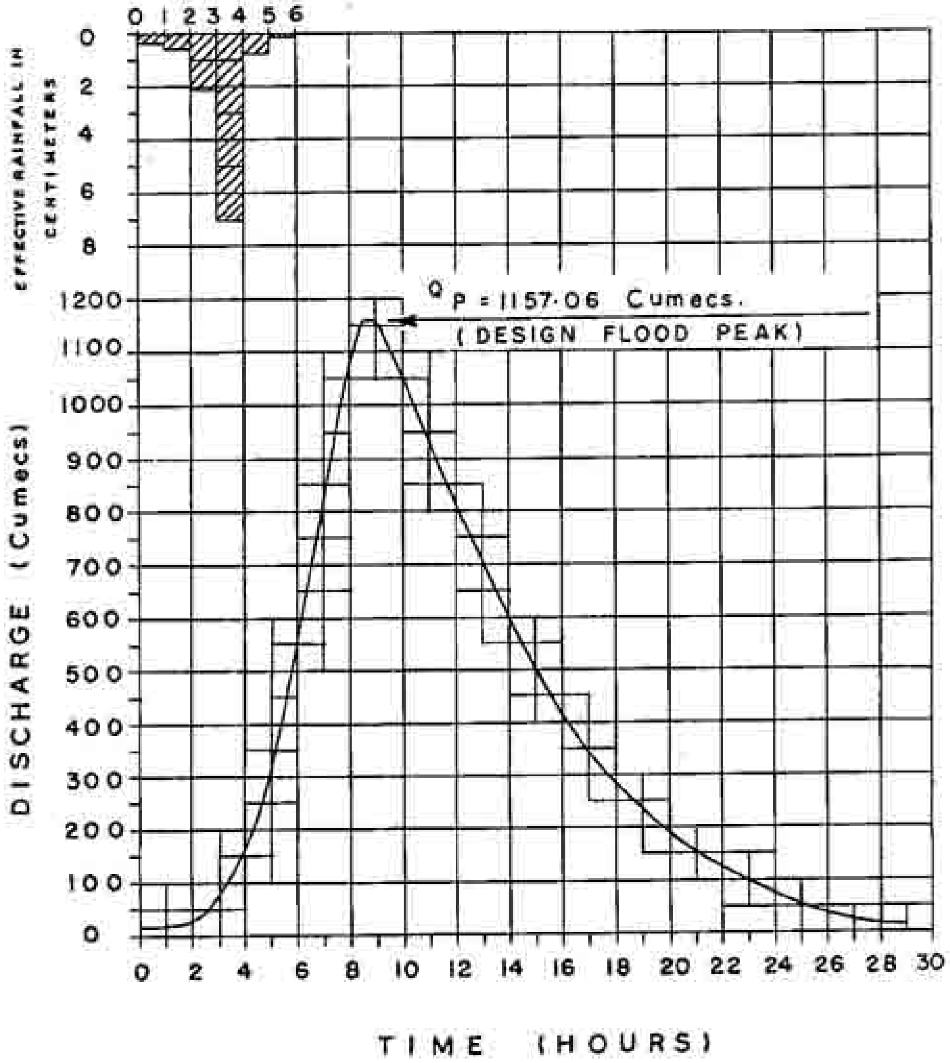
SUB ZONE 1 (d)

SYNTHETIC UNIT HYDROGRAPH

BRIDGE NO.- 1198

DRAWN BY_	CHECKED BY_
S.N. MALHOTRA L.P. NAUTIYAL	A. K. GHOSH

FIG.- A-3



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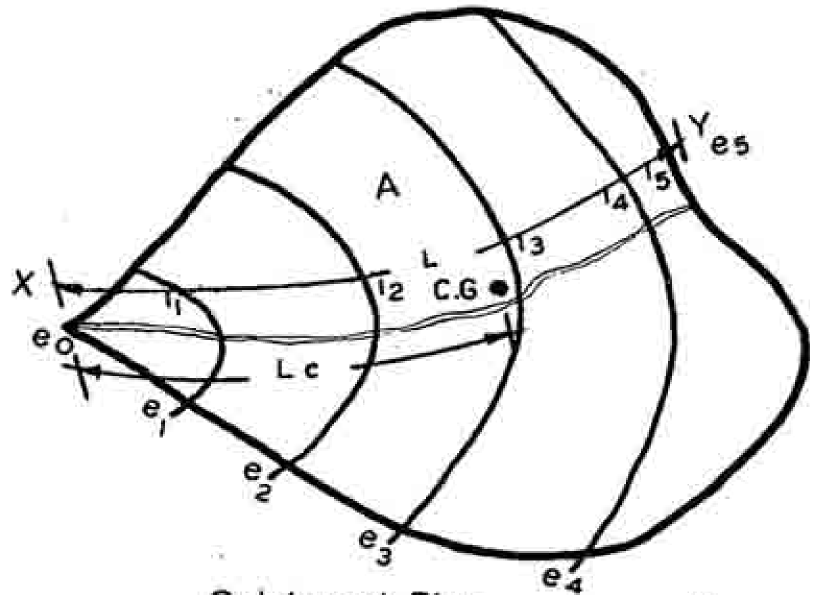
SONE

SUB ZONE I (d)

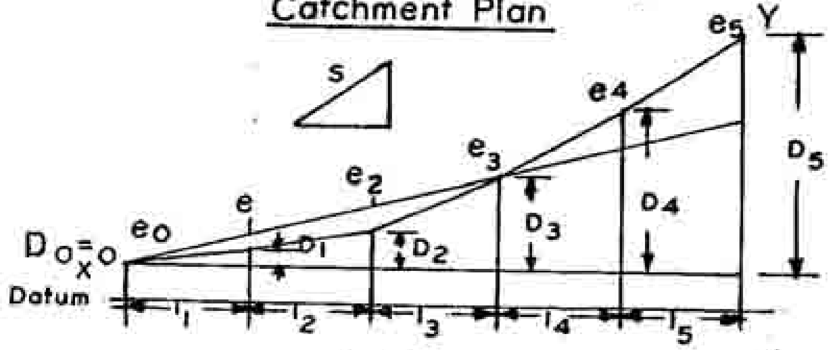
DESIGN FLOOD HYDROGRAPH
BR.NO.-1198 ON RIVER SIMRAWAL

DRAWN BY—	CHECKED BY—
S. N. MALHOTRA L. P. NAUTIYAL	A. K. GHOSH

FIG. I



Catchment Plan



L-Section

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

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)

$e_i = e_1, e_2, \ldots\ldots e_n$ = contour elevation (m)

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

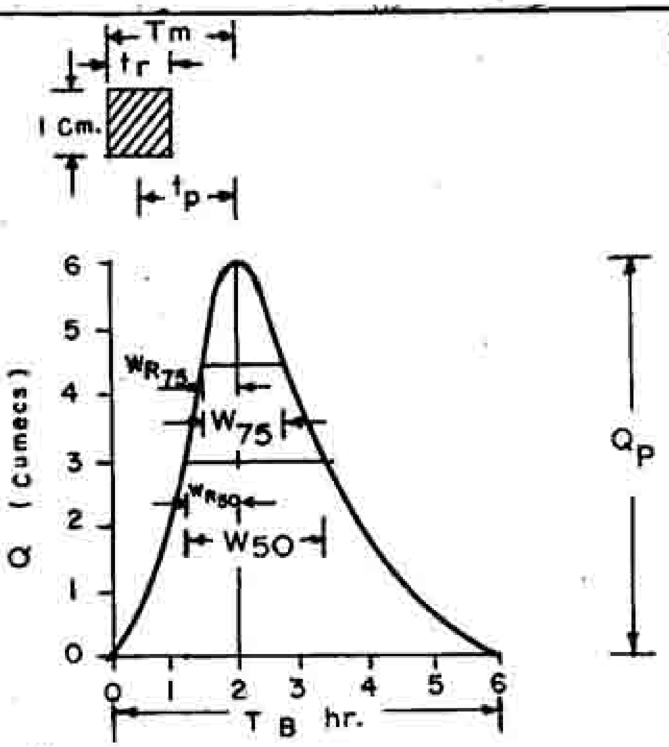
$= (e_0 - e_0), (e_1 - e_0), (e_2 - e_0) \cdots (e_n - e_0)$ (m)

A = Catchment area (km^2)

L_c = Length of longest stream course from a point opposit the centre of gravity of the catchment to the point of study (Km.)

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (SMALL CATCHMENTS) DTE.	
PHYSIOGRAPHIC PARAMETERS	
DRAWN R.N. SHARMA	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 Effective Rainfall duration to the U.G Peak (hr.)

W_{50} = Width of the U.G measured at the 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.)

TB = Base width of Unit Hydrograph (hr.)

A = Catchment Area (Sq.km.)

q_p = Q_p/A = Cumec per sq.km.

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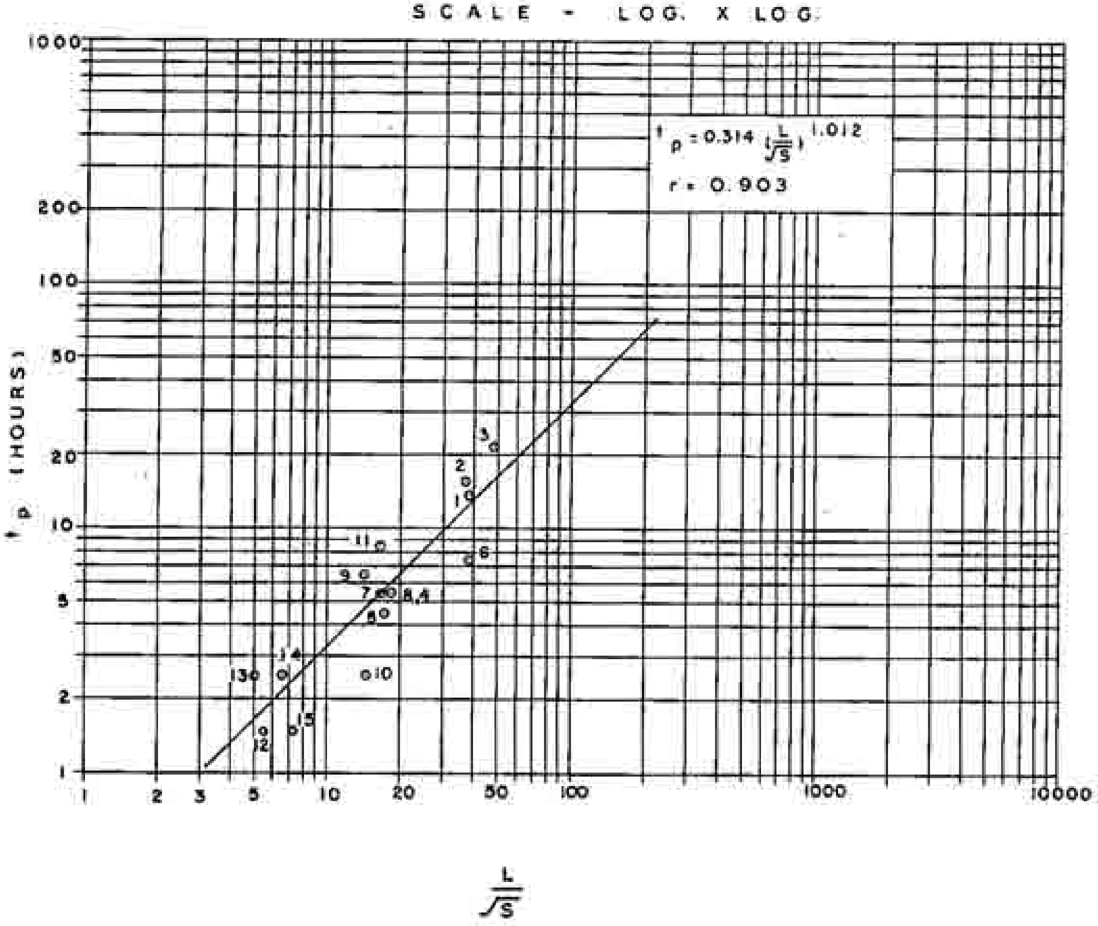
UNIT GRAPH PARAMETERS	
DRAWN BY– BHATIA, NAUTIYAL	CHECKED BY– A. K. GHOSH

FIG.- 3



SL. NO.	BR. NO.	$\frac{L}{\sqrt{S}}$	t_p (HOURS)
1	MOT-1	37.97	13.50
2	462	36.76	15.50
3	611	47.34	21.50
4	1198	18.16	5.50
5	345	17.83	4.50
6	321	38.28	7.50
7	108 K	16.73	5.50
8	184	18.06	5.50
9	155	14.11	6.50
10	240	14.60	2.50
11	1136	16.22	8.50
12	93 K	5.42	1.50
13	210	5.06	2.50
14	199	6.51	2.50
15	724	7.20	1.50

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SONE

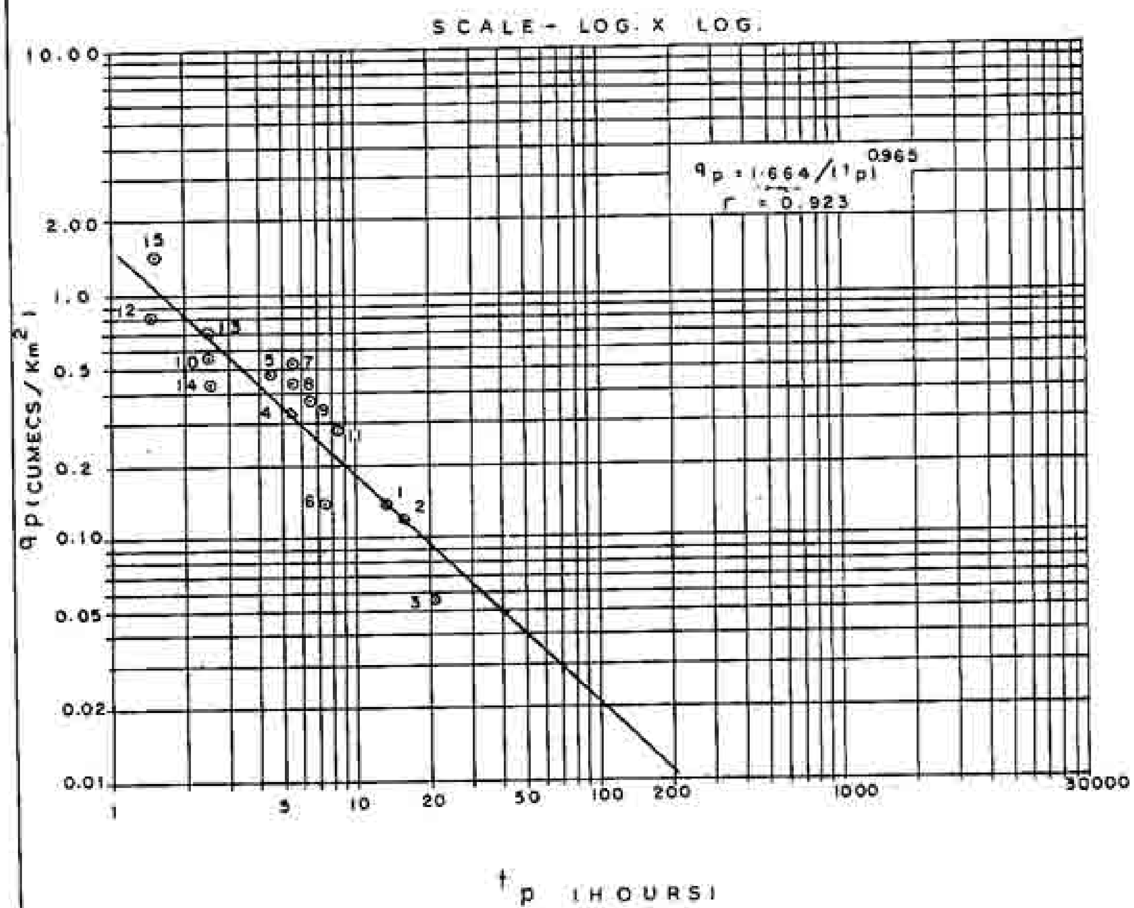
SUB ZONE 1(d)

RELATION BETWEEN t_p AND $L/\sqrt{S}$

DRAWN BY– S.N MALHOTRA, L.P. NAUTIYAL

CHECKED BY– K. K. AICH.

FIG. — 4



Sl. No.	BR.NO.	t_p (HOURS)	q_p Cumecs/Km²
1	MOT-1	13.50	0.135
2	462	15.50	0.120
3	611	21.50	0.056
4	1198	5.50	0.323
5	345	4.50	0.480
6	321	7.50	0.140
7	108K	5.50	0.540
8	184	5.50	0.440
9	155	6.50	0.370
10	240	2.50	0.560
11	1136	8.50	0.286
12	93K	1.50	0.810
13	210	2.50	0.710
14	199	2.50	0.430
15	724	1.50	1.460

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HYDROLOGY (SMALL CATCHMENTS) DTE.

SONE

SUB ZONE 1 (d)

RELATION BETWEEN q_p AND t_p

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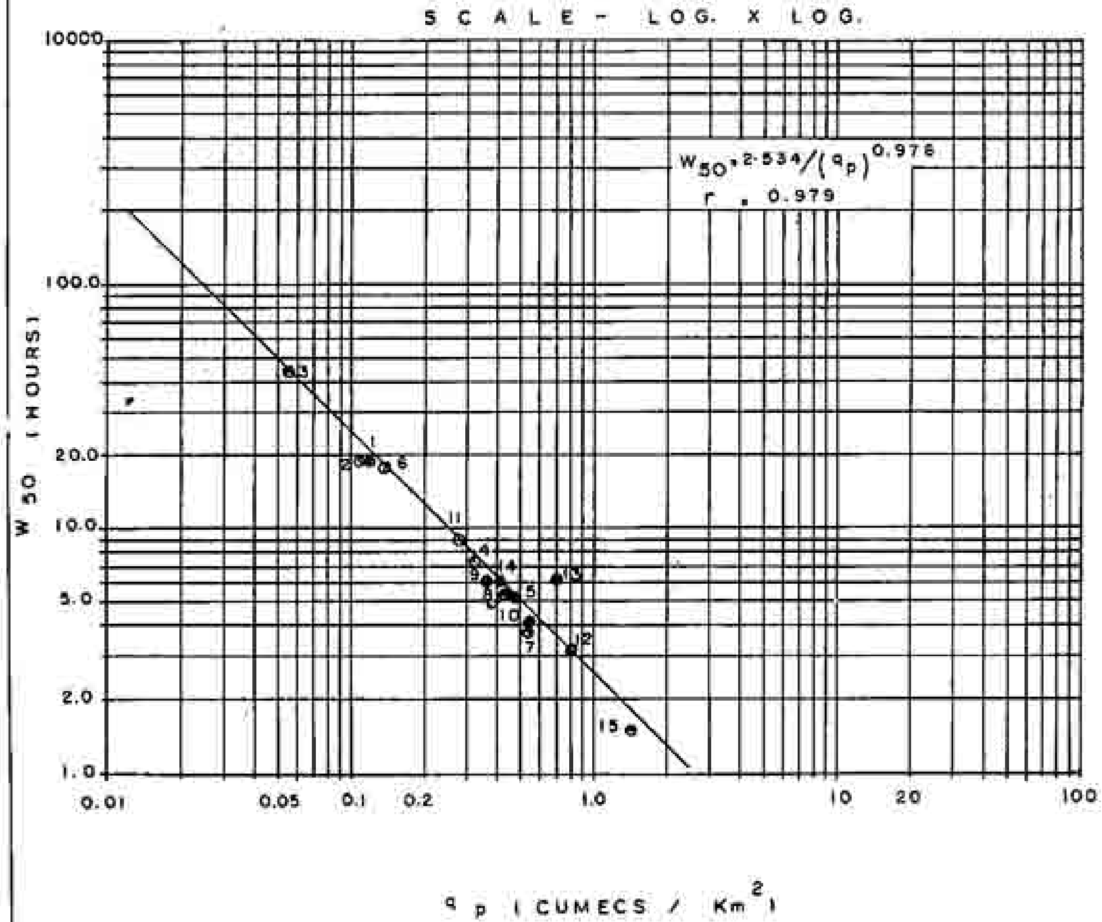
T. R. ARORA, P. N. BHALLA.	K. K. AICH

FIG. - 5



SL. NO.	BR. NO.	q_p (CUMECS/ Km^2)	W_{50} (HOURS)
1	MOT-1	0.135	18.80
2	462	0.120	18.80
3	611	0.056	44.00
4	1198	0.323	7.20
5	345	0.480	5.20
6	321	0.140	17.20
7	108 K	0.540	3.80
8	184	0.440	5.40
9	155	0.370	5.90
10	240	0.560	4.10
11	1136	0.286	9.00
12	93 K	0.810	3.15
13	210	0.710	6.20
14	199	0.430	5.95
15	724	1.400	1.50

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HYDROLOGY (SMALL CATCHMENTS) DTE.

SONE
SUB ZONE 1 (d)
RELATION BETWEEN W_{50} AND q_p

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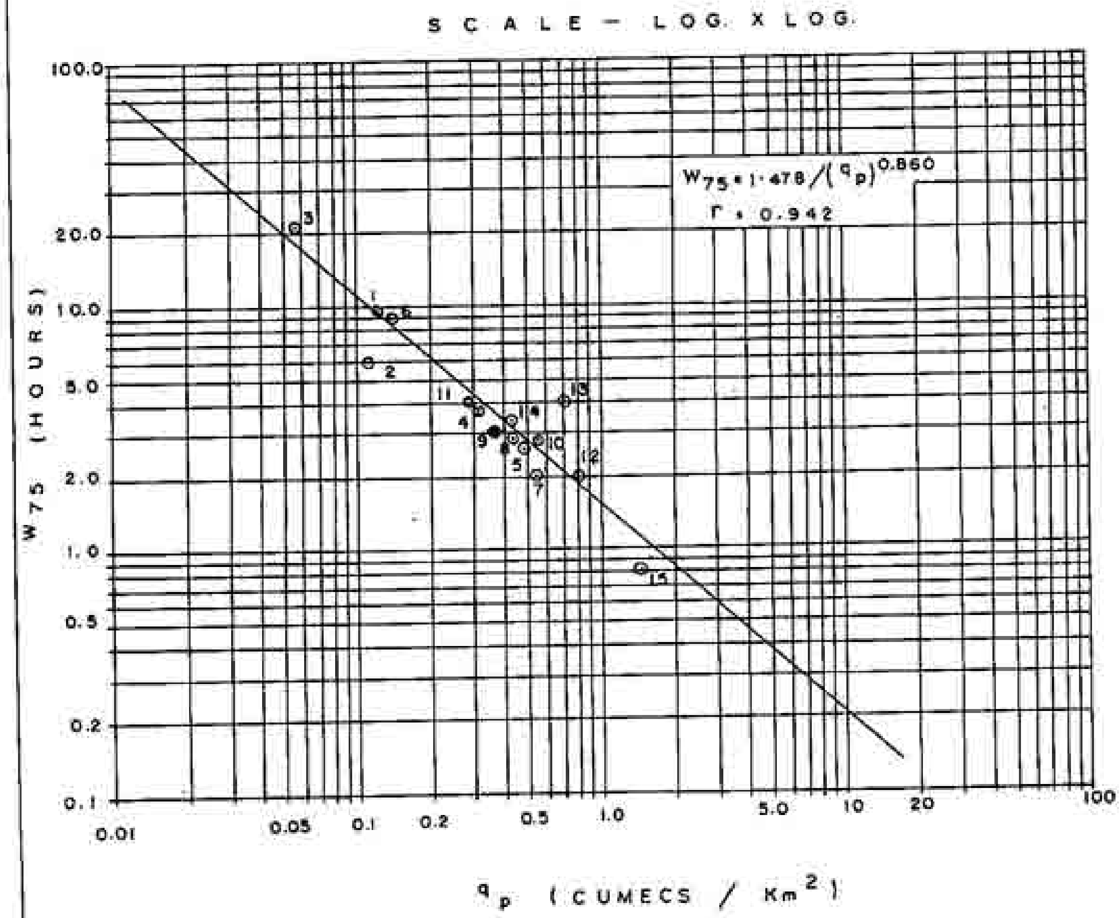
CHECKED BY. A. K. GHOSH

FIG. - 6



SL. NO.	BR.NO.	q_p (CUMECS/ Km^2)	W75 (HOURS)
1	MOT-1	0.135	9.50
2	462	0.120	6.00
3	611	0.056	21.50
4	1198	0.323	3.60
5	345	0.480	2.50
6	321	0.140	8.70
7	108K	0.540	2.00
8	184	0.440	2.80
9	155	0.370	3.00
10	240	0.560	2.70
11	1136	0.286	4.00
12	93K	0.810	2.00
13	210	0.710	4.00
14	199	0.430	3.30
15	724	1.460	0.80

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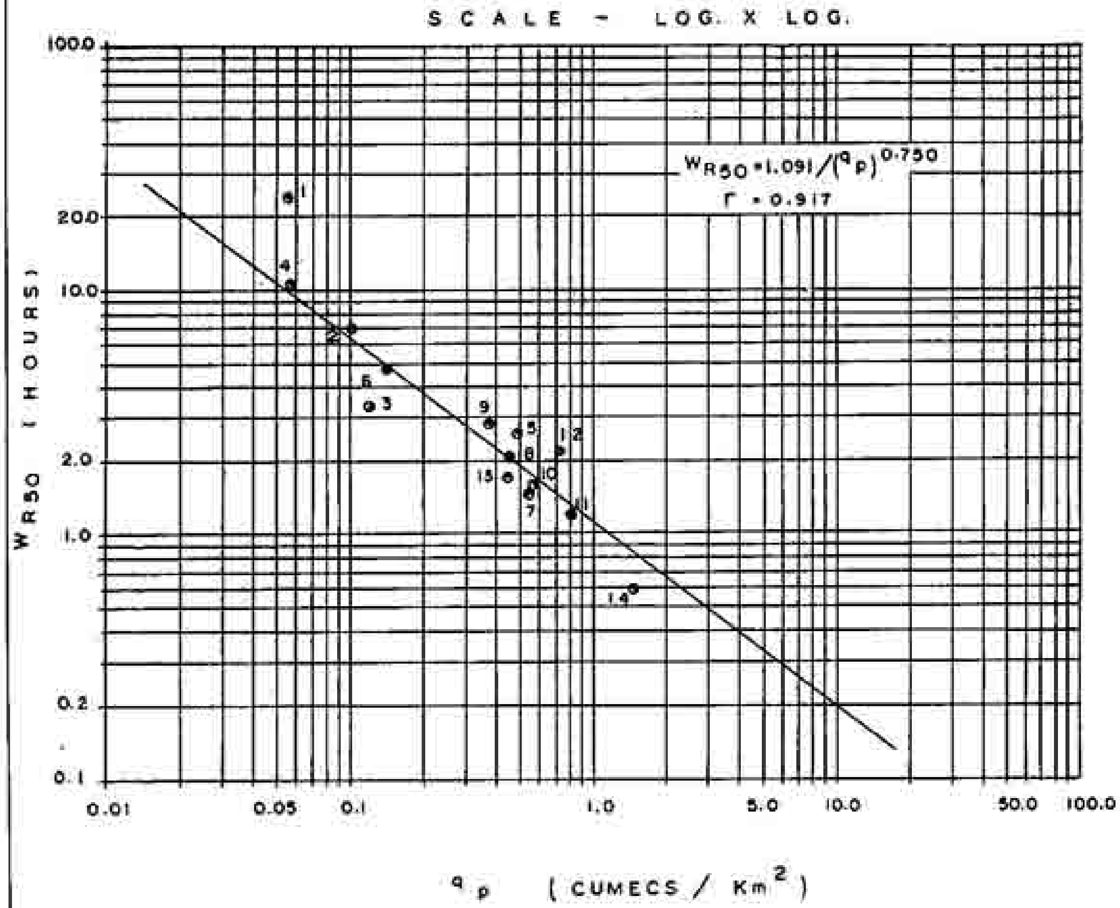
SONE
SUB ZONE 1(d)
RELATION BETWEEN W_{75} AND q_p

DRAWN BY.	CHECKED BY.
T. R. ARORA L. P. NAUTIYAL	A. K. GHOSH

FIG. - 7



SI. NO.	BR. NO.	q_p (CUMECS/ Km^2)	W_{R50} (HOURS)
1	MOT-1	0.135	4.70
2	462	0.120	3.40
3	611	0.056	11.00
4	1198	0.323	1.70
5	345	0.460	2.60
6	321	0.140	4.90
7	108K	0.540	1.50
8	184	0.440	2.10
9	155	0.370	2.90
10	240	0.560	1.60
11	1156	0.286	4.20
12	93K	0.810	1.20
13	210	0.710	2.22
14	199	0.430	1.75
15	724	1.460	0.60

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SONE

SUB ZONE 1(d)

RELATION BETWEEN W_{R50} AND q_p

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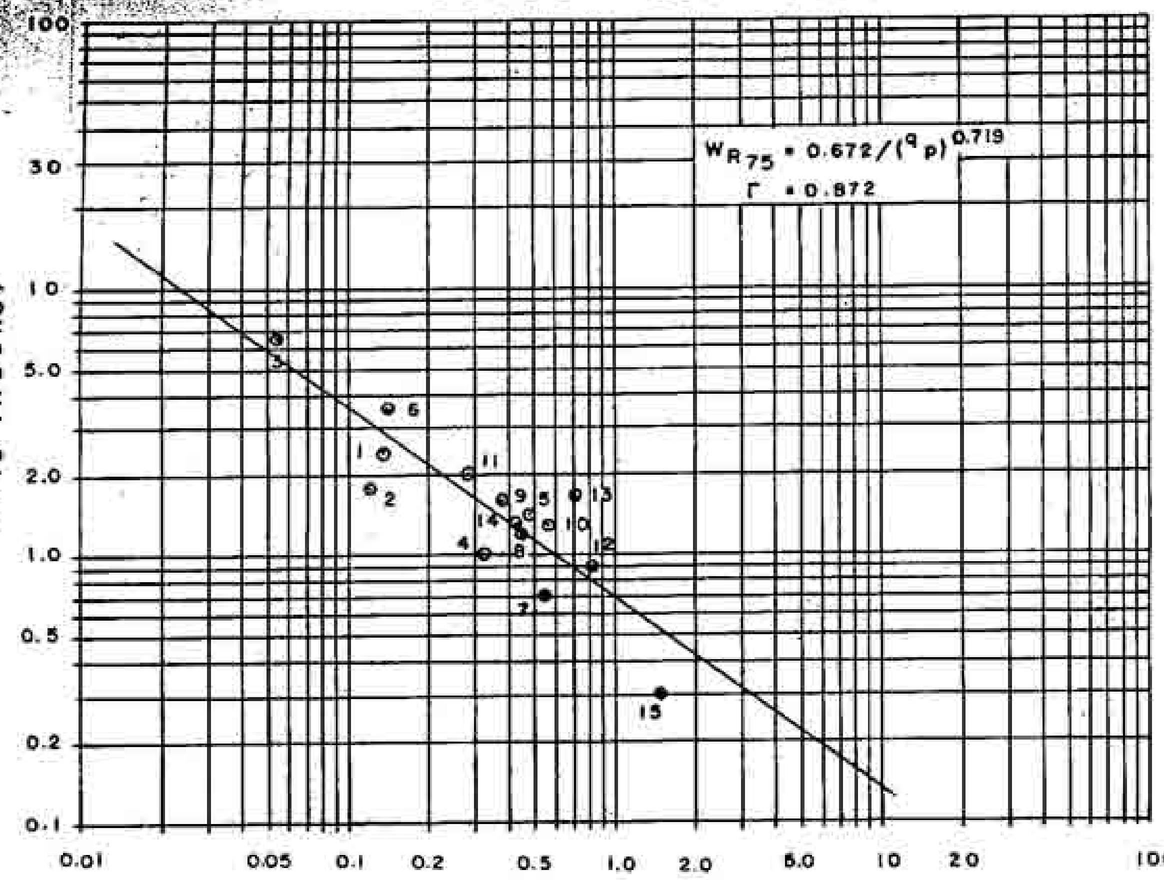
FIG. – 8



SI. NO.	BR.NO.	q_p CUMECS/ Km^2)	W_{R75} (HOURS)
1	MOT-1	0.135	2.40
2	462	0.120	1.80
3	611	0.056	6.50
4	1198	0.323	1.00
5	345	0.480	1.40
6	321	0.140	3.50
7	108 K	0.540	0.70
8	184	0.440	1.20
9	155	0.370	1.60
10	240	0.560	1.30
11	1136	0.286	2.00
12	93 K	0.810	0.90
13	210	0.710	1.66
14	199	0.430	1.30
15	724	1.460	0.30

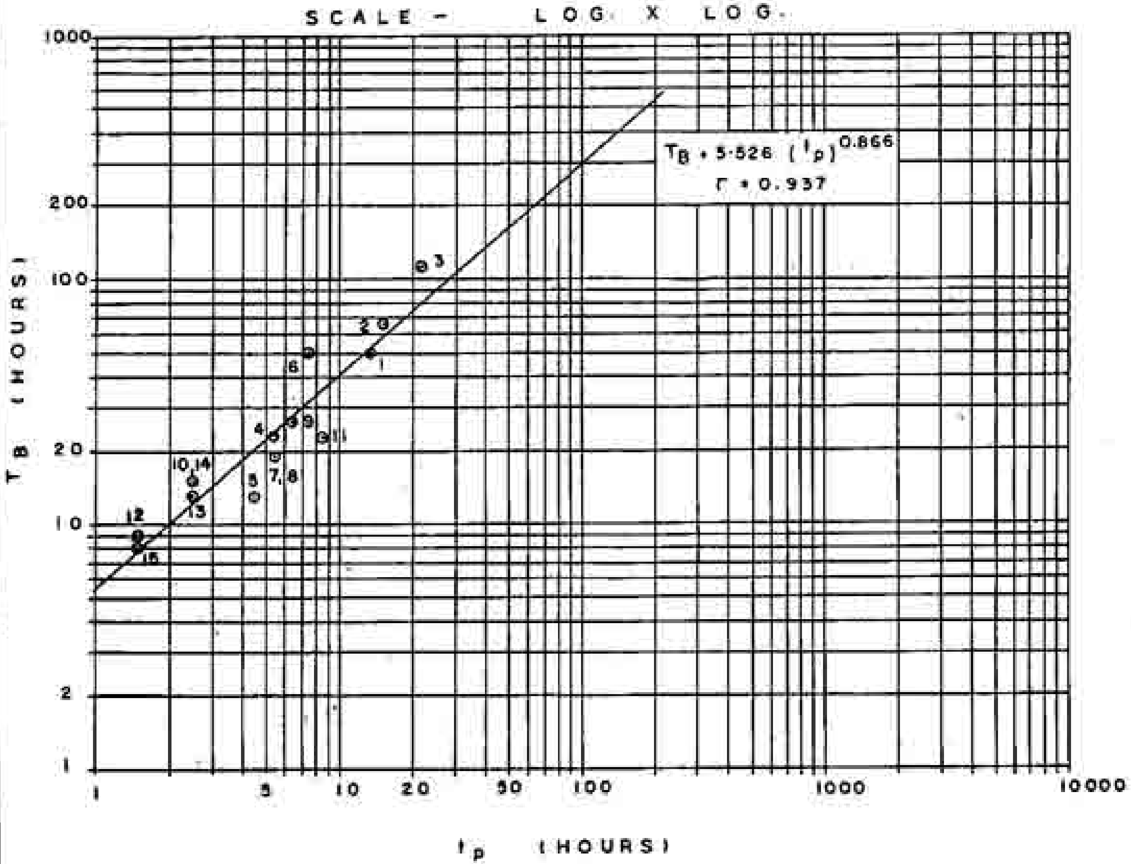
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE

SONE
SUB ZONE 1 (d)
RELATION BETWEEN
W_{R75} AND q_p

DRAWN BY. T. R. ARORA. L. P. NAUTIYAL

CHECKED BY. A. K. GHOSH.

FIG. - 9



SI. NO.	BR. NO.	t_p (HOURS)	T_B (HOURS)
1	MOT-1	13.5	50.00
2	462	15.5	66.00
3	611	21.5	112.00
4	1198	5.5	23.00
5	345	4.5	13.00
6	321	7.5	50.00
7	108K	5.5	19.00
8	184	5.5	19.00
9	155	6.5	26.00
10	240	2.5	15.00
11	1136	8.5	23.00
12	93K	1.5	9.00
13	210	2.5	13.00
14	199	2.5	15.00
15	724	1.5	8.00

GOVERNMENT OF INDIA
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HYDROLOGY (SMALL CATCHMENTS) DTE.

SONE
SUB ZONE 1(d)
RELATION BETWEEN T_B AND t_p

DRAWN BY. T.R. ARORA. P.N. BHALLA.

CHECKED BY. K. K. AICH

STATEMENT OF HIGHEST EVER RECORDED DAILY RAINFALL IN SUBZONE - 1(d)

S.No. 1	State 2	District 3	Station 4	Max. R/F 5	Date 6
	Uttar Pradesh				
1.		Allahabad	Maja	512.1	22.06.1916
2.		Varanasi	Varanasi(0)	349.5	26.09.1943
3.		Mirjapur	Chunar	318.5	08.08.1936
4.		Jaunpur	Mariahu	370.8	19.07.1955
5.		Ghazipur	Saidpur Bhartari	428.7	29.08.1940
6.		Azamgarh	Mahul	288.8	17.09.1945
7.		Rae Bareli	Moherajganj	284.7	06.09.1940
8.		Faizabad	Bikapur	273.3	02.08.1953
9.		Sultanpur	Musafirkhana	374.9	27.08.1903
10.		Balia	Rasra	320.0	03.10.1884
11.		Pratapgarh	Pratapgarh(0)	355.6	27.08.1903
	Bihar				
12.		Gaya	Arwal	266.7	22.07.1919
13.		Palamau	Patan	323.9	19.08.1907
14.		Muzafarpur	Katra	375.9	11.07.1933
15.		Darthanga	Dalsingh Sarai	417.3	05.09.1925
16.		Monghur	Jamalpur	370.6	29.08.1914
17.		Hazari Bagh	Hunterganj	467.4	01.08.1917
18.		Patna	Dinapur	498.9	25.06.1897
19.		Ranchi	Ranchi(0)	231.1	09.10.1941
20.		Shahbad	Sasaram	278.9	14.08.1910
	Madhya Pradesh				
21.		Rewa	Teonthar	317.5	09.09.1925
22.		Satna	Unchera	275.3	09.08.1919
23.		Damoh	Mala Inspection	345.7	10.08.1952
24.		Panna	Panna(0)	365.3	08.08.1919
25.		Chattarpur	Bijawar	287.8	09.09.1906
26.		Sirguja	Ambikapur	381.6	27.06.1945
27.		Mandla	Shahpura	219.4	25.06.1946
28.		Sidhi	Sidhi	304.8	02.08.1917
29.		Bilaspur	Bilaspur	271.8	23.08.1940

TABLE - 6 AREAL TO POINT RAINFALL RATIOS (PERCENTAGES)

Area in sq.km.	1-hr.	3-hr.	6-hr.	12-hr.	24-hr.
50	80	88	93	93	97
100	73	82	88	90	95
150	68	77	84	89	93
200	64	74	82	87	92
250	61	72	80	86	91
300		70	79	84	90
350		69	78	83	89
400			77	82	88
450			77	81	87
500			76	81	86
600				79	85
700				78	84
800				76	83
900				76	81
1000				75	81
1500					77
2000					76
2500					75

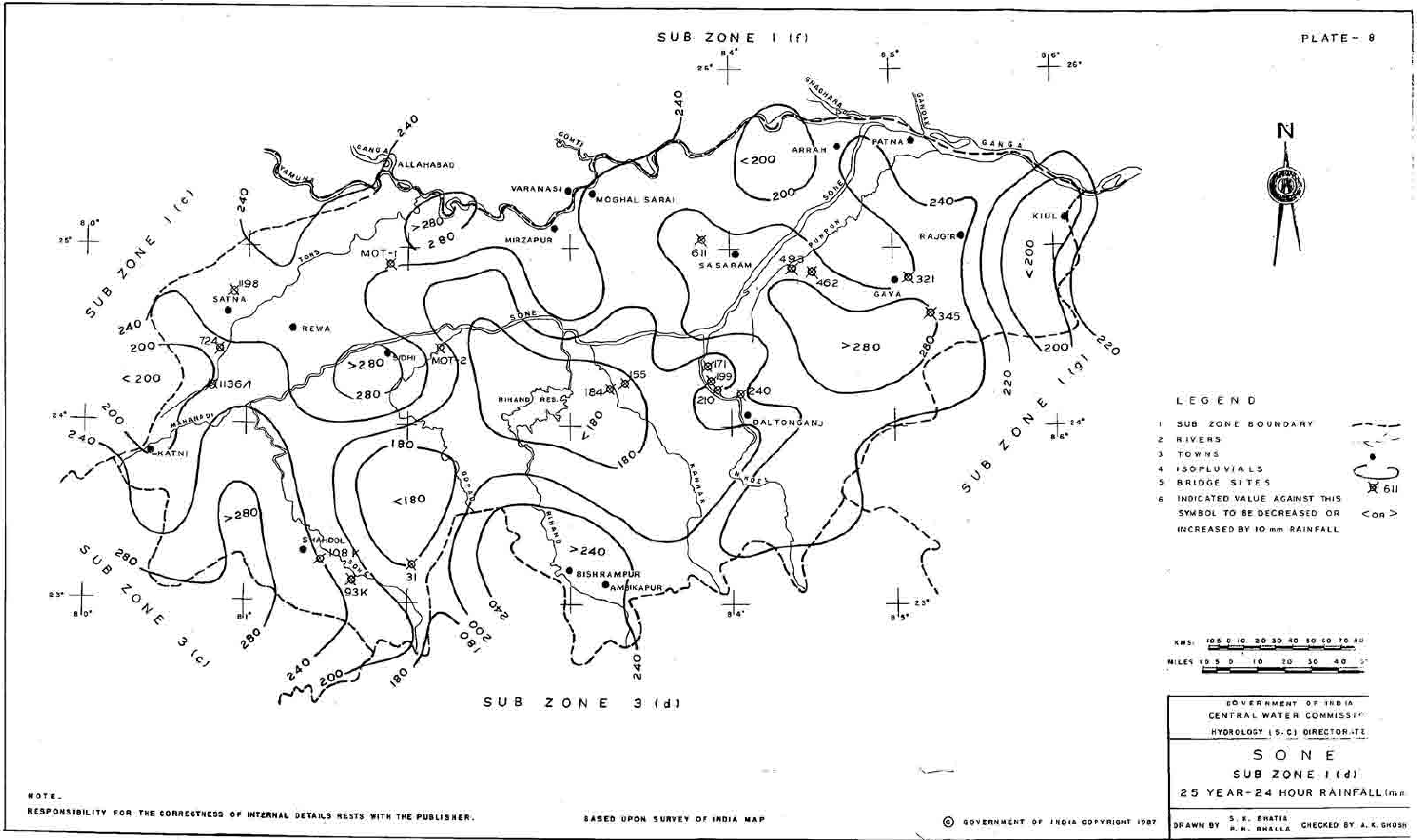
PLATE- 8
SUB ZONE 1 (f)
SUB ZONE 1 (c)
SUB ZONE 1 (g)
SUB ZONE 3 (c)
SUB ZONE 3 (d)
N
ALLAHABAD
VARANASI
MOGHAL SARAI
MIRZAPUR
ARRAH
PATNA
KIUL
RAJGIR
SASARAM
GAYA
SATNA
REWA
SIDHI
KATNI
SHAHDOL
DALTONGANJ
BISHRAMPUR
AMBIKAPUR
GANGA
YAMUNA
GOMTI
GHAGHARA
GANDAK
SONE
PUNPUN
TONS
MAHANADI
RIHAND
RIHAND RES.
KANHAR
N. KOEL
GOPAD
MOT-1
MOT-2
1198
724
1136/1
611
493
462
321
345
171
199
210
240
155
184
108 K
93K
31
<200
200
240
280
>280
220
<180
180
>240
LEGEND
1 SUB ZONE BOUNDARY
2 RIVERS
3 TOWNS
4 ISOPLUVIALS
5 BRIDGE SITES
6 INDICATED VALUE AGAINST THIS SYMBOL TO BE DECREASED OR INCREASED BY 10 mm RAINFALL
<OR>
KMS.
MILES
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S. C) DIRECTORATE
SONE
SUB ZONE 1 (d)
25 YEAR-24 HOUR RAINFALL (mm)
DRAWN BY S. K. BHATIA P. N. BHALLA
CHECKED BY A. K. GHOSH
NOTE.
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER.
BASED UPON SURVEY OF INDIA MAP
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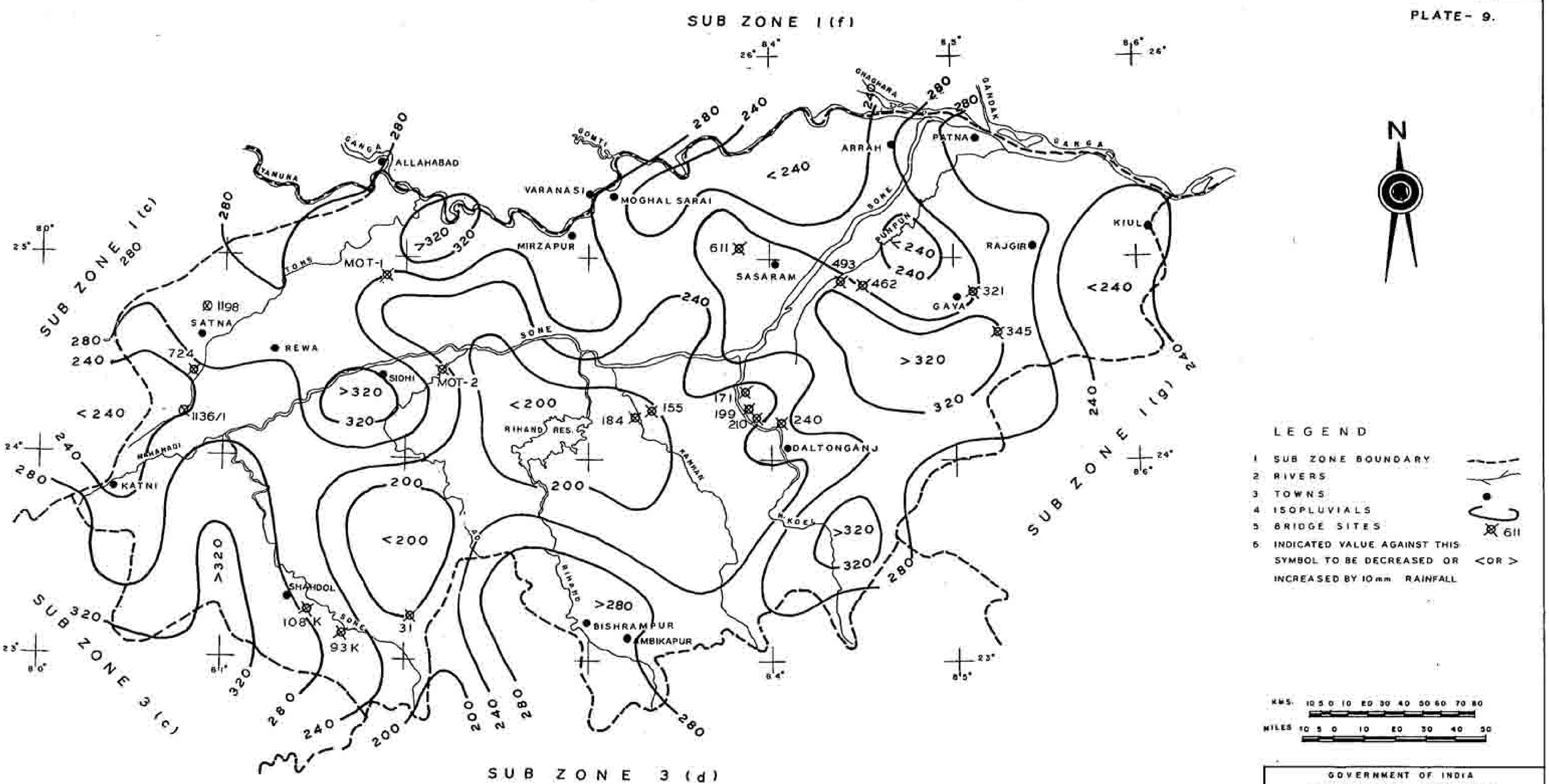

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SONE
SUB ZONE I (d)
50 YEAR-24 HOUR RAINFALL (mm)

DRAWN BY S. K. BHATIA, P. N. BHALLA — CHECKED BY A. K. GHOSH

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

BASED UPON SURVEY OF INDIA MAP

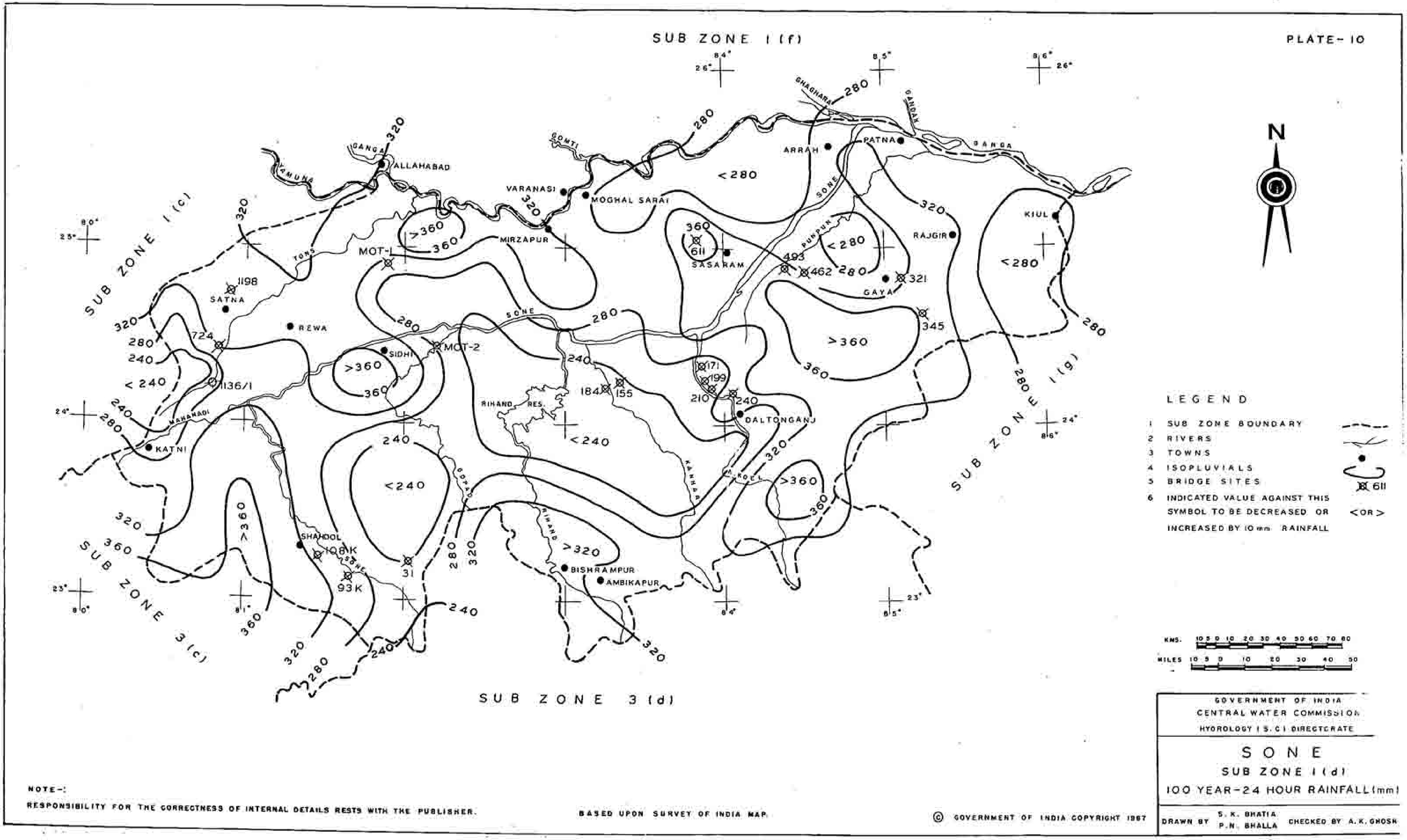
PLATE- 10
SUB ZONE 1 (f)
SUB ZONE 1 (c)
SUB ZONE 1 (g)
SUB ZONE 3 (c)
SUB ZONE 3 (d)
N
ALLAHABAD
VARANASI
MOGHAL SARAI
MIRZAPUR
ARRAH
PATNA
SASARAM
GAYA
RAJGIR
KIUL
SATNA
REWA
SIDHI
KATNI
SHAHDOL
DALTONGANJ
BISHRAMPUR
AMBIKAPUR
GANGA
YAMUNA
GOMTI
GHAGHARA
GANDAK
SONE
PUNPUN
TONS
RIHAND RES.
RIHAND
KANHAR
GOPAD
MAHANADI
MOT-1
MOT-2
LEGEND
1 SUB ZONE BOUNDARY
2 RIVERS
3 TOWNS
4 ISOPLUVIALS
5 BRIDGE SITES
6 INDICATED VALUE AGAINST THIS SYMBOL TO BE DECREASED OR INCREASED BY 10 mm RAINFALL
<OR>
KMS.
MILES
NOTE-:
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER.
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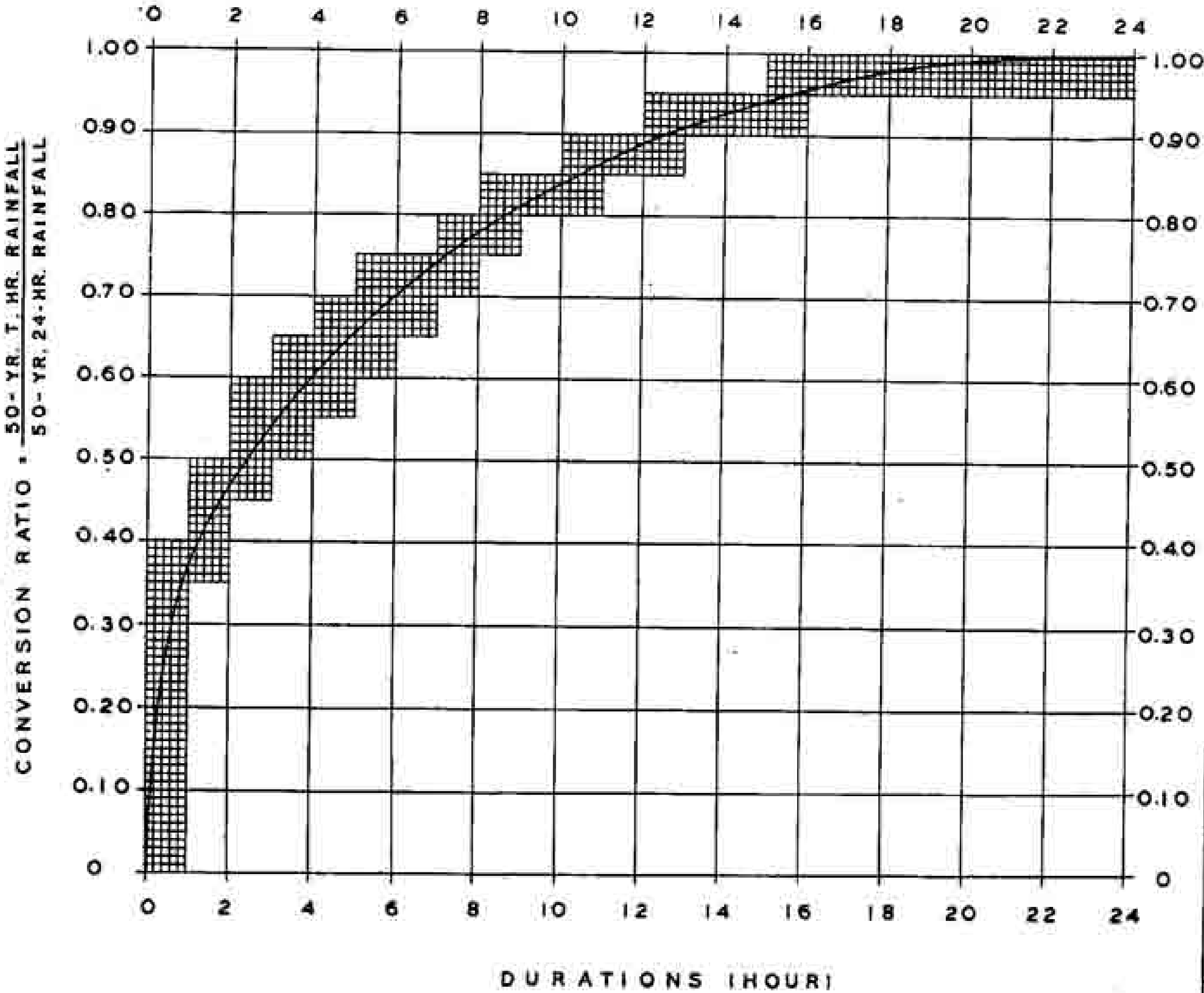
SONE
SUB ZONE 1 (d)
100 YEAR-24 HOUR RAINFALL (mm)
DRAWN BY S. K. BHATIA P. N. BHALLA
CHECKED BY A. K. GHOSH

FIG. 10



RATIOS OF 24-HR. POINT RAINFALL TO SHORT DURATION RAINFALL

DURATION (HR.)	RATIO
0	0.0
1	0.370
2	0.470
3	0.540
4	0.600
5	0.655
6	0.700
7	0.740
8	0.780
9	0.810
10	0.838
11	0.865
12	0.890
13	0.910
14	0.925
15	0.940
16	0.955
17	0.967
18	0.980
19	0.985
20	0.990
21	0.995
22	0.997
23	0.998
24	1.000

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SONE

SUB ZONE 1 (d)

DURATION VS. CONVERSION RATIO

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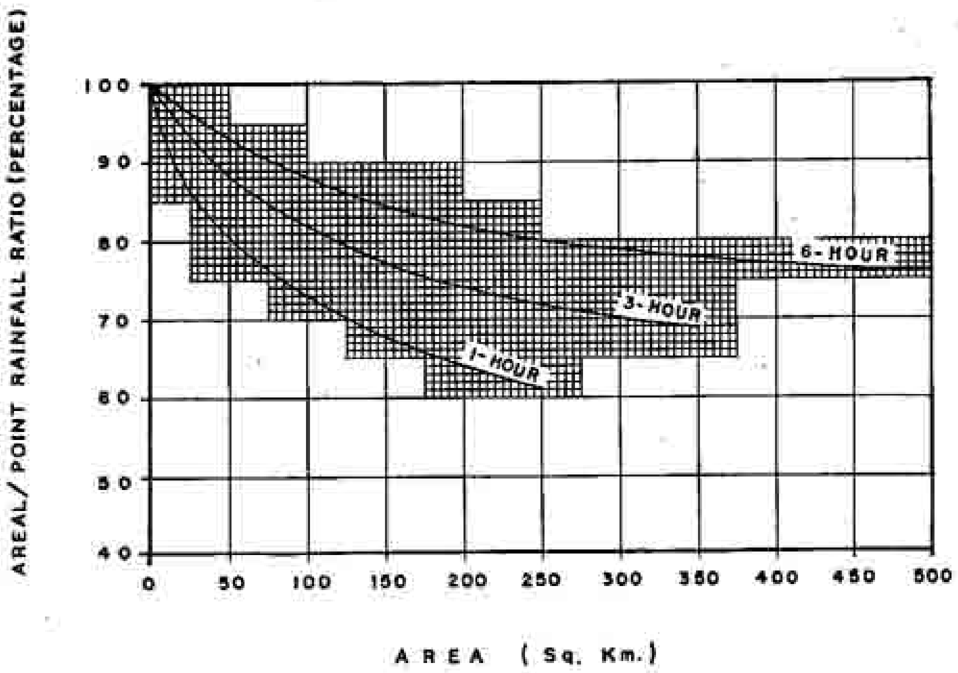
FIG.— 11 (a).



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SONE

SUB ZONE I (d)

AREAL TO POINT RAINFALL RATIO PERCENTAGE

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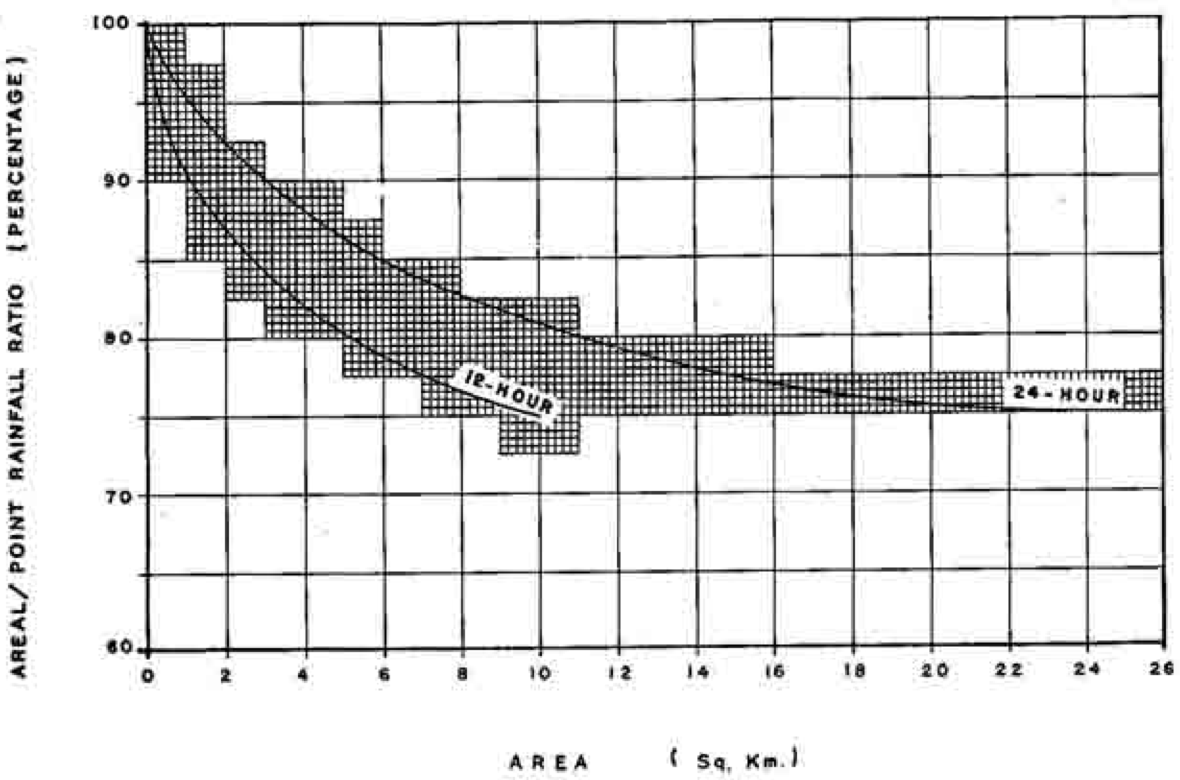
FIG. - 11 (b).



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SONE

SUB ZONE I (d)

AREAL TO POINT RAINFALL RATIO PERCENTAGE

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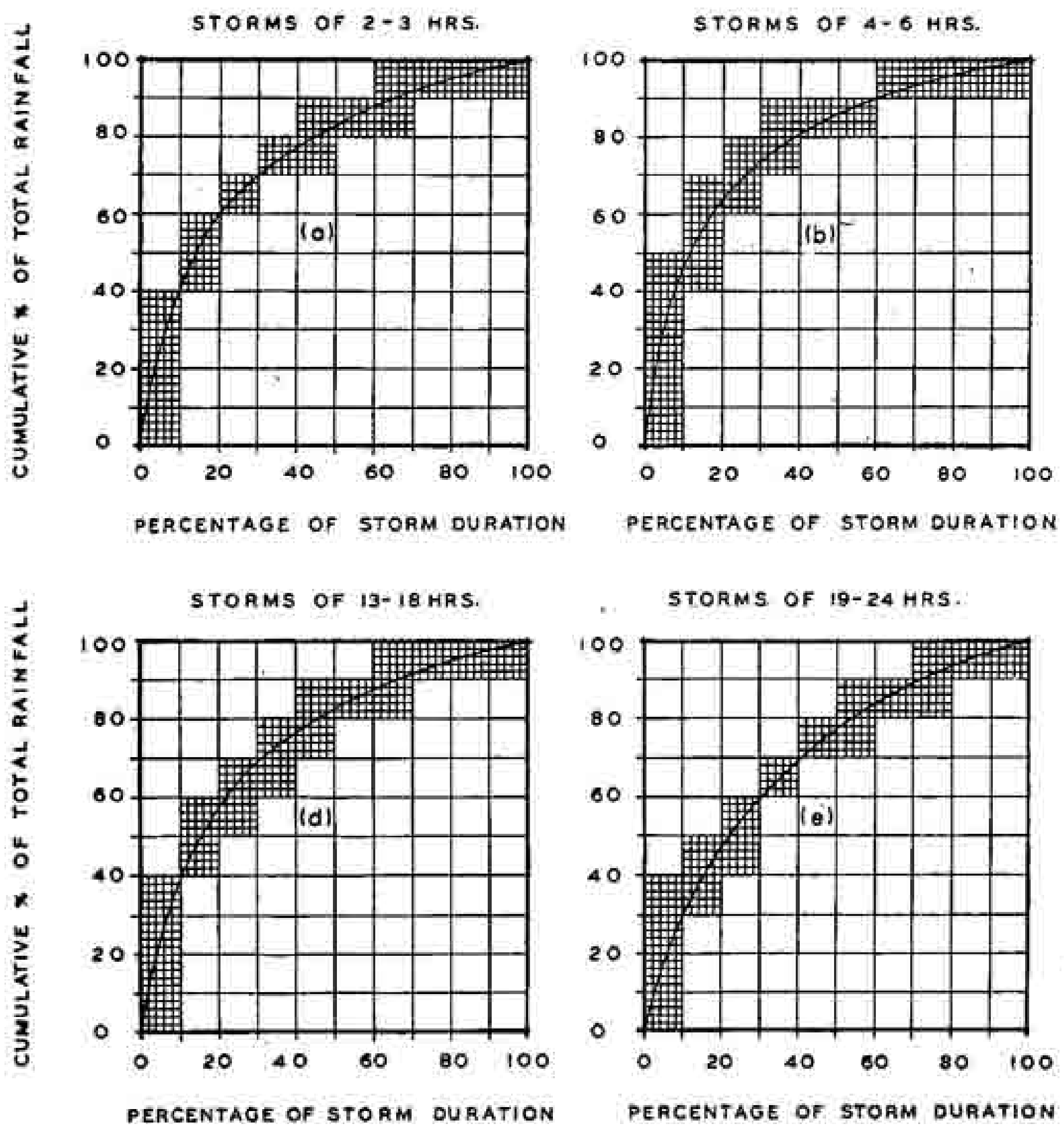
FIG. _ 12.



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SONE

SUB ZONE I (d)

MEAN AVERAGE TIME DISTRIBUTION CURVES OF STORMS OF VARIOUS DURATION

DRAWN BY_	CHECKED BY_
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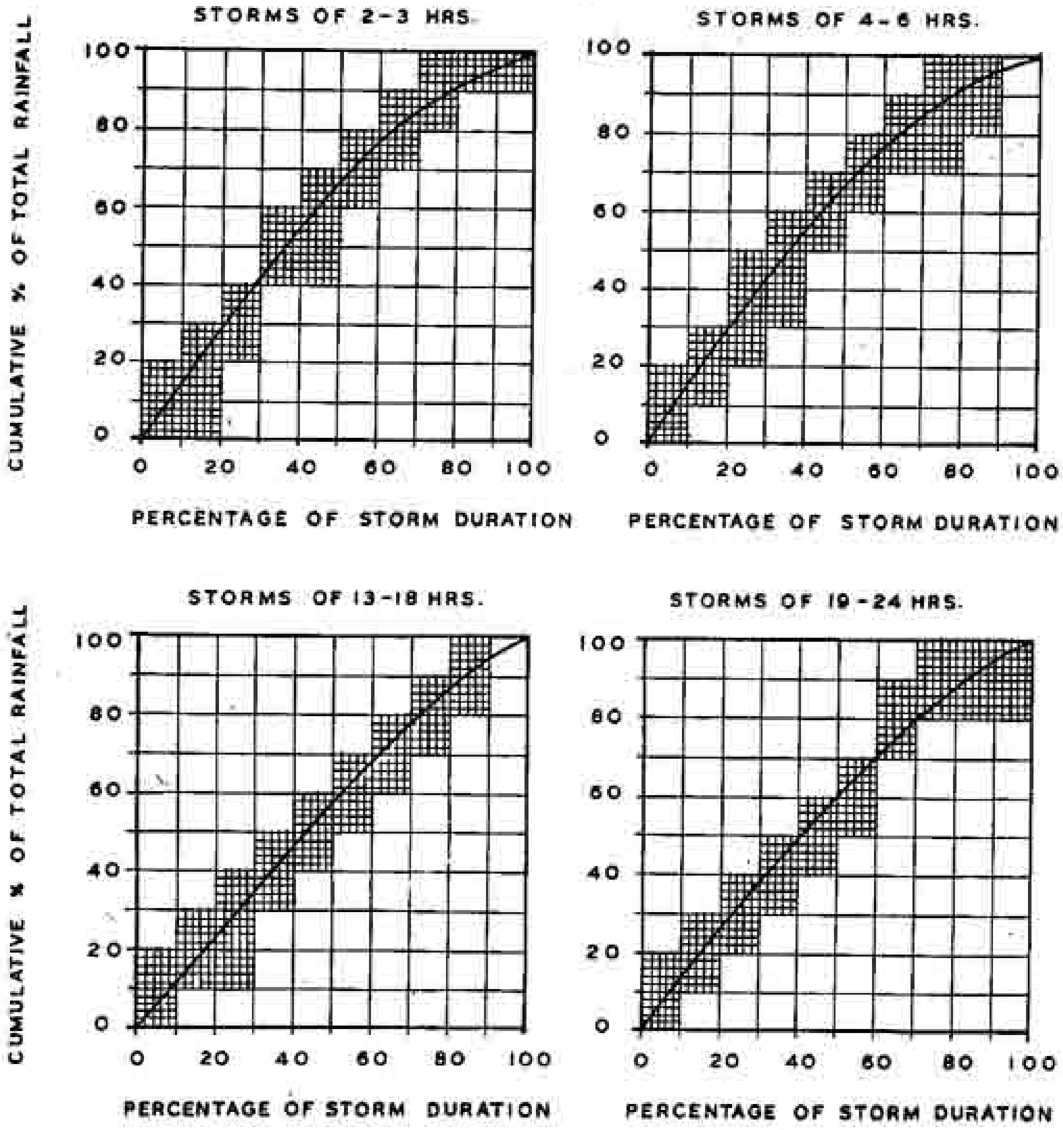
FIG. 13



NOTE.

THIS FIG. IS TO BE USED IN LIEU OF FIG. 12 EXCLUSIVELY BY RAILWAYS.

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SONE

SUB ZONE I (d)

MEAN ACTUAL TIME DISTRIBUTION CURVES OF STORMS OF VARIOUS DURATIONS (NATURAL SEQUENCE)

DRAWN BY	CHECKED BY
S. K. BHATIA P. N. BHALLA	A. K. GHOSH.

5.0 ESTIMATION OF DESIGN FLOOD FOR AN UNGAUGED CATCHMENT

Step-1 Determine the 1-hr synthetic unitgraph vide sections 3.9 and 3.10.

Step-2 Determine the design storm rainfall input vide section 4.0.

Step-3 Adopt the design loss rate as recommended vide section 3.11.

Step-4 Obtain the hourly effective rainfall units upto the design storm duration T_D=1.1 tp by subtracting the design loss rate from the hourly effective rainfall units in Step-5 of section 4.6

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

Arrange the effective rainfall units against the 1-hourly synthetic U.G. ordinates such that the maximum value of effective rainfall comes against the peak discharge of synthetic U.G., the next lower value of effective rainfall units comes against the next lower discharge ordinate and so on upto T_D = hour duration.

The sum of the product of unitgraph ordinates and the effective rainfall units as tabulated above gives the 50-yr flood peak value after due addition of base flow in Step-8.

However, the subsequent Steps-5 to 9 should be followed, for computation of design flood hydrograph.

Step-5 Reverse the sequence of effective rainfall units obtained in Step-4 which will give the critical sequence of the effective rainfall.

Step-6 Multiply the first 1-hour effective rainfall with the synthetic ordinates at 1-hr interval which will give the corresponding direct runoff ordinates. Likewise repeat the procedure with the rest of the hourly effective rainfall units giving a lag of 1-hr to successive direct runoff ordinates.

Step-7 Add the direct runoff ordinates at 1-hr interval to get the total direct runoff hydrograph.

Step-8 Obtain the base flow rate in cumecs/sq.km vide section 3.12. Multiply base flow rate in cumecs/sq.km. with the catchment areas under study to get the total base flow.

6.0 VERIFICATION OF ESTIMATED DESIGN FLOOD BASED ON SUH MODEL

Regional frequency storm rainfall-loss-synthetic unitgraph model is mainly based on the fundamental assumption that frequency storm rainfall applied to synthetic unitgraph of a catchment in a region will produce the flood of the the same frequency as that of storm rainfall. This basic assumption has been generally applied by the hydrologists in the various countries for developing this approach. It would be rather desirable to verify this assumption, rather than the authenticity of the developed model, by the application of a suitable regional flood frequency model with the available data of gauged catchments in the subzone.

In the above context regional flood frequency model for the Sone subzone-1 (d) has been developed with the annual peak discharge series varying for periods of 11 to 25 years for 11 gauged catchments varying in sizes from 34 to 517 km^2. Mean annual flood for return period of 2.33 yrs ($Q_{2.33}$), 25-yr flood (Q_{25}), 50-yr flood (Q_{50}) and 100-yr flood (Q_{100}) values were obtained by fitting a straight line relationship through the plotted positions based on Werbel's on Gumbel's Extremal value 1 graph paper for each of the 11 gauged catchments.

Following relationship between mean annual flood ($Q_{2.33}$) expressed in m^3/sec. as dependent variable and catchment area (A) in Km^2, equivalent storm slope (S) in m/km and form factor (f) = A/L^2 with L as the basin length in km as independent variables was developed by regression analysis based on least square method.

$$Q_{2.33} = 2.33\ (A)^{0.795}\ (S)^{0.567}\ (f)^{0.52}$$

The coefficient of correlation for the above relationship is 0.86 which may be expressed very good.

The regional ratios between 25-yr, 50-yr and 100-yr flood to mean annual flood were estimated as under:

$$R_{25} = 2.83, \quad R_{50} = 3.38 \text{ and } R_{100} = 3.82$$

Combining the formula for mean annual flood ($Q_{2.33}$) with the above regional ratios, the formulae for 25-yr, 50-yr, and 100-yr flood are as under:

$$Q_{25} = 6.59\ (A)^{0.795}\ (S)^{0.567}\ (f)^{0.52}$$

$$Q_{50} = 7.87\ (A)^{0.795}\ (S)^{0.567}\ (f)^{0.52}$$

$$Q_{100} = 8.90\ (A)^{0.795}\ (S)^{0.567}\ (f)^{0.52}$$

Using the above relationships, the 25-yr, 50-yr and 100-yr flood values for the 11 gauged catchments as well as for another 4 catchments were estimated and corresponding 25-yr, 50-yr and 100-yr flood based on SUH model were compared as shown in Table-7. A summary of the number of occasion the 25-yr,50-yr and 100-yr flood values estimated by SUH model for 15 catchments was higher or lesser than the corresponding flood values by Regional Flood Frequency studies based on Table is given below:-

25-Year Flood

Number of Cases										
SUH > RFF				Total	SUH < RFF			Total	Grand Total
< 19%	20 to 39%	40 to 79%	> 80%		< 5%	6 to 20%	> 20%		
3	7	2	-	12	1	1	1	3	15

50 - Year Flood

Number of Cases									
SUH > RFF				Total	SUH < RFF			Total	Grand Total
< 19%	20 to 39%	40 to 79%	> 80%		< 5%	6 to 20%	> 20%		
3	7	2	-	12	-	2	1	3	15

100 - Year Flood

Number of Cases									
SUH > RFF				Total	SUH < RFF			Total	Grand Total
< 19%	20 to 39%	40 to 79%	> 80%		< 5%	6 to 20 %	> 20%		
4	6	3	-	13	-	1	1	2	15

The above summary shows that the 25-yr, 50-yr and 100-yr flood values based on SUH are higher by 14 to 39% in 10 cases, lesser by 5 to 27% in 3 cases and higher by 40 to 79% in 2 cases only out of a total of 15 cases as compared to the corresponding frequency flood values by RFF. Since the variations in 13 cases out of 15 cases in respect of 25-yr, 50-yr and 100-yr flood values estimated by SUH as compared to RFF are within acceptable limits the regional frequency storm rainfall-synthetic unit hydrograph model for Sone subzone-1(d) may be considered reasonably good.

TABLE - 7 COMPARISON OF FREQUENCY FLOOD VALUES BY SYNTHETIC UNITGRAPH AND REGIONAL FLOOD FREQUENCY STUDIES-'SUB-ZONE'-1(d)

Sl.No.	Br. No.	CA km^2	By SUH Q_{25} CUMECS	By SUH Q_{50} CUMECS	By SUH Q_{100} CUMECS	By RFF Q_{25} CUMECS	By RFF Q_{50} CUMECS	By RFF Q_{100} CUMECS	%variations w.r.t. SUH Q_{25}	%variations w.r.t. SUH Q_{50}	%variations w.r.t. SUH Q_{100}
1.	MOT(1)	1040	1928	2307	2590	1653	1974	2231	14.26	14.43	13.86
2.	462	517	1162	1263	1415	806	963	1089	30.64	23.75	23.04
3.	611	440	795	945	1284	495	591	668	37.74	37.46	47.98
4.	1198	341	937	1160	1326	1044	1247	1406	-11.42	- 7.50	- 6.03
5.	345	298	1290	1491	1640	671	801	905	47.98	46.28	44.82
6.	321	288	606	708	809	374	446	504	38.28	37.01	37.70
7.	108K	279	1010	1156	1330	1234	1474	1665	-22.18	-27.51	-25.19
8.	184	248	619	701	867	634	757	856	- 2.42	- 7.99	1.27
9.	155	180	544	613	734	456	544	615	16.18	11.26	16.21
10.	240	162	670	768	891	506	605	684	24.48	21.22	23.23
11.	1136	158	503	586	669	416	497	561	17.30	15.19	16.14
12.	93K	74	616	734	852	450	537	607	26.95	26.84	28.76
13.	210	55	434	503	594	291	348	393	32.95	30.82	33.84
14.	199	34	198	232	277	127	152	172	35.86	34.48	37.91
15.	724	28	178	214	250	79	95	107	55.62	55.61	57.20

The various values of the roughness co-efficient for different types of channel are given in Table 5.6 "Open Channel Hydraulic" by Ven-Te-Chow.

The above procedure pertains to determination of design HFL corresponding to design flood of a river under natural conditions. With the type of structures in position there will generally be a constriction in the waterway. The effect of the constriction by way of raising the design HFL under natural conditions has to be evaluated in the water elevations to arrive at the revised design HFL under constricted conditions. The difference between upstream and downstream water levels corresponding to design flood due to constriction in the waterway may be termed as afflux. There are hydraulic methods for working out the final design HFL due to constriction by the structure. The weir formula or orfice formula of hydraulics is generally used depending on the upstream and downstream depths to estimate the revised design HFL under constricted conditions.

7.3 BACK WATER EFFECT

Sometimes it happens that the cross section of river or nalla on the downstream side of a cross drainage structure may be too narrow than the cross section at the location of a crossing site. The flood levels at the proposed structure may also be affected by the high flood levels in the main river joining downstream in proximity of the stream. In such cases, there will be backwater effect due to the narrow gorge of the river as the design flood for the crossing site will not be able to pass through the narrow gorge in the downstream and hence there will be heading up of water in its upstream side which ultimately effects on HFL of the river at the crossing site. In the latter case the tributary stream on which the bridge is located will be under the influence of the backwater affect of the main stream joining downstream. In such cases back water study shall be essential.

7.4 HYDRAULIC GRADIENT

In the absence of any observed levels of water profiles for computing hydraulic gradient, bed gradient of nalla shall be considered, after verifying that local depressions are not accounted for and bed gradient is computed on a reasonable length of atleast 300 mt. upstream and downstream of the crossing site.

7.5 UNFAVOURABLE CROSSING SITE

If the crossing site is located across the river/drainage in the unfavourable reach i.e. not complying with the usual requirement of gauge site, the design flodd elevation shall be computed in a straight reach downstream of the crossing and then from back water streams, design flood elevation of the crossing site shall be decided.

8.0 FORMULA FOR LINEAR WATERWAY OF BRIDGES

Design of bridges and culverts and cross drainage structures like acquaducts encompasses the primary fixation of the linear waterway to be provided, the HFL anticipated, number of spans to be provided, type of piers to be given, etc., apart from many other structural factors. This report focusses on the methodology to be used to estimate the flood produced from a rainfall which would occur with a 50-yr recurrence interval. Once this estimate has been made, the usage of this discharge value would logically be the next step. A perusal of prevalent rail and road bridge design codes suggest the formula for fixing the waterway.

The linear dimensions of any hydraulic structure have a bearing on the width of channel. The channel width in the case of stable river is mostly controlled by the nature of soil, slope and roughness of terrain/channel bed as also the magnitude, duration and frequency of floods over a long period in geological time. The width of the channel, therefore, remains more or less constant for discharge magnitudes of different return periods, though the flood levels and velocities vary considerably to cater to the increase in discharge magnitudes. With this concept in view, the formulae for linear waterway related to frequency floods have been developed. Considering the dimension of discharge which is L^3/T, the adoption of $\sqrt[3]{Q}$ discharge as the ruling parameter seems to be justifiable. Taking $\sqrt[3]{Q}$ into account the analysed bridges in subzone-1(d), the following simplified formula has been derived.

$$W = 8.60\ (Q_{50})^{\frac{1}{3}}$$

Where W is linear waterway in metres and Q_{50} is 50-yr flood discharge in cumecs using the modal loss rate of 0 25 cm/hr.

The design engineers may follow the following steps while fixing some of the primary parameters of the bridge.

i) Estimate Q_{50} by using the methodology outlines in the report.

ii) Estimate the linear waterway using the equation given above.

iii) Work out the design HFL expected for Q_{50} (using the modal loss rate of 0.25cm/hr) with the waterway estimated.

The linear waterway which is estimated may seem to be inadequate or excessive as per the site conditions prevalent. In that case, the design engineer is at liberty to choose a suitable waterway not much different from the estimated waterway and thereafter fix the design HFL as per normal calculations. The above mentioned equation gives only guide to the possible width which may have to be provided to pass the discharge at the bridge site. In case the design engineer feels that the importance of the structure warrants Q_{25} or Q_{100} and wants to use those values for design purpose, then the linear waterway may be worked out with the following formulae:

$$W = 9.53\ (Q_{25})^{1/3}$$

$$W = 8.07\ (Q_{100})^{1/3}$$

Where Q_{25} and Q_{100} are estimated using a modal loss rate of 0.25 cm.

THE FORMULAE GIVEN ABOVE ARE ONLY TO BE USED FOR FIXING THE LINEAR WATERWAY OF THE BRIDGES IN THE SUBZONE 1 (d). THE LACEY'S REGIME WIDTH FORMULAE WILL NOT BE APPLICABLE FOR FIXING THE LINEAR WATERWAY OF BRIDGES IN SUBZONE - 1 (d). HOWEVER, FOR DETERMINATION OF SCOUR AT BRIDGE SITES THE LACEY'S SCOUR FORMULAE BASED ON LACEY'S REGIME WIDTH AS SPECIFIED IN THE CODES FOR ROAD AND RAIL BRIDGES SHALL BE USED.

The relevant codes of practice for design flood and fixing of waterway of bridges by Indian Railway and Indian Road Congress are as under:

i) Code of practice by Indian Railways (revised 1985) sections 4.2, 4.3, 4.4 and 4.5.

ii) IRC: 5-1985 Standard specifications and code of practice for Road bridges section 1, General Features of Design sixth revision) by Indian Road Congress, 1985 clauses 103 and 104.

9.0 UTILITY OF REPORT FOR OTHER PURPOSES

The report may also be used for estimation of frequency flood for the following categories of structures as per the Indian Standard of the Indian Standards Institution.

i) <u>Small Dams</u>

The Indian Standard - guidelines for fixing spillway capacity of Dams under clauses 3.1.2 and 3.1.3 of IS : 11223 - 1985 (under print) recommends 100-year floods as inflow design flood for small dams having either gross storage behind the dam between 0.5 to 10 million mt. or hydraulic head (from normal or annual average flood level on the downstream to the maximum water level) between 7.5m to 12m. The report may be made use of for estimation of 100-year flood for safety of small dams. 100-year flood may be estimated using the modal loss rate of 0.45cm/hr.

ii) <u>Minor Cross Drainage Works</u>

The Indian Standard - code of practice for design of cross drainage works, part-1 General Features under clause 6.2 of IS : 7784 (part-1)-1975 recommends 10 to 25 years frequency flood with increased afflux for the design of waterway of minor cross drainage works. The report may be made use of for estimation of 25-year flood for fixing the waterway of minor cross drainage works. The flood of different return periods say from 10 to 20 years may be estimated by using the detailed methodology given in the report on the basis of 10 to 20 years 24-hr. point storm rainfall determined for the ungauged catchments under study.

10.0 ASSUMPTIONS, LIMITATIONS AND CONCLUSIONS

10.1 Assumptions

10.1.1 It is assumed that 50-year return period storm rainfall produces 50-year flood. Similar is the case for 25-year flood and 100 year flood.

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

10.2 LIMITATIONS

10.2.1 The data of 19 catchments has been considered for developing a generalised approach for a large subzone, However, for more reliable relationships the data of more suitable catchments would be desirable.

10.2.2 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.

10.2.3 The approach developed mostly covers the catchment with flat to moderate slopes.

10.3 CONCLUSIONS

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

10.3.2 The report also recommends the adoption of design flood of 25-yr and 100-yr return periods taking into account the type and relative importance of the structures.

10.3.3 The flood formulae with different return periods shall be used only for preliminary design. However, for final design, design flood shall be estimated by application of storm rainfall to synthetic unit hydrograph.

10.3.4 Formulae for fixing the linear waterway of cross drainage structures on streams in Sone subzone may be used at the discretion of the design engineer.

10.3.5 25-yr, 50-yr and 100-yr flood may be estimated using modal loss rate of 0.25cm/hr. 25-yr, 50-yr and 100-yr flood formulae alongwith respective formulae for linear waterway of bridges are in Annexure-1 which may be used for preliminary designs. However, for final designs, the design flood has to be estimated using the detailed procedure in the illustrative example.

10.3.6 The report is applicable for the catchment areas ranging from 25 sq. km. to 1500 sq.km. Further the report may be used for larger catchments upto 5000 sq. km. based on sound judgement and considering the data of neighbouring catchments also. However, individual site conditions may necessitate special site study. Engineer-in-charge at site is advised to take a pragmatic view while deciding the design discharge of a bridge.

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A. UNDER SHORT TERM PLAN

1.	Estimation of Design Flood Peak	(1973)

B. UNDER LONG TERM PLAN

1.	Lower Gangetic Plains subzone - 1(g)	(1978)
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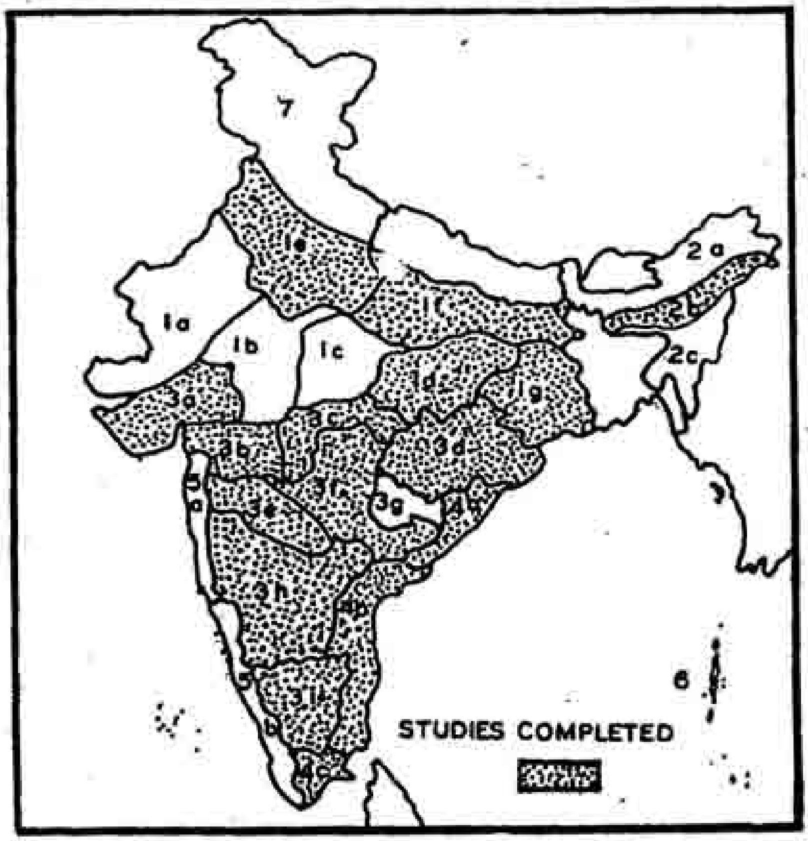
11.	Upper Godavari subzone - 3(e)	(1986)
12.	Flood Estimation Report for Mahi & Sabarmati subzone 3(a)	(1987)
13.	Eastern Coast subzone - 4(a,b & c)	(1987)



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