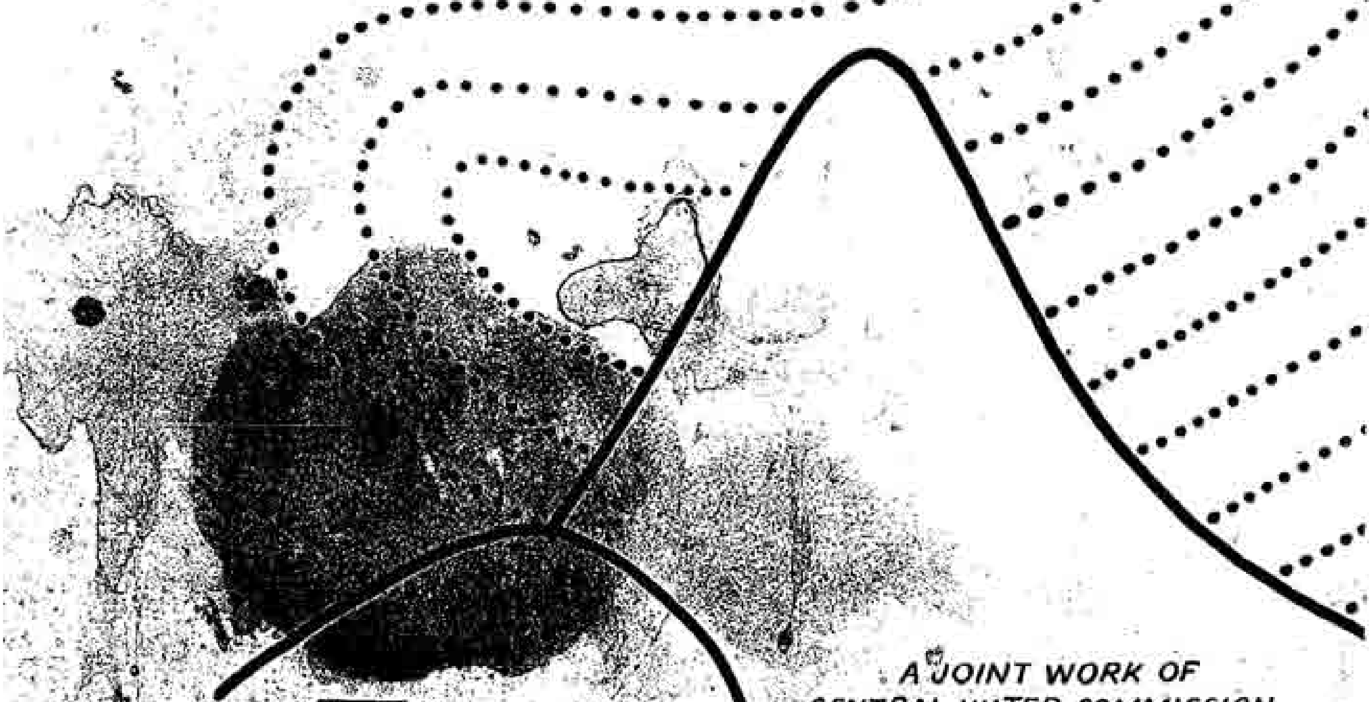
चम्बल (उप अंचल - 1 बी) की बाढ़ अनुमान रिपोर्ट

यूनिट जलारेख सिद्धान्त पर आधारित एक प्रणाली

FLOOD ESTIMATION REPORT FOR CHAMBAL SUB ZONE - 1 (b)

A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE



A JOINT WORK OF
CENTRAL WATER COMMISSION
(MIN. OF WATER RESOURCES)
RESEARCH DESIGNS & STANDARDS ORGANISATION
(MIN. OF RAILWAYS)
MIN. OF SURFACE TRANSPORT (ROAD WING)
& INDIA METEOROLOGICAL DEPTT.
(DEPTT. OF SCIENCE & TECHNOLOGY)

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

FLOOD ESTIMATION REPORT FOR CHAMBAL SUB ZONE 1(B) WAS PLACE BEFORE FLOOD ESTIMATION PLANNING AND COORDINATION COMMITTEE IN IT 48TH MEETING HELD ON 16TH SEPTEMBER 1988 AT BHOPAL (M.P.

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FLOOD ESTIMATION REPORT FOR CHAMBAL SUBZONE 1(b)

A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE
DESIGN OFFICE REPORT NO. C/16/1988.

HYDROLOGY (SMALL CATCHMENTS) DIRECTORATE
CENTRAL WATER COMMISSION
NEW DELHI

DECEMBER 1988

F O R E W O R D

The hydrologic design of rail and road bridges across small and medium streams, does not, in general, get as much attention as the design of bridges across major rivers, with the consequence, the waterway and other parameters provided in these bridges prove, in many a case, grossly inadequate. The Committee of Engineers set up by the Government of India in 1957 under the chairmanship of Dr. A.N. Khosla went into this problem and after reviewing the methods available for estimating the design flood discharge, recommended the adoption of the rational methodology, involving use of design storms and unit hydrographs for the estimation of design floods. Rational methodology is not normally adopted for small and medium structures partly due to lack of adequate rainfall and runoff data for such analyses and partly due to the time and cost involved in such analyses. For overcoming these problems and as a follow up on the recommendations of the Committee of Engineers, four organisations concerned with the design of bridges, viz., Research, Designs and Standards Organisation of the Ministry of Railways, the Ministry of Surface Transport, the India Meteorological Department and Central Water Commission have joined to gether. This joint effort aims at collection of rainfall-runoff data for a period of about 5 years in the catchments of small and medium bridges, analysing the data and developing a rational methodology based on unit hydrograph which could be generally applied. This methodology would enable, through a set of charts and graphs, quick estimation of design flood for ungauged catchments.

For this purpose the data collection work is being carried out both by the Ministry of Railways and by the Central Water Commission (on behalf of the Ministry of Surface Transport). While the rainfall analysis is being done by the India Meteorological Department, Central Water Commission develops the unit hydrograph based methodology.

Since it would be impracticable and grossly erroneous to attempt development of a single set of reference charts and graphs for the whole country, the country has been divided into 26 hydrologically homogeneous subzones. With the data presently avaiable, 22 subzones covering 81 percent of the geographical area could be studied. So far studies on 16 subzones have been completed and 14 reports covering these studies have been brought out.

The present report is the 15th in this series and covers the studies on Chambal Sub-zone 1(b). The methodologies contained in these reports will drastically reduce the time and cost involved in the hydrologic design of small and medium bridges.

In order to familiarise the design and construction engineers of various organisations with the methodology developed, CWC has conducted workshops at Calcutta, Bhubaneswar, Guwahati, Patna and Bhopal. Similar workshops are also being planned in other regions of the country.

I am sure that this very useful report would be widely referred to by the designers of small and medium bridges in this zone.

I would like to place on record my commendation of the excellent cooperative effort of the officers and staff of the four organisations mentioned above in producing this report.

New Delhi.
Nov.,1988

sd/-
(Y.D. PENDSE)
Member (Water Planning)
Central Water Commission

PREFACE

Design Engineers essentially need the design flood of a specific return period for fixing the waterway vis-a-vis the design HFL and foundation depths of bridges, culverts 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 though has the simplicity of relating the maximum flood discharge to the power of catchment area with constants. These forumlae do not take into account the basic meteorologic factor of storm rainfall intensity and 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.

Recognising the need to evolve a method for estimation of design flood peak of desired frequency, the committee of engineers headed by Dr. A.N. Khosla had recommended, in their report "Systematic and sustained collection of hydro-meteorological data at selected catchments in different climatic zones of India. The committee felt that design discharge should be the 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 characterstics obtained on the basis of design storm".

Economic constraints do not justify detailed hydrological and meteorological investigations át 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 needs long term discharge observations for the representative catchments for subjecting to statistical analysis to develop a regional flood frequency model. The other approach needs 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 at the representative catchment 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 Standards Organisation of the Ministry of Railways. Similarly the Ministry of Transport has undertaken the collection of data for 45 catchments through Central Water Commission since 1979. Such rainfall and runoff data was supplied to Hydrology(Small Catchments) Directorate of Central Water Commission and rainfall data alone 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 unit hydrographs of mostly 1-hr unit duration on the basis of data of rainfall, gauge and discharges collected during the monsoon season. The bridges and floods wing of RDSO has provided assistance as required from time to time in interpretation of data, removing inconsistencies and other additional information during analysis stage. Representative 1-hr. unit hydrographs have been obtained for each of the gauged catchments. The characterstics of the catchments and their unit hydrographs prepared for several catchments in a subzone 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 also carried out.

Studies of Rainfall-Depth-Duration-Frequency, point to areal ratios and time distribution of storm rainfall were carried out by Hydromet Cell of IMD and results were provided to Hydrology (SC) Dte., for preparing the full report for the subzone. The reports are approved by the Flood Estimation Planning and Coordination Committee (FEPCC) during their meetings. A "Foreword" as provided in the report by Member CWC recommended the extensive use of the report for estimation of design flood from small and medium catchments. The reports are published by the Central Water Commission.

Flood Estimation Reports for the following subzones have already been prepared, approved by FEPCC and 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)

14. Sone subzone-1(d) (1988)

The present report for Chambal subzone - 1(b) is based on the detailed rainfall and runoff studies of 19 representative catchments. The data at each of the 22 catchments was collected for a period varying from 1 to 10 years by Western and Central Railways under the guidance of R.D.S.O. Besides this, the data of 180 ordinary raingauge stations maintained by IMD/States alongwith data of 62 self-recording raingauge stations maintained by IMD/Railways has been made use of in preparation of this report.

The Chambal subzone- 1(b) 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 Rajasthan, M.P. and U.P. states based on design storm rainfall and synthetic unitgraph. The report is divided into five parts. The part I deals with the summary and contents of the approaches of estimation. Illustartive examples covering both the approaches are also given. General description of the subzone detailing locatons of gauging sites, river systems, rainfall, temperature and various types of soil are given in part II. It also brings out the SUH relations of the subzone along with the various regression equations for estimating Q_{25}, Q_{50} and Q_{100}. The storm studies carried out by IMD are dealt in part III of the report. The part IV is the portion where the utility of the report is described. The last part i.e. part V describes the limitations, assumptions and conclusions made in the report.

The report on subzone-1(b) is recommended for estimation of design flood from small and medium catchments varying in areas from 25 to 2500 sq. km. This report may also be used for catchment areas upto 5000 sq. km. judiciously after comparison loss rate values in the neighbouring catchments having more or less similar characteristics.

This report is a joint effort of Central Water Commission of Ministry of Water Resources, Research Designs & Standards Organisation of Ministry of Railways, Roads and Bridges wing of Ministry of Transport (Surface) and Hydromet Directorate of India Meteorological Department, Ministry of Science and Technology.

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

sd/-
(K.J.RAISINGHANI)
DIRECTOR, HYDROLOGY (SC) DTE.
CENTRAL WATER COMMISSION

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SYMBOLS AND ABBREVATIONS

SYMBOLS

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

A	Catchment Area in sq.km.
ARF	Areal Reduction Factor.
C.G.	Centre of Gravity
Cumecs	Cubic metres per second
cms	Centimetres
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.
E.R.	Effective Rainfall in cms.
Hr	Hour
H(SC),CWC	Hydrology (Small Catchments) Directorate, Central Water Commission, New Delhi.
I.M.D.	India Meteorological Department
In	Inches
Km	Kilometres
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.
M.O.S.T.	Ministry of Surface Transport (Roads Wing).
M	Metres
Min	Minutes
mm	Millimetres

Q_p	Peak Discharge of Unit Hydrograph in cubic metres per second.
Q_{25}, Q_{50} and Q_{100}	Maximum Flood Discharge with return periods of 25-yr, 50-yr and 100-yr respectively in cumecs
q_p	Peak Discharge of Unit Hydrograph per unit area in cumecs per sq. km.
R_{25}, R_{50} and R_{100}	Point Storm Rainfall Values with 25-yr, 50-yr and 100-yr return periods respectively in cm.
R.D.S.O.	Research Designs & Standards Organisation (Ministry of Railways), Lucknow.
S	Equivalent stream slope in m/km.
S.U.G.	Synthetic Unit Hydrograph
S.R.H. (D.R.H.)	Surface Runoff Hydrograph (Direct Runoff Hydrograph)
Sec	Seconds
Sq	Square
Sq. km	Square Kilometres, Km^2
T	Time Duration of Rainfall in hours
T_B	Base Width of Unit Hydrograph in hours
T_D	Design Storm Duration in hours
T_m	Time from the start of rise to the peak of Unit Hydrograph in hours
t_p	Time from the centre of Unit Rainfall Duration to the Peak of Unit Hydrograph in hours
t_r	Unit Rainfall Duration adopted in a specific study in hours
U.G.	Unit Hydrograph
W_{50}	Width of U.G. measured at 50% maximum Discharge Ordinate (Q_p) in hours.

W_{75} Width of the U.G. measured at 75% maximum Discharge Ordinate (Q_p) in hours.

W_{R50} Width of the rising side of U.G. measured at 50% of maximum Discharge Ordinate (Q_p) in hours.

W_{R75} Width of the rising side of U.G. measured at 75% of maximum Discharge Ordinate (Q_p) in hours.

% Percent.

< Cummation

PART - I

SUMMARY AND CONTENTS OF APPROACHES

1.0 Approaches for design flood estimation:

1.1.0 DETAILED SUH APPROACH AND ILLUSTRATED 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 & Number of sub-zone	Chambal 1(b)
ii) Name of site (i.e. point of study)	Rly.Br. 221
iii) Name of Rly Section	Guna-Maksi (WR)
iv) Name of Tributary	Chopan Nallah
v) Shape of catchment	Fan
vi) Location	Lat $24^{o}-31'-00"$
	Long $77^{o}-10'-08"$
vii) Topography	Moderate 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 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)	361.05 sq km
2) Length of the longest stream (L)	38.62 km
3) Equivalent stream slope (S)	3.01 m/km

Following methods are adopted for computation of slope(s)

(a) By Graphical Method

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 to replace the plotted 'L' section having different slopes such that the areas below and above the line with reference to origninal plot (of sloping lines) are equal. Then compute the slope (S) on this line.

(b) By Mathematical Calculation

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

Step-3:-Determination of Synthetic (1-hr.) Unitgraph Parameters

The following equations were used to compute the unit-graph parameters with the known values A,L and S as under

i) $t_p = 0.339/(L/\sqrt{S})^{0.826}$

$= 0.339\,(22.26)^{0.826}$

$= 4.39$ hrs

(rounded off to 4.50 hrs.)

ii) $q_p = 1.251\,(tp)^{-0.610}$

$= 1.251\,(4.5)^{-0.610}$

$= 0.499$ Cumecs per sq km

iii) $W_{50} = 2.215\,(q_p)^{-1.034}$

$= 2.215(0.499)^{-1.034}$

$= 4.54$ hrs

iv) $W_{75} = 1.190\,(q_p)^{-1.057} = 1.190(0.499)^{-1.057}$

$= 2.48$ hrs.

v) $W_{R50} = 0.834\,(q_p)^{-1.077} = 0.834(0.499)^{-1.077}$

$= 1.76$ hrs.

vi) $W_{R75} = 0.502\ (q_p)^{-1.065} = 0.502(0.499)^{-1.065}$
$= 1.05$ hrs.

vii) $T_B = 6.662(t_p)^{0.613} = 6.662(4.5)^{0.613}$
$= 16.75$ hrs.
Say 17.00 hrs.

viii) $t_m = t_p + t_r/2 = 4.5+0.5 = 5.00$ hrs

ix) $Q_p = q_p \times A = 0.499 \times 361.05 = 180.16$ cm
Rounded off = 180.50 Cumecs.

Step-4:-Drawing of 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 and multiplied by tr (=1) i.e <Qi ti = 1002.9 m^3/s as shown in Fig A-2 and compared with the volume of 1.00 cm Direct Runoff Depth over the catchment with the Formula <Qi*ti = A.d/ti*0.36

Where A = Catchment area in Sq. Km.

d = 1.0 cm depth

ti = tr (the unit duration of the UG) = 1 hr.

$$Qi*ti = \frac{A * d}{0.36 * tr} = \frac{361.05 * 1}{0.36 * 1} = 1002.90$$

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

In case the <Qiti for the unithraph drawn is higher or lowere than the valume worked out by the above formulae, then preferably falling limb and/or rising limb may be suitably modified keeping the points of the synthetic parameters as per the caluculation to get the correct volume of the unitgraph.

Step-5: Estimation of Design Storm Duration

The Design Storm Duration $(T_D) = 1.1 * (tp)$
$= 1.1 * 4.5$
$= 4.95$ say 5.0 hrs

Adjusting the design storm duration to nearest full hour, the adopted design storm duration (T_D) is 5.0 hrs.

Step-6: Estimation of Point Rainfall and Areal Rainfall

The catchment under study was located on plate - 9 showing 50-yr 24-hr point rainfall. The point rainfall is found to be 29.0 cm. Conversion factor of 0.633 was read from Fig - 10 for converting the 50-yr 24-hr point rainfall to 50-yr 5-hr point rainfall (since T_D = 5 hrs).

50-yr 5-hr point rainfall = 29.0 * 0.633 = 18.36 cm.

Areal reduction factor of 0.726 corresponding to a catchment area of 361.05 sq.km for T_D = 5-hr. was interpolated from Table 6 or Fig A-2 or Fig 11(a) for conversion of point to areal rainfal. Hence 50-yr 5-hr areal rainfall =18.36 x 0.726 cm = 13.33 cm.

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

Step-7: Time Distribution of Areal Rainfall:

50-yr 5-hr areal rainfall = 13.33 cm was distributed with the distribution coefficients (col. 5 of Table A-3) or from mean average time distribution curve for storms of 4-6 hrs in Fig 12 corresponding to 5-hrs to get 1-hr rainfall increments as follows:

Duration 1	Distribution coefficient 2	Storm Rainfall (cms) 3	Hourly rainfall increments 4
1	0.63	8.40	8.40
2	0.82	10.93	2.53
3	0.92	12.26	1.33
4	0.98	13.06	0.80
5	1.00	13.33	0.27

Step-8: Estimation of Effective Rainfall Units:

A design loss rate of 0.17 cm/hr as recommended has been adopted.

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

Time hrs	Rainfall increments (cms)	Design loss rate cm/hr	Rainfall excess (col2-col3) (cms)
1	2	3	4
1	8.40	0.17	8.23
2	2.53	0.17	2.36
3	1.33	0.17	1.16
4	0.80	0.17	0.63
5	0.27	0.17	0.10

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

Step-9: Estimation of Base Flow

The design base flow is computed by the following formulae

$$\text{ii)} \quad q_p = 0.207/(A^{0.290})$$

$$= 0.207/(361.05)^{0.290}$$

$$= 0.17 \text{ Cumecs per sq km}$$

Total Base Flow = 361.05*0.17
= 14.44 cumecs.

Step-10: 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 (hrs)	U.G. ordinate cumecs	1-hr effec. rainfall (cms)	Direct Runoff (cumecs)
1	2	3	4
1	139.00	1.16	161.24
2	180.50	8.23	1485.51
3	153.00	2.36	361.08
4	115.00	0.63	72.45
5	82.50	0.10	8.25
		Total	2088.53
		Base Flow	14.44
		50-yr Flood Peak	2102.97

Step-11: <u>Computation of Design Flood Hydrograph</u>

The 1-hr effective rainfall sequence shown in col. (3) of Table in Step-10 was reversed to obtain the critical sequence as shown below:

Time in hrs	Critical 1-hr effective rainfall sequence cms
1	0.10
2	0.63
3	2.36
4	8.23
5	1.16

For computation of design flood hydrograph, the U.G. ordinates for 1-hr interval were tabulated in col(2) of Table A-4 against time (hrs) in col. (1). The critical sequence of 1-hr effective rainfall units were entered in col.3 to 7, horizontally as shown in Table A-4. 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-hrs U.G. ordinates in col. (2) and direct runoff values were entered in vertical columns against each unit with a successive lag 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 (7). The direct runoff were added horizontally and the total direct runoff is shown in col. (8). The total base flow of 14.44 m^3/sec. was entered in col. (9), col. (10) gives the addition of col. (8) and (9) to get the design flood hydrograph ordindates. The total discharge in col. (10) were plotted against time in col. (1) to get the design flood hydrograph as shown in Fig A-3.

1.2.0 SIMPLIFIED APPROACH AND ILLUSTRATIVE EXAMPLE

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.

1.2.1 25-YR, 50-YR, AND 100-YR. FLOOD FORMULAE (SIMPLIFIED APPROACH)

In the simplified approach, the 25-yr, 50-yr and 100-yr flood peak is only estimated on the basis of regression relationship. Flood peak, with physiographic parameters and corresponding 25-yr, 50-yr and 100-yr TD-hr areal rainfall as read from the isopluvial maps (plates 9,10,11) supplied by the I.M.D. are obtained by substituting the corresponding parameters in the emperical relation developed on the basis of regression analysis. 25-yr, 50-yr and 100-yr flood values for each of the 19 gauged catchment for different sizes were computed by detailed approach. Series of Q_{25}, Q_{50} and Q_{100}, for the 19 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:

$$Q_{25} = 2.55\ (A)^{0.904}\ (L)^{-0.384}\ (S)^{0.272}\ (R_{25})^{0.960} \qquad r = 0.997$$

$$Q_{50} = 2.315\ (A)^{0.918}\ (L)^{-0.415}\ (S)^{0.279}\ (R_{50})^{1.010} \qquad r = 0.997$$

$$Q_{100} = 2.54\ (A)^{0.911}\ (L)^{-0.391}\ (S)^{0.271}\ (R_{100})^{0.964} \qquad r = 0.997$$

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

A is the 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).

L is the length of the longest main stream of the catchment upto the site.

R_{25}, R_{50} and R_{100} are design storm areal rainfall in cm for a design storm duration of

$$T_D = 0.539\ (L/\sqrt{S})^{0.724}$$

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 values (Q_{25}, Q_{50} and Q_{100}) by both the respective derived formulae and the detailed approach for the 19 catchments shown in the following table are within tolerable limits of + or - 15%.

	Variation (percentage) (+)	Range (percentage) (-)
Q_{25}	0.50 to 12.41	0.85 to 15.19
Q_{50}	1.13 to 11.89	1.28 to 14.38
Q_{100}	1.66 to 11.60	1.36 to 14.70

The flood formulae for computation of 25-yr, 50-yr and 100-yr flood may be applied only for preliminary designs. A statement showing the magnitude of 25-yr, 50-yr & 100-yr return period flood for al the bridges used in the analysis are given at Table 8.

ILLUSTRATIVE EXMAPLE

Illustrative example for estimation of 25-yr, 50-yr and 100-yr flood for catchment area upto Rly. Br. No. 221 is considered for solution of the problem by flood formulae. The physiographic and meteorologic parameters for the catchment under study are:

$A = 361.05$ sq km $S = 3.01$ m/km

$L = 38.62$ km

$T_D = 0.539\ (L/\sqrt{S})^{0.724}$

$= 0.359\ (38.62/\sqrt{3.01})^{0.724} = 5.09$ say 5.00 hrs.

$R_{25} = 11.48$ cm, $R_{50} = 13.33$ cm, $R_{100} = 15.17$ cm

$Q_{25} = 2.55\ (A)^{0.904}\ (L)^{-0.384}\ (S)^{0.272}\ (RT)^{0.960}$

$= 2.55\ (361.05)^{0.904}\ (38.62)^{-0.384}\ (3.01)^{0.272}\ (11.48)^{0.960}$
$= 1812.53$ cumecs.

$Q_{50} = 2.315\ (361.05)^{0.918}\ (38.62)^{-0.415}\ (3.01)^{0.279}\ (13.33)^{1.010}$

$= 2114.62$ cumecs.

$Q_{100} = 2.54\ (361.05)^{0.911}\ (38.62)^{-0.391}\ (3.01)^{0.271}\ (15.17)^{0.964}$

$= 2425.38$ cumecs

The precentage 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 -0.85, -0.55 and -0.75 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.

1.3.0 COMPUTATION OF DESIGN H.F.L. CORRESPONDING TO DESIGN FLOOD

1.3.1 GENERAL

The design engineer has to determine the design High Flood Level corresponding to adopted design flood for the bridges and cross drainage structures under natural and constricted conditions. This elevation is very important in the analysis for foundations, scour free board, formation levels, hydraulic forces etc.

1.3.2 STAGE DISCHARGE RELATIONSHIP

Stage discharge relationship is represented by stage vs. discharge rating curve of a river at the point of study. The most acceptable method for establishing stage discharge rating curve is based on observed gauges and discharges covering satisfactorily the lower to upper elevation ranges. Stage discharge relation defines the complex interaction of channel characteristics including cross sectional areas, shape, slope and roughness of bed and banks. The permanent stage discharge relation is a straight line or a combination of straight lines on a logarthmic plotting depending on the channel configuration; a single straight line for a single well defined channel and a combination of two straight lines for the main channel with its berm portions. The stage discharge relation may be considered more accurate depending on the reliable and adequate observed gauge and discharge data of the river at the point of study. The gauge dishcarge rating curve so determined may be used for fixing the design HFL corresponding to design flood by extrapolation if necessary.

While in the absence of observed gauge and discharge data at the point of study (bridge or cross-drainage structures location), synthetic gauge discharge rating curve has to be constructed by Area-Velocity Method, using the river cross section, slope data and nature of the cross-section. The velocity is computed by the Manning's formula.

Computation of H.F.L. is generally done with the help of Manning's formula in which Manning's 'N' is a very important factor affecting the discharge of a river or Nalla. In applying the Manning's formula the greatest difficulty lies in the determination of the roughness coefficient (N). In reality, the value of N is highly variable and depends on a number of factors. In selecting a proper value of N for various design conditions, a basic knowledge of the factors affecting Manning's roughness coefficient shoud be found very useful. The factors that exert the greatest influence upon the coefficient of roughness in natural channels are surface roughness, vegetation, channel irregularity, channel alignments, silting and scouring, obstruction, size and shape of channel, stage and discharge, seasonal change and suspended material and bed load.

The various values of the roughness co-efficient for different types of channel are given in Table 5.6 "Open Channel Hydraulics" 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 orrifice formula of hydraulics is generally used depending on the upstream and downstream depths to estimate the revised design HFL under constricted conditions.

1.3.3 BACK WATER EFFECT

Sometimes it happens that the cross section of river or nalla on the downstream side of across 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 hene there will be heading up of water in its upstream side which ultimately efffects 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.

1.3.4 HYDRAULIC GRADIENT

In the absence of any observed levels of water profilies 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 300mt. upstream and downstream of the crossing site.

1.3.5 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 flood 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.

PART - II

GENERAL DESCRIPTIONS OF CHAMBAL SUBZONE DATA COLLECTION AND ANALYSIS

2.1.0 GENERAL DESCRIPTION OF THE SUB ZONE

2.1.1 LOCATION

The Chambal subzone - 1(b) lies approximately between 73^{0}-20 and 79^{0} longitude (East) and 22^{0}-30 and 27^{0}-15´ latitude (North). Plate-1 shows the location of Chambal Subzone. Annexure - 1 shows the list of sub-zones in India.

The Chambal subzone is bounded on the north by Upper Indo-Ganga sub zone 1(e) and on the east by Betwa subzone 1(c), on the south by Lower Narmada and Tapi subzone 3(b) and Upper Narmada and Tapi subzones-3(c) and on the west by Luni Subzone 1(a) and Mahi and Sabarmati Subzone-3(a). This covers major parts of Rajasthan and Madhya Pradesh and a small portion of Uttar Pradesh. The important towns and cities in the subzone are Indore, Ujjain, Ratlam, Guna, Gwalior in Madhya Pradesh and Jaipur, Udaipur, Chitorgarh, Nasirabad, Kota, Swao Madhopur in Rajasthan.

2.1.2 RIVER SYSTEM

Plate-2 depicts the river system of the Chambal subzone. Chambal, which is the principal tributary of the Yamuna, is the main river of the subzone. Other important rivers of the subzone are Banas from the left bank and Kali Sindh, Parbati, Kunu and Kunwari from the right bank.

The drainage areas of the river system in Chambal subzone are as under:

S.No.	Name of river/tributary	Drainage area (sq.km.)
1	2	3
1.	Main Chambal & local streams	46,073.00
	Left Bank Tributary	
	(1) Banas	48,577.00
	Right Bank Tributaries	
	(i) Kali Sindh	25,741.00
	(ii) Parbati	14,122.00
	(iii) Kunu	4,507.00
	(iv) Kunwari	7,610.00
	Total area of Chambal Basin	1,46,630.00

2.1.3 TOPOGRAPHY AND RELIEF

Plate - 3 shows the general topography of Chambal subzone - 1(b). The river Chambal rises in the Vindhya range near

Mhow in the Indore district of Madhya Pradesh at an elevation of 854 m. Thereafter it flows in a generally northernly direction for a length of about 320 km in Madhya Pradesh upto its border with Rajasthan. The river than flows through Rajasthan and receives its right bank tributaries Kali Sindh and Parbati. After its confluence with Parbati, the Chambal forms a common boundary brtween Madhya Pradesh and Rajasthan. Banas, the major left bank tributary joins the Chambal in this reach near the village Rameshwar. The river thereafter forms the common boundary between Madhya Pradesh and Uttar Pradesh before its enters Uttar Pradesh. After flowing for about 46 km in UP, the Chambal outfalls into the Yamuna. The total length of the river from its source to confluence with Yamuna is about 960 km of which 320 km are in Madhya Pradesh, 226 km in Rajasthan, 251 km from the common boundary between Madhya Pradesh and Rajasthan, 117 km form the common boundary between Madhya Pradesh and Uttar Pradesh and the balance 46 km area in Uttar Pradesh.

From the source down to its junction with Yamuna, the Chambal has a total fall of about 732 m of which 244 m is in the first few km and 122 m in a distance of about 100 km from Chourashigarh fort to Kota city. For the rest of its course, the river passes through the flat fertile areas of Malwa Plateau and later in Gangetic Plains.

2.1.4 RAINFALL

Plate - 4 shows the normal annual rainfall of the Chambal subzone and the histograms of normal monthly rainfall at Jaipur, Udaipur, Gwalior, Indore. The south-west monsoon causes the rainfall in the subzone from the middle of June to September. The normal annual rainfall varies from 500 mm to 1400 mm. The rainfall is more in Madhya Pradesh and less in Rajasthan.

2.1.5 TEMPERATURE

Plate-5 shows the normal annual temperature in the subzone alongwith the histograms showing the minimum, maximum and mean monthly temperature at Jaipur and Indore. In areas of Madhya Pradesh the temperature is between $22.5^{0}c$ to $25^{0}c$ except Gwalior where temperature is between $25^{0}c$ to $27.5^{0}c$. In western parts of Rajasthan, the temperature is between $25^{0}c$ to $27.5^{0}c$. Mean monthly temperature starts rising from March with its peak during April and May. Again the mean monthly temperature starts falling from June and reaches the minimum by December and January.

2.1.6 SOIL

Plate-6 shows the soil classification in the Chambal subzone. There are mainly three type of soil viz medium black soil (38%), mixed red and black soil (21%), alluvial soil (29%). Other types of soil are red and yellow soil, gray-brown soil, deep-black soil, laterite soil and skeletal soil, as can be seen from plate-6.

2.1.7 LAND USE

Plate - 7 depicts the land use in the Chambal subzone. The arable land in the subzone is about 52%,forest cover 23%, grass land and scrub 19%. The remaining portions are waste land, urban area.

2.1.8 COMMUNICATIONS

2.1.8.1 Railway sections

The following railway sections partly or fully traverse the area of this subzone - 1(b).

1 AJMER - INDORE VIA CHITORGARH - RATLAM
2 AJMER - UDAIPUR VIA CHITORGARH
3 BARI SADRI - MARWAR VIA MAOLI
4 JAIPUR - AJMER
5 JAIPUR - BANDIKUI
6 JAIPUR - TOD RAI SINGH
7 JAIPUR - INDORE VIA KOTA, NAGDA
8 GANGAPUR - SAWAI MADHOPUR
9 KOTA - GUNA
10 GWALIOR - SHEOPUR
11 DHOLPUR - GWALIOR
12 GUNA - INDORE VIA MAKSI
13 MAKSI - BHOPAL
14 NAGDA - INDORE VIA UJJAIN - DEWAS
15 AGRA - UJJAIN
16 DHOLPUR - BHIND

2.1.8.2. Highways

The following major highways partly and fully pass through the subzone :

1. JAIPUR - AJMFR
2. JAIPUR - AGRA
3. JAIPUR - BHOPAL VIA KOTA - BIAORA
4. JAIPUR - FATEHPUR
5. DHOLPUR - INDORE VIA GWALIOR - GUNA
6. JAIPUR - DELHI

2.2.0 DESIGN FLOOD - DATA COLLECTION AND ANALYSIS

2.2.1 DESIGN FLOOD

The Khosla Committee of Engineers had recommended a design flood of 50-year return period for fixing the optimum waterway of the bridges. The design flood in other words may be defined broadly as a rational estimate of flood discharge for the design of safe and economic structure across a river. The committee of Engineers had suggested that 50-year flood may be considered as the maximum observed discharge from the yearly peak discharge records available for not less than 50-years. Where the yearly peak discharge records are not much less than 50 years, the 50-year flood may be obtained from the probability curve of peak discharges. In the absence of adequate data of peak discharges, storm rainfall and runoff data for the selected catchments shall be collected for a required period and detailed studies carried out to derive the unitgraph 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 produces a flood of the same return period (50-year) as that of storm rainfall.

2.2.2 DATA REQUIRED

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

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

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

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

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

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

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

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

2.2.3 DATA COLLECTED

The Western and Central Railways under the supervision and guidance of Research Designs and Standards Organisations (RDSO) had observed and collected the required data in Section 2.2.2 for 22 catchments in the Chambal subzone 1(b) for a period ranging from 1 to 10 years. The size of the gauged catchments vary from 26.18 sq.km to 5729.08 sq.km. Concurrent rainfall, gauge and discharge data for 115 bridge catchment years from 22 catchments were available for study.

The locations of the gauging sites are shown in Plate-2. India Meteorological Department has collected the rainfall data of additional raingauge stations maintained by IMD and states falling in Chambal subzone-1(b). Central Water Commission (CWC) has also prepared the detailed plans of gauged catchments showing information in 2.2.2 (iv). Table-1 shows the names of streams, railway bridge numbers with railway sections, their catchment areas, number of raingauge stations and the period of concurrent rainfall, gauge and discharge data. R.D.S.O. has made available the data collected to CWC and IMD for carrying out the studies.

2.3.0 ANALYSIS FOR OBTAINING 1-HOUR SYNTHETIC UNITGRAPH

The sysnthetic unitgraph is a unitgraph of unit duratiom for a catchment under study obtained from the relations established between the physiographic and unitgraph parameters of the representative catchments in a hydro-meteorologically homogenous region. In order to obtain a synthetic unitgraph the following steps have to be followed:

i) Analysis of physiographic parameters of the catchments.

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

iii) Selection of flood and corresponding storm events.

iv) Computation of hourly catchment rainfall.

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

vi) Computation of infiltration loss (ϕ-index) and 1-hourly rainfall excess unit.

vii) Derivation of 1-hourly unitgraph.

viii) Drawing of representative unitgraphs and measuring the parameters.

ix) Establishing relationships between physiographic and representative unitgraph parameters.

x) Derivation of 1-hour synthetic unitgraph using such equations for an ungauged catchment.

The above steps are briefly described as under:

2.3.1 PHYSIOGRAPHIC PARAMETERS OF THE CATCHMENT

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

2.3.1.1 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.

2.3.1.2 Length of the Main Stream (L)

This implies the Longest length of the main river from the farthest water shed boundary of the catchment area to the gauging site.

2.3.1.3 Equivalent Stream Slope (S)

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

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

where L_i = Length of the ith segment in km.

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

L = Length of the longest stream as defined in section 2.3.1.2 in km.

The physiographic parameters A, L, and S were estimated only for 19 catchments which were found suitable for analysis. These parameters are shown in Table-2.

raphs by iterative methods. The iterations were carried out till the observed and estimated direct runoff hydrographs compared favourably. Normally 5 to 15 unitgraphs are derived for each of the 19 catchments considered.

2.3.8 DRAWING OF REPRESENTATIVE UNITGRAPHS AND MEASURING THEIR PARAMETERS

The representative unitgraph is the unitgraph which reproduces in reasonable limits, the direct surface runoff hydrographs corresponding to their rainfall excess of the storm from which it has been obtained. Representative 1-hour unitgraphs were drawn from a set of superimposed 1-hour unitgraphs for each of the 19 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 t_r, t_p, T_m, Q_p, q_p, W_{50}, W_{75}, W_{R50}, W_{R75}, and T_B. These parameters for 19 catchments are listed in Table -3.

2.3.9 ESTABLISHING RELATIONSHIPS BETWEEN PHYSIOGRAPHIC AND REPRESENTATIVE UNITGRAPH PARAMETERS

Following simple model was adopted for establising the relationships between these parameters.

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

where

Y = Dependent variable
X = Independent variable
C = A constant
P = An exponent
From above equation, 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.

Various trials of relationship between the physiographic parameters (Table-2) and one of the unitgraph parameters (Table-3) for 19 gauged catchments considered suitable for the studies were made. The relationship between physiographic parameters $(L/\sqrt{S})$ and U.G. parameter tp was found to be significant. Afterwards t_p was related to unit peak discharge of the U.G. (q_p) and q_p was related to various U.G. parameters like W_{50}, WR_{50}, WR_{75}. The T_B could be significantly correlated to tp. The priniciple of least squares was used in the regression analysis to get the relationships in the form of equation 2.3.9.1 to predict the parameters of the Synthetic unitgraph in an unbiased manner. The following relationships have been derived for estimating the 1-hr unitgraph parameters in the subzone - 1(b).

Relationships 1	Equation No. 2	Fig.No. 3	correlation Coefficient (r) 4
$t_p = 0.339(L/\sqrt{S})^{0.826}$	2.3.9.1	3	0.958
$q_p = 1.251(tp)^{-0.610}$	2.3.9.2	4	0.817
$W_{50} = 2.215(qp)^{-1.034}$	2.3.9.3	5	0.984
$W_{75} = 1.191(qp)^{-1.057}$	2.3.9.4	6	0.968
$W_{R50} = 0.834(qp)^{-1.077}$	2.3.9.5	7	0.948
$W_{R75} = 0.502(qp)^{-1.065}$	2.3.9.6	8	0.932
$TB = 6.662(tp)^{0.613}$	2.3.9.7	9	0.877
$T_m = t_p + t_r/2$	2.3.9.8		
$Q_p = q_p \times A$	2.3.9.9		

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 A, L and S.

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

Considering the hydro-meteorological homogeneity of subzone-1(b), the relations established between physiographic and unitgraph parameters in section 2.3.9 for 19 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 A, L and S are determined from the catchment area plan $L/\sqrt{S}$ is calculated.

ii) Substitute $L/\sqrt{S}$ in the equation 2.3.9.3

$t_p = 0.339(L/\sqrt{S})^{0.826}$ to obtain t_p in hours. Then

$T_m = t_p + tr/2 = (t_p + 1/2)$ hours.

iii) Substitute t_p in the equation 2.3.9.4 to obtain q_p in cumces/per sq km

$$q_p = 1.215/(t_p)^{0.610}$$

and $Qp = q_p \times A$ in cumecs.

iv) Substitute the value of q_p in the following equations 2.3.9.5 to 2.3.9.8 to obtain W_{50}, W_{75}, W_{R50} and W_{R75} in hours.

$$W_{50} = 2.215/(q_p)^{1.034}$$

$$W_{75} = 1.191/(q_p)^{1.057}$$

$$W_{R50} = 0.834/(q_p)^{1.077}$$

$$W_{R75} = 0.502/(q_p)^{1.065}$$

v) Substitute the value of t_p in equation 3.9.9

$T_B = 6.662\ (t_p)^{0.613}$ to obtain T_B in hours.

vi) Plot the parameters of 1-hour unitgraph viz. T_m, T_B, Q_p, W_{50}, W_{75}, W_{R50}, and W_{R75}, on a graph paper as shown in illustrative Fig. 2 and sketch the unitgraph through these point. The discharge ordinates (Q_i) of graph at 1-hour (t_r)

interval are summed up and the direct runoff depth in cm. is obtained from the following equation.

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

where d = depth of direct runoff in cm.
Qi = discharge ordinates at 1-hour interval (cumecs)
A = Catchment area in sq.km.

In case the depth of runoff (d) for the synthetic unitgraph drawn is not equal to 1.0 cm, then suitable modification may be made in falling and rising limbs of the unitgraph to obtain 1.0 cm depth of runoff. The shape of the modified unitgraph should be kept smooth.

2.3.11 Design Loss Rate

Direct (surface) runoff is the end product of storm rainfall after infiltration into Surface soils, sub-surface and ground besides abstractions like evaporation, evapotranspiration, soil moisture and filling up of surface depressions. It is difficult rather impossible to record these various parameters at various representative locations in the catchment except by the analysis of observed storm rainfall and flood events. Conversion of gross storm rainfall units into effective rainfall units for application to unitgraph is normally done by substraction of constant loss rate (Ø-index) for the catchment, even though the loss rates in the catchments, a complex phenomena, vary due to soil conditions, soil cover complex and topography alongwith temporal and spatial variations of storm rainfall.

Following method of estimating design loss rate was adopted:

Constant loss rates were estimated based on various selected observed storm rainfall and flood events of reasonably higher magnitude for derivation of unitgraphs. About 144 flood events were analysed for 19 bridge catchments. Number of flood occasions for each bridge catchment under different loss rate ranges at intervals of .2mm/hr were tabulated. All flood events have been considered for estimating the model loss rate shown in Table-4.

The modal value of loss rate of 0.17 cm/hr is recommonded for adoption as Design Loss Rate.

2.3.12 DESIGN BASE FLOW

Studies were carried out relating average base flow rate (q_b) based on analysed flood events in cumecs/sq km for the gauged catchments with their catchment area (A) in sq km. The following relationship was derived:

$$q_b = 0.207(A)^{-0.290} \qquad ....r = 0.634$$

The above base flow rate formulae may be used to compute base flow rate for ungauged catchments. The total base flow is the product of catchment area (A) is sq km upto the point of study with the base flow rate (q_b) in cumecs/sq km.

Number of floods occations for 19 bridge catchments under different base flow ranges are tabulated as shown in Table - 5.

PART III

STORM STUDIES

3.1.1 DESIGN STORM INPUT

The areal distribution and time distribution of the rainfall are two main meteorologcal 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).

3.1.2 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). The design storm duration (T_D) for a catchment adopted equal to $1.1*t_p$ (time basin lag (t_p) of 1-hr synthetic unit hydrograph) for this subzone based on sample studies.

$$T_D = 0.539(L/\sqrt{S})^{0.724}$$

The design storm duration T_D obtained by the above formula may be rounded off to the nerest full hour.

3.1.3 RAINFALL DEPTH-DURATION-FREQUENCY ANALYSIS

India Meteorological Department have conducted this study utilizing the data of 11 Self Recording Raingauge Stations and 13 Ordinary Raingauge Stations maintained departmentally, 167 Ordinary Raingauge Stations belonging to the States of Madhya Pradesh, Uttar Pradesh, Rajasthan and Gujrat and 51 Self Recording Raingauge Stations maintained by Railways in their 11 bridge catchments falling in Subzone 1(b).

The annual maximum series of one-day rainfall were formed for each of 180 ordinary raingauge stations in and around the sub-zone using the rainfall records of 50 to 80 years. The annual extreme values series were subjected to frequency analysis by Gumbel's extreme value distribution and the rainfall estimates for one-day corresponding to 25, 50 and 100 year return periods were computed. The daily values of 25-years, 50 years and 100 years rainfall estimates were converted into 24 hour 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 sub-zone were plotted on base maps and isopluvial maps of 25-year, 50-year and 100-year return period were drawn. These maps are shown in plates 8, 9 and 10.

The hourly rainfall data recorded at 11 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 duration from 1 to 18 hours for each of the 11 stations were converted into ratios with respect of 24 hours estimates for each of the above mentioned return periods. Averaged ratios for various durations for each return period were computed for the whole sub-zone. It was noticed that for a specified duration the average ratios, except for return period less then 5-years were independent of return period. The averaged ratios for various durations for converting 24-hour rainfall into short duration rainfall are given below :-

Duration	Ratio
1	0.35
3	0.53
6	0.67
9	0.74
12	0.80
15	0.85
18	0.90
24	1.00

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

Fig. 10 shown the ratios for short duration point rainfall with respect to 24-hr point rainfall.

The short duration rainfall estimates for various short duration (1,3,6,9,12,15 & 18 hrs) 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 period can be obtained [illegible] 8, 9 & 10 and the short duration rainfall estimates* from Pl 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 atselected stations in the subzone is at Table - 7.

3.1.4 POINT TO AREAL RAINFALL

The short duration rainfall data of 11 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-year 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 station in the catchment. The areal rainfall series thus obtained was subjected to frequency analysis of 2-year areal rainfall depths for specified durations were computed. The percentage ratio of 2-year areal rainfall to 2-year representative point rainfall for the catchment was calculated and plotted against the area of the catchment for various durations. The best fit curves were drawn for specified durations on the points obtained for all the catchments. Fig. 11(a) to 11(b) give the curves for conversion of point rainfal into areal rainfall for 1,3,6,12 and 24 hours. The areal reduction factor (ARF) at different intervals of catchment areas for the above durations are given in Table 6.

3.1.5 TIME DISTRIBUTION STUDIES

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

1163 rain storms of various durations upto 24 hours occurring in various parts of the subzone were analysed based on 104 station's 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.

3.1.6 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:

Step-1: Estimate $T_D = 0.539(L/\sqrt{S})^{0.724}$ (round off the nearest full hours) by substituting the known values of L and S for the catchment under study.

Step-2: Locate bridge catchment under study on the 50-yr, 24-hr isopluvial map (plate-9) and obtain the 50-yr 24-hr point rainfall value in cms. For catchment covering more than one isohyte, 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 the given values of catchment area and T_D -hr duration from Table-6 or by interpolation from Fig. 11(a) and 11(b) in section 3.1.4.

Step-5: Apply the cumulative percentage of total rainfall against the cumulative percentage of storm duration curves in Fig. 12 or from Table A - 3 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.

Step-7: Rearangement of rainfall excess values in a specific sequence depending upon the necessity. (Peak only or full hydrograph)

PART IV

UTILITY OF THE REPORT

4.1.0 ESTIMATION OF DESIGN FLOOD FOR AN UNGAUGED CATCHMENT

The following procedure is recommonded:

Step-1 Determine the 1-hr synthetic unitgraph vide section 2.3.1.

Step-2 Determine the design storm rainfall input vide section 3.1.1 to 3.1.6.

Step-3 Adopt the design loss rate as recommended vide section 2.3.11.

Step-4 Obtain the hourly effective rainfall units upto the design storm duration T_D by subtracting the design loss rate from the hourly effective rainfall units vide section 3.1.6.

Tabulate the S.U.G. ordinates obtained from Step-1 at 1-hour interval.

Arrange the effective rainfall values 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 valuesas tabulated above gives the 50-yr flood peak value after addition of base flow in Step-8 given below.

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-hr 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 sucessive 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 2.3.12. Multiply base flow rate in cumecs/sq.km with the catchment areas under study to get the total base flow.

Step-9 Add the total base flow to the direct runoff ordinates at 1-hr interval in Step-7 to get the 50-yr flood hydrograph. Plot the hydrograph.

Likewise 25-yr flood and 100-yr flood hydrographs are computed following the above steps in section 3.1.6 and 4.1.0 corresponding the 25-yr and 100-yr storm rainfall for design storm duration $T_D = 1.1\ t_p$.

4.2.0 OTHER PURPOSES

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

i) Small Dams

The Indian Standard - gudelines for fixing spillway capacity of Dams under clauses 3.1.2 and 3.1.3 of IS :11223 - 1985 recommends 100-yr 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 7.5 m to 12 m. The report may be made use of for estimation of 100-yr flood for safety of small dams. 100-yr flood may be estimated using the modal loss rate of 0.17 cm/hr.

ii) Minor Cross Drainage Works

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 increase afflux for the design of waterway of minor cross drainage works. The report may be made use of for estimation of 25-yr 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.

PART V

ASSUMPTIONS, LIMITATIONS AND CONCLUSIONS

5.1.0 **Assumptions**

5.1.1 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.

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

5.2.0 **Limitations**

5.2.1 The data of 19 catchments has been considered for developing a generalised approach for a large sub-zone, however, for more reliable relationships the data for more suitable catchments would be desirable.

5.2.2 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.

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

5.3.0 **Conclusions**

5.3.1 The methodology for estimating the design flood of 50-yr return period incorporated in the body of the report is recommended for adoption, which also holds good for 25-yr flood and 100-yr flood.

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

5.3.3 The flood formulae with different return periods shall be used only for preliminary design. However, for final design, the design flood shall be estimated using the detailed approach in illustrative example under Part-I.

5.3.4 Formulae for fixing the linear waterway of cross drainage structures on streams in Chambal subzone 1(b) may be used at the discretion of the design engineer.

5.3.5 25-yr, 50-yr and 100-yr flood may be estimated using design loss rate of 0.17 cm/hr.

5.3.6 The report is applicable for the catchment area ranging from 25 sq km to 2500 sq km. Further the report may be used for large 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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ANNEXURE - 1

LIST OF HYDRO-METEOROLOGICAL SUBZONES

Subzone	Name of subzone	River Basins included in the subzone
1	2	3
1(a)	Luni	Luni river, Thar (Luni and other rivers of Rajasthan and Kutch and Banas river).
1(b)	Chambal	Chambal river.
1(c)	Betwa	Sind, Betwa and Ken rivers and other South Tributaries of Yamuna.
1(d)	Sone	Sone and Tons rivers and other South Bank Tributaries of Ganga.
1(e)	Upper Indi-Ganga Plains	Lower portion of Indus, Ghaggar Sahibi Yamuna, Ganga and Upper portion of Sirsa, Ramganga, Gomti and Sai river.
1(f)	Middle Ganga Plains	Middle portion of Ganga, lower portion of Gomti, Ghagra, Gandak, Kosi and middle portion of Mahanadi Basin.
1(g)	Lower Ganga Plains	Lower portion of Ganga, Hoogli river system and Subarnarekha.
2(a)	North Brahmaputra	North Bank Tributaries of Brahmaputra river and Balason river.
2(b)	South Brahmaputra	South Bank Tributaries of Brahmaputra river.
2(c)	Barak	Barak, Kalden and Manipur rivers.
3(a)	Mahi and Sabarmati	Mahi and Sabarmati including Rupen and Mechha Bhandar, Czat Shetaranji rivers of Kathiawar Peninsula.
3(b)	Lower Narmada and Tapi	Lower portion of Narmada Tapi and Dhadhar rivers.

3(c)	Upper Narmada and Tapi	Upper portion of Narmada and Tapi rivers.
3(d)	Mahanadi	Mahanadi, Baitarani and Brahmani rivers.
3(e)	Upper Godavari	Upper portion of Godavari Basin.
3(f)	Lower Godavari	Lower portion of Godavari Basin except coastal region.
3(g)	Indravati	Indravati river.
3(h)	Krishna	Krishna and Pennar rivers except coastal region.
3(i)	Kaveri	Kaveri, Palar and Ponnaiyar rivers(except coastal region).
4(a)	Upper Eastern Coastal Region	East flowing coastal rivers, between deltas of Mahanadi and Godavari rivers.
4(b)	Lower Eastern Coastal Region	East flowing coastal rivers, Manimuther, South Pennar, Cheyyar, Palar, North Pennar, Munneru, Palleru, Gundalakama and Krishna Delta.
4(c)	South Eastern Coastal Region	East flowing coastal rivers Manimuther, Vaigai, Arjuna, Tamraparni.
5(a)	Konkan Coastal Region	West flowing coastal rivers between Tapi and Mandavi rivers.
5(b)	Malabar Coastal Region	West flowing coastal rivers between Mandavi and Kanyakumari.
6.	Andaman and Nicobar	
7.	Western Himalayas	Jhelum, Upper portion of Indus Ravi and Beas rivers.

TABLE : A - 1

COMPUTATION OF EQUIVALENT SLOPE (S) OF BRIDGE NO. ; 221(1b) C.A. = 361.05 Sq Km

S.NO.	Reduced Distance Starting from Bridge Site (Point of Study) (Km)	Reduced Levels of River Bed (Mt)	Length of Each Segment L_i (Km)	Height Aboove Datum *(D)= Difference D_i Between thhe Datum and the its R.L. (Mt)	$(D_{i-1} + D_i)$ (Mt)	$L_i (D_{i-1} + D_i)$ (4) * (6) (Mt * Km)
1	2	3	4	5	6	7
1	0.00	393.90	0.00	0.00	0.00	0.00
2	11.26	415.14	11.26	21.24	21.24	239.16
3	16.09	426.72	4.83	32.82	54.06	261.11
4	19.31	457.20	3.22	63.30	96.12	309.51
5	28.64	487.68	9.33	93.78	157.08	1465.56
6	37.65	518.16	9.01	124.26	218.04	1964.54
7	38.62	519.68	0.97	125.78	250.04	242.54

$SUM\ (L_i * (D_{i-1} + D_i)) = 4482.41$

$$S = \frac{(L_i * (D_{i-1} + D_i))}{L^2} = \frac{4482.41}{1491.50} = 3.01 \text{ Mt/Km}$$

*DATUM = 393.90 i.e. REDUCED LEVEL OF RIVER BED AT THE POINT OF STUDY

POINT TO AREAL RAINFALL RATIO'S (PERCENTAGE)

Area in sq. km.	1-hr	2-hr	3-hr	4-hr	5-hr	6-hr	7-hr	8-hr	9-hr	10-hr	11-hr	12-hr
0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
50	87.00	89.00	91.00	91.67	92.33	93.00	93.17	93.33	93.50	93.67	93.83	94.00
100	78.00	81.00	84.00	85.67	87.33	89.00	89.33	89.67	90.00	90.33	90.67	91.00
150	71.00	75.00	79.00	80.67	82.33	84.00	84.67	85.33	86.00	86.67	87.33	88.00
200	66.00	70.50	75.00	77.00	79.00	81.00	82.00	83.00	84.00	85.00	86.00	87.00
250	63.00	67.50	72.00	74.00	76.00	78.00	79.17	80.33	81.50	82.67	83.83	85.00
300	60.00	64.50	69.00	71.33	73.67	76.00	77.33	78.67	80.00	81.33	82.67	84.00
350			68.00	70.33	72.67	75.00	76.33	77.67	79.00	80.33	81.67	83.00
400			67.00	69.33	71.67	74.00	75.33	76.67	78.00	79.33	80.67	82.00
450			66.00	68.33	70.67	73.00	74.33	75.67	77.00	78.33	79.67	81.00
500			65.00	67.33	69.67	72.00	73.50	75.00	76.50	78.00	79.50	81.00
600												79.00
700												78.00
800												77.00
900												77.00
1000												76.00
1500												
2000												
2500												

Area in sq. km.	13-hr	14-hr	15-hr	16-hr	17-hr	18-hr	19-hr	20-hr	21-hr	22-hr	23-hr	24-hr	Area in sq. km
0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0
50	94.25	94.50	94.75	95.00	95.25	95.50	95.75	96.00	96.25	96.50	96.75	97.00	50
100	91.33	91.67	92.00	92.33	92.67	93.00	93.33	93.67	94.00	94.33	94.67	95.00	100
150	88.33	88.67	89.00	89.33	89.67	90.00	90.33	90.67	91.00	91.33	91.67	92.00	150
200	87.33	87.67	88.00	88.33	88.67	89.00	89.33	89.67	90.00	90.33	90.67	91.00	200
250	85.42	85.83	86.25	86.67	87.08	87.50	87.92	88.33	88.75	89.17	89.58	90.00	250
300	84.42	84.83	85.25	85.67	86.08	86.50	86.92	87.33	87.75	88.17	88.58	89.00	300
350	83.42	83.83	84.25	84.67	85.08	85.50	85.92	86.33	86.75	87.17	87.58	88.00	350
400	82.42	82.83	83.25	83.67	84.08	84.50	84.92	85.33	85.75	86.17	86.58	87.00	400
450	81.50	82.00	82.50	83.00	83.50	84.00	84.50	85.00	85.50	86.00	86.50	87.00	450
500	81.42	81.83	82.25	82.67	83.08	83.50	83.92	84.33	84.75	85.17	85.58	86.00	500
600	79.50	80.00	80.50	81.00	81.50	82.00	82.50	83.00	83.50	84.00	84.50	85.00	600
700	78.50	79.00	79.50	80.00	80.50	81.00	81.50	82.00	82.50	83.00	83.50	84.00	700
800	77.50	78.00	78.50	79.00	79.50	80.00	80.50	81.00	81.50	82.00	82.50	83.00	800
900	77.42	77.83	78.25	78.67	79.08	79.50	79.92	80.33	80.75	81.17	81.58	82.00	900
1000	76.50	77.00	77.50	78.00	78.50	79.00	79.50	80.00	80.50	81.00	81.50	82.00	1000
1500												80.00	1500
2000												79.00	2000
2500												78.00	2500

Note : 1) The lowest areal to point rainfall ratios (precentages) against the catchment areas for various durations in the above table are also applicable to all the catchment areas exceeding the catchment area for which the lowest ratios are given for specific durations.

2) For catchment areas from 2,500 to 5,000 sq km the lowest ratios for various durations in the above table are applicable.

TIME DISTRIBUTION CO-EFFECIENTS OF AREAL RAINFALL
SUB-ZONE 1(b)

TIME HOURS	DISTRIBUTION CO-EFFECIENTS 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	19	20	21	22	23	24	TIME HOURS
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	0.97	21
20																			1.00	0.99	0.98	0.97	0.96	20
19																		1.00	0.99	0.98	0.97	0.95	0.94	19
18																	1.00	0.99	0.98	0.96	0.95	0.94	0.93	18
17																1.00	0.99	0.98	0.97	0.95	0.93	0.92	0.90	17
16															1.00	0.99	0.98	0.96	0.95	0.94	0.92	0.90	0.88	16
15														1.00	0.99	0.98	0.96	0.94	0.93	0.90	0.88	0.87	0.85	15
14													1.00	0.99	0.97	0.96	0.93	0.92	0.90	0.88	0.87	0.85	0.83	14
13												1.00	0.99	0.97	0.96	0.94	0.93	0.90	0.87	0.85	0.84	0.83	0.81	13
12											1.00	0.99	0.97	0.96	0.94	0.92	0.91	0.86	0.84	0.82	0.81	0.80	0.79	12
11										1.00	0.98	0.96	0.95	0.93	0.92	0.91	0.89	0.83	0.82	0.80	0.79	0.78	0.76	11
10									1.00	0.99	0.97	0.94	0.92	0.91	0.89	0.88	0.86	0.80	0.78	0.77	0.76	0.75	0.73	10
9								1.00	0.98	0.97	0.96	0.92	0.90	0.88	0.86	0.85	0.84	0.76	0.75	0.73	0.71	0.70	0.68	9
8							1.00	0.98	0.97	0.96	0.94	0.90	0.87	0.85	0.84	0.82	0.80	0.73	0.71	0.67	0.69	0.66	0.64	8
7						1.00	0.98	0.96	0.95	0.93	0.92	0.85	0.83	0.82	0.80	0.78	0.76	0.68	0.66	0.65	0.64	0.62	0.60	7
6					1.00	0.98	0.96	0.94	0.92	0.90	0.88	0.82	0.79	0.78	0.75	0.74	0.72	0.63	0.61	0.60	0.59	0.58	0.56	6
5				1.00	0.98	0.95	0.93	0.91	0.88	0.86	0.84	0.77	0.74	0.72	0.70	0.69	0.67	0.57	0.55	0.54	0.53	0.52	0.50	5
4			1.00	0.98	0.96	0.92	0.89	0.84	0.82	0.80	0.76	0.70	0.68	0.66	0.64	0.63	0.61	0.50	0.49	0.48	0.47	0.45	0.43	4
3		1.00	0.97	0.92	0.88	0.86	0.80	0.76	0.73	0.70	0.67	0.62	0.59	0.58	0.54	0.53	0.52	0.41	0.40	0.39	0.38	0.37	0.36	3
2	1.00	0.91	0.88	0.82	0.78	0.72	0.68	0.64	0.61	0.58	0.54	0.50	0.48	0.45	0.44	0.42	0.40	0.31	0.30	0.29	0.27	0.25	0.24	2
1	0.86	0.77	0.70	0.63	0.59	0.52	0.48	0.44	0.41	0.38	0.37	0.32	0.30	0.29	0.28	0.27	0.25	0.20	0.17	0.16	0.15	0.14	0.13	1

Note : Hourly rainfall distribution co-effecients are given in the vertical columns for various design storm durations from 2 - 24 hours.

Table - A - 4

COMPUTATION OF DESIGN FLOOD HYDROGRAPH

Subzone - 1(b) Br.No. 221 CA = 361.05 sq.km.

TIME IN HOURS	S.U.H. ORDINATE IN CUMEC	1-HOURLY RAINFALL EXCESS IN CMS 0.10	0.63	2.36	8.23	1.16	TOTAL DIRECT RUNOFF CUMECS	BASE FLOW IN CUMECS	TOTAL FLOOD FLOW IN CUMECS	
		DIRECT SURFACE RUN OFF IN CUMECS								
0.00	0.00	0.00					0.00	14.44	14.44	
1.00	19.40	1.94	0.00				1.94	14.44	16.38	
2.00	42.50	4.25	12.22	0.00			16.47	14.44	30.91	
3.00	76.00	7.60	26.78	45.78	0.00		80.16	14.44	94.60	
4.00	139.00	13.90	47.88	100.30	159.66	0.00	321.74	14.44	336.18	
5.00	180.50	18.05	87.57	179.36	349.78	22.50	657.26	14.44	671.70	
6.00	153.00	15.30	113.72	328.04	625.48	49.30	1131.84	14.44	1146.28	
7.00	115.00	11.50	96.39	425.98	1143.97	88.16	1766.00	14.44	1780.44	
8.00	82.50	8.25	72.45	361.08	1485.52	161.24	2088.54	14.44	2102.98	<---PEAK
9.00	60.00	6.00	51.98	271.40	1259.19	209.38	1797.95	14.44	1812.39	
10.00	45.50	4.55	37.80	194.70	946.45	177.48	1360.98	14.44	1375.42	
11.00	33.00	3.30	28.67	141.60	678.98	133.40	985.94	14.44	1000.38	
12.00	23.50	2.35	20.79	107.38	493.80	95.70	720.02	14.44	734.46	
13.00	16.50	1.65	14.81	77.88	374.47	69.60	538.40	14.44	552.84	
14.00	9.50	0.95	10.40	55.46	271.59	52.78	391.18	14.44	405.62	
15.00	5.00	0.50	5.99	38.94	193.41	38.28	277.11	14.44	291.55	
16.00	2.00	0.20	3.15	22.42	135.80	27.26	188.83	14.44	203.27	
17.00	0.00	0.00	1.26	11.80	78.19	19.14	110.39	14.44	124.83	
			0.00	4.72	41.15	11.02	56.89	14.44	71.33	
				0.00	16.46	5.80	22.26	14.44	36.70	
					0.00	2.32	2.32	14.44	16.76	
						0.00	0.00	14.44	14.44	

TABLE : A - 1

COMPUTATION OF EQUIVALENT SLOPE (S) OF BRIDGE NO. : 221(1b) C.A. = 361.05 Sq Km

S.NO.	Reduced Distance Starting from Bridge Site (Point of Study) (Km)	Reduced Levels of River Bed (Mt)	Length of Each Segment L_i (Km)	Height Above Datum *(D_i)= Difference Between the Datum and the its R.L. (Mt)	$(D_{i-1} + D_i)$ (Mt)	$L_i(D_{i-1} + D_i)$ (4) * (6) (Mt * Km)
1	2	3	4	5	6	7
1	0.00	393.90	0.00	0.00	0.00	0.00
2	11.26	415.14	11.26	21.24	21.24	239.16
3	16.09	426.72	4.83	32.82	54.06	261.11
4	19.31	457.20	3.22	63.30	96.12	309.51
5	28.64	487.68	9.33	93.78	157.08	1465.56
6	37.65	518.16	9.01	124.26	218.04	1964.54
7	38.62	519.68	0.97	125.78	250.04	242.54

$SUM(L_i * (D_{i-1} + D_i))$ = 4482.41

$$S = \frac{(L_i * (D_{i-1} + D_i))}{L^2} = \frac{4482.41}{1491.50} = 3.01 \text{ Mt/Km}$$

*DATUM = 393.90 i.e. REDUCED LEVEL OF RIVER BED AT THE POINT OF STUDY

TABLE - 4.2

POINT TO AREAL RAINFALL RATIO'S (PERCENTAGE)

Area in sq. km.	1-hr	2-hr	3-hr	4-hr	5-hr	6-hr	7-hr	8-hr	9-hr	10-hr	11-hr	12-hr	13-hr	14-hr	15-hr	16-hr	17-hr	18-hr	19-hr	20-hr	21-hr	22-hr	23-hr	24-hr	Area in sq. km
0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0
50	87.00	89.00	91.00	91.67	92.33	93.00	93.17	93.33	93.50	93.67	93.83	94.00	94.25	94.50	94.75	95.00	95.25	95.50	95.75	96.00	96.25	96.50	96.75	97.00	50
100	78.00	81.00	84.00	85.67	87.33	89.00	89.33	89.67	90.00	90.33	90.67	91.00	91.33	91:67	92.00	92.33	92.67	93.00	93.33	93.67	94.00	94.33	94.67	95.00	100
150	71.00	75.00	79.00	80.67	82.33	84.00	84.67	85.33	86.00	86.67	87.33	88.00	88.33	88.67	89.00	89.33	89.67	90.00	90.33	90.67	91.00	91.33	91.67	92.00	150
200	66.00	70.50	75.00	77.00	79.00	81.00	82.00	83.00	84.00	85.00	86.00	87.00	87.33	87.67	88.00	88.33	88.67	89.00	89.33	89.67	90.00	90.33	90.67	91.00	200
250	63.00	67.50	72.00	74.00	76.00	78.00	79.17	80.33	81.50	82.67	83.83	85.00	85.42	85.83	86.25	86.67	87.08	87.50	87.92	88.33	88.75	89.17	89.58	90.00	250
300	60.00	64.50	69.00	71.33	73.67	76.00	77.33	78.67	80.00	81.33	82.67	84.00	84.42	84.83	85.25	85.67	86.08	86.50	86.92	87.33	87.75	88.17	88.58	89.00	300
350			68.00	70.33	72.67	75.00	76.33	77.67	79.00	80.33	81.67	83.00	83.42	83.83	84.25	84.67	85.08	85.50	85.92	86.33	86.75	87.17	87.58	88.00	350
400			67.00	69.33	71.67	74.00	75.33	76.67	78.00	79.33	80.67	82.00	82.42	82.83	83.25	83.67	84.08	84.50	84.92	85.33	85.75	86.17	86.58	87.00	400
450			66.00	68.33	70.67	73.00	74.33	75.67	77.00	78.33	79.67	81.00	81.50	82.00	82.50	83.00	83.50	84.00	84.50	85.00	85.50	86.00	86.50	87.00	450
500			65.00	67.33	69.67	72.00	73.50	75.00	76.50	78.00	79.50	81.00	81.42	81.83	82.25	82.67	83.08	83.50	83.92	84.33	84.75	85.17	85.58	86.00	500
600												79.00	79.50	80.00	80.50	81.00	81.50	82.00	82.50	83.00	83.50	84.00	84.50	85.00	600
700												78.00	78.50	79.00	79.50	80.00	80.50	81.00	81.50	82.00	82.50	83.00	83.50	84.00	700
800												77.00	77.50	78.00	78.50	79.00	79.50	80.00	80.50	81.00	81.50	82.00	82.50	83.00	800
900												77.00	77.42	77.83	78.25	78.67	79.08	79.50	79.92	80.33	80.75	81.17	81.58	82.00	900
1000												76.00	76.50	77.00	77.50	78.00	78.50	79.00	79.50	80.00	80.50	81.00	81.50	82.00	1000
1500																								80.00	1500
2000																								79.00	2000
2500																								78.00	2500

Note : 1) The lowest areal to point rainfall ratios (procentages) against the catchment areas for various durations in the above table are also applicable to all the catchment areas exceeding the catchment area for which the lowest ratios are given for specific durations.

2) For catchment areas from 2,500 to 5,000 sq km the lowest ratios for various durations in the above table are applicable.

REPRESENTATIVE 1-HOUR UNIT GRAPH PARAMETERS
SUB ZONE 1 (b)

TABLE - 3

SL.NO.	BRIDGE NO.	tp IN HOURS	QP IN CUMECS	qp IN SQ/KM	tr IN HOURS	TB IN HOURS	W50 IN HOURS	W75 IN HOURS	WR50 IN HOURS	WR75 IN HOURS
1	2	3	4	5	6	7	8	9	10	11
1	94	22.50	316.00	0.14	1.00	47.00	18.80	11.35	10.60	6.20
2	519	10.50	395.00	0.25	1.00	40.00	7.50	4.00	3.73	2.00
3	72	8.50	180.30	0.28	1.00	32.00	8.65	4.65	2.75	1.58
4	283	5.50	330.00	0.56	1.00	18.00	3.60	2.40	1.50	1.00
5	198	4.50	320.00	0.76	1.00	15.00	2.62	1.40	0.98	0.68
6	221	3.50	280.00	0.78	1.00	12.00	2.60	1.50	1.00	0.70
7	272	3.50	233.00	0.67	1.00	12.00	3.30	1.65	1.50	0.75
8	140	3.50	300.00	1.09	1.00	9.00	2.10	1.20	1.00	0.60
9	437	3.50	135.00	0.57	1.00	12.00	4.20	2.10	1.20	0.80
10	39	2.50	90.00	0.62	1.00	13.00	3.90	2.10	1.50	0.90
11	51	2.50	80.60	0.57	1.00	11.00	4.50	2.50	1.70	1.10
12	44	2.50	90.00	0.83	1.00	12.00	2.85	1.40	0.95	0.45
13	495	4.50	33.30	0.50	1.00	15.00	4.70	2.20	1.60	0.80
14	406	1.50	54.00	1.14	1.00	8.00	1.95	1.05	0.75	0.45
15	1	1.50	58.00	1.30	1.00	7.00	1.65	1.05	0.85	0.55
16	306	1.50	20.00	0.46	1.00	14.00	5.40	3.60	1.40	1.20
17	118	1.50	31.10	0.75	1.00	13.00	2.49	1.14	0.95	0.54
18	35	2.50	30.00	0.76	1.00	9.00	3.10	1.60	1.40	0.80
19	77	1.50	20.00	0.76	1.00	10.00	3.30	1.65	0.90	0.45

TABLE- 4 LOSS RATE RANGES(cms/hr)-NO. OF FLOOD OCCASIONS

SUBZONE - 1(b)

SL. NO.	LOSS RANGES LB	LOSS RANGES UB	94	519	72	283	196	221	272	140	437	39	51	44	495	408	1	306	118	35	77	ROW-TOTAL
	BRIDGE NO ;---->		94	519	72	283	196	221	272	140	437	39	51	44	495	408	1	306	118	35	77	
	CATCHMENT AREA---> IN sq.Km		2297.33	1613.60	862.81	587.63	419.68	361.05	349.13	274.33	237.14	145.45	140.43	108.78	66.30	47.44	44.75	43.77	41.44	39.52	26.18	
			NUMBER OF OBSERVED FLOODS																			
1	0	0.1	2	3	1	1	0	1	0	3	0	1	6	1	1	2	1	0	1	1	0	25
2	0.1	0.3	1	3	7	5	3	1	0	3	1	0	2	3	3	2	1	0	1	0	0	36
3	0.3	0.5	1	1	1	2	0	1	1	0	1	0	2	0	0	1	0	2	2	2	0	17
4	0.5	0.7	0	0	0	3	1	1	0	2	0	3	0	1	0	1	1	1	1	0	0	15
5	0.7	0.9	0	0	0	2	2	1	0	1	1	0	3	1	0	1	2	0	4	0	0	18
6	0.9	1.1	0	0	0	1	1	1	1	0	0	0	0	2	0	0	2	0	1	1	1	11
7	1.1	1.3	0	0	0	0	2	1	0	1	1	1	0	0	0	1	0	0	0	2	0	9
8	1.3	1.5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
9	1.5	1.7	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	1	4
10	1.7	1.9	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
11	1.9	2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
12	2.1	2.3	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2
13	2.3	2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	2.5	2.7	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
15	2.7	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
16	ABOVE	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
17																						
18																						G. TOTAL
19		COL.TOTAL	4	7	9	14	12	7	3	10	4	7	13	11	4	8	8	3	10	6	4	144
20																						

TABLE- 5 BASE FLOW RANGES(cumec/sqkm.)-NO. OF FLOOD OCCASIONS

SUBZONE - 1(b)

SL. NO.	BRIDGE NO ---->		94	519	72	283	198	221	272	140	437	39	51	44	495	406	1	306	118	35	77	
	CATCHMENT AREA---> IN sq.Km		2297.33	1613.60	662.81	587.63	419.68	361.05	349.13	274.33	237.14	145.45	140.43	108.78	66.30	47.44	44.75	43.77	41.44	39.52	26.18	
	BASE FLOW RANGES		NUMBER OF OBSERVED FLOODS																			ROW-TOTAL
	LB	UB																				
1	0.00	0.01	0	2	4	3	3	0	3	4	0	0	1	1	4	0	0	0	0	0	0	25
2	0.01	0.02	2	1	3	3	2	2	0	3	1	2	2	0	0	0	0	0	0	0	1	22
3	0.02	0.03	0	2	1	1	2	1	0	0	3	1	1	0	0	0	0	1	0	0	2	15
4	0.03	0.04	0	1	1	4	2	1	0	0	0	2	1	2	0	0	0	0	1	0	0	15
5	0.04	0.05	2	1	0	1	1	0	0	0	0	0	2	0	0	1	3	1	4	0	1	17
6	0.05	0.06	0	0	0	1	2	0	0	1	0	0	1	2	0	1	0	0	0	0	0	8
7	0.06	0.07	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	1	0	0	0	4
8	0.07	0.08	0	0	0	0	0	0	0	1	0	2	0	0	0	0	1	0	1	1	0	6
9	0.08	0.09	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	2
10	0.09	0.1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	2
11	ABOVE	0.1	0	0	0	1	0	0	0	1	0	0	5	5	0	5	3	0	3	6	0	29
12			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17			0																			
18																						G.TOTAL
19		COL.TOTAL	4	7	9	14	12	7	3	10	4	7	13	11	4	8	8	3	10	7	4	145

TABLE - 6

AREAL TO POINT RAINFALL RATIOS
(PERCENTAGES)

Area in sq. km.	1-hr	3-hr	6-hr	12-hr	24-hr
50	87	91	93	94	97
100	78	84	89	91	95
150	71	79	84	88	92
200	66	75	81	87	91
250	63	72	78	85	90
300	60	69	76	84	89
350		68	75	83	88
400		67	74	82	87
450		66	73	81	87
500		65	72	81	86
600				79	85
700				78	84
800				77	83
900				77	82
1000				76	82
1500					80
2000					79
2500					78

TABLE -7

STATEMENT OF HIGHEST RECORDED DAILY RAINFALL IN SUBZONE 1(b)

S.No.	State	District	Station	Maximum Rainfall	Date
1.	Madhya Pradesh	Ujjain	Tarana	359.7	8.8.1977
2.		"	Mohidpur	434.3	29.7.1950
3.		Ratlam	Sailana	359.0	11.8.1941
4.		Mandsaur	Garoth	323.9	29.6.1945
5.		Dewas	Dewas	334.3	26.9.1961
6.		Rajgarh	Biaora	431.8	7.7.1952
7.		Shajapur	Agar	321.3	6.9.1932
8.		Morena	Joara	304.8	28.8.1919
9.		Sehore	Ashta	310.4	11.8.1941
10.		Nimar	Harsod	264.5	18.8.1972
11.	Gujrat	Sabarkantha	Ider	463.3	13.8.1941
12.	Rajasthan	Kota	Mangrol	391.7	26.6.1933
13.		Kota	Chechat	393.3	29.6.1945
14.		Kota	Atru	336.0	21.7.1908
15.		Kota	Bairam	413.2	13.8.1967
16.		Kota	Shahbad	328.9	10.7.1968
17.		Bharatpur	Nadboi	320.8	2.8.1966
18.		Nagaur	Parbatsar	306.8	24.7.1929
19.		Ajmer	Todagarh	328.9	30.7.1947
20.		Bundi	Hindoli	413.3	22.8.1942
21.		Jhalawar	Jhalawar	350.2	17.8.1969
22.		Jhalawar	Khampur	396.2	13.7.1914
23.		Sawai Madhopur	Sawai Madhopur	356.2	11.7.1967
24.		Ajmer	Kekri	313.7	8.7.1894
25.		Pali	Desuri	381.0	31.7.1952

FLOOD VALUES BY SYNTHATIC UNIT GRAPH AND FLOOD FORMULAE SUB ZONE 1(b) TABLE-8

Sl.No.	Bridge No	Area (sq.km.)	By SUH Q25 cum	By SUH Q50 cum	By SUH Q100 cum	By Flood Formulae Q25 cum	By Flood Formulae Q50 cum	By Flood Formulae Q100 cum	% Variation wrt SUH Q25 cum	% Variation wrt SUH Q50 cum	% Variation wrt SUH Q100 cum	Remarks
1	2	3	4	6	7	8	9	10	11	12	13	14
1	94	2297.33	8168.23	9364.78	10586.32	8691.59	10070.61	11278.35	-6.41	-7.54	-6.54	
2	519	1613.60	4459.85	4805.01	5723.95	4839.75	5190.50	6182.52	-8.52	-8.02	-8.01	
3	72	662.81	2884.70	3309.13	3733.45	2704.95	3104.12	3512.38	6.23	6.20	5.92	
4	283	587.63	2919.40	3282.41	3691.28	2557.18	2892.16	3263.20	12.41	11.89	11.60	
5	198	419.68	1532.51	1669.40	2038.82	1490.46	1599.31	1970.33	2.74	4.20	3.36	
6	221	361.05	1797.27	2102.97	2407.44	1812.54	2114.62	2425.38	-0.85	-0.55	-0.75	
7	272	349.13	1700.38	1954.89	2249.48	1770.16	2049.04	2345.29	-4.10	-4.82	-4.26	
8	140	274.33	1265.46	1752.17	2007.26	1207.44	1653.83	1890.95	4.58	5.61	5.79	
9	437	237.14	1452.80	1620.29	1845.27	1445.68	1620.90	1844.76	0.49	-0.04	0.03	
10	39	145.45	820.79	983.31	1105.91	831.10	995.88	1120.96	-1.26	-1.28	-1.36	
11	51	140.48	910.74	1019.23	1128.66	867.71	969.20	1079.38	4.72	4.91	4.37	
12	44	108.78	722.34	834.63	961.88	803.75	934.14	1071.06	-11.27	-11.92	-11.35	
13	495	66.30	406.68	425.24	500.51	450.67	469.73	555.45	-10.82	-10.46	-10.98	
14	406	47.44	440.52	486.15	566.51	454.29	505.88	585.64	-3.13	-4.06	-3.38	
15	1	44.75	483.75	553.09	622.44	450.11	516.09	578.79	6.95	6.69	7.01	
16	306	43.77	359.20	384.27	451.57	322.22	342.31	405.33	10.30	10.92	10.24	
17	118	41.44	407.76	472.06	536.36	401.29	466.72	527.44	1.59	1.13	1.66	
18	35	39.52	353.80	418.58	470.37	331.49	394.57	440.87	6.31	5.74	6.27	
19	77	26.18	179.27	200.25	237.10	206.51	229.04	272.16	-15.19	-14.38	-14.79	

$$Q_{25} = \frac{2.554(A)^{0.904}\ (S)^{0.272}\ (ARF)^{0.9598}}{(L)^{0.384}} \quad : \quad r = 0.997$$

$$Q_{50} = \frac{2.315(A)^{0.918}\ (S)^{0.2788}\ (ARF)^{1.010}}{(L)^{0.4148}} \quad : \quad r = 0.997$$

$$Q_{100} = \frac{2.545(A)^{0.911}\ (S)^{0.2709}\ (ARF)^{0.9638}}{(L)^{0.3906}} \quad : \quad r = 0.997$$

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.

S.R. MALHOTRA P.R. BHALLA

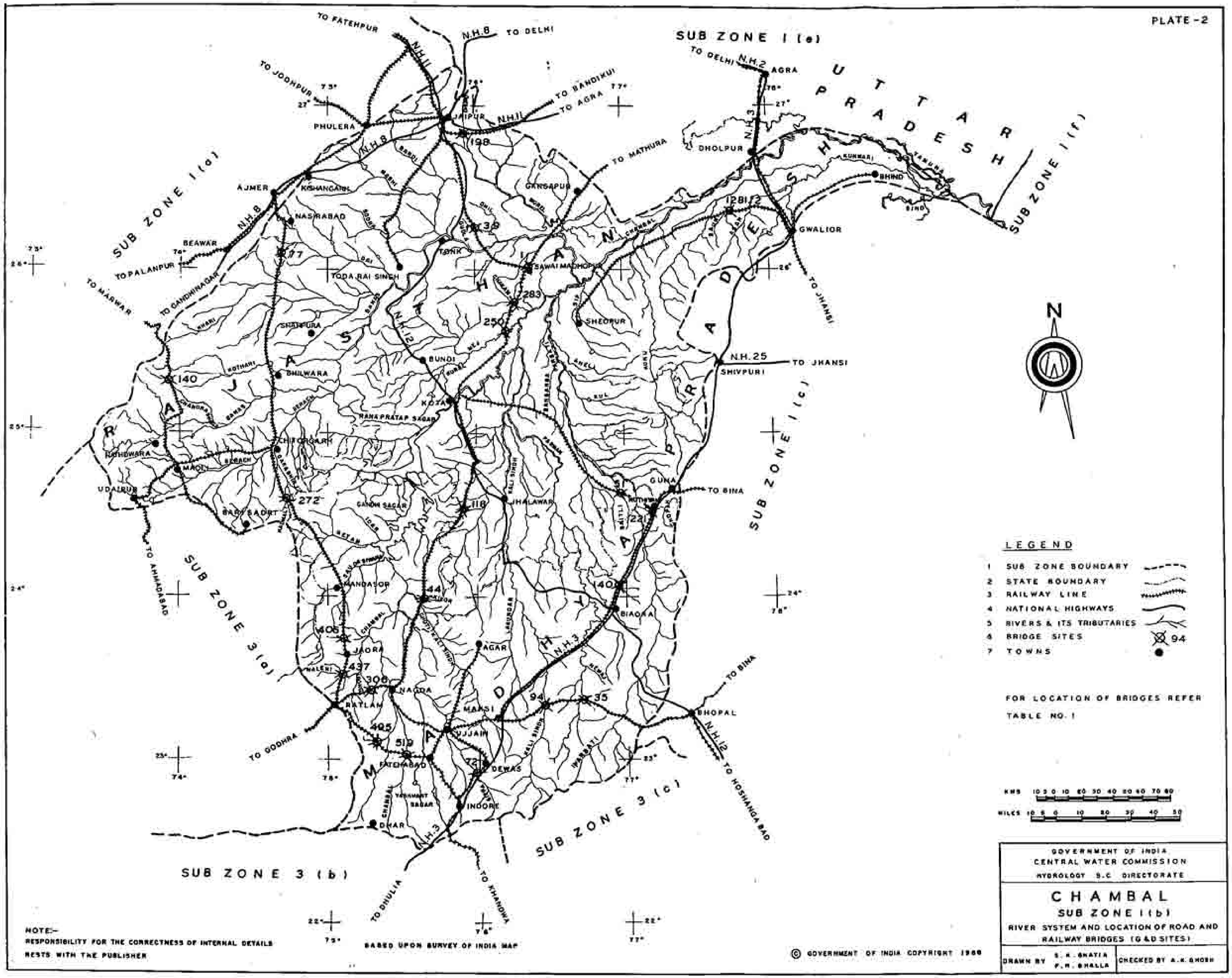
PLATE - 2
SUB ZONE 1 (e)
SUB ZONE 1 (f)
SUB ZONE 1 (a)
SUB ZONE 1 (c)
SUB ZONE 3 (a)
SUB ZONE 3 (b)
SUB ZONE 3 (c)
UTTAR PRADESH
RAJASTHAN
MADHYA PRADESH
N
TO FATEHPUR
N.H.8 TO DELHI
TO DELHI N.H.2 AGRA
TO JODHPUR
TO BANDIKUI
TO AGRA
PHULERA
JAIPUR
N.H.11
TO MATHURA
DHOLPUR
N.H.3
BHIND
AJMER
KISHANGARH
NASIRABAD
BEAWAR
TO PALANPUR
TO MARWAR
TO GANDHINAGAR
GANGAPUR
GWALIOR
TONK
SAWAI MADHOPUR
TODA RAI SINGH
TO JHANSI
SHEOPUR
SHAHPURA
BUNDI
N.H.12
N.H.25
SHIVPURI
BHILWARA
KOTA
RANA PRATAP SAGAR
CHITORGARH
NATHDWARA
MAOLI
UDAIPUR
BARI SADRI
GANDHI SAGAR
JHALAWAR
GUNA
TO BINA
TO AHMADABAD
MANDASOR
BIAORA
JAORA
AGAR
RATLAM
NAGDA
MAKSI
BHOPAL
TO GODHRA
UJJAIN
FATEHABAD
DEWAS
INDORE
DHAR
TO HOSHANGABAD
TO DHULIA
TO KHANDWA
CHAMBAL
LEGEND
1 SUB ZONE BOUNDARY
2 STATE BOUNDARY
3 RAILWAY LINE
4 NATIONAL HIGHWAYS
5 RIVERS & ITS TRIBUTARIES
6 BRIDGE SITES 94
7 TOWNS
FOR LOCATION OF BRIDGES REFER TABLE NO. 1
KMS
MILES
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY S.C DIRECTORATE
CHAMBAL
SUB ZONE 1 (b)
RIVER SYSTEM AND LOCATION OF ROAD AND RAILWAY BRIDGES (G & D SITES)
DRAWN BY S. K. BHATIA F. M. 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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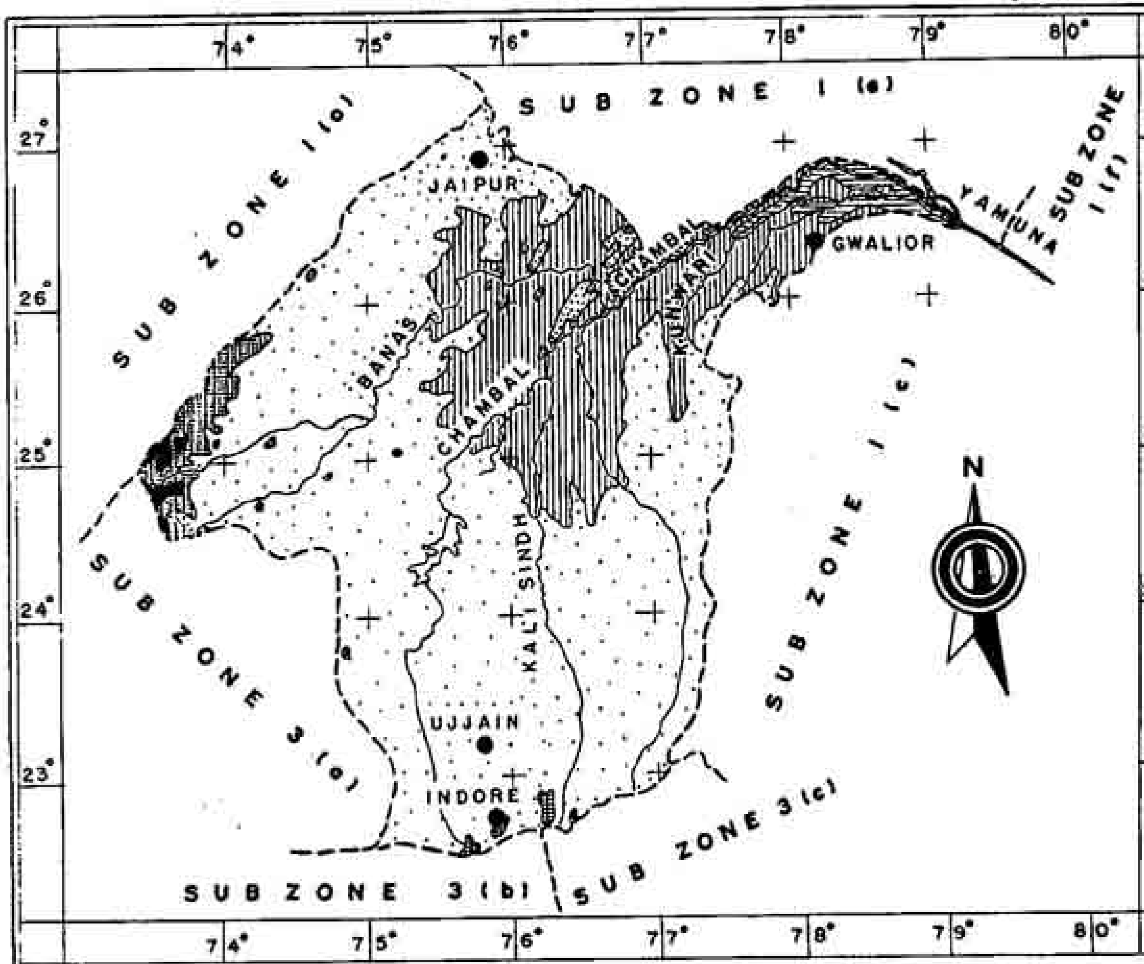
PLATE-3



LEGEND

ALTITUDE IN METERS

1. 0 – 150 . . .
2. 150 – 300 . . .
3. 300 – 600 . . .
4. 600 – 900 . . .
5. 900 – 1350 . . .

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

SCALE

50 0 50 100 150 KMS.

40 20 0 40 80 MILES

REFERENCES

1. SUB ZONE BOUNDARY . . . .
2. RIVERS . . . .
3. TOWNS . . . .

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CENTRAL WATER COMMISSION
HYDROLOGY (S. C.) DIRECTORATE

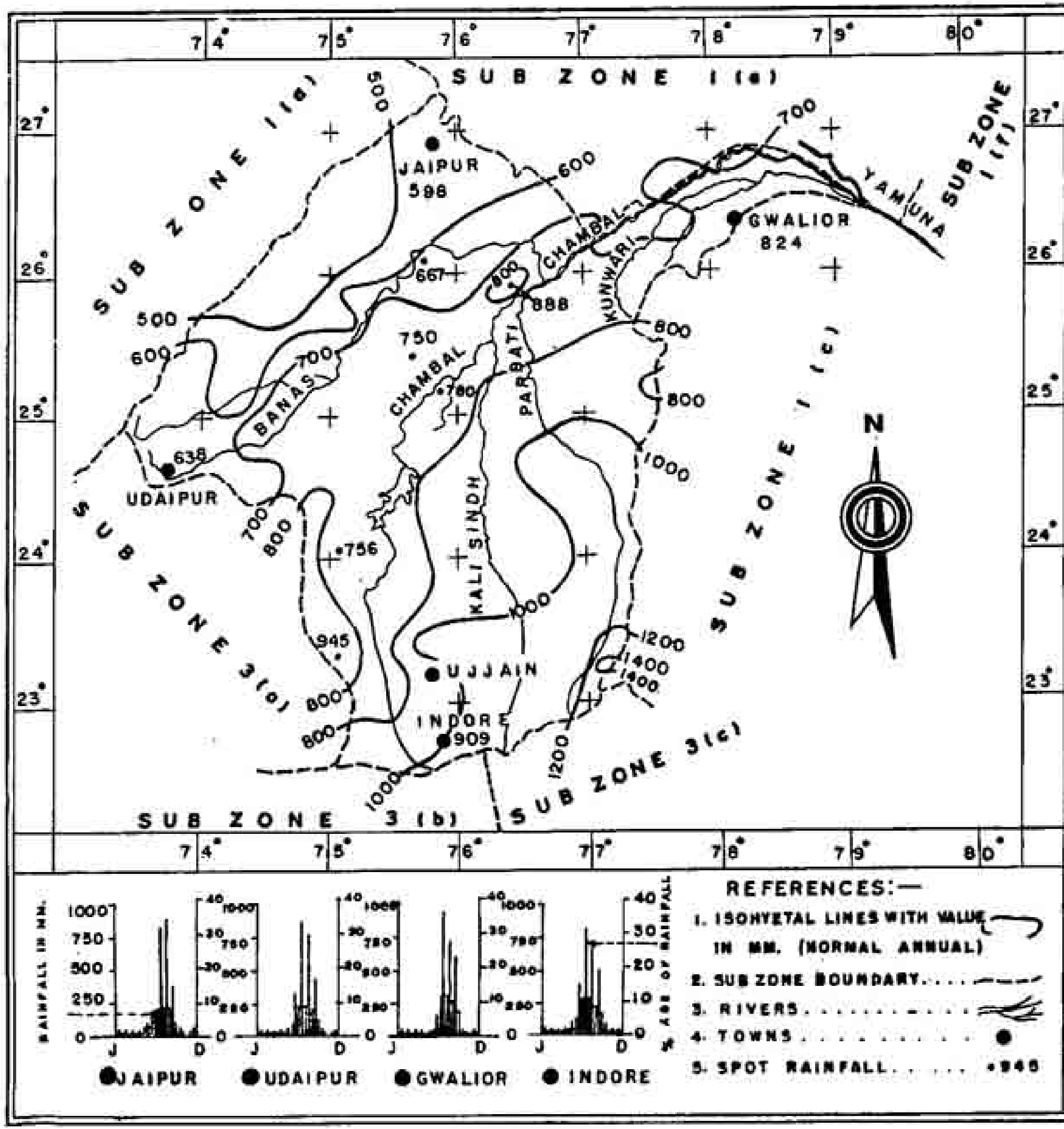
CHAMBAL

SUB ZONE I (b)

TOPOGRAPHY

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

PLATE-4



NOTES:—

1. HISTOGRAMS FOR FOUR 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 (S.C.) DIRECTORATE

CHAMBAL

SUB ZONE - 1(b)

NORMAL ANNUAL RAINFALL (mm.)

DRAWN BY—
S. N. MALHOTRA
L. P. NAUTIYAL

CHECKED BY—
A. K. GHOSH

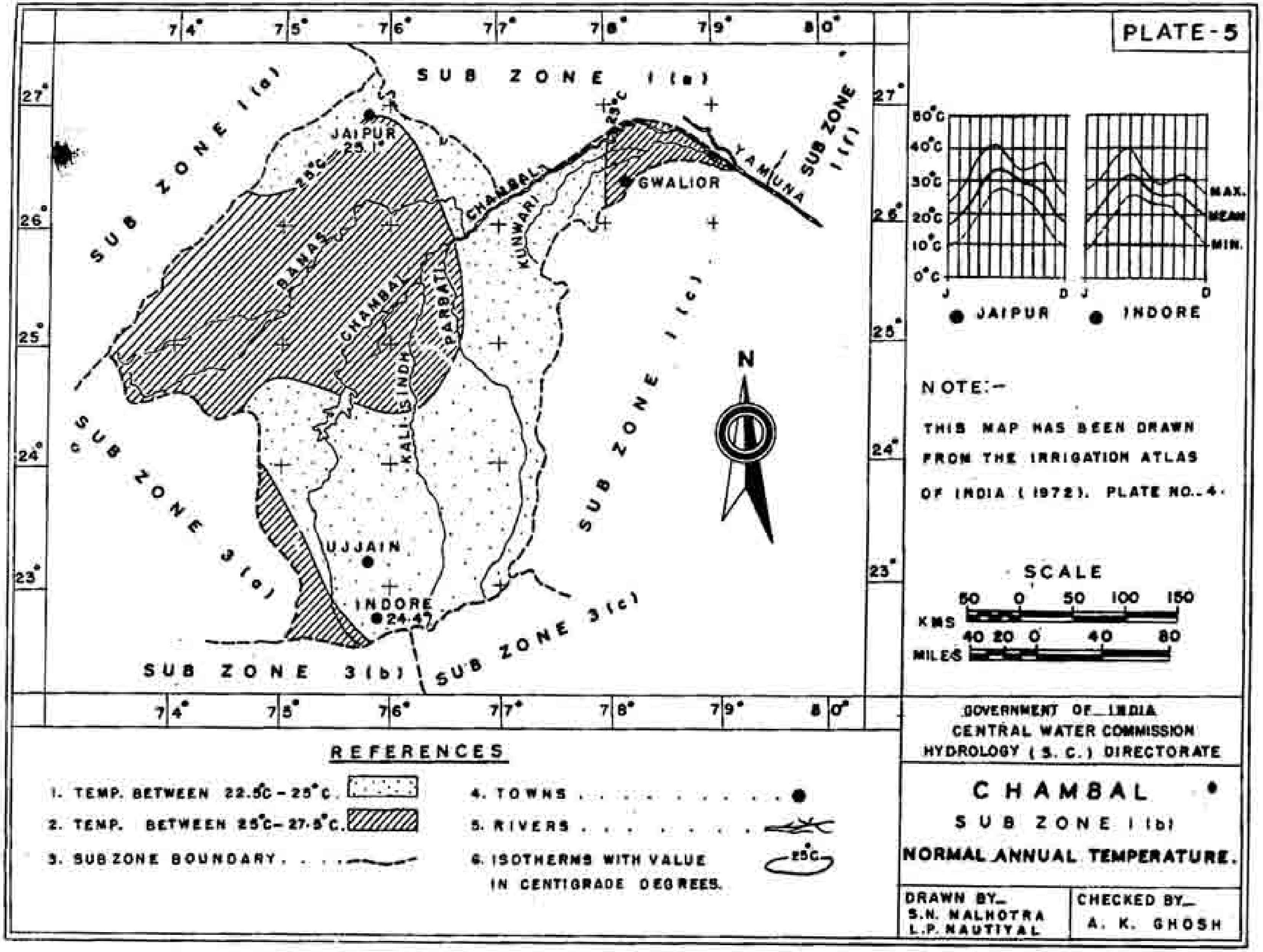


PLATE-5
SUB ZONE 1(a)
SUB ZONE 1(a)
SUB ZONE 1(c)
SUB ZONE 1(f)
SUB ZONE 3(a)
SUB ZONE 3(b)
SUB ZONE 3(c)
JAIPUR 25.1°
GWALIOR
UJJAIN
INDORE 24.4°
CHAMBAL
BANAS
PARBATI
KALI SINDH
KUNWARI
YAMUNA
25°C
23°C
N
74° 75° 76° 77° 78° 79° 80°
27° 26° 25° 24° 23°
60°C 40°C 30°C 20°C 10°C 0°C
J D J D
MAX.
MEAN
MIN.
JAIPUR
INDORE
NOTE:-
THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972). PLATE NO.-4.
SCALE
KMS 50 0 50 100 150
MILES 40 20 0 40 80
REFERENCES
1. TEMP. BETWEEN 22.5°C - 25°C.
2. TEMP. BETWEEN 25°C - 27.5°C.
3. SUBZONE BOUNDARY
4. TOWNS
5. RIVERS
6. ISOTHERMS WITH VALUE IN CENTIGRADE DEGREES.
25°C
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S.C.) DIRECTORATE
CHAMBAL
SUB ZONE 1(b)
NORMAL ANNUAL TEMPERATURE.
DRAWN BY_
S.N. MALHOTRA
L.P. NAUTIYAL
CHECKED BY_
A. K. GHOSH

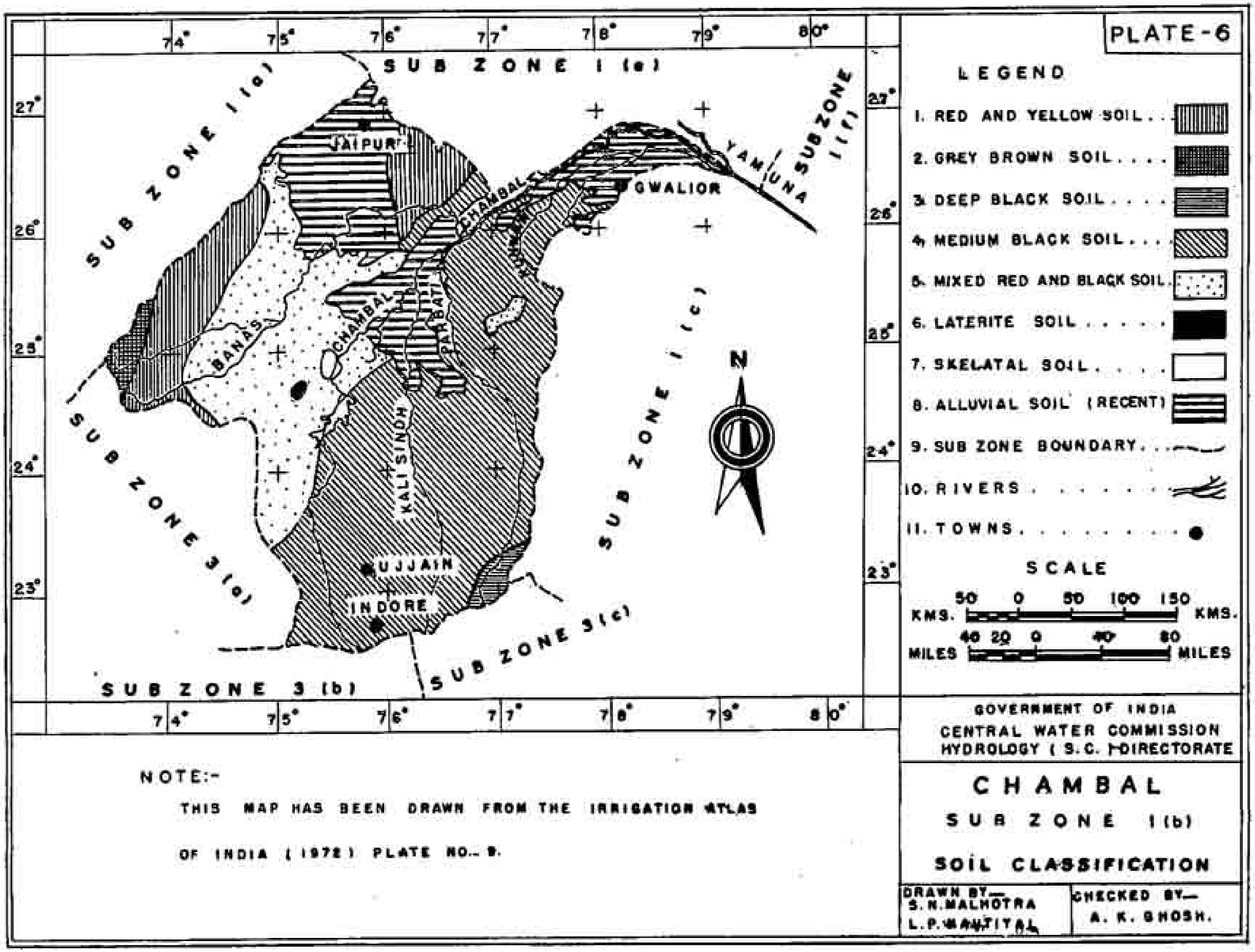
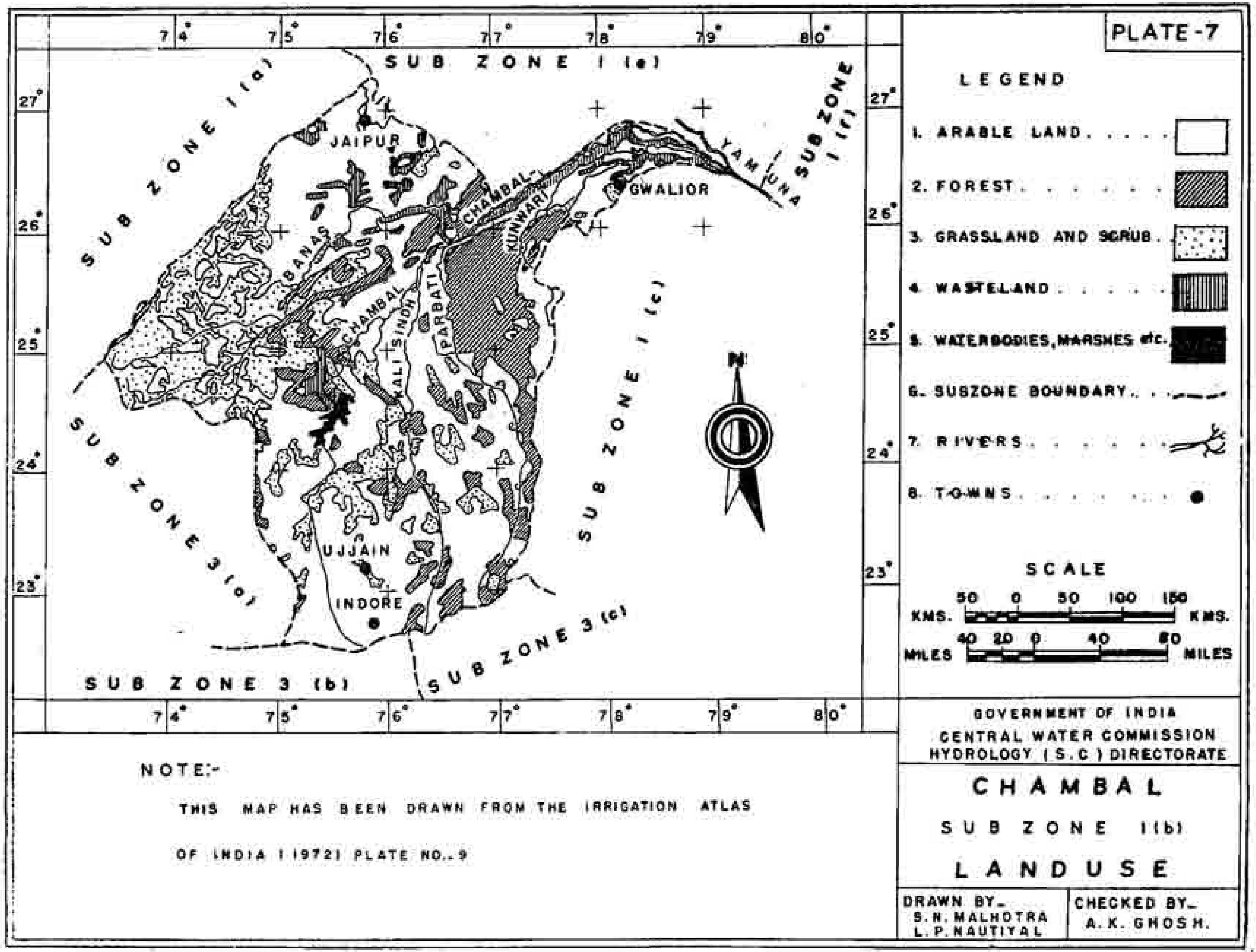


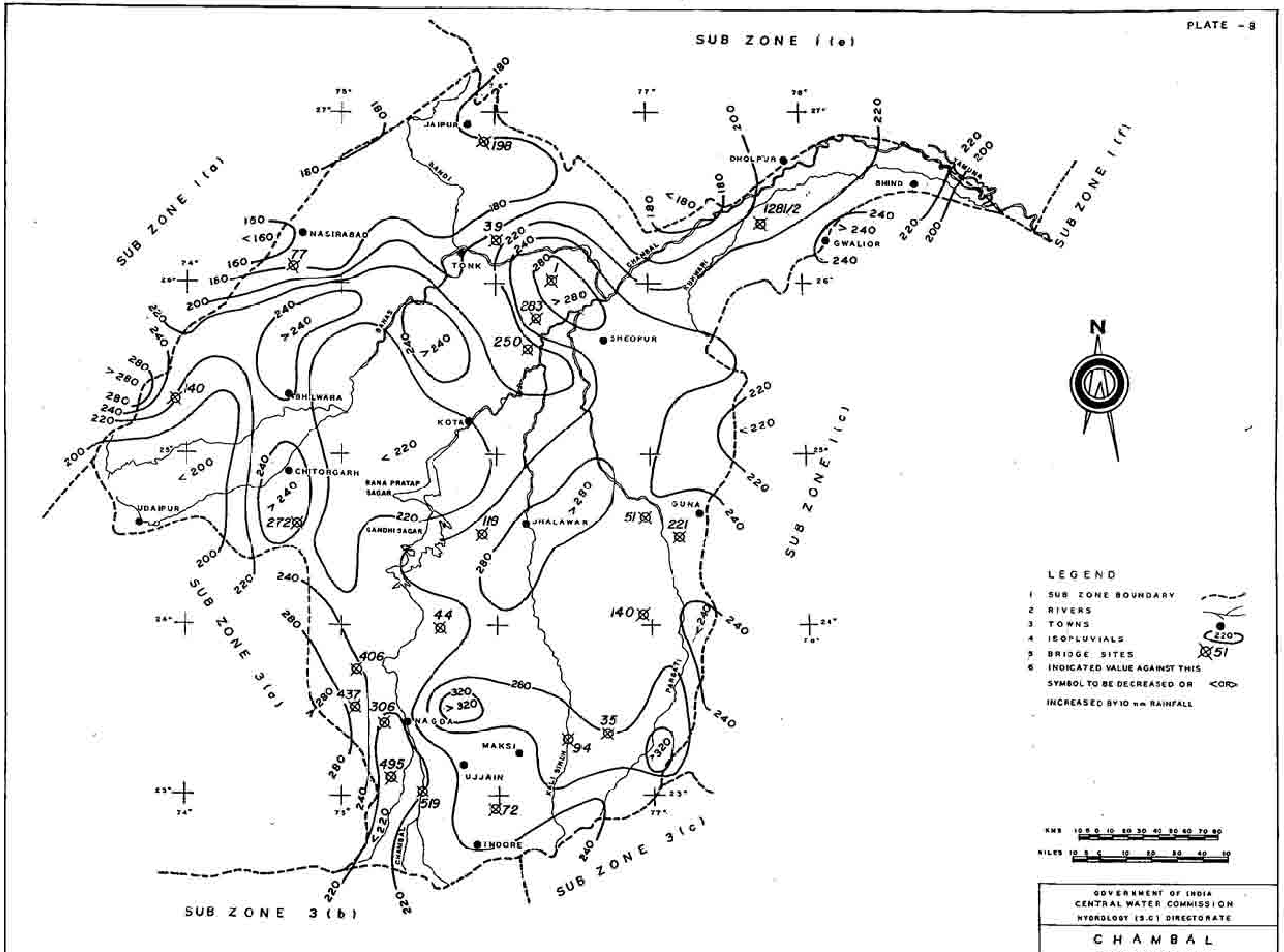
PLATE-6
SUB ZONE 1 (e)
SUB ZONE 1 (a)
SUB ZONE 1 (f)
SUB ZONE 1 (c)
SUB ZONE 3 (a)
SUB ZONE 3 (b)
SUB ZONE 3 (c)
JAIPUR
GWALIOR
YAMUNA
CHAMBAL
BANAS
PARBATI
KALI SINDH
UJJAIN
INDORE
N
74° 75° 76° 77° 78° 79° 80°
27° 26° 25° 24° 23°
LEGEND
1. RED AND YELLOW SOIL
2. GREY BROWN SOIL
3. DEEP BLACK SOIL
4. MEDIUM BLACK SOIL
5. MIXED RED AND BLACK SOIL
6. LATERITE SOIL
7. SKELATAL SOIL
8. ALLUVIAL SOIL (RECENT)
9. SUB ZONE BOUNDARY
10. RIVERS
11. TOWNS
SCALE
KMS. 50 0 50 100 150 KMS.
MILES 40 20 0 40 80 MILES
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S.C.) DIRECTORATE
CHAMBAL
SUB ZONE 1 (b)
SOIL CLASSIFICATION
DRAWN BY—
S. N. MALHOTRA
L. P. NAUTIYAL
CHECKED BY—
A. K. GHOSH.
NOTE:-
THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS
OF INDIA (1972) PLATE NO.- 9.



NOTE:-

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

PLATE - 8



GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S.C) DIRECTORATE

CHAMBAL

SUB ZONE 1(b)

25 YEAR - 24 HOUR RAINFALL (mm)

DRAWN BY P. R. BHALLA, S. K. BHATIA

CHECKED BY A. K. GHOSH

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

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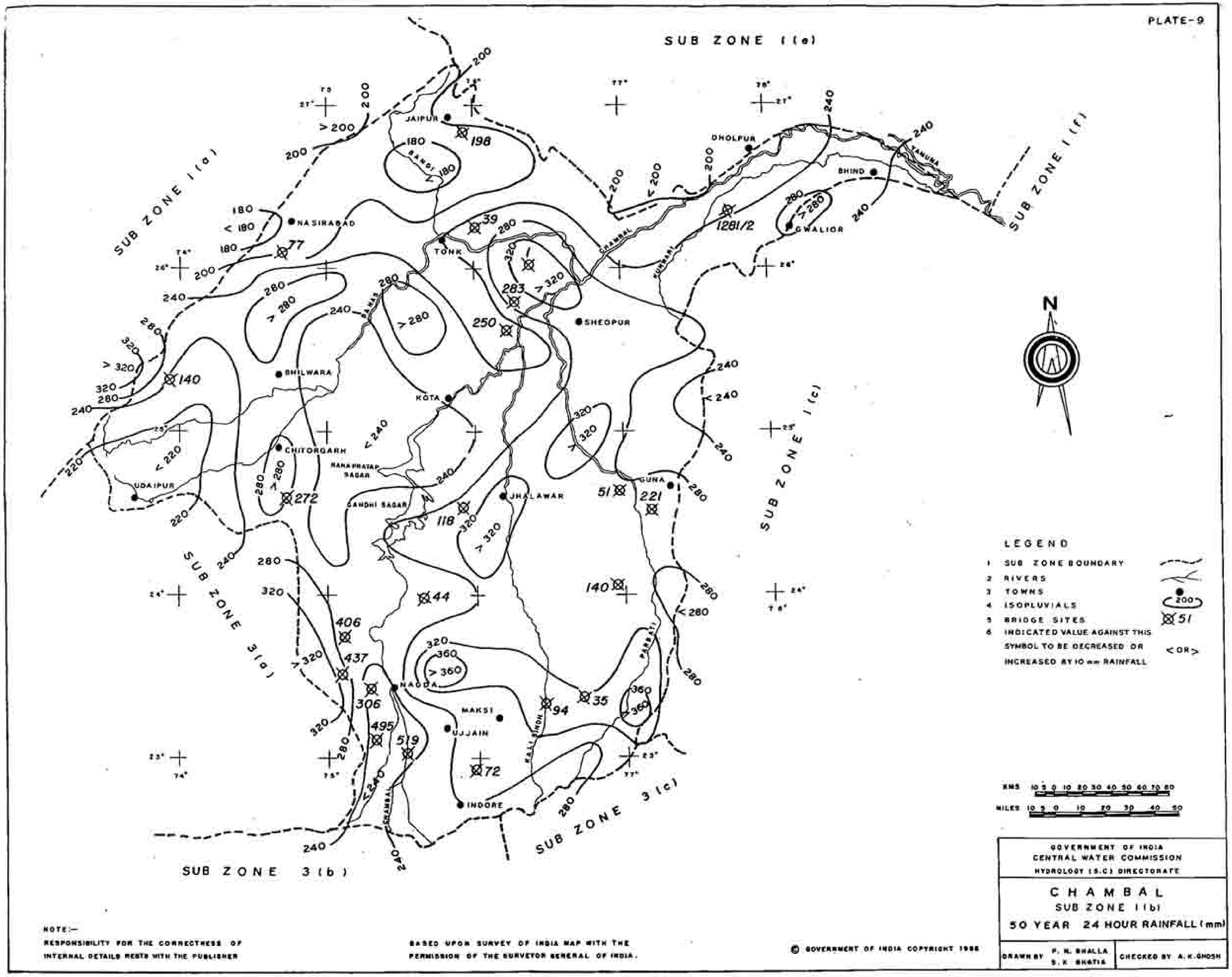
PLATE-9
SUB ZONE 1(e)
SUB ZONE 1(a)
SUB ZONE 1(f)
SUB ZONE 1(c)
SUB ZONE 3(a)
SUB ZONE 3(b)
SUB ZONE 3(c)
JAIPUR
NASIRABAD
TONK
DHOLPUR
BHIND
GWALIOR
SHEOPUR
BHILWARA
KOTA
CHITORGARH
RANA PRATAP SAGAR
GANDHI SAGAR
UDAIPUR
JHALAWAR
GUNA
NAGDA
MAKSI
UJJAIN
INDORE
BANAS
CHAMBAL
KUNWARI
YAMUNA
PARBATI
KALI SINDH
198
39
77
1281/2
283
250
140
272
118
51
221
44
406
437
306
495
519
94
35
72
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 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
CHAMBAL
SUB ZONE 1(b)
50 YEAR 24 HOUR RAINFALL (mm)
DRAWN BY P. N. BHALLA S. K. BHATIA
CHECKED BY A. K. GHOSH
NOTE:—
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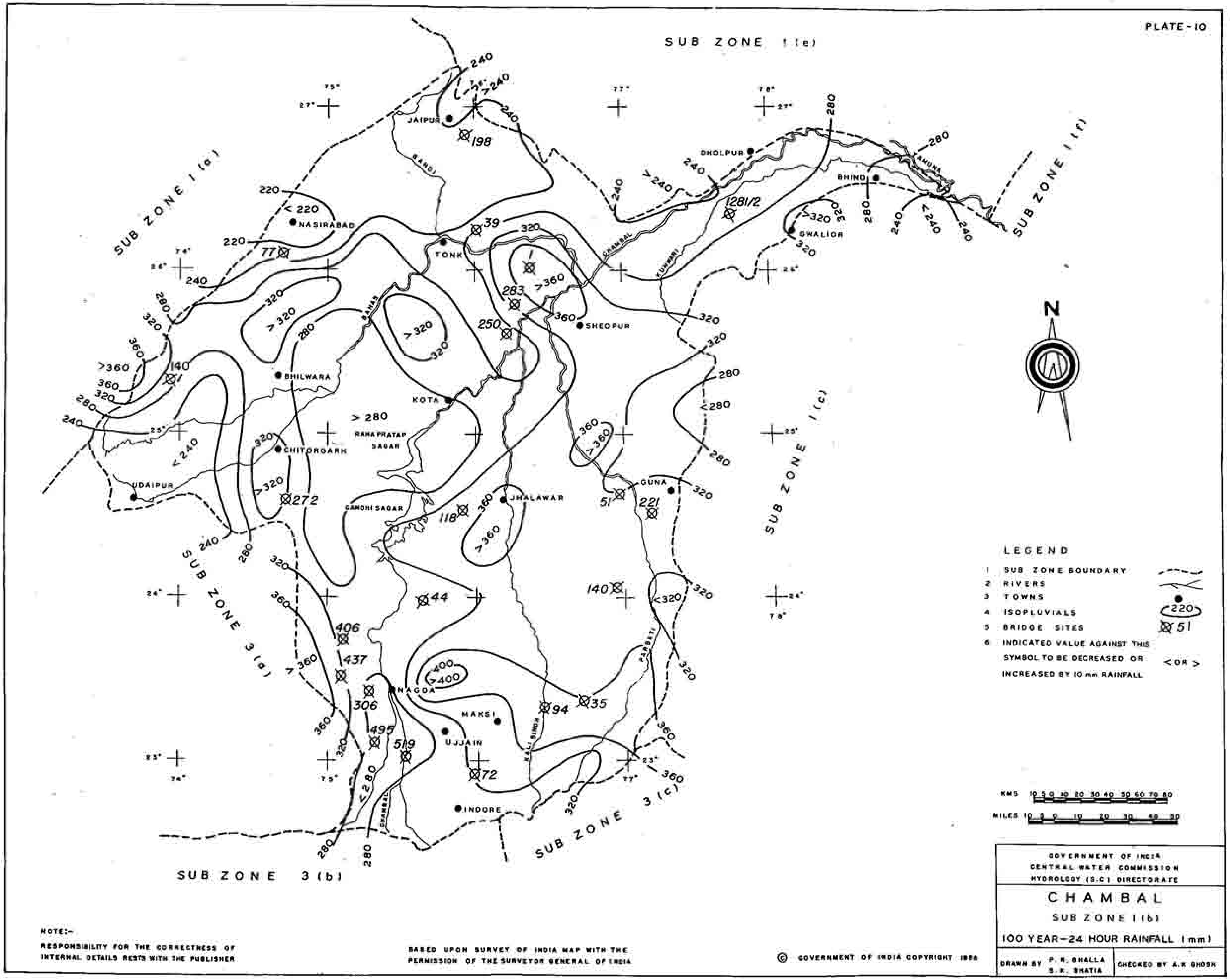
PLATE-10
SUB ZONE 1(e)
SUB ZONE 1(a)
SUB ZONE 1(f)
SUB ZONE 1(c)
SUB ZONE 3(a)
SUB ZONE 3(b)
SUB ZONE 3(c)
JAIPUR
DHOLPUR
BHIND
GWALIOR
NASIRABAD
TONK
SHEOPUR
BHILWARA
KOTA
RANA PRATAP SAGAR
CHITORGARH
UDAIPUR
GANDHI SAGAR
JHALAWAR
GUNA
NAGDA
MAKSI
UJJAIN
INDORE
CHAMBAL
BANAS
KUNWARI
PARBATI
KALI SINDH
N
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 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
CHAMBAL
SUB ZONE 1(b)
100 YEAR-24 HOUR RAINFALL (mm)
DRAWN BY P. N. BHALLA S. K. BHATIA
CHECKED BY A. K. GHOSH
NOTE:-
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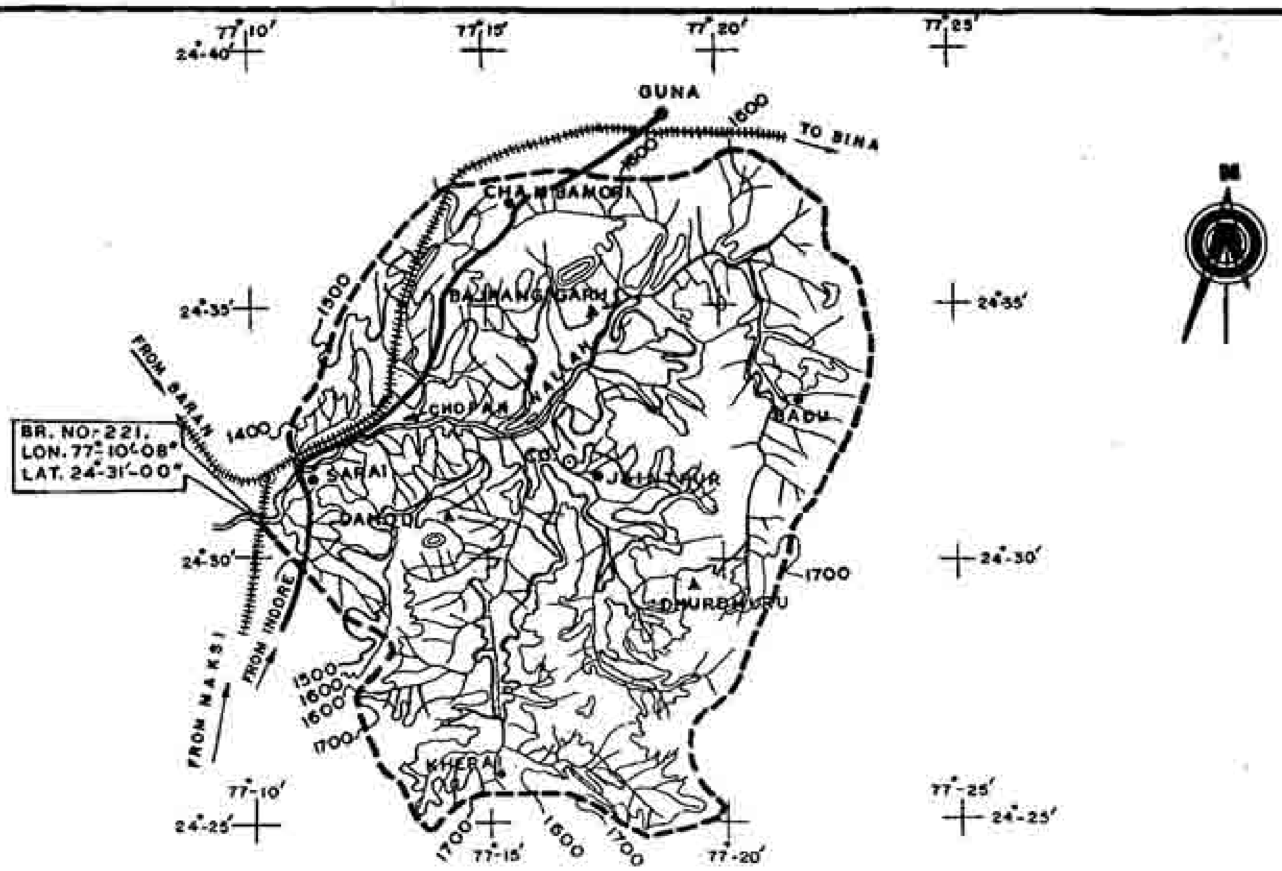
FIG.- A-1



NOTES:-

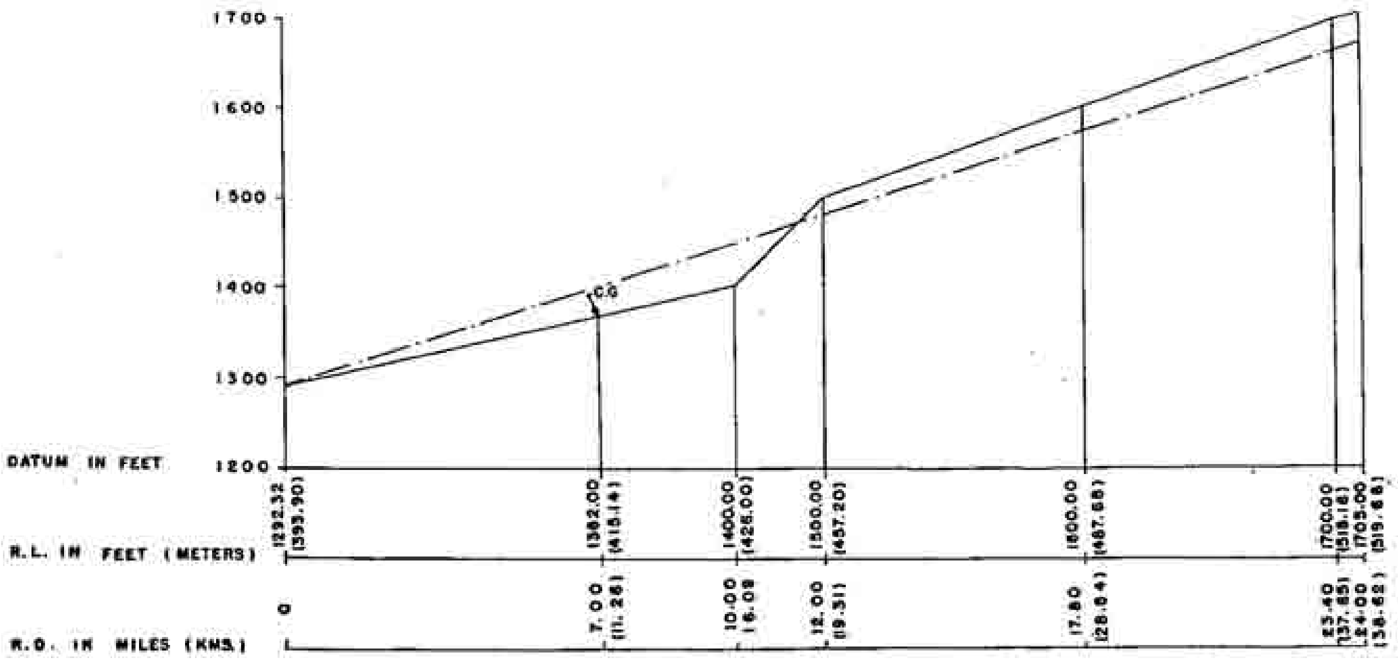
1. ALL LEVELS CORRESPOND TO G.T.S DATUM
2. H.F.L. AT BRIDGE SITE 401·00 METER

REFERENCES:-

1. CATCHMENT AREA
2. RAILWAY LINE
3. RIVERS AND IT'S TRIBUTARIES
4. ROADS
5. RAINGAUGE STATIONS
6. CONTOURS
7. TOPOSHEET NO. — 54 H/NW, SW
8. CENTRE OF GRAVITY

DETAIL OF CATCHMENT AREA

1. AREA OF THE CATCHMENT — 139.40 SQ. MILES (361.05 KM²)
2. SHAPE OF THE CATCHMENT — FAN
3. L. — 24 MILES (38·62 Kms.)
4. Lc. — 7 MILES (11.26 Kms.)
5. Wc. — 4.7 MILES (7·56 Kms.)
6. SLOPE (EQUILIBRIUM) — 3·01 M/Km.
7. Sc. (Eq.) — 1.89 M/Km.



LONGITUDINAL SECTION OF CHOPAN NALLAH

SCALE

VERTICAL: FEET 50 0 100 200

HORIZONTAL: 1 0.5 0 2 4 MILES

SL. NO.	NAME OF R.G. STATIONS	LOCATION		STATIONS WTS. 1975 – 1979
		LONG.	LATI.	
1.	BRIDGE SITE	77°-10'-08"	24°-31'-00"	0.054
2.	DAHOD	77°-14'-10"	24°-31'-00"	0.268
3.	DHURDHURU	77°-19'-25"	24°-29'-35"	0.280
4.	BAJRANGGARH	77°-17'-35"	24°-34'-45"	0.398

NOTE:- BED LEVEL AT BRIDGE SITE TAKEN FROM DATA.

SCALE

1 0.5 0 2 4 MILES

GOVERNMENT OF INDIA
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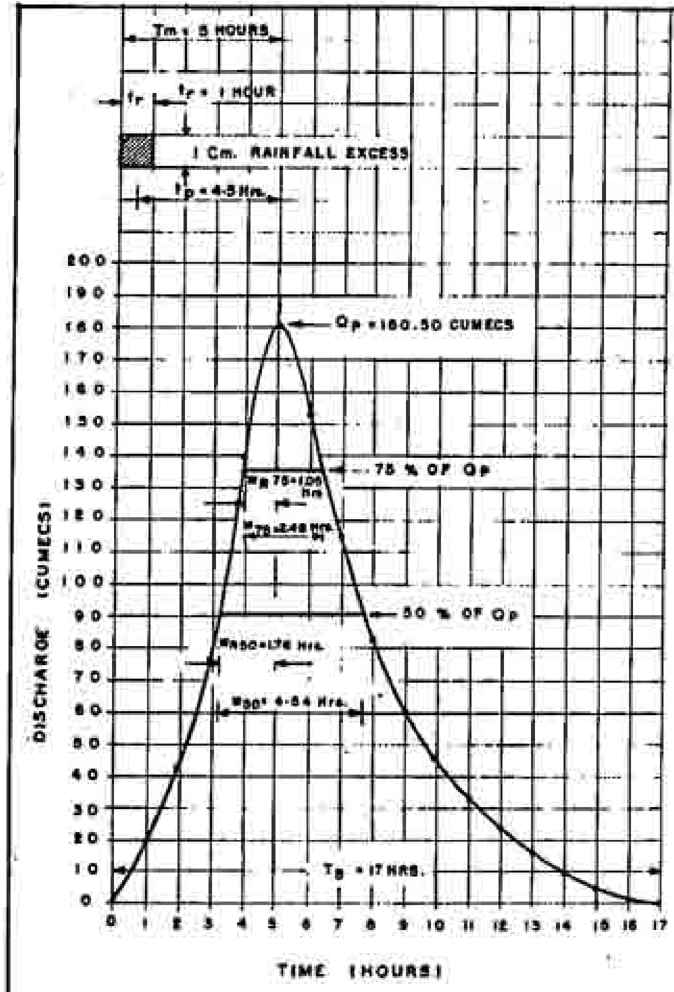
HYDROLOGY (SMALL CATCHMENTS) DTE.

CATCHMENT AREA PLAN
FOR BR.NO.- 221 AT KM.190/11-12
ON GUNA - MAKASHI SECTION
WESTERN RAILWAY SUB ZONE 1 (b).

DRAWN BY-	CHECKED BY-
S. S. JHAS. L. P. NAUTIYAL.	C. S. AGARWAL.



SYNTHETIC U.G. PARAMETER

C. A.	=	361.05 Sq. Km.
t_p	=	4.50 HOURS
T_B	=	17.00 HOURS
Q_p	=	180^50 CUMECS
W_{50}	=	4.54 HOURS
W_{75}	=	2.48 HOURS
W_{R50}	=	1.76 HOURS
W_{R75}	=	1.05 HOURS
q_p	=	0.50 M^3/ Sq. Km.
T_m	=	5.00 HOURS
$\frac{L}{\sqrt{S}}$	=	22.26
d	=	1.00 Cm.

$$\Sigma Q_i = \frac{A \times d}{t_r \times 0.36} = \frac{361.05 \times 1.00}{1.00 \times 0.36} = 1002.90 \text{ CUMECS}$$

FIG. - A - 2.

TIME IN HOURS	1 - HOUR SYNTHETIC U.G. ORDINATES (CUMECS)
0	0
1	19.40
2	42.50
3	76.00
4	139.00
5	180.50
6	153.00
7	115.00
8	82.50
9	60.00
10	45.50
11	33.00
12	23.50
13	16.50
14	9.50
15	5.00
16	2.00
17	0

TOTAL = 1002.90 CUMECS.

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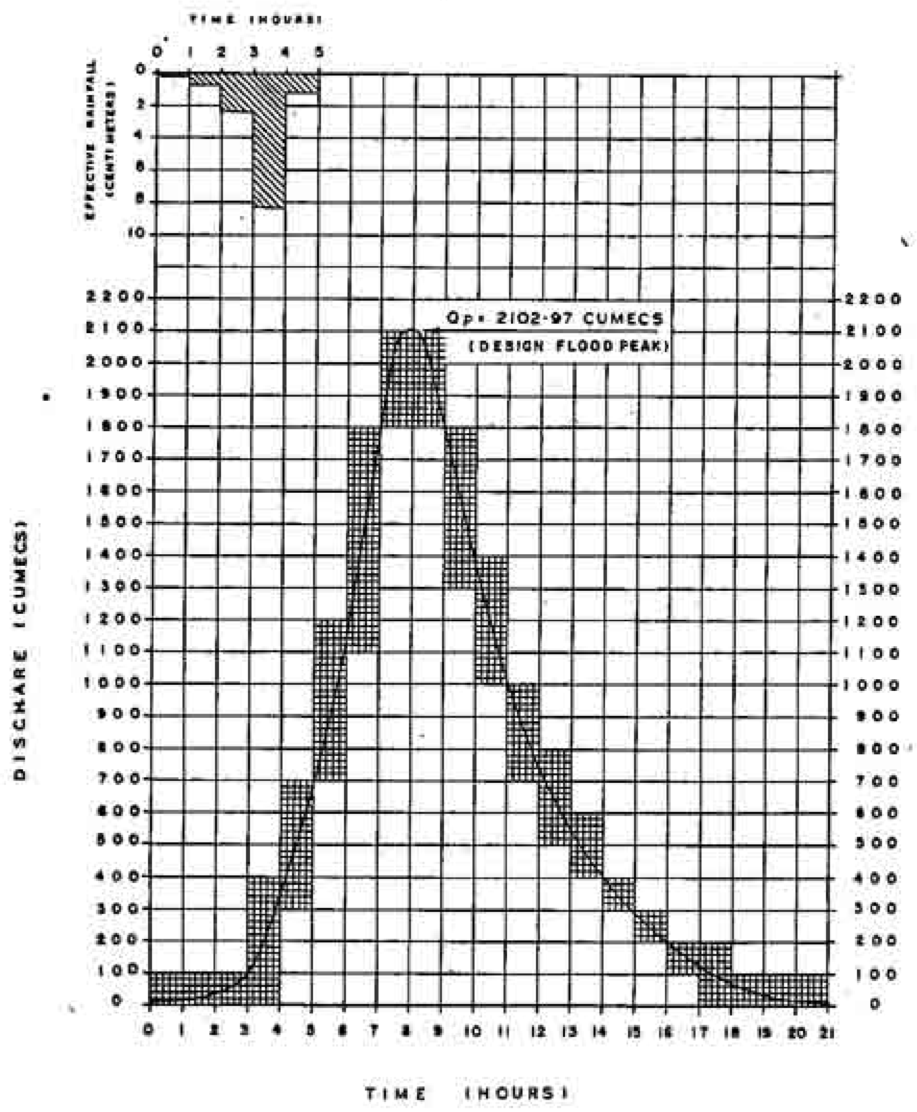
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.

CHAMBAL
SUB ZONE 1 (b)
SYNTHETIC UNIT HYDROGRAPH
BRIDGE NO. - 221.

DRAWN BY -	CHECKED BY -
B. K. BHATIA L. P. NAUTIYAL	K. K. AICH.

FIG.- A-3.



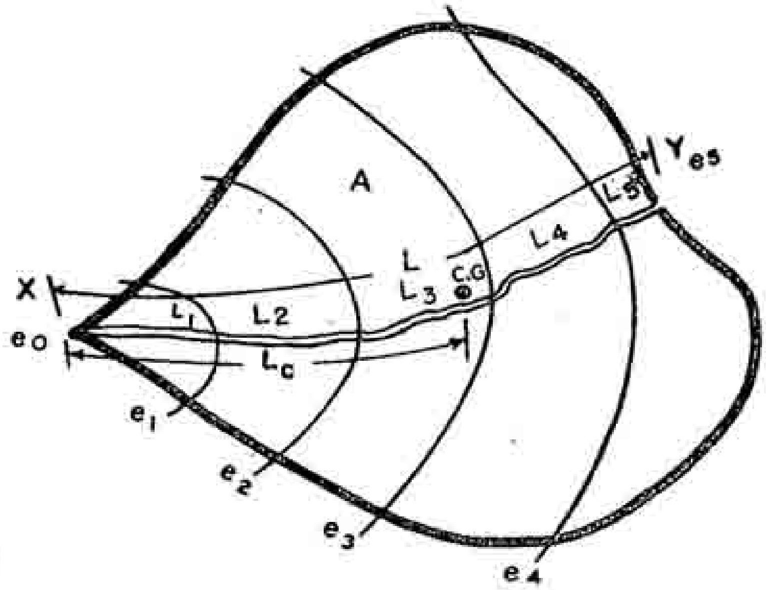
CATCHMENT AREA = 361·05 Sq. Km.

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S.C) DIRECTORATE

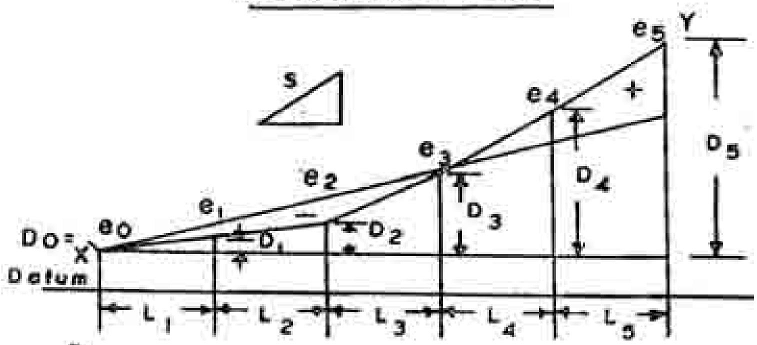
CHAMBAL
SUB ZONE-1(b)
DESIGN FLOOD HYDROGRAPH
BR. NO.- 221 ON CHOPAN NALLAH.

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

FIG.- I



Catchment Plan



L - Section

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

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

L = Length of longest stream course (km.).

$L_i = L_1, L_2, L_3$ -------- L_n Segment lengths (km.).

$e_i = e_0, e_1, e_2$-------- e_n contour elevation (m).

$D_i = D_0, D_1, D_2$ ------- D_n

$= (e_0 - e_0), (e_1 - e_0)$ --------

$(e_n - e_0)$ (m).

A = Catchment Area (Sq.km).

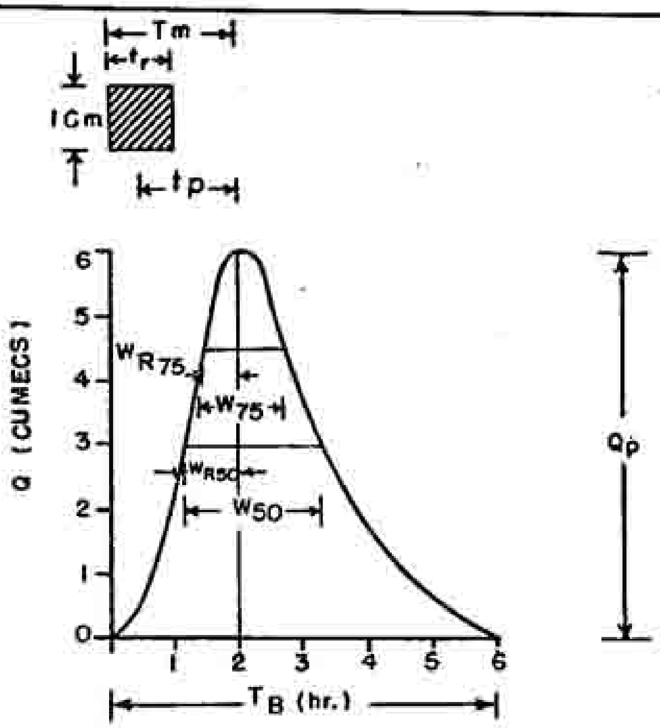
Lc = Length of Longest Stream Course from a point opposit the centre of Gravity of the Catchment to the point of Study (Km.)

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

PHYSIOGRAPHIC PARAMETERS

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

FIG. - 2



U.G. = Unit Graph

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

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

Qp = Peak Discharge of Unit Hydrograph (cumecs)

tp = Time from the centre of effective rainfall duration to the U.G peak (hr.)

W50 = Width of the U.G. measured at 50% of peak discharge ordinate (hr.)

W75 = Width of the U.G measured at 75% of peak discharge ordinate (hr.)

WR50 = Width of the rising limb of U.G. measured at 50% of peak discharge ordinate (hr.)

WR75 = Width of the rising limb of U.G. measured at 75% of peak discharge ordinate (hr.)

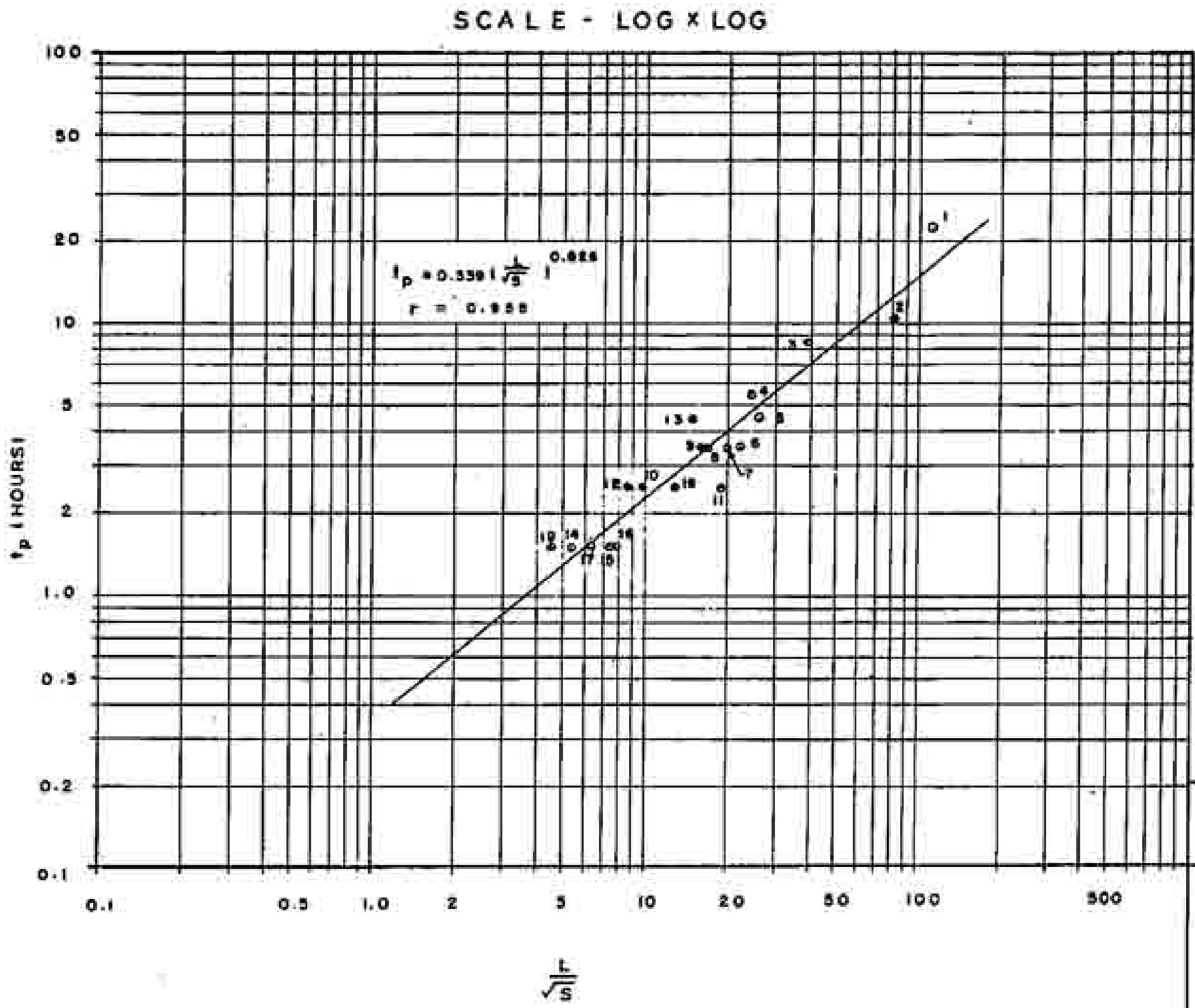
TB = Base width of Unit Hydrograph (hr.)

A = Catchment Area (Sq. km.)

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

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (SMALL CATCHMENTS) DTE.	
UNIT GRAPH PARAMETERS	
DRAWN BY- S.N. MALHOTRA, P.N. BHALLA	CHECKED BY- A. K. GHOSH

FIG.- 3



SL. NO.	BRIDGE NO.	$\frac{L}{\sqrt{S}}$	t_p (HOURS)
1	94	110.11	22.50
2	519	81.31	10.50
3	72	38.59	8.50
4	283	24.63	5.50
5	198	25.86	4.80
6	221	22.26	3.80
7	272	19.90	3.80
8	140	16.86	3.90
9	437	16.22	3.50
10	39	9.75	2.80
11	51	19.16	2.50
12	44	8.64	2.50
13	495	14.92	4.50
14	406	5.45	1.50
15	1	7.34	1.50
16	306	7.78	1.50
17	118	6.30	1.50
18	35	12.73	2.50
19	77	4.56	1.50

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

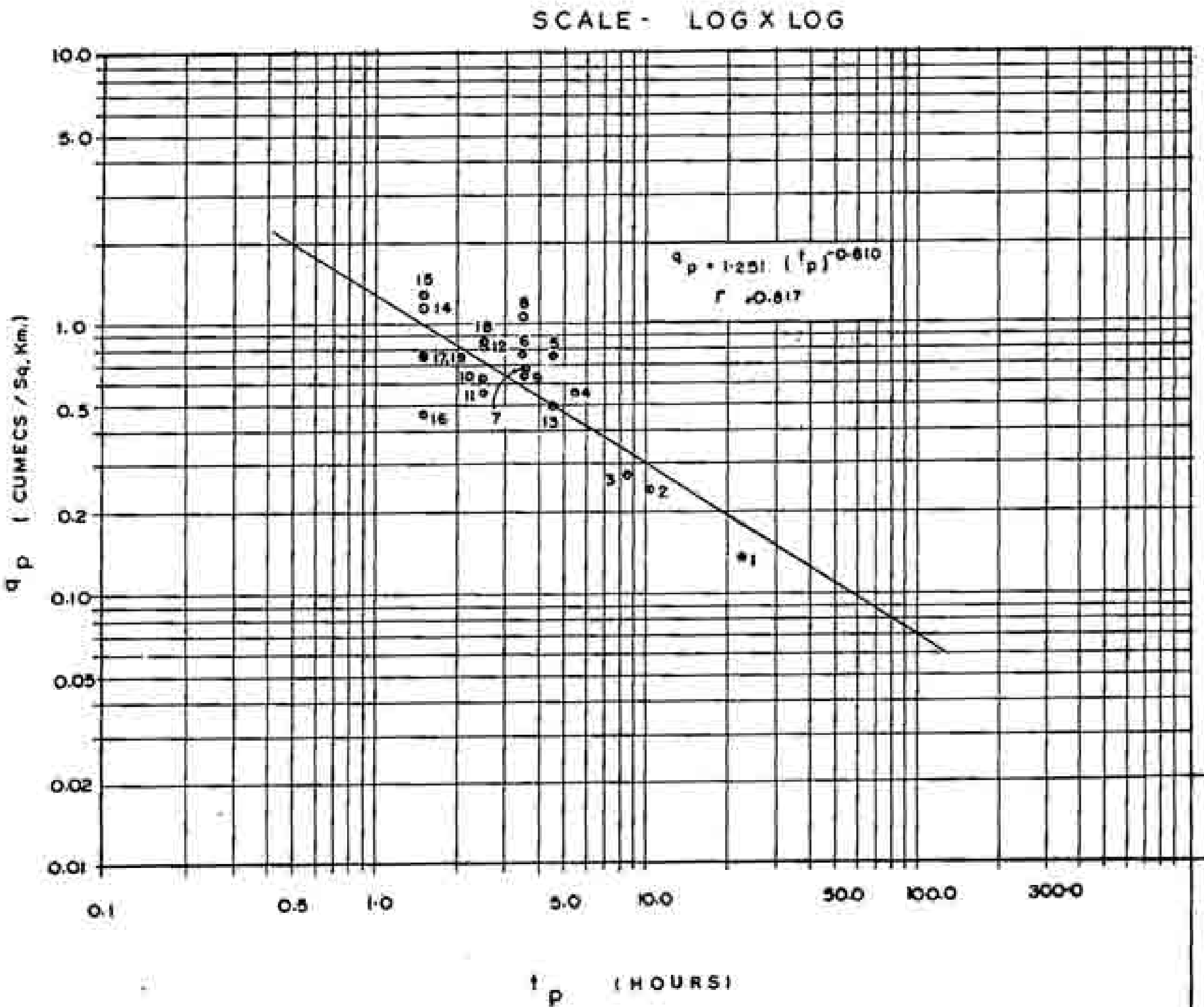
CHAMBAL

SUB ZONE 1 (b)

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

DRAWN BY	CHECKED BY.
S.N.MALHOTRA, BHALLA	S. PRASAD

FIG.- 4.



SL. NO.	BRIDGE NO.	t_p (HOURS)	q_p [illegible]
1	94	22.50	0.138
2	519	10.50	0.245
3	72	8.50	0.275
4	283	5.50	0.560
5	198	4.50	0.762
6	221	3.50	0.780
7	272	3.50	0.670
8	140	3.50	1.094
9	437	3.50	0.570
10	39	2.50	0.620
11	61	2.50	0.574
12	44	2.50	0.827
13	495	4.50	0.502
14	406	1.50	1.140
15	1	1.50	1.296
16	306	1.50	0.460
17	118	1.50	0.750
18	35	2.50	0.760
19	77	1.50	0.760

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

CHAMBAL

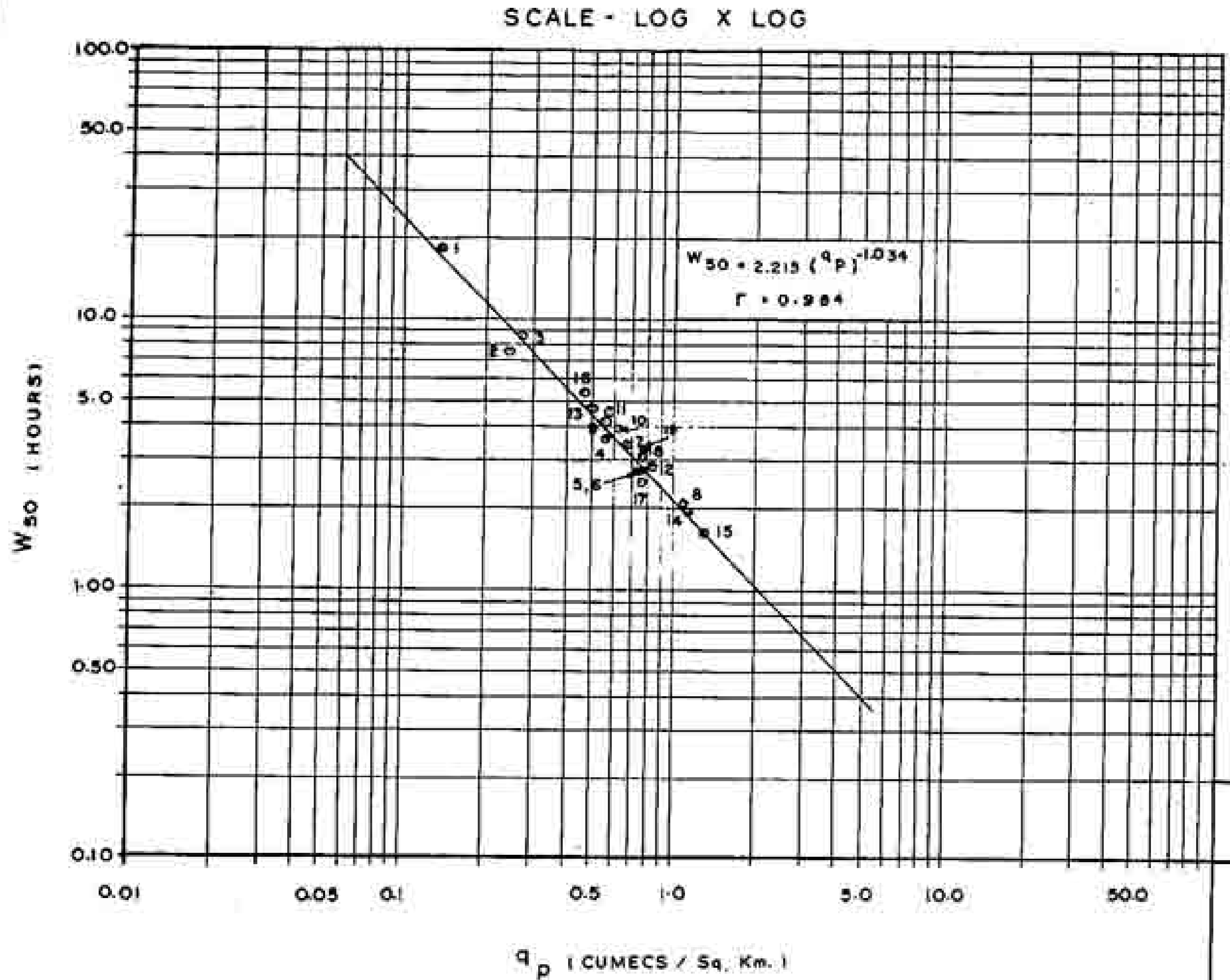
SUB ZONE 1 (b).

RELATION BETWEEN t_p AND q_p

DRAWN BY- S.K. BHATIA

CHECKED BY- B. K. AICH

FIG.- 5.



SL. NO.	BRIDGE NO.	q_p (Cum/Km²)	W_{50} (HOURS)
1	94	0.138	18.80
2	519	0.245	7.50
3	72	0.275	8.65
4	283	0.560	3.60
5	198	0.762	2.62
6	221	0.780	2.60
7	272	0.670	3.30
8	140	1.094	2.10
9	437	0.570	4.20
10	39	0.620	3.90
11	51	0.574	4.50
12	44	0.827	2.85
13	495	0.502	4.70
14	406	1.140	1.95
15	1	1.296	1.65
16	306	0.460	5.40
17	118	0.750	2.49
18	35	0.760	3.10
19	77	0.760	3.30

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

CHAMBAL

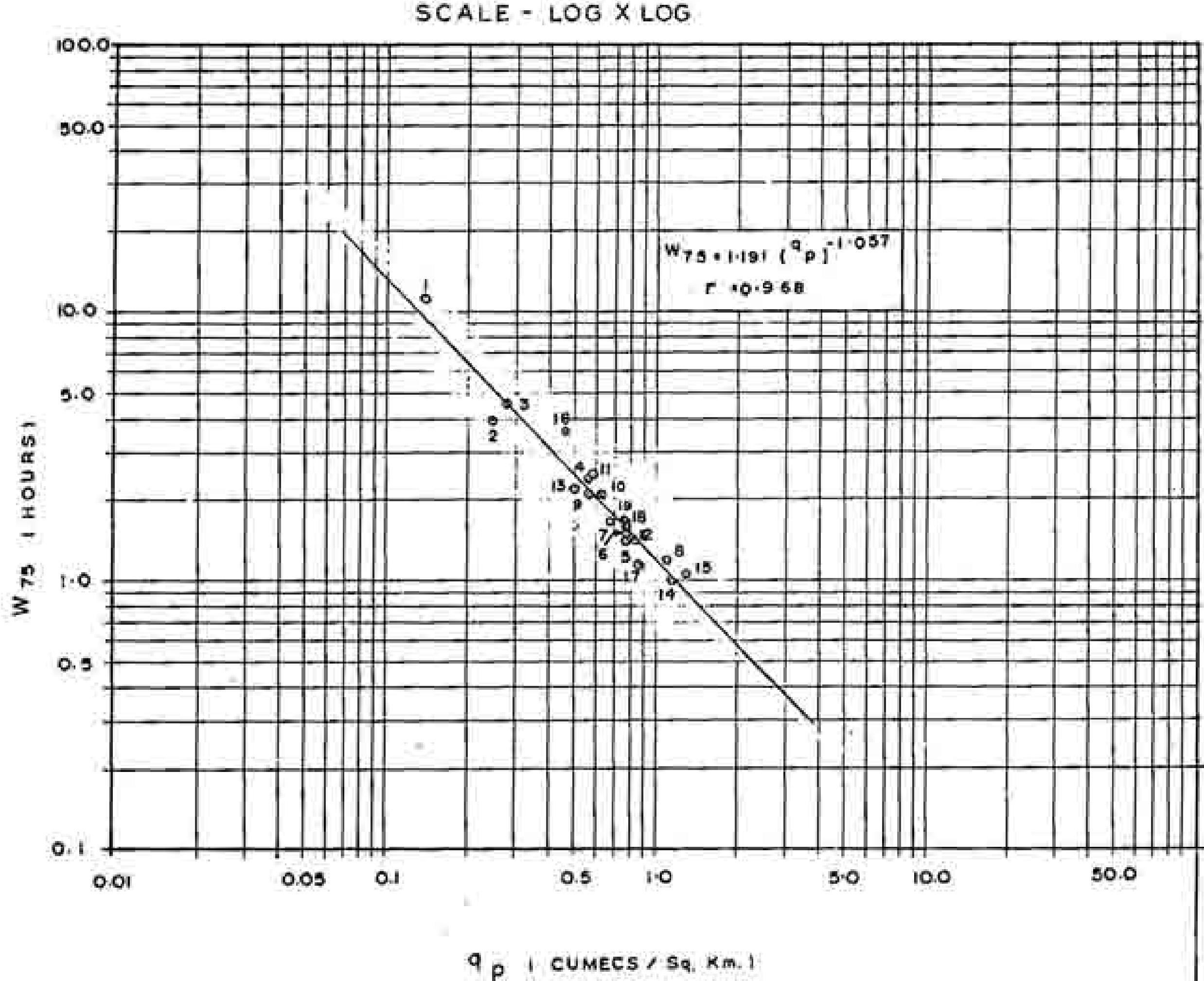
SUB ZONE I (b).

RELATION BETWEEN q_p AND W_{50}

DRAWN BY_ L. P. NAUTIYAL

CHECKED BY_ K. K. AICH

FIG. - 6.



SL. NO.	BRIDGE NO.	q_p (Cum/Km²)	W_{75} (HOURS)
1	94	0.138	11.35
2	519	0.245	4.00
3	72	0.275	4.65
4	283	0.560	2.40
5	198	0.762	1.40
6	221	0.780	1.50
7	272	0.670	1.65
8	140	1.094	1.20
9	437	0.570	2.10
10	39	0.620	2.10
11	51	0.574	2.50
12	44	0.827	1.40
13	495	0.502	2.20
14	406	1.140	1.05
15	1	1.296	1.05
16	306	0.460	3.60
17	118	0.750	1.14
18	35	0.760	1.60
19	77	0.760	1.65

GOVERNMENT OF INDIA
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HYDROLOGY (SMALL CATCHMENTS) DTE.

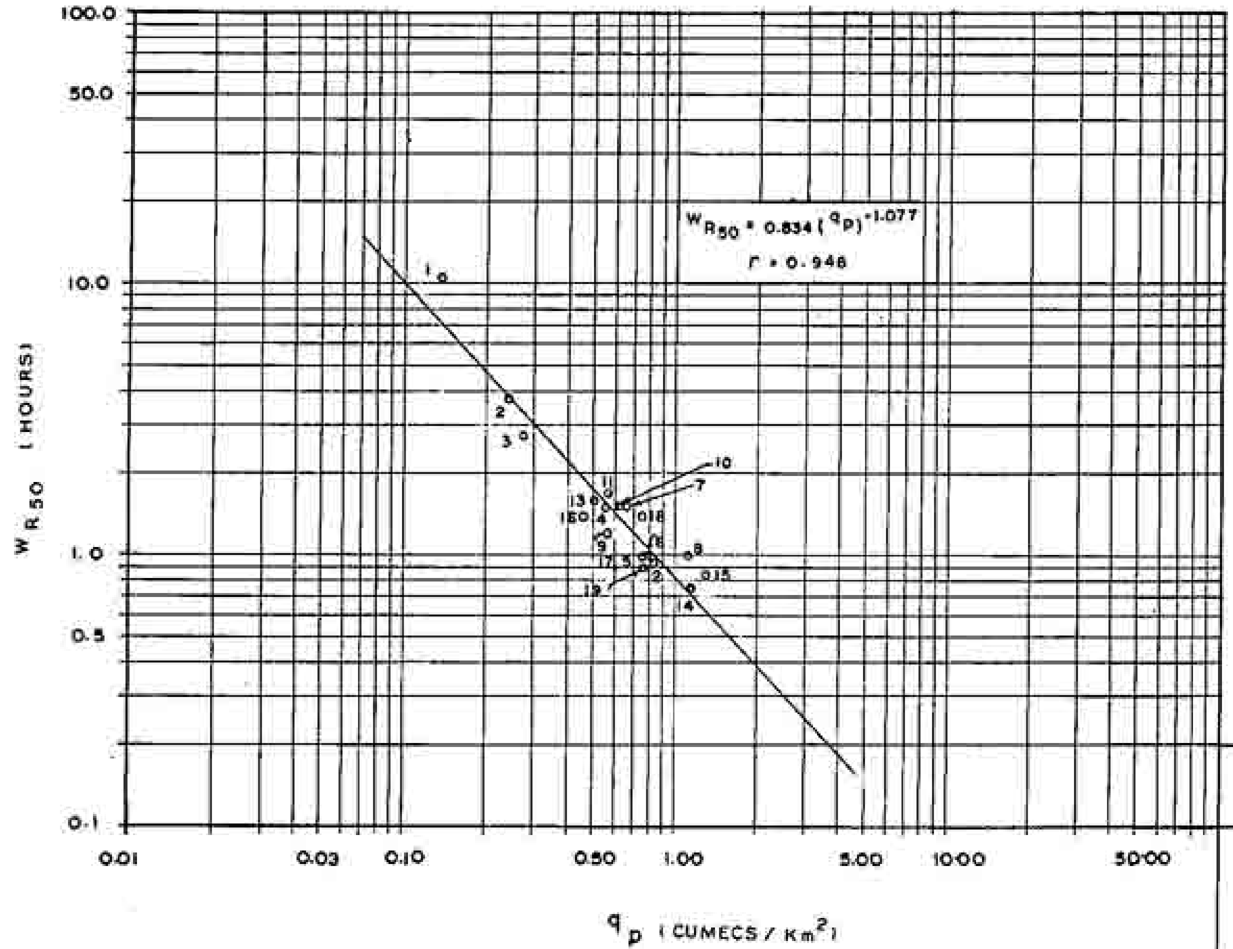
CHAMBAL

SUB ZONE 1 (b).

RELATION BETWEEN q_p AND W_{75}

DRAWN BY— S.N. MALHOTRA | CHECKED BY— K. K. AICH

FIG.- 7.



SL. NO.	BRIDGE NO.	q_p (Cum/Km^2)	W_{R50} (HOURS)
1	94	0.138	10.60
2	519	0.245	3.73
3	72	0.275	2.75
4	283	0.560	1.50
5	198	0.782	0.98
6	221	0.780	1.00
7	272	0.870	1.50
8	140	1.094	1.00
9	437	0.570	1.20
10	39	0.620	1.50
11	51	0.574	1.70
12	44	0.827	0.95
13	495	0.502	1.60
14	406	1.140	0.75
15	1	1.298	0.85
16	306	0.480	1.40
17	116	0.750	0.95
18	35	0.760	1.40
19	77	0.760	0.90

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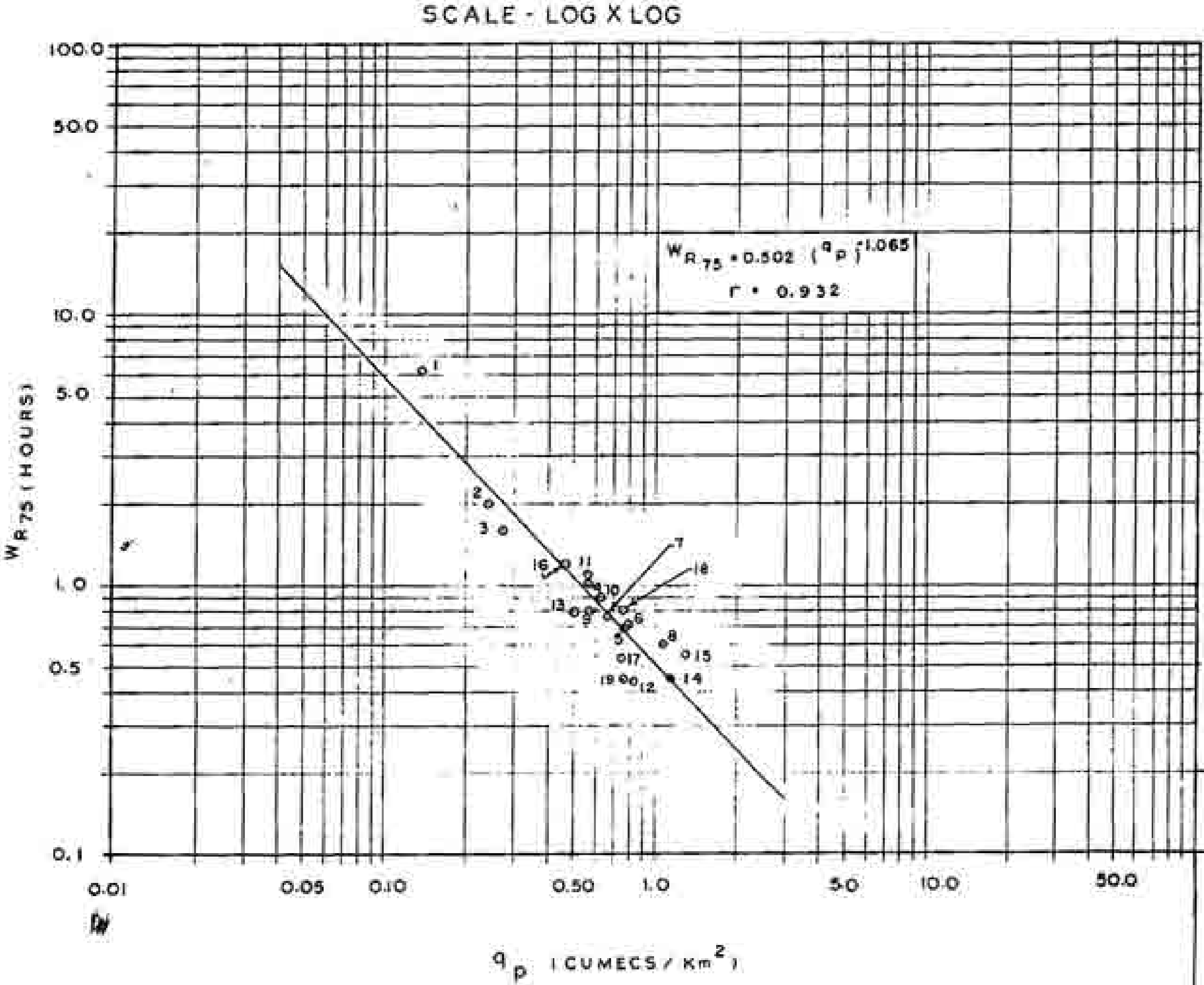
SUB ZONE I (b)
RELATION BETWEEN
q_p AND W_{R50}

DRAWN BY- ... CHECKED BY- V. V. AICH.

FIG.- 8.



SL. NO.	BRIDGE NO.	q_p Cum./Km^2	$W_{R_{75}}$ (Hours)
1	94	0.138	6.20
2	519	0.245	2.00
3	72	0.275	1.58
4	283	0.560	1.00
5	198	0.762	0.68
6	221	0.780	0.70
7	272	0.670	0.75
8	140	1.094	0.60
9	437	0.570	0.80
10	39	0.620	0.90
11	51	0.574	1.10
12	44	0.827	0.45
13	495	0.502	0.80
14	406	1.140	0.45
15	1	1.296	0.55
16	306	0.460	1.20
17	118	0.750	0.54
18	35	0.760	0.80
19	77	0.780	0.45

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

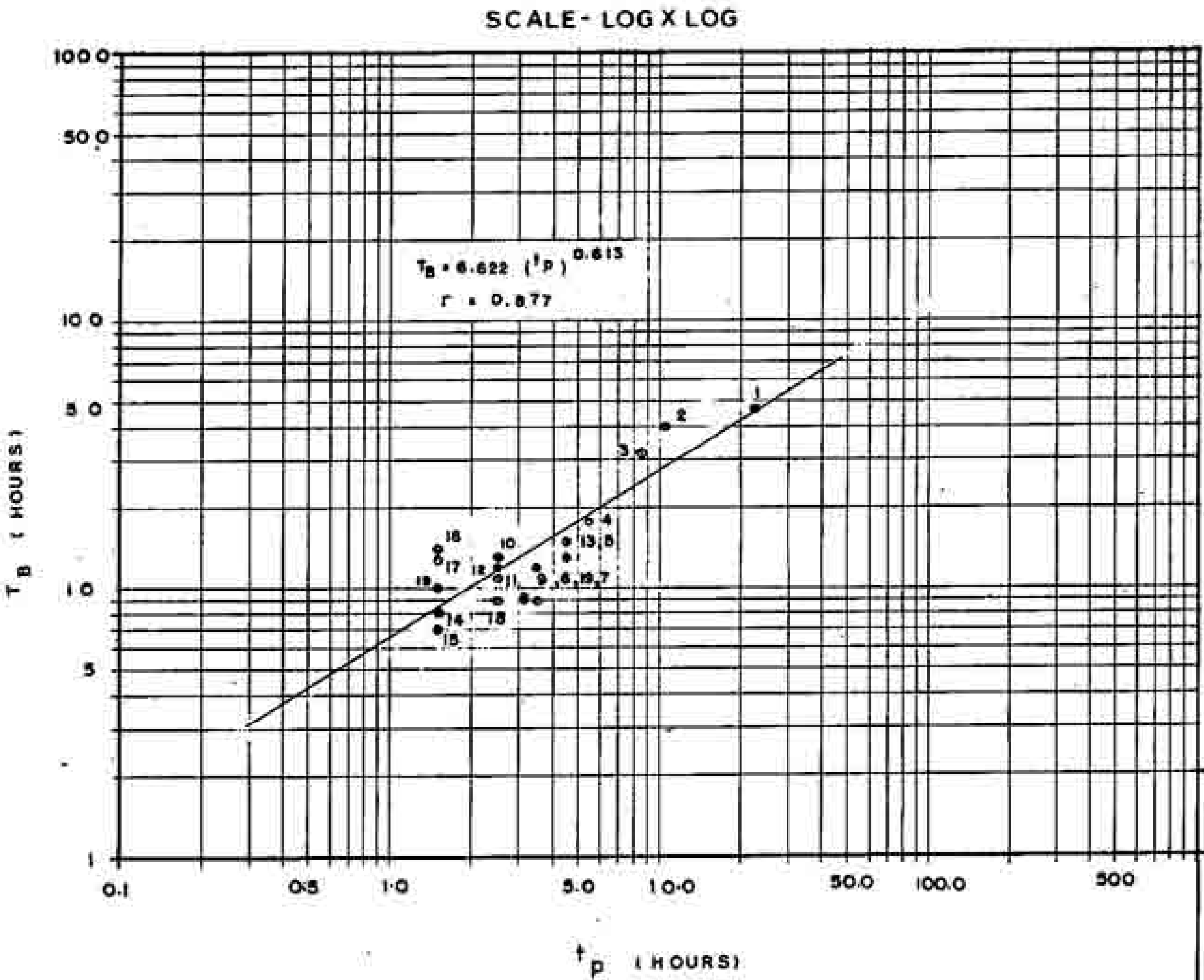
CHAMBAL

SUB ZONE 1 (b).

RELATION BETWEEN q_p AND $W_{R_{75}}$

DRAWN BY- S. K. BHATIA	CHECKED BY- K. K. AICH.

FIG.- 9.



SL. NO.	BRIDGE NO.	t_p (HOURS)	T_B (HOURS)
1	94	22.50	47.00
2	519	10.50	40.00
3	72	8.50	32.00
4	283	5.50	18.00
5	198	4.50	15.00
6	221	3.50	12.00
7	272	3.50	12.00
8	140	3.50	9.00
9	437	3.50	12.00
10	39	2.50	13.00
11	51	2.50	11.00
12	44	2.50	12.00
13	495	4.50	15.00
14	406	1.50	8.00
15	1	1.50	7.00
16	306	1.50	14.00
17	118	1.50	13.00
18	35	2.50	9.00
19	77	1.50	10.00

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HYDROLOGY (SMALL CATCHMENTS) DTE.

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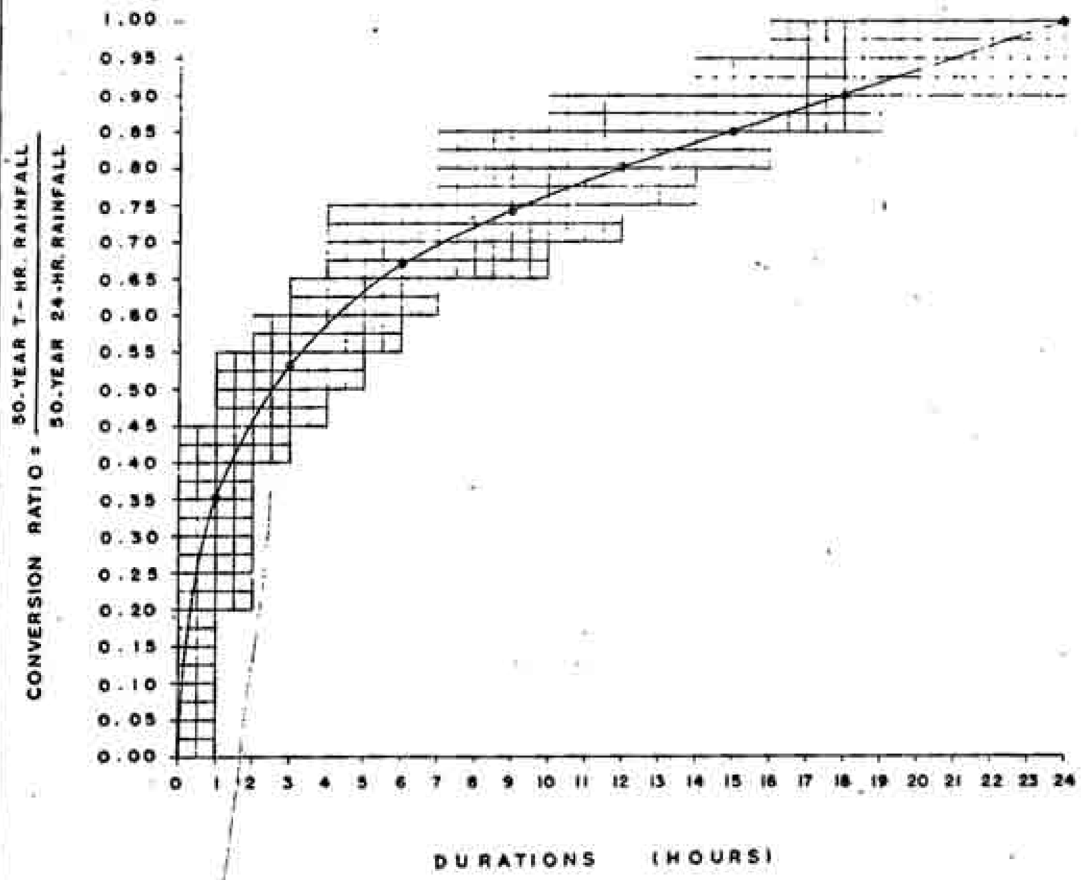
SUB ZONE 1 (b).

RELATION BETWEEN t_p AND T_B

DRAWN BY— L. P. NAUTIYAL | CHECKED BY— K. K. AICH

FIG - 10



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

DURATION (HRS)	RATIO
1	0.350
2	0.457
3	0.530
4	0.587
5	0.633
6	0.670
7	0.695
8	0.720
9	0.740
10	0.762
11	0.780
12	0.800
13	0.816
14	0.833
15	0.850
16	0.865
17	0.883
18	0.900
19	0.916
20	0.933
21	0.950
22	0.965
23	0.983
24	1.000

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CHAMBAL
SUB ZONE - I (b)
DURATION VS. CONVERSION RATIO

DRAWN BY–	CHECKED BY–
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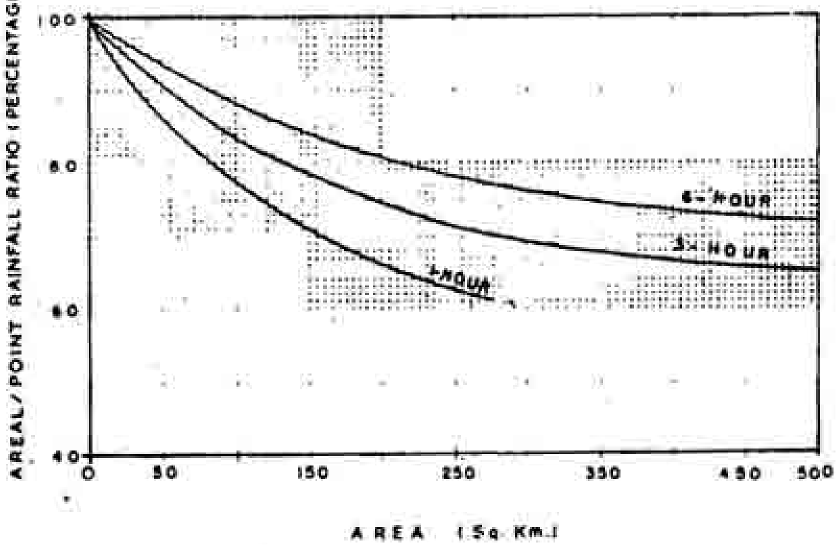
FIG-11(a)



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AREAL TO POINT RAINFALL RATIO PERCENTAGE

DRAWN BY–	CHECKED BY–
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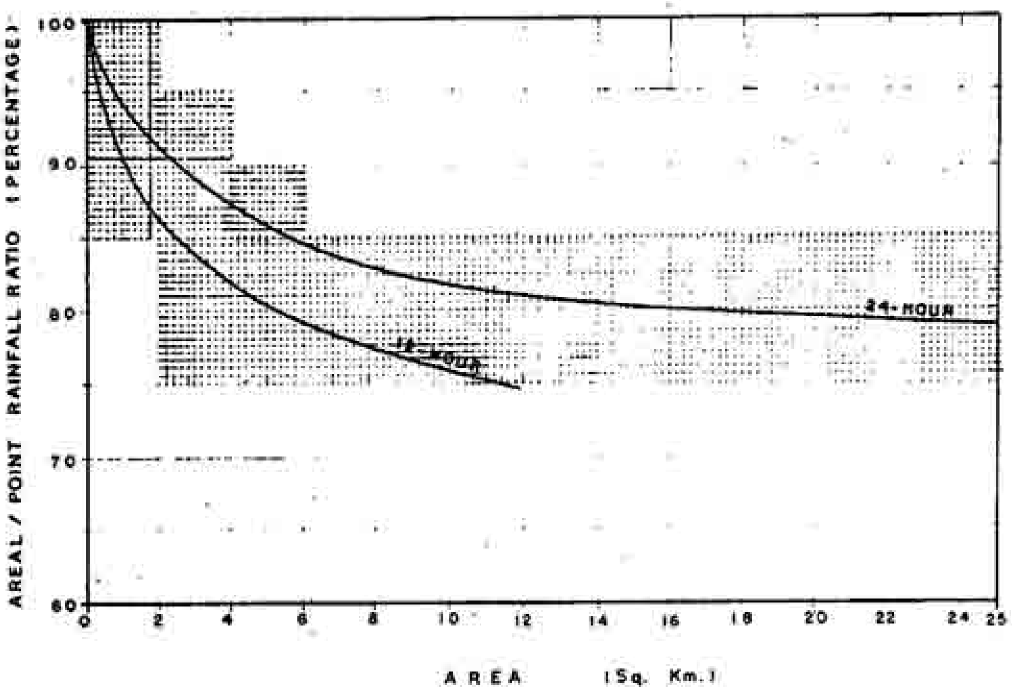
FIG.- 11 (b).



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SUB ZONE I (b)

AREAL TO POINT RAINFALL RATIO PERCENTAGE

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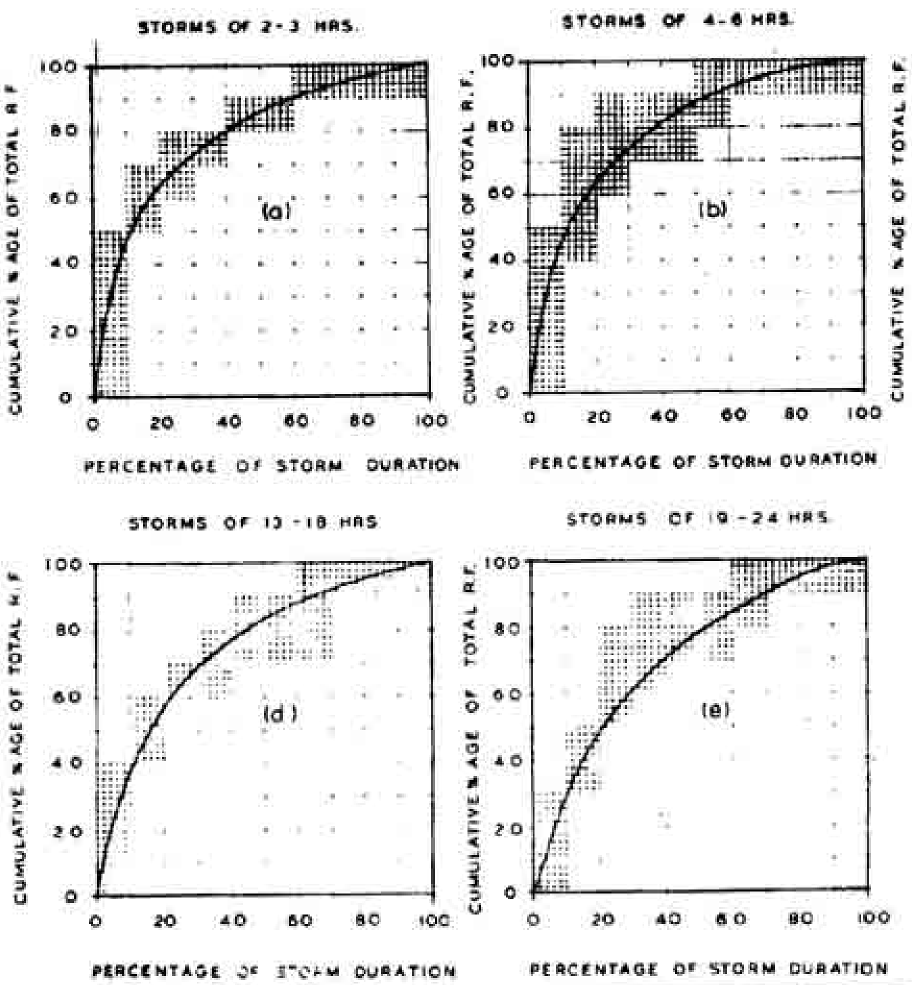
FIG. - 12.



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

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SUB ZONE-1(b)

MEAN AVERAGE TIME DISTRIBUTION CURVES OF STORMS OF VARIOUS DURATIONS.

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2.	Lower Godavari subzone-3(f)	(1981)
3.	Lower Narmada & Tapi subzone-3(b)	(1982)
4.	Mahanadi subzone-3(d)	(1982)
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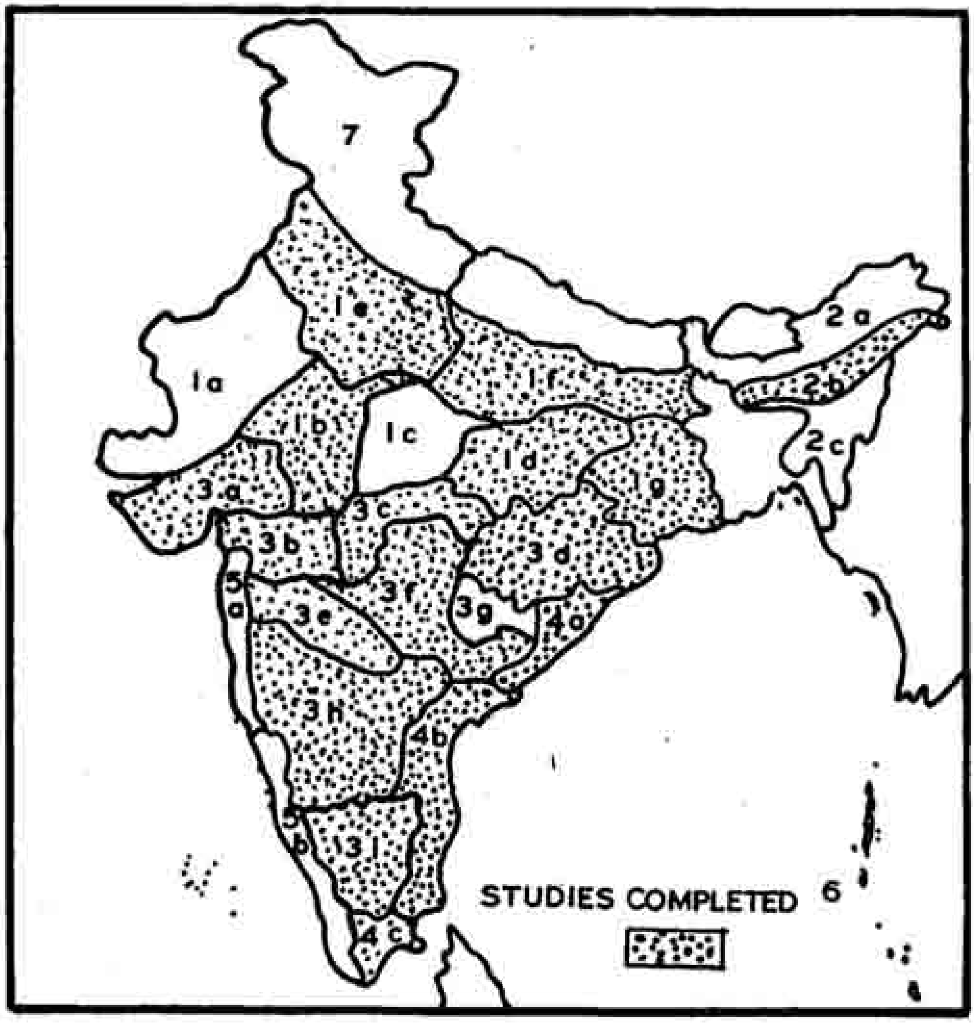

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