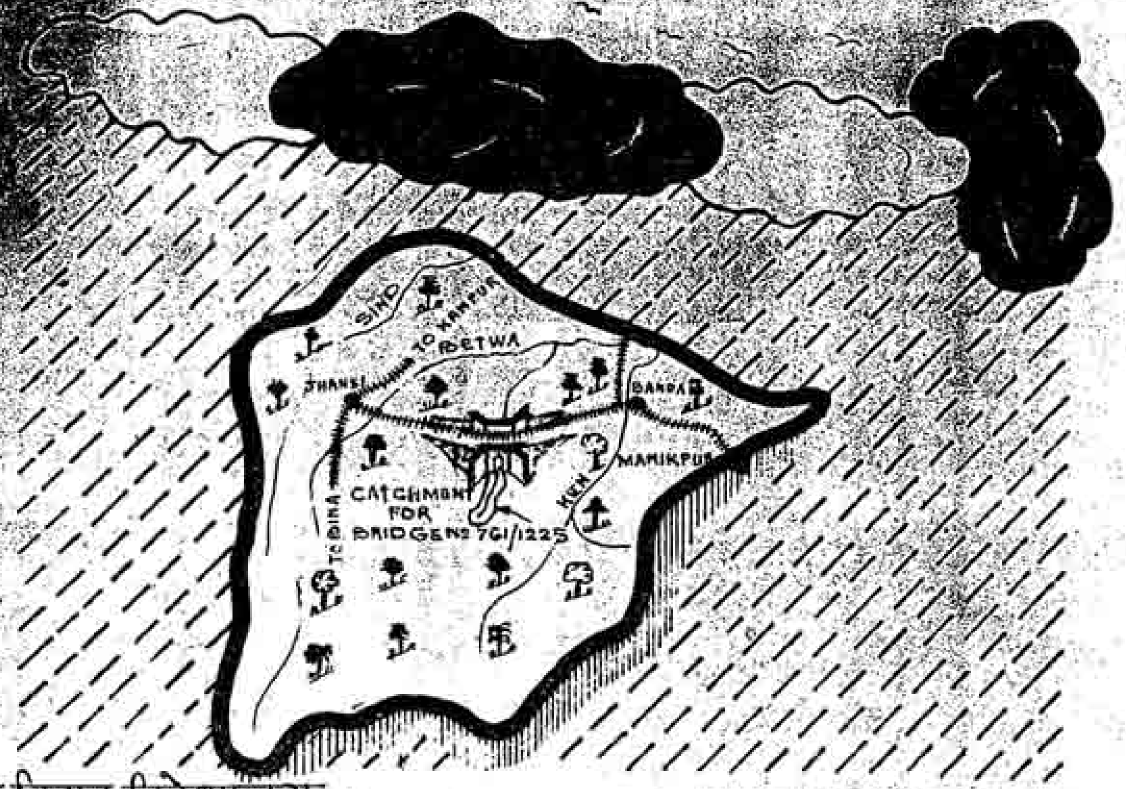
बेतवा उपक्षेत्र-1 (सी) के बाढ़ आकलन का विवरण

यूनिट जलालेख सिद्धान्त पर आधारित एक पद्धति

FLOOD ESTIMATION REPORT FOR BETWA SUB ZONE - 1(c)

A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE



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NEW DELHI - 110066.

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

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FLOOD ESTIMATION REPORT FOR BETWA SUBZONE 1(c)

A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE
DESIGN OFFICE REPORT NO. B/17/1989.

HYDROLOGY (SMALL CATCHMENTS) DIRECTORATE
CENTRAL WATER COMMISSION
NEW DELHI

JUNE 1989

FOREWORD

The hydrologic design of railway 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 Govt. 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 flood. As a follow up of the recommendations of the Committee of Engineers, four organisations concerned with the design of bridges, namely, 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 together. This joint effort aims at collection of rainfall - runoff data for a period of about 5years 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 hydrometeorologically homogeneous sub-zones. With the data presently available, 22 sub-zones covering 81 percent of the country's geographical area could be studied. So far studies on 17 sub-zones have been completed and 15 reports covering these studies have been brought out.

The present report is the 16th report in this series and covers the studies on Betwa Sub-zone-1(c). 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 so far 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 commendations of the excellent co-operative effort of the officers and staff of the four organisations mentioned above in producing this report.

New Delhi

May 1989

(Y. D. PENDSE)
MEMBER (WATER PLANNING)
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PREFACE

Design Engineers essentially need the design flood of a specific return period for fixing the waterway vis-a-vis the design 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, it 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 at every new site on a large scale and on a long term basis for estimation of design flood with a desired return period. Regional flood estimation studies become necessary for hydro-meteorologically homogeneous regions in the country. Broadly two main regional approaches are open for adoption depending on the availability of the storm rainfall and flood data. The first approach 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 15 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 Catchment) 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 perpared for sever . catchments in a subzone have been correlated by regression anal is 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)

15. Chambal subzone-1(b) (1989)

The present report for Betwa subzone - 1(c) is based on the detailed rainfall and runoff studies of 11 representative catchments. The data at each of the 11 catchments was collected for a period varying from 3 to 8 years by Western and Central Railways under the guidance of R.D.S.O. Besides this, the data of 179 ordinary raingauge stations maintained by IMD/States and data of 37 self-recording raingauge stations maintained by IMD/Railways has been made use of in preparation of this report.

The Betwa subzone- 1(c) 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 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. General description of the subzone detailing locations 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}. Illustrative examples covering both the approaches are also given. The storm studies carried out by IMD are dealt in part III of the report. The part IV is theportion 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(c) is recommended for estimation of design flood from small and medium catchments varying in areas from 25 to 2600 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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PART - IV

UTILITY OF REPORT

PART - V

LIST OF TABLES, PLATES AND FIGURES

FIGURES

SYMBOLS AND ABBREVATIONS

SYMBOLS

As far as possible well recognised letter symbols in th hydrological science have been used in this report. The list o 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.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 ~~sq.~~ 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.
M.O.T.	Ministry of Transport
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 (Qp)in hours.

% Percent.

Σ Summation

PART - I

SUMMARY AND CONTENTS OF APPROACHES

1.0 Approaches for design flood estimation:

1.1.0 Detailed S.U.H. approach

1.2.0 Regression forumla (~~developed~~ Simplified approaches)

1.2.1 Design flood level:

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

CONTENTS OF APPROACHES

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	Betwa 1(c)
ii) Name of site (i.e. point of study)	Rly.Br. 761/1225
iii) Name of Rly. Section	Jhansi-Manikpur (CR)
iv) Name of Tributary	Barma
v) Shape of catchment	Fan
vi) Location	Lat 25°-17'-30"
	Long 79°-28'-03"
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. F-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)	154.62 sq km
2) Length of the longest stream (L)	23.35 km
3) Equivalent stream slope (S)	2.62 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 F-1. Draw a sloping mean line by trial to replace the plotted 'L' section having different slopes such that the areas below and above the mean line with reference to original 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 T-1 with reference to Fig F-1 are self-explanatory.

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

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

i) $q_p = 1.331\,(L/S)^{-0.492}$
$= 1.331\,(8.912)^{-0.492}$
$= 0.454$ Cumecs per sq km

ii) $t_p = 2.195/(q_p)^{-0.944}$
$= 2.195\,(0.454)^{-0.944}$
$= 4.62$ hrs
(rounded off to 4.50 hrs.)

iii) $W_{50} = 2.040\,(q_p)^{-1.0265}$ $= 2.040(0.454)^{-1.0265}$
$= 4.59$ hrs.

iv) $W_{75} = 1.250\ (q_p)^{-0.864} = 1.250(0.454)^{-0.864}$
$= 2.47$ hrs.

v) $W_{R50} = 0.739\ (q_p)^{-0.968} = 0.739(0.454)^{-0.968}$
$= 1.59$ hrs.

vi) $W_{R75} = 0.500\ (q_p)^{-0.813} = 0.500(0.454)^{-0.813}$
$= 0.95$ hrs.

vii) $T_B = 3.917(t_p)^{0.990} = 3.917(4.5)^{0.990}$
$= 17.36$ hrs.
Say 17.00 hrs.

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

ix) $Q_p = q_p \times A = 0.454 \times 154.62$
$= 70.20$ Cumecs.

Step-4:-<u>Drawing of Synthetic Unitgraph</u>

Estimated parameters of unitgraph in step-3 were plotted to scale on a graph paper as shown in Fig F-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 $\Sigma Qi\ ti = 429.5\ m^3/s$ as shown in Fig F-2 and compared with the volume of 1.00 cm Direct Runoff Depth over the catchment with the Formula <Qi*ti = 2.78 A.d/ti.

Where A = Catchment area in Sq. Km.

d = 1.0 cm depth

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

$$Qi*ti = \frac{A * d}{0.36 * tr} = \frac{154.62 * 1}{0.36 * 1} = 429.50$$

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

Step-5:<u>Estimation of Design Storm Duration</u>

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 one 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 - 10 showing 50-yr 24-hr point rainfall = 29.5 cm. Conversion factor of 0.59 was read from Fig - 10 in section for conversion of 50-yr 24-hr point rainfall to 50-yr 5-hr point rainfall (since T_D = 5 hrs) 50-yr 5-hr point rainfall ≃ 29.5 * 0.59 ≃ 17.40 cm.

Areal reduction factor of 0.828 corresponding to a catchment area of 154.62 sq.km for T_D = 5-hr. was interpolated from Table 6 or Fig 11 in section for conversion of point to areal rainfall 50-yr 5-hr areal rainfall =17.40 x0.828 cm = 14.41 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 = 14.41 cm was distributed with the distribution coefficients (col. 5 of Table 7) or from mean average time distribution curve for storms of 4-6 hrs in Fig 12(b) 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	9.08	9.08
2	0.81	11.67	2.59
3	0.91	13.11	1.44
4	0.97	13.98	0.87
5	1.00	14.41	0.43

Step-8: Estimation of Effective Rainfall Units:

A design loss rate of 0.23 cm has been adopted.

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

Time hrs	Rainfall incre- ments (cms)	Design loss rate cm/hr	Rainfall excess (col2-col3) (cms)
1	2	3	4
1	9.08	0.23	8.85
2	2.59	0.23	2.36
3	1.44	0.23	1.21
4	0.87	0.23	0.64
5	0.43	0.23	0.20

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

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

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

Time (hrs)	U.G. ordinate cumecs	1-hr effec. rainfall (cms)	Direct Runoff (cumecs)
1	2	3	4
4	51.00	1.21	61.71
5	70.20	8.85	621.27
6	59.50	2.36	140.42
7	44.70	0.64	28.61
8	34.70	0.20	6.94
		Total	858.95
		Base Flow	2.78
		50-yr Flood Peak	861.73

Step-10: Computation of Design Flood Hydrograph

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

Time in hrs	Critical 1-hr effective rainfall sequence cms
1	0.20
2	0.64
3	2.36
4	8.85
5	1.21

For computation of design flood hydrograph, the U.G. ordinates for 1-hr interval were tabulated in col(2) of Table T-3 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 T-3. The direct runoff resulting from each of the 1-hr effective rainfall units was obtained by multiplying the 1-hr effective rainfall with the synthetic 1-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 2.78 m^3/sec. was entered in col. (9), col. (10) gives the addition of col. (8) and (9) to get the design flood hydrograph ordinates. The total discharge in col. (10) were plotted against time in col. (1) to get the design flood hydrograph as shown in Fig F-3.

1.2.0 MULTIPLE REGRESSION ANALYSIS FORMULA & ILLUSTATED EXAMPLE

1. 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 point 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 11 gauged and 9 ungauged catchment for different sizes were computed by detailed approach. Series of Q_{25}, Q_{50} and Q_{100}, for the 20 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:

$$Q_{25} = 0.643\ (A)^{0.838}\ (L)^{-0.363}\ (S)^{0.560}\ (RT)^{1.259} \qquad r = 0.999$$

$$Q_{50} = 0.861\ (A)^{0.831}\ (L)^{-0.357}\ (S)^{0.520}\ (RT)^{1.160} \qquad r = 0.998$$

$$Q_{100} = 0.9616\ (A)^{0.868}\ (L)^{-0.384}\ (S)^{0.520}\ (RT)^{1.090} \qquad r = 0.999$$

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)

R_{25}, R_{50} and R_{100} are design storm point rainfall in cm for a design storm duration of $T_D = 1.1*t_p$

$$\text{Where } t_p = 2.195\ (q_p)^{-0.944} \qquad r = 0.926$$

$$\text{and } q_p = 1.331\ (L/S)^{-0.492} \qquad r = 0.810$$

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 rainge of ...

- 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 20 catchments shown in the following table are within tolerable limits of + 15% to - 8%.

Variation (percentage)	Range (percentage)
(+)	(-)
Q_{25} — 0.05 to 4.96	0.01 to 7.65
Q_{50} — 1.30 to 14.11	1.21 to 8.78
Q_{100} — 0.474 to 5.58	0.204 to 7.84

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

ILLUSTRATED EXMAPLE

Illustrative example for estimation of 25-yr, 50-yr and 100-yr flood for catchment area upto Rly. Br. No. 761/1225 is considered for solution of the problem by flood formulae. The physiographic and meteorologic parameters for the catchment under study are:

$A = 154.62$ sq km $\qquad S = 2.62$ m/km

$L = 23.35$ km

$qp = 1.331\ (L/S)^{-0.492} = 0.454$ cum/sq. km.

$tp = 2.195\ (qp)^{-0.944} = 4.50$ hrs

$T_D = 1.1\ tp = 1.1 * 4.50 = 5.00$ hrs

$R_{25} = 15.34$ cm, $R_{50} = 17.40$ cm, $R_{100} - 19.47$ cm

$$Q_{25} = 0.643\ (A)^{0.838}\ (L)^{-0.363}\ (S)^{0.560}\ (RT)^{1.259}$$

$$= 0.643\ (154.62)^{0.838}\ (23.35)^{-0.363}\ (2.62)^{0.560}\ (15.34)^{1.259}$$

$$= 747.02 \text{ cumecs.}$$

$$Q_{50} = 0.861\ (154.62)^{0.831}\ (23.35)^{-0.357}\ (2.62)^{0.520}\ (17.40)^{1.160}$$

$$= 836.29 \text{ cumecs.}$$

$$Q_{100} = 0.9616(154.62)^{0.868}(23.35)^{-0.384}(2.62)^{0.520}(19.47)^{1.090}$$

$$= 956.71 \text{ cumecs.}$$

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 -0.01, -2.95 and -0.77 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, lope data and nature of the cross-section. The velocity is omputed 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'(TOUGHNRDD VORGGIVIRNY) 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 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 BETWA SUBZONE DATA COLLECTION AND ANALYSIS

2.1.1 LOCATION

The Betwa subzone - 1(c) lies approximately between 77^0 to 82^0 longitudes (East) and 23^0 to 27^0 latitudes (North). Plate-1 shows the location of Betwa Subzone with the appended list of hydrometeorological subzones of India.

The Betwa subzone is bounded on the north by Upper Indo-Ganga and middle Ganga plains subzones 1(e) and 1(f), on the south by Upper Narmada and Tapi subzone 3(c), on the east by Sone Subzone 1(d) and on the west by Chambal Subzone1(b) This subzone 1(c) covers parts of Madhya Pradesh and Uttar Pradesh. The important towns and cities in the subzone are Gwalior, Shivpuri, Bina, Bhopal, Lalitpur, Tikamgarh, Sagar Chhatarpur, Panna, Damoh in Madhya Pradesh and Kungh, Jhansi, Kalpi, Orai, Khairar, Karwi amd Manikpur in Uttar Pradesh.

2.1.2 RIVER SYSTEM

Plate-2 depicts the river system of the subzone. Betwa river is the biggest river in the subzone -1 (c). Besides, there are other sizable rivers like Sind, Ken. The major tributaries of Betwa are Bina, Bahaora, Guhari. River Dhasan after covering its course from south of the basin through Madhya Pradesh, joins Betwa river in Uttar Pradesh. All the rivers traversing across the Betwa subzone finally merge into Yamuna.

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

S.No.	Name of river/tributary	Drainage area (sq.km.)
1	2	3
1.	Betwa & its tributaries	43,319.00
2.	Sind	22,035.00
3.	Ken	30,047.00
4.	Others	11,068.00
	Total:	1,06,469.00

Say = 1,06,500 sq. km.

The total drainage area of Betwa subzone 1(c) is 1,06,500 sq.km.

2.1.3 TOPOGRAPHY AND RELIEF

Plate - 3 depicts the general topography of Betwa subzone - 1(c). The main rivers that flow from South to North of the catchment are Sind, Betwa and Ken. Dhasan is the major tributary of river Betwa which originates at an altitude of 150 m. The general ground level varies from 100 m. above sea level at the northern boundary of the catchment to around 625 m. at the southern end of the subzone.

The tributary which converge to the Betwa are Bina which joins at an altitude of about 425m, Keotan at an elevation of 425m, Bhadra at 440m. and Ghurai at 310m. Similary Sin is fed by Manuhar at 330m and Vaeshali at 150m.

Ken gets some flow from Shyam at about 118m. and Ahni at 640 m.

All the main rivers ultimately join Yamuna.

2.1.4 RAINFALL

Plate - 4 shows the normal annual rainfall of the Betwa subzone and the histograms of normal monthly rainfall in the different parts of the subzone varies ranging from 700mm.to as high as 1400mm, which increase with the increase in the altitude. The monsoon is spread between the month of June and September. The monsoon seasonal rainfall is about 85-90% of the annual rainfall.

2.1.5 TEMPERATURE

Plate-5 reflects the mean annual temperature of the subzone along the histograms showing the minimum, maximum and mean monthly temperature at Bhopal. In accordance with the boundary of the subzone the southern portion has a mean minimum temperature of about 25 ^{0}c. Where as in the northern portion of the subzone the mean minimum temperature touches 27.5 ^{0}c.

2.1.6 SOIL

Plate-6 shows the soil classification in the Betwa subzone. The northen portion of the subzone is covered with alluvial soils, the central area of the subzone is covered with mixed red and black soil. In between these two types of soil a belt of Red sandy soil exists which covers 10-15% of the subzone area. The southern area of subzone is covered with medium black soil with adjoining Deep black soil towards its south. A small patch of skeletal soil also forms the part of southern boundary of the catchment.

2.1.7 LAND USE

Plate - 7 delineates the land use in the Betwa subzone. About 50% of the subzone area is covered by forest with in between patches of aerable land which forms about 25% of the area. The portion of the subzone covering 20% of area are grass land and scrub. The remaining portion of around 5% is waste land.

2.1.8 IRRIGATION

Plate - 8 gives irrigation practice followed in the Betwa subzone. The major area of the subzone is irrigated by existing canals. Betwa river irrigates 83000 hectares of the area. The ken canal irrigation project and sind canal project will add to the irrigation potential in the subzone. Some of the dams are at Arjun, Dhasan and Lalitpur.

2.1.9 COMMUNICATIONS

The Betwa subzone has rail network covering the length & breadth of the subzone and has average roads across the basin.

2.1.9.1 Railway Lines

The following railway lines traverse the Betwa subzone 1(c)

Subzone - 1(c)

S.No.	Railway Section	Railway
1	JHANSI TO GWALIOR	CENTRAL RAILWAY
2	JHANSI TO BHOPAL VIA BINA	DO
3	BINA TO GUNA	WESTERN RAILWAY
4	JHANSI TO KALPI	CENTRAL RAILWAY
5	JHANSI TO MANIKPUR VIA BANDA	DO
6	BINA TO KATNI	DO
7	KHAIRA TO BHIMSEN	DO

2.1.9.2. Roads

The major highways in the subzone are:-

1. SHIVPURI TO KANPUR VIA JHANSI - NATIONAL HIGHWAY NO 25
2. AGRA TO BIAORA VIA GUNA - NH - 3
3. JHANSI TO JABALPUR - NH - 26
4. JABALPUR TO BIAORA VIA BHOPAL - NH - 12

2.2.0 DESIGN FLOOD - DATA COLLECTION FOR 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).

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 3times 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 for 11 catchments in the Betwa subzone 1(c) for a period ranging from 3 to 8 years. The size of the gauged catchments vary from 43.72 sq.km to 2610.72 sq.km. Concurrent rainfall, gauge and discharge data for 59 bridge catchment years from 11 catchments was available for study.

The locations of the gauging sites at roads and railway bridges in the Betwa subzone-1(c) are shown in Plate-2. India Meteorological Department has collected the rainfall data of additional raingauge stations maintained by IMD and states falling in Betwa subzone-1(c). Central Water Commission (CWC) has also prepared the detailed plans of gauged catchments showing the river network, location of raingauge stations and gauge-discharge sites, contours, highways and railway network, natural and man made storage; 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

To derive 1 hour SUH, the following procedures have been adopted:

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 DEFINITION OF PHYSIOGRAPHIC PARAMETERS OF THE CATCHEMENT

The representative catchments selected for the study were analysed for physiographic parameters. The defination of 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) :

$$S = \frac{\sum L_i \left(D_{i-1} + D_i \right)}{(L)^2} \qquad \ldots\ldots(3.1)$$

where Li = 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 3.1.2. in km.

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

Detailed studies were carried out for 11 gauged catchments.

The physiographic parameters A, L, and S were estimated only for 11 catchments which were found suitable for analysis. These parameters are shown in Table-2.

2.3.2 SCRUITINY OF DATA AND FINALISATION OF GAUGE DISCHARGE RATING CURVE

The data was scrutinised through arithmetical checks. Where wide dispersions were observed in the stage-discharge curve, log-log fitting was adopted. The stages for conceivable floods were converted into discharges initially identified with reference to rise and fall in the stages of the river.

2.3.3 SELECTION OF FLOOD AND CORRESPONDING STORM EVENTS

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

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

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

2.3.4 COMPUTATION OF HOURLY CATCHMENT RAINFALL

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

2.3.5 SEPARATION OF BASE FLOW

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

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

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

2.3.7 DERIVATION OF 1-HOUR UNITGRAPH

A unit duration of 1-hour was adopted for derivation of unitgraphs. The 1-hour unitgraphs were derived from the rainfall excess hyetographs and their corresponding direct runoff hydrographs by iterative methods. The iterations were carried out till the observed and estimated direct runoff hydrographs compared favourably. Normally 6 to 10 unitgraphs are derived for each of the 11 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 11 catchments and their parameters noted. The parameters of the representative unitgraph illustrated in Fig.2 were measured for each of the catchments. The parameters of the representative unitgraphs are t_r, t_p, T_m, Q_p, q_p, W_{50}, W_{75}, W_{R50}, W_{R75}, and T_B. These parameters for 11 catchments are listed in Table -3.

2.3.9 ESTABLISHING RELATIONSHIPS BETWEEN PHYSIOGRAPHIC AND REPRESENTATIVE UNITGRAPH PARAMETERS

Physiographic parameters like A,L,Lc, S and the parameters of 1-hour unitgraphs like tp, Q_P, T_B, W_{50}, W_{75}, WR_{50}, WR_{75} for 11 gauged catchments in sub zone-1(c) were estimated as shown in Tables - 2 &. 3 respectively.

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

$$Y = C\ X^{P} \quad \longleftrightarrow \quad 3.9.1$$

where

Y - Dependent variable
X - Independent variable
C - A constant
P - An exponent
From equation 3.9.1, it follows that

$$\text{Log } Y = \text{Log } C + P \log X \quad \longleftrightarrow \quad 3.9.2$$

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

Alternative studies were carried out for relating physiographic parameters with the corresponding parameters of the 1-hr representative unitgraphs of the 11 gauged catchments. For instance, the basin lag t_p was related to $LLc/\sqrt{S}$, $L/\sqrt{S}$, $Lc/\sqrt{S}$ and $Lc/\sqrt{Sc}$. Similarly q_p, W_{50}, W_{75}, W_{R50}, W_{R75} and T_B were related to physiographic parameters and also to their suitable unitgraph parameters.

Synthetic unitgraph relationships developed by regression analysis using least square method alongwith their coefficients of correlation (r) are listed in Annexure 1. Out of the derived relationships, the relationship for qp vs L/S gives a highest correlation coefficients and the next higher correlation coefficient is for tp vs.L/s. The relation giving highest correlation coefficient has been adopted. The relationships for qp vs.L/S is suggested because of simplicity as it excludes Lc and Sc involving the centre of gravity of the catchment. The following relation ships are suggested for determining the 1-hr synthetic unitgraph parameters of ungauged catchment in Betwa subzone-1(c):

Relationships	Equation No.	Fig.No.	correlation Coefficient (r)
1	2	3	4
$q_p = 1.331(L/S)^{-0.492}$	3.9.3	3	0.810
$t_p = 2.195(qp)^{-0.944}$	3.9.4	4	0.926
$W_{50} = 2.04\ (qp)^{-1.026}$	3.9.5	5	0.925
$W_{75} = 1.25\ (qp)^{-0.864}$	3.9.6	6	0.819
$W_{R50} = 0.739(qp)^{-0.968}$	3.9.7	7	0.874
$W_{R75} = 0.500(qp)^{-o.813}$	3.9.8	8	0.760
$TB = 3.917(tp)^{0.990}$	3.9.9	9	0.942

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

T_m	$\simeq t_p + t_r/2$	3.9.10	3.9.10
Q_p	$\simeq q_p \times A$	3.9.11	3.9.11

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

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

Considering the hydro-meteorological homogeneity of subzone-1(c), the relations established between physiographic and unitgraph parameters in section 3.9 for 11 representative catchments are applicable for derivation of 1-hour Synthetic unitgraph for an ungauged catchment in the same subzone.

The steps for derivation of 1-hour unitgraph are :

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

ii) Substitute L/S in the equation 3.9.3 to obtain qp in Cumecs/Sq.Km.

iii) Substitute (qp) in the equation 3.9.4 to obtain tp in hours.

Then Tm $\simeq$ tp + tr/2 $\simeq$ tp + 1/2 hrs.

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

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

v) Substitute the value of t_p in equation 3.9.9 to obtain T_B

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 and sketch the unitgraph through these points. The discharge ordinates (Q_i) of the unitgraph at 1-hour (tr) interval are summed up and the direct runoff depth in cm. is obtained from the following equation 3.9.12.

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

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.

3.3.11 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 w.s 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 95 flood events were analysed for 11 bridge catchments. Number of flood occasions the constant loss rates so estimated for each bridge catchment under different loss rate ranges at intervals of 5 mm/hr were tabulated in Table-4. Out of 102 flood events analysed. A modal value of 0.23 cm/hr as shown in table-4 is recommended as the design loss rate for the subzone.

2.3.12 DESIGN BASE FLOW

Similarly number of occasions with different base flow under various intervals for 102 flood events are shown in Table-5. For 30 flood events out of 102 the base flow rates fall under the range of 0.009 to 0.027 m^3/sq km. An average base flow rate of 0.018 cumecs/sq.km for this range may be adopted for estimating the design base flow for a catchment under study.

PART III

STORM STUDIES

3.1.1 DESIGN STORM INPUT

The design storm input is the rainfall of chosen return period for T_D hour duration.

The areal distribution and time distribution of this rainfall are two main meteorologocal 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). Alternative studies are to be carried out assuming $T_D \simeq 1.1\ t_p$ and $T_D = T_B$ for estimating 25-yr, 50-yr and 100-yr flood. Here for 20 catchments by synthetic unit hydrograph relations with loss rates of 0.23 cm / hour a comparison of the 25-yr flood, 50-yr flood and 100-yr flood with $T_D = 1.1\ t_p$ and $T_D \simeq T_B$ showed that in 60 to 75% of the cases $T_D \simeq 1.1\ t_p$ gives higher discharge. Therefore, the design storm duration (T_D) for a catchment in adopted $\simeq 1.1\ t_p$ in this case. The designer must compute both $TD \simeq 1.1tp$ and $TD = TB$ and the value giving higher peak value be adopted.

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 30 Ordinary Raingauge Stations maintained departmentally, 149 Ordinary Raingauge Stations belonging to the States of Madhya Pradesh, Uttar Pradesh, and 26 Self Recording Raingauge Stations maintained by Railways in their 7bridge catchments falling in Sub-Zone 1(c).

The annual maximum series of one-day rainfall were formed for each of 179 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 values 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 station 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 9, 10 and 11.

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 correspon-ding to duration from 1 to 18 hours for each of the 11 stations were converted into ratios with respect of 24hours 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	0.32
3	0.50
6	0.65
9	0.72
12	0.79
15	0.84
18	0.90
24	1.00

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

These ratios when multiplied by 24-hour rainfall for a specified return period will generate 1 hr, 3 hr, 9hr, 12hr, 15hr, 18hr and 24hr rainfall estimates corresponding to that return period. Statement of highest ever recorded daily rainfall at selected stations is at table T-2.

3.1.4 POINT TO AREAL RAINFALL

The short duration rainfall data of 7 bridge catchments were used for this study. The data of remaining bridge catche-ments could not be utilised as the period of data were either less than 4 years and/or concurrent years data were not recorded conti-nuously 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 cat-chment 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

1906 rain storms of various durations upto 24 hours occurring in various parts of the subzone were analysed based on 135 station's year data. Rain storms selected at each station were grouped under the avove 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 $T_D = 1.1\ tp$ -(round off the nearest full hours) by substituting the known values of L and S for the catchment under study. Obtain tp & qp Where $tp = 2.195(qp)^{-0.944}$ and $qp = 1.331(L/S)^{-0.492}$

Step-2: Locate bridge catchment under study on the 50-yr, 24-hr isopluvial map (plate-10) 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 4.3.

Step-5: Apply the cumulative percentage of total rainfall against the cumulative percentage of storm duration curves in Fig. 12(a) to (e) or from Table 7 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 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 and loss rate are assumed to hold good during the design flood event.

5.2.0 Limitations

5.2.1 The data of 20 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.

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, design flood shall be estimated by application of storm rainfall to synthetic unit hydrograph.

5.3.4 Formulae for fixing the linear waterway of cross drainage structures on streams in Betwa subzone 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 modal loss rate of 0.23 cm/hr. 25-yr, 50-yr and 100-yr flood formulae alongwith respective formulae for linear waterway of bridges are in Annexure-1 which may be used for preliminary designs. Hwever, for final designs, the design flood has to be estimated using the detailed procedure in the illustrative example.

5.3.6 The report is applicable for the catchment area ranging from 25 sq km to 2600 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.

5.4.0 <u>Scope for refinement in values of design discharge</u>

Whereever it is possible to derive reliable unit hydrograph/design storm/design loss rate value based on local observation data, such UG/design storm/design loss rate values could be used in preference to regionalised values given in this report.

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LIST OF PHYSICAL AND UNIT HYDROGRAPH PARAMETERS STUDIES TO ESTABLISH RELATIONSHIPS WITH THEIR COEFFICIENT OF CORRELATION SUBZONE - 1(c)

Sl. No.	Independent variables Physiographic Parameters/unit graph parameters	Dependent Variables			Coefficient of correlation
		Constant	Unitgraph Parameter	Exponent	
1	2	3	4	5	6
1	L/S	1.711	tp	0.457	0.740
2	L/S	1.331	qp	-0.492	0.810
3	L/_/S	2.182	qp	-0.613	0.723
4	L/_/S	14.370	tp	-0.215	0.330
5	L	1.372	tp	0.444	0.447
6	L	1.329	qp	-0.419	0.419
7	Lc/_/Sc	1.169	qp	-0.548	0.681
8	Lc/_/Sc	11.580	tp	-0.195	0.320
9	LLc/_/S	14.020	tp	-0.113	0.290
10	LLc/_/S	2.059	qp	-0.323	0.632
11	qp	2.195	tp	-0.944	0.926
12	qp	2.040	W_{50}	-1.026	0.925
13	qp	1.250	W_{75}	-0.864	0.820
14	qp	0.739	WR_{50}	-0.968	0.875
15	qp	0.500	WR_{75}	-0.813	0.760
16	tp	3.917	TB	0.990	0.942

Relationship adopted SL 2, 11,12,13,14,15 & 16

TABLE : T - 1

COMPUTATION OF EQUIVALENT SLOPE (S) OF BRIDGE NO. : 761/1225 C.A. = 59.70 Sq.Miles (154.62 Sq Km)
L = 14.50 Miles (23.35 Km) Lc = 6.10 Miles (9.82 Km)

S.NO.	Reduced Distance Starting from Bridge Site (Point of Study) (Mile)	Reduced Levels of River Bed (Ft)	Length of Each Segment L_i (Mile)	Height Above Datum *(D)= Difference D_i Between the Datum and the its R.L. (Ft)	$(D_{i-1} + D_i)$ (Ft)	$L_i (D_{i-1} + D_i)$ (4) * (6) (Ft * M)
1	2	3	4	5	6	7
1	0.00	586.40	0.00	0.00	0.00	0.00
2	4.60	650.00	4.60	63.60	63.60	292.56
3	9.30	700.00	4.70	113.60	177.20	832.84
4	12.00	750.00	2.70	163.60	277.20	748.44
5	13.60	800.00	1.60	213.60	377.20	603.52
6	14.50	850.00	0.90	263.60	477.20	429.48

SUM $(L_i * (D_{i-1} + D_i))$ = 2906.84

$$S = \frac{(L_i * (D_{i-1} + D_i))}{L^2} = \frac{2906.84}{210.25}$$

= 13.82563 Ft/Mile

= 0.002618 Ft/Ft

= 2.62 M/Km

DATUM = 586.40 i.e. REDUCED LEVEL OF RIVER BED AT THE POINT OF STUDY

TABLE T - 2

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

S.No.	State	District	Station	Maximum Rainfall 300 mm	Date
1.	Madhya Pradesh	Raesein	Raesein(o)	365.8	10.8.1933
2.		"	Keriakheri/ Gohanganj	371.3	22.8.1919
3.		Sehore	Ashta	342.5	30.8.1973
4.		Jabalpur	Jabalpur	342.9	30.7.1915
5.		"	Bijerarogarh	365.0	1.9.1926
6.		"	Pariat	391.2	25.8.1952
7.		Panna	Panna	365.3	8.8.1919
8.		Damoh	Mala	345.7	10.8.1952
9.		Bhilsa	Basoda	360.2	31.7.1951
10.		Rajgarh	Biaora	431.8	7.7.1952
11.		Sagar	Khurai	310.6	10.7.1919
12.		Morena	Sheopur	388.0	15.7.1979
13.		Rewa	Rewa	773.4	16.6.1882
14.		Satna	Satna	562.5	16.6.1882
15.		Chatarpur	Nowgong	462.8	20.6.1887
16.		Narsingapur	Narsingapur	422.1	7.9.1891
17.		Shadol	Umaria	365.3	19.8.1923
18.	Uttar Pradesh	Lucknow	Malihabad	324.6	1.9.1915
19.		Unnao	Hasanganj	412.5	1.9.1915
20.		Raebareli	Solon	318.0	9.9.1893
21.		Pratapgarh	Pratapgarh	355.6	27.8.1903
22.		Banda	Badausa	406.4	16.6.1982
23.		"	Karwi	421.6	30.7.1875
24.		Kanpur	Derapur	508.0	18.6.1882
25.		Fatehpur	Khajwa	514.9	31.8.1915
26.		Allahabad	Allahabad(o)	393.2	30.7.1875
27.		"	Meja	512.1	22.6.1916
28.		Jhansi	Lalitpur	384.0	10.9.1941
29.		Jalaun	Kunch	368.3	29.7.1881
30.		Hamirpur	Mandhera	334.0	30.9.1923

Table - T - 3

COMPUTATION OF DESIGN FLOOD HYDROGRAPH

Subzone - 1(c) River BARMA CR Br.No. 761/1225 CA = 154.62 sq.km.

TIME IN HOURS	S.U.H. ORDINATE IN CUMEC	1-HOURLY RAINFALL EXCESS IN CMS 0.20	0.64	2.36	8.85	1.21	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	2.78	2.78	
1.00	5.00	1.00	0.00				1.00	2.78	3.78	
2.00	14.20	2.84	3.20	0.00			6.04	2.78	8.82	
3.00	28.20	5.64	9.09	11.80	0.00		26.53	2.78	29.31	
4.00	51.00	10.20	18.05	33.51	44.25	0.00	106.01	2.78	108.79	
5.00	70.20	14.04	32.64	66.55	125.67	6.05	244.95	2.78	247.73	
6.00	59.50	11.90	44.93	120.36	249.57	17.18	443.94	2.78	446.72	
7.00	44.70	8.94	38.08	165.67	451.35	34.12	698.16	2.78	700.94	
8.00	34.70	6.94	28.61	140.42	621.27	61.71	858.95	2.78	861.73	<---PEAK
9.00	29.00	5.80	22.21	105.49	526.58	84.94	745.02	2.78	747.80	
10.00	24.50	4.90	18.56	81.89	395.60	72.00	572.94	2.78	575.72	
11.00	20.50	4.10	15.68	68.44	307.10	54.09	449.40	2.78	452.18	
12.00	16.50	3.30	13.12	57.82	256.65	41.99	372.88	2.78	375.66	
13.00	13.00	2.60	10.56	48.38	216.83	35.09	313.46	2.78	316.23	
14.00	9.50	1.90	8.32	38.94	181.43	29.65	260.23	2.78	263.01	
15.00	6.20	1.24	6.08	30.68	146.03	24.81	208.83	2.78	211.61	
16.00	2.80	0.56	3.97	22.42	115.05	19.97	161.96	2.78	164.74	
17.00	0.00	0.00	1.79	14.63	84.08	15.73	116.23	2.78	119.01	
			0.00	6.61	54.87	11.50	72.97	2.78	75.75	
				0.00	24.78	7.50	32.28	2.78	35.06	
					0.00	3.39	3.39	2.78	6.17	
						0.00	0.00	2.78	2.78	

TABLE -1

LIST OF SELECTED RAILWAY BRIDGE CATCHMENTS IN SUB-ZONE 1(C) AND AVAILABILITY OF GAUGE, DISCHARGE AND RAINFALL DATA

Sl.No	Name of Stream	Name of Section where bridge is located with Railway zone/Road Section		Railway bridge No./ site No.	G.Site Location						Catch-ment area (sq.km)	No of rain-gauge	Data availability	No. of years
					Latitude			Longitude						
					Deg.	Min.	SEc.	Deg.	Min.	Sec.				
1	BINA	ITARSI - JHANSI	CR	966/600	24°	07'	03"	78°	07'	05"	2610.72	6	1966-73	8
2	SIND	KOTA - BINA	WR	22	24	39	40	77	30	00	1757.88	9	1975-78-79	5
3	SHYAM	BHIMSEN-KHAIRAR END	CR	820/1321	25	32	27	80	10	20	297.85	5	1957,59-63	6
4	GHORARI	BINA - JHS	CR	687	25	16	0	78	27	40	256.40	8	1957-62	6
5	BARNA	JHANSI-MANIKPUR	CR	761/1225	25	17	30	79	28	83	154.62	5	1957,66,70-74	7
6	ANGOORI	GWALIOR-JHANSI	CR	1145	25	35	08	78	29	0	143.44	3	1972-74-77	6
7	ALONI	BINA - KATNA	CR	1222	23	54	25	80	18	30	123.03	3	1977-82	6
8	SILAR	BHOPAL-JHANSI	CR	603	24	9	8	78	9	21	85.47	3	1964-66	3
9	BAHADRA	KOTA - BINA	WR	11-B	24	31	15	77	51	15	68.05	2	1964-66	3
10	GOHANI	JHANSI-KANPUR	CR	1239/770	25	58	35	79	26	20	64.23	3	1961-66	6
11	AMAONI	BINA - KATNI	CR	650/1046	23	50	20	78	42	55	43.72	2	1964-66	3

TABLE - 2

BASIN CHARACTERISTICS OF SUBZONE - 1(c)

Sl.No.	Bridge No	Area (sq.km.)	L (km)	Lc (km)	SEQ (m/km)	L/Sq S
1	2	3	4	5	6	7
1	966/600	2610.72	139.75	81.79	1.33	105.075
2	22	1757.88	90.16	36.39	0.675	133.57
3	820	297.85	42.75	22.75	0.755	56.623
4	687	256.40	34.40	16.40	3.06	11.242
5	761/1225	154.62	23.35	9.82	2.62	8.912
6	1145	143.44	25.76	11.27	2.27	11.348
7	1222/1	123.03	28.26	12.08	1.84	15.359
8	603	85.47	26.23	17.22	1.13	1.675
9	11-(b)	68.00	21.20	10.60	2.6	23.212
10	1239/770	64.23	22.70	8.96	0.61	8.154
11	650/1046	43.72	9.65	4.02	5.76	37.213

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

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	966/600	14.50	391.60	0.15	1.00	56.00	14.25	7.00	5.00	2.50
2	22	6.50	355.80	0.20	1.00	34.00	12.00	5.40	3.20	1.80
3	820/1321	11.50	50.00	0.17	1.00	30.00	16.40	10.20	6.60	4.40
4	687	5.50	145.00	0.57	1.00	21.00	1.70	0.80	0.60	0.30
5	761/1225	3.50	77.00	0.50	1.00	14.00	5.00	2.60	1.80	1.00
6	1145	3.50	95.00	0.66	1.00	17.00	2.90	1.60	0.75	0.50
7	1222	8.50	35.00	0.28	1.00	29.00	7.80	4.60	2.80	1.60
8	603	10.50	23.00	0.27	1.00	32.00	8.80	5.40	3.30	2.10
9	11-B	5.50	30.00	0.44	1.00	16.00	5.30	2.75	2.25	1.30
10	1239/770	21.50	5.40	0.08	1.00	125.00	20.00	6.00	5.50	2.00
11	650/1046	1.50	42.50	0.97	1.00	6.00	2.70	1.60	1.00	0.70

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

SUBZONE - 1(c)

SL. NO.	BRIDGE NO --->		996/600	22	820	687	761	1145	1222	603	11	1239	650		
	CATCHMENT AREA---> IN sq.Km		2610.72	1757.88	297.85	256.4	154.82	143.44	123.03	85.47	68.05	64.23	43.72		
	LOSS RANGES		NUMBER OF OBSERVED FLOODS											ROW-TOTAL	
	LB	UB													
1	0	0.1	3	1	0	1	1	1	0	0	0	2	0	9	F1
2	0.1	0.3	1	8	1	3	2	2	2	3	4	0	3	29	Fm
3	0.3	0.5	1	3	0	2	3	0	1	0	6	1	1	18	F2
4	0.5	0.7	1	0	0	3	3	2	0	0	1	0	0	10	
5	0.7	0.9	0	0	1	0	0	2	2	0	2	0	0	7	
6	0.9	1.1	0	0	1	0	0	0	1	1	2	0	0	5	
7	1.1	1.3	1	0	1	0	1	2	0	1	0	0	0	6	
8	1.3	1.5	0	0	0	0	0	1	0	0	0	0	2	3	
9	1.5	1.7	0	0	0	0	0	1	3	0	0	0	0	4	
10	1.7	1.9	0	1	0	0	0	1	1	0	0	0	1	4	
11	1.9	2.1	0	0	0	0	0	0	0	0	0	0	1	1	
12	2.1	2.3	0	0	0	0	0	1	0	0	0	0	0	1	
13	2.3	2.5	0	0	0	0	1	0	0	0	0	0	0	1	
14	2.5	2.7	0	0	0	0	0	0	0	0	0	0	0	0	
15	2.7	3	0	0	0	0	0	0	0	0	0	0	0	0	
16	ABOVE	3	0	0	3	0	0	0	0	0	1	0	0	4	
17															
18														G.TOTAL	
19	COL.TOTAL			13	7	9	11	13	10	5	16	3	8	102	
20															

$$\text{MODAL LOSS RATE} = L1 + \frac{(Fm - F1)*(h)}{(2Fm-F1-F2)} = 0.23 \text{ cms/hr}$$

WHERE L1 : LOWER LIMIT OF THE MODAL CLASS

Fm : FREQUENCY OF THE MODAL CLASS
F1 : FREQUENCY OF THE CLASS PRECEEDING THE MODAL CLASS
F2 : FREQUENCY OF THE CLASS SUCCEEDING THE MODAL CLASS
h : WIDTH OF THE MODAL CLASS

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

SUBZONE - 1(c)

SL. NO.	BRIDGE NO ---->		996/600	22	820	687	761	1145	1222	603	11	1239	650	
	CATCHMENT AREA---> IN sq.Km		2610.72	1757.88	297.85	256.4	154.62	143.44	123.03	85.47	68.05	64.23	43.72	
	BASE FLOW RANGES		NUMBER OF OBSERVED FLOODS											ROW-TOTAL
	LB.	UB												
1	0	0.009	2	3	3	2	1	1	0	0	0	0	3	15
2	0.009	0.018	3	3	1	2	0	2	0	1	0	0	0	12
3	0.018	0.027	1	3	2	4	3	0	3	0	0	0	2	18
4	0.027	0.036	0	1	0	0	2	2	1	0	1	1	1	9
5	0.036	0.045	1	1	0	0	1	1	2	0	5	0	0	11
6	0.045	0.054	0	1	0	0	4	2	1	2	2	1	0	13
7	0.054	0.063	0	1	0	1	0	1	0	0	2	0	1	6
8	0.063	0.072	0	0	1	0	0	1	2	0	2	0	1	7
9	0.072	0.081	0	0	0	0	0	0	0	0	2	0	0	2
10	0.081	0.09	0	0	0	0	0	0	0	0	0	0	0	0
11	0.09	0.099	0	0	0	0	0	1	0	1	2	0	0	4
12	0.099	0.108	0	0	0	0	0	0	0	0	0	1	0	1
13	0.108	0.117	0	0	0	0	0	0	0	0	0	0	0	0
14	0.117	0.126	0	0	0	0	0	0	0	0	0	0	0	0
15	0.126	0.135	0	0	0	0	0	0	0	0	0	0	0	0
16	ABOVE	0.15	0	0	0	0	0	2	1	1	0	0	0	4
ERR			0											
ERR														G.TOTAL
	COL.TOTAL		7	13	7	9	11	13	10	5	16	3	8	102

Average base flow = 0.018 ~~cu/hr~~ cumecs/km²

TABLE - 6

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
50	85	88	91	92	93	94	94	94	94	94	95	95	95	95	95	96	96	96	96	96	97	97	97	97
100	77	81	84	86	88	89	90	90	91	91	92	92	92	92	92	93	93	93	94	94	94	95	95	95
150	70	75	79	81	83	85	86	87	88	89	90	90	90	90	91	91	91	92	92	92	92	93	93	93
200	65	70	75	77	80	82	83	84	85	86	87	88	88	88	89	89	90	90	91	91	91	92	92	92
250	62	67	72	75	78	80	81	82	83	84	85	86	86	87	87	88	88	89	89	90	90	91	91	91
300	60	65	70	73	76	78	79	80	81	82	84	85	85	86	86	87	87	88	88	89	89	90	90	90
350			69	72	75	77	78	79	80	81	83	84	84	85	85	86	86	87	87	88	88	89	89	89
400						76	77	78	79	80	82	83	83	84	84	85	85	86	86	87	87	88	86	88
450						75	76	77	78	79	81	82	82	83	83	84	84	85	85	86	86	87	87	87
500						75	76	77	78	79	80	81	81	82	82	83	83	84	84	85	85	86	86	86
600												79	80	80	80	81	81	82	82	83	83	84	84	85
700												78	79	79	79	80	80	81	81	82	82	83	83	84
800												77	78	78	78	79	79	80	80	81	81	82	82	83
900												77	77	78	78	79	79	80	80	81	81	82	82	82
1000												76	76	77	77	72	78	79	79	80	80	81	81	81
1500																								78
2000																								77
2500																								76

TABLE - 7

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

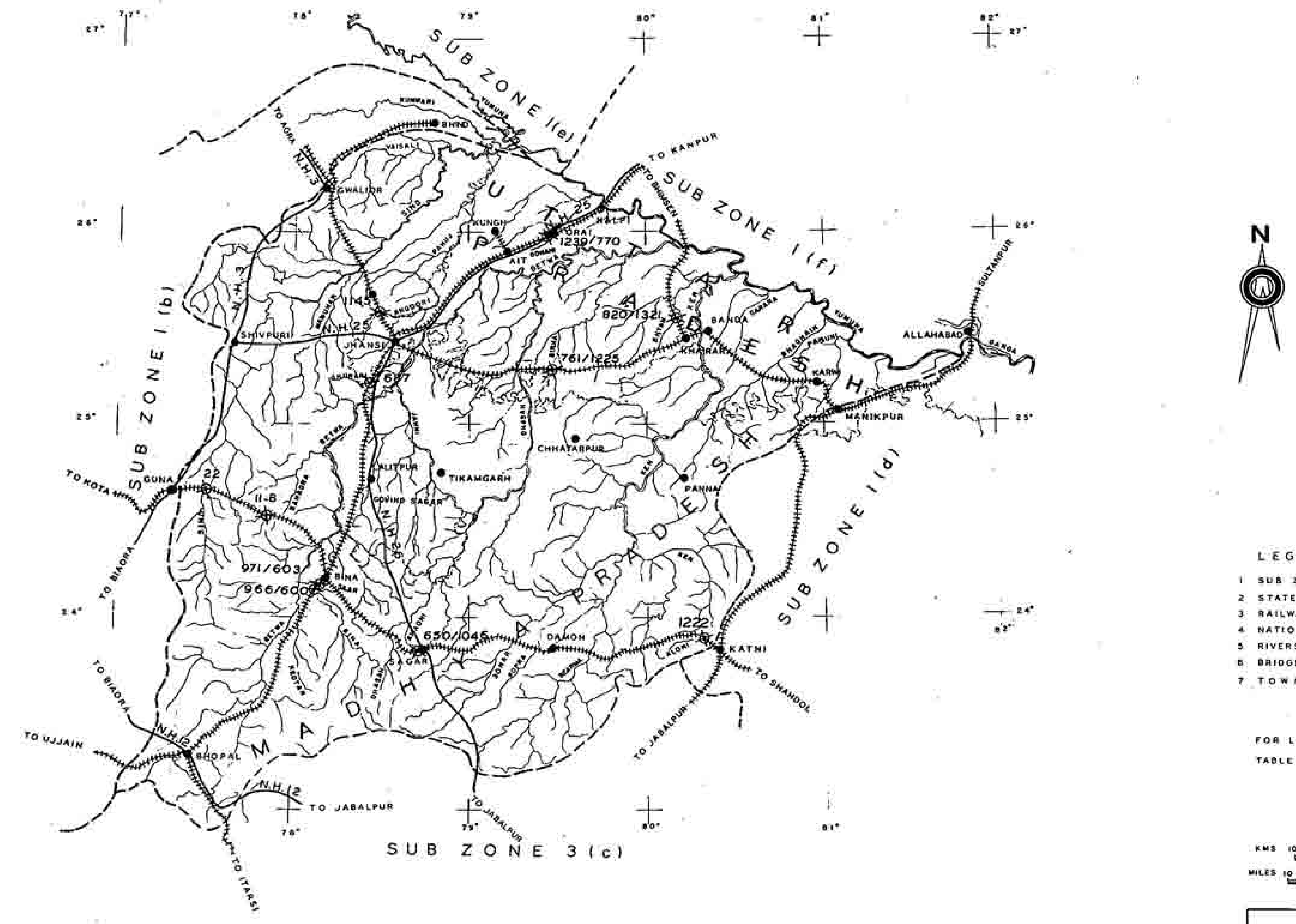
TIME HOURS	DISTRIBUTION CO-EFFECIENTS FOR DESIGN STORM DURATION OF 2 -24 HOURS																						TIME HOURS
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
24																							1.00	24
23																						1.00	0.99	23
22																					1.00	0.98	0.97	22
21																				1.00	0.98	0.97	0.96	21
20																			1.00	0.98	0.97	0.96	0.94	20
19																		1.00	0.98	0.97	0.95	0.94	0.93	19
18																	1.00	0.98	0.97	0.95	0.94	0.92	0.91	18
17																1.00	0.99	0.96	0.95	0.94	0.92	0.91	0.90	17
16															1.00	0.98	0.97	0.95	0.93	0.92	0.90	0.89	0.88	16
15														1.00	0.98	0.97	0.96	0.93	0.91	0.89	0.88	0.87	0.85	15
14													1.00	0.98	0.97	0.96	0.94	0.91	0.89	0.87	0.86	0.85	0.83	14
13												1.00	0.98	0.97	0.95	0.93	0.92	0.88	0.87	0.85	0.84	0.82	0.81	13
12											1.00	0.98	0.96	0.95	0.93	0.91	0.90	0.86	0.84	0.82	0.81	0.79	0.78	12
11										1.00	0.98	0.96	0.94	0.92	0.91	0.89	0.88	0.83	0.81	0.79	0.78	0.76	0.75	11
10									1.00	0.98	0.96	0.94	0.91	0.90	0.90	0.87	0.85	0.80	0.78	0.76	0.74	0.73	0.72	10
9								1.00	0.98	0.96	0.94	0.91	0.89	0.87	0.85	0.84	0.82	0.76	0.74	0.73	0.72	0.70	0.69	9
8							1.00	0.98	0.95	0.93	0.91	0.87	0.86	0.84	0.82	0.80	0.78	0.73	0.71	0.69	0.67	0.66	0.64	8
7						1.00	0.97	0.94	0.92	0.90	0.88	0.84	0.82	0.80	0.78	0.75	0.74	0.68	0.67	0.64	0.63	0.62	0.61	7
6					1.00	0.97	0.94	0.91	0.89	0.86	0.84	0.80	0.77	0.75	0.72	0.70	0.68	0.63	0.61	0.60	0.58	0.57	0.56	6
5				1.00	0.97	0.92	0.90	0.87	0.84	0.82	0.79	0.73	0.70	0.68	0.67	0.65	0.63	0.57	0.56	0.54	0.52	0.51	0.50	5
4			1.00	0.97	0.93	0.88	0.84	0.81	0.78	0.76	0.73	0.66	0.64	0.62	0.60	0.58	0.57	0.50	0.48	0.46	0.45	0.44	0.41	4
3		1.00	0.96	0.91	0.87	0.80	0.76	0.74	0.71	0.68	0.66	0.58	0.56	0.54	0.53	0.51	0.50	0.40	0.39	0.37	0.36	0.34	0.33	3
2	1.00	0.93	0.87	0.81	0.76	0.69	0.66	0.63	0.60	0.57	0.53	0.47	0.45	0.43	0.41	0.40	0.38	0.28	0.27	0.26	0.25	0.24	0.23	2
1	0.86	0.76	0.69	0.63	0.58	0.50	0.46	0.44	0.41	0.38	0.35	0.30	0.27	0.26	0.26	0.24	0.22	0.15	0.14	0.13	0.12	0.12	0.11	1

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

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 — F.R. BHALLA.

PLATE - 2



LEGEND

1. SUB ZONE BOUNDARY
2. STATE BOUNDARY
3. RAILWAY LINE
4. NATIONAL HIGHWAYS
5. RIVERS & ITS TRIBUTARIES
6. BRIDGE SITES
7. TOWNS

FOR LOCATION OF BRIDGE REFER: TABLE NO. 1

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

BETWA

SUB ZONE I(c)

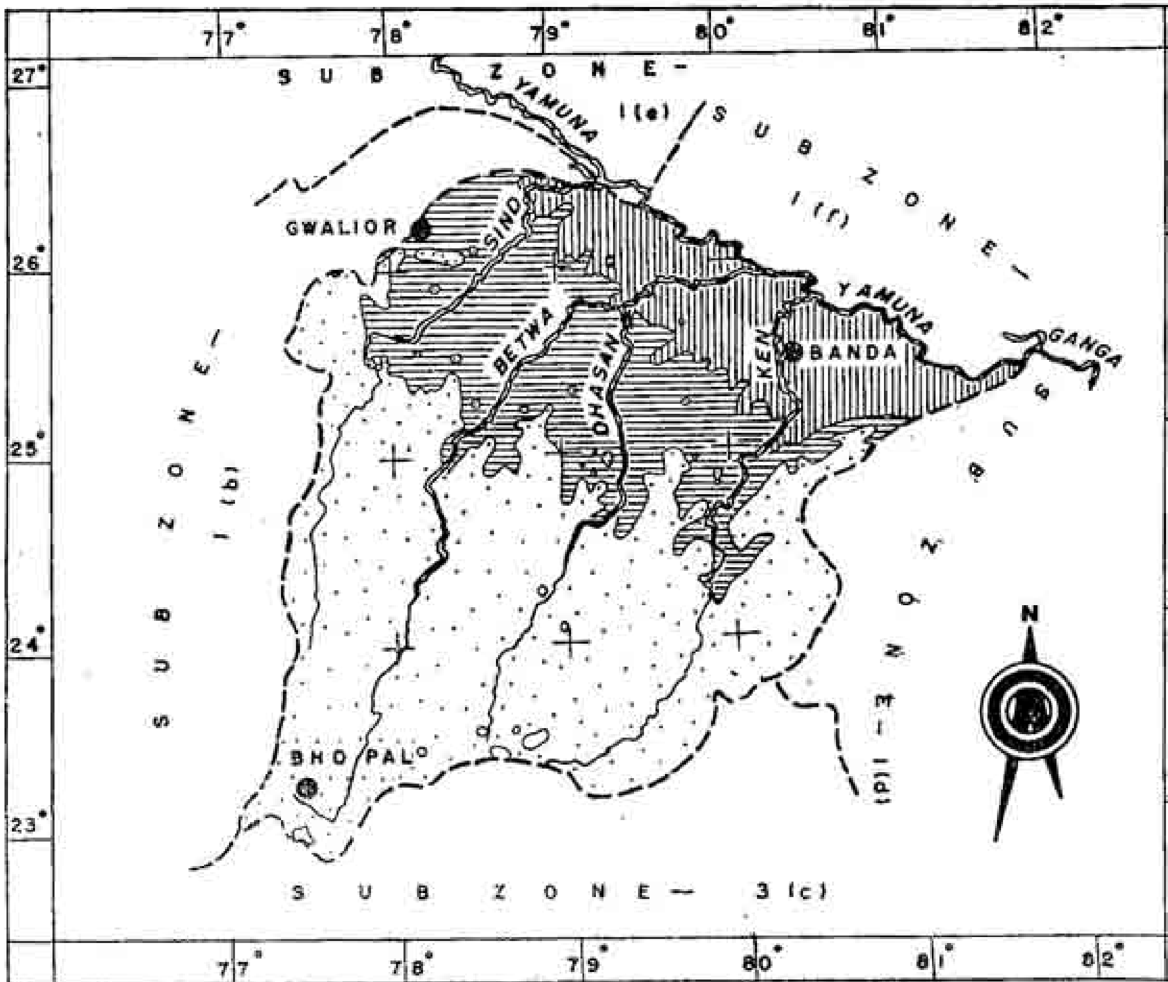
RIVER SYSTEM AND LOCATION OF ROAD AND RAILWAY BRIDGES (G & D SITES)

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

RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER

BASED UPON SURVEY OF INDIA MAP

PLATE-3.



LEGEND—

ALTITUDE IN METERS

1. 0 — 150 . . .
2. 150 — 300 . . .
3. 300 — 600 . . .
4. 600 — 900 . . .

SCALE

50 0 50 100 150 KMS.

25 0 25 50 75 MILES

REFERENCES—

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

NOTE—

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

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

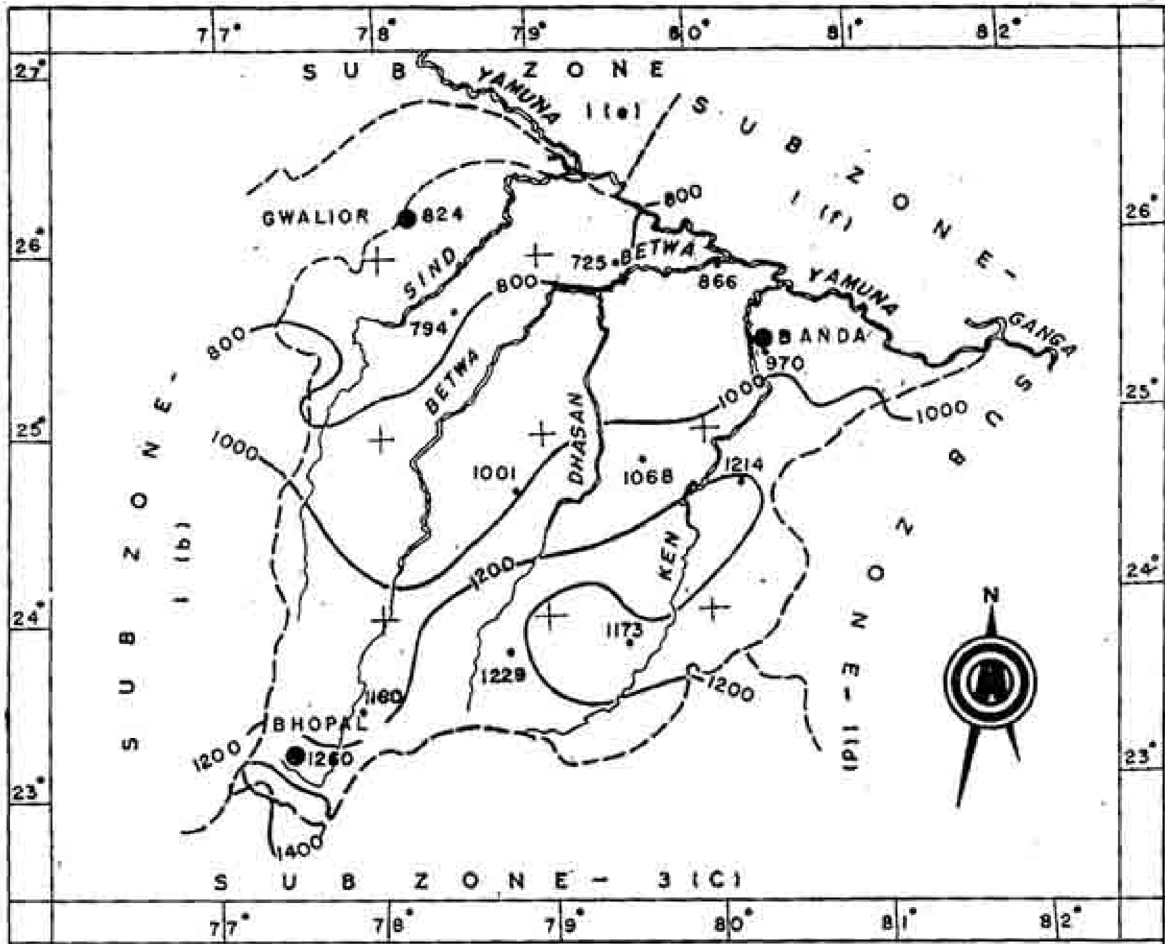
BETWA

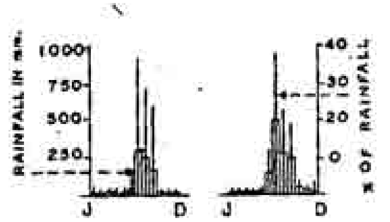
SUB ZONE I(c)

PHYSIOGAPHY

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

PLATE - 4.





● GWALIOR ● BHOPAL

REFERENCES

1. SUB ZONE BOUNDARY . . .
2. TOWNS . . . . ●
3. RIVERS . . . .
4. ISOHYETAL LINES . . . 800
5. SPOT RAINFALL (mm.) • 725

SCALE

50 0 50 100 150 KMS.

25 0 25 50 75 MILES

NOTES

1. HISTOGRAMS FOR TWO STATIONS WITH NAMES, EACH VERTICAL COLUMN IN THIS LINES REPRESENTS THE MEAN MONTHLY RAINFALL FOR EACH MONTH. THE THICK VERTICAL LINES AT THE CENTRE OF EACH COLUMN INDICATES THE PERCENTAGE OF RAINFAL IN THE MONTH TO THE MEAN ANNUAL TOTAL.

2. THIS MAP HAS BEEN DRAWN FROM FROM THE IRRIGATION ATLAS OF INDIA (1972), PLATE NO.- 6.

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

BETWA

SUB ZONE - 1 (C)

NORMAL ANNUAL RAINFALL.

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

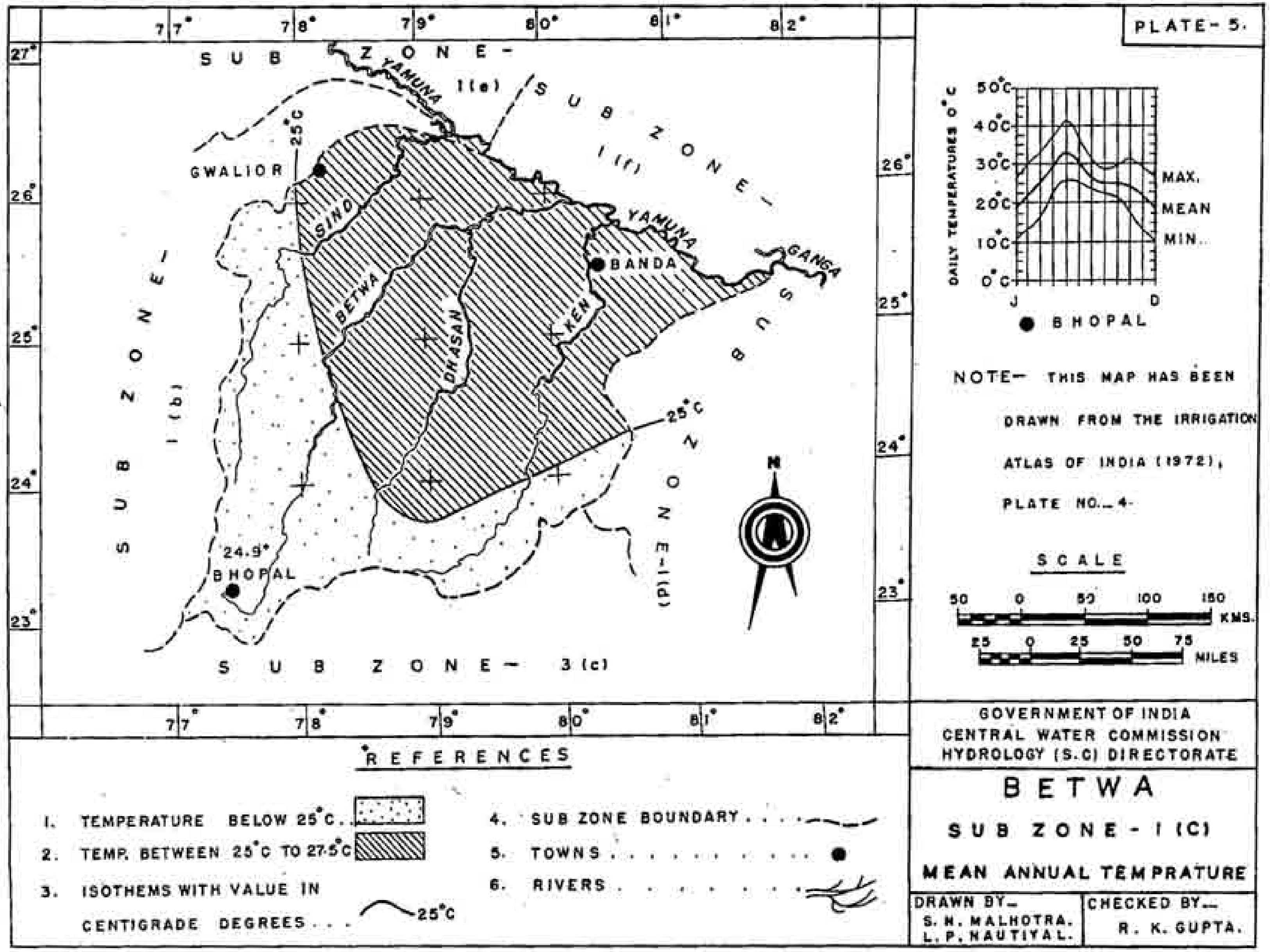
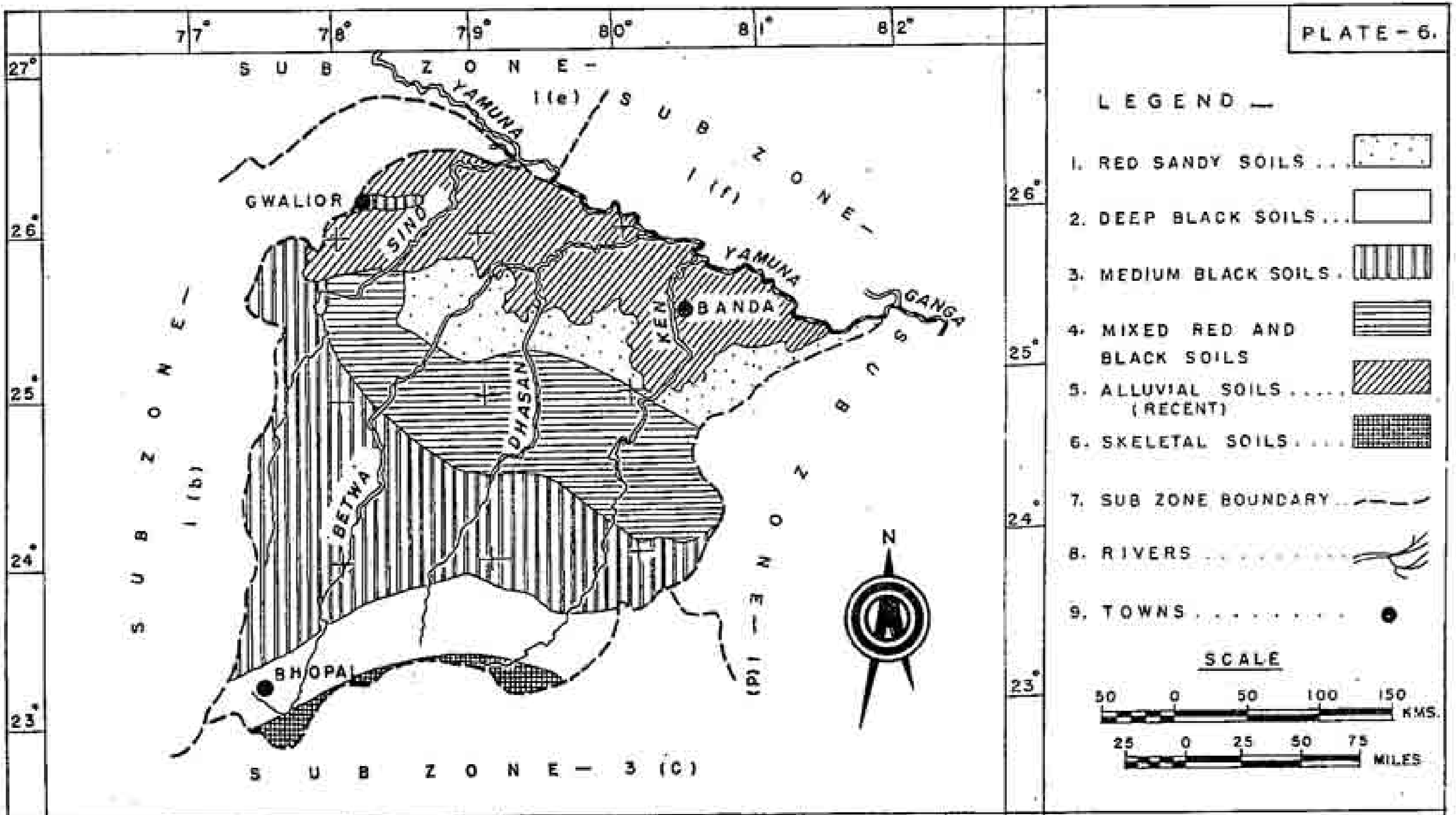


PLATE- 5.
SUB ZONE- 1(e)
SUB ZONE- 1(f)
SUB ZONE- 1(b)
SUB ZONE- 1(d)
SUB ZONE- 3(c)
GWALIOR
BANDA
24.9°
BHOPAL
25°C
YAMUNA
GANGA
SIND
BETWA
DHASAN
KEN
N
DAILY TEMPERATURES 0°C
50°C
40°C
30°C
20°C
10°C
0°C
J
D
MAX.
MEAN
MIN.
BHOPAL
NOTE— THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972), PLATE NO._4.
SCALE
50 0 50 100 150 KMS.
25 0 25 50 75 MILES
REFERENCES
1. TEMPERATURE BELOW 25°C
2. TEMP. BETWEEN 25°C TO 27.5°C
3. ISOTHEMS WITH VALUE IN CENTIGRADE DEGREES ... 25°C
4. SUB ZONE BOUNDARY
5. TOWNS
6. RIVERS
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S.C) DIRECTORATE
BETWA
SUB ZONE - I (C)
MEAN ANNUAL TEMPRATURE
DRAWN BY—
S. N. MALHOTRA.
L. P. NAUTIYAL.
CHECKED BY—
R. K. GUPTA.

PLATE – 6.



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

BETWA

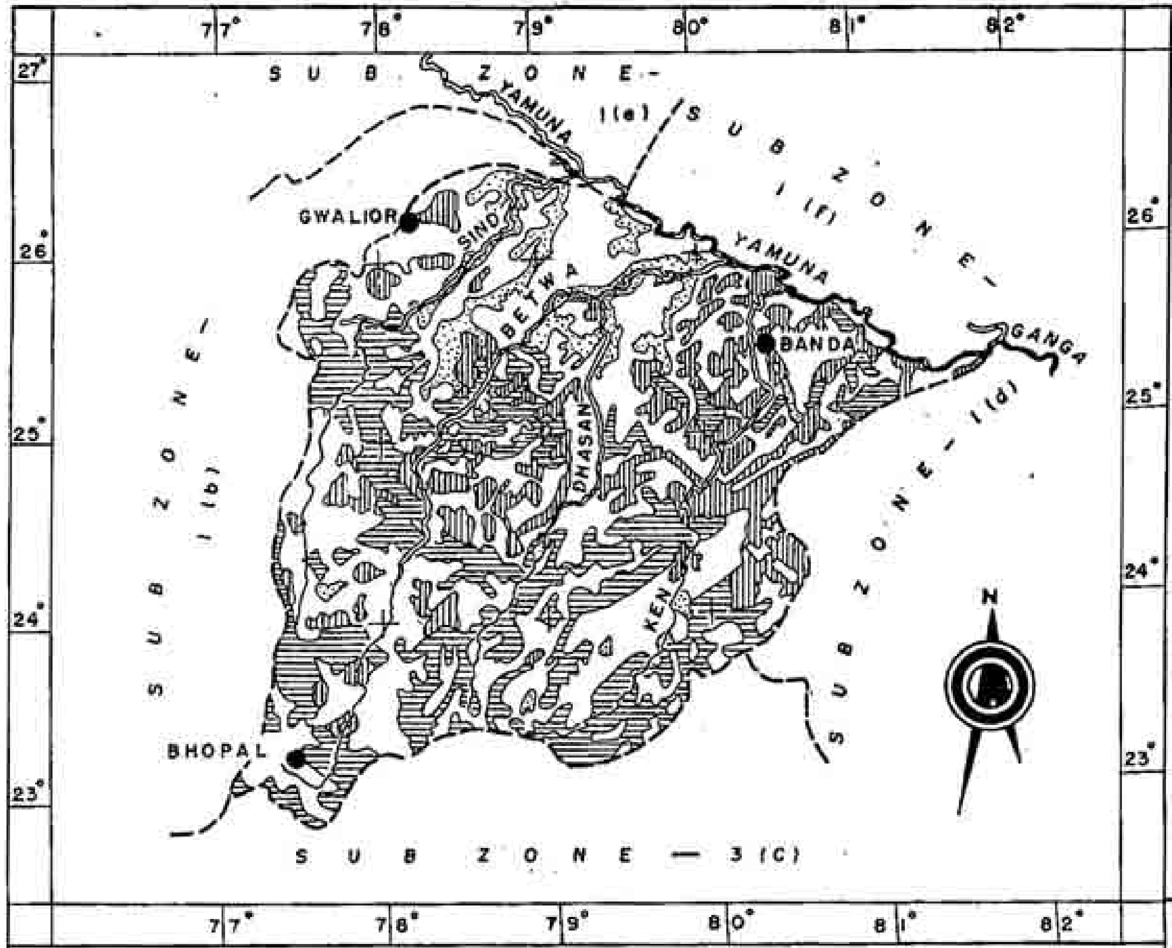
SUB ZONE I(c)

SOIL CLASSIFICATION

DRAWN BY–	CHECKED BY–
S. N. MALHOTRA L. P. NAUTIYAL	R. K. GUPTA

NOTE— THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972), PLATE NO.– 8.

PLATE-7.



LEGEND —

1. ARABLE LAND....
2. FOREST.......
3. GRASS LAND & SCRUB
4. WASTE LAND....
5. SUB ZONE BOUNDARY
6. RIVERS......
7. TOWNS.........

SCALE

50 0 50 100 150 KM.

25 0 25 50 75 MILES

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

BETWA

SUB ZONE 1(c)

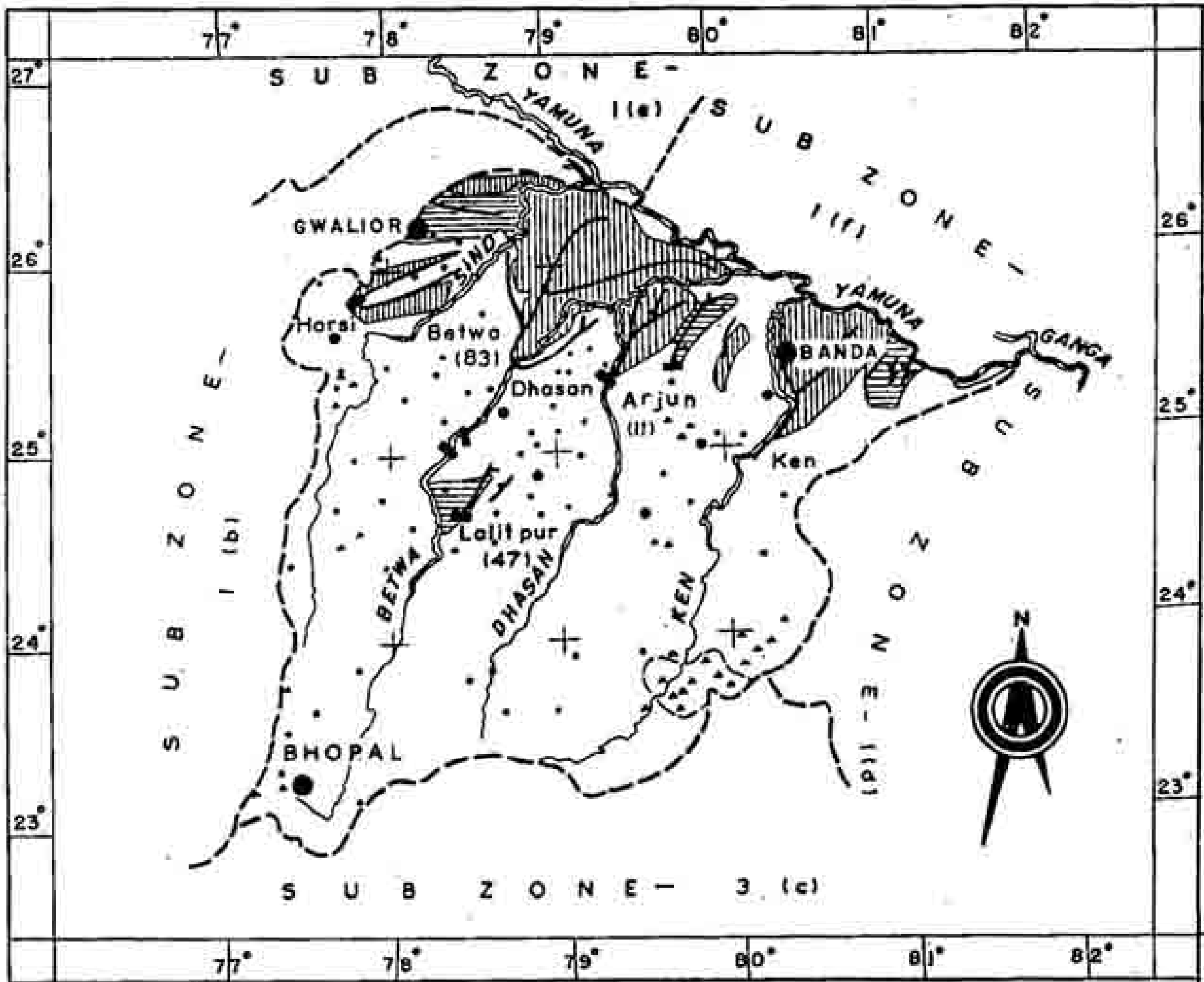
LAND USE

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

NOTES —

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

PLATE-8.



LEGEND—

1. AREA IRRIGATED BY CANALS IN '000 HECTARES DENOTED BY FIGURES . . . Betwa (83)
2. AREA IRRIGATED BY PERENNIAL CANALS . . . .
3. AREA TO BE IRRIGATED BY CANAL PROJECT UNDER CONST.
4. IMPORTANT CANAL IRRIGATION PROJECTS . . . . Ken
5. CANAL, BARRAGE, DAM . . .
6. AREA MAINLY IRRIGATED BY TANK . . . .
7. AREA IRRIGATED BY WELLS
8. TANKS . . . .

SCALE

50 0 50 100 150 KMS.

25 0 25 50 75 MILES

REFERENCES—

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

NOTE—

THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972), PLATE NO.- 17.

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

BETWA

SUB. ZONE - 1(C)

IRRIGATION

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

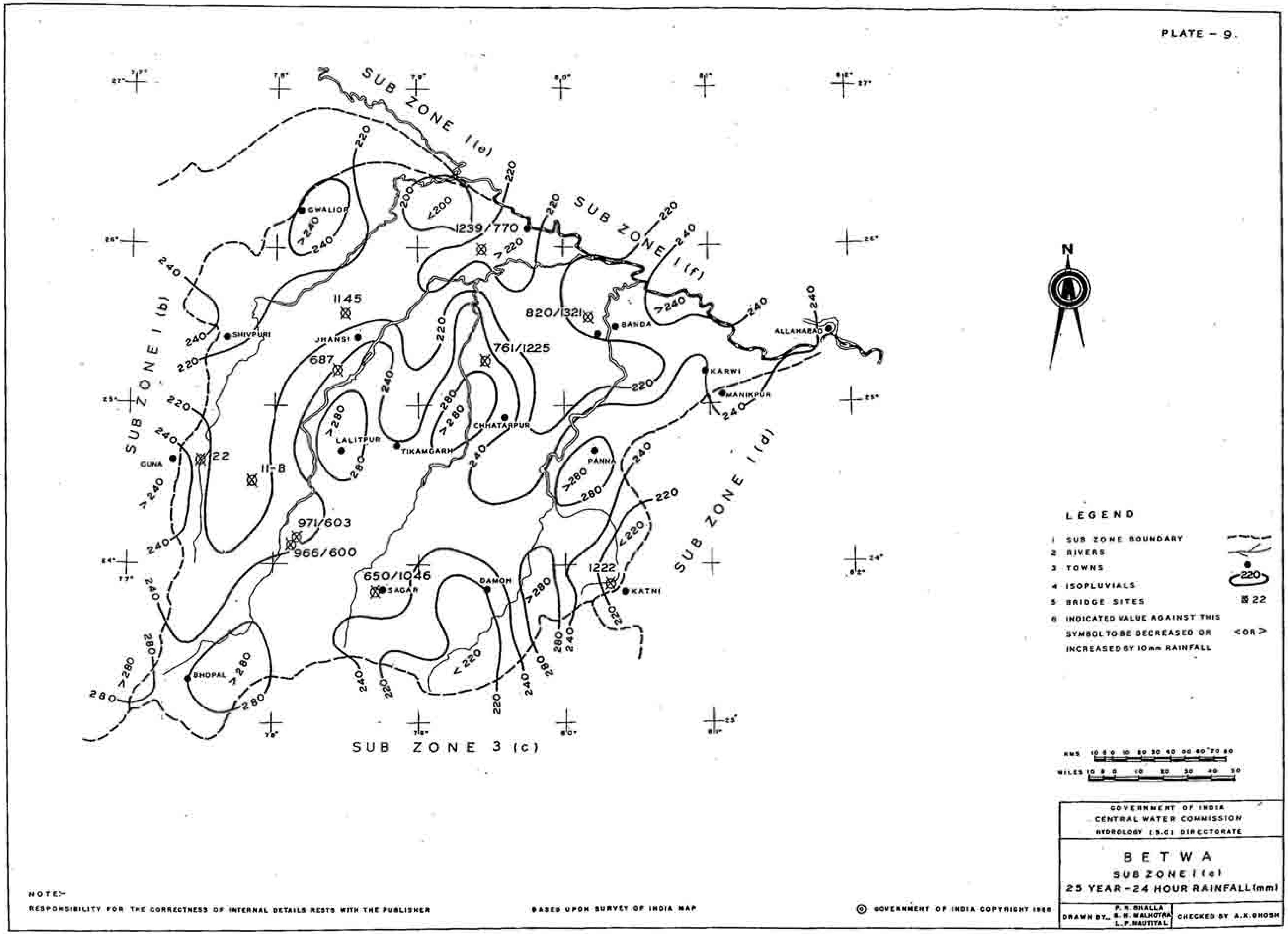


PLATE - 9.
SUB ZONE I (e)
SUB ZONE I (f)
SUB ZONE I (b)
SUB ZONE I (d)
SUB ZONE 3 (c)
N
GWALIOR
SHIVPURI
JHANSI
LALITPUR
TIKAMGARH
CHHATARPUR
BANDA
ALLAHABAD
KARWI
MANIKPUR
PANNA
GUNA
SAGAR
DAMOH
KATNI
BHOPAL
1239/770
1145
820/1321
761/1225
687
22
11-B
971/603
966/600
650/1046
1222
LEGEND
1 SUB ZONE BOUNDARY
2 RIVERS
3 TOWNS
4 ISOPLUVIALS
5 BRIDGE SITES
6 INDICATED VALUE AGAINST THIS SYMBOL TO BE DECREASED OR INCREASED BY 10mm RAINFALL
<OR>
KMS
MILES
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S.C) DIRECTORATE
B E T W A
SUB ZONE I (c)
25 YEAR - 24 HOUR RAINFALL (mm)
DRAWN BY... P. R. BHALLA, S. N. MALHOTRA, L. P. NAUTIYAL
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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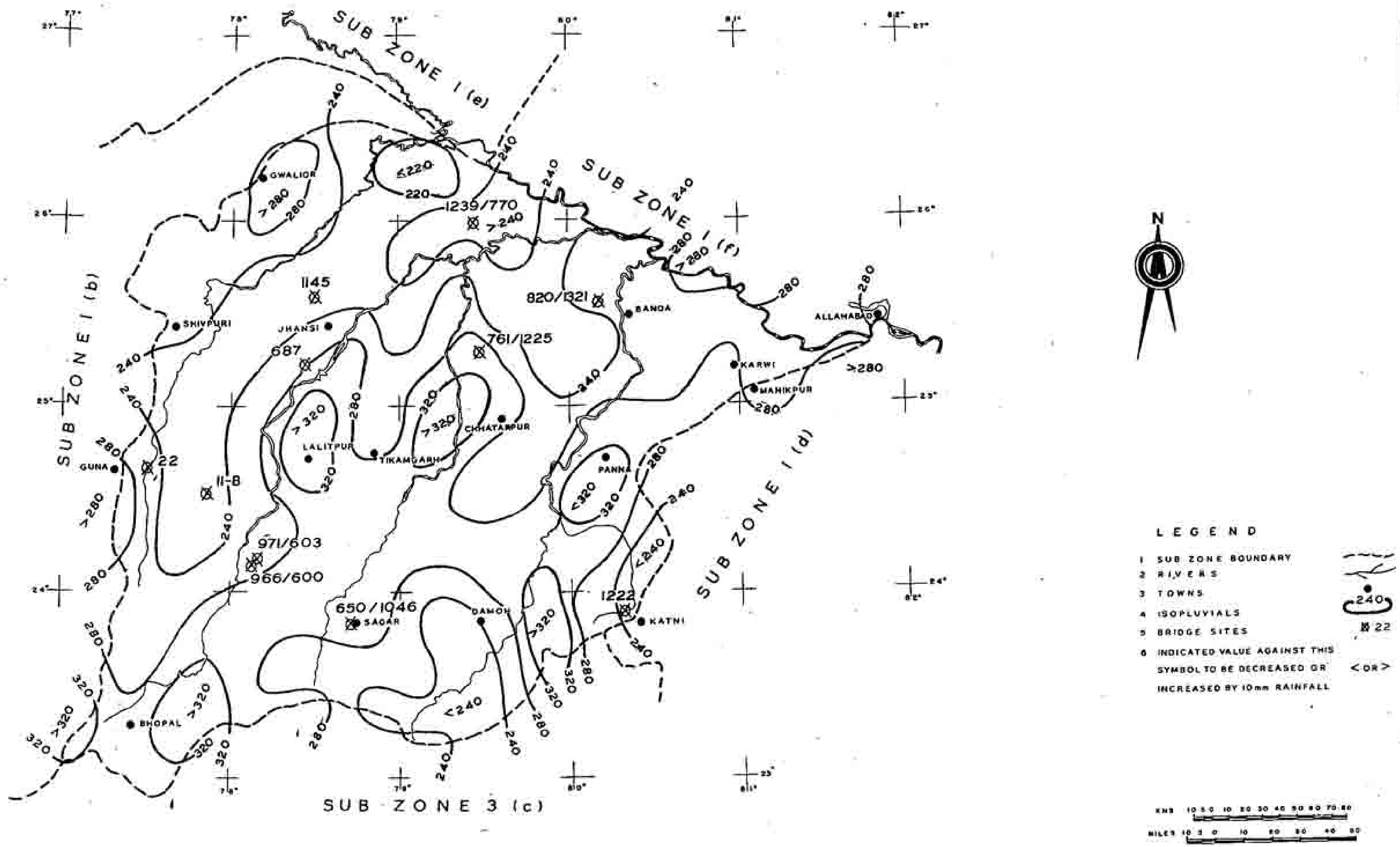
PLATE - 10



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

BETWA

SUB ZONE 1 (c)

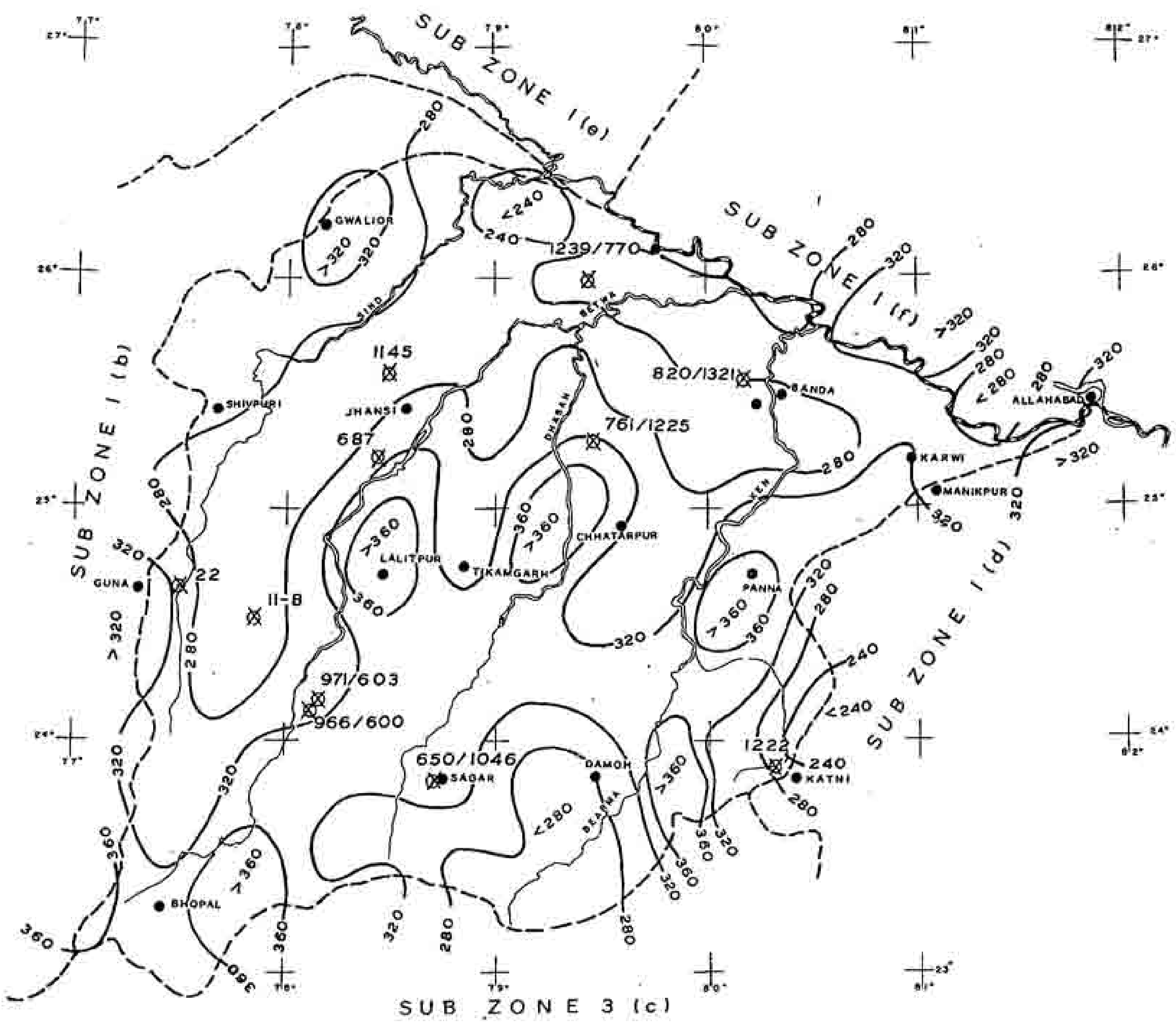
50 YEAR - 24 HOUR RAINFALL (mm)

DRAWN BY_ S.K. BHATIA, P.N. BHALLA, L.P. NAUTIYAL.	CHECKED BY_ A. K. GHOSH

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

BASED UPON SURVEY OF INDIA MAP

PLATE - II



LEGEND

1 SUB ZONE BOUNDARY
2 RIVERS
3 TOWNS
4 ISOPLUVIALS — 240
5 BRIDGE SITES — 22
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

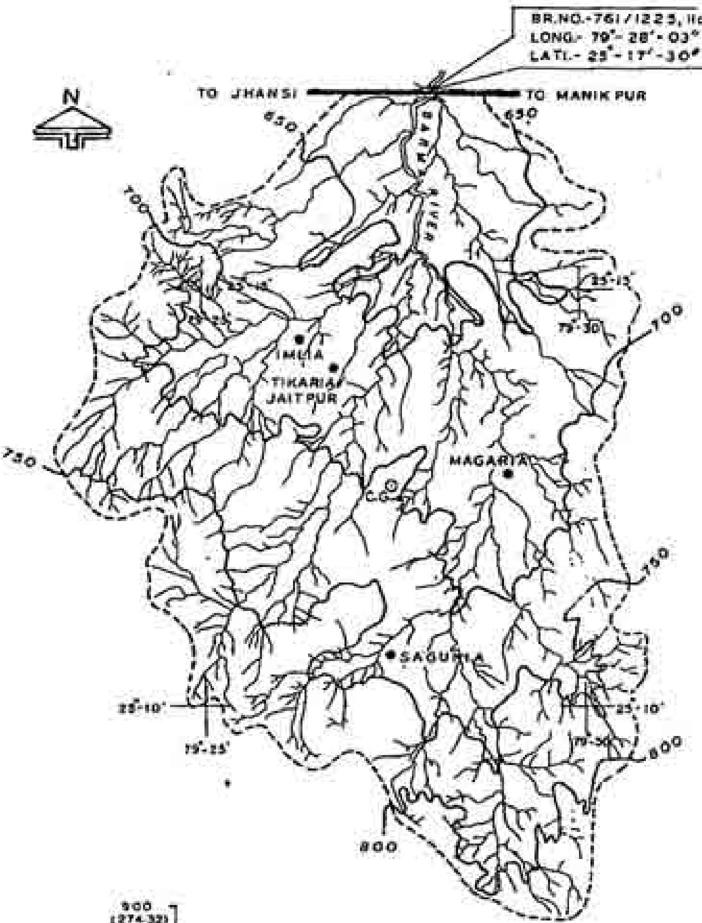
BETWA
SUB ZONE 1(c)
100 YEAR - 24 HOUR RAINFALL (mm)

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

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

BASED UPON SURVEY OF INDIA MAP

FIG.- F - 1.



NOTES:-

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

REFERENCES

1. CATCHMENT BOUNDARY . . . . .
2. RAILWAY LINE . . . .
3. RIVER AND IT'S TRIBUTARIES . . .
4. CENTRE OF GRAVITY . . . . . . C.G.
5. RAINGAUGE STATION . . . . . .
6. CONTOURS 700
7. TOPO SHEET NO. 54-O/7,8,11,12

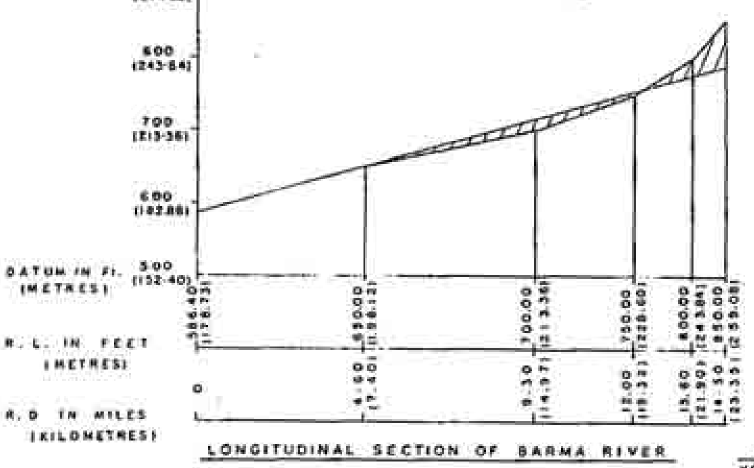
DETAIL OF CATCHMENT

1. CATCHMENT AREA . . . . 39.70 Sq. MILES (154.62 Sq.Km.)
2. SHAPE OF THE CATCHMENT . . . FAN
3. L . . . . 14.50 MILES (23.35 Km.)
4. Lc . . . . 6.10 MILES (9.82 Km.)
5. Wc . . . . 8.00 MILES (12.88 Km.)
6. Sst. . . . . 15.26 Ft./MILES (2.95 M/Km.)
7. Seq. . . . . 13.83 Ft/MILES (2.62 M/Km.)

NAME OF R.G STATION	LOCATION	
	LONG.	LATI.
BRIDGE SITE	79°- 28'- 03"	25°- 17'- 30"
IMLIA	79°- 26'- 18"	25°- 14'- 28"
TIKARIA/ JAITPUR	79°- 26'- 45"	25°- 14'- 03"
MAGARIA	79°- 29'- 00"	25°- 12'- 43"
SAGUNIA	79°- 27'- 20"	25°- 37'- 00"

SCALE

FURLONGS 8 6 4 2 0 1 2 MILES



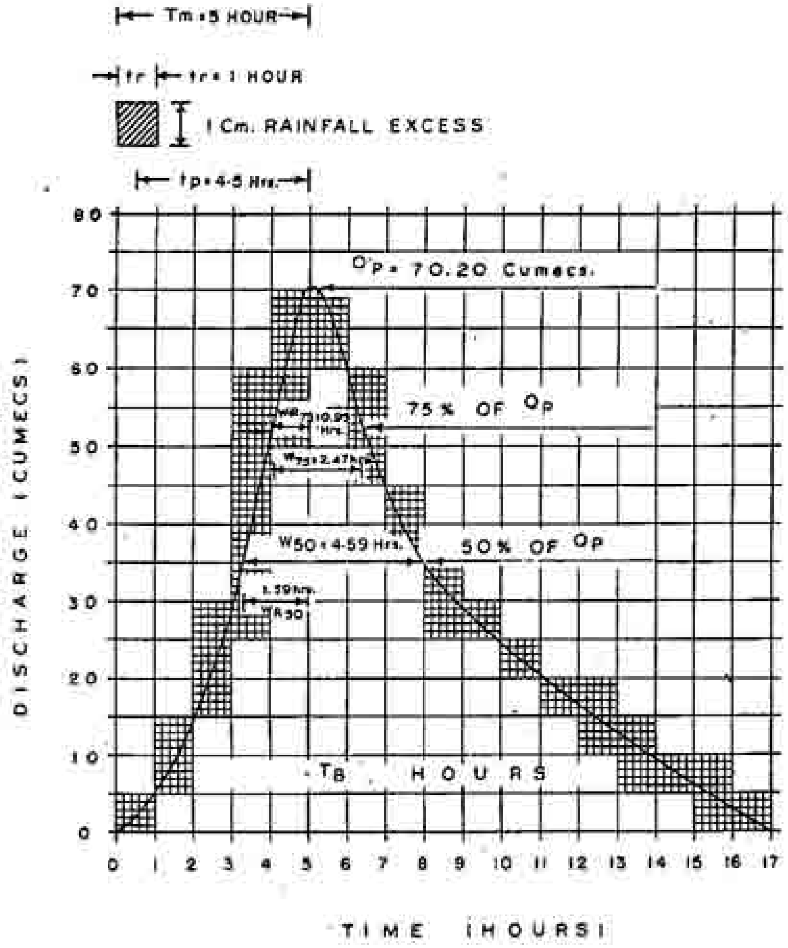
LONGITUDINAL SECTION OF BARMA RIVER

SCALE:-
HOR.- 1"=2 MILES
VER.- 1"=100 Ft.

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

CATCHMENT AREA PLAN FOR BR. NO.- 761/1225 AT KM. 1225/10-1226/1 ON JHANSI - MANIKPUR SECTION CENTRAL RAILWAY, SUB ZONE 1(c).

DRAWN BY.-	CHECKED BY.-
S.K. BHATIA, L.P. NAUTIYAL.	A. K. GHOSH.



SYNTHETIC U.G PARAMETERS

C.A = 154.62 Sq. Km.
t_p = 4.50 HOURS
T_B = 17.00 HOURS
Q_p = 70.20 CUMECS
W_{50} = 4.59 HOURS
W_{75} = 2.47 HOURS
W_{R50} = 1.59 HOURS
W_{R75} = 0.95 HOURS
q_p = 0.454 CUMECS/ Km^2
$\frac{L}{\sqrt{S}}$ = 8.192
d = 1.00 Cm.
Tm = 5.00 HOURS

$$\Sigma Q(t) = \frac{A \times d}{t_r \times 0.36} = \frac{154.62 \times 1.00}{1.00 \times 0.36} = 429.50 \text{ CUMECS}$$

FIG.- F-2.

TIME IN (HOURS)	1- HOUR SYNTHETIC U.G ORDINATES (Cumecs)
0	0
1	5.00
2	14.20
3	28.20
4	51.00
5	70.20
6	59.50
7	44.70
8	34.70
9	29.00
10	24.50
11	20.50
12	16.50
13	13.00
14	9.50
15	6.20
16	2.80
17	0.00
TOTAL	429.50

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

BETWA

SUB ZONE 1(C)

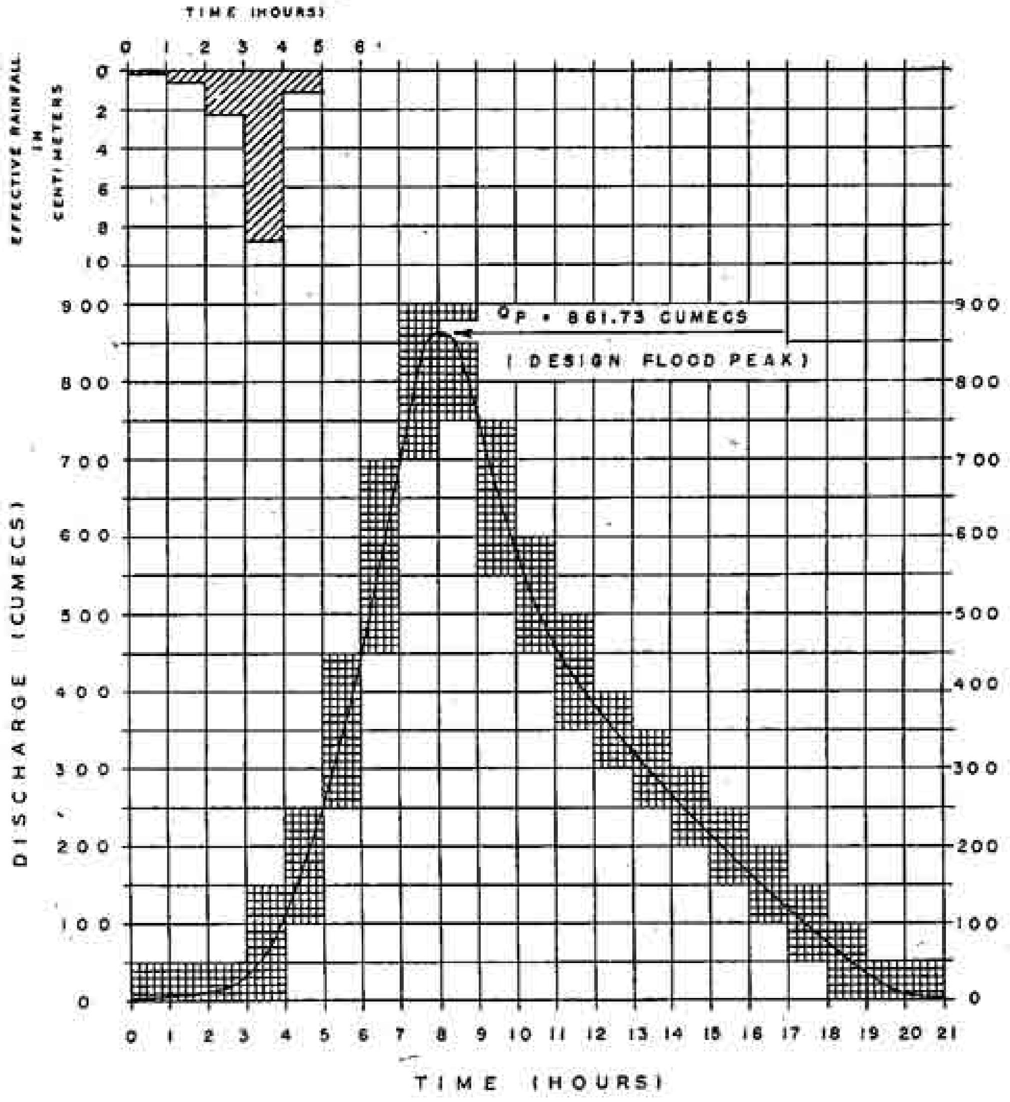
SYNTHETIC UNIT HYDROGRAPH

BR. NO.- 761/1225.

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

CHECKED BY— A. K. GHOSH.

FIG. – F – 3.



CATCHMENT AREA = 59.70 SQ. MILES (154.62 KM.^{2})

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

B ETWA

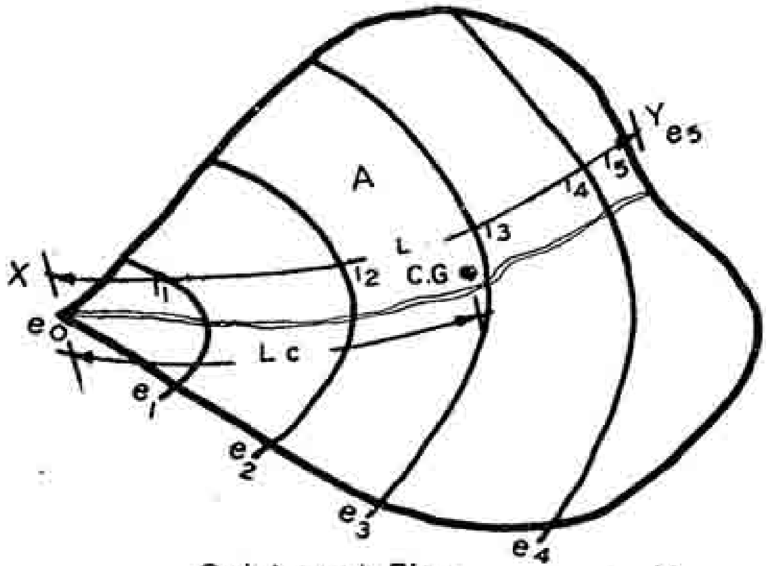
SUB ZONE 1(C)

DESIGN FLOOD HYDROGRAPH

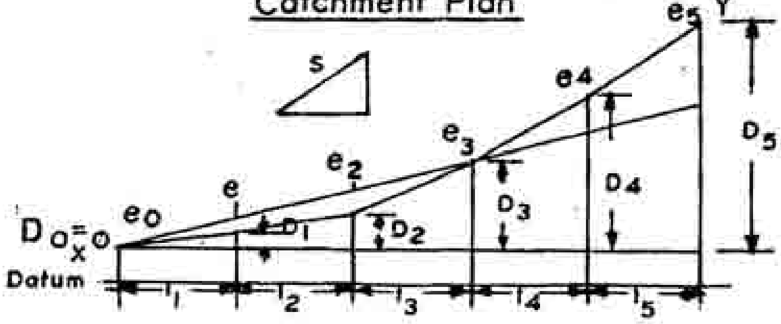
BR.NO.-761/1225.ON BARMA RIVER.

DRAWN BY–	CHECKED BY–
S. N. MALHOTRA L. P. NAUTIYAL	R. K. GUPTA.

FIG. I



Catchment Plan



L- Section

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

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

L = Length of longest stream course (km)

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

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

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

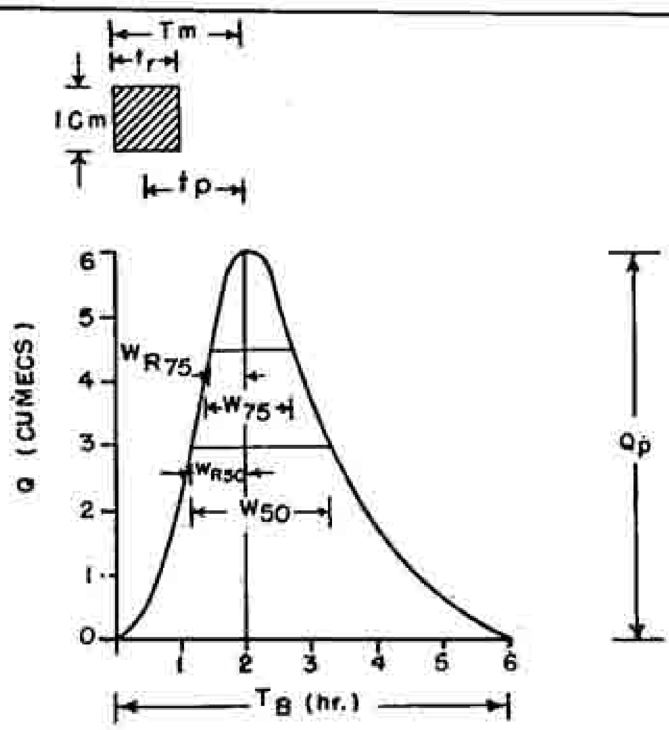
$= (e_0 - e_0), (e_1 - e_0), (e_2 - e_0) \cdots (e_n - e_0)$ (m)

A = Catchment area (km²)

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 R.N. SHARMA	CHECKED A.K. GHOSH

FIG. – 2



U.G. = Unit Graph

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

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

Q_p = Peak Discharge of Unit Hydrograph (cumecs)

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

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

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

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

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

T_B = Base width of Unit Hydrograph (hr.)

A = Catchment Area (Sq. km.)

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

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HYDROLOGY (SMALL CATCHMENT) DTE.

UNIT GRAPH PARAMETERS

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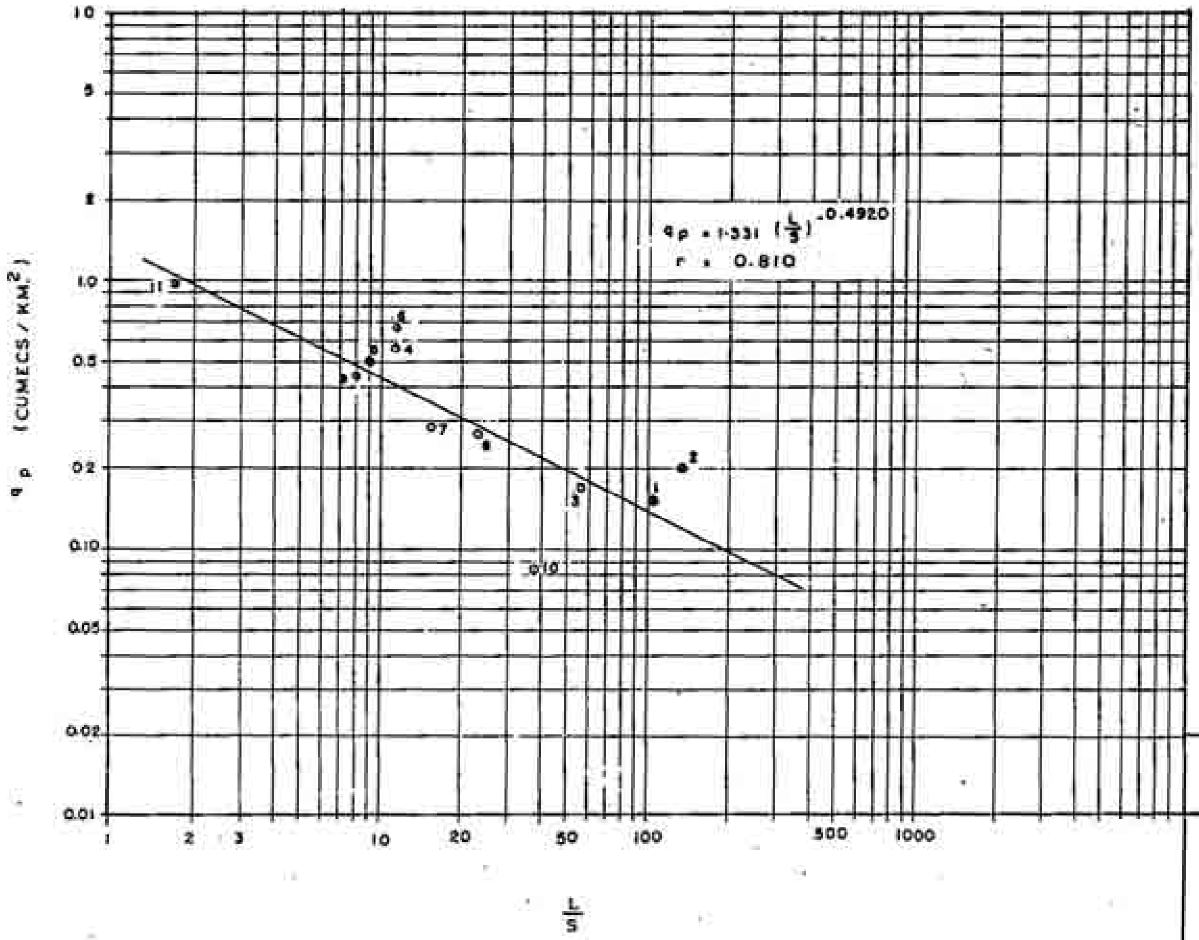
FIG. - 3.

SCALE - LOG. X LOG.



SL. NO.	BR. NO.	$\frac{L}{S}$	q_p (cumecs/km^2)
1	848/600	105.075	0.150
2	22	133·570	0.200
3	820/1321	56.825	0.170
4	687	11.242	0.570
5	761/1225	8.912	0.498
6	1145	11.348	0.682
7	1122	15.359	0.284
8	603	23.212	0.269
9	11-B	8.154	0.441
10	1239/770	37·213	0.084
11	650/1046	1.675	0.970

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BETWA

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RELATION BETWEEN q_p AND $\frac{L}{S}$

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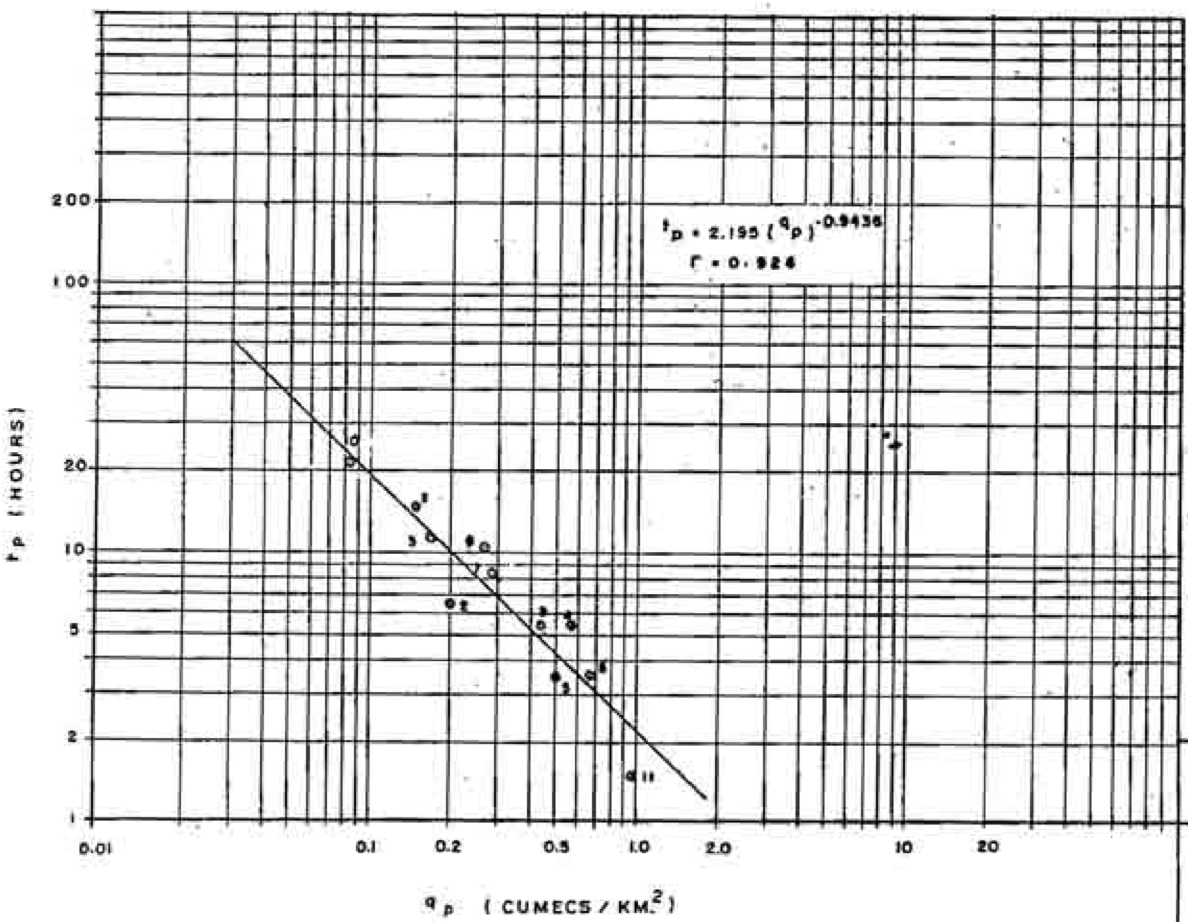
FIG. - 4

SCALE - LOG. X LOG.



SL. NO.	BR. NO.	q_p (cumecs / km^2)	t_p (HOURS)
1	966/600	0.150	14.50
2	22	0.200	6.50
3	820/1321	0.170	11.50
4	687	0.570	5.50
5	761/1225	0.498	3.50
6	1145	0.662	3.50
7	1222	0.284	8.50
8	603	0.269	10.50
9	11-B	0.441	5.50
10	1239/770	0.084	21.50
11	650/1046	0.970	1.50

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RELATION BETWEEN t_p AND q_p

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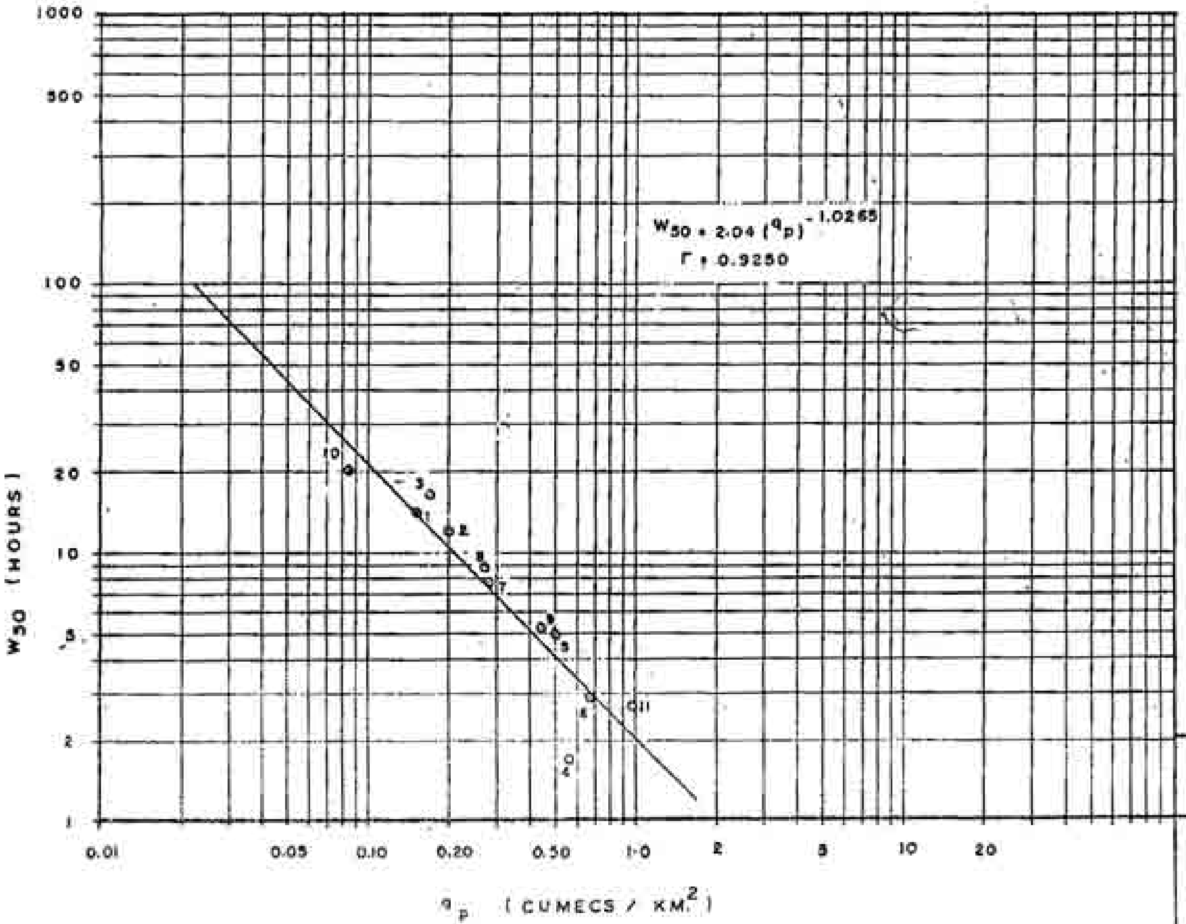
CHECKED BY - R.K. GUPTA.

FIG.- 5.

SCALE - LOG. X LOG.



SL. NO	BR. NO.	q_p (cumecs/km^2)	W_{50} (HOURS)
1	966/600	0.150	14.25
2	22	0.200	12.00
3.	820/1321	0.170	16.40
4	687	0.570	1.70
5	761/1225	0.498	5.00
6	1145	0.662	2.90
7	1222	0.284	7.80
8	603	0.269	8.80
9	11-B	0.441	5.50
10	1239/770	0.084	20.00
11	650/1046	0.970	2.70

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RELATION BETWEEN W_{50} AND q_p

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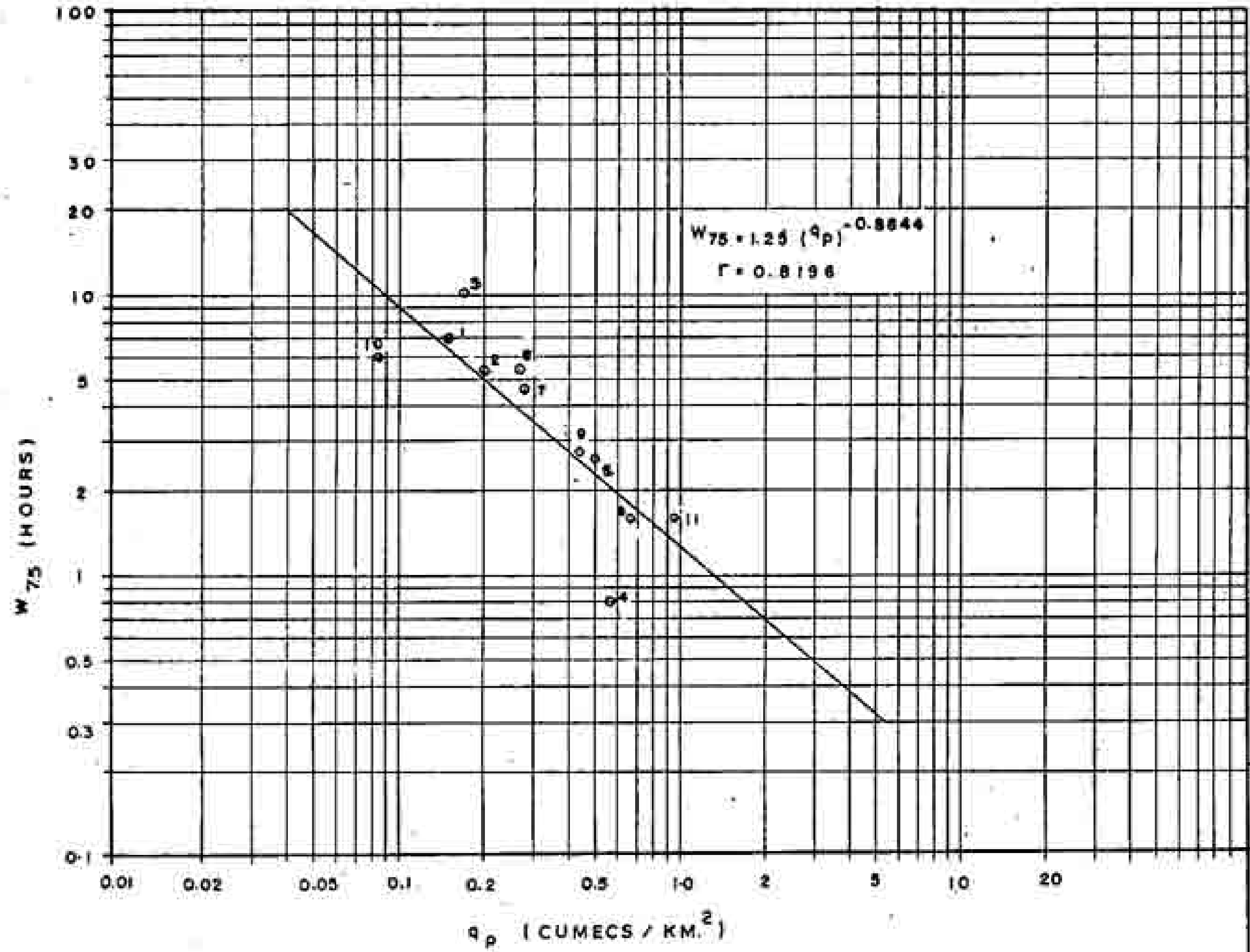
FIG.- 6.

SCALE - LOG. X LOG.



SL. NO.	BR. NO.	q_p (cumecs/km^2)	W_{75} (HOURS)
1	966/600	0.150	7·00
2	22	0.200	5.40
3	820/1321	0.170	10.20
4	687	0.570	0.80
5	761/1225	0.498	2.60
6	1145	0.662	1.60
7	1222	0.284	4.60
8	603	0.269	5.40
9	11-8	0.441	2.75
10	1239/770	0.084	6.00
11	650/1046	0.070	1.60

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CENTRAL WATER COMMISSION
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SUB ZONE 1(C)

RELATION BETWEEN
W_{75} AND q_p

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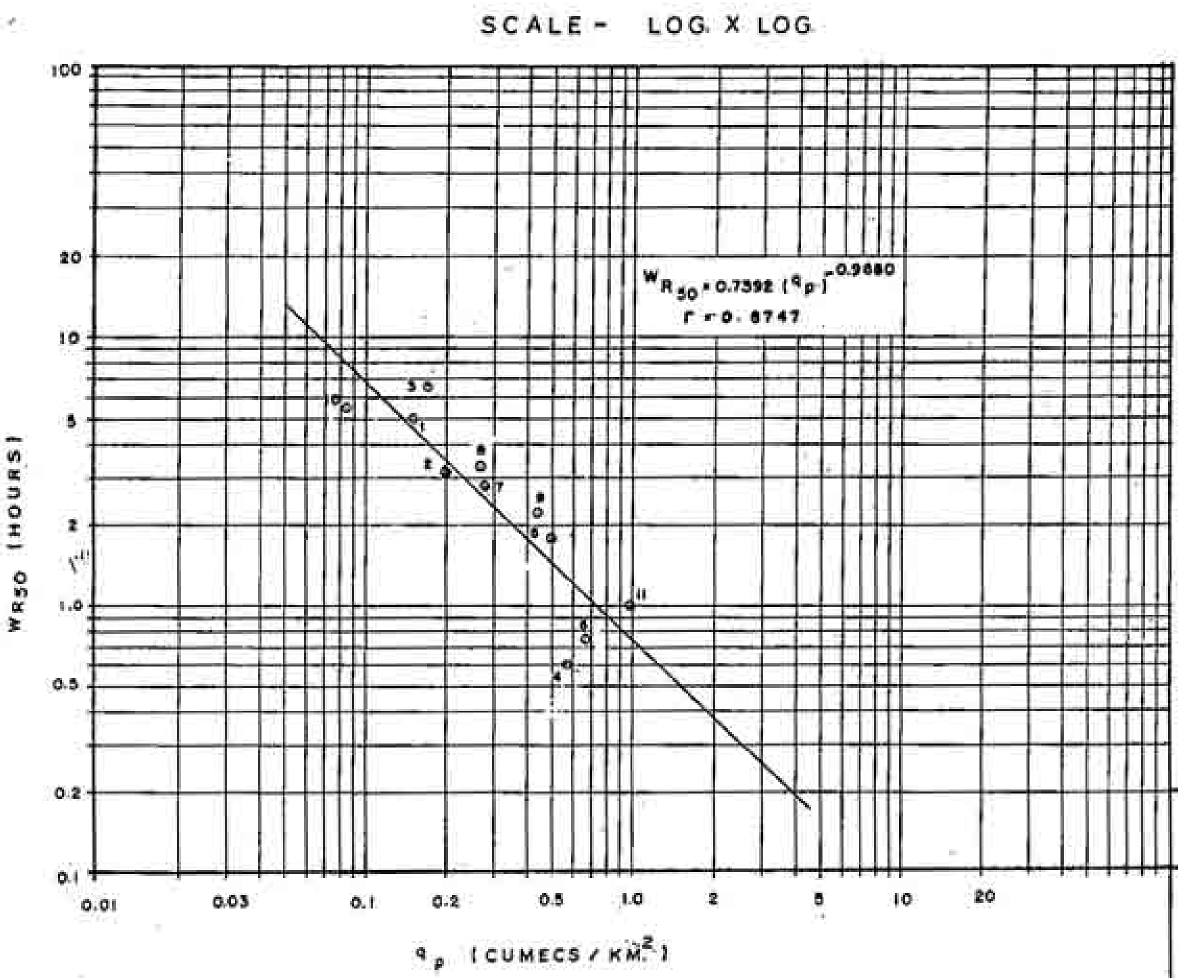
CHECKED BY - A. K. GHOSH.

FIG. - 7.



SL. NO.	BR. NO.	q_p (cumecs/ km²)	W_{R50} (HOURS)
1	966/600	0.150	5.00
2	22	0.200	3.20
3	820/1321	0.170	6.60
4	687	0.570	0.60
5	761/1225	0.498	1.80
6	1145	0.662	0.75
7	1222	0.284	2.80
8	603	0.269	3.30
9	11-B	0.441	2.25
10	1239/770	0.084	5.50
11	650/1046	0.970	1.00

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RELATION BETWEEN W_{R50} AND q_p

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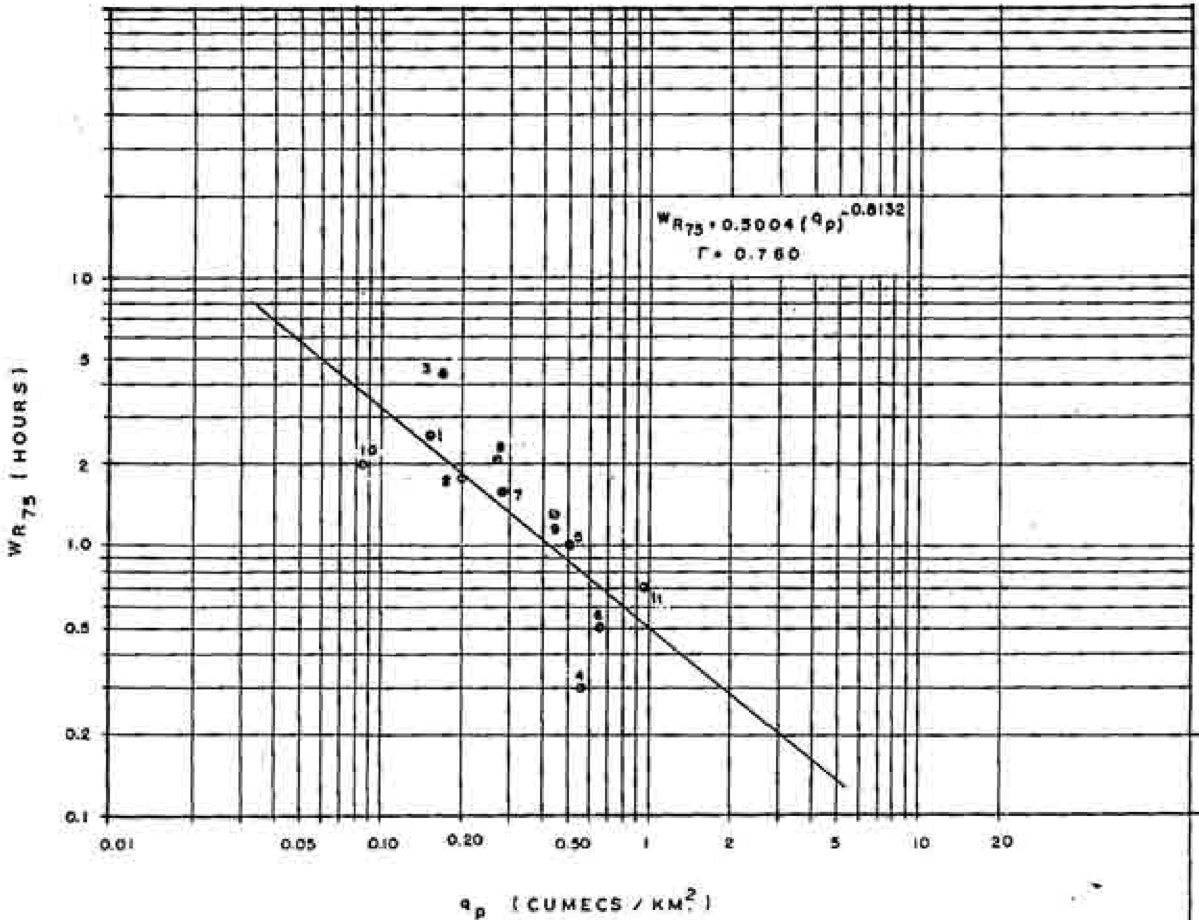
CHECKED BY- A. K. GHOSH.

FIG. - 8.

SCALE - LOG. X LOG.



SL. NO.	BR. NO.	q_p (cumecs/km^2)	$W_{R_{75}}$ (HOURS)
1	966/600	0.150	2.50
2	22	0.200	1.80
3	820/1321	0.170	4.40
4	687	0.570	0.30
5	761/1225	0.498	1.00
6	1145	0.662	0.50
7	1222	0.284	1.60
8	603	0.269	2.10
9	11-B	0.441	1.30
10	1239/770	0.084	2.00
11	650/1046	0.970	0.70

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

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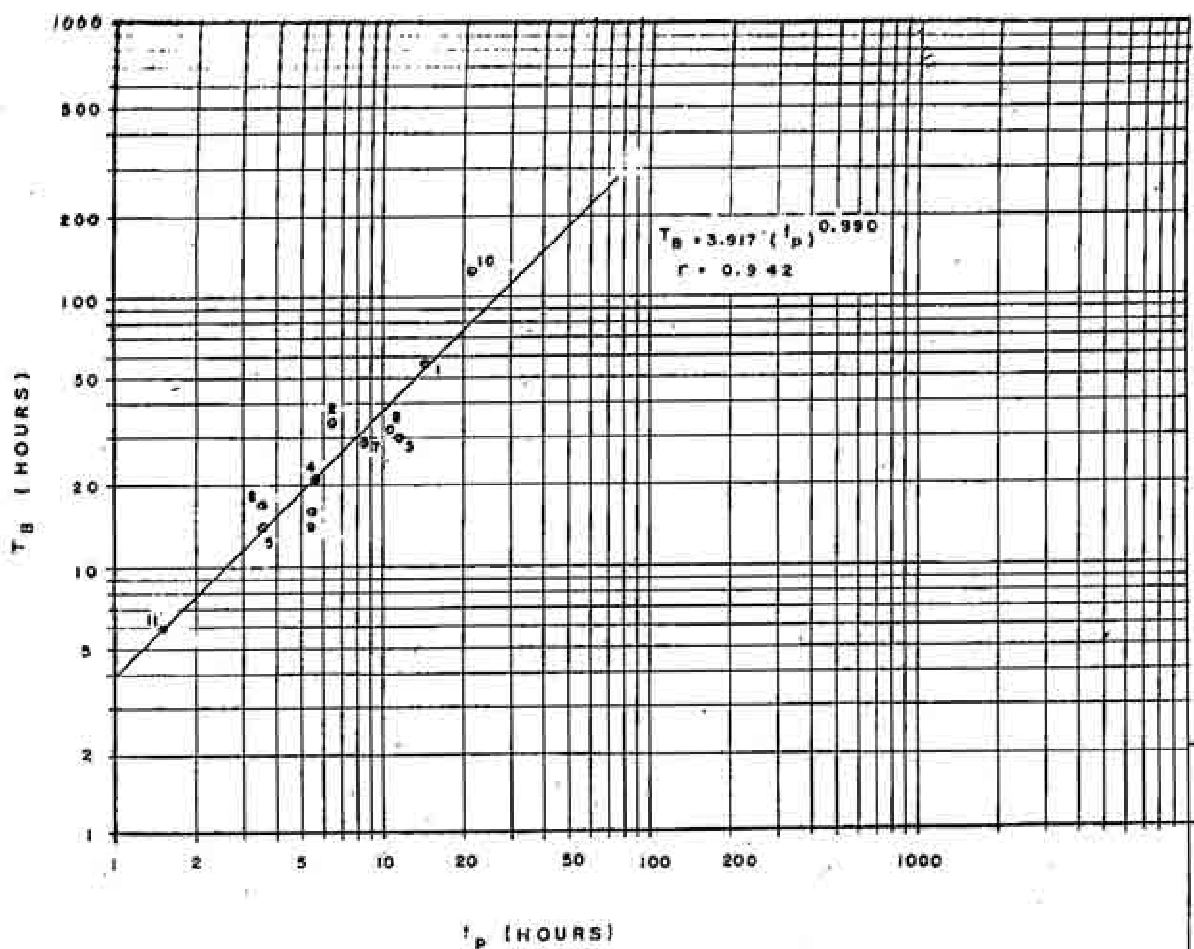
FIG. - 9

SCALE :- LOG X LOG



SL. NO.	BR. NO.	t_p (HOURS)	T_B (HOURS)
1	966/100	14.50	56.00
2	22	6.50	34.00
3	620/1321	11.50	30.00
4	667	5.50	21.00
5	761/1225	3.50	14.00
6	1145	3.50	17.00
7	1222	8.50	29.00
8	603	10.50	32.00
9	11-B	5.50	16.00
10	1239/770	21.50	125.00
11	650/1046	1.50	6.00

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RELATION BETWEEN T_B AND t_p

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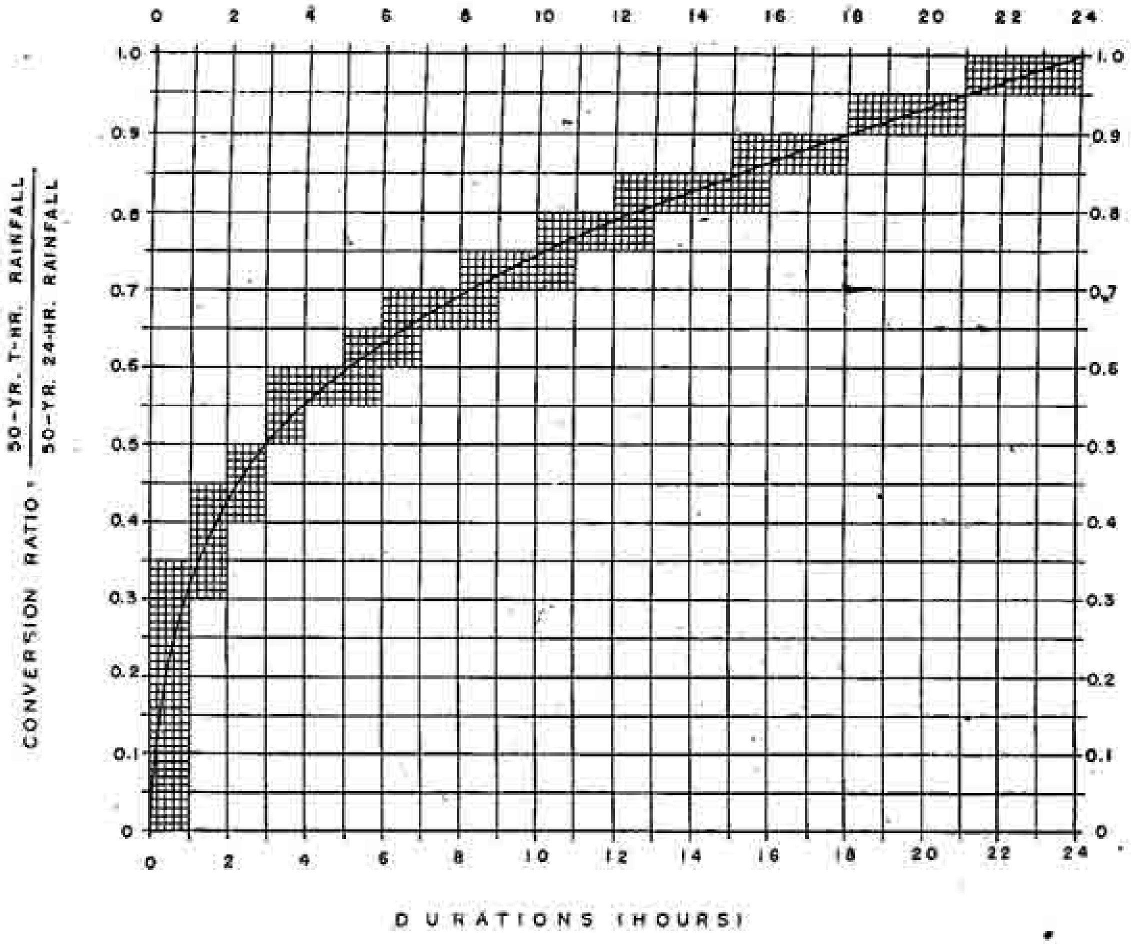
FIG.- 10.



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

DURATION (HRS.)	RATIO
0	0.000
1	0.320
2	0.430
3	0.500
4	0.550
5	0.590
6	0.630
7	0.660
8	0.690
9	0.720
10	0.745
11	0.770
12	0.790
13	0.810
14	0.830
15	0.840
16	0.860
17	0.880
18	0.900
19	0.915
20	0.930
21	0.950
22	0.965
23	0.983
24	1.000

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DURATION Vs. CONVERSION RATIO

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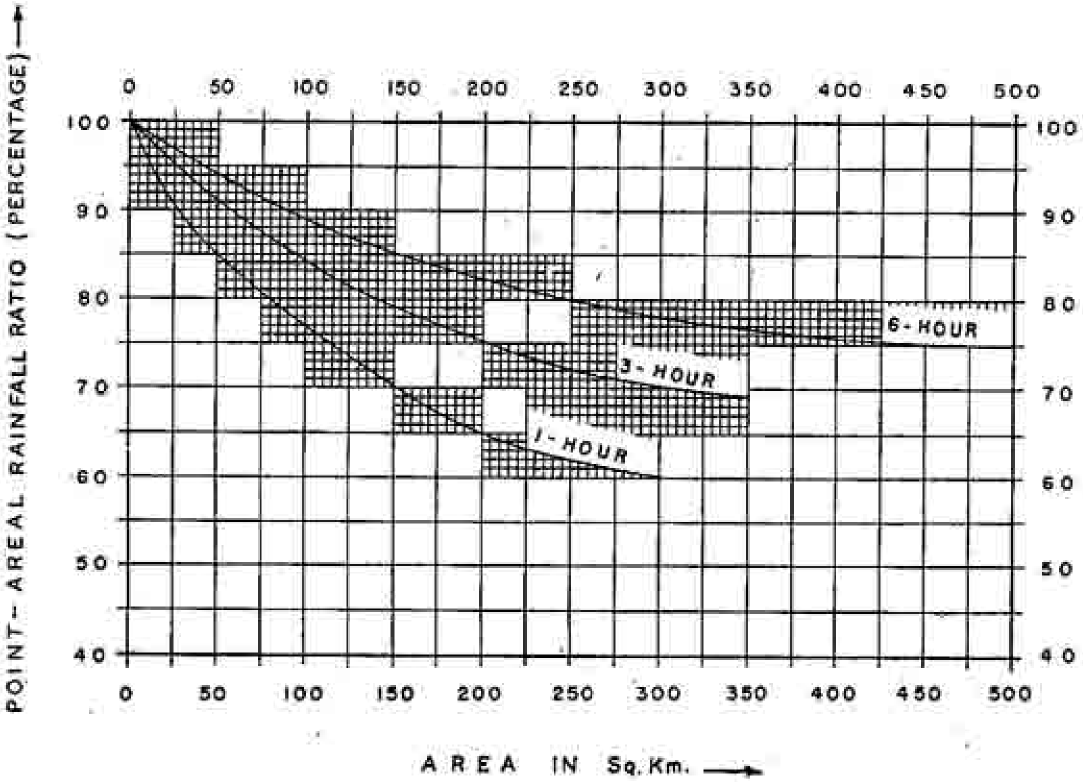
FIG. – 11 (a).



NOTE – REFER TABLE – 6 FOR POINT TO AREAL RAINFALL RATIOS FOR DURATION FROM 1 TO 24 HRS. AND FOR CATCHMENT AREAS UP TO 2500 SQ. KM.

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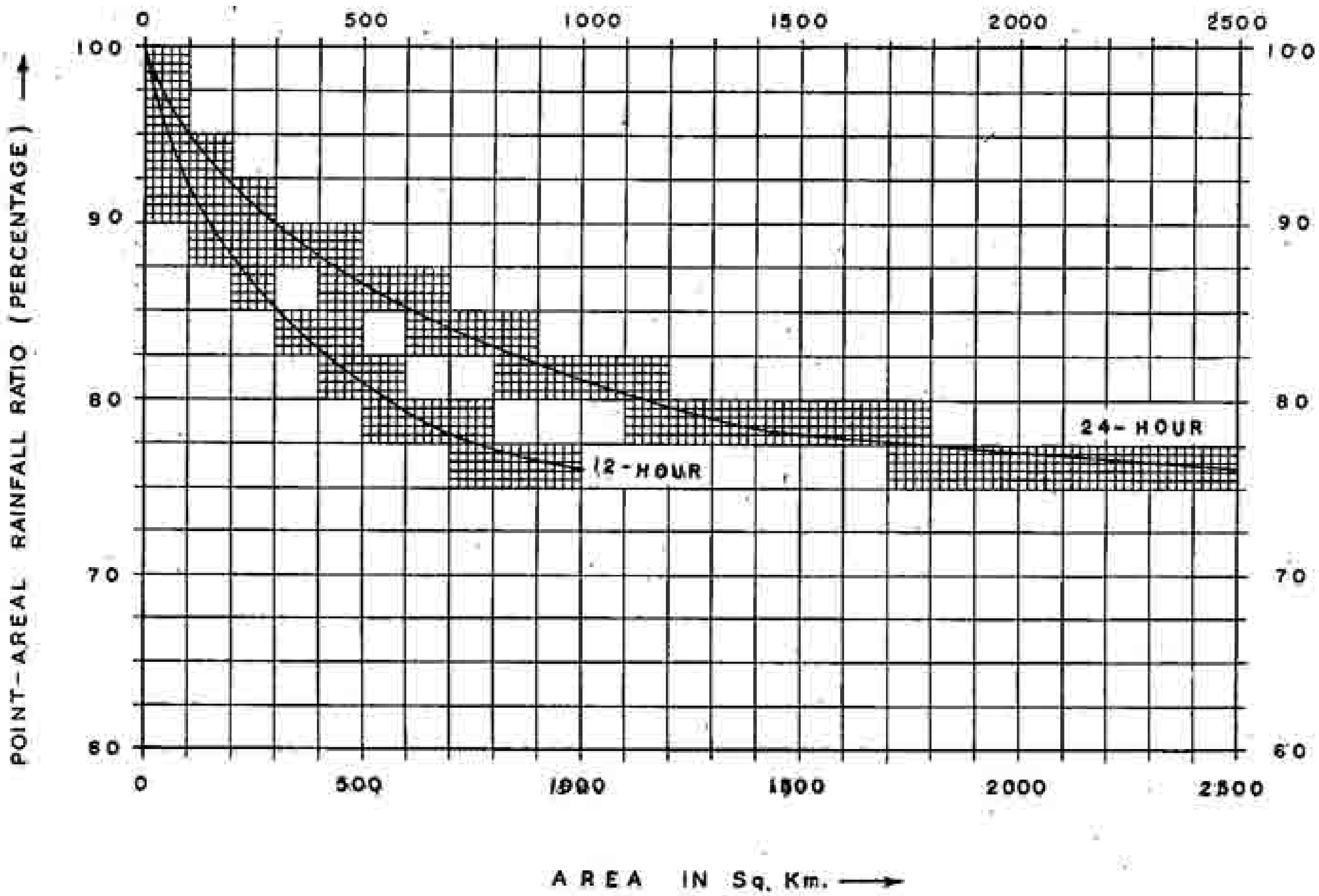
POINT- AREAL RAINFALL RATIO (PERCENTAGE)

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

FIG.– 11 (b).



NOTE – REFER TABLE-6 FOR POINT TO AREAL RAINFALL RATIOS FOR DURATION FROM 1 TO 24 HRS. AND FOR CATCHMENT AREAS UP TO 2500 SQ. KM.

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SUB ZONE 1(C)

POINT-AREAL RAINFALL RATIO (PERCENTAGE)

DRAWN BY—	CHECKED BY—
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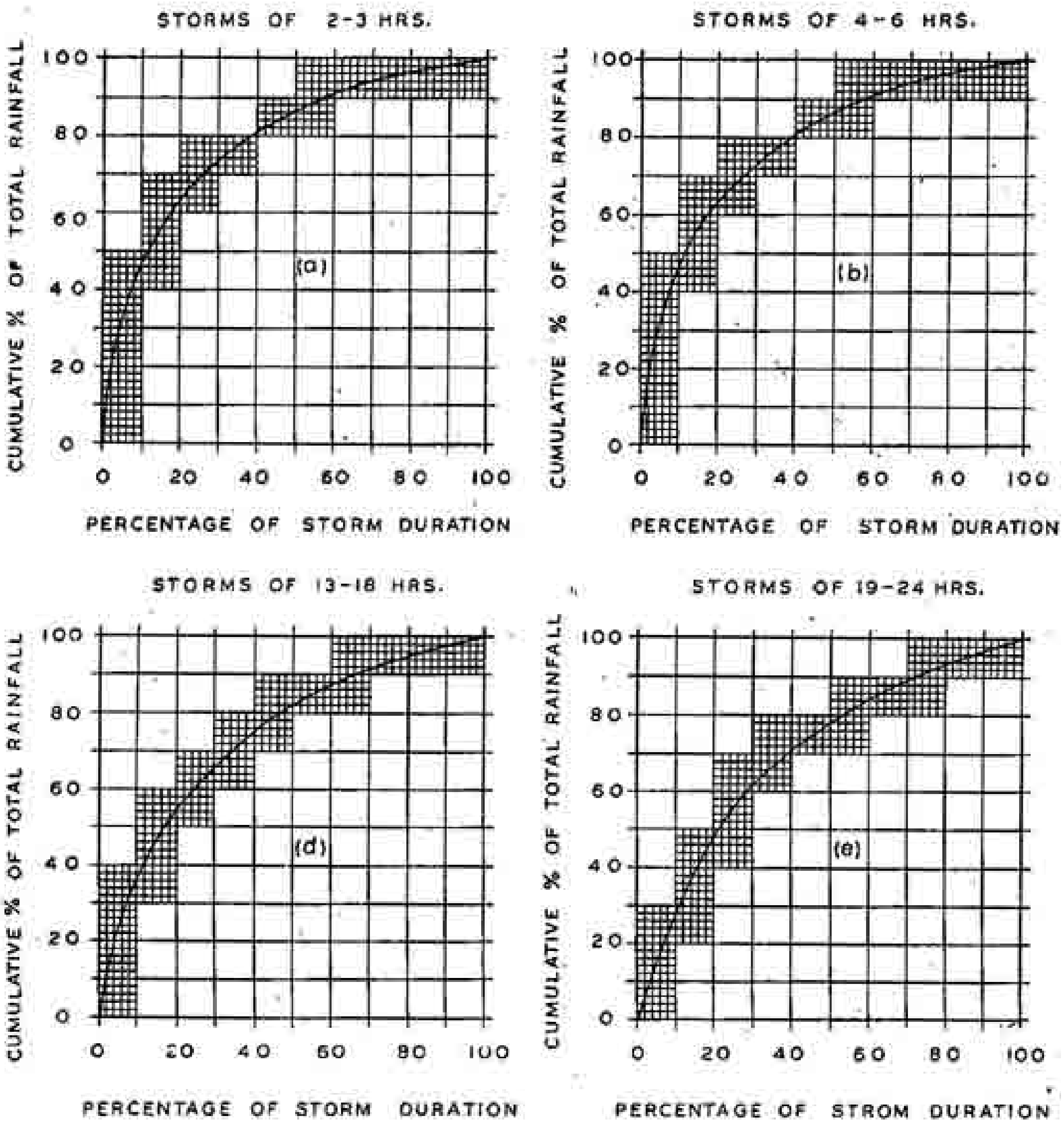
FIG. - 12.



GOVERNMENT OF INDIA
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HYDROLOGY (S. C) DIRECTORATE

BETWA BASIN

SUB ZONE - 1(c)

MEAN AVERAGE TIME DISTRIBUTION CURVES OF STORMS OF VARIOUS DURATION'

DRAWN BY_	CHECKED BY_
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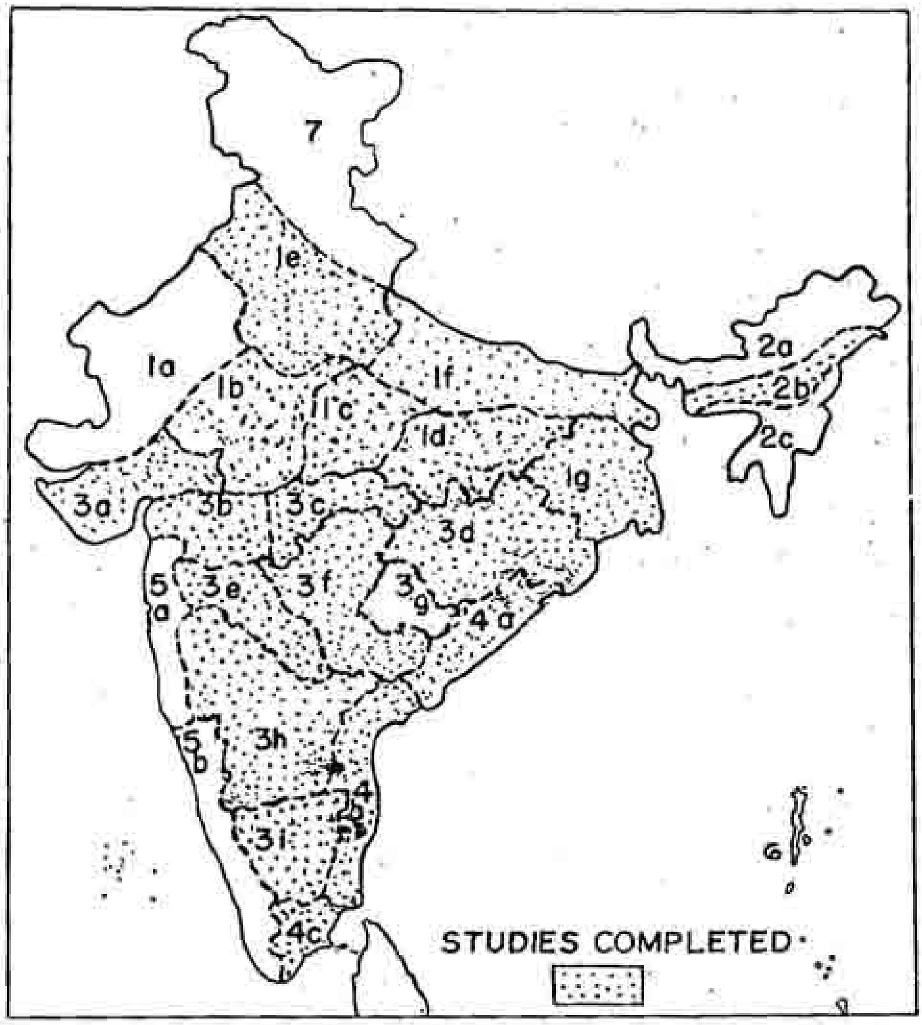

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