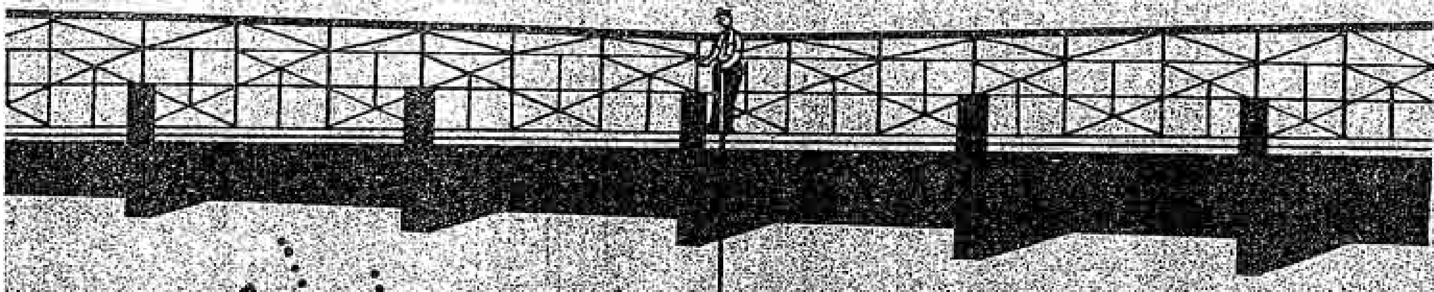
Only O/C

मध्य गंगा के मैदानों के लिए (उपअंचल-1एफ) बाढ़ आकलन का विवरण

यूनिट जलारेख सिद्धान्त पर आधारित एक पद्धति

FLOOD ESTIMATION REPORT FOR MIDDLE GANGA PLAINS (SUB ZONE-1f)

A METHOD BASED ON
UNIT HYDROGRAPH PRINCIPLE



A JOINT WORK OF
CENTRAL WATER COMMISSION
RESEARCH DESIGNS & STANDARDS ORGANISATION
(MIN. OF RAILWAYS)
& INDIA METEOROLOGICAL DEPTT. & MIN. OF TRANSPORT

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

FLOOD ESTIMATION REPORT FOR MIDDLE GANGA PLAINS SUBZONE-1 (f) WAS APPROVED BY THE FOLLOWING MEMBERS OF THE PLANNING AND COORDINATION COMMITTEE IN ITS 41ST MEETING HELD ON 30.1.1985 AT I.M.D., NEW DELHI.

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FLOOD ESTIMATION REPORT

FOR

MIDDLE GANGA PLAINS

(SUBZONE 1-f)

A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE

DESIGN OFFICE REPORT NO. GP/10/1984

(REPORT PREPARED UNDER LONG TERM PLAN

AND

APPROVED BY PLANNING & COORDINATION COMMITTEE)

HYDROLOGY (SMALL CATCHMENTS) DIRECTORATE

CENTRAL WATER COMMISSION

NEW DELHI

OCTOBER 1985

FOREWORD

The empirical approaches generally followed for estimation of design flood of bridges, culverts and cross drainage works may lead to erroneous conclusions. Studies are under way for rational and scientific estimation of floods of various return periods for safe and yet economic design of structures. Such studies for 8 subzones viz. Lower Gangetic Plains - 1(g), Lower Godavari Basin - 3(f), Lower Narmada and Tapi Basins - 3(b), Mahanadi Basin - 3(d), Upper Narmada and Tapi Basins - 3(c), Krishna and Penner Basins - 3(h), South Brahmaputra Basin - 2(b) and Upper Indo Ganga Plains - 1(e) have been published in the form of Flood Estimation Reports under long term plan. The present report presents the studies for Middle Ganga Plains subzone - 1(f). The report was approved by the Planning & Coordination Committee in its 41st meeting held on 30th January, 1985 at India Meteorological Department, New Delhi.

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

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

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

Sd/-

(N.K. Sarma)

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

PREFACE

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

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

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

A procedure for estimation of design flood peak with storm rainfall and the basin characteristics as parameters has been evolved in the short term plan utilising the hydro-meteorological data that was readily available. Systematic and sustained collection of hydro-meteorological data from the representative catchments in the different subzones of India also have been started since 1965. For this purpose, the country has been divided into 7 major zones, which are in turn sub-divided into 26 hydro-meteorologically homogenous subzones. Out of 26 subzones, river and raingauging has been/is being carried out in 22 subzones, and in each subzone 10 to 25 catchments had been selected for this purpose. The results of the study made utilising the data of representative catchments located in Lower Gangetic Plains subzone - 1(g), Lower Godavari subzone - 3(f), Lower Narmada and Tapi subzone - 3(b), Mahanadi subzone 3(d), Upper Narmada and Tapi subzone - 3(c), Krishna & Penner Basins subzone - 3(h), South Brahmaputra subzone - 2(b) and Upper Indo-Ganga Plains subzone - 1(e) have been brought out earlier in separate reports.

In the present report on Middle Ganga Plains subzone - 1(f) studies have been made on the data collected in the subzone and the method is recommended for the estimation of design flood. The gauging data of 161 bridge years collected for 25 railway bridges during the period 1961 to 1982 has been considered for analysis in this report. The gauging data was collected by North-Eastern, Northern, North-Frontier and Central Railways under the supervision of Bridges and Flood Wing of R.D.S.O., Ministry of Railways. The Central Water Commission is collecting the data of 4 road bridge catchments in the subzone on behalf of Ministry of Shipping and Transport.

Hydrology (Small Catchments) Directorate of CWC has carried out the analysis of selected storm rainfall and floods for the gauged catchments to derive 6-hr. unit hydrographs on the basis of data of rainfall, gauge and discharges collected during the monsoon season. Representative 6-hr. unit hydrographs have been obtained for each of the gauged catchments. The parameters of the catchments and their respective representative unit hydrographs have been cor-related by regression analysis and the equation for synthetic unit hydrographs for the subzone were derived. The loss rate and base flow studies were carried out. Methodology for estimation of design flood (50-yr. flood) for ungauged/inadequately gauged catchments has been indicated.

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

The present report deals with the estimation of design flood for small and medium catchments in Middle Ganga Plains subzone - 1(f) based on 50-yr. design storm rainfall and synthetic unitgraph. This report is recommended for estimation of design flood (50-yr. flood) for fixing the waterway of the bridges/culverts on streams with their catchment areas from 30 to 4,500 sq.km. This report can be used for estimation of 100-yr. flood, if required, with the given 100-yr. point rainfall map.

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

The views expressed in this report do not necessarily represent the views of Central Water Commission

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

NEW DELHI

C O N T E N T S

LIST OF TABLES, PLATES AND FIGURES

TABLES

PLATES

SYMBOLS AND ABBREVIATIONS

SYMBOLS

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

A	:	Catchment Area in sq.km.
C.G.	:	Centre of Gravity.
L	:	Length of main stream along the river course in km.
L_c	:	Length of the main stream from a point opposite to centroid of the catchment area to the gauging site in km. along the main stream.
L_i	:	Length of the ith segment of L-Section in km.
D_{i-1}, D_i	:	The depth of the river at the point of intersection of (i-1) and ith contours from the base line (datum) drawn at the level of the point of study in metres.
S	.	Equivalent stream slope in m/km.
U.G.	:	Unit Hydrography.
S.U.H.	:	Synthetic Unit Hydrograph.
t_r	:	Unit rainfall duration adopted in a specific study in hours.
t_p	:	Time from the centre of unit rainfall duration to the peak of unit hydrograph in hours.
T_m	:	Time from the start of rise to the peak of Unit Hydrograph (hr.)
T	:	Time duration of rainfall in hours.
T_B	:	Base width of unit hydrograph in hours.
T_D	:	Design storm duration in hours.

q_p	:	Peak discharge of unit hydrograph per unit area in cumecs per sq.km.
Q_p	:	Peak discharge of unit hydrograph in cumecs.
W_{50}	:	Width of the U.G. measured at 50% of maximum discharge ordinate (Q_p) in hours.
W_{75}	:	Width of the U.G. measured at 75% of maximum discharge ordinate (Q_p) in hours.
W_{R50}	:	Width of the rising side of U.G. measured at 50% of maximum discharge ordinate (Q_p) in hours.
W_{R75}	:	Width of the rising side of U.G. measured at 75% of maximum discharge ordinate (Q_p) in hours.
Q_{50}	:	Maximum flood peak with a return period of 50 years in cumecs.
ARF	:	Areal reduction factor
%	:	Percent
Σ	:	Summation.

ABBREVIATIONS

Cumecs	:	Cubic metres per second
Cms	:	Centimetres
Hr.	:	Hour
M.	:	Metres
Min.	:	Minutes
Km.	:	Kilometres
Sq.Km.	:	Square Kilometres, Km^2
In.	:	Inches
Sec.	:	Seconds
Sq.	:	Square
R.D.S.O.	:	Research Designs and Standards Organisation (Ministry of Railways), Lucknow.
H(SC), CWC	:	Hydrology (Small Catchments) Directorate, Central Water Commission, New Delhi.
I.M.D.	:	India Meteorological Department
C.W.C.	:	Central Water Commission
M.O.S.T.	:	Ministry of Shipping & Transport, New Delhi.

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INTRODUCTION

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

The report consists of six sections preceded by the "APPLICATION OF THE REPORT" with (A) detailed and (B) simplified approaches.

The detailed apporach explains the various steps involved to estimate the design flood peak and hydrograph in accordance with the methodology contained in the report along with an illustrative example.

THE SIMPLIFIED APPROACH CONSISTS OF A SIMPLE DIRECT 50-YR. FLOOD FORMULA ALONGWITH AN ILLUSTRATIVE EXAMPLE FOR THE CONVENIENCE OF FIELD ENGINEERS TO ESTIMATE THE DESIGN FLOOD PEAK.

Section - 1 briefly narrates the river system, topographical features, monsoon rainfall and temperature pattern, types of soil, land use, railways and road communications in the subzone. The size of the subzone is 1,71,350 sq.km. covering eastern half of Uttar Pradesh and northern parts of Bihar.

Section - 2 comprises of the nature of data collected for 45 representative catchments in the subzone. Northern, North-Eastern Railways and Central Railways had collected the data of 41 catchments under the overall supervision of Research Designs and Standards Organisation (Railways). Central Water Commission has also collected the data of 4 catchments on behalf of Ministry of Transport.

Section - 3 deals with the analysis of storm rainfall and floods and derivation of 6-hour unitgraphs (U.G.) for each of the 25 catchments found suitable out of 45 catchments to prepare their representative 6-hour U.G.'s. The parameters of the representative U.G.'s were measured. The physiographic parameters of the catchments were estimated. A simple modal ($Y = C X^P$) was adopted to establish relationship between dependent variable Y and independent variable X with constant 'C' and an exponent 'P'. The relationships were established with the simple model based on the sets of physiographic and U.G. parameters of 25 catchments. These relations are given in the form of equations and also on log-log graph which shall be utilised to estimate the parameters of synthetic U.G. for the ungauged catchments with their known physiographic parameters. Based on the synthetic U.G. parameters, a synthetic 6-hour U.G. is drawn. Besides, modal values of design loss rate and base flow have also been suggested.

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

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

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

The report herein recommends the estimation of design flood for small and medium catchments varying in size from 30 to 4,500 sq.km. As far as possible, the compatibility of the physiographic parameters of the ungauged with the gauged catchments used for the study may be kept in view.

APPLICATION OF REPORT

A. DETAILED APPROACH

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

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

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

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

iii) Determination of 6-hour synthetic unitgraph parameters i.e. peak discharge per sq.km. (q_p), the peak discharge (Q_p), the basin lag (t_p), the peak time of U.G. (T_m), widths of the unitgraphs at 50% and 75% of Q_p (W_{50} and W_{75}), widths of the rising limb of U.G. at 50% and 75% of Q_p (W_{R50} and W_{R75}) and time base of unitgraph (T_B)

iv) Drawing of a synthetic unitgraph.

v) Estimation of design storm duration (T_D).

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

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

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

ix) Estimation of base flow.

x) Computation of design flood peak.

xi) Computation of design flood hydrograph.

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

Illustrative Example

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

i)	subzone	1(f)
ii)	Name of site	Br. No. 152
iii)	Name of river/tributary	Dunda-Rhanraha
iv)	Shape of the catchment upto the point of study	Approx. rectangular
v)	Location	26°16'30" (Latitude) and 85°8'50" (Longitude)
vi)	Topography	Flat slope

The procedure is explained step by step.

Step - 1 Preparation of Catchment Area Plan

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

Step - 2 Determination of Physiographic Parameters

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

i) Area (A) = 299.53 sq.km.

ii) Length of the longest stream = 27.03 km.

iii) Equivalent stream slope (S) $= \sum L_i (D_{i-1} + D_i)/L^2$
$= 0.048$ m/km

where L_i = Length of ith segment in km.

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

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

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

iv) $L/\sqrt{S} = 27.03/\sqrt{0.048} = 123.37$

Step - 3 Determination of Synthetic Unitgraph Parameters

6-hour unit duration for the unitgraph i.e. unitgraph produced due to one cm. depth of rainfall excess in 6-hour duration has been considered.

The 6-hour Synthetic U.G. parameters may be found out by using one of the following approaches:

(I) By using the Synthetic Relations

(II) By using Coaxial Diagram.

(I) By using Synthetic Relations

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

Sl.No.1 Calculation of (q_p)

Substitute the value of $L/\sqrt{S} = 123.37$ as found out in (iv) of Step - 2 in equation 3.9.3 to obtain the value of q_p.

Sl.No.2 Calculation of (Q_p)

$Q_p = q_p \times A = 0.046 \times 299.53 = 13.8$ cumecs

Sl. No. 3&4 Calculation of (t_p, T_m and T_D)

Substitute the value of q_p in equation given in col.(4) of Table A-2 to obtain the corresponding value of t_p. The calculated value of t_p is rounded off to the nearest 1-hour. Table A-3 shows the range of values of calculated t_p (rounded off to nearest 1-hour) and the corresponding values of t_p, T_m (peaking time) and T_D (design storm duration) to be adopted for ready reference of the users.

The calculated value of t_p in Sl.No.3 is 29.4 hours which is rounded off to 29.0 hours. t_p of 29 hours falls in the range of t_p from 24 to 29 hours and the corresponding values to be adopted for t_p, T_m and T_D are 27, 30 and 24 hours respectively as seen from Sl.No. 5 of Table A-3

t_p = 27 hrs., T_m = 30 hrs. and T_D = 24 hrs.

Sl.No. 5,6, 7&8 Calculation of W_{50}, W_{75}, W_{R50} and W_{R75}

Substitute the value of q_p in respective equations in col.(4) of Table A-2 to obtain the corresponding parameters of W_{50}, W_{75}, W_{R50} and W_{R75} in col.(5).

Sl.No. 9 Calculation of (T_B)

Substitute the adopted value of t_p in equation given in col.(4) of Table A-2 to obtain T_B, the value of which may be rounded off to nearest mult'ple of 6-hour as shown in col.(6) of Table A-2.

(II) By usi g Coaxial Diagram

Coaxial diagram based on Synthetic Relations vide equations 3.9.3 to 3.9.9 under Section-3 has been drawn in Fig.A-2 for esti-mating the parameters of Synthetic Unitgraph. The application of Coaxial Diagram in Fig. A-2 with respect to the above illus-trative example is expalined as under:

i) Calculate $L/\sqrt{S}$ for L = 27.03 and S = 0.048

$L/\sqrt{S}$ = $27.03/\sqrt{0.048}$ = 123.37

ii) Find out q_p corresponding to $L/\sqrt{S}$ = 123.37 from curve No. 1 as shown by the dotted lines. The value of q_p = 0.046 cumecs/sq.km. is read from the curve No.1.

iii) Find out t_p corresponding to q_p = 0.046 from curve No. 2 as shown by dotted lines. The value of t_p = 29.5 hrs is read from curve No.2 which may be rounded off to 29.0 hrs.

iv) For arriving at adopted values of t_p, T_m and T_D, refer to Table A-3.

t_p of 29.0 hrs. as estimated in (iii) above falls in the range of 24 to 29 hours in Sl.No.5 of Table A-3 for which the corresponding adopted values are t_p = 27.0 hrs., T_m = 30.0 hrs. and T_D = 24.0 hrs.

v) Find out the values of W_{50}, W_{75}, W_{R50}, and W_{R75} from respective curve Nos. 3, 4, 5 and 6 corresponding to q_p = 0.046 as shown by dotted lines. The values so read from the respective curves are as under:

W_{50} = 52.2 hrs., W_{75} = 27.3 hrs., W_{R50} = 12.8 hrs., W_{R75} = 7.7 hrs.

vi) Find out the values of T_B corresponding to adopted values of t_p = 27.0 hrs. in (iv) above from Curve No. 7 as shown by dotted lines. The value of T_B for t_p = 27.0 hrs. read from Curve No. 7 is 138.0 hours.

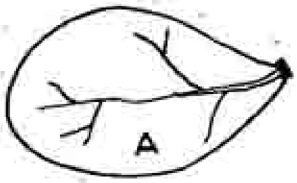
Thus all the parameters of 6-hour Synthetic U.G. have been estimated.

Step - 4 Preparation of 6-hour Synthetic Unitgraph

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

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

$$= \underset{(sq.m.)}{\left[A \times 1000 \times 1000 \right]} \times \underset{(m)}{\left[d/100 \right]} = (\qquad)$$ expressed in cubic-metres.



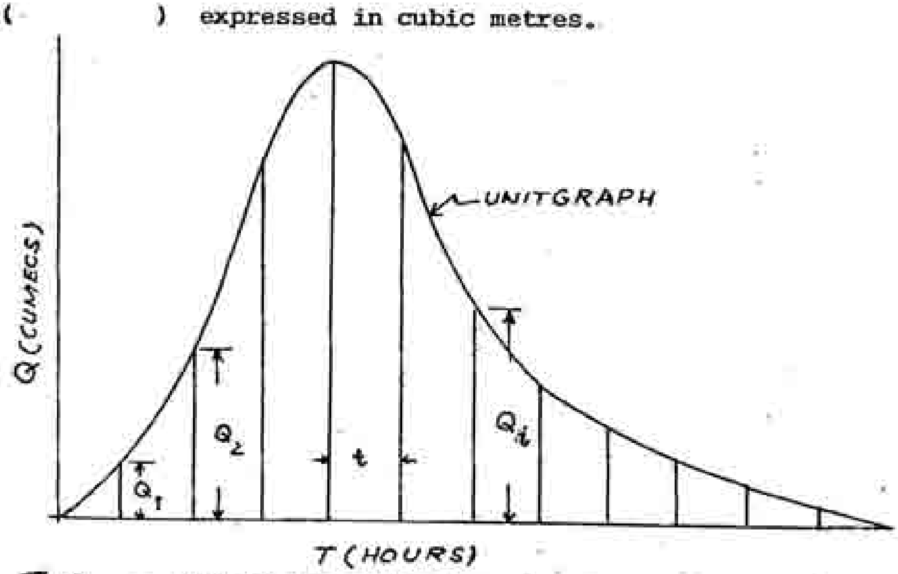
1 cm = 1/100 m depth of direct runoff over the catchment area (A) in sq.km.

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

$= \sum Q_i \quad \times \quad t_r \quad \times \quad 3600$ seconds

Cubicmetre per sec.

= (   ) expressed in cubic metres.



$\sum Q_i$ = sum of the ordinates of unitgraph at t-hr. interval (in this case 6-hr.)

(a) should be equal to (b)

i.e. $A \times 1000 \times 1000 \times d/100 = \sum Q_1 \times t_r \times 3600$

Therefore $\sum Q_i = A/(0.36\ t_r)$

$t_r = 6$ in this case

Therefore $\sum Q_i = A/(0.36 \times 6) = A/2.16$

All the ordinates of Synthetic U.G. so obtained in Fig.A-3 were summed up at 6-hr. interval to get a total volume of 138.7 cumecs which tallied with the computed value from $A/(0.36\ t_r) = 299.53/(0.36 \times 6) = 138.7$ cumecs. Therefore, the 6-hour Synthetic U.G. so drawn in Fig. A-3 was found to be in order.

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

Step - 5 Estimation of Design Storm Duration

The design storm duration is

$T_D = 1.1 \times t_p = 1.1 \times 27 = 29.7$ hrs.

T_D is limited to 24 hrs. (due to infrequent occurrence of longer storm duration).

However, in general, T_D may be adopted as per guidance given in Table A-3.

Step - 6 Estimation of Point Rainfall and Areal Rainfall

For this catchment the point rainfall estimates of 50-year return period for duration of 24-hour are first read from isopluvial map (Plate-8) in Section 4.2. The value of 50-yr. 24-hr. point rainfall = 34.0 cm since the design storm duration (T_D) for the catchment is 24 hours.

The above point rainfall estimates of 34.00 cm was multiplied by areal reduction factor of 0.91 corresponding to a catchment area of 299.53 sq.km. and 24 hours duration given in Table A-4 to obtain areal rainfall of 34 x 0.91 = 31.00 cm.

For estimation of point rainfall corresponding to the design storm duration (T_D) of the catchment less than 24 hours, the 50-year T_D- hour point rainfall to 50-year 24-hour rainfall ratios given in Table under Section 4.2 may be applied to 50-year 24-hour point rainfall of the catchment.

Step - 7 Time Distribution of Areal Rainfall

50-yr. areal rainfall depth (R) = 31.0 cm for design storm duration (T_D) = 24 hrs. from Step-6 is critically distributed at 6-hr. intervals (since the unit duration of SUG is 6 hours) by using the curve (e) for duration of 19-24 hours in Fig. 12 or Table A-5 as shown in the following Table which is self-explanatory:

Duration hrs.	% of storm duration Col.(1)x100 / 24	Cumulative % of rainfall for col.(2) read from curve (e) of Fig. 12	Distribution Coefficients of rainfall read from Table A-5.	Cumulative rainfall col.(3)x R/100 or col.(4) xR (cm)	6-hr. gross rainfall incre-ments (cm)
1	2	3	4	5	6
0	0	0	0	0	0
6	25	70	0.7	21.70	21.70
12	50	84	0.84	26.04	4.34
18	75	93	0.93	28.83	2.79
24	100	100	1.00	31.00	2.17
				Total	31.00

Step - 8 Estimation of Rainfall Excess Units

Col.5 of the Table in Step-7 gives the 6-hourly gross rainfall units. A design value of loss rate of 0.3 cm/hr. as recommended in Section 3.11 is subtracted from each of the rainfall units to get the rainfall excess units. For 6-hours, the loss rate to be subtracted is = 6 x 0.3 = 1.8 cm.

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

Hr.	Gross rainfall col.(5) of Step-7	Loss/6-hr. cm	Rainfall excess cm. col.(2) - col.(3)
1	2	3	4
0	0	-	-
6	21.70	1.80	19.90
12	4.34	1.80	2.54
18	2.79	1.80	0.99
24	2.17	1.80	0.37

Step - 9 Estimation of Base Flow

It has been shown in Section 3.12 that the modal value of base flow for Middle Ganga Plains subzone - 1(f) is 0.05 cumec/sq.km.

The total base flow for the catchment of 299.53 sq.km in question = 0.05 x 299.53 = 14.98 cumecs.

Step - 10 Estimation of Design Flood (Peak only)

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

In the present case, the maximum peak discharge ordinate of U.G. was occurring at 30th hour. The maximum 6-hourly rainfall excess unit was placed against the peak discharge of U.G. likewise, the next lower rainfall excess unit was placed against the next lower U.G. ordinate in the following table and so on. Summation of products of cols.(2) and (3) gives the total direct runoff to which base flow is added to get the total peak discharge:

Time hrs.	U.G. Ordinate cumecs	6-hr. rainfall excess cm	Direct ruroff cume s
(1)	(2)	(3)	(4) = ( )x(3)
24	11.8	0.37	4.37
30	13.8	19.90	274.62
36	13.0	2.54	33.02
42	11.9	0.99	11.78
		Total	323.79
		Add Base Flow from Step - 9	14.98
		Total Peak Discharge = (50-Yr. Flood Peak)	338.77 cumecs

Step - 11 Computation of Design Flood Hydrograph

The 6-hour rainfall excess sequence shown in col.(3) of Table in Step-10 was reversed to obtain the critical sequence for obtaining the maximum peak of the design flood hydrograph as shown below:

Time hrs.	Critical 6-hr. rainfall excess sequence
(1)	(2)
6	0.99
12	2.54
18	19.90
24	0.37

For computation of design flood hydrograph, the U.G. ordinates for 6-hour interval were tabulated in col.(2) of Table A-4 against time (hrs.) in col.(1). The critical sequence of rainfall excess units as given above were entered in cols.(3) to (6) horizontally as shown in Table - A.4. The direct runoff resulting from each of the rainfall excess units was obtained by multiplying the rainfall excess unit with the U.G. ordinates in col.(2) and the direct runoff values were entered in vertical columns against each units with a successive lag of 6-hours, since the unit duration of U.G. was 6-hours. The direct runoff so obtain is shown in cols. (3) to (6). The direct runoff were added horizontally and the total direct runoff is shown in col.(7). The total base flow of 14.98 cumecs was entered in col.(8). Col.(9) gives the addition of cols.(7) and (8) to get the design flood hydrograph ordinate.

The design flood hydrograph so obtained gives the same value of maximum peak discharge of 338.77 cumecs as computed in Step-10.

The total discharge ordinate in col.(9) were plotted against time in col.(1) to get the design flood hydrograph in Fig. A-4.

B. SIMPLIFIED APPROACH

B.I Direct 50-Year Flood Peak Formula

For the field engineers interested in the 50-year flood peak only for preliminary assessment of waterway of bridges and cross drainage structures, a direct 50-year flood peak formula, an easy and simple one, has been evolved based on the studies contained in this report. The basic equation for computation of 50-year flood peak can be expressed as follows:

$$Q_{50} = C \times q_p \times A \times R \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where Q_{50} = 50-year flood peak (cumecs)

q_p = peak discharge of unitgraph per unit area of catchment (cumec/sq.km.)

A = catchment area (sq.km.)

R = 50-year point rainfall (cm) for design storm duration (T_D).

C = a constant factor

In the above equation (1), the equation relating q_p with the physiographic parameters like L and S i.e. $q_p = 0.409/(L/\sqrt{S})^{0.456}$ was substituted to get the following derived equation.

$$Q_{50} = 0.409\ C\ A\ R\ (\sqrt{S}/L)^{0.456} \quad \ldots\ldots\ldots(2)$$

where Q_{50}, A and R are same as in equation (1)

L = Length of longest main stream (km)

S = equivalent slope (m/km) of the main stream

K = represents the effects of point to areal reduction factor, temporal distribution of rainfall, design loss rate and base flow depending on the size of the catchment.

= 0.409xC

The 50-year storm point rainfall R(cm) pertaining to design storm duration $(T_D) = 1.1 \times t_p$ where $t_p = 3.065\ (L/\sqrt{S})^{0.471}$ Therefore $T_D = 3.37\ (L/\sqrt{S})^{0.471}$.

However, the values of T_D (hrs.) to be adopted corresponding to the calculated values of t_p rounded off to nearest one hour falling in the various ranges of t_p are suggested as under:

t_p range (hrs.)	T_D (hrs.)
3 to 5	6
6 to 11	12
12 to 17	18
18 to 75	24

The 50-year flood peaks (Q_{50}) were computed for all the 25 railway bridge catchments listed in Table - 2 of the report using the methodology contained therein. Individual values of K were estimated for each of the 25 catchments by substituting their values of Q_{50}, A, R, S and L in equation (2). The values of K and the corresponding values of catchment areas (A) were plotted on a graph paper and an average curve was drawn through the plotted points. These curves are shown in Figures B-1(a) and 1(b). The maximum variations in the 50-year flood peak by both the methods viz. by formula and by detailed studies were found to be ± 7%.

2. Application of Flood Formula

The 50-year flood formula applicable to subzone - 1(f) is as under:

$$Q_{50} = K\ A\ R\ (\sqrt{S}/L)^{0.456} \quad \ldots\ldots\ldots\ldots(2)$$

The following steps are followed to compute the 50-year flood peak from the above formula for an ungauged or inadequately gauged catchment.

Step (1) : The catchment boundary upto the point of study (proposed cross drainage structure site) on a stream is marked on the Survey of India toposheets. The catchment area (A) in sq.km. and the length of the longest stream (L) in km is measured. The equivalent slope (S) in m/km of the main stream is computed as shown in Table - A.1 of the "APPLICATION". Prepare the catchment plan showing the catchment boundary and river system for record.

Step (2) : t_p for the catchment is calculated with the equation $t_p = 3.065\ (L/\sqrt{S})^{0.471}$ which is rounded off to the nearest one hour.

Step (3) : Select the design storm duration (T_D) from the following table corresponding to 't_p' value falling in a particular range.

t_p range (hrs.)	T_D (hrs.)
3 to 5	6
6 to 11	12
12 to 17	18
18 to 72	24

Step (4) : The point rainfall is obtained for the bridge site location marked on 50-year 24-hour isopluvial map (plate - 8).

Step (5) : Obtain the point rainfall (R) in cm for the design storm duration (T_D) by multiplying with the ratio of T_D to 24 hour rainfall graph (Fig.10 vide Section 4.2) to the 50-year 24-hour rainfall calculated in Step (4).

Step (6) : Obtain the value of K for the catchment area (A) in Step (1) from the graph (Fig.B-1) of K vs catchment area (A).

Step (7) : List out the values of A, L and S from Step (1) R from Step (5) and K from Step (6).

Step (8) : Substitute the listed values of A, L, S, R and K in the following 50-year flood peak formula in equation (2) to obtain 50-year flood peak (cumec).

$$Q_{50} = K\,A\,R\,(\sqrt{S}/L)^{0.456}$$

3. Solution Of The Problem

The particulars of railway bridge catchment (treated as ungauged) for illustrating the procedure for application of 50-year flood peak formula stepwise are as under:

Details of catchment location

Subzone	1(f)
Name of site (point of study)	Rly. Br. No. 152
Name of river/tributary	Dunda - Rhanraha
Br. site location	26° 16' 30" (N) Latitude
	85° 8' 50" (E) Longitude

Step (1): The boundaries of the catchment under study after locating the bridge site on the tributary from the given latitude and longitude on the Survey of India toposheet or from any map of the area already prepared from the toposheet were marked. Catchment area plan upto Rly. Br. No. 152 (Fig.A-1) was prepared. The catchment area (A) in sq.km. and length (L) in km. of the longest main stream upto the point of study were measured. Equivalent stream slope (S) in m/km was calculated as shown in Step - 2 and Table A-1 - under A- "APPLICATION". The values of A,L and S so obtained are as under:

A = 299.53 sq.km., L = 27.03 km and S = 0.048 m/km

Step (2) : Time lag (t_p) was calculated with the following formula by substituting the values of L and S from Step (1).

$$t_p = 3.065 \left(L/\sqrt{S}\right)^{0.471}$$

$$= 3.065 \left(27.03/\sqrt{0.048}\right)^{0.471} = 29.4 \text{ hrs. say } 29.0 \text{ hrs.}$$

Alternatively t_p value of 29.5 hrs. say 29.0 hrs. was read from Curve No. 1 showing $L/\sqrt{S}$ s t_p in the coaxial diagram (Fig. A-2) for the value of $L/\sqrt{S} = 27.03/\sqrt{0.048} = 123.425$

Step (3) : Design storm duration (T_D) 24-hours was found out from the Table in Step (3) (B-2) corresponding to t_p of 27 hours falling in t_p range of 18 to 72 hours.

Step (4) & (5) : The point rainfall (R) = 34.0 cm was obtained for the bridge location (latitude 26°16' 30" (N) and 85°8'50" (E) on the 50-year, 24-hour isopluvial map (plate - 8).

Note: Step (4) and (5) of B.2 may have to be followed for design storm duration (T_D) less than 24 hours.

Step (6) : The value of K = 0.278 was read from the curve of K vs A in Fig. B-1 corresponding to catchment area of 299.53 sq.km.

Step (7) : The values of A, L, S from Step (1), R from Steps (4) and (5) and K from Step (6) were listed as under:

A = 299.53 sq.km., L= 27.03 km., S = 0.048 m/km

R = 34.0 cm and K = 0.278

Step (8) : The values of A, L, S, R and K in Step (7) were substituted in the following 50-year flood peak formula:

$$Q_{50} = K\,A\,R \left(\sqrt{S}/L\right)^{0.456}$$

$$= 0.278 \times 299.53 \times 34 \left(\sqrt{0.048}/27.03\right)^{0.456}$$

$$= 315.71 \text{ cumecs say } 316 \text{ cumecs}$$

Q_{50} of 316.0 cumec may be adopted for preliminary designs since this value is less by 6.87% only as compared to Q_{50} = 339.0 cumecs based on detailed studies.

TABLE A-1

COMPUTATION OF EQUIVALENT SLOPE(S)

Sl. No.	Reduced distance starting from gauging site (Kms)	Reduced levels of River bed (m)	Length of each segment Li (Km)	Height above datum* (D_i) difference between the datum & the ith R.L. (m)	$(D_{i-1}+D_i)$ (m)	Li $(D_{i-1}+D_i)$ (4) x(6) (mxKm)
1	2	3	4	5	6	7
1.	0	55.79	0	0	0	0
2.	10.79	56.40	10.79	0.61	0.61	6.58
3.	20.77	56.65	9.98	0.86	1.47	14.67
4.	22.38	56.71	1.61	0.92	1.78	2.87
5.	27.05	57.32	4.67	1.53	2.45	11.44

$$\sum Li(D_{i-1}+D_i) = 35.56$$

$$S = \frac{\sum Li\ (D_{i-1}+D_i)}{L^2} = \frac{35.56}{731.70} = 0.048 \text{ m/km.}$$

* Datum = 55.79 m (i.e. reduced level of river bed at the point of study).

TABLE A-2

COMPUTATION OF 6-HOUR SYNTHETIC UNITGRAPH PARAMETERS

Sl. No.	Evaluated Parameters	Unknown Parameters	Synthetic Relationship	Calculated value	Remarks
1	2	3	4	5	6
1.	$L/\sqrt{S} = 123.37$	q_p (Cumec/ Sq.Km.)	$q_p = 0.409/(L/\sqrt{S})^{0.456}$ (See equation 3.9.3)	0.046	
2.	q_p	Q_p (Cumecs)	$Q_p = q_p \times A$	13.8	
3.	q_p	t_p (Hours)	$t_p = 1.217/(q_p)^{1.034}$ (See equation 3.9.4) $= 3.065(L/\sqrt{S})^{0.471}$	29.4	adopted 27.0 (See Sl.No.5 of Table A-3) (By substituting the value of q_p from Sl. No.1)
4.	t_p	T_m (Hours)	$T_m = t_p + (tr/2)$	30.0	
5.	q_p	W_{50} (Hours)	$W_{50} = 1.743/(q_p)^{1.104}$ (See equation 3.9.5)	52.2	
6.	q_p	W_{75} (Hours)	$W_{75} = 0.902/(q_p)^{1.108}$ (See equation 3.9.6)	27.3	
7.	q_p	W_{R50} (Hours)	$W_{R50} = 0.736/(q_p)^{0.928}$ (See equation 3.9.7)	12.8	
8.	q_p	W_{R75} (Hours)	$W_{R75} = 0.478/(q_p)^{0.902}$ (See equation 3.9.8)	7.7	
9.	t_p	TB (Hours)	$TB = 16.432 \times (t_p)^{0.646}$ (See equation 3.9.9)	138.2	Adopted 138.0

TABLE A-3

ADOPTED VALUES OF t_p, T_m AND T_D

Sl. No.	Range of t_p (Hrs) (t_p calculated vide equation 3.9.4 and rounded off to nearest one hr)	Adopted values (Hrs)		
		t_p	T_m	T_D
1	2	3	4	5
1.	3 to 5	3	6	6
2.	6 to 11	9	12	12
3.	12 to 17	15	18	18
4.	18 to 23	21	24	24
5.	24 to 29	27	30	24
6.	30 to 35	33	36	24
7.	36 to 41	39	42	24
8.	42 to 47	45	48	24
9.	48 to 53	51	54	24
10.	54 to 59	57	60	24
11.	60 to 65	63	66	24
12.	66 to 71	69	72	24

NB:- The value of T_D is limited to 24 hrs.

TABLE A - 4

AREAL REDUCTION FACTORS

Area (SQ.Km.)	6-hr.	12-hr.	18-hr	24-hr
50	0.95	0.96	0.96	0.97
100	0.90	0.94	0.95	0.96
150	0.87	0.92	0.94	0.95
200	0.84	0.90	0.92	0.93
250	0.82	0.88	0.90	0.92
300	0.80	0.87	0.89	0.91
350	0.78	0.86	0.88	0.9
400	0.77	0.85	0.87	0.89
450	0.76	0.84	0.86	0.88
500	0.76	0.83	0.85	0.87
600	-	0.81	0.83	0.86
700	-	0.79	0.81	0.84
800	-	0.78	0.80	0.83
900	-	0.77	0.79	0.82
1000	-	0.76	0.78	0.81
1200	-	0.74	0.76	0.79
1400	-	-	0.74	0.78
1600	-	-	0.74	0.77
1800	-	-	0.73	0.76
2000	-	-	0.73	0.75
2200	-	-	0.72	0.75
2400	-	-	0.72	0.74
4500	-	-	-	0.74

TABLE A - 5

Time Distribution Coefficients of Areal Rainall

Duration (hrs)	DESIGN STORM DURATIONS (hrs)			
	6	12	18	24
	DISTRIBUTION COEFFICIENTS			
24				1.00
18			1.00	0.93
12		1.00	0.90	0.84
6	1.00	0.84	0.74	0.70

TABLE - A - 6

COMPUTATION OF DESIGN FLOOD HYDROGRAPH

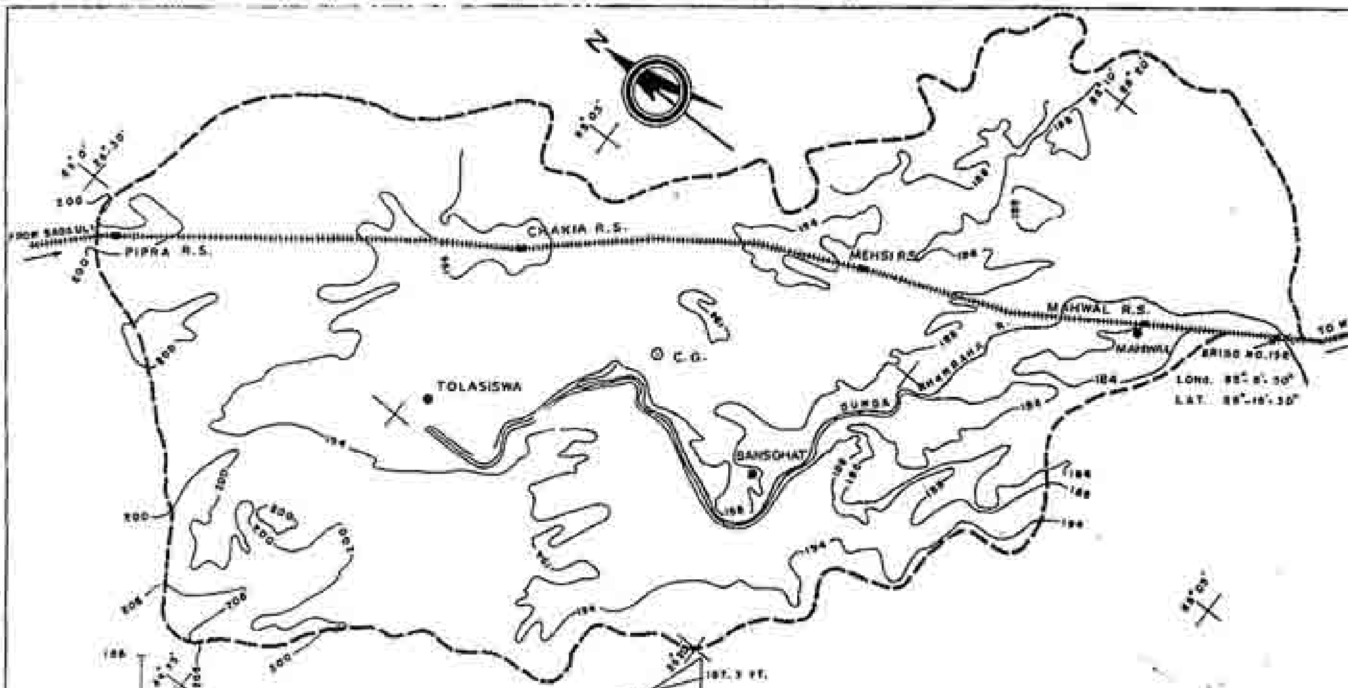
AT RLY. BR. NO. 152. SUBZONE - 1(f)

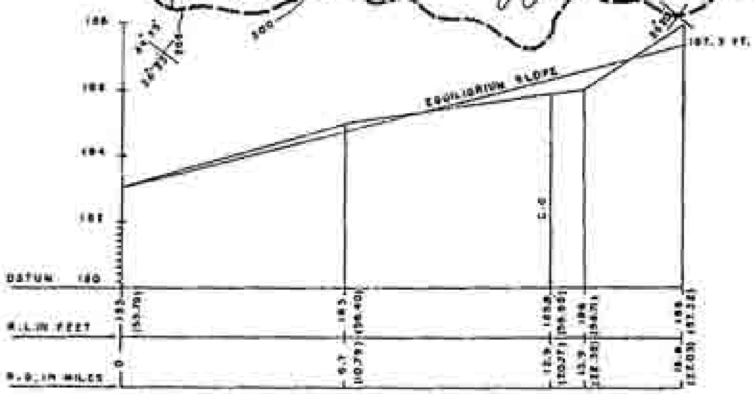
Time Hrs.	S.U.H ordinates (Cumecs)	6-hr Rainfall excess units (cm) 0.99 DIRECT RUNOFF (CUMECS)	2.54	19.90	0.37	Total DRH (Cumecs)	Base flow (Cumecs)	Flood flow (Cumecs)
1	2	3	4	5	6	7	8	9
0	0	0				0	14.98	14.98
6	2.1	2.08	0			2.08	"	17.06
12	4.4	4.36	5.33	0		9.69	"	24.67
18	7.4	7.33	11.18	41.79	0	60.30	"	75.28
24	11.8	11.68	18.80	87.56	0.78	118.82	"	133.80
30	13.8	13.66	29.97	147.26	1.63	192.52	"	207.50
36	13.0	12.87	35.05	234.82	2.74	285.48	"	300.46
42	11.9	11.78	33.02	274.62	4.37	323.79	"	338.77 Peak
48	10.8	10.69	30.23	258.70	5.11	304.73	"	319.71
54	9.7	9.60	27.43	236.81	4.81	278.65	"	293.63
60	8.7	8.61	24.64	214.92	4.40	252.57	"	267.55
66	7.6	7.52	22.10	193.03	4.00	226.65	"	241.63
72	6.7	6.63	19.30	173.13	3.59	202.65	"	217.63
78	6.0	5.94	17.02	151.24	3.22	177.42	"	192.40
84	5.2	5.15	15.24	133.33	2.81	156.53	"	171.51
90	4.6	4.55	13.21	119.40	2.48	139.64	"	154.62

Contd. on page 20

1	2	3	4	5	6	7	8	9
96	4.0	3.96	11.68	103.48	2.22	121.34	14.98	136.32
102	3,3	3.27	10.16	91.54	1.92	106.89	"	121.87
108	2.7	2.67	8.38	79.60	1.70	92.35	"	107.33
114	2.1	2.08	6.86	65.67	1.48	76.09	"	91.07
120	1.5	1.48	5.33	53.73	1.22	61.76	"	76.74
126	1.0	0.99	3.81	41.79	1.00	47.59	"	62.57
132	0.4	0.40	2.54	29.85	0.78	33.57	"	48.55
138	0	0	1.02	19.90	0.56	21.48	"	36.46
144			0	7.96	0.37	8.33	"	23.31
150				0	0.15	0.15	"	15.13
156					0	0	"	14.98

FIG. NO. A-1





L - SECTION OF DUNDA - BHANRAHA RIVER

SCALE:- HOR. 1" = 2 MILES
VER. 1" = 2 FEET

NOTES:-

1 ALL LEVELS CORRESPOND TO G.T.S DATUM
2 H.F.L. AT GAUGE SITE 187.3 feet OR 57.10 metre.

REFERENCES

1 CATCHMENT BOUNDARY
2 RAILWAY LINE
3 RIVER
4 RAINGAUGE STATIONS
5 CONTOURS
6 CENTRE OF GRAVITY
7 TOPO SHEET NO. 72 B/15-F/3

DETAILS OF CATCHMENT

1 AREA OF THE CATCHMENT 299.33 Sqkm.
2 SHAPE OF CATCHMENT APPROX. RECTANGULAR
3 L ------------27.03 Kms.
4 Lc ------------20.77 Kms.
5 Wc ------------10.71 Kms.
6 S EQUILIBRIUM ------ 0.048 m / Km

SCALE 1 INCH = 1 MILE

SL.	NAME OF THE R.G. STATION	LAT.	LONG.	ST. WT. YEAR	WT.
1	TOLASISWA	26°-24'-50"	85°-0'-30"	63-66	0.46
2	BANSGHAT	26°-20'-50"	85°-2'-30"	63-66	0.28
3	MAHWAL	26°-18'-0"	85°-7'-30"	63-66	0.26

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

CATCHMENT AREA PLAN FOR BR. NO.152 ON MUZAFFAR PUR - SAGAULI SEC. N.E. RAILWAY

SUB ZONE - 1(f)

DRAWN BY T. R. ARORA | CHECKED BY C.L. BAJAJ

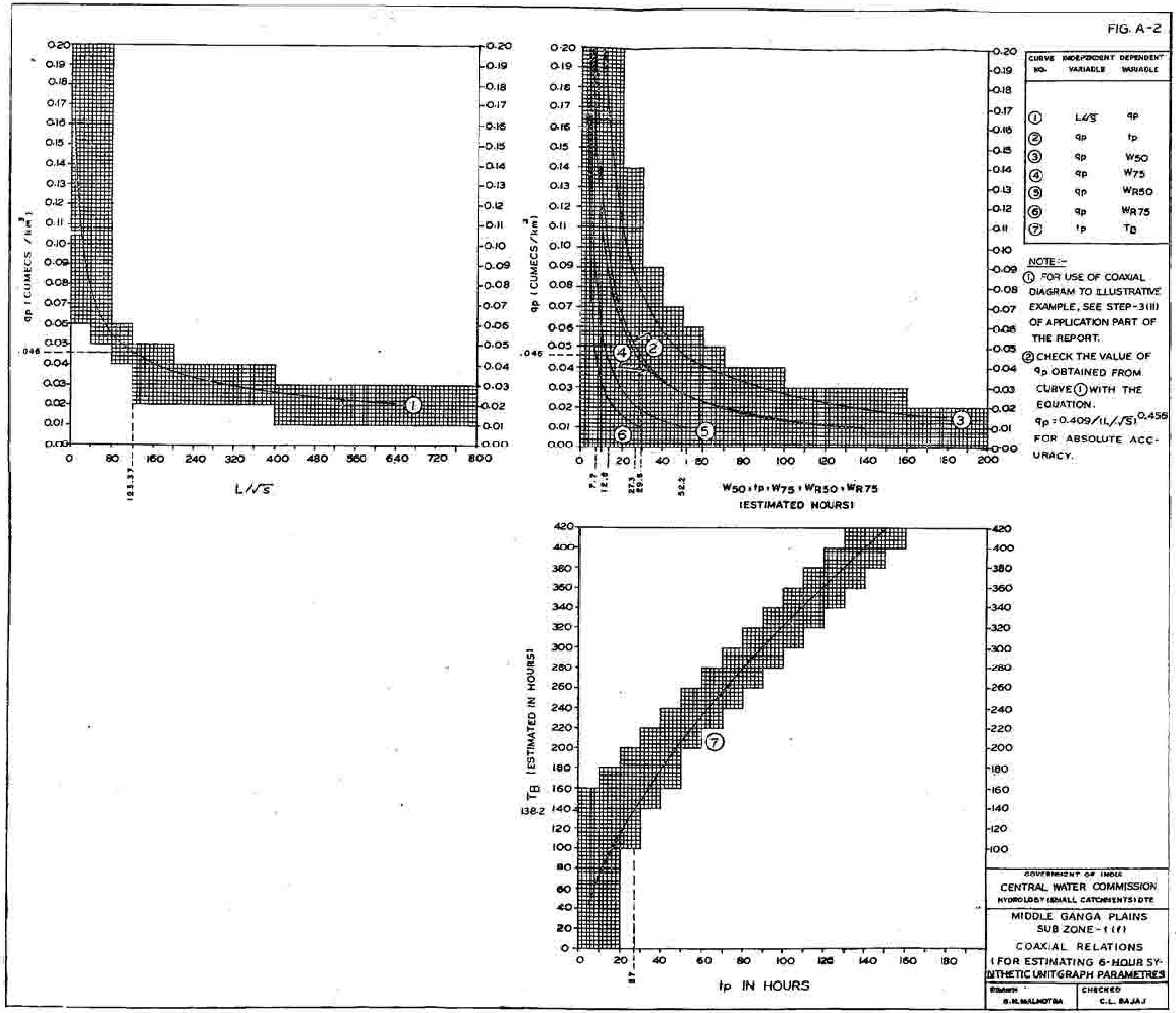
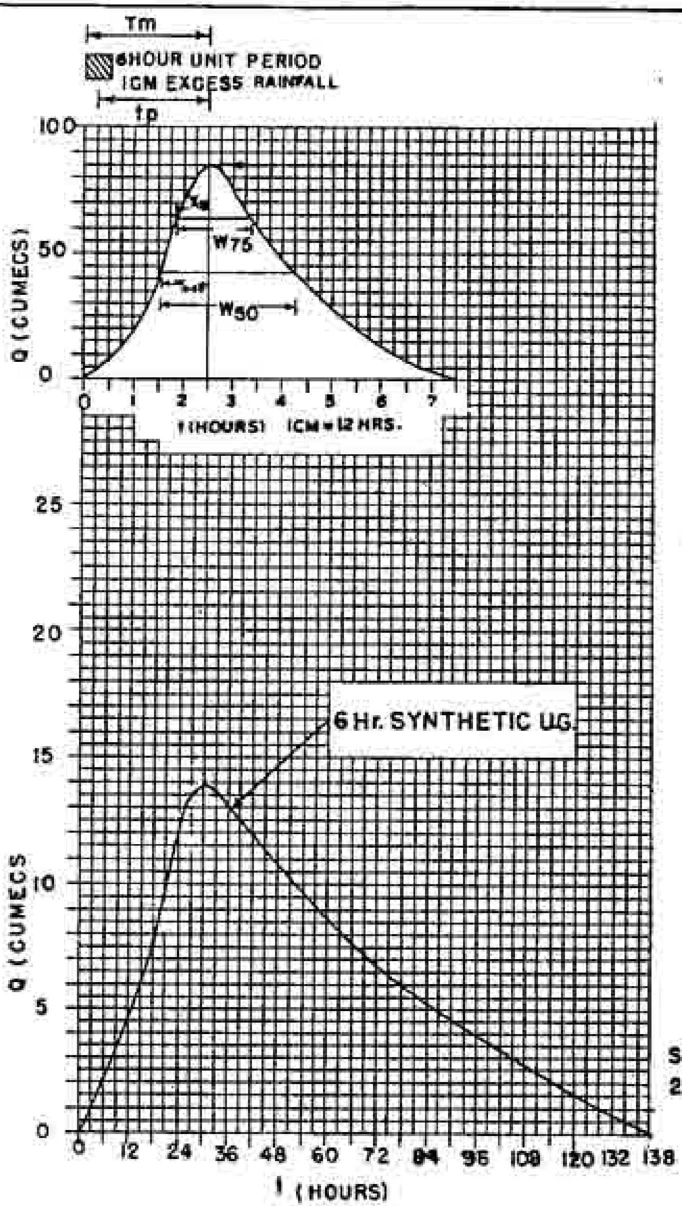


FIG. A-2
qp (CUMECS / km²)
L/√S
.046
123.37
W50 : tp : W75 : WR50 : WR75
(ESTIMATED HOURS)
7.7
12.8
27.3
29.6
52.2
TB (ESTIMATED IN HOURS)
138.2
27
tp IN HOURS
CURVE NO. | INDEPENDENT VARIABLE | DEPENDENT VARIABLE
① L/√S qp
② qp tp
③ qp W50
④ qp W75
⑤ qp WR50
⑥ qp WR75
⑦ tp TB
NOTE:-
① FOR USE OF COAXIAL DIAGRAM TO ILLUSTRATIVE EXAMPLE, SEE STEP-3(II) OF APPLICATION PART OF THE REPORT.
② CHECK THE VALUE OF qp OBTAINED FROM CURVE ① WITH THE EQUATION.
qp = 0.409/(L/√S)^0.456
FOR ABSOLUTE ACCURACY.
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE
MIDDLE GANGA PLAINS
SUB ZONE - 1 (f)
COAXIAL RELATIONS
(FOR ESTIMATING 6-HOUR SYNTHETIC UNITGRAPH PARAMETRES
DRAWN
S.K. MALHOTRA
CHECKED
C.L. BAJAJ

FIG. A-3



TIME IN HOURS	SYN.U.G. ORDIN.	TIME IN HOURS	SYN.U.G. ORDIN.
0	0	78	6.0
6	2.1	84	5.2
12	4.4	90	4.6
18	7.4	96	4.0
24	11.8	102	3.3
30	13.8	108	2.7
36	13.0	114	2.1
42	11.9	120	1.5
48	10.8	126	1.0
54	9.7	132	0.4
60	8.7	138	0
66	7.6	TOTAL =	138.7
72	6.7		

SUM OF 6 HR. U.G. ORDINATES = A/0.36X6 = 299.53/0.36 X 6 = 138.70 CUMECS.

SYNTHETIC U.G. PARAMETERS.

Sl.NO.	SYMBOL	SYN.U.G.
1	t_p	27.0 HOURS
2	T_M	30.0 HOURS
3	T_B	138.0 HOURS
4	W_{50}	52.2 HOURS
5	W_{75}	27.3 HOURS
6	W_{R50}	12.8 HOURS
7	W_{R75}	7.7 HOURS
8	Q_p	13.8 CUMECS.

GOVERNMENT OF INDIA
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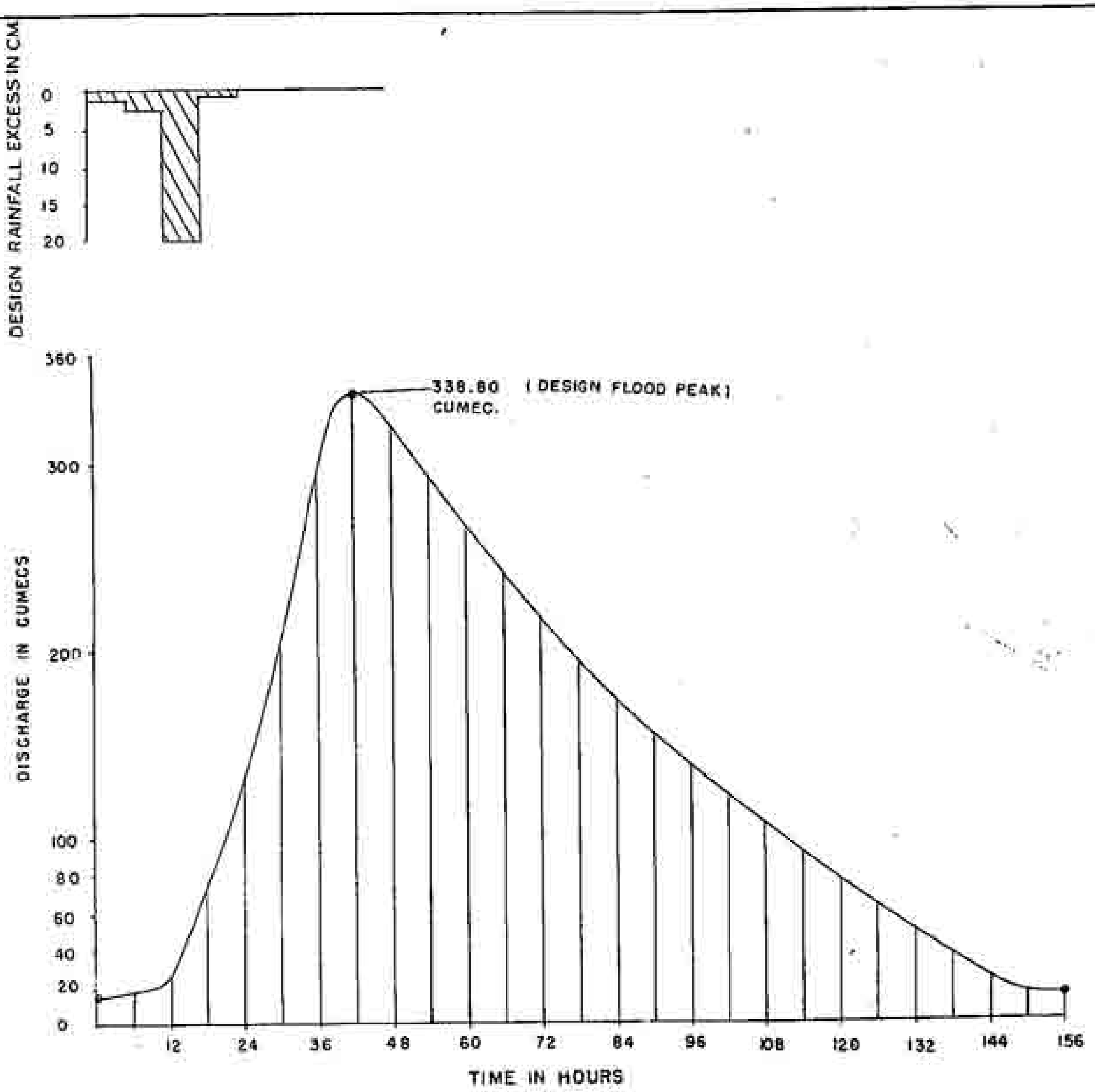
HYDROLOGY (SMALL CATCHMENTS) DTE.

MIDDLE GANGA PLAINS
SUB ZONE 1(f)
SYNTHETIC UNIT HYDROGRAPH
BRIDGE NO-152

DRAWN:	CKD:
S. N. MALHOTRA	C. L. BAJAJ.

FIG. A-4



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

MIDDLE GANGA PLAINS
SUB ZONE - 1 (f)
DESIGN FLOOD HYDROGRAPH.
BR. NO. 152, ON RIVER
DUNDA - RHANRAHA

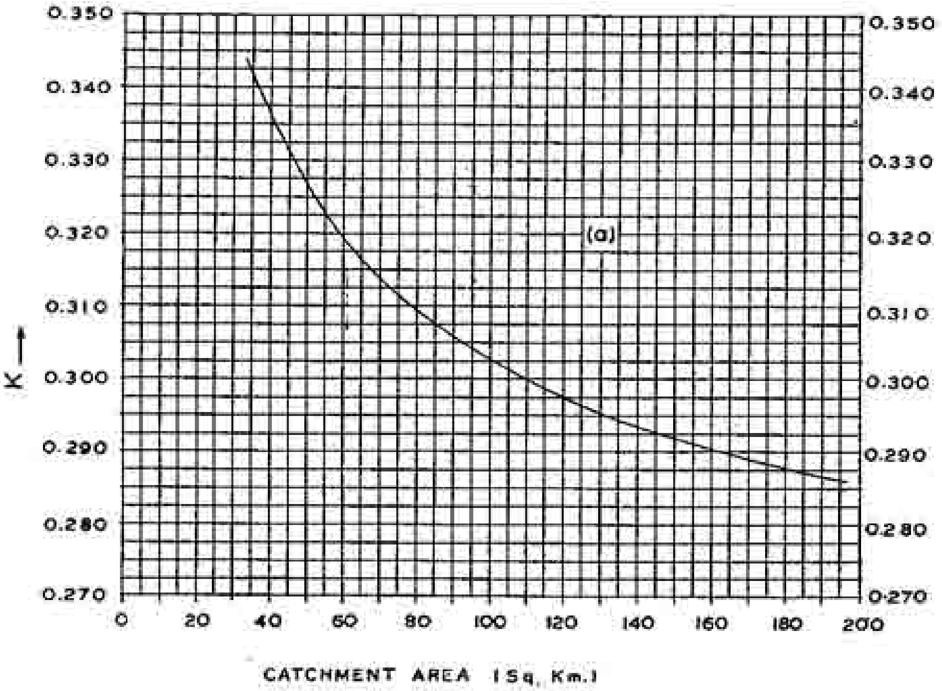
DRAWN.	CKD.
P.S. BHATIA	C.L. BAJAJ

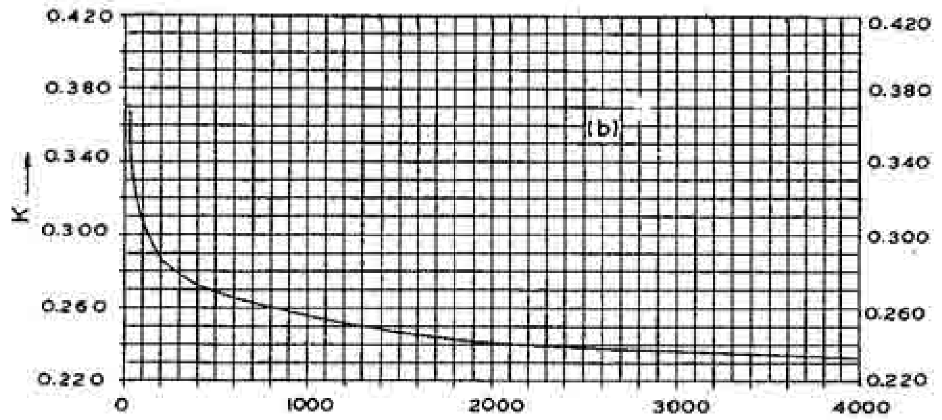
FIG. B-1

NOTE_

FOR AREAS FROM 25 TO 200 Sq.Km.

USE CURVE IN FIG. B-1(a).





CATCHMENT AREA (Sq. Km.)

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

MIDDLE GANGA PLAINS
SUB ZONE-1(f).

CATCHMENT AREA Vs K.VALUE CURVE.

DRAWN BY_	CHECKED BY_
S. N. MALHOTRA	A. K. GHOSH

1.0 GENERAL DESCRIPTION OF THE MIDDLE GANGA PLAINS SUBZONE-1(f)

1.1 Location

The subzone - 1(f) lies between longitude 80° to 89° East and latitude 24° to 29° North. It covers parts of Uttar Pradesh, Bihar and West Bengal. The Middle Ganga Plains is bounded on the North by Nepal, on the South by Chambal, Sone and Hoogly basins (subzones - 1(c), 1(d) and 1(g), on the East by Bangladesh and on the West by Upper Indo-Gangetic Plains (Subzone -1(e). Plate-1 shows the location of the subzone. The important cities in the subzone are Kanpur, Lucknow, Allahabad, Gorakhpur, Varanasi in U.P., Darbangha, Saharsa, Purnea and Katihar in Bihar and Siliguri and Malda in West Bengal.

1.2 River System

Plate-2 shows the river system of the subzone. The main rivers flowing in this subzone are Yamuna, Ganga, Ghagra, Gomti, Gandak, Kosi and Mahananda. The areas covered by each of these rivers is given below.

Sl.No.	River/Tributary	Drainage area (sq.km.)
1.	Yamuna	7530
2.	Ganga	14400
3.	Ghagra	35950
4.	Gomati	25270
5.	Gandak	26380
6.	Rapti	14160
7.	Kosi including Kamla	17900
8.	Mahananda	16830
9.	Others	12930
	Total:	171350

The total area of the subzone - 1(f) is 1,71,350 sq.km.

1.3 Topography and Relief

The Middle Ganga Plains subzone - 1(f) comprises mostly of plains and a small portion of the foothills of Tarai area in the North. The elevation in the Tarai area exceeds 150 m. In the plain area the elevation lies between 150 m and 75m and goes on decreasing Eastwards to Bangladesh. The rivers Yamuna and Ganga form the Southern boundary of the alluvial plains for major part of the subzone - 1(f). The subzone includes the lower courses of Ghagra, Gandak, Rapti, Kosi and Mahananda rivers.

The Middle Ganga Plains have thick alluvium. The low lying flood plains adjacent to river banks are formed of new alluvium sloping towards Southeast and Southwest.

The rivers in this subzone-1(f) have a meandering tendency with wide and shallow channels. Plate-3 depicts the physiography.

1.4 Rainfall

Plate-4 depicts the mean annual rainfall with the Histograms showing the mean monthly rainfall at Dehradun, Bareilly, Lucknow, Allahabad, Gorakhpur, Varanasi and Darbhangha. The mean annual rainfall varies between 800mm to 1200mm in the plains and goes upto 2000 mm in the portion of foothills in the North of the subzone. The major portion of rainfall is received between June/ July to September/October in the subzone due to Southwest monsoon.

1.5 Temperature

The climate of subzone 1(f) presents extremes of hot and cold due to its location. The temperature rises slowly till the end of March when the hot spell begins in April and continues for next three months. From the onset of monsoon in June/July, the temperature begins to fall as the hot winds receive moisture. Towards the Northwest in Tarai region, the mean annual temperature lies between 22.5^{o}Cto 25^{o}c For the rest of the subzone, the mean annual temperature lies between 25^{o} c to 27.5^{o}c. Plate-5 depicts the Bargraphs of temperature at Lucknow, Gorakhpur, Allahabad, Varanasi and Darbangha.

The minimum temperature is in January (15^{o} - 20^{o}c) with the fall of winter rains. The mean temperature during April is 25^{o} - 30^{o}c for the Northern portion of subzone and 30^{o} - 35^{o}c for the southern part of subzone. Plate-5 shows the isotherms of annual temperature.

1.6 Soils

As shown in Plate-6, major portion of the subzone has alluvial soils of recent origin excepting Tarai region and the plains on the North-Eastern side between Rapti and Kosi rivers where Tarai and Calcarious alluvium soils are encountered respectively.

1.7 Land Use

The plains of subzone -1(f) are fertile and cultivable. Most of the parts are also irrigated. Forests are seen in a part of Tarai portion of the subzone. Most of the land in the subzone is arable and well irrigated. Plate-7 depicts the land use.

1.8 Communications

1.8.1 Railways

The following railway sections partly or wholly traverse the area of this subzone.

1.	KATIHAR	-	SILIGURI	N.F. Railway
2.	GONDA	-	KATARIAGHAT	N.E. "

3.	GONDA	-	NANPARA	N.E. Railway
4.	GONDA	-	LUCKNOW	" "
5.	GONDA	-	GORAKHPUR	" "
6.	LUCKNOW	-	KANPUR	" "
7.	KANPUR	-	KASGANJ	" "
8.	MAU	-	AUNRIHAR	" "
9.	LUCKNOW	-	JAUNPUR	N.R.
10.	ALLAHABAD	-	RAIBAREILY	N.R.
11.	PRATAPGARH	-	VARANASI	N.R.
12.	SAMASTIPUR	-	DARBHANGA	N.E. "
13.	NARKATIAGANJ	-	SAMASTIPUR	" "
14.	GORAKHPUR	-	BHATNI	" "
15.	PURNEA	-	SAHARSA	" "
16.	JHANSI	-	KANPUR	C.R.
17.	BALAMAU	-	SITAPUR	N.R.
18.	LUCKNOW	-	BALAMAU	N.R.
19.	NARKATIAGANJ	-	BHIKINATHAURI	N.E. "
20.	GHAZIABAD	-	KANPUR	N.R.
21.	LUCKNOW	-	MAILANI	N.E. "
22.	BAREILLY	-	MAILANI	" "
23.	VARANASI	-	ALLAHABAD	" "

1.8.2 Highways

The following National Highways are partly or fully passing through the subzone

1. Grand Trunk Road - N.H.1.
2. Moradabad - Varanasi via Lucknow
3. Bareilly - Haldwani
4. Pilibhit - Shahjahanpur

LIST OF HYDRO-METEOROLOGICAL SUB ZONES

Sub-Zone	Name of subzone (designated earlier)	Name of subzone (designated now)	River basins included in the subzone.
1	2	3	4
1(a)	Luni basin & Thar (Luni & other rivers of Rajasthan & Kutch)	Luni	Luni river, Thar (Luni & other rivers of Rajasthan & Kutch and Banas river)
1(b)	Chambal basin	Chambal	Chambal river
1(c)	Betwa basin & other tributories	Betwa	Sind, Betwa and Ken rivers & other South tributories of Yamuna.
1(d)	Sone basin & right bank tributories	Sone	Sone and Tons river & other South Bank tributories of Ganga.
1(e)	Punjab plains including parts of Indus, Yamuna, Ganga and Ramganga basins	Upper Indo-Ganga Plains	Lower portion of Indus, Ghaggar Sahibi Yamuna, Ganga and Upper portion of Sirsa, Ramganga, Gomti and Sai rivers.
1(f)	Gangetic plains including Gomti, Ghagra, Gandak, Kosi and other	Middle Ganga Plains	Middle portion of Ganga, Lower portion of Gomti, Ghagra, Gandak, Kosi and middle portion of Mahanadi basin.
1(g)	Lower Gangetic Plains including Subernarekha & other east-flowing rivers between Ganga & Baitarani	Lower Ganga Plains	Lower portion of Ganga, Hoogli river system & Subernarekha.
2(a)	North Brahmaputra basin.	North Brahmaputra	North bank tributories of Brahmaputra river and Balason river.
2(b)	South Brahmaputra Basin	South Brahmaputra.	South bank tributories of Brahmaputra river.
2(c)	Barak and others	Barak	Barak, Kalden and Manipur rivers.
3(a)	Mahi, including the Dhadar, Sabarmati and rivers of Saurashtra	Mahi and Sabarmati	Mahi and Sabarmati including Rupen & Mechha Bhandar, Ozat Shetaranji rivers of Kathiawad Peninsula.

1	2	3	4
3(b)	Lower Narmada & Tapi basin	Lower Narmada & Tapi	Lower portion of Narmada, Tapi and Dhadhar rivers.
3(c)	Upper Narmada & Tapi basin	Upper Narmada & Tapi	Upper portion of Narmada & Tapi rivers
3(d)	Mahanadi basin including Brahmani and Baitarani rivers	Mahanadi	Mahanadi, Baitarani and Brahmani rivers
3(e)	Upper Godavari basin	Upper Godavari	Upper portion of Godavari basin
3(f)	Lower Godavari basin except coastal region	Lower Godavari	Lower portion of Godavari basin
3(g)	Indrawati basin	Indrawati	Indrawati river
3(h)	Krishna subzone including Pennar basin except coastal region	Krishna	Krishna & Pennar rivers except coastal region
3(i)	Kaveri & east flowing rivers except coastal region	Kaveri	Kaveri river(except coastal) region
4(a)	Circars including east flowing rivers between Mahanadi & Godavari	Upper Eastern Coast	East flowing coastal rivers between deltas of Mahanadi and Godavari rivers
4(b)	Coromandal coast including east flowing rivers between Godavari & Cauveri	Lower eastern coast	East flowing coastal rivers-Manimukta, South Pennar, Cheyyar, Palar, North Pennar, Munneru, Palleru, Cundalakama & Krishna Delta.
4(c)	Sandy Coroman belt (east flowing rivers between the Kaveri & Kanyakumari)	South Eastern coast	East flowing coastal rivers Manmuther, Vaigai, Arjuna, Tamra-Parni
5(a)	Konkan Coast (west flowing rivers between the Tapi & Panaji)	Konkan coast	West flowing coastal rivers between Tapi & Mahdavi rivers.
5(b)	Malabar coast (west flowing rivers between Kanyakumari & Panaji)	Malabar coast	West flowing coastal rivers between Mahdavi and Kanyakumari

1	2	3	4
6.	Andaman and Nicobar	Andaman & Nicobar	
7.	J&K Kumson Hills (Indus basin)	Western Himalayas	Jhelum, Upper portion of Indus, Ravi & Beas rivers

5. Lucknow - Kanpur
6. Lucknow - Gorakhpur via Faizabad
7. Kanpur - Varanasi
8. Varanasi - Gorakhpur via Gazipur
9. Lucknow - Varanasi
10. Varansi - Shiliguri via Muzaffarpur, Darbhanga and Purnea
11. Purnea - Katihar
12. Siliguri - Malda
13. Siliguri - Darjiling

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

NOTE:-

(1) RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER.

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

S.K. BHATIA
R.N. SHARMA

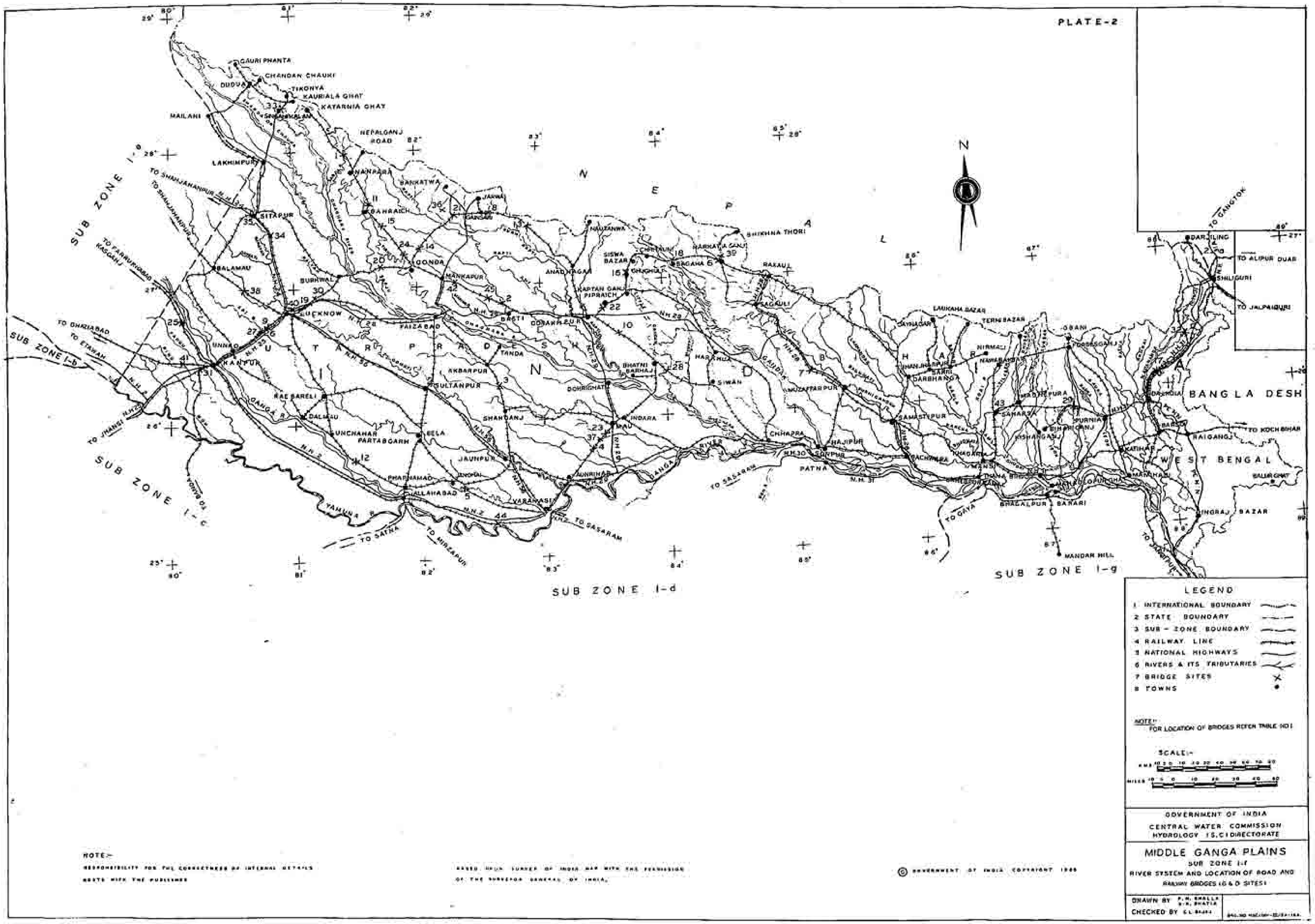


PLATE-2
LEGEND
1 INTERNATIONAL BOUNDARY
2 STATE BOUNDARY
3 SUB - ZONE BOUNDARY
4 RAILWAY LINE
5 NATIONAL HIGHWAYS
6 RIVERS & ITS TRIBUTARIES
7 BRIDGE SITES
8 TOWNS
NOTE:- FOR LOCATION OF BRIDGES REFER TABLE NO I
SCALE:-
KMS
MILES
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S.C) DIRECTORATE
MIDDLE GANGA PLAINS
SUB ZONE 1-f
RIVER SYSTEM AND LOCATION OF ROAD AND RAILWAY BRIDGES (G & D SITES)
DRAWN BY
CHECKED BY
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.
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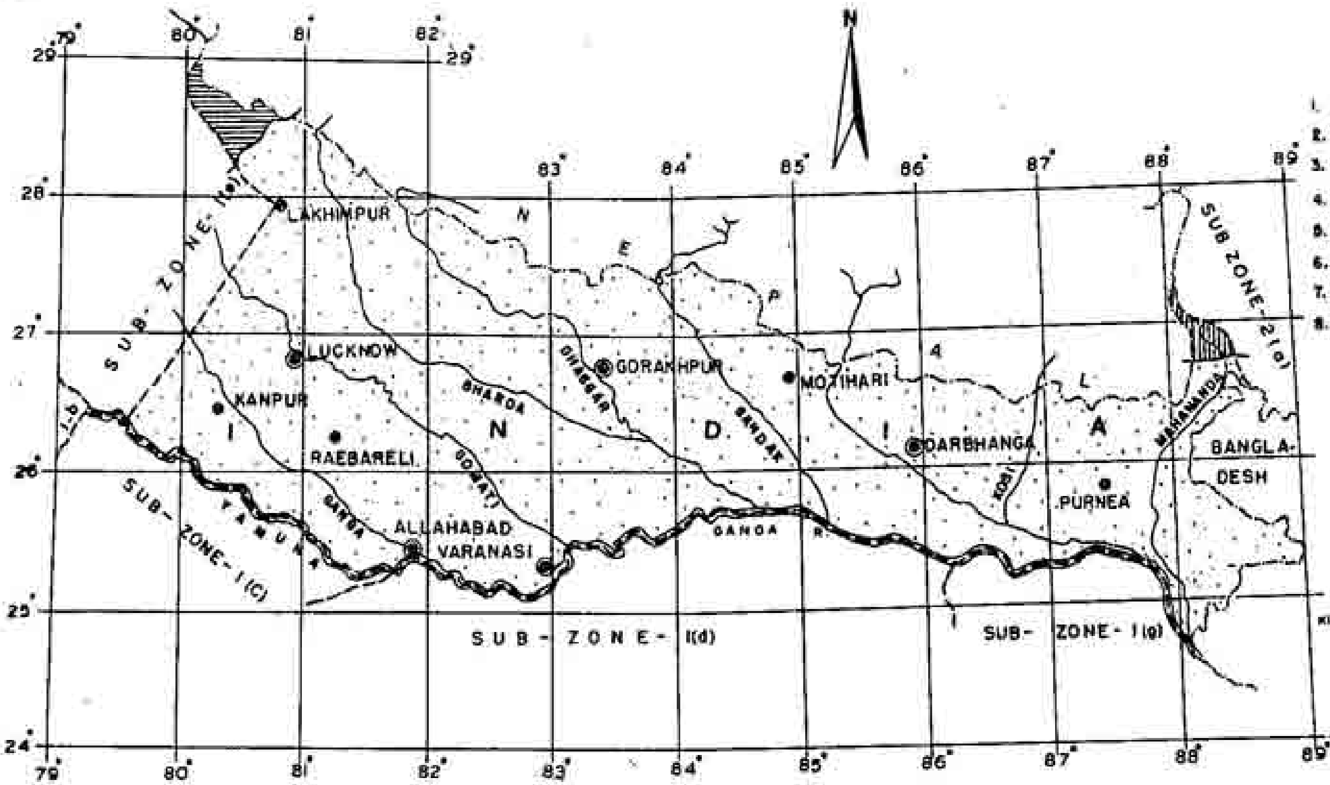
N
NEPAL
UTTAR PRADESH
BIHAR
WEST BENGAL
BANGLA DESH
SUB ZONE 1-b
SUB ZONE 1-c
SUB ZONE 1-d
SUB ZONE 1-e
SUB ZONE 1-g
LUCKNOW
KANPUR
ALLAHABAD
VARANASI
PATNA
GORAKHPUR
FAIZABAD
BHAGALPUR
DARJILING
SHILIGURI

PLATE-3



REFERENCES:—

1. HEIGHT FROM 0 TO 150 MTS.
2. HEIGHT FROM 150 TO 300 MTS.
3. HEIGHT ABOVE 300 MTS.
4. INTERNATIONAL BOUNDARY.
5. SUB ZONE BOUNDARY.
6. RIVERS.
7. TOWNS.
8. NAME OF THE HQ. OF STATES.

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

SCALE

KILOMETRES 50 0 50 100 150

MILES 25 0 25 50 75 100

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

MIDDLE GANGA PLAINS

SUB-ZONE- 1(f)

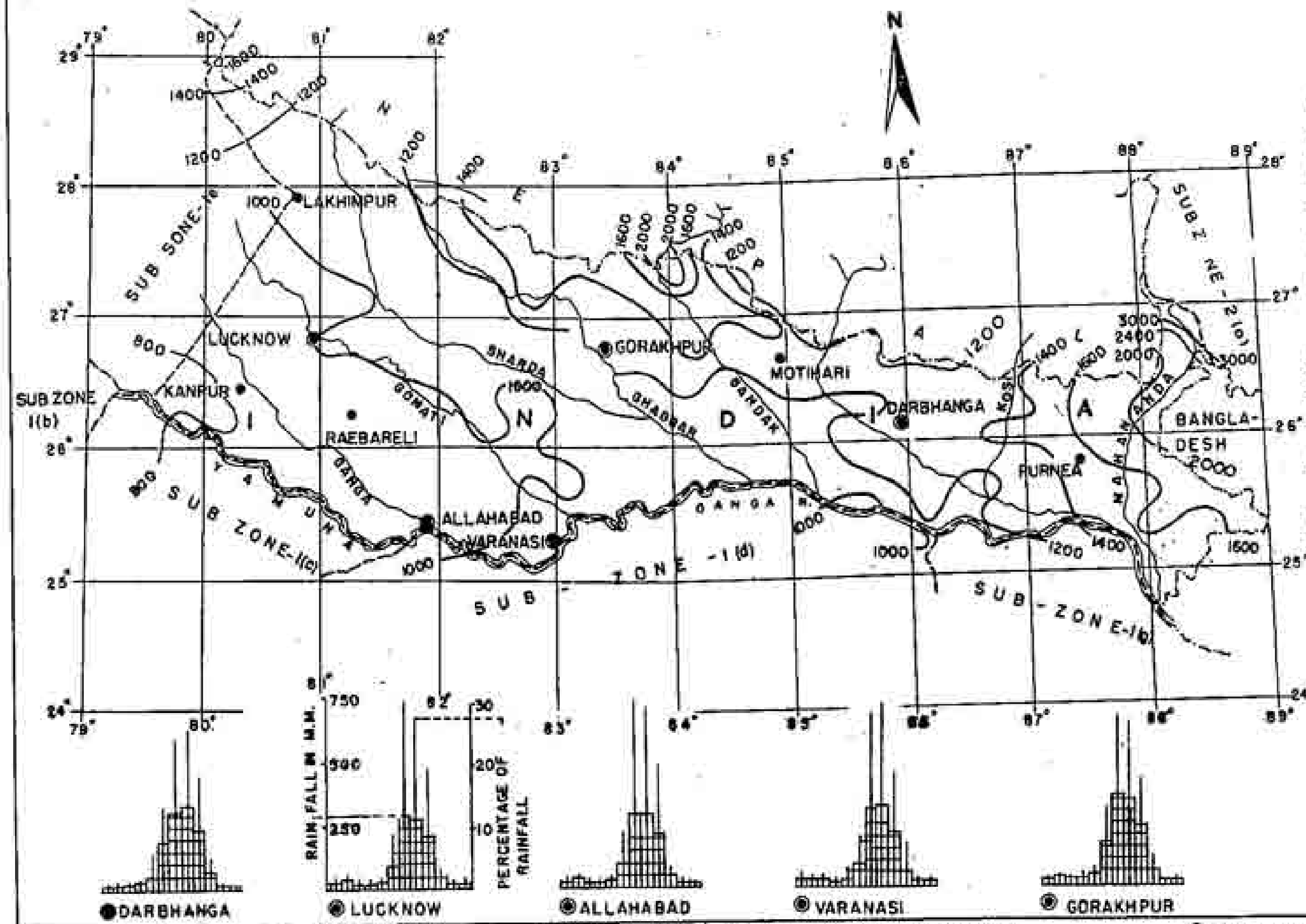
PHYSIOGRAPY.

DRAWN BY S.N.MALHOTRA R.N. SHARMA | CHECKED BY A.K. GHOSH

RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS REST WITH THE PUBLISHER

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

PLATE - 4



HISTOGRAMS FOR FIVE STATIONS WITH NAMES EACH VERTICAL COLUMN REPRESENTS THE MEAN MONTHLY RAINFALL FOR EACH MONTH. THE VERTICAL LINES AT THE CENTRE OF EACH COLUMN INDICATES THE PERCENTAGE OF RAINFALL IN THE MONTH TO THE MEAN ANNUAL TOTAL.

REFERENCES

1. INTERNATIONAL BOUNDARY.
2. SUB-ZONE BOUNDARY
3. RIVERS & ITS TRIBUTORIES
4. TOWNS.
5. NAME OF THE HEAD QUARTER OF STATE.
6. ISOHYETAL LINES WITH VALUE IN M.M.

NOTE:- THIS MAP HAS BEEN DRAWN FROM IRRIGATION ATLAS OF INDIA (YEAR 1972) PLATE NO.6.

SCALE

KM. 50 0 50 100 150

MILES 25 0 25 50 75 100

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

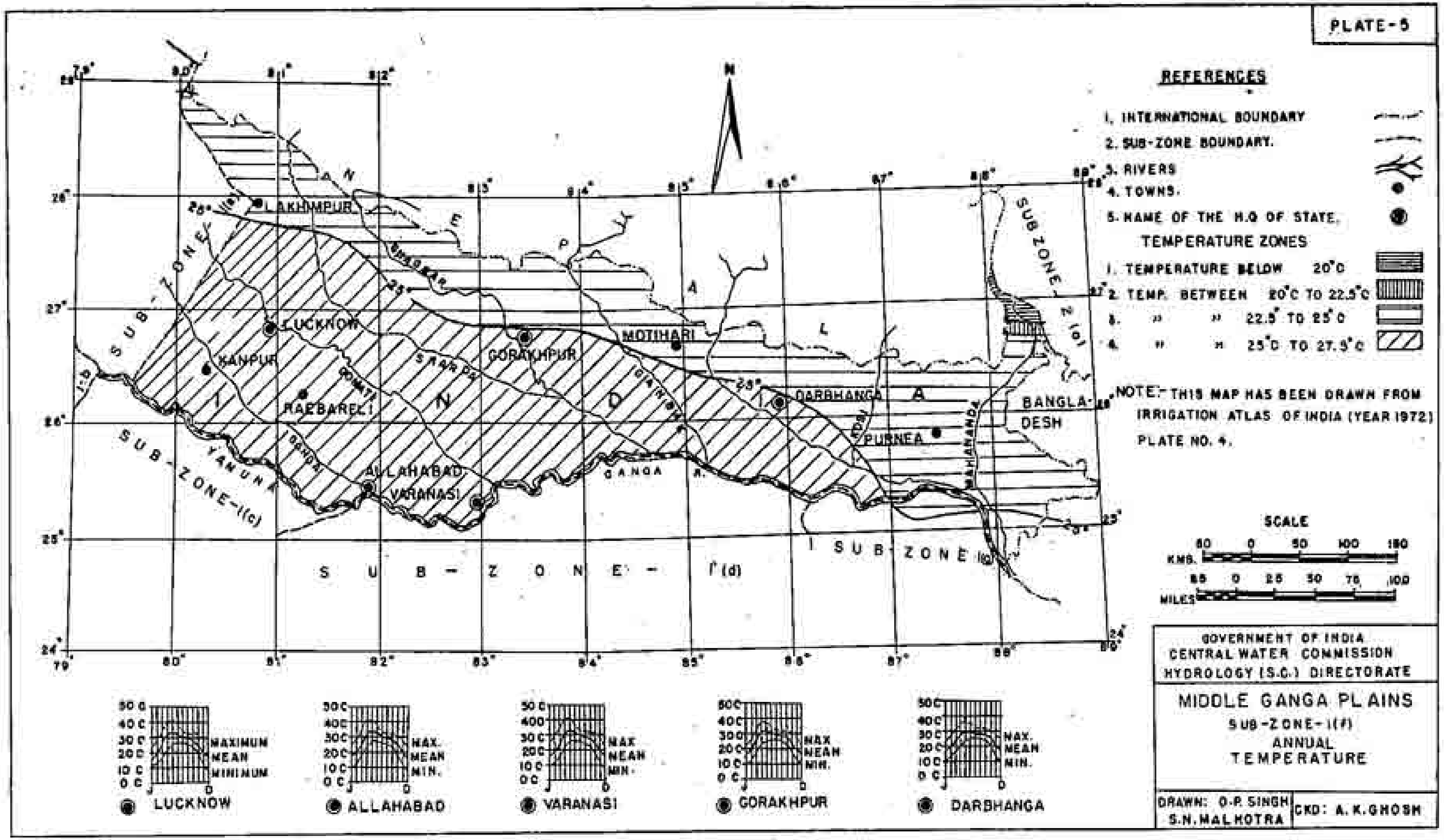
MIDDLE GANGA PLAINS
SUB-ZONE-1(f)

ANNUAL RAINFALL

DRAWN: O.P. SINGH, S.N. MALHOTRA | CKD: A.K. GHOSH

RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS REST WITH THE PUBLISHER.

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



RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS REST WITH THE PUBLISHER.

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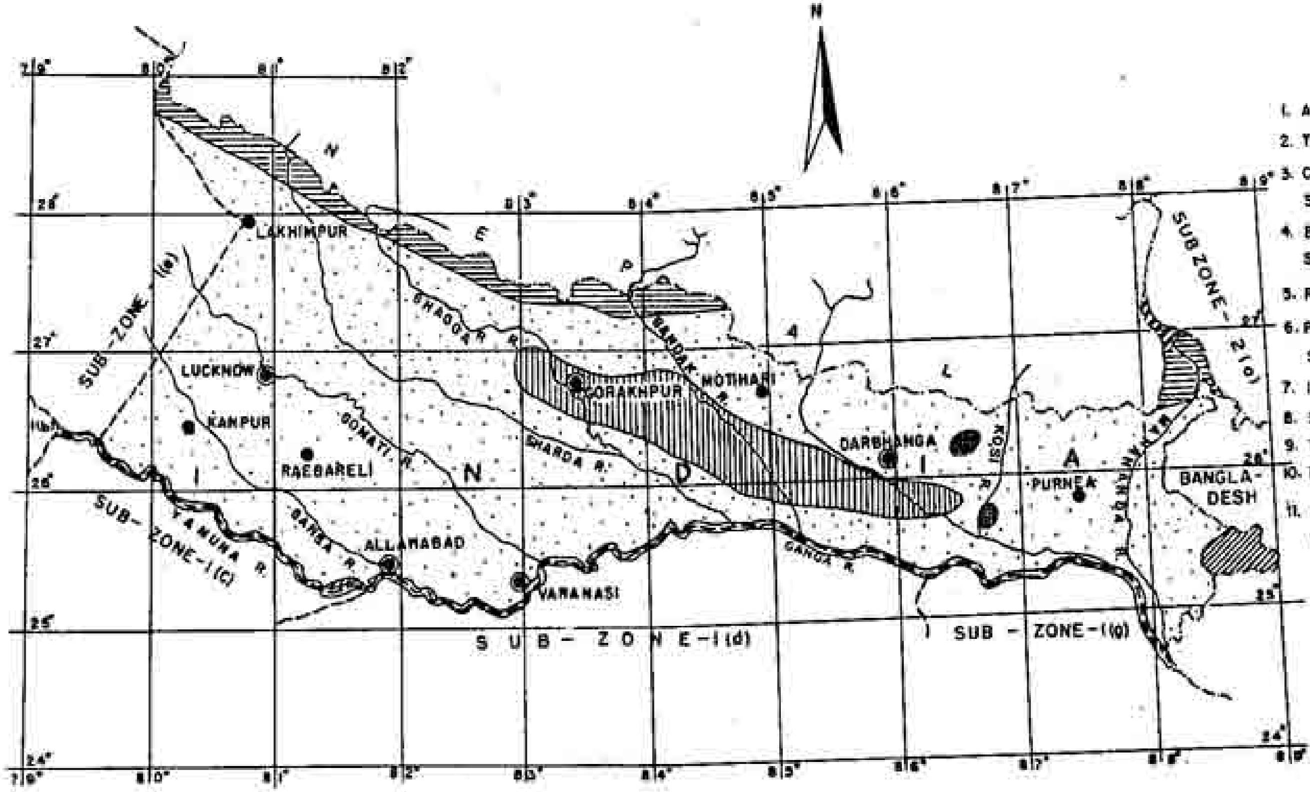
PLATE-6



REFERENCES

1. ALLUVIAL SOILS (RECENT)
2. TARAI SOILS
3. CALCAREOUS ALLUVIAL SOILS.
4. BROWN HILL SOILS (ON SANDSTONE & SHALES)
5. RED AND YELLOW SOILS
6. PEATY & SALINE PEATY SOILS.
7. INTERNATIONAL BOUNDARY
8. SUB-ZONE BOUNDARY
9. TOWNS
10. RIVERS
11. NAME OF THE H.Q. OF STATE

SCALE

KMS. 50 0 50 100 150

MILES 25 0 25 50 75 100

NOTE:- THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972) PLATE NO-8.

RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS REST WITH THE PUBLISHER.

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

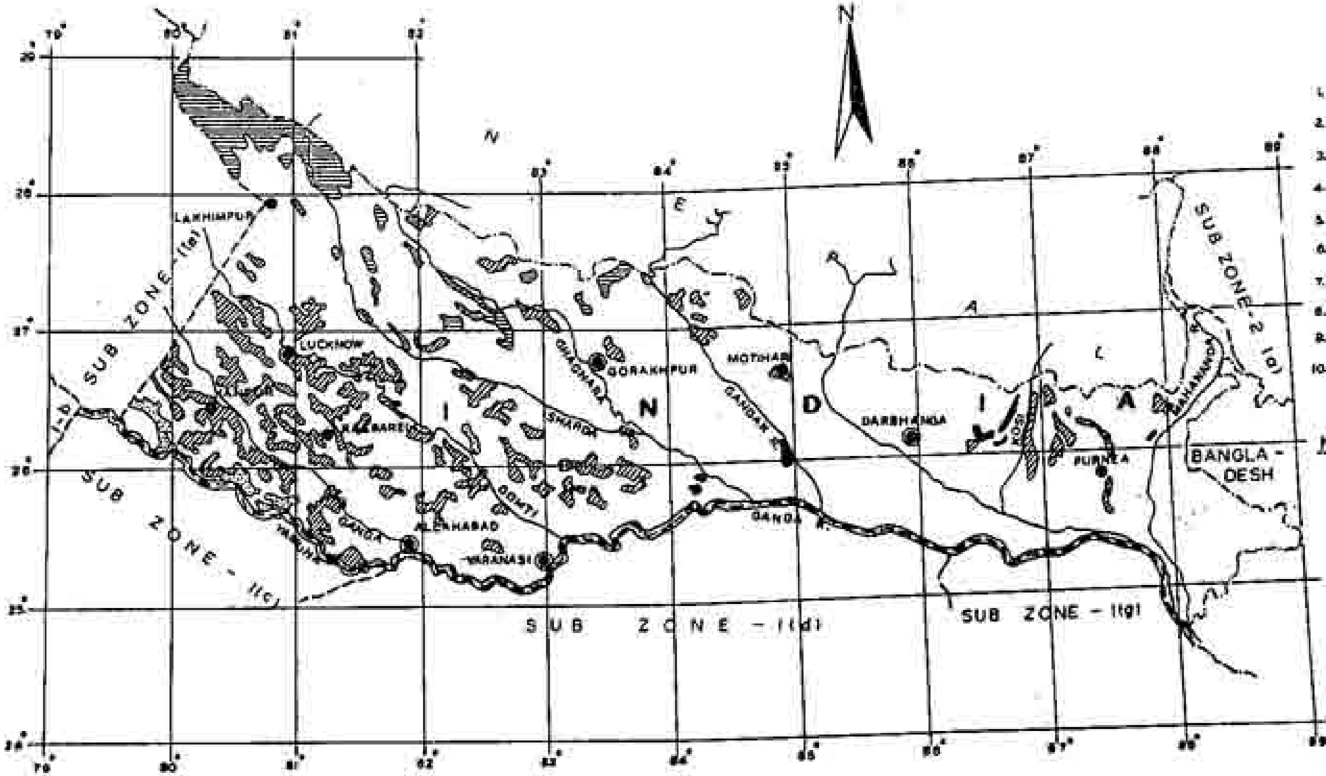
MIDDLE GANGA PLAINS

SUB-ZONE-I(f)

SOILS

DRAWN: O.P. SINGH, S.K.MALHOTRA | CKD:- A. K. GHOSH

PLATE – 7



REFERENCES

1. FOREST
2. ARABLE LAND
3. GRASS LAND & SCRUB
4. WASTE LAND
5. WATER BODIES, MARSHES ETC.
6. INTERNATIONAL BOUNDARY
7. SUB ZONE BOUNDARY
8. RIVERS
9. TOWNS
10. NAME OF THE H.Q. OF STATES.

NOTE :-

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

SCALE

K.MTS. 50 0 50 100 150

MILES 25 0 25 50 75 100

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

MIDDLE GANGA PLAINS

SUB ZONE – 1(f)

LAND USE

DRAWN BY S.H. MALHOTRA, R.N. SHARMA | CHECKED BY A.K. GHOSH

RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS REST WITH THE PUBLISHER.

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2.0 DESIGN FLOOD, DATA AND THE METHOD ADOPTED FOR ANALYSIS

2.1 Design flood

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

2.2 Data Required

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

- i) Hourly gauge data at the gauging site (Bridge site) round the clock.
- ii) Gauge & discharge data observed 2 to 3 times a day at the gauging site (bridge site).
- iii) Hourly rainfall data of raingauge stations in the catchment. Raingauge stations are to be self-recording or manually operated.
- iv) Catchment area plan showing the river network, location of raingauge stations and gauge & discharge sites, contours, highway and railway network, natural and man made storages, habitations, forests, agricultural and irrigated areas, soils etc.
- v) Cross sections at the bridge site (gauging site) upstream and downstream of the bridge site.

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

2.3 Data Collected

The Northern, Central, North-eastern and North East Frontier Railway under the supervision of Research and Designs Standards Organisation (RDSO) had observed and collected the required data in section 2.2 for 41 catchments in the Middle Ganga Plains subzone-1(f) for a period of 1 to 11 years for each of the catchments. Central Water Commission on behalf of Ministry of Transport has also observed and collected the required data since 1981 for four catchments in this subzone. The size of the catchments varied from 30 sq.km. to 4479 sq. km. The location of the gauging sites at road and railway bridges in subzone - 1(f) are shown in Plate-2. IMD has collected the rainfall data of additional raingauge stations maintained by IMD. CWC has also prepared the detailed plans of gauged catchments showing information in section 2.2 (iv). Table-1 shows the name, number of bridges, location of the gauging sites, name of streams, catchment areas, number of raingauges and period of availability of data alongwith observational agency. RDSO has made available the data collected to CWC and IMD for carrying out the studies.

2.4 Description of the Method Adopted

In this repor", section-3 explains the procedure for obtaining the synthetic unitgraph f r ungauged catchments in subzone - 1(f).

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

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

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

3.0 ANALYSIS FOR OBTAINING 6-HOUR SYNTHETIC UNITGRAPH

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

i) Analysis of physiographic parameters of the catchments.

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

iii) Selection of flood and corresponding storm events.

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

v) Computation of infiltration loss (ø - index) and 6 hourly rainfall excess units.

vi) Derivation of 6 hourly unitgraphs.

vii) Drawing of representative unitgraphs and measuring the parameters.

viii) Establishing relationships between physiographic and representative unitgraph parameters.

ix) Derivation of 6 hour synthetic unitgraph for an ungauged catchment.

The above steps are briefly described as under :

3.1 Analysis of Physiographic Parameters of the Catchment :

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

3.1.1 Catchment Area (A)

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

3.1.2 Length of the Main Stream (L)

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

3.1.3 Equivalent Stream Slope (S)

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

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

Where L_i = Length of the ith segments in km.

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

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

Out of 45 gauged catchments, the physiographic parameters A, L and S were estimated only for 25 catchments which were found suitable for analysis. These parameters are shown in Table -2.

3.2 Scrutiny of Data and Finalisation of Gauge Discharge Rating Curve

The data was scrutinised through arithmatical checks. The gauge (stage) vs. area curves and the stage vs. velocity curves were prepared to identify the outliers and reconcile the data in the plotted points of the stage-discharge curves. At many places, the average trends of the stage-area curves and the stage velocity curve was used to obtain the discharges at various levels. Where wide dispersion were not observed in the stage-discharge curve, log-log fitting was adopted. The stages for conceivable floods were converted into discharge initially identified with reference to rise and fall in the stages of the river.

3.3 Selection of Flood and Corresponding storm events

The General guidelines adopted for selection of flood events for each 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.

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

3.4 Computation of Hourly Catchment Rainfall

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

3.5 Separation of Base Flow

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

3.6 Computation of Infilteration Loss (Ø Index) and 6-hourly Rainfall Excess Unit

With the known values of 6-hourly catchment rainfall in section 3.4 and the direct runoff depth in section 3.5 for each flood event, the infilteration loss (constant loss rate) by trials was estimated to obtain the direct runoff depth. The 6-hourly infilteration loss was deducted from the 6-hourly rainfall to get the 6-hourly rainfall excess units.

3.7 Derivation of 6 hour Unitgraphs

A unit duration of 6-hours was adopted for derivation of unitgraphs to reduce computational work as the floods from the catchment with flat slopes were of long duration. The 6 hour unit graphs were derived from the rainfall excess hyetographs and their corresponding direct runoff hydrographs by iterative methods. The iterations were carried out till the observed and estimated direct runoff hydrographs compared favourably. Normally 5 to 15 unitgraphs are derived for each of the 25 catchments considered.

3.8 Drawing of Representative Unitgraphs

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 6 hour unit graphs were drawn from a set of superimposed 6 hour unitgraphs for each of the 25 catchments and their parameters noted. The parameters of the representative unitgraphs illustrated in Fig.2 were measured for each of the catchments. The parameters of the representative unitgraph are t_r, t_p, T_m, Q_p qp, W_{50} W_{75}, W_{R-50}, W_{R-75} and T_B. These parameters for 25 catchments are listed in Table-3.

3.9 Establishing Relationships between Physiographic and Representative Unitgraph Parameters.

Physiographic parameters like L, Lc, S and A and the parameters of the 6 hour unitgraph like tp, Q_p, T_B, W_{50}, W_{75}, W_{R-50}, W_{R-75} for 25 gauged catchments out of 45 catchments in subzone-1(f) were estimated as shown in Table-2 and 3 respectively. The reasons for eliminating the 20 catchments in this study are indicated in Table-1. Following simple model was adopted for establishing the relationships between these parameters :

$$Y = C \quad x^{P} \quad \ldots\ldots\ldots\ldots\ldots\ldots 3.9.1$$

Where

Y = Dependent variable
X = Independent variable
C = A constant
P = An exponent

From equation 3.9.1, it follows that

$$\text{Log } Y = \text{Log } C + P \text{ Log } x \ldots\ldots\ldots 3.9.2$$

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

Various trials of relationship between the physiographic parameters and one of the unitgraph parameters themselves were made. The relationship between the physiographic parameter $(L/\sqrt{S})$ and unit peak discharge of the U.G. (q_p) was found to be significant. Similarly the relationships between qp were individually found to be significant with the U.G. parameters of tp, W50, W75, W_R-50 and W_R-75 as dependent variables. The time base (TB) could be significantly correlated to (tp). Principle of least squares was used in the regression analysis to get the above relationship in equation 3.9.1 above to predict the parameters of the synthetic unitgraph in an unbiased manner.

The following relationships have been derived for estimating the 6 hour unitgraph parameters in the subzone 1(f).

Sl. No.	Relationship	Corr. Coeff.	Equ. No.	Fi No.
1.	$q_p = 0.409/(L/\sqrt{S})^{0.456}$	0.79	3.9.3	3
2.	$t_p = 1.217/(qp)^{1.034}$	0.85	3.9.4	4
3.	$W_{50} = 1.743/(qp)^{1.104}$	0.99	3.9.5	5
4.	$W_{75} = 0.902/(qp)^{1.108}$	0.97	3.9.6	6
5.	$W_{R50} = 0.736/(qp)^{0.928}$	0.86	3.9.7	7
6.	$W_{R75} = 0.478/(qp)^{0.902}$	0.83	3.9.8	8
7.	$T_B = 16.432 \times (tp)^{0.646}$	0.85	3.9.9	9

$$Q_p = qp \times A$$

$$T_m = tp + tr/2$$

The above relationships may be utilised to estimate the parameter of 6 hour synthetic unitgraph for an ungauged catchment with its known physiographic parameter L, A and S.

3.10 Derivation of 6 hour synthetic unitgraph for an ungauged catchment.

Considering the hydro-meteorological homogenity of subzone -1(f), the relations established between physiographic and unitgraph parameters in section 3.9. are applicable for derivation of 6 hour synthetic unitgraph for an ungauged catchment in the same subzone.

The steps for derivation of 6 hour unitgraph are:

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

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

$$q_p = 0.409/(L\sqrt{S})^{0.456}$$

to obtain q_p in cumec/sq.km.

Then $Q_p = q_p \times A$ in cumec

iii) Substitute q_p in equation 3.9.4

$$t_p = 1.217/(q_p)^{1.034}$$

to obtain t_p in hours and then round off to nearest one hour

$$T_m = t_p + t_r/2$$

$$= t_p + 6/2 = (t_p + 3) \text{ hour}$$

for unit duration of unitgraph $(t_r) = 6$ hours.

The values of t_p and T_m may be adopted for calculated value of t_p falling in various ranges of t_p, as shown in Table A-3 under A- "APPLICATION." t_p and T_m is so adjusted to make T_m a multiple of 6 hours without much affecting the value of 50-year flood.

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

$$W_{50} = 1.743/(q_p)^{1.104}$$

$$W_{75} = 0.902/(q_p)^{1.108}$$

$$W_{R50} = 0.736/(q_p)^{0.928}$$

$$W_{R75} = 0.478/q_p)^{0.902}$$

v) Substitute t_p in equation 3.9.9

$$T_B = 16.432 \times (t_p)^{0.646}$$ to obtain T_B in hours.

vi) Plot the parameters of 6-hour unitgraph viz. T_m, T_B, Q_p, W_{50}, W_{75}, W_{R50}, W_{R75} on a graph paper as shown in illustrative fig.2 and sketch the unitgraph through these points. The discharge ordinates (Q_i) of the unitgraph at 6-hour (t_r) interval are summed up and the direct runoff depth (d) in cm. is obtained from the following equation 3.9.10

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

Where d = depth of direct runoff in cm.

Qi = Discharge ordinates at 6-hour interval (cumecs)

A = Catchment area in sq.km.

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

3.11 Design Loss Rate

Surface runoff occurs when the gross rainfall has met with the losses due to infiltration, evapotranspiration etc. Since each and every parameter can not be observed at various locations, there is perhaps no other alternative but to adopt an average value of loss rate representing all the abstractions.

Variations due to the soil condition and topography alongwith the spa tial variation in rainfall make it a complex phenomenon. In this report, the loss rate study based on Ø index approach using the actual data of flood hydrographs provided guidance in arriving at the design loss rate. In Table-4 the ranges of loss rate are presented against the number of events falling in each category for each catchment. There could perhaps be two alternatives. One was to adopt the lowest value of loss rate and the second to adopt the modal value of loss rate. Since this report is intended at providing 50 year estimates which may not be a very rare event when considered from design point of view. A modal value of design loss rate of 3.0 mm per hour is recommended for adoption.

3.12 Base Flow for Design Flood

The number of events with various ranges of base flow are shown in Table-5. Out of 158 number of flood events, 87 flood events fall in the range of 0.01 to 0.09 cumecs per sq.km. An average value of base flow of 0.05 cumec per sq.km. is recommended for adoption in the subzone.

TABLE - I

LIST OF SELECTED RAILWAY BRIDGE CATCHMENTS IN SUBZONE 1(f) 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 BR. NO./ SITE NO	G. AND D. SITE LOCATION LATITUDE (APPROX)	LONGITUDE (APPROX)	CATCHMENT AREA IN SQ.KM.	NO. OF R.G. STATION	DATA AVAILABILITY	NO. OF YEARS	REMARKS
1	2	3		4	5	6	7	8	9	10	11
		A: BRIDGES CONSIDERED FOR REGRESSION ANALYSIS									
1	SARJU	GONDA - KATARNIA GHAT	N.E.R.	6	27°-57'	81°-27'	4479.10	5	1966, 67	2	
2	KUWANA	BASTI - GONDA	"	79A	26°-53'	82°-41'	2472.40	9	1965, 71-76	7	
3	MAJHOI	LUCKNOW - JAUNPUR	N.R.	177	26°-15'	82°-38'	712.25	6	1970-73	4	
4	MANGAI	MAU - AUNRIHAR	N.E.R.	7	25°-46'	83°-24'	673.40	5	1968-74	7	
5	VARUNA	JANGHAI - VARANASI	N.R.	187	25°-32'	82°-19'	670.39	6	1966 -72, 82	8	
6	HARBORA	NARKATIA GANJ - BAGAHA	N.E.R.	30	27°-06'	84°-27'	447.76	5	1960-62, 64-70	10	
7	DUNDA RHANRAHA	MUZAFFARPUR - SAGAULI	"	152	26°-16'	85°-09'	299.53	3	1961-67	7	← USED FOR AN ILLUSTRATIVE EXAMPLE
8	BHAWAR	GORAKHPUR - GONDA (LOOP)	"	48	27°-31'	82°-35'	234.11	3	1966-74	9	
9	NAGWA	KANPUR - LUCKNOW	N.R.	33	26°-44'	80°-47'	192.40	5	1962, 64-67	5	
10	MAJHNA	BHATNI - GORAKHPUR	N.E.R.	18	26°-38'	83°-38'	150.40	5	1962 - 70	9	
11	MOHAMMADA	GONDA - NANPARA	"	3(I)	27°-38'	81°-38'	146.70	5	1961, 62, 70-74	7	
12	DUAR	ARC - BRANCH	N.R.	85	25°-44'	81°-29'	136.70	2	1966-71, 74	7	
13	SOTWA	GONDA - GORAKHPUR (LOOP)	N.E.R.	20 (60 NEW)	27°-26'	82°-54'	130.00	3	1968-73	6	
14	BISUNI	GORAKHPUR - GONDA (LOOP)	"	9	27°-17'	82°-02'	122.24	3	1961, 62, 64, 65	4	
15	JAMWAR	GONDA - NANPARA	"	66	27°-27'	81°-44'	72.26	2	1961-65	5	
16	HIRNI	CHHITAUNI - KAPTAN GANJ	"	24	27°-04'	83°-43'	69.75	2	1968-73	6	
17	RAMJAN	KATIHAR - SHILIGURI	N.F.R.	141	26°-06'	87°-56'	59.83	2	1961, 62, 64, 67-69	7	
18	CHHOTI HARHA	NARKATIAGANJ - BAGAHA	N.E.R.	59	27°-08'	84°-07'	54.39	2	1962, 64-67, 71-76	11	
19	THAKUR DUARA	GONDA - LUCKNOW	"	459	26°-52'	81°-04'	48.07	3	1961-67	7	
20	CHANDU	" - "	"	23	27°-08'	81°-43'	47.91	1	1961-65	5	
21	DUNDRA	" - GORAKHPUR (LOOP)	"	31	27°-31'	82°-19'	39.30	2	1961, 62, 66	3	
22	ZAIDI	GORAKHPUR - KAPTAN GANJ	"	4	26°-49'	83°-30'	34.05	3	1961-65	5	
23	LARHUI	MAU - AUNRIHAR	"	3	25°-53'	83°-30'	32.89	2	1961-69	9	
24	GHAGHAWAN	GONDA - NANPARA	"	55	27°-14'	81°-55'	32.37	2	1961-67	7	
25	TRIBUTARY OF GANGA	KANPUR - KASGANJ	"	63	26°-47'	80°-05'	30.56	1	1962-65	4	
		B: BRIDGES NOT CONSIDERED FOR REGRESSION ANALYSIS									
26	SAI R	LUCKNOW - KANPUR	N.R.	39	26°-42'	80°-43'	2744.40		1962, 64, 65	3	
27	SAI R	" - "	"	40	26°-41'	80°-42'	2744.40		1962, 64, 65	3	
28	LITTLE GANDAK	BHATNI - SONPUR	"	27	26°-20'	84°-0'	2500.00	6	1966	1	
29	KOSIDHAR	PURNEA - SAHARSA		MOT-2	25°-52'	87°-15'	663.00	2	1982, 83	2	
30	[illegible]	[illegible]	N.E.R.	[illegible]	[illegible]	[illegible]	432.78	10	1961	1	
31		JHANSI - KANPUR	C.R.	831	26°-26'	80°-15'	427.52	5	1957, 58	2	
32	DONK	KATIHAR - SILIGURI	N.F.R.	112	26°-21'	88°-10'	387.46	1	1958, 61	2	
33	JAURAHA	SINGAHI KALAN - KAURIALA GHAT		MOT-4	28°-21'	80°-56'	314.00	2	1981-83	3	
34	GOAN	LUCKNOW - MAILANI	N.E.R.	84	27°-24'	80°-48'	311.00	3	1966, 67	2	
35	SARAYAN	BALAMAU - SITAPUR	"	61 (II)	27°-34'	80°-39'	278.92	3	1968, 70-73	5	
36	KHARJHAR	N. A.		MOT-3	27°-33'	82°-14'	245.00	2	1981, 82, 83	3	
37	BHAINSAHI	MAU - AUNRIHAR	N.E.R.	4	25°-51'	83°-28'	244.75	6	1961, 62	2	
38	BEHTA	LUCKNOW - BALAMAU	N.R.	846	27°-0'	80°-35'	235.70	3	1973, 74	2	
39	PANDAI	NARKATIA GANJ - BHIKHNA THORI		8	27°-08'	84°-29'	198.91	2	1962, 66	2	
40	KUKRAIL	GONDA - LUCKNOW	N.E.R.	8	26°-52'	80°-58'	141.40	3	1968-73	6	
41	SUPA	GHAZIABAD - KANPUR	N.R.	289	26°-28'	80°-06'	130.25	2	1966, 67	2	
42	MANWAR	GONDA - GORAKHPUR	N.E.R.	8J	27°-02'	82°-17'	121.98	4	1961, 62	2	
43	TILABEH	SAHARSA - KISHAN GANJ		MOT-1	25°-53'	86°-39'	118.00	3	1981, 82	2	
44		VARANASI - ALLAHABAD	N.E.R.	27	25°-15'	82°-36'	42.47	1	1962-65	4	
45	MANAWARI	GORAKHPUR - GONDA	"	74	26°-54'	82°-34'	34.37	3	1961-63, 65	4	

BASIN CHARACTERISTICS SUBZONE - 1(f) **Table - 2**

Sl. No.	Bridge No.	C.A. Sq.Km.	L. Km.	S m/km.	$\frac{L}{\sqrt{S}}$
1	2	3	4	5	6
1	6	4479.10	286.58	0.62	363.96
2	79A	2472.40	227.20	0.126	640.06
3	177	712.25	66.00	0.140	176.39
4	7	673.40	110.50	0.125	312.54
5	187	670.39	53.43	0.145	140.31
6	30	447.76	56.83	1.79	42.48
7	152	299.53	27.03	0.048	123.37
8	48	234.11	40.63	5.099	17.99
9	33	192.40	35.82	0.258	70.52
10	18	180.40	43.47	0.144	114.55
11	3(i)	146.70	34.00	0.344	57.97
12	85	136.70	20.53	0.276	39.08
13	20	130.00	45.00	0.70	53.79
14	9	122.24	28.96	0.319	51.27
15	66	72.26	14.89	0.65	18.47
16	24	69.75	15.00	0.78	16.98
17	141	59.83	41.06	0.31	73.75
18	59	54.39	18.02	0.583	23.60
19	459	48.07	10.14	1.36	8.69
20	23	47.91	12.33	0.467	18.04
21	31	39.30	7.75	1.37	6.62
22	4	34.05	13.06	0.35	22.08
23	3	32.89	6.84	0.53	9.40
24	55	32.37	13.15	0.72	15.50
25	63	30.56	9.65	1.203	8.80

Table-- 3

REPRESENTATIVE 6-HR UNITGRAPHS PARAMETERS IN SUBZONE - 1(f)

Sl.No.	Bridge No.	tr (hr.)	tp (hr.)	Q_p (Cumecs)	q_p (Cumecs/ (sq.K.m.))	T_B (hr.)	W_{50} (hr.)	W_{75} (hr.)	W_{R50} (Hr.)	W_{R75} (hr.)
1	2	3	4	5	6	7	8	9	10	11
1.	6	6	33	268.0	0.060	144	34.8	19.20	15.60	8.40
2.	79(A)	6	75	43.0	0.017	360	153.50	89.00	40.80	21.90
3.	177	6	75	23.47	0.033	216	74.4	45.00	16.20	11.40
4.	7	6	45	23.49	0.035	210	69.00	35.00	21.00	11.00
5.	187	6	69	14.47	0.022	288	120.60	71.40	37.20	27.60
6.	30	6	9	47.00	0.105	78	20.50	7.00	4.50	2.00
7.	152	6	21	18.30	0.061	102	43.00	24.00	11.50	8.00
8.	48	6	3	85.30	0.364	24	4.20	2.40	1.80	1.10
9.	33	6	9	8.70	0.045	144	57.00	28.50	6.00	4.50
10.	18	6	15	10.39	0.069	126	33.60	18.00	4.80	3.60
11.	3(i)	6	15	10.00	0.068	120	33.00	15.00	5.00	2.40
12.	85	6	9	11.20	0.082	114	22.80	11.40	4.80	3.00
13.	20	6	27	7.20	0.055	102	48.00	25.20	14.40	7.80
14.	9	6	51	4.73	0.039	168	67.20	31.20	24.00	10.80
15.	66	6	27	6.83	0.095	120	23.50	14.00	8.00	6.00
16.	24	6	21	4.50	0.065	96	39.60	21.60	12.00	8.40
17.	141	6	27	2.80	0.047	156	52.20	27.60	10.20	4.80
18.	59	6	27	4.00	0.074	120	29.75	14.50	10.75	5.75
19.	459	6	9	8.90	0.185	36	13.80	7.10	4.80	2.50
20.	23	6	21	4.68	0.098	126	15.50	9.00	6.00	4.80

Contd. on Page 37

1	2	3	4	5	6	7	8	9	10	11
21.	31	6	15	7.80	0.198	42	12.00	7.60	6.80	4.60
22.	4	6	15	2.65	0.078	162	24.50	10.50	3.50	2.00
23.	3	6	9	2.60	0.079	96	30.00	14.50	6.00	3.50
24.	55	6	9	3.96	0.122	54	21.40	12.00	5.80	4.20
25.	63	6	3	8.40	0.275	30	8.40	4.50	2.60	1.70

Table - 4

LOSS RATE RANGES FOR OBSERVED FLOODS IN SUBZONE - 1(f)

Sl. No.	Bridge No.	Catchment area in Sq.Kms.	0.1 to 2	2 to 4	4 to 6	6 to 8	8 to 10	10 to 12	12 to 14	14 to 16	16 to 18	18 to 20	20 to 22	22 to 24	24 to 26	26 to 28	28 to 30	30 to 32	32 to 34	Total
			LOSS RATES (mm/hr) – NUMBER OF OBSERVED FLOODS																	
1.	79(A)	2472.00	3																	3
2.	177	712.25	2	1																3
3.	7	673.40	2	2	1															5
4.	187	670.387			1	1	1													3
5.	30	447.76	11	2																13
6.	152	299.53			1		1													2
7.	48	234.11	4	3	5	1	2			2		1								18
8.	33	192.40	6	6	1					1										14
9.	18	150.40	5	1																6
10.	3(i)	146.70		2		2														4
11.	85	136.70	1	1					1											3
12.	9	122.24	2	1	1	1				1										6
13.	66	72.26	1	2	1															4
14.	24	64.75	1	2	2															5
15.	141	59.83	1	3	1	1														6
16.	59	54.39	6	2	2	1														11
17.	459	48.07			1	3	1	1	1											7
18.	23	47.90	1	1	1	4														7
19.	31	39.30				1		1	1			1								4
20.	4	34.05	2			1								1						4
21.	3	32.89	9	2	1															12
22.	55	32.37	1		1	1	2													5
23.	63	30.56			2			1					1	1					1	6
			58 +	31	21	18	6	4	3	4		2	1	2					1	151

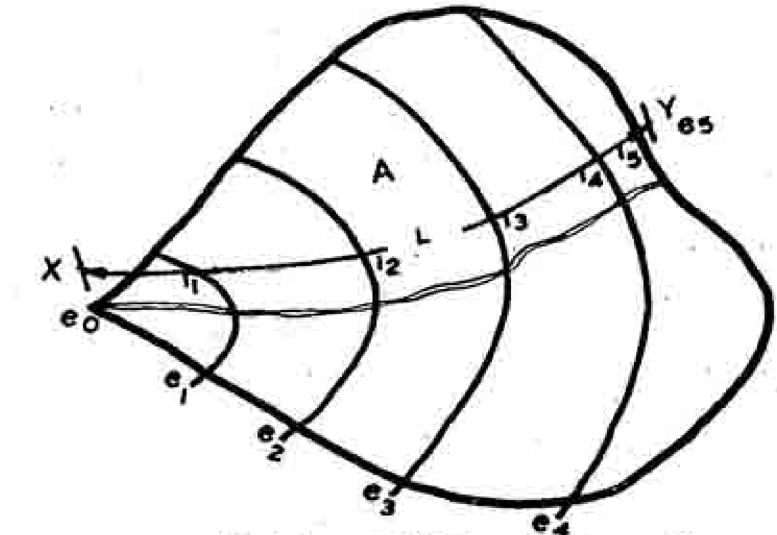
*

Table - 5I

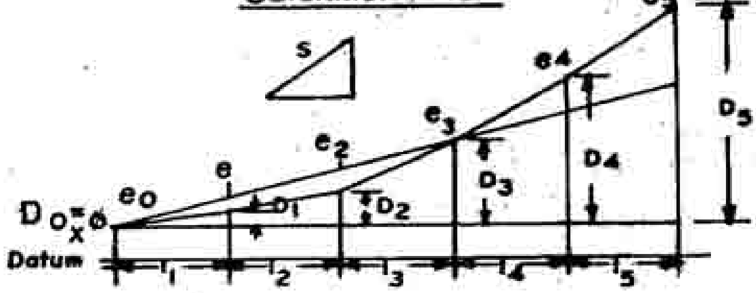
AVERAGE BASE FLOW RANGES FOR OBSERVED FLOODS IN SUBZONE - 1(f)

Sl.No.	Bridge No.	AVERAGE BASE FLOW (Cumec/sq.km.)					
		0.001 to 0.005	0.0051 to .009	0.01 to 0.09	0.10 to 0.19	0.20 and above	Total
		(NUMBER OF OBSERVED FLOODS)					
1.	6	1	1	2			4
2.	79(A)		2	1			3
3.	177			3			3
4.	7	4		1			5
5.	187	2	1				3
6.	30	1		11	1		13
7.	152	1	1				2
8.	48		1	12	5		18
9.	33	6	1	7			14
10.	18			3	2	1	6
11	3(i)	1		3			4
12.	85		2	1			3
13.	20			3			3
14.	9	2		4			6
15.	66			4			4
16.	24			2	3		5
17.	141	2		3	1		6
18.	59			5		6	17
19.	459	2	2	3			7
20.	23	2	2	2	1		7
21.	31			2	2		4
22.	4			2	1	1	4
23.	3	4	2	6			12
24.	55			4		1	5
25.	63	2	1	3			6
Total		30	16	87	16	9	158

FIG. I



Catchment Plan



L-Section

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

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

L = Length of longest stream course (km)

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

$e_i = e_1, e_2, \ldots\ldots\ldots e_n$ = 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)

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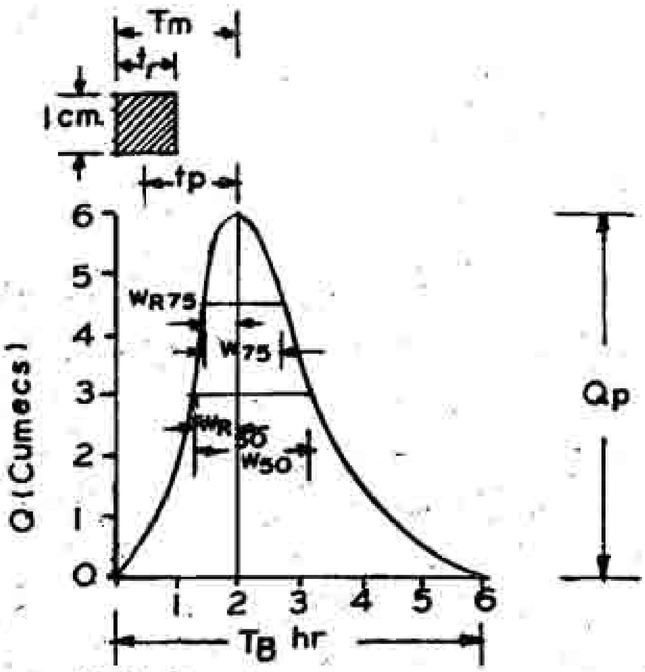
FIG. 2



U.G. = Unit Graph

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

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

Qp = Peak Discharge of Unit Hydrograph (cumecs).

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

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

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

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

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

T_B = Base width of Unit Hydrograph (hr.).

A = Catchment Area (sq.km.)

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

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UNIT GRAPH PARAMETERS

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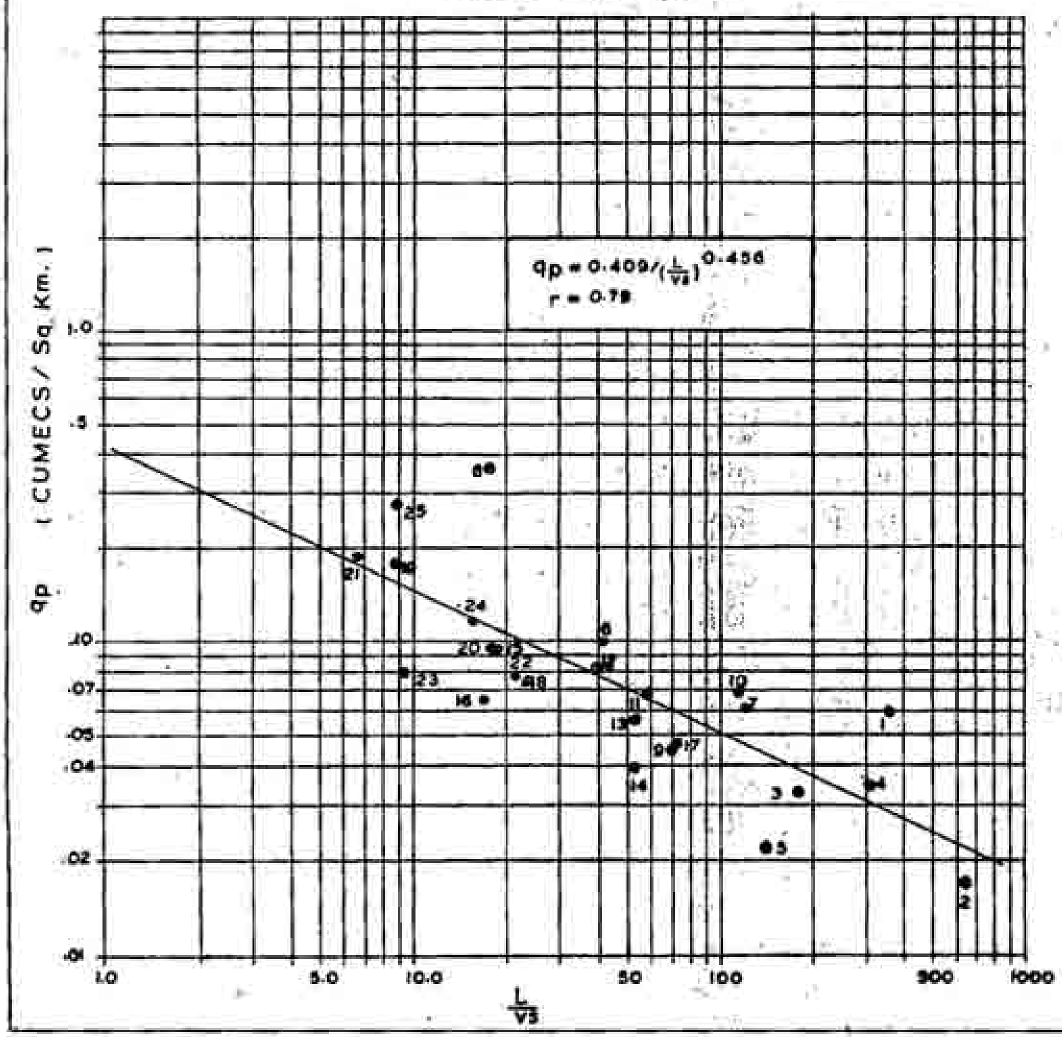
FIG. 3

SCALE = LOG X LOG



SL. NO.	BRIDGE NO.	L/√S	qp
1	6	363.96	.060
2	79 A	640.06	.017
3	177	176.39	.033
4	7	312.54	.035
5	187	140.31	.022
6	30	42.40	.105
7	152	123.37	.061
8	46	17.99	.364
9	33	[illegible]52	.045
10	18	114.55	.069
11	3(1)	57.97	.068
12	85	39.08	.082
13	20	53.70	.055
14	9	51.27	.039
15	66	18.47	.095
16	24	16.98	.065
17	141	73.75	.047
18	56	23.60	.074
19	458	8.69	.185
20	23	18.04	.098
21	31	6.62	.198
22	4	22.08	.078
23	3	9.40	.079
24	55	15.50	.122
25	63	8.80	.275

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MIDDLE GANGA PLAINS
SUB ZONE - 1(f)
RELATION BETWEEN
L/√S AND qp

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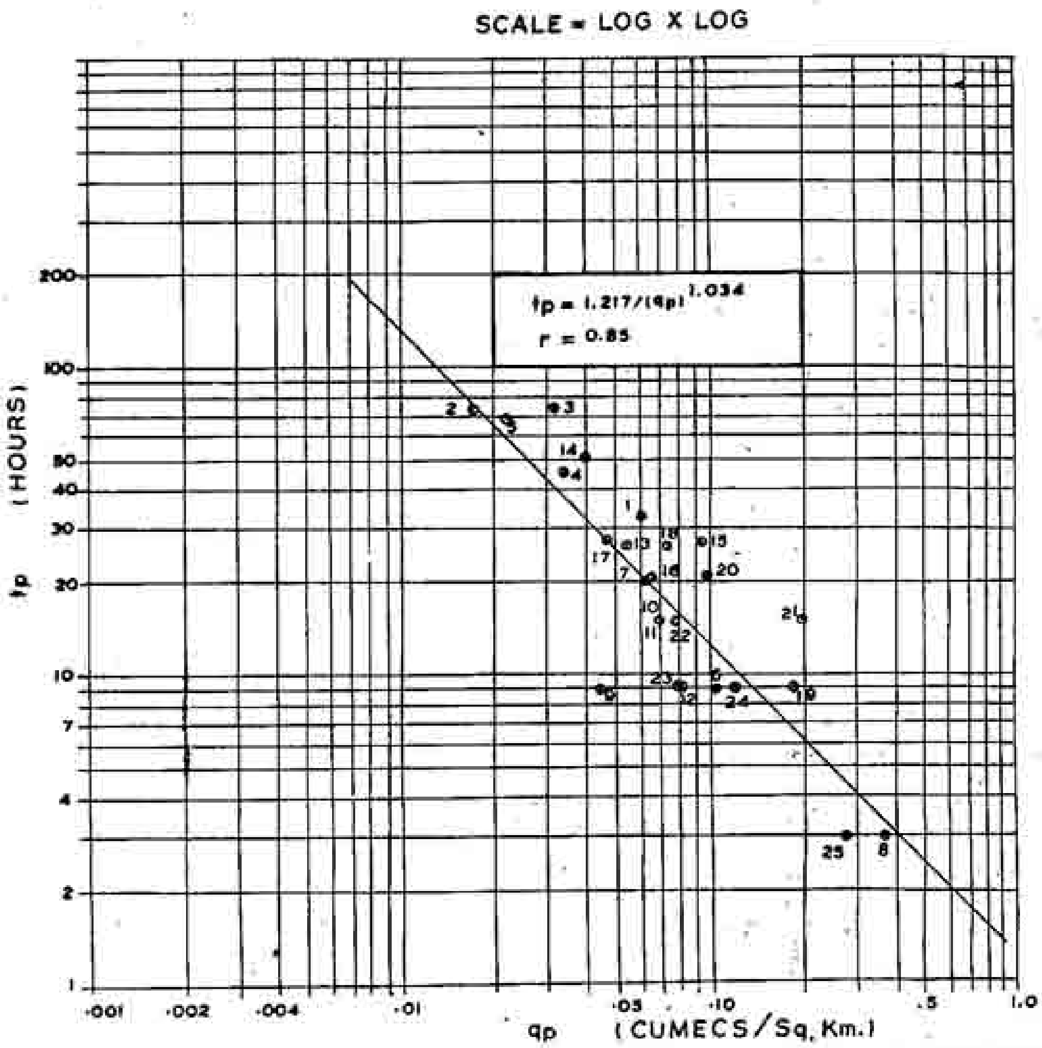
FIG. 4



SL. NO.	BRIDGE NO.	q_p	t_p
1	6	·060	33
2	79 A	·017	75
3	177	·033	75
4	7	·035	45
5	187	·022	69
6	30	·105	9
7	152	·061	21
8	48	·384	3
9	33	·045	9
10	18	·069	15
11	3 (I)	·068	15
12	85	·082	9
13	20	·055	27
14	9	·039	51
15	66	·095	27
16	24	·065	21
17	141	·047	27
18	39	·074	27
19	459	·185	9
20	23	·098	21
21	31	·198	15
22	4	·078	15
23	3	·079	9
24	55	·122	9
25	63	·275	3

GOVERNMENT OF INDIA
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MIDDLE GANGA PLAINS
SUB ZONE - 1 (f)
RELATION BETWEEN
t_p AND q_p

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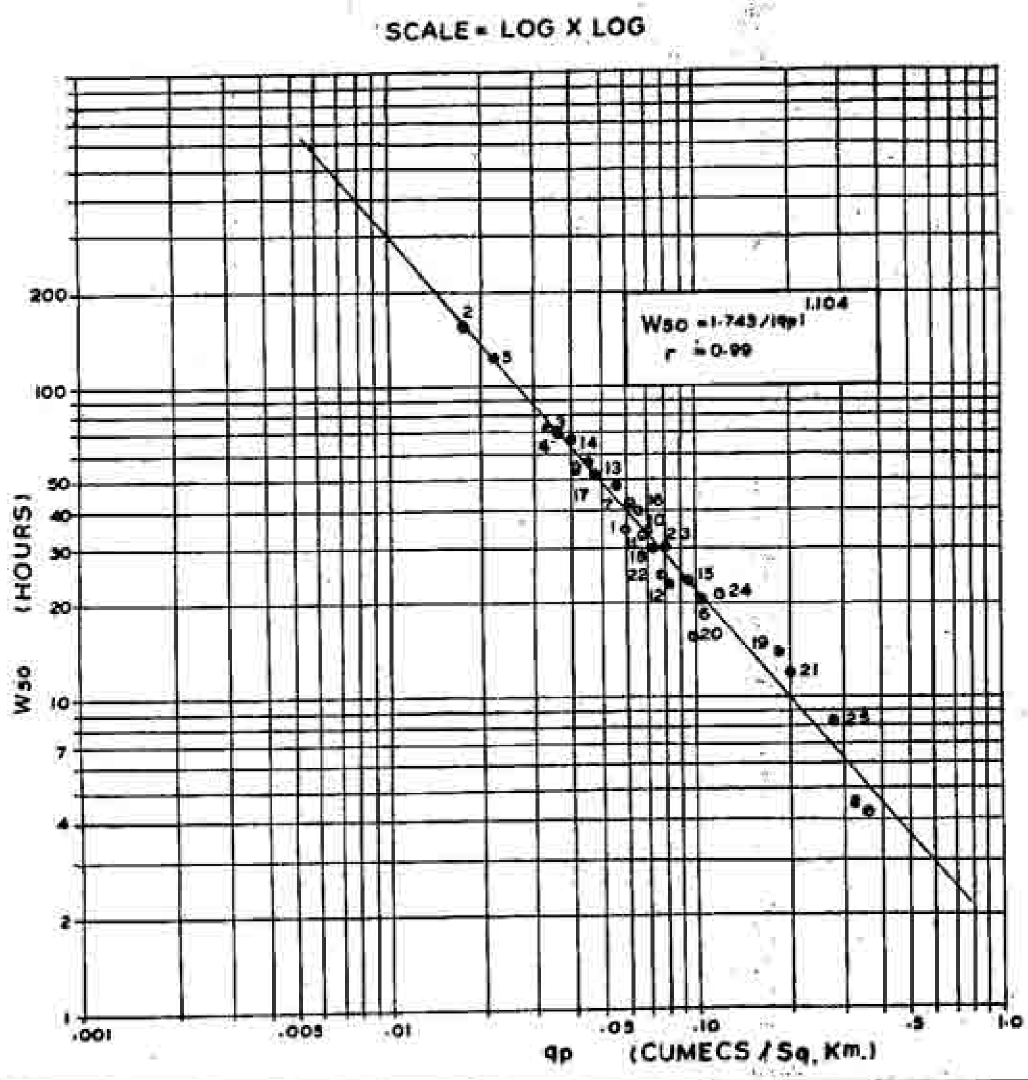
CHECKED BY
C.L. BAJAJ

FIG. 5.



SL. NO.	BRIDGE NO.	qp	W50
1	6	·060	34.80
2	79(A)	·017	153.50
3	177	·033	74.40
4	7	·035	69.00
5	187	·022	120.60
6	30	·105	20.50
7	152	·061	43.00
8	48	·384	4.20
9	33	·045	57.00
10	16	[illegible]	33.60
11	3(i)	·068	33.00
12	85	·082	22.80
13	20	·055	48.00
14	9	·039	67.20
15	66	·095	23.50
16	24	·065	39.60
17	141	·047	52.20
18	59	·074	29.75
19	459	·185	13.80
20	23	·098	15.60
21	31	·198	12.00
22	4	·078	24.50
23	3	·079	30.00
24	55	·122	21.40
25	63	·275	8.40

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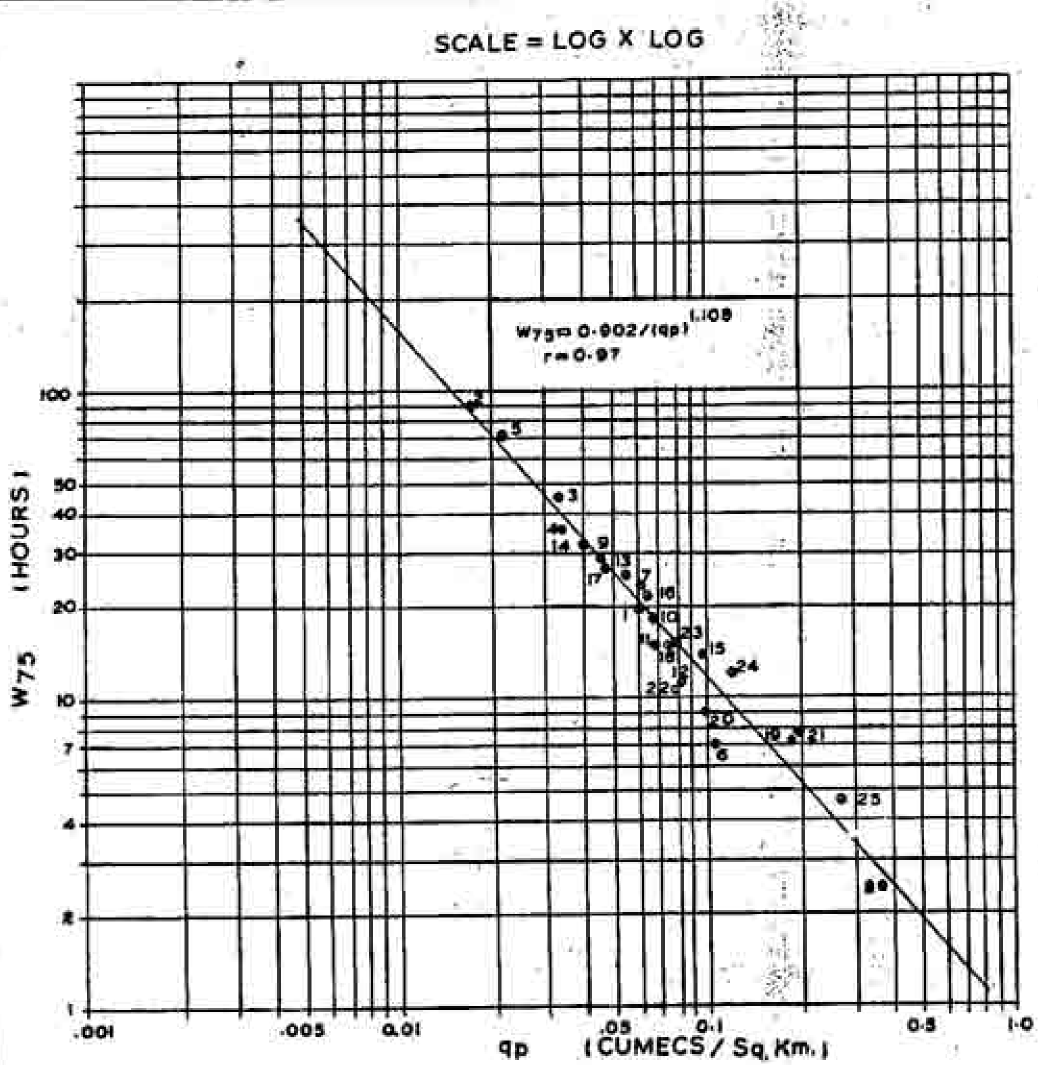
MIDDLE GANGA PLAINS
SUB ZONE-1 (f)
RELATION BETWEEN
W_{50} AND q_p

DRAWN BY S.N. MALHOTRA, R.N. SHARMA

CHECKED BY C.L. BAJAJ

FIG. 6.



St. NO.	BRIDGE NO.	qp	W75
1	6	·060	19.20
2	79 A	·017	89.00
3	177	·033	45.00
4	7	·035	35.00
5	187	·022	71.40
6	30	·105	7.00
7	152	·061	24.00
8	48	·364	2.40
9	33	·045	28.50
10	18	·069	18.00
11	3(1)	·068	15.00
12	85	·082	11.40
13	20	·055	25.20
14	9	·039	31.20
15	66	·095	14.00
16	24	·065	21.60
17	141	·047	27.60
18	59	·074	14.50
19	459	·185	7.10
20	23	·098	9.00
21	31	·198	7.60
22	4	·078	10.50
23	3	·079	14.50
24	55	·122	12.00
25	63	·275	4.50

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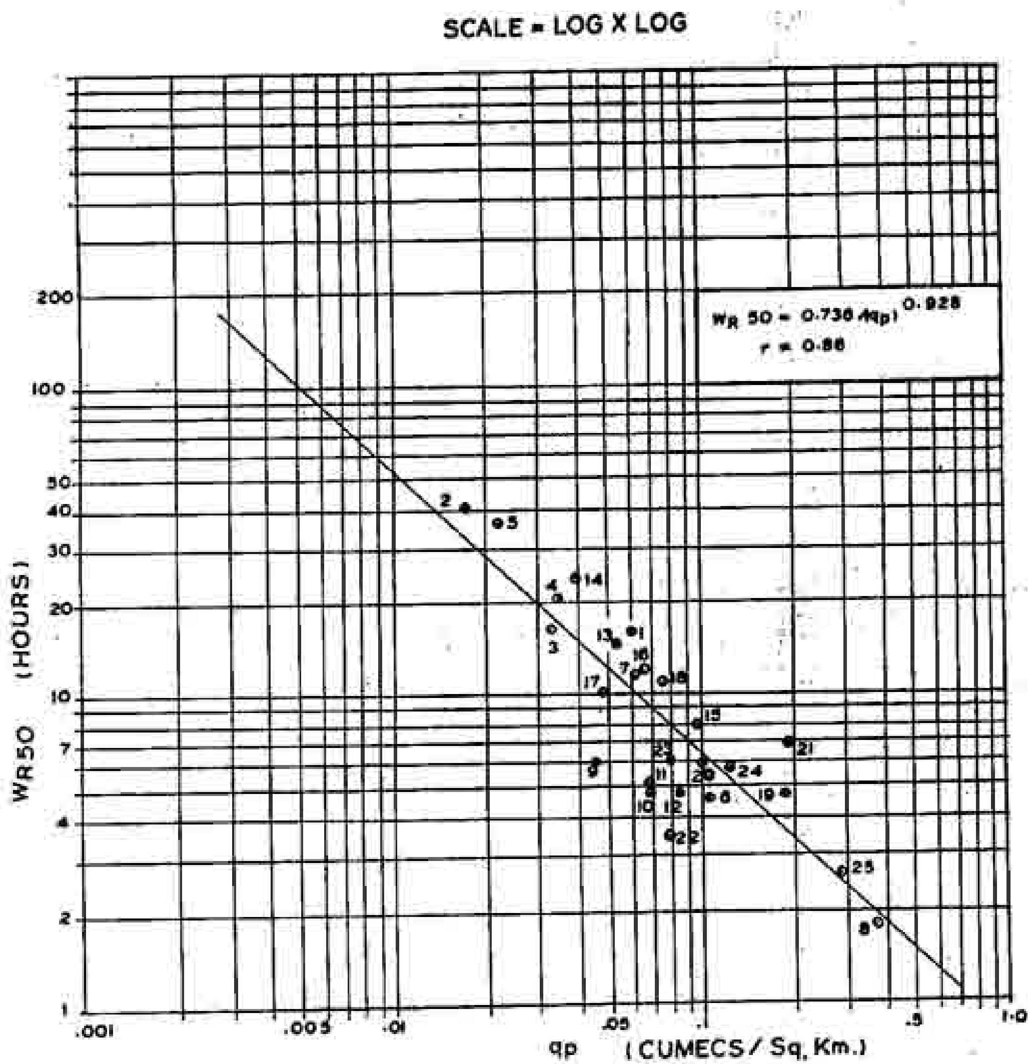
MIDDLE GANGA PLAINS
SUB ZONE- 1 (f)
RELATION BETWEEN
W75 AND q_p

DRAWN BY	CHECKED BY
R.S. SINGH R.N. SHARMA	C.L. BAJAJ

FIG. 7



SL. NO.	BRIDGE NO.	qp	WR50
1	6	.060	15.60
2	79 A	.017	40.80
3	177	.033	16.20
4	7	.035	21.00
5	187	.022	37.20
6	30	.105	4.50
7	152	.061	11.50
8	49	.364	1.80
9	33	.045	6.00
10	18	.069	4.80
11	3(1)	.068	5.00
12	65	.082	4.80
13	20	.055	14.40
14	9	.039	24.00
15	66	.095	8.00
16	24	.065	12.00
17	141	.047	10.20
18	59	.074	10.75
19	459	.185	4.80
20	23	.098	6.00
21	31	.198	6.80
22	4	.078	3.50
23	3	.079	6.00
24	55	.122	5.80
25	63	.275	2.60

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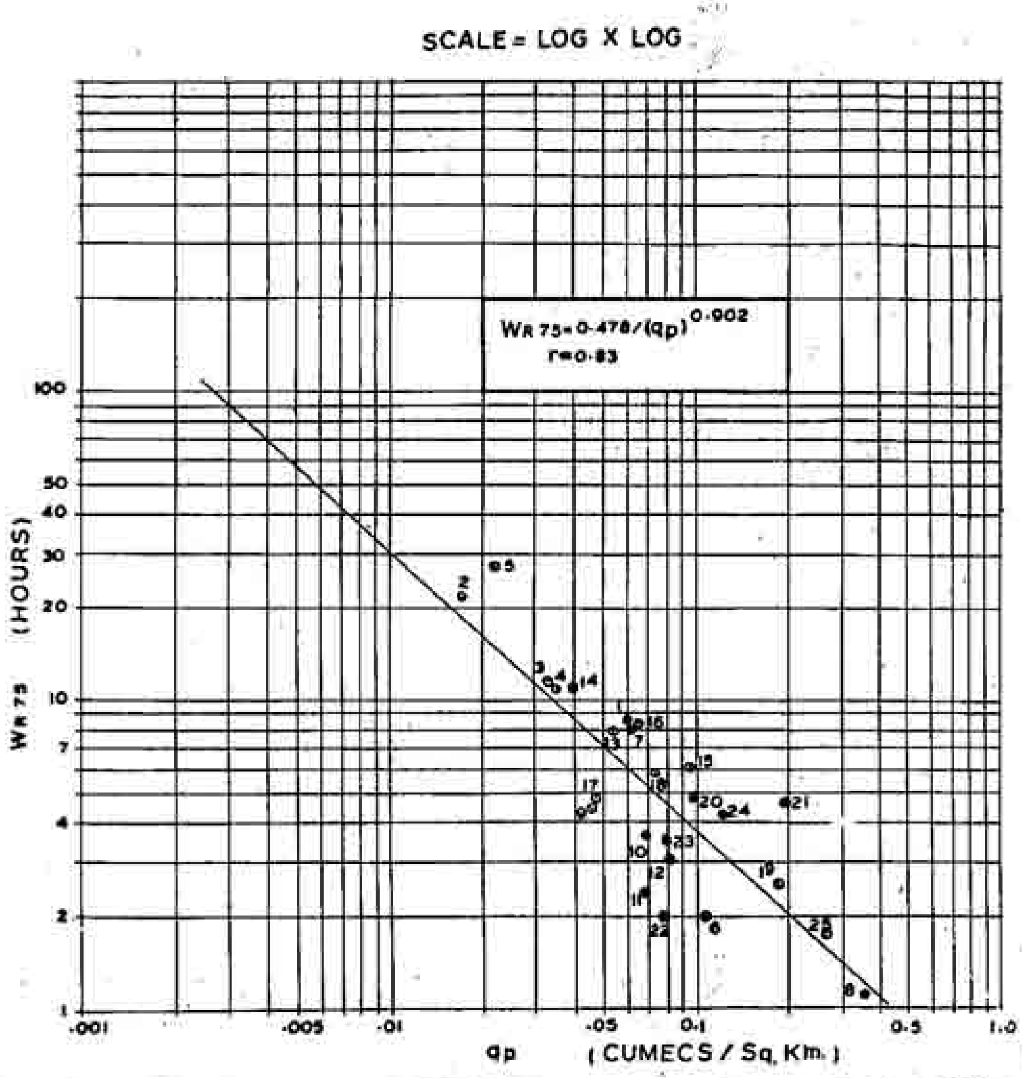
MIDDLE GANGA PLAINS
SUB ZONE-1(f)
RELATION BETWEEN
$W_R 50$ AND q_p

DRAWN BY
S.N. MALHOTRA
R.N. SHARMA

CHECKED BY
C.L. BAJAJ

FIG. 8



SL. NO.	BRIDGE NO.	qp	WR75
1	6	.060	8.40
2	79 A	.017	21.80
3	177	.033	11.40
4	7	.035	11.00
5	187	.022	27.60
6	30	.105	2.00
7	152	.061	8.00
8	48	.364	1.10
9	33	.045	4.50
10	18	.069	3.60
11	3(i)	.068	2.40
12	85	.082	3.00
13	20	.055	7.80
14	9	.039	10.80
15	66	.095	6.00
16	24	.065	8.40
17	141	.047	4.80
18	59	.074	5.75
19	459	.185	2.50
20	23	.098	4.80
21	31	.198	4.60
22	4	.078	2.00
23	3	.079	3.50
24	55	.122	4.20
25	63	.275	1.70

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MIDDLE GANGA PLAINS
SUB ZONE-1 (f)
RELATION BETWEEN
$W_{R}75$ AND q_p

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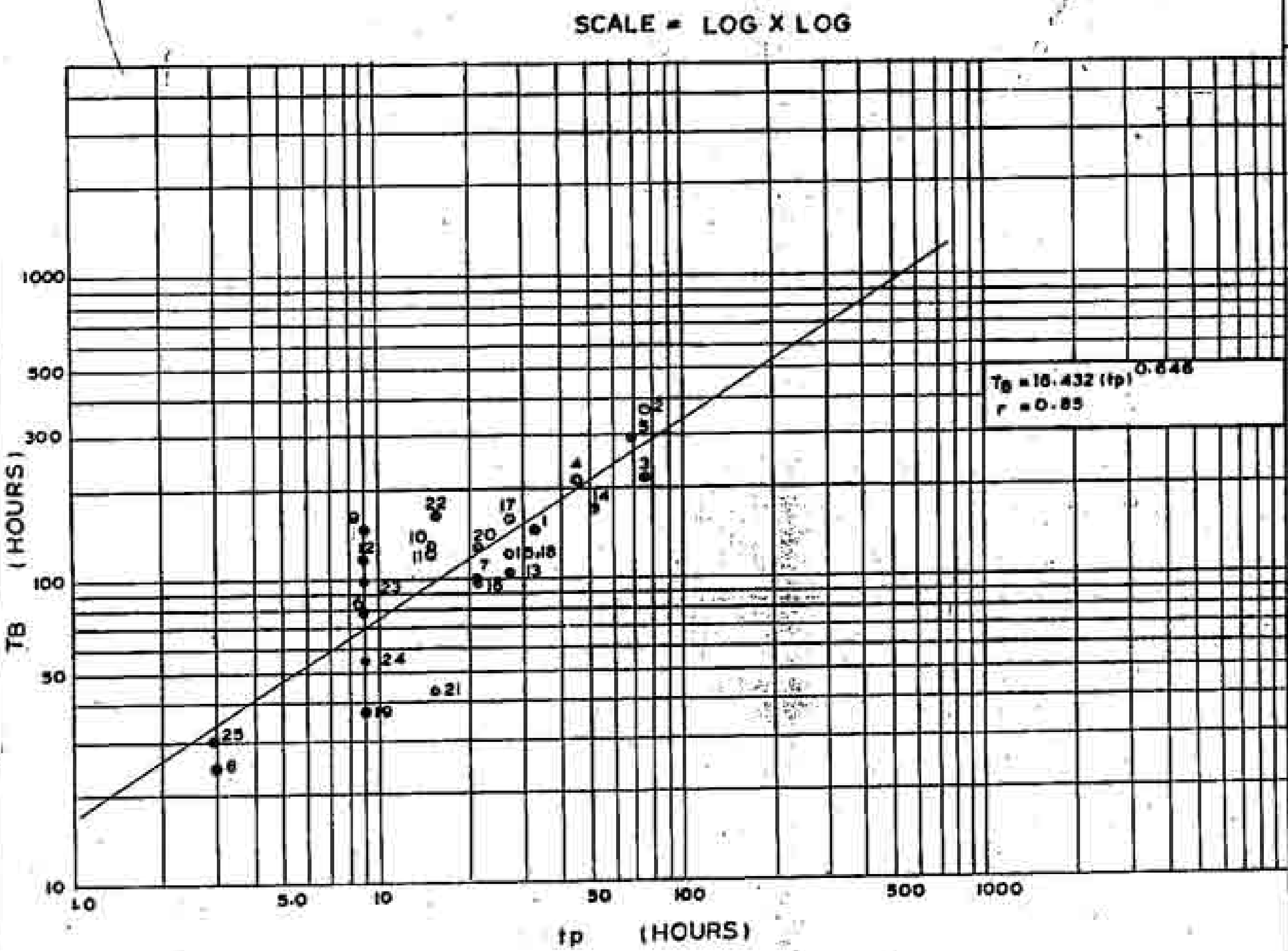
CHECKED BY C.L. BAJAJ

FIG.9



SL. NO.	BRIDGE NO.	tp	T_B
1	6	33	144
2	79A	75	360
3	177	75	216
4	7	45	210
5	187	69	288
6	30	9	78
7	152	21	102
8	48	3	24
9	33	9	144
10	18	15	126
11	3(I)	15	120
12	85	9	114
13	20	27	102
14	9	51	168
15	66	27	120
16	24	21	96
17	141	27	156
18	59	27	120
19	459	9	36
20	23	21	126
21	31	15	42
22	4	15	162
23	3	9	96
24	55	9	54
25	63	3	30

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MIDDLE GANGA PLAINS
SUB ZONE-1(f)
RELATION BETWEEN
T_B AND t_p

DRAWN BY S.N.MALHOTRA | CHECKED C.L.BAJAJ

4.0 DESIGN STORM INPUT

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

4.1 Design Storm Duration

The duration of the storm rainfall which causes the maximum discharge in a drainage basin is called the design storm duration. The design storm duration (T_D) for a catchment may be adopted as per Table A-3 depending upon the range of t_p calculated from equation 3.9.4.

4.2 Rainfall Depth Duration Frequency Studies

India Meteorological Department have conducted this study on the basis of 26 self-recording raingauge stations and 208 ordinary raingauge stations maintained by IMD/States and 15 SRRG stations maintained by Railways in 6 bridge catchments in subzone - 1(f).

The annual maximum series for all the ordinary raingauge stations in and around the subzone were computed for each station from the daily rainfall data of the stations for the period varying from 50 to 70 years of records. The annual extreme value series was subjected to frequency analysis by Gumbel's extreme value distribution and the rainfall estimates for 50-year return periods were computed. The daily values of rainfall estimates were converted into 24-hour rainfall estimates by using the conversion factor of 1.15. These 24-hour rainfall estimates for all the stations in the subzone were plotted on a base map of the subzone and isopluvial map of 50-year return period was drawn and shown in plate-8.

The hourly rainfall data recorded by 26 SRRG stations maintained by I.M.D. for the period were processed by frequency analysis (partial duration series method) and the rainfall estimates for 50-year return period for specified duration namely 1,3,6,9,12,15,18 and 24 hours were computed.

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

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

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

Duration	Ratio
24	1.00
28	0.94
15	0.89
12	0.82
9	0.75
6	0.65
3	0.50
1	0.31

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

The short duration rainfall estimates for various short durations (1,3,6,9,12,15 and 18 hours) can be computed by using the respective ratios. The value of 24-hour rainfall estimates for a particular station for 50-yr. return period can be interpolated from Plate-8 and the short duration rainfall estimates can be obtained by multiplying with the corresponding ratio for that particular short duration obtained from Fig.10.

4.3 Conversion of Point to Areal Rainfall

The short duration rainfall data of only 6 bridge catchments were used for this study. The data of remaining bridge catchments could not be utilised as the period of data was less than 4 years and concurrent years data were not recorded over the stations in a bridge catchment. 2-yr. point rainfall values for specified duration for each station in the catchment were computed by frequency analysis. Arithematic average of 2-yr. point rainfall of all the stations in the catchment was calculated to get the 2-yr. representative point rainfall for the catchment. Events of maximum average depth for a particular duration in each year were selected on the basis of simultaneous occurrence of rainfall at each station in the catchment. The areal rainfall series thus obtained was subjected to frequency analysis and 2 yr. areal rainfall depths for specified durations were computed. The percentage ratio of 2 yr. areal rainfall to 2-yr. representative point rainfall for the catchment was calculated and plotted against the area of the catchment of various durations. The best fit curves were drawn for specified durations on the points obtained for all the catchments. Curves pertaining to percentage ratio of areal to point rainfall vs. catchment area for storm durations of 1,3 & 6 hours are shown in Fig. 11(a) and similar curves for durations of 12 and 24 hours are shown in Fig. 11(b). The areal reduction factor (ARF) for 1-hr., 3-hr., 6-hr., 12-hr. and 24-hr. for areas ranging from 50 to 4,500 sq.km. are given in Table-6.

4.4 Time Distribution of Input Storms

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

1. Rain storm of 2 to 3 hours
2. Rain storm of 4 to 6 hours
3. Rain storm of 7 to 12 hours
4. Rain storm of 13 to 18 hours
5. Rain storm of 19 to 24 hours

About 3240 rain storms of various durations upto 24 hours occurring in various parts of the subzone were analysed based on 216 station year data. Rain storm selected at such stations were grouped under the above 5 categories and plotted on different graphs on dimensionless curves with cumulative percentage of total rainfall along the ordinates and percentage of storm duration along the abscissa. Thus, five different graphs were prepared for each station corresponding to various durations and were then examined. The average time distribution curves for the various durations were drawn for each station. All the average curves for the stations thus obtained were plotted on a single graph and a single average curve for the subzone as a whole was drawn for storms of different durations and are shown in Fig.12(a), (b), (c), (d) and (e).

4.5 100-year 24-hour Point Rainfall Map

Under earlier Section 4.2, Rainfall Depth Duration Fequency Studies 50-yr., 24-hour point rainfall map in plate-9 and 50-year short duration point rainfall to 50-year 24-hr. point rainfall ratios for conversion of 24-hr. point rainfall to 1,3,6,9,12,15 and 18 hrs. were provided for estimation of 50-year flood.

However, those interested in the design flood (100-year flood) 100-year 24-hr. point rainfall map is shown in plate-9. To obtain 6,9,12,15 and 18 hrs. from 100-year 24-hr. rainfall, the ratios given in Section 4.2 may be used. Similarly, Sections 4.3 and 4.4 may be used for conversion of point to areal rainfall and time distribution of input storm respectively. Synthetic unit-graph, design loss rate and base flow will remain the same as in the case of 50-yr. flood.

4.6 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 $q_p = 0.409/(L/\sqrt{S})^{0.456}$ by substituting the known values of L and S for the catchment. Then substitute the calculated value of q_p in the equation $t_p = 1.217/(q_p)^{1.034}$. The value of t_p may be rounded off to the nearest one hour.

The design storm duration T_D is equal to $1.1 \cdot t_p$. For the purpose of actual computation the values T_D for different ranges of t_p (for estimating the 50-yr. 24-hour storm rainfall from the isopluvial map) shown in the following table may be adopted.

t_p range (hrs.)	T_D (hrs.)
3 to 5	6
6 to 11	12
12 to 17	18
18 to 72	24

Step (2): Locate bridge site/catchment area under study on the 50-yr., 24-hr. rainfall isopluvial map (plate-8) and obtain the 50-yr.24-hr. point rainfall value.

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

Step (4): Convert the 50-year T_D-hour point rainfall to 50-year T_D-hour areal rainfall by multiplying with the areal reduction factor (ARF) corresponding to catchment area under study and for T_D hour 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), (b), (c), (d) and (e) corresponding to design storm duration, T_D to obtain the depths at 6-hours interval since the unit duration of synthetic U.G. is 6-hours.

Step (6): Obtain the 6-hourly rainfall increments from subtraction of sucessive 6-hours cumulative value of rainfall in Step-5.

5.0 ESTIMATION OF DESIGN FLOOD FOR AN UNGAUGED CATCHMENT

The following procedure is recommended:

Step (1): Determine the Synthetic Unitgraph vide Section 3.9 and 3.10

Step (2): Determine the design storm rainfall input vide Section 4.0

Step (3): Adopt the design loss rate of 0.3 cm/hr. vide Section 3.11.

Step (4): Obtain the hourly rainfall excess units upto the design storm duration T_D by subtracting the design loss rate of 1.8 cm/6-hr. from the 6-hourly rainfall increments in Step-6 of Section 4.6.

Step (5): The peak period (T_m) value is having even number (i.e. multiple of 6 since the unit duration is 6 hours).

Tabulate the U.G. discharge values obtained from Step-1 at 6-hour intervals.

Arrange the rainfall excess increments against the 6-hourly Synthetic U.G. ordinates such that the maximum value of rainfall excess comes against the peak discharge of Synthetic U.G., the next lower value of rainfall excess increment comes against the next lower discharge ordinate and so on upto T_D-hour duration.

The sum of the product of unitgraph ordinates and the rainfall excess as tabulated above gives the 50-year flood peak value after due addition of base flow in Step-9.

However, the subsequent Steps-6 to 10 should be followed for computation of design flood hydrograph.

Step (6): Reverse the sequence of rainfall excess increments obtained in Step-5 which will give the critical sequence of the rainfall excess.

Step (7): Multiply the first 6-hour rainfall excess with the Synthetic U.G. ordinates at 6-hour interval which will give the corresponding direct runoff ordinates. Likewise repeat the procedure with the rest of the 6-hourly rainfall excess increments giving a lag of 6-hours to successive direct runoff ordinates.

Step (8): Add the direct runoff ordinates at 6-hours interval to get the direct runoff hydrograph.

Step (9): Obtain the average base flow of 0.05 cumec/sq.km. vide Section 3.12. Multiply average base flow of 0.05 cumec/sq.km. with the catchment area under study to get the total base flow.

Step (10): Add the total base flow to the direct runoff ordinates at 6-hour interval in Step-8 to get the 50-year flood hydrograph. Plot the hydrograph.

6.0 ASSUMPTIONS, LIMITATIONS AND CONCLUSIONS

6.1 Assumptions

6.1.1 It is assumed that 50-year return period storm rainfall produces 50-year flood.

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

6.1.3 Likely spatial non-uniformity of rainfall due to oblong shapes of most of the catchments has been assumed to be uniform for unitgraph studies.

6.1.4 The hydrological data has been collected in various representative catchments for periods generally ranging from 2 to 11 years during the years 1960 to 1982. Consequent to manmade changes in the catchments and river courses, the pattern of floods had changed considerably. The slope of the land is also very flat in most parts of the subzone and spilling and spreading of flood water are quite common. The results of the analysis contained in the report generally represent the above complex conditions. Due to above factors, the critical design storm duration has been judiciously limited to a maximum value of 24 hours. The data used for storm study had also indicated that the number of storms of more than 24 hours duration are negligible. Therefore, for values of estimated design storm duration (T_D) more than 24 hours, the adopted design storm duration shall be limited to 24 hours.

6.2 Limitations

6.2.1 The data of 25 catchments has been considered for developing generalised approach for a large subzone. Due to inconsistencies of data and non-availability of suitable floods, about 50% of the gauged catchments could not be utilised for developing relationships. This may have introduced some limitations in the study. However, for more reliable relationships, data of more suitable catchments would be desirable.

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

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

6.3 Conclusions

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

6.3.2 The report is generally applicable for the catchment areas ranging from 30 sq.km. to 4,500 sq.km. However, individual site conditions may necessitate special site study. Engineer-in-charge at site is advised to take a pragmative view while deciding the design discharge of a bridge.

TABLE - 6

AREAL TO POINT RAINFALL
RATIOS (PERCENTAGE)

Area (Sq.Km.	1 hr	3 hr.	6 hr.	12 hr.	24 hr.
50	88	93	95	96	97
100	80	87	90	94	96
150	74	82	87	92	95
200	-	77	84	90	93
250	-	73	82	88	92
300	-	71	80	87	91
350	-	-	78	86	90
400	-	-	77	85	89
450	-	-	76	84	88
500	-	-	76	83	87
600	-	-	-	81	86
700	-	-	-	79	84
800	-	-	-	78	83
900	-	-	-	77	82
1000	-	-	-	76	81
1200	-	-	-	74	79
1400	-	-	-	-	78
1600	-	-	-	-	77
1800	-	-	-	-	76
2000	-	-	-	-	75
2200	-	-	-	-	75
2400	-	-	-	-	74
4500	-	-	-	-	74

7.0 APPLICATION OF SUBZONE-1(f) REPORT TO PLAIN AREAS OF LOWER GANGA PLAINS SUBZONE-1(g)

Lower Ganga Plains subzone-1(g), previously designated as Lower Gangetic Plains subzone-1(g), mainly consists of two distinct parts; hilly areas of Damodar and Subernarekha Basins, and the remaining plain areas. Bifurcation of hilly and plain areas in subzone-1(g) is shown in Plate-10. Report on subzone-1(g) was published and circulated since 1978. Synthetic unitgraph relations were developed for subzone-1(g) on the basis of storm rainfall and runoff analysis of railway bridge catchments having statistical slope steeper to moderate in the hilly areas of the subzone. Small and medium catchments in the plain areas of subzone-1(g) could not be gauged for concurrent rainfall and runoff data and as such the data was not available for analysis. Under this constraint it was assumed that the synthetic unitgraph relations developed for catchments with steeper to moderate slopes may be applied to the plain areas of subzone-1(g).

Flood Estimation Report for the Middle Ganga Plains subzone-1(f) comprises almost of plain areas with flat slopes. The plain areas of lower Ganga Plains in subzone-1(g) as demarcated in Plate-10 are alluvial plains resembling the plain areas of the Middle Ganga Plains subzone-1(f). Isopluvial patterns of storm rainfall for different return periods and for shorter durations are more or less similar for the plain areas of subzone-1(f) and 1(g). Synthetic unitgraph relations developed for subzone-1(f) may be reasonably assumed to apply also to the plain areas of subzone-1(g) as shown in Plate-10.

7.1 Application of Subzone-1(f) Report

For estimation of 50-yr. flood for ungauged or inadequately gauged catchments in plain areas of Lower Ganga Plains subzone-1(g), stepwise procedure in the illustrative example (subzone-1(f)) with the following relevant sections, plates and figures in the Flood Estimation Reports for subzones-1(f) and 1(g) may be followed.

Step No.	Illustrative Example stepwise-1(f) Report	Report with Relevant References
1	2	3
1	Preparation of catchment area plan.	1(f) catchment location in plain areas shown in plate-10 - Sections 3.1 and 3.1.1
2.	Determination of physiographic parameters.	1(f) - Sections 3.1, 3.1.1 to 3.1.3
3.	Determination of unitgraph parameters	1(f)
(i)	By using synthetic relations	1(f) - Table A-2, A-3, Sections 3.8, 3.9 and 3.10.
(ii)	By using Coaxial Diagram	1(f) - Fig. A-2.
4.	Preparation of 6-hr. synthetic unitgraph.	1(f) - Section 3.10

5.	Estimation of Design Storm Duration.	1(f) - Table A-3, Section 4.1
6.	Estimation of point rainfall and areal rainfall.	1(g) - point rainfall vide Figs.12 to 21 in conjunction with Plate-10 of 1(f) showing demarcation of plain areas. Areal rainfall -1(f) table under Section 4.2 or Figs. 11-A and 11-B. Table A-4.
7.	Time distribution of areal rainfall.	1(f) - Fig.12. Section 4.4
8.	Estimation of rainfall excess units.	1(f)-Section 3.11
9.	Estimation of base flow	1(f) - Section 3.12
10.	Estimation of design flood (peak only)	1(f) - Step-5 of Section 5.0
11.	Computation of design flood hydrograph.	1(f) - Steps 6 to 7 of Section 5.0

It may be seen from the above that the methodology for estimation of 50-yr. flood for plain areas in Lower Ganga Plains (Plate-10) based on the "Flood Estimation Report for Subzone-1(f)" using all its Tables, Figures and Plate-10 may be followed except estimation of the 50-yr. point rainfall maps of different durations depicted in Figs. 12 to 21 in the report of Lower Ganga Plains subzone-1(g).

7.2 Application of Flood Formula in Subzone-1(f) Report

Following 50-yr. flood formula developed for subzone-1(f) may also be applied to the plain areas of Lower Ganga Plains subzone-1(g):

$$Q_{50} = 0.409\ K\ A\ R\ (\sqrt{S}/L)^{0.456}$$

In the above formula, R (50-yr. point rainfall) may be obtained from Figs.12 to 21 of 1(g) report corresponding to design storm duration T_D obtained from Table in Step (3) of "Application of Flood Formula" after calculation of t_p in Step (2). All the other parameters like A,L and S, and also coefficient K are same as given in "2. Application of Flood Formula" in subzone-1(f) report.

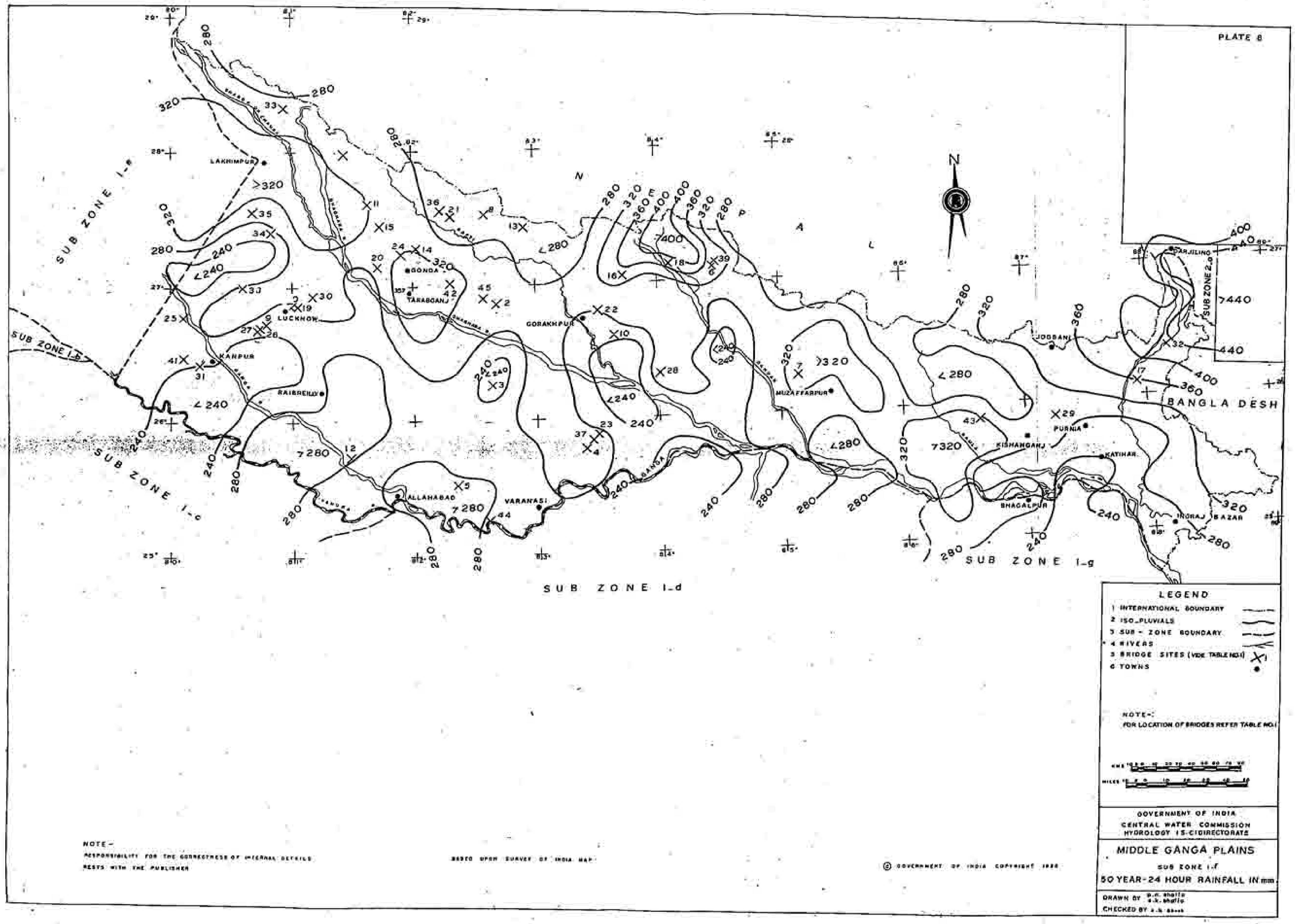

PLATE 8
SUB ZONE I-e
SUB ZONE I-b
SUB ZONE I-c
SUB ZONE I-d
SUB ZONE I-g
SUB ZONE 2-c
N
NEPAL
BANGLA DESH
LAKHIMPUR
LUCKNOW
KANPUR
RAIBREILLY
GONDA
TARABGANJ
GORAKHPUR
ALLAHABAD
VARANASI
MUZAFFARPUR
JOGBANI
DARJILING
PURNIA
KISHANGANJ
KATIHAR
BHAGALPUR
INGRAJ BAZAR
LEGEND
1 INTERNATIONAL BOUNDARY
2 ISO-PLUVIALS
3 SUB-ZONE BOUNDARY
4 RIVERS
5 BRIDGE SITES (VIDE TABLE NO.1)
6 TOWNS
NOTE:-
FOR LOCATION OF BRIDGES REFER TABLE NO.1
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S-C) DIRECTORATE
MIDDLE GANGA PLAINS
SUB ZONE 1-f
50 YEAR-24 HOUR RAINFALL IN mm
DRAWN BY
CHECKED BY
NOTE-
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER
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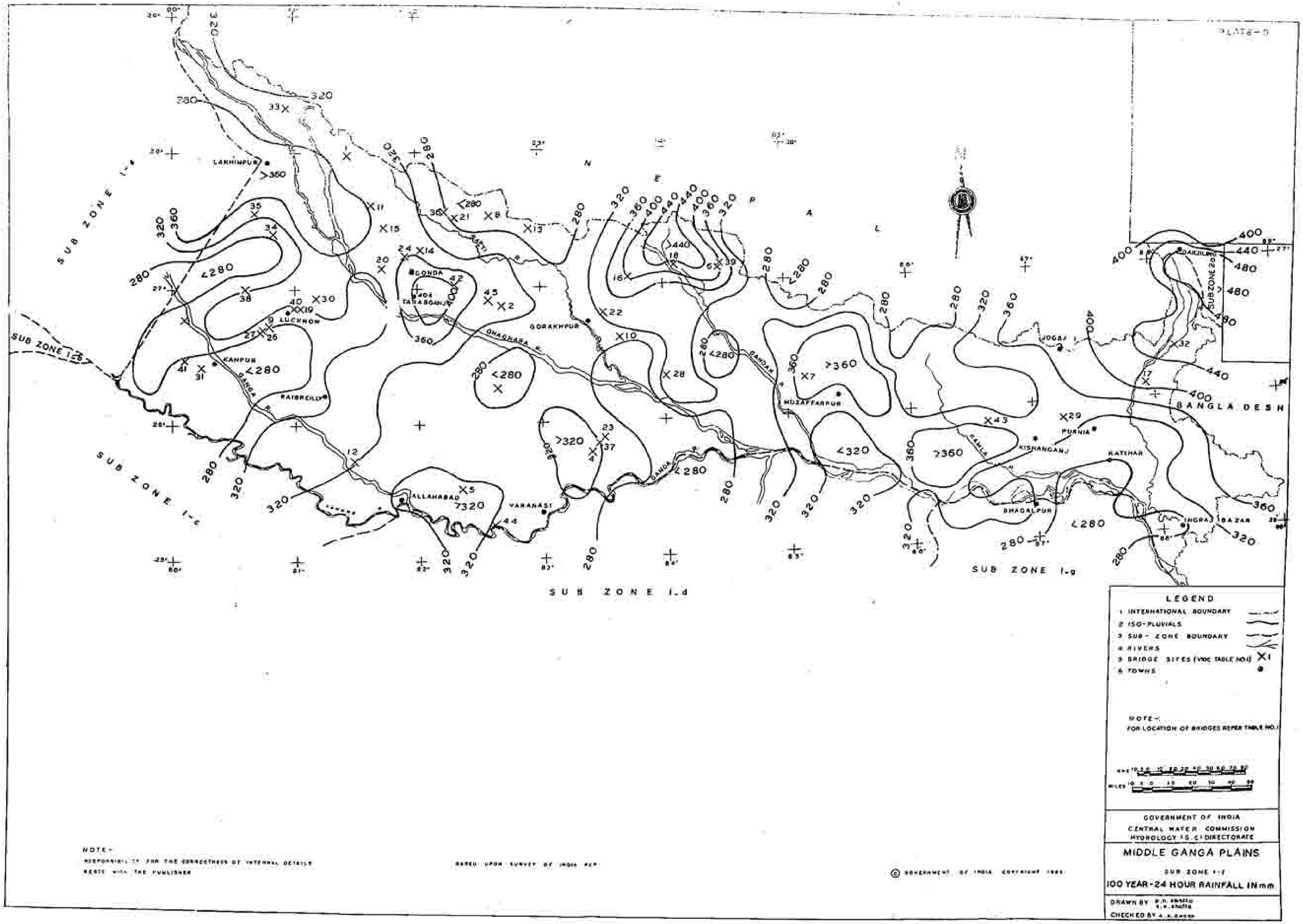
PLATE-5
LEGEND
1 INTERNATIONAL BOUNDARY
2 ISO-PLUVIALS
3 SUB-ZONE BOUNDARY
4 RIVERS
5 BRIDGE SITES (VIDE TABLE NO.1)
6 TOWNS
NOTE:-
FOR LOCATION OF BRIDGES REFER TABLE NO.1
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S.C) DIRECTORATE
MIDDLE GANGA PLAINS
SUB ZONE 1-f
100 YEAR-24 HOUR RAINFALL IN mm
SUB ZONE 1-e
SUB ZONE 1-b
SUB ZONE 1-c
SUB ZONE 1-d
SUB ZONE 1-g
SUBZONE 2(c)
NEPAL
BANGLA DESH
LAKHIMPUR
LUCKNOW
KANPUR
RAIBRELLY
GONDA
TARABGANJ
GORAKHPUR
ALLAHABAD
VARANASI
MUZAFFARPUR
JOGBANI
KISHANGANJ
PURNIA
KATIHAR
BHAGALPUR
DARJILING
GHAGHARA R.
GANGA R.
GANDAK R.
KAMLA R.
YAMUNA
RAPTI R.
NOTE:-
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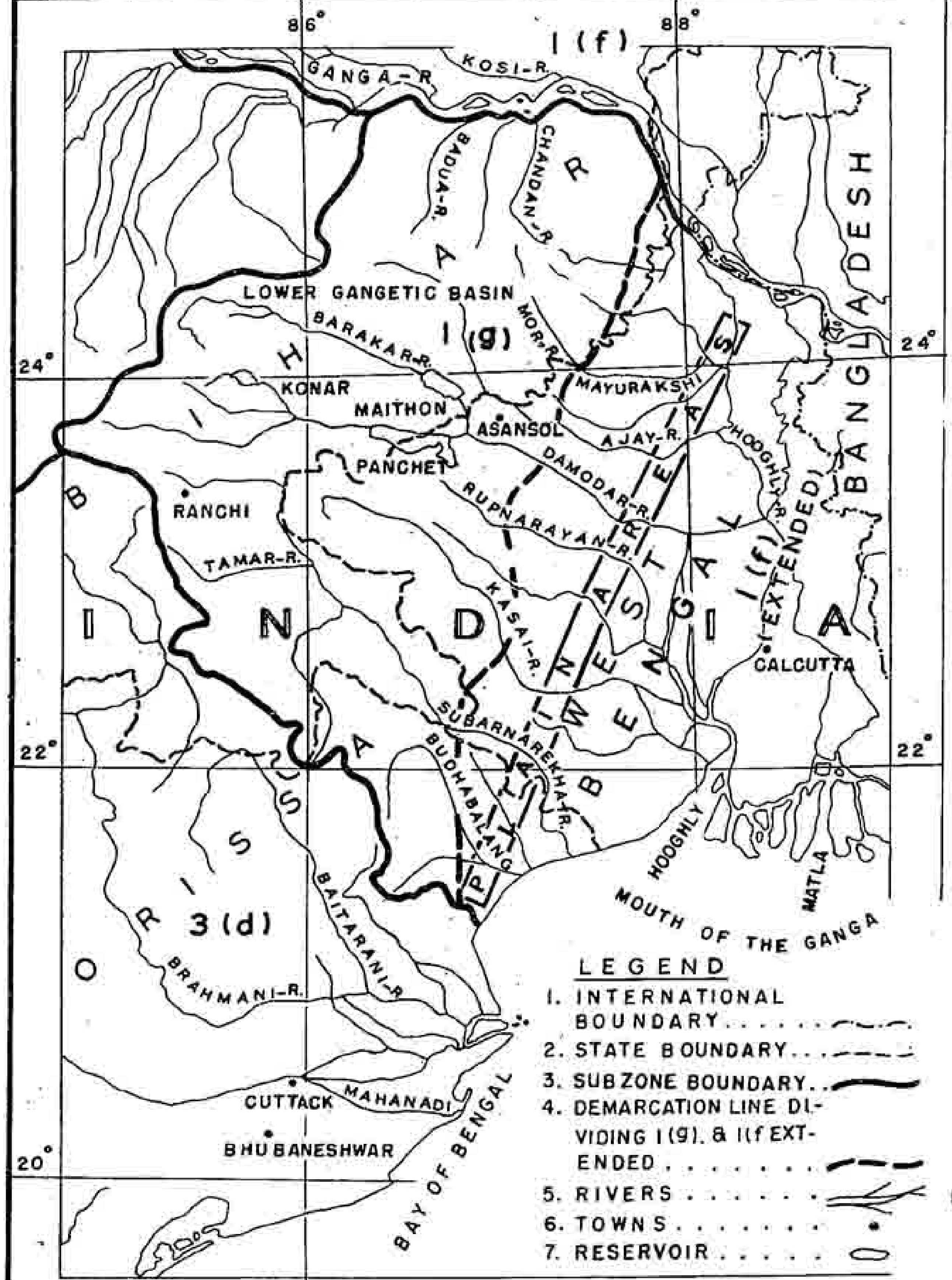
PLATE- 10



EXPLANATORY NOTE :–

1. LOWER GANGETIC PLAINS SUB ZONE I (g) DIVIDED INTO TWO PARTS AND RENAMED AS UNDER :–
   (i) I (g) :- DAMODAR AND SUBARNAREKHA BASINS.
   (ii) I (f– EXTENDED) :- LOWER GANGA PLAINS FORMS A PART OF SUB ZONE - I (f).
2. (i) REPORT ON SUB ZONE I (g) APPLICABLE ONLY TO DAMODAR AND SUBARNAREKHA BASINS.
   (ii) REPORT ON SUB ZONE-I (f) APPLICABLE ONLY TO EXTENDED PORTION OF SUB ZONE-I (f) AS SHOWN IN THIS PLATE.
3. REPORT ON MIDDLE GANGA PLAINS SUB ZONE-I (f) AS APPLICABLE TO EXTENDED PORTION OF SUB ZONE I (f) SUPPLIMENTED WITH 50 YEAR RAINFALL MAPS OF DIFFERENT DURATIONS VIDE FIGURES 12 TO 21 IN THE SUB ZONAL REPORT OF-I (g).
4. PLATE-10 IS REPRODUCED FROM FIGURE - 2 OF REPORT ON I (g).

SCALE :–

KMS. 20 0 20 40 60 80 120 140 160 180 KMS.

MILES 10 0 20 40 60 80 100 MILES

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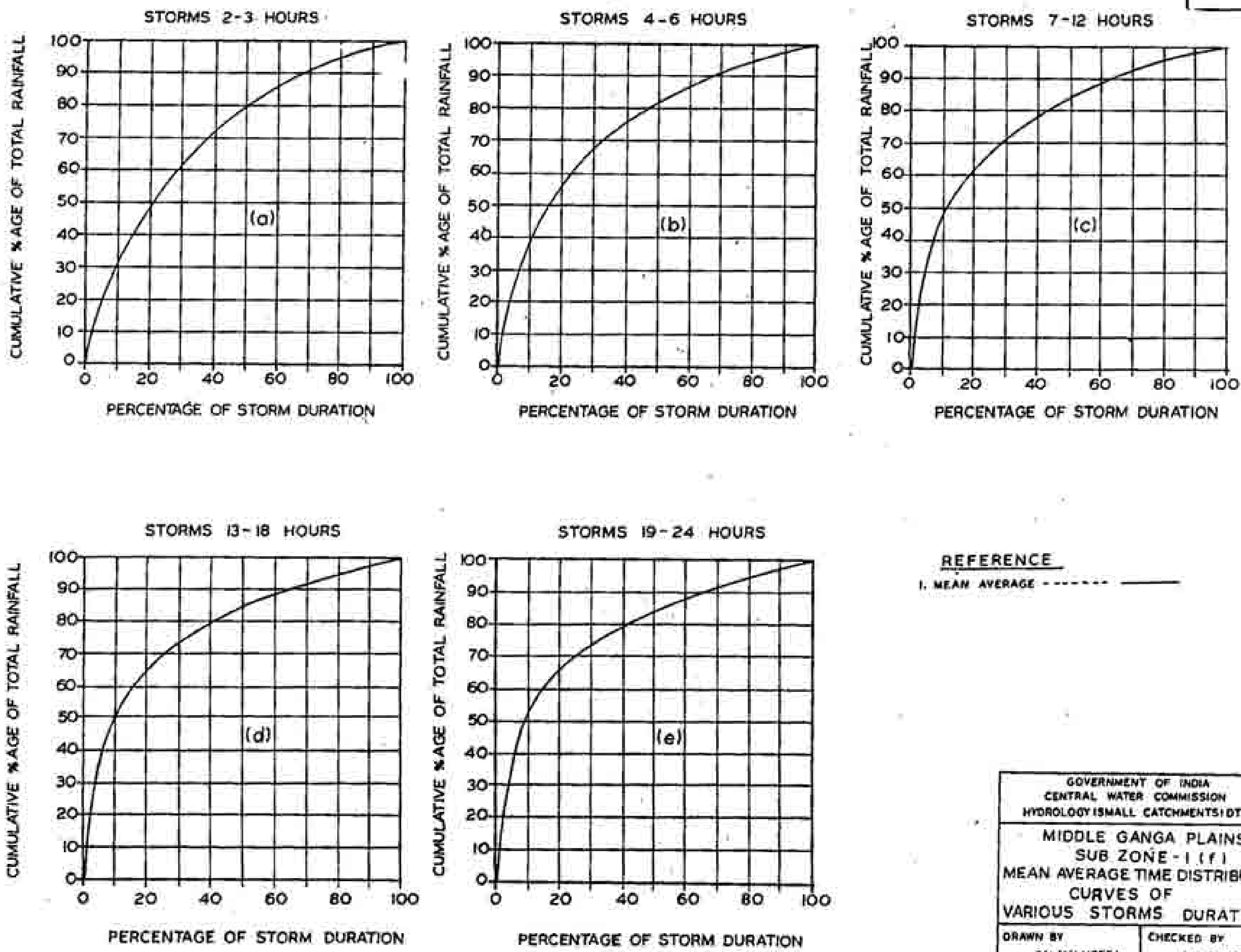
BIFURCATION OF SUB ZONE-I (g) FOR APPLICATION OF REPORTS ON SUB ZONES-I (g) AND I(f).

TRACED :–	CHECKED :–
S. N. MALHOTRA L. P. NAUTIYAL	A. K. GHOSH A. D.

FIG. 12



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MIDDLE GANGA PLAINS
SUB ZONE - 1 (f)
MEAN AVERAGE TIME DISTRIBUTION
CURVES OF
VARIOUS STORMS DURATIONS

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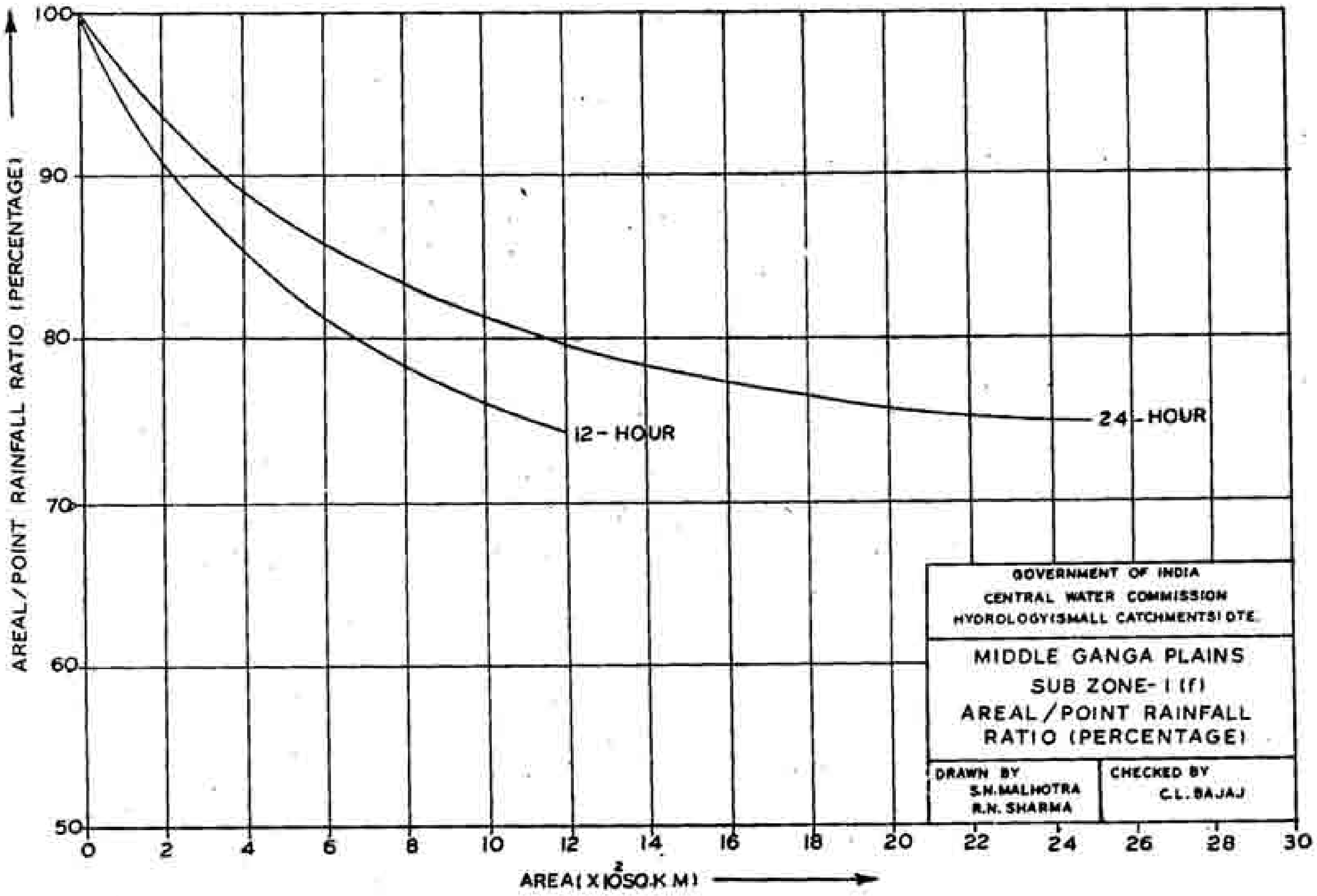
FIG.- 11 (b)



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MIDDLE GANGA PLAINS
SUB ZONE- 1 (f)
AREAL/POINT RAINFALL
RATIO (PERCENTAGE)

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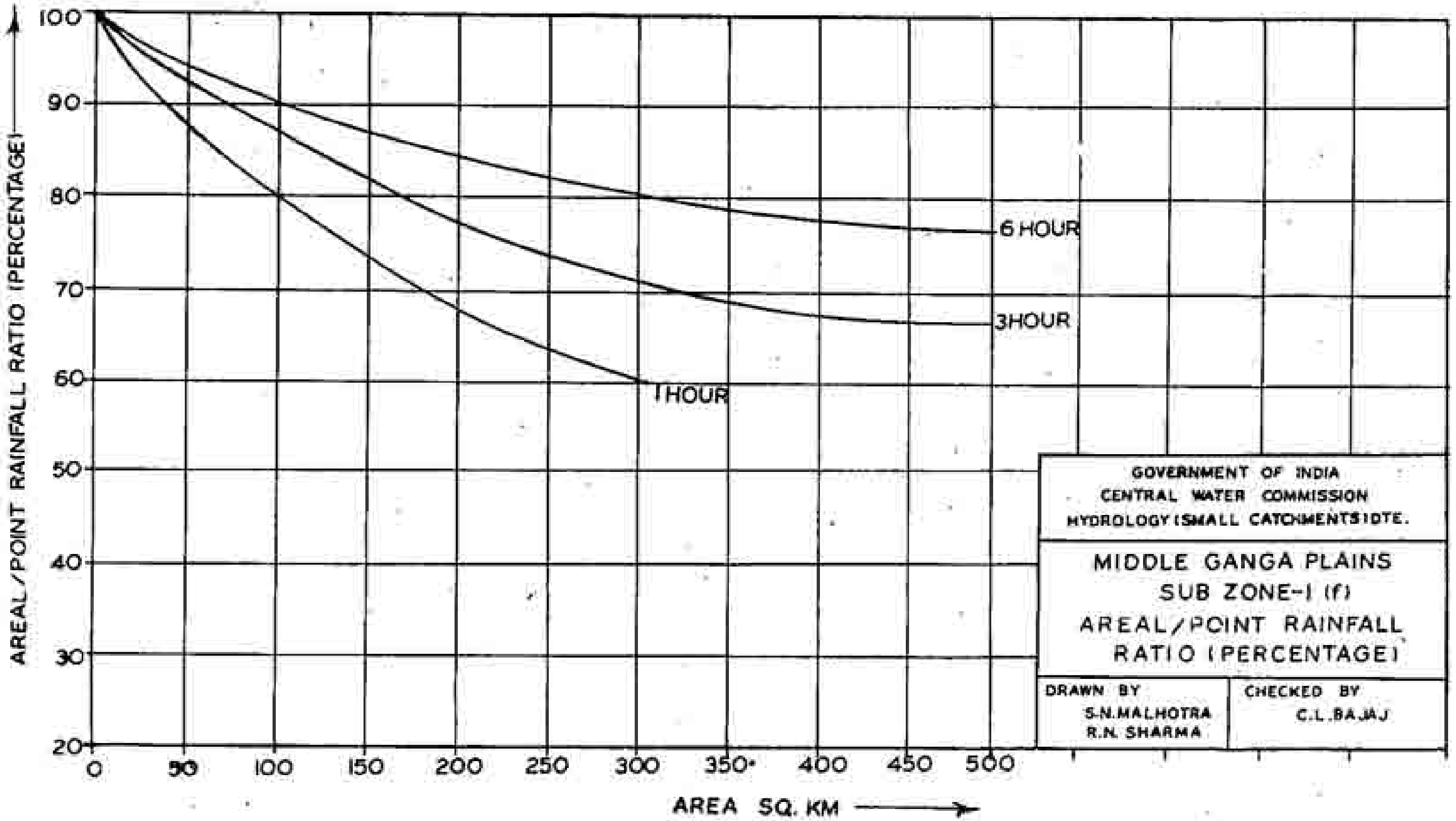
FIG.- II (a)



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MIDDLE GANGA PLAINS
SUB ZONE-1 (f)
AREAL/POINT RAINFALL
RATIO (PERCENTAGE)

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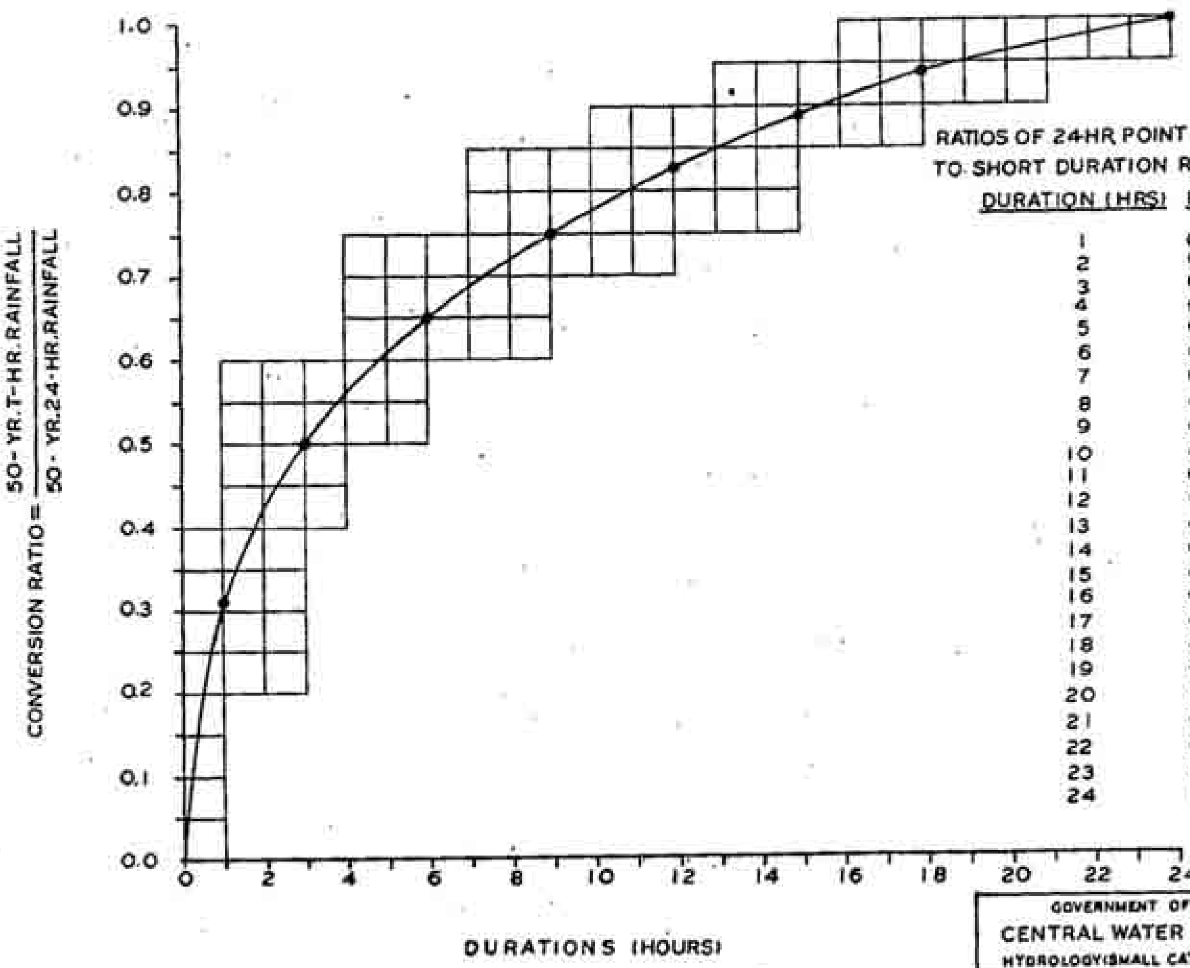
FIG.-10



RATIOS OF 24HR POINT RAINFALL TO SHORT DURATION RAINFALL

DURATION (HRS)	RATIO
1	0.310
2	0.425
3	0.500
4	0.555
5	0.605
6	0.650
7	0.685
8	0.720
9	0.750
10	0.775
11	0.805
12	0.825
13	0.850
14	0.870
15	0.890
16	0.910
17	0.925
18	0.940
19	0.950
20	0.960
21	0.970
22	0.980
23	0.990
24	1.000

GOVERNMENT OF INDIA
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MIDDLE GANGA PLAINS
SUB ZONE- 1(f)

DURATION Vs CONVERSION RATIO

DRAWN BY.- S. N. MALHOTRA, L. P. NAUTIYAL	CHECKED BY.- C.L. BAJAJ

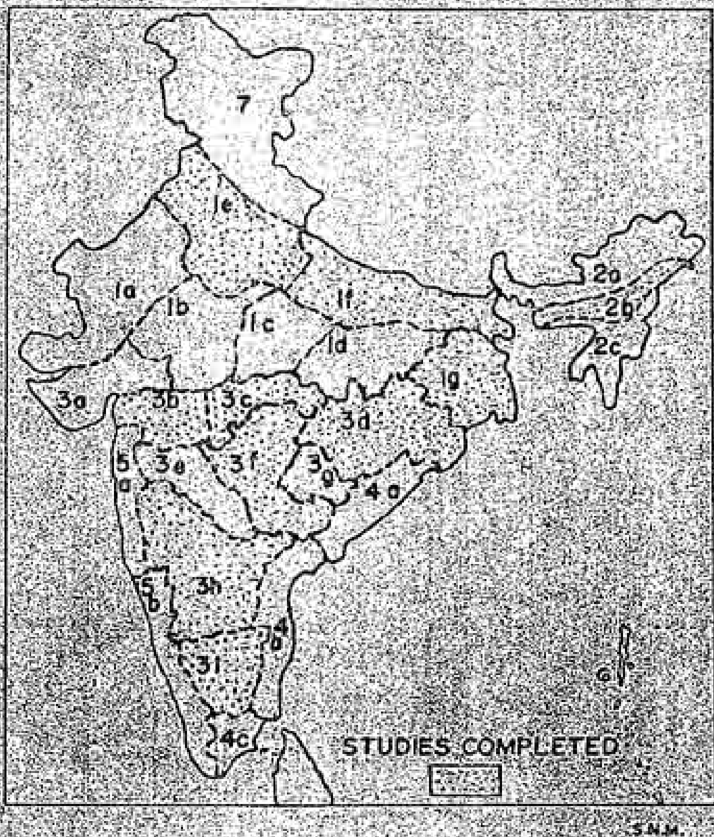
LIST OF FLOOD ESTIMATION REPORTS PUBLISHED

Under Short Term Plan

1. Estimation of Design Flood Peak		(1973)

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 and Tapi subzone	- 3(c)	(1983)
6. Krishna and Penner subzone	- 3(h)	(1983)
7. South Brahmaputra subzone	- 2(b)	(1984)
8. Upper Indo-Ganga Plains subzone	- 1(e)	(1985)



S.N.M.

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