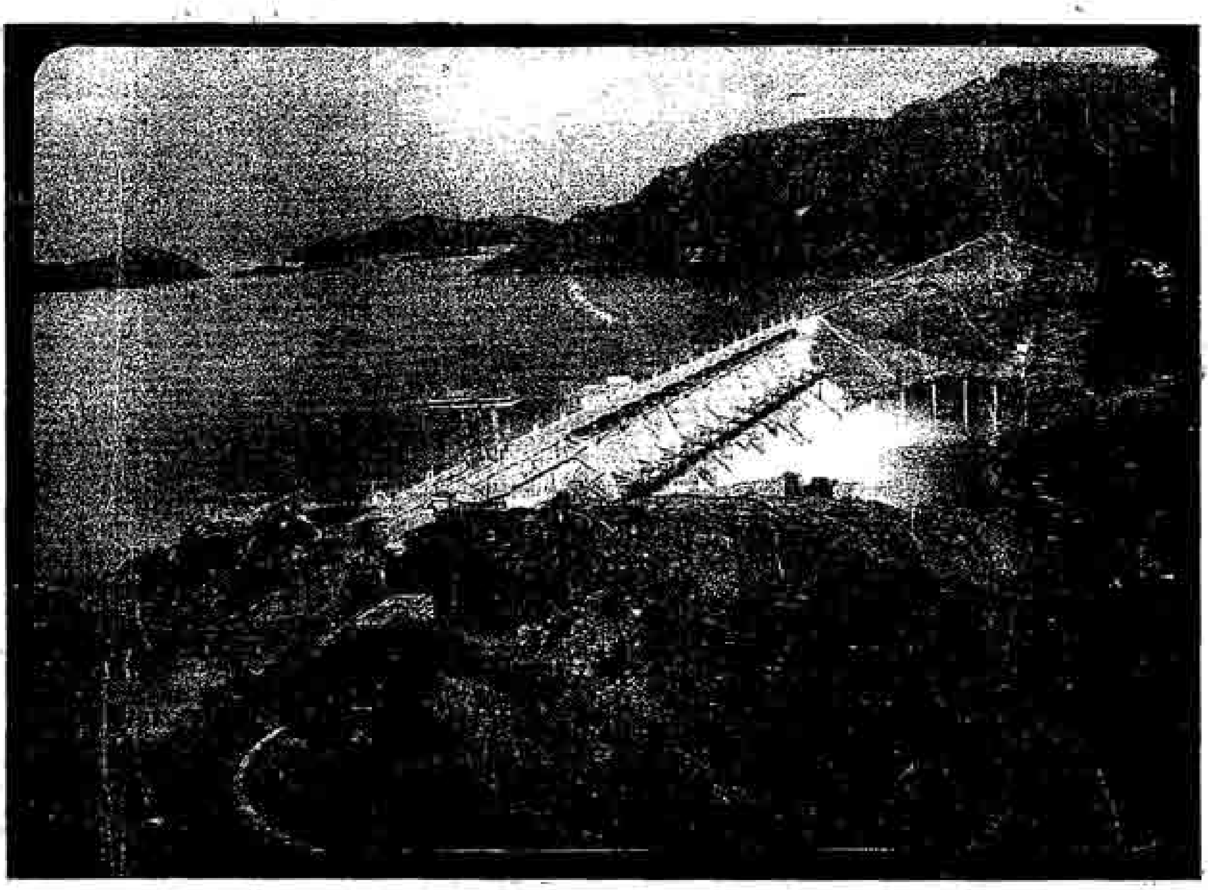
FLOOD ESTIMATION REPORT FOR MAHI & SABARMATI (SUB-ZONE-3a)



● DHAROI DAM ACROSS RIVER SABARMATI-GUJARAT

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

FLOOD ESTIMATION REPORT FOR MAHI AND SABARMATI SUBZONE-3(a) WAS DISCUSSED AND APPROVED BY THE FOLLOWING MEMBERS OF THE PLANNING AND COORDINATION COMMITTEE IN ITS 44TH MEETING HELD ON 7TH AND 8TH AUGUST, 1986 AT GANDHINAGAR HOSTED BY THE GUJARAT IRRIGATION DEPARTMENT.

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FLOOD ESTIMATION REPORT FOR MAHI AND SABARMATI
(SUBZONE - 3a)

A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE
DESIGN OFFICE REPORT NO.M5/13/1986

HYDROLOGY (SMALL CATCHMENTS) DIRECTORATE
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JANUARY 1987

F O R E W O R D

A large number of bridges were designed and constructed in this country in the latter half of the last century on the basis of technical knowledge and with the data then available. Engineering Hydrology in this sphere had since advanced considerably. The Government of India in the Ministry of Railways decided to set up a Committee of Engineers in March 1957 to investigate and review the methods of estimating the design discharge from catchment areas in order to determine the waterway of bridges.

The Committee of Engineers in their report in October, 1959 had recommended the systematic collection of requisite rainfall and runoff data of catchments all over the country for the preparation of flood estimation reports for hydrometeorologically homogeneous regions/zones in the country under long term plan using the rational methodology of recommendations were accepted by the concerned Ministries of the Government of India.

The rainfall and runoff data of the Railway bridge catchments has been collected all over the country by the Ministry of Transport (Railways) under the overall guidance and supervision of the Research Designs and Standards Organisation in a phased manner and the Ministry of Transport (Surface) is also collecting similar data through Central Water Commission. This data is being supplied to Hydrology (small Catchments) Directorate of Central Water Commission for analysis and study to prepare the flood estimation reports under long term plan.

Studies are underway for rational and scientific estimation of floods for safe and yet economic design of structures. Such studies in the form of Flood Estimation Reports for the ten subzones (out of 24 sub Basins proposed) have been published and circulated to user agencies.

This report presents the studies for Mahi and Sabarmati Subzone-3(a) which was discussed and approved by the Planning and Coordination Committee in its 44th meeting held on 7th & 8th August, 1986 at Gandhinagar. The rainfall, gauge and discharge data of selected catchments in Mahi and Sabarmati Subzone was collected by the Western Railways. The rational methodology contained in this report is recommended for estimation of 25-yr, 50-yr and 100-yr flood for the type and relative importance of the structures.

The report is a joint effort by Central Water Commission of the Ministry of Water Resources, Research Designs & Standards Organisation of the Ministry of Transport (Deptt. of Railways), Roads Wing of the Ministry of Transport (Deptt. of Surface Transport) and India Meteorological Department, in pursuance of the recommendations of the Khosla Committee of Engineers. Review of the reports may be possible in the light of advancements in refined techniques in due course when pertinent data becomes available.

Such studies represent a land mark in the country in the field of Hydrology of small and medium catchments.

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P R E F A C E

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

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

The need to evolve a method of estimation of design flood peak of desired frequency knowing the physical characteristics of the catchments and design rainfall has been recognised and a committee of engineers under the chairmanship of Dr. A.N. Khosla have recommended, "Systematic and sustained collection 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 much less than 50 years, the design flood should be 50 year flood determined from probability curve on the basis of recorded floods during the period. In case where the requisite data, as above are not available, the design flood should be decided based on the ground and meteorological characteristics obtained on the basis of design storm."

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

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

Hydrology (Small Catchments) Directorate of CWC has carried out the analysis of selected storm rainfall and floods for the gauged catchments to derive 1-hr. unit hydrographs on the basis of data of rainfall, gauge and discharges collected during the monsoon season. Representative 1-hr. unit hydrographs have been obtained for each of the gauged catchments. The parameters of the catchments and their respective representative unit hydrographs have been correlated by regression analysis and the equations for synthetic unit hydrographs for the subzone were derived. The loss rate and base flow studies were carried out. Methodology for estimation of design flood (50-yr. flood) for ungauged/inadequately gauged catchments has been indicated.

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

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

A. UNDER SHORT TERM PLAN

1. Estimation of Design Flood Peak (1973)

B. UNDER LONG TERM PLAN

1. Lower Gangetic Plains subzone-1(g) (1978)
2. Lower Godavari subzone-3(f) (1981)
3. Lower Narmada & Tapi subzone-3(b) (1982)
4. Mahanadi subzone-3(d) (1982)
5. Upper Narmada and Tapi subzone-3 (c) (1983)
6. Krishna & Penner subzone-3(h) (1983)
7. South Brahmaputra Basin subzone-2(b) (1984)

8. Upper Indo-Ganga Plains subzone-1(e) (1984)
9. Middle Ganga Plains subzone-1(f) (1985)
10. Kaveri Basin subzone-3(i) (1986)
11. Upper Godavari subzone-3(e) (1986)

The present report on Mahi & Sabarmati subzone-3(a) is based on the detailed storm rainfall and runoff studies of 19 representative catchments. The data of each of the 20 catchments collected for a period varying from 4 to 9 years by the Western Railways under the guidance of R.D.S.O. Besides the data of 130 ordinary raingauge stations maintained by IMD/States along with data of 47 self-recording raingauge stations maintained by IMD/Railways has been made use of.

The Mahi and Sabarmati subzone-3(a) report deals with the estimation of design flood of 25-yr. and 50-yr. and 100-yr. return periods for small and medium catchments in this subzone covering the parts of Gujarat, Rajasthan and Madhya Pradesh states based on design storm rainfall and synthetic unitgraph. Formulae for 25-yr., 50-yr. and 100-yr. flood for easy and quick application are given in the report for the preliminary designs only. Illustrative example under (i) detailed and (ii) simplified approaches are also given for application of the report. Besides a formula for fixing the waterway of bridges and cross drainage structures on subzone-3(a) has been given. The utility of the report under section-7 has been dealt with for the guidance of the design engineers.

The report on subzone-3(a) is recommended for estimation of design flood for small and medium catchments varying in areas from 25 to 1500 sq.km. This report may also be used for catchment areas upto 5000 sq.km. judiciously after comparison of available rainfall and runoff data of neighbouring catchments with similar characteristics.

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

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

Sd/-

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C O N T E N T S

LIST OF TABLES, PLATES AND FIGURES

TABLES

PLATES

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SYMBOLS AND ABBREVIATIONS

SYMBOLS

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

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

Q_p	:	Peak Discharge of Unit Hydrograph in cumecs.
W_{50}	:	Width of U.G. measured at 50% maximum Discharge Ordinate (Q_p) in hours
W_{75}	:	Width of the U.G. measured at 75% maximum Discharge Ordinate (Q_p) in hours.
W_{R50}	:	Width of the rising side of U.G. measured at 50% of maximum Discharge Ordinate (Q_p) in hours.
W_{R75}	:	Width of the rising side of U.G. measured at 75% of maximum Discharge Ordinate (Q_p) in hours
Q_{25}, Q_{50} and Q_{100}	:	Maximum Flood Discharge with return periods of 25-yr, 50-yr and 100-yr respectively in cumecs.
R_{25}, R_{50} and R_{100}	:	Point Storm Rainfall Values with return periods of 25-yr, 50-yr and 100-yr respecitvely in cms.
E.R.	:	Effective Rainfall in cms
S.R.H. (D.R.H.)	:	Surface Runoff Hydrograph (Direct Runoff Hydrograph)
ARF	:	Areal Reduction Factor
%	:	Percent
Σ	:	Summation

ABBREVIATIONS

Cumecs	:	Cubic metres per second
mm	:	Millimetres
cms	:	Centimetres
Hr.	:	Hour
M	:	Metres
Min.	:	Minutes
Km.	:	Kilometres
Sq.km.	:	Square Kilometres; Km^2
In.	:	Inches
Sec.	:	Seconds

Sq.	:	Square
M.O.T. (DOR)	:	Ministry of Transport (Deptt. of Rlys.)
R.D.S.O.	:	Research Designs & Standards Organisation (Ministry of Railways), Lucknow.
H(SC), CWC	:	Hydrology (Small Catchments) Directorate, Central Water Commission, New Delhi.
I.M.D.	:	India Meteorological Department
M.O.T. (DOST)	:	Ministry of Transport (Department of Surface Transport)

INTRODUCTION

Flood Estimation Report for Mahi and Sabarmati subzone-3(a), presented herein, furnishes the rational methodology to estimate the design flood for fixing the waterway of bridges, culverts and cross drainage structures.

Flood Frequency Formulae to estimate 25-yr., 50-yr. and 100-yr. flood are given to create interest for the users.

After the sets of N-year flood formulae, the reports consists of three main parts. The first two parts 'A' & B' pertain to "Application of the Report" with (A) Detailed and (B) Simplified Approach. The third part (C) is to main report of eight sections dealing with general features of Mahi and Sabarmati, nature and period of data collected, analysis of storm rainfall and flood events to derive the unitgraph, relationships between physiographic and unitgraph for ungauged catchment, design storm rainfall, design loss, base flow, computation of design flood peak, hydrograph for ungauged catchments, formulae for linear waterway of the cross drainage structures, utility of the report and finally assumptions and conclusions of the report.

The report herein recommends the estimation of design flood for small and medium catchments varying in size from 25 to 1500 sq.km. Further the report may be used for larger catchments upto 5000 sq.km. based on sound judgement and considering the data of neighbouring catchments also.

SUMMARY OF FLOOD FREQUENCY FORMULAE

$$Q_{25} = \frac{1.005(A)^{0.978}(S)^{0.251}(R_{25})^{1.190}}{(L)^{0.618}} \qquad r = 0.993$$

$$Q_{50} = \frac{1.164\,(A)^{0.947}\,(S)^{0.242}\,(R_{50})^{1.143}}{(L)^{0.566}} \qquad r = 0.947$$

$$Q_{100} = \frac{1.161\,(A)^{0.960}\,(S)^{0.241}\,(R_{100})^{1.126}}{(L)^{0.568}} \qquad r = 0.994$$

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

A is catchment area upto the point of study in sqkm.

L is length of longest stream in km.

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

R_{25}, R_{50} and R_{100} are the design storm point rainfall values in cms. for the design storm duration $T_D = T_B = 5.452\ (L/\sqrt{S})^{0.360}$ in hrs. The rainfall values are found after locating the catchment on the isopluvial maps (Plates 9,10 & 11).

Note: (i) Application of these formulae are illustrated in Simplified Approach.

(ii) Flood estimates from the above formulae are to be used for PRELIMINARY DESIGN ONLY.

(iii) r = correlation coefficient

APPLICATION OF REPORT

(A) Detailed Approach

The flood estimation report for Mahi and Sabarmati subzone-3(a) 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 catchment area plan of the ungauged catchment in question.

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

iii) Determination of 1-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 unitgraph at 50% and 75% of Q_p (W_{50} and W_{75}), widths of the rising limb of U.G. at 50% and 75% of Q_p (W_R50 and W_R75) and time base of unitgraph (T_B).

iv) 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 effective rainfall units after substraction 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.

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

Illustrative Example

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

i)	Name & number of subzone	: Mahi & Sabarmati Subzone-3(a)
ii)	Name of site (i.e.point of study)	: Railway Bridge No.129
iii)	Name of railway section	: Dehod-Ratlam
iv)	Name of Tributary	: Kali Nadi
v)	Shape of the catchment	: Oblong
vi)	Site location	: 22^{o} 52' 00" (Latitude) 74^{o} 22' 00" (Longitude)
vii)	Topography	: Moderately steep slope

The procedure is explained stepwise:

Step-1: Preparation of Catchment Area Plan

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

Step-2: Determination of Physiographic Parameters

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

i) Area (A) : 136.36 sqkm

ii) Length of the longest stream (L): 33.50 km

iii) Equivalent stream slope (S) : 3.26 m/km

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

(a) By Graphical Method

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

(b) By Mathematical Calculation

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

Step-3: Determination of Synthetic 1-hr Unitgraph Parameters

The equations 3.9.3 to 3.9.11 in section 3.9 were used to compute the unitgraph parameters with the known values of A, L and S as under: ~~1.331~~/

i) t_p	$= 0.433(L/\sqrt{S})^{0.704}$		3.9.3
	$= 0.433(33.50/\sqrt{3.26})^{0.704}$	$= 3.38$ hrs. rounded off to 3.5 hrs.	
ii) q_p	$= 1.161/(t_p)^{0.635}$		3.9.4
	$= 1.161/(3.5)^{0.635}$	$= 0.254$ cumec/sqkm	
iii) W_{50}	$= 2.284/(q_p)^{1.00}$		3.9.5
	$= 2.284/(0.254)^{1.00}$	$= 4.36$ hrs	
iv) W_{75}	$= 1.331/(q_p)^{0.991}$		3.9.6
	$= 1.331/0.254)^{0.991}$	$= 2.52$ hrs	
v) W_{R50}	$= 0.827/(q_p)^{1.023}$		3.9.7
	$= 0.827/(0.254)^{1.023}$	$= 1.60$ hrs	
vi) W_{R75}	$= 0.561/(q_p)^{1.037}$		3.9.8
	$= 0.561/(0.254)^{1.037}$	$= 1.10$ hrs	
vii) T_B	$= 8.375(t_p)^{0.512}$		3.9.9
	$= 8.375(3.5)^{0.512}$	$= 15.90$ hrs say 16 hrs	
viii) T_m	$= t_p + t_r/2$		3.9.10
	$= 3.5 + ½$	$= 4.0$ hrs	
ix) Q_p	$= q_p \times A$		3.9.11
	$= 0.254 \times 136.36$	$= 71.50$ cumecs	

Step-4: Drawing of a Synthetic Unitgraph

Estimated parameters of unitgraph in Step-3 were plotted to scale on a graph paper as shown in Fig.A-2. The plotted points were joined to draw synthetic unitgraph. The discharge ordinates (Q_i) of the unitgraph at $t_i = t_r = 1$ hr interval were summed up i.e. $\sum Q_i t_i = 378.8$ cumec/hr as shown in Fig. A-2 and compared with the volume of 1.00 cm Direct Runoff Depth over the catchment with the formula $\sum Q_i t_i = 2.78\, A.d/t_i$

where A = catchment area in sqkm

d = 1.0 cm depth

$t_i = t_r$ (the unit duration of the UG) = 1.00 hr

$$\sum Q_i t_i \frac{A x d}{0.36 x\ tr} = \frac{136.36 \times 1}{0.36 \times 1} = 378.8$$

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

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

Step-5 : Estimation of Design Storm Duration

The design storm duration (T_D) = T_B = 16.00 hrs

Step-6 : Estimation of Point Rainfall and Area Rainfall

The catchment under study was located on Plate-10 showing 50-yr 24-hr point rainfall. 50-yr 24-hr point rainfall = 32.0 cm. Conversion factor of 0.905 was read from Fig. 10 in section 4.2 for conversion of 50-yr 24-hr point rainfall to 50-yr 16-hr point rainfall since T_D = 16 hrs. 50-yr. 16-hr point rainfall = 32.00 x 0.905 = 28.96 cm.

Areal Reduction Factor of 0.915 corresponding to a catchment area of 136.36 sqkm for T_D = 16 hrs was interpolated from Table-4 or Fig.11(b) in section 4.3 for conversion of point to areal rainfall. 50-yr 16-hr areal rainfall = 28.96 x 0.915 = 26.50 cm.

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

Step-7 : Time Distribution of Areal Rainfall

50-yr 16-hr areal rainfall = 26.50 cm was distributed with the distribution coefficients (Col. 16 of Table A-2) or from mean average time distribution curve for storms of 13-18 hrs in Fig. 12 (c) corresponding to 16-hrs to get 1-hr rainfall increments as follows:

Durations (hr)	Distribution co-efficients	Storm rainfall (cm)	1-hr rainfall increment (cm)
(1)	(2)	(3)=(2)x26.50	(4)
1	0.28	7.42	7.42
2	0.41	10.86	3.44
3	0.53	14.04	3.18
4	0.60	15.90	1.86
5	0.66	17.49	1.59
6	0.73	19.34	1.85
7	0.77	20.40	1.06
8	0.82	21.73	1.33
9	0.86	22.79	1.06
10	0.88	23.32	0.53
11	0.91	24.11	0.79
12	0.94	24.91	0.80
13	0.96	25.44	0.53
14	0.98	25.97	0.53
15	0.99	26.23	0.26
16	1.00	26.50	0.27

Step-8 : Estimation of Effective Rainfall Units

Design loss rate of 0.45 cm/hr under section 3.11 has been adopted.

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

Durations (hr)	1-hr rainfall (cm)	Design loss Rate (cm/hr)	1-hr Effective Rainfall (cm)
(1)	(2)	(3)	(4)
1	7.42	0.45	6.97
2	3.44	"	2.99
3	3.18	"	2.73
4	1.86	"	1.41
5	1.59	"	1.14
6	1.85	"	1.40
7	1.06	"	0.61
8	1.33	"	0.88
9	1.06	"	0.61
10	0.53	"	0.08
11	0.79	"	0.34
12	0.80	"	0.35
13	0.53	"	0.08
14	0.53	"	0.08
15	0.26	"	-
16	0.27	"	-

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

Step-9 : Estimation of Base Flow

The design base flow is computed by the following formulae vide section 3.12

$$q_b = 0.109 / A^{0.126}$$

$$q_b = \frac{0.109}{(136.36)^{0.126}} = 0.059 \text{ cumec/sqkm}$$

Total Base Flow = 136.36 x 0.059 = 8.04 cumecs

Step-10 : Estimation of 50-Yr Flood (Peak only)

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

Time	U.G. Ordinate (cumecs)	1-hr. Effective Rainfall (cm)	Direct Runoff (cumecs)
(1)	(2)	(3)	(4)
1	9.00	0.34	3.06
2	25.00	1.14	29.07
3	58.00	2.73	158.34
4	71.50	6.97	498.35
5	61.00	2.99	182.39
6	44.50	1.41	62.74
7	32.70	1.40	45.78
8	24.50	0.88	21.56
9	18.00	0.61	10.98
10	12.70	0.61	7.75
11	9.50	0.35	3.32
12	5.70	0.08	0.46
13	3.50	0.08	0.28
14	2.00	0.08	0.16
			1024.24
		Base Flow	8.04
		50-Yr Flood Peak	1032.28 cumecs

Those interested in computation of design flood hydrograph may go to Step-11.

Step-11: Computation of Design Flood Hydrograph

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

For computation of design flood hydrograph, the U.G. ordinates for 1-hr interval were tabulated in col.(2) of Table A-3 against time (hrs) in col.(1). The critical sequence of 1-hr effective rainfall units were entered in col.(3) to (16) horizontally as shown in Table A-3. The direct runoff resulting from each of the 1-hr effective rainfall unit was obtained by multiplying the 1-hr effective rainfall with the synthetic 1-hr U.G. ordinates in col. (2) and the direct runoff values were entered in vertical columns against each unit with a successive lag of 1-hr since the unit duration of S.U.G. is 1-hr. The direct runoff so obtained are shown in col.(3) to (16). The direct runoff were added horizontally and the total direct runoff is shown in col.(17). The total base flow of 8.04 cumecs was entered in col.(18). Col.(19) gives the addition of col.(17) and col.(18) to get the design flood hydrograph ordinates. The total discharge in col.(19) were plotted against time in col.(1) to get the design flood hydrograph in Fig. A-3.

Table A-1 :COMPUTATION OF EQUIVALENT SLOPE (S) OF BRIDGE NO. 129

SUB-ZONE -3(a) C.A. .... 136.36 Sq.Km.

Sl.No.	Reduced distance starting from Bridge Site	Reduced levels of river bed	Length of each segment	Height above *datum (D_i)= difference between the datum & its R.L.	$D_{i-1}+D_i$	$L_i(D_{i-1}+D_i)$
	(K.M.)	(M)	(K.M.)	(M)	(M)	(K.M. x M)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	0	* 265.00	0	0	0	0
2.	6.72	280.33	6.72	15.33	15.33	103.02
3.	14.40	300.65	7.68	35.65	50.98	391.53
4.	19.68	320.97	5.28	55.97	91.62	483.75
5.	24.48	340.57	4.80	75.57	131.54	631.39
6.	27.36	362.21	2.88	97.21	172.78	497.61
7.	29.76	380.44	2.40	115.44	212.65	510.36
8.	31.68	401.95	1.92	136.95	252.39	484.59
9.	32.64	418.26	0.96	153.26	290.21	278.60
10.	33.50	437.96	0.86	172.96	326.22	280.55
				$\sum Li(D_{i-1}+Di)$	=	3661.40

$$\text{Eq.Slope} = \frac{\sum Li\,(D_{i-1}+Di)}{L^2} = \frac{3661.40}{(33.5)^2} = 3.26 \text{ M/Km.}$$

* Datum = 265.00 i.e. Reduced level of river bed at the stage of study.

TABLE-A-2 : TIME DISTRIBUTION COEFFICIENTS OF AREAL RAINFALL
MAHI AND SABARMATI BASIN, SUBZONE-3(a)

Time in hours	Distribution Coefficient for Design Storm Duration of 2-24 hrs.																							Time in hours
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
24																							1.00	24
23																						1.00	0.99	23
22																					1.00	0.99	0.98	22
21																				1.00	0.99	0.98	0.97	21
20																			1.00	0.98	0.98	0.97	0.95	20
19																		1.00	0.99	0.97	0.96	0.95	0.94	19
18																	1.00	0.98	0.98	0.96	0.95	0.94	0.93	18
17																1.00	0.99	0.97	0.97	0.95	0.93	0.92	0.90	17
16															1.00	0.99	0.97	0.96	0.95	0.93	0.90	0.89	0.87	16
15														1.00	0.99	0.98	0.96	0.94	0.93	0.90	0.88	0.86	0.84	15
14													1.00	0.98	0.98	0.97	0.94	0.91	0.89	0.88	0.85	0.84	0.82	14
13												1.00	0.98	0.97	0.96	0.94	0.93	0.68	0.86	0.94	0.83	0.80	0.78	13
12											1.00	0.98	0.97	0.96	0.94	0.93	0.90	0.85	0.84	0.82	0.80	0.78	0.77	12
11										1.00	0.99	0.96	0.94	0.92	0.91	0.89	0.87	0.82	0.80	0.78	0.77	0.76	0.74	11
10									1.00	0.99	0.98	0.94	0.92	0.91	0.88	0.86	0.85	0.78	0.76	0.75	0.74	0.73	0.71	10
9								1.00	0.99	0.97	0.96	0.91	0.89	0.87	0.86	0.83	0.82	0.76	0.74	0.72	0.71	0.69	0.67	9
8							1.00	0.98	0.97	0.96	0.93	0.87	0.86	0.83	0.82	0.80	0.76	0.72	0.70	0.68	0.67	0.65	0.63	8
7						1.00	0.98	0.96	0.95	0.92	0.88	0.83	0.82	0.79	0.77	0.76	0.73	0.66	0.65	0.63	0.62	0.61	0.59	7
6					1.00	0.98	0.96	0.93	0.90	0.86	0.84	0.79	0.76	0.75	0.73	0.70	0.68	0.63	0.61	0.59	0.58	0.57	0.55	6
5				1.00	0.97	0.96	0.92	0.86	0.84	0.82	0.79	0.72	0.70	0.68	0.66	0.64	0.62	0.56	0.55	0.53	0.52	0.51	0.50	5
4			1.00	0.96	0.93	0.87	0.84	0.82	0.77	0.75	0.73	0.66	0.64	0.62	0.60	0.58	0.57	0.50	0.48	0.47	0.46	0.43	0.42	4
3		1.00	0.95	0.93	0.87	0.80	0.74	0.73	0.71	0.67	0.65	0.58	0.56	0.55	0.53	0.52	0.51	0.41	0.40	0.39	0.38	0.36	0.35	3
2	1.00	0.94	0.88	0.82	0.76	0.68	0.66	0.60	0.58	0.57	0.52	0.47	0.45	0.43	0.41	0.40	0.39	0.33	0.32	0.31	0.30	0.28	0.27	2
1	0.87	0.75	0.68	0.61	0.54	0.50	0.43	0.42	0.39	0.37	0.36	0.32	0.30	0.29	0.28	0.24	0.22	0.22	0.21	0.18	0.16	0.14	0.13	1

Note : Hourly rainfall distribution coefficients are given in the vertical columns for various design storm durations from 2 to 24 hrs.

TABLE A-3: COMPUTATION OF DESIGN FLOOD HYDROGRAPH

SUBZONE-3(a) RIVER - KALINADI SITE - RAILWAY BRIDGE NO. 129 C.A. - 136.36 SQKM

Time (hrs.)	1-hr Synthetic Unit-graph (cumecs)	EFFECTIVE RAINFALL UNITS (cm)														Total Direct Runoff (cumecs)	Base Flow (cumecs)	Flood (cumecs)	Remarks
		0.08	0.08	0.08	0.35	0.61	0.61	0.88	1.40	1.41	2.99	6.97	2.73	1.14	0.34				
		DIRECT RUNOFF (cumecs)																	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
0	0	0.00														0.00	8.04	8.04	
1	9.00	0.72	0.00													0.72	8.04	8.76	
2	25.50	2.04	0.72	0.00												2.76	8.04	10.80	
3.	58.00	4.64	2.04	0.72	0.00											7.40	8.04	15.44	
4.	71.50	5.72	4.64	2.04	0.12	0.00										12.52	"	20.56	
5.	61.00	4.88	5.72	4.64	8.93	6.49	0.00									30.66	"	38.70	
6.	44.50	3.56	4.88	5.72	20.30	15.56	6.49	0.00								56.51	"	64.55	
7.	32.70	2.62	3.56	4.88	25.03	35.38	15.56	7.92	0.00							94.95	"	102.99	
8.	24.50	1.96	2.62	3.56	21.35	43.62	35.38	22.44	12.60	0.00						143.53	"	151.57	
9.	18.00	1.44	1.96	2.62	15.58	37.21	43.62	51.04	35.70	1.99	0.00					191.16	"	199.20	
10.	12.70	1.02	1.44	1.96	11.45	27.15	37.21	62.92	81.20	35.96	26.91	0.00				287.22	"	295.26	
11.	9.50	0.76	1.02	1.44	8.58	19.95	27.15	53.88	100.10	81.78	78.25	48.58	0.00			419.29	"	427.33	
12.	5.70	0.46	0.76	1.02	6.30	14.95	19.95	39.16	85.40	100.82	173.42	177.74	24.57	0.00		644.55	"	652.59	
13.	3.50	0.28	0.46	0.76	4.45	10.98	14.95	28.78	62.30	86.01	213.79	404.26	69.62	10.26	0.00	909.90	"	917.94	
14.	2.00	0.16	0.28	0.46	3.32	7.75	10.98	21.56	45.78	62.74	182.39	498.35	158.34	29.07	8.06	1024.24	"	1032.28	Peak
15.	0.80	0.06	0.16	0.28	2.00	5.80	7.75	15.84	34.30	46.11	133.06	425.17	195.20	66.12	8.67	940.52	"	948.56	
16.	0.00	0.00	0.06	0.16	1.23	3.78	5.80	11.78	25.20	34.55	97.77	310.17	166.53	81.51	19.72	758.26	"	766.30	
			0.00	0.06	0.70	2.14	3.78	8.36	17.78	25.38	73.26	227.92	121.49	69.54	24.31	574.72	"	582.76	
				0.00	0.28	1.22	2.14	5.02	13.30	17.91	53.82	170.77	89.27	50.73	20.74	425.20	"	433.24	
					0.00	0.49	1.22	3.08	7.98	13.40	37.97	125.46	66.89	37.28	15.13	308.90	"	316.94	
						0.00	0.49	1.76	4.90	8.04	28.41	88.52	49.14	27.93	11.12	222.56	"	230.60	
							0.00	0.70	2.80	4.94	17.04	66.22	34.67	20.52	8.33	155.22	"	163.26	
								0.00	1.12	2.82	10.47	39.73	25.94	14.48	6.12	100.68	"	108.72	
									0.00	1.13	5.98	24.40	15.56	10.83	4.32	62.22	"	70.26	
										0.00	2.39	13.94	9.56	6.50	3.23	35.62	"	43.66	
											0.00	5.58	5.46	3.99	1.94	16.97	"	25.01	
												0.00	2.18	2.28	1.19	5.65	"	13.69	
													0.63	0.91	0.66	1.59	"	9.63	
														0.00	0.27	0.27	"	8.31	
															0.00	0.00	"	8.04	

(B) SIMPLIFIED APPROACH

1. Flood Formulae by Multiple Regression Analysis Theory

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

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

where A, L, L_c, S and R_N are same as in Flood Peak

Formulae as independent variables. a, b, c, d and e are multiple regression coefficients when a logarithmic transformation is applied to all variables. Principle of least square was used in the regression analysis to get the above relationship.

2. 25-yr, 50-yr and 100-yr Flood Formulae

25-yr, 50-yr and 100-yr flood values for each of the 19 gauged and 4 ungauged catchments for different sizes were computed by detailed approach. Series of Q_{25}, Q_{50}, and Q_{100} for the 23 catchments as dependent variables were related by multiple regression analysis to their respective physiographic parameters A, L, S and meteorologic parameters of point storm rainfall R_{25}, R_{50} and R_{100} as independent variables applying the least square method. The derived flood formulae for Q_{25}, Q_{50} and Q_{100} with their respective coefficient of correlation (r) are as under:

$$Q_{25} = \frac{1.005(A)^{0.978}(S)^{0.251}(R_{25})^{1.190}}{(L)^{0.618}} \qquad r = 0.993$$

$$Q_{50} = \frac{1.164(A)^{0.947}(S)^{0.242}(R_{50})^{1.143}}{(L)^{0.566}} \qquad r = 0.947$$

$$Q_{100} = \frac{1.161(A)^{0.960}(S)^{0.241}(R_{100})^{1.126}}{(L)^{0.568}} \qquad r = 0.994$$

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

A is catchment area upto point of study in sqkm

L is length of longest main stream in km

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

R_{25}, R_{50} and R_{100} are the design storm point rainfall in cms for the design storm duration $T_D = T_B = 5.452(L/\sqrt{S})^{0.360}$ in hrs.

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

The coefficients of correlations for all the above relationships are extremely high and therefore the relationships derived are very reasonable. Further overall range of the + and - percentage variations in the computed flood (Q_{25}, Q_{50} and Q_{100})by both the respective derived formulae and the detailed approach for the 23 catchments shown in the following table are within tolerable limits of ± 25%.

	% variation (+)	Range (-)
Q_{25}	0.23 to 12.33	0.82 to 16.82
Q_{50}	0.71 to 13.47	0.44 to 15.78
Q_{100}	0.75 to 12.51	0.91 to 16.52

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

3. Solution of the Problem

Illustrative example for estimation of 25-yr, 50-yr and 100-yr flood for catchment area upto Rly. Bridge No.129 is considered for solution of the problem by Flood Formulae (Regression Analysis). The physiographic and meteorologic parameters for the catchment under study are:

$A = 136.36$ sqkm, $L = 33.50$ km, $S = 3.26$ m/km, $t_p = 0.433(L/\sqrt{S})^{0.704}$

$T_D = T_B = 8.375(t_p)^{0.512} = 16$ hrs

$R_{25} = 26.24$ cm, $R_{50} = 28.96$, $R_{100} = 33.48$ cm

$$Q_{25} = \frac{1.005(136.36)^{0.978}(3.26)^{0.251}(26.24)^{1.190}}{(33.50)^{0.618}} = 922.26 \text{ cumecs}$$

$$Q_{50} = \frac{1.164(136.36)^{0.947}(3.26)^{0.242}(28.96)^{1.143}}{(33.50)^{0.566}} = 1046.02 \text{ cumecs}$$

$$Q_{100} = \frac{1.161(136.36)^{0.960}(3.26)^{0.241}(33.48)^{1.126}}{(33.50)^{0.568}} = 1228.28 \text{ cumecs}$$

The percentage variations in the values of Q_{25}, Q_{50} and Q_{100} by the detailed approach and the flood formulae with respect to the flood values by detailed approach for the catchment under study are +0.23, +1.34 and +0.75 respectively. Therefore, the flood values for 25-yr, 50-yr and 100-yr return periods estimated by the respective flood formulae are reasonable for adoption in preliminary designs.

1.0 GENERAL DESCRIPTION OF MAHI AND SABARMATI SUBZONE-3(a)

1.1 LOCATION

The Mahi and Sabarmati Subzone-3(a) lies roughly between 69^o to 75^o east Longitude and 21^o to 25^o North Latitude. It covers more than half of Gujarat State and small parts of southern Rajasthan and western Madhya Pradesh States. Some of the important towns and cities are Gandhinagar, Vadodra, Jamnagar, Rajkot, Veraval, Porbandar, Banswara, Dohad Godhra, Deotis, Phalagsia and Durgarpur. The subzone-3(a) is bounded on the north by Luni basin subzone-1(a) on the south by Lower Narmada and Tapi subzone-3(b), on the east by Chambal basin subzone-1(b) and on the west by the Arabian sea. Plate-1 shows the location of Mahi and Sabarmati subzone-3(a) with the appended list of hydrometeorological subzones of India.

1.2 RIVER SYSTEM

Plate-2 shows the river system of the subzone-3(a). The rivers flowing in this subzone are Mahi, Sabarmati, Saraswati and a large number of coastal streams in Kathiawar Peninsula. The drainage area covered by each river system is detailed as under:

Sl.No.	River	Drainage area (sqkm)	
1.	Mahi	36,558	
2.	Sabarmati	22,235	
3.	Saraswati	2,905	
4.	Coastal streams of Kathiawar Peninsula	51,581	
5.	Other area	25,139	
	Total	1,38,418	Say 1,38,400

The total drainage area of Mahi and Sabarmati subzone-3(a) is 1,38,400 sqkm.

The Mahi river flows for a total length of 583 km through the States of Madhya Pradesh, Rajasthan and Gujarat before outflowing into the Gulf of Khambhat. The major tributary of Som joins the right bank of Mahi. Along the left bank of Mahi, Anas and Panam are the major tributaries.

The Sabarmati river outfalls into Gulf of Cambay after traversing a course of 371 km. through Rajasthan and Gujarat States. The major left bank tributaries of Sabarmati are Wakal, Harnav, Hathmati and Watrak. Sei is a major tributary along the right bank of Sabarmati, Wakal, Harnav and Sei drain the upper reaches Hathmati and Watrak mostly flow in the plains.

The Saraswati flows for a total length of 144 km in Gujarat State before outfalling into the little Rann of Kachchh.

In Kathiawar Peninsula, large number of streams flow readily with their outfalls in the little Ran of Kachchh, Gulf of Kachchh, Arabian Sea and Gulf of Cambay. Most of these streams have short courses.

1.3 TOPOGRAPHY AND RELIEF

The topography of the subzone-3(a) is mainly constituted of upper reaches draining the parts of Aravali ranges, Vindhya ranges and Malwa Plateau, Gujarat Plains and Kathiawar Peninsula. The upper reaches of Mahi and Sabarmati rivers vary in elevations from 300 m to 600 m. The general elevation of Gujarat plains varies between 150 m to 300 m and that of Kathiawar peninsula, from 0 m to 150 m along the southern fringes and 150 m to 300 m for the remaining portion with high elevation of 300 m to 600 m in the centre and the southern Gir ranges varying from 150 m to 300 m (Plate-3).

The Mahi rises on the northern slopes of Vindhyas at an elevation of about 500 m in the Dhar District of Madhya Pradesh State. The Sabarmati rises in the Aravalli hills at an elevation of 762 m in the Rajasthan State. The Saraswati rises at an elevation of 450 m in Gujarat State.

1.4 RAINFALL

Plate-4 depicts the normal annual rainfall isohyets along with the histograms showing the mean monthly rainfall for raingauge stations at Veraval, Ahmedabad, Vadodra and Rajkot. The normal annual isohyets of 60 cm to 80 cm cover the upper reaches of Sabarmati. The normal annual rainfall varies from 80 cm to 100 cm over the Mahi basin whereas it varies from 40 cm to 60 cm over the Kathiawar peninsula. The major sources of rainfall is south-west monsoon during June to September. About 90% of the annual rainfall occurs during the monsoon season. The maximum mean monthly rainfall of 20 cm to 30 cm is in July during the monsoon season as seen from the histograms of Veraval, Ahmedabad, Vadodra and Rajkot. The subzone lies in the semi-arid zone.

1.5 TEMPERATURE

Plate-5 shows the variations in temperature in the subzone along with bargraphs of minimum, mean and maximum of daily mean temperatures during various months for the Veraval, Rajkot, Ahmedabad and Vadodra stations. The daily mean annual temperature in the subzone varies between 25^{o} to 27.5^{o}c except for areas around Ahmedabad with temperatures above 27.5^{o}c. The lowest minimum to mean daily temperature of 13^{o}c is recorded in January. The temperature increases from February onwards and reaches the maximum in May. Thereafter, the temperature again begins to decrease. The maximum mean daily temperature recorded in May over the subzone is 41^{o}c except in the coastal station of Veraval with 31^{o}c.

1.6 SOILS

The soils in the upper and lower parts of Mahi basin are medium black. The middle part of Mahi basin is covered with red and alluvial soils along with laterite soils. The Sabarmati and Saraswati basins are constituted of grey brown soils. The Kathiawar peninsula is mostly covered with shallow, medium and black soils except the southern coastal belt of alluvial soils and northern coastal areas of deltaic alluvial soils. Vide Plate-6.

1.7 Land Use

Plate-7 shows the land use in the subzone. The subzone is mostly constituted of arable land interspersed with forests, grassland and scrub.

1.8 Irrigation

Plate-8 depicts the extent of irrigation in the subzone. Irrigation by open well and tubewells is extensively practised in the subzone. The major source of irrigation is through a large number of minor and medium storage dams and diversion works. Some of the existing dams are Bhader, Shatrunji, Hatmati and Mahi (Upper). The major existing projects in the subzone are Kadana and Mahi (lower). The area under irrigation is stated to be 318,000 Ha as per the Irrigation Committee's Atlas (1972).

1.9 Communications

1.9.1 Railways

The following railway sections are in the subzone-3(a):

Sl.No.	Railway Section	Railways
1.	OKHAIKANALUS-JAMJODHPUR-PORBANDAR	Western Railway (W.R.)
2.	JAMJODHPUR-JETPUR-KHIJADIYA-DHASA-SIHOR-MAHUVA-VICTOR	W.R.
3.	JETPUR-JUNAGADH-AMRELI-KHIJADIYA	W.R.
4.	JUNAGADH-DELVADA	W.R.
5.	DHASA-VICTOR	W.R.
6.	JAMNAGAR-RAJKOT-JETPUR	W.R.
7.	NAVLAKHI-MORBI-WANKANER-RAJKOT-JETPUR	W.R.
8.	SIHOR-BOTAD-SURENDRANAGAR-DHARNGADHRA-KANDAL	W.R.
9.	SURENDRANAGAR-VIRAMGAM-KATOSAN ROAD-MEHSANA-KAROSI	W.R.
10.	DABHOI-BARODA-NADIAD-AHMADABAD-SABARMATI-KALOL-MEHSANA-SIDHPUR-PLANPUR A	W.R.
11.	BOTAD-DHOLKA-SABARMATI	W.R.

Sl.No.	Railway Section	Railways
12.	SABARMATI-VIRAMGAM-KHARAGHODA	Western Railway (W.R.)
13.	AHMADABAD-HIMATNAGAR-UDAIPUR	W.R.
14.	GODHRA-DOHAD-RATLAM	W.R.
15.	LUNVADA-GODHRA-SAILAYA-DABHOI	W.R.
16.	BARODA-JAMBUSAR-KAVI	W.R
17.	WANKANER-SURENDRANAGAR-SAYLA	W.R.
18.	MEHSANA-KALOL-KATOSAN ROAD-HARIJ	W.R.
19.	JUNAGADH-SARADIYA	W.R.
20.	SIHOR-PALLITANA	W.R.

1.9.2 Roads

The major highways in the subzone are:

1. NATIONAL HIGHWAY No. 8 - BARODA TO UDAIPUR
2. NATIONAL HIGHWAY No. 8A - PORBANDAR TO AHMEDABAD AND MORBI TO BAMANHER
3. NATIONAL HIGHWAY NO. 8C - THROUGH GANDHINAGAR

LIST OF HYDRO-METEOROLOGICAL SUBZONES

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 tributaries	Betwa	Sind, Betwa and Kan rivers & other South tributaries of Yamuna.
1(d)	Sone basin & right bank tributaries	Sone	Sone and Tons river & other South Bank tributaries of Ganga.
1(e)	Punjab plains including parts of Indus, Yamuna, Ganga and Ramganga basins	Upper Indo-Ganga Plains	Lower portion of Indus, Ghaggar Sahibi Yamuna, Ganga and Upper portion of Sirsa, Ramganga, Gomti and Sai rivers.
1(f)	Gangetic plains including Gomti, Ghagra, Gandak, Kosi and others	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 tributaries of Brahmaputra river and Balason river.
2(b)	South Brahmaputra basin	South Brahmaputra	South bank tributaries of Brahmaputra river.
2(c)	Barak and others	Barak	Barak, Kalden and Manipur rivers.
3(a)	Mahi including the Dhadhar, Sabarmati and rivers of Saurashtra	Mahi and Sabarmati	Mahi and Sabarmati including Rupen & Mechha Bhandar, Ozat Shataranji rivers of Kathiawad Peninsula.
3(b)	Lower Narmada & Tapi basin	Lower Narmada & Tapi	Lower portion of Narmada, Tapi and Dhadhar rivers.

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

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

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.

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R.K. SHARMA

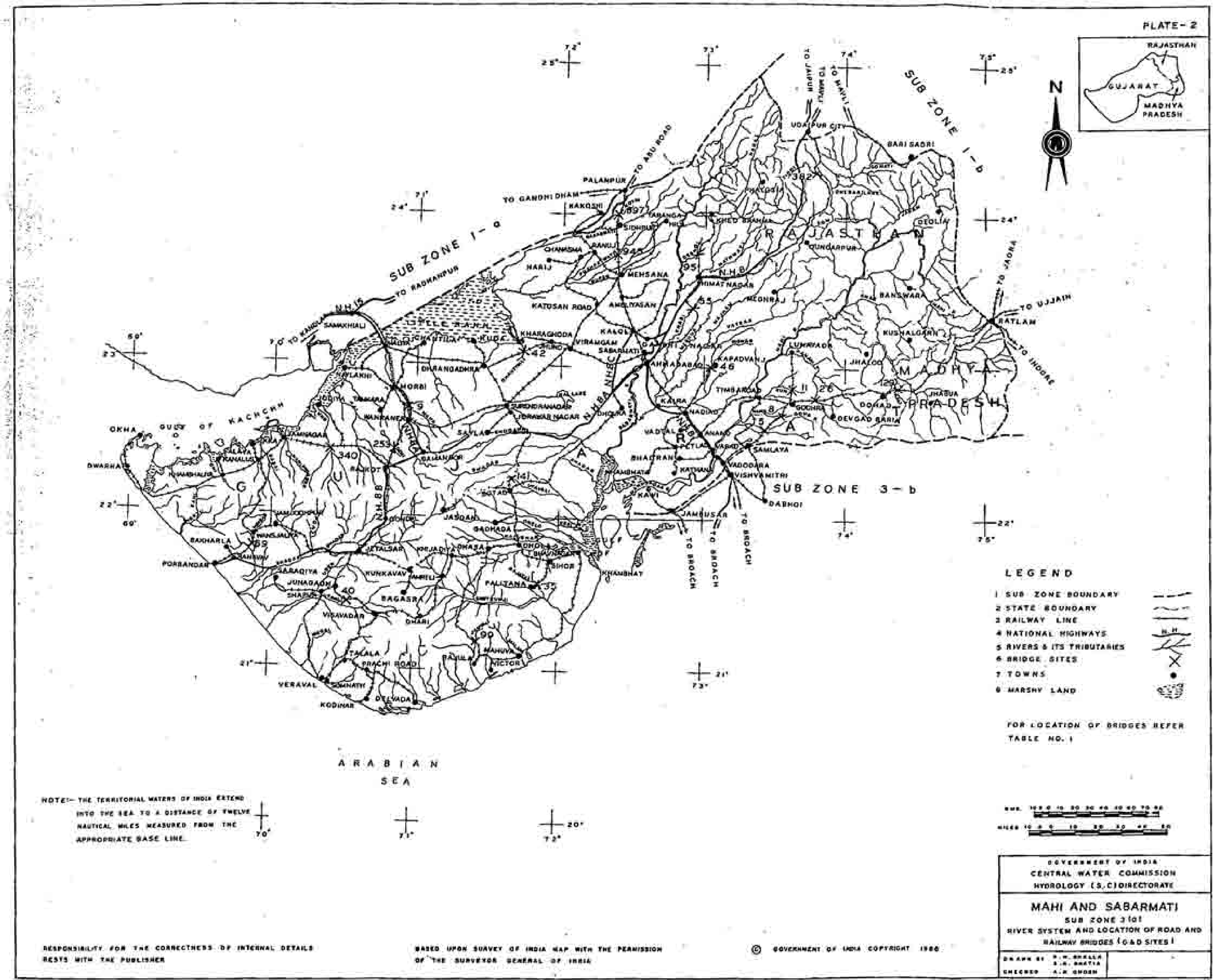
PLATE- 2
RAJASTHAN
GUJARAT
MADHYA PRADESH
SUB ZONE I - a
SUB ZONE I - b
SUB ZONE 3 - b
RAJASTHAN
MADHYA PRADESH
GUJARAT
GULF OF KACHCHH
ARABIAN SEA
LEGEND
1 SUB ZONE BOUNDARY
2 STATE BOUNDARY
3 RAILWAY LINE
4 NATIONAL HIGHWAYS
5 RIVERS & ITS TRIBUTARIES
6 BRIDGE SITES
7 TOWNS
8 MARSHY LAND
FOR LOCATION OF BRIDGES REFER TABLE NO. 1
NOTE:- THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER
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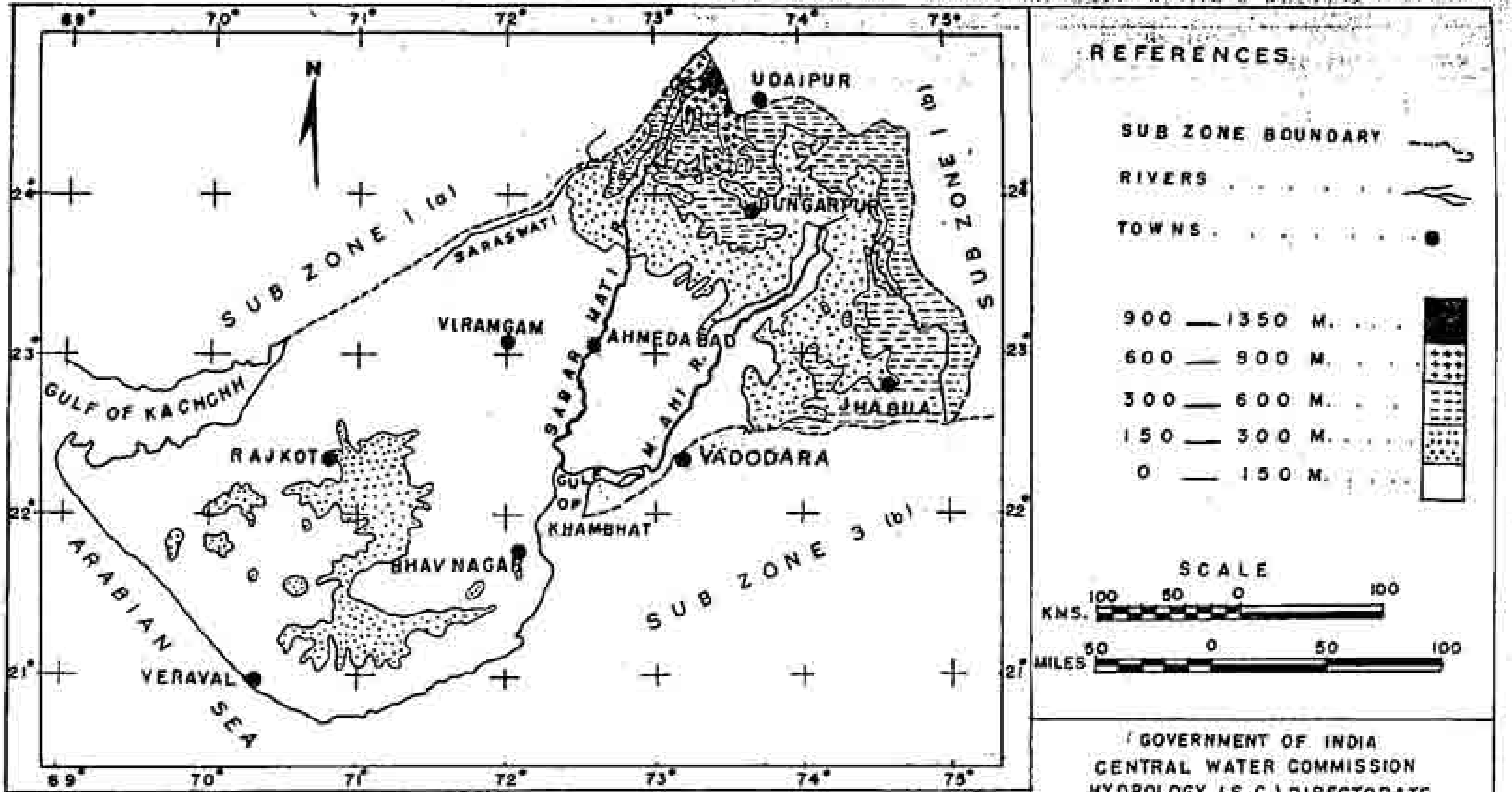
MAHI AND SABARMATI
SUB ZONE 3 (a)
RIVER SYSTEM AND LOCATION OF ROAD AND RAILWAY BRIDGES (G&D SITES)

PLATE-3



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MAHI AND SABARMATI BASIN

SUB ZONE 3 (a)

PHYSIOGRAPHY

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THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

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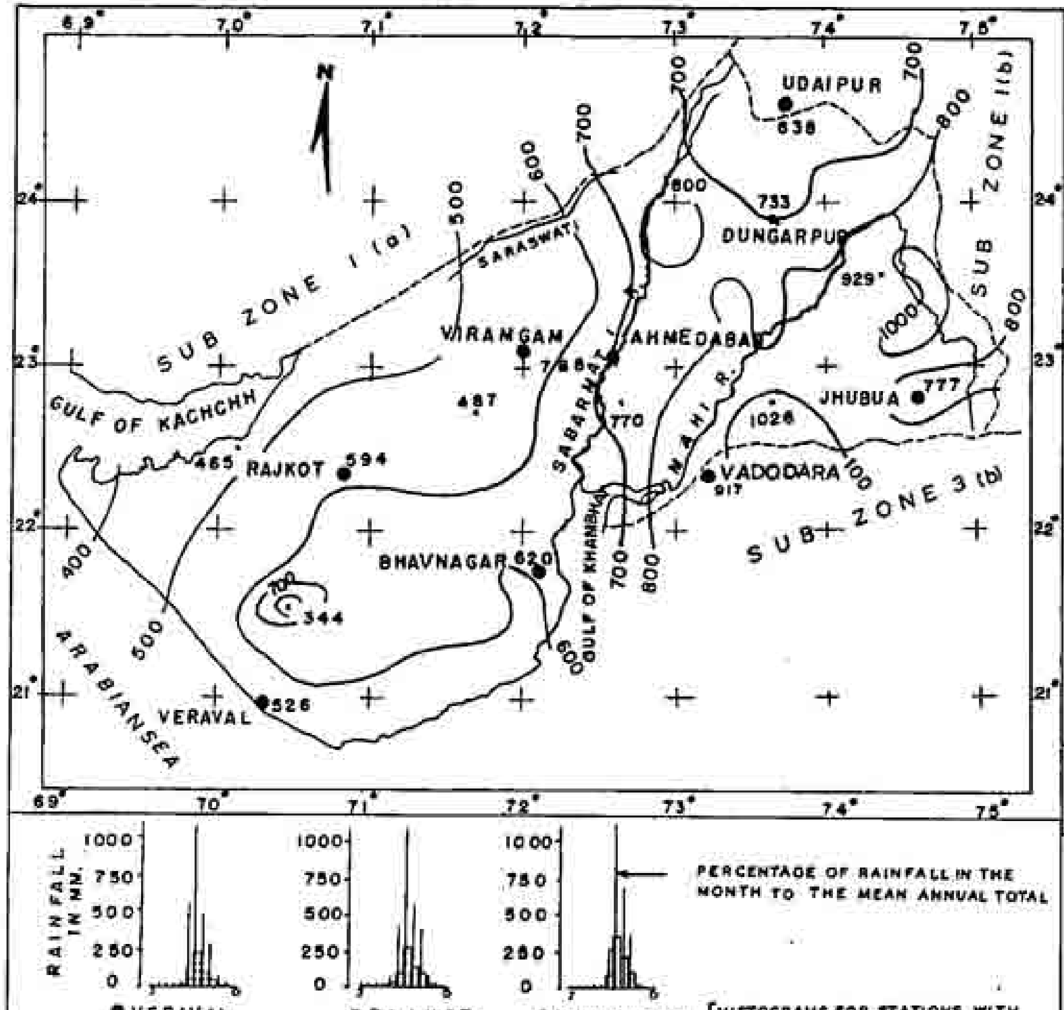
BASED UP ON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.

PLATE - 4.



HISTOGRAMS FOR STATIONS WITH NAME.

EACH VERTICAL COLUMN REPRESENTS THE MEAN MONTHLY RAINFALL FOR EACH MONTH (FROM JAN. TO DEC.) IN MM.

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

REFERENCES

ISOHYETAL LINE WITH VALUE IN MM. (800)

SUB ZONE BOUNDARY

RIVERS

TOWNS

NOTE:-

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THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

SCALE

KMS. 100 0 100

MILES 50 0 50 100

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MAHI AND SABARMATI BASIN

SUB ZONE 3 (a)

ANNUAL RAINFALL

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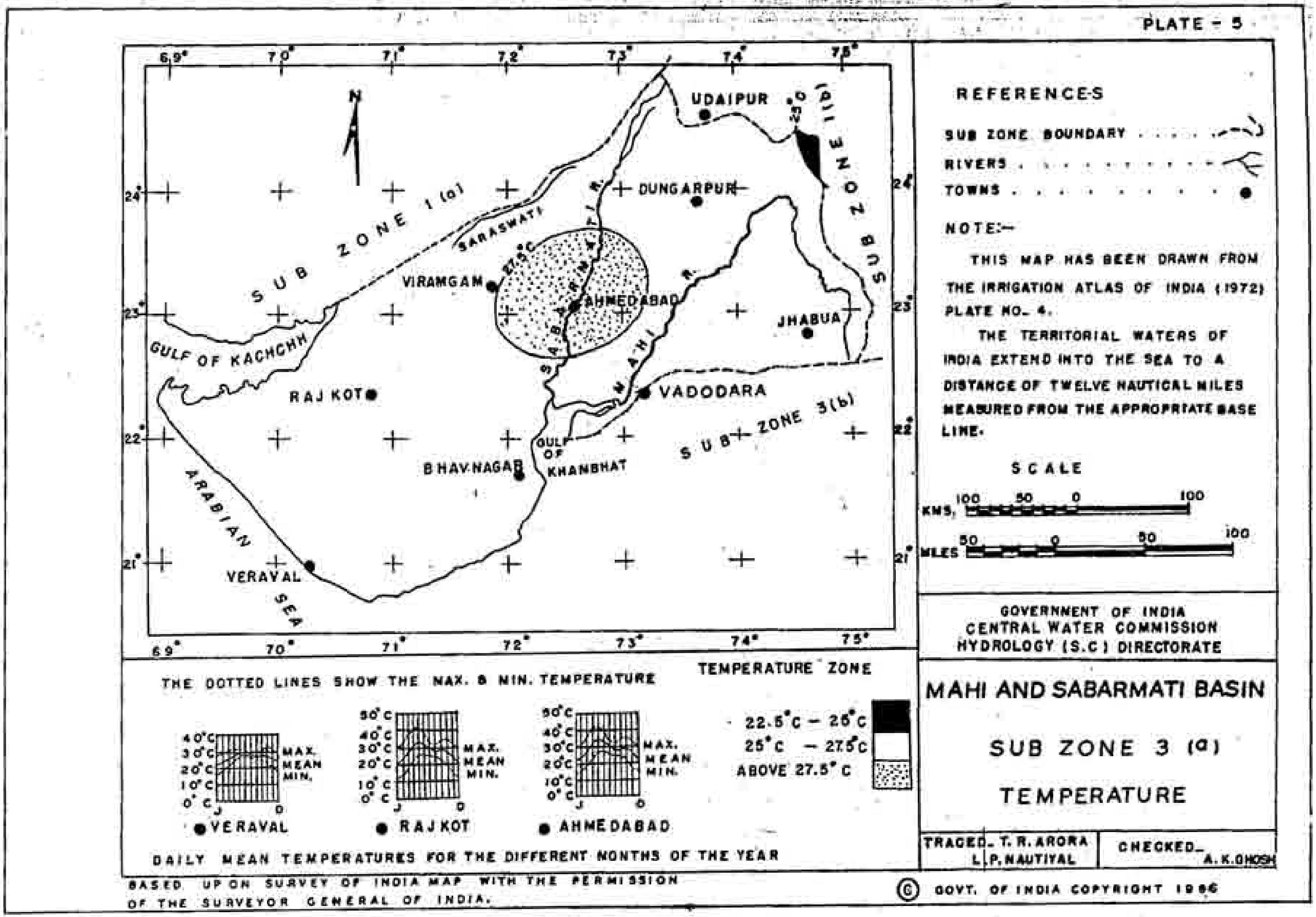
PLATE - 5
SUB ZONE 1 (a)
SUB ZONE 1 (b)
SUB ZONE 3 (b)
UDAIPUR
DUNGARPUR
SARASWATI
VIRAMGAM
AHMEDABAD
SABARMATI R.
MAHI R.
JHABUA
GULF OF KACHCHH
RAJKOT
VADODARA
GULF OF KHAMBHAT
BHAVNAGAR
ARABIAN SEA
VERAVAL
27.5°C
23°C
REFERENCES
SUB ZONE BOUNDARY
RIVERS
TOWNS
NOTE:—
THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972) PLATE NO. 4.
THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.
SCALE
KMS. 100 50 0 100
MILES 50 0 50 100
GOVERNMENT OF INDIA
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THE DOTTED LINES SHOW THE MAX. & MIN. TEMPERATURE
VERAVAL
RAJKOT
AHMEDABAD
MAX.
MEAN
MIN.
DAILY MEAN TEMPERATURES FOR THE DIFFERENT MONTHS OF THE YEAR
TEMPERATURE ZONE
22.5°C – 25°C
25°C – 27.5°C
ABOVE 27.5°C
MAHI AND SABARMATI BASIN
SUB ZONE 3 (a)
TEMPERATURE
TRACED_ T. R. ARORA
L. P. NAUTIYAL
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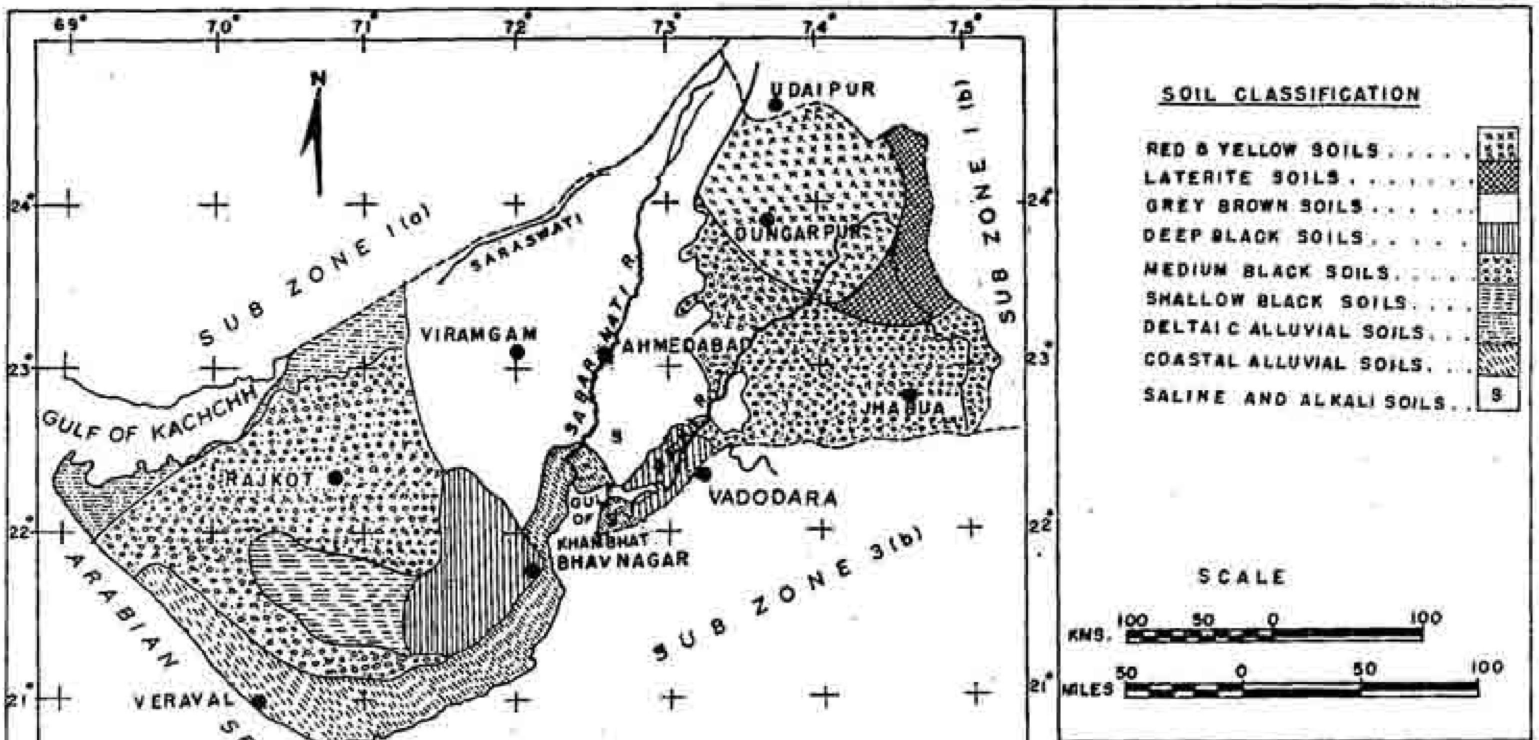

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REFERENCE

SUB ZONE BOUNDARY . . . . .

RIVERS . . . .

TOWNS . . . .

NOTE:-

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

THE TERRITORIAL WATERS OF INDIA EXTFND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

MAHI AND SABARMATI BASIN

SUB ZONE 3 (a)

SOIL CLASSIFICATON

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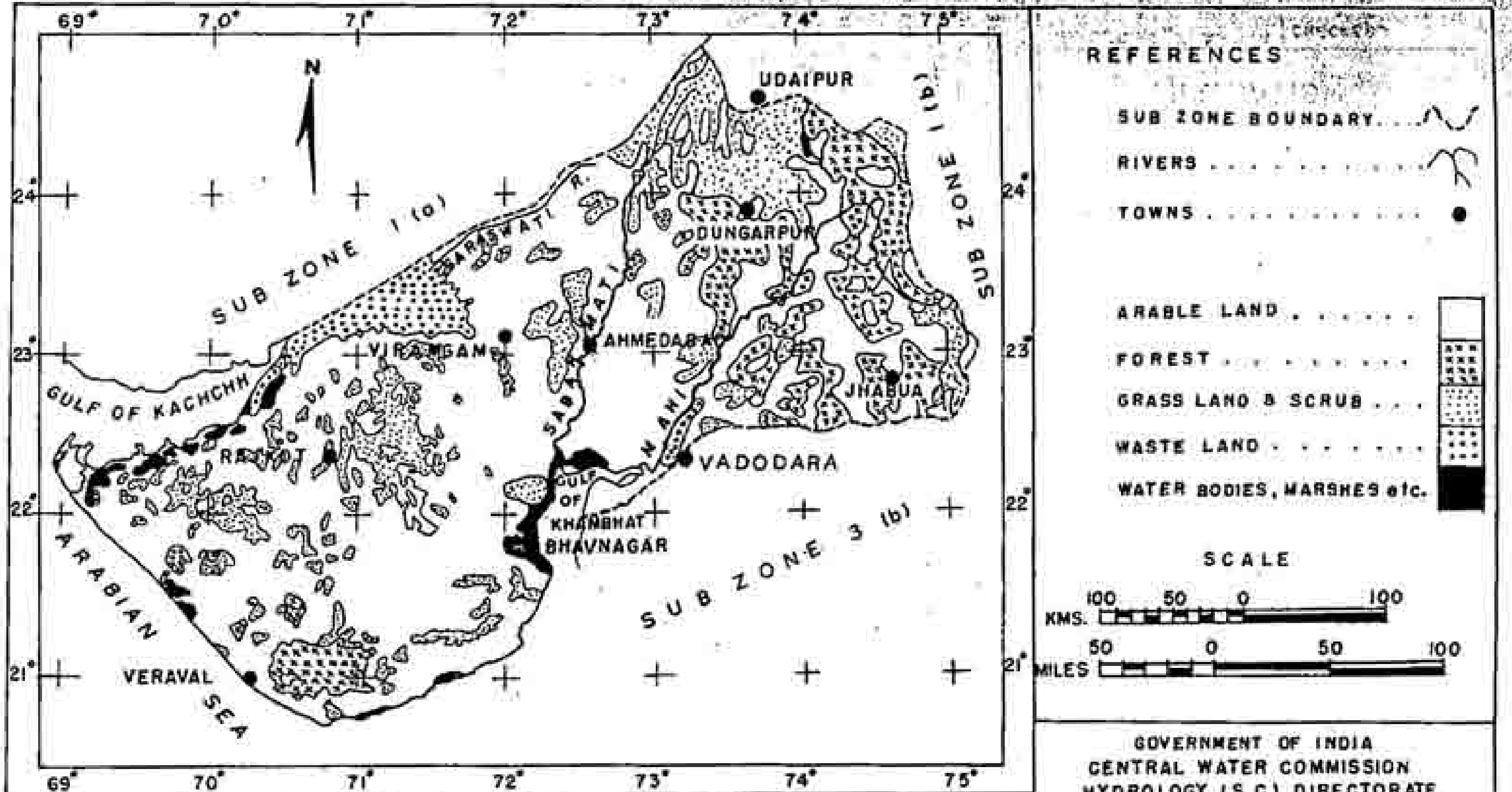
PLATE - 7



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MAHI AND SABARMATI BASIN

SUB ZONE 3 (a)

LAND USE

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

THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

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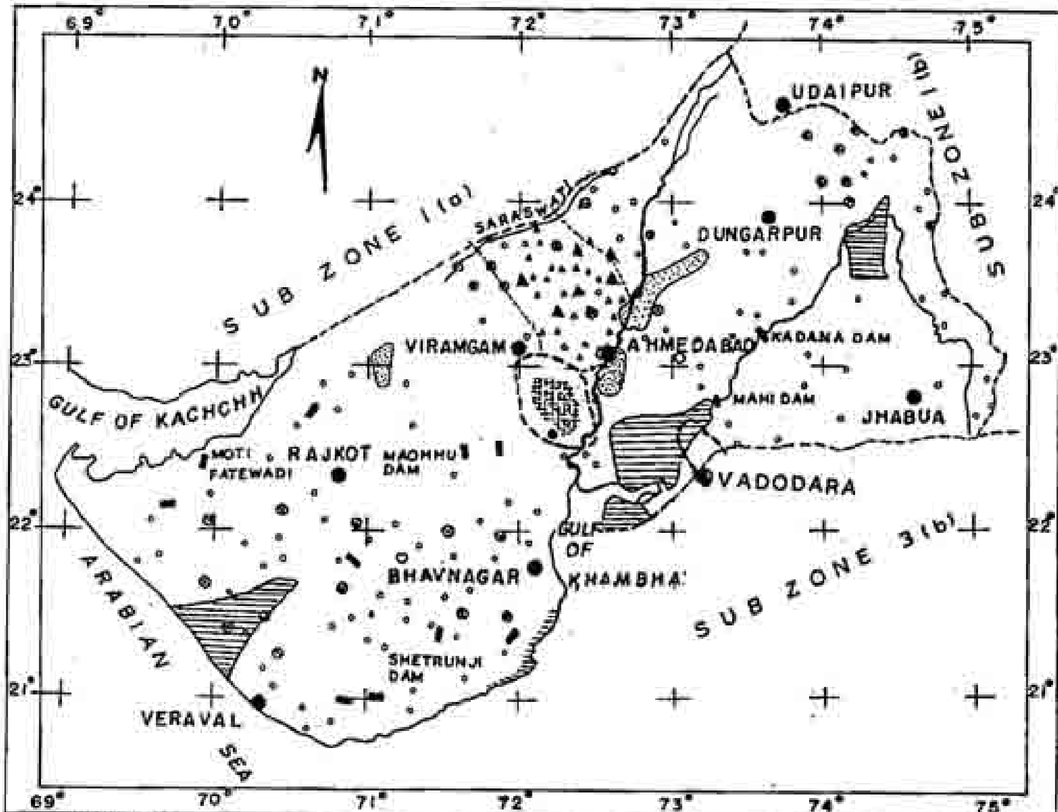
PLATE- 8



NOTE:-

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

THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

LEGEND_

SUB ZONE BOUNDARY . . . . .

RIVERS . . . .

TOWNS . . . .

REFERENCES

AREA IRRIGATED BY CANALS

1. PERENNIAL . . . .
2. NON-PERENNIAL . . . . .
3. CANAL UNDER CONSTRUCTION
4. CANAL, DAMS . . . . . .

AREA IRRIGATED BY_

1. TUBE WELLS . . . .
2. WELLS . . . .
3. TANKS . . . .

SCALE

KMS. 100 50 0 100

MILES 50 0 50 100

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MAHI AND SABARMATI BASIN

SUB ZONE 3 (a)

IRRIGATION

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

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

i) Hourly gauge data at the gauging site (bridge site), upstream and downstream at a reasonable distance from the gauging site.

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

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

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

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

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

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

Western Railways under the supervision of Research Designs and Standards Organisation had observed and collected the required data for 20 catchments in Mahi and Sabarmati Basin subzone-3 (a) for a period of 5 to 9 years for each of the catchments. The sizes of the gauged catchments varied from 30 to 1094 sqkm. The location of the gauging sites at road and railway bridges are shown in Plate-2. India Meteorological Department has collected rainfall data of IMD's SRRGs stations. Table-1 shows the name of the stream, bridge numbers, coordinates of gauging sites, catchment areas, number of raingauge stations and period of availability of data.

2.3 Description of the Method Adopted

In this report, Section-3 explains the procedure for obtaining the Synthetic Unitgraph for ungauged catchments in sub-zone-3 (a).

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

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

Section-6 deals with the formula for linear waterway of bridges and also the guidelines for fixing the design HFL at the bridge site and the cross drainage structures.

The adoption of synthetic unitgraph is recommended for estimation of 25-yr, 50-yr and 100-yr flood for ungauged or inadequately gauged catchments. However, for gauged catchments with adequate data, representative unitgraph based on actual data should be preferred for estimation of design flood.

TABLE-I

LIST OF SELECTED RAILWAY BRIDGE CATCHMENTS IN SUB-ZONE-3 (a). (MAHI AND SABARMATI) AND DATA AVAILABILITY OF GAUGE, DISCHARGE AND RAINFALL

SL. NO.	NAME OF STREAM	NAME OF SECTION WHERE Br. IS LOCATED WITH RLY. ZONE/ ROAD SECTION.	RLY.Br. NO./ SITE NO.	G&D SITE LOCATION LATITUDE DEG. MIN. SEC	LONGITUDE DEG. MIN. SEC.	CATCHMENT AREA (Sq.Km.)	NO. OF R.G. STATIONS	DATA AVAILABILITY.	NO. OF YEARS	REMARKS
1	2	3	4	5	6	7	8	9	10	11
(A)	BRIDGES CONSIDERED FOR REGRESSION ANALYSIS:-									
1	PANAM	GODHRA-DOHAD W/R	26	22-47-55	73-47-35	1094.00	9	1966-73	8	
2	UND	RAJKOT-JAMNAGAR W/R	340	22-25-10	70-24-00	1026.47	9	1976-78,80,81	5	
3	MOHAR/WARASI	NADIAD-KAPADVANJ W/R	46	23-00-15	73-03-22	580.00	8	1966-74	9	
4	TIDDI	UDAIPUR-HIMAT NAGAR W/R	382	24-18-10	73-47-00	406.25	4	1980-84	5	
5	MAHA	WANKANER-NAVLAKHI W/R	9	22-42-20	70-56-08	401.30	3	1966-71	6	
6	PUSHPAVATI N.	PALANPUR-SABARMATI W/R	945	23-44-11	72-23-20	253.00	2	1966-70, 73	6	
7	KHARI	AHMADABAD-KHEDBRAHMA W/R	55	23-23-16	72-55-06	252.63	3	1967,68,70,73	4	
8	GOMA RIVER	VADODARA-GODHRA W/R	5	22-35-36	73-25-25	230.00	3	1966-68,70,73	5	
9	RAJAVAL	PALITANA-SIHOR W/R	35	21-34-35	71-51-55	194.25	3	1980-84	5	
10	MINSAR	KANALUS-PORBANDAR W/R	69	21-47-22	69-52-10	149.42	3	1970,75-78,80-82	8	
11	JAMVALI NADI	DHASA-MAHUVA W/R	99	21-10-50	71-26-30	144.50	3	1966-74	9	
12	KALI NADI	DOHAD-RATLAM W/R	129	22-52-00	74-22-27	136.36	3	1980-82,84	4	
13	KUN	GODHRA-LUNAVADA W/R	11	22-51-54	73-37-16	98.16	2	1968-73	6	
14	UTAVALI	JUNAGADH-VISAVADAR W/R.	40	21-25-40	70-37-35	94.85	2	1978-82	5	
15	UTAVALI NADI	SURENDRA NGR.-BHAV NGR. W/R	141	22-15-38	71-40-18	73.19	2	1970,71,75-77	5	
16	DEBHOL NADI	AHMADABAD-KHEDBRAHMA W/R	95	23-45-12	72-57-05	57.70	2	1980, 81-84	5	
17	GHANTIYALI	VIRAMGAM-DHRANGADHRA W/R	42	23-05-30	71-44-30	50.35	2	1980-82,84	4	
18	DEMI	RAJKOT-WANKANER W/R	253	22-26-00	70-51-10	48.43	1	1962-66,68	6	
19	BAPOI	VADODARA-GODHRA W/R	8	22-42-48	73-33-22	30.14	2	1962-67	6	
(B)	BRIDGE NOT CONSIDERED FOR REGRESSION ANALYSIS									
20	KOTRI	PALANPUR-SABARMATI W/R	897	24-01-00	72-24-00	77.70	2	1965-68	4	

O.P.SINGH

3.0 DERIVATION OF SYNTHETIC UNIT HYDROGRAPHS

The synthetic 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 the synthetic unitgraph, the following steps have to be followed:

i) Analysis of physiographic parameters of the catchments.

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

iii) Selection of flood and corresponding storm events.

iv) Computation of hourly catchment rainfall.

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

vi) Computation of infiltration loss (Ø-index) and 1-hourly rainfall excess units.

vii) Derivation of 1-hourly unitgraphs.

viii) Drawing of representative unitgraph and measuring the parameters.

ix) Establishing relationships between physiographic and representative unitgraph parameters.

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

The above steps are briefly described as under:

3.1 Analysis of Physiographic Parameters of the Catchment

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

3.1.1 Catchment Area (A)

On the Survey of India toposheet, the watershed boundary is marked upto the gauging site. The area enclosed within this boundary in the catchment area.

3.1.2 Length of the Main Stream (L)

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

3.1.3 Equivalent Stream Slope (S)

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

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

Where L_i = Length of the ith segment in km

D_{i-1}, D_i = Depths of the river bed profile(L-Section) at the points of intersection of (i-1)th and i contours above the base line (datam) drawn at the level of the point of study in meters.

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

Rapids or vertical falls in the L-Section shall not be considered for computation of slope, Table-2 shows the physiographic parameters like A, L and S for 19 catchments considered suitable for analysis.

3.2 Scrutiny of Data and Finalisation of Gauge Discharge Rating Curve

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

3.3 Selection of Flood and Corresponding Storm Events

The general guidelines adopted for selection of flood events for each of the gauged 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.

Table - 2: BASIN CHARACTERISTICS OF SUBZONE-3(a)

S.No.	Br.No.	A (sq.km.)	L (km.)	S (eq) m/km.	$\frac{L}{\sqrt{S}}$
1	2	3	4	5	6
1.	26	1094.00	67.62	2.31	44.49
2.	340	1026.47	41.34	1.88	30.15
3.	46	580.00	67.62	1.25	60.48
4.	382	486.25	55.90	5.93	22.96
5.	9	401.30	43.00	1.99	30.48
6.	945	253.00	43.44	1.64	33.92
7.	55	252.63	43.44	1.43	36.33
8.	5	230.00	53.77	3.01	30.99
9.	35	194.25	22.22	1.17	20.54
10.	69	149.42	26.48	3.29	14.60
11.	99	144.50	17.70	6.41	6.99
12.	129	136.36	33.50	3.26	18.55
13.	11	98.16	20.77	2.49	13.17
14.	40	94.85	16.90	8.89	5.67
15.	141	73.19	19.60	2.67	12.00
16.	95	57.70	16.20	3.47	6.70
17.	42	50.35	11.40	2.07	7.92
18.	253	48.43	10.46	3.52	5.58
19.	8	30.14	17.38	2.77	10.44

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 of the flood events.

3.6 Computation of Infiltration Loss (Ø-index) and 1-hourly Rainfall Excess Units.

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

3.7 Derivation of 1-hour Unitgraph

A unit duration of 1-hour was adopted for derivation of unitgraphs. The 1-hour unitgraphs were derived from the rainfall excess hyetographs and their corresponding direct runoff hydrographs by iterative methods. The iterations were carried out till the observed and estimated direct runoff hydrographs compared favourably.

Normally 4 to 10 unitgraphs are derived for each of the 19 catchments considered.

3.8 Drawing of Representative Unitgraphs and Measuring their Parameters.

The representative unitgraph is the unitgraph which reproduces in reasonable limits the direct surface runoff hydrographs corresponding to their rainfall excess of the storm from which it has been obtained. Representative 1-hour unitgraphs were drawn from a set of superimposed 1-hour unitgraphs for each of the 19 catchments and their parameters noted. The parameters of the representative unitgraph illustrated in Fig.2 were measured for each of the catchments. The parameters of the representative unitgraphs are t_r, t_p, T_m, q_p, Q_p, W_{50}, W_{75}, W_{R50}, W_{R75}, and T_B. These parameters for 19 catchments are listed in Table-3.

3.9 Establishing Relationships between Physiographic and Representative Unitgraph Parameters

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

$$Y = C x^P \qquad \ldots . 3.9.1$$

Where Y = Dependent variable

x = Independent variable

C = A constant

P = An exponent

From equation 3.9.1 it follows that

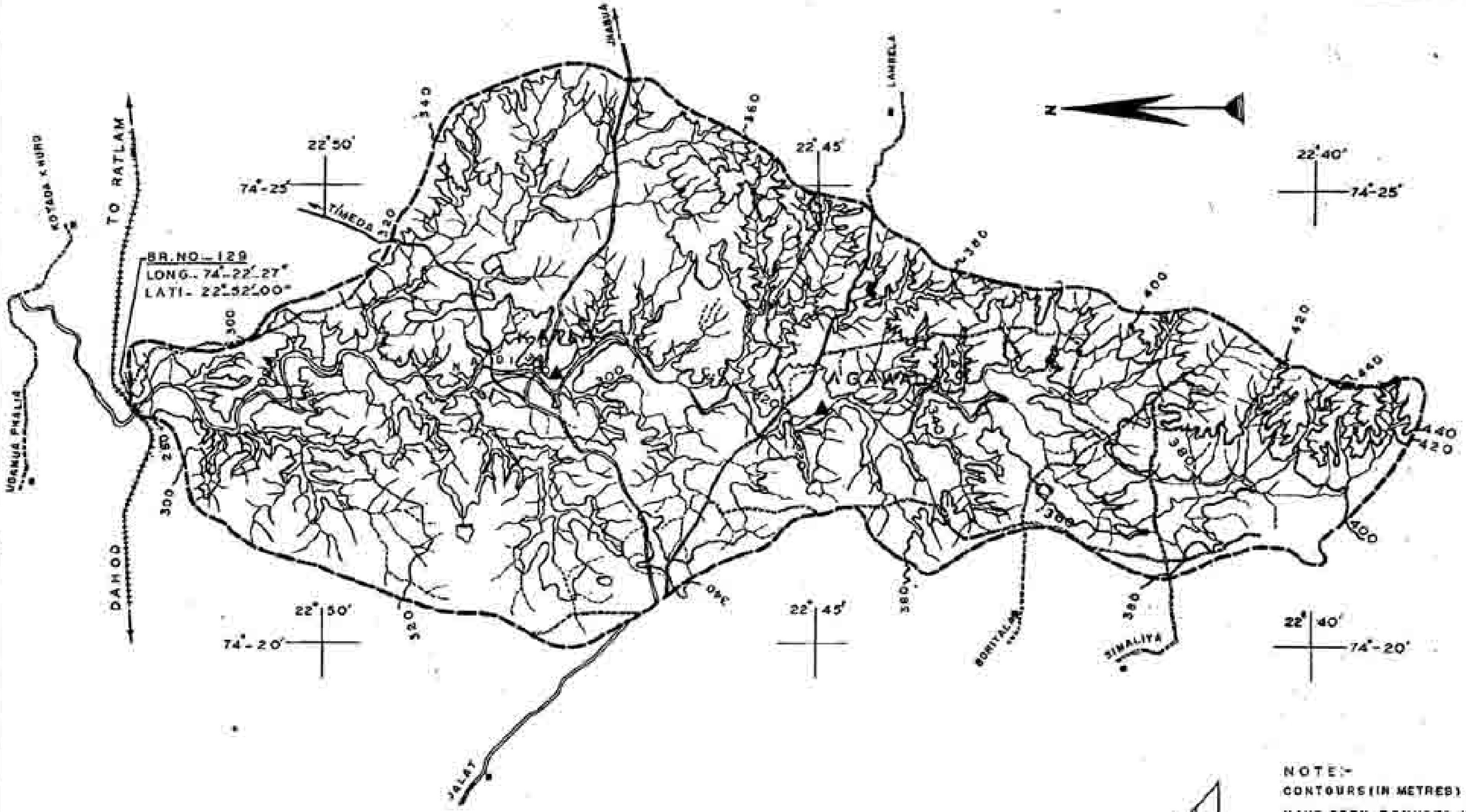
$$\text{Log } Y = \text{Log } C + P \text{ Log } x \qquad \ldots . 3.9.2$$

TABLE-3 REPRESENTATIVE I Hr. UNITGRAPH PARAMETERS

SUB-ZONE - 3 (a)

Sr. No.	Bridge No.	t_p (Hrs.)	Q_p (cumecs)	qp (Cumecs/ Sq.Km)	t_r (Hrs)	TB (hrs)	W 50 (Hrs)	W 75 (Hrs)	WR_{50} (Hrs)	WR_{75} (Hrs)
1	2	3	4	5	6	7	8	9	10	11
1	26	5.5	456.00	0.42	1	25.00	4.50	2.30	1.80	1.00
2.	340	4.5	403.87	0.39	1	22.00	5.80	3.00	2.60	1.60
3.	46	9.5	180.31	0.31	1	29.00	6.90	4.90	3.70	2.70
4.	382	4.5	220.00	0.54	1	16.00	4.10	2.50	1.60	1.20
5.	9	6.5	140.00	0.35	1	20.00	6.85	4.00	2.95	2.00
6.	945	3.5	177.70	0.70	1	12.00	3.30	1.65	1.20	0.65
7.	55	4.5	89.06	0.35	1	15.00	7.55	4.90	3.20	2.50
8.	5	6.5	55.00	0.24	1	26.00	10.40	5.90	2.80	2.10
9.	35	2.5	121.52	0.63	1	11.00	3.70	2.30	1.40	1.10
10.	69	3.5	109.81	0.73	1	13.00	2.87	1.70	0.90	0.54
11.	99	1.5	115.00	0.79	1	10.00	3.10	2.00	1.00	0.80
12.	129	3.5	65.87	0.48	1	19.00	4.75	2.40	1.85	1.10
13.	11	2.5	50.30	0.51	1	19.00	3.80	2.05	0.95	0.80
14.	40	1.5	90.93	0.96	1	11.00	2.35	1.45	1.25	0.85
15.	141	2.5	57.62	0.79	1	10.00	3.03	1.80	1.28	[illegible].00
16.	95	2.5	32.55	0.55	1	14.00	4.40	2.60	1.20	0.70
17.	42	1.5	34.20	0.68	1	14.00	3.35	1.70	0.90	0.60
18.	253	1.5	48.70	1.01	1	11.00	2.38	1.55	0.90	0.70
19.	8	2.5	26.72	0.89	1	10.00	2.62	1.45	0.92	0.55

FIG- A-I



NOTES

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

REFERENCES

1. CATCHMENT BOUNDARY
2. RAILWAY LINE
3. RIVER AND IT'S TRIBUTARIES
4. ROADS
5. RAIN GAUGE STATIONS
6. CONTOURS — 300, 320
7. TOPO SHEET NO. — 46 J/5, J/6
8. CENTRE OF GRAVITY — ⊙

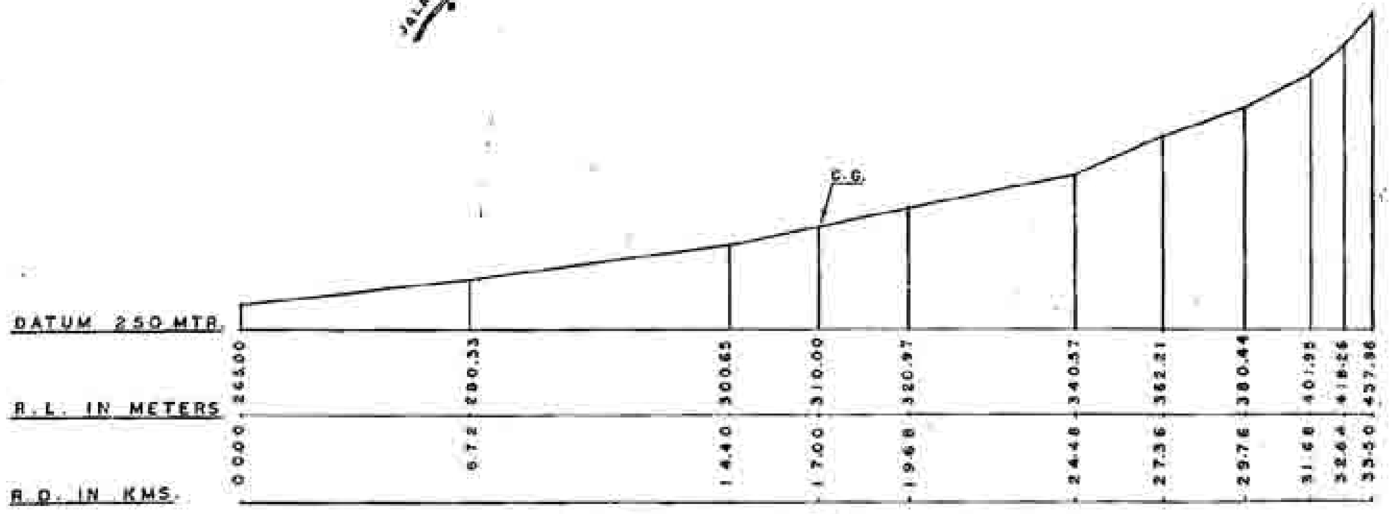
DETAIL OF CATCHMENT AREA

1	AREA OF THE CATCHMENT	136.36 Sq.Km.
2	SHAPE OF CATCHMENT	ELONGATED
3	L.	33.50 Km.
4	Lc.	17.00 Km.
5	Wc.	7.95 Km.
6	SLOPE (EQUILIBRIUM)	3.263 Mt/Km.
7	D.	3.065 Km./Sq.Km.

NOTE:-
CONTOURS (IN METRES) SHOWN ON THE PLAN HAVE BEEN ROUNDED UP AFTER CONVERSION FROM FEET TO METRE
LONGITUDINAL SECTION IS DRAWN WITH THE ACTUAL VALUES OF CONTOUR IN METRES

SI. NO	NAME OF R.G. STATION	LOCATION LONG.	LOCATION LATI.	STATION WTS. 1981 – 1984
1	KATLA	74°-22'-55"	22°-47'-40"	0.408
2	AGAWADA	74°-22'-35"	22°-45'-00"	0.495
3	BR. SITE	74°-22'-27"	22°-52'-00"	0.097

SCALE
0.5 0 1.0 2.0 3.0 4.0 5.0



LONGITUDINAL SECTION OF KALI NADI

SCALE
VERTICAL
20 0 20 40 60 80 100 120 140 160 180 200
HORIZONTAL
1.0 0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0

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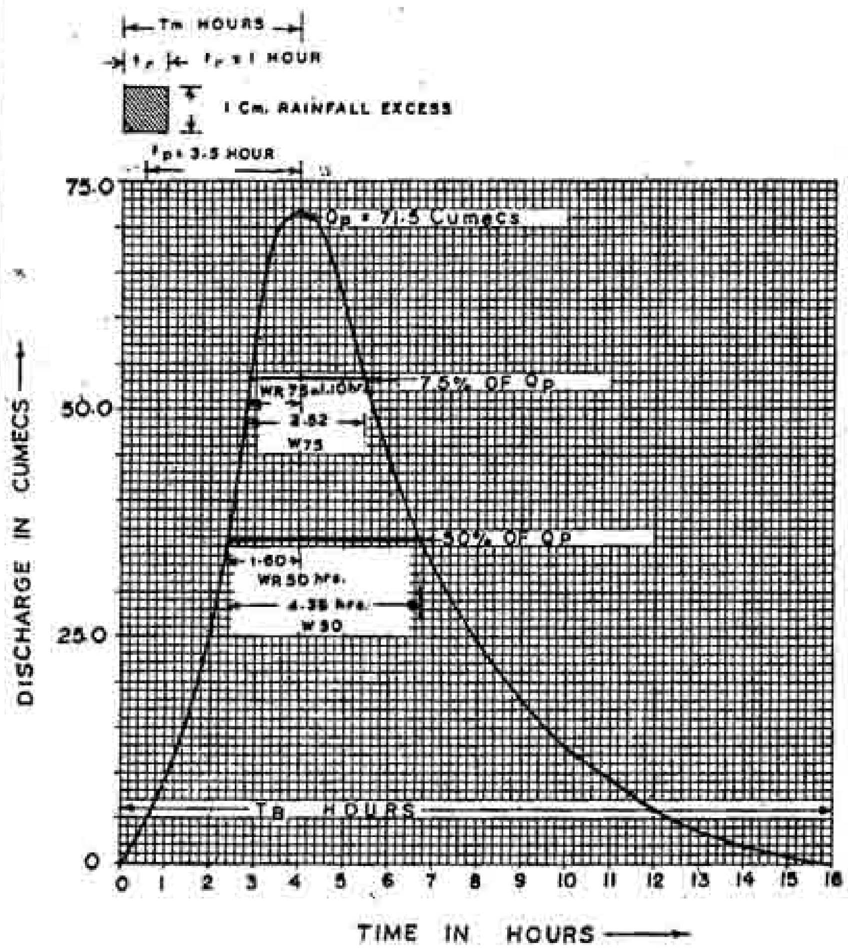
HYDROLOGY (SMALL CATCHMENTS) DTE

CATCHMENT AREA PLAN
FOR BR. NO. 129 AT KM. 554/13-14
ON DAHOD - RATLAM SECTION
WESTERN RLY. SUB ZONE 3 (a)

DRAWN BY— S. B. AHUJA, P. N. BHALLA
CHECKED BY— K. N. ROY, E.A.D

FIG.-A-2



SYNTHETIC U.G. PARAMETERS

C.A. = 136.36 SQ.KM.

t_p = 3.5 hrs.

T_B = 16.0 hrs.

Q_p = 71.5 Cumecs.

W_{50} = 4.36 hrs.

W_{75} = 2.52 hrs.

W_{R50} = 1.60 hrs.

W_{R75} = 1.10 hrs.

q_p = 0.524 Cumecs/Sq. Km.

$\frac{L}{\sqrt{S}}$ = 19.0

Tm = 4.0 hrs.

d = 1.00 Cm.

$$\Sigma Qi = \frac{A \times d}{t_r \times 0.36} = \frac{136.36 \times 1.00}{1.00 \times 0.36} = 378.80 \text{ Cumecs.}$$

TIME IN (HOURS)	1-HOUR SYNTHETIC U.G. ORDINATES (CUMECS)
0	0
1	9.00
2	25.50
3	58.00
4	71.50
5	61.00
6	44.50
7	32.70
8	24.50
9	18.00
10	12.70
11	9.50
12	5.70
13	3.50
14	1.90
15	0.80
16	0
TOTAL	378.80

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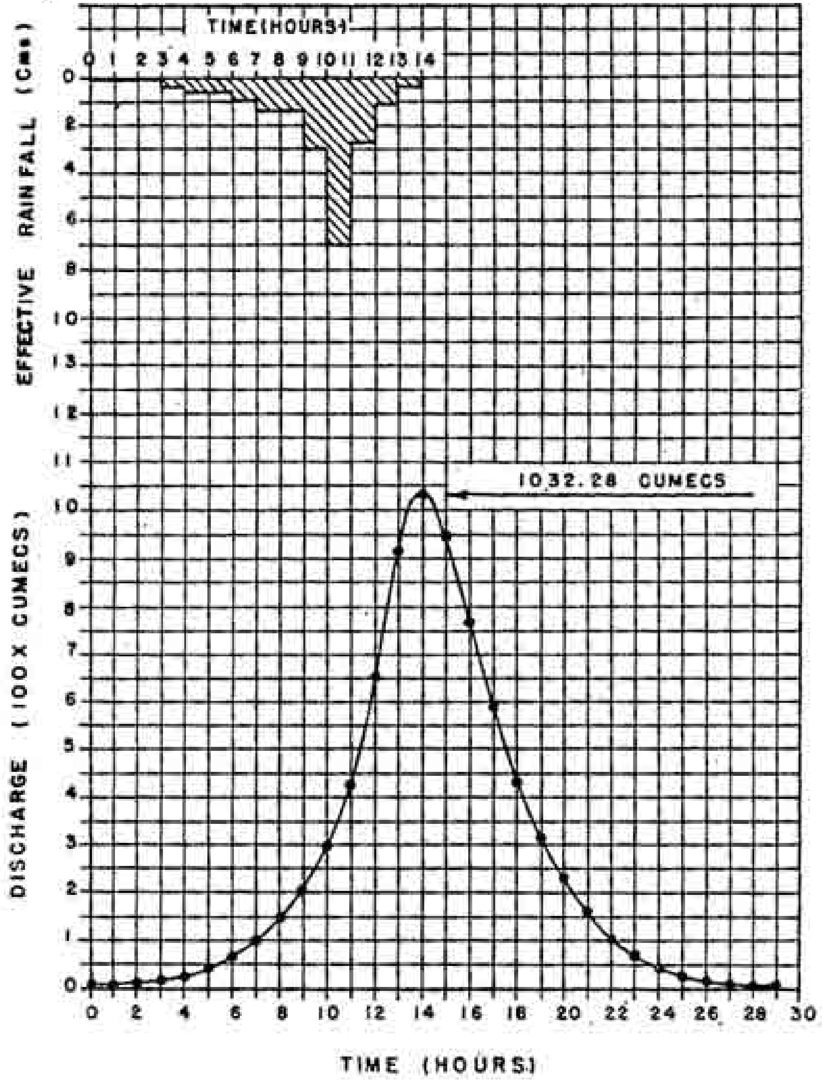
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.

MAHI AND SABARMATI
SUB ZONE-3 (a)
SYNTHETIC UNIT HYDROGRAPH
BRIDGE NO 129

DRAWN BY—	CHECKED BY—
R.N. SHARMA L. P. NAUTIYAL	A.K. GHOSH

FIG. A.3

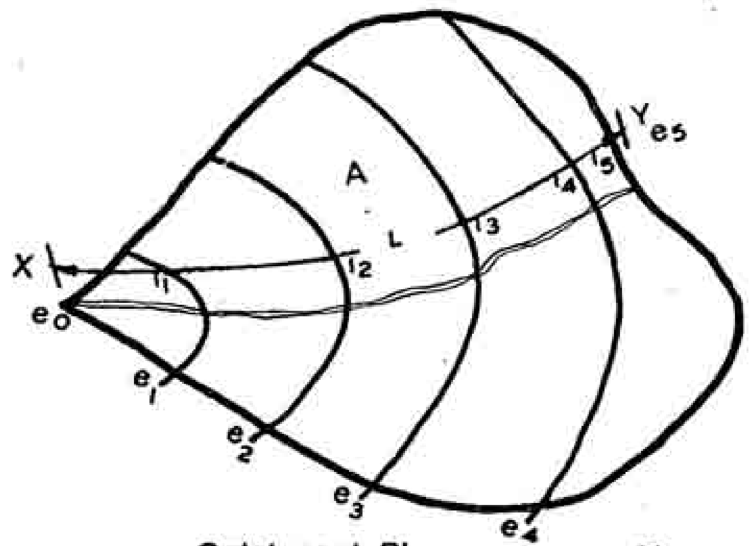


GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY(SMALL CATCHMENTS) DTE.

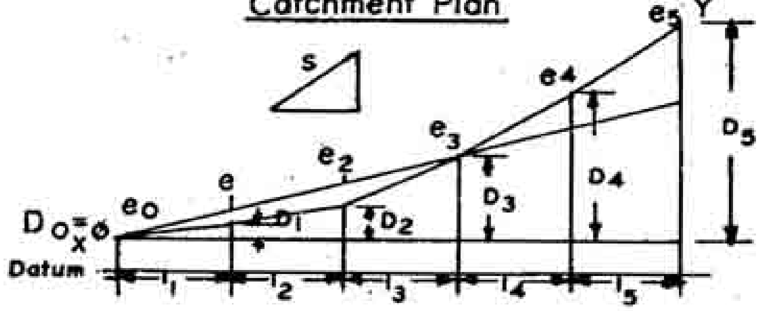
MAHI AND SABARMATI
SUB ZONE - 3(a)
DESIGN FLOOD HYDROGRAPH
BRIDGE NO. 129 (KALI NADI)
DAHOD — RATLAM

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

FIG. I



Catchment Plan



L - Section

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

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

L = Length of longest stream course (km)

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

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

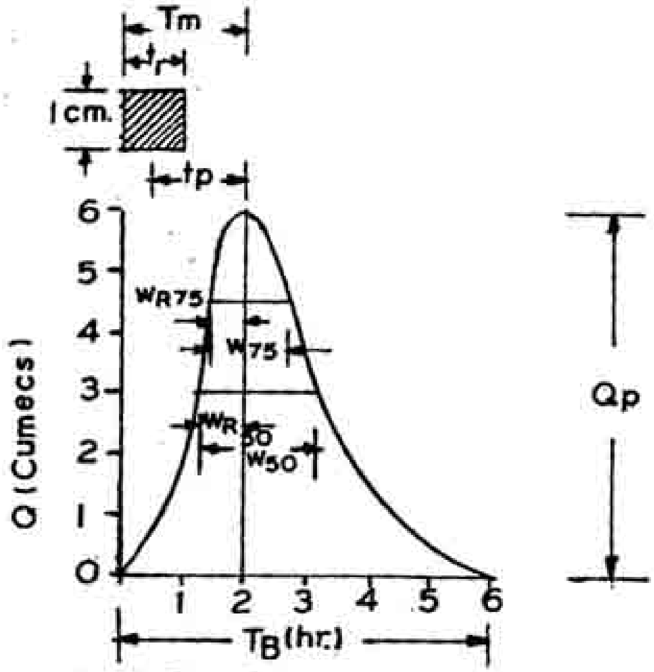
$D_i = D_0, D_1, D_2, \cdots D_n$

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

A = Catchment area (km²)

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (SMALL CATCHMENTS) DTE.	
PHYSIOGRAPHIC PARAMETERS	
DRAWN R. N. SHARMA	CHECKED A. K. GHOSH

FIG. 2



U.G. = Unit Graph

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

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.)

qp = Qp/A = cumec per sq.km.

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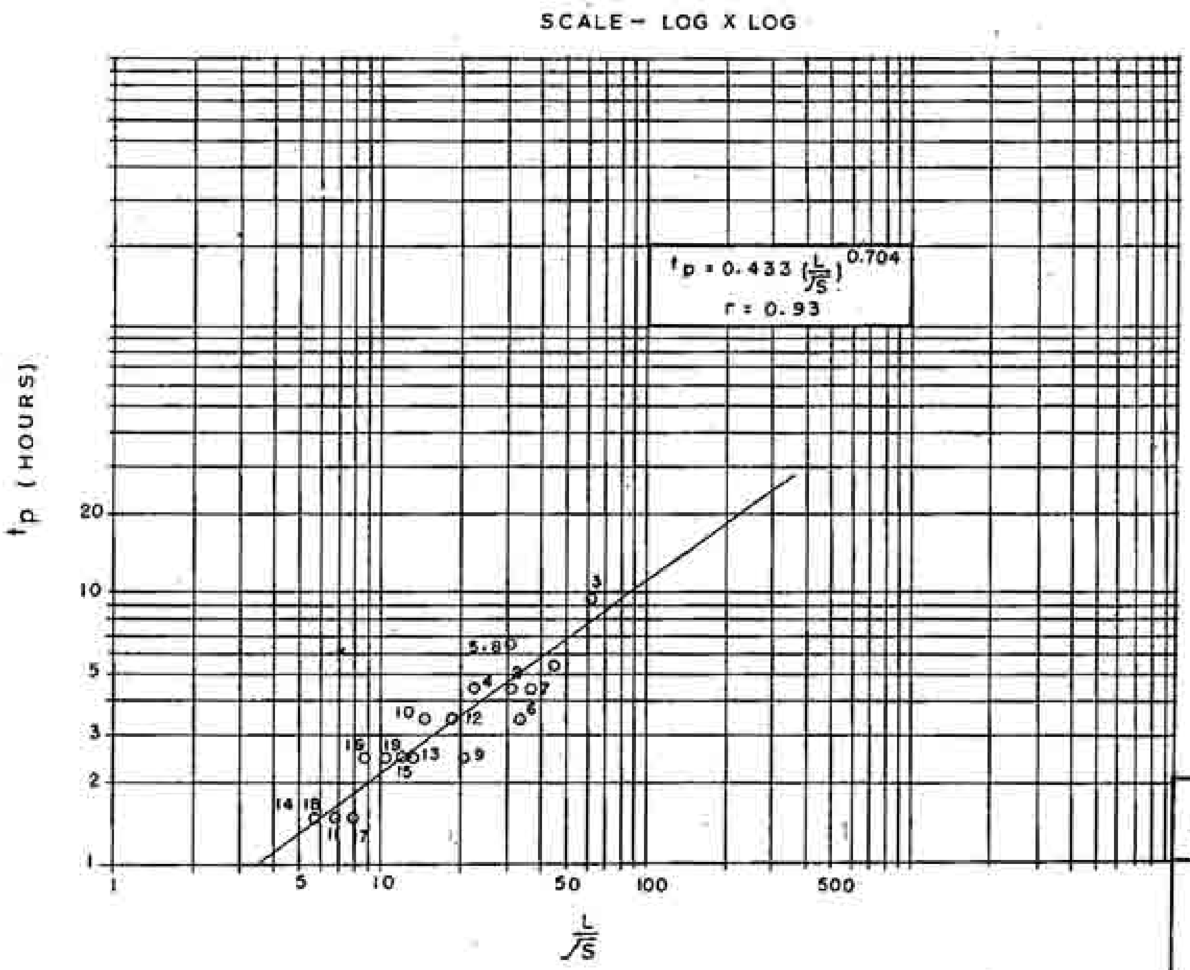
UNIT GRAPH PARAMETERS	
DRAWN T.R. ARORA R.H. SHARMA	CHECKED C.L. BAJAJ

FIG.- 3



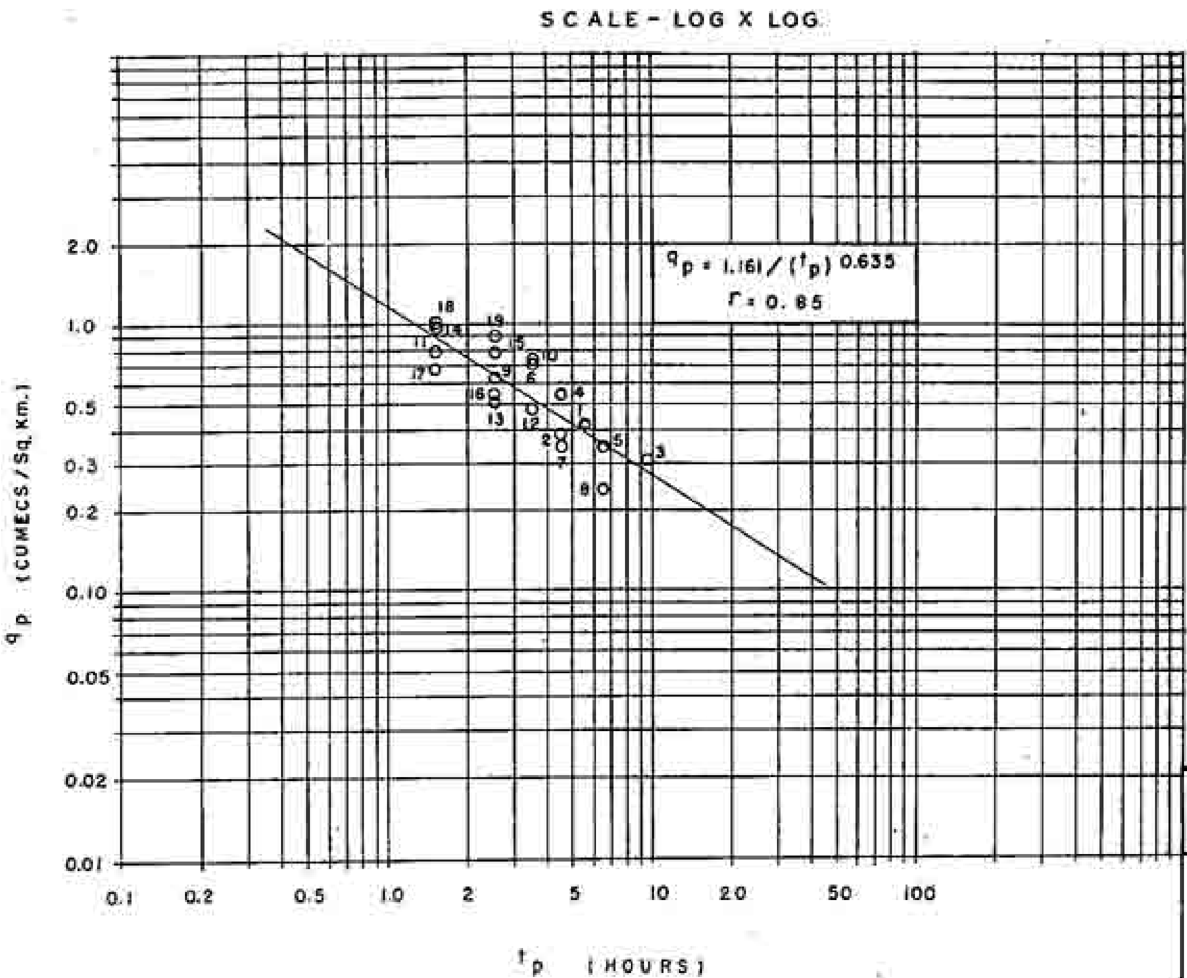
SL. NO.	BRIDGE NO.	$\frac{L}{\sqrt{S}}$	t_p (Hr)
1	26	44.49	5.50
2	340	30.15	4.50
3	46	60.48	9.50
4	382	22.96	4.50
5	9	30.48	6.50
6	945	33.92	3.50
7	55	36.33	4.50
8	5	30.99	6.50
9	35	20.54	2.50
10	69	14.60	3.50
11	99	6.99	1.50
12	129	18.55	3.50
13	11	13.17	2.50
14	40	5.67	1.50
15	141	12.00	2.50
16	95	8.70	2.50
17	42	7.92	1.50
18	253	5.58	1.50
19	8	10.42	2.50

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

MAHI AND SABARMATI
SUB ZONE 3 (a)
RELATION BETWEEN $\frac{L}{\sqrt{S}}$ AND t_p

DRAWN BY- NAUTIYAL. S. K. BHATIA.
CHECKED BY- A. K. GHOSH.

FIG.— 4



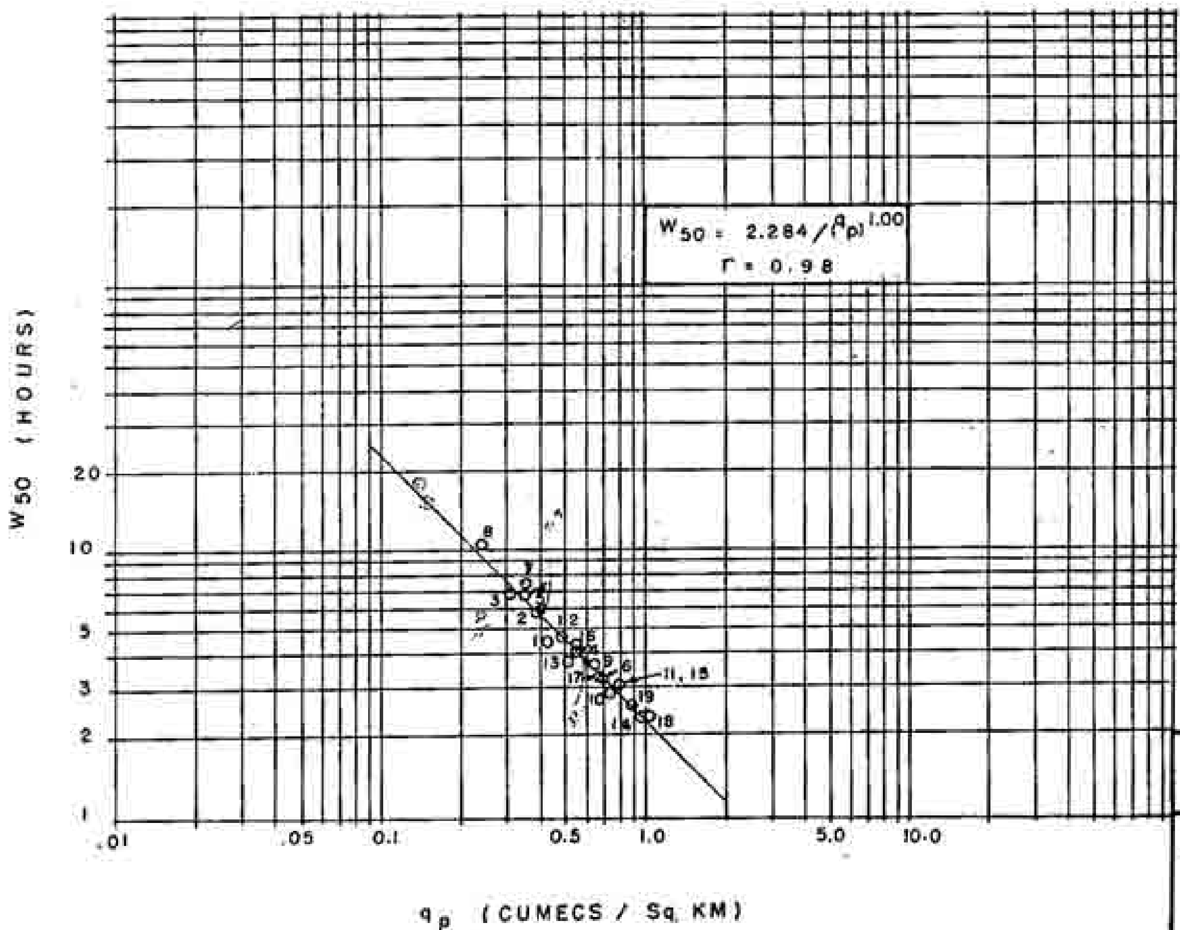
SL. NO.	BRIDGE NO.	t_p (HOURS)	q_p (CUM./KM²)
1	26	5.50	0.42
2	340	4.50	0.39
3	46	9.50	0.31
4	382	4.50	0.54
5	9	6.50	0.35
6	945	3.50	0.70
7	55	4.50	0.35
8	5	6.50	0.24
9	35	2.50	0.63
10	69	3.50	0.73
11	99	1.50	0.79
12	129	3.50	0.48
13	11	2.50	0.51
14	40	1.50	0.96
15	141	2.50	0.79
16	95	2.50	0.55
17	42	1.50	0.68
18	253	1.50	1.01
19	8	2.50	0.89

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

MAHI AND SABARMATI
SUB ZONE 3 (a)
RELATION BETWEEN
t_p AND q_p

DRAWN BY.- MALHOTRA L.P. NAUTIYAL.	CHECKED BY.- A. K. GHOSH.

FIG. – .5



SL. NO.	BRIDGE NO.	q_p (Cum./Sq.Km)	W_{50} (HR.)
1	26	0.42	4.50
2	340	0.39	5.80
3	46	0.31	6.90
4	382	0.54	4.10
5	9	0.35	6.85
6	945	0.70	3.30
7	55	0.35	7.55
8	5	0.24	10.40
9	35	0.63	3.70
10	69	0.73	2.87
11	99	0.79	3.10
12	129	0.48	4.75
13	11	0.51	3.80
14	40	0.96	2.35
15	141	0.79	3.03
16	95	0.55	4.40
17	42	0.68	3.35
18	253	1.01	2.38
19	8	0.89	2.62

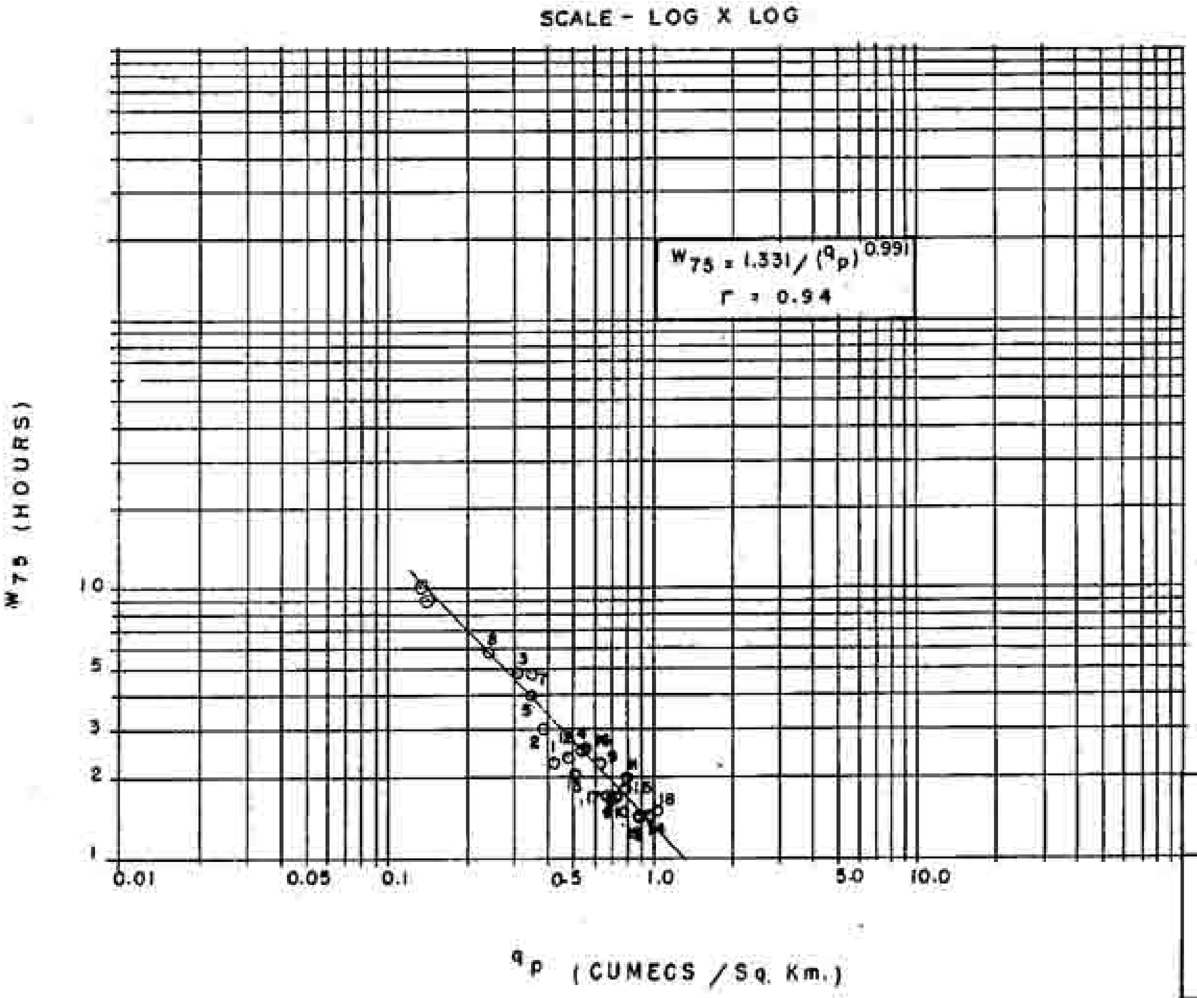
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.

MAHI AND SABARMATI
SUB ZONE 3(a)
RELATION BETWEEN
q_p AND W_{50}

DRAWN BY. MALHOTRA, L. A NAUTIYAL.	CHECKED BY. A. K. GHOSH.

FIG.- 6

SL. NO.	BRIDGE NO.	q_p (CUM./SQ.KM.)	W_{75} (HOURS)
1	26	0.42	2.30
2	340	0.39	3.00
3	46	0.31	4.90
4	382	0.54	2.50
5	9	0.35	4.00
6	945	0.70	1.65
7	55	0.35	4.90
8	5	0.24	5.90
9	35	0.63	2.30
10	69	0.73	1.70
11	99	0.79	2.00
12	129	0.48	2.40
13	11	0.51	2.05
14	40	0.96	1.45
15	141	0.79	1.80
16	95	0.55	2.60
17	42	0.68	1.70
18	253	1.01	1.55
19	8	0.89	1.45

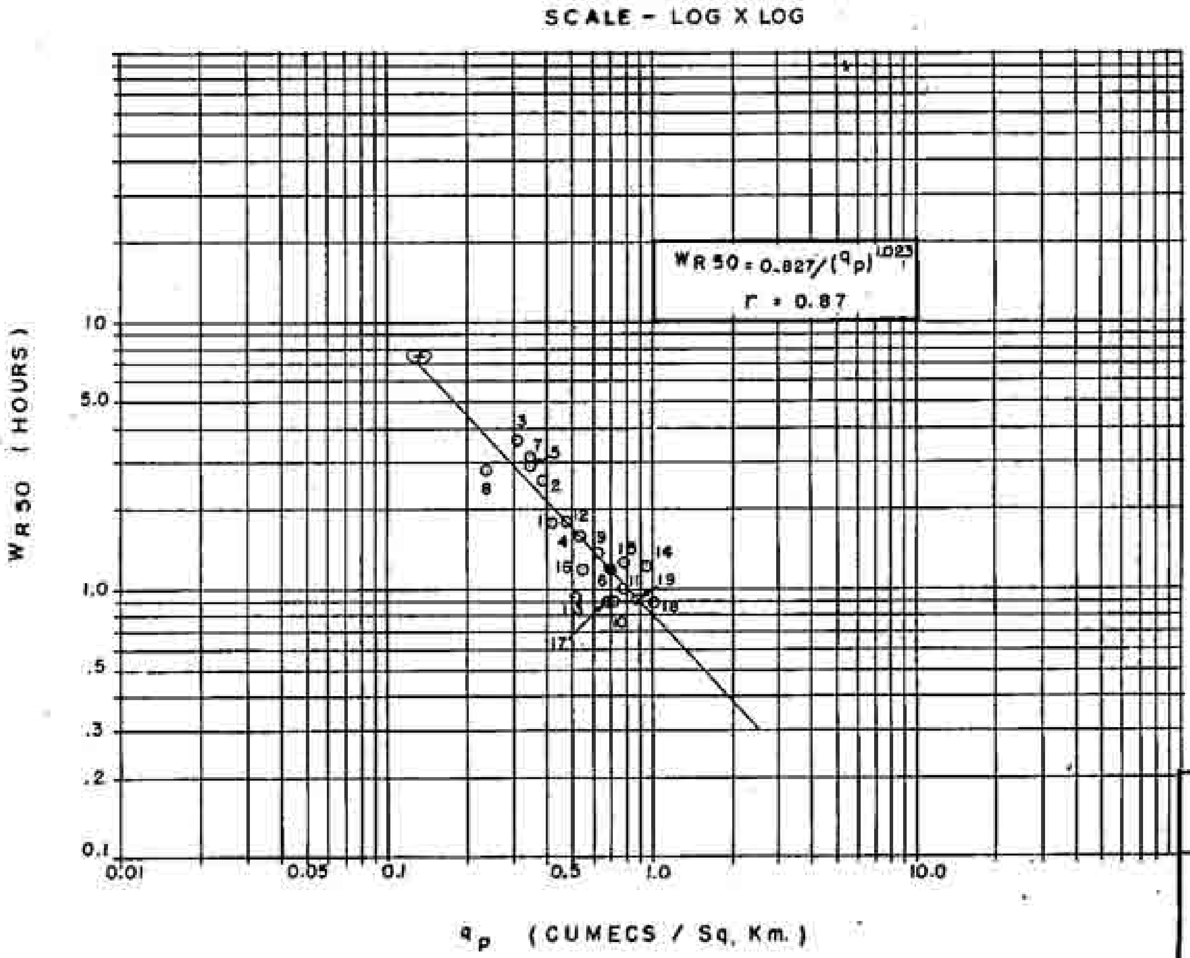


GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.

MAHI AND SABARMATI
SUB ZONE 3 a
RELATION BETWEEN
q_p AND W_{75}

DRAWN BY- MALHOTRA L. P. NAUTIYAL	CHECKED BY- K. K. AICH.

FIG.— 7



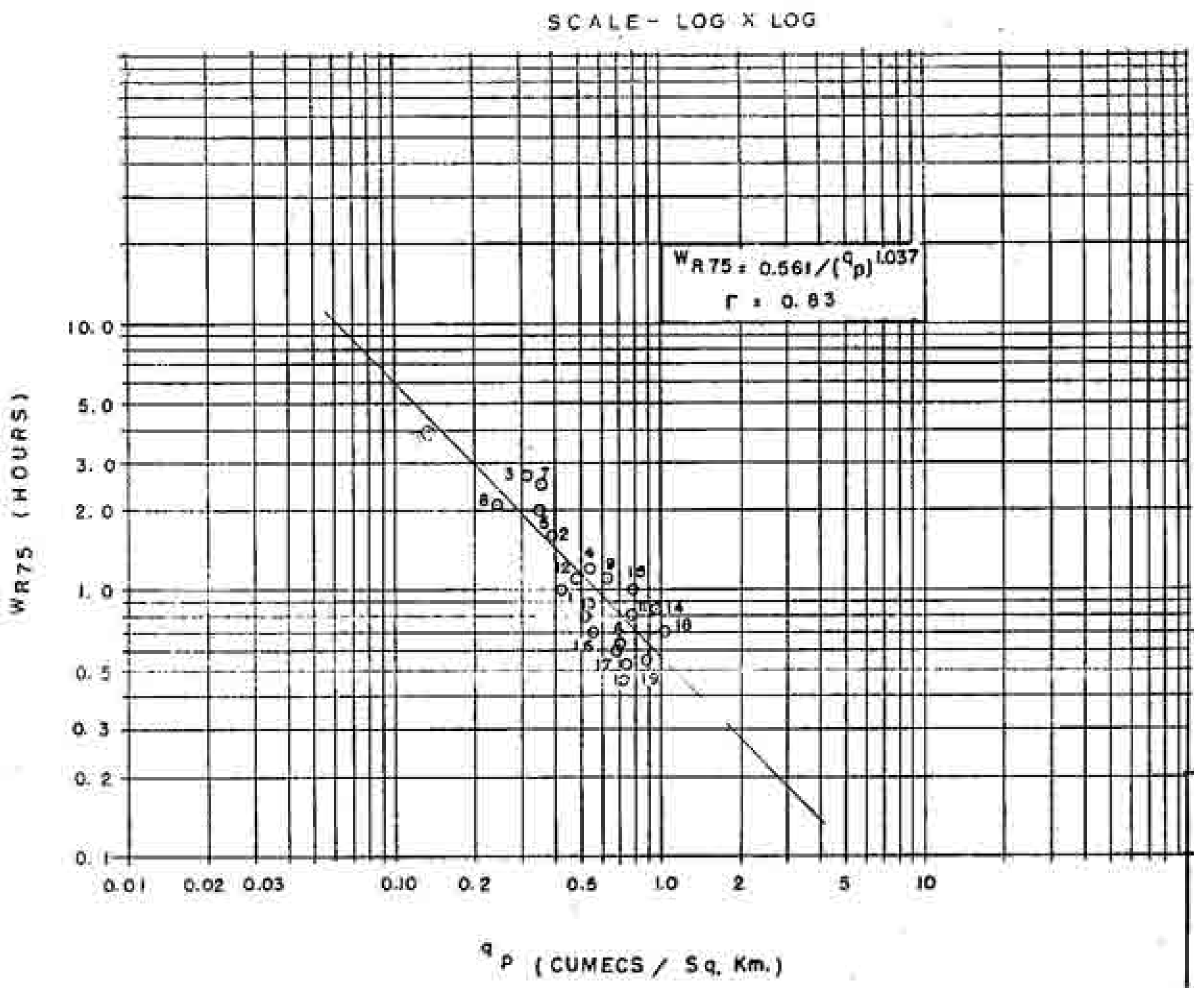
SL. NO.	BRIDGE NO.	q_p (CUM./SQ.KM)	W_{R50} (HR.)
1	26	0.42	1.80
2	340	0.39	2.60
3	46	0.31	3.70
4	382	0.54	1.60
5	9	0.35	2.95
6	945	0.70	1.20
7	55	0.35	3.20
8	5	0.24	2.80
9	35	0.63	1.40
10	69	0.73	0.90
11	99	0.79	1.00
12	129	0.48	1.85
13	11	0.51	0.95
14	40	0.96	1.25
15	141	0.79	1.28
16	95	0.55	1.20
17	42	0.68	0.90
18	253	1.01	0.90
19	8	0.89	0.92

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

MAHI AND SABARMATI
SUB ZONE 3 (a)
RELATION BETWEEN
q_p AND W_{R50}

DRAWN BY.- ARORA L. P. NAUTIYAL	CHECKED BY.- A. K. GHOSH.

FIG.— 8



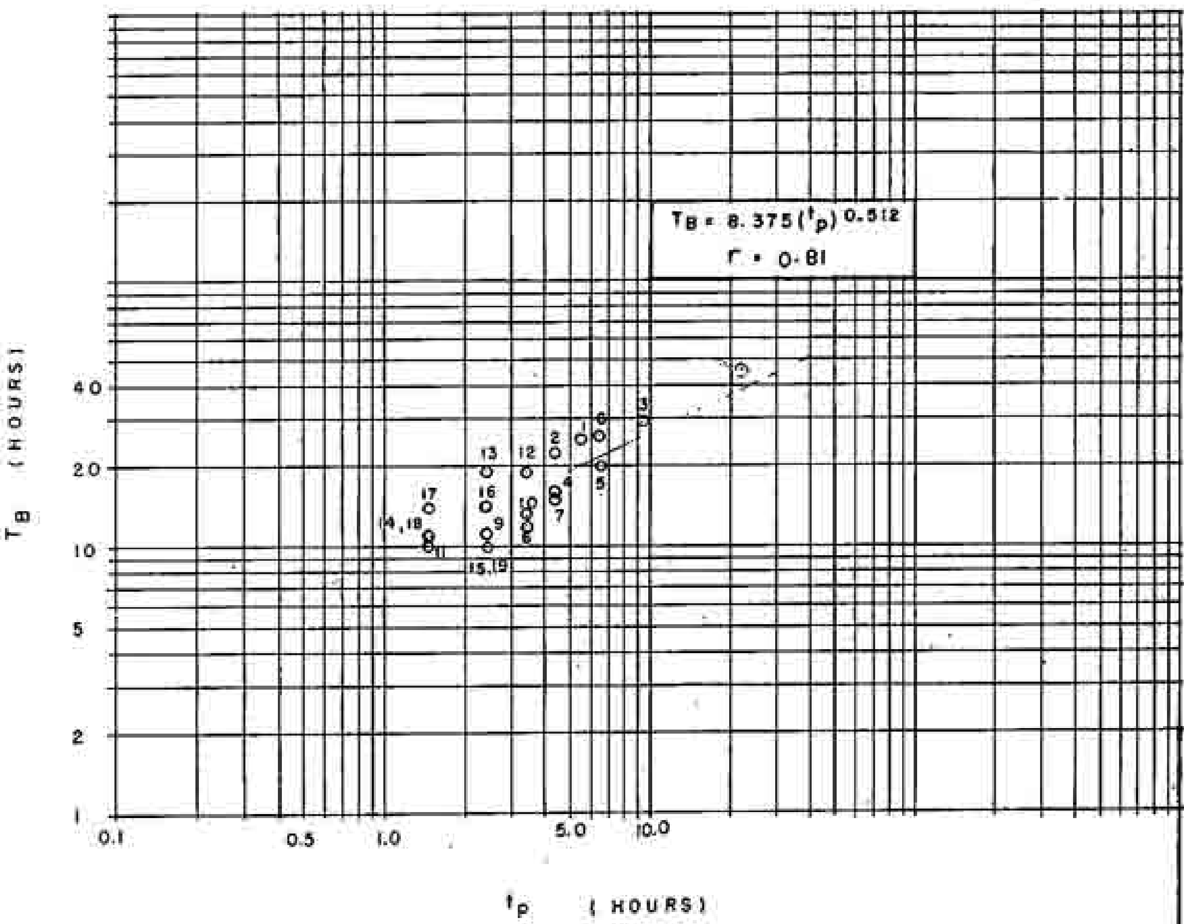
SL. NO	BRIDGE NO.	q_p (CUM./KM²)	W_{R75} (HOURS)
1	26	0.42	1.00
2	340	0.39	1.60
3	46	0.31	2.70
4	382	0.54	1.20
5	9	0.35	2.00
6	945	0.70	0.65
7	55	0.35	2.50
8	5	0.24	2.10
9	35	0.63	1.10
10	69	0.73	0.54
11	99	0.79	0.80
12	129	0.48	1.10
13	11	0.51	0.80
14	40	0.96	0.85
15	141	0.79	1.00
16	95	0.55	0.70
17	42	0.68	0.60
18	253	1.01	0.70
19	8	0.89	0.55

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

MAHI AND SABARMATI
SUB ZONE 3 (a)
RELATION BETWEEN
q_p AND W_{R75}

DRAWN BY. MALHOTRA L.P. NAUTIYAL	CHECKED BY- A. K. GHOSH.

FIG.- 9



SL. NO.	BRIDGE NO.	t_p (HOURS)	T_B (HOURS)
1	26	5.50	25.00
2	340	4.50	22.00
3	46	9.50	29.00
4	382	4.50	16.00
5	9	6.50	20.00
6	945	3.50	12.00
7	55	4.50	15.00
8	5	6.50	26.00
9	35	2.50	11.00
10	69	3.50	13.00
11	99	1.50	10.00
12	129	3.50	19.00
13	11	2.50	19.00
14	40	1.50	11.00
15	141	2.50	10.00
16	95	2.50	14.00
17	42	1.50	14.00
18	253	1.50	11.00
19	8	2.50	10.00

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

MAHI AND SABARMATI
SUB ZONE 3 (a)
RELATION BETWEEN
t_p AND T_B

DRAWN BY. BHALLA, L. P. NAUTIYAL | CHECKED BY. A. K. GHOSH

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

Various trials of relationship between the physiographic parameters (Table-2) and one of the unitgraph parameters and among the unitgraph parameters (Table-3) themselves for 19 gauged catchments considered suitable for the studies were made. The relationship between physiographic parameters $L/\sqrt{S}$ and U.G. parameter t_p was found to be significant. Afterwards t_p was related to unit peak discharge of the U.G. (q_p) and q_p was related to various U.G. parameters like W_{50}, W_{75}, W_{R50}, and W_{R75}. The time base (T_B) could be significantly correlated to t_p. The principle of least squares was used in the regression analysis to get the relationships in the form of equation 3.9.1 to predict the parameters of the synthetic unitgraph in an unbiased manner. The following relationships have been derived for estimating the 1-hr unitgraph parameters in subzone-3(a) Vide Table-4

TABLE-4: Relationship for estimating the 1-hr Unitgraph Parameters in subzone-3(a)

Relationship	Correlated Coefficient(r)	Equation No.	Fig.No.
(1)	(2)	(3)	(4)
$t_p = 0.433(L/\sqrt{S})^{0.704}$	0.93	3.9.3	3
$q_p = 1.161/(t_p)^{0.635}$	0.85	3.9.4	4
$W_{50} = 2.284/(q_p)^{1.00}$	0.98	3.9.5	5
$W_{75} = 1.331/(q_p)^{0.991}$	0.94	3.9.6	6
$W_{R50} = 0.827/(q_p)^{1.023}$	0.87	3.9.7	7
$W_{R75} = 0.561/(q_p)^{1.037}$	0.83	3.9.8	8
$T_B = 8.375(t_p)^{0.512}$	0.81	3.9.9	9
$T_m = t_p + t_r/2$		3.9.10	
$Q_p = q_p \times A$		3.9.11	

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

3.10 Derivation of 1-Hour Synthetic Unitgraph for an Ungauged Catchment

Considering the hydro-meteorological homogenity of subzone-3(a), the relations established between physiographic and unitgraph parameters in section 3.9 for 19 representative catchments are applicable for derivation of 1-hr synthetic unitgraph for an ungauged catchment in the same subzone.

The steps for derivation of 1-hr unitgraph are:

i) Physiographic parameters of the ungauged catchment viz 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 the value of $L/\sqrt{S}$ in the equation 3.9.3 $t_p = 0.433 (L/\sqrt{S})^{0.704}$ to obtain t_p in hours. The calculated t_p is rounded of to nearest half an hour. Then $T_m = t_p + t_r/2 = t_p + \frac{1}{2}$ hr.

iii) Substitute the value of t_p in the equation 3.9.4 to obtain q_p in cumec/sqkm

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

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

$$W_{50} = \frac{2.284}{(q_p)^{1.00}}$$

$$W_{75} = \frac{1.331}{(q_p)^{0.991}}$$

$$W_{R50} = \frac{0.827}{(q_p)^{1.023}}$$

$$W_{R75} = \frac{0.561}{(q_p)^{1.037}}$$

v) Substitute the value of t_p in equation 3.9.9

$T_B = 8.375(t_p)^{0.512}$ to obtain T_B in hours.

vi) Plot the parameters of 1-hr unitgraph viz. T_m, T_B, Q_p, W_{50}, W_{75}, W_{R50} and W_{R75} on a graph paper as shown in illustration Fig.2 and sketch the unitgraph through these points. The discharge ordinates (Q_i) of the unitgraph at 1-hr (t_r) interval are summed up and the direct runoff depth in cm is obtained from the following equation 3.9.10:

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

Where d = depth of direct runoff in cm

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

A = catchment area in sqkm

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

3.11 Design Loss Rate

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

Following two approaches were adopted to arrive at the design loss rate namely (i) Modal loss Rate and (ii) Empirical Loss Rate:

i) Modal Loss Rate

Constant loss rates were estimated based on various selected observed storm rainfall and flood events of reasonably higher magnitudes for derivation of unitgraphs. About 148 flood events were analysed for 19 bridge catchments. Number of flood occasions, the constant loss rates so estimated for each bridge catchment, under different loss rate ranges at intervals of 0.25 cm/hr were tabulated in Table-5. In other words, the frequency (number of total occasions) of loss rates under each loss rate ranges in Table-5 shows that the maximum number of occasions (f_m) is 39 for loss rates range of 0.25 to 0.57 cm/hr with its lower limit of 0.25 cm/hr (L).preceded by 21 occasions (f_1) for range of 0 to 0.25 cm/hr with range interval (h).

The mode is given by the formula:

$$\text{Mode} = L + \frac{f_m - f_1}{2f_m - f_1 - f_2} \times h$$

$$= 0.25 + \frac{(39 - 21)}{2 \times 39 - 21 - 24} \times 0.25$$

$$= 0.46 \text{ cm/hr say rounded off to } 0.45 \text{ cm/hr}$$

The modal value of loss rate is, therefore 0.45 cm/hr which is suggested as design loss rate for conversion of gross rainfall units into effective rainfall.

ii) Empirical Loss Rate

All the loss rate values upto 1.5 cm/hr were considered for design conditions by relating with the corresponding observed storm rainfalls and the duration by multiple correlation.

Table - 5 LOSS RATE RANGES (cm/hr)-NUMBER OF FLOOD OCCASIONS
SUBZONE-3 (a)

Sl.No.	Br.No.	Catch-ment area (Sq.Km.)	Loss Rate Ranges (cm/hr)														Total
			0 to 0.25	0.25 to 0.50	0.50 to 0.75	0.75 to 1.00	1.00 to 1.25	1.25 to 1.50	1.50 to 1.75	1.75 to 2.00	2.25 to 2.50	2.50 to 2.75	2.75 to 3.00	3.25 to 3.50	4.25 to 4.50	5.25 to 5.50	
			Number of Flood Occasion														
1	26	1094	3	5	2	1											11
2	35	194		4		1	2										7
3	141	73	1			1	1	1		1		2				1	8
4	55	253	1		1	3	1						1				7
5	945	231		1	1		1										3
6	95	58	1	4	1												6
7	129	136	1		3												4
8	8	40			3	1	2	2		1			1				10
9	40	95					2				1						3
10	42	50		1	2				1			2					6
11	5	218	3	2	1	1		2									9
12	11	98	2	3	3	1			1	1							11
13	46	565	3	2	3	1	2		1								12
14	99	144	4	7		4											15
15	382	381		1	1	1	2		1	1				1			7
16	69	150		3						1							4
17	253	48				1		2		1					1		6
18	340	1026	1	3	1	3											8
19	9	381	1	3	2	2	1	1		1							11
		Total :	21	39	24	21	14	8	4	7	1	4	2	1	1	1	148

Loss rate formula based on 123 Nos. samples upto 1.5 cm/hr was derived as under:

$$\text{Loss Rate (cm/hr)} = \frac{0.56(R)^{0.66}}{(T)^{0.59}}$$

The above formula may be used for computation of loss rates corresponding to storm rainfall (R) in cm for design storm duration (T_D) in hrs. Therefore, design storm duration (T_D) is substituted in place of (T) in the above formula.

The final loss rate formula is:

$$\text{Loss Rate (cm/hr)} = \frac{0.56\,(R_f)^{0.66}}{(T_D)^{0.59}}$$

Where R_f is the 25-yr, 50-yr or 100-yr design storm rainfall in cm for design storm duration (T_D) in hrs.

$$T_D = T_B = 5.452(L/\sqrt{S})^{0.360} \text{ in hrs.}$$

In this formula the loss rates will vary depending on the design storm rainfall and duration. The formula gives higher loss rate for higher storm rainfall and for shorter design storm duration.

In the earlier approach, a modal value of loss rate was suggested under the assumption that the catchment is thoroughly wet due to storm rainfall occurrence preceding the design storm rainfall. Hence the Antecedent Precipitation Index (API) was ignored. However, in the latter approach of empirical loss rate formula it is assumed that the loss rate occur under average conditions by extension of the related observed parameters of storm rainfall and duration for design storm rainfall and duration to reflect the interaction of varying hydrologic conditions of soils and soil cover complex in an indirect way.

The design engineer may adopt modal value of loss rate and also the loss rate by the empirical formula, for estimation of flood discharges of a catchment under study to get a comparison so as to fix the final value of flood discharge keeping in view the existing hydrologic conditions and also the site conditions for the location of the structure.

3.12 Design Base Flow

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

$$q_b = 0.109/(A)^{0.126}$$

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

4.0 DESIGN STORM INPUT

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

4.1 Design Storm Duration

The duration of the storm rainfall which causes the maximum discharge in a drainage basin is called the design storm duration. The design storm duration (T_D) for a catchment is adopted equal to base period (T_B) of 1-hr synthetic unitgraph:

$$T_D = T_B = 5.452 \, (L/\sqrt{S})^{0.360}$$

4.2 Rainfall Depth Duration Frequency Studies

India Meteorological Department have conducted this study on the basis of 12 self-recording raingauge stations and 130 ordinary raingauge stations maintained by IMD/States and 35 SRRG Stations maintained by Railway in 11 bridge catchments in subzone-3(a).

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 40 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-yr. return periods were computed. The daily values of rainfall estimates were converted into 24-hr rainfall estimates by using the conversion factor of 1.15. These 24-hr rainfall estimates for all the stations in the subzone were plotted on a base map of the subzone and isopluvial map of 50-yr. return period was drawn and shown in plate-10.

The hourly rainfall data recorded by 12 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-yr return period for specified duration namely 1, 3, 6, 9, 12, 15, 18 and 24 hours computed.

The ratios of short duration of 1, 3, 6, 9, 12, 15 and 18 hours rainfall estimates with respect to 24-hr 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 duration of 1, 3, 6, 9, 12, 15 and 18 hours with respect to 24-hr rainfall are as under:

Duration	Ratio
24	1.00
18	0.93
15	0.89
12	0.85
9	0.78
6	0.70
3	0.57
1	0.36

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

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

The short duration rainfall estimates for various short durations (1, 3, 6, 9, 12, 15 & 18 hours) can be computed by using the respective ratios. The value of 24-hr rainfall estimates for a particular station for 50-yr return period can be interpolated from Plate-10 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 11 bridge catchments were used for this study. The data of remaining bridge catchments could not be utilised as the period of data were either less than 4 years and/or concurrent years data were not recorded continuously for 4 years over the stations in a bridge catchment. 2-yr point rainfall values for specified duration for each station in the catchments were computed by frequency analysis. Arithematic average of 2-yr point rainfall of all the stations in the catchment was calculated to get the 2-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 of 2-yr areal rainfall depths for specified duration were computed. The percentage ratio of 2-yr areal rainfall to 2-yr representative point rainfall, for the catchment was calculated and plotted against the area of the catchment for various durations. The best fit curves were drawn for specified duration on the points obtained for the catchments. Fig. 11(a) and 11(b) give the curves for conversion of point rainfall into areal rainfall for 1,3,6,12 and 24 hrs. The areal reduction factor (ARF) at different intervals of catchment areas for the above durations are given in Table-6.

Data for bridge catchment is available only upto 1100 sqkm and point to areal curves have been extrapolated upto 2500 sqkm on the basis of limited ARF's obtained from bridges having area less than 1100 sqkm. Point to areal rainfall values may, therefore, be used with caution for areas more than 1100 sqkm.

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 duration-

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 1286 rain storms of various durations upto 24 hours occurring in various parts of the subzone were analysed based on 127 stations 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 abcissa. Thus five different graphs were prepared for each station corresponding to various durations and were then examined. The average time distribution curves for the various durations were drawn for each station. All the average curves for the stations thus obtained were plotted on a single graph and a single average curve for the subzone as a whole was drawn for storms of different durations and are shown in Fig. 12(a) to (e).

4.5 25-Year and 100-Year 24-Hour Point Rainfall Maps

For those interested in the design flood (25-yr and 100-yr flood) 25-yr and 100-yr 24-hr point rainfall maps are shown in plates - 9 & 11. To obtain 6,9,12,15 and 18 hrs from 25-yr and 100-yr 24-hr rainfall, the ratios given in section 4.2 may be used. Similarly, section 4.3 and 4.4 may be used for conversion of point to areal rainfall and time distribution of input storm respectively. Synthetic unitgraph, 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 $T_D = T_B = 5.452\ (L/\sqrt{S})^{0.360}$ (rounded off to the nearest full hour) by substituting the known values of L and S for the catchment under study.

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

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

Step-4: Convert the 50-yr T_D-hr point rainfall to 50-yr T_D-hr areal rainfall by multiplying with the areal reduction factor (ARF) corresponding to catchment area and for T_D-hr duration from Table-4 or by interpolation from Fig.11(a) and 11(b) in Section 4.3.

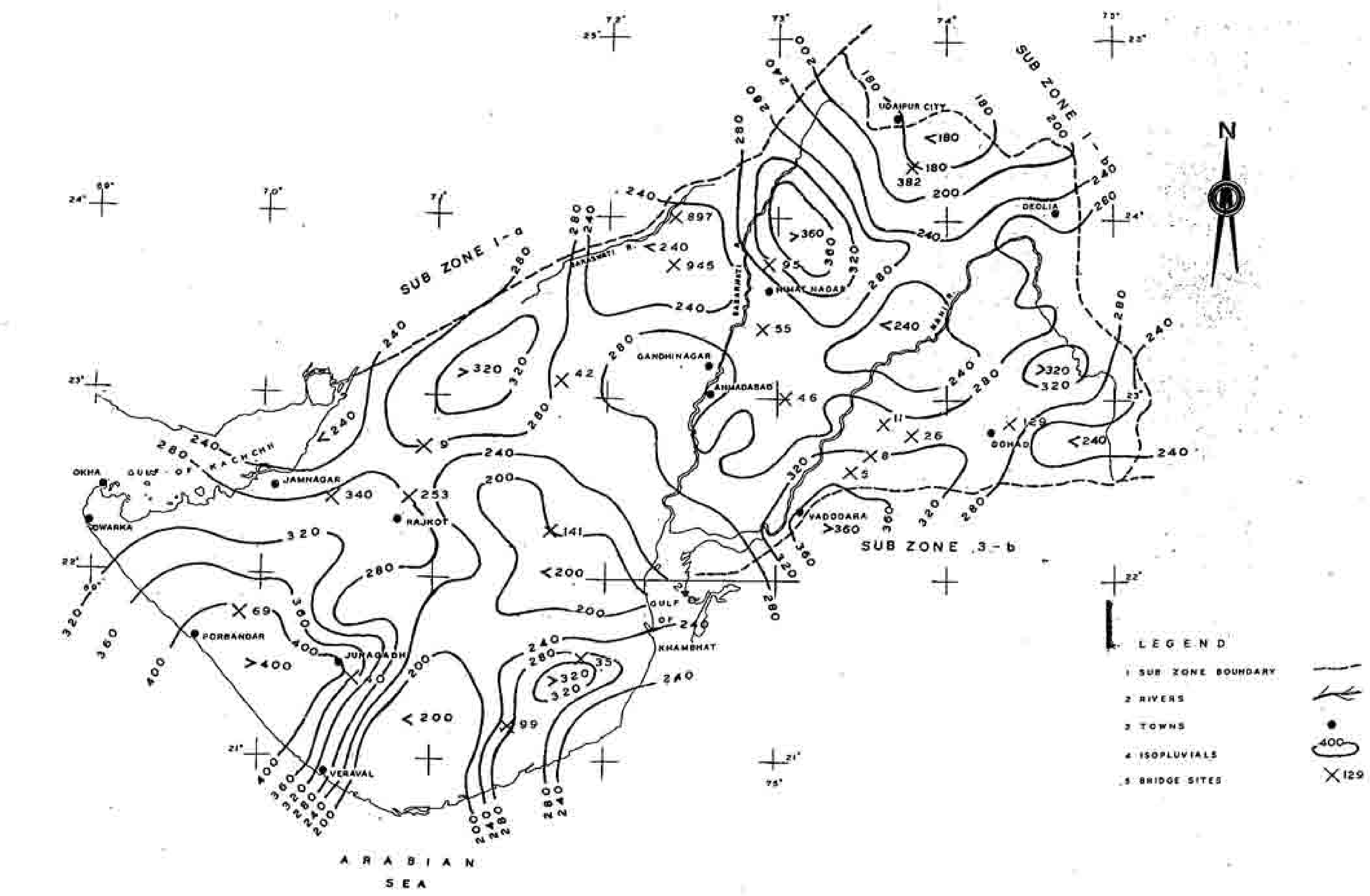
TABLE - 6: AREAL TO POINT RAINFALL RATIO (PERCENTAGE)

Area in Sq.Kms.	1-hr.	3-hr.	6-hr.	12-hr.	24-hrs.
0	100	100	100	100	100
50	84	89	91	96	97
100	74	82	85	92	95
150	67	76	81	90	93
200	63	72	78	88	92
250	60	69	76	87	91
300	-	68	75	85	89
350	-	-	74	84	88
400	-	-	-	83	87
450	-	-	-	82	86
500	-	-	-	81	85
600	-	-	-	80	84
700	-	-	-	79	83
800	-	-	-	78	82
900	-	-	-	77	81.5
1000	-	-	-	76	81
1500	-	-	-	74	80
2000	-	-	-	-	79
2500	-	-	-	-	78

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

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

PLATE-9



NOTE:- THE TERRITORIAL WATER OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

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

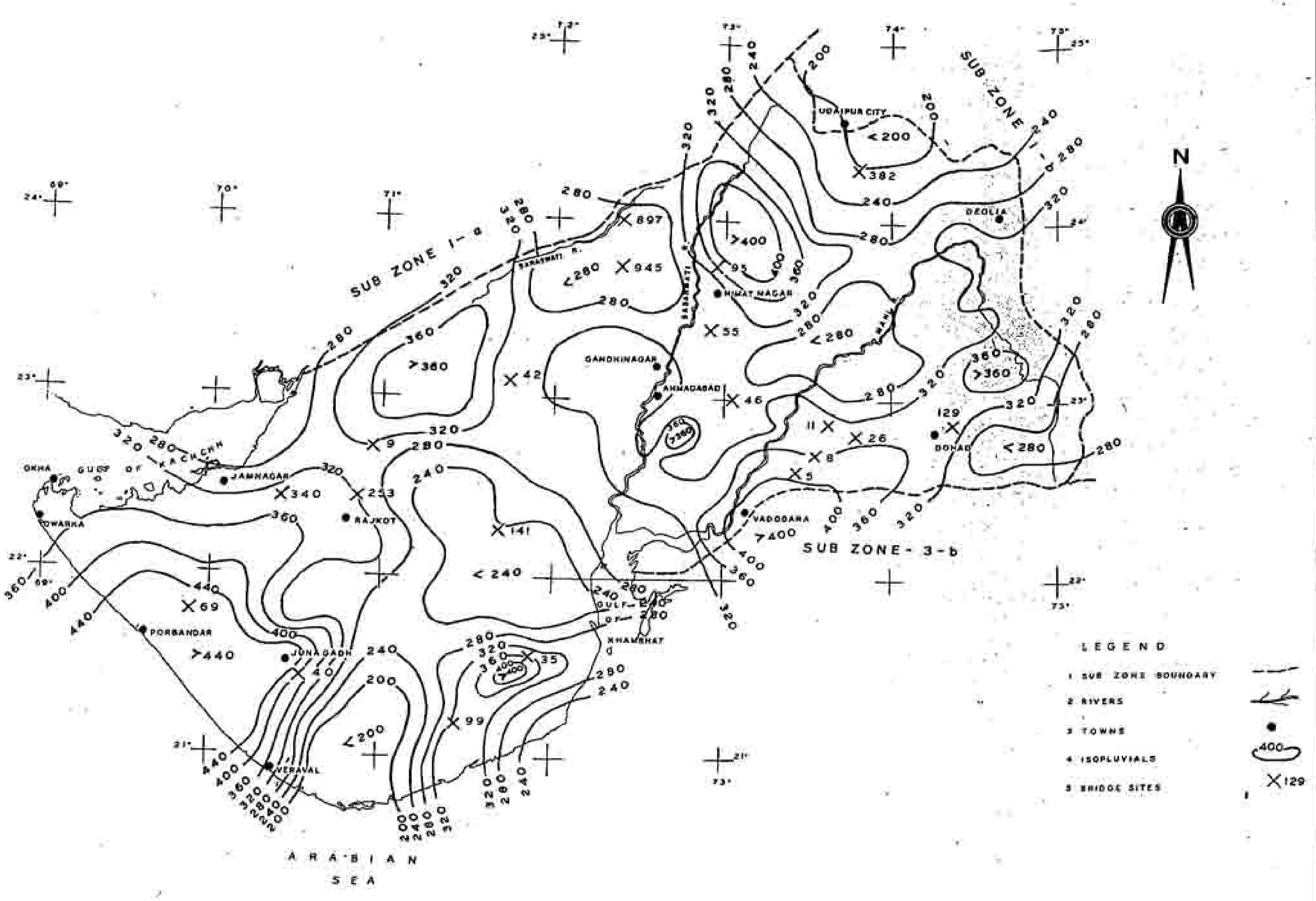
MAHI AND SABARMATI
SUB ZONE 3(a)
25 YEAR 24 HOUR RAINFALL (mm)

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

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.

PLATE-10



NOTE-: THE TERRITORIAL WATER OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

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CENTRAL WATER COMMISSION
HYDROLOGY (S.C) DIRECTORATE

MAHI AND SABARMATI

SUB ZONE 3(a)

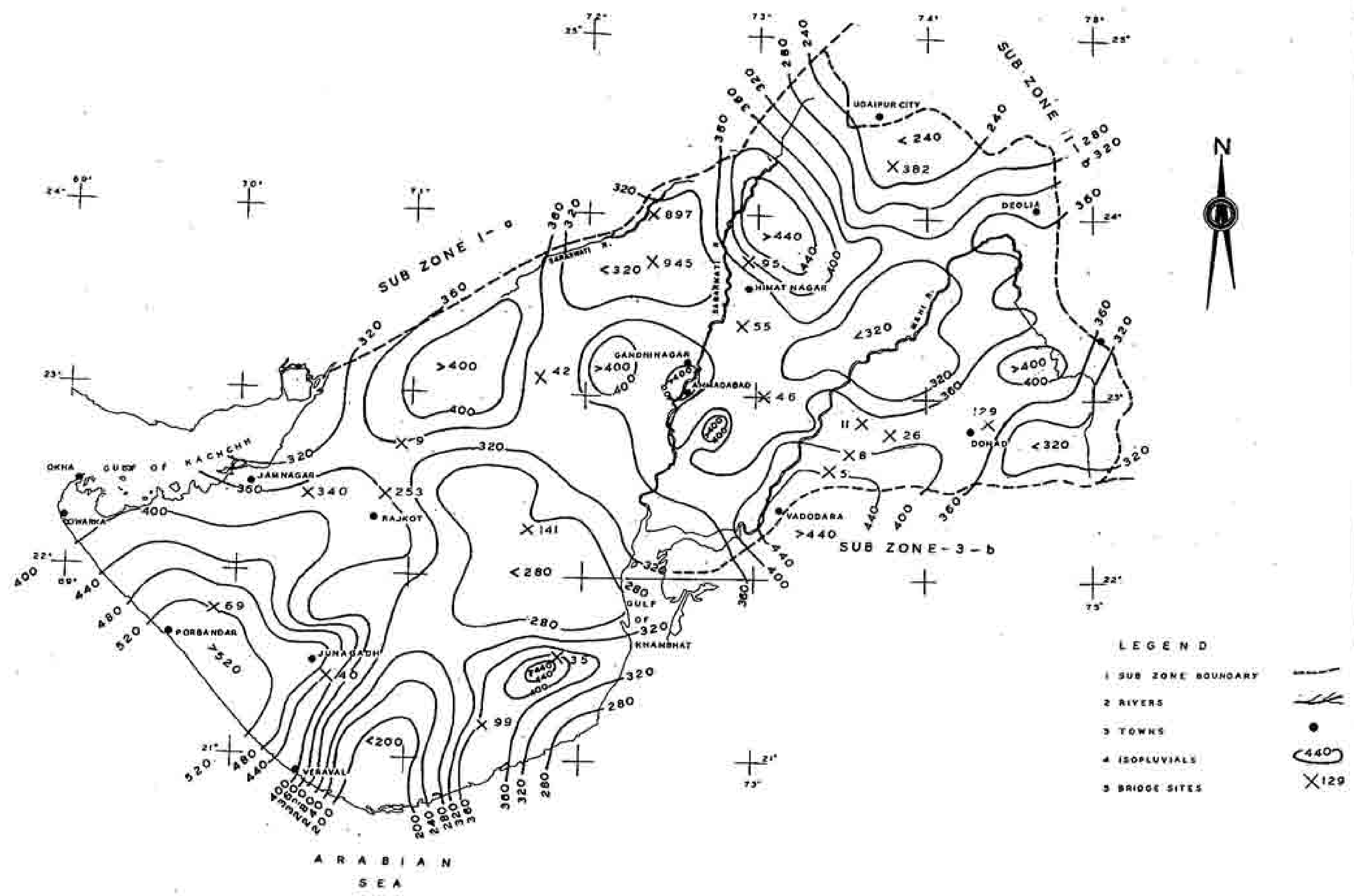
50 YEAR 24 HOUR RAINFALL (mm)

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

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.

PLATE-II



NOTE:- THE TERRITORIAL WATER OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

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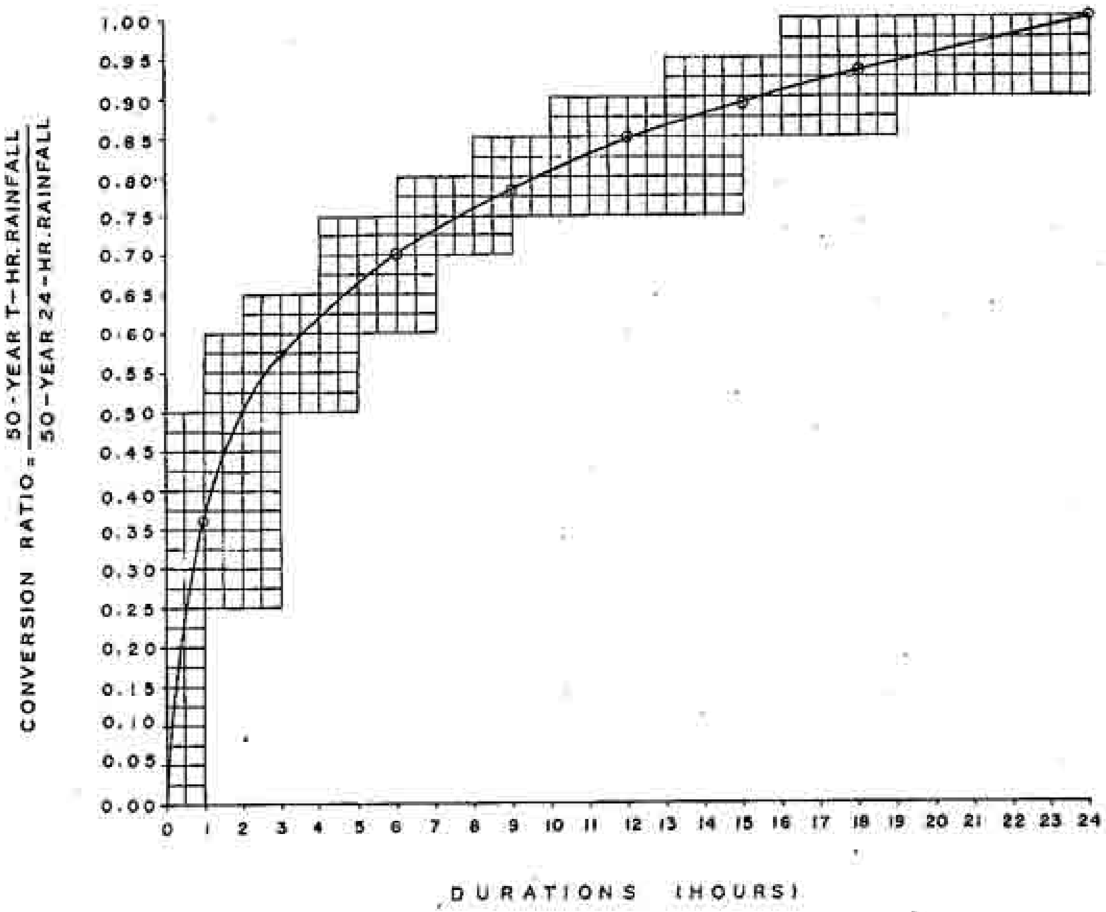
MAHI AND SABARMATI
SUB ZONE 3(a)
100 YEAR 24 HOUR RAINFALL (mm)

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.

FIG.- 10



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

DURATION (HRS.)	RATIO
1	0.360
2	0.505
3	0.570
4	0.620
5	0.665
6	0.700
7	0.730
8	0.760
9	0.780
10	0.805
11	0.825
12	0.850
13	0.860
14	0.875
15	0.890
16	0.905
17	0.920
18	0.930
19	0.945
20	0.960
21	0.970
22	0.980
23	0.990
24	1.000

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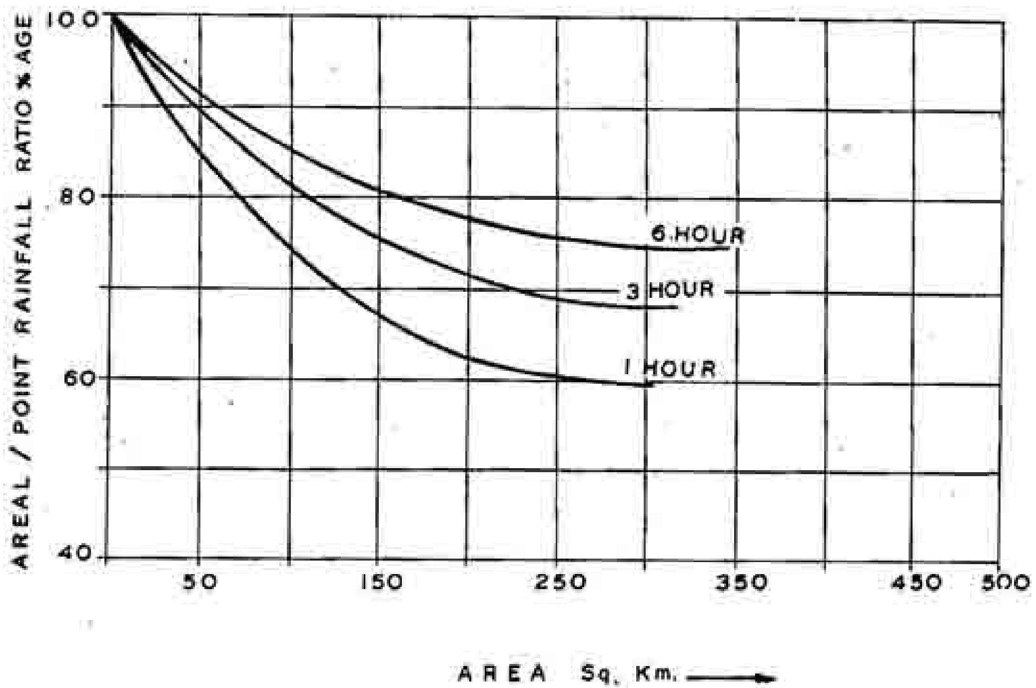
MAHI AND SABARMATI
SUB ZONE - 3 (a)

DURATION Vs CONVERSION RATIO

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

FIG.-11 (a)



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MAHI AND SABARMATI

SUB ZONE - 3 (a)
AREAL / POINT RAINFALL
RATIO (PERCENTAGE)

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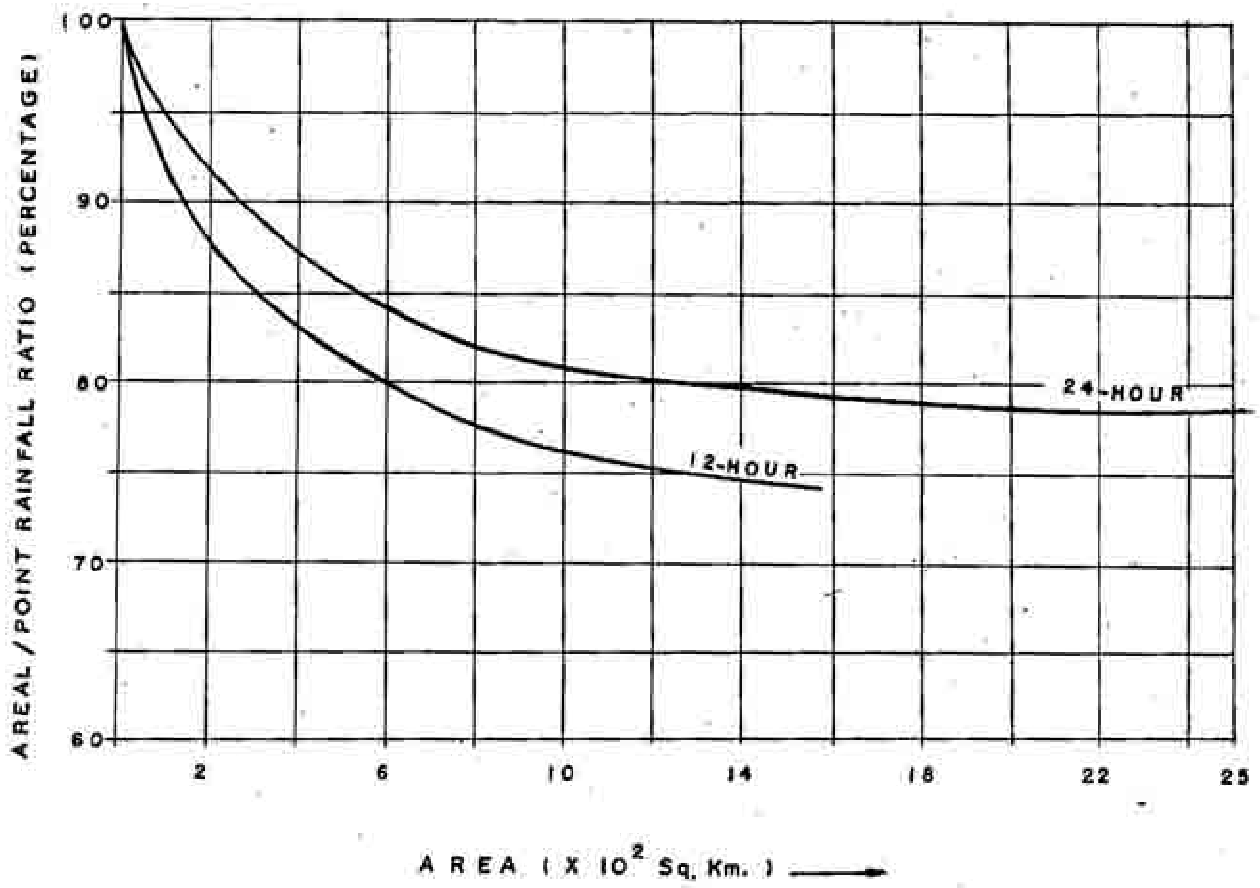
S.N. MALHOTRA R.N. SHARMA	A. K. GHOSH

FIG.— II (b)



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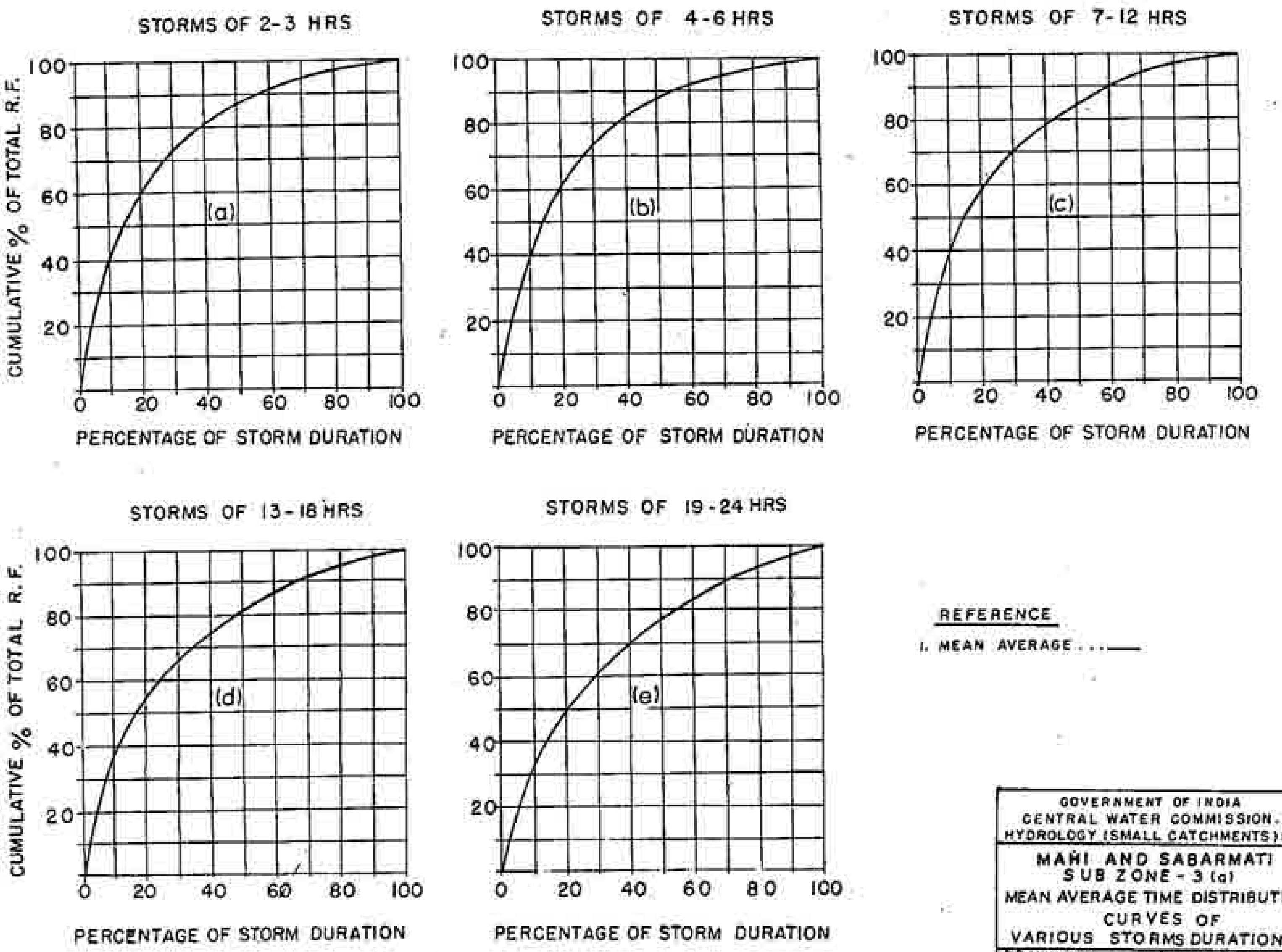
MAHI AND SABARMATI
SUB ZONE - 3 (a)
AREAL / POINT RAINFALL
RATIO (PERCENTAGE)

DRAWN BY—	CHECKED BY—
T. R. ARORA L. P. N AUTIYAL	A. K. GHOSH

FIG. - 12.



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MAHI AND SABARMATI
SUB ZONE - 3 (a)
MEAN AVERAGE TIME DISTRIBUTION
CURVES OF
VARIOUS STORMS DURATIONS

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

5.0 ESTIMATION OF DESIGN FLOOD FOR AN UNGAUGED CATCHMENT

Step-1 : Determine the 1-hr 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 as recommended vide section 3.11.

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

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

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

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

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

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

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

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

Step-8 : Obtain the base flow rate in cumecs/sqkm vide section 3.12. Multiply base flow rate in cumecs/sqkm with the catchment area under study to get the total base flow.

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

Likewise 25-yr. flood and 100-yr flood hydrographs are computed following the above steps in section 4.6 and 5.0 corresponding to 25-yr and 100-yr storm rainfall for design storm duration $T_D = T_B$.

6. FORMULA FOR LINEAR WATERWAY OF BRIDGES

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

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

$$W = 7.28 \quad (Q_{50})^{1/3}$$

Where W is linear waterway in metres and Q_{50} is 50-year flood discharge in cumecs using the modal loss rate of 0.45 cm/hr.

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

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

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

iii) Work out the design HFL expected for Q_{50} (using the modal loss rate of 0.45 cm/hr) with the waterway estimated.

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

$$W = 7.69 \ (Q_{25})^{1/3}$$

$$W = 6.96 \ (Q_{100})^{1/3}$$

Where Q_{25} and Q_{100} are estimated using a modal loss rate of 0.45 cm/hr.

THE FORMULAE GIVEN ABOVE ARE ONLY TO BE USED FOR FIXING THE LINEAR WATERWAY OF THE BRIDGES IN THE MAHI AND SABARMATI SUBZONE 3 (a). THE LACEY'S REGIME WIDTH FORMULAE WILL NOT BE APPLICABLE FOR FIXING THE LINEAR WATERWAY OF BRIDGES IN SUBZONE-3 (a). HOWEVER, FOR DETERMINATION OF SCOUR AT BRIDGE SITES THE LACEY'S SCOUR FORMULAE BASED ON LACEY'S REGIME WIDTH AS SPECIFIED IN THE CODES FOR ROAD AND RAIL BRIDGES SHALL BE USED.

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

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

ii) Standard specifications and code of practice for Road bridges, section 1, General Features of Design (fifth revision) by Indian Roads Congress, 1983 clauses 103 and 104.

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

7.1 General

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

7.2 Stage Discharge Relationship

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

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

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

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

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

7.3 Back Water Effect

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

7.4 Hydraulic Gradient

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

7.5 Unfavourable Crossing Site

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

8.0 UTILITY OF REPORT FOR OTHER PURPOSES

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

i) Small Dams

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

ii) Minor Cross Drainage Works

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

9.0 ASSUMPTIONS, LIMITATIONS AND CONCLUSIONS

9.1 Assumptions

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

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

9.2 Limitations

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

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

9.2.3 The approach developed mostly covers the catchments with flat to moderate slopes.

9.3 Conclusions

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

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

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

9.3.4 Formulae for fixing the linear waterway of cross drainage structures on streams in Mahi & Sabarmati subzone may be used at the discretion of the design engineer.

9.3.5 25-yr,50-yr and 100-yr flood may be estimated using modal loss rate of 0.45 cm/hr and the empirical loss rate formula. However, the design engineer may adopt Design flood for a structure either using modal loss rate or empirical loss rate formula depending on the relative importance of the structure. 25-yr, 50-yr and 100-yr flood formulae along with respective formulae for linear waterway of bridges are in Annexure-1 which may be used for preliminary designs. However, for final designs, the design flood has to be estimated using the empirical loss rate formula as per the procedure in the illustrative example.

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

9.3.7 The report is also applicable to the adjoining north-western parts of Gujarat (Kachchh area excluding Rann of Kachchh).

9.3.8 Two different approaches have been recommended for design loss rate in this report viz; one based on a formula and the other a fixed value. The purpose behind this is flexibility which is essential for accommodating the changing patterns of parameters influencing loss rate even within the subzone. Incidentally this flexibility would cater to the changing needs of different organisations utilising the report for varied purposes.

MAHI AND SABARMATI SUBZONE - 3 (a)

1) 25-yr, 50-yr and 100-yr Flood Formula
(Based on Empirical Loss Rate Formula in Section 3.11 (ii))

i) $$Q_{25} = \frac{1.002\ (A)^{0.991}\ (S)^{0.261}\ (R_{TD})^{1.134}}{(L)^{0.642}} \qquad r = 0.992$$

ii) $$Q_{50} = \frac{1.141\ (A)^{0.955}\ (S)^{0.255}\ (R_{TD})^{1.03}}{(L)^{0.592}} \qquad r = 0.993$$

iii) $$Q_{100} = \frac{1.079\ (A)^{0.970}\ (S)^{0.257}\ (R_{TD})^{1.106}}{(L)^{0.603}} \qquad r = 0.993$$

Where symbols are same as given in (B) (2) Simplified Approach.

2) Equations for Linear Waterway

$$W = 8.16\ (Q_{25})^{1/3}$$

$$W = 7.76\ (Q_{50})^{1/3}$$

$$W = 7.42\ (Q_{100})^{1/3}$$

Where W is linear waterway in meters, Q_{25}, Q_{50} and Q_{100} are 25-yr, 50-yr and 100-yr flood estimated by formula in (1) above.

REFERENCES

1. Report of the Khosla Committee of Engineers (October,1959) Government of India, Ministry of Railways.

2. "Hand Book of Hydrology", Ven Te Chow

3. "Open Channel Hydraulics", Ven Te Chow

4. Guide to Hydrological Practices (Third Edition) World Meteorological Organisation No.168, 1974.

5. Estimation of Design Flood "Recommended Procedures, September, 1972, Government of India, Central Water Commission, New Delhi.

6. "Engineering Hydrology" Wilson E.M.

7. Code of Practice by Indian Railways (Revised 1985).

8. Code of Practice for Road Bridges, Section-1, General Features of Design (5th Revision), 1983, Indian Roads Congress.

9. "The Design of Small Bridges and Culverts" Goverdhan Lal.

10. Flood Studies Report, Vol.I, Hydrological Studies, Natural Environment Research Council, 27, Claring Cross Road, London, 1975.

11. "Economics of Water Resources Planning" L. Douglas James/Robert R. Lee.

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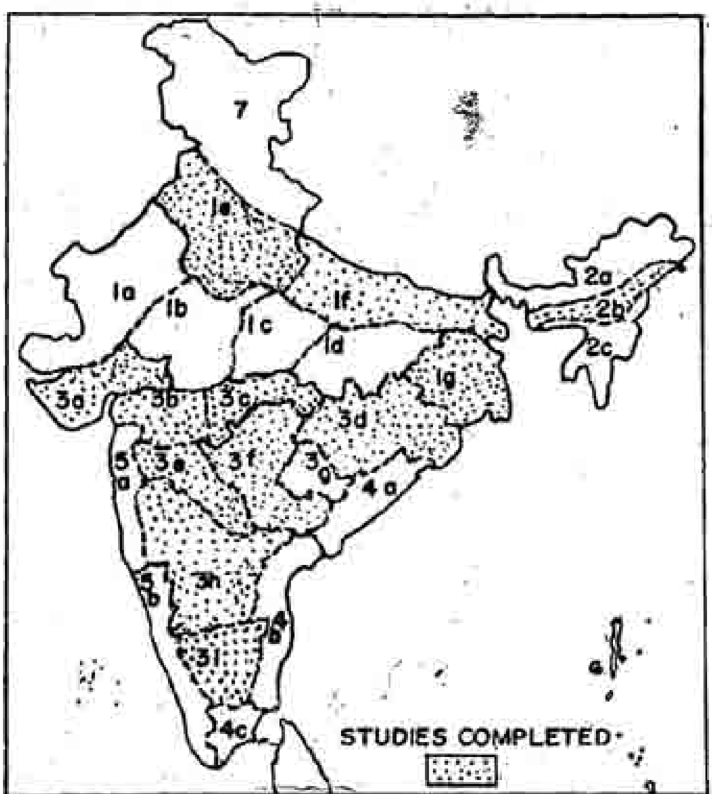
A. UNDER SHORT TERM PLAN

1.	Estimation of Design Flood Peak	(1973)

B. UNDER LONG TERM PLAN

1.	Lower Gangetic Plains subzone-1(g)	(1978)
2.	Lower Godavari subzone-3(f)	(1981)
3.	Lower Narmada and Tapi subzone-3(b)	(1982)
4.	Mahanadi subzone-3(d)	(1982)
5.	Upper Narmada and Tapi subzone-3(c)	(1983)
6.	Krishna and Pennar subzone-3(h)	(1983)
7.	South Brahmaputra Basin subzone-2(b)	(1984)
8.	Upper Indo-Gangetic Plains subzone-1(e)	(1985)
9.	Middle Ganga Plains subzone-1(f)	(1985)
10.	Kaveri Basin subzone-3(i)	(1986)
11.	Upper Godavari subzone-3(e)	(1986)



Designed and Printed at CWC Offset Press, New Delhi/