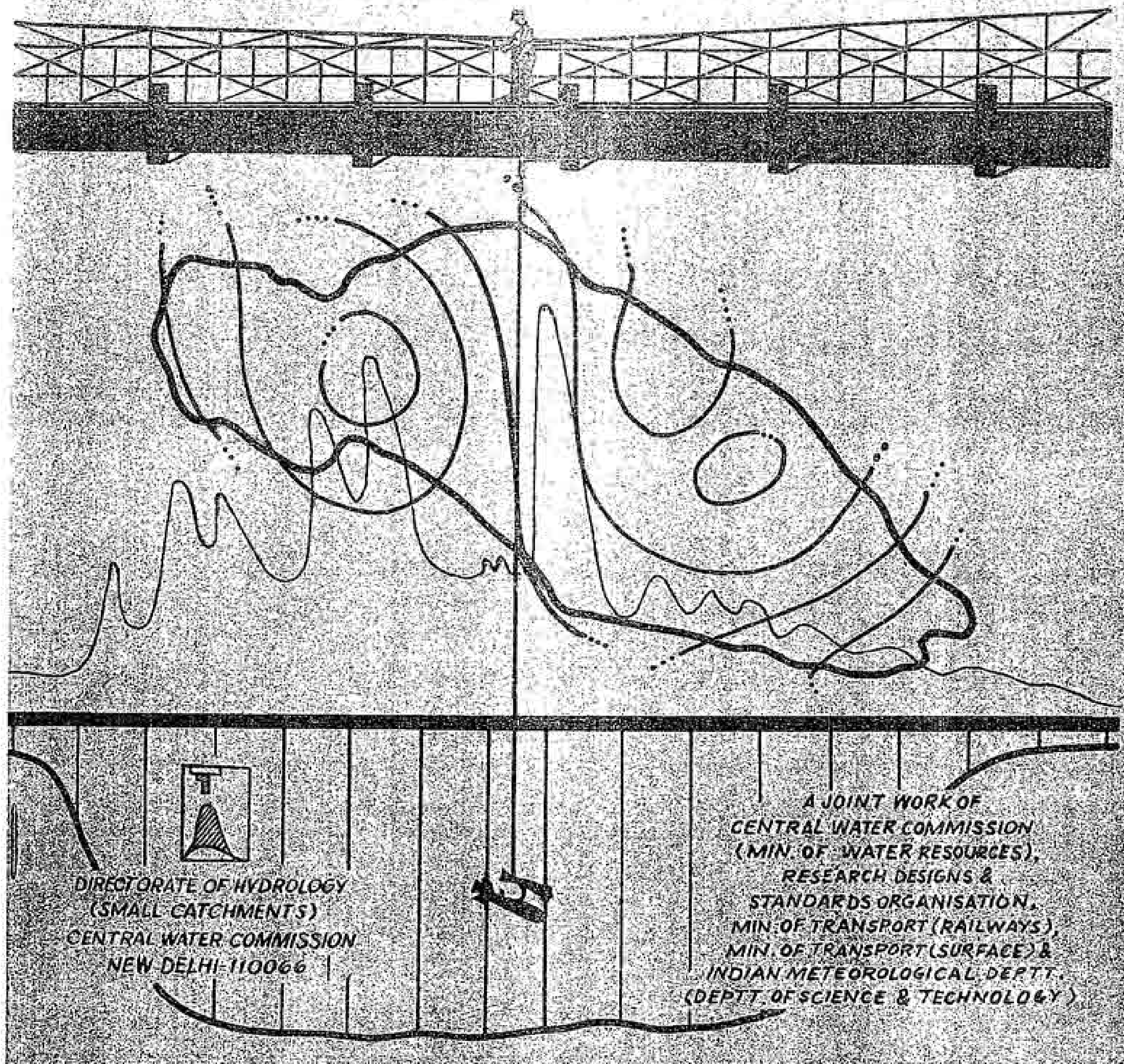
ऊपरी गोदावरी (उपक्षेत्र - 3 ई) की बाढ़ आकलन का विवरण

यूनिट जलालेख सिद्धान्त पर आधारित एक प्रणाली

FLOOD ESTIMATION REPORT FOR UPPER GODAVARI (SUB ZONE-3 e)

A METHOD BASED ON
UNIT HYDROGRAPH PRINCIPLE



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

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

FLOOD ESTIMATION REPORT FOR UPPER GODAVARI SUBZONE-3(e) WAS DISCUSSED AND APPROVED BY THE FOLLOWING MEMBERS OF THE PLANNING AND COORDINATION COMMITTEE IN ITS 43RD MEETING HELD ON 21ST AND 22ND JANUARY, 1986 AT PUNE.

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FLOOD ESTIMATION REPORT FOR UPPER GODAVARI

SUBZONE-3 (e)

A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE

DESIGN OFFICE REPORT NO. CB/12/1985

HYDROLOGY (SMALL CATCHMENTS) DIRECTORATE

CENTRAL WATER COMMISSION

NEW DELHI

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 homogenous regions/zones in the country under long term plan using the rational methodology of unit hydrograph and design storm rainfall. The Committee's 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 Standard 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 Upper Godavari Subzone-3(e), which was discussed and approved by the Planning and Coordination Committee in its 43rd meeting held on 21st and 22nd January, 1986 at Pune. The rainfall, gauge and discharge data of selected catchments in Upper Godavari was collected by the Central Railways.

The report is a joint effort by Central Water Commission of the Ministry of Water Resources, Research Designs and Standards Organisation of the Ministry of Transport (Railways), Roads Wing of the Ministry of Transport (Surface) 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.

This represents land mark in the country in the field of Hydrology of small and medium catchments.

Sd/-

(N.K. SARMA)
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PREFACE

The design engineer essentially requires design flood for the design of waterways and foundations of the bridges, culverts and other cross drainage structures like acquaducts etc. for safely negotiating the design flood consistant with economy and safety of the structures. The study of flood hydrology of rivers, therefore, becomes absolutely necessary for estimation of design flood at the point of study.

The road/railway and irrigation canal networks cross a large number of small and medium size streams with bridges and cross drainage structures on them. For determining the waterway of bridges and their depth of foundations the design flood of specific frequency are required. Detailed hydrological and meteorological investigations for a large number of small and medium catchments upto each and every new site and for adequate periods is not possible due to economic constraints. Waterway should be adequate to pass safely the design flood, but at the same time it should not be too wide involving higher cost. Therefore, it becomes necessary to reasonably estimate the flood discharge of the required return period of stream at the point of study with sufficient care. A casual approach can lead in extreme cases to loss and destruction of structure due to floods of magnitude higher than expected or over design of structures leading to uneconomical and problematic situation.

In the early years, design discharges were calculated by well known empirical formulae viz: Dickens, Ryves, Inglis and Ali Nawaz Jung etc. In these formulae, flood discharge is related to catchment areas only and effect of all other factors are included in a constant which is to be decided by the designer from his experience. Even intensity of the storm rainfall which is a prime factor responsible for the flood and which varies substantially from place to place is not included in the above formulae. The need to evolve a method on estimation of design flood peak of desired frequency knowing the physical characteristics of the catchments and design rainfall has been recognised and a committee of engineers under the chairmanship of Dr. A.N. Khosla have recommended "_systematic and sustained collection of hydrometeorological 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 recorded floods during the period. In case, where the requisite data, as above are not available, the design flood should be decided based on the ground and meteorological characteristics obtained on the basis of design storm. Accordingly in this report, a method based on synthetic unit hydrograph and design rainfall has been evolved to represent physiographic and meteorological characteristics to estimate the design flood.

Based on the studies made utilizing the data of representative catchments, the following preliminary and subzonal reports have been brought out so far.

Under Short Term Plan

Estimation of Design Flood Peak No.1/73 (Preliminary)

Under Long Term Plan

Sl.No.	Subzone	Report No.
1.	Lower Gangetic Plains subzone-1(g)	2/1974
2.	Lower Godavari subzone-3(f)	3/1980
3.	Lower Narmada & Tapi subzone-3(b)	LNT/4/1981
4.	Mahanadi subzone-3(d)	M/5/1981
5.	Krishna & Penner subzone-3(h)	K/6/1982
6.	Upper Narmada & Tapi Subzone-3(c)	UNT/7/1983
7.	South Brahmaputra Basin subzone-2(b)	SB/8/1984
8.	Upper Indo-Ganga Plains subzone-1(e)	UGP/9/1984
9.	Middle Ganga Plains subzone-1(f)	MGP/10/1984
10.	Kaveri Basin subzone-3(i)	KB/11/1985

The present report for Upper Godavari Basin is the culmination of the coordinated efforts of Central Railway, Research Directorate (BEF Wing) of R.D.S.O., Hydrology (Small Catchments) Directorate and SC&WRS Cell of Central Water Commission, Hydromet Directorate of India Meteorological Department and Ministry of Transport (Surface).

The present report deals with the estimation of 50-yr. flood for small and medium catchments in Upper Godavari Basin subzone-3(e) based on 50-yr. design storm rainfall and synthetic unitgraph. Besides, 25-yr. and 100-yr. 24-hr. storm rainfall maps of Upper Godavari Subzone have been incorporated in the report for estimation of 25-yr. and 100-yr. flood using the same procedure.

The report necessarily begins with 25-yr., 50-yr. and 100-yr. flood formulae to create interest in the users for estimation of 25-yr., 50-yr. and 100-yr. flood for ungauged catchments for preliminary designs with minimum effort. These sets of formulae are based on multiple regression method giving more or less the same results with lesser accuracy as compared to the detailed method.

"Application of the Report" with an illustrative example based on (I) simplified and (II) detailed approaches is incorporated in the report after "Introduction" for quick and correct understanding of the users. The basic theory behind the flood formulae by both the methods is covered in the simplified approach.

Subsequent parts of the report deal with the general aspects of the Upper Godavari Basin subzone, nature and availability of data, analysis of storm rainfall and floods, derivation of synthetic unitgraph with synthetic unitgraph relations, base flow, infiltration losses, design storm rainfall and procedure for estimation of design flood peak as well as hydrograph. The report finally ends with the assumptions and conclusions.

This report is recommended for estimation of design flood (25-yr., 50-yr. and 100-yr. flood) for fixing the waterway vis-a-vis design H.F.L. for cross drainage structures according to their importance, resources available and site conditions for catchment areas ranging in size from 25 to 2500 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 catchment also. A formula for fixing the linear waterway of the bridges for the guidance of design engineers has also been incorporated. Flexibility has also been imparted to the report by suggesting the adoption of different constant loss rates under special conditions at the discretion of design engineer.

Further, the report may also be used for estimation of frequency flood like 100-yr. flood for safety of small dams and 10 to 25 years flood for the design of waterway of minor cross-drainage works as per the Indian Standards of the Indian Standards Institution.

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

(S.M. HUQ)
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NEW DELHI

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LIST OF TABLES, PLATES AND FIGURES

FIGURES

SYMBOLS AND ABBREVIATIONS

SYMBOLS

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

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

I_f : Design loss rate in cm/hr.

q_b : Design base flow rate in cumecs/sq.km.

q_p : Peak discharge of unit hydrograph per unit area in cumecs per sq.km.

Q_p : Peak discharge of unit hydrograph in cumecs.

W_{50} : Width of the U.G. measured at 50% of maximum discharge (Q_p) in hours.

W_{75} : Width of the U.G. measured at 75% of maximum discharge ordinate (Q_p) in hours.

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

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

Q_{25} : 25-year flood peak in cumecs.

Q_{50} : 50-year flood peak in cumecs.

Q_{100} : 100-year flood peak in cumecs.

ARF : Areal reduction factor

% : Percent

Σ : Summation

ABBREVIATIONS

Cumecs : Cubic metres per second

Cms : Centimetres

Hr. : Hour

M. : Metres

Min. : Minutes

Km. : Kilometres

Sq.km. : Square kilometres, Km^2

In.	:	Inches
Sec.	:	Seconds
Sq.	:	Square
R.D.S.O.	:	Research Designs and Standards Organisation (Ministry of Railways), Lucknow.
H(SC), CWC	:	Hydrology (Small Catchments) Directorate, Central Water Commission, New Delhi.
I.M.D.	:	India Meteorological Department
C.W.C.	:	Central Water Commission
M.O.S.T.	:	Ministry of Shipping & Transport, New Delhi.

*25-YEAR, 50-YEAR AND 100-YEAR FLOOD PEAK FORMULA (BY MULTIPLE REGRESSION ANALYSIS)

$$Q_{25} = \frac{2.967(A)^{0.868}\ (S)^{0.167}\ (R_{TD-25\ yr.})^{0.760}}{(L)^{0.431}} \qquad r = 0.993$$

$$Q_{50} = \frac{3.317(A)^{0.871}\ (S)^{0.162}\ (R_{TD-50\ yr.})^{0.718}}{(L)^{0.426}} \qquad r = 0.994$$

$$Q_{100} = \frac{3.569\ (A)^{0.876}\ (S)^{0.158}\ (R_{TD-100\ yr.})^{0.717}}{(L)^{0.443}} \qquad r = 0.994$$

The symbols in the above formulae are as under:

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

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

L is length of longest stream in km.

S is equivalent slope in m/km. (see step-2 of illustrative example)

$R_{TD-25yr.}$, $R_{TD-50\ yr.}$, $R_{TD-100\ yr.}$ are the design storm point rainfall values (cm) for the design storm duration TD = $0.799\ (L/\sqrt{S})^{0.59}$ in hrs. (rounded upto nearest one hour) after location of catchment under study on the 25-yr., 50-yr. and 100-yr. TD-hour storm rainfall maps (plates 9,10 and 11) corresponding to 25-yr., 50-yr. and 100-yr. flood respectively.

Note: (i) Application of these formulae are illustrated in B - "SIMPLIFIED APPROACH"

(ii) Flood estimates from the above formulae are to be used for preliminary designs only.

*** With loss rate formula vide section 3.11**

INTRODUCTION

The purpose of the report entitled "Flood Estimation Report for Upper Godavari Subzone-3(e)" presented herein is to estimate the design flood for fixing the waterway of bridges and culverts.

The report begins with sets of flood formulae based on regression analysis to estimate the 25-yr. flood 50-yr. flood and 100-yr. flood. ~~with loss rates of 0.5 cm/hr.~~

After the sets of N-year flood formulae, the report 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 the main report of six sections dealing with general features of the Upper Godavari nature and period of data collected, analysis of storm rainfall and flood events to derive the unitgraphs, relationships between physiographic and unitgraph parameters of the gauged catchments to derive synthetic unitgraph for ungauged catchment, design storm rainfall, design loss rates, base flow, computation of design flood peak and hydrograph for ungauged catchments, formula for linear waterway of the cross drainage structures 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 2500 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.

The utility of the report for frequency flood estimation in respect of small dams and minor cross drainage structures has also been brought out.

(continued from opposite page)

The following formulae are based on design loss rate of 0.5 cm/hr

$$Q_{25} = \frac{3.728(A)^{0.833}(S)^{0.193}(R_{TD-25\ yr})^{0.920}}{(L)^{0.446}} \qquad r = 0.992$$

$$Q_{50} = \frac{4.102(A)^{0.837}(S)^{0.186}(R_{TD-50\ yr})^{0.875}}{(L)^{0.434}} \qquad r = 0.992$$

$$Q_{100} = \frac{4.348(A)^{0.843}(S)^{0.181}(R_{TD-100\ yr})^{0.861}}{(L)^{0.438}} \qquad r = 0.993$$

Note: Explanations for The symbols in the formulae are same as in the earlier formulae on the opposite page.

APPLICATION OF REPORT

I. (A) SIMPLIFIED APPROACH

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

$$Q_N = a \; A^b \; L^c \; L_c^d \; S^e \; R_N^f$$

Where A, L, L_c, S and R_N are same as in Section B-1 as independent variables, a, b, c, d, e and f 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 peak flood values (Q_{25}) for 17 gauged and 10 ungauged catchments of different sizes were computed by detailed Approach. Similarly 50-yr and 100-yr peak flood values (Q_{50} and Q_{100}) were computed for the 27 catchments.

The estimated values of Q_{25}, Q_{50} and Q_{100} for the 27 catchments as dependent variables were related to their respect. The physiographic parameters A, L, S and meteorologic parameters of point storm rainfall $R_{TD-25\ yr}$, $R_{TD-50\ yr}$, and $R_{TD-100\ yr}$ as independent variables applying the least square method. The derived flood formulae with their respective coefficient of correlation (r) by multiple regression analysis are as under:

$$Q_{25} = \frac{2.967(A)^{0.868} \quad (S)^{0.167} \quad (R_{TD-25\ yr})^{0.760}}{(L)^{0.431}} \qquad r = 0.993$$

$$Q_{50} = \frac{3.317(A)^{0.871} \quad (S)^{0.162} \quad (R_{TD-50\ yr})^{0.718}}{(L)^{0.426}} \qquad r = 0.994$$

$$Q_{100} = \frac{3.569(A)^{0.876} \quad (S)^{0.158} \quad (R_{TD-100yr})^{0.717}}{(L)^{0.443}} \qquad r = 0.994$$

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

A is the catchment area in Sq.Km. upto the point of study.
S is the equivalent stream slope in m/km.
L is the length of the longest stream in km.

$R_{TD-25yr}$, $R_{TD-50yr}$ and $R_{TD-100yr}$ are 25yr, 50yr and 100yr point storm rainfall values in cm. for design storm duration (T_D) in hrs respectively.

The design storm duration (T_D) for the catchment under study is obtained by the formula $T_D = 0.799 \left(L/\sqrt{S}\right)^{0.59}$ in hrs (rounded upto nearest one hour).

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 27 catchments shown in the following table are within tolerable limits of ± 25%.

	% variation range	
	+	-1
Q_{25}	0.31 to 24.47	0.62 to 17.76
Q_{50}	0 to 22.93	0.70 to 17.80
Q_{100}	0.12 to 22.85	0.51 to 17.83

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

(3) Solution of the problem

Illustrative example for estimation of 25yr, 50yr and 100yr flood for catchment area upto Rly. Br.No. 234 is considered for solution of the problem by Flood Formulae (Regression Analysis). The physiographic and meteorologic parameters for the catchment under study are:

A = 2227.39 sq.km., L=96.60 km., S=1.54 m/km, $T_D = 0.799 \left(L/\sqrt{S}\right)^{0.59}$
i.e. T_D = 10 hrs.

R_{25} = 12.97 cm., R_{50} = 14.76 cm., R_{100} = 16.76 cm.

$$Q_{25} = \frac{2.967(2227.39)^{0.868} \quad (1.54)^{0.167} \quad (12.97)^{0.760}}{(96.6)^{0.431}} = 2477.78 \text{ cumecs}$$

$$Q_{50} = \frac{3.317(2227.39)^{0.871} \quad (1.54)^{0.158} \quad (16.76)^{0.718}}{(96.6)^{0.443}} = 2893.07 \text{ cumecs}$$

$$Q_{100} = \frac{3.569(2227.39)^{0.876} \quad (1.54)^{0.158} \quad (16.76)^{0.717}}{(96.6)^{0.443}} = 3273.36 \text{ Cumec}$$

The percentage variations in the values of Q_{25}, Q_{50} and Q_{100} by the detailed approach and the flood formula with respect to the flood values by detailed approach for the catchment under study are- 4.92,-4.68 and -6.13 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.

II.(B) DETAILED APPROACH

The flood estimation report for Upper Godavari subzone-3(e) 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 of 50% and 75% of Q_p (W_{50} and W_{75}), widths of the rising limb of U.G. at 50% and 75% of Q_p (W_{R50} and W_{R75}) and time base of unitgraph (T_B).

iv) Drawing of a synthetic unitgraph.

v) Estimation of design storm duration (T_D).

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

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

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

ix) Estimation of base flow.

x) Computation of design flood peak.

xi) Computation of design flood hydrograph.

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

Illustrative Example

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

i)	Name and number of subzone	:	Upper Godavari Subzone-3(e)
ii)	Name of site (i.e. point of study)	:	Railway Br. No. 234
iii)	Name of railway section	:	Aurangabad - Parbhani
iv)	Name of Tributary	:	Dudna
v)	Shape of the catchment	:	Fan-shaped
vi)	Site location	:	19°-40'0" (Latitude) 70°-04'-0" (Longitude)
vii)	Topography	:	Mild slope

The procedure is explained step by step.

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 main river, contours and spot levels was prepared.

Step-2 : Determination of Physiographic Parameters

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

i) Area (A) = 2227.39 sq.km.

ii) Length of the longest stream (L) = 96.60 km.

iii) Equivalent Stream Slope (S) $= \sum L_i (D_{i-1} + D_i)/L^2$ = 1.54 m/km

Where L_i = length of ith segment in km

D_i, D_{i-1} = heights above datum (with reduced level at the point of study) with respect to reduced levels of contours along the longest stream at ith and (i-1) the locations in metres.

L = length of the longest stream in km.

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

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

$$L/\sqrt{S} = 96.60/\sqrt{1.54} = 77.84 \qquad \text{say } 78$$

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

t_r = 1-hour unit duration for the unitgraph i.e. unitgraph produced due to one centimeter depth of rainfall excess in 1-hour duration has been considered.

The 1-hr. Synthetic U.G. parameters may be found out by using one of the following approaches:

(I) By using the Synthetic Relations

(II) By using Coaxial Diagram

(I) By Using the Synthetic Relations

The following relationships have been derived for estimating the 1-hour unitgraph parameters of a catchment in the Upper Godavari subzone-3(e).

(i) $t_p = 0.727\,(L/\sqrt{S})^{0.59}$ (3.9.3)

(ii) $q_p = 2.020/(t_p)^{0.88}$ (3.9.4)

(iii) $W_{50} = 2.228/(q_p)^{1.04}$ (3.9.5)

(iv) $W_{75} = 1.301/(q_p)^{0.96}$ (3.9.6)

(v) $W_{R50} = 0.880/(q_p)^{1.01}$ (3.9.7)

(vi) $W_{R75} = 0.540/(q_p)^{0.96}$ (3.9.8)

(vii) $T_B = 5.485(t_p)^{0.73}$ (3.9.9)

(viii) $T_m = t_p + \frac{t_r}{2}$ (3.9.10)

(ix) $Q_p = q_p \times A$ (3.9.11)

In the above equations, the physiographic parameters L and S of the catchment (Fig. A-1) and 1-hr. unitgraph (Fig.A-2) parameter t_r, t_p, t_m, q_p, Q_p, W_{50}, W_{75}, W_{R50}, W_{R75} and T_B for the catchment under study upto Br. No. 234 signify as under:

L, S and A already explained in Step - 2.

t_r = unit duration of unitgraph = 1.0 hr.

t_p = time from the centre of rainfall excess (1.0 cm) in 1-hr. unit duration to the U.G. peak in hours.

T_m = time from the start of rise to the peak of U.G. (hrs.)

q_p = peak discharge of U.G. for unit area (cumecs per sqkm)

Q_p = peak discharge of U.G. (cumecs)

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

W_{75} = width of the U.G. on the rising side at 50% of peak discharge ordinate (hr.)

W_{R50} = width of the U.G. on the rising side at 75% of peak discharge ordinate (hr.)

W_{R75} = width of the U.G. on the rising side at 75% of peak discharge ordinaate (hr.)

T_B = Base width of the U.G. (hr.)

Using the above relationships, the 1-hr, U.G. parameters were calculated as under:

(i) Calculation of t_p using the equation 3.9.3 by substituting the value of $L/\sqrt{S}$ = 78 estimated in Step-2.

$$t_p = 0.727(78)^{0.59} = 9.503 \text{ hr.}$$

Rounded off to 9.50 hrs.

(ii) Calculation of q_p using the equation 3.9.4 by substituting the value of t_p = 9.50 hrs.

$$q_p = 2.020/(9.5)^{0.88} = 0.279 \text{ cumecs/sq.km}$$

(iii) Calculation of W_{50} using the equation 3.9.5 by substituting the value of q_p = 0.279 cumecs/sqkm.

$$W_{50} = 2.228/(0.279)^{1.04} = 8.40 \text{ hrs.}$$

(iv) Calculation of W_{75} using the equation 3.9.6 by substituting the value of q_p = 0.279 cumecs/sqkm.

$$W_{75} = 1.301/(0.279)^{0.96} = 4.43 \text{ hrs.}$$

(v) Calculation of W_{R50} using the equation 3.9.7 by substituting the value of q_p = 0.279 cumecs/sqkm.

W_{R50} = $0.880/(0.279)^{1.01}$ = 3.19 hrs.

(vi) Calculation of W_{R75} using the equation 3.9.8 by substituting the value of q_p = 0.279 cumecs/sqkm.

W_{R75} = $0.540/(0.279)^{0.96}$ = 1.84 hrs.

(vii) Calculation of T_B using the equation 3.9.9 by substituting the value of t_p = 9.5 hrs.

T_B = $5.485(9.5)^{0.73}$ = 28.37 hrs. say 28 hrs.

(viii) Calculation of T_m using the equation 3.9.10 by substituting the values of t_p = 9.5 hrs. and t_r = 1.0 hrs.

T_m = 9.5 + ½ = 9.5 + 0.5 = 10.00 hrs.

(ix) Calculation of Q_p using the equation 3.9.11 by substituting the value of q_p = 0.279 cumecs/sqkm and

A = 2227.39

Q_p = 0.279 x 2227.39 = 621.44 cumecs

(II) <u>By using Coaxial Diagram</u>

Coaxial diagram based on synthetic relations vide equation 3.9.3 to 3.9.9 under Section-3 has been drawn in Fig. A-3 for estimating the parameters of synthetic unitgraphs. The application of coaxial diagram in Fig.A-3 with respect to the above illustrative example is explained as under:

i) Calculation $L/\sqrt{S}$

L = 96.60 km and S = 1.54 m/km as found out in Step-2 of illustrative example.

$L/\sqrt{S}$ = $96.60 / \sqrt{1.54}$ = 77.84 say 78

ii) Move vertically upwards for the value of $L/\sqrt{S}$ = 78 to read from Curve-1 the value of t_p = 9.50 hrs.

iii) Move horizontally for t_p = 9.5 hrs. to read from Curve-2 the value of q_p = 0.279 cumecs/sqkm.

iv) Move vertically downwards for q_p = 0.279 cumecs/sqkm to read from Curve-3 the value of W_{50} = 8.40 hrs. from Curve -4 the value of W_{75} = 4.40 hrs., from Curve-5 the value of W_{R50} = 3.20 hrs. and from Curve-6 the value of W_{R75} = 1.80 hrs.

v) Move vertically upwards for t_p = 9.50 cumecs/sqkm to read from Curve-7 the value of T_B = 28.40 say 28 hrs.

vi) T_m (peaking time) = $t_p + t_r/2$

= 9.5 + 0.5 = 10.00 hrs.

vii) Q_p (peak discharge of U.G) = q_p x A

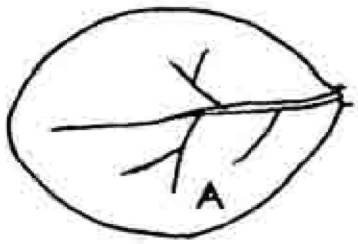
= 0.279 x 2227.39 = 621.44 cumecs.

Step-4: <u>Preparation of 1-hour Synthetic Unitgraph</u>

The parameters got in Step-3 above were plotted to scale on a graph paper as shown in Fig. A-1. The points were joined to fit a trial Synthetic Unitgraph. By definition, the volume of the Unitgraph must be equivalent to 1.0 cm depth of direct runoff over the entire catchment (A) in sq.km.

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

= A x 1000 x 1000 x d/100 = (   ) expressed in cubicmetres
(sq.m.)   (m)



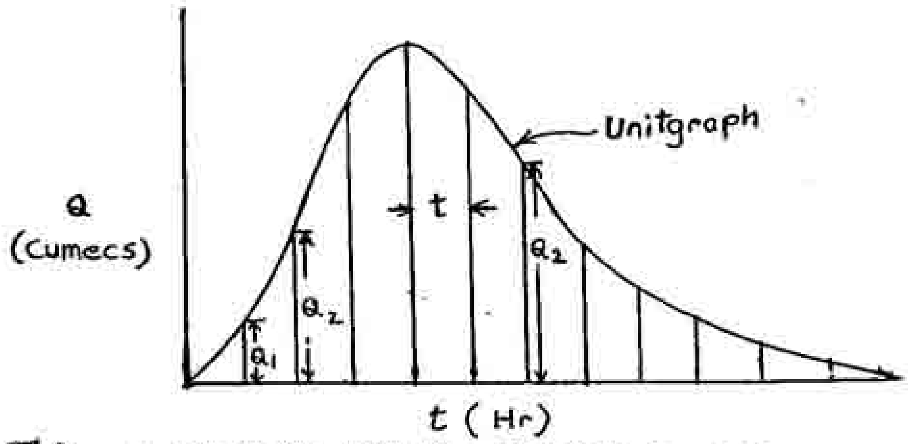
1 cm = 1/100 m depth of direct runoff over the catchment area (A) in sq.km.

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

= $\sum Q_i$ x t_r x 3600

cubicmetre per sec.   seconds

= (   ) expressed in cubic metres.



$\sum Q_i$ = sum of the ordinates of unitgraph at t-hr. interval (in this case 1-hr.)

(a) should be equal to (b)

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

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

$t_r = 1$ in this case

Therefore $\sum Q_i = A/(0.36 \times 1) = A/0.36$

All the ordinates of Synthetic U.G. so obtained in Fig. A-2 were summed up at 1-hr. interval to get a total volume of 6187.19 cumecs which tallied with the computed value from $A/(0.36\ t_r) = 2227.39/(0.36 \times 1) = 6187.19$ cumecs. Therefore, the 1-hour Synthetic U.G. so drawn in Fig. A-2 was found to be in order.

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

Step (5): Estimation of Design Storm Duration

The design storm duration is

$T_D = 1.1 \times t_p = 1.1 \times 9.5 = 10.45$ hrs.

Adjusting the design storm duration to nearest one hour, the adopted design storm duration (T_D) is 10.0 hrs.

Step (6): Estimation of Point Rainfall and Areal Rainfall

The point rainfall estimate for 50-year return period and for duration of 24-hr. is read against the location of Rly. Br. No. 234 from 50-yr. 24-hr.

isopluvial map (see Plate-10 in Section 4.2). The value of 50-yr. 24-hr. point rainfall = 18.5 cm.

The design storm duration (T_D) for the catchment is 10.0 hrs. The point rainfall estimate for 10.0 hrs. was obtained by multiplying the 50-yr. 24-hr. point rainfall of 18.50 cm with the value of 0.798 read from Fig.10 in Section 4.2.

50-yr. 10-hr. point rainfall = 18.50 x 0.798 = 14.76 cm.

The above point rainfall estimate of 14.76 cm was multiplied by areal reduction factor of 0.76 corresponding to a catchment area of 2227.39 sq.km. and for a design storm duration of 10 hrs. as interpolated from Table-6 (areal to point rainfall ratios) or from Fig. 11(a).

50-yr. 10-hr. areal rainfall = 14.76 x 0.76 = 11.22

Step (7): Time Distribution of Areal Rainfall

The areal rainfall estimate for 50-yr. 10-hr. areal rainfall of 11.22 cm was distributed to give one hourly gross rainfall units by using the Distribution Co-efficients for duration of 10-hrs. from Table A-3: Time Distribution Co-efficients of Areal Rainfall as under:

Duration (hrs.)	Distribution Co-efficients	Storm rainfall (cm)	1-hr. rainfall (cm)
(1)	(2)	(3)	(4)
10	1.00	11.22	0.22
9	0.98	11.00	0.23
8	0.96	10.77	0.34
7	0.93	10.43	0.44
6	0.89	9.99	0.45
5	0.85	9.54	0.68
4	0.79	8.86	1.01
3	0.70	7.85	1.45
2	0.57	6.40	2.14
1	0.38	4.26	4.26

Storm rainfall values in col. (3) for durations of 9,8,7,6,5,4,3,2 and 1 hrs. in col. (1) were obtained by multiplying the 10-hr. storm rainfall value of 11.22 cm with the distribution coefficients in col. (2) for respective durations. 1-hr. rainfall units in col. (4) were obtained by substraction of successive values of storm rainfall from 1-hr. onwards in col. (3).

Step (8): Estimation of Rainfall Excess Units.

Design Loss Rate was computed by the following formula vide Section 3.11:

$$I_f = 0.672 \frac{(R)^{0.883}}{(T)^{0.773}}$$

where (I_f) is a constant loss rate in cm/hr., (R) is storm rainfall in cm for design storm duration (TD) in hrs.

Design storm duration TD=10 hrs. and 50-yr. 10-hr. rainfall (R) = 11.22 cm was substituted in the above formula to obtain the design loss rate (I_f) in cm/hr:

$$I_f = 0.672 \frac{(11.22)^{0.883}}{(10)^{0.773}} = 0.96 \text{ cm/hr.}$$

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

Duration (hr.) (1)	1-hr. rainfall (cm) (2)	Design Loss rate 1-hr. (cm/hr.) (3)	rainfall excess (cm) (4)
1	4.26	0.96	3.30
2	2.14	0.96	1.18
3	1.45	0.96	0.49
4	1.01	0.96	0.05
5	0.68	0.96	-
6	0.45	0.96	-
7	0.44	0.96	-
8.	0.34	0.96	-
9.	0.23	0.96	-
10.	0.22	0.96	-

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

Step (9): Estimation of Base Flow

The design base flow rate is computed by the following formula vide Section 3.12:

$$q_b = 0.122/(A)^{0.304}$$

The catchment area (A) upto the point of study = 2227.39 sq.km. was substituted in the above formula to obtain the design base flow rate (q_b)

$$q_b = \frac{0.122}{(2227.39)^{0.304}} = 0.012 \text{ cumecs/sq.km.}$$

Therefore, the total base flow for a catchment area 2227.39 sq.km. = 2227.39 x 0.012 = 26.73 cumecs.

Step (10): Estimation of Design Flood (Peak only)

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

In the present case, the maximum discharge ordinate of U.G. is 621.40 cumecs at 10-hrs. vide Fig. A-2. The maximum 1-hour rainfall excess unit of 3.30 cm (from Step-8) was placed against the maximum discharge ordinate of 621.40 cumecs. Likewise the lower rainfall excess unit was placed against the next lower U.G. ordinate in the following Table and so on. Summation of the products of cols. (2) and (3) gives the total direct runoff to which base flow is added to get the maximum discharge.

Time (hrs.)	U.G. Ordinate (cumecs)	1-hr. rainfall excess (cm)		Direct runoff (cumecs)
9	550.00	0.49		269.50
10	621.40	3.30		2050.62
11	562.00	1.18		663.16
12	502	0.05		25.10
			Total	3008.38
		Add Base Flow from Step - 9		26.73
		Total Peak Discharge		3035.11

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

Step (11): Computation of Design Flood Hydrograph

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

Time (hrs.) (1)	Critical 1-hr. rainfall excess (cm) sequence (2)
1	0.05
2	1.18
3	3.30
4	0.49

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 rainfall sequence of 1-hr. rainfall excess units as given above were entered in cols. (3) to (6) horizontally as shown in Table A-3. The direct runoff resulting from each of the 1-hr. rainfall excess units was obtained by multiplying the 1-hr. rainfall excess unit with the synthetic 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-hour. The direct runoff so obtained are shown in cols.(3) to (6). The direct runoffs were added horizontally and the total direct runoff is shown in col. (7). The total base flow of 26.73 cumecs was entered in col. (8) Col. (9) gives the addition of cols. (7) and (8) to get the design flood hydrograph ordinates. The total discharge ordinates in col. (9) were plotted against time in col. (1) to get the design flood hydrograph in Fig. A-3.

Table No. A-1

COMPUTATION OF EQUIVALENT SLOPE (S) OF BRIDGE NO. 234 SUB-ZONE - 3 (e)

Sl. No.	Reduced distance starting from Bridge Site (Miles)	Reduced Levels of river bed Ft.	Length of each segment Miles	Height above datum (Di) difference between the datum & the ith R.L. Ft.	Di-1 +Di Ft.	Li (Di-1 +Di) Ft.x Miles
1	2	3	4	5	6	7
1.	0	1440	0	0	-	0.00
2.	8.60	1500	8.60	60	60	516.00
3.	30.60	1660	22.00	220	280	6160.00
4.	44.00	1750	13.40	310	530	7102.00
5.	55.60	2000	11.60	560	870	10092.00
6.	60.00	2100	4.40	660	1220	5368.00
				$\sum L_i (D_{i-1} + D_i)$ =		29238.00

Eq. Slope $= \frac{\sum Li\ (Di-1 + Di)}{L^2} = \frac{29238.00}{60 \times 60}$ = 8.122 ft/mile = 0.00154 ft/ft.=1.54 m/km.

* Datum = 1440 ft. (i.e. reduced level of river bed at the point of study)

Table A-2 Time Distribution Coefficients of Areal Rainfall

Upper Godavari Sub-Zone-3(e)

Time hours	Distribution Coefficient for Design Storm Duration of 2-24 hrs.																						Times 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	
(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	0.98	23
22																					1.00	0.98	0.96	22
21																				1.00	0.98	0.96	0.94	21
20																			1.00	0.98	0.96	0.94	0.92	20
19																		1.00	0.98	0.96	0.94	0.92	0.90	19
18																	1.00	0.98	0.96	0.94	0.92	0.90	0.88	18
17																1.00	0.99	0.95	0.93	0.92	0.90	0.88	0.86	17
16															1.00	0.99	0.97	0.92	0.91	0.89	0.87	0.86	0.84	16
15														1.00	0.99	0.97	0.95	0.90	0.88	0.87	0.85	0.84	0.82	15
14													1.00	0.98	0.97	0.95	0.92	0.87	0.86	0.85	0.83	0.82	0.80	14
13												1.00	0.98	0.96	0.93	0.91	0.90	0.86	0.84	0.82	0.80	0.79	0.78	13
12											1.00	0.98	0.95	0.92	0.90	0.89	0.87	0.82	0.81	0.79	0.78	0.76	0.75	12
11										1.00	0.98	0.95	0.92	0.90	0.87	[illegible]	0.82	0.80	0.78	0.76	0.75	0.73	0.72	11
10									1.00	0.98	0.96	0.91	0.89	0.87	0.83	0.81	0.79	0.77	0.75	0.73	0.71	0.69	0.68	10
9								1.00	0.98	0.96	0.94	0.87	0.84	0.82	0.79	0.78	0.75	0.72	0.70	0.69	0.68	0.66	0.65	9
8							1.00	0.98	0.96	0.93	0.91	0.83	0.80	0.78	0.75	0.72	0.71	0.69	0.67	0.65	0.63	0.62	0.61	8
7						1.00	0.98	0.94	0.93	0.90	0.88	0.77	0.74	0.72	0.71	0.69	0.68	0.63	0.62	0.60	0.59	0.57	0.56	7
6					1.00	0.98	0.93	0.91	0.89	0.87	0.85	0.74	0.71	0.69	0.67	0.65	0.63	0.59	0.57	0.56	0.54	0.52	0.51	6
5				1.00	0.97	0.92	0.90	0.87	0.85	0.82	0.80	0.68	0.66	0.63	0.60	0.59	0.58	0.52	0.51	0.50	0.49	0.48	0.46	5
4			1.00	0.96	0.92	0.88	0.85	0.82	0.79	0.76	0.72	0.61	0.59	0.57	0.55	0.54	0.53	0.46	0.44	0.42	0.41	0.40	0.38	4
3		1.00	0.95	0.89	0.84	0.81	0.78	0.72	0.70	0.68	0.64	0.52	0.50	0.49	0.47	0.46	0.45	0.39	0.38	0.37	0.37	0.36	0.34	3
2	1.00	0.89	0.84	0.78	0.73	0.70	0.64	0.60	0.57	0.55	0.52	0.40	0.39	0.38	0.36	0.36	0.35	0.31	0.30	0.30	0.27	0.27	0.24	2
1	0.83	0.69	0.65	0.59	0.55	0.46	0.42	0.39	0.38	0.37	0.35	0.25	0.24	0.24	0.23	0.23	0.23	0.20	0.20	0.20	0.20	0.17	0.17	1

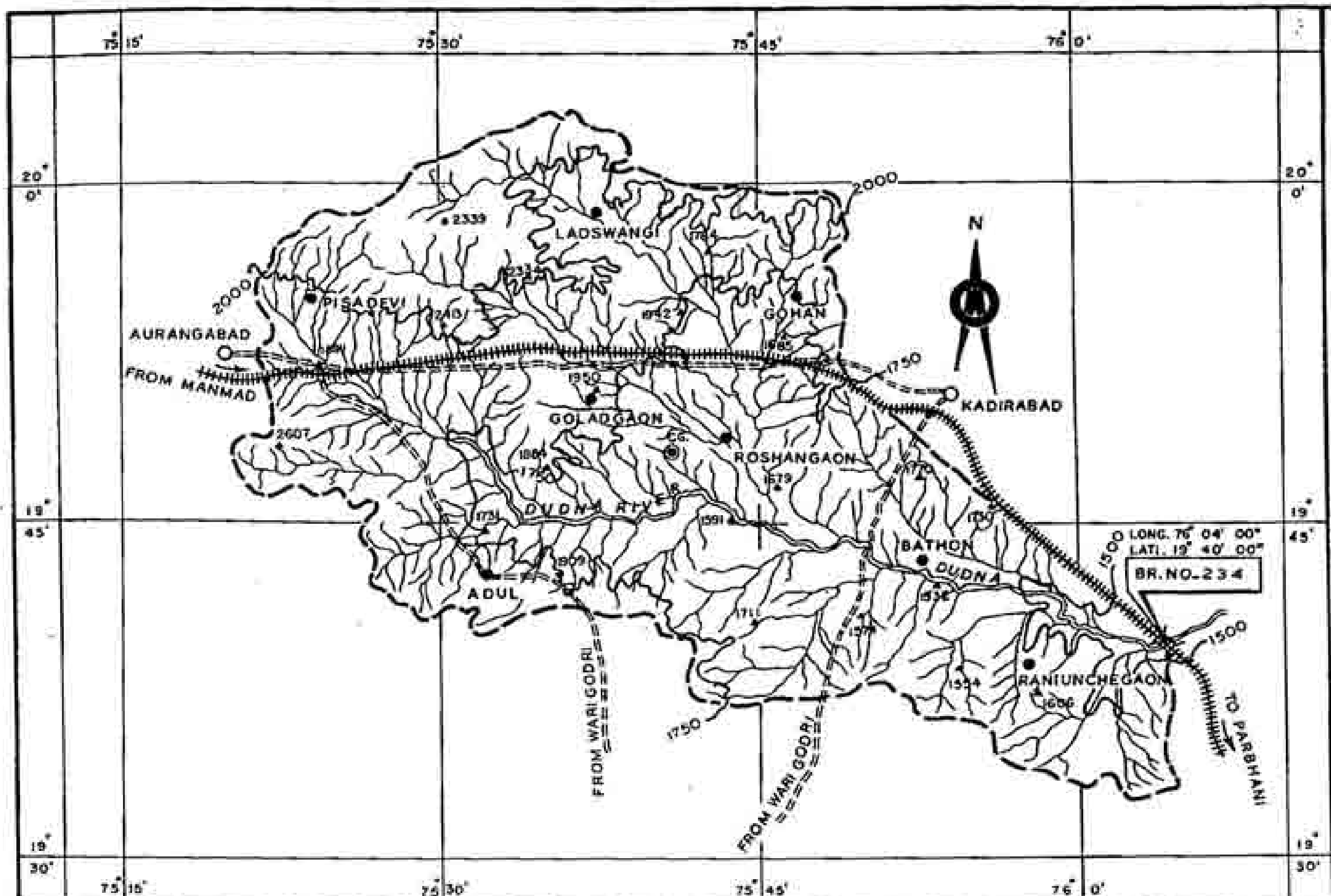
TABLE - A-3

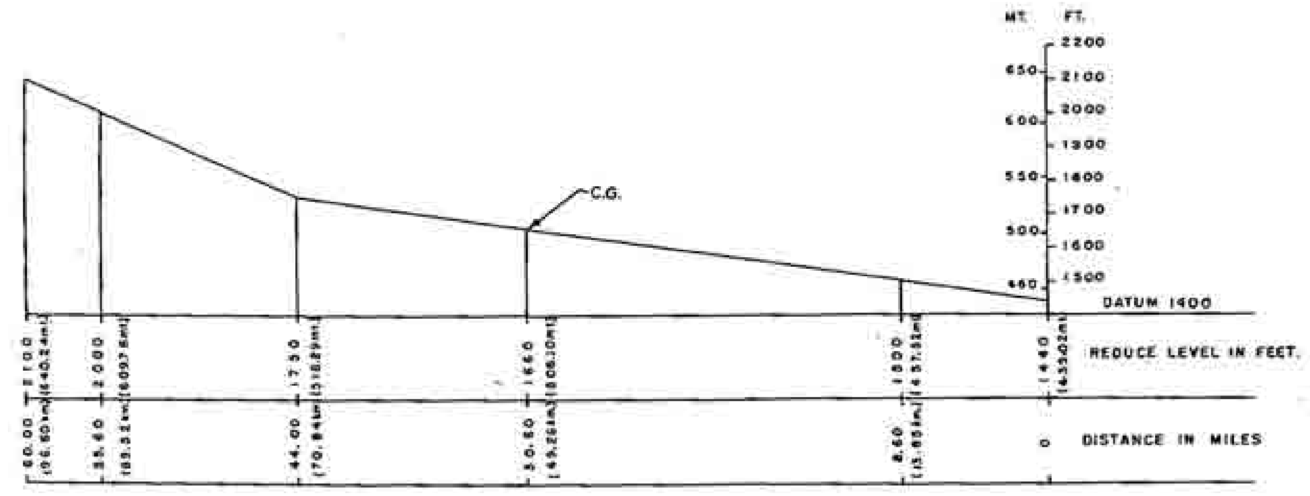
C.A - 2227.39 sq.km.

Computation of Design Flood Hydrograph at Rly. Br. No.234, subzone 3(e)

Time Hrs.	S.U.H. Ordinates (cumecs)	1-hourly Rainfall Excess in cm.				Total (cumecs)	Base flow (cumecs)	Total (cumecs)	Remarks
		0.05	1.18	3.30	0.49				
		Direct Runoff (cumecs)							
1	2	3	4	5	6	7	8	9	10
0	0	0				0	26.73	26.73	
1.	20.0	1.00	0			1.00	26.73	27.73	
2.	42.0	2.10	23.60	0		25.70	26.73	52.43	
3.	76.0	3.80	49.56	66.00	0	119.36	26.73	146.09	
4.	120.0	6.00	89.68	138.60	9.80	244.08	26.73	270.81	
5.	175.0	8.75	141.60	250.80	20.58	421.73	26.73	448.46	
6.	245.0	12.25	206.50	396.00	37.24	651.99	26.73	678.72	
7.	327.0	16.35	289.10	577.50	58.80	941.45	26.73	968.18	
8.	445.0	22.25	385.86	808.50	85.75	1302.36	26.73	1329.09	
9.	550.0	27.50	525.10	1079.10	120.05	1751.75	26.73	1778.48	
10.	621.4	31.07	649.00	1468.50	160.23	2308.80	26.73	2335.53	
11.	562.0	28.10	733.25	1815.00	218.05	2794.40	26.73	2821.13	
12.	502.0	25.10	663.16	2050.62	269.50	3008.38	26.73	3035.11	Peak
13.	442.0	22.10	592.36	1854.60	304.49	2773.55	26.73	2800.28	
14.	382.0	19.10	521.56	1656.60	275.38	2472.64	26.73	2499.37	
15.	325.0	16.25	450.76	1458.60	245.98	2171.59	26.73	2198.32	
16.	275.0	13.75	383.50	1260.60	216.58	1874.43	26.73	1901.16	
17.	231.0	11.55	324.50	1072.50	187.18	1595.73	26.73	1622.46	
18.	194.0	9.70	272.58	907.50	159.25	1349.03	26.73	1375.76	
19.	170.0	8.50	228.92	762.30	134.75	1134.47	26.73	1161.20	
20.	126.0	6.30	200.60	640.20	113.19	960.29	26.73	987.02	
21.	104.0	5.20	148.68	561.00	95.06	809.94	26.73	836.67	
22.	80.0	4.00	122.72	415.80	83.30	625.82	26.73	652.55	
23.	63.7	3.19	94.40	343.20	61.74	502.53	26.73	529.26	
24.	46.0	2.30	75.17	264.00	50.96	392.43	26.73	419.16	
25.	32.0	1.60	54.28	210.21	39.20	305.29	26.73	332.02	
26.	21.79	1.09	37.76	151.80	31.21	221.86	26.73	248.59	
27.	10.0	0.50	25.71	105.60	22.54	154.35	26.73	181.08	
28.	0	0	11.80	71.91	15.68	99.39	26.73	126.12	
29.			0	33.00	10.68	43.68	26.73	70.41	
30.				0	4.90	4.90	26.73	31.63	
31.					0	0	26.73	26.73	

FIG. A - I





LONGITUDINAL SECTION OF RIVER DUDNA

SCALE

HORIZONTAL — MILES 4 3 2 1 0 4 8 12 16

VERTICAL — 200 100 0 200 400 600 800 FEET

NOTES.-

ALL LEVELS CORRESPOND TO G.T.S. DATUM

REFERENCES.-

1 CATCHMENT BOUNDARY
2 RAILWAY LINE
3 RIVER AND IT'S TRIBUTARIES
4 TOWNS
5 RAINGAUGE STATIONS
6 SPOT LEVELS ▲ 1730
7 CONTOURS 1750
8 ROADS
9 TOPOSHEETS 1" = 4 Miles NO. 46 P, 47M AND 56A (1948 EDITION)

DETAILS OF THE CATCHMENT AREA.-

1 CATCHMENT AREA ------------ 2227.39 Sq. Km.
2 SHAPE OF THE CATCHMENT -------- LEAF
3 L ------------------ 96.60 Kms.
4 Lc ------------------ 49.26 Kms.
5 Eq. SLOPE ---------------- 1.54 m./Kms.

SCALE

FURLONGS 32 24 16 8 0 4 8 MILES

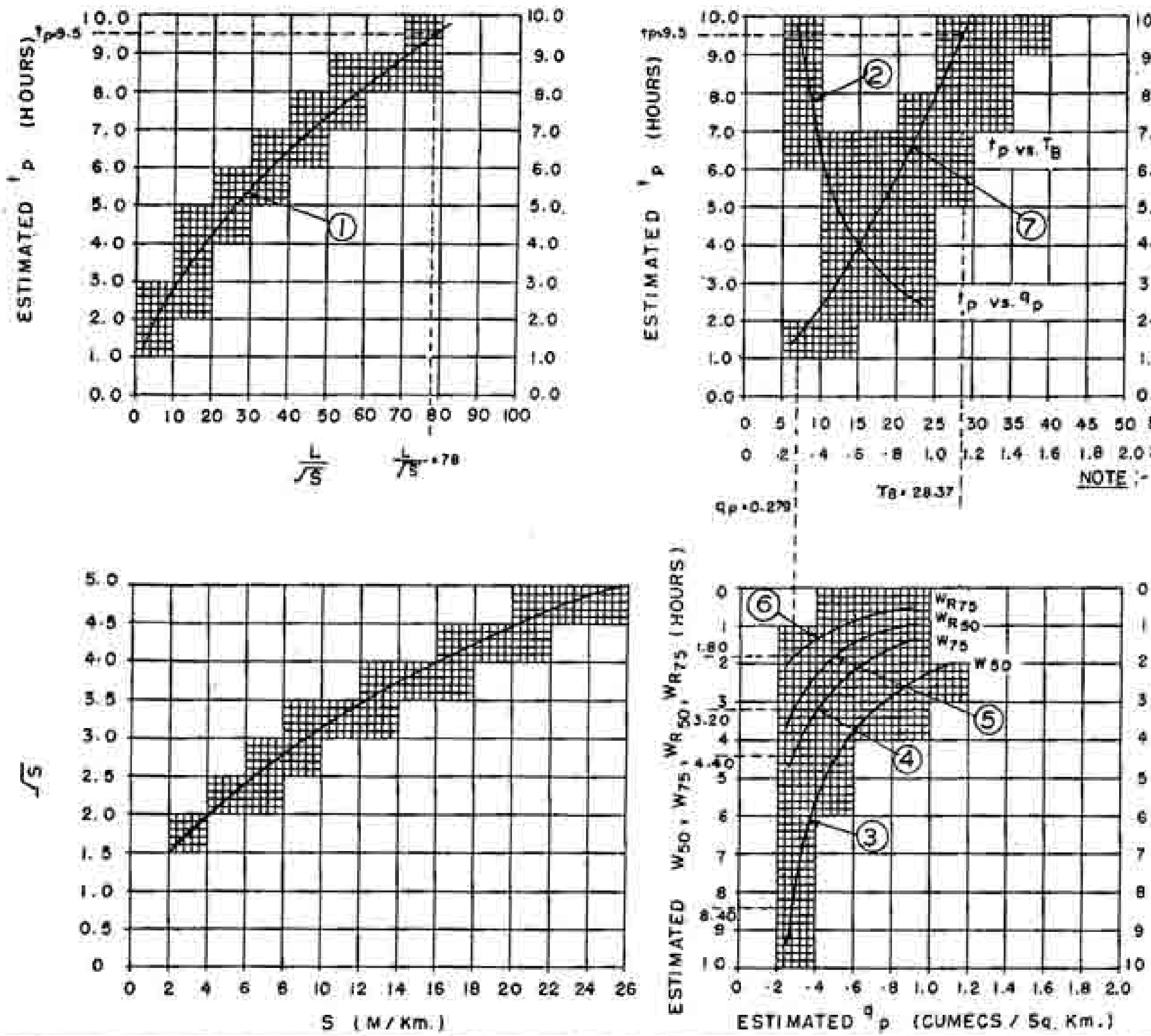
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.

CATCHMENT AREA PLAN OF BR. NO.- 234. ON RIVER DUDNA

SUB ZONE 3(e)

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

FIG. — A-2



CURVE NO.	INDEPENDENT VARIABLE	DEPENDENT VARIABLE
①	$\frac{L}{\sqrt{S}}$	t_p
②	t_p	q_p
③	q_p	W_{50}
④	q_p	W_{75}
⑤	q_p	W_{R50}
⑥	q_p	W_{R75}
⑦	t_p	T_B

NOTE :- 1. FOR USE OF COAXIAL DIAGRAM TO ILLUSTRATIVE EXAMPLE, SEE - OF APPLICATION PART OF THE REPORT.

2. CHECK THE VALUE OF t_p OBTAINED FROM CURVE 1 WITH THE EQUATION $t_p = 0.727 \left(\frac{L}{\sqrt{S}}\right)^{0.59}$ FOR ABSOLUTE ACCURACY.

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

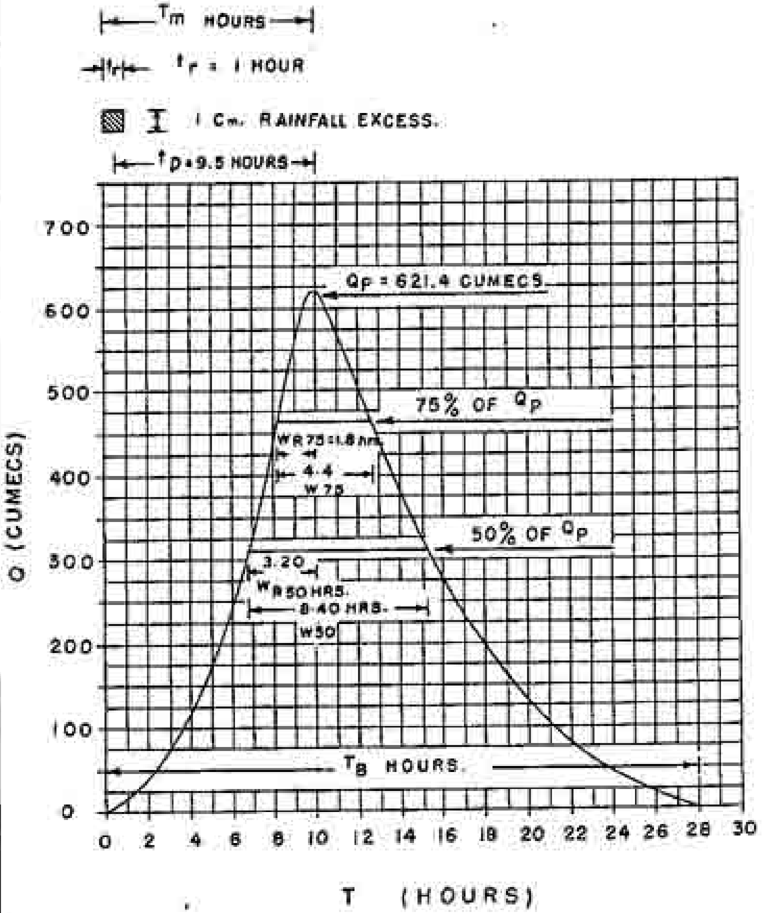
UPPER GODAVARI

SUB ZONE - 3(e)

COAXIAL RELATIONS FOR ESTIMATING 1-HR. SYNTHETIC UNITGRAPH PARAMETERS

DRAWN BY - T. R. ARORA, L. P. NAUTIYAL	CHECKED BY - K. K. AICH.

FIG.– A-3



SYNTHETIC U.G PARAMETERS

C.A = 2227.39 Sq. Kms.

t_p = 9.50 HOURS

T_B = 28.00 HOURS

Q_P = 621.40 CUMECS

W_{50} = 8.40 HOURS

W_{75} = 4.40 HOURS

W_{R50} = 3.20 HOURS

W_{R75} = 1.80 HOURS

q_p = 0.279 CUMECS/Sq. Kms.

$\frac{L}{\sqrt{S}}$ = 78.0

Tm. = 10 HOURS.

d = 1.00 Cm.

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

$$= \frac{2227.39 \times 1.00}{100 \times 0.36}$$

= 6187.19 CUMECS.

TIME IN HOURS.	1 HOUR SYNTHETIC U.G. ORDINATES (CUMECS)
0	0
1	20.00
2	42.00
3	76.00
4	120.00
5	175.00
6	245.00
7	327.00
8	445.00
9	550.00
10	621.40
11	562.00
12	502.00
13	442.00
14	382.00
15	325.00
16	275.00
17	231.00
18	194.00
19	170.00
20	126.00
21	104.00
22	80.00
23	63.00
24	46.00
25	32.00
26	21.79
27	10.00
28	0.00
TOTAL	6187.19

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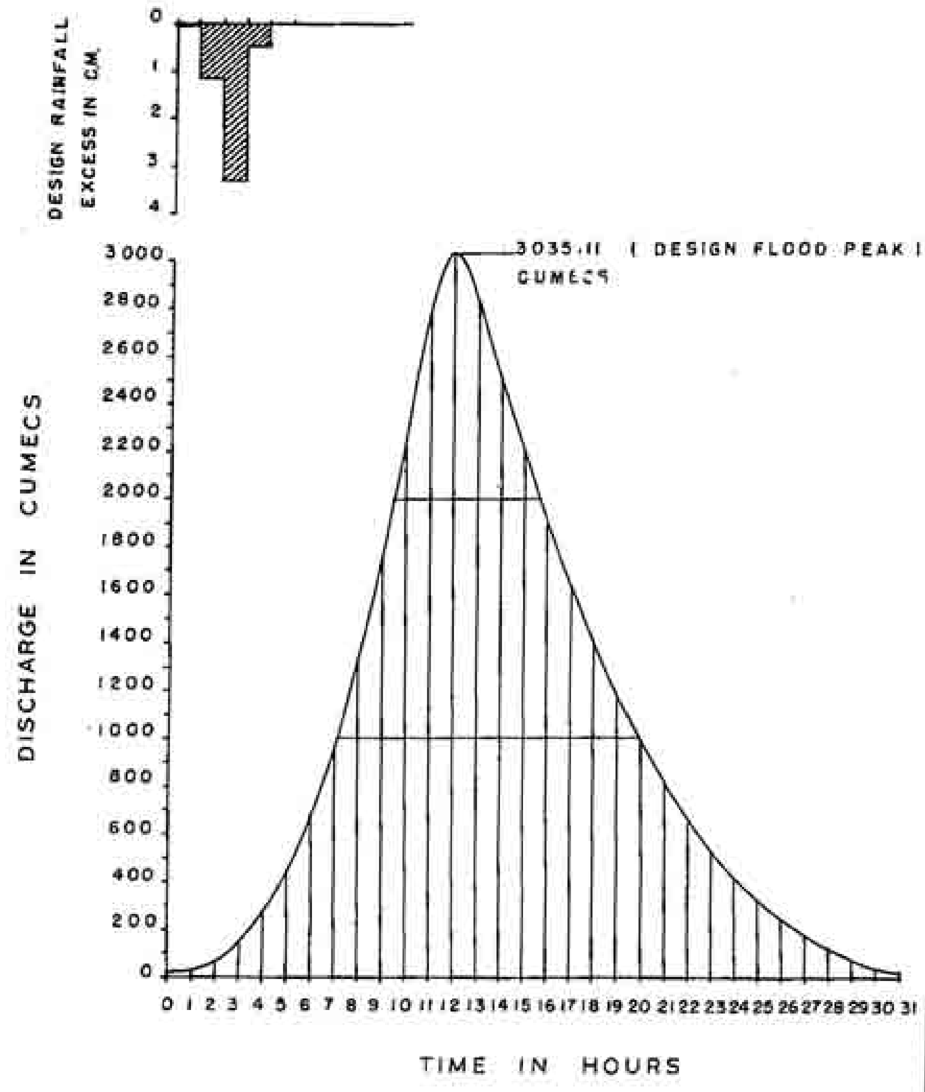
HYDROLOGY (SMALL CATCHMENTS) DTE.

UPPER GODAVARI
SUB ZONE-3(a)
SYNTHETIC UNIT HYDROGRAPH
BRIDGE NO. 234.

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

FIG. A-4



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

UPPER GODAVARI
SUB ZONE - 3(e)
DESIGN FLOOD HYDROGRAPH
BR. NO. 234 ON RIVER DUDNA

DRAWN P.N. BHALLA | CKD. A.P. KHANNA

1.0 General Description of Upper Godavari subzone 3(e)

1.1 Location

The Upper Godavari subzone-3(e) lies between longitude 73° 30' to 78° 45' East and latitude 17° 25' to 20° 35' North. The Godavari river system in its upper reaches upto Manjra confluence constitutes the Upper Godavari subzone. The Godavari river rises in the eastern side of the western ghats at an elevation of 1067 m. It flows for a total length of 584 km in the subzone before entering the Lower Godavari subzone-3(f). The Upper Godavari subzone is bounded on the north by Upper and Lower Narmada and Tapi subzones-3(b) and 3(c), on the south by Krishna and Pennar subzone-3(h), on the east by Lower Godavari subzone-3(f) and on the west by Konkan Coast subzone-5(a). Plate-1 shows the location of Upper Godavari subzone-3(e) along with the list of hydrometeorological subzones of India. The major portion of the subzone covers a part of Maharashtra State and the minor portions in the south-east of the subzone cover small parts of Andhra and Karnataka States. The important towns and cities in the subzone are Nasik, Aurangabad, Parbhani, Bidar, Bir and Nander.

1.2 River System

Plate-2 shows the river system of the subzone. The right bank tributaries of Godavari river in the subzone are Parvara, Sindphana, Wan, Manar and Manjra. The left bank tributaries of Godavari are Shiv and Purna.

The drainage areas covered by the tributaries of Godavari are as under:

Sl.No.	River/Tributary	Drainage areas (sq.km.)
1.	Parvara	6761
2.	Sindphana	4327
3.	Wan	1042
4.	Manar	2824
5.	Manjra	28975
6.	Purna	16216
7.	Shiv	2424
8.	Upper reaches of Godavari upto Shiv Confluence	9865
9.	Local catchments	16436
	Total	88870

The total drainage area of the subzone is 88,870 sq. km.

1.3 Topography and Relief

The Godavari river originates at an elevation of 1350 m. in the western ghats. The western ghats on the western periphery generally rises from 900 m to 1350 m. The areas in the subzone along the north-western, western and southern boundary vary in elevations from 600 to 900 m. The rest of the area in the subzone is a plateau ranging in elevation from 300 to 600 m. Plate-3 depicts the physiography of the Upper Godavari subzone.

1.4 Rainfall

Plate-4 exhibits the mean annual rainfall variation in the subzone along with histogram of mean rainfall and percentage variation monthwise from January to December at Aurangabad. Along the ghats, the mean annual rainfall decreases from 160 to 80 cm. with the decrease in elevation. Further down upto Aurangabad the mean annual rainfall ranges from 60 to 70 cm. Thereafter in the rest of the subzone, mean annual rainfall is of the order of 80 cm. with a patch of heavy rainfall of 100 cm. along the eastern periphery. The subzone experiences the south-west monsoon during June to October with the maximum mean monthly rainfall in July and September.

1.5 Temperature

Plate - 5 shows the mean annual isotherms along with Bargraph of maximum and minimum daily mean temperatures at Aurangabad. The mean annual temperature in a large part of the subzone varies from 25^{o} to 27.5^{o}c except in the south-western part with temperatures varying from 22.5^{o} to 25^{o}c. The mean daily temperature gradually rises from 22^{o}c in January to 32^{o}c in May and gradually falls down to 20^{o}c in December as seen from the Bargraph in Plate-5. The minimum daily temperature of 12^{o}c is experienced in December, whereas the maximum daily temperature of 40^{o}c is experienced in May.

1.6 Soils

Plate-6 exhibits the soils classification in the subzone. The subzone is mostly covered with medium black soils with a strip of deep black soils from east to west in the middle and red sandy soils in south-east extremity. Patches of shallow black soils are found in north.

1.7 Land Use

Plate-7 depicts the general land use in the subzone. The subzone is covered mostly with arable land with patches of forests along the northern and eastern periphery and grass land and scrub mostly along the south-western portion. Plate-8 depicts the cultivable land in the subzone. Percentage of arable land under multiple cropping to total arable land varies from 0 to 10 in most parts of the subzone.

1.8.1 Communications

1.8.1 Railways

The following railway sections are located in the subzone:

Sl.No.	Railway Section	Zonal Railways
1.	Igatpuri - Manmad	Central Railway
2.	Manmad - Ahmedabad	"
3.	Manmad - Secunderabad	"
4.	Parbhani - Vikarabad	"
5.	Latur - Tadwalla	"
6.	Mudkhed - Bhokar	"
7.	Purna - Hingoli	"

1.8.2 Roads

The National Highways located in the subzone are as under:

Sl.No.	National Highways	
1.	Igatpuri - Nasik - Chandor	NH-3
2.	Nasik - Bote	NH-50
3.	Matala - Secunderabad	NH-9
4.	Secunderabad - Binnur	NH-7

LIST OF HYDRO-METEOROLOGICAL SUB-ZONES

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

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

2.0 DESIGN FLOOD, DATA AND THE METHOD ADOPTED FOR ANALYSIS

2.1 Design Flood

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

2.2 Data

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) round the clock.

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

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

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

CONTENTS

LIST OF TABLES, PLATES AND FIGURES

FIGURES

SYMBOLS AND ABBREVIATIONS

SYMBOLS

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

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

I_f : Design loss rate in cm/hr.

q_b : Design base flow rate in cumecs/sq.km.

q_p : Peak discharge of unit hydrograph per unit area in cumecs per sq.km.

Q_p : Peak discharge of unit hydrograph in cumecs.

W_{50} : Width of the U.G. measured at 50% of maximum discharge (Q_p) in hours.

W_{75} : Width of the U.G. measured at 75% of maximum discharge ordinate (Q_p) in hours.

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

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

Q_{25} : 25-year flood peak in cumecs.

Q_{50} : 50-year flood peak in cumecs.

Q_{100} : 100-year flood peak in cumecs.

ARF : Areal reduction factor

% : Percent

$\sum$: Summation

ABBREVIATIONS

Cumecs : Cubic metres per second

Cms : Centimetres

Hr. : Hour

M. : Metres

Min. : Minutes

Km. : Kilometres

Sq.km. : Square kilometres, Km^2

In.	:	Inches
Sec.	:	Seconds
Sq.	:	Square
R.D.S.O.	:	Research Designs and Standards Organisation (Ministry of Railways), Lucknow.
H(SC), CWC	:	Hydrology (Small Catchments) Directorate, Central Water Commission, New Delhi.
I.M.D.	:	India Meteorological Department
C.W.C.	:	Central Water Commission
M.O.S.T.	:	Ministry of Shipping & Transport, New Delhi.

25-YEAR, 50-YEAR AND 100-YEAR FLOOD PEAK FORMULA
(BY MULTIPLE REGRESSION ANALYSIS)

$$Q_{25} = \frac{2.967(A)^{0.868} (S)^{0.167} (R_{TD-25\ yr.})^{0.760}}{(L)^{0.431}} \qquad r = 0.993$$

$$Q_{50} = \frac{3.317(A)^{0.871} (S)^{0.162} (R_{TD-50\ yr.})^{0.718}}{(L)^{0.426}} \qquad r = 0.994$$

$$Q_{100} = \frac{3.569\ (A)^{0.876} (S)^{0.158} (R_{TD-100\ yr.})^{0.717}}{(L)^{0.443}} \qquad r = 0.994$$

The symbols in the above formulae are as under:

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

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

L is length of longest stream in km.

S is equivalent slope in m/km.
(see step-2 of illustrative example)

$R_{TD-25yr.}$, $R_{TD-50\ yr.}$, $R_{TD-100\ yr.}$ are the design storm point rainfall values (cm) for the design storm duration $TD = 0.799\ (L/\sqrt{S})^{0.59}$ in hrs. (rounded upto nearest one hour) after location of catchment under study on the 25-yr., 50-yr. and 100-yr. TD-hour storm rainfall maps (plates 9,10 and 11) corresponding to 25-yr., 50-yr. and 100-yr. flood respectively.

Note: (i) Application of these formulae are illustrated in B - "SIMPLIFIED APPROACH"

(ii) Flood estimates from the above formulae are to be used for preliminary designs only.

TABLE-I

LIST OF SELECTED RAILWAY BRIDGE CATCHMENTS IN SUB-ZONE-3 (a) : (UPPER GODAVARI) 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		CATCHMENT AREA (Sq. Km.)	NO.OF R.G. STATIONS	DATA AVAILABILITY	NO.OF YEARS	REMARKS
				LATITUDE DEG. MIN. SEC.	LONGITUDE DEG. MIN. SEC.					
1	2	3	4	5	6	7	8	9	10	11
(A)	BRIDGES CONSIDERED FOR REGRESSION ANALYSIS:-									
1	DUDNA	AURANGABAD-PARBHANI C.R	234	19-40-00	76-04-00	2227.39	8	1966-73	8	
2	SHIV NADI	SECUNDERABAD-MANMAD "	76	19-56-10	74-59-20	1197.76	10	1972-76	5	
3	DUDNA (TRI)	MANMAD-PARBHANI C.R	289	19-23-56	76-29-50	458.00	5	1975-76,79	3	
4	DHEKU	MANMAD-PARBHANI C.R.	74	19-56-35	74-58-20	409.22	5	1966-71	6	
5	DEVAN RIVER	VIKARABAD-PURLI C.R	182	18-13-20	77-11-20	398.86	7	1966-74,82,83	11	
6	TIRNA NADI	KURDUVADI-LATUR C.R.	172/448/2	18-21-13	76-01-00	227.14	3	1970-73	4	
7	BORI NADI	SECUNDERABAD-MANMAD "	66	19-57-10	74-52-10	157.55	3	1975-76,78,79	4	
8	BORNA-NALLAH	PARBHANI-PURLI C.R	44	18-54-56	76-36-32	152.53	3	1975-81	7	
9	KAUM	SECUNDERABAD-MANMAD C.R	125	19-51-45	75-17-50	141.67	5	1961-63	3	
10	SITA	-DO- C.R	368	19-09-12	77-29-40	136.75	2	1969-73	5	
11	SUKNA RIVER	-DO- C.R	139	19-51-30	75-25-00	93.60	4	1961-65	5	
12	KOLA RIVER	-DO- C.R	295	19-20-45	76-33-16	77.70	1	1968-74	7	
13	TRIBUTORY OF GODAVARI	-DO- C.R.	346	19-11-05	77-08-40	64.88	2	1967-73	7	
14	NARANGI NALLAH	-DO- C.R.	51	19-57-15	74-44-50	61.90	4	1961-66	6	
15	LENDI RIVER	-DO- C.R.	79	19-55-10	75-01-40	35.22	2	1967-74	8	
16	TRIBUTORY OF GODAVARI	PARBHANI-PURLI C.R.	55	18-51-35	76-32-33	31.31	2	1962,64-67	5	
17	TRIBUTORY OF UNDAHAL	IGATPURI-BHUSAWAL C.R.	100/2	19-49-27	73-42-40	25.90	1	1962-65	4	
(B)	BRIDGE NOT CONSIDERED FOR REGRESSION ANALYSIS:—									
18	UNDUHAI	IGATPURI-BHUSAWAL C.R.	160/1	19-49-10	73-42-10	152.81	2	1966-71	6	

Table - 1

LIST OF SELECTED RAILWAY BRIDGE CATCHMENTS IN UPPER GODAVARI SUBZONE-3 (e) AND DATA AVAILABILITY OF GAUGE DISCHARGE AND RAINFALL

Sl. No.	Name of Stream	Name of Section where Bridge is located with railway zone.		Railway Bridge No.	G & D Site Location Latitude °	'	"	Longitude °	'	"	Catchment Area (Sq. Km.)	No. of Raingauge Stations	Date availability	No. of Years
1.	Dudna	Aurangabad - Parbhani	Central Railway	234	19	40	00	76	4	00	2227.39	8	1966-73	8
2.	Shiv Nadi	Secunderabad - Manmad	(C.R.)	76	19	56	10	74	59	20	1197.76	10	1972-76	5
3.	Dudna	Manmad - Parbhani	(C.R.)	289	19	23	26	76	29	50	458.00	5	1975-76,79	3
4.	Gheku	Manmad - Parbhani	(C.R.)	74	19	56	35	14	58	20	409.22	5	1966-71	6
5.	Devan River	Vikarabad - Purli	(C.R.)	182	18	13	20	77	11	20	398.86	7	1966-74, 1982&83	11
6.	Tirna Nadi	Kurduwadi - Latur	(C.R.)	172/448/2	18	21	13	76	1	00	227.14	3	1970-73	4
7.	Bori Nadi	Secunderabad-Manmad	(C.R.)	66	19	57	10	74	52	10	157.55	3	1975-76, 1978&79	4
8.	Borna Nallah	Parbhani - Purli	(C.R.)	44	18	54	56	76	36	32	152.53	3	1975-81	7
9.	Kaum	Secunderabad - Mann	(C.R.)	125	19	51	45	75	17	50	141.67	5	1961-63	3
10.	Situ	Secunderabad - Manmad	(C.R.)	368	19	9	12	77	29	40	136.75	2	1969-73	5
11.	Sukna River	Secunderabad - Manmad	(C.R.)	139	19	51	30	75	25	00	93.60	4	1961-65	5
12.	Kola River	Secunderabad - Manmad	(C.R.)	295	19	20	45	76	33	16	77.70	1	1968-74	7
13.	Tributary of Godavari	Secunderabad - Manmad	(C.R.)	346	19	11	05	77	8	40	64.88	2	1967-73	7
14.	Narangi Nallah	Secunderabad - Manmad	(C.R.)	51	19	57	15	74	44	50	61.90	4	1961-66	6
15.	Lendi River	Secunderabad - Manmad	(C.R.)	79	19	55	10	75	1	40	35.22	2	1967-74	8
16.	Tributary of Godavari	Parbhani - Purli	(C.R.)	55	18	51	35	76	32	33	31.31	2	1962,64-67	5
17.	Tributary of Unduhal	Igatpuri - Bhusaval	(C.R.)	100/2	19	49	27	73	42	40	25.90	1	1962-65	4

Table-2

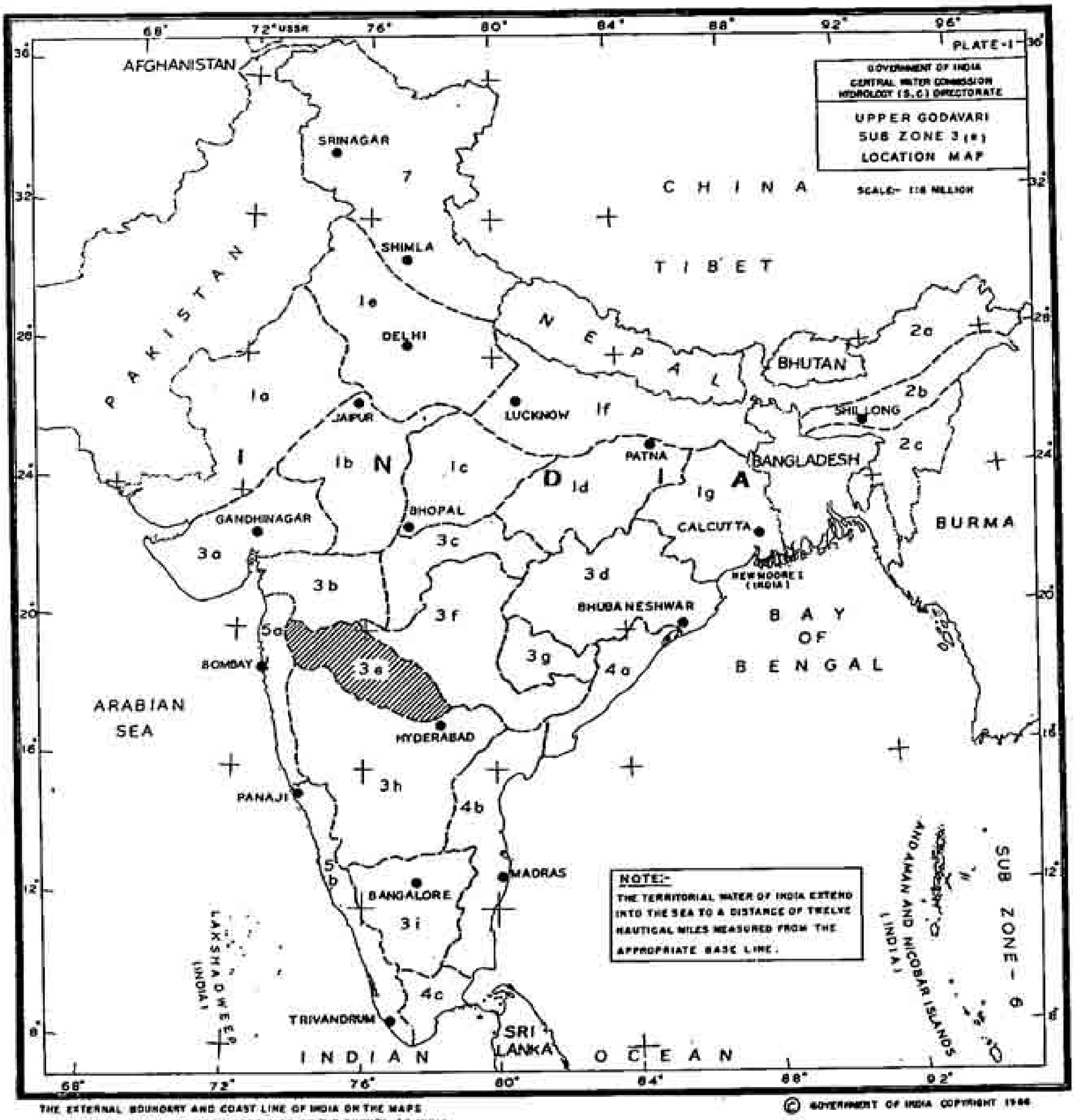
BASIN CHARACTERISTICS SUB-ZONE - 3 (e)

Sl. No.	BR. No.	A Sq. Km.	L Km.	S M/Km.	$\frac{L}{\sqrt{S}}$
1	2	3	4	5	6
1.	234	2227.39	96.60	1.54	78
2.	76	1197.76	74.01	2.22	50
3.	289	458.00	51.33	1.34	44
4.	74	409.22	53.53	1.78	40
5.	182	398.86	40.25	2.48	26
6.	172/448/2	227.14	28.18	2.51	18
7.	66	157.55	24.62	3.21	14
8.	44	152.53	29.25	5.35	13
9.	125	141.67	23.97	6.51	9
10.	368	136.75	22.83	3.54	12
11.	139	93.60	16.91	6.11	7
12.	295	77.70	12.87	4.03	6
13.	346	64.88	12.10	2.03	8
14.	51	61.90	15.12	4.22	7
15.	79	35.22	15.30	5.54	6
16.	55	31.31	20.93	6.88	8
17.	100/2	25.90	6.44	15.78	2

Table-3

REPRESENTATIVE 1-HR. UNITGRAPH PARAMETERS FOR SUBZONE - 3 (e)

Sl. No.	Bridge No.	t_r hrs.	t_p hrs.	Q_p Cumecs	q_p Cumecs/	T_B hrs.	W_{50} hrs.	W_{75} hrs.	WR_{50} hrs.	WR_{75} hrs.
1	2	3	4	5	6	7	8	9	10	11
1.	234	1	9.5	598.00	0.268	25.0	9.50	5.30	4.90	2.90
2.	76	1	7.5	362.00	0.302	24.0	7.80	3.80	3.20	1.70
3.	289	1	8.5	166.00	0.362	30.0	5.90	3.40	2.00	1.30
4.	74	1	8.5	124.50	0.304	26.0	7.90	4.20	3.00	1.70
5.	182	1	4.5	193.00	0.484	16.0	4.80	2.80	1.80	1.00
6.	172	1	3.5	145.00	0.638	14.0	3.50	1.95	1.30	0.75
7.	66	1	2.5	178.00	1.130	10.0	2.10	1.40	0.90	0.60
8.	44	1	2.5	145.50	0.954	10.0	2.50	1.35	0.80	0.55
9.	125	1	3.5	96.00	0.678	15.0	3.50	2.00	1.70	1.00
10.	368	1	2.5	108.00	0.789	12.0	2.70	1.80	1.10	0.70
11.	139	1	1.5	118.00	1.261	7.0	1.90	1.35	0.90	0.65
12.	295	1	2.5	45.50	0.586	13.0	3.95	1.75	1.03	0.55
13.	346	1	2.5	48.50	0.747	10.0	3.20	1.75	1.10	0.65
14.	51	1	2.5	86.00	1.389	8.0	1.55	0.85	0.65	0.35
15.	79	1	1.5	60.50	1.718	6.0	1.40	0.80	0.60	0.35
16.	55	1	3.5	27.00	0.862	15.0	2.11	1.15	0.67	0.48
17.	100/2	1	1.5	33.00	1.274	10.0	1.48	0.88	0.68	0.38



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

P. R. BHALLA
S.N. MALHOTRA

NOTE:-
(i) RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISER
(ii) BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA

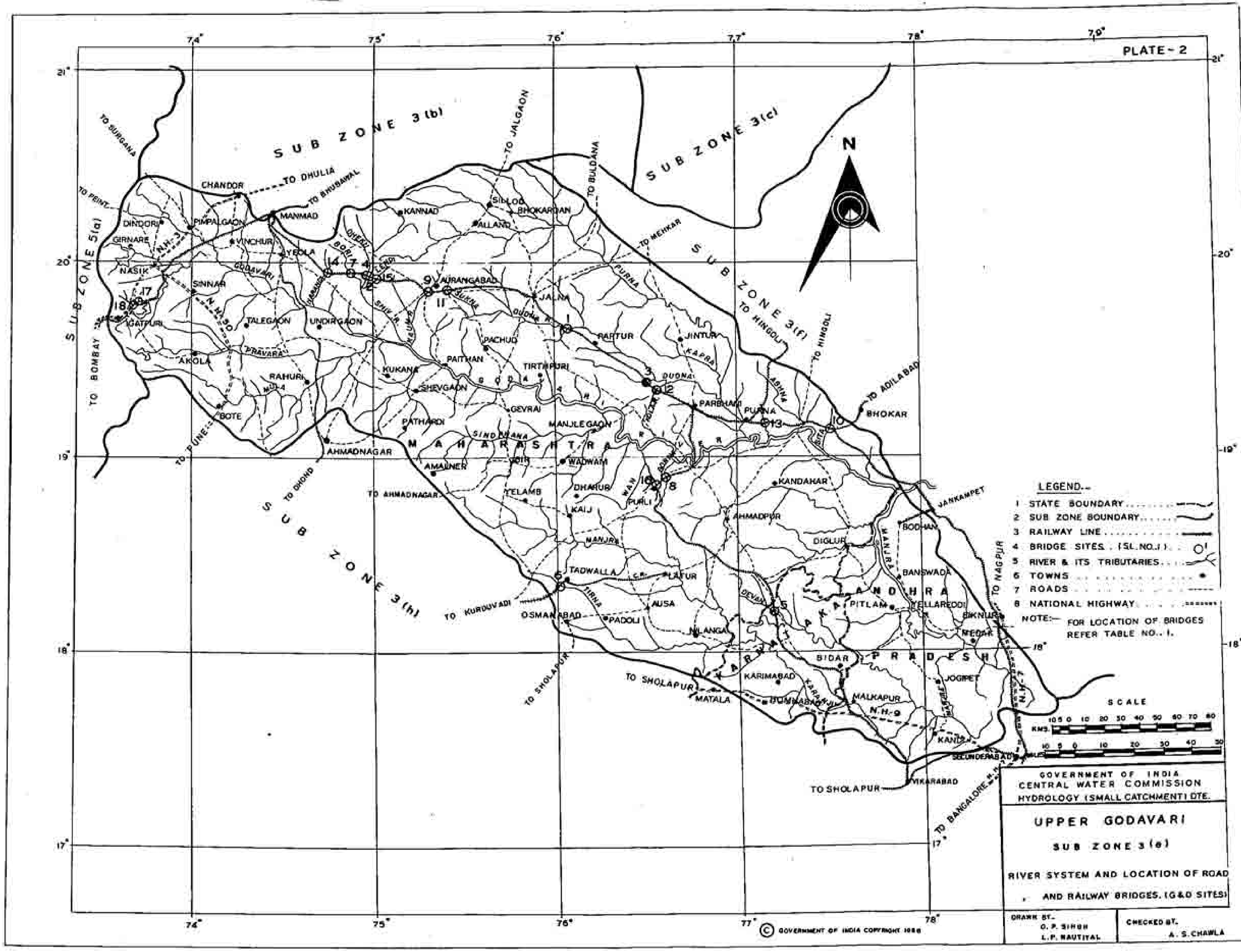


PLATE - 2
SUB ZONE 3(b)
SUB ZONE 3(c)
SUB ZONE 3(f)
SUB ZONE 3(h)
SUB ZONE 5(a)
N
MAHARASHTRA
KARNATAKA
ANDHRA PRADESH
NASIK
MANMAD
CHANDOR
AURANGABAD
JALNA
PAITHAN
AHMADNAGAR
PARBHANI
PURNA
BHOKAR
BIDAR
OSMANABAD
LATUR
SECUNDERABAD
LEGEND.-
1 STATE BOUNDARY
2 SUB ZONE BOUNDARY
3 RAILWAY LINE
4 BRIDGE SITES. (SL.NO.)
5 RIVER & ITS TRIBUTARIES
6 TOWNS
7 ROADS
8 NATIONAL HIGHWAY
NOTE:- FOR LOCATION OF BRIDGES REFER TABLE NO. 1.
SCALE
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENT) DTE.
UPPER GODAVARI
SUB ZONE 3(e)
RIVER SYSTEM AND LOCATION OF ROAD AND RAILWAY BRIDGES. (G&D SITES)
DRAWN BY.- O. P. SINGH L. P. NAUTIYAL
CHECKED BY.- A. S. CHAWLA
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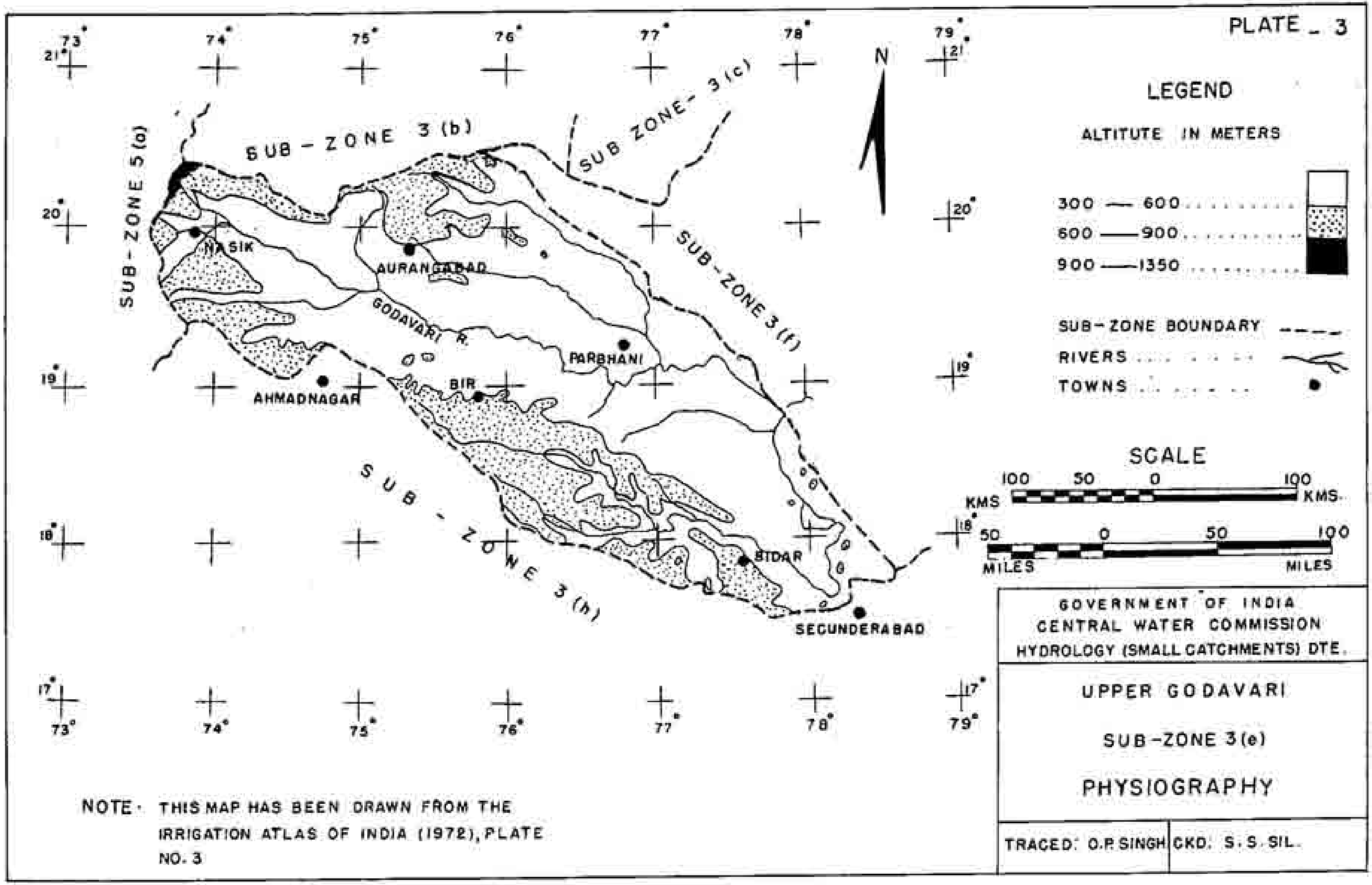
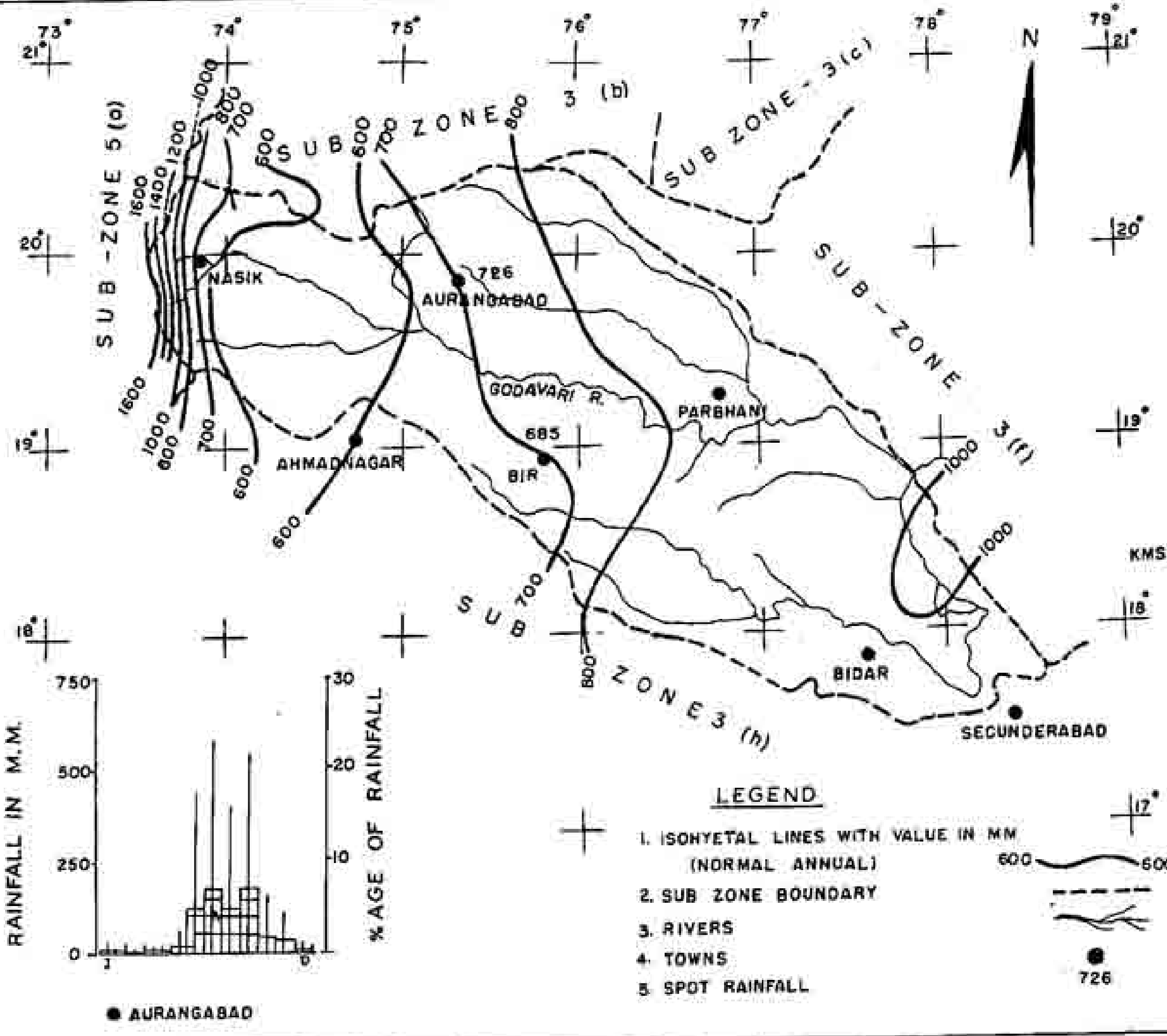


PLATE _ 3
LEGEND
ALTITUTE IN METERS
300 — 600
600 — 900
900 — 1350
SUB-ZONE BOUNDARY
RIVERS
TOWNS
SCALE
100 50 0 100 KMS
50 0 50 100 MILES
N
SUB - ZONE 5 (a)
SUB - ZONE 3 (b)
SUB ZONE- 3 (c)
SUB-ZONE 3 (f)
SUB - ZONE 3 (h)
NASIK
AURANGABAD
GODAVARI R.
PARBHANI
AHMADNAGAR
BIR
BIDAR
SECUNDERABAD
73° 74° 75° 76° 77° 78° 79°
21° 20° 19° 18° 17°
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.
UPPER GODAVARI
SUB-ZONE 3(e)
PHYSIOGRAPHY
TRACED: O.P. SINGH
CKD: S.S. SIL.
NOTE · THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972), PLATE NO. 3

PLATE- 4



NOTES:-

1. HISTOGRAM FOR ONE STATION WITH NAME.
2. EACH VERTICAL COLUMN REPRESENTS THE MEAN MONTHY RAINFALL FOR EACH MONTH (FROM JANUARY TO DECEMBER)
3. THE THICK VERTICAL LINES AT THE CENTRE OF EACH COLUMN INDICATES THE PERCENTAGE OF RAINFALL IN THE MONTH TO THE MEAN ANNUAL TOTAL.
4. THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972), PLATE 6.

SCALE:-

KMS. 100 50 0 100 KMS.

50 0 50 100 MILES MILES

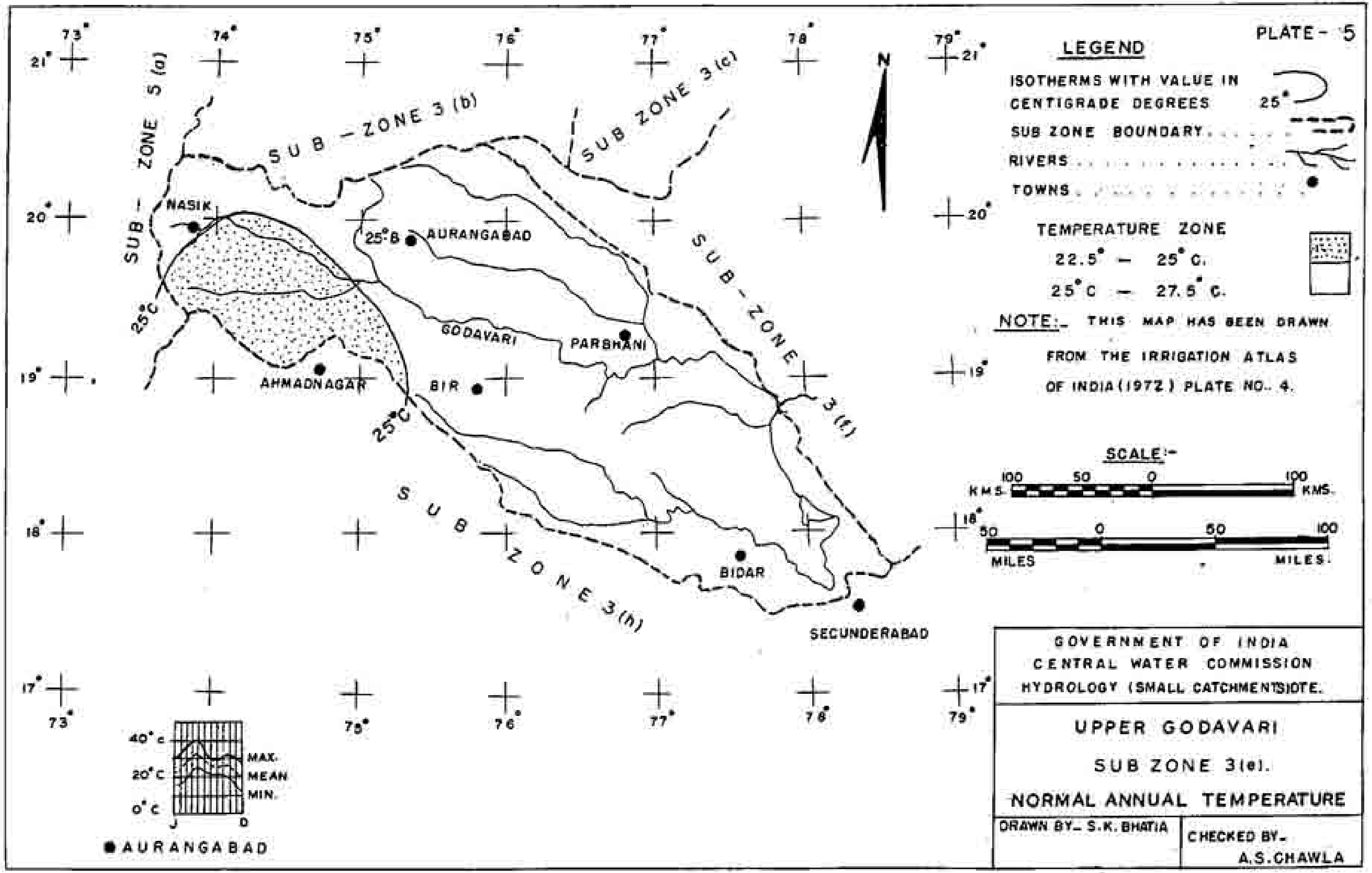
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.

UPPER GODAVARI
SUB ZONE 3(e)

NORMAL ANNUAL RAINFALL (mm.)

DRAWN BY P.N.BHALLA	CHECKED BY A. S. CHAWLA.

PLATE- 5



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

UPPER GODAVARI
SUB ZONE 3(e).

NORMAL ANNUAL TEMPERATURE

DRAWN BY - S.K. BHATIA	CHECKED BY - A.S. CHAWLA

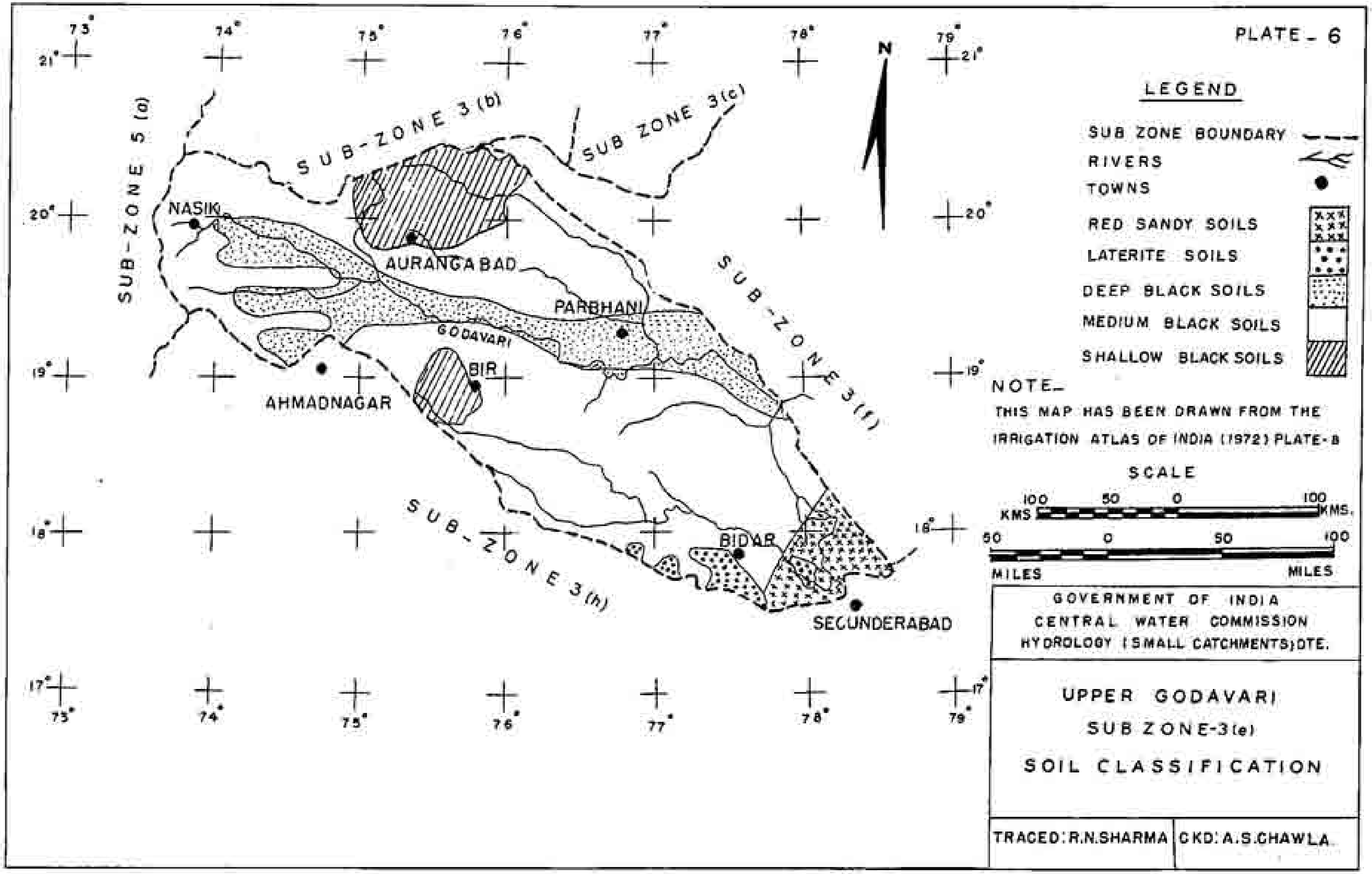


PLATE - 6
LEGEND
SUB ZONE BOUNDARY
RIVERS
TOWNS
RED SANDY SOILS
LATERITE SOILS
DEEP BLACK SOILS
MEDIUM BLACK SOILS
SHALLOW BLACK SOILS
NOTE_
THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972) PLATE-8
SCALE
KMS 100 50 0 100 KMS.
MILES 50 0 50 100 MILES
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.
UPPER GODAVARI
SUB ZONE-3(e)
SOIL CLASSIFICATION
TRACED: R.N.SHARMA
CKD: A.S.CHAWLA
N
SUB-ZONE 5 (a)
SUB-ZONE 3 (b)
SUB ZONE 3(c)
SUB-ZONE 3(f)
SUB-ZONE 3(h)
NASIK
AURANGABAD
PARBHANI
GODAVARI
BIR
AHMADNAGAR
BIDAR
SECUNDERABAD
73° 74° 75° 76° 77° 78° 79°
21° 20° 19° 18° 17°

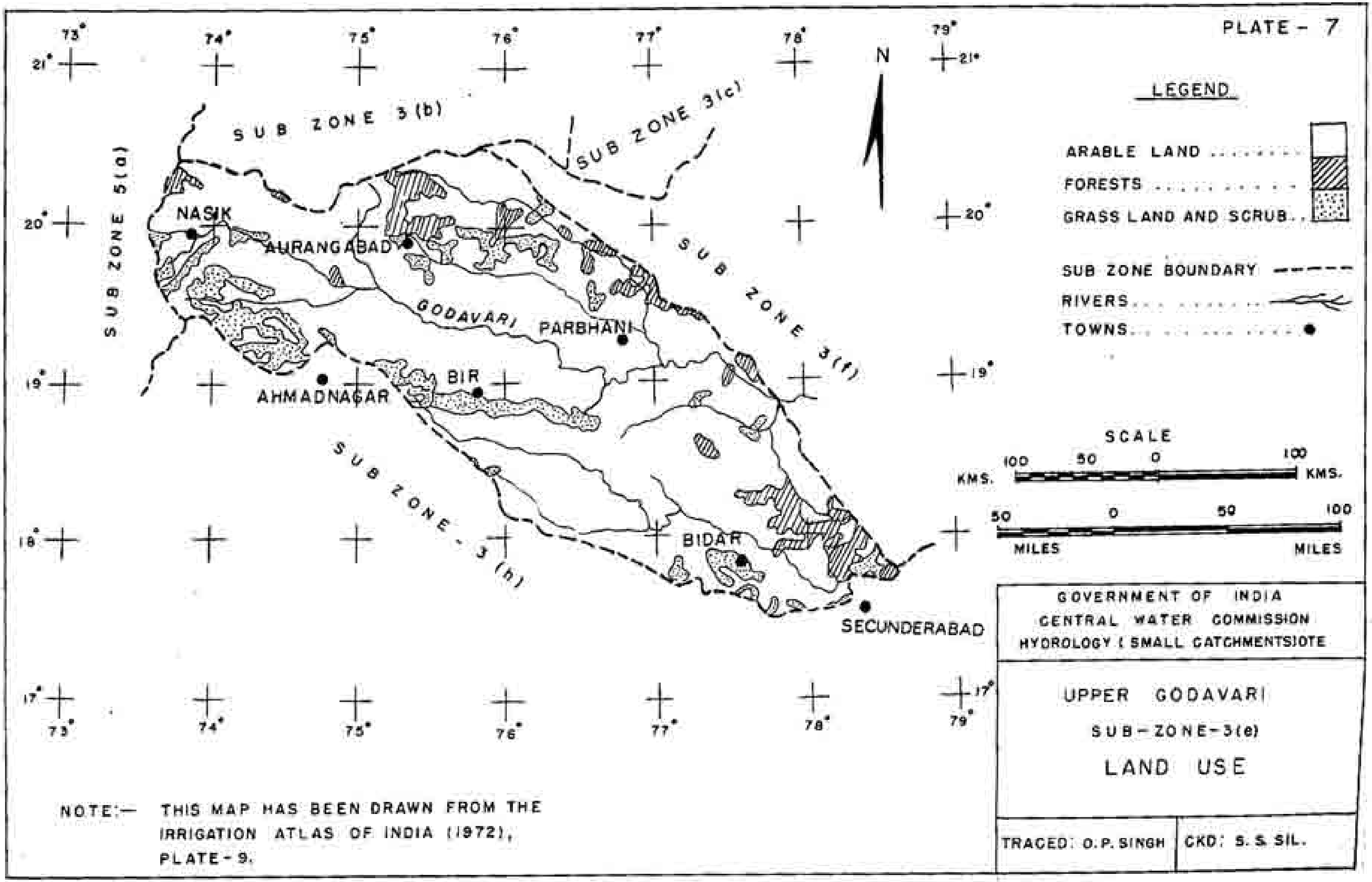
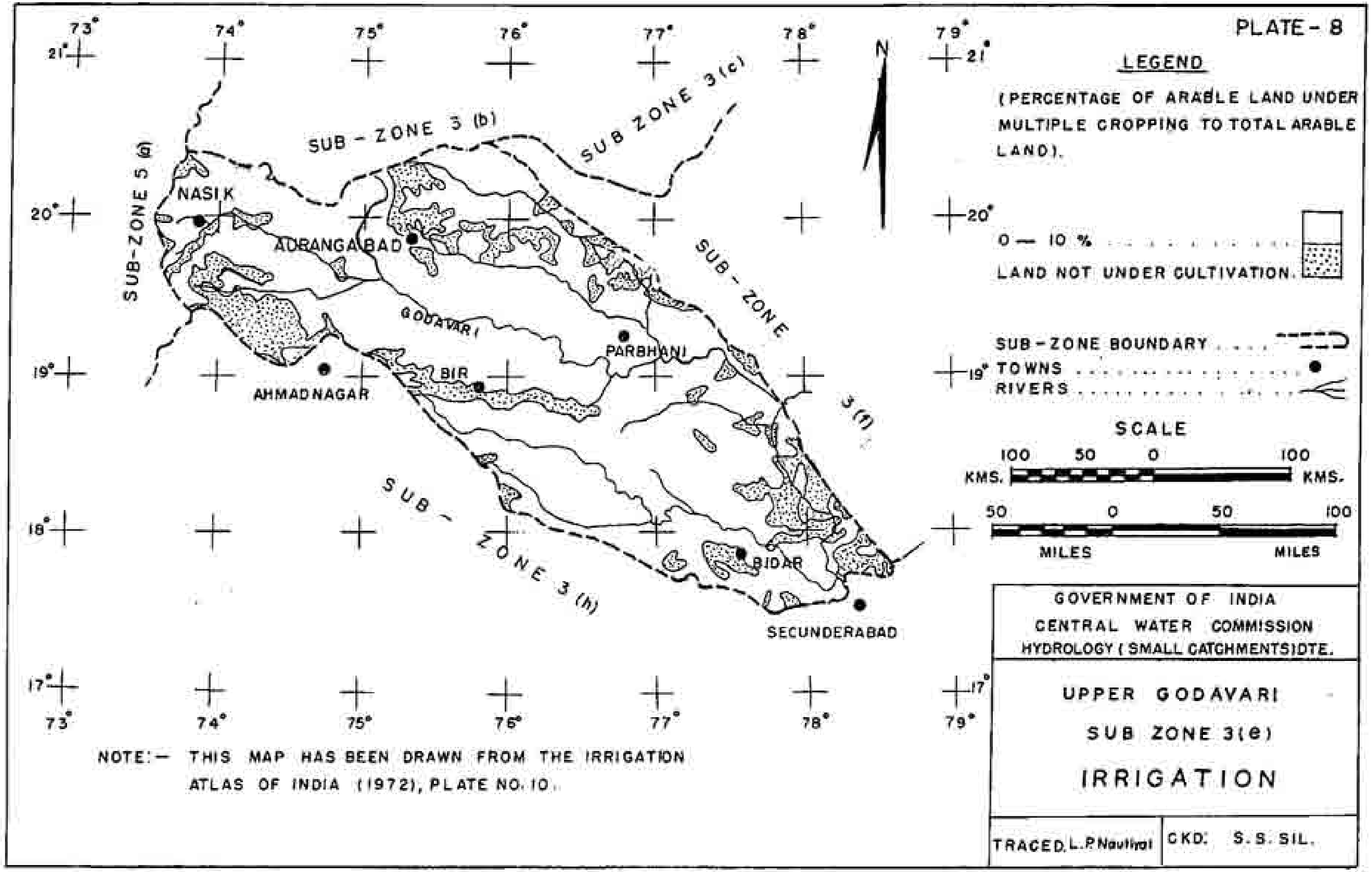
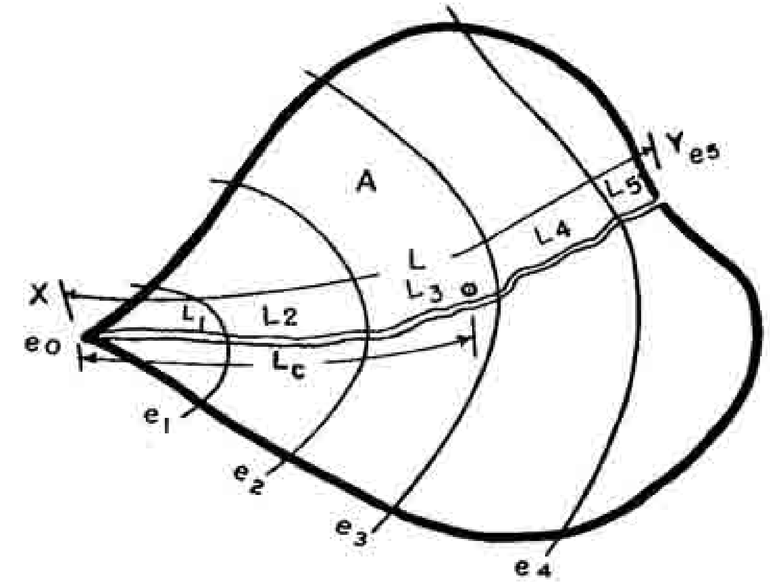


PLATE - 7
LEGEND
ARABLE LAND
FORESTS
GRASS LAND AND SCRUB
SUB ZONE BOUNDARY
RIVERS
TOWNS
SCALE
100 50 0 100 KMS.
50 0 50 100 MILES
N
SUB ZONE 3 (b)
SUB ZONE 3(c)
SUB ZONE 3 (f)
SUB ZONE - 3 (h)
SUB ZONE 5(a)
NASIK
AURANGABAD
GODAVARI
PARBHANI
AHMADNAGAR
BIR
BIDAR
SECUNDERABAD
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS)DTE
UPPER GODAVARI
SUB-ZONE-3(e)
LAND USE
TRACED: O.P. SINGH
CKD: S. S. SIL.
NOTE:— THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972), PLATE-9.

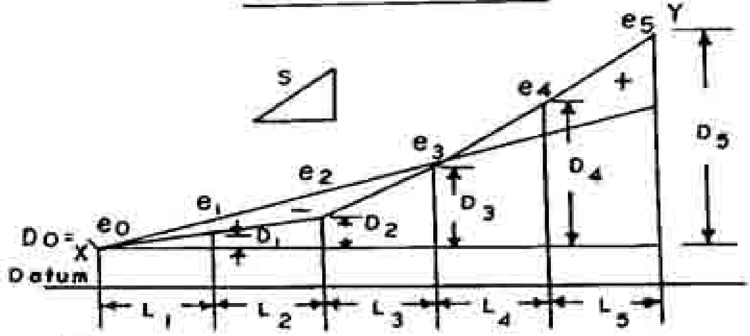


NOTE:— THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972), PLATE NO. 10.

FIG.-1



Catchment Plan



L - Section

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

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

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

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

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

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

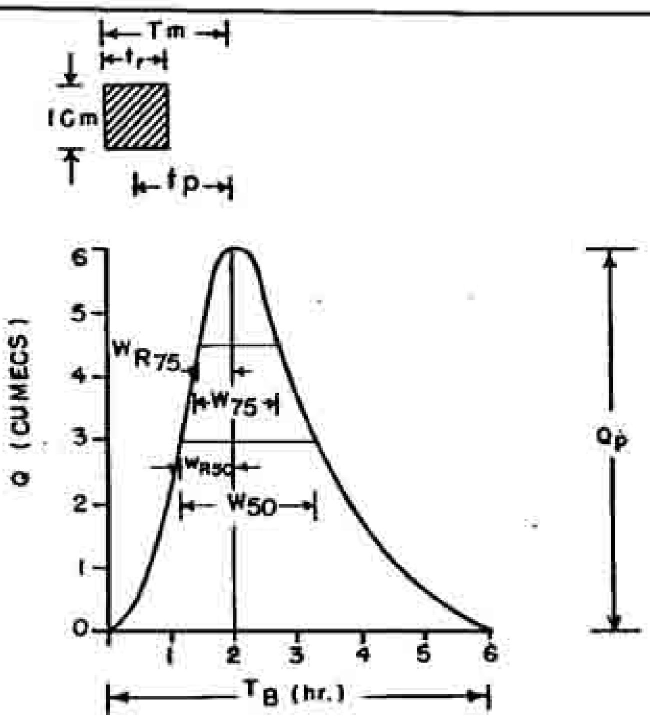
$= (e_0 - e_0), (e_1 - e_0)$ --------

$(e_n - e_0)$ (m).

A = Catchment Area (Sq.km).

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

t_p = 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.)

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

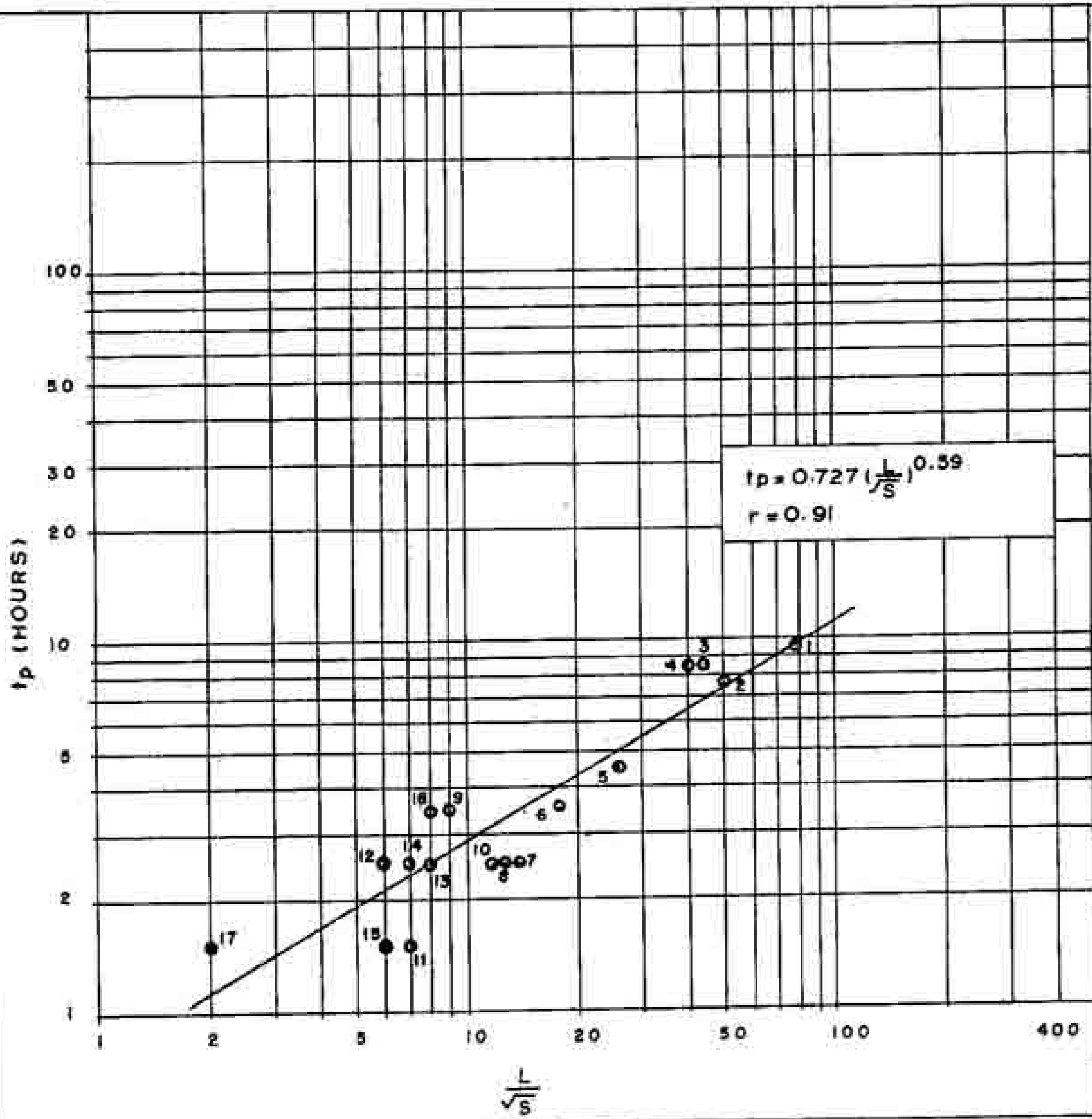
T_B = Base width of Unit Hydrograph (hr.)

A = Catchment Area (Sq. km.)

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

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

FIG. 3



SL. NO.	BR. NO.	$\frac{L}{\sqrt{S}}$	t_p (HOURS)
1	234	78	9.5
2	76	50	7.5
3	289	44	8.5
4	74	40	8.5
5	182	26	4.5
6	172	18	3.5
7	66	14	2.5
8	44	13	2.5
9	125	9	3.5
10	368	12	2.5
11	139	7	1.5
12	295	6	2.5
13	346	8	2.5
14	51	7	2.5
15	79	6	1.5
16	55	8	3.5
17	100/2	2	1.5

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

UPPER GODAVARI
SUB ZONE 3 (e)
RELATION BETWEEN
$\frac{L}{\sqrt{S}}$ AND t_p

DRAWN BY O. P. SINGH

CHECKED BY A. S. CHAWLA

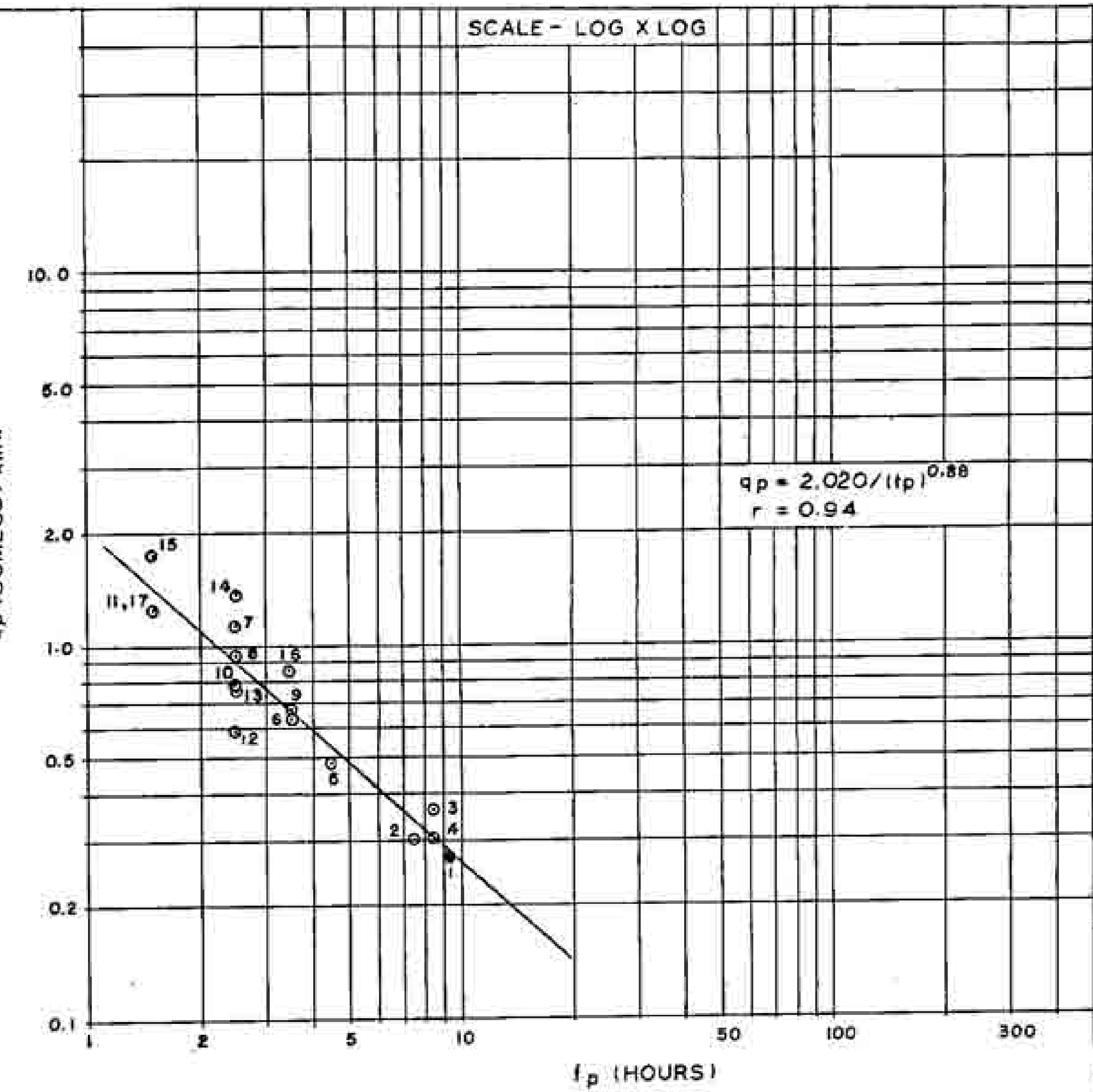


FIG. 4

Sl. NO.	BR. NO.	t_p (HOURS)	q_p CUMECS/KM²
1	234	9.5	0.268
2	76	7.5	0.302
3	289	8.5	0.362
4	74	8.5	0.304
5	182	4.5	0.484
6	172	3.5	0.638
7	66	2.5	1.130
8	44	2.5	0.954
9	126	3.5	0.678
10	368	2.5	0.789
11	139	1.5	1.261
12	295	2.5	0.586
13	346	2.5	0.747
14	81	2.5	1.389
15	79	1.5	1.718
16	55	3.5	0.862
17	100/2	1.5	1.274

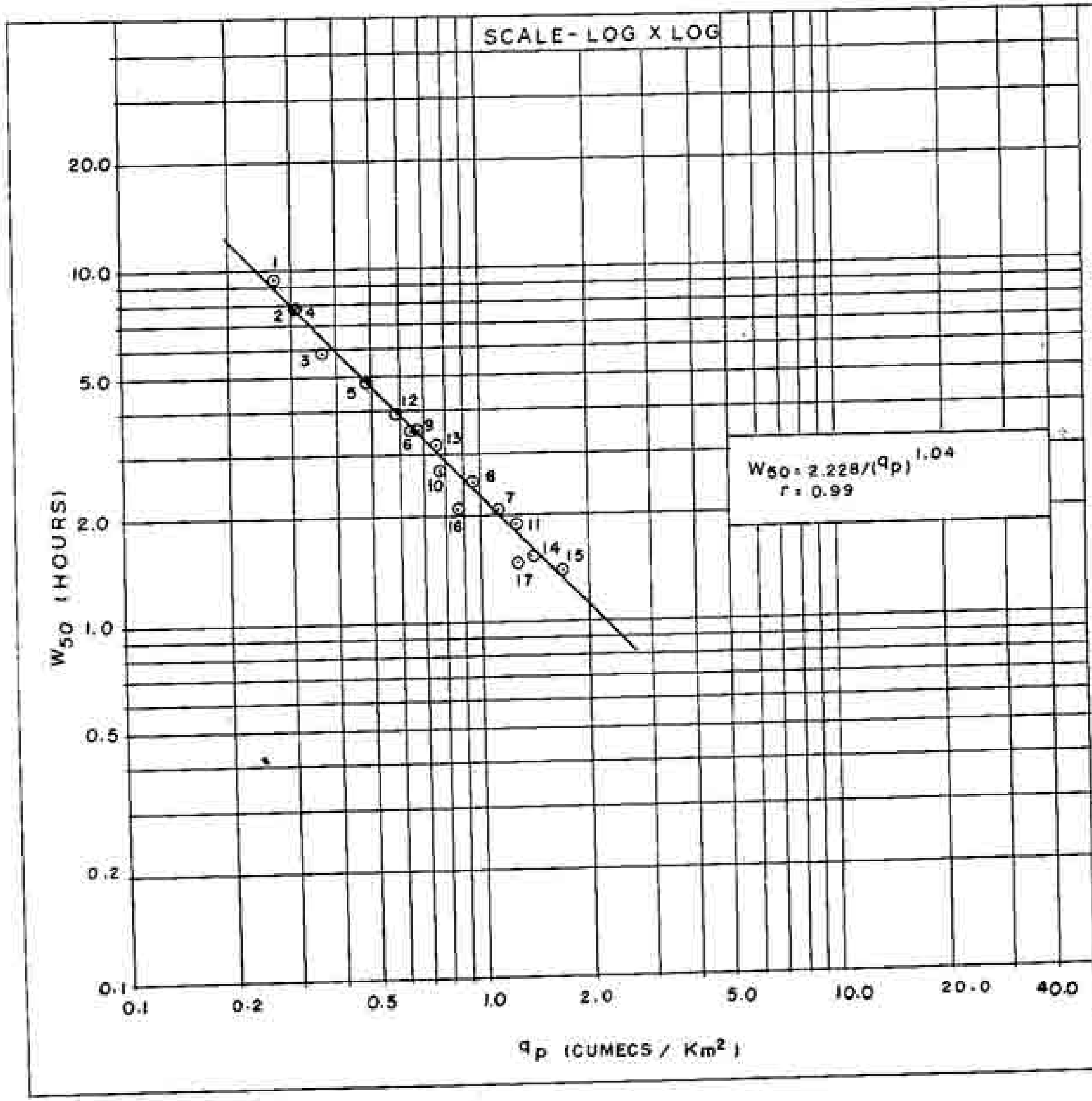
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.

UPPER GODAVARI
SUB ZONE 3 (e)
RELATION BETWEEN
t_p AND q_p

DRAWN BY R.N. SHARMA

CHECKED BY A.S. CHAWLA

FIG. 5



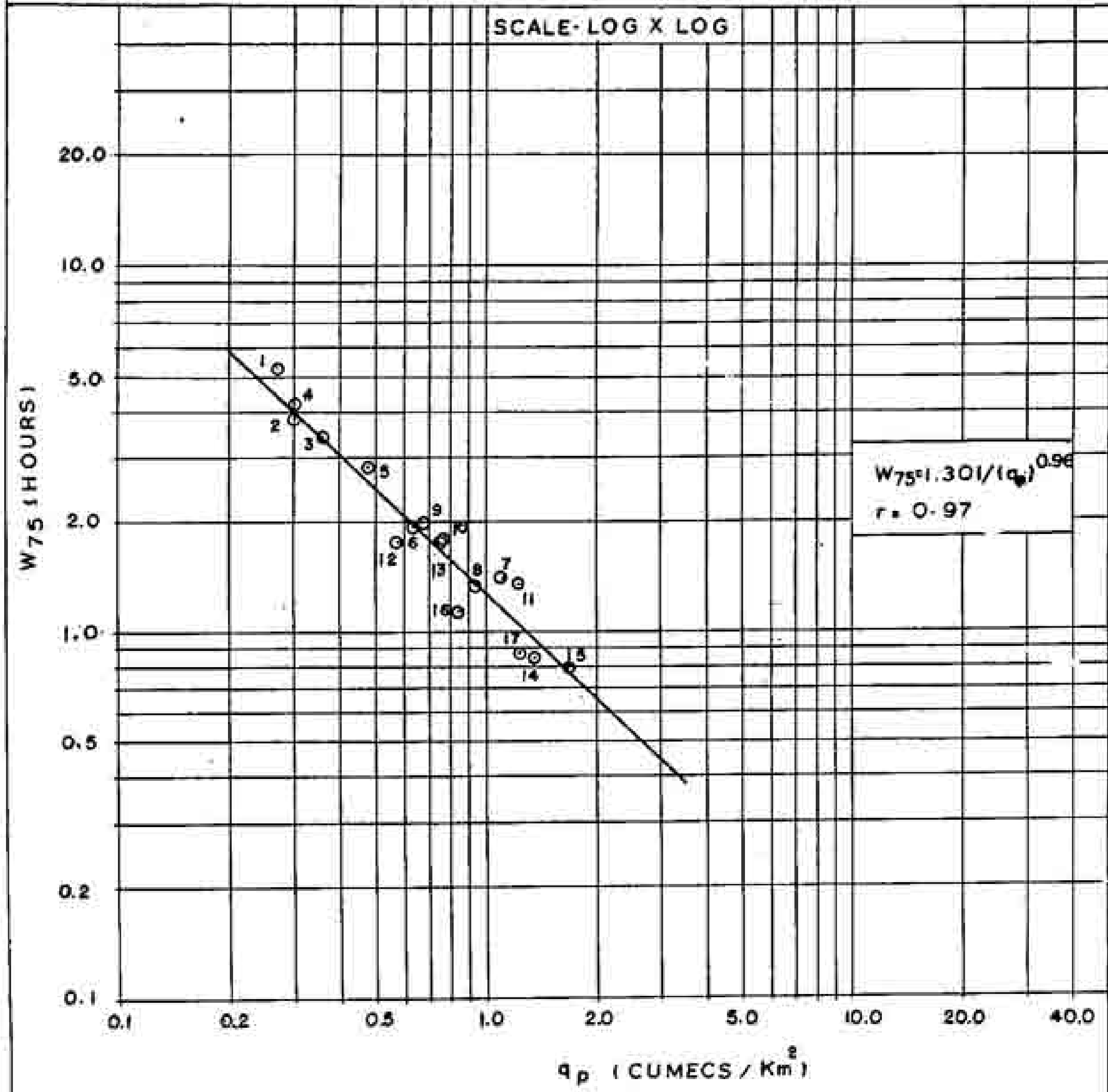
S.NO.	BR. NO.	q_p (CUMECS/KM²)	W_{50} (HOURS)
1	234	0.268	9.50
2	76	0.302	7.80
3	289	0.362	5.90
4	74	0.304	7.90
5	182	0.484	4.80
6	172	0.638	3.50
7	66	1.130	2.10
8	44	0.954	2.50
9	125	0.678	3.50
10	366	0.789	2.70
11	139	1.261	1.90
12	295	0.586	3.95
13	346	0.747	3.20
14	51	1.389	1.55
15	79	1.718	1.40
16	55	0.862	2.11
17	100/2	1.274	1.48

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

UPPER GODAVARI
SUB ZONE 3 (e)
RELATION BETWEEN
q_p AND W_{50}

DRAWN BY S. K. BHATIA | CHECKED BY A. S. CHAWLA

FIG. 6



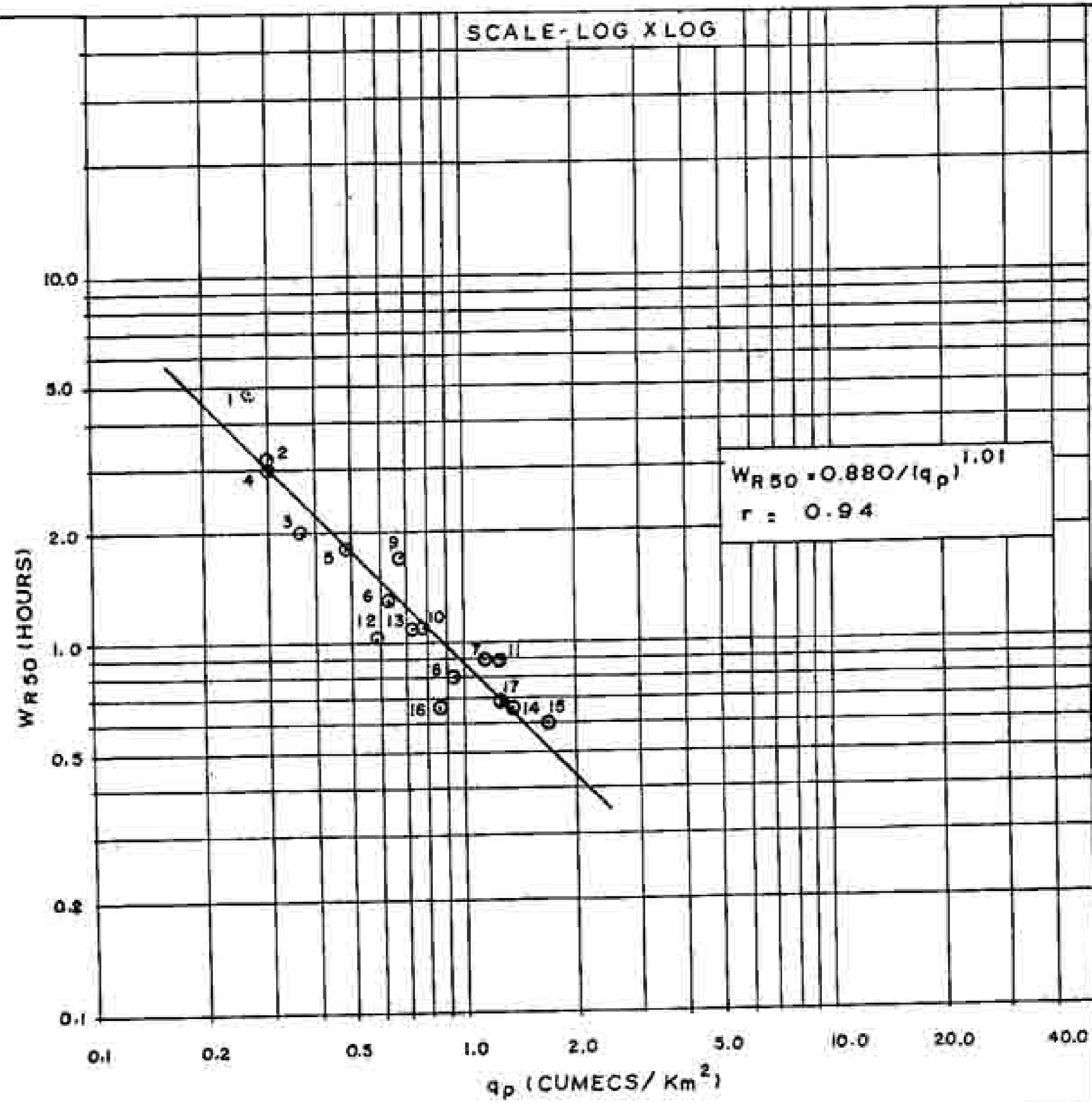
Sl. NO.	BR. NO.	q_p CUMECS/KM^2	W_{75} (HOURS)
1	234	0.268	5.30
2	76	0.302	3.80
3	289	0.362	3.40
4	74	0.304	4.20
5	182	0.484	2.80
6	172	0.638	1.95
7	66	1.130	1.40
8	44	0.954	1.35
9	125	0.678	2.00
10	368	0.789	1.80
11	139	1.261	1.36
12	295	0.586	1.75
13	346	0.747	1.75
14	51	1.389	0.85
15	79	1.718	0.80
16	55	0.862	1.15
17	100/2	1.274	0.88

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

UPPER GODAVARI
SUB ZONE 3 (e)
RELATION BETWEEN
q_p AND W_{75}

DRAWN BY P. N. BHALLA | CHECKED BY A. S. CHAWLA

FIG. 7



SL.NO.	BR. NO.	q_p CUMECS/KM^2	W_{R50} (HOURS)
1	234	0.268	4.90
2	76	0.302	3.20
3	289	0.362	2.00
4	74	0.304	3.00
5	182	0.484	1.80
6	172	0.638	1.30
7	66	1.150	0.90
8	44	0.954	0.80
9	125	0.678	1.70
10	368	0.789	1.10
11	139	1.261	0.90
12	295	0.686	1.03
13	346	0.747	1.10
14	51	1.369	0.68
15	79	1.718	0.60
16	66	0.862	0.67
17	100/2	1.274	0.68

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

UPPER GODAVARI
SUB ZONE 3 (e)
RELATION BETWEEN q_p AND W_{R50}

DRAWN BY- L. P. NAUTIYAL
CHECKED BY A. S. CHAWLA

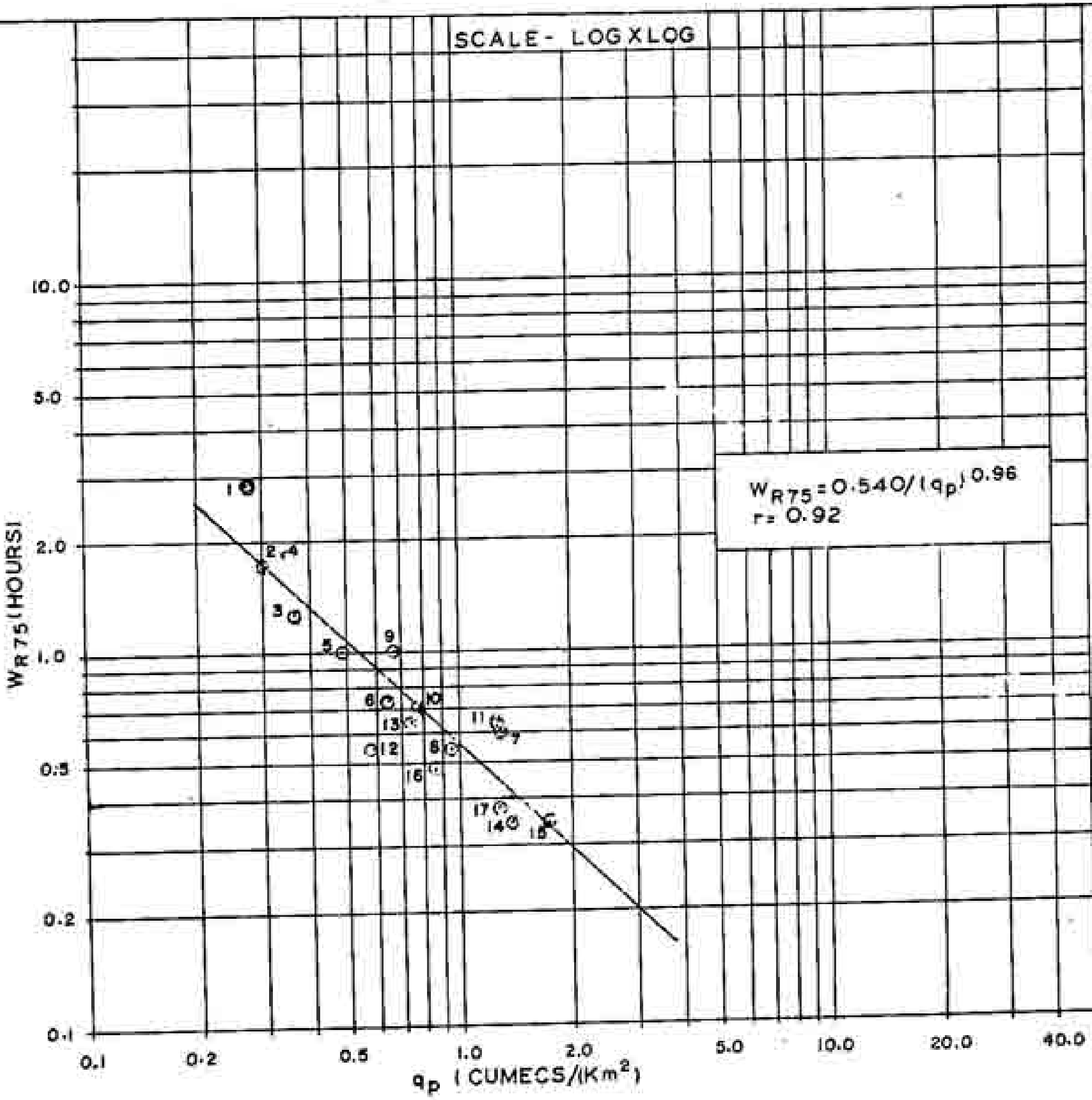


FIG. 8

SL. NO	BR. NO.	q_p CUMECS/KM^2	W_{R75} (HOURS)
1	234	0.268	2.90
2	76	0.302	1.70
3	289	0.362	1.30
4	74	0.304	1.70
5	182	0.484	1.00
6	172	0.638	0.75
7	66	1.130	0.60
8	44	0.954	0.56
9	125	0.678	1.00
10	368	0.789	0.70
11	139	1.261	0.65
12	295	0.586	0.55
13	346	0.747	0.65
14	51	1.389	0.35
15	79	1.718	0.35
16	55	0.882	0.48
17	100/2	1.274	0.38

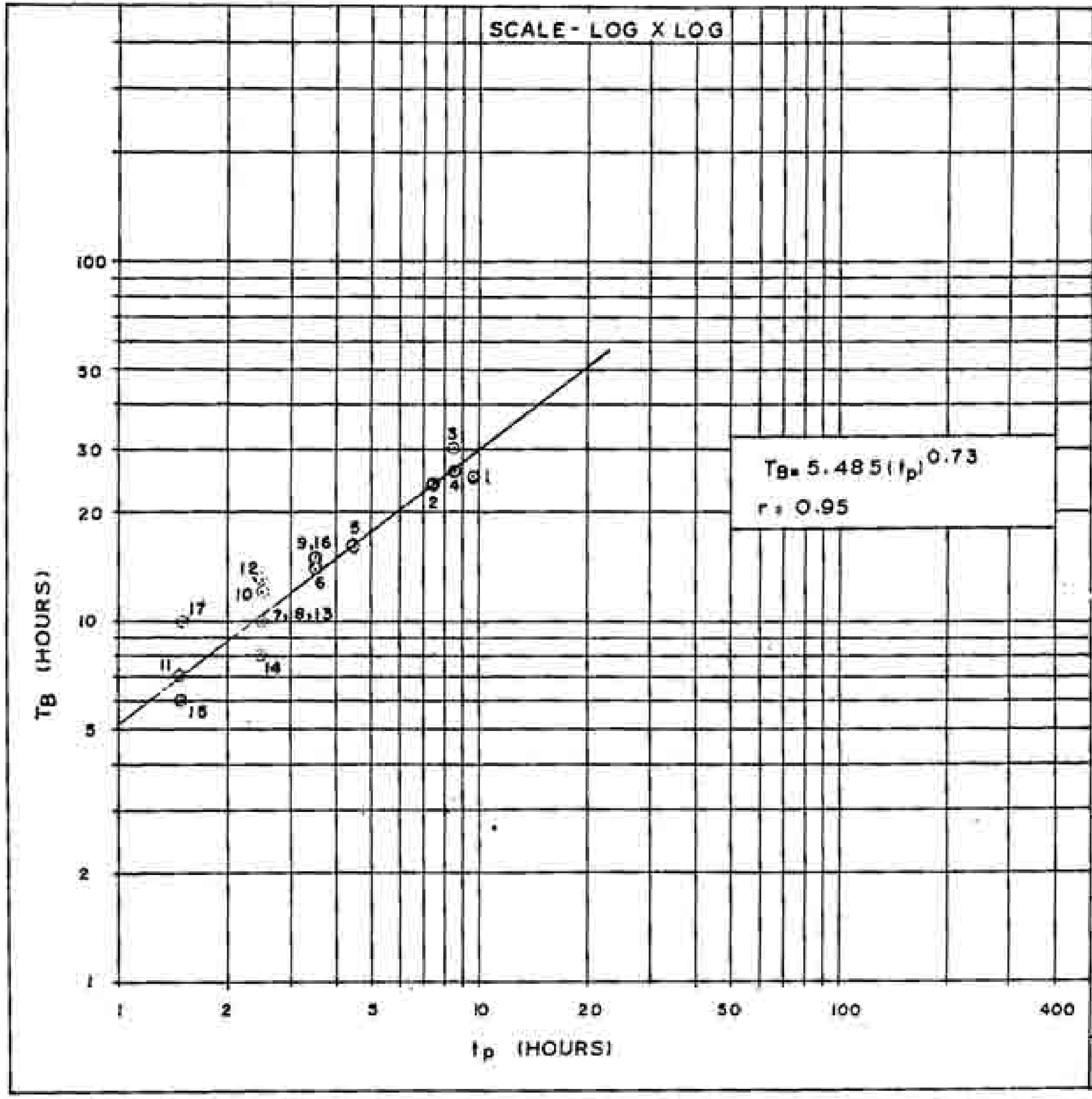
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.

UPPER GODAVARI
SUB ZONE 3 (e)
RELATION BETWEEN q_p AND W_{R75}

DRAWN BY T.R. ARORA

CHECKED BY A.S. CHAWLA

FIG. 9



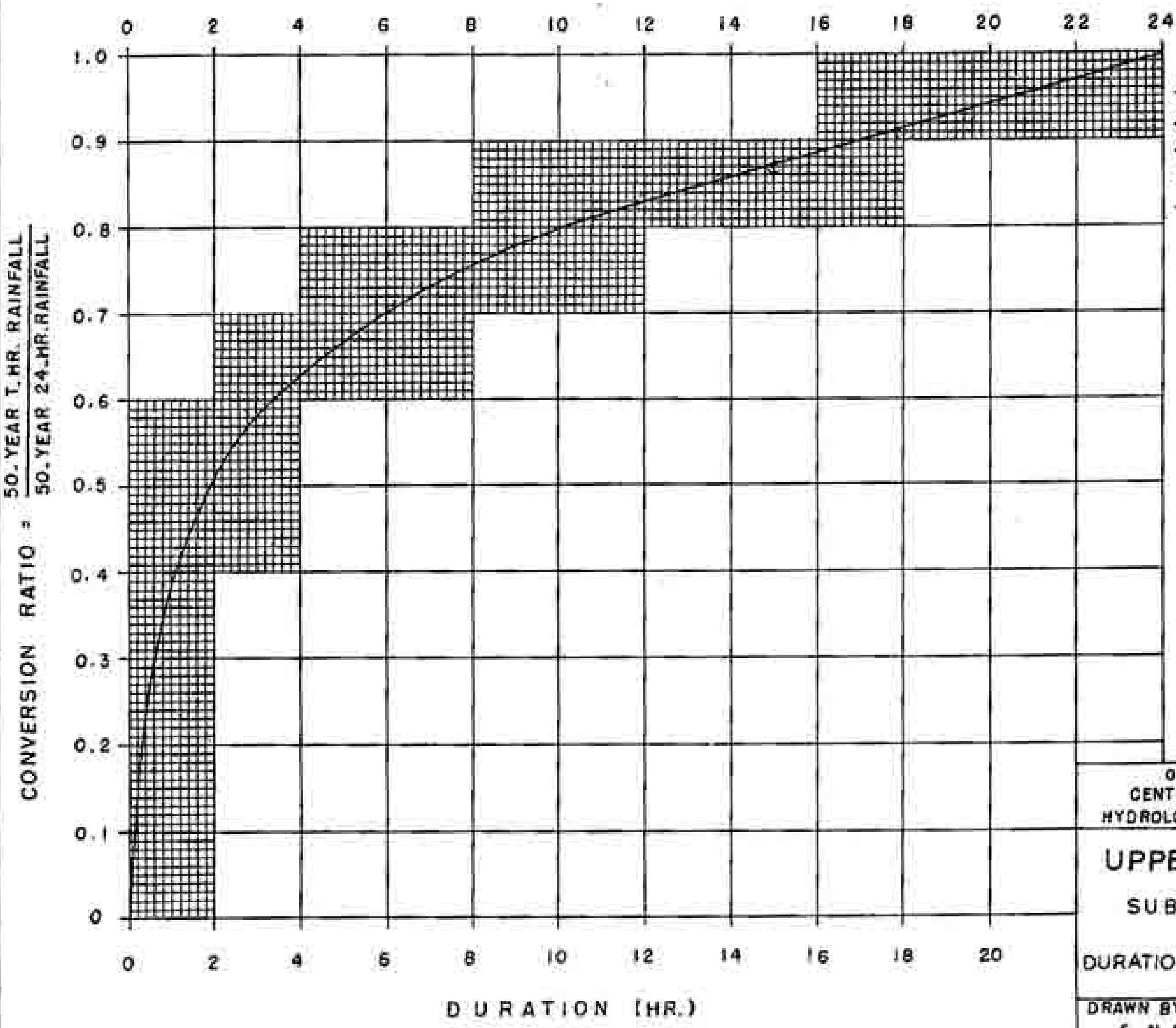
SL.NO.	BR.NO	t_p (HOURS)	T_B (HOURS)
1	234	9.5	25
2	76	7.5	24
3	289	8.5	30
4	74	8.5	26
5	182	4.5	16
6	172	3.5	14
7	66	2.5	10
8	44	2.5	10
9	125	3.5	15
10	368	2.5	12
11	139	1.5	7
12	295	2.5	13
13	346	2.5	10
14	51	2.0	8
15	79	1.5	6
16	55	3.5	15
17	100/2	1.5	10

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

UPPER GODAVARI
SUB ZONE 3 (e)
RELATION BETWEEN
t_p AND T_B

DRAWN BY T. R. ARORA | CHECKED BY A.S. CHAWLA

FIG.—10



RATIO OF 24HR. POINT RAINFALL TO SHORT DURATION RAINFALL.

DURATION (HR.)	RATIO
0	0.000
1	0.380
2	0.510
3	0.580
4	0.627
5	0.665
6	0.700
7	0.730
8	0.756
9	0.780
10	0.798
11	0.814
12	0.830
13	0.843
14	0.857
15	0.870
16	0.885
17	0.900
18	0.913
19	0.929
20	0.942
21	0.956
22	0.970
23	0.985
24	1.000

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

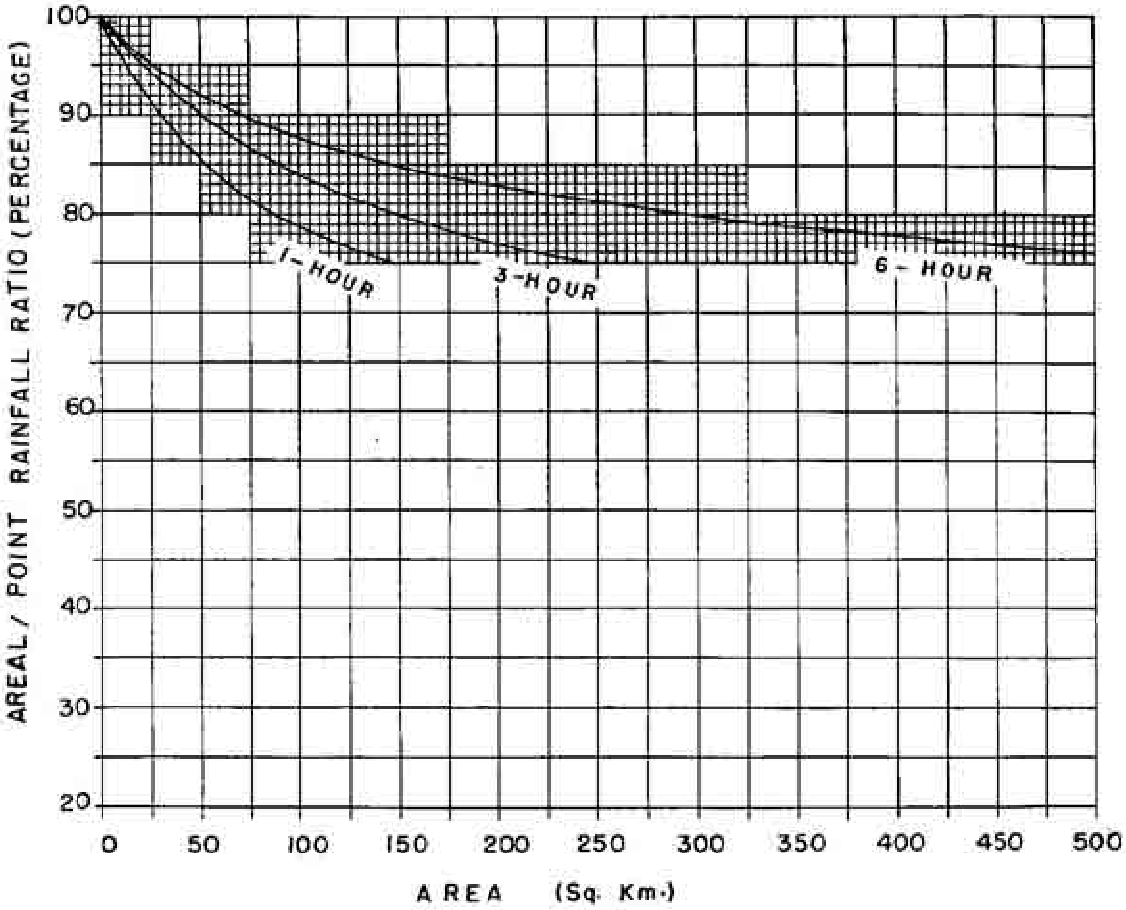
UPPER GODAVARI

SUB ZONE — 3 (e)

DURATION Vs. CONVERSION RATIO.

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

FIG. 11(a)

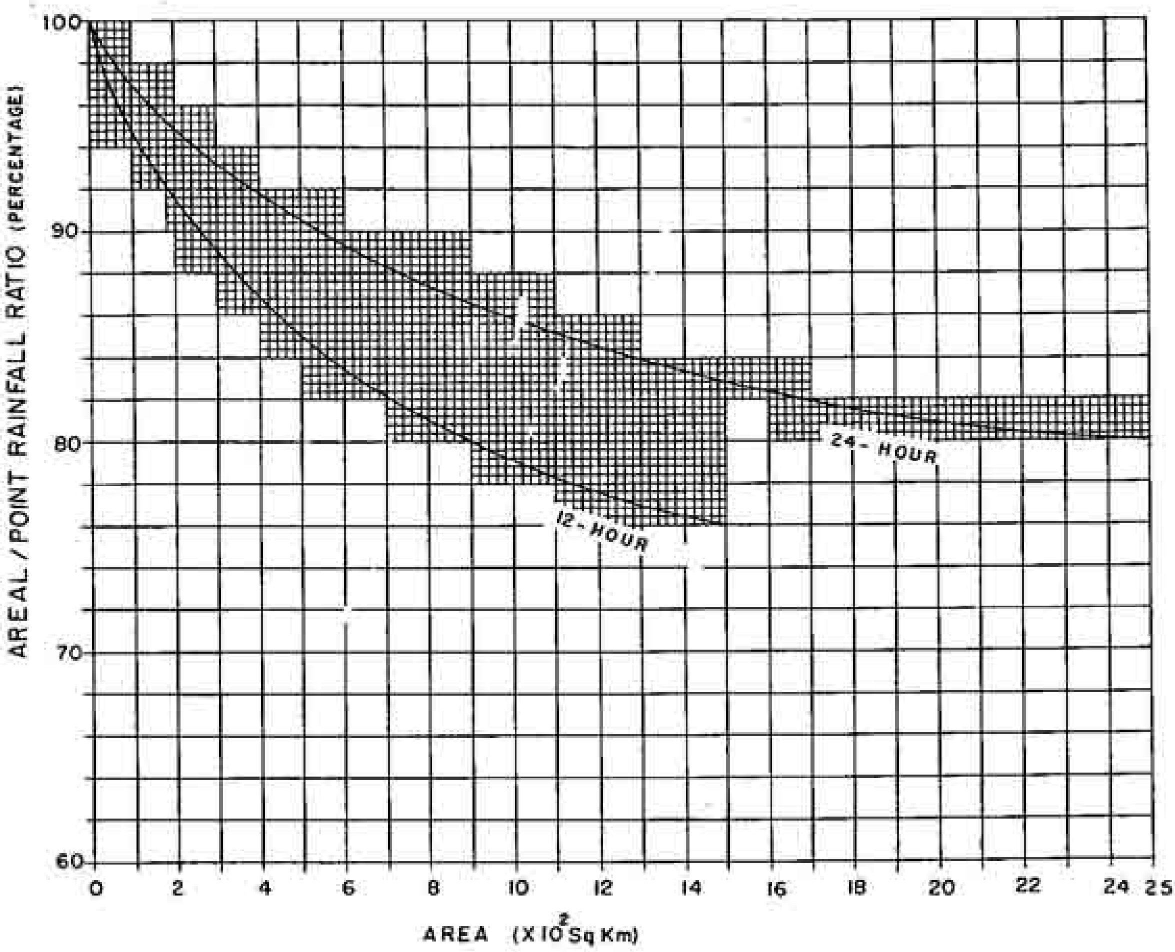


NOTE:- REFER TABLE 6 FOR POINT TO AREAL RAINFALL RATIOS FOR DURATION FROM 1 TO 24 HOURS AND FOR CATCHMENT AREAS UP TO 2500 Sq. Km.

GOVT. OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (SMALL CATCHMENTS) DTE.
UPPER GODAVARI SUB ZONE — 3 (e) AREAL TO POINT RAINFALL RATIO (PERCENTAGE)

DRAWN: S.N. MALHOTRA	CKD: A. K. GHOSH.

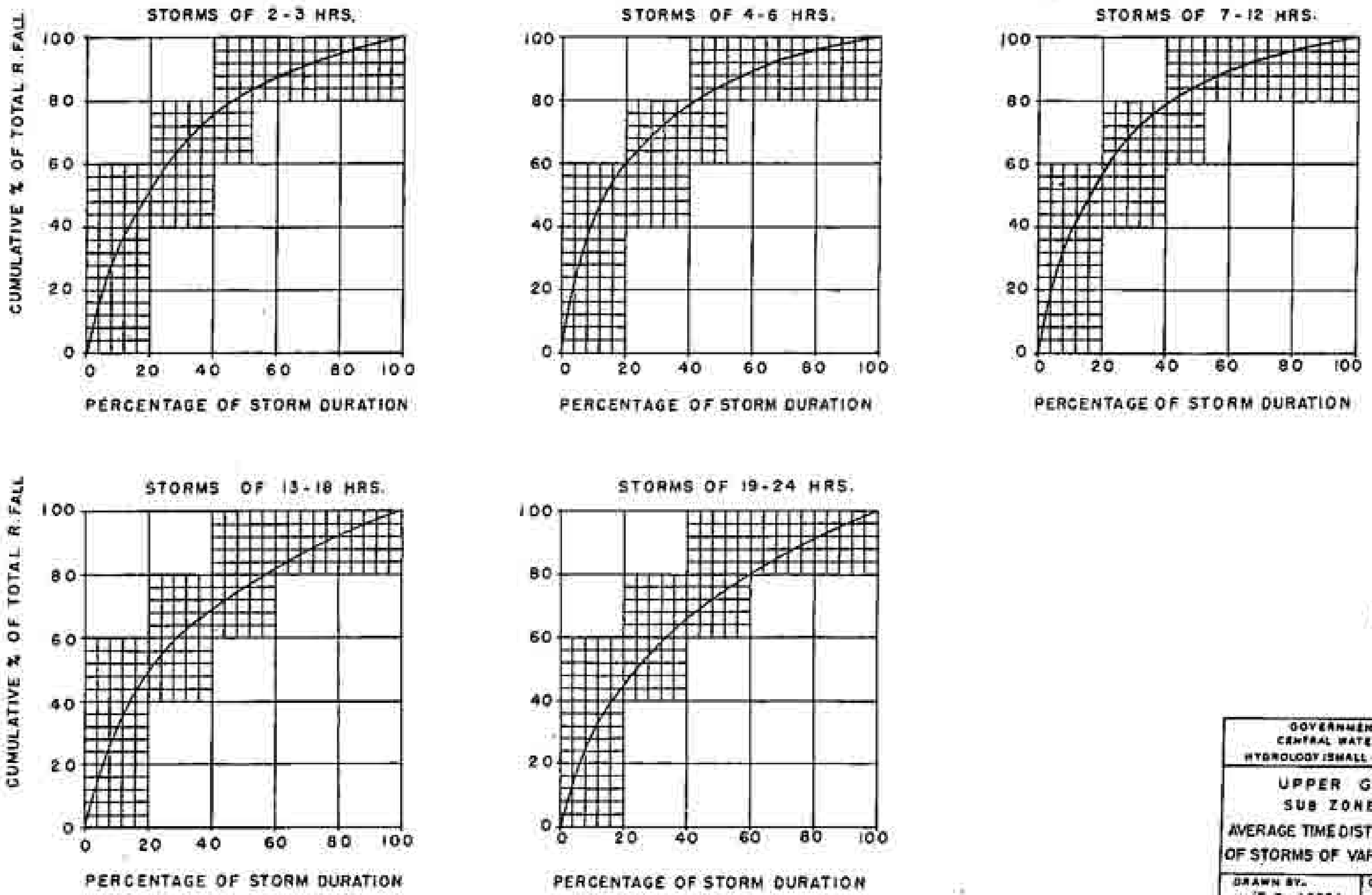
FIG. II(b)



NOTE:- REFER TABLE 6 FOR POINT TO AREAL RAINFALL RATIOS FOR DURATION FROM 1 TO 24 HOURS AND FOR CATCHMENT AREAS UP TO 2500 Sq. Km.

GOVT. OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (SMALL CATCHMENTS) DTE.	
UPPER GODAVARI SUB - ZONE - 3(e) AREAL/POINT RAINFALL RATIO (PERCENTAGE)	
DRAWN: S.N. MALHOTRA	CHECKED: A. K. GHOSH.

FIG.-12



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

UPPER GODAVARI
SUB ZONE - 3 (e)

AVERAGE TIME DISTRIBUTION CURVES OF STORMS OF VARIOUS DURATION.

DRAWN BY-	CHECKED BY-
T. R. ARORA P. H. BHALLA	A. K. GHOSH A. D.

4.0 DESIGN STORM INPUT

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

4.1 Design Storm Duration

The duration of the storm rainfall which causes the maximum discharge in a drainage basin is called the design storm duration. The design storm duration (T_D) for a catchment is 1.1 t_p. $T_D = 1.1\ t_p$.

4.2 Rainfall Depth Duration Frequency Studies

India Meteorological Department have conducted this study on the basis of 15 self-recording raingauge stations and 126 ordinary raingauge stations maintained by IMD/States and 30 SRRG stations maintained by Railways in 8 bridge catchments in subzone 3(e).

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

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

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

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

Duration	Ratio
24	~~1.00~~
18	1.00
15	0.91
12	0.87
9	0.83
6	0.78
3	0.70
1	0.58
	0.38

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

Fig.10 shows the ratios for short duration point rainfall with respect to 24-hour 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-hour 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 8 bridge catchments were used for this study. The data of remaining bridge catchments could not be utilised as the period of data were either less than 4 years and/or concurrent years data were not recorded continuously for 4 years over the stations in a bridge catchment. 2-year point rainfall values for specified duration for each station in the catchment were computed by frequency analysis. Arithmetic average of 2-year point rainfall of all the stations in the catchment was calculated to get the 2-year representative point rainfall for the catchment. Events of maximum average depth for a particular duration in each year were selected on the basis of simultaneous occurrence of rainfall at each station in the catchment. The areal rainfall series thus obtained was subjected to frequency analysis of 2-year areal rainfall depths for specified durations were computed. The percentage ratio of 2-year areal rainfall to 2-year representative point rainfall for the catchment was calculated and plotted against the area of the catchment for various durations. The best fit curves were drawn for specified durations on the points obtained for all the catchments. Fig.11(a) and 11(b) give the curves for conversion of point rainfall into areal rainfall for 1,3,6,12 and 24 hours. The areal reduction factor (ARF) at different intervals of catchment areas for the above durations are given in Table-A-3.

Data for bridge catchment is available only upto 1200 sq.km. and point to areal curves have been extrapolated upto 2500 sq.km. on the basis of limited ARF's obtained from bridges having area less than 1200 sq.km. Point to areal rainfall values may, therefore, be used with caution for areas more than 1200 sq.km.

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 1480 rain storms of various durations upto 24 hours occurring in various parts of the subzone were analysed based on 184 station year data. Rain storm selected at such stations were grouped under the above 5 categories and plotted on different graphs on dimensionless curves with cumulative percentage of total rainfall along the ordinates and percentage of storm duration along the abcissa. Thus five different graphs were prepared for each station corresponding to various durations and were than 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.

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

For those interested in the design flood (25-year and 100-year flood) 25-year and 100-year 24-hr. point rainfall maps are shown in Plates-9 & 11. To obtain 6,9,12,15 and 18 hrs. from 25-year and 100-year 24-hr. rainfall, the ratios given in section 4.2 may be used. Similarly, sections 4.3 and 4.4 may be used for conversion of point to areal rainfall and time distribution of input storm respectively. Synthetic unitgraph, design loss rate and base flow will remain the same as in the case of 50-year 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 $t_p = 0.727 \left(\frac{L}{\sqrt{S}}\right)^{0.59}$ by substituting the known values of L, and S for the catchment. Calculate the design storm duration $(T_D) = 1.1\ t_p$. The value of T_D may be rounded off to the nearest 1-hour.

Step (2): Locate bridge site/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.

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

Step (4): Convert the 50-year T_D-hour point rainfall to 50-year T_D-hour areal rainfall by multiplying with the areal reduction factor (ARF) corresponding to catchment area under study and for T_D-hour duration from Table-6 or by interpolation from Fig.11(a) and 11(b) in Section 4.3.

Step (5): Apply the cumulative percentage of total rainfall against the cumulative percentage of storm duration curves in Fig.12 or from Table A-2 corresponding to design storm duration T_D to obtain the depths at 1-hour 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 value of rainfall in Step-5.

5.0 ESTIMATION OF DESIGN FLOOD FOR AN UNGAUGED CATCHMENT

The following procedure is recommended:

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

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

Step(3) : Adopt the design loss rate of 0.5 cm/hr. or (based on design (?) formula) vide Section 3.11.

Step(4) : Obtain the hourly rainfall excess units upto the design storm duration T_D by substracting the design loss rate ~~of 0.5 cm/hr~~. from the hourly rainfall increments in Step-6 of Section 4.6.

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

Arrange the rainfall excess increments against the 1-hourly Synthetic U.G. ordinates such that the maximum value of rainfall excess comes against the peak discharge of Synthetic U.G., the next lower value of rainfall excess increment comes against the next lower discharge ordinate and so on upto T_D hour duration.

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

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

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

Step 7: Multiply the first 1 hour rainfall excess with the synthetic U.G. ordinates at 1-hour interval which will give the corresponding direct runoff ordinates. Likewise repeat the procedure with the rest of the 1 hourly rainfall excess increments giving a log of 1-hour to successive direct runoff ordinates.

Step-8 Add the direct runoff ordinates at 1-hour interval to get the direct runoff hydrograph.

Step-9: Obtain the base flow rate in cumec/sq.km. vide section 3.12. Multiply base flow rate in cumec/sq.km. with the catchment area under study to get the total base flow.

Step 10 : Add the total base flow to the direct runoff ordinates at 1-hour interval in Step-8 to get the 50-year flood hydrograph. Plot the hydrograph.

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

6. FORMULA FOR LINEAR WATERWAY OF BRIDGES

Design of bridges and culverts and cross drainage structure 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-year 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 dimension of any hydraulic structure have a bearing on the width of channel. The channel width in the case of a 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 very 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(e), the following simplified formula has been derived:

$$W = 5.77 \; (Q_{50})^{1/3}$$

Where W is linear waterway in metres and Q_{50} is 50-yr.flood discharge in cumecs.

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

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

(2) Estimate the linear waterway using the equation given above.

(3) Work out the design HPL expected for Q_{50} with the waterway estimated.

The linear waterway which is estimated may seem to be in-adequate or excessive as per the site conditions prevalent. In that case, the design engineer is at liberty to choose a suitable waterway not much different from the estimated waterway and thereafter fix the design HFL as per normal calculations. The above mentioned equation gives only a 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:

$$W = 6.00\ (Q_{25})^{1/3}$$

$$W = 5.55\ (Q_{100})^{1/3}$$

THE FORMULAE GIVEN ABOVE ARE ONLY TO BE USED FOR FIXING THE LINEAR WATERWAY OF THE BRIDGES IN THE UPPER GODAVARI SUBZONE-3(e). THE LACEY'S REGIME WIDTH FORMULA WILL NOT BE APPLICABLE FOR FIXING THE LINEAR WATERWAY OF BRIDGES IN SUBZONE-3(e). 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 Railways 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 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 a gross storage behind the dam between 0.5 to 10 million m^3 or hydraulic head (from normal or annual average flood level on the downstream to the maximum waterlevel) between 7.5m to 12m. The report may be made use of for estimation of 100-year flood for safety of small dams.

(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 year, 24-hr. point storm rainfall determined for the ungauged catchments under study.

8. ASSUMPTIONS, LIMITATIONS AND CONCLUSIONS

8.1 Assumptions

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

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

8.2 Limitations

8.2.1 The data of 17 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.

8.2.2 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.

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

8.3 Conclusions

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

8.3.2 The report also recommends the adoption of design flood of 25 year and 100 year return periods taking into account the relative importance of the structures.

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

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

8.3.5 The report is applicable for the catchment areas ranging from 25 to 2500 sq.Km. Further the report may be used for larger catchments upto 5000 sq.Km. based on sound judgement and considering the data of neighbouring catchments also. However, individual site conditions may necessitate special site study. Engineer-in-charge at site is advised to take a pragmatic view while deciding the design discharge or a bridge.

8.3.6 For structures with relatively greater importance requiring higher factor safety, the design flood of 25-yr., 50-yr. and 100-yr. return periods may be estimated by adopting a constant loss rate of 0.5 cm/hr. (instead of applying the loss rate formula given in section 3.11).

8.3.7 The inflow design flood (100-year flood) for small dams mentioned in section 7.0 (i) may also be estimated by adopting a constant loss rate of 0.5 cm/hr.

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Table-4

AREAL TO POINT RAINFALL RATIOS (PERCENTAGE) FOR SUBZONE 3 (e)

Area (Sq. Km.)	1. hr.	3 hr.	6 hr.	12 hr.	24 hr.
1	2	3	4	5	6
50	86	90	92	97	98
100	79	84	88	95	97
150	75	81	86	93	96
200		77	83	92	95
250		75	82	90	94
300			80	89	93
350			79	88	93
400			78	87	92
450			77	86	91
500			76	85	90
600				83	89
700				82	88
800				81	88
900				80	87
1000				79	86
1500				76	83
2000					81
2500					80

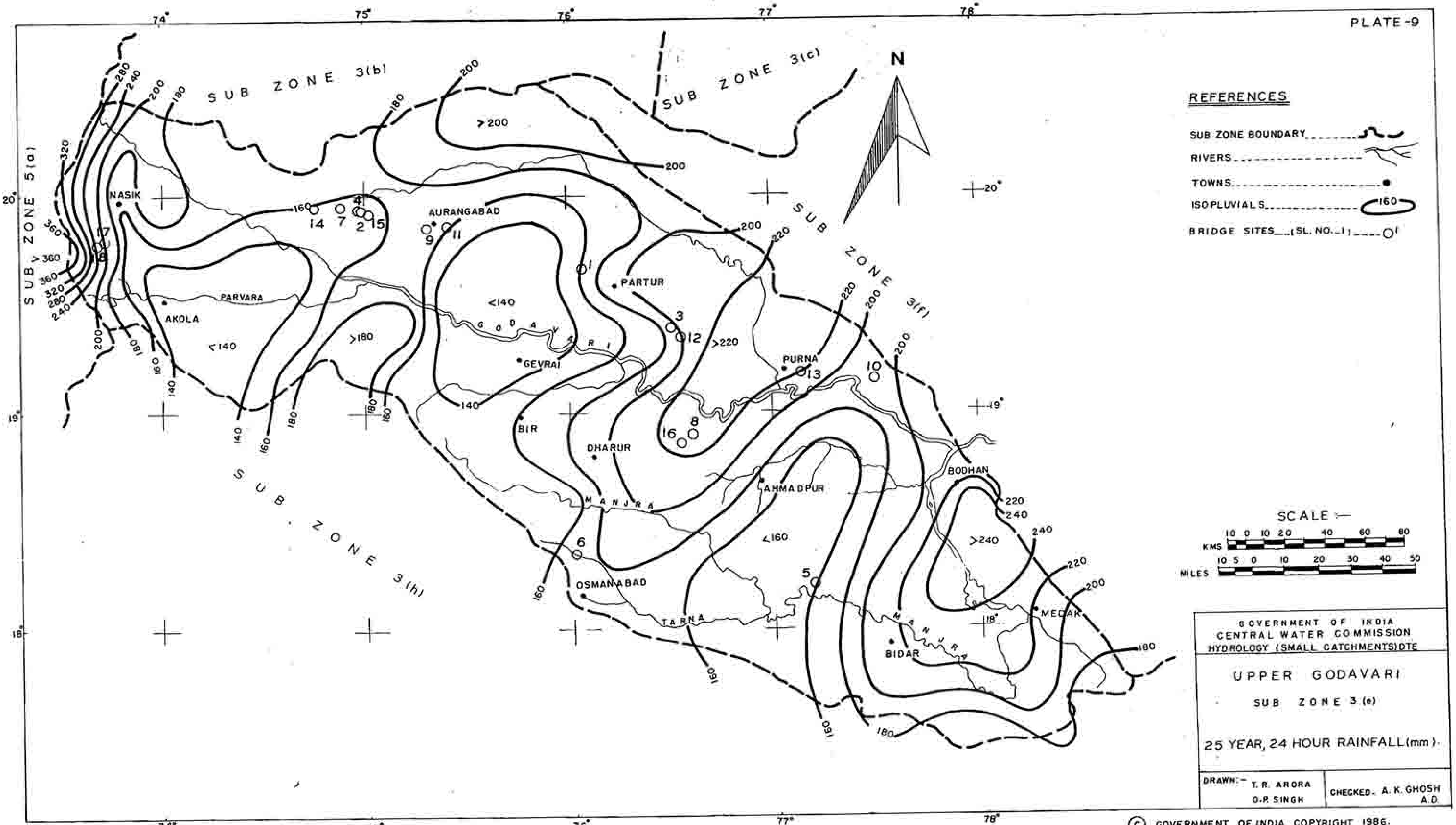
PLATE-9
SUB ZONE 3(b)
SUB ZONE 3(c)
SUB ZONE 3(f)
SUB ZONE 3(h)
SUB ZONE 5(a)
N
REFERENCES
SUB ZONE BOUNDARY
RIVERS
TOWNS
ISOPLUVIALS
BRIDGE SITES (SL. NO. 1)
SCALE :-
KMS
MILES
NASIK
AKOLA
PARVARA
AURANGABAD
PARTUR
GODAVARI
GEVRAI
PURNA
BIR
DHARUR
MANJRA
AHMADPUR
BODHAN
OSMANABAD
TARNA
BIDAR
MEDAK
>200
<140
>180
>220
<160
>240
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE
UPPER GODAVARI
SUB ZONE 3 (e)
25 YEAR, 24 HOUR RAINFALL (mm).
DRAWN:- T. R. ARORA
O. P. SINGH
CHECKED- A. K. GHOSH
A.D.

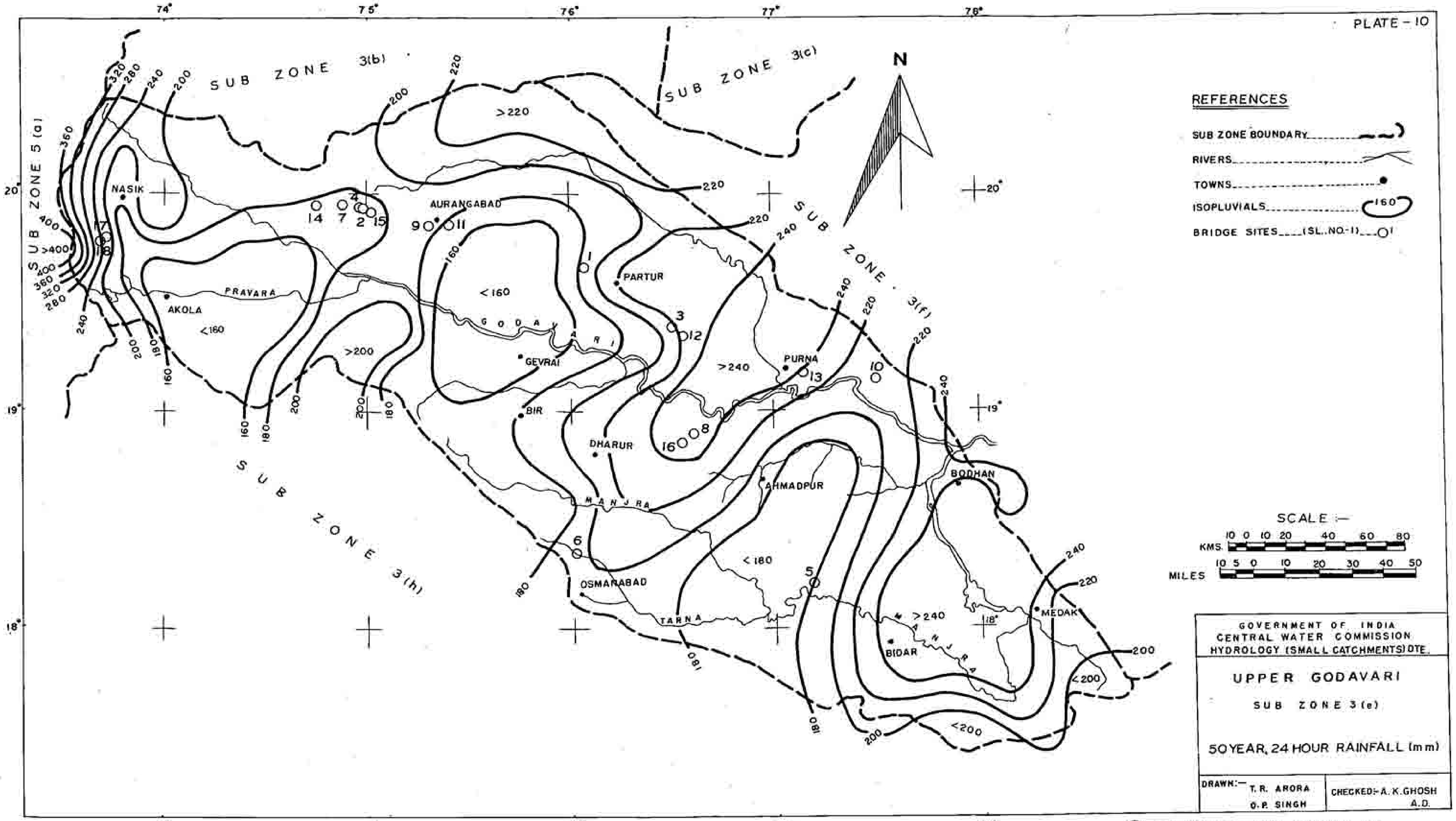
PLATE - 10
SUB ZONE 3(b)
SUB ZONE 3(c)
SUB ZONE 5(a)
SUB ZONE 3(f)
SUB ZONE 3(h)
N
REFERENCES
SUB ZONE BOUNDARY
RIVERS
TOWNS
ISOPLUVIALS
BRIDGE SITES (SL. NO.-1)
NASIK
AKOLA
AURANGABAD
PARTUR
GEVRAI
BIR
DHARUR
PURNA
AHMADPUR
OSMANABAD
BODHAN
BIDAR
MEDAK
PRAVARA
GODAVARI
MANJRA
TARNA
SCALE :-
KMS.
MILES
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.
UPPER GODAVARI
SUB ZONE 3 (e)
50 YEAR, 24 HOUR RAINFALL (mm)
DRAWN:— T. R. ARORA
O. P. SINGH
CHECKED:- A. K. GHOSH
A.D.

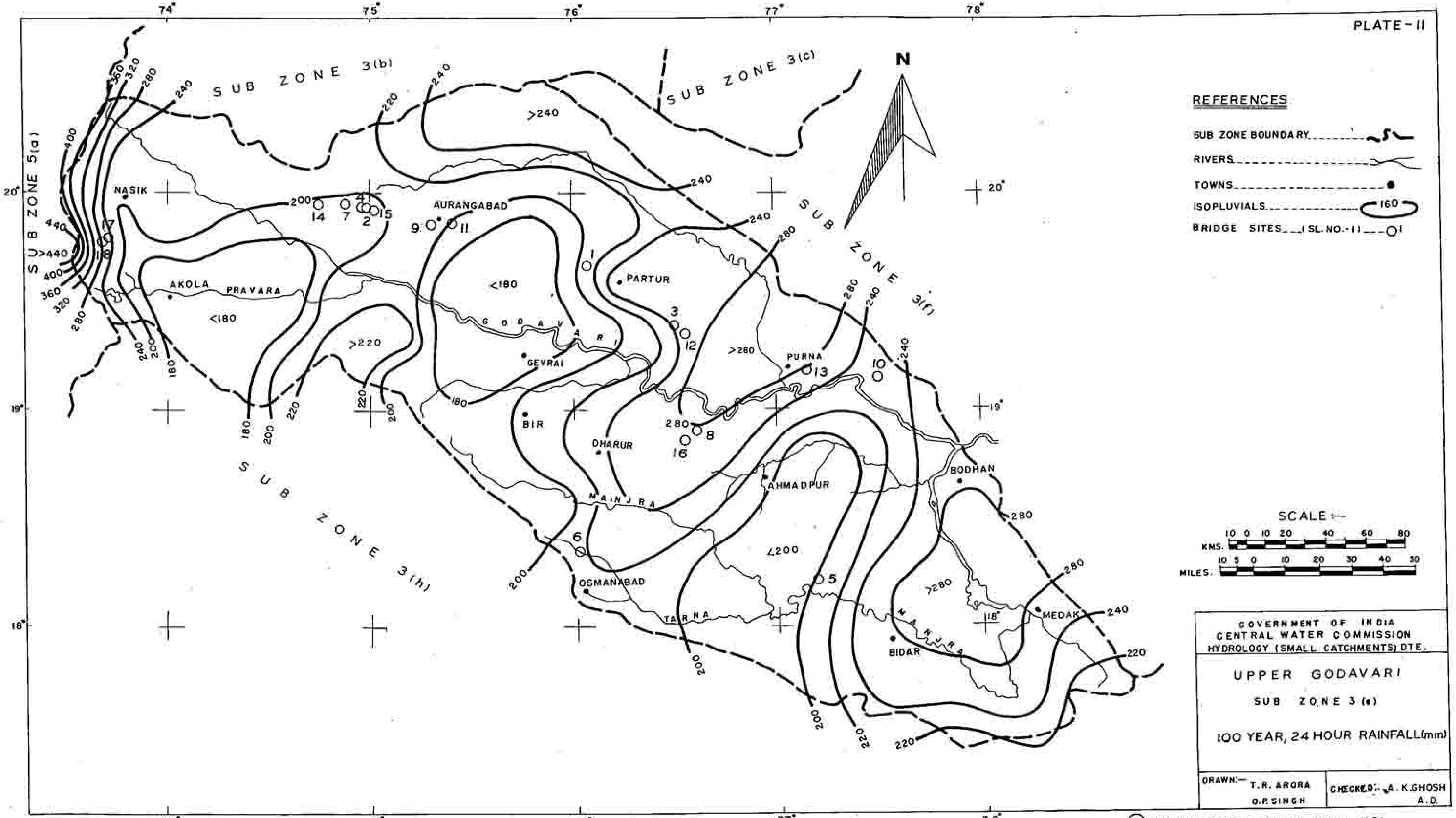
PLATE - II
REFERENCES
SUB ZONE BOUNDARY
RIVERS
TOWNS
ISOPLUVIALS
BRIDGE SITES (SL. NO.-1)
SCALE :-
KMS.
MILES.
N
SUB ZONE 3(b)
SUB ZONE 3(c)
SUB ZONE 3(f)
SUB ZONE 3(h)
SUB ZONE 5(a)
NASIK
AKOLA
PRAVARA
AURANGABAD
PARTUR
GODAVARI
GEVRAI
BIR
DHARUR
PURNA
MANJRA
AHMADPUR
BODHAN
OSMANABAD
TARNA
BIDAR
MEDAK
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.
UPPER GODAVARI
SUB ZONE 3 (e)
100 YEAR, 24 HOUR RAINFALL(mm)
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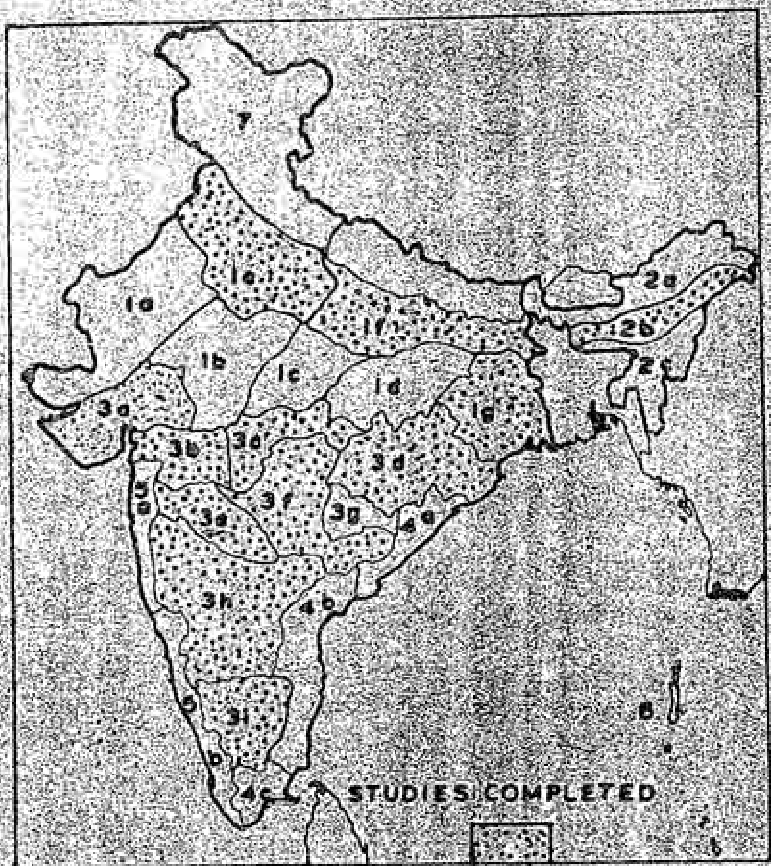
LIST OF FLOOD ESTIMATION REPORTS PUBLISHED

Under Short Term Plan

1. Estimation of Design Flood Peak (1973)

Under Long Term Plan

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



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