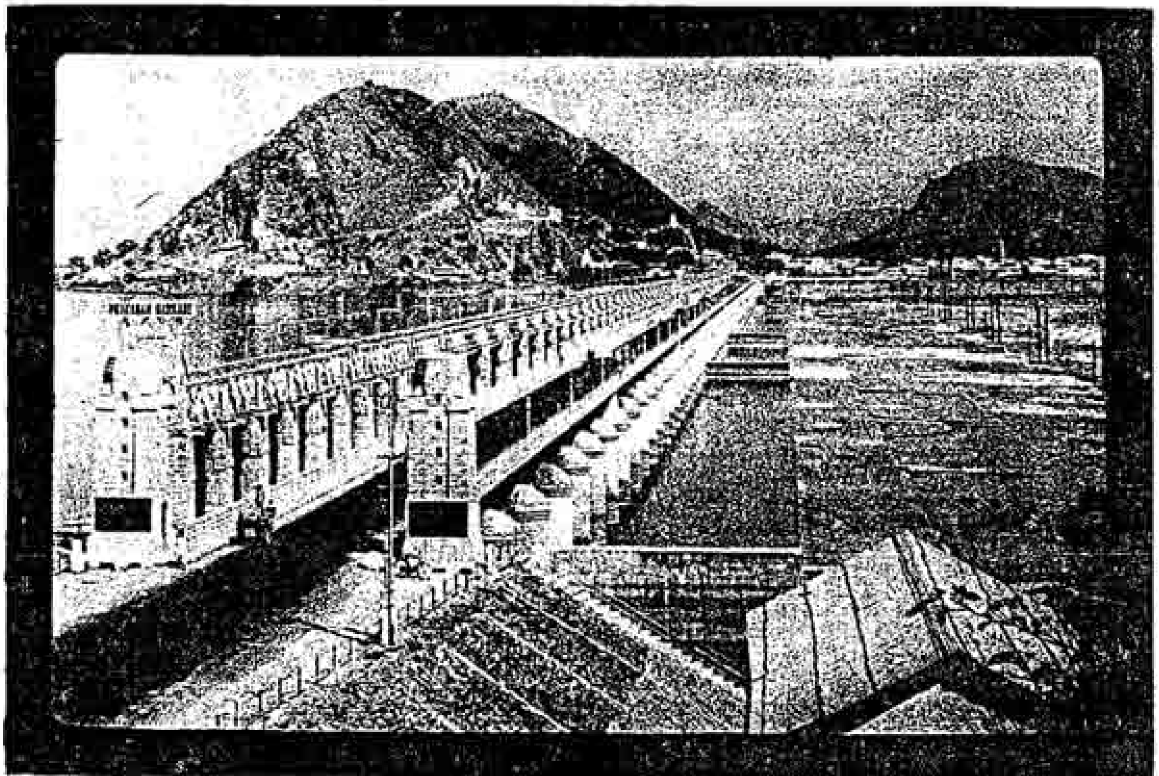
FLOOD ESTIMATION REPORT
FOR
EASTERN COAST REGION

(UPPER, LOWER & SOUTH)
SUB ZONES-4 (a, b & c)



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

FLOOD ESTIMATION REPORT FOR EASTERN COAST REGION (UPPER, LOWER AND SOUTH) SUBZONES-4 (a, b & c) WAS DISCUSSED AND APPROVED BY THE FOLLOWING MEMBERS OF THE FLOOD ESTIMATION PLANNING AND COORDINATION COMMITTEE IN ITS 45TH MEETING HELD ON 8TH AND 9TH JANUARY, 1987 AT VIJAYAWADA

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FLOOD ESTIMATION REPORT FOR EASTERN COAST REGION

(UPPER, LOWER AND SOUTH)

SUBZONES-4(a), 4(b) AND 4(c)

With the Best Compliments
to Dr. P Seethapathi Rao

from CWC

A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE

DESIGN OFFICE REPORT NO. EC(U,L&S)/14/1986

HYDROLOGY (SMALL CATCHMENTS) DIRECTORATE

CENTRAL WATER COMMISSION

NEW DELHI

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FOREWORD

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 data then available. The Government of India setup a Committee of Engineers in March 1957 under the Chairmanship of Dr. A.N. Khosla to review, inter alia, the methods for estimating maximum flood discharge in order to determine waterway and other parameter of bridges. In their report in October 1959, this Committee recommended systematic collection of rainfall and runoff data of small and medium catchments and the use of rational methodology of unit hydrograph and design storm rainfall. As a result, large scale joint efforts have been taken up by Railway Designs and Standards Organisation, Ministry of Transport, India Meteorological Department and Central Water Commission. The country was divided into 26 subzones for the study. In each subzone, the rainfall-runoff data for bridge catchments is being collected for a period of about 5 years by the Railways and also by CWC on behalf of the MOT. While storm analysis is done by IMD, the development of the unit graph based methodology and preparation of flood estimation report is being done by the Hydrology (Small Catchment) Directorate of CWC.

So far flood estimation reports based on the hydrometeorological approach have been finalised for 12 subzones and published for 11 subzones. The present report was discussed and approved by the Flood Estimation Planning and Coordination Committee in its 45th meeting held in January 1987 at Vijayawada.

This report represents another step in the fulfilment of the joint effort envisaged by the Khosla Committee in 1957. Out of 26 subzones in which country has been divided, with the planned data collection activities, reports can be prepared for 22 subzones covering 81 percent of the country's geographical area. This report covering 3 subzones marks the completion of 15 subzonal reports which together cover 60 percent of geographical area. Now the efforts have also to be directed towards reviewing and updating these reports on one hand and ensuring the acceptability and utilisation of these methods by large number of users engaged in the design and construction of railway and road bridges, cross-drainage works and hydraulic structures on small and medium catchments.

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PREFACE

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

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

The need to evolve a method of estimation of design flood peak of desired frequency knowing the physical characteristics of the catchments and design rainfall has been recognised and a committee of engineers under the chairmanship of Dr. A.N. Khosla have recommended, "--- Systematic and sustained collection of hydro-meteorological data of selected catchments in different climatic zones of India for evolution of a rational approach for determination of flood discharges. The Committee felt that design discharge should be maximum flood on record for a period not less than 50 years. Where adequate records are available extending over a period of not much less than 50 years, the design flood should be 50 year flood determined from probability curve on the basis of recorded floods during the period. In case where the requisite data, as above are not available, the design flood should be decided based on the ground and meteorological characteristics obtained on the basis of design storm."

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

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

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

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

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

A. UNDER SHORT TERM PLAN

1. Estimation of Design Flood Peak (1973)

B. UNDER LONG TERM PLAN

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

...

6. Krishna & Penner subzone-3(h) (1983)

7. South Brahmaputra Basin subzone-2(b) (1984)

8. Upper Indo-Ganga Plains subzone-1(e) (1984)

9. Middle Ganga Plains subzone-1(f) (1985)

10. Kaveri Basin subzone-3(i) (1986)

11. Upper Godavari subzone-3(e) (1986)

12. Mahi and Sabarmati subzone-3(a) (1986)

The present report on Eastern Coast Region(Upper, Lower and South) sub-zones-4(a, b & c) is based on the detailed storm rainfall and runoff studies of 25 representative catchments. The data of each of the 32 bridge catchments was collected for a period varying from 2 to 11 years by the South, South-central and South-eastern Railways under the guidance of R.D.S.O. Similarly CWC on behalf of Ministry of Surface Transport (Roads Wing) has collected the data of 5 road bridge catchments for a period varying from 4 to 7 years. Besides the data 376 ordinary raingauge stations maintained by IMD/States along with data of 69 self-recording raingauge stations maintained by IMD/Railways has been made use of.

This report deals with the estimation of design flood of 25-yr, 50-yr and 100-yr return periods for small and medium catchments in this subzone covering parts of Andhra Pradesh. Tamil Nadu and Orissa States based on design storm rainfall and synthetic unit hydrograph. Principally the report consists of 4 parts, A, B, C and D with introduction. Part-A deals with the Simplified Approach consisting of flood formulae with illustrative example for easy and quick application for preliminary designs only. Part-B deals with the Detailed Approach with illustrative example. Part-C gives the general description of the Eastern Coast Region, data collection, analysis and the methodology adopted for estimation of design flood with application of design storm rainfall to synthetic unit hydrograph. Part-D deals with the formulae for linear waterway, guidelines on linear waterway and fixing of flood levels for the bridges and cross drainage structures, utility of the report and conclusions for the guidance of the design engineers.

The report on sub-zones-4(a, b and c) is recommended for estimation of design flood for small and medium catchments varying from 25 to 2500 sqkm. This report may also be used for catchment areas up to 5000 sqkm. judiciously after comparison of available rainfall and runoff data of neighbouring catchments with similar characteristics.

This report is a joint effort of Central Water Commission of Ministry of Water Resources, Research Designs and Standards Organisation of Ministry of Railways and Roads Wing of Ministry of Surface Transport and Hydromet Directorate of India Meteorological Department.

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

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SYMBOLS AND ABBREVIATIONS

SYMBOLS

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

A	:	Catchment Area in sqkm
C.G.	:	Centre of Gravity
L	:	Length of longest main stream along the river course in km.
L_c	:	Length of the longest main stream from a point opposite to centroid of the catchment area to the gauging site along the main stream in km.
L_i	:	Length of the i th segment of L-section in km.
D_{i-1}, D_i	:	Elevations of River Bed at Intersection Points of Contours reckoned from the Bed Elevation at Point of Interest considered as Datum and D(i-1) and D_i are the heights of successive Bed Locations at Contours Intersections.
S	:	Equivalent Stream Slope in m/km
U.G.	:	Unit Hydrograph & Unitgraph
S.U.G.	:	Synthetic Unit Hydrograph or Synthetic Unitgraph
t_r	:	Unit Rainfall Duration adopted in a specific study in hours
t_p	:	Time from the Centre of Unit Rainfall Duration to the Peak of Unit Hydrograph in hours
T_m	:	Time from the start of rise to the Peak of Unit Hydrograph in hours
T	:	Time Duration of Rainfall in hours
T_B	:	Base Width of Unit Hydrograph in hours
T_D	:	Design Storm Duration in hours

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

ABBREVIATIONS

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

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

INTRODUCTION

The purpose of this report is to provide a rational methodology, simplified and detailed, for estimating floods of 25-yr, 50-yr and 100-yr return periods for small and medium catchments ranging in size from 25 to 2,500 sqkm with scope for catchments upto 5,000 sqkm lying in the East Coast (Upper, Lower and South) subzones-4 (a, b & c). The report consists of four parts namely A, B, C and D.

Part - A : Simplified Approach (Flood Formulae) with an Illustrative Example.

Part - B : Detailed Approach with an Illustrative Example (Synthetic unitgraph, application of effective rainfall units from design storm rainfall to synthetic unitgraph for estimation of design flood)

Part - C : General Description of Subzone, Data collection and Analysis.

Part - D : Guidelines for Linear Waterway, Fixing of Flood Levels, Utility of Report and Conclusions.

SUMMARY OF FLOOD FORMULAE

$$Q_{25} = \frac{1.899(S)^{0.206}(A)^{0.853}(R_{25})^{1.317}}{(L)^{0.312}(L_c)^{0.455}} = \qquad r = 0.994$$

$$Q_{50} = \frac{1.854(S)^{0.199}(A)^{0.847}(R_{50})^{1.308}}{(L)^{0.335}(L_c)^{0.394}} \qquad r = 0.994$$

$$Q_{100} = \frac{1.887(S)^{0.199}(A)^{0.862}(R_{100})^{1.266}}{(L)^{0.297}(L_c)^{0.438}} \qquad r = 0.995$$

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

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

L is length of longest stream in km,

L_c Length of the longest stream opposite the centre of gravity of the catchment to the point of study in km.

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

R_{25}, R_{50} and R_{100} are the design storm point rainfall values in cms. for the design storm duration

$T_D = 0.414(LL_c/\sqrt{S})^{0.434}$ in hrs. The rainfall values are found after locating the catchment on the isopluvial maps.
(Plates 8.4(a) to 8.4(c)to 9.4 (c) and 10.4 (a) to 10.4 (c))

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

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

(iii) r = correlation coefficient.

PART-A

APPLICATION OF REPORT

SIMPLIFIED APPROACH

The procedure explained in Part-B involves detailed computations. For engineers who prefer to avoid detailed synthetic unitgraph approach and would like to have a simple and rapid procedures for estimation of design flood, the following Simplified Approach has been developed:

The peak discharges with 25-yr, 50-yr and 100-yr return periods have been computed through detailed synthetic unitgraph approach (Part-B) for a number of catchments in the subzone and these values have been correlated with rainfall and catchment characteristics of respective catchments using multiple regression techniques.

The derived flood formulae for Q_{25}, Q_{50} and Q_{100} with their coefficient of correlation (r) are as under:

$$Q_{25} = \frac{1.899(S)^{0.206}(A)^{0.853}(R_{25})^{1.317}}{(L)^{0.312}(L_c)^{0.455}} \qquad r = 0.994$$

$$Q_{50} = \frac{1.854(S)^{0.199}(A)^{0.847}(R_{50})^{1.308}}{(L)^{0.335}(L_c)^{0.394}} \qquad r = 0.994$$

$$Q_{100} = \frac{1.887(S)^{0.199}(A)^{0.862}(R_{100})^{1.266}}{(L)^{0.297}(L_c)^{0.438}} \qquad r = 0.995$$

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

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

L is length of longest stream in km.

L_c is length of the longest stream opposite the centre of gravity of the catchment to the point of study in km.

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

R_{25}, R_{50} and R_{100} are the design storm point rainfall values in cms for the design storm duration.

$T_D = 0.414(LL_c/\sqrt{S})^{0.434}$ in hrs. The rainfall values are found after locating the catchment on the isopluvial maps (Plates 8.4(a) to 8.4(c), 9.4(a) to 9.4(c) and 10.4(a) to 10.4(c))

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

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

(iii) r = correlation coefficient.

ILLUSTRATIVE EXAMPLE

Application of the above flood formulae to estimate 25-yr, 50-yr and 100-yr flood with respect to the catchment under study upto Railway Bridge No.85 in subzone-4(b) are as under:

(For details of the catchment under study see the illustrative example in Part-B - Detailed Approach).

i) location of the catchment under the illustrative example;

ii) A, L, L_c and S in Steps 1 & 2

iii) 50-yr 24-hr point rainfall and 50-yr 7-hr point rainfall (R_{50}) in Step-6.

Similarly R_{25} and R_{100} have been estimated. The data of the catchment found out is:

A = km.785.00 sqkm, L = 52.00 km, L_c = 24.71 km, S = 4.12 m/km

Design Storm Duration $(T_D) = 0.414\ (LL_c/\sqrt{S})^{0.434}$

$= 0.414(52 \times 24.71/(4.12)^{0.434} = 7.15$ hrs

rounded off to 7.0 hrs.

25-yr	7-hr point rainfall (R_{25}) = 15.84 cm	(See Step 6 in Part B Detailed approach)
50-yr	7-hr point rainfall (R_{50}) = 16.92 cm	
100-yr	7-hr point rainfall (R_{100}) = 21.60 cm	

Substitute A, L, L_c, S, R_{25}, R_{50} and R_{100} in the flood formulae

$$Q_{25} = \frac{1.899(4.12)^{0.206}(785)^{0.853}(15.84)^{1.317}}{(52)^{0.312}(24.71)^{0.455}} = 1929.39 \text{ cumecs}$$

Q_{25} = 1929.39 cumecs as against 1959.73 cumecs by detailed approach.

$$Q_{50} = \frac{1.854(4.12)^{0.199}(785)^{0.847}(16.92)^{1.308}}{(52)^{0.335}(24.71)^{0.455}} = 2120.18 \text{ cumecs}$$

Q_{50} = 2120.18 cumecs as against 2149.53 cumecs by detailed approach.

$$Q_{100} = \frac{1.887(4.12)^{0.199}(785)^{0.862}(21.60)^{1.266}}{(52)^{0.297}(24.71)^{0.438}} = 2907.17 \text{ cumecs}$$

Q_{100} = 2907.17 cumecs as against 2971.32 cumecs by detailed approach.

The variations in estimated flood by flood formulae and detailed approach are nominal and within permissible limits.

DETAILED APPROACH

This detailed approach may be used for estimation of design flood (50-year flood) for ungauged and inadequately gauged catchments in the subzone.

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), Lc the length of the longest stream opposite the C.G. to point of study and equivalent stream slope (S).

iii) Determination of 1-hour synthetic unitgraph parameters i.e. peak discharge per sqkm. (q_p), the peak discharge (Q_p), the basin lag (t_p), the peak time of U.G. (T_m), widths of the unitgraph at 50% and 75% of Q_p(W_{50} and W_{75}), widths of the rising limb of U.G. at 50% and 75% of Q_p (W_{R50} and W_{R75}) and time base of unitgraph (T_B).

iv) Drawing of a synthetic unitgraph.

v) Estimation of design storm duration (T_D).

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

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

viii) Estimation of effective rainfall units after 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.

In order to elucidate the procedure, an illustrative example is given below with relevant details:

Illustrative Example

The particulars of the Railway Bridge Catchment under study are as under:

i)	Name & Number of subzone	:	Lower Eastern Coast Region subzone-4(b)
ii)	Name of site (i.e. point of study)	:	Railway Bridge No. 85
iii)	Name of Railway Section	:	Arkonam-Renigunta (Southern Railway)
iv)	Name of Tributary	:	Nagari
v)	Shape of the Catchment	:	Fan shape
vi)	Site location	:	13^{o} 25' 00" (Latitude 79^{o} 27' 30" (Longitude)
vii)	Topography	:	Moderately steep slope.

The procedure is explained stepwise.

Step-1: Preparation of Catchment Area Plan

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

Step-2: Determination of Physiographic Parameters

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

i)	Area (A)	:	785.00 sqkm
ii)	Length of the longest stream (L)	:	52.00 km
iii)	Length of the longest stream from a point opposite C.G. of catchment to point of study (L_c)	:	24.71 km

iv) Equivalent stream slope(S) : 4.12 m/km

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

(a) By Graphical Method

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

(b) By Mathematical Calculation

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

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

The equation 3.9.3 to 3.9.11 in Section 3.9 were used to compute the unitgraph parameters with the known values of A, L, L_c and S as under:

i) $t_p = 0.376\ (LL_c/\sqrt{S}\ )^{0.434}$ --- 3.9.3

$= 9.376(52 \times 24.71\ /\sqrt{4.12}\ )^{0.434}$ = 6.18 hrs. rounded of to 6.5 hrs.

ii) $q_p = 1.215/(t_p)^{0.691}$ --- 3.9.4

$= 1.215/(6.5)^{0.691}$ = 0.3333 cumec/sqkm

iii) $W_{50} = 2.211/(q_p)^{1.07}$ --- 3.9.5

$= 2.211/(0.3333)^{1.07}$ = 7.16 hrs.

iv) $W_{75} = 1.312/(q_p)^{1.003}$ --- 3.9.6

$= 1.312/(0.3333)^{1.003}$ = 3.95 hrs

v) $W_{R50} = 0.808/(q_p)^{1.053}$ --- 3.9.7

$= 0.808/(0.3333)^{1.053}$ = 2.57 hrs.

vi) $W_{R75} = 0.542/(q_p)^{0.965}$ = --- 3.9.8

$= 0.542/(0.3333)^{0.965}$ = 1.56 hrs.

vii) $T_B = 7.621\ (t_p)^{0.623}$ --- 3.9.9

$= 7.621\ (6.5)^{0.623}$ = 24.46 hrs.

Say 24.00 hrs.

---

viii) $Q_p = q_p \times A$ --- 3.9.10

$= 0.3333 \times 785 = 261\ 65$ cumecs

ix) $T_m = t_p + t_r/2$ --- 3.9.11

$= 6.5 + ½ = 7.0$ hrs.

Step-4: Drawing of a Synthetic Unitgraph

Estimated parameters of unitgraph in Step-3 were plotted to scale on a graph paper as shown in Fig. A-2. The plotted points were joined to draw synthetic unitgraph. The discharge ordinates (Q_i) of the unitgraph at $t_i = t_r = 1$ hr. interval were summed up i.e. $\Sigma Q_i\ t_i = 2180.6$ cumec/hr as shown in Fig. A-2 and compared with the volume of 1.00 cm Direct Runoff Depth over the catchment with the formula $\Sigma Q_i\ t_i = A\ d/(t_i \times 0.36)$

Where A = catchment area in sqkm

d = 1.0 cm depth

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

$$\Sigma Q_i\ t_i = A \times d\ /(0.36 \times t_r) = \frac{785 \times 1}{0.36 \times 1} = 2180.6$$

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

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

Step-5: Estimation of Design Storm Duration

The design storm duration (T_D) = 1.1 t_p = 1.1 x 6.5 =7.15 hrs

rounded of to 7.00 hrs.

Step-6: Estimation of Point Rainfall and Areal Rainfall

The catchment under study was located on Plate-9.4(b) for subzone-4(b) showing 50-yr. 24-hr. point rainfall. 50-yr 24-hr point rainfall =23.5 cm. Conversion factor of 0.72 was read from Fig.8 in Section 4.2 for conversion of 50-yr 24-hr point rainfall to 50-yr 7-hr point rainfall since T_D = 7 hrs. 50-yr. 7-hr point rainfall = 23.50 x 0.72 =16.92 cm.

Areal Reduction Factor of 0.76 corresponding to a catchment area of 785.00 sqkm for T_D = 7 hrs was interpolated from Table A-2 or Fig. 12(b) in Section 4.4 for conversion of point to areal rainfall. 50-yr 7-hr areal rainfall = 16.92 x 0.76 = 12.86 cm.

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

Step-7: Time Distribution of Areal Rainfall

50-yr 7-hr areal rainfall = 12.86 cm was distributed with the distribution coefficients (col.7 of Table A-3) or from mean average time distribution curve for storms of 7 to 12 hrs in Fig. 11(c) corresponding to 7-hrs to get 1-hr rainfall increments as under:

Durations (hr.)	Distribution co-efficients	Storm rainfall (cm)	1-hr rainfall increment (cm)
(1)	(2)	(3) = (2)x12.86	(4)
1	0.53	6.82	6.82
2	0.70	9.00	2.18
3	0.81	10.42	1.42
4	0.88	11.32	0.90
5	0.95	12.22	0.90
6	0.98	12.60	0.38
7	1.00	12.86	0.26

Step-8: Estimation of Effective Rainfall Units

Design loss rate of 0.75 cm/hr under Section 3.11 has been adopted.

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

Durations (hr)	1-hr rainfall (cm)	Design Loss Rate (cm/hr)	1-hr Effective Rainfall (cm)
(1)	(2)	(3)	(4)
1	6.82	0.75	6.07
2	2.18	"	1.43
3	1.42	"	0.67
4	0.90	"	0.15
5	0.90	"	0.15
6	0.38	"	0
7	0.26	"	0

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

Step-9: Estimation of Base Flow

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

$$q_b = 0.536/(A)^{0.523}$$

$$q_b = 0.536/(785)^{0.523} = 0.0164 \text{ cumecs/sqkm}$$

Total Base Flow = 785 x 0.0164 = 12.88 cumecs.

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

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

Time	U.G. Ordinate (cumecs)	1-hr Effective Rainfall (cm)	Direct Runoff (cumecs)
(1)	(2)	(3)	(4)
1	6.00		
2	18.00		

(1)	(2)	(3)	(4)
3	50.00		
4	106.00		
5	168.00		
6	228.00	0.67	152.76
7	261.56	6.07	1587.67
8	236.00	1.43	337.48
9	208.00	0.15	31.20
10	180.00	0.15	27.00
11	152.00		
12	124.00		
			2136.11
		Base Flow	12.88
		50-Yr Flood Peak	2148.99 cumecs

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

Step-11: Computation of Design Flood Hydrograph

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

For computation of design flood hydrograph, the U.G. ordinates for 1-hr interval were tabulated in col.(2) of Table A-4 against time (hrs) in col.(1). The critical sequence of 1-hr effective rainfall units were entered in col.(3) to (7) horizontally as shown in Table A-4. The direct runoff resulting from each of the 1-hr effective rainfall unit was obtained by multiplying the 1-hr effective rainfall with the synthetic 1-hr U.G. ordinates in col.(2) and the direct runoff values were entered in vertical columns against each unit with a successive lag of 1-hr since the unit duration of S.U.G. is 1-hr. The direct runoff so obtained are shown in col.(3) to (7). The direct runoff were added horizontally and the total direct runoff is shown in col.(8). The total base flow of 12.88 cumecs was entered in col.(9). Col.(10) gives the addition of col.(8) and col.(9) to get the design flood hydrograph ordinates. The total discharge in col.(10) were plotted against time in col.(1) to get the design flood hydrograph in Fig. A-3.

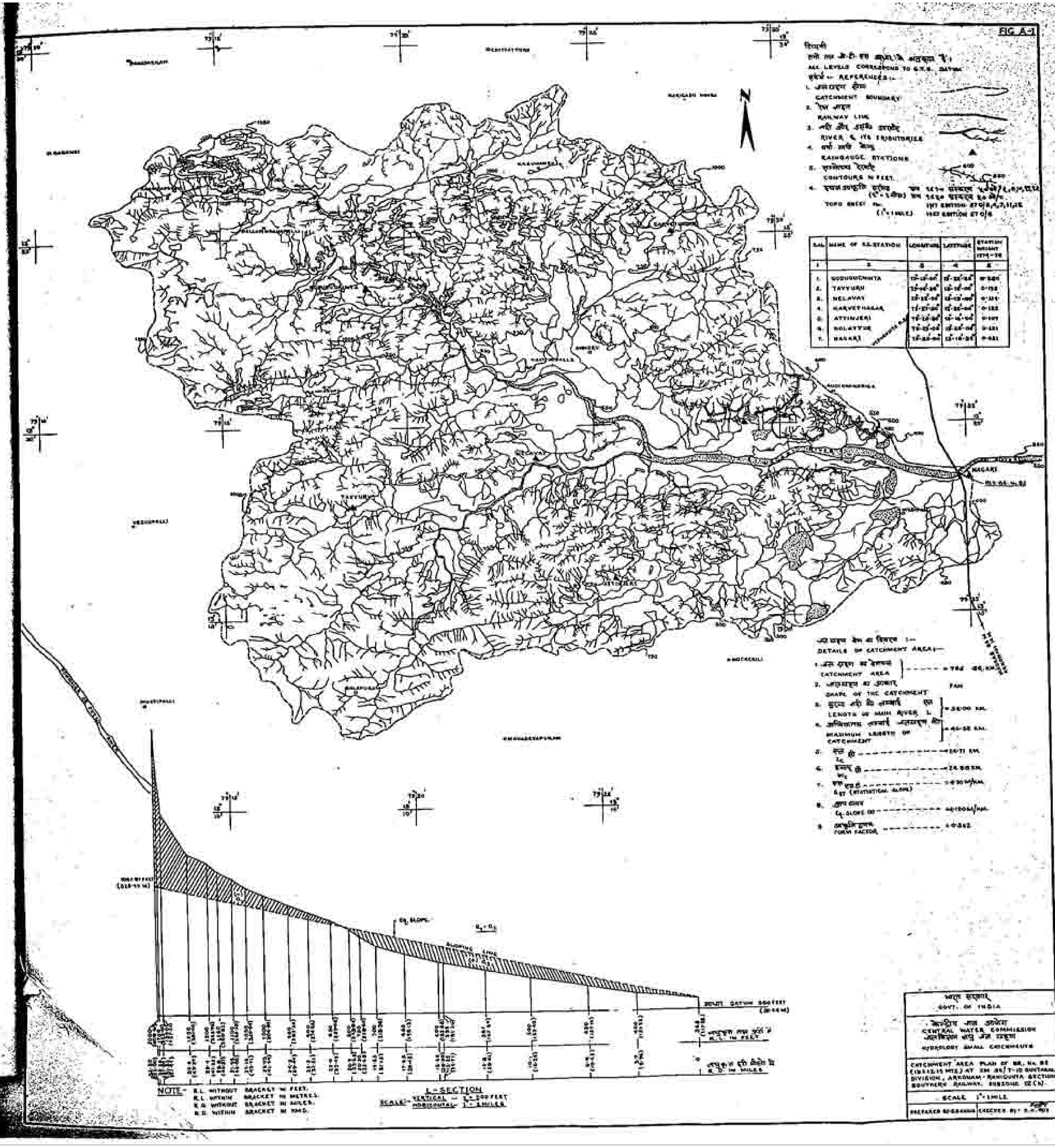
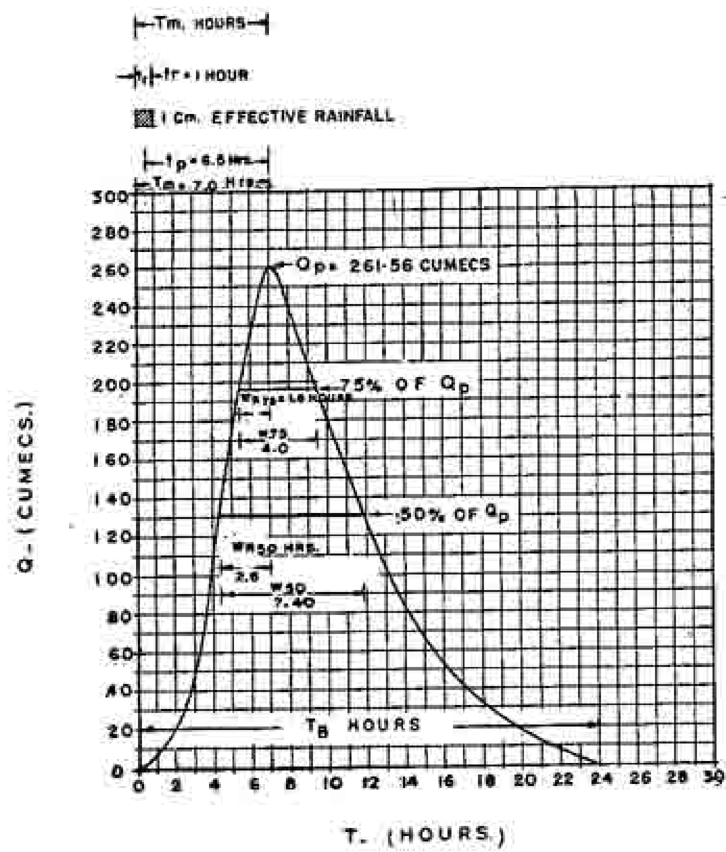


FIG. A-1
ALL LEVELS CORRESPOND TO G.T.S. DATUM
REFERENCES:-
CATCHMENT BOUNDARY
RAILWAY LINE
RIVER & ITS TRIBUTORIES
RAINGAUGE STATIONS
CONTOURS IN FEET
TOPO SHEET No.
S.No. | NAME OF R.G. STATION | LONGITUDE | LATITUDE | STATION WEIGHT
GODUGUCHINTA
TAYYURU
NELAVAY
KARVETNAGAR
ATTINJERI
NAGARI
DETAILS OF CATCHMENT AREA:-
CATCHMENT AREA
SHAPE OF THE CATCHMENT
FAN
LENGTH OF MAIN RIVER L
MAXIMUM LENGTH OF CATCHMENT
FORM FACTOR
NAGARI
L-SECTION
NOTE - R.L. WITHOUT BRACKET IN FEET.
R.L. WITHIN BRACKET IN METRES.
R.D. WITHOUT BRACKET IN MILES.
R.D. WITHIN BRACKET IN KMS.
GOVT. OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY SMALL CATCHMENTS
SOUTHERN RAILWAY
SCALE 1"=1 MILE

FIG.– A-2



SYNTHETIC U.G. PARAMETERS.

C. A	=	785 Sq. Kms.
t_p	=	6.50 HOURS.
T_B	=	24.00 HOURS.
Q_p	=	261·56 CUMECS.
W_{50}	=	7.40 HOURS
W_{75}	=	4.00 HOURS.
W_{R50}	=	2.60 HOURS.
W_{R75}	=	1.60 HOURS.
q_p	=	0.333 CUMECS / Sq. Km.
$\frac{L L_c}{\sqrt{S}}$	=	633.03
d	=	1.00 Cm.
T_m	=	7 HOURS.
ΣQ_i	=	$\frac{A \times d}{t_r \times 0.36}$
	=	$\frac{785.00 \times 1.00}{1.00 \times 0.36}$
	=	2180.56 CUMECS.

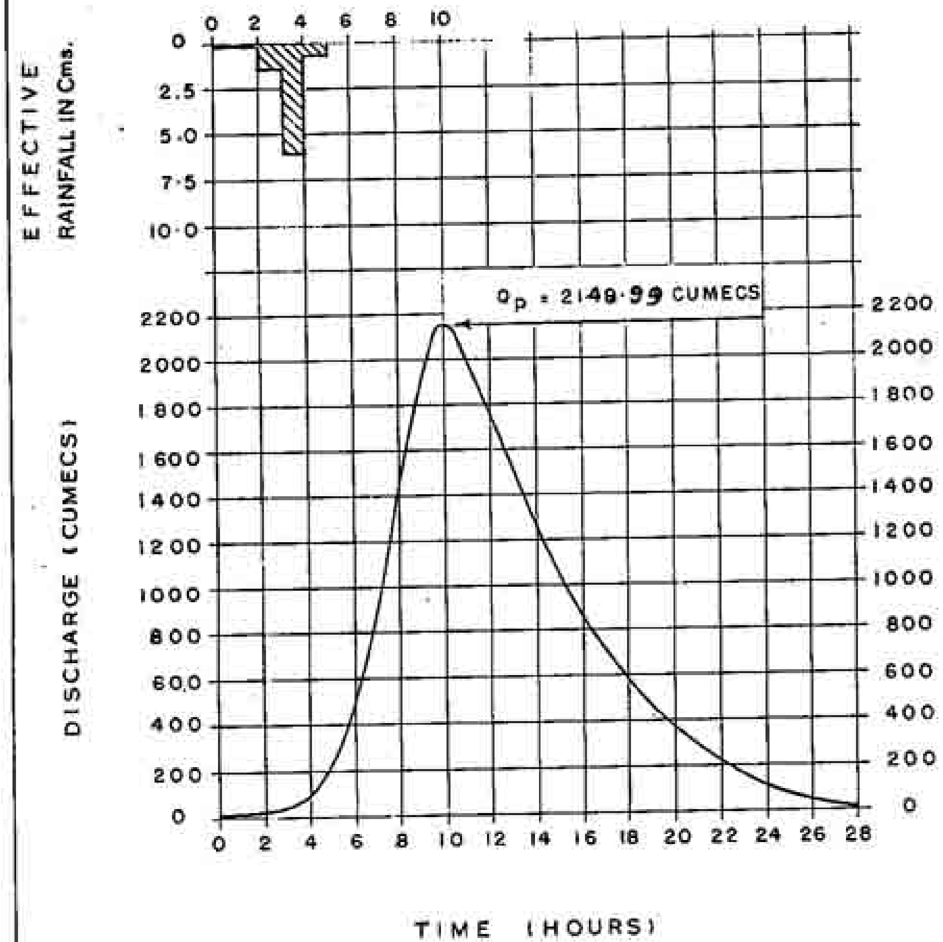
TIME IN HOURS	1-HOUR SYNTHETIC U.G. ORDINATES (CUMECS)
0	0.00
1	6.00
2	18.00
3	50.00
4	106.00
5	168.00
6	228.00
7	261.56
8	236.00
9	208.00
10	180.00
11	152.00
12	124.00
13	100.00
14	82.00
15	66.00
16	54.00
17	42.00
18	34.00
19	26.00
20	18.00
21	12.00
22	6.00
23	3.00
24	0.00
	TOTAL – 2180.56

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

EASTERN COAST
SUB ZONE – (4a, b & c)
SYNTHETIC UNIT HYDROGRAPH.
BRIDGE NO.– 85.

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

FIG. - A-3



NOTE-:

CATCHMENT AREA = 785 SQ.KMS.

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

EASTERN COAST
SUB ZONE-(4a,b &c)

DESIGN FLOOD HYDROGRAPH
BR. NO. 85. ON RIVER NAGARI

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

Table A-1: COMPUTATION OF EQUIVALENT SLOPE (S)

S.No.	Reduced Distance Starting from Gauging Site (Point of Study) (kms)	Reduced Levels of River Bed (m)	Length of Each Segment L_i (km)	Height Above Datum *(D_i Difference Between the Datum and the ith R.L. (m)	$(D_{i-1} + D_i)$	$L_i(D_{i-1} + D_i)$ (4) x (6) (m x km)
1	2	3	4	5	6	7
1	0	111.35	0	0	0	0
2	5.96	121.92	5.96	10.57	10.57	63.00
3	10.63	137.16	4.67	25.81	36.33	169.89
4	16.26	152.40	5.63	41.05	66.86	376.42
5	20.61	167.64	4.35	56.29	97.34	423.43
6	25.20	182.88	4.59	71.53	127.32	586.69
7	28.42	198.12	3.22	86.77	158.30	509.73
8	31.15	213.36	2.73	102.01	188.78	515.37
9	32.68	228.60	1.53	117.25	219.26	335.47
10	33.65	243.84	0.97	132.49	249.74	242.25
11	35.42	259.08	1.77	147.73	280.22	495.99
12	37.51	274.32	2.09	162.97	310.70	649.36
13	39.44	289.56	1.93	178.21	341.18	658.48
14	41.94	304.80	2.50	193.45	371.66	929.15
15	43.71	320.04	1.77	208.69	402.14	711.79
16	45.00	335.28	1.29	223.93	432.62	558.08
17	46.37	350.52	1.37	239.17	463.10	634.45
18	47.33	365.76	0.96	254.41	493.58	473.84
19	49.27	381.00	1.94	269.65	524.06	1016.68
20	51.44	457.21	2.17	345.86	615.51	1335.66
21	51.84	533.41	0.40	422.06	767.92	307.17
22	52.00	609.61	0.16	498.26	920.32	147.25

$$\Sigma L_i(D_{i-1} + D_i) = 11140.15$$

$$S = \frac{\Sigma L_i(D_{i-1} + D_i)}{L^2} = \frac{11140.15}{(52.00)^2} = 4.120 \text{ m/km}$$

NOTE: DATUM IS THE REDUCED LEVEL AT THE POINT OF STUDY

TABLE A-2: AREAL TO POINT RAINFALL RATIO EASTERN COAST, SUBZONE-4 (a,b & c)

Area Sq.Km.	Durations (Hrs.)																								Area (Sq.Km.)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
	Point to Areal Rainfall Ratio																								
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0
50	0.92	0.93	0.94	0.94	0.94	0.95	~~0.95~~	0.95	0.95	0.95	0.95	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.97	0.97	0.97	0.97	0.97	0.97	50
100	0.85	0.86	0.88	0.89	0.90	0.91	0.91	0.92	0.93	0.93	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.95	0.95	0.95	0.95	0.95	0.95	100
150	0.79	0.82	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.90	0.91	0.92	0.92	0.92	0.92	0.93	0.93	0.93	0.93	0.94	0.94	0.94	0.94	0.94	150
200	0.75	0.78	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.87	0.88	0.89	0.89	0.89	0.89	0.90	0.90	0.90	0.90	0.91	0.91	0.91	0.92	0.92	200
250	0.72	0.75	0.78	0.79	0.81	0.82	0.83	0.84	0.85	0.85	0.86	0.87	0.87	0.87	0.88	0.88	0.88	0.89	0.89	0.89	0.90	0.90	0.91	0.91	250
300			0.76	0.78	0.80	0.81	0.82	0.83	0.84	0.84	0.85	0.86	0.86	0.86	0.87	0.87	0.87	0.88	0.88	0.88	0.89	0.89	0.90	0.90	300
350			0.74	0.76	0.78	0.79	0.80	0.81	0.82	0.82	0.83	0.84	0.84	0.85	0.86	0.86	0.86	0.87	0.87	0.87	0.88	0.88	0.89	0.89	350
400						0.79	0.80	0.80	0.81	0.81	0.82	0.83	0.83	0.84	0.85	0.85	0.85	0.86	0.86	0.86	0.87	0.87	0.88	0.88	400
450						0.76	0.77	0.78	0.79	0.80	0.81	0.82	0.82	0.83	0.84	0.84	0.84	0.85	0.85	0.85	0.86	0.86	0.87	0.87	450
500						0.76	0.77	0.78	0.78	0.79	0.80	0.80	0.80	0.81	0.82	0.82	0.82	0.83	0.83	0.84	0.85	0.85	0.86	0.86	500
600												0.78	0.79	0.79	0.80	0.81	0.81	0.82	0.82	0.83	0.84	0.84	0.85	0.85	600
700												0.77	0.78	0.78	0.79	0.80	0.80	0.81	0.81	0.82	0.83	0.83	0.84	0.84	700
800												0.76	0.77	0.77	0.78	0.79	0.79	0.80	0.80	0.81	0.82	0.82	0.83	0.83	800
900												0.75	0.76	0.76	0.77	0.78	0.78	0.79	0.79	0.80	0.81	0.81	0.82	0.82	900
1000												0.74	0.75	0.75	0.76	0.76	0.77	0.78	0.78	0.79	0.80	0.80	0.81	0.81	1000
1500												0.71	0.72	0.73	0.74	0.75	0.76	0.77	0.77	0.78	0.79	0.79	0.80	0.80	1500
2000																								0.79	2000
2500																								0.79	2500

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

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

TABLE-A-3 : TIME DISTRIBUTION COEFFICIENTS OF AREAL RAINFALL EASTERN COAST, SUBZONES-4(a,b & c)

Time in hours	DISTRIBUTION COEFFICIENT FOR DESIGN STORM DURATION OF 2-24 HOURS																							Time in hours
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
24																							1.00	24
23																						1.00	0.99	23
22																					1.00	0.99	0.98	22
21																				1.00	0.99	0.98	0.97	21
20																			1.00	0.99	0.98	0.97	0.96	20
19																		1.00	0.99	0.97	0.97	0.96	0.94	19
18																	1.00	0.99	0.98	0.96	0.95	0.94	0.93	18
17																1.00	0.99	0.98	0.97	0.95	0.93	0.92	0.91	17
16															1.00	0.99	0.98	0.96	0.95	0.93	0.91	0.90	0.88	16
15														1.00	0.99	0.98	0.96	0.94	0.93	0.91	0.89	0.88	0.86	15
14													1.00	0.99	0.98	0.97	0.95	0.92	0.91	0.88	0.87	0.85	0.84	14
13												1.00	0.99	0.98	0.96	0.95	0.94	0.89	0.88	0.86	0.84	0.83	0.81	13
12											1.00	0.99	0.98	0.96	0.94	0.93	0.91	0.87	0.85	0.83	0.81	0.80	0.78	12
11										1.00	0.99	0.97	0.96	0.94	0.92	0.90	0.88	0.84	0.82	0.80	0.78	0.77	0.75	11
10									1.00	0.99	0.98	0.95	0.93	0.91	0.89	0.87	0.85	0.80	0.79	0.77	0.75	0.74	0.72	10
9								1.00	0.99	0.97	0.96	0.92	0.90	0.88	0.86	0.84	0.82	0.77	0.75	0.73	0.71	0.70	0.68	9
8							1.00	0.98	0.97	0.95	0.93	0.86	0.86	0.84	0.82	0.80	0.78	0.72	0.71	0.69	0.67	0.65	0.64	8
7						1.00	0.99	0.96	0.94	0.91	0.90	0.83	0.82	0.80	0.78	0.76	0.74	0.67	0.66	0.63	0.62	0.61	0.60	7
6					1.00	0.98	0.96	0.92	0.90	0.87	0.85	0.80	0.77	0.75	0.73	0.71	0.69	0.62	0.61	0.59	0.57	0.50	0.55	6
5				1.00	0.98	0.95	0.91	0.88	0.86	0.81	0.80	0.73	0.71	0.69	0.67	0.65	0.64	0.56	0.55	0.53	0.52	0.50	0.49	5
4			1.00	0.97	0.92	0.88	0.86	0.81	0.80	0.76	0.75	0.66	0.64	0.62	0.61	0.59	0.58	0.49	0.48	0.47	0.46	0.44	0.43	4
3		1.00	0.92	0.90	0.86	0.81	0.78	0.73	0.71	0.70	0.68	0.58	0.56	0.55	0.53	0.51	0.50	0.42	0.41	0.40	0.38	0.37	0.36	3
2	1.00	0.91	0.86	0.81	0.74	0.70	0.68	0.63	0.61	0.59	0.58	0.57	0.45	0.43	0.42	0.41	0.40	0.32	0.31	0.30	0.29	0.28	0.27	2
1	0.85	0.75	0.68	0.61	0.54	0.53	0.50	0.48	0.47	0.43	0.40	0.30	0.29	0.28	0.27	0.26	0.25	0.22	0.21	0.20	0.19	0.18	0.17	1

Table : A-4: COMPUTATION OF FLOOD HYDROGRAPH FOR RLY. BR. NO. 85, SUBZONES 4(a,b&c)

Time in Hrs.	Synthetic Hydrograph Ordinates (Cumecs)	1-Hourly Effective Rainfall in Cms. 0.15	0.15	1.43	6.07	0.67	Total (Cumecs)	Base Flow (Cumecs)	Total (Cumecs)	Remarks
		Direct Surface Runoff (Cumecs)								
0	0.00	0.00					0.00	12.88	12.88	
1	6.00	0.90	0.00				0.90	12.88	13.78	
2	18.00	2.70	0.90	0.00			3.60	12.88	16.48	
3	50.00	7.50	2.70	8.58	0.00		18.78	12.88	31.66	
4	106.00	15.90	7.50	25.74	36.42	0.00	85.56	12.88	98.44	
5	168.00	25.20	15.90	71.50	109.26	4.02	225.88	12.88	238.76	
6	228.00	34.20	25.20	151.58	303.50	12.06	526.54	12.88	539.42	
7	261.56	39.23	34.20	240.24	643.42	33.50	990.59	12.88	1003.47	
8	236.00	35.40	39.23	326.04	1019.76	71.02	1491.45	12.88	1504.33	
9	208.00	31.20	35.40	374.03	1383.96	112.56	1937.15	12.86	1950.03	
10	180.00	27.00	31.20	337.48	1587.67	152.76	2136.11	12.88	2148.99	-- PEAK
11	152.00	22.80	27.00	297.44	1432.52	175.25	1955.01	12.88	1967.89	
12	124.00	18.60	22.80	257.40	1262.56	158.12	1719.48	12.88	1732.36	
13	100.00	15.00	18.60	217.36	1092.60	139.36	1482.92	12.88	1495.80	
14	82.00	12.30	15.00	177.32	922.64	120.60	1247.86	12.88	1260.74	
15	66.00	9.90	12.30	143.00	752.68	101.84	1019.72	12.88	1032.60	
16	54.00	8.10	9.90	117.26	607.00	83.08	825.34	12.88	838.22	
17	42.00	6.30	8.10	94.38	497.74	67.00	673.52	12.88	686.40	
18	34.00	5.10	6.30	77.22	400.62	54.94	544.18	12.88	557.06	
19	26.00	3.90	5.10	60.06	327.78	44.22	441.06	12.88	453.94	
20	18.00	2.70	3.90	48.62	254.94	36.18	346.34	12.88	359.22	
21	12.00	1.80	2.70	37.18	206.38	28.14	276.20	12.88	289.08	
22	6.00	0.90	1.80	25.74	157.82	22.78	209.04	12.88	221.92	
23	3.00	0.45	0.90	17.16	109.26	17.42	145.19	12.88	158.07	
24	0.00	0.00	0.45	8.58	72.84	12.06	93.93	12.88	106.81	
25			0.00	4.29	36.42	8.04	48.75	12.88	61.63	
26				0.00	18.21	4.02	22.23	12.88	35.11	
27					0.00	2.01	2.01	12.88	14.89	
28						0.00	0.00	12.88	12.88	
Total:	2180.56									

PART-B

GENERAL DESCRIPTION OF EAST COAST

SUBZONE-4 (a,b&c)

1.0 GENERAL DESCRIPTION OF SUBZONES DATA COLLECTION AND ANALYSIS

1.1 LOCATION

The eastern coastal belt, comprising of Upper, Lower and South subzones-4(a), 4(b) and 4(c) lies roughly between 77° to 85° longitude (east) and 8° to 20° latitude (north). Plate-1 shows location of the three subzones 4(a), 4(b), and 4(c) with the appended list of hydro-meteorological subzones of India.

The eastern coastal belt extends roughly from Mahanadi Delta to Kanniya Kumari. This eastern belt is bounded on the north by the Mahanadi subzone-3(d), on the south by the Indian Ocean, on east by the Bay of Bengal and on the west by the Indravati, Lower Godavari, Krishna, Kaveri and Malabar Coast subzones-3(g), 3(f), 3(h), 3(i) and 5(b) respectively.

The detailed plans of the subzones-4(a), 4(b) and 4(c) are shown separately in Plates-2(a), 2(b) and 2(c) respectively. The eastern coastal belt covers parts of Orissa, Andhra Pradesh and Tamil Nadu States and Union Territory of Pondicherry. The important towns and cities in the 3 subzones are Rajahmundary, Vishakhapatnam, Cocanada, Berhampur, Madras City, Tiruchirapalli, Thanjavur, Cuddalore, Ellore, Guntur, Vijayawada, Madurai, Tirunelveli and Ramanathpuram.

1.2 RIVER SYSTEM

There are large number of small and medium coastal streams besides the outfall reaches of Godavari, Krishna, Kaveri, Vellar, Ponniyar, Pallar and Penner in the eastern coastal belt outfalling into the Bay of Bengal and the Indian Ocean. The sizeable coastal rivers flowing in the eastern coastal belt are Vamsadhara, Chayyar Musi, Munneru, Tamileru, Tambaraparani, Vaipparu, Vaigai and Vellar (Chittar) as shown in plates 2.4(a), 2.4(b) and 2.4(c).

The coastal streams rise in the eastern ghats and overflow their banks during the periods of heavy rainfall in their catchment areas. Similarly the other rivers flowing in the plains also overflow their banks during floods. The rivers flowing into the Bay of Bengal and Indian Ocean are also affected by the sea tides near their outfall reaches.

The drainage areas of the sizable coastal streams alongwith minor streams and deltaic areas in the eastern coastal belt are as follows:

Sl.No.	Name of river and Coastal Delta	Drainage area (sq.km.)
1.	Tambaparani	5,605
2.	Vaipparu	5,509
3.	Vaigai	7,812
4.	Vamsadhara	11,418
5.	Other streams alongwith Kaveri, Krishna and Godavari Delta.	196,400
		226,400

The total drainage area of the eastern coastal belt is about 226,400 sq.km.

Area subzonewise are as under:

Name of subzone	Area (sq.km.)
Upper Coast subzone-4(a)	59,300
Lower Coast subzone-4(b)	131,000
South Coast subzone-4(c)	36,100
	226,400

Areawise the subzone-4(b) is the largest followed by subzones 4(a) and 4(c). The total area of the three subzones is 226,400.

1.3 TOPOGRAPHY AND RELIEF

The east coast belt all along the east is skirted by the Bay of Bengal except the southern most part by the Indian Ocean. The coastal belt extends from Kanniya Kumari to the Mahanadi delta for a length of 1710 km. The major deltas of Kaveri and Krishna form parts of subzone-4(b). The Godavari delta falls in subzone-4(a) The eastern coastal plains are mostly rich alluvial tracts. The average width of the plains vary from 80 to 110 km.(Vide Plate-3).

The eastern ghats almost form the western boundary of the three subzones except the gaps through which the major rivers of Kaveri, Krishna and Godavari and medium rivers of Vellar, Ponniyar and Pallar flow across the plains. The general elevation of the plains in Andhra Pradesh is less than 152 m above sea level. The hills of eastern ghats in Andhra Pradesh climb to an altitude of 1067 m above sea level. The eastern ghats in Orissa in subzone-4(a) rise abruptly and sharply to the east and slope gently to a dissected plateau in the west. The eastern ghats in Tamil Nadu vary in height from 1100 m to 1650 m.

1.4 RAINFALL

Plate-4 depicts the mean annual rainfall in the eastern coastal belt along with histograms showing the mean monthly rainfall at Machllipatam, Vishakapatnam, Madras and Tiruchirappali. The mean annual rainfall along the coastal plains from the coast to eastern ghat varies from 100 to 120 cm whereas the mean annual rainfall in the eastern ghat ranges varies from 140 to 160 cm.

About 81% of the annual rainfall in subzone-4(a) occurs during June to September, under the influence of southwest monsoon. About two thirds of the annual rainfall occurs in the northern and middle parts of subzone-4(b) during the period of southwest monsoon from June to September. The southern portions of subzone-4(b) receive the rainfall from southwest monsoon during June to August and also from northeast monsoon during September to November. The rainfall during the northeast monsoon is higher as compared to the rainfall from the southwest monsoon in the southern portions of the subzone-4(b). The mean monthly rainfall is maximum in this portion of the subzone during the months of September and October, under the influence of northeast monsoon.

The subzone-4(c) receives rainfall only in the northeast monsoon period from September to November. The mean monthly rainfall is maximum in November.

1.5 TEMPERATURE

Plate-5 shows the isotherms of mean annual temperature along with Bargraphs of temperature at Vishakhapatnam, Machlipatam, Madras and Tiruchirappalli. The mean annual temperature in the northern portions of the east coast belt varies between 25°c to 27.5°c whereas the temperature in the south portion is above 27.5°c. The temperatures start rising from January to April or May and then start falling upto end of December.

The mean monthly temperature variations at the following stations are:

	Mean Monthly Temperatures Degree Centigrade		
	January	May	December
Tiruchirappalli	20	32	21
Madras	25	35	25
Machlipatam	25	33	25
Vishakhapatnam	25	30	25

The coastal areas experience a mild summer.

1.6 SOILS

Plate-6 depicts the types of major soil groups in the eastern coastal belt. Soils in the eastern coastal belt are mostly coastal alluvial soils. Coastal sandy soils and coastal deltaic soils in the deltas of Godavari, Krishna and Kaveri. Besides patches of red loamy soils and red sandy soils are interspersed in the coastal belt. Laterite soils are found in northeastern part of subzone-4(c) Godavari alluviam is black fertile mud, rich in lime, phosphates and potash. Kaveri alluvium is poor in plant neutrients.

1.7 LAND USE

Plate-7 depicts the land use. About 70 percent of east coast belt is arable land. 10 percent of the area is covered with grass land and scrub. The remaining 20 percent of the area in this east belt is covered with forest. The arable land is mostly under irrigated agriculture. Deltas of Kaveri, Krishna and Godavari are irrigated. There are a number of minor and medium storage and diversion works on coastal streams mainly for irrigation. There are three well known lakes namely Chilka, an estuary in Orissa falling in subzone-4(a), Kolleru Lake, an inland lake and Pulicat Lake, an estuary in subzone-4(b) of Andhra Pradesh.

1.8 COMMUNICATIONS

1.8.1 Railways

The following railway Sections partly or wholly traverse the eastern coastal belt:

Subzone-4(a)

1. Rajahmundri - Bhubneswar via Vizianagaram (SER)
2. Simhachalam - Vishakhapatnam (SER)
3. Vizianagaram - Ambodala (SER)
4. Bobbili - Salur (SER)

5. 5. Naupada - Gunupur (SER)

Subzone-4(b)

1. Tiruchirappalli - Nagappattinam (SR)
2. Tiruchirappalli - Tranquebar via Thanjavur (SR)
3. Pattukkottai - Villupuram (SR)
4. Tiruchirappalli - Rajahmundri via Madras, Nellore, Vijayawada (SR)
5. Salem - Cuddalore (SR)

6. Villupuram - Katpadi (SR)

7. Chingleput - Cuddapah via Renigunta (SR)

8. Renigunta - Kadiri (SR)

9. Madras - Katpadi via Arkonam (SR)

10. Gudur - Madras (SR)

11. Renigunta - Gudur (SR)

12. Chelama - Rajahmundri via Guntur (SR)

13. Vijayawada - Khammam (SR)

14. Vijayawada - Bandarport (SR)

15. Vijayawada - Narasapur (SR)

Subzone-4(c)

1. Tiruchehendur - Tiruchirappalli via Tenkasi, Virudunagar, Madurai (SR)

2. Tenkasi - Quilon (SR)

3. Palayankottai - Tuticorin (SR)

4. Maniyachchi - Madurai (SR)

5. Madurai - Bodinayakkanm (SR)

6. Rameswaram - Pattukkottai (SR)

7. Karaikkudi - Tiruchirappalli (SR)

1.8.2 Highways

The following national highways are passing, partly or fully, through the east coast belt:

Subzone-4(a)

1. Rajahmundri - Bhubaneswar NH-5

2. Jagdalpur - Natavalasa NH-43

Subzone-4(b)

1. Dindigul-Madras NH-45
2. Madras - Rajahmundri NH-5
3. Pondicherry - Villupuram NH-45A
4. Madras - Renipet NH-4

Subzone-4(c)

1. Kanniya Kumari - Dindigul	NH-7
2. Madurai - Rameswaram	NH-49
3. Palayankottai - Tuticorin	NH-7A

NOTE:- RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER
BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA

S.R. MALHOTRA   P.N. BHALLA.

LIST OF HYDRO-METEOROLOGICAL SUBZONES

Sub-zone	Name of subzone (designated earlier)	Name of subzone (designated now)	River Basins included in the subzone
1	2	3	4
1(a)	Luni Basin & Thar (Luni & other rivers of Rajasthan 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 and Mechha Bhandar, Czat 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 except coastal region
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)	Cauveri & east flowing rivers except coastal region	Kaveri	Kaveri, Palar and Ponnaiyar rivers (except coastal region)
4(a)	Circars including east flowing rivers between Mahanadi & Godavari	Upper Eastern Coastal Region	East flowing coastal rivers, between deltas of Mahanadi and Godavari rivers.
4(b)	Coromandal Coast including east flowing rivers between Godavari and Cauvery	Lower Eastern Coastal Region	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 Coastal Region	East flowing coastal rivers- Manimuther, Vaigai, Arjuna, Tamraparni
5(a)	Konkan Coast (west flowing rivers between Tapi and Panaji)	Konkan Coastal Region	West flowing coastal rivers between Tapi and Mandavi rivers
5(b)	Malabar Coast (West flowing rivers between Kanyakumari and Panaji)	Malabar Coastal Region	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

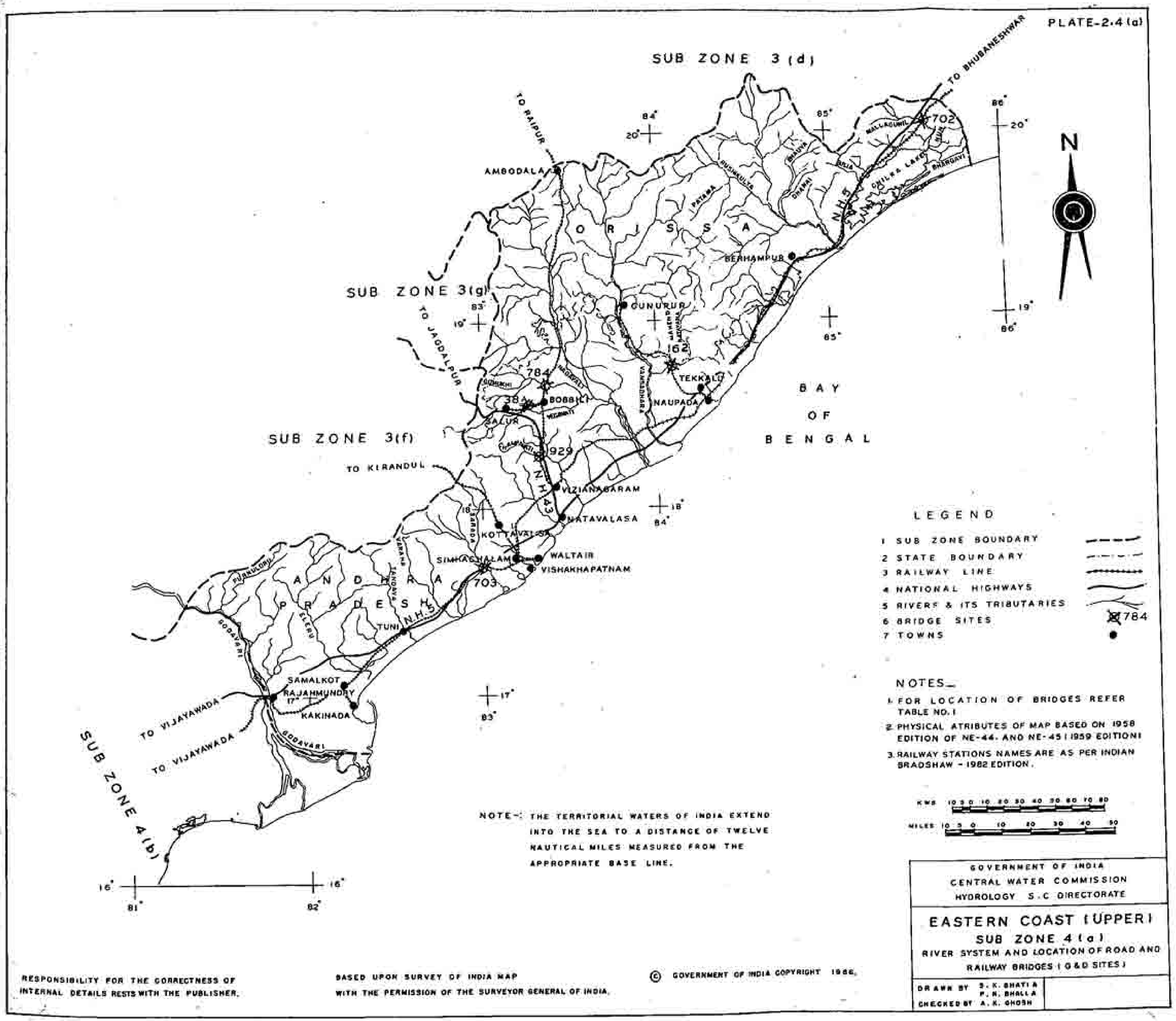


PLATE-2.4 (a)
SUB ZONE 3 (d)
SUB ZONE 3(g)
SUB ZONE 3(f)
SUB ZONE 4 (b)
TO BHUBANESHWAR
TO RAIPUR
TO JAGDALPUR
TO KIRANDUL
TO VIJAYAWADA
TO VIJAYAWADA
N
O R I S S A
A N D H R A P R A D E S H
B A Y O F B E N G A L
AMBODALA
BERHAMPUR
GUNUPUR
TEKKALI
NAUPADA
BOBBILI
SALUR
VIZIANAGARAM
NATAVALASA
KOTTAVALSA
WALTAIR
SIMHACHALAM
VISHAKHAPATNAM
TUNI
SAMALKOT
RAJAHMUNDRY
KAKINADA
CHILKA LAKE
N.H.5
N.H.43
702
162
784
384
929
703
GODAVARI
LEGEND
1 SUB ZONE BOUNDARY
2 STATE BOUNDARY
3 RAILWAY LINE
4 NATIONAL HIGHWAYS
5 RIVERS & ITS TRIBUTARIES
6 BRIDGE SITES
7 TOWNS
784
NOTES_
1. FOR LOCATION OF BRIDGES REFER TABLE NO. 1
2. PHYSICAL ATRIBUTES OF MAP BASED ON 1958 EDITION OF NE-44. AND NE-45 (1959 EDITION)
3. RAILWAY STATIONS NAMES ARE AS PER INDIAN BRADSHAW - 1982 EDITION.
KMS
MILES
NOTE-: THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY S.C DIRECTORATE
EASTERN COAST (UPPER)
SUB ZONE 4 (a)
RIVER SYSTEM AND LOCATION OF ROAD AND RAILWAY BRIDGES (G&D SITES)
DRAWN BY S. K. BHATIA
P. K. BHALLA
CHECKED BY A. K. GHOSH
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER.
BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.
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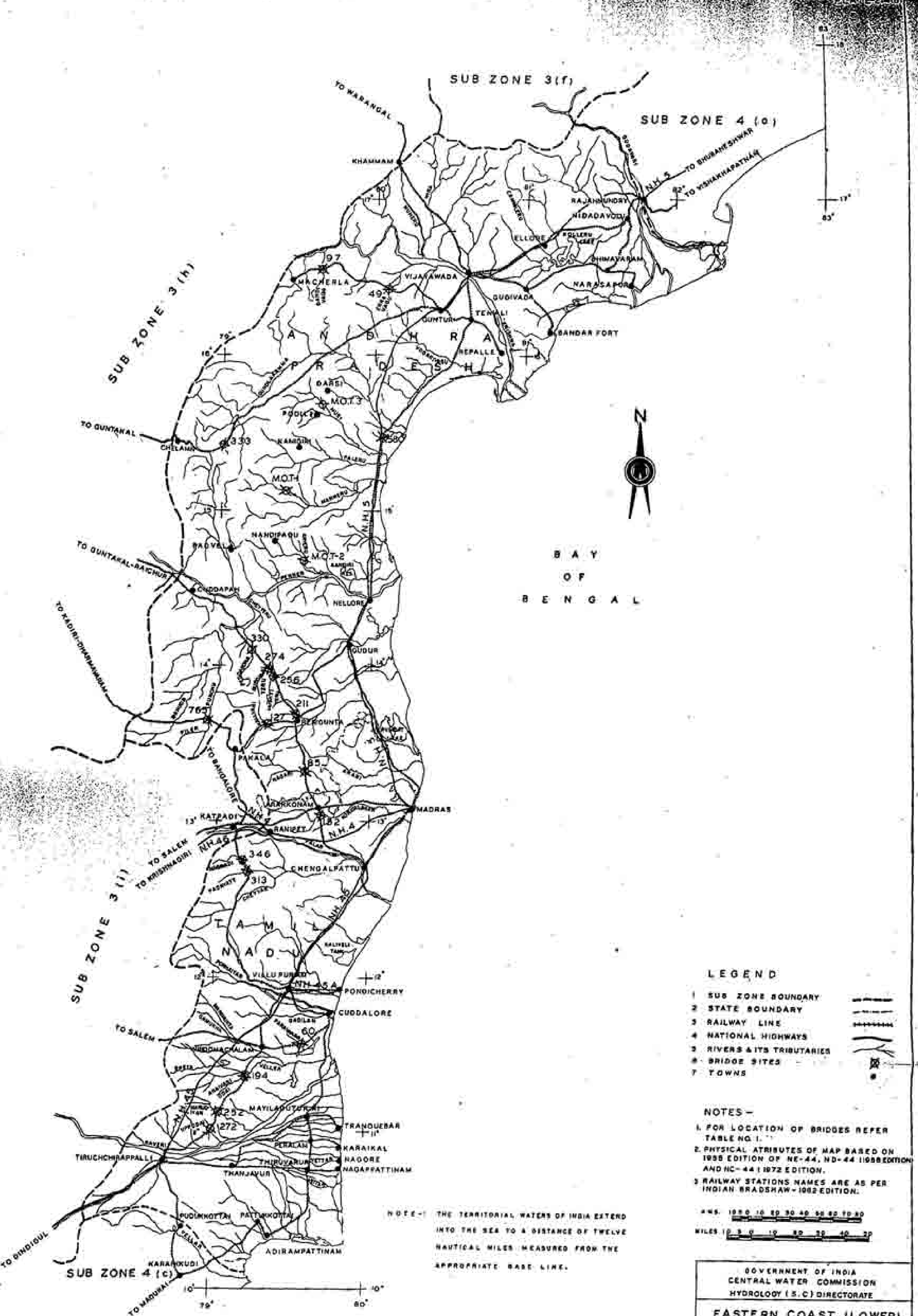


LEGEND

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

NOTES –

1. FOR LOCATION OF BRIDGES REFER TABLE NO. I.
2. PHYSICAL ATRIBUTES OF MAP BASED ON 1958 EDITION OF NE-44, ND-44 (1958 EDITION) AND NC-44 (1972 EDITION.
3. RAILWAY STATIONS NAMES ARE AS PER INDIAN BRADSHAW - 1982 EDITION.

KMS. 10 5 0 10 20 30 40 50 60 70 80

MILES 10 5 0 10 20 30 40 50

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

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

EASTERN COAST (LOWER)
SUB ZONE 4 (b)
RIVER SYSTEM AND LOCATION OF ROAD AND RAILWAY BRIDGES (G&D SITES)

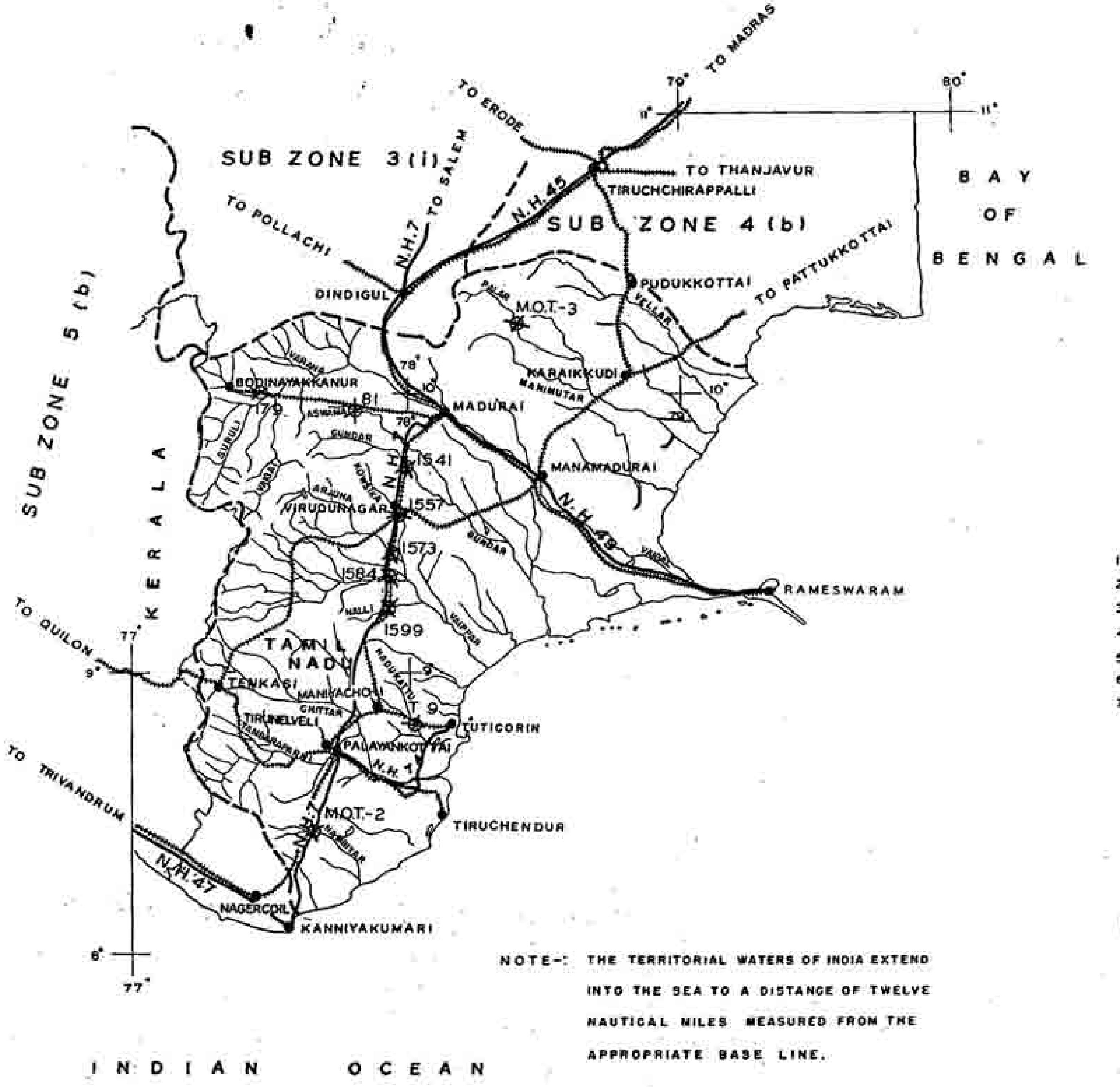
DRAWN BY S.K. BHATIA
F.R. BHALLA
CHECKED BY A. K. Ghosh

8

RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER

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

PLATE-2.4 (C)



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

LEGEND

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

NOTES -

1. FOR LOCATION OF BRIDGES REFER TABLE NO. 1.
2. PHYSICAL ATRIBUTES OF MAP BASED ON 1963 EDITION OF NC-43 AND NC-44 (1972 EDITION)
3. RAILWAY STATIONS NAMES ARE AS PER INDIAN BRADSHAW - 1982 EDITION.

KMS. 10 5 0 10 20 30 40 50 60 70 80

MILES 10 5 0 10 20 30 40 50

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

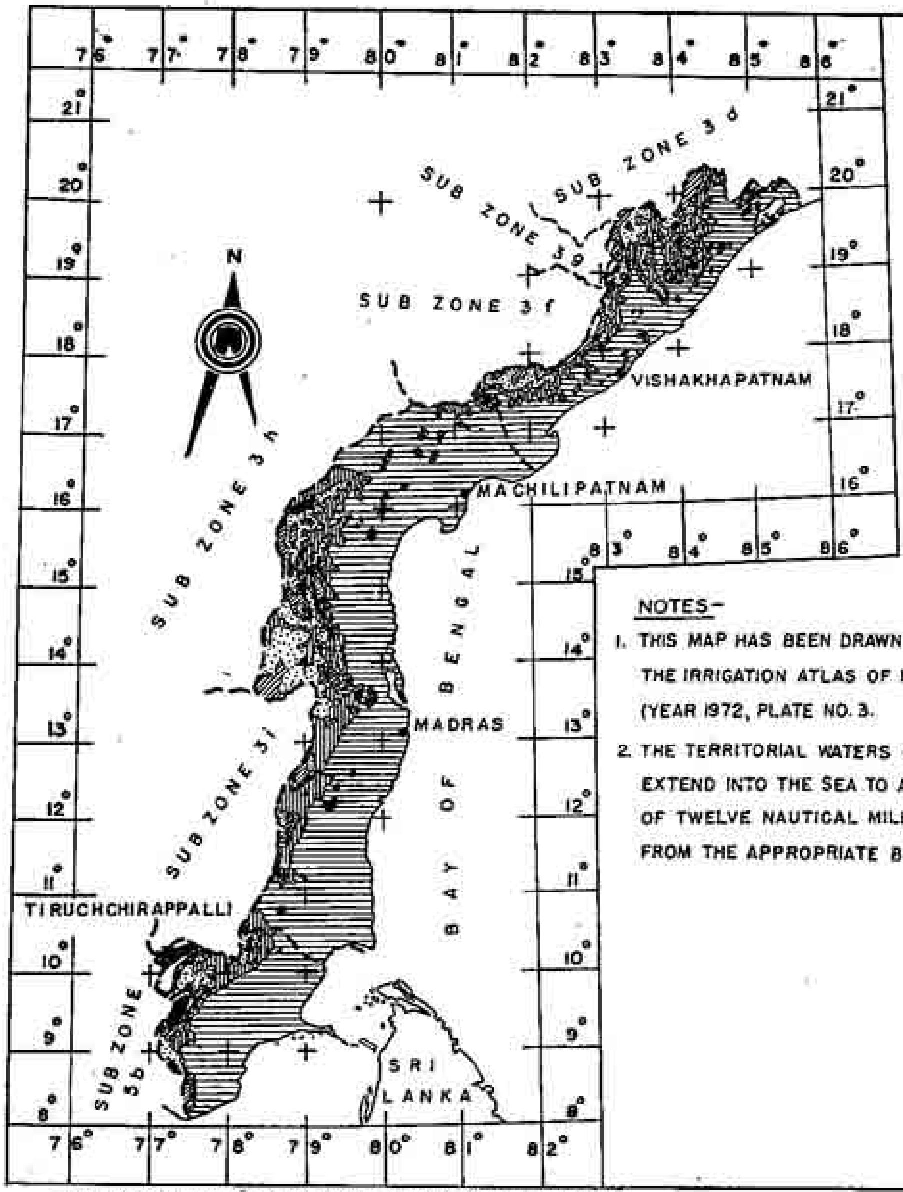
EASTERN COAST (SOUTH)
SUB ZONE 4 (c)
RIVER SYSTEM AND LOCATION OF ROAD AND RAILWAY BRIDGES (G&D SITES)

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

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

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

PLATE - 3



LEGEND

	ALTITUDE IN	METERS
1	0	150
2	150	300
3	300	600
4	600	900
5	900	1350
6	1350	1800
7	1800	3000

8 SUB ZONE BOUNDARY

9 TOWNS

NOTES-

1. THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (YEAR 1972, PLATE NO. 3.
2. THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

100 50 0 100 200 300 KM.

50 0 50 100 150 200 MILES

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

EASTERN COAST

(UPPER LOWER & SOUTH)

SUB ZONES 4 (a,b,c)

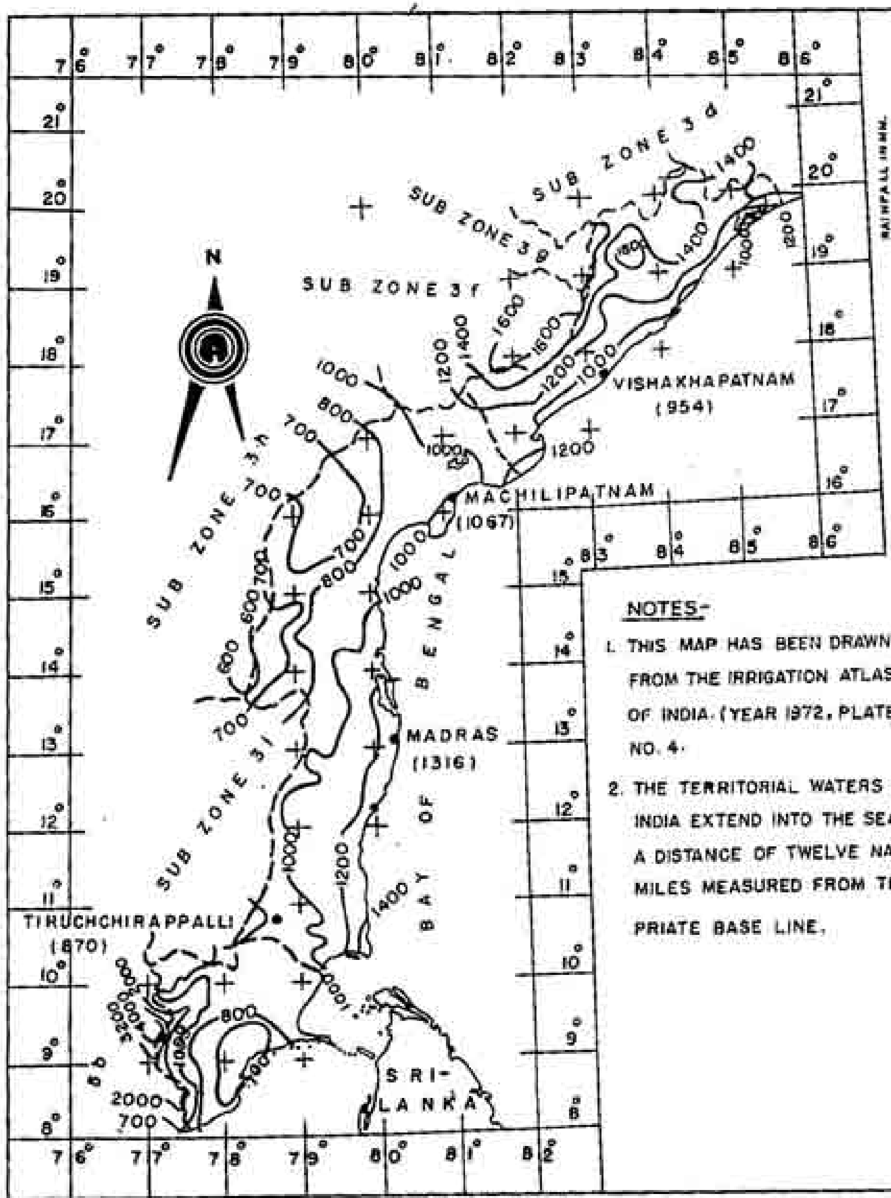
PHYSIOGRAPHY

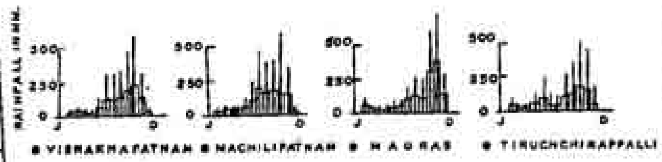
DRAWN BY- S. N. MALHOTRA, L. P. NAUTIYAL

CHECKED BY- A. K. GHOSH

THE COAST LINE OF INDIA ON THE MAP AGREE WITH THE RECORD COPY CERTIFIED BY THE SURVEY OF INDIA.

PLATE - 4





NOTES—

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

NOTES-

1. THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA. (YEAR 1972, PLATE NO. 4.
2. THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

REFERENCES

1. SUB ZONE BOUNDARY
2. TOWNS
3. ISOHYETAL LINES — 800
4. MEAN ANNUAL RAINFALL — .954

SCALE—

100 50 0 100 200 300 KM.

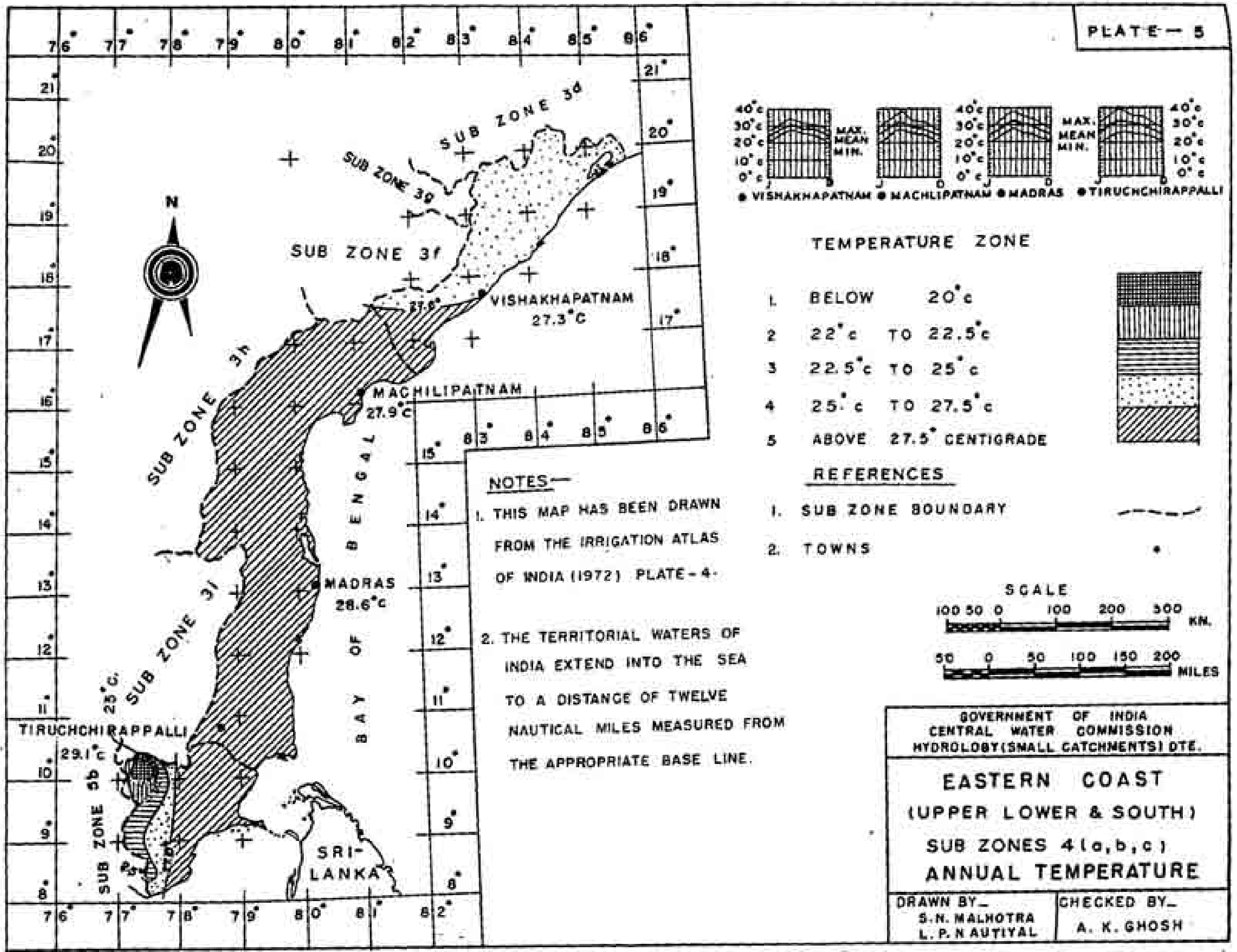
50 0 50 100 150 200 MILES

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

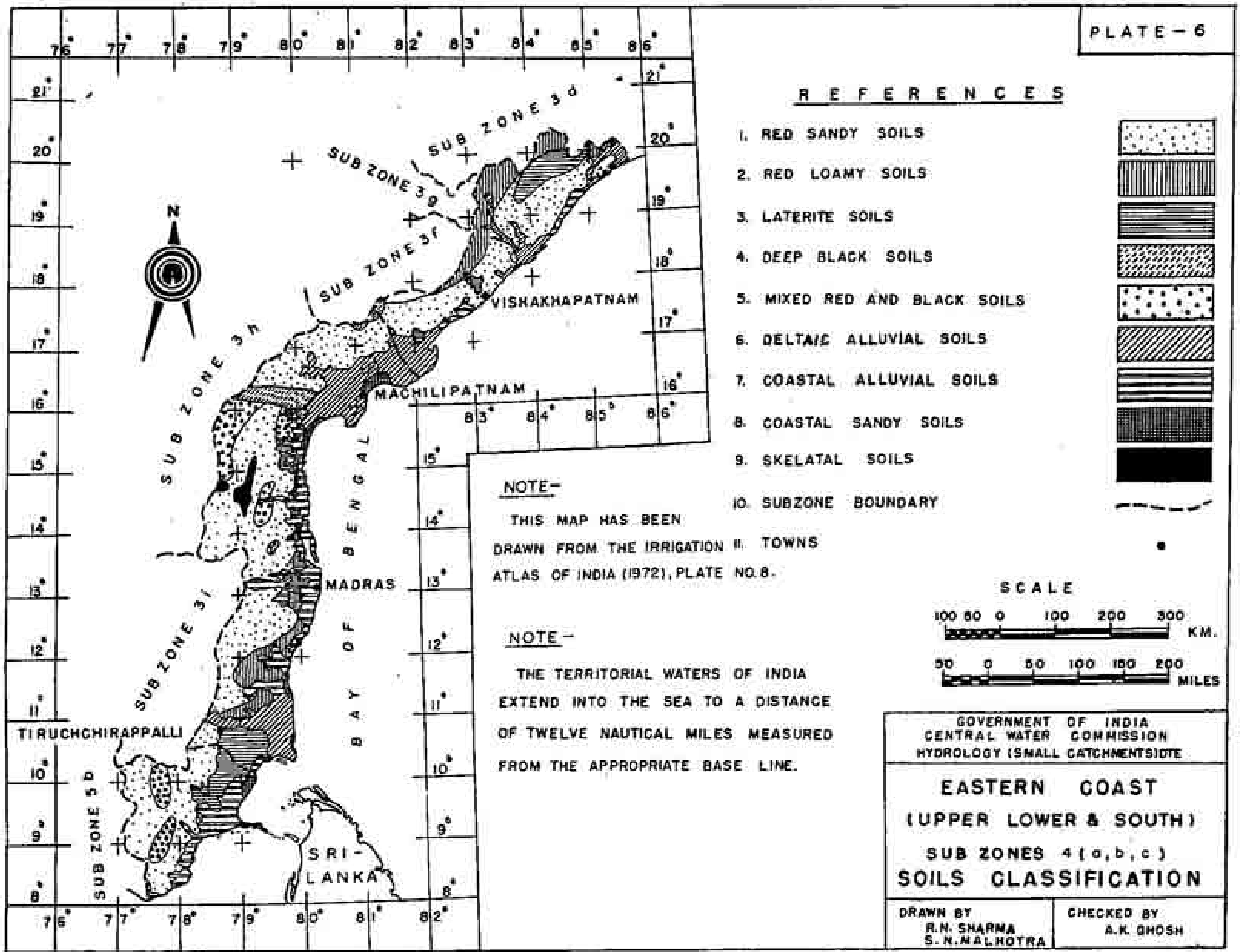
EASTERN COAST
(UPPER, LOWER & SOUTH)
SUB ZONES 4 (a, b, c)
NORMAL ANNUAL RAINFALL

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

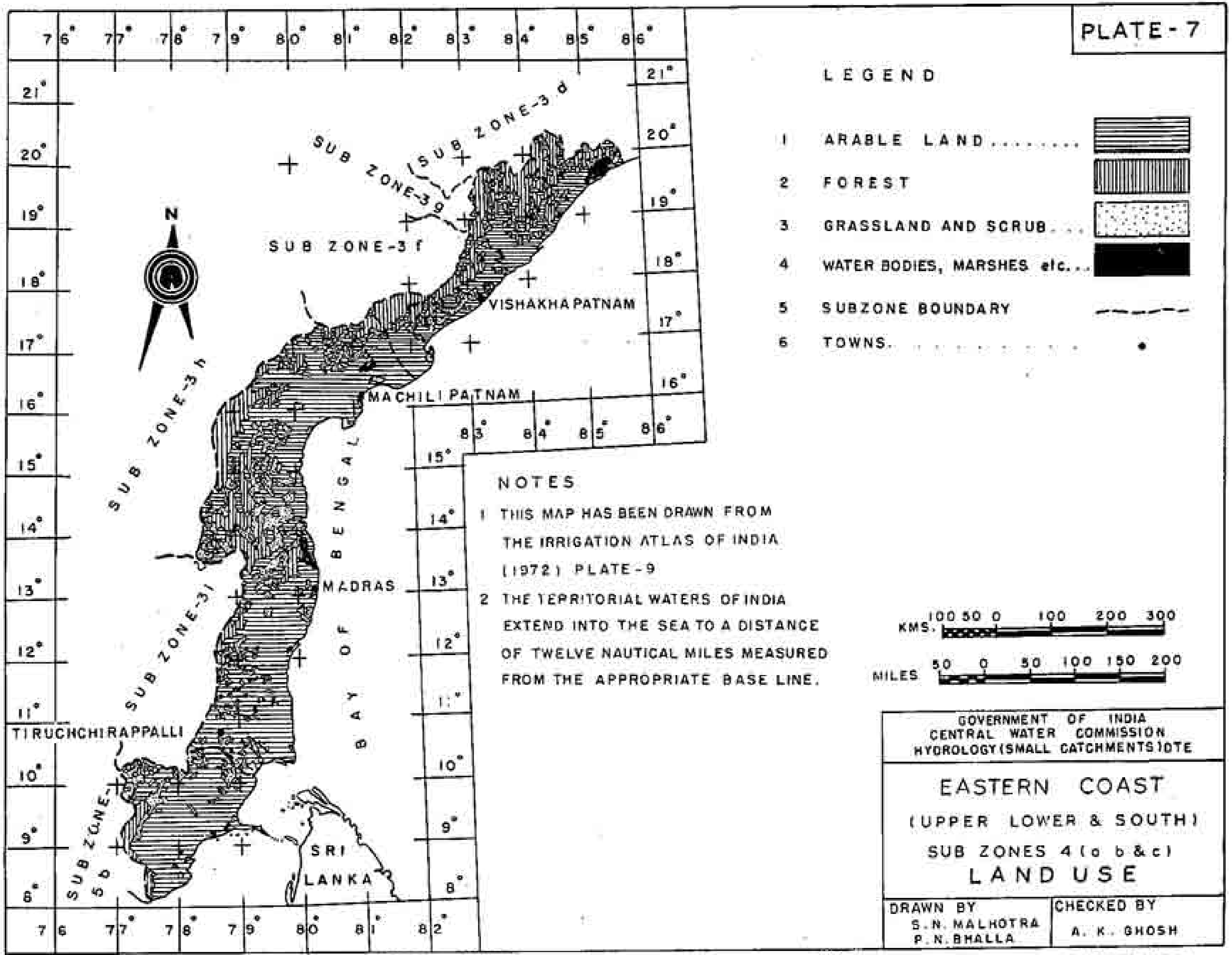
THE COAST LINE OF INDIA ON THE MAP AGREE WITH THE RECORD COPY CERTIFIED BY THE SURVEY OF INDIA.



THE COAST LINE OF INDIA ON THE MAP AGREE WITH RECORD COPY CERTIFIED BY THE SURVEY OF INDIA.



THE COAST LINE OF INDIA ON THE MAP AGREE WITH THE RECORD COPY CERTIFIED BY THE SURVEY OF INDIA.



THE COAST LINE OF INDIA ON THE MAP AGREE WITH THE RECORD COPY CERTIFIED BY THE SURVEY OF INDIA.

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 structures across a river. The Committee of Engineers had suggested that the design discharge may be considered as the maximum observed discharge from the yearly peak discharge records available for over 50 years. However, the present Indian Railways Substructure Code recommends that the design discharge may be computed as a 50-year flood using records of larger than/equal to/less than 50 years. 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 sub-zone-wise 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).

2.2 DATA REQUIRED

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

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

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

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

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

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

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

2.3 DATA COLLECTED

The Southern, South-Central and South-Eastern Railways under the supervision and guidance of Research Designs and Standards Organisation (R.D.S.O.) had observed and collected the required data in Section 2.2 for 32 catchments in the eastern coastal belt subzones 4(a,b,c) for a period ranging from 2 to 11 years for each of the catchments. Central Water Commission on behalf of the Ministry of Transport (Surface) has also observed and collected the required data since 1979 for 3 catchments and from 1982 for 2 catchments in these subzones. The sizes of the gauged catchments vary from 43 to 2015 sq.km. Concurrent rainfall, gauge and discharge data for 216 bridge catchment years from 37 catchments was available for study. The number of gauged catchments in subzones-4(a), 4(b) and 4(c) are 6, 21 and 10 respectively.

The locations of the gauging sites at road and railway bridges in the three subzones-4(a, b and c) are shown in Plates-2(a, b and c). India Meteorological Department has collected the rainfall data of additional 376 ordinary raingauge stations and 24 self recording raingauges maintained by IMD and the states falling in the three subzones. Central Water Commission (CWC) has also prepared the detailed plans of the gauged catchments showing information in Section 2.2(iv). Table-1 shows, the name of stream, railway bridge numbers with railway sections, the concerned subzone, location of the gauging sites, catchment areas, number of raingauge stations and period of availability of concurrent rainfall, gauge and discharge data. R.D.S.O. has made available the data collected to CWC and IMD for carrying out the studies.

2.4 DESCRIPTION OF THE METHOD ADOPTED

The following three main sections deal with specific studies in the report:

Section-3 explains the procedure for obtaining the synthetic unitgraphs for small and medium catchments in the eastern coastal belt subzones-4(a, b and c). Design loss and base flow rate are also included in this Section.

Section-4 explains the procedure for obtaining the design storm rainfall of 50-year return period. It also deals with 25-year and 100-year design storm rainfall.

Section-5 explains the steps to be followed for obtaining a design flood of 50-year return period which could also be adopted for estimation of 25-year and 100-year flood.

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

TABLE-I

LIST OF SELECTED RAILWAY AND ROAD BRIDGE CATCHMENTS IN EASTERN COAST (UPPER, LOWER & SOUTH) SUB ZONE 4(a,b&c) AND DATA AVAILABILITY OF GAUGE, DISCHARGE & RAINFALL

SL. NO.	NAME OF STREAM	NAME OF SECTION ROAD / RAIL WHERE BRIDGE IS LOCATED WITH RLY ZONE	RLY Br. NO./ SITE NO.	SUB-ZONE	G&D SITE LOCATION LATITUDE DEG. MIN. SEC.	G&D SITE LOCATION LONGITUDE DEG. MIN. SEC.	CATCHMENT AREA (Sq. Km)	NO. OF R.G. STATIONS	DATA AVAILABILITY	NO. OF YEARS	REMARKS
1	2	3	4	5	6	7	8	9	10	11	12
(A)	BRIDGES CONSIDERED FOR REGRESSION ANALYSIS.										
1	VAIPPAR	VIRUDU NAGAR – MANIYACHCHI (S.R)	1584	4(c)	09 21 30	77 58 00	2015	9	1966 - 74	9	
2	GOMUKHI	RAIPUR – VIZIANAGARAM (S.E.R)	784	4(a)	18 40 00	83 22 00	1024	6	1966 - 67	2	
3	ARJUNA	VIRUDU NAGAR – MANIYACHCHI (S.R)	1573	4(c)	09 26 00	77 55 30	1023	8	1975 - 79	5	
4	MUSI	PODILE – DARSI ROAD	MOT(3)	4(b)	15 41 20	79 39 00	843	7	1979 - 85	7	
5	NAGARI	ARKONAM – RENIGUNTA (S.R)	85	4(b)	13 18 40	79 34 40	785	7	1974 - 82	9	
6	KAVERI	NANDIPADU – NELLORE ROAD	MOT(2)	4(b)	14 40 20	79 33 30	760	6	1979 - 85	7	
7	GUNDAR	MADURAI – VIRUDU NAGAR (S.R)	1541	4(c)	09 44 27	77 59 20	609	8	1975 - 85	11	
8	MANNERU	KANIGIRI – BADVEL ROAD	MOT(1)	4(b)	15 07 40	79 25 15	478	4	1979 - 85	7	
9	MARUDAIYAR	VILLUPURAM - TIRUCHCHIRAPPALLI (S.R)	252	4(b)	11 07 00	79 03 10	401	7	1961 - 66	6	
10	NAGAVADI	VILLUPURAM – KATPADI (S.R)	346	4(b)	12 44 45	79 10 00	267	9	1962, 66-74	10	
11	ANAIVARI – ODAI	VILLUPURAM - TIRUCHCHIRAPPALLI (S.R)	184	4(b)	11 19 52	79 12 36	264	3	1975 - 85	11	
12	CHAMPAVATI	RAIPUR – VIZIANAGARAM (S.E.R)	929	4(a)	18 18 40	83 20 00	256	4	1958 - 63	6	
13	KOWSIKA	VIRUDU NAGAR – MANIYACHCHI (S.R)	1557	4(c)	09 34 00	77 57 30	247	3	1966, 68 - 74	8	
14	NADUKATTU-ODAI	MANIYACHCHI – TUTICORIN (S.R)	T-8	4(c)	08 49 30	78 00 00	271	5	1978 - 85	8	
15	PEDDAKONA	RENIGUNTA – GUNTAKAL (S.C.R)	330	4(b)	14 06 56	79 12 38	205	3	1980 - 85	6	
16	HALLI	MADURAI – MANIYACHCHI (S.R)	1509	4(c)	09 14 30	77 55 30	195	8	1961-62 70-74	7	
17	DANDI VAGU	GUNTUR – MACHERLA (S.C.R)	97	4(b)	16 33 05	79 38 45	151	3	1970 - 73	4	
18	PARAVANAR	VRIDDHACHALAM – CUDDALORE (S.R)	60	4(b)	11 33 47	79 34 50	97	2	1961 - 66	6	
19	ERRAVAGU	GUNTUR – MACHERLA (S.C.R)	49	4(b)	16 28 15	80 03 45	93	3	1961 - 66	6	
20	ASWAMA	MADURAI – BODINAYAKKANUR (S.R)	81	4(c)	09 57 00	77 47 30	85	2	1973 - 77	5	
21	KURAGEDDA	BOBBILI – SALUR BRANCH (S.E.R)	30A	4(a)	18 32 30	83 15 10	74	2	1966, 67	2	
22	NALLAVAGU	MADRAS – VIJAYAWADA (S.R)	580	4(b)	15 27 45	80 03 20	71	3	1981 62, 64-65	4	
23	MUSHTI YERU	RENIGUNTA – GUNTAKAL (S.R)	256	4(b)	13 57 30	79 20 30	66	2	1975 - 79	5	
24	PAIDIVAGU	GUNTAKAL – GUNTUR (S.C.R)	333	4(b)	15 26 04	79 01 27	48	2	1974 - 81	8	
25	UPPODAI	VILLUPURAM - TIRUCHCHIRAPPALLI (S.R)	272	4(b)	11 00 40	78 53 40	43	2	1975 - 81	7	
(B)	BRIDGES NOT CONSIDERED FOR REGRESSION ANALYSIS										
26	SARADA	SAMALKOT – WALTAIR (S.R)	703	4(a)	17 42 00	82 59 00	2031	7	1966	1	SUITABLE FLOODS NOT AVAILABLE FOR UNIT HYDROGRAPH STUDIES.
27	MAHENDRA TAYANA	GUNUPUR – NAUPADA (S.E.R)	162	4(a)	18 45 00	84 05 10	888	4	1966 - 67	2	
28	PILER	PAKALA – DHARMAVARAM (S.C.R)	765	4(b)	13 39 30	78 55 30	663	6	1979 - 85	7	
29	KORATALAYAR	ARKONAM – CHINGLEPUT (S.R)	152	4(b)	13 02 10	79 40 40	627	6	1966 - 73	8	
30	MALLAGUNIL	KHURDA ROAD – VIZIANAGARAM (S.E.R)	702	4(a)	20 01 00	83 32 00	541	1	1966 - 67	2	
31	PALAR	MADURAI – TRICHY HIGHWAY	MOT(3)	4(c)	10 15 40	78 23 15	275	2	1982 - 85	4	
32	KOTAKUDI – R	MADURAI – BODINAYKKANUR (S.R)	179	4(c)	10 00 30	77 23 20	263	3	1967 - 73	6	
33	PADAVATT	VILLUPURAM – KATPADI (S.R)	313	4(b)	12 40 30	79 12 00	259	3	1966 - 74	7	
34	KALLYANI	PAKALA – RENIGUNTA (S.R)	127	4(b)	13 36 40	79 19 20	152	2	1966	1	
35	GUNDALAYERU	ARKONAM – RAICHUR (S.R)	274	4(b)	13 39 30	79 18 30	136	2	1966	1	
36	NAMBIYAR	TIRUNELVELI – NAGARCOLI	MOT(2)	4(c)	08 28 30	77 38 45	108	2	1982 - 85	4	
37	AVACHARIKONI	RENIGUNTA – GUNTAKAL (S.C.R)	211	4(b)	13 41 20	79 01 27	60	2	1979 - 85	7	

P.N. BHALLA

3.0 ANALYSIS FOR OBTAINING 1-HOUR SYNTHETIC UNITGRAPH

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

i) Analysis of physiographic parameters of the catchments.

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

iii) Selection of flood and corresponding storm rainfall events.

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

v) Computation of infiltration loss (Ø-index) and 1-hourly effective rainfall units.

vi) Derivation of 1-hourly unitgraphs.

vii) Drawing of representative unitgraphs and measuring the parameters.

viii) Establishing relationships between physiographic and representative unitgraph parameters.

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

The above steps are briefly described as under:

3.1 ANALYSIS OF PHYSIOGRAPHIC PARAMETERS OF THE CATCHMENT:

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

3.1.1 Catchment Area (A)

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

3.1.2 Length of the Main Stream (L) and (L_c)

The L is the longest length of the main river course from the farthest watershed boundary to the point of study. L_C is the longest length of the main river course from a point opposite to the centre of gravity to the point of study.

3.1.3 Equivalent Stream Slope (S)

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

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

where L_i = Length of the ith segment in km.

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

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

Rapids or vertical falls in the L-section shall not be considered for computation of slope.

Detailed studies were carried out for the 37 gauged catchments out of which 25 catchments have been considered for the unitgraph studies. The remaining 12 catchments had to be excluded due to non-availability of suitable floods conforming to the criteria laid down in the subsequent section 3.3. The physiographic parameters like A, L, L_c and S for the 25 catchments are shown in Table-2.

3.2 SCRUTINY OF DATA AND FINALISATION OF GAUGE DISCHARGE RATING CURVE

The data was scrutinised through arithmetical checks. The gauge (stage) vs. area curves and the stage vs. velocity curves were prepared to identify the outliers and reconcile the data in the plotted points of the stage-discharge curves. At many places, the average trend of the stage-area curve and the stage-velocity curve was used to obtain the discharges at various levels. Where wide dispersions were observed in the stage-discharge curve, log-log fitting was adopted. The stages for conceivable floods were converted into discharges initially identified with reference to rise and fall in the stages of the river.

Table-2: BASIN CHARACTERISTICS OF SUBZONES 4(a), 4(b) & 4(c)

Sl.No.	Bridge No.	Sub Zone	C.A. (Sq.km.)	L (Km)	L_c (Km)	S (m/Km)	$LLC / \sqrt{S}$
1	2	3	4	5	6	7	8
1.	1584	4(c)	2015.00	81.92	43.84	2.80	2147.00
2.	784	4(a)	1024.47	83.49	34.69	7.25	1075.65
3.	1573	4(c)	1023.00	75.67	35.42	3.59	1414.57
4.	MOT 3	4(b)	843.00	48.30	20.93	2.44	647.61
5.	85	4(b)	785.00	52.00	24.71	4.12	633.03
6.	MOT 2	4(b)	760.00	60.54	20.96	2.40	975.40
7.	1541	4(c)	608.65	62.31	30.91	2.66	1180.53
8.	MOT 1	4(b)	478.00	50.15	23.81	4.16	585.33
9.	252	4(b)	401.32	47.50	21.33	2.05	708.32
10.	346	4(b)	266.76	35.74	15.13	9.62	174.34
11.	194	4(b)	264.18	30.90	13.60	1.65	327.20
12.	929	4(a)	256.13	43.95	19.00	9.00	278.36
13.	1557	4(c)	247.14	30.59	12.08	2.06	257.46
14.	T-9	4(c)	216.50	25.12	12.35	2.27	206.15
15.	330	4(b)	204.90	46.85	16.74	11.31	233.20
16.	1599	4(c)	194.90	22.19	10.87	2.42	155.05
17.	97	4(b)	150.68	26.79	12.31	3.42	178.25
18.	60	4(b)	96.60	15.05	7.89	3.48	63.65
19.	49	4(b)	93.24	27.05	13.28	3.21	200.50
20.	81	4(c)	85.41	17.00	7.85	15.68	33.70
21.	38A	4(a)	74.21	14.33	3.86	4.70	25.51
22.	580	4(b)	70.60	12.88	5.47	1.32	61.39
23.	256	4(b)	65.79	23.34	13.28	11.89	89.90
24.	333	4(b)	48.30	14.77	7.24	3.79	54.90
25.	272	4(b)	42.94	10.38	5.07	3.70	27.36

3.3 SELECTION OF FLOOD AND CORRESPONDING STORM EVENTS

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

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

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

3.4 COMPUTATION OF HOURLY CATCHMENT RAINFALL

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

3.5 SEPARATION OF BASE FLOW

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

3.6 COMPUTATION OF INFILTRATION LOSS (Ø-Index) AND 1-HOURLY EFFECTIVE RAINFALL UNITS

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

3.7 DERIVATION OF 1-HOUR UNITGRAPH

A unit duration of 1-hour was adopted for derivation of unitgraphs. The 1-hour unitgraphs were derived from the effective rainfall hyetographs and their corresponding direct runoff hydrographs by interative methods. The interations were carried out till the observed and estimated direct runoff hydrographs compared favourably. Normally 5 to 15 unitgraphs were derived for each of the 25 catchments considered.

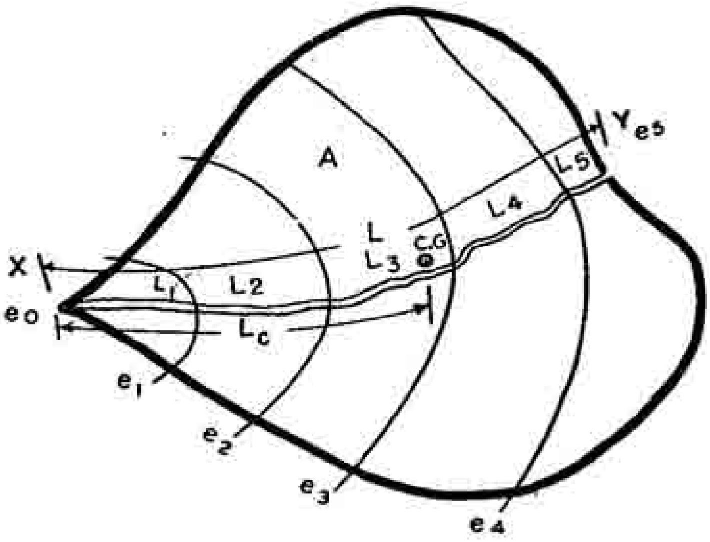
3.8 DRAWING OF REPRESENTATIVE UNITGRAPHS AND MEASURING THEIR PARAMETERS

The representative unitgraph is the unitgraph which reproduces in reasonable limits the direct surface runoff hydrographs corresponding to their effective rainfall of the storm from which it has been obtained. Representative 1-hour unitgraphs were drawn from a set of superimposed 1-hour unitgraphs for each of the 25 catchments and their parameters noted. The parameters of the representative unitgraphs illustrated in Fig.2 were measured for each of the catchments. The parameters of the representative unitgraphs are t_r, t_p, T_m, Q_p, q_p, W_{50}, W_{75}, W_{R50}, W_{R75} and T_B. These parameters for 25 catchments are listed in Table-3.

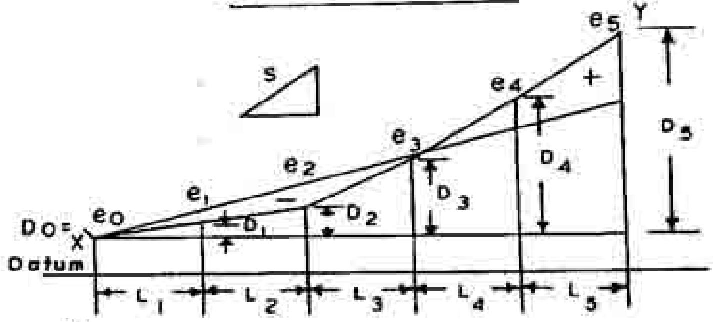
Table-3: REPRESENTATIVE-1-HOUR U.G. PARAMETERS SUBZONE 4(a), 4(b) & 4(c).

S.No.	Bridge No.	Subzone	T_R (Hrs.)	Q_p (cumecs)	q_p (Cumecs/Sq.Km)	t_r (Hr.)	T_B (Hr.)	W_{50} (Hr.)	W_{75} (Hr.)	WR_{50} (Hr.)	WR_{75} (Hr.)
1	2	3	4	5	6	7	8	9	10	11	12
1.	1584	4(c)	10.5	747.23	0.37	1	25	6.17	3.83	3.17	2.23
2.	784	4(a)	6.5	230.50	0.23	1	28	11.60	6.90	4.30	2.90
3.	1573	4(c)	10.5	221.66	0.22	1	36	10.40	3.70	3.20	1.50
4.	HOT 3	4(b)	8.5	149.13	0.18	1	30	15.40	9.70	5.50	3.80
5.	85	4(b)	6.5	251.51	0.32	1	26	8.00	4.60	3.10	2.00
6.	HOT 2	4(b)	7.5	200.00	0.26	1	33	8.60	4.00	4.40	1.40
7.	1541	4(c)	5.5	285.44	0.47	1	18	5.20	4.25	2.60	2.15
8.	HOT 1	4(b)	5.5	165.60	0.39	1	20	6.30	4.30	2.90	1.90
9.	252	4(b)	6.5	134.23	0.33	1	21	7.20	4.00	3.00	1.60
10.	346	4(b)	3.5	231.46	0.87	1	17	2.10	1.30	0.80	0.60
11.	194	4(b)	4.5	149.60	0.57	1	17	4.20	2.40	1.60	1.10
12.	929	4(a)	3.5	113.50	0.44	1	24	4.80	2.50	1.80	1.20
13.	1557	4(c)	4.5	52.99	0.21	1	25	12.50	7.60	3.00	2.20
14.	T-9	4(c)	4.5	89.00	0.41	1	18.	5.95	3.02	2.20	1.18
15.	330	4(b)	4.5	122.00	0.60	1	17	3.80	2.35	1.05	0.80
16.	1599	4(c)	5.5	83.32	0.43	1	22	4.80	2.10	1.30	0.60
17.	97	4(b)	2.5	80.10	0.53	1	12	4.80	2.60	1.80	1.20
18.	60	4(b)	2.5	62.80	0.65	1	15	3.15	1.75	1.20	0.67
19.	49	4(b)	3.5	77.00	0.83	1	13	2.20	1.05	0.90	0.45
20.	81	4(c)	1.5	45.00	0.53	1	15	4.70	2.38	0.65	0.48
21.	38 A	4(a)	1.5	77.10	1.04	1	7	2.60	1.60	1.10	0.70
22.	580	4(b)	2.5	36.81	0.52	1	20	4.00	2.20	1.40	1.00
23.	256	4(b)	3.5	35.40	0.54	1	18	4.93	2.48	1.65	1.08
24.	333	4(b)	1.5	42.20	0.87	1	8	2.80	1.80	1.05	0.80
25.	272	4(b)	1.5	56.47	1.32	1	6	1.96	1.15	0.65	0.40

FIG.- I



Catchment Plan



L - Section

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

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

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

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

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

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

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

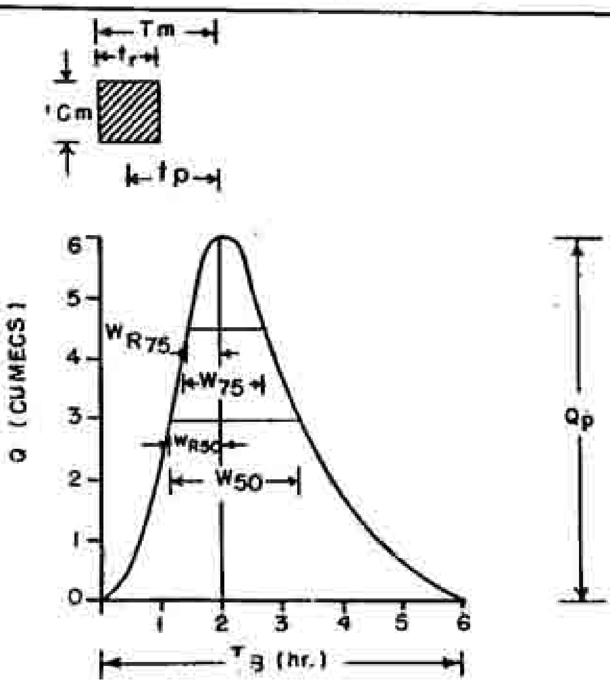
$(e_n - e_0)$ (m).

A = Catchment Area (Sq. km).

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

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (SMALL CATCHMENTS) DTE.	
PHYSIOGRAPHIC PARAMETERS	
DRAWN BY- 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 effective rainfall duration to the U.G peak (hr.)

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

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

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

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

T_B = Base width of Unit Hydrograph (hr.)

A = Catchment Area (Sq. km.)

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

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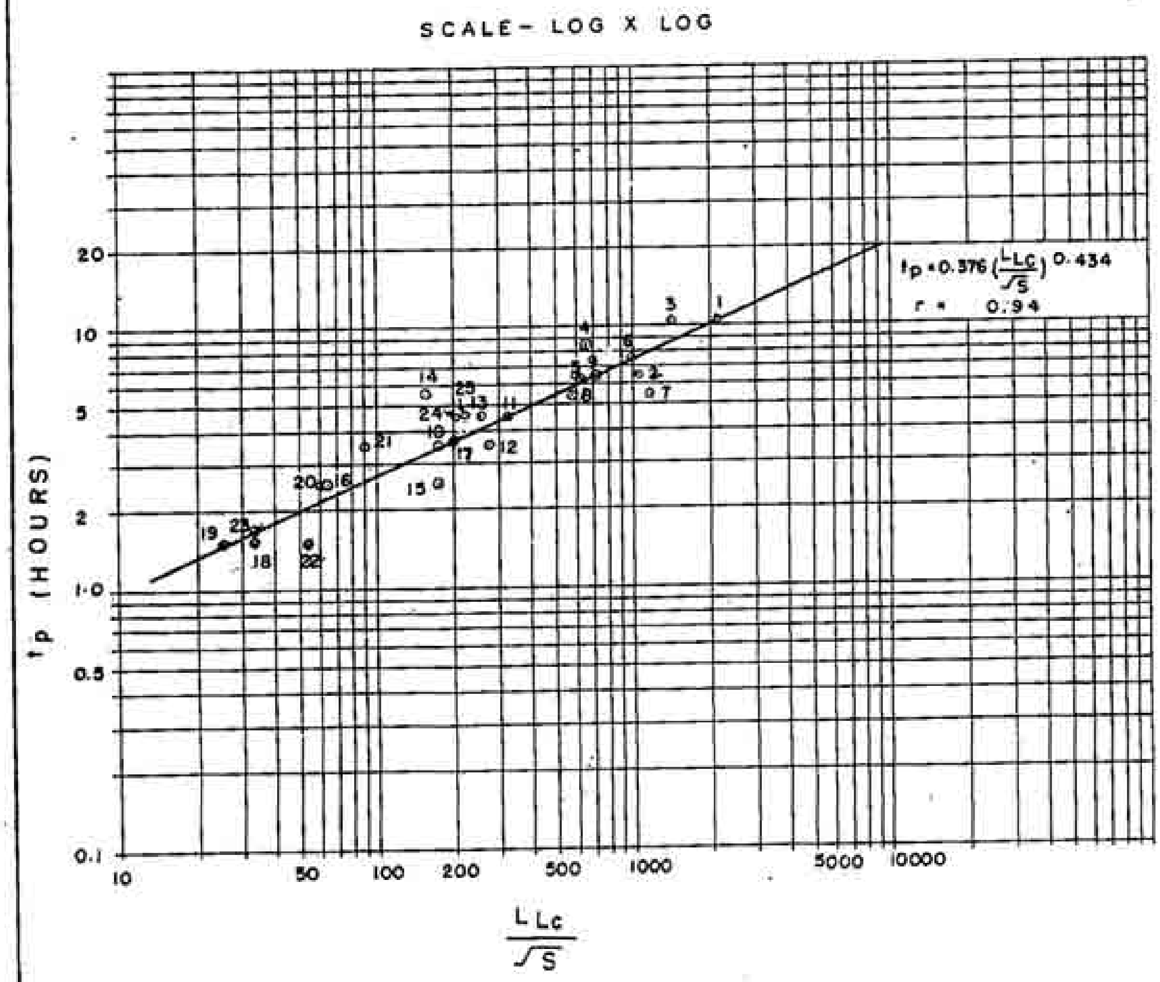
UNIT GRAPH PARAMETERS

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

FIG. 3.



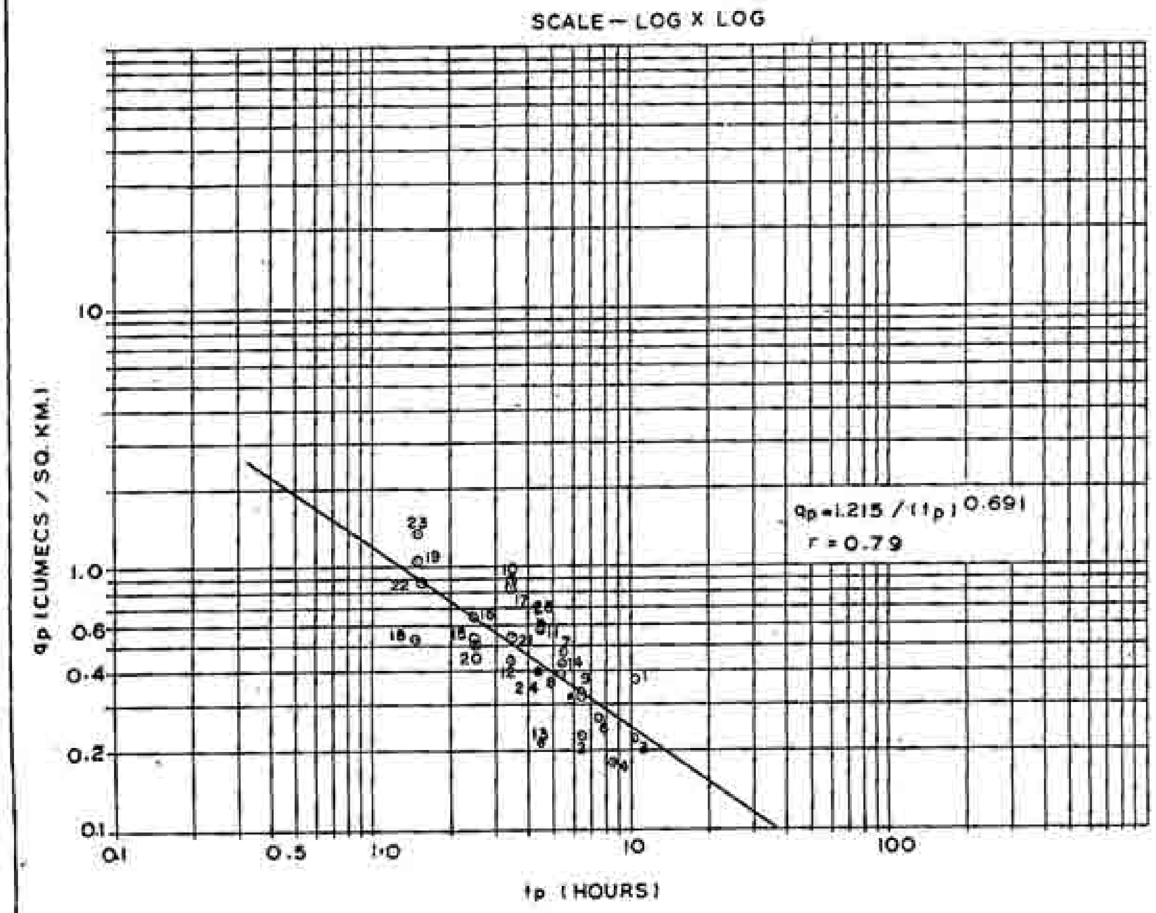
		ACTUAL	
SL. NO.	BRIDGE NO.	$\frac{L L_c}{\sqrt{S}}$	t_p (HOURS)
1	1584	2147.00	10.50
2	784	1075.64	6.50
3	1573	1414.57	10.50
4	MOT-3	647.61	8.50
5	85	633.03	6.50
6	MOT-2	975.40	7.50
7	1541	1185.53	5.50
8	MOT-1	585.33	5.50
9	252	708.32	6.50
10	346	174.34	3.50
11	194	327.20	4.50
12	929	278.36	3.50
13	1557	257.46	4.50
14	1599	155.05	5.50
15	97	178.25	2.50
16	60	63.65	2.50
17	49	200.50	3.50
18	81	33.70	1.50
19	38A	25.51	1.50
20	580	61.39	2.50
21	256	89.90	3.50
22	333	54.90	1.60
23	272	27.36	1.50
24	T-9	206.15	4.50
25	330	233.20	4.50

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

EASTERN COAST
(UPPER, LOWER & SOUTH) SUB ZONES 4 (a, b & c)
RELATION BETWEEN t_p AND $L L_c/\sqrt{S}$

DRAWN BY R.N. SHARMA, T.R. ARORA
CHECKED BY K.K. AICH

FIG. - 4



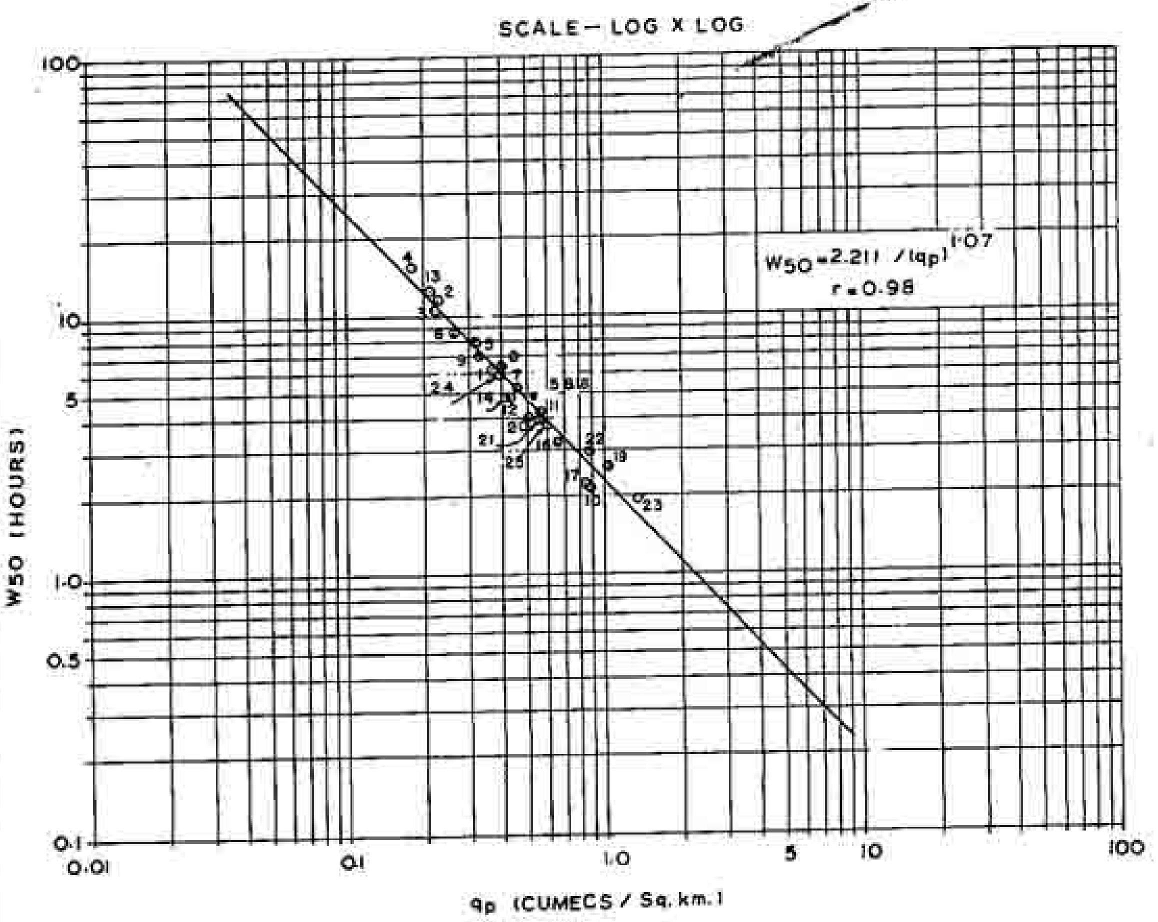
SL. NO.	BRIDGE NO.	ACTUAL t_p (HOURS)	ACTUAL q_p (Cums./Km²)
1	1584	10.50	0.370
2	784	6.50	0.225
3	1573	10.50	0.220
4	MOT-3	8.50	0.180
5	85	6.50	0.320
6	MOT-2	7.50	0.260
7	1541	5.50	0.470
8	MOT-1	5.50	0.390
9	252	6.50	0.330
10	346	3.50	0.870
11	194	4.30	0.570
12	929	3.50	0.440
13	1557	4.50	0.210
14	1599	5.50	0.430
15	97	2.50	0.330
16	60	2.50	0.650
17	49	3.50	0.830
18	81	1.50	0.530
19	38A	1.50	1.040
20	580	2.50	0.520
21	236	3.50	0.540
22	333	1.50	0.870
23	272	1.30	1.320
24	T-9	4.50	0.410
25	330	4.50	0.595

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

EASTERN COAST
(UPPER, LOWER & SOUTH)
SUB ZONES 4 (a, b & c)
RELATION BETWEEN
q_p AND t_p

DRAWN BY_	CHECKED BY_
T. R. ARORA R. N. SHARMA	K. K. AICH

FIG. - 5



SL. NO.	BRIDGE NO.	ACTUAL q_p (Cums. Km^2)	ACTUAL W 50 (HOURS)
1	1584	0.370	6.17
2	784	0.225	11.60
3	1573	0.220	10.40
4	MOT-3	0.180	15.40
5	85	0.320	8.00
6	MOT-2	0.260	8.60
7	1541	0.470	5.20
8	MOT-1	0.390	6.30
9	252	0.330	7.20
10	346	0.870	2.10
11	194	0.570	4.20
12	929	0.440	4.80
13	1557	0.210	12.50
14	1599	0.430	4.80
15	97	0.530	4.80
16	60	0.650	3.15
17	49	0.830	2.20
18	81	0.530	4.70
19	38A	1.040	2.60
20	580	0.520	4.00
21	256	0.540	3.93
22	333	0.870	2.80
23	272	1.320	1.95
24	T-9	0.410	5.95
25	330	0.595	3.80

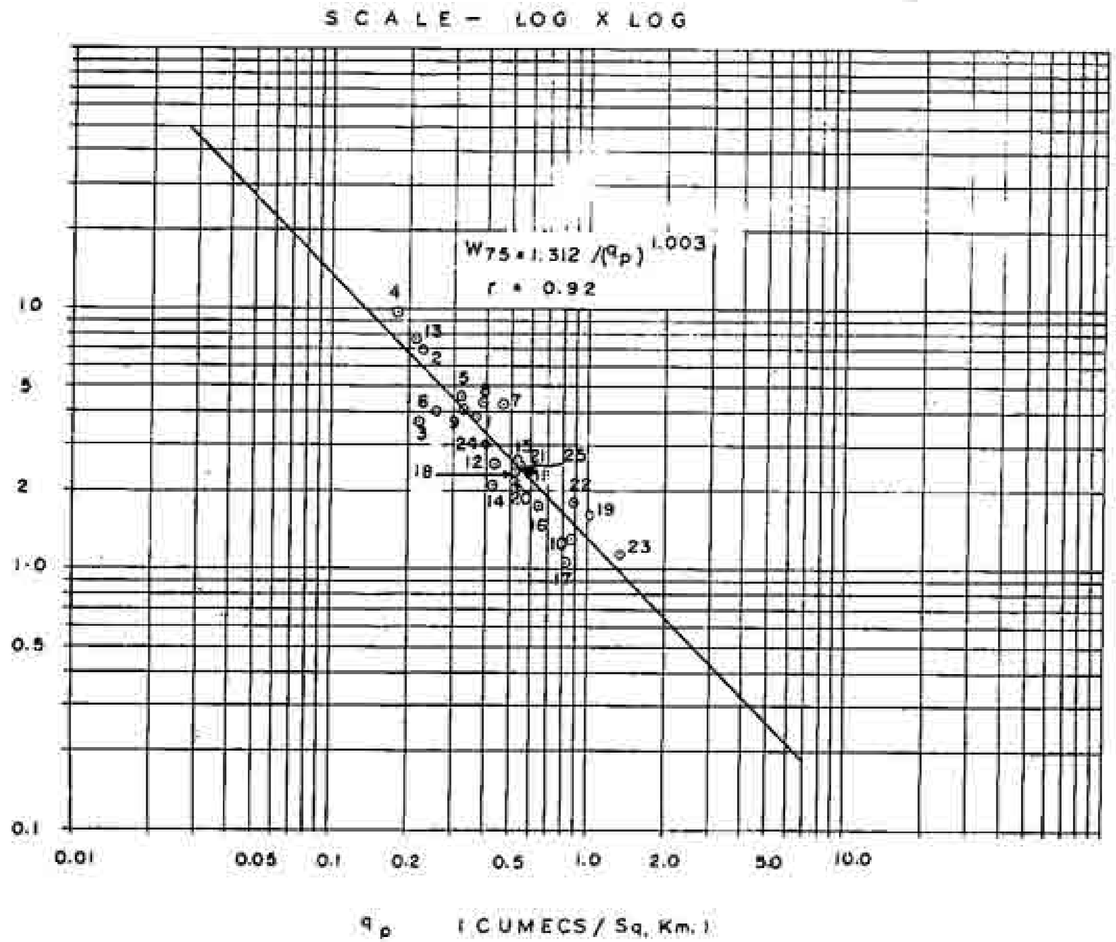
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.

EASTERN COAST
(UPPER, LOWER & SOUTH)
SUB ZONES 4 (a, b & c)
RELATION BETWEEN
W_{50} AND q_p

DRAWN BY- T.R.ARORA, R.N.SHARMA

CHECKED BY- K.K.AICH

FIG. - 6



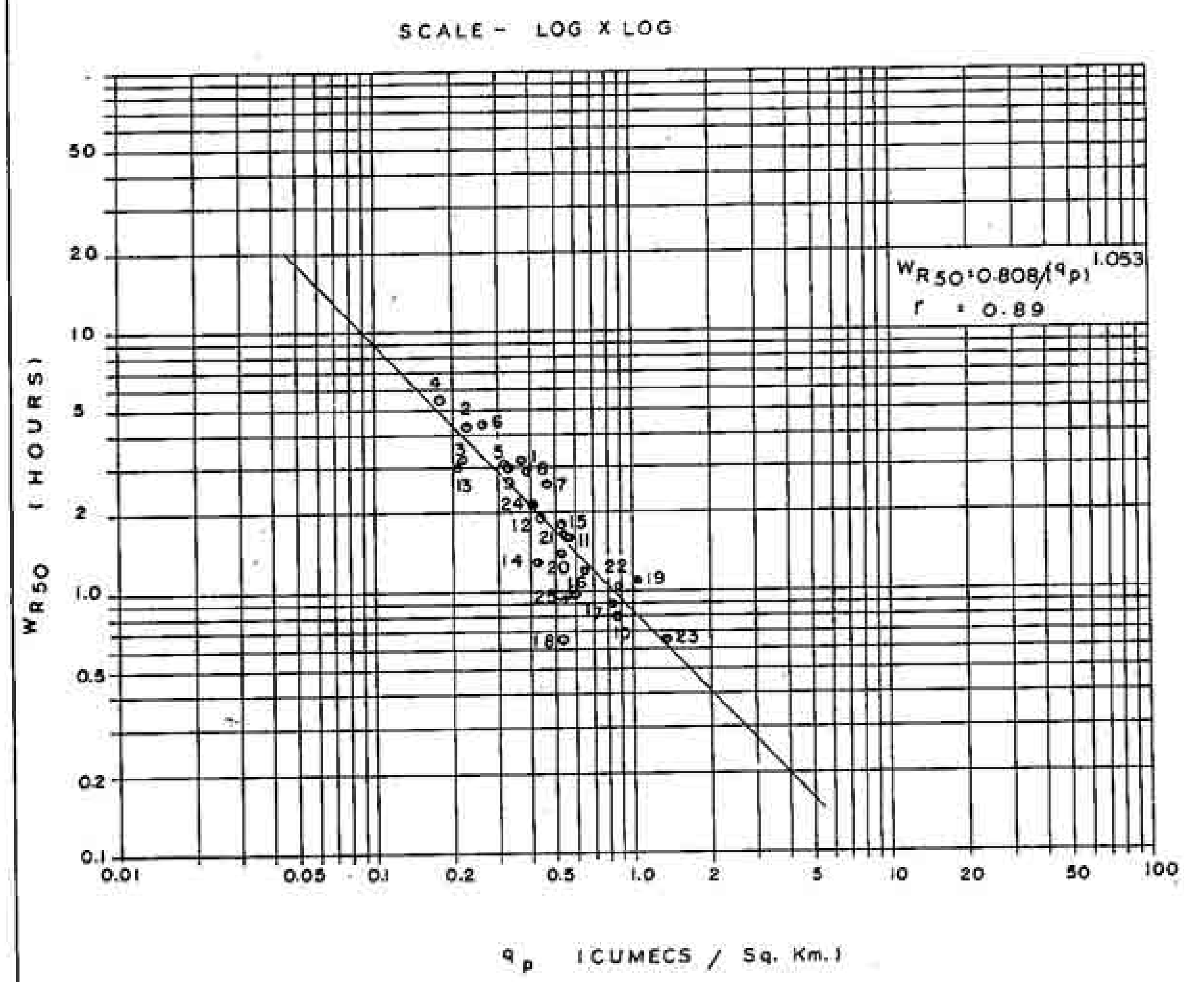
SL. NO.	BRIDGE NO.	ACTUAL q_p (Cums./Km²)	ACTUAL W_{75} (HOURS)
1	1584	0.370	3.83
2	784	0.225	6.90
3	1573	0.220	3.70
4	MOT-3	0.180	9.70
5	85	0.320	4.60
6	MOT-2	0.260	4.00
7	1541	0.470	4.25
8	MOT-1	0.390	4.30
9	252	0.330	4.00
10	346	0.870	1.30
11	194	0.570	2.40
12	929	0.440	2.50
13	1557	0.210	7.60
14	1599	0.430	2.10
15	97	0.530	2.60
16	60	0.650	1.75
17	49	0.830	1.05
18	81	0.530	2.38
19	38A	1.040	1.60
20	580	0.520	2.20
21	256	0.540	2.48
22	333	0.870	1.80
23	272	1.320	1.15
24	T-9	0.410	3.02
25	330	0.595	2.35

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

EASTERN COAST
(UPPER, LOWER & SOUTH)
SUB ZONES 4 (a, b & c)
RELATION BETWEEN
W_{75} AND q_p

DRAWN BY-	CHECKED BY-
T. R. ARORA R. N. SHARMA	K. K. AICH

FIG. - 7



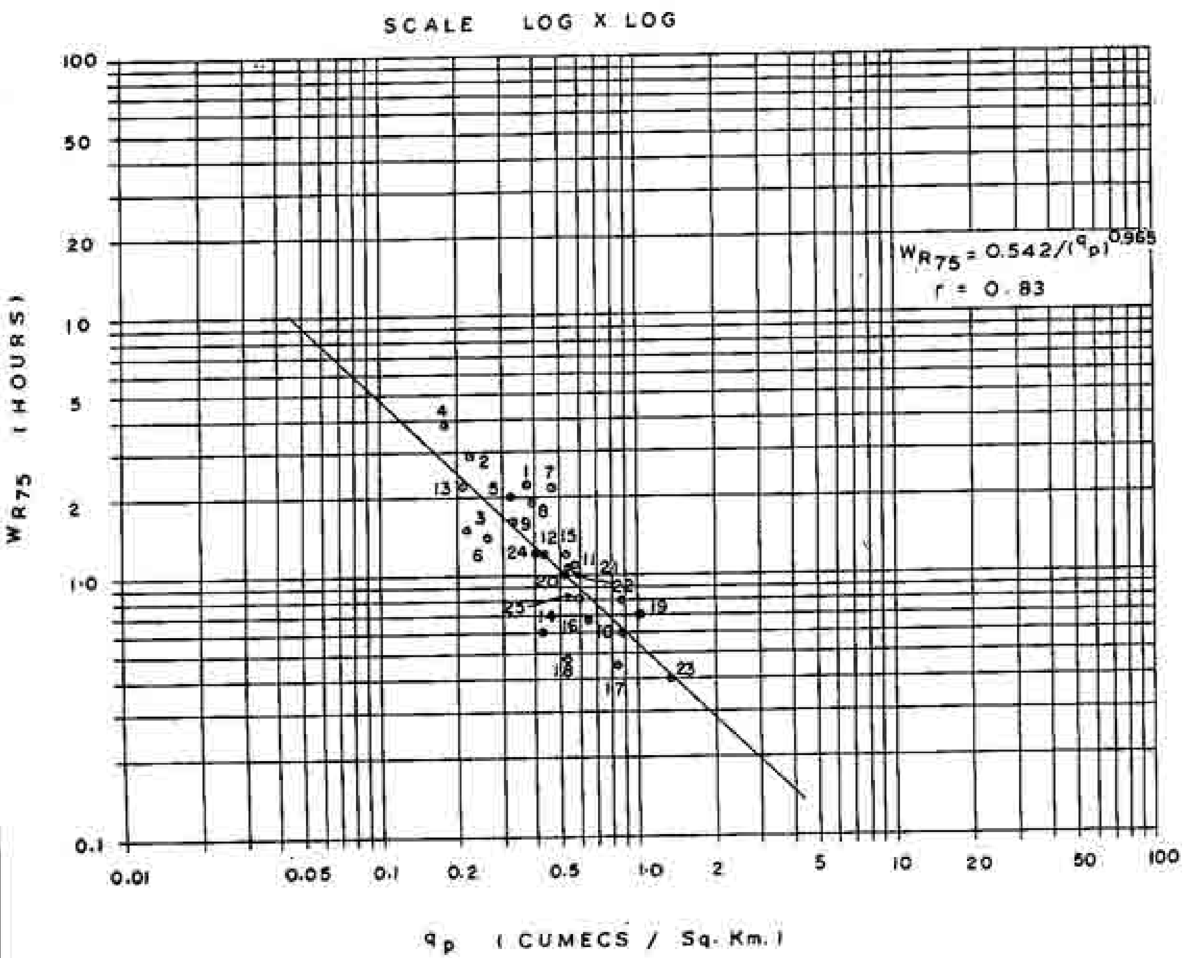
		ACTUAL	
SL. NO.	BRIDGE NO.	q_p (Cums./Km^2)	W_{R50} (HOURS)
1	1584	0.370	3.17
2	784	0.225	4.30
3	1573	0.220	3.20
4	MOT-3	0.180	5.50
5	85	0.320	3.10
6	MOT-2	0.260	4.40
7	1541	0.470	2.60
8	MOT-1	0.390	2.90
9	252	0.330	3.00
10	346	0.870	0.80
11	194	0.570	1.60
12	929	0.440	1.80
13	1557	0.210	3.00
14	1599	0.430	1.30
15	97	0.530	1.80
16	60	0.650	1.20
17	49	0.830	0.90
18	81	0.530	0.65
19	38 A	1.040	1.10
20	580	0.520	1.40
21	256	0.540	1.65
22	333	0.870	1.05
23	272	1.320	0.65
24	T-9	0.410	2.20
25	330	0.595	1.05

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

EASTERN COAST
(UPPER, LOWER & SOUTH)
SUB ZONES 4 (a, b & c)
RELATION BETWEEN
W_{R50} AND q_p

DRAWN BY_	CHECKED BY_
S. N. MALHOTRA L. P. NAUTIYAL	K. K. AICH

FIG.- 8



		ACTUAL	
SL. NO.	BRIDGE NO.	q_p (Cums./Km²)	WR 75 (HOURS)
1	1584	0.370	2.23
2	784	0.225	2.90
3	1573	0.220	1.50
4	MOT-3	0.180	3.80
5	85	0.320	2.00
6	MOT-2	0.260	1.40
7	1541	0.470	2.15
8	MOT-1	0.390	1.90
9	252	0.330	1.60
10	346	0.870	0.60
11	194	0.570	1.10
12	929	0.440	1.20
13	1557	0.210	2.20
14	1599	0.430	0.60
15	97	0.530	1.20
16	60	0.650	0.67
17	49	0.830	0.45
18	81	0.530	0.48
19	38A	1.040	0.70
20	580	0.520	1.00
21	256	0.540	1.08
22	333	0.870	0.80
23	272	1.320	0.40
24	T-9	0.410	1.18
25	330	0.595	0.80

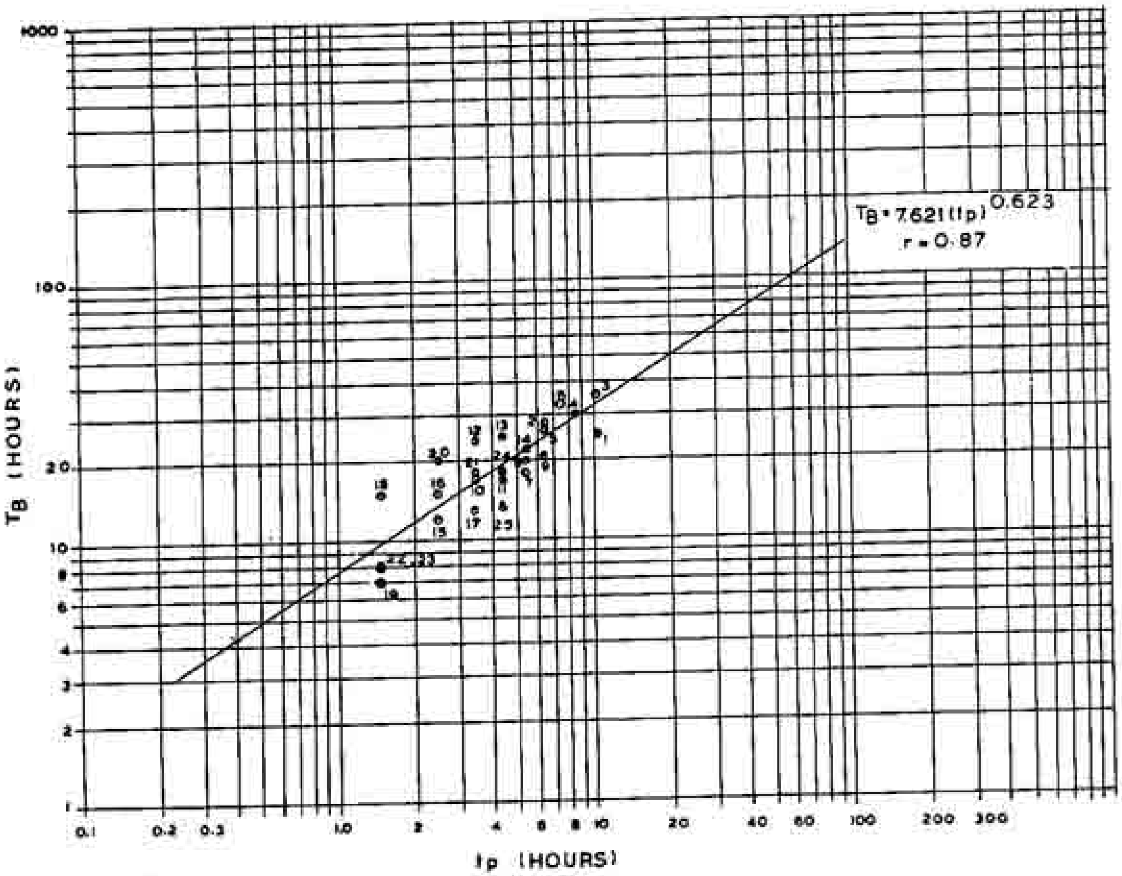
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.

EASTERN COAST
(UPPER, LOWER & SOUTH)
SUB ZONES 4 (a, b & c)
RELATION BETWEEN
W_{R75} AND q_p

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

FIG. – 9

SCALE — LOG X LOG



		ACTUAL	
SL. NO.	BRIDGE NO.	t_p (HOURS)	T_B (HOURS)
1	1584	10.50	25
2	784	6.50	28
3	1573	10.50	36
4	MOT-3	8.50	30
5	85	6.50	26
6	MOT-2	7.50	33
7	1541	5.50	18
8	MOT-1	5.50	20
9	225	6.50	21
10	346	3.50	17
11	194	4.50	17
12	929	3.50	24
13	1557	4.50	25
14	1589	5.50	22
15	97	2.50	12
16	60	2.50	15
17	49	3.50	13
18	81	1.50	15
19	38A	1.50	7
20	580	2.50	20
21	256	3.50	18
22	333	1.50	8
23	272	1.50	8
24	T-9	4.50	19
25	330	4.50	17

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

EASTERN COAST
(UPPER, LOWER & SOUTH)
SUB ZONES 4 (a, b & c)
RELATION BETWEEN
T_B AND t_p

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

CHECKED BY
K. K. AICH

3.9 ESTABLISHING RELATIONSHIPS BETWEEN PHYSIOGRAPHIC AND REPRESENTATIVE UNITGRAPH PARAMETERS

Physiographic parameters like L, L_c, S and A and the parameters of 1-hour unitgraphs like t_p, Q_p, T_B, W_{50}, W_{75}, W_{R50}, W_{R75}, for 25 gauged catchments out of 37 catchments in subzones-4(a), 4(b) and 4(c) were estimated as shown in Table-2 and 3 respectively. Following simple model was adopted for establishing the relationships between these parameters:

$$Y = C X^p \quad \text{... 3.9.1}$$

where

Y = Dependent variable

X = Independent variable

C = A constant

P = An exponent

From equation 3.9.1, it follows that

$$\text{Log } Y = \text{Log } C + p \text{ Log } X \quad \text{... 3.9.2}$$

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

Various trials of relationships between the physiographic parameters and one of the unitgraphs parameters and among the unitgraph parameters themselves were made. The relationship between the physiographic parameters $LL_c/\sqrt{S}$ and time lag of the U.G. (t_p) was found to be significant. The relationship between q_p and t_p was significant. Similarly, the relationships between q_p were individually found to be significant with the U.G. parameters of t_p, W_{50}, W_{75}, W_{R50} and W_{R75} as dependent variables. The time base (T_B) could be significantly correlated to (t_p). Principle of least squares was used in the regression analysis to get the above relationship in equation 3.9.1 above to predict the parameters of the Synthetic Unitgraph in an unbiased manner.

The following relationships have been derived for estimating the 1-hour unitgraph parameters in the subzones-4(a), 4(b) and 4(c).

Sl. No.	Relationship	Corr. Coeff.	Equ. No.	Fig. No.
1	2	3	4	5
1.	$t_p = 0.376 \left[\frac{(LL_c)}{(\sqrt{S})} \right]^{0.434}$	0.94	3.9.3	3

3.9 ESTABLISHING RELATIONSHIPS BETWEEN PHYSIOGRAPHIC AND REPRESENTATIVE UNITGRAPH PARAMETERS

Physiographic parameters like L, L_c, S and A and the Parameters of 1-hour unitgraphs like t_p, Q_p, T_B, W_{50}, W_{75}, W_{R50}, W_{R75}, for 25 gauged catchments out of 37 catchments in subzones-4(a), 4(b) and 4(c) were estimated as shown in Table-2 and 3 respectively. Following simple model was adopted for establishing the relationships between these parameters:

$$Y = C X^p \qquad \text{... 3.9.1}$$

where

Y = Dependent variable

X = Independent variable

C = A constant

P = An exponent

From equation 3.9.1, it follows that

$$\text{Log } Y = \text{Log } C + p \text{ Log } X \qquad \text{... 3.9.2}$$

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

Various trials of relationships between the physiographic parameters and one of the unitgraphs parameters and among the unitgraph parameters themselves were made. The relationship between the physiographic parameters $LL_c/\sqrt{S}$ and time lag of the U.G. (t_p) was found to be significant. The relationship between q_p and t_p was significant. Similarly, the relationships between q_p were individually found to be significant with the U.G. parameters of t_p, W_{50}, W_{75}, W_{R50} and W_{R75} as dependent variables. The time base (T_B) could be significantly correlated to (t_p). Principle of least squares was used in the regression analysis to get the above relationship in equation 3.9.1 above to predict the parameters of the Synthetic Unitgraph in an unbiased manner.

The following relationships have been derived for estimating the 1-hour unitgraph parameters in the subzones-4(a), 4(b) and 4(c).

Sl. No.	Relationship	Corr. Coeff.	Equ. No.	Fig. No.
1	2	3	4	5
1.	$t_p = 0.376 \left[\frac{(LL_c)}{(\sqrt{S})} \right]^{0.434}$	0.94	3.9.3	3

1	2	3	4	5
2.	$q_p = 1.215/(t_p)^{0.691}$	0.79	3.9.4	4
3.	$W_{50} = 2.211/(q_p)^{1.07}$	0.98	3.9.5	5
4.	$W_{75} = 1.312/(q_p)^{1.003}$	0.92	3.9.6	6
5.	$W_{R50} = 0.808/(q_p)^{1.053}$	0.89	3.9.7	7
6.	$W_{R75} = 0.542/(q_p)^{0.965}$	0.83	3.9.8	8
7.	$T_B = 7.621\ (t_p)^{0.623}$	0.87	3.9.9	9

$$Q_p = q_p \times A$$

$$T_m = t_p + (t_r/2)$$

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

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

Considering the hydro-meteorological homogenity of subzones-4(a), 4(b) and 4(c), the relations established between physiographic and unitgraph parameter in Section 3.9 for 25 representative catchments are applicable for derivation of 1-hour Synthetic Unitgraph for an ungauged catchment in these subzones.

The steps for derivation of 1-hour unitgraph are:

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

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

$$t_p = 0.376(LL_c/\sqrt{S})^{0.434}$$ to obtain t_p in hrs.

t_p is rounded of to nearest multiple of 0.5 hr.

$$T_m = t_p + t_r/2 = (t_p + 0.5) \text{ hours.}$$

iii) Substitute t_p in the following equation 3.9.4

$$q_p = 1.215/(t_p)^{0.691}$$ to obtain q_p in cumecs/sqkm.

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

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

$$W_{50} = 2.211/(q_p)^{1.07}$$

$$W_{75} = 1.312/(q_p)^{1.003}$$

$$W_{R50} = 0.808/(q_p)^{1.053}$$

$$W_{R75} = 0.542/(q_p)^{0.965}$$

v) Substitute t_p in the following equation 3.9.9

$$T_B = 7.621(t_p)^{0.623}$$ to obtain T_B in hours. (rounded of to nearest full hour).

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

$$d = \frac{0.36 \times \sum (Q_i \times t_r)}{A} \quad \text{... 3.9.10}$$

where d = depth of direct runoff in cm

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

A = catchment area in sqkm

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

3.11 DESIGN LOSS RATE

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

Following method of estimating the model loss rate was adopted:

Constant loss rates were estimated based on various selected observed storm rainfall and flood events of reasonably higher magnitudes for derivation of unitgraphs. About 161 flood events were analysed for 26 bridge catchments. The number of flood occasions at intervals of 0.50 cm/hr were tabulated. Out of 161 flood events, 143 flood events have been considered for estimating the modal loss rate. In other words, the frequency (number of total occasions) of loss rates under each loss rate ranges in Table-4 shows that the maximum number of occasions (f_m) is 49 for loss rate ranges of 0.51 to 1.00 cm/hr. with its lower limit of 0.51 cm/hr (l) preceded by 45 occasions (f_1) for a range of 0 to 0.50 cm/hr and succeeded by 21 occasions (f_2) for range of 1.01 to 1.50 cm/hr with range interval (h).

The modal value is given by the formula:

$$\text{Modal} = l + \frac{f_m - f_1}{2f_m - f_1 - f_2} \times h$$

$$= 0.51 + \frac{(49 - 45)}{2 \times 49 - 45 - 21} \times 0.50$$

$$= 0.57 \text{ cm/hr say rounded off to } 0.60 \text{ cm/hr}$$

The modal value of loss rate therefore works out to 0.60 cm/hr.

It may further be seen from Table-4 that 133 (about 82%) flood events out of a total of 161 fall in the loss rate range of 0.01 to 1.50 cm/hr. The average loss rate of 0.75 cm/hr in the loss rate range of 0 to 1.50 cm/hr may be considered reasonable in view of the modal loss rate of 0.60 cm/hr. The Design Loss Rate of 0.75 cm/hr is recommended for adoption.

3.12 DESIGN BASE FLOW

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

$$q_b = 0.536/(A)^{0.523}$$

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

TABLE-4: LOSS RATE RANGES (cm/hr) - NUMBER OF FLOOD OCCASIONS

S.No.	Br.No.	C.A.(sq.Km)	LOSS RATE RANGES (cm/hr) 0.01 to 0.50	0.51 to 1.00	1.01 to 1.50	1.51 to 2.00	2.01 to 2.50	2.51 to 3.00	3.01 to 3.50	Total
1	2	3	4	5	6	7	8	9	10	11
			Number of Flood Occasions							
1.	1584	2015.00	5	2	-	-	-	-	-	7
2.	784	1024.47	-	1	1	1	-	-	-	3
3.	1573	1023.00	1	3	-	-	-	-	-	4
4.	MOT 3 4(b)	843.00	3	1	-	-	1	1	-	6
5.	85	785.00	-	2	-	-	-	-	-	2
6.	MOT 2 4(b)	760.00	6	3	-	-	-	-	-	9
7.	1541	608.65	-	2	1	-	-	-	-	3
8.	MOT 4(c) PAMERU	478.00	6	1	-	1	-	-	-	8
9.	252	401.32	4	7	1	2	-	1	-	15
10.	MOT 3 4(c)	275.00	2	2	1	-	-	-	-	5
11.	346	266.76	4	2	3	-	-	-	-	9
12.	194	264.18	6	1	-	-	-	-	-	7
13.	179	262.57	3	4	4	-	-	-	-	11
14.	313	258.55	1	1	1	1	-	-	-	4
15.	929	256.13	2	1	1	2	1	-	-	7
16.	1557	247.14	2	-	2	1	2	-	-	7
17.	1599	194.90	1	3	1	-	-	-	-	5
18.	97	150.68	5	1	-	-	-	-	-	6
19.	60	96.60	2	3	1	1	-	-	-	7
20.	49	93.24	2	3	-	-	1	-	-	6
21.	81	85.41	1	1	-	-	-	-	-	2
22.	384	74.21	2	-	-	-	-	-	-	2
23.	580	70.60	3	3	1	1	-	-	-	8
24.	256	65.79	-	-	-	2	1	-	-	3
25.	333	48.30	2	2	2	2	1	-	-	9
26.	272	42.94	-	-	1	1	1	2	1	6
	Total:		63	49	21	15	8	4	1	161

4.0 DESIGN STORM INPUT

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

4.1 Design Storm Duration

The duration of the storm rainfall which causes the maximum discharge in a drainage basin is called the design storm duration (T_D). The design storm duration (T_D) for a catchment is adopted equal to 1.1 times basin lag (t_p) of 1-hr synthetic unit hydrograph, for this subzone based on sample studies.

$$T_D = 1.1\ t_p = 0.414\ (LL_c/\sqrt{S})^{0.434}$$

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

4.2 RAINFALL DEPTH DURATION FREQUENCY STUDIES

India Meteorological Department have conducted this study on the basis of 24 self recording raingauge stations and 376 ordinary raingauge stations maintained by I.M.D./States and 43 S.R.R.G. Stations maintained by Railways in 10 bridge catchments in subzones - 4 (a) 4 (b) and 4 (c).

The annual maximum series for all the ordinary raingauge stations in and around the subzone were computed for each stations from the daily rainfall data of the stations for the period varying from 50 to 70 years of records. The annual extreme value series were subjected to frequency analysis by Gumbel's extreme value distribution and the rainfall estimates for 50 year return period were computed. The daily values of rainfall estimates were converted into 24 hour rainfall estimates by using the conversion factor of 1.15. These 24 hour rainfall estimates for all the stations in the subzone were plotted on a base map of the subzone and isopluvial map for 50 year return period was drawn. The isopluvial (point rainfall) maps for 24-hr duration with 50-yr return period are shown in Plates 9.4 (a) to 9.4 (c) respectively.

Similarly the isopluvial (point rainfall) maps for 24-hr duration with 25-yr and 100-yr return periods are also shown in Plates 8.4 (a) to 8.4 (c) and 10.4 (a) to 10.4 (c) respectively.

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

The ratios of short durations (1,3,6,9,12,15 and 18 hours) rainfall estimates with respect to 24-hr. rainfall estimates were worked out for all the SRRG Stations in the subzones. The average values of the ratio for each specified duration was computed for the subzone assuming the subzone as a unit. The ratios for various short durations to be adopted for converting 24-hr. rainfall into short duration rainfall are given below:

Duration	Ratio
24	1.00
18	0.94
15	0.90
12	0.84
9	0.77
6	0.69
3	0.58
1	0.42 (0.35)*

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

* It is however suggested that stations located very near to coast, a ratio of 0.35 may be adopted for one hour duration.

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

The short duration rainfall estimates for various short durations (1,3,6,9,12,15 and 18 hours) can be computed by using the respective ratios. The value of 24-hr rainfall estimate for a particular station for 50-year return period can be interpolated from plate 9.4 (a) to 9.4 (c) and the short duration rainfall estimate can be obtained by multiplying 24-hr rainfall by the corresponding ratio for that particular short duration.

The above ratios may also be adopted for estimating 25-yr and 100-yr rainfall for various short durations from 24-hr isopluvial maps of 25-yr and 100-yr return period.

4.3 TIME DISTRIBUTION STUDIES

The time Distribution Studies have been carried out by the India Meteorological Department for the following rainfall durations:

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

5007 rain storms of various durations upto 24 hours occurring in various parts of the subzone were analysed based on 297 stations year data. Rain storms selected at each station were grouped under the above 5 categories and plotted on different graphs as dimensionless curves with cumulative percentage of the total rainfall along the ordinate and the percentage of the storm duration along the abscissa. 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 were drawn for storms of different durations and are shown in Fig.11(a) to (e).

4.4 POINT TO AREAL RAINFALL

The short duration rainfall data of only 10 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 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 2-year areal rainfall depth series thus obtained was subjected to frequency analysis and 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.12 (a) and 12(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-5.

4.5 25-YEAR AND 100-YEAR 24-Hour POINT RAINFALL MAPS

For those interested in the 25-yr and 100-yr flood, point rainfall maps (Plates 8.4 (a) to 8.4 (c) and 10.4 (a) to 10.4 (c) in section 4.2 may be used. Similarly short duration rainfall ratios in Section 4.2, time distribution curves in Section 4.3 and point to areal rainfall percentages or curves in Section 4.4 are also applicable to 25-yr and 100-yr storm rainfall. Synthetic unitgraph in Section 3.9, design lossrate in Section 3.11 and design base flow in Section 3.12 are applicable for estimation of 25-yr and 100-yr flood.

4.5.1 Maximum 1-day rainfall values at raingauge stations district-wise in the Eastern Coast Region are shown in Table-6 for reference of the users.

4.6 PROCEDURE FOR ESTIMATION OF DESIGN STORM RAINFALL

The following procedure is recommended to be adopted for estimation of critical distribution of storm rainfall to cause the maximum flood due to rainfall of a specified duration.

Step-1 Estimate $T_D = 0.414 (L L_c / \sqrt{S})^{0.434}$ (rounded off to the nearest full hour) by substituting the known values of L, L_c and S for the catchment under study.

Step-2 Locate bridge catchment area under study on the 50-yr 24-hr rainfall isopluvial maps (Plate-9.4 (a) to 9.4 (c) to obtain the 50-yr 24-hr point rainfall value in cms. For catchment covering more than one isohyet, compute the average point storm rainfall.

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

Step-4 Convert the 50-yr T_D-hr point rainfall to 50-yr T_D-hr areal rainfall by multiplying with the areal reduction factor (ARF) corresponding to catchment area and for T_D-hr duration from Table-4 or by interpolation from Fig.11 (a) and 11 (b) in Section 4.4.

Step-5 Apply the cumulative percentage of total rainfall against the cumulative percentage of storm duration curves in Fig.12 or from Table A-3 corresponding to design storm duration T_D to obtain the depths at 1-hr interval from 1-hr to T_D-hrs. since the unit duration of synthetic U.G. is 1-hour.

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

TABLE - 5: AREAL TO POINT RAINFALL RATIOS (PERCENTAGE) FOR SOBZONE - 4 (a, b & c)

Area in (sqkm)	DURATIONS (hrs.)				
	1	3	6	12	24
(1)	(2)	(3)	(4)	(5)	(6)
0	100	100	100	100	100
50	92	94	95	96	97
100	85	88	91	94	95
150	79	84	87	92	94
200	75	81	84	89	92
250	72	78	82	87	91
300	-	76	81	86	90
350	-	74	79	84	89
400	-	-	77	83	88
450	-	-	76	82	87
500	-	-	76	80	86
600	-	-	-	78	85
700	-	-	-	77	84
800	-	-	-	76	83
900	-	-	-	75	82
1000	-	-	-	74	81
1500	-	-	-	71	80
2000	-	-	-	-	79
2500	-	-	-	-	79

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

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

TABLE-6: MAXIMUM OBSERVED 1-DAY RAINFALL AT RAINGAUGE STATIONS DISTRICTWISE IN EASTERN COAST REGION

Station	District	Maximum Observed 1-day Rainfall (cm)	Date
Tamil Nadu			
Sriperumbuden	Chingleput	41.6	10.10.1943
Kanchepuram	Chingleput	45.7	10.10.1943
Wallajah	North Arcot	30.3	20.11.1912
Cuddalore	South Arcot	57.2	1.05.1943
Ayikudi	Tirunelveli	31.2	16.12.1923
Magapattinam	Tanjore	40.3	5.12.1983
Tranqubar	Tanjore	38.0	25.11.1932
Kodaikanal (O)	Madurai	34.6	16.11.1935
Vattanam	Ramanathapuram	43.9	2.12.1955
Vedaraniyam	Tanjavur	50.0	18.11.1918
Jayamkaudam	Trichunappalli	41.5	10.11.1913
Andhra Pradesh			
Sattenapally	Guntur	38.6	19.11.1879
Sitapall	Kanyakumari	30.5	30.11.1922
Itchapur	Srikakulam	35.1	19.11.1923
Konda	Visakhapalnam	38.7	18.11.1923
Kakinoda	E.Godavari	50.1	2.06.1941
Bhimavaram	W.Godavari	33.4	31.08.1964
Tada	Nellore	42.0	8.10.1943
Puttur	Chittoor	44.7	10.11.1960
Nandyal	Kurnool	38.9	23.05.1952
Venukonda	Ongole/Guntur	32.0	20.12.1906
Vijaywada	Krishna	32.4	17.05 1925
Rajamundry	E.Godavari	33.4	26.09.1908
Orissa			
Jeypore	Karaput	32.7	3.08.1910
Puri (o)	Puri	31.6	3.10.1928
Mohana	Ganjam	32.7	10.10.1928
Phulbani	Bedhphulbani	32.3	28.06.1925
Kerala			
Devikulam	Kottayan	48.4	17.07.1924
Nendumangal	Trivandrum	31.7	28.11.1970

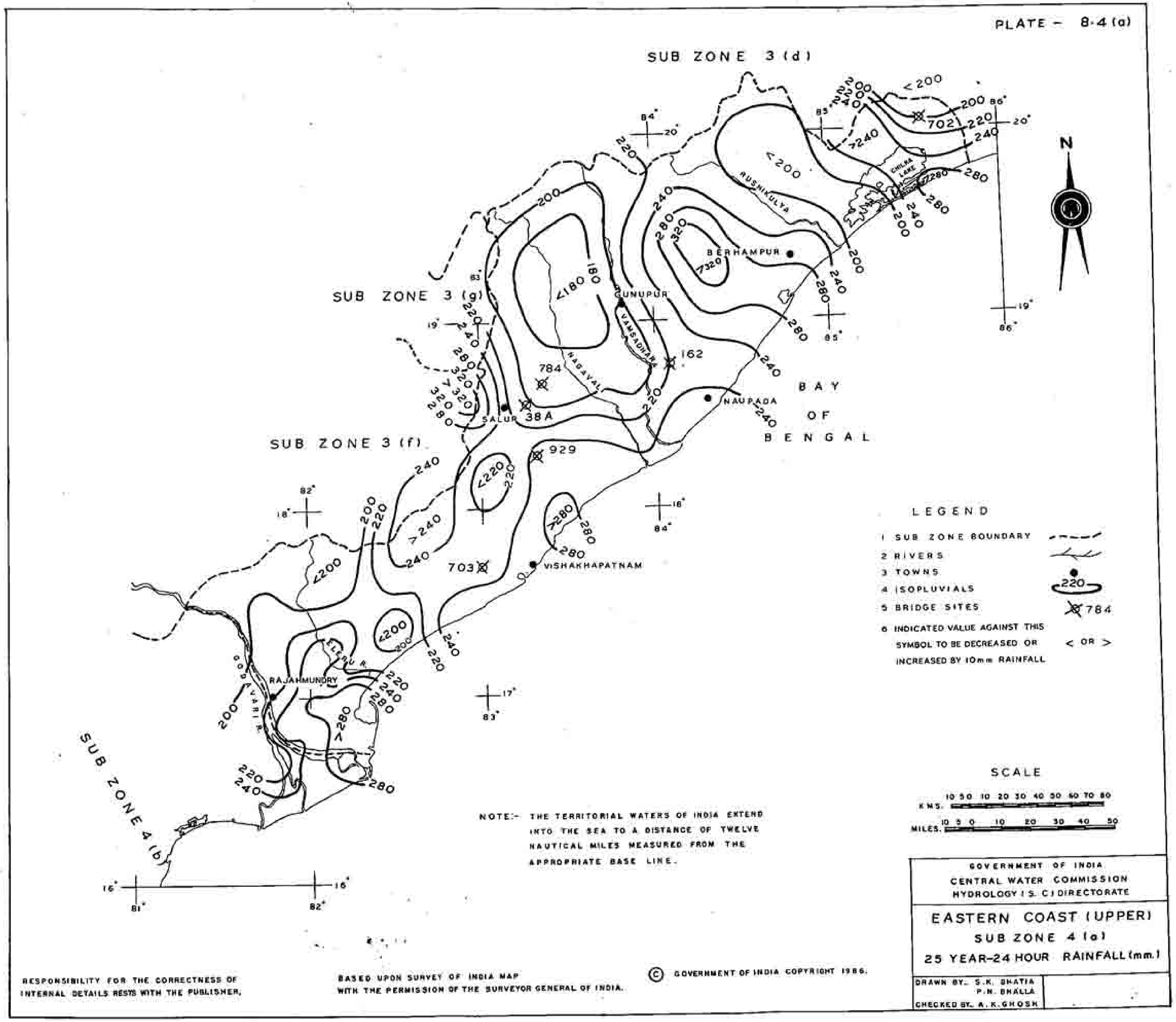


PLATE – 8.4 (a)
SUB ZONE 3 (d)
SUB ZONE 3 (g)
SUB ZONE 3 (f)
SUB ZONE 4 (b)
BAY OF BENGAL
BERHAMPUR
GUNUPUR
SALUR
NAUPADA
VISHAKHAPATNAM
RAJAHMUNDRY
RUSHIKULYA
VAMSADHARA
NAGAVALI
GODAVARI R.
ELERU R.
CHILKA LAKE
N
LEGEND
1 SUB ZONE BOUNDARY
2 RIVERS
3 TOWNS
4 ISOPLUVIALS
5 BRIDGE SITES
6 INDICATED VALUE AGAINST THIS SYMBOL TO BE DECREASED OR INCREASED BY 10mm RAINFALL
< OR >
SCALE
KMS.
MILES.
NOTE:- THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S. C) DIRECTORATE
EASTERN COAST (UPPER)
SUB ZONE 4 (a)
25 YEAR-24 HOUR RAINFALL (mm.)
DRAWN BY.. S.K. BHATIA
P.N. BHALLA
CHECKED BY.. A.K. GHOSH
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER.
BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.
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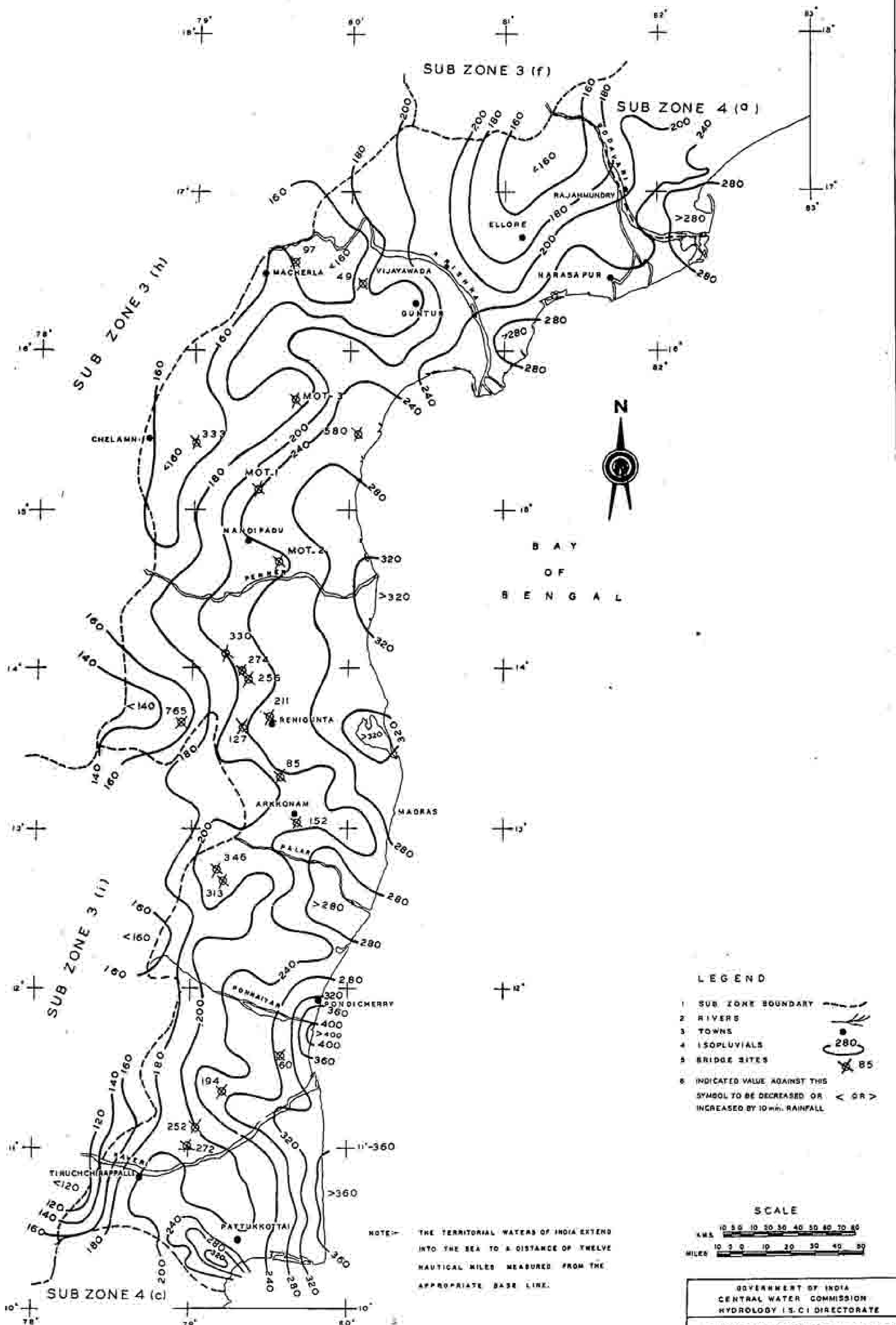
PLATE-8.4 (b)



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

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

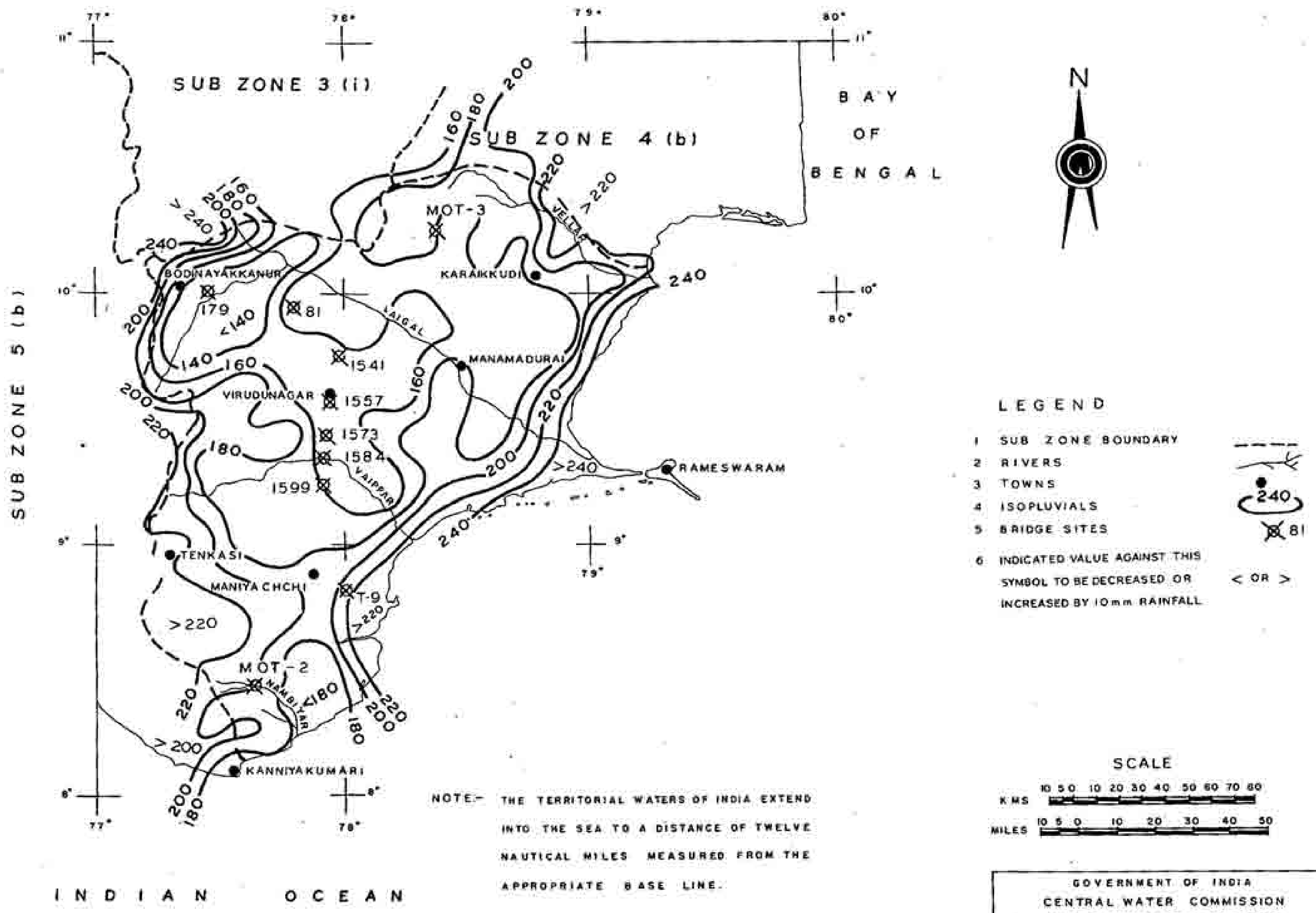
EASTERN COAST (LOWER)
SUB ZONE 4 (b)
25 YEAR 24-HOURS RAINFALL (mm)

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

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

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

PLATE - 8.4 (c)



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

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

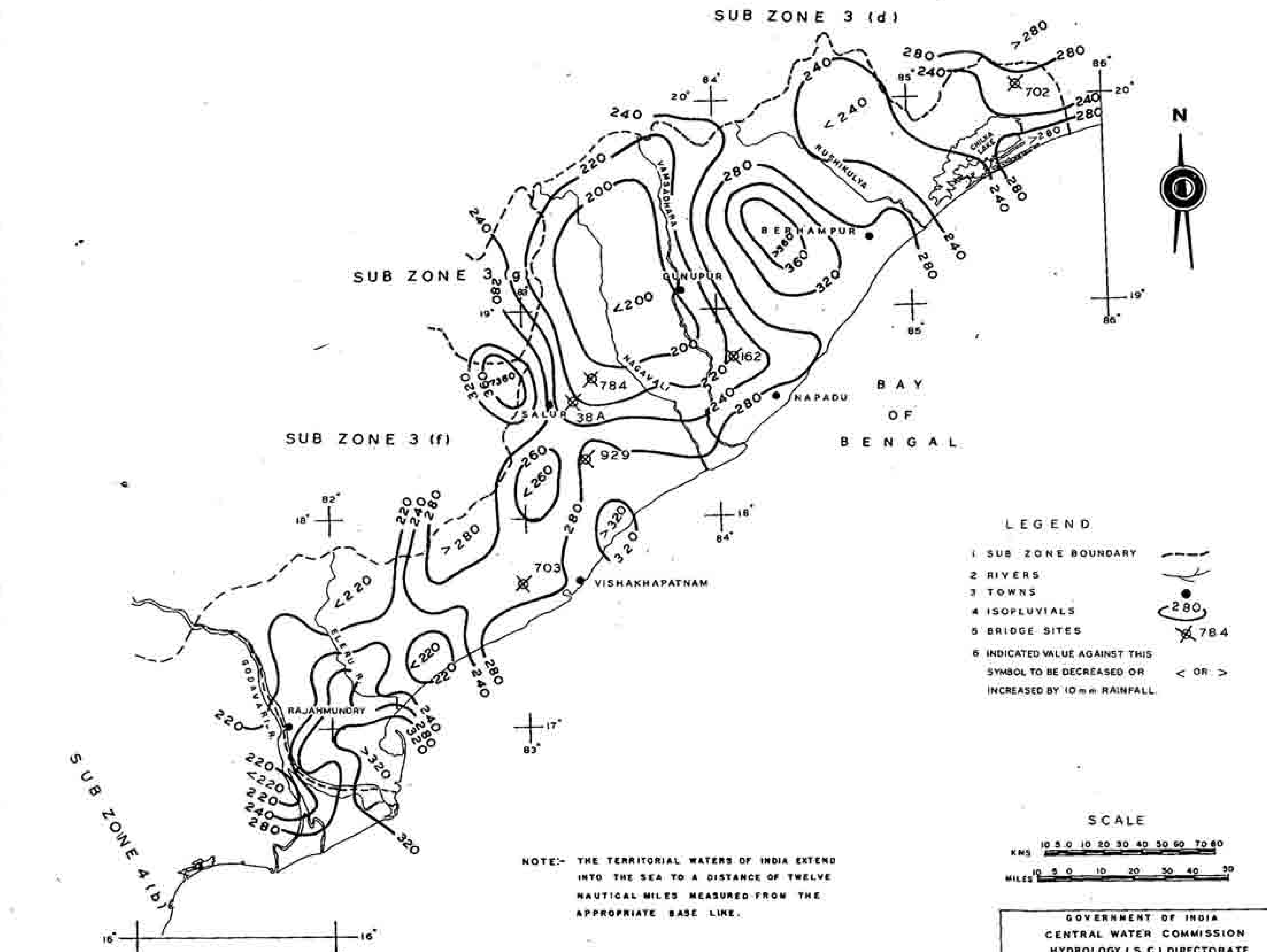
EASTERN COAST (SOUTH)
SUB ZONE 4 (c)
25 YEAR 24-HOUR RAINFALL (mm)

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

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

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

PLATE – 9.4 (a)



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

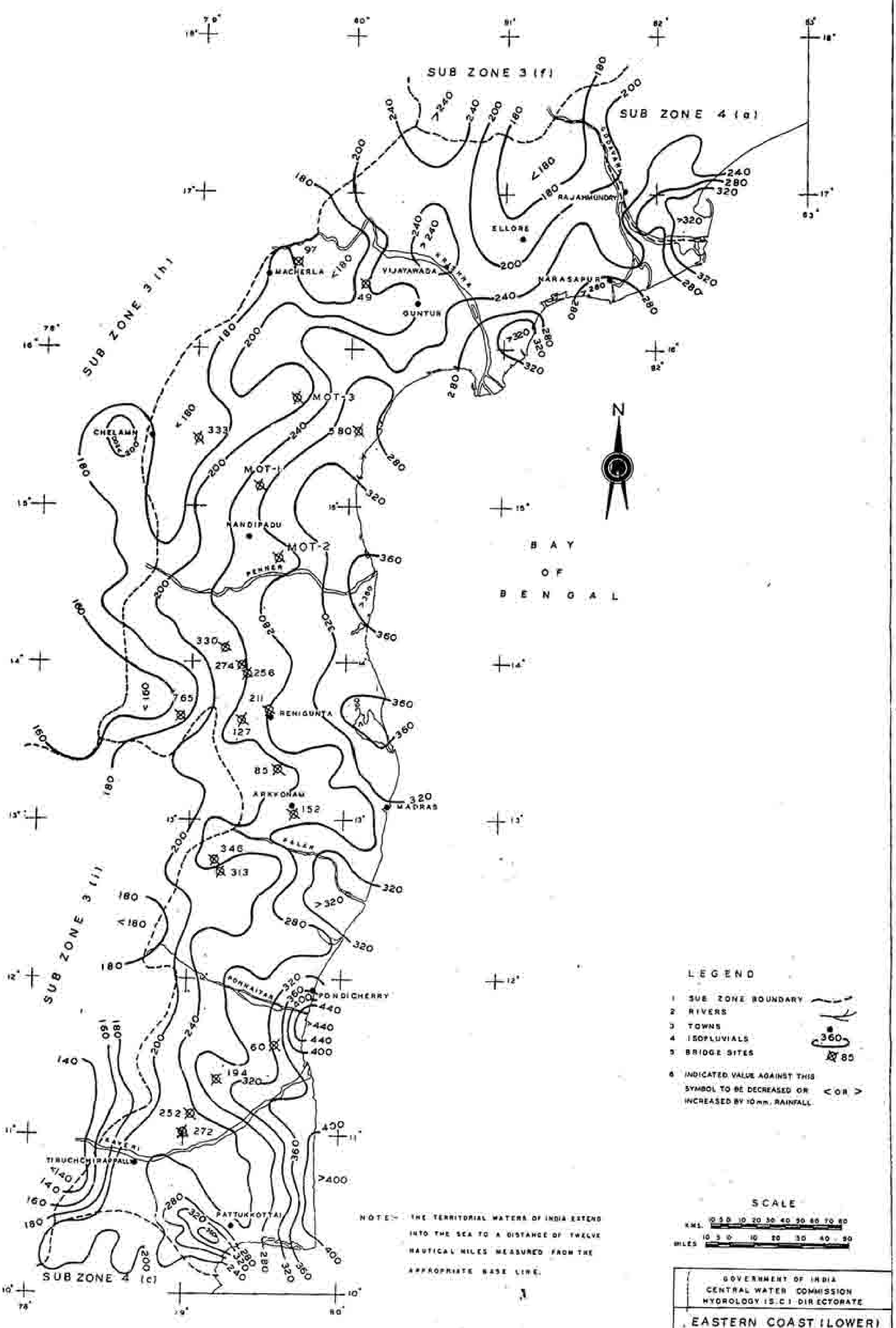
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S.C) DIRECTORATE

EASTERN COAST (UPPER)
SUB ZONE 4 (a)
50 YEAR–24 HOUR RAINFALL (mm.)

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

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

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



LEGEND

1. SUB ZONE BOUNDARY
2. RIVERS
3. TOWNS
4. ISOPLUVIALS
5. BRIDGE SITES
6. INDICATED VALUE AGAINST THIS SYMBOL TO BE DECREASED OR INCREASED BY 10 mm. RAINFALL < OR >

SCALE

KMS. 10 5 0 10 20 30 40 50 60 70 80

MILES 10 5 0 10 20 30 40 50

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

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

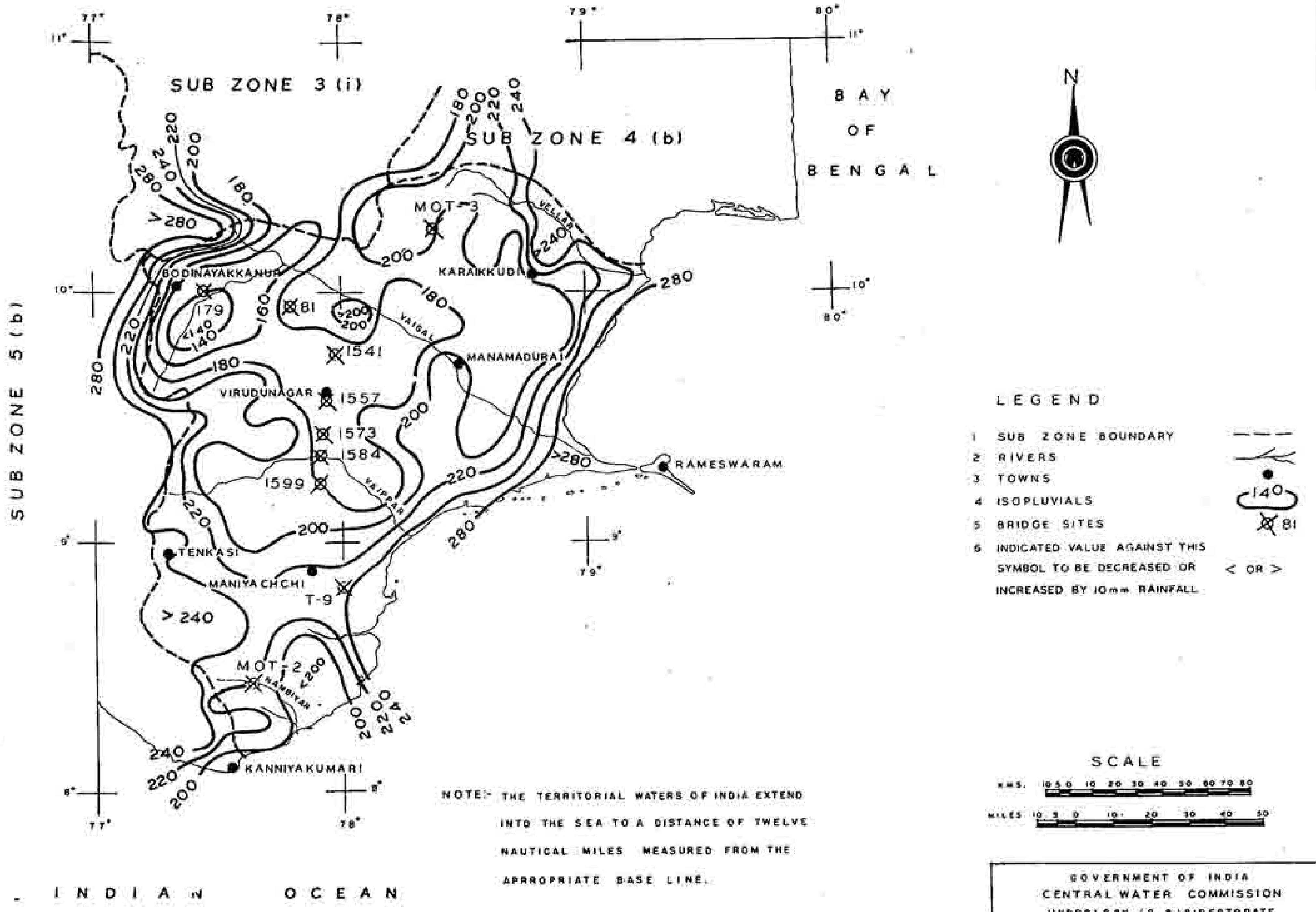
EASTERN COAST (LOWER)
SUB ZONE 4 (b)
50 YEAR 24-HOUR RAINFALL (mm.)

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

RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER

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

PLATE-9.4 (c)



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CENTRAL WATER COMMISSION
HYDROLOGY (S. C) DIRECTORATE

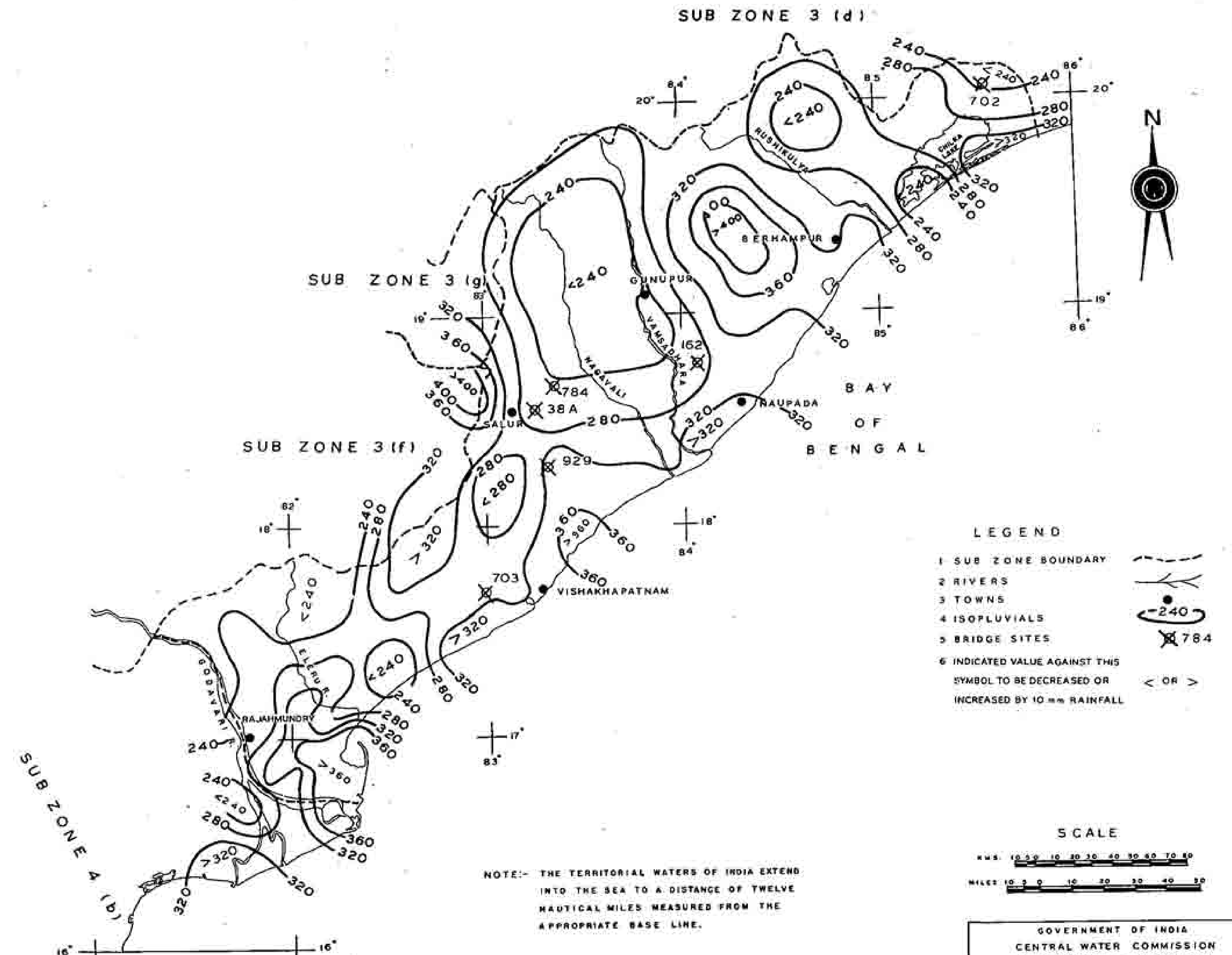
EASTERN COAST (SOUTH)
SUB ZONE 4 (c)
50 YEAR-24 HOUR RAINFALL (mm)

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

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

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

PLATE 10.4(a)



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

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

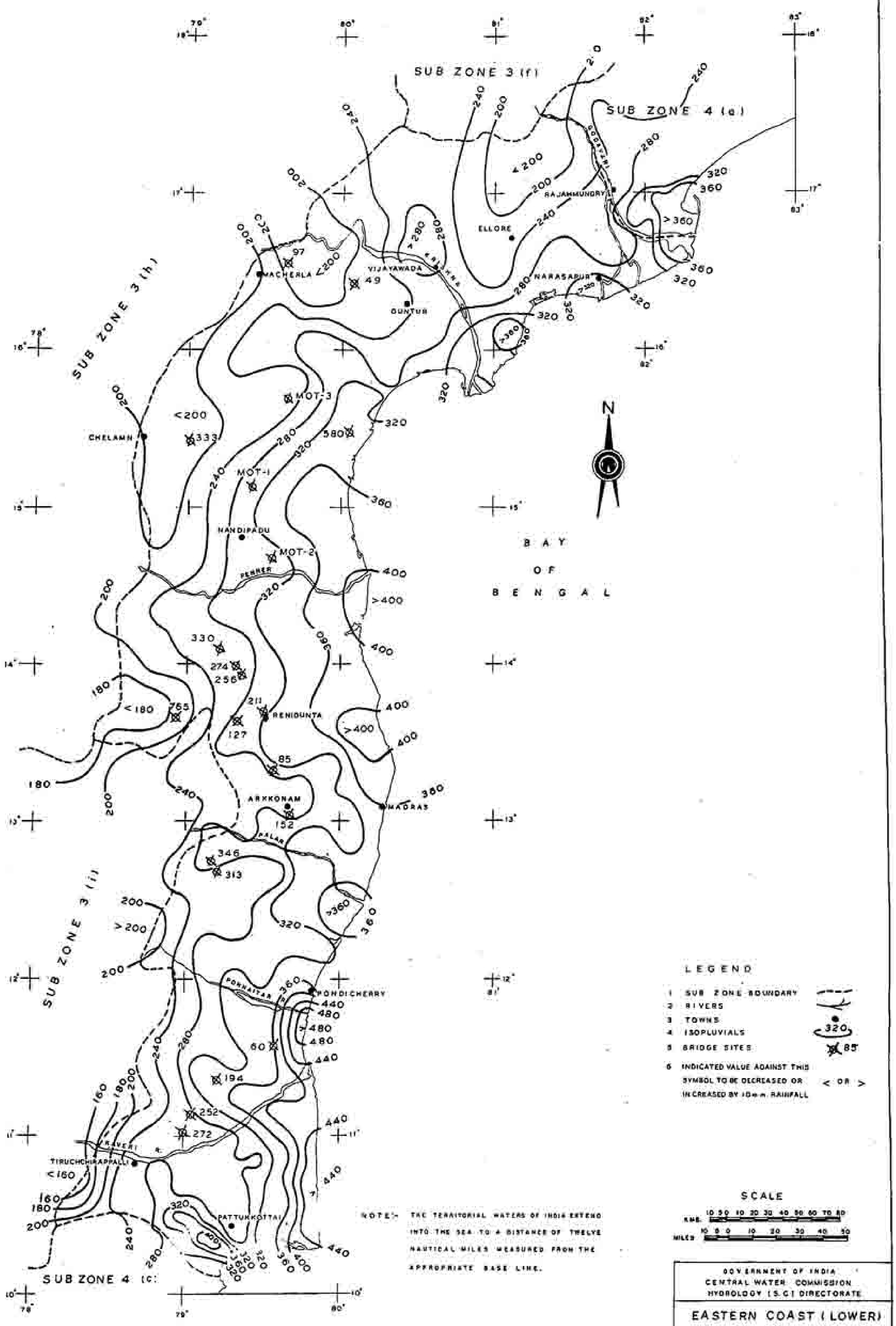
EASTERN COAST (UPPER)
SUB ZONE 4 (a)
100 YEAR–24 HOUR RAINFALL (mm)

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

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

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

PLATE-10.4(b)



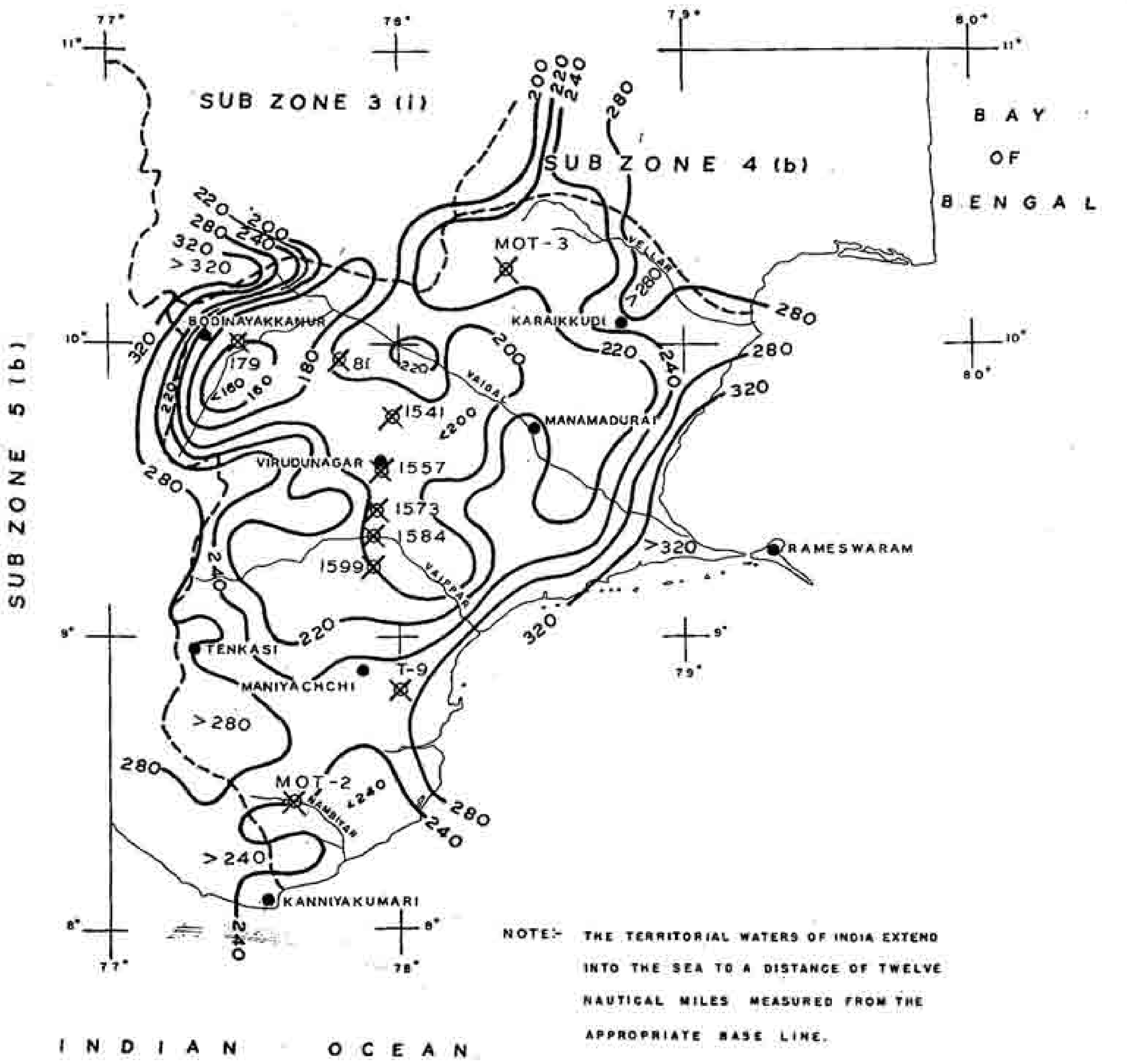
NOTE:- THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

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

EASTERN COAST (LOWER)
SUB ZONE 4 (b)
100 YEAR 24-HOUR RAINFALL (mm)

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

PLATE - 10·4(c)



LEGEND

1 SUB ZONE BOUNDARY
2 RIVERS
3 TOWNS
4 ISOPLUVIALS
5 BRIDGE SITES
6 INDICATED VALUE AGAINST THIS SYMBOL TO BE DECREASED OR INCREASED BY 10mm RAINFALL < OR >

SCALE

KMS.

MILES

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

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

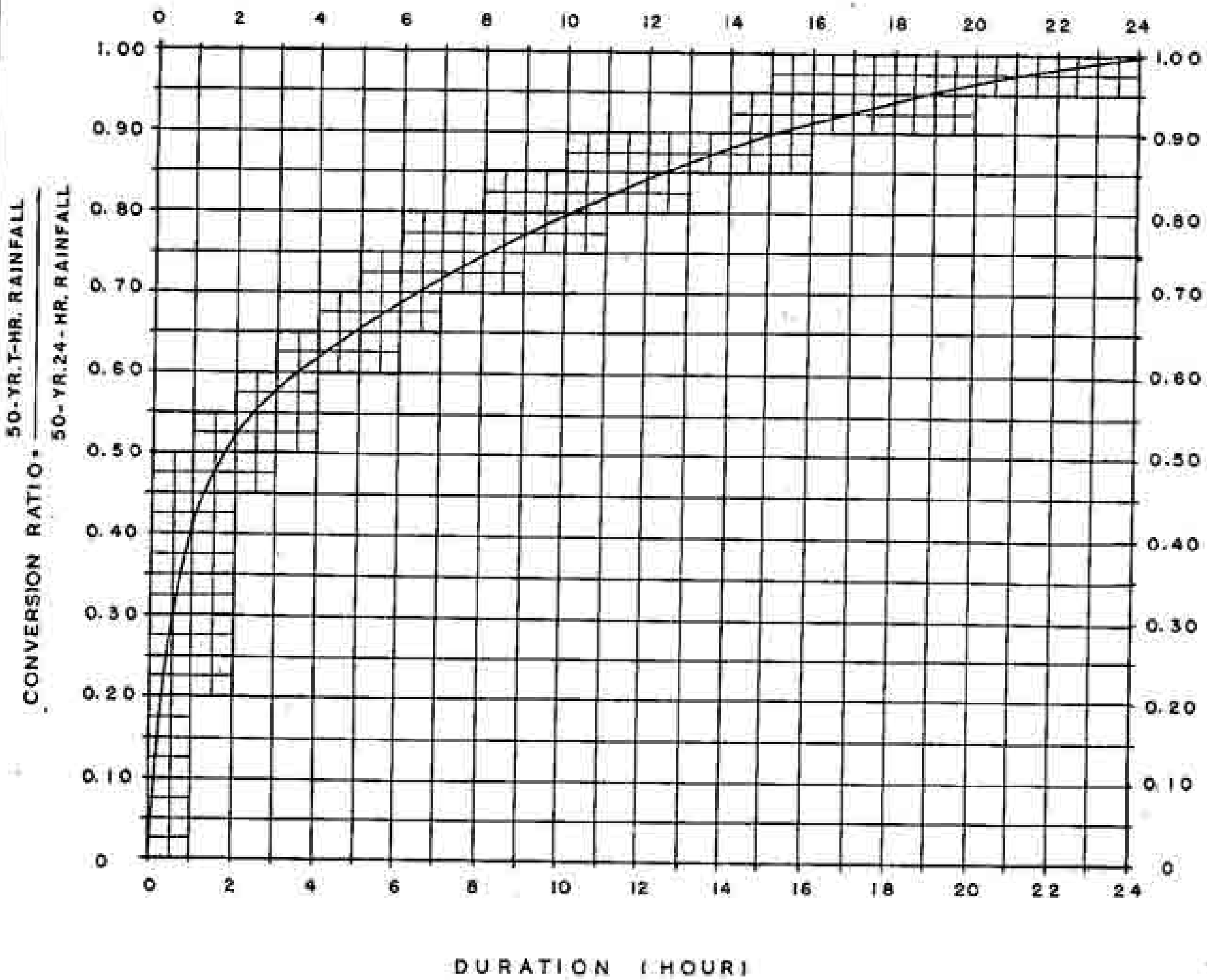
EASTERN COAST (SOUTH)
SUB ZONE 4 (c)
100 YEAR 24-HOUR RAINFALL (mm)

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

RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER

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

FIG.- 10



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

DURATION (HR.)	RATIO
1	0.420(*)
2	0.525
3	0.580
4	0.617
5	0.655
6	0.690
7	0.720
8	0.745
9	0.770
10	0.795
11	0.820
12	0.840
13	0.865
14	0.885
15	0.900
16	0.915
17	0.930
18	0.940
19	0.955
20	0.965
21	0.970
22	0.985
23	0.990
24	1.000

(*) NOTE:- 0.35 MAY BE ADOPTED FOR 1-HR. DURATION FOR CATCHMENTS NEAR TO THE COAST.

GOVERNMENT OF INDIA
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HYDROLOGY (SMALL CATCHMENTS) DTE.

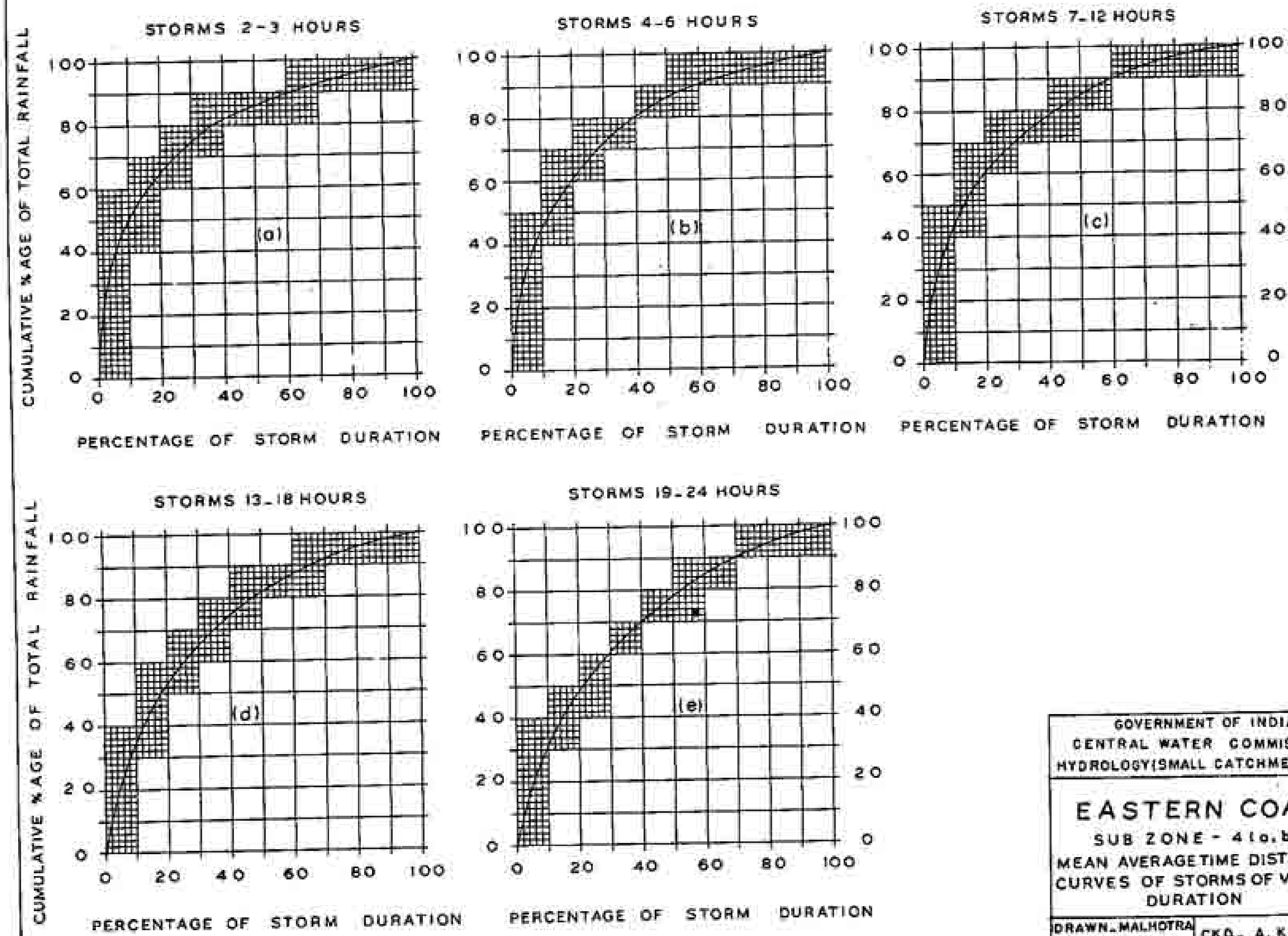
EASTERN COAST

SUB ZONE- 4 (a,b &c)

DURATION Vs. CONVERSION RATIO

DRAWN.- L.K. PANT. L. P. NAUTIYAL | CKD.- A.K. GHOSH.

FIG.- 11



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

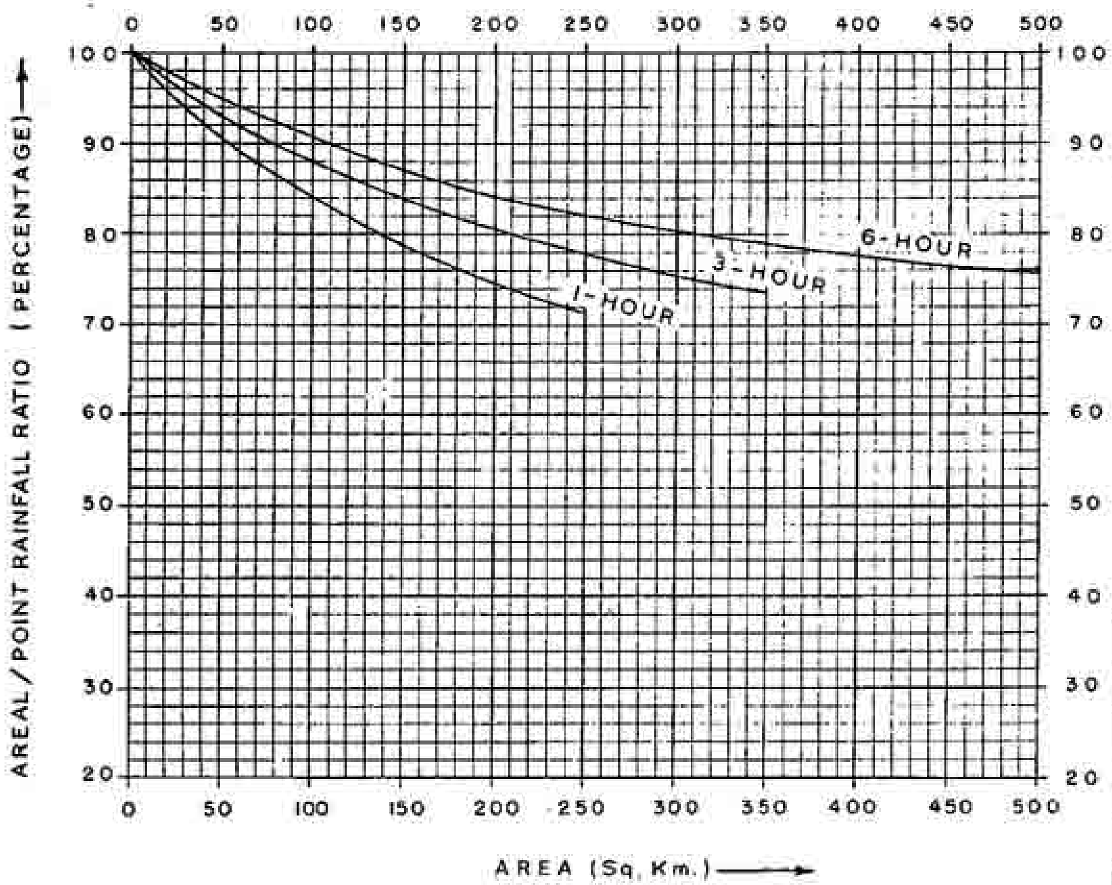
EASTERN COAST

SUB ZONE - 4 (a, b & c)

MEAN AVERAGE TIME DISTRIBUTION CURVES OF STORMS OF VARIOUS DURATION

DRAWN - MALHOTRA L. P. NAUTIYAL	CKD. - A. K. GHOSH

FIG.- 12(a.)



NOTE:-

REFER TABLE - 4 FOR POINT TO AREAL RAINFALL RATIOS FOR DURATION FROM 1 TO 24 Hrs. AND FOR CATCHMENT AREAS UP TO 2500 Sq. Km.

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CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DTE.

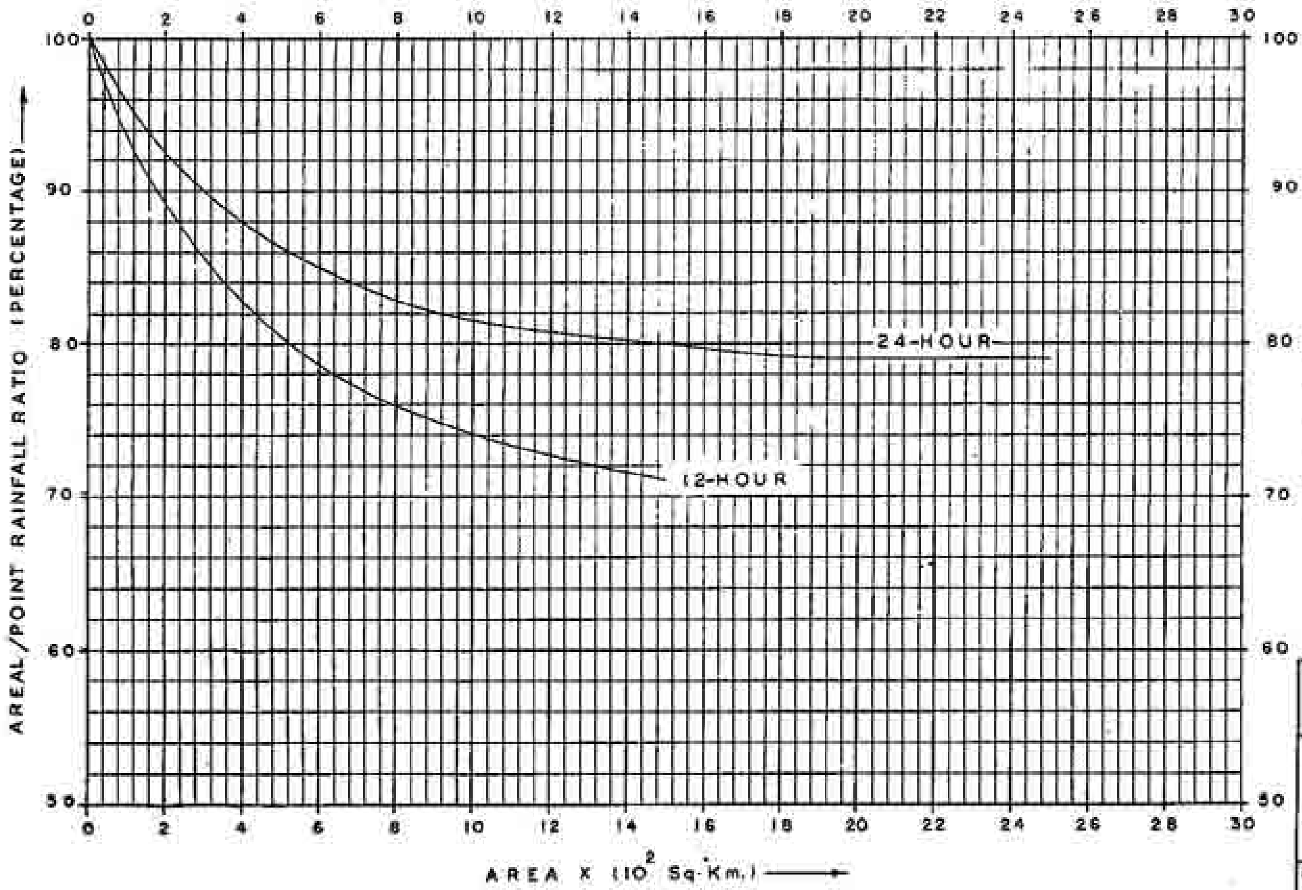
EASTERN COAST

SUB ZONE- 4(a, b & c)

AREAL TO POINT RAINFALL RATIO
(PERCENTAGE)

DRAWN.- MALHOTRA L.P. NAUTIYAL.	CKD.- A.K. GHOSH.

FIG.- 12(b).



NOTE:- REFER TABLE- 4 FOR POINT TO AREAL RAINFALL RATIOS FOR DURATION FROM 1 TO 24 Hrs. AND FOR CATCHMENT AREAS UPTO 2500 Sq. Km.

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

EASTERN COAST
SUB ZONE- 4 (a, b & c)
AREAL TO POINT RAINFALL RATIO (PERCENTAGE)

DRAWN BY- MALHOTRA, L. P. NAUTIYAL | CKD.- A. K. GHOSH.

5.0 ESTIMATION OF DESIGN FLOOD FOR AN UNGAUGED CATCHMENT

The following procedure is recommended

Step-1 Determine the 1-hr Synthetic Unitgraph vide Section 3.10.

Step-2 Determine the design storm rainfall input vide Section 4.0 and 4.6.

Step-3 Adopt the design loss rate as recommended vide section 3.11.

Step-4 Obtain the one hourly effective rainfall units upto the design storm duration T_D by subtracting the design loss rate from the hourly rainfall units in Step-6 of Section 4.6.

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

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

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

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

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

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

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

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

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

Likewise 25-yr flood and 100-yr flood hydrographs are computed following the above steps in Section 4.6 and 5.0 corresponding to 25-yr and 100-yr storm rainfall for design storm duration $T_D = 1.1\ t_p$.

6.0 FORMULA FOR LINEAR WATERWAY FOR BRIDGES

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

The linear dimensions of any hydraulic structure has a bearing on the width of channel. The channel width in the case of stable river is mostly controlled by the nature of soil, slope and roughness of terrain/channel bed as also the magnitude, duration and frequency of floods over a long period in geological time. The width of the channel, therefore, remains more or less constant for discharge magnitudes of different return periods, though the flood levels and velocities vary considerably to cater to the increase in discharge magnitudes. With this concept in view, the formulae for linear waterway related to frequency floods have been developed. Considering the dimension of discharge which is L^3/T, the adoption of $\sqrt[3]{Q}$ discharge as the ruling parameter seems to be justifiable. Taking into account the analysed bridges in the East Coast subzones-4(a, b & c), the following simplified formula has been derived empirically based on existing channel widths.

$$W = 9.84\ (Q_{50})^{1/3}$$

Where W is linear waterway in metres and Q_{50} is 50-year flood discharge in cumecs using the modal loss rate of 0.75 cm/hr.

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

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

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

iii) Work out the design HFL expected for Q_{50} (using the modal loss rate of 0.75 cm/hr) with the waterway estimated.

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

$$W = 8.67\ (Q_{25})^{1/3}$$

$$W = 8.20\ (Q_{100})^{1/3}$$

where Q_{25} and Q_{100} are estimated using a modal loss rate of 0.75 cm/hr.

THE FORMULAE GIVEN ABOVE ARE ONLY TO BE USED FOR FIXING THE LINEAR WATERWAY OF THE BRIDGES IN THE EAST COAST SUBZONES - 4 (a, b & c). THE LACEY'S REGIME WIDTH FORMULAE WILL NOT BE APPLICABLE FOR FIXING THE LINEAR WATERWAY OF BRIDGES ON NONALLUVIAL RIVERS IN SUBZONES - 4 (a, b & c). HOWEVER, FOR ESTIMATION 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 ALONG WITH APPROPRIATE MULTIPLYING COEFFICIENTS.

The relevant codes of practice for design flood and fixing of waterway of bridges by Indian Railway and Indian Road 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.

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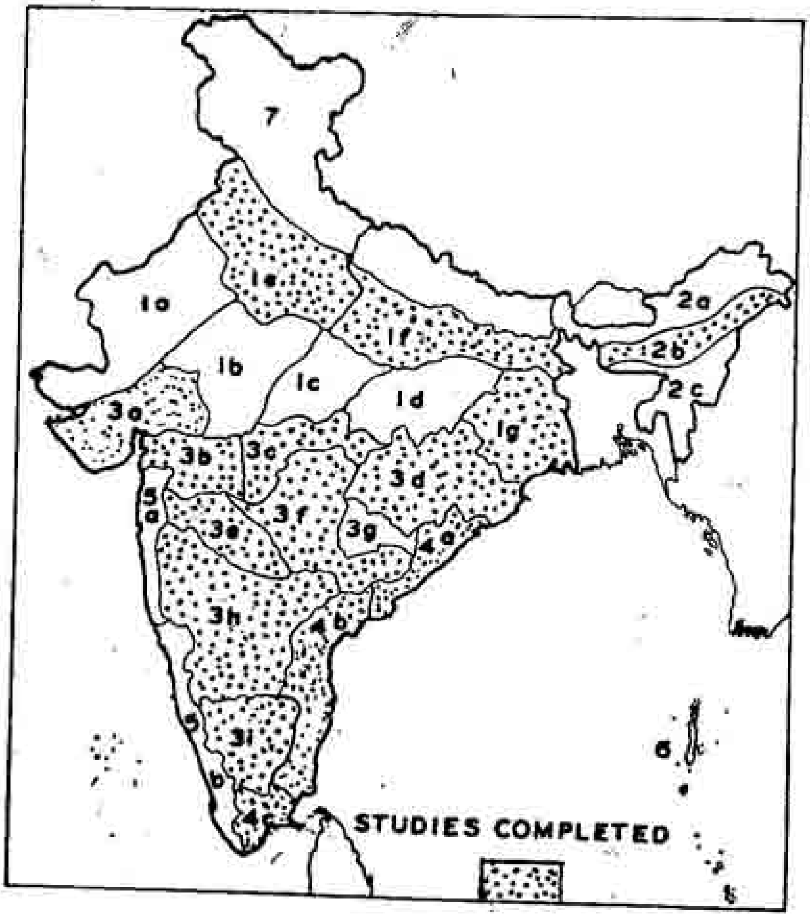

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7.0 COMPUTATION OF DESIGN H.F.L. CORRESPONDING TO DESIGN FLOOD

7.1 GENERAL

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

7.2 STAGE DISCHARGE RELATIONSHIP

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

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

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

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

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

7.3 BACK WATER EFFECT

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

7.4 HYDRAULIC GRADIENT

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

7.5 UNFAVOURABLE CROSSING SITE

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

8.0 UTILITY OF REPORT FOR OTHER PURPOSES

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

i) Small Dams

The Indian Standard - guidelines for fixing spillway capacity of Dams under clause 3.1.2 and 3.1.3 of IS: 11223 - 1985 (under print) recommends 100-year flood as inflow design flood for small dams having either gross storage behind the dam between 0.5 to 10 million mt. or hydraulic head (from normal or annual average flood level on the downstream to the maximum water level) between 7.5 m to 12 m. The report may be made use of for estimation of 100-year flood for safety of small dams. 100-year flood may be estimated using the design loss rate of 0.75 cm/hr.

ii) Minor Cross Drainage Works

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

9.0 ASSUMPTIONS, LIMITATIONS AND CONCLUSIONS

9.1 ASSUMPTIONS

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

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

9.2 LIMITATIONS

9.2.1 The data of 25 catchments has been considered for developing a generalised approach for a large subzone. However, for more reliable relationships the data of more suitable catchments would be desirable.

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

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

9.3 CONCLUSIONS

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

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

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

9.3.4 Formulae for fixing the linear waterway of cross drainage structures on streams in Eastern Coast Subzones-4 (a, b & c) may be used at the discretion of the design engineer.

9.3.5 25-yr, 50-yr and 100-yr flood may be estimated using design loss rate of 0.75 cm/hr. However, the design engineer may use the discretion to adopt a minimum value of 0.5 cm/hr and a maximum value of 1.5 cm/hr for estimation of design flood depending upon the catchment and site conditions and also the relative importance of the structures.

9.3.6 The report is applicable for the catchment areas ranging from 25 sq km to 2,500 sqkm. Further the report may be used for larger catchments upto 5,000 sqkm based on sound judgement and considering the data of neighbouring catchments also. However, individual site conditions may necessitate special site study. Engineer-in-Charge at site is advised to take a pragmatic view while deciding the design discharge of a bridge.

9.3.7 The Eastern Coastal region is affected by cyclonic storms in its track resulting mostly in breaching of tanks with adverse affect on the neighbouring bridges. This report does not cater for such disastrous affect due to tank breaches in estimating the design flood.

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