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DESIGN OFFICE REPORT
M-3 (d) / R-3 / 25 / 97

केन्द्रीय जल आयोग

CENTRAL WATER COMMISSION

महानदी उप अँचल - 3 (डी) का बाढ़ आँकलन विवरण (परिशोधित)

FLOOD ESTIMATION REPORT FOR MAHANADI SUB ZONE - 3 - (d) (REVISED)

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STANDARDS ORGANISATION
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Flood Estimation Report for Mahanadi Subzone 3(d) - Revised was discussed and approved by the following members of Flood Estimation Planning and Co-ordination Committee in 54th meeting held on 10th October,1996 at R.D.S.O., Lucknow.

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FLOOD ESTIMATION REPORT OF MAHANADI
SUBZONE 3 (d)
(REVISED)

A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE
DESIGN OFFICE REPORT NO. M -3(d)/R-3/25/1996

HYDROLOGY (REGIONAL STUDIES) DIRECTORATE
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Feb, 1997

FOREWORD

In the past the waterways of bridge structures on railways, roads, cross drainage works and spillways of minor tanks have generally been based on design flood worked out by empirical formulae. These formulae were evolved with a small data base for a particular region as available at various points of time. There was, therefore, a need for evolving a suitable rational method for estimating or updating the design floods of small and medium ungauged catchments.

For the purpose of evolving a method of estimation of design flood of desired frequency on regional basis by hydrometeorological approach, the country has been divided into 7 zones and 26 hydrometeorological homogenous subzones. So far, 21 flood estimation reports covering 24 subzones have been published.

In addition to above, there is also periodic revision of such subzonal reports, whenever additional data sets become available and sophisticated analysis becomes due. The flood estimation reports of Lower Ganga Plains subzone 1(g) and Lower Godavari subzone 3 (f), published in 1975 and 1981 respectively have already been revised and published. The present report is the revision of flood estimation report of Mahanadi subzone 3(d), published in the year 1982. It gives the method to compute design flood of 25/50/100 year return period for ungauged catchments located in Mahanadi subzone 3(d).

The report is a joint effort of Central Water Commission (CWC), India Meteorological Department (IMD), Research, Designs and Standards Organisation (RDSO) of Ministary of Railways and Ministry of Shipping and Transport (MOST).

I would like to place on record my appreciation of the cooperative efforts of the officers and staff of the four organisations in bringing out this report.

New Delhi, Feb, 1997.

Ramesh Chandra
(Ramesh Chandra)
Chairman, CWC

PREFACE

Design engineers essentially need the design flood of a specific return period for fixing the waterway vis-a-vis the design highest flood level (HFL) and foundation depths of bridges, culverts and cross drainage structures depending on their life and importance to ensure safety as well as economy. A casual approach may lead to under-estimation or over-estimation of design flood resulting in the loss and destruction of structure or un-economic structure with problematic situation.

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

Recognising the need to evolve a method for estimating design flood peak of desired frequency, the committee of engineers headed by Dr. A.N. Khosla have recommended, in their report that the design discharge should be the maximum flood on record for a period of not less than 50 years. Where adequate records are available, extending over a period not much less than 50 years, the design flood should be the 50-years flood determined from the probability curve prepared on the basis of the recorded floods during that 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 storms necessitating the systematic and sustained collection of hydro-meteorological data at selected catchments in different climatic zones of India.

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 thus become necessary for hydro-meteorologically homogeneous regions in the country. Broadly, two main regional approaches, namely flood frequency and hydrometeorological approaches are open for adoption depending on the availability of the storm rainfall and flood data. The first approach involves long term discharge data observations for the representative catchments for subjecting the data to statistical analysis to develop a regional flood frequency model. The other approach needs concurrent storm rainfall and run-off data of the representative catchments over a period of 5 to 10 years to develop representative unit hydrographs of the catchments located in the region, so that synthetic unit hydrograph may be obtained for the region (subzones) and long term rainfall records at a large number of stations to develop design storm values. This approach has been adopted for preparing of flood estimation reports under short term and long term plan.

Under short term plan, the report on estimation of design flood peak utilising hydromet data available for 60 bridge catchments, spread throughout the country, was brought out in 1973, wherein the method has been recommended for estimating the design flood peak for catchment areas ranging from 25 to 500 sq.km in the country.

Under long term plan, country has been divided into 26 hydro-meteorologically homogenous subzones. For preparing the flood estimation reports for these subzones, systematic and sustained collection of hydrometeorological data at the representative catchments, numbering 10 to 30, for a period of 5 to 10 years in different 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 Ministry of Railways. Similarly, the Ministry of Transport had undertaken the collection of data for 45 catchments through Central Water Commission since 1979.

Hydrology Regional Studies Dte., Central Water Commission (CWC) carries out analysis of selected concurrent rainfall and flood data for the gauged catchments to derive unit hydrographs of mostly one hour duration on the basis of rainfall data, gauge and discharge data collected during the monsoon season. Representative unit hydrographs are obtained for each of the gauged catchments. The characteristics of the catchments and their unit hydrographs, prepared for several catchments in a subzone are correlated by regression analysis and the equations for synthetic unit hydrograph for the subzone are derived for estimating design flood for ungauged catchments. Studies are also carried out by the CWC to arrive at suitable recommendations for estimating loss rate and base flow for ungauged catchments.

India Meteorological Department (IMD) conducts depth - duration - frequency analysis of rainfall for each subzone to provide hydrometeorological input for estimation of design flood.

The subzonal reports incorporating studies carried out by CWC and IMD are prepared and published by CWC on approval of Flood Estimation Planning and Coordination Committee (FEPCC).

So far, following 21 flood estimation reports (FERs) covering 24 subzones have been published :

1.	Lower Ganga Plains subzone 1(g)	(1978)
2.	Lower Godavari subzone 3(f)	(1981)
3.	Lower Narmada & Tapi subzone 3(b)	(1982)
4.	Mahanadi subzone 3(d)	(1982)
5.	Upper Narmada & Tapi subzone 3(c)	(1983)
6.	Krishna & Pennar subzone 3(h)	(1983)
7.	South Brahmaputra subzone 2(b)	(1984)
8.	Upper Indo-Ganga Plains subzone 1(e)	(1984)
9.	Middle Ganga Plains subzone 1(f)	(1985)
10.	Kaveri Basin subzone 3(i)	(1986)
11.	Upper Godavari subzone 3(e)	(1986)
12.	Mahi & Sabarmati subzone 3(a)	(1987)
13.	East Coast subzones 4(a), (b) & (c)	(1987)
14.	Sone subzone 1(d)	(1988)
15.	Chambal subzone 1(b)	(1989)
16.	Betwa subzone 1(c)	(1989)
17.	North Brahmaputra subzone 2(a)	(1991)

18. West Coast Region subzone 5(a) & (b) (1992)
19. Luni subzone 1(a) (1993)
20. Indravati subzone 3(g) (1993)
21. Western Himalayas zone 7 (1994)

Hydrometeorological inputs in the FERs at serial number 1 to 7 were based on self recording raingauges (SRRGs) data alone and consisted of (i) Isopluvial maps for 24 hour and / or shorter durations corresponding to 50 year return period (ii) Time distribution of storm rainfall and (iii) Point to areal rainfall ratios. However in the subsequent reports, IMD modified the methodology and prepared the hydrometeorological inputs based on conjunctive use of ordinary raingauge (ORG) and SRRG data. It was accordingly, decided by the FEPCC to revise the FERs at serial No. 1 to 7, so that these FERs also include same hydrometeorological components as given in the FERs at serial No. 8 onwards. It was further decided to revise hydrological study also of these reports. The hydrological study was to be revised based on the additional hydrological data, collected subsequent to the preparation of the original reports. The FER for Lower Ganga Plains subzone 1(g), published in 1974 and Lower Godavari subzone 3 (f), published in 1981, have already been revised where the hydrometeorological input has been included as per revised methodology.

Present report is the revision of the flood estimation report of Mahanadi subzone 3 (d) (report no M/5/1981) and deals with the estimation of flood of 25 year, 50 year and 100 year return period for small and medium catchments in the subzone . It covers parts of area of the river Mahanadi in the States of Orissa , Maharashtra, Madhya Pradesh and Bihar.

The rainfall-runoff data of 26 catchments having catchment area more than 25 Sq.km for a period of 5 to 10 years during the period 1958 to 1979 was collected by the Railways . Data of 16 catchments for 116 bridge years found suitable was utilised in study carried out earlier. In the present study, additional data of 31 bridge years for 5 catchments, collected subsequently alongwith the earlier data, thus totalling 147 bridge years has been used for unit hydrograph study .

The storm study has been conducted by IMD. The rainfall data of 210 O.R.G. stations maintained by IMD and State Governments, 28 S.R.R.G stations maintained by IMD in and around the subzone, have been utilised in the study. Short duration data (hourly/ half hourly rainfall) of the stations in the subzone maintained by RDSO was not utilised for the storm studies because of fairly dense net-work of IMD's SRRG data.

The report covers six parts. Part - I of the report Introduction " gives the summary of the earlier and revised studies. Description of the subzone detailing river system, rainfall, temperature and types of the soil is given in Part - II. Part- III brings out the synthetic unit hydrograph (SUH) relations to be used for ungauged catchments in the subzone.

The storm studies carried out by IMD are dealt in Part - IV of the report. Criterion and standards in regard to design flood of structures and procedures to compute the design flood of ungauged catchments are described in Part - V along with an illustrative example. Part - VI highlights the limitations, assumptions and conclusions.

The report on subzone 3 (d) is recommended for estimation of design flood for small and medium catchments varying in areas from 25 sq.km to 1000 sq.km. This report may also be used for catchments having areas upto 5000 sq.km, judiciously after comparing the neighbouring catchments having more or less similar characteristics. For catchments of areas less than 25 sq.km, the method given in the report No. RBF - 16 published by RDSO may be used.

The method adopted and conclusions arrived at, are subject to periodical review and revision in the light of adequate data being collected and analysed and also the advancements in theory and technique.

This report is a joint effort of Hydrology (Regional Studies) Dte., Central Water Commission (CWC) of Ministry of Water Resources, India Meteorological Department (IMD) of Ministry of Science and Technology, Research Designs Standards Organisation (RDSO) , Ministry of Railways and Ministry of Shipping and Transport (MOST).

(Kailash Nath)
Director, Hydrology (RS) Dte.
Central Water Commission

Oct.' 96

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PART -VI

ASSUMPTIONS, LIMITATIONS AND CONCLUSIONS

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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 km^2.
ARF	Areal Reduction Factor.
C.G.	Centre of Gravity
Cumecs	Cubic metres per second
cms	Centimetres
D_{i-1} & D_i	Depths between the river bed profile (L-section) based on the levels of (i-1) and ith contours at the inter-section points and the level of the base line (datum) drawn at the point of study in metres.
E.R.	Effective Rainfall in cms.
Hr	Hour
H(RS),CWC	Hydrology (Regional Studies) Directorate, Central Water Commission, New Delhi.
I.M.D.	India Meteorological Department
in	Inches
km	Kilometres
L	Length of longest main stream along the river course in km.
L_c	Length of the longest main stream from a point opposite to centroid of the catchment area to the gauging site along the main stream in km.
L_i	Length of the ith segment of L-section in km.
M.O.S.T.	Ministry of Shipping and Transport (Roads Wing).
m	Metres
min	Minutes
mm	Millimetres
Q_p	Peak Discharge of Unit Hydrograph in cubic metres per second.
Q_{25}, Q_{50} and Q_{100}	Flood Discharge with return periods of 25-yr, 50-yr and 100-yr respectively in cumecs.
q_p	Peak Discharge of Unit Hydrograph per unit area in cumecs per sq.km.

R_{25}, R_{50} and R_{100}	Point Storm Rainfall Values for 25-yr,24-hour 50-yr 24-hour and 100-yr 24-hour return periods respectively in cm.
R.D.S.O.	Research Designs & Standards Organisation (Ministry of Railways),Lucknow.
S	Equivalent stream slope in m/km.
S.U.G.	Synthetic unit hydrograph
S.R.H.	Surface runoff hydrograph
D.R.H.	Direct runoff hydrograph
sec	Seconds
sq	Square
Sq.km	Square Kilometres, Km^2
T	Time duration of rainfall in hours
T_B	Base width of unit hydrograph in hours
T_D	Design Storm Duration in hours
T_m	Time from the start of rise to the peak of Unit Hydrograph in hours
t_p	Time from the centre of Unit Rainfall Duration to the Peak of Unit Hydrograph in hours
t_r	Unit rainfall duration adopted in a specific study in hours
U.G.	Unit hydrograph
W_{50}	Width of U.G. measured at 50% peak discharge ordinate (Qp) in hours.
W_{75}	Width of the U.G. measured at 75% peak Discharge Ordinate (Qp) in hours.
W_{R50}	Width of the rising side of U.G. measured at 50% peak Discharge Ordinate (Qp) in hours.
W_{R75}	Width of the rising side of U.G. measured at 75% peak Discharge Ordinate (Qp) in hours.
%	Percent.
Σ	Summation

PART - I

INTRODUCTION

Mahanadi subzone 3(d) is one of the 26 hydrometeorologically homogeneous subzones, into which the country has been divided for developing the regional methodology for assessing the design flood of small and medium catchments. Annexure-1.1 shows various subzones into which the country has been divided.

The flood estimation report of Mahanadi subzone 3 (d), (Design Office report No. M/5/1981) was published in 1982. The present report is revision of the earlier report.

The earlier report contained inputs for estimating the design flood of 50 year return period, whereas the present report provides inputs for estimating design floods of 25, 50 and 100 year return period.

1.1 Need for revision of report

Rainfall maps of 50 year return period for duration 15, 30 and 45 minutes and 1 3, 6, 9, 12, 15 and 24 hours were furnished in 7 flood estimation reports , published till 1983, viz. 1(g), 2(b), 3(b), 3(c), 3(d), 3(f) and 3(h). These reports were based on data of sparse self-recording raingauge network. After bringing out 7 such subzonal reports, IMD modified the methodology, based on storm study, for preparing the rainfall maps using rainfall data of ORG and SRRG in and around the subzone.

FEPCC in its 51st meeting decided to revise these reports in a phased manner, incorporating the isopluvial maps prepared using ORG and SRRG data for 25, 50 and 100 year for 24 hour duration and other inputs. It was also decided by FEPCC to review and revise the hydrological study of these reports, utilizing additional rainfall-runoff data collected subsequent to the preparation of the reports.

1.2 Revised study

Hydrological and storm studies contained in the earlier report and in the revised report are as under:-

1.2.1 Hydrological study

The hydrological study carried out earlier was based on rainfall-runoff data of 16 catchments observed for a period of 5 to 10 years during the period 1958 to 1979. Representative unit hydrographs of 1 hr. duration were derived. The equations relating unit hydrograph parameters and basin parameters were developed for deriving 1-hr. synthetic unit hydrograph.

Subsequent to the preparation of the earlier report, additional data in respect of 2 key gauging sites (12 and 698), for a period of 13 years from 1982 to 1994 and 3 bridge sites (235, 478 and 25) for a period of 1- 2 years was made available by RDSO. These data have been utilised in the present study .

Equivalent slope has been considered as one of the physiographic parameters in the revised study in place of statistical slope. Recommendations regarding the suitable values of loss rate and base flow have also been revised considering additional data .

The hydrological study carried out by CWC is given in Part-III of the report.

1.2.2 Storm Study

The published report contained isopluvial maps of 50 year return period for different durations, time distribution curves and areal to point rainfall ratios. The present report contains (i) isopluvial maps of 25, 50 and 100 year for 24-hours based on available rainfall data of ORG and SRRG in and around the subzone, (ii) short duration rainfall ratios for converting 24 hours rainfall to short duration rainfall, (iii) time distribution curves for storms of various durations and (iv) point to areal ratios for different durations. In the present study, IMD has utilised the rainfall data of 210 ORG maintained by IMD and State Govts. and 28 SRRG stations maintained by IMD. Besides this data, RDSO has also made available hourly/half hourly concurrent rainfall data in selected bridge catchments for conducting point to areal rainfall study . However, in the present study the necessity of this data did not arise because of the concurrent SRRG data from a dense network of IMD's stations in some districts of Orissa becoming available.

The storm studies carried out by IMD are given in Part-IV of the report.

1.3 Procedure to estimate design flood

[redacted]

PART-II

GENERAL DESCRIPTION OF THE SUBZONE

2.1 Location

Mahanadi subzone 3 (d) is located between East Longitudes 80^{o} 25' to 87^{o} and North Latitudes 19^{o} 15' to 23^{o} 35'. Plate-1 shows location of Mahanadi subzone on map of India. Annexure 1.1 shows list of various hydrometeorological subzones in India.

The subzone is bounded on the East by subzone 1-g (Lower Ganga Plains including Subernarekha and other East flowing rivers), on the West by subzone 3-f (Lower Godavari Basin) and subzone 3-c (Upper Narmada and Tapi Basin), on the North by subzone 1-d (Sone Basin) and on the South by subzone 3-g (Indravati Basin) and subzone 4-a (Circars) and the Bay of Bengal.

The subzone comprises parts of Maharashtra,Madhya Pradesh, Orissa, and Bihar.

2.2 River System

The area covered by the subzone is shown in Plate - 2. The subzone comprises of Mahanadi, Brahmani and Baitarani basins. The Mahanadi, Brahmani and Baitarani are peninsular rivers, outfalling into the Bay of Bengal. Important tributaries of Mahanadi river are Seonath, Hasdeo, Mand and Ib joining from North, and Jonk, Ong and Tel joining from South. The total length of Mahanadi river is about 850 Km. The river lengths of Brahmani and Baitarani are about 705 km and 333 km respectively. Hirakud Dam (multi-purpose project) in Orissa lies in the centre of the Mahanadi subzone.

The total drainage area of the subzone is 1,95,256 Sq.km, out of which catchment area of Mahanadi is 1,40,628 Sq.km, which is 72 % of the total area.

The catchment area of the Mahanadi, Brahmani, Baitarani rivers and free drainage area of the basin is given in Table 2.1.

Table 2.1 : Catchment Area

Sl. no.	Basin/ sub-basin	Drainage area (sq km.)
a)	Mahanadi	
1)	Northern tributaries	
i)	Seonath	30,500
ii)	Hasdeo	10,457
iii)	Mand	6,851
iv)	Ib	12,981
2)	Southern tributaries	
i)	Ong	4,688
ii)	Tel	18,390
iii)	Jonk	23,438
3)	Free drainage area	33,323
	Total area of Mahanadi basin	1,40,628
b)	Brahmani	35,337
c)	Baitarani	19,291
	Total area of subzone	1,95,256

The Mahanadi, Brahmani and Baitarani outfall into the Bay of Bengal through a large number of channels in the Deltaic plains.

Plate-2 shows the river system/ gauge and discharge sites in the subzone.

2.3 General topographical features

2.3.1 Topography and relief

Plate-3 depicts the general topography of the subzone. About 50% of the area is hilly varying in height from 300 m to 1350 m. The remaining 50% of the area lies between 0 - 300 m on both sides of the Mahanadi river. The hilly area is mostly on the North, South and Southwest of the region.

2.3.2 Soils

Plate - 4 shows the different types of soils in the region. The red and yellow soils cover major part of the subzone. The red sandy, submontane and coastal alluvial soils cover the remaining part of the subzone.

2.3.3 Land use

Plate -5 shows broadly the land use of the subzone. The subzone has an extensive area under forest. Paddy is the main crop grown on the cultivable land. Most of the irrigated area is in Sambalpur district under the canals of Hirakud project. In the deltaic area around Cuttack, the irrigation is mostly done by inundation canals.

2.4 Climatological features of subzone (as contributed by IMD)

2.4.1 Rainfall

2.4.1.1 Annual normal rainfall: The isohyetal map of the annual normal rainfall of the subzone is presented in Plate-6. The isohyetal pattern is cellular in nature, the annual normal rainfall ranging from about 1200 to slightly over 1700 mm.

2.4.1.2 Monthly rainfall distribution: Monthly rainfall distribution at six representative stations viz. Durg and Kathghora in Madhya Pradesh, Cuttack, Bhawanipatna and Jharsuguda in Orissa and Lohardaga in Bihar is illustrated through bar charts appended to the annual normal rainfall map (Plate - 6). In the bar charts alphabets along abscissa indicate names of months whereas heights of rectangles are proportional to normal rainfall of respective months. Value mentioned at the top of each rectangle indicate the month's rainfall as percent of the annual rainfall.

It is brought out in the bar charts that the period June to October constitutes the main rainy season over the subzone. This is because of early onset and late withdrawal of southwest monsoon over the subzone. Normal rainfall for the five months (June - October) at Durg, Kathghora, Cuttack , Bhawanipatna, Jharsuguda and Lohardaga is 89.9 %, 91.9 %, 85.7 %, 90.8 %, 92.1 % and 86.5 % respectively of the annual rainfall. Further, the rainfall in the months of July and August is considerable and together constitute 45 % to 60 % of the annual rainfall.

2.4.2 Temperature

2.4.2.1 Mean daily temperatures (Annual): Mean daily temperature distribution over the subzone is shown in Plate - 7. The mean daily temperatures are worked out as average of mean maximum and mean minimum temperatures over the year. It may be seen from the map that mean daily temperatures are in the range $27^{o}c$ - $28^{o}c$ over the central belt of the subzone extending Eastwest from Cuttack in Orissa to Raipur in Madhya Pradesh. The mean daily temperatures decrease Northwest as well as Southwest of this belt to less than $24^{o}c$ over parts of the subzone lying in Bihar and adjoining Madhya Pradesh in the North and in Southwest Orissa in the South.

2.4.2.2 Monthly temperature variation at selected stations:

Monthly variations of mean maximum, mean minimum and mean daily temperatures for six representative stations viz Raipur and Pendra in Madhya Pradesh, Ranchi in Bihar and Sambalpur, Cuttack and Titlagarh in Orissa are shown graphically in Plate - 7, below the map of mean daily temperatures. It may be seen from these that the highest mean maximum temperatures are observed in the month of May at all the six selected stations, their magnitudes being 42.3^{o}c at Raipur, 39.3^{o}c at Pendra, 37.9^{o}c at Ranchi, 42.1^{o}c at Sambalpur, 38.8^{o}c at Cuttack and 41.5^{o}c at Titlagarh. Mean minimum temperatures at all the six selected stations are observed in the month of December with their magnitudes being 13.2^{o}c at Raipur, 10.1^{o}c at Pendra, 9.9^{o}c at Ranchi, 12.2^{o}c at Sambalpur, 15.5^{o}c at Cuttack and 13.2^{o}c at Titlagarh. Mean daily temperatures are highest at all the six selected stations in the month of May.

2.5 Communications

2.5.1 Railways

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

Sl.No.	Section	Railways
1.	Howrah - Waltair	South-eastern Railway
2.	Nergundi - Talcher	do
3.	Bilaspur - Katni	do
4.	Ranchi - Bondamunda	do
5.	Jharsuguda - Sambalpur	do
6.	Rajkaraswar - Gua	do
7.	Jharasuguda - Bilaspur	do
8.	Raipur - Vizianagram	do
9.	Bilaspur - Howrah	do
10.	Kharagpur - Bhadrak	do
11.	Raipur - Nagpur	do

2.5.2 Roads

The major highways in the subzone are :

Sl.No.	Highway No.	Road section
1.	National Highway No. 6	Nagpur - Howrah
2.	National Highway No. 43	Raipur - Jagdalpur
3.	National Highway No. 5	Cuttack - Visakhapatnam
4.	National Highway No. 42	Sambalpur - Cuttack
5.	National Highway No. 23	Cuttack - Talcher
6.	National Highway No. 54	From NH 5 - Paradip

PART-III

SYNTHETIC UNIT HYDROGRAPH STUDIES

3.1 Synthetic unit hydrograph (SUG)

Hydrometeorological approach has been adopted for developing a regional method for estimating design flood for small and medium catchments in various hydrometeorologically homogeneous subzones. In this approach, the design storm after converting it into effective rainfall (input) is applied to the unit hydrograph (transfer function) to obtain a design flood (basin response). It is possible to develop unit hydrograph if site specific concurrent rainfall- runoff data is available for 3-4 years. Collection of adequate concurrent rainfall - runoff data for every site, is however neither practicable nor economically feasible. In such a situation, the regional method for developing Synthetic Unit Hydrograph (SUG) is resorted to.

SUG in the present study is a unit hydrograph of unit duration for a catchment developed from relations established between physiographic and unit hydrograph parameters of the representative gauged catchments in hydrometeorologically homogenous region (subzone). Data collected and analysed for obtaining subzonal SUG equations are discussed in succeeding paragraphs.

3.2 Data required

For conducting the unit hydrograph studies for development of equations for derivation of SUG, following concurrent rainfall and runoff data for a number of catchments of small and medium size, representatively located in a subzone are required for a period of 5 to 8 years during the monsoon season:

i) Hourly gauge data at the gauging site (bridge site)

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

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

The following catchment details are also required.

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

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

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

3.3 Data collected

South-eastern railway had observed and collected data at 26 railway bridge catchments having catchment area more than 25 sq.km for a period of 5 to 10 years during 1958-79. The data of 169 bridge years was available for hydrological studies, out of which data of 116 bridge years of 16 catchments was found suitable for developing co-relation between unit hydrograph and physiographic parameters for derivation of SUG.

Additional data for 31 bridge years for 5 bridge sites shown in Table 3.1, were collected by RDSO subsequent to the preparation of the report .

Table 3.1: Additional data for 5 Bridge sites

Sl. no.	Site	Additional data	Bridge years
1.	12 *	1982-94	13
2.	235	1980	01
3.	698 *	1982-94	13
4.	478 **	1980-81	02
5.	25 **	1980-81	02

* Key gauging stations where rainfall and discharge observations are continued .

** The data available up to 1979 was not found suitable in earlier study. The additional data received from RDSO was analysed and even this data was not found suitable for UG studies.

Annexure 3.1 shows the name of the stream, railway bridge No., railway section, catchment area, no.of rain gauge stations and period of availability of rainfall-runoff data of 26 bridge catchments having catchment area more than 25 Sq.Km. This also includes additional data of 5 catchments, collected subsequent to the preparation of the report. It can be seen from the Annexure 3.1 that the catchment area of gauge sites lie between 27 to 3108 sq.km.

3.4 Derivation of synthetic unit hydrograph

Procedure to obtain physiographic parameters and unit hydrograph parameters of the catchments and establishing relationships between these parameters to derive SUG is described in the following paragraphs.

3.4.1 Physiographic parameters

The physiographic parameters considered in the present study are catchment area (A); length of main stream (L) length of the main stream from a point near the centre of gravity of catchment to the bridge site (L_C) and equivalent slope (S), as indicated in Figure -1. These are explained in the following paras.

3.4.1.1 Catchment area (A)

The gauging site is located on a toposheet and the watershed boundary is marked. The area enclosed in this boundary upto the gauging site may be referred to as the catchment area (A).

3.4.1.2 Length of the Main Stream (L)

This implies the longest length of the main river from the farthest watershed boundary of the catchment area to the gauging site.

3.4.1.3 Length of the main stream from a point near the centre of gravity of catchment to the bridge site(Lc)

For finding the centre of gravity of the catchment, usually the boundary of the catchment is cut on a card board, which is then hung in three different directions in vertical planes and the plumb lines are drawn from the point of hanging. The point of intersection gives the centre of gravity of the catchment. The stream may or may not pass through the centre of gravity but the nearest point to the centre of gravity is considered to find the length of the main river from the centre of gravity to the point of study (L_C).

3.4.1.4 Equivalent stream slope (S)

One of the physiographic parameters is slope. The slope may be equivalent or statistical . In the present study equivalent stream slope has been used for developing the SUG relation in place of statistical slope, used in the previous study. Equivalent slope can be computed by the following methods.

(a) Graphical method

Longitudinal section (L-section) of the main stream was prepared from the values of the contours across the stream or the spot levels near the banks with respect to their distances from the point of interest on the L-section such that the areas of the L-section (profile) above and below the line are equal. This line is called equivalent stream slope line.

(b) Analytical method

L-section is broadly divided into 3 to 4 segments representing the broad ranges of the slopes of the segments and the following formula is used to calculate the equivalent slope (S):

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

L_i = Length of the ith segment in km.

D_{i-1}, D_i	=	Elevations of river bed at ith. intersection points of contours reckoned from the bed elevation at points of interest considered as datum and D(i-1) and Di are the heights of successive bed location at contour and intersections.
L	=	Length of the longest stream as defined in section 3.4.1.2 in km

Physiographic parameters A, L, Lc and S obtained for 16 catchments found suitable for analysis are shown in Annex. 3.2.

3.4.2 Unit hydrograph parameters

3.4.2.1 Scrutiny of data and finalisation of gauge discharge rating curve

Out of the 26 gauged catchments, data of 16 catchments (116 bridge years) was found suitable for the unit hydrograph study contained in the earlier report.

The additional data of 5 catchments viz. 12, 235, 698, 478, and 25 (31 bridge years) was scrutinized through arithmetical checks and gauge and discharge rating curve(s) were drawn on log-log scale. The hourly discharges for the durations of the selected floods were obtained from the rating curves.

3.4.2.2 Selection of floods and corresponding storm events

In the previous study, 101 flood events of 16 catchments were found suitable for U.G. studies.

The general guidelines followed earlier for selecting flood events from the additional data are given below:

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

ii) The selected flood should result from significant rainfall excess not less than 1 cm.

Flood events shown in Table 3.2 were found to be suitable from the additional data collected for Bridge No. 12, 235, 698.These catchments were amongst 16 catchments considered in the previous study. Suitable flood was not found in the additional data collected for Bridge No. 25 and 478 and these catchments were also not considered in the previous study. The catchments considered in the present study are the same catchments found suitable in the previous study. Guidelines followed for selecting flood events in the previous study are adopted for identifying flood events from the additional data.

Table 3.2 : Selected flood events

No.	Site	From data utilised earlier	From additional data	Total
1.	12	3	8	11
2.	235	3	3	6
3.	698	13	17	30

3.4.2.3 Computation of hourly catchment rainfall

As there is no change in raingauge network of 3 catchments (12, 698 and 235), station weights computed earlier were used for obtaining weighted rainfall of the catchment for different flood events.

3.4.2.4 Separation of base flow

The selected flood events of 3 Bridge catchments were plotted on the normal graph paper. The base flow was separated through the normal procedure to obtain direct surface runoff hydrographs and the direct runoff depth over the catchment was computed for each flood event.

3.4.2.5 Computation of Infiltration loss (ϕ-index) and 1-hour effective rainfall units

With the known values of 1-hour catchment rainfall and the direct runoff depth for each flood event, the infiltration loss (constant loss rate) by trials was estimated for selected flood events of 3 Bridge catchments viz. 12, 698 and 235.

3.4.2.6 Derivation of 1-hour unit hydrograph

The studies to derive 1-hour unit hydrograph were confined to only those flood events found suitable in the additional data of 27 bridge catchments viz, 12, 235 and 698. The 1-hour unitgraphs were derived from the rainfall excess hyetograph, obtained by subtracting loss rate from 1-hour rainfall and their corresponding direct runoff hydrographs. Break-up of unit hydrographs derived from suitable flood events from 3 catchments is shown in Table 3.2.

3.4.2.7 Drawing of representative unitgraphs and measuring their parameters

The representative unit hydrograph (RUG) of 3 catchments were derived utilising UGs obtained from the additional data and unit hydrographs derived earlier.

Integrated RUGs of 3 sites have been tested on observed floods. RUGs of remaining 13 sites developed earlier were utilised as such without any modifications.

Following parameters of RUGs as indicated in Figure- 2, of 16 catchments were obtained and are furnished in Annexure 3.3.

a) Time from the centre of unit rainfall duration to the peak of unit hydrograph in hours (t_p).

b) Peak discharge of unit hydrograph in cubic meters per second (Q_p). This is the product of peak discharge per sq km (q_p) and catchment area (A).

c) Base width of unit hydrograph in hours (T_B).

d) Width of unit hydrograph measured at discharge ordinate equal to 50% of Q_p in hours (W_{50}).

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

f) Width of the rising side of U.G. measured in hours at discharge ordinates equal to 50% of Q_p (W_{R50}).

g) Width of the rising side of U.G. measured in hours at discharge ordinates equal to 75% of Q_p (W_{R75}).

h) Time from the start of rise to the peak of the unit hydrograph (T_m) .This is the summation of t_p and $0.5*t_r$

3.4.3 Establishing relationships between physiographic and representative unitgraph parameters

Linear and non-linear equations were tried for establishing the relationship between RUG parameters and physiographic parameters of the catchments and nonlinear equation as described below was found to be the best fit.

$Y = C * X^P$ 3.4.3.1

where

Y = Dependent variable

X = Independent variable

C = A constant

P = An exponent

Various relationships attempted are shown in Annexure 3.4. The relationship between computed parameter L*Lc//S and U.G. parameter t_p was found to be significant. Unit peak discharge of the U.G. (q_p) was related to t_p. UG Parameters W_{50}, W_{75}, W_{R50}, W_{R75} were related to q_p . The UG parameter T_B could be significantly correlated to t_p. The principle of least square errors was used in the regression analysis to get the relationship in the form of equation 3.4.3.1 to obtain the parameters of the Synthetic unitgraph in an unbiased manner.

The following relationships have been derived for estimating the 1-hr unitgraph parameters in the subzone 3(d).

Table 3.3 : Recommended SUG relations

Sl.No.	Relationship	Equation No.
1.	$t_p = 1.757\ (LLc/\sqrt{S})^{0.261}$	3.4.3.2
2.	$q_p = 1.260\ (t_p)^{-0.725}$	3.4.3.3
3.	$W_{50} = 1.974\ (q_p)^{-1.104}$	3.4.3.4
4.	$W_{75} = 0.961\ (q_p)^{-1.125}$	3.4.3.5
5.	$W_{R50} = 1.150\ (q_p)^{-0.829}$	3.4.3.6
6.	$W_{R75} = 0.527\ (q_p)^{-0.932}$	3.4.3.7
7.	$T_B = 5.411\ (t_p)^{0.826}$	3.4.3.8
8.	$T_m = t_p + t_r/2$	3.4.3.9
9.	$Q_p = q_p * A$	3.4.3.10

Relations developed are shown in Figures 3 to 9. List of catchment and unit hydrograph parameters studied to establish relationships and co-efficients of correlations is given in Annexure-3.4. The 25, 50 and 100 year flood peaks for 16 selected bridges have been computed using the recommended relations given in Table 3.3 and also from the RUGs of these bridges taking storm duration as $t_d = 1.1 * t_p$, as explained in para 5.2 . Annexure 3.5 shows the comparison of flood peaks using SUGs and RUGs. As can be seen from the Annexure, the maximum variation for 50 year flood peak lies between + 37.67% to -34.62 % .

The above relationships are recommended to estimate the parameters of 1-hour Synthetic unitgraph for an ungauged catchment with its known physiographic characteristics A, L, L_c and S.

3.4.4 Derivation of 1-hour synthetic unit hydrograph for an ungauged catchment

Considering the hydro-meteorological homogeneity of subzone, the relations established between physiographic and unitgraph parameters in section 3.4.3 are applicable for derivation of 1-hour synthetic unitgraph for an ungauged catchment in the subzone.

The steps for derivation of 1-hour unitgraph are:

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

ii) Obtain tp, q_p, W_{50}, W_{75}, W_{R50}, W_{R75} and T_B substituting appropriate basin/unit hydrograph parameters given in equations 3.4.3.2 to 3.4.3.10.

iii) Plot the parameters of 1-hour unitgraph viz. T_m, T_B, Q_p, W_{50}, W_{75}, W_{R50} and W_{R75} on a graph paper as shown in illustrative Figure 2 and sketch the unitgraph through these points.

Sum of discharge ordinates of t_r-hr unitgraph is obtained and compared with the value found by using the following equation:

$$\Sigma Q_i = \frac{2.78 * A}{t_r}$$

Where Q_i = discharge ordinates at 1-hour interval (cumecs)

A = Catchment area in sq.km

t_r = Unit duration in hours.

Suitable modifications can be made in falling limb upto W_{50} points, and a smooth unitgraph be drawn.

3.5 Design loss rate

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

In the pre-revised edition of the report, the loss rates of 132 events analysed were plotted against the storm durations and an average design loss rate curve, shown in figure 13 was obtained to compute the design loss rate. Attempts were made to modify the curve on the basis of loss rate data of 28 flood events selected from the additional data received recently. As these points lie considerably outside the curve, it was felt that the curve may not be modified on the basis of loss rate values of 28 flood events, obtained from the new data. It is therefore recommended that the loss rate curve, contained in the earlier report and enclosed at Figure 13 may be used for computing the loss rate values for ungauged catchments.

3.6 Design Base flow

Base flow values for 129 flood events inclusive of additional flood events of 3 catchments tabulated in different ranges are shown in Annexure 3.6. Out of 129 flood events, 96 flood events fall under the range of 0.01-0.19 cumecs/sq. km. The average base flow rate of 0.10 cumecs/sq.km may be adopted for estimating base flow for a catchment. The designer may however adopt any other suitable value as per site conditions.

Part-IV

RAINFALL STUDIES

4.1 Introduction

4.1.1: The India Meteorological Department (IMD) has conducted detailed rainfall studies for the subzone. The study covers Depth-Duration-Frequency analysis of available daily/short duration rainfall data in and around the subzone. The design storm components have been derived in the form of (i) 25, 50 and 100-year 24-hour isopluvial maps, (ii) 24 hours to short duration (1 to 23 hours) rainfall ratios, (iii) Time distribution curves for storms of various durations (2 to 24 hours) and (iv) Point to areal rainfall ratios for specific durations (1, 3, 6, 12 and 24 hours). The methodology applied for analysis of each component and the procedure for design storm estimation is discussed in the subsequent paras.

4.1.2: The results of the study serve as basic input for design flood estimation for small and medium catchments.

4.2 Data collected

The following rainfall data for a large number of stations in and around the subzone for as long a period as possible have been collected for the purpose of this study.

4.2.1: Ordinary raingauge (ORG) data (daily rainfall) of 210 stations, 18 maintained by IMD and 192 maintained by the State Governments, in 28 districts - 13 in Orissa, 9 in Madhya Pradesh, 4 in Bihar and 2 in Maharashtra - covering the subzone with 14 districts partly/fully outside the subzone. Of these, 110, 51 and 49 stations have respectively 51-70 years, 31-50 years and 11-30 years record. This was necessary in order to cover the areas where the raingauge network is sparse.

4.2.2: Self recording raingauge (SRRG) data (hourly rainfall) of 28 stations inside the subzone maintained by IMD in 13 districts - 11 in Orissa and 2 in Madhya Pradesh. Of these 6, 7, and 15 stations have respectively 8-16 years (79 station years), 4-7 years (30 station years), and 1-3 years (29 station years) data. All the 28 SRRG stations lie inside the subzone.

Normally RDSO makes available hourly/half hourly concurrent rainfall data in selected bridge catchments for conducting point to areal rainfall studies of the concerned subzone. However, in the present studies the necessity of this data did not arise because of the concurrent SRRG data from a dense network of IMD's stations in some districts of Orissa becoming available.

4.3 Data used

ORG data mentioned in para 4.2.1 above available from

IMD's National Data Centre have been extensively utilised for deriving the first component of the study, viz. preparation of 25, 50 and 100-year isopluvial maps.

SRRG data of all the 28 SRRG stations (138 Station- years) have been used for deriving the components (ii), (iii) and (iv) mentioned under para 4.1.1 above. The data available being vast, appropriate subsets of the data have been utilised for working out different components .

4.4 Depth-Duration-Frequency analysis

4.4.1 Isopluvial maps

For each of the 210 ORG stations in and around the subzone a series of annual maximum one-day rainfall was generated. The 210 station series thus formed were subjected to frequency analysis using Gumbel's extreme value distribution for computing one day rainfall estimates for 25, 50 and 100-year return periods. These daily rainfall estimates (210x3) were converted into any 24-hour rainfall estimates by using the conversion factor of 1.15. For each return period, the 24-hour estimates for 210 stations were plotted on a base map and isopluvials were drawn. The isopluvial maps of 25, 50 and 100-year 24-hour rainfall are shown in Plates 8, 9 and 10 respectively, which can be used to derive 24-hour rainfall estimates for specific return periods at any desired location in the subzone.

4.4.2 Short duration ratios

For each of the 6 SRRG stations inside the subzone having at least 8 years record, the hourly rainfall data were subjected to frequency analysis using partial duration series for computing T-year t-hour rainfall estimates for T = 2, 5, 10, 25 and 50 years and t = 1, 3, 6, 9, 12, 15, 18 and 24 hours. These estimates (6x8x5) were converted into ratios with respect to the corresponding 24-hour estimates. Average ratios (8x5) for the subzone as a whole (mean of 6 stations ratios) were then computed for each T-year t-hour pair. It was noticed that for a specified duration t, the average ratios beyond T=5 years were comparable in magnitude. As such the average ratios (8) corresponding to 10-year t-hour rainfall have been recommended to be adopted uniformly for converting 24-hour rainfall into t-hour rainfall. The 8 conversion ratios for t=1, 3, 6, 9, 12, 15, 18 and 24 hours given below were plotted on a graph and a smooth curve was drawn as shown in graph at Fig. 10 which can be used to derive conversion ratios for any duration t in general, including the intermediate duration (see table alongside graph).

Table No. 4.1: Conversion ratios for different durations

Rainfall Duration (t) in hours	Conversion ratio = 10-year t-hour rainfall / 10-year 24-hour rainfall
1	0.390
3	0.610
6	0.760
9	0.820
12	0.860
15	0.880
18	0.920
24	1.000

Any 25, 50 or 100-year 24-hour point rainfall in the subzone as read from isopluvial maps in Plates 8, 9 and 10 can be converted into corresponding 25, 50 or 100-year t-hour rainfall by multiplying with t-hour ratio as read from the curve in Fig. 10.

4.4.3 Time distribution curves

Based on hourly rainfall data of all the 28 SRRG stations inside the subzone a total of 2688 rainstorms of durations ranging from 2 to 24 hours were analysed and grouped station-wise into the following 5 categories :

1) rainstorms of 2 to 3-hour duration (891.of all stations)

2) rainstorms of 4 to 6-hour duration (787)

3) rainstorms of 7 to 12-hour duration (586)

4) rainstorms of 13 to 18-hour duration (242)

5) rainstorms of 19 to 24-hour duration (182)

For each station , 5 different graphs corresponding to each group of rainstorms were prepared by plotting the cumulative percentage of the total storm rainfall against percentage of the storm duration and the average time distribution curves (28x5) were drawn. Average time distribution curves (5) for the subzone as a whole were then drawn by plotting 28 station curves on the same graph and these are shown in Fig. 11, which can be used to derive the time distribution coefficients of storm rainfall in the subzone for rainstorms of any duration (see Annexure 4.1).

4.4.4 Point to areal rainfall ratios

In the present study, the availability of a fairly dense SRRG network in the subzone in some districts of Orissa made it possible to adopt the best scientific procedure for deriving point to areal relationship based on SRRG data alone in preference to bridge data.

The hourly rainfall records of 28 SRRG stations inside the subzone were scanned for short durations t =1, 3, 6, 12 and 24 hours to select t-hour representative storms based on consideration of maximum central value and concurrent surrounding data indicating an appreciable gradient. Isohyetal maps of 5 representative storms described hereunder were then prepared using concurrent rainfall values of stations corresponding to the date and time of each representative storm.

Table No. 4.2: Representative storms

Duration (hour)	Station	Rainfall (mm)	Date & time of occurrence (clock hour)	Concurrent data (No of stations)
1	Telkoi	26.0	2.9.78 (02-03)	6
3	Anandpur	54.0	8.8.79 (01-04)	6
6	Telkoi	130.0	2.9.78 (00-06)	6
12	Telkoi	202.4	2.9.78 (00-12)	6
24	Telkoi	244.9	1/2.9.78 (14-14)	6

By planimetering each isohyetal map around the storm centre and plotting the percentage ratios of areal rainfall depths to representative point rainfall against the areas, the best fit curves (5) were drawn as shown in graphs at Fig. 12(a) and 12(b), which can be used to derive the percentage areal reduction factors for converting point rainfall of any duration in the subzone into corresponding areal rainfall for any particular small catchment in the subzone (Annexure 4.2).

4.5 Heaviest rainfall records

4.5.1 ORG data

The highest ever recorded one-day station rainfall (24 hours rainfall ending 0830 hrs of date) along with date of occurrence in each of the 36 districts covering subzone - 3(d) have been compiled from the ORG data and presented in Annexure 4.3. However, in case of districts with stations recording > 35 cm all such stations have been included. Normal annual rainfall for each selected station is also given in the Annexure.

4.5.2 SRRG data

The heaviest storm rainfall in durations of 24, 12, 6, 3 and 1 hour alongwith date and time of occurrence in all the 13 districts covering all the 28 SRRG stations have been compiled from the available autographic records and are presented in Annexure 4.4.

4.6 Procedure for design storm rainfall estimation

For a specified design storm duration T_D hour (time of concentration) for a particular bridge catchment in the subzone, the design storm rainfall and its temporal distribution in the catchment can be computed by adopting the following procedure :

STEP :1 Locate bridge catchment under study on the 50-year, 24-hour isopluvial map in Plate - 8 and obtain the 50-year 24- hour point rainfall value in cm. For a catchment covering more than one isopluvial, compute the average point rainfall.

STEP :2 Read the conversion ratio for storm duration T_D from Fig.10 and multiply the 50-year 24-hour point rainfall in Step-1 to obtain 50-year T_D-hour point rainfall.

STEP :3 Read the areal reduction factor corresponding to storm duration T_D and the given area of catchment from Fig.12(a)/12(b) or Annexure 4.2 and multiply the 50-year T_D -hour point rainfall in Step-2 by this factor to obtain the 50-year T_D-hour areal rainfall over the catchment.

STEP :4 Read the time distribution co-efficients for 1,2,.....(T_{D-1}) hours corresponding to storm duration T_D from relevant graph in Fig.11 or Annexure 4.1 and multiply the 50- year T_D-hour areal rainfall in Step-3 by these co-efficients to obtain the cumulative depths of 1,2....(T_{D-1}) hour catchment rainfall.

STEP :5 Obtain the depths of storm rainfall occurring every hour in the bridge catchment by subtraction of the successive cumulative depths of 1,2....(T_{D-1}) and T_D hours in Step-4.

PART-V

DESIGN FLOOD ESTIMATION

5.1 Criteria and standards in regard to design flood of structures of small and medium catchments

Khosla Committee of Engineers had recommended a design flood of 50-year return period for fixing the waterway of the bridges. The committee had also recommended to design the foundation and protection work for larger discharge by increasing the design flood for waterways by 30% for small catchments up to 500 sq.km, 25 to 20% for medium catchments upto 500 to 5000 sq.km, 20 to 10% for large catchments upto 5000 to 25000 sq.km and less than 10% for very large catchments above 25000 sq.km.

Criteria and standards followed for design flood for bridges, cross-drainage structures and small dams are given below:-

a) Indian Railway Standard Bridges Substructures and Foundation Code revised in 1985 stipulates that all bridges shall be designed with adequate waterway for design discharge. This shall normally be the computed flood with probable recurrence interval of 50 years. However, at discretion of Chief Engineer/Chief Bridge Engineer, if a bridge is likely to have severe consequences, it may be designed for floods with a probable recurrence interval of more than 50 years, while bridges on less important lines or sidings may be designed for floods with a probable recurrence interval of less than 50 years.

b) Indian Road Congress - IRC 5-1985, clause 103 of Section-I "General Features of Design" Specifies that the waterway of a bridge is to be designed for a maximum flood of 50-yr return period. To provide for adequate margin of safety, the foundation and protection works should be designed for larger discharge. The recommended percentage increase over the design discharge specified in clause 103 is same as suggested by the Committee of Engineers.

c) Indian Standard Code of "Practice for design of cross drainage works-IS: 7784 Part-I, 1975" recommends that the waterway for cross drainage works should be designed for a 25 yr return period flood. To provide adequate margin of safety, the foundation and protection works should be designed for larger discharges. The percentage increase over the design discharge recommended in the code is same as suggested by the Committee of Engineers.

d) Central Water Commission's criteria of 1968 specifies that the diversion dams and weirs should be designed for floods of frequency of 50-100 yrs.

e) Indian Standards Guideline for "fixing spillway capacity of dams under clauses 3.1.2 and 3.1.3 of IS :11223- 1985" recommends 100 yr return period flood as inflow design flood for small dams having either gross storage of the dam between 0.5 and 10 Mm^3 or hydraulic head between 7.5 m and 12 m.

5.2 Estimation of design flood

To obtain design flood of required return period the effective rainfall for design storm duration is to be applied to the unit hydrograph of a catchment.

Procedure for computing design flood peak and design flood hydrograph for T - year return period by SUG approach is as under:

Step-1: Synthetic unit hydrograph

Derive the synthetic unit hydrograph as per section 3.4.4 and tabulate 1 hour U.G. ordinates.

Step-2: Design storm duration

The duration of storm, which causes maximum flow in a river at a specified location is called "Design Storm Duration". The SUG of 16 catchments have been derived using the parameters computed from recommended equations given in Table-3.3. Annexure 5.1 shows the computed UG parameters. The excess rainfall increments for different storm durations T_D=1.1*t_p and T_D = T_B have been obtained for 25, 50 and 100 year return period and applied on SUGs derived to obtain the flood peaks of 25, 50 and 100 year return period. The computed flood peaks are shown in Annexure 5.2. It is seen from the Annexure 5.2 that maximum flood peak has been obtained using the storm duration as 1.1 * t_p for nearly all the catchments.

It is therefore, recommended to adopt the value of T_D as 1.1*t_p. The design engineer may adopt the value of T_D as 1.1*t_p or any other value which gives the maximum value of discharge.

Step-3: Design storm rainfall

i) Adopt suitable design storm duration(T_D) as explained in Step-2.

ii) Obtain design storm rainfall and hourly areal rainfall units vide section 4.6.

iii) Adopt design loss rate as recommended in section 3.5.

iv) Obtain hourly effective rainfall increments by subtracting the design loss rate.

Step-4

a) Design flood peak

i) Arrange 1 hour effective areal rainfall values against the 1 hour U.G. ordinates such that the maximum value of effective rainfall against the maximum ordinate of U.G., the next lower value of effective rainfall against the next lower U.G. ordinate and so on upto T-hour duration.

ii) Obtain the base flow for the catchment area under study vide section 3.6.

iii) Obtain total surface runoff by summing the product of unit hydrograph ordinates as tabulated in Step- 3 (iv).

iv) Obtain flood peak by adding base flow to total surface runoff as per step- 4 (iii).

b) Design flood hydrograph

For computation of design flood hydrograph, carry out the steps from 1 to 3 and in addition, carry out the following steps.

Step- 5

Reverse the sequence of effective rainfall units obtained in Step- 4(i) to get the critical sequence of the effective rainfall units.

Step- 6

Multiply the first 1- hr effective rainfall with the ordinates of U.G. to get the corresponding direct runoff ordinates. Likewise, repeat the procedure with the rest of the hourly effective rainfall values giving a lag of 1-hr to successive direct runoff ordinate.

Step- 7

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

Step- 8

Add the base flow as given in Step- 4(ii) to the direct runoff ordinates at 1-hr interval in Step-7 to get the 50-year flood hydrograph.

5.2.1 Illustrative example

An example, taking bridge number 385 as ungauged catchment has been worked out for illustrating the procedure to compute 50- year design flood. The catchment plan is enclosed at Fig. A-1.

The particulars of the catchment under study are as follows:

i)	Name of subzone	Mahanadi
ii)	Name of Tributary	Sondur

iii)	Name of Rail section	Raipur - Vijayanagram
iv)	Shape of catchment	Leaf
v)	Location	Lat 20^{o} 04' 36" Long 83^{o} 21' 00"
vi)	Topography	Moderate slope

Step-wise procedure is explained below:

Step- 1: Physiographic parameters

Physiographic parameters obtained are as under :

1)	Area (A) {refer Fig. A-1}	194.00 sq.km
2)	Length of the longest stream (L)	39.36 km
3)	Length of the longest stream from a point opposite to C.G. of catchment to point of study (L_c)	15.13 km
4)	Equivalent stream slope (S) (Refer Annex. 5.3)	4.36 m/km

Step- 2: 1-hr Synthetic unitgraph

Synthetic unit hydrograph parameters as given below were computed using equations in para 3.4.3.

t^p = 7.50 hr (rounded)

q_p = 0.29 cum/km.

W_{50} = 7.74 hr

W_{75} = 3.87 hr

W_{R50} = 3.21 hr

W_{R75} = 1.67 hr

T_B = 29.00 hr

Q_p = 56.26 cumecs

Estimated parameters of unitgraph in step- 2 were plotted 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 and multiplied by t_r = 1 i.e. $\Sigma Q_i * t_i$ = 538.89 cumecs as shown in Fig. A - 2 and compared with the volume of 1.00 cm Direct Runoff Depth over the catchment, computed from the formula:

$$Q = (A * d) / (t_i * 0.36)$$

Where A = Catchment area in sq.km

$d = 1.0$ cm depth

$t_i = t_r = 1$ hr.(the unit duration of UG)

$$Q = \frac{A * d}{0.36 * t_r} = \frac{194 * 1}{0.36 * 1} = 538.89 \text{ cumecs}$$

Note: In case, $Q_i * t_i$ for the unitgraph drawn is higher or lower than the volume of 1 cm., the falling limb of hydrograph may be suitably modified without altering the points of synthetic parameters.

Step- 3: Estimation of design storm

(a) Design storm duration

The Design Storm Duration (T_D) has been adopted as 1.1 $*t_p$ as this value of storm duration gave higher value of flood peak (refer Step- 2, section 5.2). Rounding of the design storm duration to nearest hour, its value came as 8 hrs.

(b) Estimation of point rainfall and areal rainfall for storm duration

Catchment under study was located on Plate- 8 showing 50 year- 8 hr point rainfall. The point rainfall was found to be 32.00 cm. The conversion factor of 0.780 was read from Figure-10 to convert the 50 year- 24 hour point rainfall to 50 year- 8 hour point rainfall (since T_D = 8 hrs). 50 year-8 hr point rainfall was 24.96 cm.

Areal reduction factor of 0.9144 corresponding to the catchment area of 194 sq.km for T_D = 8 hour was interpolated from Annexure 4.2 or Fig. 12 (a) for conversion of point rainfall to areal rainfall. 50 year-8 hr areal rainfall thus worked out to be 22.82 cm.

The 50 year-8 hour areal rainfall was split into 1- hour rainfall increments using time distribution coefficients given in Annexure 4.1 or Figure 11.

A design loss rate of 0.21 cm/hr as recommended in para 3.5 was applied to get effective rainfall hyetograph.

The Table 5.1 given below gives the hourly effective rainfall increments.

Table - 5.1 : Hourly effective rainfall increments

Duration (hr)	Distribution coeff.	Storm rainfall (cm)	Rainfall increments (cm)	Loss per hr (cm)	Effective rainfall increments (cm)
1	2	3	4	5	6
1	0.48	10.96	10.96	0.21	10.75
2	0.62	14.15	3.20	0.21	2.99
3	0.73	16.66	2.51	0.21	2.30
4	0.81	18.49	1.83	0.21	1.62
5	0.88	20.08	1.60	0.21	1.39
6	0.94	21.45	1.37	0.21	1.16
7	0.98	22.36	0.91	0.21	0.70
8	1.00	22.82	0.46	0.21	0.25

Step- 4: Estimation of base flow

Taking design base flow of 0.10 cumecs per sq.km as recommended in para 3.6, the base flow was estimated to be 19.40 cumecs for the catchment area of 194 sq.km

Step- 5: Estimation of 50- year flood peak

a) Computation of flood peak

For estimation of the peak discharge, the effective rainfall increments were re-arranged against ordinates such that the maximum effective rainfall is placed against the maximum U.G. ordinate, next lower value of effective rainfall against next lower value of U.G. ordinate and so on, as shown in col. (2) and (3) in Table 5.2. Sum of the product of U.G. ordinates and effective rainfall increments gives total direct surface runoff to which base flow is added to get total peak discharge.

Table - 5.2 : 50- year flood peak

Time (hrs)	U.G ordinate (cumecs)	1 hr effec. rainfall (cms)	direct runoff (cumecs)
1	2	3	4
5	30.5	0.25	7.63
6	40.2	1.39	55.88
7	49.0	2.30	112.70
8	56.26	10.75	604.80
9	50.00	2.99	149.50
10	43.80	1.62	70.96
11	37.70	1.16	43.73
12	31.30	0.70	21.91
Total DSRO			1067.10
Base flow			19.40
Total peak discharge			1086.50 cumecs

(b) Computation of design flood hydrograph

Effective rainfall increments shown in col. (3) of Table 5.2 in Step- 5 were reversed to obtain critical sequence as shown below:

Table - 5.3 :Critical sequence of rainfall

Time (hr)	Critical 1-hr effective rainfall sequence (cm)
12	0.70
11	1.16
10	1.62
9	2.99
8	10.75
7	2.30
6	1.39
5	0.25

For computation of design flood hydrograph, the U.G. ordinates were tabulated in col (2) of Annex. 5.4. The critical sequence of effective rainfall increments were entered in col.3 to 10 horizontally. Direct runoff resulting from each of the columns are added horizontally. Direct runoff resulting from each of the effective rainfall depths with the synthetic U.G. ordinate in col.(2) and direct runoff values were entered in columns against each unit with a successive lag of 1 hr since the unit duration of S.U.G. is 1 hr. Direct runoff values are shown in col (3) to (10). Direct runoff values were added horizontally and total direct runoff is shown in col. (11) Adding total base flow of 12.10 m^3/sec. (col.12), design flood hydrograph ordinates (col. 13) were obtained. Design Flood Hydrograph was plotted against time as shown in Fig. A-3. The peak obtained was 1086.50 m^3/s which tallies with the peak shown in Table - 5.2.

5.3 Computation of Design H.F.L.

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.

Stage discharge relationship is represented by stage vs. discharge rating curve of a river at the point of study. The most acceptable method for establishing stage discharge rating curve is based on observed gauges and discharges covering satisfactorily the lower to upper elevation ranges. Stage discharge relation defines the complex interaction of channel characteristics including cross sectional areas, shape, slope and roughness of bed and banks. The permanent stage discharge relation is a straight line or a combination of straight lines on a logarithmic 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 firm 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.

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

Computation of HFL is generally done with the help of Manning's formula in which roughness coefficient ('N') is an important factor affecting the discharge of a river or Nalla. The value of N is highly variable and depends on a number of factors. viz, surface roughness, vegetation, channel irregularity, channel alignments, silting and scouring, obstruction, size and shape of channel, stage and discharge, seasonal change and suspended material and bed load.

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

The above procedure pertains to determination of design HFL corresponding to design flood of a river under natural conditions. With the type of structures in position there will generally be a constriction in the waterway. The effect of the constriction by way of raising the design HFL under natural conditions has to be evaluated in the water elevation 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 orifice formula of hydraulics is generally used depending on the upstream and downstream depths to estimate the revised design HFL under constricted conditions.

Sometimes it happens that the cross section of river or nalla on the downstream side of a cross drainage structure may be narrow than the cross section at the location of a crossing site.

The flood levels at the proposed structure may also be affected by the high flood levels in the main river joining downstream in proximity of the stream. In such cases, there will be backwater effect due to the narrow gorge of the river as the design flood for the crossing site will not be able to pass through the narrow gorge in the downstream. There will, therefore, be heading up of water in its upstream side which ultimately affects HFL of the river at the crossing site. In the latter case the tributary/stream on which the bridge is located will be under the influence of the backwater effect of the main stream joining downstream. In such cases backwater study may be carried out.

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

If the crossing site is located across the river/drainage in the unfavorable reach i.e. not complying with the usual requirements of gauge site, the design flood elevation may be computed in a straight reach downstream of the crossing and design flood elevation may be worked out by undertaking backwater studies.

PART-VI

ASSUMPTIONS , LIMITATIONS AND CONCLUSIONS

6.1 Assumptions

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

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

6.2 Limitations

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.

The generalised values of base flow and loss rate have been assumed to hold good for the whole subzone. The designer may adopt other suitable values of base flow and loss rate as per site conditions.

The data of 16 catchments have been considered for developing a generalised approach. However, for more reliable results , the data of more catchments uniformly distributed would be desirable.

6.3 Conclusions

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

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

The report is applicable for the catchment areas ranging from 25 sq km to 1000 sq km. Further the report may be used for large catchments upto 5000 sq km based on sound judgment and considering the data of neighbouring catchments also. However, individual site conditions may necessitate special study. Engineer-in-charge at site is advised to take a pragmatic view while deciding the design discharge of a bridge.

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ANNEXURE 1.1

LIST OF HYDRO-METEOROLOGICAL SUB-ZONES

SUB-ZONE	NAME OF SUBZONE (designated earlier)	Name of sub-zone(designated now)	River Basins included in the subzone
1(a)	Luni basin and Thar (Luni and other rivers of Rajasthan and Kutch)	Luni	Luni river and Thar (Luni & other rivers of Rajasthan & Kutch and Banas rivcher)
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 & 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)	Ganga 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
1(g)	Lower Ganga 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 Machhu, Bhadar, Ozat, Shetranji rivers of Kathiawad Peninsula.

3(b)	Lower Narmada and Tapi Basin	Lower Narmada and Tapi	Lower portion of Narmada, Tapi and Dhadhar rivers
3(c)	Upper Narmada and Tapi Basin	Upper Narmada & Tapi	Upper portion of Narmada and Tapi rivers
3(d)	Mahanadi Basin including Brahmani and Baitarani rivers	Mahanadi	Mahanadi, Baitarani and Brahmani rivers
3(e)	Upper Godavari Basin	Upper Godavari	Upper portion of Godavari Basin
3(f)	Lower Godavari Basin except coastal region	Lower Godavari	Lower portion of Godavari Basin
3(g)	Indravati Basin	Indravati	Indravati river
3(h)	Krishna subzone including Pennar Basin except coastal region	Krishna	Krishna and Pennar rivers except coastal region
3(i)	Kaveri & East flowing rivers except coastal region	Kaveri	Kaveri, Palar and Ponnaiyar rivers except coastal region
4(a)	Circars including east flowing rivers between Mahanadi and Godavari	Upper Eastern Coast	East flowing coastal rivers between Deltas of Mahanadi and Godavari rivers
4(b)	Coromandal Coast including east flowing rivers between Godavari and Kaveri	Lower Eastern Coast	East flowing coastal rivers, Manimukta, South Pennar, Cheyyar, Palar, North Pennar, Munneru, Palleru, Cundalakama and Krishna Delta
4(c)	Sandy Coroman Belt (east flowing rivers between Cauvery and Kanyakumari	South Eastern Coast	East flowng coastal rivers, Manimuthar, Vaigai, Arjuna, Tamraparni
5(a)	Konkan Coast (west flowing river between Tapi and Panaji)	Konkan Coast	West flowing coastal rivers between Tapi and Mandavi rivers
5(b)	Malabar Coast (west flowing rivers between Kanyakumari and Panaji	Malabar Coast	West flowing coastal rivers between Mandavi and Kanyakumari
6	Andaman and Nicobar	Andaman & Nicobar	
7	J & K, Kumaon Hills (Indus Basin)	Western Himalayas	Jhelum, Upper portion of Indus, Ravi and and Beas rivers

LIST OF RAILWAY BRIDGE CATCHMENTS AND AVAILABILITY OF GAUGE & DISCHARGE AND RAINFALL DATA

Sl.No.	Bridge No.	Name of stream	Name of section	LOCATION Longitude Deg.	Longitude Min.	Longitude Sec.	Latitude Deg.	Latitude Min.	Latitude Sec.	Catchment area (sq.km.)	No. of rain gauges	Data availability	Catchment years
1	7	Bhadon	Jharsuguda-Titlagarh	21	47	6	84	2	0	3108	9	1966-68,70-73	7
2	121	Kelo	Jharsuguda-Bilaspur	21	57	45	83	18	18	1150	9	1966-73	8
3	489	Karo	Bondamunda-Ranchi	22	58	24	84	56	36	823	7	1967-73	7
4	12 *	Lilagar	Kharagpur-Nagpur	22	2	0	82	20	0	666	5	1959-65,82-94	20
5	195	Jira	Sambalpur-Titlagarh	21	16	0	83	38	18	615	9	1975-79	5
6	235	Ranjhor	Sambalpur-Titlagarh	21	7	48	83	35	12	312	4	1975-80	6
7	332 (ii)	Parri	Raipur-Nagpur	21	6	36	81	3	48	225	3	1965-74	10
8	385	Sandur	Raipur-Viziram	20	4	36	83	21	0	194	3	1966-74	9
9	69	Borai	Jharsuguda-Bilaspur	22	0	36	82	58	42	173	3	1970-74	5
10	59 (b)	Karwar	Khargpur-Nagpur	22	1	0	82	53	42	136	3	1966-74	9
11	698 *	Bisra	Bondamunda-Ranchi	22	15	18	84	57	12	113	3	1965-74,82-94	23
12	48	Barajhor	Nergundi-Talcher	20	41	0	85	35	12	109	5	1961-65	5
13	79	Kisindajh	Nergundi-Talcher	20	49	6	85	17	24	67	7	1961-68	8
14	37	Barajhor	Nergundi-Talcher	20	34	36	85	43	48	64	2	1966-73	8
15	154	Aherajhor	Khargpur-Nagpur	21	51	38	83	41	35	58	2	1966-73	8
16	59 (s)	Dungajhor	Khargpur-Nagpur	22	8	13	84	25	37	47	2	1961-65	5
17	139	Karo	Rajkharaswar-Gua	22	15	10	85	25	0	374	3	1966	1
18	90	Phaljhor	Bhilai-Dhallirajhare	20	50	12	81	17	0	193	3	1966,75-79	6
19	332 (i)	Pitakalia	Kharagpur-Walter	21	14	48	86	38	24	175	3	1966-74	9
20	66 (k)	Mallania	Bilaspur-Katni	22	40	0	81	56	0	154	8	1958-66	9
21	478	Gokena	Bilaspur-Raipur	22	3	12	82	8	24	144	4	1975-81	7
22	25	Nun	Kharagpur-Puri	20	3	30	85	45	0	132	3	1975-81	7
23	40 (k)	Sargood	Bilaspur-Katni	22	32	54	81	56	42	115	1	1966-69	4
24	176	Sildana	Raipur-Vizinagram	20	50	48	85	32	24	66	4	1961-65	5
25	42	Barjhor	Nergundi-talcher	20	37	10	85	39	0	49	2	1969-73	5
26	325	Khuragedd	Raipur-Vizinagram	20	23	40	83	8	30	27	1	1965-67,69	4

Note 1:- Bridges from SL.No.1 to 16 only were found suitable for UG analysis

Note 2:- * These are key gauging sites and hydrological observation are continued

SUBZONE 3 (d) **ANNEXURE 3.2**

PHYSIOGRAPHIC PARAMETERS OF SELECTED CATCHMENTS

SL.NO.	BR.NO.	C.A. (sq.km)	L (km.)	L_C (km)	SEQ. (mt/km)
1	7	3108	96.60	51.84	0.59
2	121	1150	80.50	38.64	5.03
3	489	823	64.40	25.74	2.74
4	12	666	66.82	25.75	1.14
5	195	615	53.94	28.16	1.64
6	235	312	41.06	21.09	1.62
7	332(ii)	225	30.59	13.52	1.32
8	385	194	39.36	15.13	4.36
9	69	173	35.42	18.50	2.37
10	59(B)	136	28.18	11.26	5.90
11	698	113	26.57	14.40	9.06
12	48	109	19.32	10.46	2.68
13	79	67	17.71	8.45	2.08
14	37	64	17.71	7.24	7.14
15	154	58	12.48	9.65	5.20
16	59(S)	47	13.07	8.29	3.30

ONE HOUR R.U.G. PARAMETERS OF SELECTED CATCHMENTS

S.NO.	BR.No.	t_p (hrs)	Q_p (cumecs)	q_p cum/sq km	t_r (hrs)	T_B (hrs)	W_{50} (hrs)	W_{75} (hrs)	W_{R50} (hrs)	W_{R75} (hrs)
1	7	16.50	559.44	0.18	1	57	10.97	5.25	6.17	2.60
2	121	12.50	332.00	0.28	1	37	7.00	3.60	3.00	1.80
3	489	8.50	271.59	0.33	1	29	6.00	3.00	2.00	1.50
4	12	15.50	111.70	0.17	1	45	15.50	8.50	6.10	3.40
5	195	10.50	123.00	0.20	1	38	11.20	5.05	4.00	2.30
6	235	11.50	52.50	0.17	1	61	15.60	7.30	3.65	2.18
7	332 (11)	6.50	85.50	0.38	1	21	6.00	2.97	3.00	1.56
8	385	7.50	58,20	0.30	1	24	7.75	4.50	3.20	1.80
9	69	9.50	38.06	0.22	1	31	11.70	5.53	2.87	2.10
10	59 (B)	6.50	40.80	0.30	1	31	6.48	3.48	3.40	1.39
11	698	4.50	52.20	0.46	1	22	4.60	1.60	2.65	1.00
12	48	7.50	20.71	0.19	1	38	12.80	6.85	4.20	2.60
13	79	4.50	27.47	0.41	1	16	6.12	3.74	2.60	1.27
14	37	5.50	24.32	0.38	1	18	6.67	3.40	2.20	1.30
15	154	5.50	23.20	0.40	1	20	5.45	3.32	2.20	1.20
16	59 (S)	5.50	17.39	0.37	1	28	5.30	2.20	2.70	1.20

SUBZONE 3(d) **Annexure 3.4**

PHYSIOGRAPHIC AND UNIT HYDROGRAPH PARAMETERS STUDIED

Sl.No.	X	Y	A	B	r
1.	$L*L_c/S^{0.5}$	q_p	0.723	-0.163	0.67
2.*	do	t_p	1.757	0.261	0.92
3.*	t_p	q_p	1.260	-0.725	0.88
4.	$L/S^{0.5}$	q^p	0.636	-0.273	0.69
5.	do	t_p	0.636	-0.417	0.89
6.	t_p	W_{50}	1.798	0.726	0.76
7.*	q_p	do	1.974	-1.104	0.96
8.	t_p	W_{75}	0.849	0.749	0.71
9.*	q_p	do	0.961	-1.125	0.91
10.	t_p	W_{R50}	0.922	0.615	0.74
11.*	q_p	do	1.150	-0.829	0.83
12.	t_p	W_{R75}	0.387	0.721	0.86
13.*	q_p	do	0.527	-0.932	0.92
14.*	t_p	T_B	5.411	0.826	0.84

NOTE:

1. Equation is of the form of $Y = A * X^B$
2. Recommended relations for derivation of S.U.G are marked as "*"

SUBZONE 3(d)

ANNEXURE 3.5

COMPARISION OF FLOOD PEAKS BASED ON RUG's AND SUG's

SL.NO.	BR.NO.	Q25 IN CUMECS			Q50 IN CUMECS			Q100 IN CUMECS		
		RUG	SUG	% DIF	RUG	SUG	% DIF	RUG	SUG	% DIF
1	7	9646	8961	+ 7.64	10929	10163	+7.64	12210	11366	+7.42
2	121	4601	3731	+33.31	5089	4133	+33.31	5752	4668	+23.22
3	489	3086	2242	+37.62	3841	2790	+37.62	4218	3064	+37.66
4	12	1516	1685	-10.01	1592	1769	-10.01	1816	2014	-9.81
5	195	2023	2091	- 3.28	2062	2130	-3.28	2327	2406	-3.28
6	235	972	1325	-26.63	1083	1475	-26.63	1192	1624	-26.60
7	332 (ii)	1188	913	+30.14	1339	1029	+30.14	1491	1145	+30.16
8	385	998	943	+ 5.79	1149	1086	+5.79	1300	1227	+5.92
9	69	594	688	-13.64	712	825	-13.64	804	932	-13.71
10	59 (B)	593	617	- 4.32	701	740	-4.32	799	835	-4.35
11	698	768	562	+36.37	892	654	+36.37	923	696	+32.54
12	48	371	568	-34.62	400	612	-34.62	429	656	-34.61
13	79	415	373	+11.06	467	421	+11.06	520	468	+11.09
14	37	403	419	- 3.68	458	476	-3.68	513	532	-3.66
15	154	448	442	+1.33	516	510	+1.33	554	547	+1.33
16	59 (S)	282	287	-1.56	331	345	-1.56	369	376	-1.64

SUBZONE 3(d)

ANNEXURE-3.6

AVERAGE BASE FLOW RANGES OF OBSERVED FLOOD EVENTS

Sl.No.	BR.No.	C.A.	0.000 to 0.009	0.010 to 0.090		0.100 to 0.190	0.200 to above	TOTAL
			IN CUMECS PER SQUARE KILOMETERS					
1	7	3108	-	-	4	-	-	4
2	121	1150	-	-	4	-	-	4
3	489	823	2	-	1	1	-	4
4	12	666	-	5	4	2	-	11
5	195	615	-	-	4	3	-	7
6	235	312	-	-	3	3	-	6
7	332 (11)	225	1	3	-	6	-	10
8	385	194	-	-	3	1	1	5
9	69	173	-	1	4	1	2	8
10	59 (8)	136	-	-	3	3	3	9
11	698	113	-	-	9	9	12	30
12	48	109	-	-	1	5	-	6
13	79	67	-	-	4	1	1	6
14	37	64	1	-	4	-	-	5
15	154	58	-	-	2	5	-	7
16	59 (S)	47	-	-	6	-	1	7
TOTAL FLOOD EVENTS			4	9	56	40	20	129

SUBZONE 3 (d)

ANNEXURE 4.1

TIME DISTRIBUTION CO-EFFICIENTS (PERCENTAGE) OF CUMMULATIVE HOURLY RAINFALL

INTER-MEDIATE HOURS	DESIGN STORM DURATION (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	INTER-MEDIATE HOURS
1	100	89	80	70	64	59	50	48	45	43	42	39	35	34	33	31	30	29	23	22	21	20	19	19	1
2		100	94	87	83	78	66	62	59	57	55	53	48	46	44	43	42	41	33	32	31	30	29	28	2
3			100	96	91	87	77	73	69	67	64	62	57	55	53	51	50	49	41	40	39	38	37	36	3
4				100	97	93	85	81	78	75	72	70	64	62	60	58	57	56	48	46	45	44	43	42	4
5					100	97	92	88	85	81	78	76	70	68	66	64	62	61	55	53	52	51	50	48	5
6						100	97	94	90	87	84	81	75	73	71	69	67	66	60	58	57	56	54	53	6
7							100	98	95	92	89	86	80	78	76	74	72	70	64	62	61	60	59	58	7
8								100	98	95	93	90	85	83	81	78	76	74	68	66	65	63	62	61	8
9									100	98	96	94	89	86	84	81	80	78	72	70	69	67	66	65	9
10										100	98	96	92	88	86	84	82	81	76	74	72	70	69	68	10
11											100	98	95	93	90	88	86	84	79	77	75	73	72	71	11
12												100	98	96	94	91	89	87	82	80	79	77	75	74	12
13													100	98	96	94	92	90	85	83	81	79	77	76	13
14														100	98	96	94	93	87	85	84	81	80	79	14
15															100	98	97	95	91	89	87	85	83	82	15
16																100	98	97	93	91	89	87	85	84	16
17																	100	98	96	93	91	89	87	86	17
18																		100	98	96	94	92	90	89	18
19																			100	98	96	94	92	91	19
20																				100	98	96	94	93	20
21																					100	98	96	94	21
22																						100	99	96	22
23																							100	99	23
24																								100	24

AREAL REDUCTION FACTORS (PERCENTAGE) FOR POINT TO AREAL RAINFALL

CATCHMENT 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	CATCHMENT AREA (sq km)
0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0
50	94.00	95.12	96.25	96.75	97.25	97.75	97.79	97.83	97.87	97.92	97.96	98.00	98.06	98.12	98.19	98.25	98.31	98.38	98.44	98.50	98.56	98.62	98.69	98.75	50
100	89.25	91.00	92.75	93.67	94.58	95.50	95.58	95.67	95.75	95.83	95.92	96.00	96.06	96.12	96.19	96.25	96.31	96.38	96.44	96.50	96.56	96.62	96.69	96.75	100
150	85.25	87.38	89.50	90.67	91.83	93.00	93.21	93.42	93.62	93.83	94.04	94.25	94.40	94.54	94.69	94.83	94.98	95.12	95.27	95.42	95.56	95.71	95.85	96.00	150
200	81.75	84.12	86.50	87.83	89.17	90.50	90.83	91.17	91.50	91.83	92.17	92.50	92.69	92.88	93.06	93.25	93.44	93.62	93.81	94.00	94.19	94.37	94.56	94.75	200
250	78.50	81.00	83.50	85.17	86.83	88.50	88.92	89.33	89.75	90.17	90.58	91.00	91.19	91.38	91.56	91.75	91.94	92.12	92.31	92.50	92.69	92.87	93.06	93.25	250
300	75.50	78.38	81.25	83.00	84.75	86.50	87.00	87.50	88.00	88.50	89.00	89.50	89.77	90.04	90.31	90.58	90.85	91.12	91.40	91.67	91.94	92.21	92.48	92.75	300
350			79.00	80.83	82.67	84.50	85.08	85.67	86.25	86.83	87.42	88.00	88.31	88.62	88.94	89.25	89.56	89.87	90.19	90.50	90.81	91.12	91.44	91.75	350
400			77.25	79.17	81.08	83.00	83.58	84.17	84.75	85.33	85.92	86.50	86.85	87.21	87.56	87.92	88.27	88.62	88.98	89.33	89.69	90.04	90.40	90.75	400
450			75.50	77.50	79.50	81.50	82.17	82.83	83.50	84.17	84.83	85.50	85.88	86.25	86.62	87.00	87.37	87.75	88.12	88.50	88.87	89.25	89.62	90.00	450
500			74.25	76.25	78.25	80.25	80.92	81.58	82.25	82.92	83.58	84.25	84.65	85.04	85.44	85.83	86.23	86.62	87.02	87.42	87.81	88.21	88.60	89.00	500
600												82.00	82.46	82.92	83.37	83.83	84.29	84.75	85.21	85.67	86.12	86.58	87.04	87.50	600
700												80.25	80.73	81.21	81.69	82.17	82.65	83.12	83.60	84.08	84.56	85.04	85.52	86.00	700
800												78.50	79.00	79.50	80.00	80.50	81.00	81.50	82.00	82.50	83.00	83.50	84.00	84.50	800
900												77.00	77.50	78.00	78.50	79.00	79.50	80.00	80.50	81.00	81.50	82.00	82.50	83.00	900
1000												76.00	76.50	77.00	77.50	78.00	78.50	79.00	79.50	80.00	80.50	81.00	81.50	82.00	1000
1100												74.50	75.08	75.67	76.25	76.83	77.42	78.00	78.58	79.17	79.75	80.33	80.92	81.50	1100
1200												74.00	74.56	75.12	75.69	76.25	76.81	77.37	77.94	78.50	79.06	79.62	80.19	80.75	1200
1300																								80.50	1300
1400																								79.50	1400
1500																								79.25	1500
2000																								78.50	2000

Sub-zone 3(d)

Annexure 4.3

Statistics of Heaviest Rainfall & Annual Normal Rainfall in sub-zone 3(d)

SN	State/District	Station	Heaviest Rainfall > 35cm	Heaviest Rainfall < 35cm	Date of occurance	Annual Normal rainfall in cm
1	2	3	4	5	6	7
	ORISSA					
1.	Sambalpur	1. Sambalpur	58.2	-	19.08.1982	163.4
		2. Padampur	36.8	-	07.09.1939	132.1
		3. Jharsuguda	35.0	-	29.06.1925	161.8
2.	Balasore	4. Chandbali (Obsy.)	51.5	-	16.09.1879	170.9
		5. Bhadrak	42.9	-	20.08.1907	152.5
		6. Soro	40.1	-	19.10.1945	194.4
		7. Balasosre	39.9	-	18.07.1987	158.6
		8. Jaleswar	39.4	-	23.07.1894	137.4
		9. Balipal	37.2	-	18.10.1946	150.8
3.	Cuttack	10. Jagatsingpur	49.9	-	20.07.1889	169.5
		11. Cuttack(Obsy)	41.7	-	10.08.1934	153.9
		12. Kendrapara	40.2	-	27.06.1925	143.7
4.	Puri	13. Puri (Obsy)	48.0	-	21.10.1862	137.3
		14. Gop	35.6	-	06.11.1891	169.3
5.	Mayurbhanj	15. Baripada	46.7	-	12.10.1973	146.7
		16. Karanjia	36.3	-	30.07.1927	165.1
6.	Bolangir	17. Bolangir	40.2	-	30.08.1982	145.8
		18. Sonepur	36.6	-	16.06.1918	140.7
7.	Baudh-Phulbani	19. Bulandapara	39.5	-	15.06.1936	213.9
8.	Keonjhar	20. Anandpur	-	34.3	09.07.1941	145.9
9.	Koraput	21. Koraput	-	33.7	25.06.1914	161.9
10.	Sundargarh	22. Bonaigarh	-	33.4	20.07.1920	165.9
11.	Ganjam*	23. Mohana	-	31.7	10.10.1938	131.8
12.	Kalahandi	24. Bhawanipatna	-	31.1	02.07.1930	145.7
13.	Dhenkanal	25. Pallahara	-	30.7	04.10.1936	178.2
	BIHAR					
14.	Hazaribagh	26. Hunterganj	46.7	-	01.08.1917	131.6
		27. Chatra	37.0	-	02.08.1917	134.4
15.	Palamau*	28. Mahuaduar	36.4	-	27.06.1923	141.3
		29. Garu	35.6	-	20.06.1911	160.3

1	2		3	4	5	6	7
16.	Singhbhum	30.	Majhgaon	35.7	-	30.07.1927	153.0
17.	Ranchi	31.	Chainpur	-	26.1	06.10.1936	158.6
	MADHAYA PRADESH						
18.	Shahdol*	32.	Pushparajgarh	41.9	-	25.06.1946	150.1
		33.	Umaria	36.5	-	19.08.1923	137.5
19.	Raipur	34.	Raipur	37.0	-	04.08.1910	138.5
20.	Balaghat*	35.	Palhera	36.8	-	22.08.1931	164.2
21.	Raigarh	36.	Raigarh	36.1	-	10.07.1958	163.9
22.	Durg	37.	Dongargarh	35.9	-	01.08.1959	130.6
23.	Mandla*	38.	Bichhia	35.9	-	21.09.1926	170.9
24.	Bilaspur	39.	Champa(Obsy)	-	34.7	26.07.1947	149.9
25.	Sarguja	40.	Ambikapur	-	34.2	27.06.1945	165.8
26.	Baster	41.	Antagarh	-	30.8	30.06.1959	177.2
	MAHARASHTRA						
27.	Chanda	42.	Ghorajheri	40.0	-	19.07.1959	135.6
28.	Bhandara*	43.	Pangree	39.5	-	25.07.1937	155.5
		44.	Sakoli	38.4	-	26.06.1908	157.2
		45.	Bodalkasa	37.6	-	31.08.1947	137.9

Note: Col.2: Districts underlined/asterisked* are/fully outside the sub-zone.

Heaviest 24-hour's & shorter durations rainfall recorded in Subzone 3(d)

STATE/ District	SRRG Station	Highest Storm Rainfall (mm) & Duration (hours)	Date & Time of Occurance (clock hour)
(1)	(2)	(3)	(4)
ORISSA			
1. Keonjhar (5)	1. Telkoi*	245 (24)	1-2.9.78 (14-14)
		202 (12)	2.9.78 (00-12)
		130 (6)	(00-06)
		95 (3	12.8.78 (18-21)
		50 1	(19-20)
2. Dhenkanal (4)	2. Talcher*	236 (24)	12-13.8.76 (14-14)
		113 (6)	13.8.76 (00-06)
		103 (3)	(17-20)
	3. Pallahera	185 (12)	1-2.9.78 (22-10)
	4. Rangoli	80 (1)	2.8.79 (13-14)
3. Cuttack (4)	5. Paradip	234 (24)	8-9.8.74 (12-12)
		219 (6)	29.8.76 (00-06)
	6. Akhuapada	225 (12)	27.8.78 (03-15)
	7. Naraj	158 (3)	1.8.76 (20-23)
		83 (1)	(21-22)
4. Sambalpur (2)	8. Jharsuguda	213 (24)	19-20.8.75 (01-01)
		179 (12)	19.8.75 (11-23)
		149 (6)	13.8.69 (11-17)
		135 (3)	(13-16)
		68 (1)	26.8.75 (04-05)
5. Bilaspur (2)	9. Champa	197 (24)	7-8.8.79 (17-17)
		153 (6)	21-22.8.71 (20-08)
		139 (3)	27.2.71 (07-13)
		139 (1)	(07-10)
		87 (12)	(07-08)
6. Puri (2)	10. Bhubaneshwar	164 (24)	29.7.69 (04-04)
		127 (6)	21-22.6.71 (20-02)
		110 (3)	(23-02)
		83 (1)	23.6.79 (19-20)
	11. Puri	139 (12)	8.8.81 (01-13)
7. Kalahandi (1)	12. Nawapara*	162 (24)	19-20.7.76 (07-07)
		121 (12)	20.7.76 (00-12)
		116 (6)	(01-07)
		82 (3)	(03-06)
		43 (1)	(03-04)

(1)		(2)		(3)	(4)
8.	Balasore (1)	13.	Chandbali*	125 (24) 74 (12) 72 (6) 72 (3) 50 (1)	12-13.8.75 (08-08) 17-18.8.75 (18-06) 7.8.75 (10-16) (10-13) (10-11)
9.	Sundargarh	14.	Pamposh*	122 (24) 116 (12) 115 (6) 89 (3) 53 (1)	27-28.7.78 (17-17) 8-9.8.77 (14-02) (19-01) 8.8.77 (19-22) 23.8.78 (00-01)
10.	Mayurbhanj	15.	Thakurmunda*	105 (24) 90 (12) 81 (6) 70 (3) 55 (1)	7-8.8.79 (10-10) 16-17.4.79 (16-04) 16.4.79 (16-22) (20-23) (20-21)
11.	Baudh-Khondmals	16.	Phulbani*	94 (24) 88 (12) 63 (6) 61 (3) 38 (1)	1-2.8.76 (10-10) (16-04) 27.7.75 (14-20) (14-17) 12.7.75 (14-15)
Madhya Pradesh					
12.	Bastar	17.	Kanker	235 (24) 176 (12) 163 (6) 115 (3) 79 (1)	17-18.9.80 (15-15) (22-10) 16-17.9.69 (19-01) 18.9.80 (02-05) 26.6.74 (23-24)
13.	Raigarh	18.	Raigarh*	183 (24) 161 (12) 112 (6) 85 (3) 42 (1)	23-24.9.73 (07-07) (19-07) 24.9.73 (00-06) 9-10.8.74 (23-02) 10.8.74 (01-02)

Note:

Col (1) Districts underlined are partly outside the subzone and figures in the parenthesis indicate total number of SRRG stations in the district.

Col (2) Stations asterisked* have data for less than five years.

LIST OF SUG PARAMETERS OBTAINED FROM EQUATIONS

SL.NO.	BR.NO.	CA (sq.km.)	t_r (hrs)	q_p (cumec/km^2)	W_{50} (hrs)	W_{75} (hrs)	W_{R50} (hrs)	W_{R75} (hrs)	T_B (hrs)	1 cm.Vol. (cumecs)	Q_p (cumecs)
1	7	3108	17.50	0.16	14.93	7.55	5.25	2.91	58	8633.33	497.28
2	121	1150	11.50	0.21	11.06	5.56	4.19	2.26	41	3194.44	241.50
3	489	823	10.50	0.23	10.00	5.02	3.89	2.07	38	2286.11	189.29
4	12	666	12.50	0.20	11.67	5.88	4.37	2.36	44	1850.00	133.20
5	195	615	11.50	0.25	9.12	4.57	3.63	1.92	41	1708.33	153.75
6	235	312	9.50	0.25	9.12	4.57	3.63	1.92	35	866.67	78.00
7	332(11)	225	8.50	0.27	8.38	4.19	3.40	1.79	32	625.00	60.75
8	385	194	7.50	0.29	7.74	3.87	3.21	1.67	29	538.89	56.26
9	69	173	8.50	0.27	8.38	4.19	3.40	1.79	32	480.56	46.71
10	59(B)	136	6.50	0.32	6.94	3.46	2.96	1.52	25	377.78	43.52
11	698	113	6.50	0.32	6.94	3.46	2.96	1.52	25	313.89	36.16
12	48	109	6.50	0.32	6.94	3.46	2.96	1.52	25	302.78	34.88
13	79	67	5.50	0.37	5.92	2.94	2.62	1.33	22	186.11	24.79
14	37	64	4.50	0.42	5.14	2.55	2.36	1.18	19	177.78	26.88
15	154	58	4.50	0.42	5.14	2.55	2.36	1.18	19	161.11	24.36
16	59(S)	47	5.50	0.37	5.92	2.94	2.62	1.33	22	130.56	17.39

SUBZONE 3(d)

ANNEXURE 5.2

COMPARISION OF Q50 USING TD = 1.1*t_p & T_D = T_B

SL.NO.	BR.No.	C.A. in (sq km.)	Q50 (Cumecs)	
			T_D = 1.1*t_p	T_D=T_B
1	7	3108.00	10162.74	9914.07
2	121	1150.00	4132.89	4063.31
3	489	823.00	2790.00	2617.81
4	12	666.00	1768.66	1678.35
5	195	615.00	2130.40	2032.03
6	235	312.00	1475.05	1344.21
7	332(ii)	225.00	1029.03	925.01
8	385	194.00	1086.50	973.07
9	69	173.00	825.19	739.98
10	59(B)	136.00	739.97	646.09
11	698	113.00	653.76	564.37
12	48	109.00	612.40	530.56
13	79	67.00	420.79	355.12
14	37	64.00	475.78	386.64
15	154	58.00	509.67	443.51
16	59(S)	47.00	344.75	283.96

SUBZONE 3(d) ANNEXURE 5.3

COMPUTATION OF EQUIVALENT SLOPE OF BRIDGE CATCHMENT NO 385

SL. NO.	REDUCED DISTANCE		REDUCED LEVEL		LENGTH OF EACH SEG.	HEIGHT ABOVE DATUM	$D_{i-1}+D_i$	$L_i (D_{i-1}+D_i)$
	RD Miles	RD Kms.	RL Feet	RL m	L_i m	D_i m	m	km.* m
1	0.00	0.00	736	224.33	0.00	0.00	0.00	0.00
2	7.50	12.08	850	259.08	12.08	34.75	34.75	419.61
3	10.00	16.10	900	274.32	4.03	49.99	84.74	341.08
4	12.70	20.45	950	289.56	4.35	65.23	115.22	500.86
5	14.50	23.35	1000	304.80	2.90	80.47	145.70	422.24
6	21.00	33.81	1250	381.00	10.47	156.67	237.14	2481.67
7	23.60	38.00	1500	457.20	4.19	232.87	389.54	1630.61
8	24.00	38.64	1750	533.40	0.64	309.07	541.94	349.01
9	24.15	38.88	2000	609.60	0.24	385.27	694.34	167.68
10	24.30	39.12	2250	685.80	0.24	461.47	846.74	204.49
11	24.45	39.36	2500	762.00	0.24	537.67	999.14	241.29
							SUM	6758.54

$$S = \frac{L_i * (D_{i-1} + D_i)}{L^2} = \frac{6758,54}{15449.56} = 4.36 \text{ m/km.}$$

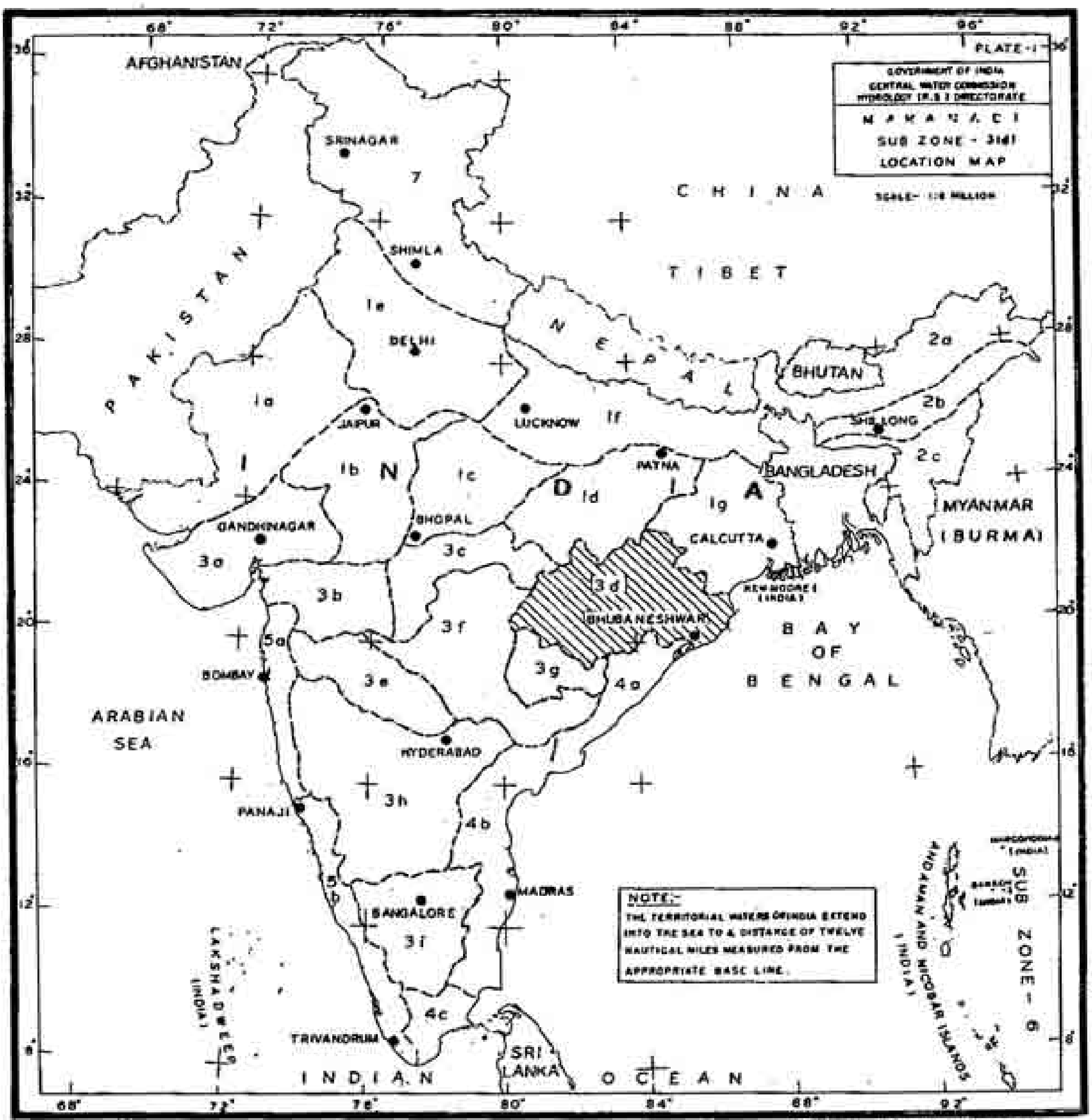
DATUM = 736.00 m i.e R . L. of river bed at point of study

SUBZONE 3(d)

ANNEXURE 5.4

COMPUTATION OF DESIGN FLOOD HYDROGRAPH OF BRIDGE CATCHMENT NO. 385

TIME (hrs)	S.U.H. ORDI-NATES	RAINFALL EXCESS IN Cm								TOTAL DSRO IN CUMECS	BASE FLOW IN CUMECS	TOTAL FLOW IN CUMECS
		0.70	1.16	1.62	2.99	10.75	2.30	1.39	0.25			
		DIRECT RUNOFF (CUMECS)										
1	2	3	4	5	6	7	8	9	10	11	12	13
0	0.00	0.00								0.00	19.40	19.40
1	3.70	2.59	0.00							2.59	19.40	21.99
2	9.10	6.37	4.29	0.00						10.66	19.40	30.06
3	15.20	10.64	10.56	5.99	0.00					27.19	19.40	46.59
4	22.00	15.40	17.63	14.74	11.06	0.00				58.84	19.40	78.24
5	30.50	21.35	25.52	24.62	27.21	39.78	0.00			138.48	19.40	157.88
6	40.20	28.14	35.38	35.64	45.45	97.83	8.51	0.00		250.94	19.40	270.34
7	49.00	34.30	46.63	49.41	65.78	163.40	20.93	5.14	0.00	385.60	19.40	404.99
8	56.26	39.38	56.84	65.12	91.20	236.50	34.96	12.65	0.93	537.57	19.40	556.97
9	50.00	35.00	65.26	79.38	120.20	327.88	50.60	21.13	2.28	701.72	19.40	721.12
10	43.80	30.66	58.00	91.14	146.51	432.15	70.15	30.58	3.80	862.99	19.40	882.39
11	37.70	26.39	50.81	81.00	168.22	526.75	92.46	42.40	5.50	993.52	19.40	1012.92
12	31.30	21.91	43.73	70.96	149.50	604.79	112.70	55.88	7.63	1067.10	19.40	1086.50
13	26.00	18.20	36.31	61.07	130.96	537.50	129.40	68.11	10.05	991.60	19.40	1011.00
14	22.30	15.61	30.16	50.71	112.72	470.85	115.00	78.20	12.25	885.50	19.40	904.90
15	19.00	13.30	25.87	42.12	93.59	405.28	100.74	69.50	14.07	764.46	19.40	783.86
16	15.70	10.99	22.04	36.13	77.74	336.48	86.71	60.88	12.50	643.46	19.40	662.86
17	13.00	9.10	18.21	30.78	66.68	279.50	71.99	52.40	10.95	539.61	19.40	559.01
18	11.00	7.70	15.08	25.43	56.81	239.73	59.80	43.51	9.43	457.48	19.40	476.88
19	9.00	6.30	12.76	21.06	46.94	204.25	51.29	36.14	7.83	386.57	19.40	405.97
20	7.70	5.39	10.44	17.82	38.87	168.78	43.70	31.00	6.50	322.49	19.40	341.89
21	6.50	4.55	8.93	14.58	32.89	139.75	36.11	26.41	5.58	268.80	19.40	288.20
22	5.40	3.78	7.54	12.47	26.91	118.25	29.90	21.82	4.75	225.43	19.40	244.83
23	4.40	3.08	6.26	10.53	23.02	96.75	25.30	18.07	3.93	186.94	19.40	206.34
24	3.50	2.45	5.10	8.75	19.44	82.78	20.70	15.29	3.25	157.75	19.40	177.15
25	2.70	1.89	4.06	7.13	16.15	69.88	17.71	12.51	2.75	132.07	19.40	151.47
26	2.00	1.40	3.13	5.67	13.16	58.05	14.95	10.70	2.25	109.31	19.40	128.71
27	1.33	0.93	2.32	4.37	10.47	47.30	12.42	9.04	1.93	88.77	19.40	108.17
28	0.60	0.42	1.54	3.24	8.07	37.63	10.12	7.51	1.63	70.15	19.40	89.55
29	0.00	0.00	0.70	2.15	5.98	29.03	8.05	6.12	1.35	53.37	19.40	72.77
			0.00	0.97	3.98	21.50	6.21	4.86	1.10	38.62	19.40	58.02
				0.00	1.79	14.30	4.60	3.75	0.88	25.32	19.40	44.72
					0.00	6.45	3.06	2.78	0.68	12.96	19.40	32.36
						0.00	1.36	1.85	0.50	3.73	19.40	23.13
							0.00	0.83	0.33	1.17	19.40	20.57
								0.00	0.15	0.15	19.40	19.55
									0.00	0.00	19.40	19.40

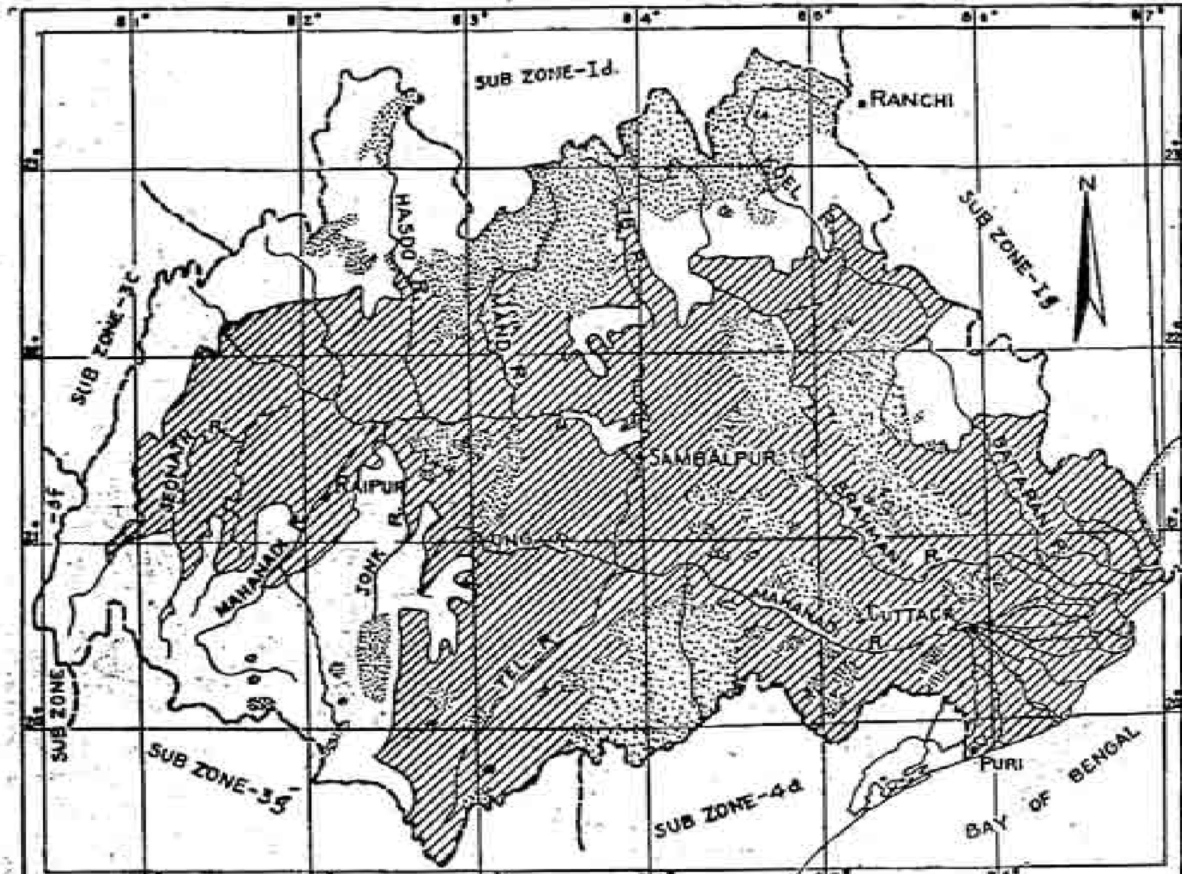


NOTES:- i) BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.

ii) RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS SHOWN ON THE MAPS RESTS WITH THE PUBLISHER.

L. P. NAUTIYAL, L.R. PANT

PLATE: 3



REFERENCES

1. EAST COAST
2. MOUNTAINS
3. GREAT PLAIN

NOTE

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

SCALE

50 0 50 100 150 KILOMETRES

25 0 25 50 75 100 MILES

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

FLOOD ESTIMATION REPORT

MAHANADI SUB ZONE – 3 d.

PHYSIOGRAPHY

DRAWN BY:	CHECKED BY:
L. K. PANT	K.K. AICH

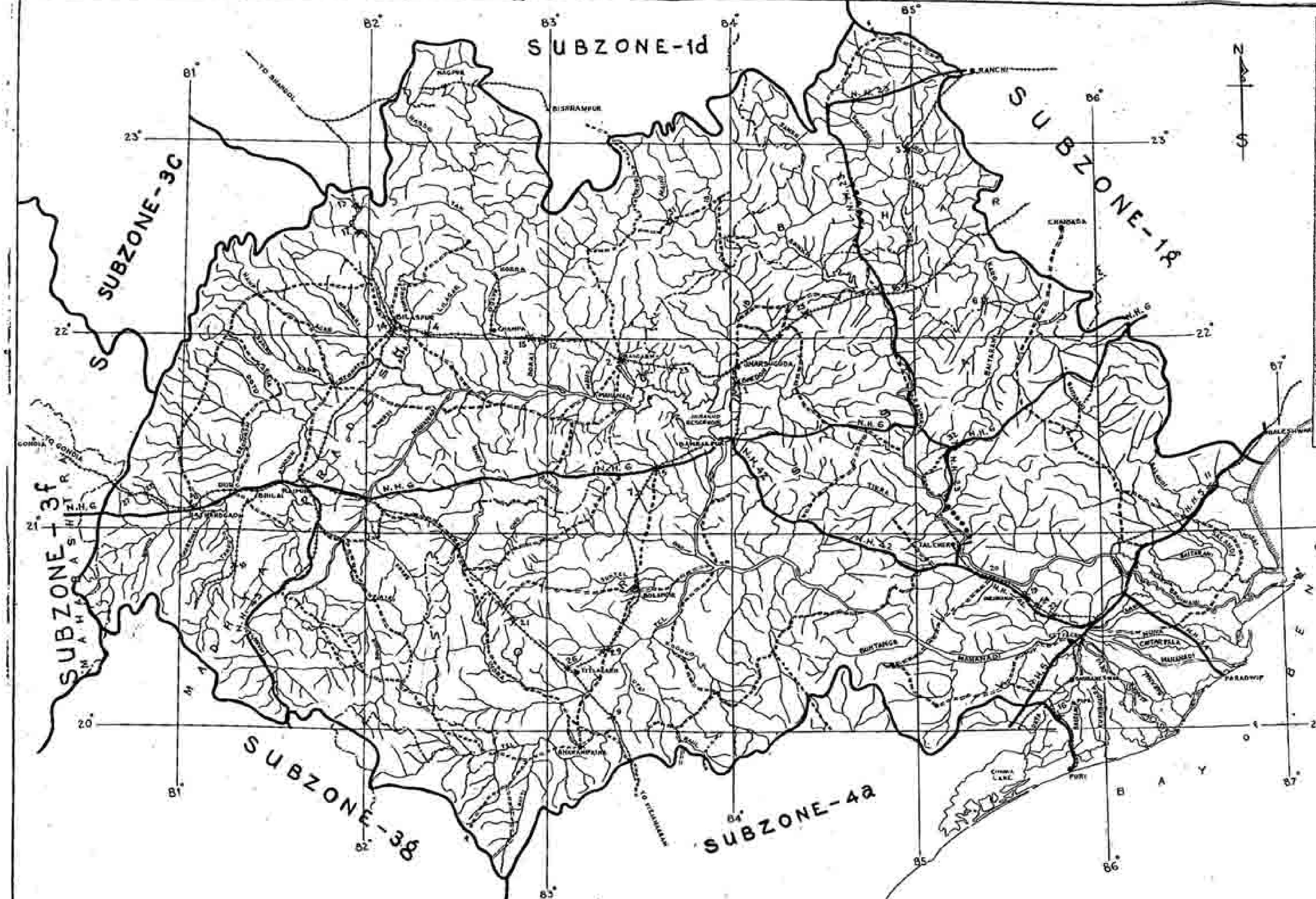
BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.

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

PLATE-2

SL. NO.	BR. NO.	RLY. SECTION	STREAM	C.A. IN SQ.KM	DATA AVAILABILITY
1	7	JHARSUGUDA-TITLAGARH	BHEDON-R	3106	1966-68 & 70-73
2	121	JHARSUGUDA-BILASPUR	KELO-R	1150	1966-73
3	409	BONDAMUNDA-RANCHI	KARO-R	823	1967-73
4	12	KHARAGPUR-NAGPUR	LILAGAR-R	666	1959-63 82-94
5	195	SAMBALPUR-TITLAGARH	JIRA-R	615	1975-79
6	199	RAJKHARASWAR-GUA	KARO-R	374	1966
7	235	SAMBALPUR-TITLAGARH	RANJ JHOR-R	312	1975-79, 80
8	531(?)	RAIPUR-NAGPUR	PARRI-NALA	225	1965-74
9	350	RAIPUR-VIZIANAGRAM	SANDUR-R	194	1966-74
10	90	BHILAI-DHALLIRAJHARA	PHULJHAR-N	193	1966, 1975-79
11	533(?)	KHARAGPUR-WALTAIR	PITAKALIA-N	175	1966-74
12	69	JHARSUGUDA-BILASPUR	BORAI-R	173	1970-74
13	66K	BILASPUR-KATNI	MAILANIA-R	154	1958-66
14	476	BILASPUR-RAIPUR	GOKLHA-N	144	1975-79, 80-81
15	510(?)	KHARAGPUR-NAGPUR	KARWAR NALA	136	1966-74
16	25	KHURDA ROAD-PURI	NUN-N	132	1975-79, 80-87
17	60K	BILASPUR-KATNI	SARGOD-N	115	1966-69
18	696	BONDAMUNDA-RANCHI	BISRA-N	113	1965-74, 82-94
19	48	NERGUNDI-TALCHER	BARA JHOR-R	109	1961-65
20	79	NERGUNDI-TALCHER	KISINDA JHOR	67	1961-68
21	176	RAIPUR-VIZIANAGRAM	SILOHA-N	66	1961-65
22	37	NERGUNDI-TALCHER	BARA JHOR	64	1966-73
23	154	KHARAGPUR-NAGPUR	ANERA JHOR-R	58	1966-73
24	42	NERGUNDI-TALCHER	BAR JHORA-R	49	1969-73
25	57(?)	KHARAGPUR-NAGPUR	DUNGA JHOR	47	1961-65
26	325	RAIPUR-VIZIANAGRAM	KURAGEDDA	29	1965-67 & 69
27	306	RAIPUR-DONGARGARH	SUKHANALA	21	1964-65
28	306	RAIPUR-NAGPUR	KOLERA-R	17	1961-65
29	426	JHARSUGUDA-TITLAGARH	NALA	16	1964-65
30	29	TUMSAR-TIRODI	NALA	12	1961, 63 & 64

SL. NO.	SITE	SITE UNDER CWC/M.O.S.T	STREAM	C.A. IN SQ.KM	DATA AVAILABILITY
31	1	PATHALGAON-KUNKURI ROAD C.W.C. (M.O.S.T)	MAINI	708	1979 (ESTABLISHED)
32	2	MALLAHARA-GOVINDPUR ROAD C.W.C. (M.O.S.T)	MANHARA	154	1979 (")



LEGEND

1. SUB-ZONE BOUNDARY
2. RAILWAY LINE
3. RIVERS
4. ROADS
5. BRIDGE SITES
6. CATCHMENT AREA .... C.A.
7. MINISTRY OF SHIPPING AND TRANSPORT ... M.O.S.T.
8. NATIONAL HIGHWAYS N.H.42
9. STATE BOUNDARY

NOTES _

1. FOR LOCATION OF BRIDGES REFER ANNEXURE-3.1
2. PHYSICAL ATRIBUTE OF MAP BASED ON MAP NE.44, NE.45 AND NF-44, NF-45
3. RAILWAY STATIONS NAMES ARE AS PER INDIAN BRADSHAW.

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

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

GOVT. OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENT) DTE.

MAHANADI, (BRAHMANI & BAITARANI)
SUBZONE-3d

RIVER SYSTEM AND LOCATION OF RLY. BRIDGES (G & D SITES)

DRAWN BY :- L. K. PANT
CHECKED BY :- C. S. A. GARWAL

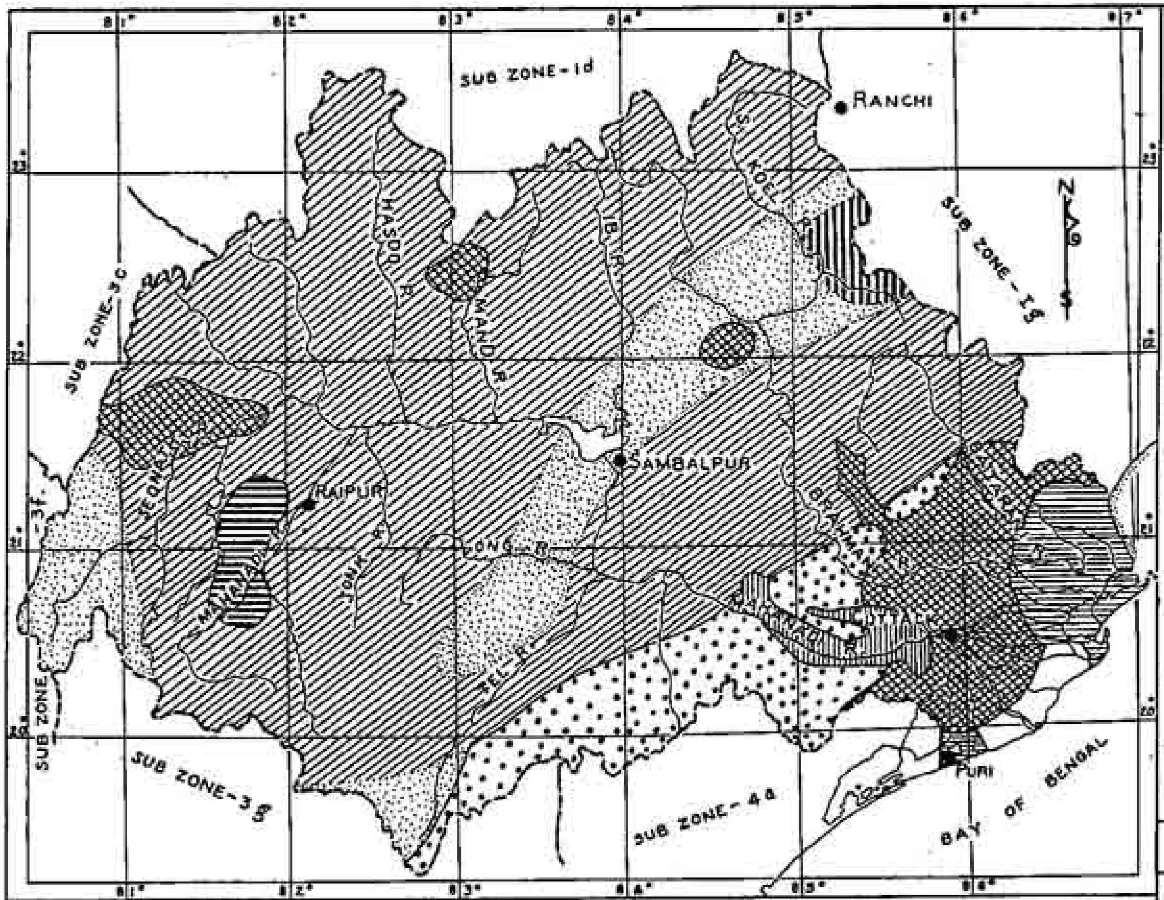


PLATE : 4

REFERENCES :

1. RED SANDY SOIL
2. RED LOAMY SOIL
3. RED & YELLOW SOIL
4. LATERITE SOIL
5. DEEP BLACK SOIL
6. DELTAIC ALLUVIAL SOIL
7. COASTAL SANDY SOIL
8. ALLUVIAL SOIL (RECENT)
9. MIXED RED AND BLACK SOIL
10. TOWNS

SCALE

50 0 50 100 150 KILOMETRES

25 0 25 50 75 100 MILES

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

FLOOD ESTIMATION REPORT

MAHANADI SUB ZONE - 3d.

SOIL CLASSIFICATION

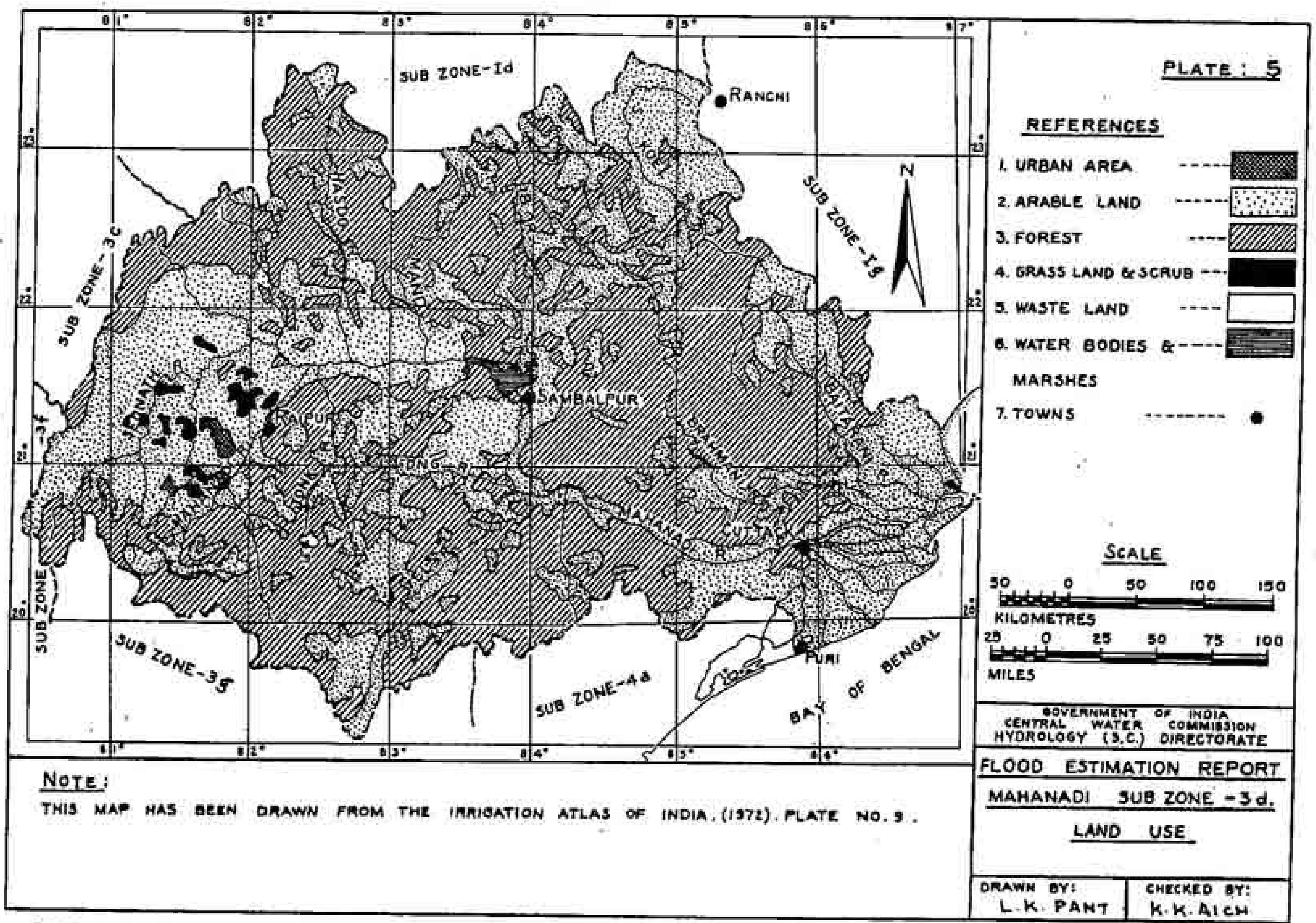
DRAWN BY:	CHECKED BY:
L. P. NAUTIYAL	K. K. AICH

NOTE :

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

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

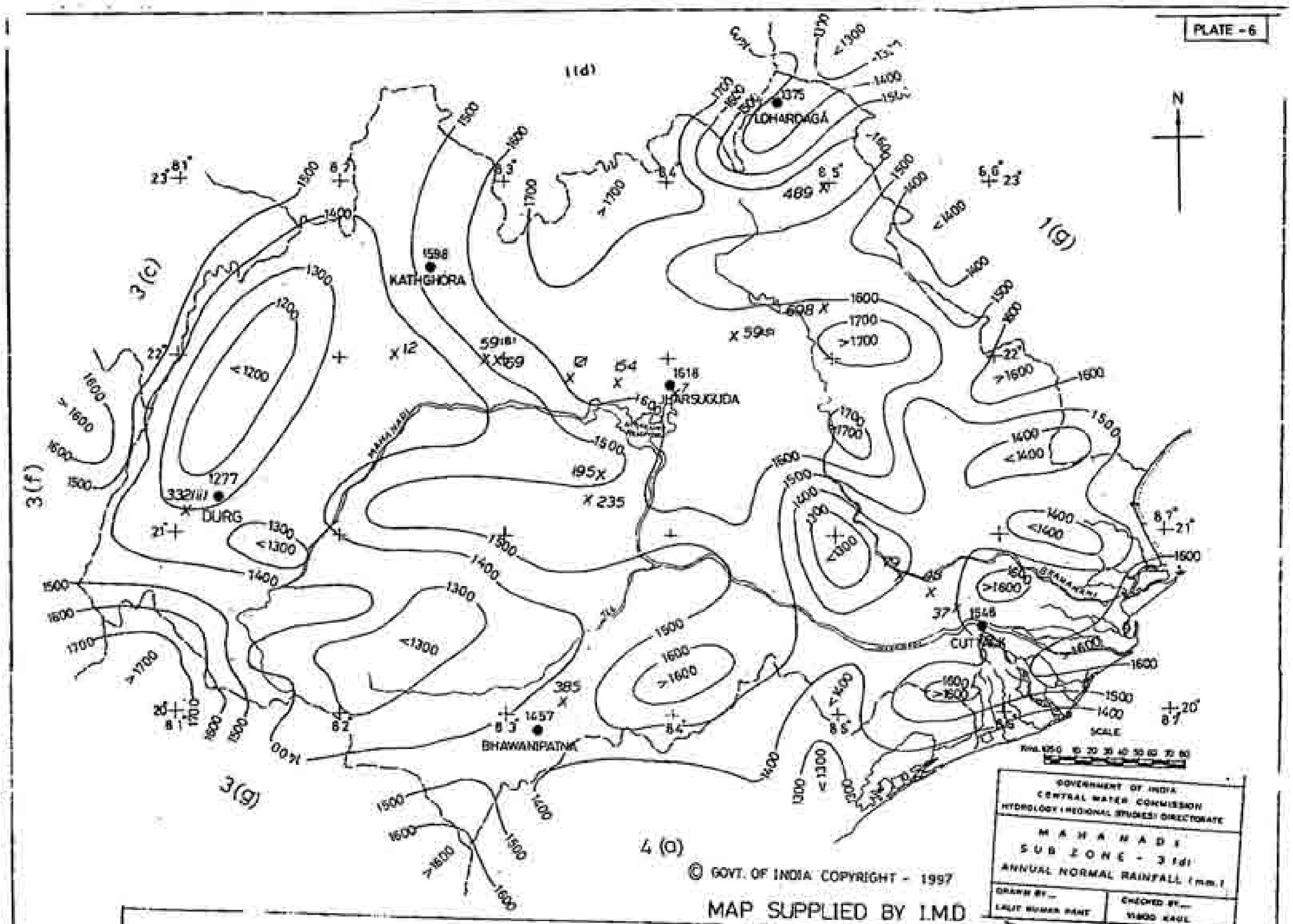
THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.



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

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

PLATE - 6



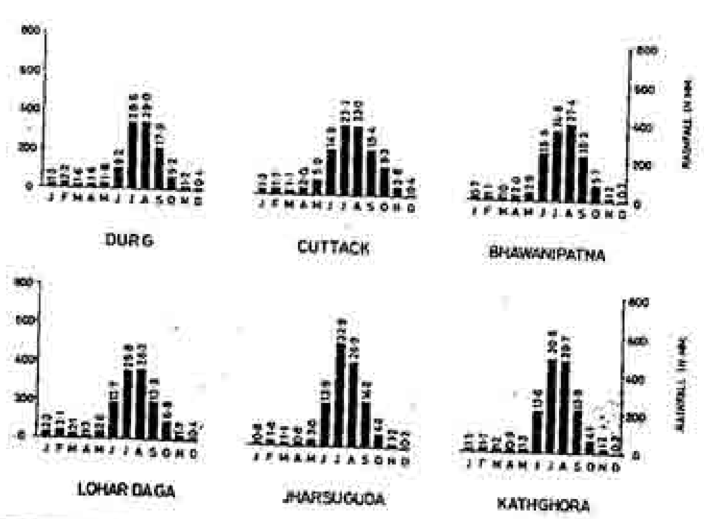
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DIRECTORATE

M A H A N A D I
S U B Z O N E - 3 (d)
ANNUAL NORMAL RAINFALL (mm.)

DRAWN BY— LALIT KUMAR PANT | CHECKED BY— VINOD KAUL

MAP SUPPLIED BY I.M.D

MONTHLY RAINFALL DISTRIBUTION



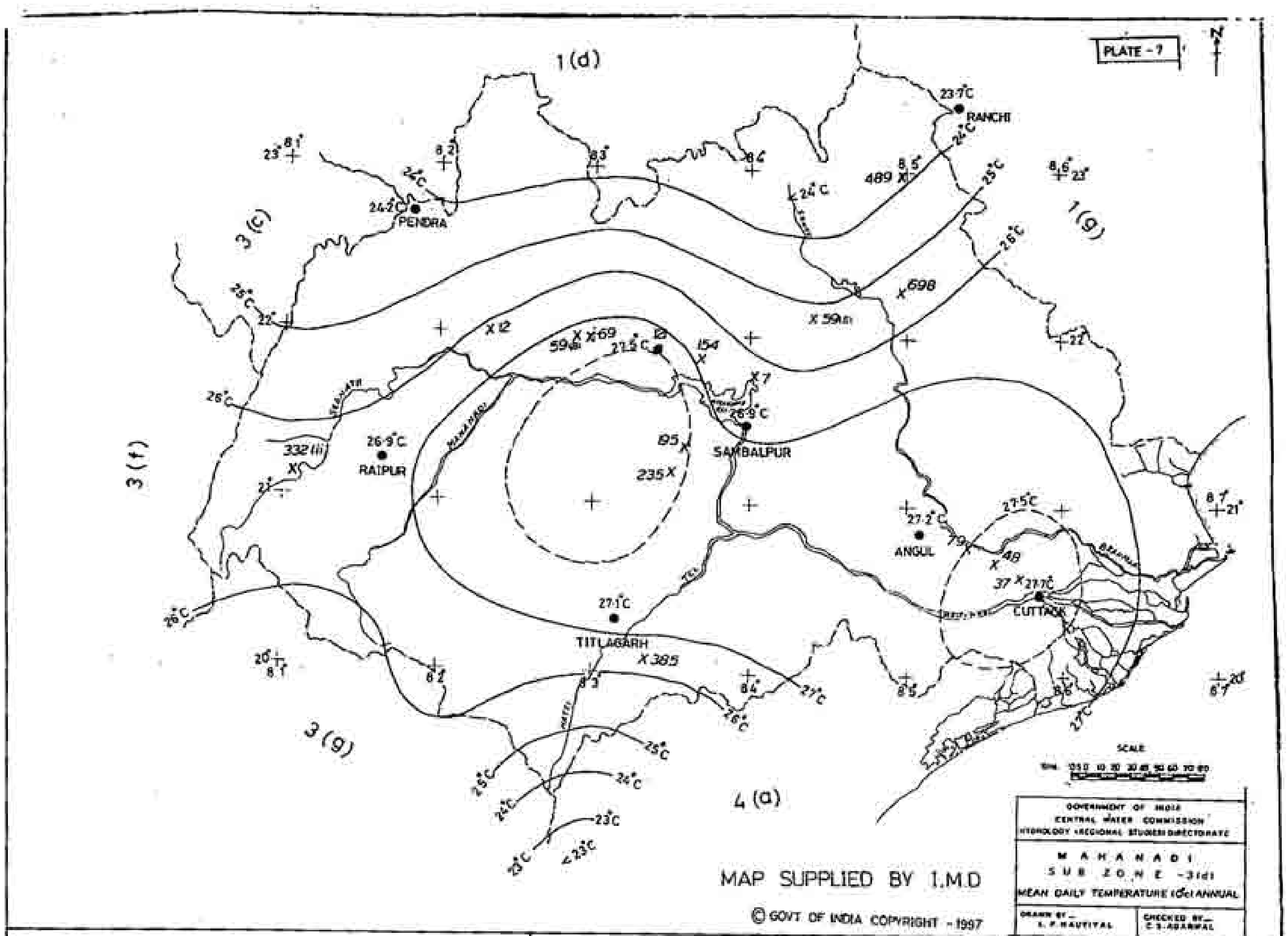
REFERENCES

1. ISOHYETES IN MM (ANNUAL NORMAL)
2. SUBZONE BOUNDARY
3. TOWNS
4. RIVERS
5. BRIDGE SITES

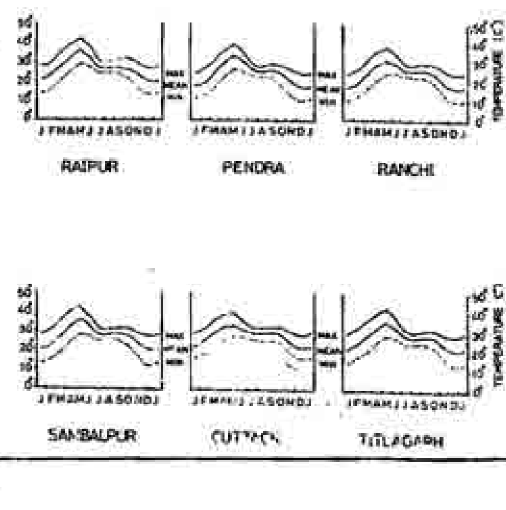
NOTES —

1. THE ALPHABETS ALONG ABCISSA INDICATE NAME OF MONTHS.
2. COLUMN HEIGHTS REPRESENT RAINFALL IN MM.
3. FIGURES ABOVE COLUMN INDICATE MONTHLY RAINFALL AS PERCENT OF ANNUAL RAINFALL.
4. RESPONSIBILITY FOR CORRECTNESS OF INTERNAL DETAILS SHOWN ON THE MAP RESTS WITH PUBLISHER.
5. BASED UPON SURVEY OF INDIA WITH PERMISSION OF THE SURVEYOR GENERAL OF INDIA.

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



MONTHLY TEMPERATURE VARIATIONS



REFERENCES

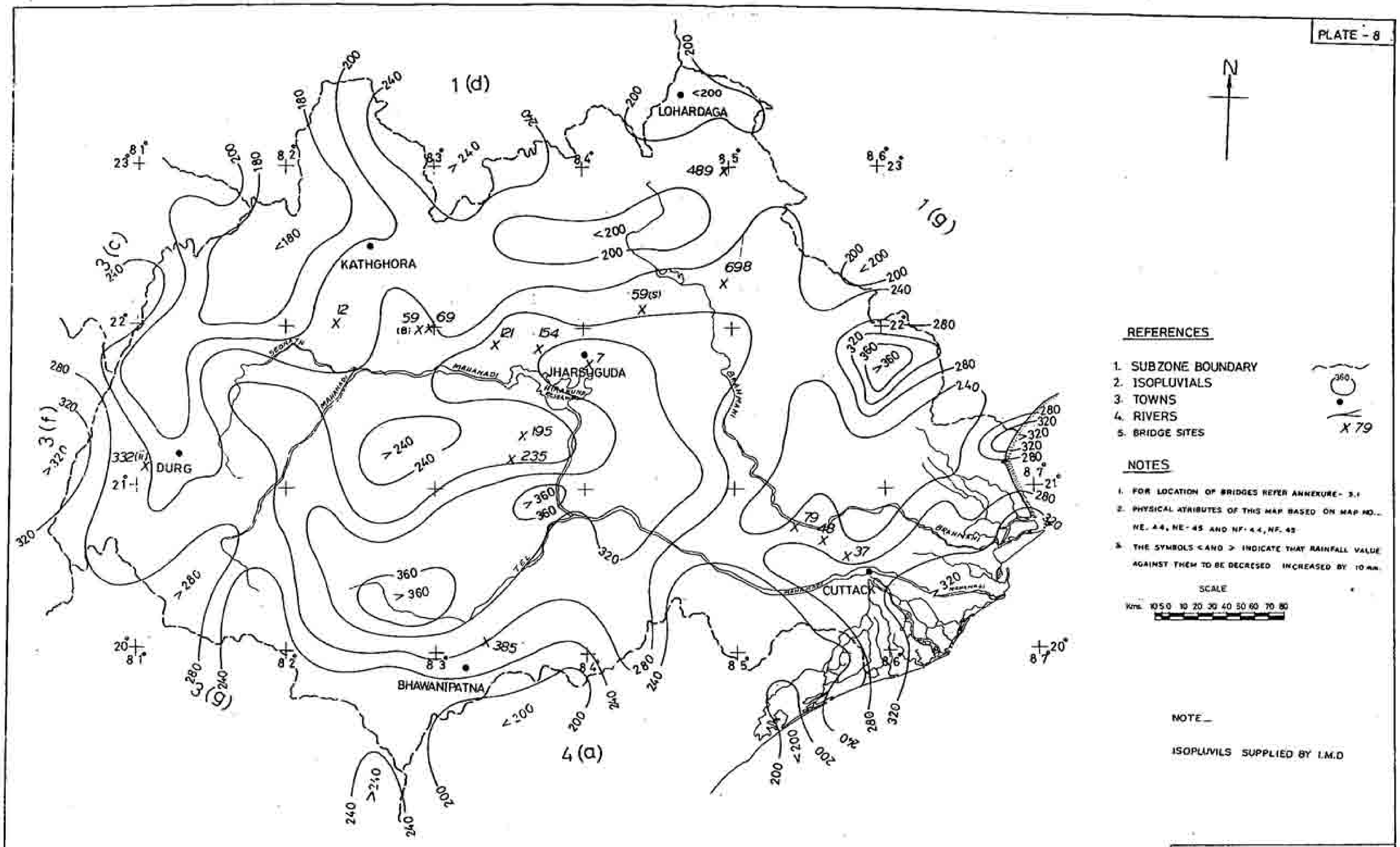
1. ISOTHERMS (DEGREES CELSIUS)
2. SUBZONE BOUNDARY
3. TOWNS
4. RIVERS
5. BRIDGE SITES — X 79

NOTES _

1. RESPONSIBILITY FOR CORRECTNESS OF INTERNAL DETAILS SHOWN ON THE MAP RESTS WITH PUBLISHER.
2. BASED UPON SURVEY OF INDIA MAP WITH PERMISSION OF THE SURVEYOR GENERAL OF INDIA.

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

PLATE - 8



REFERENCES

1. SUBZONE BOUNDARY
2. ISOPLUVIALS
3. TOWNS
4. RIVERS
5. BRIDGE SITES

NOTES

1. FOR LOCATION OF BRIDGES REFER ANNEXURE- 3.1
2. PHYSICAL ATRIBUTES OF THIS MAP BASED ON MAP NO. NE. 44, NE- 45 AND NF- 44, NF. 45
3. THE SYMBOLS < AND > INDICATE THAT RAINFALL VALUE AGAINST THEM TO BE DECRESED INCREASED BY 10 mm.

SCALE

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

NOTE_

ISOPLUVILS SUPPLIED BY I.M.D

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

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

RESPONSIBILITY FOR CORRECTNESS OF INTERNAL DETAILS SHOWN ON THE MAP RESTS WITH PUBLISHER

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DIRECTORATE

MAHANADI
SUB ZONE - 3 (d)
25 YEAR 24-HOUR RAINFALL (mm.)

DRAWN BY —	CHECKED BY —
L. K. PANT	K.K. AICH

PLATE - 9

REFERENCES

1. SUBZONE BOUNDARY
2. ISOPLUVIALS
3. TOWNS
4. RIVERS
5. BRIDGE SITES X 79

NOTES

1. FOR LOCATION OF BRIDGES REFER ANNEXURE - 3.1
2. PHYSICAL ATRIBUTES OF THIS MAP BASED ON MAP NO., NE-44, NE. 45 AND NF.44, NF.45.
3. THE SYMBOLS < AND > INDICATE THAT RAINFALL VALUE AGAINST THEM TO BE DECREASED / INCREASED BY 10mm.

SCALE

Kms 10 5 0 10 20 30 40 50 60 70 80

NOTE -
ISOPLUVIAL SUPPLIED BY I.M.D

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

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

RESPONSIBILITY FOR CORRECTNESS OF INTERNAL DETAILS SHOWN ON THE MAP RESTS WITH PUBLISHER.

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DIRECTORATE

MAHANADI
SUB ZONE - 3(d)
50 - YEAR 24 - HOUR RAINFALL (mm)

DRAWN BY -	CHECKED BY -
L.P. NAUTIYAL	VINOD KAUL

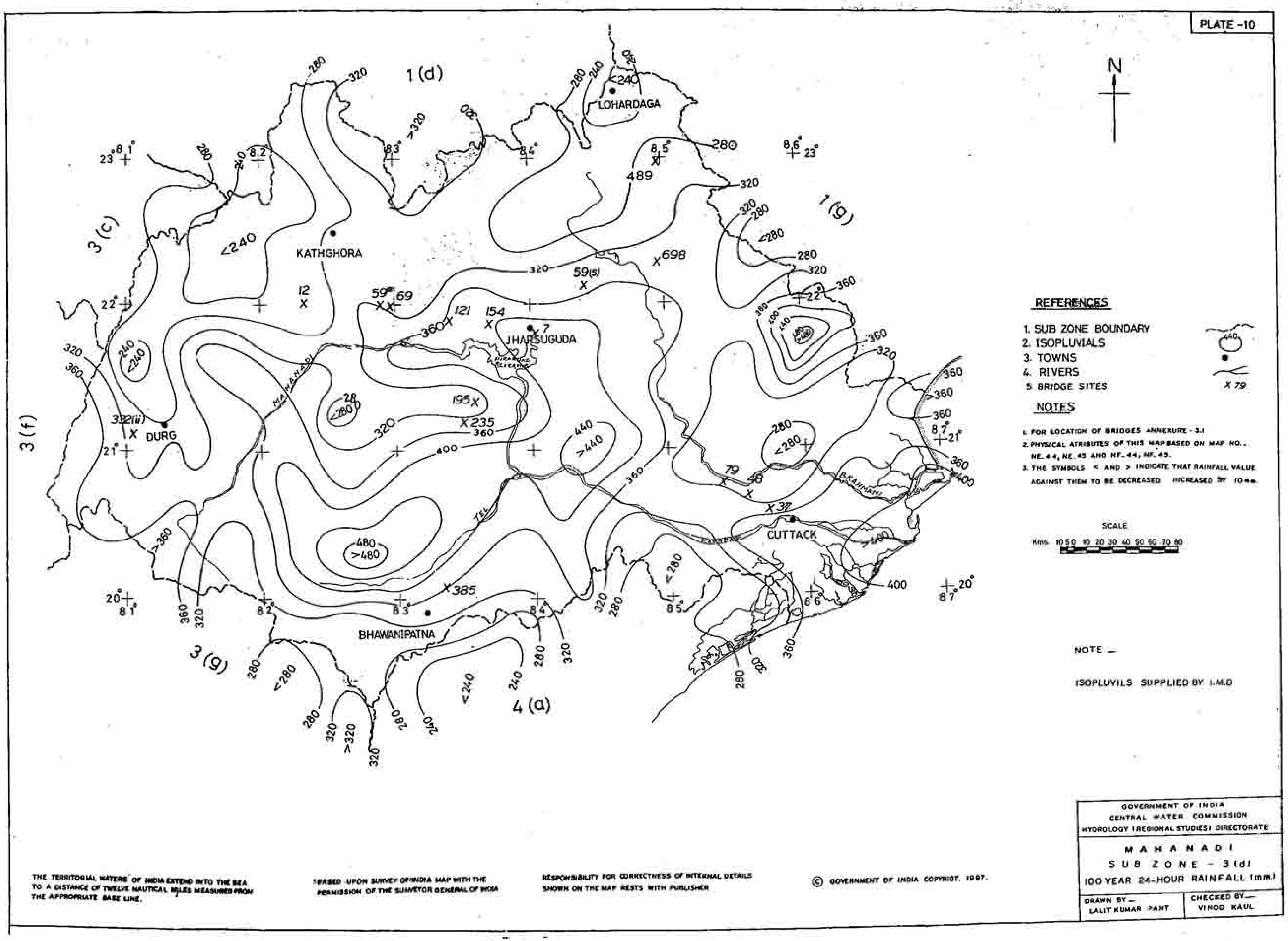


PLATE -10
N
1(d)
1(g)
3(c)
3(f)
3(g)
4(a)
LOHARDAGA
KATHGHORA
JHARSUGUDA
DURG
CUTTACK
BHAWANIPATNA
MAHANADI
REFERENCES
1. SUB ZONE BOUNDARY
2. ISOPLUVIALS
3. TOWNS
4. RIVERS
5 BRIDGE SITES
NOTES
1. FOR LOCATION OF BRIDGES ANNEXURE - 3.1
2. PHYSICAL ATRIBUTES OF THIS MAP BASED ON MAP NO., NE-44, NE-45 AND NF-44, NF-45.
3. THE SYMBOLS < AND > INDICATE THAT RAINFALL VALUE AGAINST THEM TO BE DECREASED INCREASED BY 10mm.
SCALE
Kms. 10 5 0 10 20 30 40 50 60 70 80
NOTE -
ISOPLUVILS SUPPLIED BY I.M.D
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DIRECTORATE
MAHANADI
SUB ZONE - 3(d)
100 YEAR 24-HOUR RAINFALL (mm)
DRAWN BY - LALIT KUMAR PANT
CHECKED BY - VINOD KAUL
THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.
BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA
RESPONSIBILITY FOR CORRECTNESS OF INTERNAL DETAILS SHOWN ON THE MAP RESTS WITH PUBLISHER
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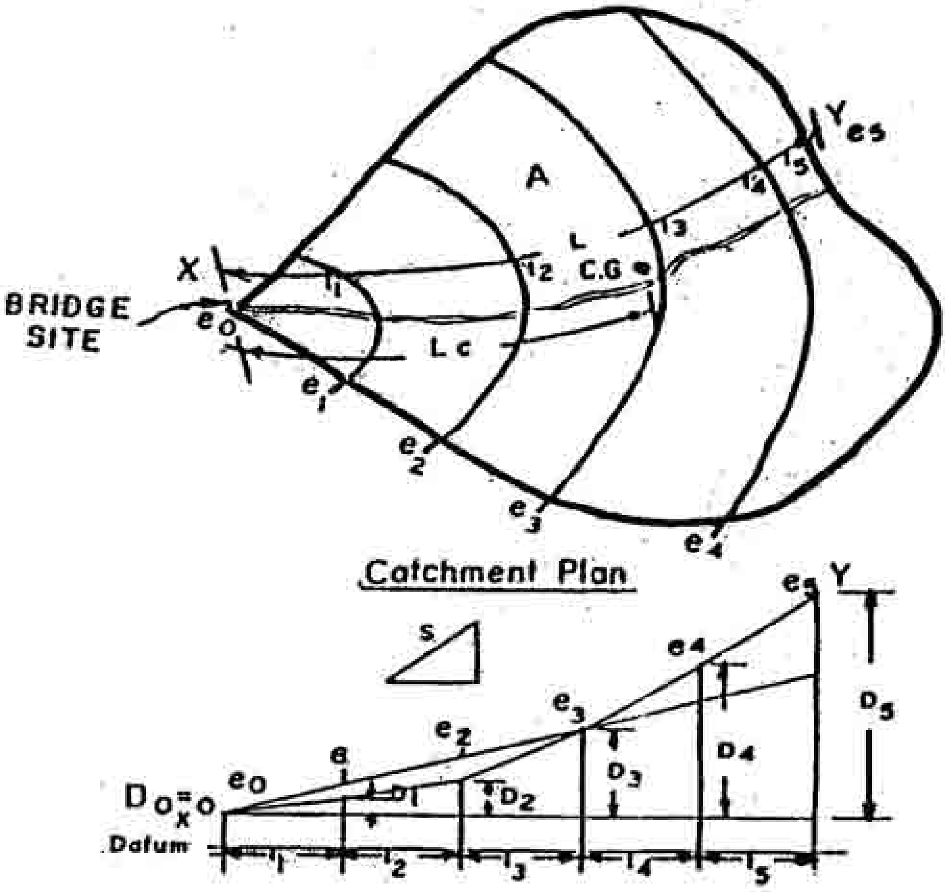
FIG.1



L - Section

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

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

L = Length of longest stream course (km)

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

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

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

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

A = Catchment area (km^2)

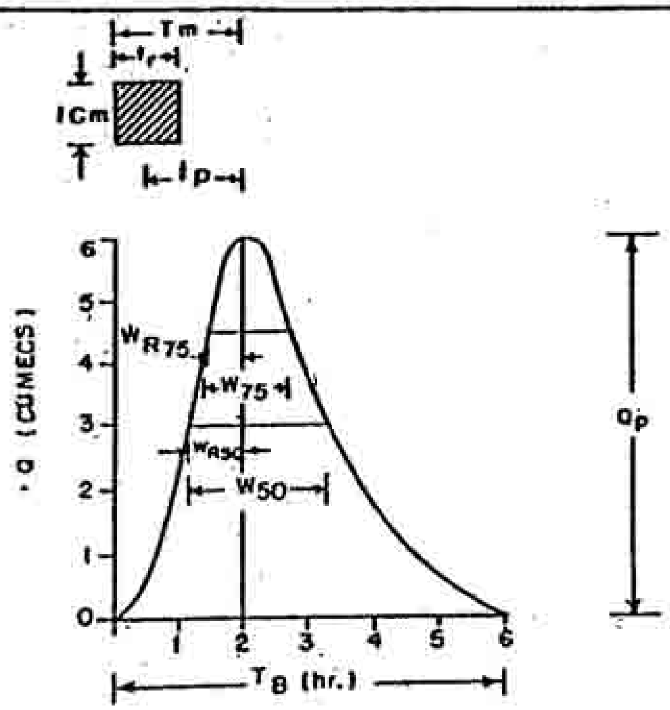
Lc = Length of longest stream course from a point opposite the centre of gravity of the catchment to the point of study (Km.)

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

PHYSIOGRAPHIC PARAMETERS

DRAWN.	CHECKED
L. P. NAUTIYAL	C.S. AGARWAL

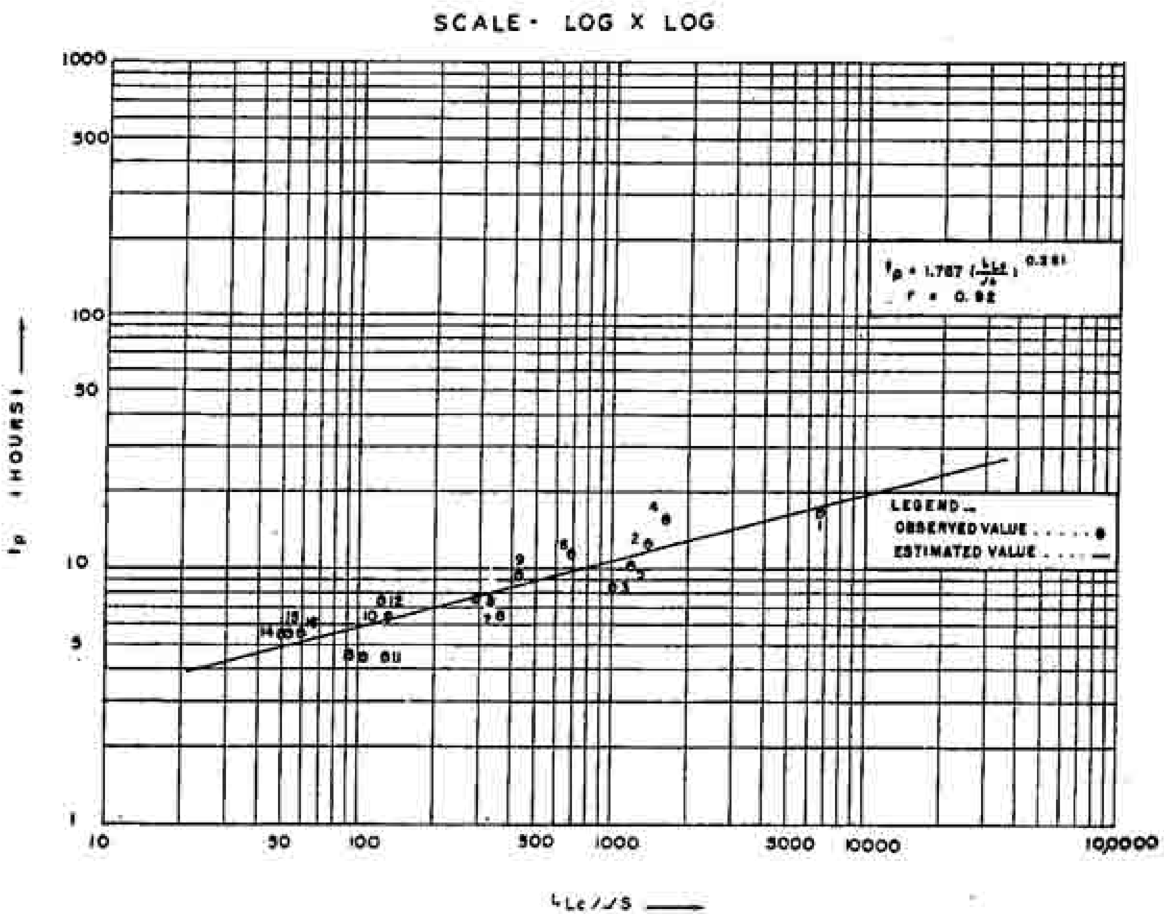
FIG. - 2



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.

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (SMALL CATCHMENT) DTE.	
UNIT GRAPH PARAMETERS	
DRAWN BY- L.K. PANT	CHECKED BY- C.S. AGARWAL

FIG. — 3.



Sl. No.	Bridge No.	$\frac{L L_c}{\sqrt{S}}$	t_p Hours OBS. VALUE	t_p Hours ESTI. VALUE
1	7	8620	16.50	17.32
2	121	1387	12.50	11.87
3	489	1001	8.50	10.83
4	12	1611	15.50	12.03
5	195	1188	10.50	11.11
6	235	680	11.50	9.81
7	332 (II)	560	8.00	9.14
8	385	285	7.50	7.66
9	69	426	9.50	8.51
10	88(8)	131	6.50	6.26
11	698	127	4.60	6.21
12	48	123	7.50	6.16
13	79	104	4.80	5.89
14	37	48	5.50	4.82
15	154	53	5.50	4.94
16	59 (2)	60	5.50	5.11

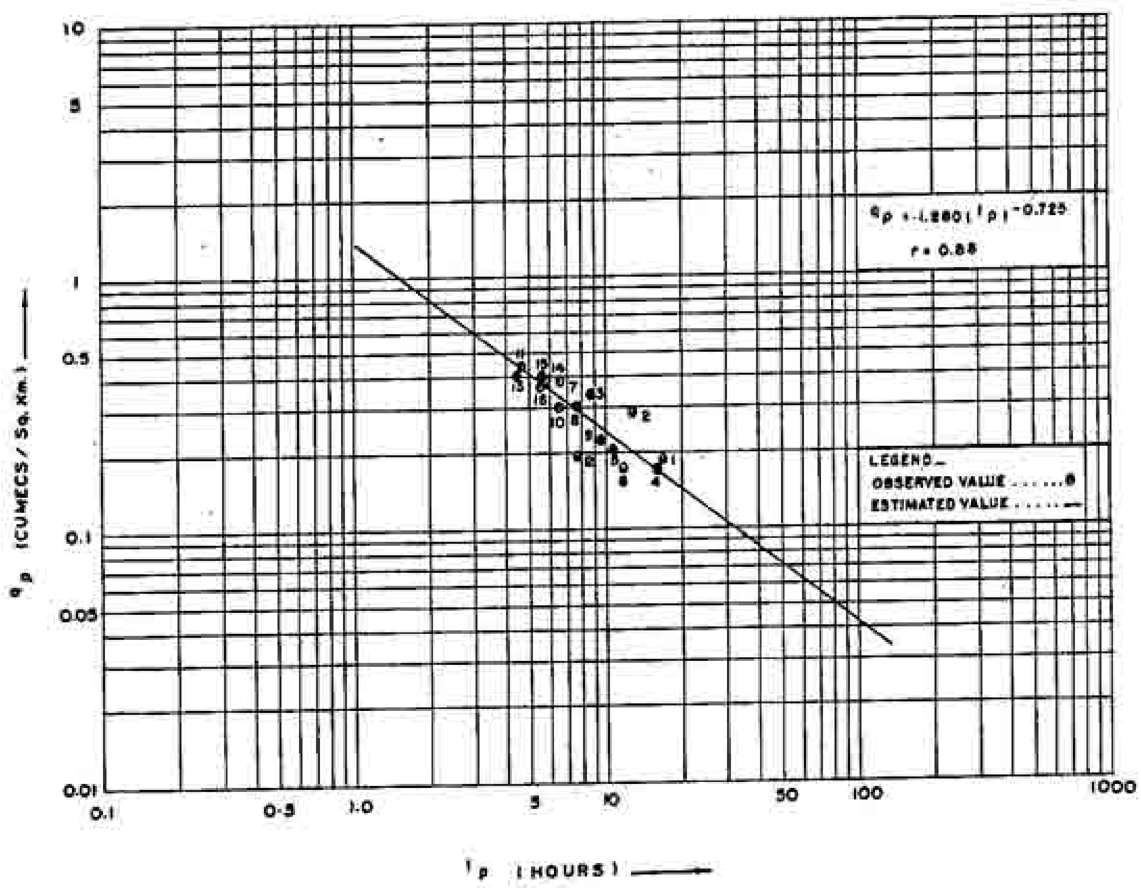
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

MAHANADI
SUBZONE - 3(d)
RELATION BETWEEN
$L L_c / \sqrt{S}$ AND t_p

DRAWN BY — L.P. NAUTIYAL | CHECKED BY — C.S. AGARWAL

FIG.— 4.

SCALE - LOG X LOG



Sl. No.	Bridge No.	t_p Hours	q_p Cumecs/ Km^2 Observed Value	q_p Cumecs/ Km^2 Estimated Value
1	7	16.50	0.18	0.16
2	121	12.50	0.28	0.20
3	489	8.50	0.33	0.27
4	12	16.50	0.17	0.17
5	185	10.50	0.20	0.23
6	235	11.50	0.17	0.21
7	332(I)	6.50	0.36	0.32
8	385	7.50	0.30	0.29
9	69	9.50	0.22	0.25
10	59(9)	6.50	0.50	0.32
11	698	4.50	0.46	0.42
12	48	7.50	0.19	0.29
13	79	4.50	0.41	0.42
14	37	5.50	0.38	0.37
15	154	5.50	0.40	0.37
16	59(5)	5.50	0.37	0.37

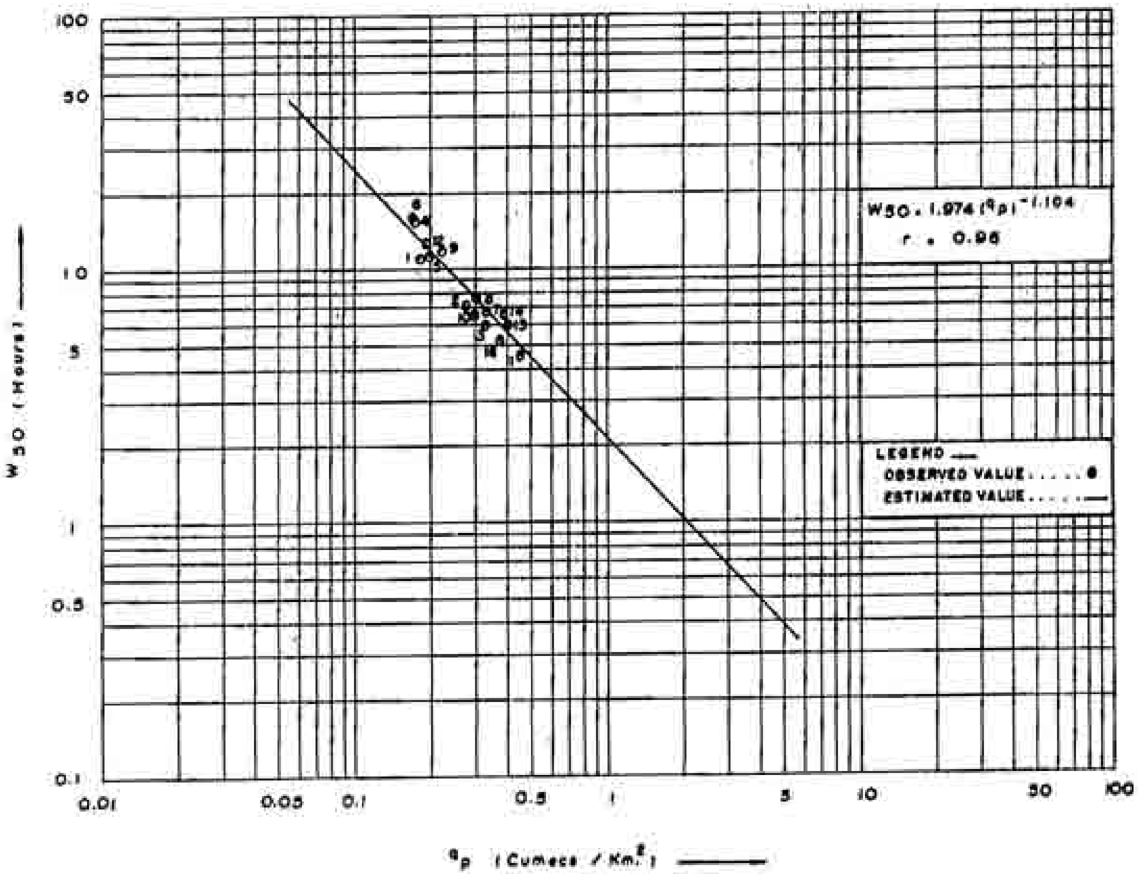
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

MAHANADI
SUB ZONE - 3(d)
RELATION BETWEEN
t_p AND q_p

DRAWN BY— L. P. NAUTIYAL	CHECKED BY— C. S. AGARWAL

FIG. — 5.

SCALE - LOG X LOG



Sl. No.	Bridge No.	q_p cumecs/ km.^{2}	W_{50} (Hours)	
			Observed Value	Estimated Value
1	7	0.180	10.97	13.12
2	121	0.280	7.00	8.05
3	469	0.330	6.00	6.73
4	12	0.170	15.50	13.97
5	196	0.200	11.20	11.68
6	235	0.170	15.60	13.87
7	332 (II)	0.380	6.00	5.75
8	385	0.300	7.75	7.46
9	69	0.220	11.70	10.51
10	59 (B)	0.300	6.48	7.46
11	898	0.460	4.50	4.65
12	48	0.190	12.80	12.36
13	79	0.410	6.12	5.29
14	37	0.380	6.67	5.75
15	154	0.400	5.45	5.43
16	59 (B)	0.370	5.30	5.92

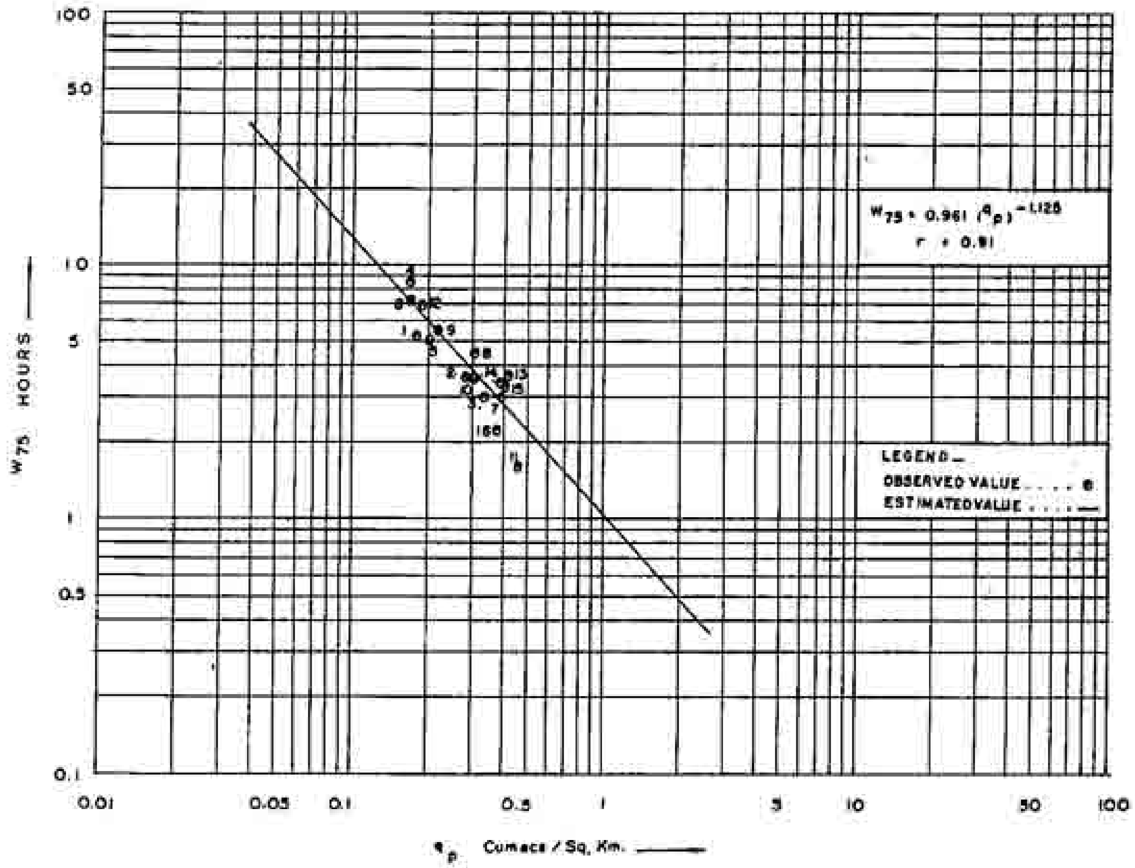
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

MAHANADI
SUB ZONE - 3 (d)
RELATION BETWEEN
q_p AND W_{50}

DRAWN BY —	CHECKED BY —
L. P. KAUTIYAL	C. S. AGARWAL

FIG – 6.

SCALE – LOG. X LOG.



Sl. No.	BRIDGE NO.	q_p CUM./Km²	W_{75} HOURS Obs. Value	W_{75} HOURS Est. Value
1	7	0.16	5.25	6.62
2	121	0.28	3.60	4.03
3	469	0.33	3.00	3.35
4	12	0.17	8.50	7.06
5	193	0.20	5.05	5.88
6	235	0.17	7.30	7.06
7	332 (II)	0.38	2.97	2.86
8	385	0.30	4.80	3.73
9	88	0.22	5.53	5.28
10	59 (B)	0.30	3.48	3.73
11	698	0.46	1.60	2.30
12	48	0.19	6.80	6.23
13	79	0.41	3.74	2.62
14	37	0.38	3.40	2.86
15	154	0.40	3.32	2.69
16	59 (5)	0.37	2.20	2.94

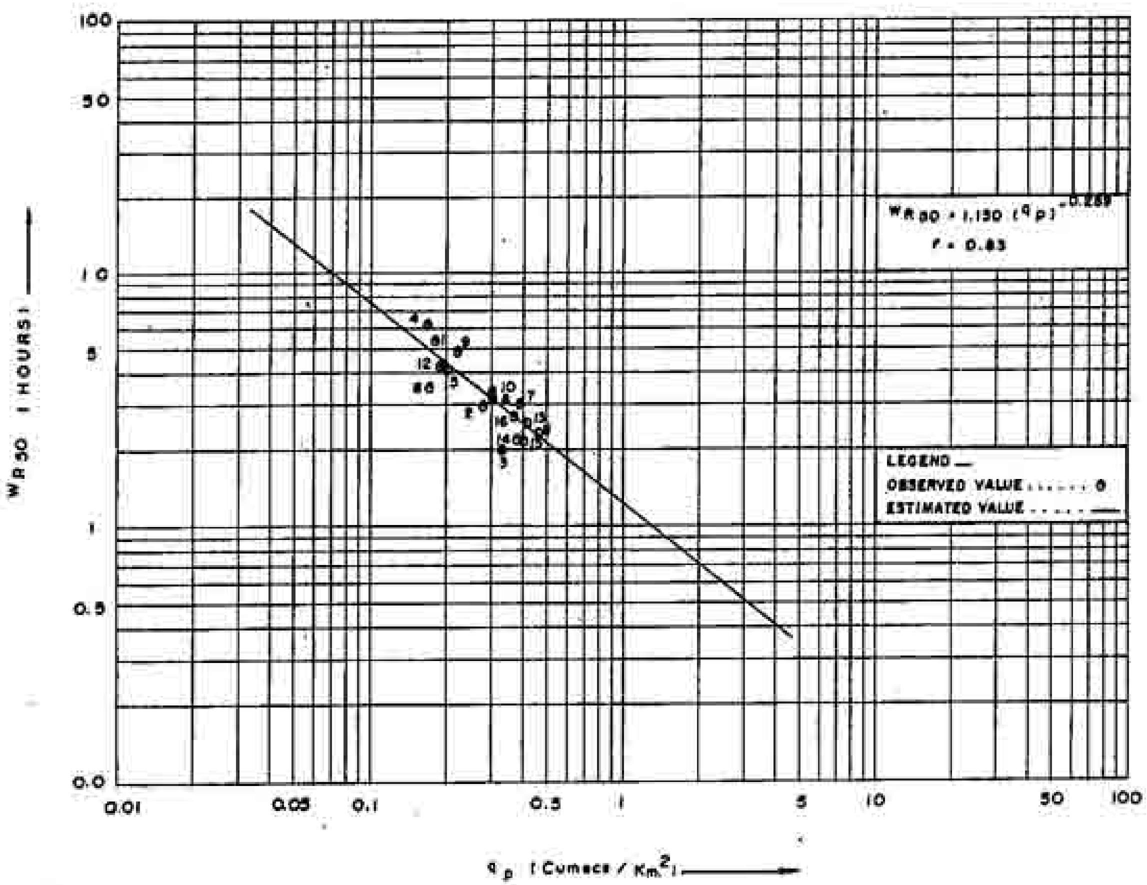
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

MAHANADI
SUB ZONE – 3 (d)
RELATION BETWEEN q_p AND W_{75}

DRAWN BY – L.K. PANT | CHECKED BY – C.S. AGARWAL

FIG.— 7.

SCALE — LOG X LOG



Sl. NO.	BRIDGE NO.	q_p (Cumecs/ Km^2)	W_{R50} (HOURS)	
			OBS. VALUE	ESTI. VALUE
1	7	0.180	6.17	4.77
2	121	0.280	3.00	3.30
3	489	0.330	2.00	2.88
4	12	0.170	6.10	5.00
5	195	0.200	4.00	4.37
6	236	0.170	3.65	5.00
7	332(II)	0.380	3.00	2.56
8	385	0.300	3.20	3.12
9	89	0.220	4.87	4.04
10	59(8)	0.300	3.40	3.12
11	698	0.460	2.68	2.19
12	48	0.190	4.20	4.56
13	79	0.410	2.60	2.41
14	37	0.380	2.20	2.56
15	154	0.400	2.20	2.46
16	59 (5)	0.370	2.70	2.62

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

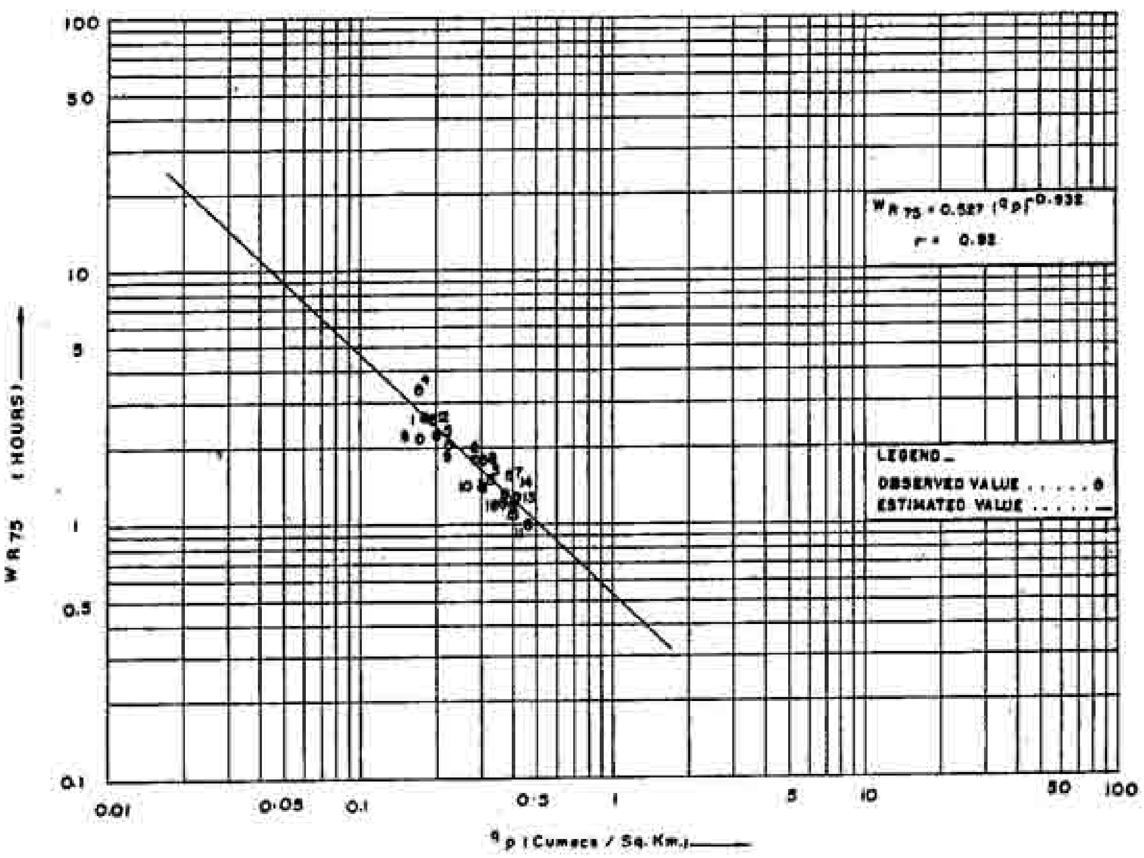
MAHANADI

SUB ZONE – 3 (d)
RELATION BETWEEN
q_p AND W_{R50}

DRAWN BY— L. K. PANT | CHECKED BY— C. S. AGARWAL

FIG — 8

SCALE - LOG X LOG.



Sl. No	Bridge No.	q_p (Cumecs/Km²)	W_{R75} (Hours) Obs. Value	W_{R75} (Hours) Esti. Value
1	7	0.180	2.60	2.60
2	121	0.280	1.80	1.73
3	489	0.330	1.50	1.48
4	12	0.170	3.40	2.75
5	195	0.200	2.30	2.36
6	235	0.170	2.18	2.75
7	332 (II)	0.380	1.86	1.30
8	200	0.300	1.80	1.62
9	65	0.220	2.10	2.16
10	58 (B)	0.300	1.39	1.62
11	555	0.460	1.00	1.08
12	48	0.190	2.80	2.48
13	79	0.410	1.27	1.21
14	37	0.380	1.30	1.30
15	154	0.400	1.20	1.24
16	59 (3)	0.370	1.20	1.33

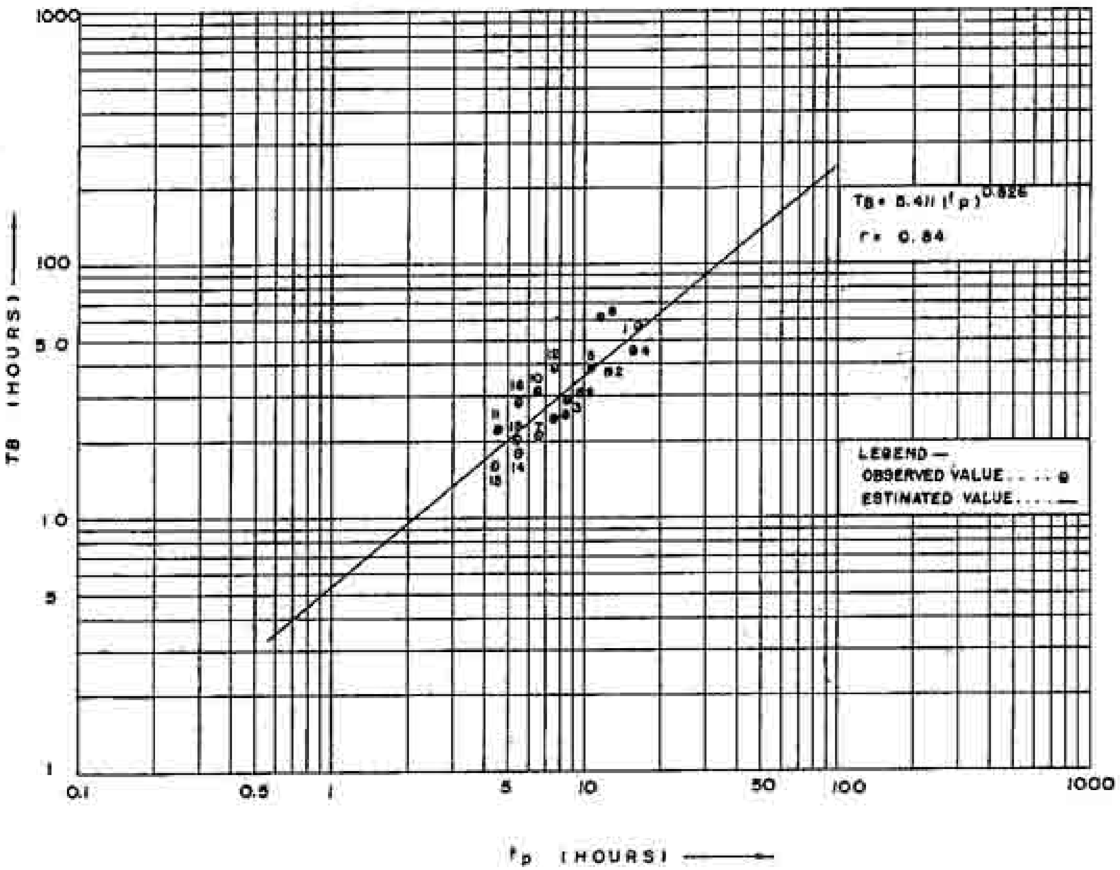
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

MAHANADI
SUB ZONE - 3 (d)
RELATION BETWEEN
q_p AND W_{R75}

DRAWN —	CHECKED —
L. K. PANT	C. S. AGARWAL

FIG _ 9

SCALE - LOG X LOG.



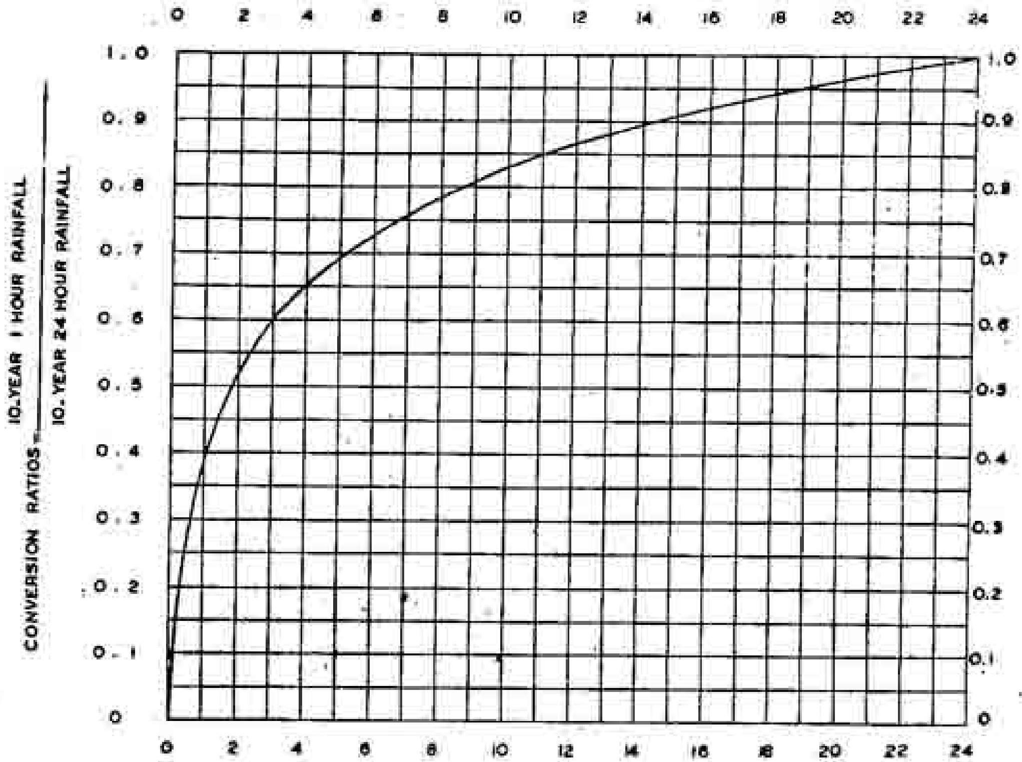
Sl. No.	BRIDGE NO.	t_p HOURS	TB HOURS OBS. VALUE	TB HOURS ESTI. VALUE
1.	7	16.50	57.00	54.77
2	121	12.50	37.00	43.55
3	469	8.50	29.00	31.67
4	12	15.50	45.00	52.01
5	195	10.50	55.00	37.71
6	235	11.50	61.00	40.85
7	332(ii)	6.50	21.00	25.36
8	385	7.50	24.00	28.86
9	69	9.50	31.00	34.72
10	59(B)	6.50	31.00	25.36
11	696	4.50	22.00	18.73
12	48	7.50	36.00	28.86
13	7.9	4.50	16.00	18.73
14	37	5.50	18.00	22.11
15	184	5.50	20.00	22.11
16	59(S)	5.50	26.00	22.11

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

M A H A N A D I
SUB ZONE - 3 (d)
RELATION BETWEEN
t_p AND TB

DRAWN BY — L. P. NAUTIYAL | CHECKED BY — C.S. AGARWAL

FIG. – 10



DURATION HOURS (t) ⟶

RATIOS OF 24-HOURS POINT RAINFALL TO SHORT DURATION RAINFALL

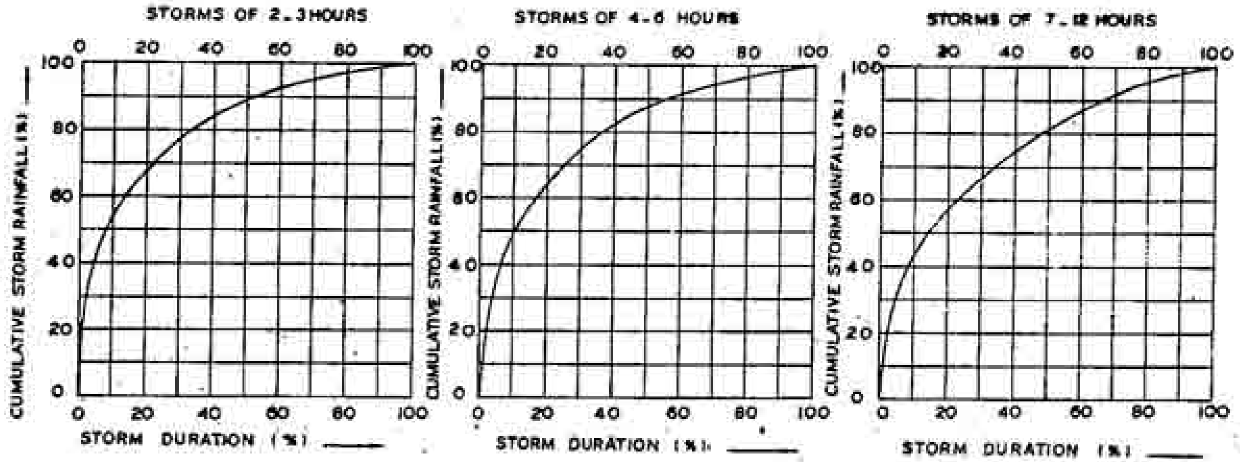
DURATION (HOURS)	RATIOS
1	0.380
2	0.515
3	0.598
4	0.650
5	0.690
6	0.725
7	0.765
8	0.780
9	0.805
10	0.830
11	0.850
12	0.865
13	0.880
14	0.898
15	0.910
16	0.920
17	0.930
18	0.945
19	0.955
20	0.965
21	0.978
22	0.985
23	0.990
24	1.000

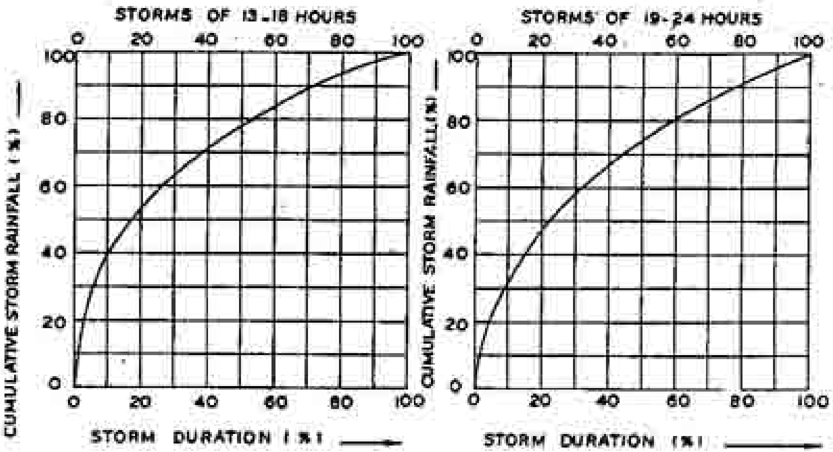
NOTE –

CURVE SUPPLIED BY I.M.D

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (REGIONAL STUDIES) DTE.	
MAHANADI SUB ZONE - 3 (d) DURATION Vs. CONVERSION RATIO	
DRAWN BY– L. K. PANT	CHECKED BY– VINOD KAUL

FIG. - 11.





NOTE —

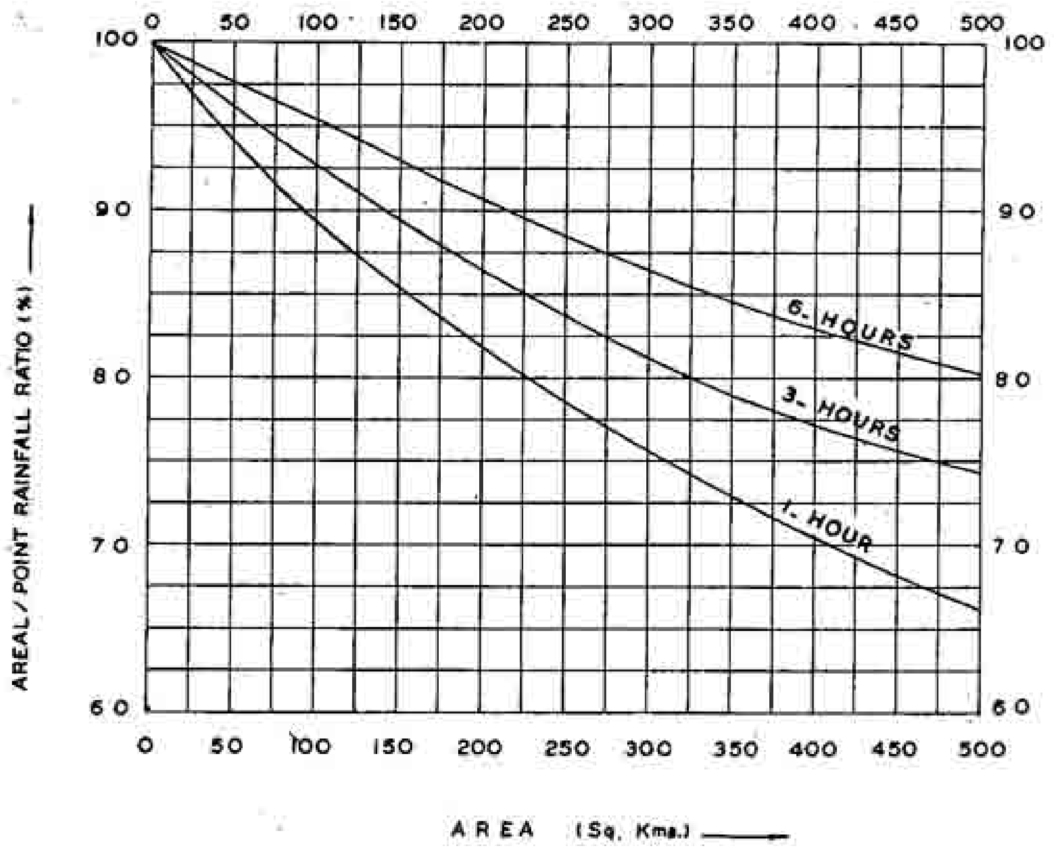
REFER ANNEXURE - 4.1 SHOWING TIME DISTRIBUTION CO-EFFICENTS OF AREAL RAINFALL FOR VARIOUS DURATION OF 2, 3, 4 . . . . 23, 24 HOURS.

NOTE —

CURVES SUPPLIED BY I.M.D

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (REGIONAL STUDIES) DTE.
MAHANADI SUB ZONE - 3(d)
MEAN AVERAGE TIME DISTRIBUTION CURVES OF STORMS OF VARIOUS DURATION
DRAWN BY — L.P. NAUTIYAL / CHECKED BY — C.S. AGARWAL

FIG.-12(a).



NOTE—

I) REFER ANNEXURE-4-2 FOR AREAL TO POINT RAINFALL RATIOS FOR DURATION FROM 1 – 24 HOURS.

II) REFER FIG.-12(b) AREAL TO POINT RAINFALL RATIO FOR DURATIONS 12- HOURS AND 24- HOURS

NOTE—

CURVES SUPPLIED BY I.M.D

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

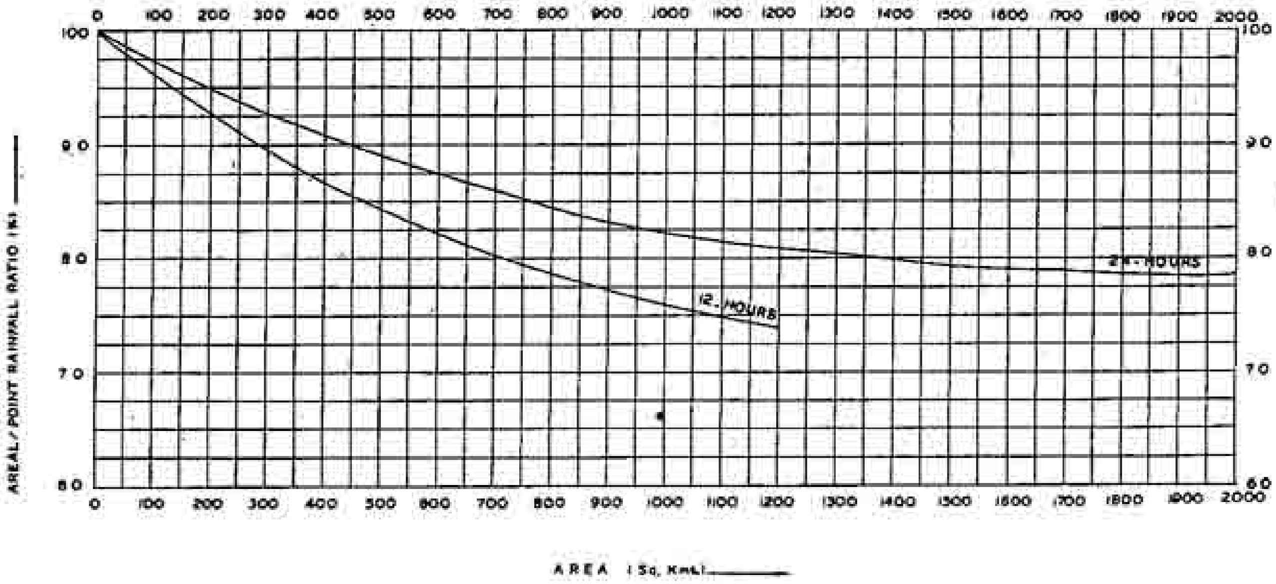
MAHANADI

SUB ZONE - 3(d)

AREAL TO POINT RAINFALL RATIO FOR 1-Hr., 3-Hrs. & 6. Hrs. (%)

DRAWN BY–	CHECKED BY–
L. K. PANT	K. K. AICH

FIG.-12 (b).



NOTE -

i) REFER ANNEXURE - 4-E FOR AREAL TO POINT RAINFALL RATIOS FOR DURATION FROM 1 TO 24 HOURS AND FOR CATCHMENT AREA UP TO 2000 Km²

ii) REFER FIG.-12 (a) FOR AREAL TO POINT RAINFALL RATIOS FOR DURATION 1-HOUR, 3 HOURS AND 6-HOURS.

NOTE -

CURVES SUPPLIED BY I.M.D

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (REGIONAL STUDIES) DTE	
MAHANADI SUB ZONE - 3 (d)	
AREAL TO POINT RAINFALL RATIO FOR 12-Hrs. & 24-Hrs. (%)	
DRAWN BY - L. P. NAUTIYAL	CHECKED BY - C. S. AGARWAL

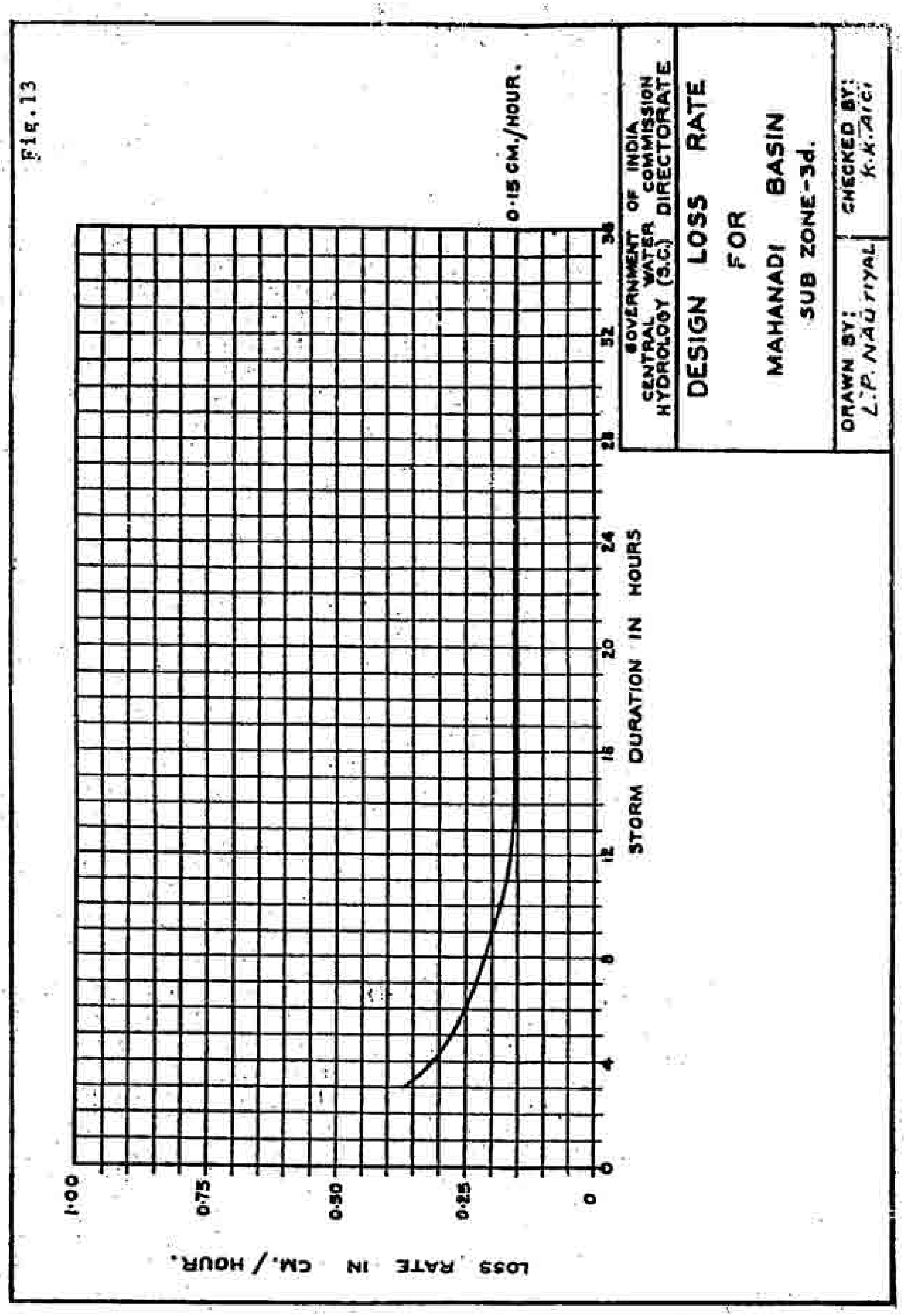
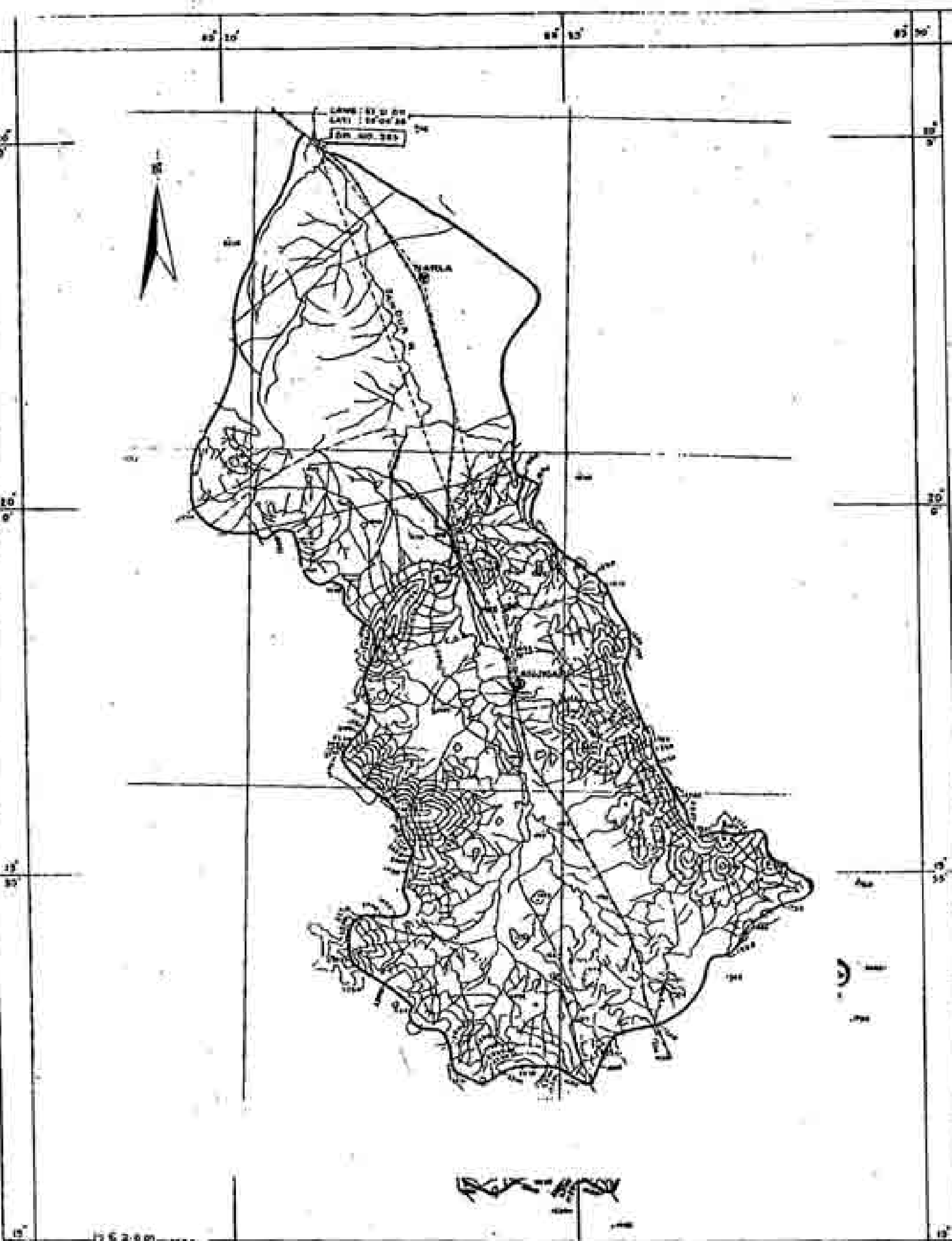


Fig.13
0·15 CM./HOUR.
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (S.C.) DIRECTORATE
DESIGN LOSS RATE
FOR
MAHANADI BASIN
SUB ZONE-3d.
DRAWN BY: L.P. NAUTIYAL
CHECKED BY: K.K. AICH
STORM DURATION IN HOURS
0
4
8
12
16
20
24
28
32
36
LOSS RATE IN CM./HOUR.
0
0·25
0·50
0·75
1·00



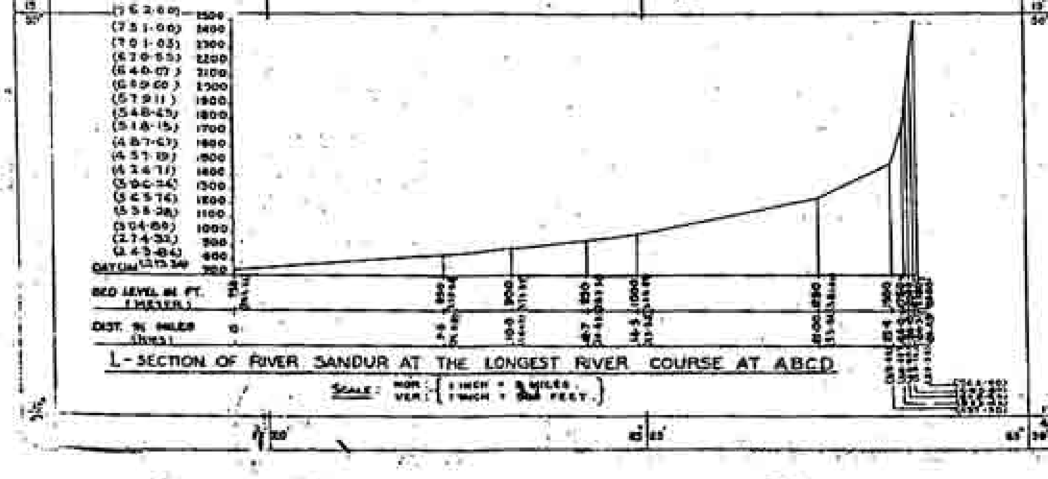


FIG. _ A. I

NOTES:

1. ALL LEVELS CORRESPOND TO G.T.S. DATUM.
2. H.F.L. AT GAUGING SITE 228·61 MTS.

REFERENCES:

1. CATCHMENT BOUNDARY
2. RAILWAY LINE
3. RIVER & ITS TRIBUTARIES
4. ROADS
5. RAINGAUGE STATIONS
6. CONTOURS
7. SPOT LEVELS
8. CONTOURS INTERVAL 250' OR 76·20 MTS.
9. TOPO SHEET NOS. (1" = 1 MILE) 1933 & 1939 EDITION ---- 64 P/9, 65 M/5
10. CENTRE OF GRAVITY

LAND USE

1. CULTIVATED LAND ---- 34·63%
2. BARREN LAND ---- 9·56%
3. FOREST ---- 40·31%

SOIL TYPE

1. ROCKEY SOIL (HARD SOIL = 49% & CLAY = 33%)

DETAIL'S OF THE CATCHMENT AREA

1. CATCHMENT AREA = 75·00 SQ. MILES OR 194·60 SQ. K. MTS
2. SHAPE OF THE CATCHMENT ---- LEAF
3. TOTAL LENGTH OF RIVER & ITS TRIBUTARIES = 254 MILES = 409·94 K.M.
4. L ---- 24·45 MILES OR 39·35 K MT
5. L_c ---- 9·40 " OR 15·13 K.MT
6. W_c ---- 4·20 " OR 6·76 K MT
7. D ---- 3·39 MILES/SQ.MILE OR 2·11 KM/SQ.K MT.
8. S_{SL} ---- 28·31 FT/MILE OR 5·37 M/KMT
9. S_{EE} ---- 15·87696 FT/MILE OR 3·007 MT/KMT
10. S_L ---- 657·360 FT/MILE OR 124·50 MT/K MT.
11. SF ---- 4·36 MT/HR

S. NO	NAME OF THE R.G. STATION	LONG.	LAT.	ST. WEIGHTS 1966 – 71	ST. WEIGHTS 1972 – 74
1	LANJIGARH	83°14'10"	19°56'34"	0·4687	0·4487
2	KARLA	83°12'30"	20°02'30"	0·5313	0·2816
3	BR. SITE	83°21'00"	20°04'34"	–	0·0697

SCALE: 1" = 1 MILE OR 1" = 1·609 K. MTS.

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

CATCHMENT AREA PLAN FOR BR. NO. 385 AT K MTS. 233·34 ON RAIPUR–VIZIANAGARAM SEC., S.E. RAILWAY, SUB ZONE – 3d.

SHOWING

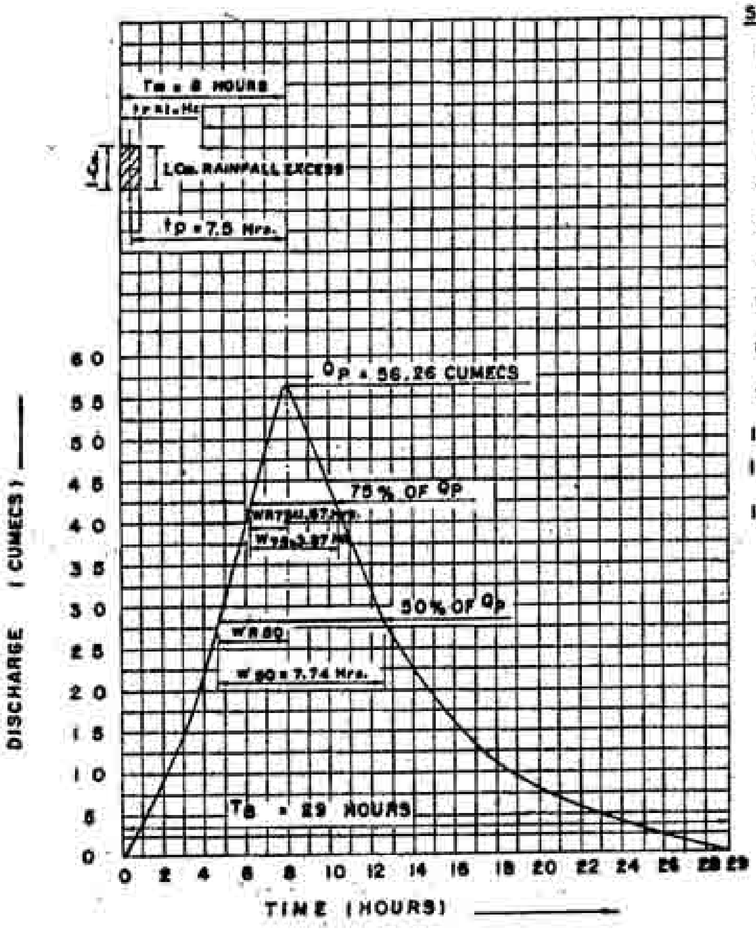
DRAWN BY – L. N. PANT

CHECKED BY – K. K. AICH

DRG. NO. HSC/3-1/E/34-14

-72-

FIG. A-2



SYNTHETIC U.G PARAMETERS

1. C. AREA = 194.00 Km²
2. t_r = 1.00 Hr.
3. Q_p = 56.26 CUMECS
4. q_p = 0.29 CUM./Km²
5. t_p = 7.50 HOURS
6. T_m = 8.00 HOURS
7. T_B = 29.00 HOURS
8. W_{50} = 7.74 HOURS
9. W_{75} = 3.87 HOURS
10. W_{R50} = 3.21 HOURS
11. W_{R75} = 1.67 HOURS
12. d = 1.00 Cm.

$$\Sigma Q_i = \frac{A \times d}{T_r \times 0.36}$$

$$= \frac{194 \times 1.00}{1.00 \times 0.36}$$

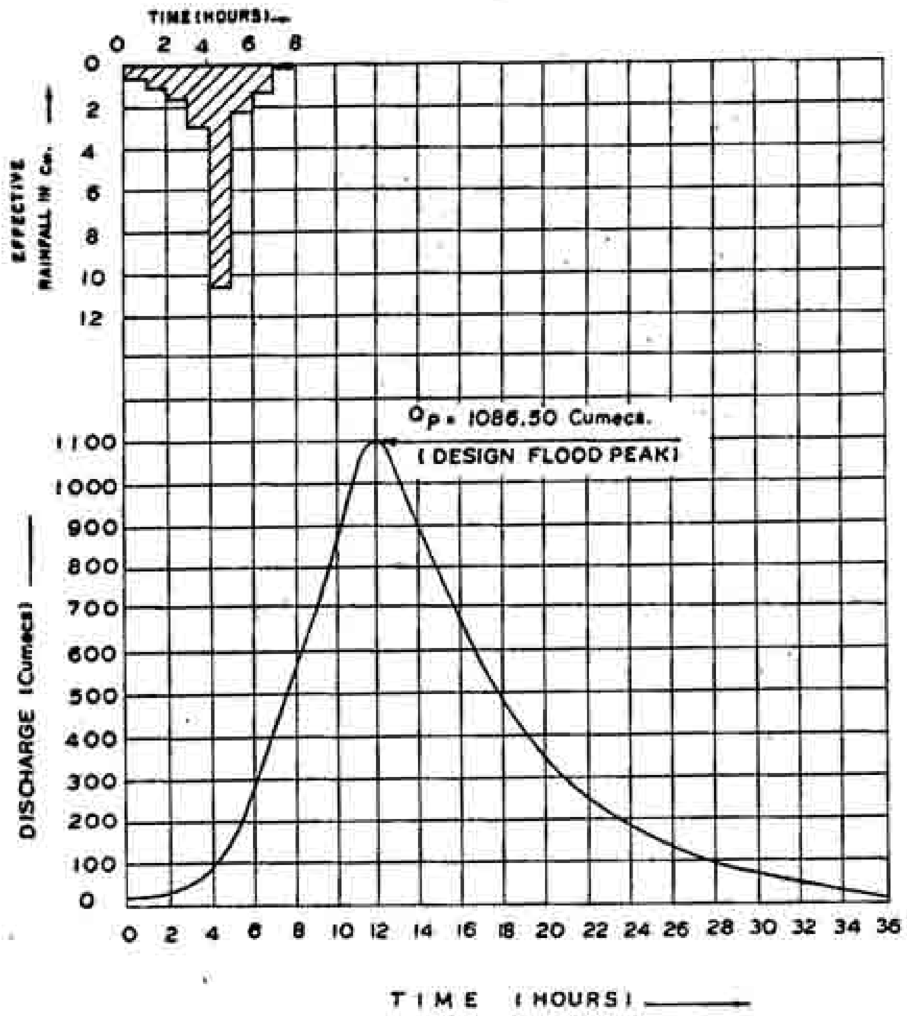
= 538.89 CUMECS

1 - HOUR SYNTHETIC U.G. ORDINATES

0	0
1	2.70
2	9.10
3	16.20
4	22.00
5	30.60
6	40.20
7	49.00
8	56.26
9	50.00
10	43.80
11	37.70
12	31.30
13	26.00
14	21.30
15	19.00
16	16.70
17	13.00
18	11.00
19	9.00
20	7.70
21	6.60
22	5.40
23	4.40
24	3.30
25	2.70
26	2.00
27	1.33
28	0.60
29	0
TOTAL	538.89 CUMECS

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (REGIONAL STUDIES) DTE.	
MAHANADI SUB ZONE - 3 (d) SYNTHETIC UNIT HYDROGRAPH OF BRIDGE NO. - 385.	
DRAWN BY - L. K. PANT	CHECKED BY - K. K. AICH

FIG. – A.3



NOTE — REFER ANNEXURE – 5.4 FOR COMPUTATION OF DESIGN FLOOD HYDROGRAPH.

CATCHMENT AREA = 194.00 Km^2

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (REGIONAL STUDIES) DTE.	
MAHANADI SUB ZONE - 3 (d) DESIGN FLOOD HYDROGRAPH OF BRIDGE NO. 385.	
DRAWN BY – L.P. NAUTIYAL	CHECKED BY – K. K. AICH

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3.	Shri S. Das Sharma	Meteorologist
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1.	Estimation of Design Flood Peak	(1973)

B. UNDER LONG TERM PLAN

1.	Lower Ganga Plains subzone-1(g)	(1978)
2.	Lower Godavari subzone-3(f)	(1981)
3.	Lower Narmada & Tapi subzone-3(b)	(1982)
4.	Mahanadi subzone-3(d)	(1982)
5.	Upper Narmada & Tapi subzone-3(c)	(1983)
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7.	South Brahmaputra subzone-2(b)	(1984)
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9.	Middle Ganga Plains subzone-1(f)	(1985)
10.	Kaveri Basin subzone-3(i)	(1986)
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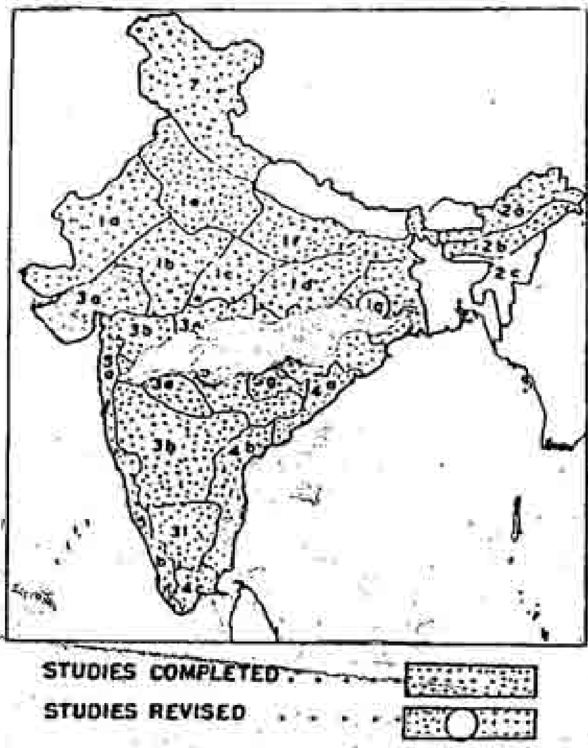
12.	Mahi & Sabarmati subzone-3(a)	(1987)
13.	East Coast subzone-4(a),(b) & (c)	(1987)
14.	Sone subzone-1(d)	(1988)
15.	Chambal subzone 1(b)	(1989)
16.	Betwa subzone 1(c)	(1989)
17.	North Brahmaputra subzone 2(a)	(1991)
18.	West Coast Region subzone 5(a) & (b)	(1992)
19.	Luni subzone 1(a)	(1993)
20.	Indravati subzone 3(g)	(1993)
21.	Western Himalayas zone-7	(1994)

C. REVISED UNDER LONG TERM PLAN

1.	Lower Ganga Plains subzone-1(g)	(1994)
2.	Lower Godavari subzone-3(f)	(1995)



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