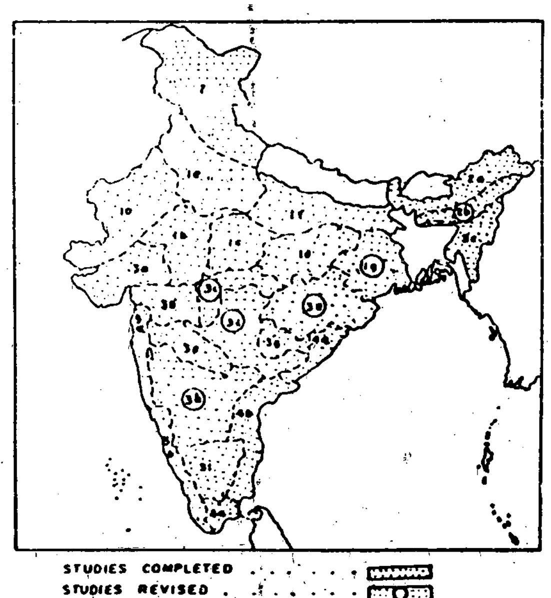
A.	**UNDER SHORT TERM PLAN**		
1.	Estimation of Design Flood Peak		(1973)
B.	**UNDER LONG TERM PLAN**		
1.	Lower Ganga Plains Subzone 1(g)		(1978)
2.	Lower Godavari Subzone 3(f)		(1981)
3.	Lower Narmada and Tapi subzone 3(b)		(1982)
4.	Mahanadi Subzone 3(d)		(1982)
5.	Upper Narmada & Tapi Subzone 3(c)		(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 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)
Revised Flood Estimation Reports			
1.	Lower Ganga Plains Subzone 1(g)		(1994)
2.	Lower Godavari Subzone 3(f)		(1995)
3.	Mahanadi Subzone 3(d)		(1997)
4.	South Brahmaputra Subzone 2(b)		(2000)
5.	Krishna & Pennar Subzone 3(h)		(2000)
6.	Upper Narmada and Tapi Subzone 3(c)		(2002)
7.	Lower Narmada and Tapi Subzone 3(b)		(2005)



Designed and Printed at Publication Division, Central Water Commission R.K.Puram, New Delhi
CWC-30/2005 200 Copies

अभिकल्प कार्यालय विवरण
DESIGN OFFICE REPORT
न.:एलएनटी/3(बी)/आर-7/47/2004
No.: LNT/3(b)/R-7/47/2004

केन्द्रीय जल आयोग
CENTRAL WATER COMMISSION

निचली नर्मदा एवं तापी (उप अँचल - 3 बी) का बाढ़ ऑकलन विवरण (परिशोधित)

FLOOD ESTIMATION REPORT FOR LOWER NARMADA AND TAPI SUBZONE - 3(b) (REVISED)

ल विज्ञान (क्षेत्रीय अध्ययन) निदेशालय
ल विज्ञान अध्ययन संगठन
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भारत मौसम विभाग
अनुसंधान अभिकल्प एवं मानक संगठन, रेल मंत्रालय
भूतल परिवहन मंत्रालय का संयुक्त कार्य

A JOINT WORK OF
CENTRAL WATER COMMISSION
INDIA METEOROLOGICAL DEPARTMENT
RESEARCH DESIGN AND STANDARDS ORGANISATION, MINISTRY OF RAILWAYS
MINISTRY OF SURFACE TRANSPORT

अक्तूबर 2005
October, 2005

Revised Flood Estimation Report for Lower Narmada and Tapi subzone 3(b) was discussed and approved by the following members of Flood Estimation Planning and Co-ordination Committee in its 57th Meeting held on 12.01.05 at Central Water Commission, New Delhi.

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DESIGN OFFICE REPORT
NO. LNT/3(b)/R-7/47/2004

CENTRAL WATER COMMISSION

FLOOD ESTIMATION REPORT FOR LOWER NARMADA AND TAPI SUBZONE-3(b) (REVISED)

HYDROLOGY (REGIONAL STUDIES) DIRECTORATE
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NEW DELHI

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 the simplicity of relating the maximum flood discharge to the catchment area with constants. But these formulae do not take into account the basic meteorological component of storm rainfall 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. They also do not have frequency concept.

Recognising the need to evolve a rational and scientific method for estimating design flood peak of desired frequency, the committee of engineers headed by Dr. A.N. Khosla have recommended, in their report in the year 1959, that the design discharge for bridges 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 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. Broadly, two main regional approaches, namely flood frequency and hydrometeorological approaches are open for adoption depending upon 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, viz; hydrometeorological approach involves assessment of the causative factor i.e. rainfall and catchment response function, antecedent conditions etc. separately. In this method concurrent storm rainfall and runoff data of the catchment over a period of 5-10 years is used to develop representative unit hydrographs of the catchments located in the region, so that synthetic unit hydrograph may be obtained for the region (subzones). The long term rainfall records at a large number of stations is used to develop design storm values. This hydrometeorological approach has been adopted for preparing flood estimation reports.

The regional flood estimation was attempted on both short term and long term plans. 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, the entire country was divided into 7 zones and 26 hydro-meteorologically-homogeneous 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 (RDSO) of Ministry of Railways. Similarly, the Ministry of Surface Transport (MOST) had undertaken the collection of data for 45 catchments through Central Water Commission since 1979.

Hydrology (Regional Studies) Directorate, Central Water Commission (CWC) carried out analysis of collected concurrent rainfall and flow data for the gauged catchments to derive unit hydrographs of mostly one-hour duration. Representative unit hydrographs are prepared for each of the gauged catchments from the selected flood events. The characteristics of the catchments and the 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. The response functions on convolution with the storm input as studied and provided by IMD gives the estimated design flood for that ungauged catchment. 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 meteorological 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 and 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 duration corresponding to 50 year return period only;

(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 raingauges (ORG) and SRRG data. It was accordingly, recommended and desired by the FEPCC to revise the FERs at serial No. 1 to 7, so that all the reports are uniform so far as methodology is concerned. It was further decided while updating the meteorologoical component, validation of hydrological studies must also be carried out to find out any significant changes. 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 1978; Lower Godavari Subzone 3 (f), published in 1981; Mahanadi Subzone 3 (d) published in 1982; South Bramhaputra subzone 2(b), published in 1984 Krishna & Pennar Subzone 3(h), published in 1983 and Upper Narmada and Tapi Sobzone 3(c) published in 1983 have already been revised, where the additional hydrometeorological input has been included as per revised methodology.

Present report is the revision/validation of the flood estimation report of Lower Narmada and Tapi Subzone 3 (b) and deals with the estimation of design flood of 25 year, 50 year and 100 year return period for small and medium catchments in the Subzone.

The original flood estimation report of Subzone 3 (b) was prepared and published in 1982. The rainfall-runoff data of 17 catchments having catchment area between 53 Sq.km to 828 Sq.km. for period of 2 to 9 years during the period from 1958 to 1979 have been collected from Railways. 92 bridge years' data of 17 catchments was utilized for the study carried out earlier. In the present study, additional data of 21 bridge years for 3 catchments was collected subsequent to the preparation of earlier report. Thus, a total of 113 bridge years' data from 17 catchments has been used for present unit hydrograph study.

IMD while updating the storm studies used the rainfall data of 200 O.R.G. stations and 25 Self Recording Raingauge (SRRG) stations in the study.

The report is in six parts. Part-I of the report "Introduction" gives the summary of the earlier and revised studies. Physiographic, climatic and hydrometeorological features of the subzone have been explained 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 (b) is recommended for estimation of design flood for small and medium catchments varying in areas from 25 Sq.km. to 2500 Sq.km. This report may also be used for catchments having areas up to 5000 Sq.km. judiciously after comparing the neighbouring catchments having more or less similar characteristics.

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 and Standards Organisation (RDSO) of Ministry of Railways and Ministry of Surface Transport (MOST).

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New Delhi

May,2004

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LIST OF ANNEXURES, PLATES AND FIGURES

PLATES

SYMBOLS AND ABBREVIATIONS

Symbols

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

A	Catchment area in km^2
ARF	Area of Reduction Factor
C.G.	Centre of Gravity
Di_{-1} & Di	Depths between the river bed profile (L-Section) based on the levels of i-th and (i-1) th contours at the inter-section points and the level of the base line (datum) drawn at the points of study in metres
F	Shape factor of catchment ($F = L^2/A$)
Q_{25}, Q_{50}	Flood Discharge with a return period of 25-year, 50-year and 100- year And Q_{100} respectively in cumecs
Q_p	Peak discharge of Unit Hydrograph (cumecs)
q_p	Peak Discharge of Unit Hydrograph per Unit Area in cumecs per sq.km
S	Equivalent stream slope (m/km)
S_1, S_2	Slope of Individual Channel Segment (m/km)
T_B	Base period of Unit Hydrograph in hours.
T_D	Design Storm Duration (hr)
T_m	Time from start of rise to the peak of unit hydrograph ($T_m = t_p + t_r/2$)
t_p	Time lag from centre of unit rainfall duration to the peak of Unit hydrograph in hours
t_r	Unit rainfall duration in hours
U.G.	Unit Hydrograph
W_c	Minimum width of catchment area through the centre of gravity of the catchment
W_{50}	Width of Unit Hydrograph measured at 50% of maximum peak discharge (Q_p) in hours.

W_{75}	Width of Unit Hydrograph measured at 75% of peak discharge (Q_p) in hours
W_{R50}	Width of the Hydrograph at 50% of Q_p between the rising limb and Q_p ordinate in hours
W_{R75}	Width of the Unit Hydrograph at 75% of Qp between the rising limb of unit hydrograph and Qp ordinate in hours
%	Percent
Σ	Summation

ABBREVIATIONS

Cumec	Cubic metre per second
Cms.	Centimetres
Hr.	Hour
In.	Inches
Min.	Minutes
M.	Metre
Km.	Kilometres
Sec.	Seconds
Sq.km.	Square kilometre
Yr.	Year
mm	Milimetre

PART – I

INTRODUCTION

1.1 GENERAL

Background of the Committee:

The Committee of Engineers headed by Dr. A.N. Khosla recommended to develop regional methodology for estimating design flood for small and medium catchments. On the recommendations of the committee, the country was divided into 7 zones and 26 hydrometeorological homogeneous subzones. The various subzones into which the country has been divided are listed in Annexure 1.1.

Lower Narmada and Tapi Subzone 3 (b) is one of the 26 hydrometeorologically homogeneous subzones. The flood estimation report of Lower Narmada and Tapi Subzone 3 (b), (Design Office Report No. LNT/4/81) was published in 1982. The present report is validation/revision of the earlier report.

The report published in 1982 contained inputs for estimation the design flood of 50 year return period only whereas the present report provides inputs for estimating design floods of 25, 50 and 100 year return period.

1.2 NEED FOR REVISION OF REPORT

Rainfall maps of 50 year return period for duration of 1, 3, 6, 9, 12, 15 and 24 hours were furnished in flood estimation reports, published till 1982. These reports were based on data of sparse self-recording raingauges network. After publication of these subzonal reports, India Meteorological Department (IMD) upgraded the methodology of storm study, for preparing the isopluvial maps using rainfall data of ORG and SRRG in and around the subzone, in addition to the data within the subzone.

Flood Estimation Planning and Coordination Committee (FEPCC) in its 51st meeting agreed to revise these reports in a phased manner, incorporating the revised isopluvial maps prepared using ORG and SRRG data for 25, 50 and 100 year for 24 hour duration and other corresponding inputs. It was also decided by FEPCC to review and revise/validate the hydrological study of these reports, utilising additional rainfall-runoff data collected subsequent to the preparation of the reports.

1.3 REVISED STUDY

Hydrological and Storm Studies as carried out in the earlier report and in the revised/validated report are as follows :

1.3.1 Hydrological study

The hydrological study carried out earlier in 1982 was based on rainfall-runoff data of 17 catchments. observed for a period varying from 2 to 9 years during the period 1958-79 Representative Unit Hydrograph (RUG) of 1-hour duration were derived from the selected flood events from the available data. 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 3 bridge sites (479/3 T, 411/1T, 50 N) for a period varying from 3 – 9 years was made available by Research Design and Standards Organisation (RDSO). These data have now been utilised and integrated with the earlier studies.

The parameter of Statistical Slope used in the earlier report has been replaced with equivalent 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.

1.3.2 Storm Study

The earlier report contained isopluvial maps of 50-year return period for different duration, 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 duration.
(iv) Point to areal rainfall ratios for different duration.

In the present study, IMD has utilised the rainfall data of 200 ORG stations maintained by IMD and State Governments and 25 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, SRRG data from a network of IMD's stations in and around the Subzone are used. The storm studies carried out by IMD are given in Part – IV of the report.

1.4 PROCEDURE TO ESTIMATE DESIGN FLOOD

The flood estimation report for Subzone 3 (f) may be used for estimation of design flood (25-year, 50-year and 100-year) for ungauged or inadequately gauged catchments in the Subzone. Part-V explains procedure for obtaining the design flood of specified return period along with an illustrative example.

PART - II

GENERAL DESCRIPTION OF LOWER NARMADA AND TAPI SUBZONE

2.1 LOCATION

In Plate 1, the location of Lower Narmada and Tapi subzone - 3 (b) has been shown in map of India, as also delineation of 26 subzones into which the country has been divided for the purpose of hydrometeorological studies. The subzone 3 (b) is bounded by Chambal basin on the North, Ran of Kutch and Arabian Sea on the West, Upper Godavari and Konkan on the South and Upper Narmada and Tapi basin on the East. Important cities and towns within the subzone are Surat, Vadodara, Jalgaon, Khandwa and Bhusaval. The total area of the subzone is about 77700 sq.km.

2.2 RIVER SYSTEM

Plate 2 shows the river system, hydrological data observation sites and network of Railway/Highways in the subzone 3 (b).

The subzone 3 (b) is traversed by the lower reaches of river Narmada and Tapi and their tributaries. The subzone constitutes an area of about 50% of the Narmada and Tapi basins. The river Tapi rises in the Satpura plateau and has narrow and long basin. Flowing westward, it joins Gulf of Cambay in the Arabian Sea, about 20 km west of Surat without forming a delta. The Narmada has its origin in Maikal range at Amarkantak, 1057 m above the sea. The river flows westwards and falls into the Arabian Sea near Bharuch after traversing the narrow valley between Bhawron and Maikal ranges and the main Vindhya and Satpura ranges. Like Tapi, this river also has no delta mouth.

The subzone is covered by lower reaches of Narmada and its tributaries to the extent of about 52% and the rest by lower reaches of Tapi and its tributaries to the extent of about 48%. The subzone comprises of the Kanar, Kayam, Man, Hathani, Hiran, Bhakti Bhadar, Goi, Korjan, Girna, Bori, Buray, Gomai and other tributaries. The areas drained by the above tributaries within the subzone are as under :

Sl. No.	Sub Basin	Area/Sq.Km.	Remarks
1.	Kanar	2826	Sl.No. 1 to 9 fall under Lower Narmada Basin
2.	Kayam	1272	
3.	Man	2665	
4.	Hatori	4112	
5.	Hiran	5704	
6.	Bhakti Bhadar	6321	
7.	Badar	6443	
8.	Goi	5023	
9.	Karjan & Other tributaries	5865	

10	Girna	13329	Sr. No. 10 to 14 fall under Lower Tapi Basin
11.	Bori	5746	
12.	Buray	5224	
13.	Ganai & other five tributaries	6570	
14.	Other small tributaries	6600	
	Total Area of Subzone	77700	

2.3 GENERAL TOPOGRAPHICAL FEATURES

2.3.1 Physiography

Plate 3 shows the physiography of the area. Lower Narmada and Tapi subzone is essentially semi arid region with mean annual rainfall varying from 600 mm to 1600 mm and covers parts of areas in the states of Maharashtra, Gujarat and Madhya Pradesh. The subzone is rectangular in shape and extends from longitude 72° – 30' to 76° – 30 East and Latitude 20° - 30 to 22° - 40' North.

The Lower Narmada and Tapi subzone has a complex relief. Plains of medium heights upto 300 m exist on Western and Eastern sides and in centre of the subzone. Low plateaus in range of 300 – 600 m exist in Eastern, Southern and Central portions. High plateaus in range of 600 – 900 m lie in two patches on Northern side and also on Southern side.

2.3.2 Soils

Plate 4 shows the main soil classification in the subzone. The broad soil group in the subzone is black soil, and coastal alluvial soils at the mouth of the river Tapi. There is, however, a small patch of laterite soil on the western side of the subzone. Black soils are classified as deep black, medium black and shallow black soils and these are clayey in texture and are derived from trap rocks. Only former two groups of black soil are present in this subzone. At micro level (i.e. when small and medium catchments are considered), the soil type may vary considerably from the above indicated groups.

2.3.3 Land – Use

Plate 5 shows the land use map of the subzone. Approximately 70% of the area of this subzone is arable land, 25% forest and the rest is grass and waste land.

2.4 CLIMATOLOGICAL FEATURES

2.4.1 RAINFALL FEATURES

2.4.1.1 Annual Normal Rainfall

The isohyetal map of annual normal rainfall for the subzone 3(b) is shown in plate-6. The subzone receives most of the rainfall from South West monsoon. About 90% rainfall is received in months of June to October. In the Western part of the subzone, rainfall varies from 800mm to 1600 mm rainfall from North to South. The South-Central part of the subzone receives as low as 600 mm rainfall annually. The rainfall again increases towards NE; the far North-Eastern part of the subzone receives rainfall of the order of 1000 mm.

2.4.1.2 Monthly rainfall distribution

Monthly rainfall distribution at six representative stations, viz, Baroda, Surat, Buldhana, Malegaon, Nandurbar and Khandwa is illustrated through bar charts appended to the annual normal rainfall maps (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.

It can be seen from the bar charts that the period June to September constitute the main rainy season over the subzone. The month of October is also the month of good rainfall activity.. Normal rainfall for the monsoon season (June to September) Baroda, Surat, Buldhana, Malegaon, Nandurbar and Khandwa is 95%, 95%, 85%, 81%,88% & 88% of the annual rainfall, respectively.

Normal rainfall for the five months (June to October) at the five representative stations except Malegaon is in the range of 90% to 98% of the annual rainfall whereas at Malegaon, which lies in the lowest rainfall region, it is 88%.

2.4.2 TEMPERATURE DISTRIBUTION

2.4.2.1 Mean daily temperature (annual)

Mean daily temperature distribution over the subzone is shown in plate-7. The Mean daily temperature are worked out as average of mean maximum and mean minimum temperature over the year.

It may be seen from the map that almost entire subzone is having a mean temperature greater than 25°C. The central part of the subzone extending from East to West experiences a higher mean daily temperature ranging from 27.3°C to 27.8°C. The temperature decreases upto 25°C towards South as well as towards North-Eastern part of the subzone.

2.4.2.2 Monthly Temperature variations at selected stations

Monthly variations of mean maximum, mean minimum and mean daily temperature for six representative stations viz, Buldhana, Malegaon,, Nadurbar, Baroda, Surat, and Thikri are shown graphically in plate-7 below the map of mean daily temperature.

It may be seen from these graphs that the highest maximum temperatures are observed in the month of May at five representative stations except at Surat where it is observed in the month of April. Minimum temperature is observed in the month of January at all the six representative stations.

Mean daily temperatures are highest in the month of May and lowest in the month of January at all the six representative stations.

2.5 COMMUNICATION

2.5.1 Railways

The important railway section of Central and Western Railways exist in the suzone are given in Table 2.2 as follow.

Table 2.2
(Railway Section)

SL.No.	Railway Section	Railway
1	Igatpui - Bhusaval	Central Railway
2	Bhusaval - Badnera	Central Railway
3	Bhusaval- Itarsi	Central Railway
4	Pachora - Jamne	Central Railway
5	Chalisgaon - Dhule	Central Railway
6	Udhna - Jalgaon	Central Railway
7	Mhow - Khandwa	Western Railway
8	Dabhoi - Timba Road	Western Railway
9	Kosamba - Umarpada	Western Railway
10	Viswamitri - Chhotaudaipur	Western Railway
11	Chhuchhopura - Tankhala	Western Railway
12	Ankleshwar - Rajpipala	Western Railway
13	Surat - Vadodara	Western Railway

2.5.2 Roads

The important National highways in the subzone are given in Table 2.3.

Table 2.3
(National Highway)

Sl. No.	Highway	Section
1	NH - 8	Mumbai - Ahmedabad
2	NH - 3	Mumbai - Agra
3	NH - 6	Dhule - Nagpur

PART III

SYNTHETIC UNIT HYDROGRAPH STUDIES

3.1 SYNTHETIC UNIT HYDROGRAPH (SUG)

SUG 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 hydrometeorolgically homogeneous region (Subzone).

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) i.e. by subtracting loss rates 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 5-8 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 referred to. Data collected and analysed for obtaining subzonal SUG equations are discussed in succeeding paragraphs.

3.2 DATA REQUIRED

For carrying out the unit hydrograph studies for development of equations for derivation of Synthetic UG parameters 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 atleast 5-8 years during the monsoon season.

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

ii) Gauge and discharge data observed preferably 2 to 3 times a day or more frequently at the gauging site. In the absence of this, even daily discharge data at the these stations can be used for S-D curve development for converting hourly gauges into discharges.

iii) Hourly rainfall data of raingauge stations in and around the catchments. 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 types, land slopes 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

Central Railways, Western Railways, under the overall guidance and supervision of Research Design and Statndards Organisation, Lucknow had collected rainfall, gauge and discharge data of 21 bridge catchments for a period of 2 to 9 years collected during 1958-1979. Data of 17 bridge catchments for 92 bridge years found suitable were utilised in the study carried out during 1982. Additional data for 21 bridge years for 3 bridge sites shown in Table 3.1 was collected subsequent to the preparation of the report. Thus, a total of 43 bridge year data has been used for developing co-relation between unit hydrograph and physiographic parameters for developing of Synthetic Unit Hydrograph (SUG).

Table 3.1

(Additional data for 3 bridge sites)

Sl.No.	Site	Additional data	Bridge years
1	479/3 T	1983,1984, 1986	3
2	411/1 T	1987-1995	9
3	50 N	1987-95	9
		Total	21 years

Annexure 3.1 shows the name of the stream, railway bridge number, Railway Section, and catchment area, No. of rain gauge stations and period of availability of rainfall runoff data of 21 bridge catchments having catchment areas more than 25 sq.km. This also includes additional data of 3 catchments, collected subsequent to the preparation of the report. It can be seen from Annexure 3.1 that the catchment area of gauge sites lie between 53 sq.km. to 828 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 develop 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 main stream from a point near the centre of gravity of catchment the observation site (L_c) and equivalent stream slope (S). The parameters are indicated in Figure-1. Estimation of these are explained in the following paragraphs.

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 length of the longest main stream/river from the farthest point on the 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 observation site (L_c).

For finding the center of gravity of the catchment, usually the boundary of the catchment is cut on a cardboard, which is then hung freely 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 (Lc).

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 instead 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 using the contour plain (topographic maps). In case the contours are not directly available, the nearest spot level is used. The basic concept of equivalent slope line so drawn is that on an average basis the cutting and filling of ground are equal (Ref Figure 1) i.e. 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 10 or 12 segments representing the broad ranges of the slopes of the segments and the following formula is used to calculate the equivalent slope (S) in m/km.

$$S = [\Sigma L_i (D_{i-1} + D_i)] / (L)^2$$

Where,

L_i = Length of the ith segments in km.

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

L = Length of the longest stream as defined in section 3.4.1.2. in km.

Physiographic parameters A, L, Lc and S are obtained for 17 catchments used for analysis and are shown in Annexure 3.2.

3.4.2 UNIT HYDROGRAPH PARAMETERS

3.4.2.1 Scrutiny of data and finalisation of gauge discharge rating curve

Out of 21 catchments, data of 17 catchments (92 bridge years) was found suitable for the unit hydrograph study contained in the earlier report. The additional data of catchments,viz. 479/3 T, 411/1 T and 50 N (21 bridge years) was scrutinized through arithmetical checks and gauge and discharge rating curve(s) were developed. The hourly discharges for the duration 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 205 flood events of 17 catchments were found suitable for U.G. studies. The general guidelines followed for selecting a flood event are given below.

i) The flood should not have undue stagnant water levels.
ii) The selected flood should result from significant excess of rainfall, not less than 1 cm.

25 Flood events shown in Table 3.2 were found suitable from the additional data collected at 3 bridge catchments make a total of 230 flood events. The catchments considered in the present study are the same catchments that were found suitable in the previous study.

Table 3.2
(Selected flood events)

SL.NO.	SITE	EVENTS		TOTAL EVENTS
		Utilised Earlier	Additional Events	
1	479/3 T	9	4	13
2	411/1 T	14	12	26
3	50 N	19	9	28

3.4.2.3 Computation of hourly catchment rainfall

The 3-catchments viz. 479/3 T, 411/1 T and 50 N for which additional data was received the raingauge network remains the same and the station weights computed earlier were used.

3.4.2.4 Separation of base flow

The selected flood events of 3 Bridge catchments were plotted on the usual graph paper. The base flow was separated through the normal procedure to obtain direct surface runoff hydrograph 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

With the known values of 1-hour catchment rainfall and the direct runoff depth for each flood event, the infiltration loss (constant loss rate) was estimated for selected flood events of 3 Bridge catchments viz. 479/3 T, 411/1 T and 50 N.

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 from the additional data of 3 bridge catchments. 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 hydrograph.

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 hydrograph derived earlier. Integrated RUGs of 3 sites have been tested on observed floods. RUGs of remaining 14 sites developed earlier were utilised as such without any modifications. Following parameters of RUGs as indicated in Figure-2 for 17 catchments were obtained and are furnished at Annexure 3.3.

(a) Time from the centre of unit excess rainfall duration to the peak of unit hydrograph in hours (tp).
(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 unit hydrograph measured in hours at discharge ordinate equal to 75% of Q_p (W_{75}).
(f) Width of the rising side of unit hydrograph measured in hours at discharge ordinates equal to 50% of Q_p (WR_{50}).
(g) Width of the rising side of unit hydrograph measured in hours at discharge ordinates equal to 75% of Q_p (WR_{75}).

(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*tr where tr is the unit duration of unit hydrograph.

3.4.3 Establishing relationships between physiographic and representative unitgraph parameters.

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

$$Y = C * X^{p} \quad \text{.......... 3.4.3.1}$$

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 $LLc/\sqrt{S}$ as some of the physiographic parameters and t_p as one of the U.G. parameter was developed and found to be significant. Similarly, q_p was related to time to peak discharge of the UG (t_p). UG parameters W_{50}, W_{75}, WR_{50}, WR_{75} were related to q_p. The UG parameter T_B is correlated to t_p. The principle of least square errors was used in the regression analysis to establish 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 for an ungauged catchment in the Subzone 3 (b) as shown in Table 3.3 as follows:

Table 3.3
(Recommended SUG relation)

Sl. No	Relationship		Equation No.
	Based on Report of 1983	Revised Relationship	
1	$t_p = 0.523\ (LLc/\sqrt{s})^{0.323}$ $r = 0.95$	$t_p = 0.583\ (LLc/\sqrt{s})^{0.302}$ $r = 0.94$	3.4.3.2
2	$q_p = 1.92\ (t_p)^{-0.78}$ $r = 0.87$	$q_p = 1.914\ (t_p)^{-0.763}$ $r = 0.87$	3.4.3.3
3	$W_{50} = 1.83\ (q_p)^{-0.97}$ $r = 0.93$	$W_{50} = 1.849 (q_p)^{-0.976}$ $r = 0.94$	3.4.3.4
4	$W_{75} = 0.924\ (q_p)^{-0.792}$ $r = 0.86$	$W_{75} = 0.955\ (q_p)^{-0.792}$ $r = 0.92$	3.4.3.5
5	$W_{R50} = 0.745\ (q_p)^{-0.725}$ $r = 0.88$	$W_{R50} = 0.738\ (q_p)^{-0.781}$ $r = 0.87$	3.4.3.6
6	$W_{R75} = 0.434\ (q_p)^{-0.616}$ $r = 0.86$	$W_{R75} = 0.438\ (q_p)^{-0.641}$ $r = 0.87$	3.4.3.7

6	$W_{R75} = 0.434\ (q_p)^{-0.616}$ $r = 0.86$	$W_{R75} = 0.438\ (q_p)^{-0.641}$ $r = 0.87$	3.4.3.7
7	$T_B = 6.908\ (t_p)^{0.592}$ $r = 0.93$	$T_B = 7.042\ (t_p)^{0.559}$ $r = 0.94$	3.4.3.8
8	$T_m = t_p + t_r/2$	$T_m = t_p + t_r/2$	3.4.3.9
9	$Q_p = q_p \times A$	$Q_p = q_p \times A$	3.4.3.10

Relations developed are shown in Figures 3 to 9. Details of relationships so developed using physiographic and unit hydrograph parameters and their co-efficients of correlation is given in Annexure 3.4.. The 25, 50 and 100 year flood peaks for 17 selected bridges have been computed using the new relations given in Table 3.3 and also from the RUGs of these bridges taking critical 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 corresponding RUGs.

It can be seen from the above table, that the coefficient of correlation for some relations have been has reduced and for others it has increased in the present study when compared to earlier one. This can be explained due to the reason that the additional data for three bridge catchments have been used in developing the integrated RUG. The RUG parameters of these three catchments are as follows:

Sl.No	**Bridge No479 (C.A. 240Km²)**			**Bridge No.411/1 (C.A. 262 Km²)**			**Bridge No.50N (C.A. 194 Km²)**		
	AsPer Earlier Report (1971-73)	Additional Data (1983,84, 86)	Integrated Data	As Per Report (1968-73)	Additional Data (1987-95)	Integrated Data	As Per Report (1967-68) (1970-73)	Additional Data (1987-95)	Integrated Data
Q_p	200.0	247	223.5	133.0	214.0	173.5	123.0	138.0	130.5
q_p	0.83	1.03	0.93	0.51	0.77	0.66	0.71	0.63	0.67
t_p	3.50	3.50	3.50	4.50	4.50	4.50	3.50	3.50	3.50
T_B	14.0	12.0	13.0	18.0	14.0	16.0	13.0	15.0	14.0
W_{50}	2.40	1.90	2.15	3.7	2.50	3.10	2.80	2.40	2.60
W_{75}	1.50	1.15	1.32	1.50	1.40	1.10	1.34	1.10	1.22
W_{R50}	1.00	0.70	0.85	1.00	0.90	0.90	0.90	0.90	0.90
W_{R75}	0.50	0.50	0.50	0.60	0.60	0.57	0.50	0.50	0.50

From the above, it can be seen that RUG parameters have changed. This may be due to the developmental activities resulting in changes in the physiographic features of the catchment. The effect of these three catchments have affected the overall coefficient of correlation.

It would have been better, if data of all the catchments could have been collected to study the man made changes in the subzone. In the absence of these details and till such times the same are collected, the present relations will hold good.

3.4.4 Derivation of 1-hour Synthetic Unit Hydrograph for an ungauged catchment.

Considering the hydro-meteorologically 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 t_p, q_p W_{50}, W_{75} WR_{50} WR_{75} and T_B by 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}, WR_{50} and WR_{75} on a graph paper as shown in illustrative Figure 2 and sketch and adjust the unitgraph through these points.

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

$$\Sigma Qi = [2.78*A] / tr$$

Where

Qi = discharge ordinates at 1-hour interval (cumecs)
A = catchment area in Sq.km.
t_r = Unit duration in hours.

Suitable adjustment can be made in falling limb region from W_{50} point to the tail of the unitgraph and a smooth curve be drawn to make the volume equal to the volume of the unitgraph.

3.5 SIMPLIFIED APPROACH

To quickly assess the peak of 25 year, 50 year and 100 year return period flood, a simplified approach has been developed. The physiographic parameters and corresponding 25 year, 50 year and 100 year 24-hr. point rainfall as read from the isopluvial maps (plates 8,9,10) supplied by IMD are obtaired and substituted in the empirical relation developed on the basis of regression analysis using 25 year, 50 year and 100 year flood peaks for each of the 17 gauged catchment for different sizes as computed by detailed approach. The values of Q_{25}, Q_{50} and Q_{100} for the 17 catchments so obtained are treated as dependent variables were related to their respective physiographic parameters A, L, Lc and 24 hour point rainfall values at that observation site for 25, 50 and 100 years as (R_{25}, R_{50} and R_{100}) as independent variables using multiple regression analysis and using method of least square techniques for fitting. The derived flood formulae for Q_{25}, Q_{50} and Q_{100} and their respective coefficient of correlation 'r' are as under. The correlation of dependent variables Q_{25}, Q_{50} and Q_{100} with independent variables were studied.

$$Q_{25} = 1.0196(A)^{0.9412}(L)^{-0.3366}(Lc)^{-0.1009}(S)^{0.0568}(R_{100})^{1.0988} \quad r = 0.991$$

$$Q_{50} = 1.1327(A)^{0.9415}(L)^{-0.3525}(Lc)^{-0.0864}(S)^{0.0521}(R_{100})^{1.0735} \quad r = 0.991$$

$$Q_{100} = 1.1038(A)^{0.9458}(L)^{-0.3451}(Lc)^{-0.0877}(S)^{0.0556}(R_{100})^{1.0685} \quad r = 0.992$$

Where Q_{25}, Q_{50} and Q_{100} are 25 year, 50 year and 100 years flood in cumec respectively.

A	is the catchment area upto point of study in Sq.km.
L	is the length of longest main stream along the river course in km.
Lc	is the length of the longest main stream from a point opposite to the centroid of the catchment area to the gauging site along the main stream in km.

R_{25}, R_{50} and R_{100} are 24 hour point storm rainfall values in cm for 25 year, 50-year and 100 year return periods respectively.

3.6 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/assess 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 rate in the catchments, is complex phenomena, varying due to soil conditions, soil cover and topography along with temporal and spatial variations of storm rainfall.

In the annexure 3.6, the variation of the loss rate can be seen. There is a wide variation in the loss rate ranging from 0.1 mm/hr to a high of 18 mm/hr. The loss so assessed is a complex phenmenon as the estimation of catchment rainfall depends on many hydrological factors such as antecedent moisture condition, size of the catchment, soil type etc, but also the estimation of catchment rainfall depends upon the location of the raingauge stations, which also affects the estimation of the areal rainfall depth with respect to runoff observed at the outlet of the catchment.

As the flood potential of a catchment will depend on the loss rate, we can see from the Annexure 3.6 that for more than 50% of the floods in the catchment, the loss rate ranges from 2 mm/hr to 8 mm/hr. A value of 5 mm/hr is therefore, recommended for adoption.

3.7 DESIGN BASE FLOW

Base flow values for 228 flood events inclusive of additional flood events of 3 catchments tabulated in different ranges are shown in Annexure 3.7. Out of 228 flood events, 127 flood events fall under the range of 0.01 - 0.09 cumec/Sq.km. The average base flow rate of 0.05 cumec/Sq.km. is recommended for estimating base flow for a catchment in the Subzone. The designer may, however, adopt any other suitable value as per site condition.

PART- IV

STORM STUDIES

4.1 INTRODUCTION

4.1.1 The India Meteorological Department (IMD) has conducted detailed rainfall studies for Lower Narmada & Tapi Basin Subzone 3 (b). 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 storm of different durations (2 to 24 hours), and (iv) point to areal rainfall ratios for specified durations (1,3,6,12 and 24 hours). The methodology for analysis of each component and the procedure for design storm estimation is discussed in Section-4.5. The results of the study serve as basic input for design flood estimation for small and medium catchments.

4.1.2 Subzone 3 (b) covers parts of Madhya Pradesh, Maharashtra and Gujarat. One district of Madhya Pradesh, one district of Gujarat and two districts of Maharashtra are fully inside the subzone, whereas nine districts (three in Gujarat, four in Madhya pradesh and two in Maharashtra) are having most of its area inside the subzone.

4.2 DATA USED

The rainfall data for a large number of stations in and around the subzone for as long a period as possible have been used. Ordinary raingauge (ORG) data of 200 stations and self recording rainguage (SRRG) data of 25 stations have been utilised.

4.3 DEPTH DURATION FREQUENCY ANALYSIS

4.3.1 ISOPLUVIAL MAPS

For each of the 200 ORG stations in and around the subzone, a series of annual maximum one-day rainfall was generated. The 200 stations 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 (200 x 3) were converted into 24 - hour rainfall estimates by using the conversion factor of 1.15. For each return period, the 24-hour esfimates for 200 stations were plotted on the 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.

4.3.2 SHORT DURATION RATIOS

There are 25 SRRG stations in the subzone and most of the stations are having data of more than 7 years. 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 (25 x 8 x 5) were converted into ratio with respect to the corresponding 24 - hour estimates. Average ratio (8 x 5) for the zone as a whole (mean of 25 station ratio) 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. These 8 conversion ratios for t = 1, 3, 6, 9, 12, 15, 18 and 24 hours given below were plotted on 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 durations.

Duration (t) In Hours	Conversion Ratio = 10 – Year t - Hour Rainfall / 10 – Year 24 Hour Rainfall
1	0.31
3	0.49
6	0.63
9	0.73
12	0.81
15	0.87
18	0.92
24	1.00

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 or, by making use of table alongside the graph.

4.3.3 TIME DISTRIBUTION CURVES

Based on hourly rainfall data of all the 25 SRRG stations, a total of 3241 rainstorms of durations ranging from 2 to 24 hours were analyzed and grouped station wise into the following 5 categories.

a) rainstorms of 2 to 3 - hour duration (714 of all stations)
b) rainstorms of 4 to 6 - hour duration (775 of all stations)
c) rainstorms of 7 to 12 - hour duration (954 of all stations)
d) rainstorms of 13 to 18 - hour duration (393 of all stations)
e) rainstorms of 19 to 24 - hour duration (405 of all stations)

For each station, 5 different graphs corresponding to each group of rainstorms were prepared by plotting the cumulative percentage of the total storm duration and the average time distribution curves (25 x 5) were drawn. Average time distribution curves (5) for the subzone, as a whole, were then drawn by plotting 25 station curves on the same graph and average curves are drawn, which are given in Fig.11. These curves can be used to derive the time distribution co-efficient of storm rainfall in the sub zone for the rainstorms of any duration (Annexure 4.3).

4.3.4 POINT TO AREAL RAINFALL RATIOS

In the present study, the availability of a fairly dense network of SRRGs in the subzone made it possible to adopt the best scientific procedure for deriving point to areal relationship based on SRRG data and concurrent ORG data in preference to bridge data. The data of 25 SRRG stations in and around the catchment were used. SRRG data of 25 stations were scrutinized to collect the rainstorms of various durations (t = 1,3,6,12 & 24 hrs). The hourly rainfall records of SRRG's and daily rainfall data of surrounding ORG's were carefully examined for various storm durations (5) to select t - hour representative rainstorms based on the following considerations :

(i) A maximum central value of t-hour rainfall being nearest to the corresponding 24-hour rainfall ending 0830 hours;
(ii) The availability of adequate concurrent data of surrounding ORG stations;
(iii) Each duration t being entirely contained in the 24-hour period ending 0830 hours.

About 90 representative rainstorms were selected for analysis. For each representative rainstorm, the ratio of rainstorm rainfall to corresponding 24-hour rainfall was computed and the daily rainfall values of surrounding ORG stations were reduced in the same proportion. Isohyetal maps of 90 representative rainstorms were then prepared using concurrent rainfall values of SRRG stations and surrounding ORG stations (reduced values) corresponding to the date and time of each representative rainstorm. By planimetering each isohyetal map around the rainstorm centre and plotting the ratios of areal rainfall depth to point rainfall against the areas, the best fit curves (5) were drawn as shown in the graph at Figs. 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 4.4)

4.4 HEAVIEST RAINFALL RECORDS

4.4.1 ORG Data

The highest ever recorded one day station rainfall (24 hours rainfall ending 0830 hrs. of date) alongwith date of occurrence in each of the 13 districts covering subzone 3(b) have been compiled from the ORG data and presented in Annexure 4.1. Annual Normal rainfall for each station is also given in the Annexure.

4.4.2 SRRG Data

The heaviest storm rainfall in duration of 24, 12, 6, 3 and 1 hour along with date and time of occurrence at the 13 SRRG stations have been compiled and presented in Annexure 4.2.

4.5 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 9 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) and 12(b) or Annexure - 4.4 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 4.3 and multiply the 50 yr. 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 occuring every hour in the bridge catchment by subtraction of 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 upto 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 Railway 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 the 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 road 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 as computed under clause 103. The recommended percentage increase over the design discharge specified in clause 103 is given under clause 110.1.2 of IRC-5-1985. These recommendations are the same as given in the report of the Committee of Engineers and are reproduced as under.

Sl. No.	Catchment Area	Increase In Design Discharge
1	Upto 500 Km^2	30% to 25% decreasing with increase in area.
2	500 to 5000 Km^2	25% to 20% decreasing with increase in area.
3	5000 to 25000 Km^2	20% to 10% decreasing with increase in area
4	Above 25000 Km^2	Less 10%

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 percentage increase over the design discharge recommended in the code is same as suggested by the Committee of Engineers and reproduced in para (b) above.

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

e) **Indian Standards Guidelines 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 in 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 17 catchments have been derived using the parameters computed from recommended equations given in Table-3.3. Annexure 5.1 shows the computed UG parameters. It has been studied that the critical storm duration, which causes severe floods in small and medium catchments as used in this subzone, is equal to 1.1*tp. The flood peaks of 25 yrs, 50 yrs and 100 yrs return period is computed for this storm duration.

It is, therefore, recommended to adopt the value of design storm duration (T_D) as 1.1*tp. The design engineer may adopt the value of T_D as 1.1*tp. or any other values 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 4.5.

iii) Adopt design loss rate as recommended in section 3.6.

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 falls 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_D hour duration.

ii) Obtain the base flow for the catchment area under study vide section 3.7.

iii) Obtain total surface runoff by summing the product of unit hydrograph ordinates and effective rainfall consecutively

iv) Obtain the total flow by adding the base flow to the computed total surface runoff in step (iii) above. This will give the peak value of the flood.

b) Design flood hydrograph.

For the 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 all the hourly effective rainfall values giving a lag of 1-hr each time to successive direct runoff ordinate.

Step –7:

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

Step –8:

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

5.2.1. Illustrative example.

1. Bridge No.485/4 at mile 11/12-13 on Bhusaval-Badnera, Central Railway has been marked out as ungauged catchment for illustrating the procedure to compute 50-year design Flood. The catchment plan is enclosed at figure A-1.

The particulars of the catchment under study are as follows:

(i) Name of Subzone	:	Lower Narmada & Tapi
(ii) Name of Tributary	:	Wughur
(iii) Name of Railway Section	:	Bhusaval-Badnera
(iv) Shape of catchment	:	Normal
(v) Location	:	Lat 20° 54' Long 76° 08'
(vi) Topography	:	Moderate slope

Procedure is explained below:

Step-1 : Physiographic Parameters

Physiographic parameters obtained are given below:

1) Area (A)-Refer fig. A-1 = 285 Sq.km
2) Length of the longest stream (L) = 34.45 km
3) Length of the longest stream from a point opposite to C.G.(Lc) = 14.45 km
4) Equivalent stream slope (S_{eq}) = 2.48 m/km

The computation of equivalent Slope is shown at Annexure 5.2.

Step 2 : 1 hr Synthetic Unitgraph

Unitgraph parameters of the synthetic unit hydrograph were computed using equation in para 3.4.3. The results are given in the following table.

Table 5.1
(Synthetic UG Parameters)

Sl. No	SUG Parameters
1	$t_p = 0.583 (LLc/\sqrt{s})^{0.302}$ = 2.50 hrs
2	$q_p = 1.914 (t_p)^{-0.753}$ = 0.75 cumec/sq.km
3	$W_{50} = 1.849(q_p)^{-0.976}$ = 2.50 hrs
4	$W_{75} = 0.955 (q_p)^{-0.792}$ = 1.22 hrs
5	$W_{R50} = 0.738 (q_p)^{-0.781}$ = 0.94 hrs
6	$W_{R75} = 0.438 (q_p)^{-0.641}$ = 0.53 hrs

7	T_B	$= 7.042\ (t_p)^{0.359}$	= 14.0 hrs
8	T_m	$= t_p + t_r/2$	= 3.0 hrs
9	Q_p	$= q_p \times A$	= 212.0 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 (Qi) of the unitgraph at ti = tr=1 hr interval were summed up and multiplied by tr=1 i.e. $Q_i \times t_i$ = 791.4 cumecs and compared with the theoretical volume of 1.00 cm. direct run off depth over the catchment, computed from the formula Q = (A x d) (t_i x 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)

$$Q = \frac{A \times d}{0.36 \times tr} = \frac{285 \times 1}{0.36 \times 1} = 791.4 \text{ cumec.}$$

Note: In case, $\Sigma Qi*ti$ 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 such that the sum of all the ordinates under the UG is equal to theoretical value as computed above.

Step 3: Estimation of design storm

a) Design storm duration

The design storm duration (T_D) has been adopted as 1.1 x t_p

The value of 1.1 x t_p	= 1.1 x 2.5
	= 2.75
Rounded off to nearest full hour	= 3 hrs.
∴Design Storm Duration (T_D)	= 3 hrs.

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

The site under study was located on plate 9 showing 50 year, 24 hr point rainfall. The point rainfall was found to be 21.00 cm. The conversion factor of 0.49 was read from Fig. 10 to convert the 50 year-24 hour point rainfall to 50 year, T_D (3.00) hrs point rainfall. 50 yrs, 3 hr point rainfall, thus worked out to be 0.49 x 21 cm = 10.29 cm.

Areal reduction factor of 0.786 corresponding to the catchment area of 285 Sq.km. for T_D = 3.00 hour was interpolated from Annexure 4.4 or fig. 12(a) for conversion of point rainfall to areal rainfall. 50 yr, 3.00 hr. areal rainfall thus works out to be 0.786 x 10.29 cm = 8.09 cm.

The 50 yr., 3.00 hour areal rainfall has been split into 1 hour rainfall increments using time distribution coefficients given in Annexure 4.3 or figure 11. The hourly ordinates are given in Table 5.2.

A design loss rate of 0.50 cm/hr, recommended in para 3.6 was applied to get effective rainfall hyetograph.

Table 5.2
(Hourly effective rainfall increments)

Duration (hr)	Distribution co-efficient	Storm rainfall (cm)	Rainfall increments (cm)	Loss rate/hour (cm)	Effective Hourly Rainfall (cm)
1	**2**	**3**	**4**	**5**	**6**
1	0.77	6.23	6.23	0.50	5.73
2	0.93	7.52	1.29	0.50	0.79
3	1.00	8.09	0.57	0.50	0.07

Step 4: Estimation of base flow

Adopting a design base flow of 0.05 cumec per sq.km. recommended for this zone (Para 3.7) the base flow for the catchment under study was estimated to be 0.05 x 285 = 14.25 cumecs.

Step 5 : Estimation of 50 year flood peak

(a) Computation of Flood Peak.
For estimation of the peak discharge, the effective rainfall increments were rearranged against ordinates such that the maximum rainfall is placed against the maximum U.G.ordinate, next lower value of effective rainfall against next lower value of SUG ordinate and so on, as shown in col. 2 & 3 in Table 5.3. Sum of the product of SUG ordinates and effective hourly rainfall gives total direct surface run off to which base flow is added to get total peak discharge.

Table 5.3
(50 year Flood Peak)

Time in Hours.	S.U.G. Ordinates (cumec)	1-Hour Effective Rainfall (cm)	Direct Runoff (cumec)
1	**2**	**3**	**4**
4	101.00	0.07	7.07
5	212.4	5.73	1217.05
6	138.00	0.79	109.02
		Total:	1333.14
		Add Base Flow	14.25
		Peak discharge (Q_{50})	1347.39

(b) Computation of design flood hydrograph

Effective hourly rainfall shown in col.(3) of Table 5.3 in Step 5(a) were reversed to obtain critical sequence as shown in Table 5.4.

Table 5.4
(Critical Sequence of Rainfall)

Time (Hrs)	Critical 1-hr. Effective rainfall sequence in cm.
1	2
1	0.79
2	5.73
3	0.07

For computation of design flood hydrograph, the SUG ordinates were tabulated in col 2 of Annexure 5.3. The critical sequence of effective rainfall increments were entered in col.3 to col.5 horizontally. Direct run off resulting from each of the effective rainfall depths with the U.G. ordinates in Col (2) were entered in columns against each unit with a successive lag of 1 hour since the unit duration of SUG is 1 hr. Direct runoff values were added horizontally and total direct runoff is shown in col. 6. Total hydrograph ordinates were obtained by adding base flow of 14.25 m^3/s in col. 6 and are given in col. 8. Design Flood Hydrograph was plotted against time as shown in Fig. A-3. The peak of the flood hydrograph obtained was 1347.39 m3/sec which tallies with the Peak shown in table 5.3.

5.3. COMPUTATION OF FLOOD PEAK USING FLOOD FORMULAE

For estimation of 25 year, 50 year, and 100 year, the same bridge catchment No.485/4 is considered for selection of the problem by flood formula. The physiographic and meteorologic parameters for the catchment under study are :

Catchment area (A) = 285 Sq.km.

Length of the longest stream (L) = 34.45 km.

Length of the longest stream from a point opposite to C.G. of catchment to point of study (Lc) = 14.75 km.

Equivalent slope (S_{eq}) = 2.48 m/km.

25 yr., 24 hr point rainfall (R_{25}) = 18 cm
50 yr., 24 hr point rainfall (R_{50}) = 21 cm
100 yr., 24 hr point rainfall (R_{100}) = 24 cm

$$Q_{25} = 1.0196(A)^{0.9412}(L)^{-0.3366}(Lc)^{-0.1009}(S)^{0.0568}(R_{100})^{1.0988}$$
$$= 1.0196(285)^{.9412}(31.39)^{-0.3366}(13.68)^{-0.1009}(2.82)^{0.0568}(18)^{1.0988}$$
$$= 1269.75$$

$$Q_{50} = 1.1327(A)^{0.9415}(L)^{-0.3525}(Lc)^{-0.0864}(S)^{0.0521}(R_{100})^{1.0735}$$
$$= 1.1327(285)^{0.9415}(31.39)^{-0.3525}(13.68)^{-0.0864}(2.48)^{0.0521}(21)^{1.0735}$$
$$= 1516.85$$

$$Q_{100} = 1.1038(A)^{0.9458}(L)^{-0.3451}(Lc)^{-0.0877}(S)^{0.0556}(R_{100})^{1.0685}$$
$$= 1.1038(285)^{0.9458}(31.39)^{-0.3451}(13.68)^{-0.0877}(2.48)^{0.0556}(24)^{1.0685}$$
$$= 1584.24$$

The percentage variations in the values of Q_{25}, Q_{50} and Q_{100} as estimated by the detailed approach and as estimated by the flood formulae for the catchment under study are shown in Table no.5.5.

Table No. 5.5
(Comparison of Results)

Br. No	Catch-ment Area (Km^2)	By SUG			By Flood Formula			Variation With Respect to SUG (%)		
		Q_{25}	Q_{50}	Q_{100}	Q_{25}	Q_{50}	Q_{100}	Q_{25}	Q_{50}	Q_{100}
1	285	1129.30	1350.24	1573.58	1269.75	1516.85	1584.24	+12.47	+12.34	+0.68

The variation is within acceptable limit. Therefore, the flood values for 25 yr, 50 yr. and 100 yr. return periods estimated by the respective flood formulae are reasonable for adoption in preliminary designs.

5.4 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 line on a logarithmic plotting depending on the channel configuration; a single straight 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 can be obtained from any standard text book on channel hydraulic. 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 added to the water elevation to arrive at the revised H.F.L 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, CONCLUSIONS AND RECOMMENDATION

6.1 ASSUMPTIONS

Following assumptions have been made in the present study:-

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

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

3. The catchments used in the analysis are treated as homogeneous.

6.2 LIMITATIONS

1. 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.
2. The generalised values of base flow and loss rate has 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.
3. The data of only 17 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-yr. flood and 100 yr. flood.

The report also recommends the adoption of design flood of 25 yr. 50 yr.and 100-yr. 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 2500 Sq. km. Further, the report may be used for large catchments upto 5000 Sq. km. based on sound judgement 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.

6.4 RECOMMENDATIONS

1. In case the physiographic parameters of the ungauged catchment matches with any of the gauged catchment, the unit hydrograph parameters of the gauged catchments can be proportionately transposed to the ungauged catchment and UG, so derived, be adjusted.

2. When the parameters of ungauged catchment do not match with any of the gauged catchment, preference can be given to gauged catchment close to location of ungauged catchment.

3. When none of the above two conditions are fulfilled one should go in for the use of recommended relations.

REFERENCES

1. Engineering Hydrology : Wilson E.M.

2. Estimation of Design Flood "Recommended Procedures" (September 1972) : Central Water Commission, New Delhi.

3. Guide to Hydrological Practices (Third Edition) : World Meteorological Organisation No. 168, 1994.

4. IRC: 5-1985 – Standard specifications and code of practice for Road Bridges, Section-1, General Features of Design (6th Revision) 1985, Indian Roads Congress.

5. Indian Railway Standard code of Practice for Structures and Foundation of Bridges (Revised – 1985 Edition).

6. Irrigation Atlas of India (Revised 1989).

7. Report of Irrigation Commission (1972).

8. Report of the Khosla Committee of Engineers (October, 1959), government of India, Ministry of Railways.

LIST OF HYDRO-METEOROLOGICAL SUB ZONES

Sub Zone	Name Of Subzone (Designated Earlier)	Name Of Subzone (Designated Now)	River Basins Included In The Subzone
1(a)	Luni basin and Thar (Luni and other rivers of Rajasthan and Kutch).	Luni	Luni river and Thar (Luni & other rivers of Rajasthan and Kutch and Banas rivers)
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 others.	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 rivers 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.	

Sub-Zone	Name of Subzone (Designated earlier)	Name of Subzone (Designated now)	River Basins included in the Subzone
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 & Pennar	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 Coromandal Belt (east flowing rivers between Cauvery and Kanyakumari)	South Eastern Coast.	East flowing 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 & Nicobar	Andaman and Nicobar.	
7	J & K, Kumaon Hills (Indus Basin)	Western Himalayas.	Jhelum, Upper portion of Indus, Ravi and Beas rivers).

LIST OF RAILWAY/ROAD BRIDGE IN SUBZONE – 3(b) (LOWER NARMADA & TAPI) AND AVAILABILITY OF GAUGE, DISCHARGE AND RAINFALL DATA

Sl. No.	Name of the Stream	Railway/Road Section	Railway/ Road Bridge Site No	Bridge Site Location		Catch-Ment Area (Km^2)	No. of Rain Gauge Stations	Data Availa-bility	No.of Years	Remarks
				Latitude Deg –min	Longitude Deg- min.					
1	2	3	4	5	6	7	8	9	10	11
		A: BRIDGES CONSIDERED FOR REGRESSION ANALYSIS								
1	Bari	Chalisgaon-Dhulia.CR	361/2 T	20 44	74 53	828	7	1970-74	5	
2	Kim	Kosamba-Umarpad.WR	21	21 28	73 04	542	5	1967-70,73	5	
3	Gan	Bhusaval-Badnera.CR	523 T	20 49	76 28	525	7	1958-62	5	
4	[illegible]	Dabhoi-Timba.WR	24[illegible] N	22 17	73 28	378	4	1966-74	9	
5	Maier	Manmad-Chalisgaon.CR	293/1 T	20 19	74 43	371	5	1975-79	5	
6	Biswa	Bhusaval-Badnera.CR	507 T	20 53	76 20	365	5	1958-59	2	
7	Waghur	Bhusaval-Badnera.CR	485/4 T	20 54	76 08	285	4	1968-73	6	
8	Waghoor	Pachora-Jamner.CR	411/1 T	20 41	75 41	262	4	1968-73,1987-95	15	
9	Bookree	Bhusaval-Itarsi.CR	479/3 T	21 14	76 03	240	4	1959,1970 -73,1983,84&86	8	
10	Hiwara	Pachora-Jamner.CR	374/1 T	20 41	75 22	226	3	1966-69	4	
11	Choral	Ajmer-Khandwa.WR	666 N	22 27	75 46	202	3	1968-74	7	
12	Ashwan	Chhuchhapure-Tankhala.WR	50 N	22 03	73 46	194	3	1967-68,70-73 & 87-95	15	
13	Meria	Vishwamitri-Chhota Udipur.WR	86 N	22 17	73 45	174	3	1967,68,70	3	
14	Ootavali	Bhusaval-Itarsi.CR	502/1 T	21 22	76 15	106	4	1961-66	6	
15	Madhuvati	Ankhleshwar-Rajpipala.WR	53 N	21 46	73 14	103	2	1970,75-78	5	
16	Ajanta	Bhusaval-Itarsi.CR	476/1 T	21 13	76 02	101	3	1975-79	5	
17	Oomanala	Bhusaval-Badnera.CR	497/1 T	20 53	76 14	53	2	1966-73	8	

T = Tapi Basin N = Narmada Basin

PHYSIOGRAPHIC PARAMETRS OF SELECTED CATCHMENTS

Sl.No.	Br. No.	Catchment Area (A) (Sq.Km.)	Length (L) (Km)	Length from Centroid of the Catchment to the Outlet (L_c) (Km)	Equivalent Slope (Seq) m/km
1	2	3	4	5	6
1	361/2	828	65.98	28.97	4.61
2	21	542	68.59	33.80	1.15
3	523	525	74.46	37.03	2.90
4	21(N)	378	39.94	27.37	1.71
5	293/1	371	26.56	16.10	5.38
6	507	365	74.32	37.03	2.82
7	485/4	285	34.45	14.45	2.48
8	411/1	262	47.23	26.56	6.03
9	479/3	240	41.03	21.60	6.45
10	374/1	226	40.20	19.25	7.59
11	666	202	26.18	16.00	9.92
12	50	194	28.75	18.51	3.49
13	86	174	31.22	14.80	2.56
14	502/1	106	18.66	7.24	8.59
15	53	103	32.98	15.45	5.02
16	476/1	101	22.54	9.66	6.18
17	497/1	53	20.11	9.66	2.33

ONE HOUR REPRESENTATIVE UNIT-HYDROGRAPH PARAMETERS OF SELECTED CATCHEMNTS FOR UPPER NARMADA AND TAPI BASIN

Sl.No	Br. Catchment No.	Catchment (km^2)	Q_p (Cumec)	Q_p (Cumec/Sq. km.)	t_r (Hour)	T_B (Hour)	W_{50} (Hour)	W_{75} (Hour)	W_{R50} (Hour)	W_{R75} (hour)
1	2	3	4	5	6	7	8	9	10	11
1	361/2	828	695.52	0.8400	1.0	15	2.20	1.20	0.70	0.50
2	21	542	220.00	0.4057	1.0	20	5.00	2.10	1.80	0.80
3	523	525	300.00	0.5700	1.0	18	2.90	1.10	1.10	0.50
4	21(N)	378	238.00	0.6300	1.0	17	3.30	1.50	1.10	0.60
5	293/1	371	280.00	0.7500	1.0	12	2.00	1.15	0.90	0.50
6	507	365	227.00	0.5225	1.0	19	3.50	1.20	1.20	0.65
7	485/4	285	209.00	0.7335	1.0	13	3.00	1.40	1.00	0.70
8	411/1	262	173.50	0.6622	1.0	16	3.00	1.45	0.95	0.60
9	479/3	240	223.50	0.9312	1.0	13	2.15	1.32	0.85	0.50
10	374/1	226	200.00	0.8800	1.0	14	2.00	1.00	0.70	0.50
11	666	202	170.00	0.8400	1.0	12	2.00	1.00	0.90	0.50
12	50	194	130.50	0.6727	1.0	14	2.60	1.22	0.90	0.50
13	86	174	131.00	0.7549	1.0	14	2.20	1.30	0.90	0.60
14	502/1	106	165.00	1.516	1.0	9	1.30	0.60	0.60	0.30
15	53	103	73.00	0.7069	1.0	14	2.20	1.10	1.00	0.30
16	476/1	101	105.00	1.0400	1.0	11	1.80	0.90	0.70	0.40
17	497/1	53	50.00	0.9500	1.0	12	2.00	1.00	0.80	0.45

tp column to iserted

RELATION BETWEEN PHYSIOGRAPHIC AND UNIT HYDROGRAPH PARAMETERS STUDIED

Sl.No.	X	Y	A	B	R
1	$LLc/\sqrt{S}$	t_p	0.5830	0.302	0.94
2	t_p	q_p	1.9140	-0.753	0.87
3	q_p	W_{50}	1.8490	-0.976	0.94
4	q_p	W_{75}	0.9550	-0.792	0.83
5	q_p	WR_{50}	0.7380	-0.781	0.92
6	q_p	WR_{75}	0.4380	-0.641	0.87
7	t_p	T_B	7.0420	0.559	0.94

NOTE : Equation is of the form of $Y = A * X^B$

COMPARISON OF FLOOD PEAK BASED ON RUGs and SUGs

Sl.No.	Br. No.	Q_{25} in cumec			Q_{50} in cumec			Q_{100} in cumec		
		RUG	SUG	% Diff.	RUG	SUG	% Diff.	RUG	SUG	% Diff.
1	361/2	3520.18	2624.31	25.45	3754.05	2791.06	25.65	4678.64	3494.69	25.31
2	21	2665.08	3062.68	-14.92	3081.14	3527.35	-14.48	3404.92	3905.83	-14.71
3	523	1549.16	1692.78	-9.27	1754.5	1918.75	-9.36	2127.43	2318.17	-8.97
4	21N	2532.48	2957.46	-16.78	2834.86	3308.92	-16.72	3224.00	3761.27	-16.66
5	293/1	1374.70	1749.68	-27.28	1640.82	2090.09	-27.38	2005.40	2555.35	-27.42
6	507	1349.38	1185.86	12.12	1482.68	1259.23	15.07	1752.53	1482.27	15.42
7	485/4	1150.48	1129.3	1.84	1379.35	1350.24	2.11	1607.57	1573.58	2.11
8	411/1	1020.80	926.50	9.24	1222.20	1108.73	9.28	1426.97	1292.59	9.42
9	479/3	1374.07	1064.50	22.53	1578.70	1221.74	22.61	1702.12	1355.98	20.34
10	374/1	1152.56	985.76	14.47	1221.76	1047.34	14.28	1395.56	1197.59	14.19
11	666	1143.26	1314.21	-14.95	1414.54	1626.35	-14.97	1656.88	1904.66	-14.95
12	50	1383.32	1477.73	-6.82	1589.07	1693.4	-6.57	1768.78	1882.66	-6.44
13	86	1447.41	1393.22	3.74	1705.25	1639.14	3.88	1911.28	1842.9	3.58
14	502/1	1033.14	937.77	9.23	1142.13	1036.72	9.23	1306.24	1184.68	9.31
15	53	1039.24	966.51	7.00	1160.63	1089.07	6.17	1276.39	1212.00	5.04
16	476/1	714.94	598.92	16.23	795.80	666.00	16.31	876.88	732.58	16.46
17	497/1	344.1.00	350.12	-1.75	405.33	412.37	-1.74	436.45	444.00	-1.73

Annexure 3.6

LOSS RATE RANGES - NUMBER OF FLOOD EVENTS

Sl. No.	Br. No.	CA (Km²)	LOSS RATE (mm/hour)										Total	Remarks
			0.1 to2	2 to4	4 to6	6 to 8	8 to10	10to 12	12 to 14	14 to 16	16 to 18	18 and above		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	361/2	828	1	1	4					1			7	
2	21	542	1	3	3	1	1						9	
3	523	525	2	5	2	1	1	2					13	
4	21(N)	378		5	8	5	3		1				23	
5	293/1	371	1	3	1	5			1		1	1	12	
6	507	365				2			2				5	
7	485/4	285	1	6	4	1	1	1	1				16	
8	411/1	262	4	9	5	1	1	2	1	1	1	1	26	
9	479/3	240	1	2	2	3	1		1	1			13	
10	374/1	226	2	2									4	
11	666	202	1		1	1	2				1	1	6	
12	50	194	3	5	6	6	2	1			2	2	28	
13	86	174	2		1		1	1					5	
14	502/1	106		2	2	3	2		1				11	
15	53	103	3	6	2	4			2				18	
16	476/1	101	1	3	3	1	3	7					19	
17	497/1	53	4	3	2		1	1	1				15	
			27	55	46	34	19	15	11	3	5	15	230	

AVERAGE BASE FLOW RANGES FOR STUDIED FLOOD EVENTS

(In cumec per Sq.Km.)

SL. NO.	BRIDGE NO.	AVERAGE BASE FLOW RANGES(CUMEC/SQ.KM.)					TOTAL
		0.0010 TO 0.0050	0.0051 TO 0.0090	0.01TO 0.09	0.1000 0.1900	0.2000 AND ABOVE	
1	2	3	4	5	6	7	8
1	361/2	-	1	4	-	-	5
2	21	-	-	7	2	-	9
3	523	5	4	4	-	-	13
4	21(N)	1	1	21	-	-	23
5	293/1	1	2	5	4	-	12
6	507	-	1	4	-	-	5
7	485/4	-	-	3	13	-	16
8	411/1	4	3	18	-	1	26
9	479/3	1	1	11	-	-	13
10	374/1	-	1	3	-	-	4
11	666	-	-	4	2	-	6
12	50	-	5	16	6	1	28
13	86	1	-	1	2	1	5
14	502/1	6	4	1	-	-	11
15	53	-	1	7	6	4	18
16	476/1	10	4	5	-	-	19
17	497/1	-	1	13	1	-	15
	Total	29	29	127	36	7	228

FLOOD VALUES BY SYNTHETIC UNIT GRAPH AND FLOOD FORMULAE

Sl.No.	Bridge No.	By S.U.G.			By Flood Formulae			Variation withrespect to S.U.G. (%)		
		Q_{25}	Q_{50}	Q_{100}	Q_{25}	Q_{50}	Q_{100}	Q_{25}	Q_{50}	Q_{100}
1	361/2	2624,3	2791,1	3494,7	2274,0	2570,9	2791,1	13,3	7,9	11,2
2	21	3062,7	3527,4	3905,8	2728,9	3318,5	3527,4	10,9	5,9	-4,4
3	523	1692,8	1918,8	2318,2	1346,5	1609,5	1918,8	20,5	16,1	15,4
4	21 N	2957,5	3308,9	3761,3	2358,1	2814,0	3308,9	20,3	15,0	9,0
5	293/1	1749,7	2090,1	2555,4	1562,3	1976,7	2090,1	10,7	5,4	10,4
6	507	1185,9	1259,2	1482,3	1008,4	1137,8	1259,2	15,0	9,6	8,5
7	485/4	1129,3	1350,2	1573,6	1086,6	1366,3	1350,2	3,8	-1,2	-3,5
8	411/1	926,5	1108,7	1292,6	872,2	1100,9	1108,7	5,9	0,7	6,3
9	479/3	1064,5	1221,7	1356,0	942,0	1146,3	1221,7	11,5	6,2	14,1
10	374/1	985,8	1047,3	1197,6	889,3	1004,1	1047,3	9,8	4,1	11,4
11	666	1314,2	1626,4	1904,7	1093,1	1435,7	1626,4	16,8	11,7	20,3
12	50	1477,7	1693,4	1882,7	1364,4	1670,9	1693,4	7,7	1,3	1,4
13	86	1393,2	1639,1	1842,9	1252,6	1566,5	1639,1	10,1	4,4	2,0
14	502/1	937,8	1036,7	1184,7	705,4	828,8	1036,7	24,8	20,1	27,0
15	53	966,5	1089,1	1212,0	843,6	1012,1	1089,1	12,7	7,1	10,2
16	476/1	598,9	666,0	732,6	571,4	675,3	666,0	4,6	-1,4	4,5
17	497/1	350,1	412,4	444,0	291,8	364,8	412,4	16,7	11,5	9,4

NUMBER OF FLOOD EVENTS STUDIED

Sl. No.	Br. No.	No. of Flood Events
1	361/2	5
2	21	9
3	523	13
4	21(N)	23
5	293/1	12
6	507	5
7	485/4	16
8	411/1	26
9	479/3	13
10	374/1	4
11	666	6
12	50	28
13	86	5
14	502/1	11
15	53	18
16	476/1	19
17	497/1	15
Total		228

Statistics of Heaviest Daily Rainfall (ORG) & Annual Normal Rainfall in Subzone 3 (b).

Sl.No.	State/District	Station	ORG Heaviest Daily Rainfall (Cm)	Date Of Occurrence	Annual Normal Rainfall (Cm)
1	2	3	4	5	6
GUJARAT					
1.	BROACH	BROACH (O)	46.0	5.8.1976	88.4
2.	SURAT	SURAT(O)	45.9	2.7.1941	110.1
3.	BARODA	BARODA	46.0	24.9.1945	92.0
4.	PANCHMAHALS	HALOL	48.5	24.9.1945	106.4
MADHYA PRADESH					
1.	EAST NIMAR	KHANDWA	27.9	13.6.1976	85.1
2.	WEST NIMAR	KHARGONE	40.0	20.6.1938	79.5
3.	JHABUA	JHABUA	29.2	26.7.1913	77.0
4.	DHAR	MANAWAR	38.3	15.9.1959	72.9
5.	INDORE	INDORE	29.3	27.7.1913	94.4
MAHARASHTRA					
1.	BULDHANA	BULDHANA	33.8	9.9.1930	87.7
2.	DHULIA	NAVAPUR	34.3	5.8.1968	113.4
3.	JALGAON	JAMNER	29.9	1.7.1941	80.1
4.	NASIK	IGATPURI	37.8	25.7.1952	35.7

Annexure 4.2

Heaviest 24-Hours & Shorter Durations Rainfall Recorded in Subzone 3 (b)

State/District	SRRG Station	Highest Observed Storm Rainfall (mm)	Duration (hrs)	Date & Time Of Occurrence	Clock Hour
1	2	3	4	5	6
MADHYA PRADESH					
1.EAST NIMAR	1. KHANDWA	304	24	12-13.06.1970	(13-13)
		243	12	12-13.06.1970	(15-03)
		201	6	13.06.1970	(00-06)
		147	3	13.06.1970	(00-03)
		73	1	9.07.1979	(03-04)
2.WEST NIMAR	1.MORTAKKA	305	24	5-6.09.1994	(20-20)
		194	12	5-6.09.1994	(20-08)
		152	6	25-26.09.1990	(23-05)
		132	3	26.09.1990	(02-05)
		72	1	26.09.1990	(03-04)
	2.THIKRI	295	24	13-14.06.1970	(16-16)
		233	12	14.06.1970	(02-14)
		174	6	14.06.1970	(04-10)
		107	3	5-6.09.1970	(22-01)
		84	1	07.08.1973	(14-15)
	3.BARWANI	213	24	16-17.08.1990	(11-11)
		168	12	16-17.08.1990	(15-03)
		110	6	16-17.08.1990	(22-04)
		89	3	17.08.1990	(01-04)
		64	1	11.07.1991	(05-06)
	4.MANDALESHWAR	176	24	22-23.08.1990	(14-14)
		130	12	30.07.1991	(04-16)
		115	6	23.08.1990	(05-11)
		102	3	30.07.1993	(11-14)
		80	1	17.07.1979	(12-13)
GUJARAT					
1.SURAT	1.SURAT	300	24	6-7.09.1970	(01-01)

		235	12	6.09.1970	(02-14)
		191	6	11.08.1975	(03-09)
		152	3	11.08.1975	(04-07)
		74	1	08.08.1983	(06-07)
2.BARODA	1.BARODA	256	24	4-5.06.1976	(20-20)
		149	12	4-5.06.1976	(20-08)
		119	6	7-8.10.1985	(19-01)
		107	3	01.07.1983	(18-21)
		68	1	20.06.1975	(18-19)
3.BROACH	2. RAJPIPLA	215	24	23-24.08.1990	(08-08)
		170	12	23.08.1990	(12-24)
		109	6	16-17.08.1990	(21-03)
		104	3	31.08.1988	(02-05)
		60	1	27.06.1983	(21-22)
MAHARASHTRA					
1.DHULIA	1.NANDURBAR	279	24	27.06.1977	(00-24)
		175	12	27.06.1977	(02-14)
		99	6	27.06.1977	(08-14)
		77	3	04.06.1973	(18-21)
		72	1	04.06.1973	(18-19)
	2.GIDHODE	229	24	05-06.06.1976	(16-16)
		143	12	06.06.1976	(02-14)
		91	6	29.08.1986	(15-21)
		90	3	29.08.1986	(16-19)
		65	1	14.06.1980	(00-01)
2. JALGAON	1JALGAON	181	24	16-17.08.1990	(05-05)
		122	12	16.08.1990	(09-21)
		91	6	28-29.09.1988	(19-01)
		91	3	28.09.1988	(19-22)
		52	1	12.09.1979	(04-05)
3.NASIK	1.MULHER	135	24	06-07 06.1980	(10-10)
		105	12	27-28.06.1977	(13-01)
		82	6	06.06.1980	(11-17)
		62	3	03.05.1989	(16-19)
		57	1	03.05.1989	(17-18)
	2.MALEGAON	125	24	23-24.09.1975	(13-13)
		91	12	23.06.1981	(01-13)
		79	6	24.09.1975	(02-08)
		71	3	19.09.1983	(18-21)
		42	1	29.09.1978	(17-18)

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

Inter-Mediate Hours	Design Storm Duration (Hours)																							Inter-Mediate Hours
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1	100	87	77	67	61	57	49	46	42	40	38	33	29	26	25	23	22	21	19	18	17	16	15	14	1
2	-	100	93	86	80	76	69	64	61	58	55	53	45	43	41	40	38	37	32	30	29	27	26	25	2
3	-	-	100	95	91	86	80	76	73	70	67	65	56	53	52	51	50	48	41	39	37	36	35	34	3
4	-	-	-	100	94	93	87	84	81	78	75	72	66	64	61	59	57	54	49	48	46	45	43	42	4
5	-	-	-	-	100	97	92	89	87	84	82	79	73	71	68	66	64	63	55	54	53	52	50	48	5
6	-	-	-	-	-	100	97	93	91	88	87	85	80	76	74	72	70	68	63	61	60	57	56	54	6
7	-	-	-	-	-	-	100	97	94	92	90	88	85	82	79	77	74	73	67	66	64	63	61	59	7
8	-	-	-	-	-	-	-	100	97	95	93	91	88	86	84	82	79	77	72	71	69	67	66	65	8
9	-	-	-	-	-	-	-	-	100	98	95	93	91	89	87	85	83	82	77	75	74	72	70	69	9
10	-	-	-	-	-	-	-	-	-	100	96	95	94	92	90	88	87	86	81	79	77	76	74	72	10
11	-	-	-	-	-	-	-	-	-	-	100	98	97	95	93	91	90	88	85	82	80	79	77	75	11
12	-	-	-	-	-	-	-	-	-	-	-	100	99	97	95	94	92	90	87	85	84	83	81	79	12
13	-	-	-	-	-	-	-	-	-	-	-	-	100	99	97	96	94	92	90	88	87	85	84	82	13
14	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	98	96	94	92	91	89	88	86	85	14
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	98	96	93	92	91	90	89	87	15
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	98	96	95	93	91	90	89	16
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	97	96	95	93	92	91	17
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	98	96	95	94	92	18
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	98	96	95	94	19
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	98	97	96	20
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		100	99	98	97	21
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		100	99	98	22
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	23
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	24

Annexure-4.4

AREAL REDUCTION FACTORS (%) FOR POINT TO AREAL RAINFALL

CATCH MENT AREA (KM²)	Design Storm Duration (Hours)																								CATCH MENT AREA (KM²)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
00	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	00
50	92.50	93.50	94.50	94.83	95.17	95.45	95.79	96.08	96.37	96.67	96.96	97.25	97.31	97.38	97.44	97.50	97.56	97.62	97.69	97.75	97.81	97.88	97.94	98.00	50
100	82.00	88.12	89.50	90.17	90.83	91.50	92.00	92.50	93.00	93.50	94.00	94.50	94.65	94.79	94.94	95.08	95.23	95.38	95.52	95.67	95.81	95.96	96.10	96.25	100
150	78.00	83.62	85.25	86.17	87.08	88.00	88.75	89.50	90.25	91.00	91.75	92.50	92.67	92.83	93.00	93.17	93.33	93.50	93.67	93.83	94.00	94.17	94.33	94.50	150
200	74.50	80.00	82.00	83.08	84.17	85.25	86.04	86.83	87.62	88.42	89.21	90.00	90.25	90.50	90.75	91.00	91.25	91.50	91.75	92.00	92.25	92.50	92.75	93.00	200
250	72.00	76.75	79.00	80.33	81.47	83.00	83.87	84.75	85.62	86.50	87.37	88.25	88.52	88.79	89.06	89.33	89.60	89.87	90.15	90.42	90.69	90.96	91.23	91.50	250
300		74.25	76.50	77.92	79.33	80.75	81.71	82.67	83.62	84.58	85.54	86.50	86.79	87.08	87.38	87.67	87.96	88.25	88.54	88.83	89.12	89.42	88.71	90.00	300
350			74.50	75.83	77.17	78.50	79.58	80.67	81.75	82.83	83.92	85.00	85.29	85.58	85.88	86.17	86.46	86.75	87.04	87.33	87.62	87.92	88.21	88.50	350
400			72.75	74.17	75.58	77.00	78.08	79.17	80.25	81.33	82.42	83.50	83.79	84.08	84.38	84.67	84.96	85.25	85.54	85.83	86.12	86.42	86.71	87.00	400
450			71.25	72.58	73.92	75.25	76.37	77.50	78.62	79.75	80.87	82.00	82.33	82.67	83.00	83.33	83.67	84.00	84.33	84.67	85.00	85.33	85.67	86.00	450
500			70.00	71.33	72.67	74.00	75.12	76.25	77.37	78.50	79.62	80.75	81.10	81.46	81.81	82.17	82.52	82.87	83.23	83.58	83.94	84.29	84.65	85.00	500
600												78.75	79.12	79.50	79.87	80.25	80.62	81.00	81.37	81.75	82.12	82.50	82.87	83.25	600
700												77.00	77.42	77.83	78.25	78.67	79.08	79.50	79.92	80.33	80.75	81.17	81.58	82.00	700
800												76.00	76.38	76.75	77.12	77.50	77.87	78.25	78.62	79.00	79.37	79.75	80.12	80.50	800
900												74.50	74.92	75.33	75.75	76.17	76.58	77.00	77.42	77.83	78.25	78.67	79.08	79.50	900
1000												74.00	74.38	74.75	75.12	75.50	75.87	76.25	76.62	77.00	77.37	77.75	78.12	78.50	1000
1100												73.00	73.42	73.83	74.25	74.67	75.08	75.50	75.92	76.33	76.75	77.17	77.58	78.00	1100
1200												72.50	72.88	73.25	73.62	74.00	74.37	74.75	75.12	75.50	75.87	76.25	76.62	77.00	1200
1300																								76.50	1300
1400																								76.25	1400
1500																								76.00	1500
2000																								75.00	2000

LIST OF SUG PARAMETERS OBTAINED FROM EQUATIONS

Sl.No.	Br.No.	C.A. (Km^2)	Q_P Cumec	q_p Cumec per sq.km	tp Hrs	W_{50} Hrs	W_{75} Hrs	WR_{50} Hrs	WR_{75} Hrs	T_B Hrs.	1 Cm Volume (Cumec)
1	2	3	4	5	6	7	8	9	10	11	12
1	361/2	828	510.60	0.62	4.50	2.19	1.10	0.85	0.49	16	2300.00
2	21	542	253.40	0.47	5.50	4.48	1.95	1.49	0.78	20	1505.60
3	523	525	323.80	0.62	4.50	3.20	1.49	1.14	0.63	16	1458.30
4	21(N)	378	281.70	0.75	3.50	2.90	1.38	1.06	0.59	14	1050.00
5	293/1	371	356.20	0.90	2.50	2.45	1.20	0.92	0.53	12	1030.60
6	507	365	193.50	0.53	4.50	3.48	1.60	1.23	0.66	18	1013.00
7	485/4	285	212.40	0.75	2.50	2.50	1.22	0.94	0.53	14	791.70
8	411/1	262	161.00	0.62	3.50	2.76	1.32	1.02	0.57	16	727.80
9	479/3	240	178.80	0.75	2.50	1.98	1.01	0.78	0.46	14	666.70
10	374/1	226	168.40	0.75	2.50	2.09	1.06	0.82	0.48	14	627.80
11	666	202	193.90	0.96	2.50	2.19	1.10	0.85	0.49	12	561.10
12	50	194	144.60	0.75	2.50	2.72	1.31	1.01	0.56	14	538.90
13	86	174	129.70	0.75	2.50	2.43	1.19	0.92	0.52	14	483.30
14	502/1	106	149.50	1.41	1.50	1.20	0.67	0.52	0.33	9	294.40
15	53	103	76.80	0.75	2.50	2.59	1.26	0.97	0.55	14	286.10
16	476/1	101	97.00	0.96	1.50	1.78	0.93	0.72	0.43	12	280.60
17	497/1	53	50.90	0.96	2.50	1.84	0.99	0.77	0.45	12	147.20

COMPUTATION OF EQUIVALENT SLOPE OF BRIDGE CATCHMENT NO. 485/4

Sl. No.	RD (Km)	RL (Km)	Length of Each segment (Li) (Km)	Height above the datum (Di) (m)	Di-1+Di (m)	Li (Di-1 + Di) (Km.m)
1	2	3	4	5	6	7
1	0	250.00	0	0	0	0
2	6.75	260.00	6.75	10.00	10.00	67.50
3	13.50	280.00	6.75	30.00	40.00	270.00
4	14.75	283.00	1.25	33.00	63.00	78.75
5	22.50	300.00	7.75	50.00	83.00	643.25
6	27.65	320.00	5.15	70.00	120.00	618.00
7	31.40	340.00	3.75	90.00	160.00	600.00
8	33.10	360.00	1.70	110.00	200.00	340.00
9	34.45	380.00	1.35	130.00	240.00	324.00
				SUM		2941.50

Datum (i.e. R.L. of river bed at point of study) = 250 m

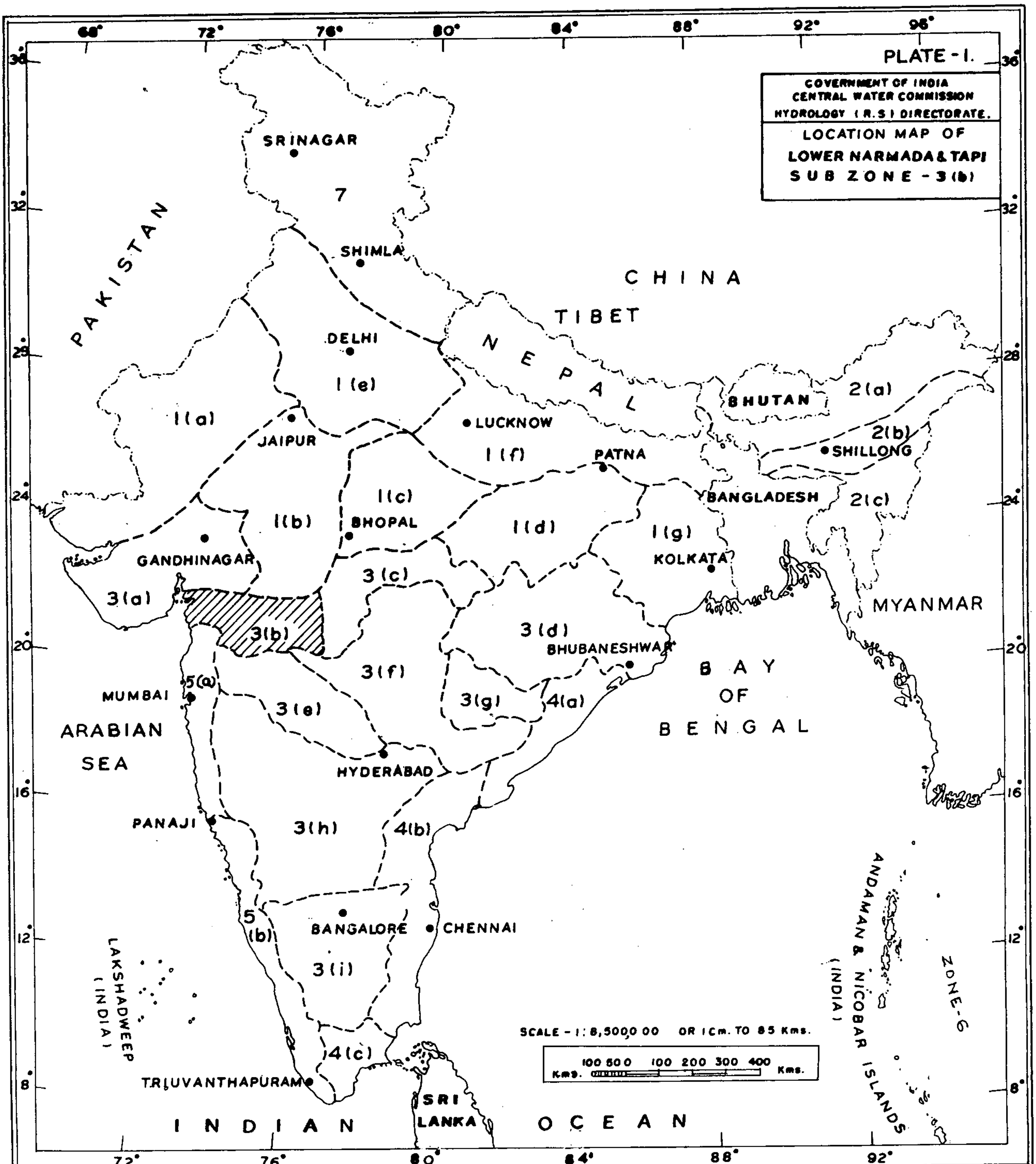
$$S_{eq} = \frac{\Sigma \, Li\,(Di_{-1}+Di)}{(L)^2}$$

$$= \frac{2941.50}{(34.45)^2}$$

$$= 2.48 \text{ m/km}$$

COMPUTATION OF DESIGN FLOOD HYDROGRAPH OF BRIDGE CATCHMENT NO. 485/4

Hours	SUH Ordinates (m^3/s)	Rainfall Excess in (cm)			Total DSRO (m^3/s)	Base Flow (m^3/s)	Total Flow (m^3/s)
		0.79	5.73	0.07			
		Direct Runoff (m^3/s)					
1	2	3	4	5	6	7	8
0	0.00	0.00			0.00	14.25	14.25
1	33.00	26.07	0.00		26.07	14.25	40.32
2	101.00	79.79	189.09	0.00	268.88	14.25	283.13
3	212.40	167.80	578.73	2.31	748.84	14.25	763.09
4	138.00	109.02	1217.05	7.07	1333.14	14.25	1347.39
5	86.00	67.94	790.94	14.87	873.55	14.25	887.80
6	62.00	48.98	492.78	9.66	551.42	14.25	565.67
7	47.00	37.13	355.26	6.02	398.41	14.25	412.67
8	37.00	29.23	269.31	4.34	302.88	14.25	317.13
9	28.00	22.12	212.01	3.29	237.42	14.25	252.67
10	20.00	15.80	160.44	2.59	178.83	14.25	193.08
11	14.00	11.06	114.60	1.96	127.62	14.25	141.87
12	9.00	7.11	80.22	1.40	88.73	14.25	102.98
13	4.00	3.16	51.57	0.98	55.71	14.25	69.96
14	0.00	0.00	22.92	0.63	23.55	14.25	37.80
15			0.00	0.28	0.28	14.25	14.53
16				0.00	0.00	14.25	14.25

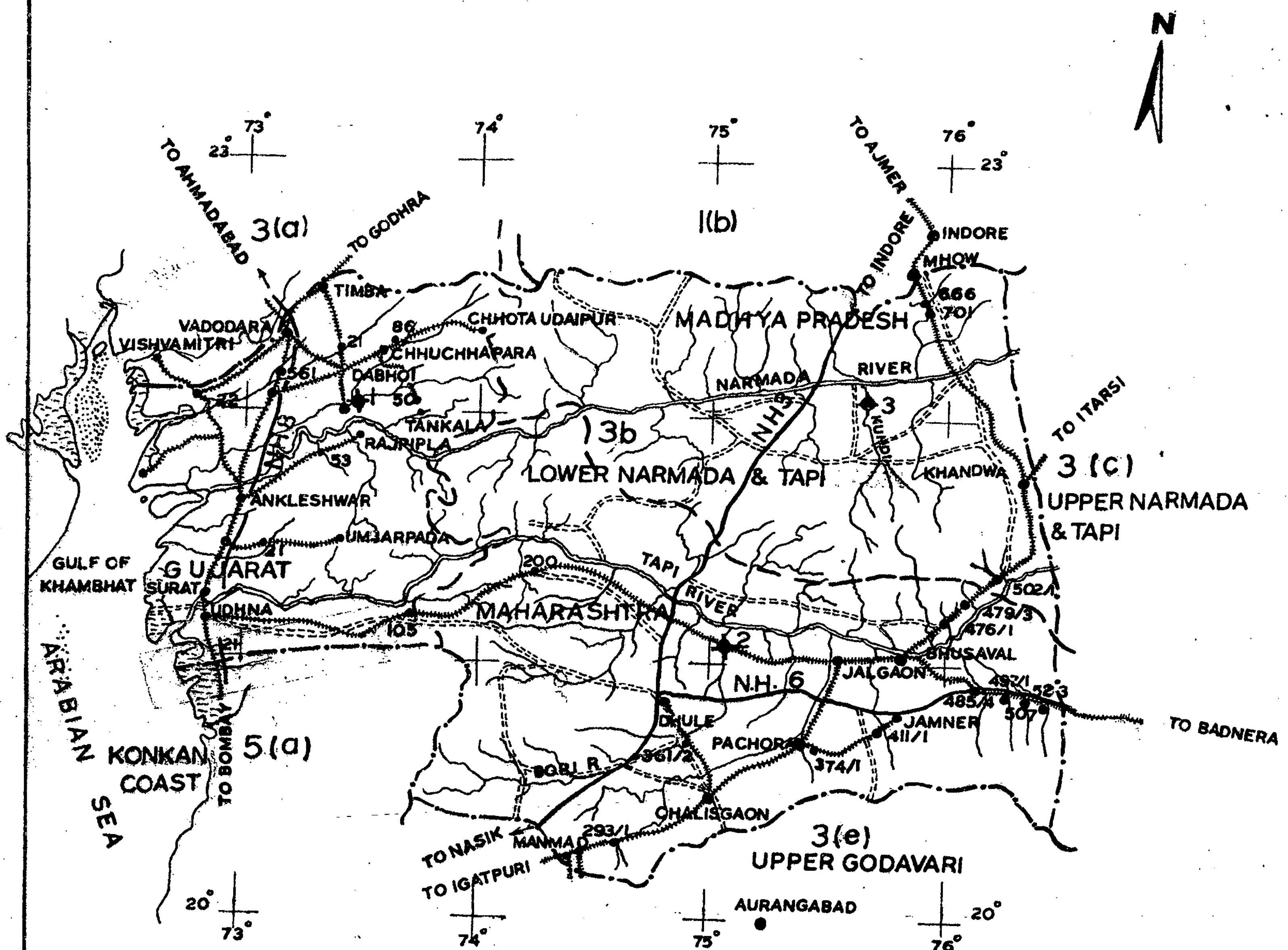


- BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA
- THE RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS RESTS WITH THE PUBLISHER.
- THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

P-I.

DRAWN BY - L.P. NAUTIYAL, L.K. PANT D/MAN GR. II

PLATE-2



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

LEGEND:

- SUB ZONE BOUNDARY
- RIVERS
- BRIDGE SITES (RLY)
- RAILWAYS
- ROADS
- C.W.C. SITES (M.O.T.)
- STATE BOUNDARY
- NATIONAL HIGHWAYS — N.H-3

SL. NO.	BRIDGE NO.	NAME OF RAILWAY	SECTION	C.A. SQ.KM.	DATA AVAILABLE
1.	523	CENTRAL	BHUSAVAL - BADNERA	525.00	1958-62
2.	507	"	BHUSAVAL - BADNERA	365.00	1958-59
3.	479/3	"	BHUSAVAL - ITARSI	240.00	1958, 70-73,83,84,86
4.	374/1	"	PACHORA - JAMNER	226.00	1966-69
5.	361/2	"	CHALISGAON - DHULE	828.00	1970-74
6.	497/1	"	BHUSAVAL - BADNERA	53.00	1966-73
7.	411/1	"	PACHORA - JAMNER	262.00	1968-73,87-95
8.	485/4	"	BHUSAVAL - BADNERA	285.00	1968-73
9.	476/1	"	BHUSAVAL - ITARSI	101.00	1975-79
10.	293/1	"	MANMAD - CHALISGAON	371.00	1975-79
11.	502/1	"	BHUSAVAL - ITARSI	106.00	1961-66
12.	666	WESTERN	AJMER - KHANDWA	202.00	1968-74
13.	21	"	DABHOI - TIMBA ROAD	378.00	1966-74
14.	21	"	KOSAMBA - UMARPADA	542.00	1967-70,73
15.	86	"	VISHVAMITRI - CHHOTAUDAIPUR	174.00	1967, 68,70
16.	50	"	CHHUCHHAPURA - TANKALA	194.00	1967,68,70-73,87-95
17.	53	"	ANKLESHWAR - RAJPIPLA	103.00	1970,75-78
18.	561	"	SURAT - VADODARA	893.00	1975-79
19.	701	"	AJMER - KHANDWA	28.00	1964-69
20.	105	"	UDHNA - JALGAON	59.60	1962-66
21.	200	"	UDHNA - JALGAON	19.00	1962,64-67,69

KMS 20 0 20 60 100 140 180

C.W.C. SITES ON BEHALF OF M.O.T.

SL. NO.	BR. NO.	RIVER	SITE	AGENCY
1	–	ORSANG	CHARWADA	C.W.C.
2	–	BORI	MALKHAD	-DO-
3	–	KUNDI	KOGAON	-DO-

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (RS) DIRECTORATE

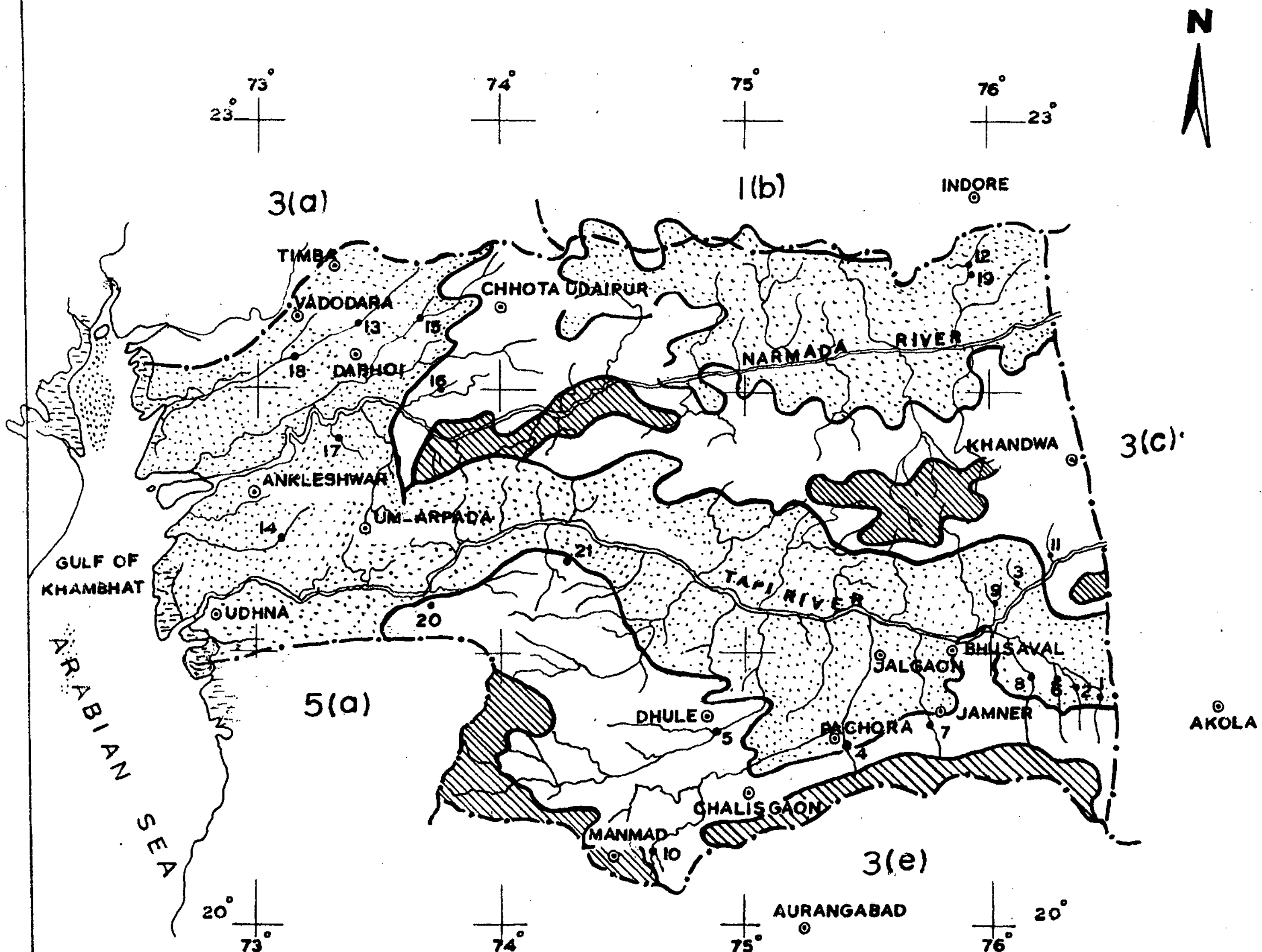
FLOOD ESTIMATION REPORT LOWER NARMADA & TAPI SUB-ZONE 3(b)

RIVER SYSTEM, HYDROLOGICAL OBSERVATION SITES, RAILWAYS & HIGHWAYS.

DRAWN BY – L. K. PANT

CHECKED BY – M.R. CHAKRABORTY

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



NOTE: 1. BRIDGE SITES HAVE BEEN INDICATED BY SERIAL NOS AS GIVEN IN TABLE IN PLATE-2.

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

REFERENCES:

ALTITUDE IN METRES
- 0 - 300
- 300 - 600
- 600 - 900

BRIDGE SITES

RIVERS

TOWN/CITY

KMS 20 0 20 60 100 140 180

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

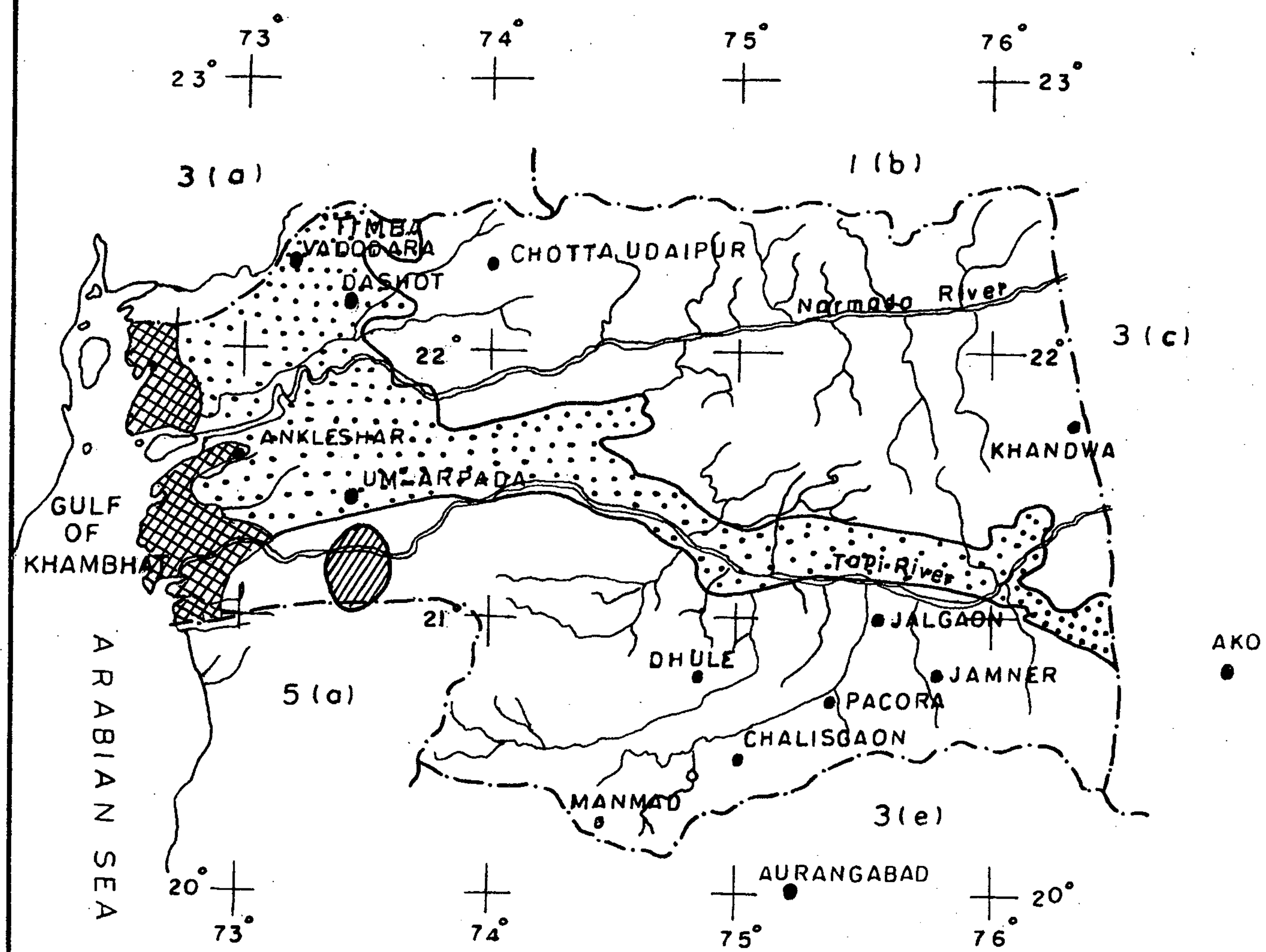
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (RS) DIRECTORATE

FLOOD ESTIMATION REPORT LOWER NARMADA & TAPI SUB-ZONE 3(b) PHYSIOGRAPHY

DRAWN BY L. P. NAUTIYAL	CHECKED BY M. R. CHAKRBORTY

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

PLATE – 4 .



NOTE 1. BRIDGE SITES HAVE BEEN INDICATED BY SERIAL NOS AS GIVEN IN TABLE IN PLATE - 2.
2. THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (YEAR_1972) PLATE - 8.

REFERENCES

DEEP BLACK SOIL . . . .
MEDIUM BLACK COTTON SOIL . . . .
COASTAL ALLUVIAL SOIL . . . . .
LATERITE SOIL . . . .
RIVERS . . . .
TOWN / CITY . . . . . .

NOT TO SCALE.

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

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

FLOOD ESTIMATION REPORT
LOWER NARMADA & TAPI
SUB ZONE- 3 (b)

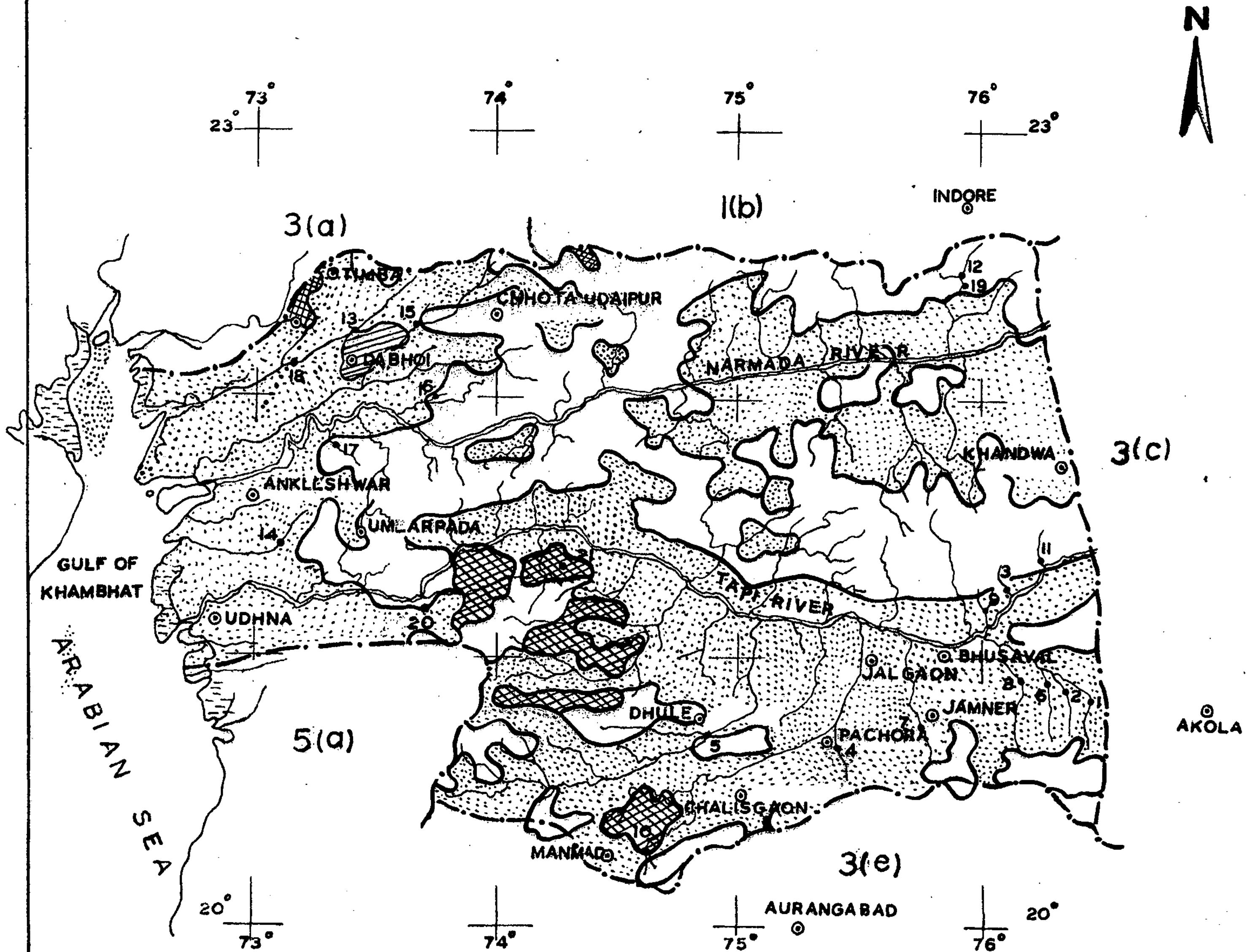
SOIL CLASSIFICATION

DRAWN BY _ L. K. PANT

CHECKED BY _ P. K. GUIN.

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

PLATE- 5.



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

NOTE:
1. BRIDGE SITES HAVE BEEN INDICATED BY SERIAL NOS. AS GIVEN IN TABLE IN PLATE- 2.
2. THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (YEAR-1972) PLATE NO. 9.

REFERENCES:

ARABLE LAND
FOREST
GRASS LAND AND SCRUB
WASTE LAND
BRIDGE SITES
RIVERS
TOWN/ CITY

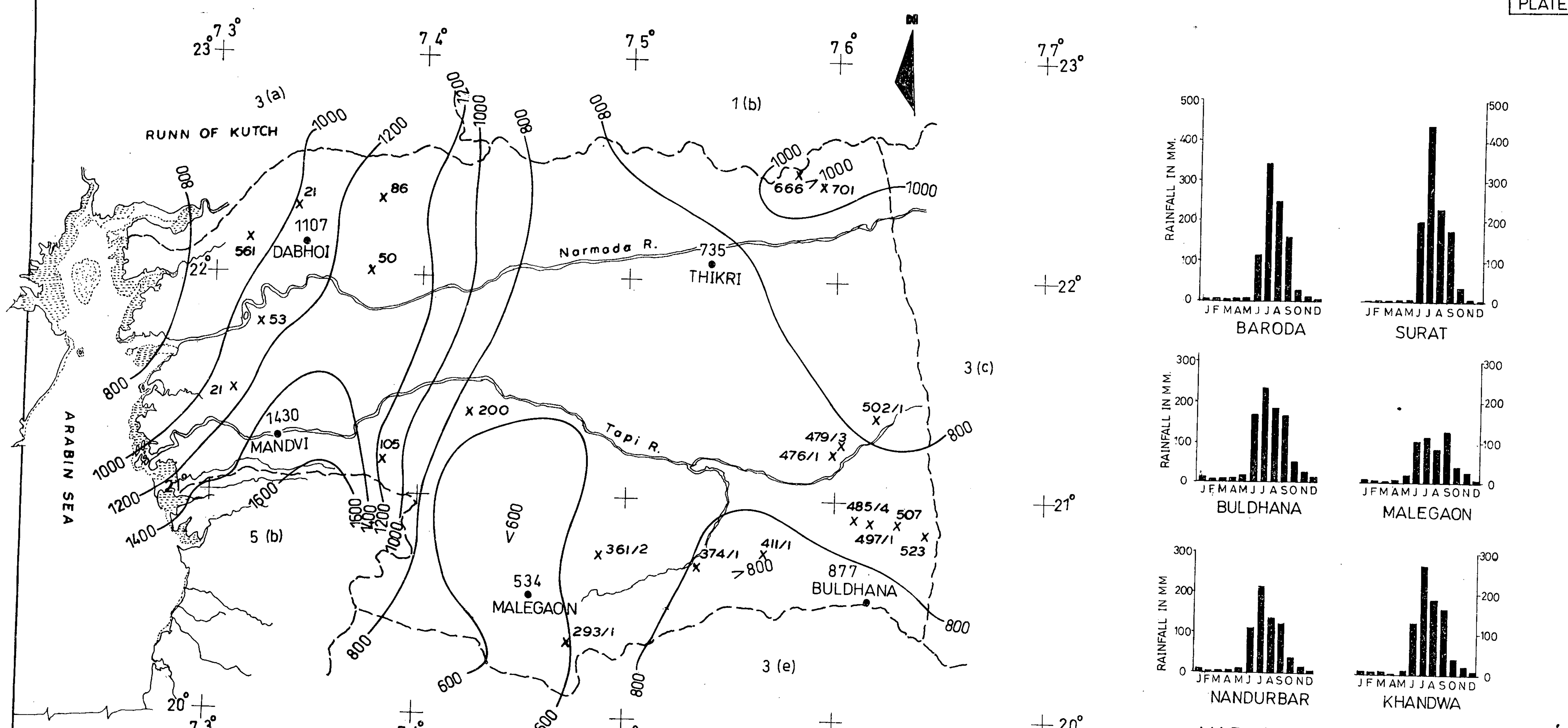
KMS 20 0 20 60 100 140 180

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY(RS) DIRECTORATE

FLOOD ESTIMATION REPORT
LOWER NARMADA & TAPI
SUB-ZONE 3(b)
LAND USE

DRAWN BY — L. K. PANT	CHECKED BY — M. R. CHAKRABORTY

PLATE-6



MAP SUPPLIED BY I.M.D

REFERENCES

1. NATIONAL BOUNDARY
2. SUBZONE BOUNDARY
3. TOWNS
4. ISOHYETES IN MM.
5. RIVERS
6. BRIDGE SITES

NOTES

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

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

SCALE

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

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

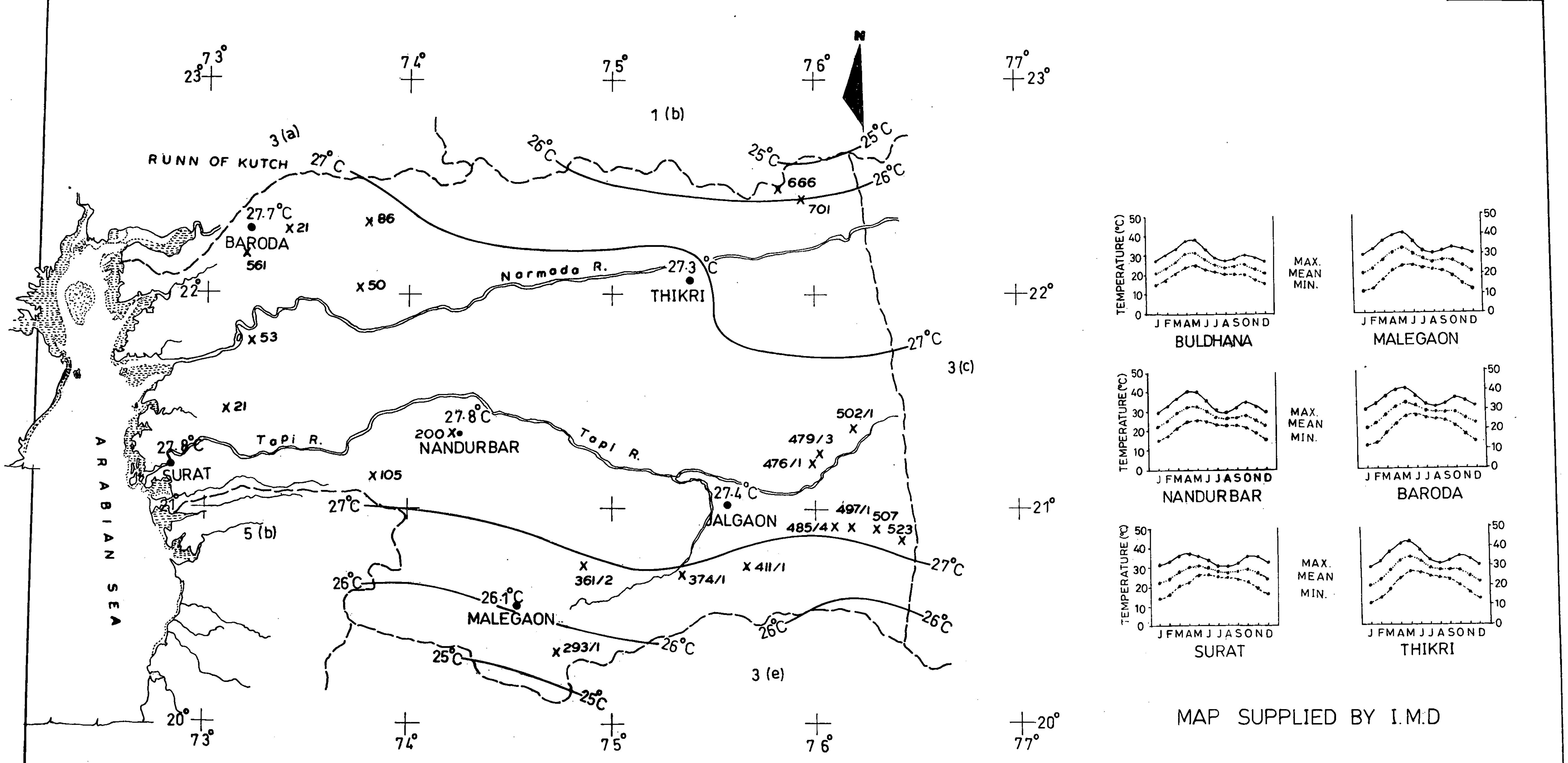
LOWER NARMADA & TAPI BASIN

SUB ZONE - 3 (b)

ANNUAL NORMAL RAINFALL (m m.)

DRAWN BY —	CHECKED BY —
L. P. NAUTIYAL	M. R. CHAKRABORTY

PLATE-7



SCALE

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

REFERENCES

1. NATIONAL BOUNDARY
2. SUBZONE BOUNDARY
3. TOWNS
4. ISOTHERMS (°C)
5. RIVERS
6. BRIDGE SITES

x 51

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 EXTENDED INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.

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

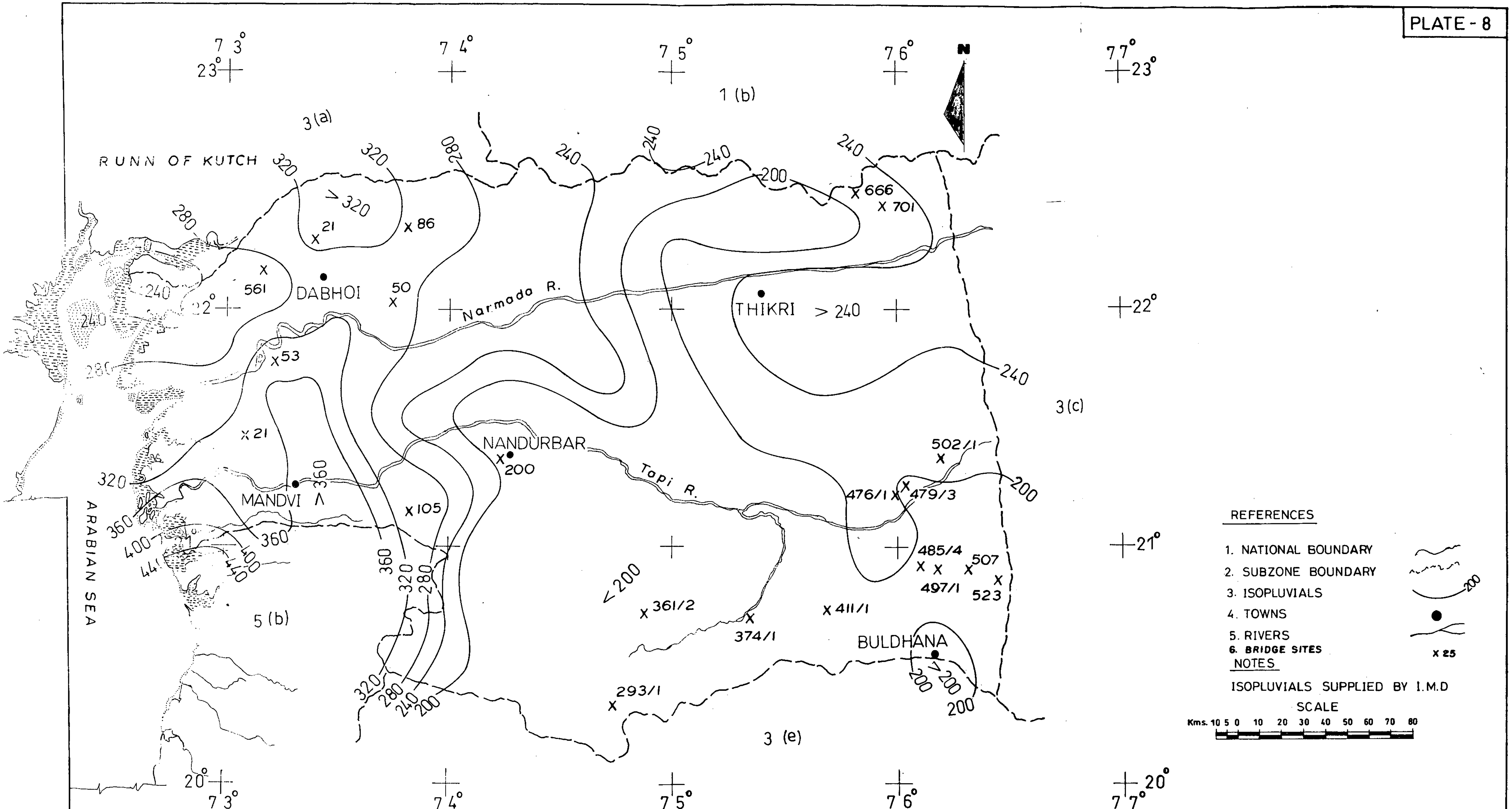
LOWER NARMADA & TAPI BASIN

SUB ZONE - 3 (b)

MEAN DAILY TEMPERATURE (0°c) ANNUAL

DRAWN BY —	CHECKED BY —
L. K. PANT	M. R. CHAKRABORTY

PLATE - 8



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

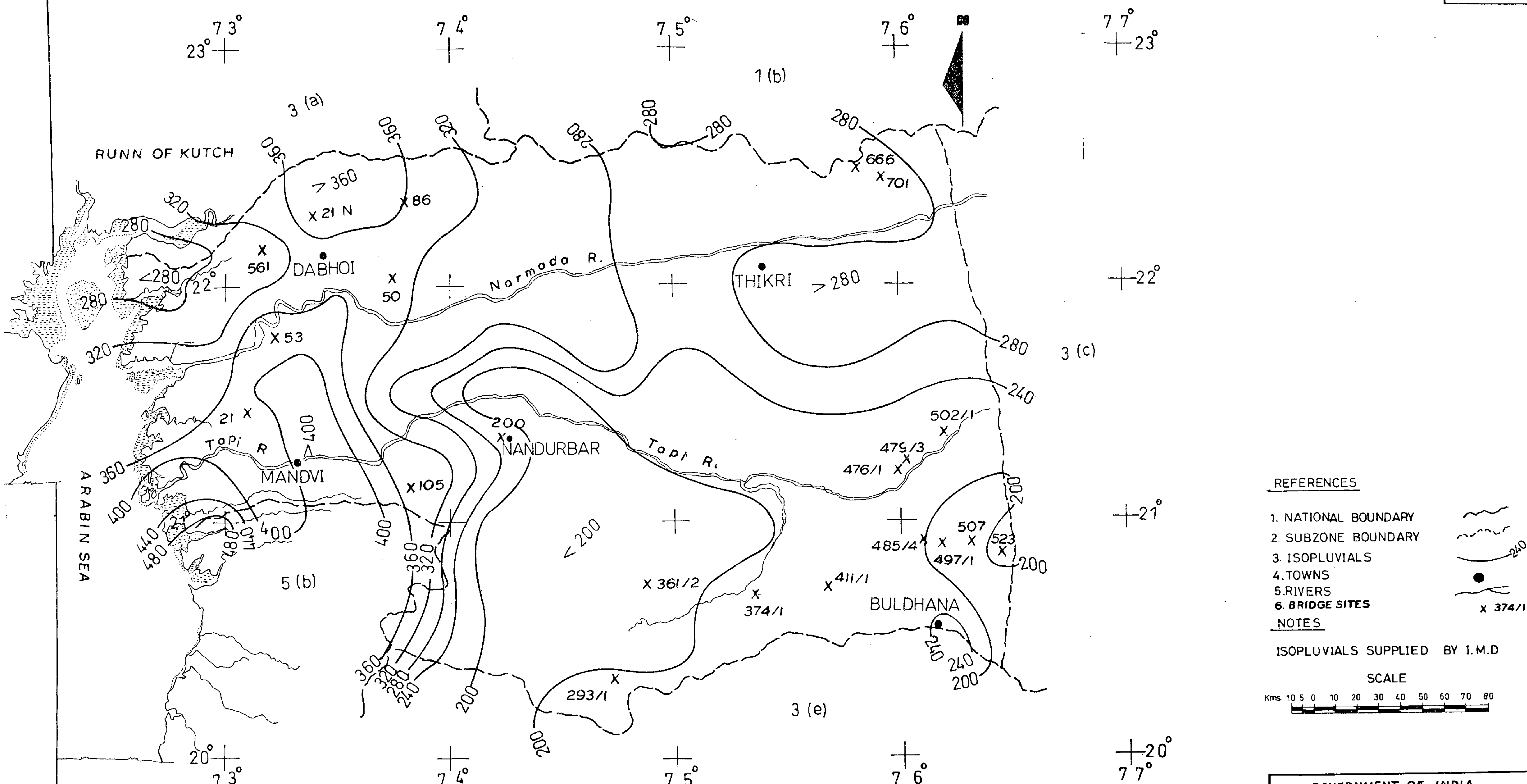
LOWER NARMADA & TAPI BASIN

SUB ZONE - 3 (b)

25-YEAR 24-HOUR RAINFALL (mm.)

DRAWN BY— L.K. PANT	CHECKED BY— M.R. CHAKRABORTY

PLATE-9



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.

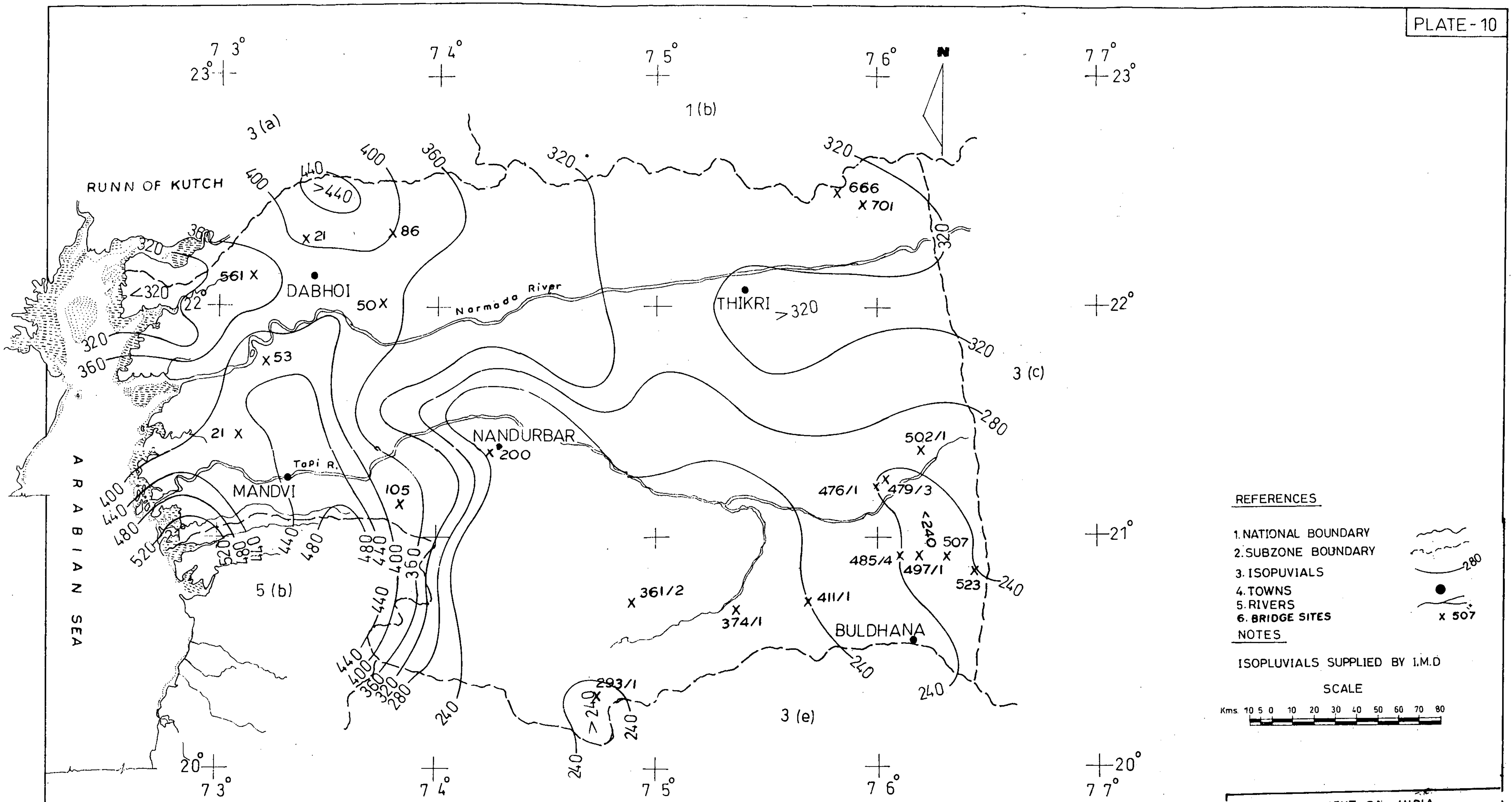
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (R. S.) DIRECTORATE

LOWER NARMADA & TAPI BASIN

SUB ZONE - 3 (b)

50-YEAR 24-HOUR RAINFALL (mm.)

DRAWN BY —	CHECKED BY —
L. P. NAUTIYAL	M. R. CHAKRABORTY



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 (R.S.) DIRECTORATE

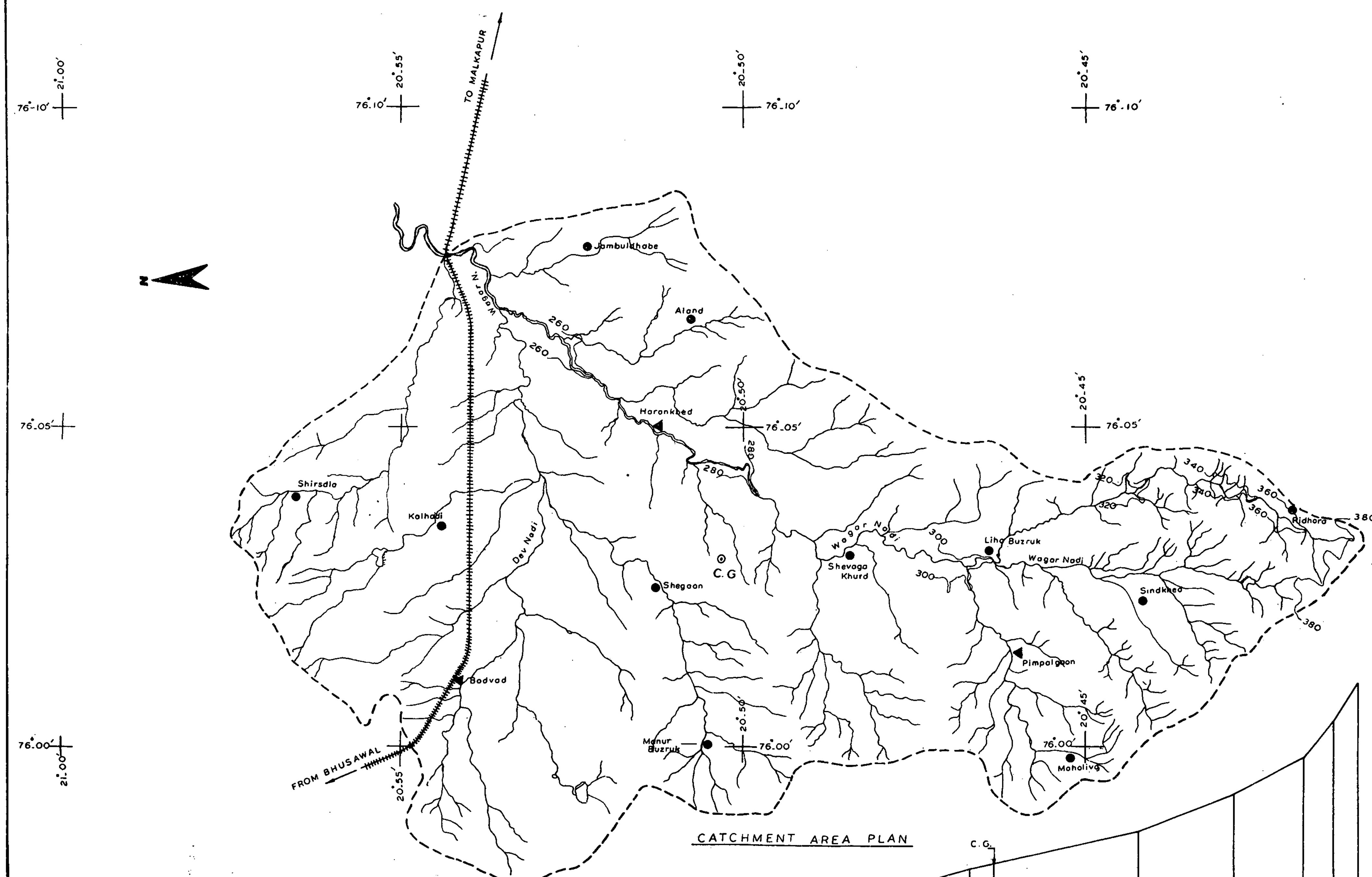
LOWER NARMADA & TAPI BASIN

SUB ZONE-3 (b)

100 YEAR 24-HOUR RAINFALL (mm.)

DRAWN BY—	CHECKED BY—
L. K. PANT	M. R. CHAKRABORTY

FIG.- A.1



CATCHMENT AREA PLAN

NOTE -

1. ALL LEVELS CORRESPOND TO G.T.S. DATUM

REFERENCES -

1. CATCHMENT BOUNDARY
2. RAILWAY LINE
3. RIVER AND ITS TRIBUTARIES
4. RAIN GAUGE STATIONS
5. CONTOURS (360)
6. TOPO SHEET NO 46P/13,14.55D/1,2
7. CENTER GRAVITY

DETAILS OF CATCHMENT AREA

1. AREA OF CATCHMENT .... 285 Km.²
2. SHAPE OF CATCHMENT .... FAN
3. L .... 34.45 Km.
4. Lc .... 14.75 Km.
5. Seq. .... 2.48 Mt./Km.
6. TOWNS

SL. NO.	NAME OF R.G STATIONS	LOCATION LONG.	LOCATION LATI.	STATION WEIGHTAGE
1.	BODVAD.	76°-01′-10″	20°-54′-10″	0.277
2.	HARANKHED	76°-04′-55″	20°-51′-00″	0.380
3.	PIMPALGAON	76°-01′-30″	20°-46′-00″	0.343

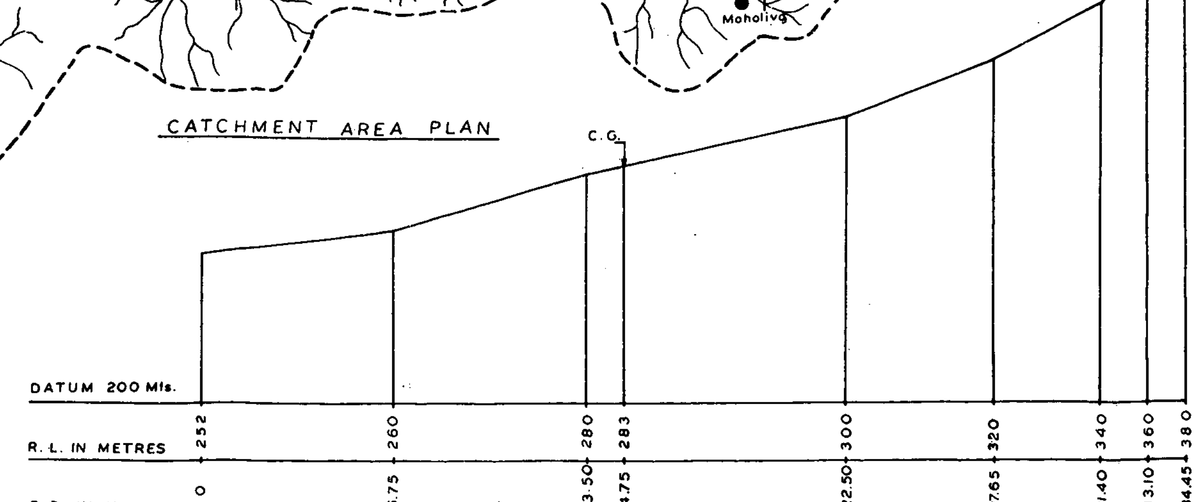
SCALE

1 : 50,000

2 Cm = 1 Km.

Mtrs. 1000 500 0 1 2 3 4 5 Kms.

(CONTOURS INTERVELS 20 Mtrs.)



L-SECTION OF RIVER WAGAR NADI

SCALE - VERT. 1 Cm.= 10 Km. / HORI. 1 Cm.= 1 Km.

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CENTRAL WATER COMMISSION
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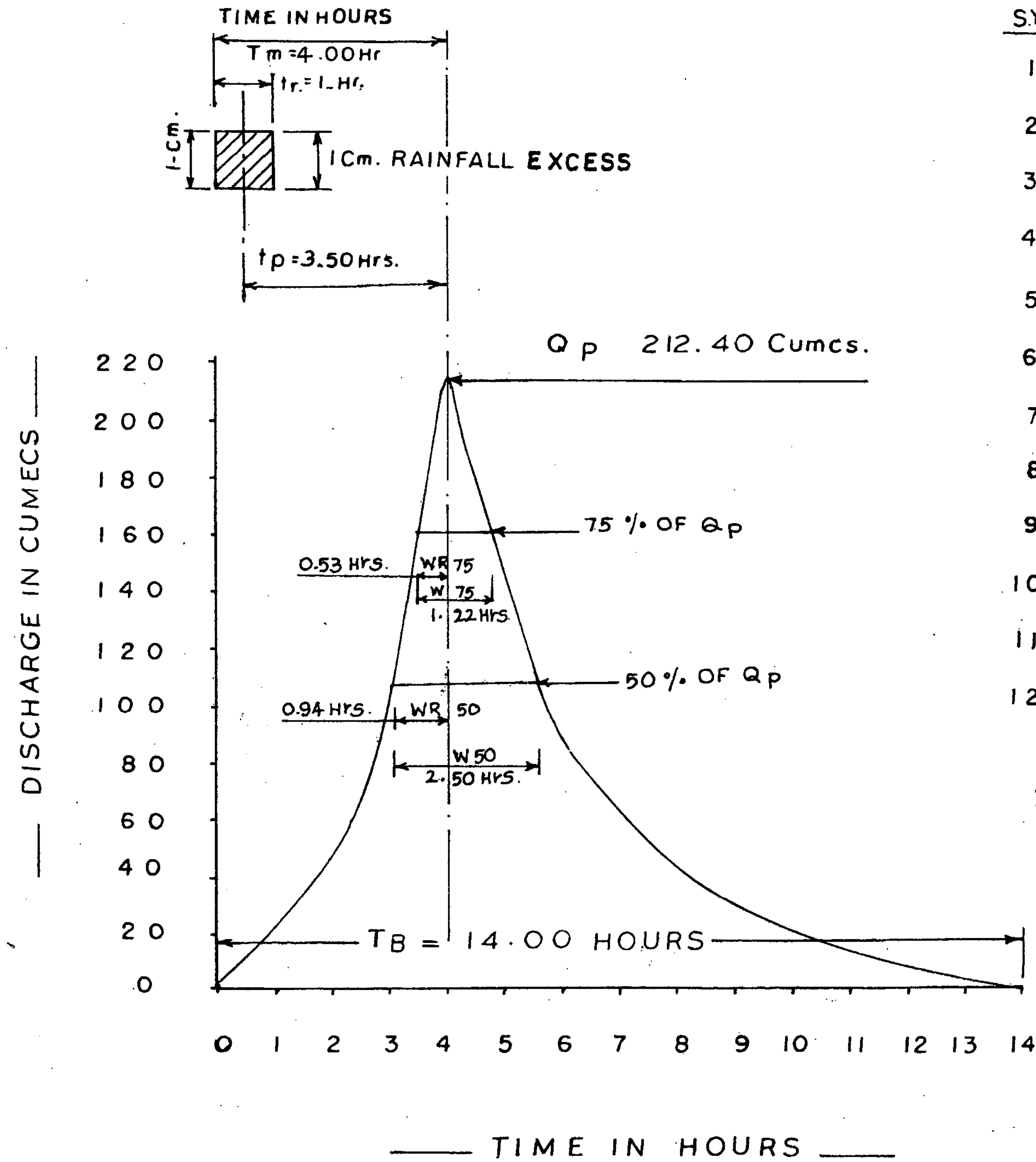
CATCHMENT AREA PLAN OF BRIDGE NO. 485/A AT 485/15-486/1 SECTION BSL-BD CENTRAL RAILWAY.
SUB ZONE-3(b).

DRAWN BY -	CHECKED BY -
L. P. NAUTIYAL L. K. PANT	P. K. GUIN

FIG._A.2.



SYNTHETIC U.G PARAMETRES

1.	C. AREA		285.00 Km^2
2	t_r	=	1.00 Hrs.
3	Q_p	=	212.40 Cums.
4	t_p	=	3.50 Hrs.
5	q_p	=	0.75 Cums/Km^2
6	T_m	=	4.00 Hrs.
7	T_B	=	14.00 Hrs.
8	W_{50}	=	2.50 Hrs.
9	W_{75}	=	1.22 Hrs.
10	W_{R50}	=	0.94 Hrs.
11	W_{R75}	=	0.53 Hrs.
12	d	=	1.00 Cm.

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

$$\Sigma Q_i = \frac{285.00 \times 1.00}{1.00 \times 0.36}$$

= 791.50 CUMECS.

1_Hrs. S.U.G ORDINATES

0	0
1	22
2	48
3	106
4	212
5	140
6	85
7	61
8	42
9	30
10	20
11	14
12	8
13	3.5
14	0
	791.50 Cums.

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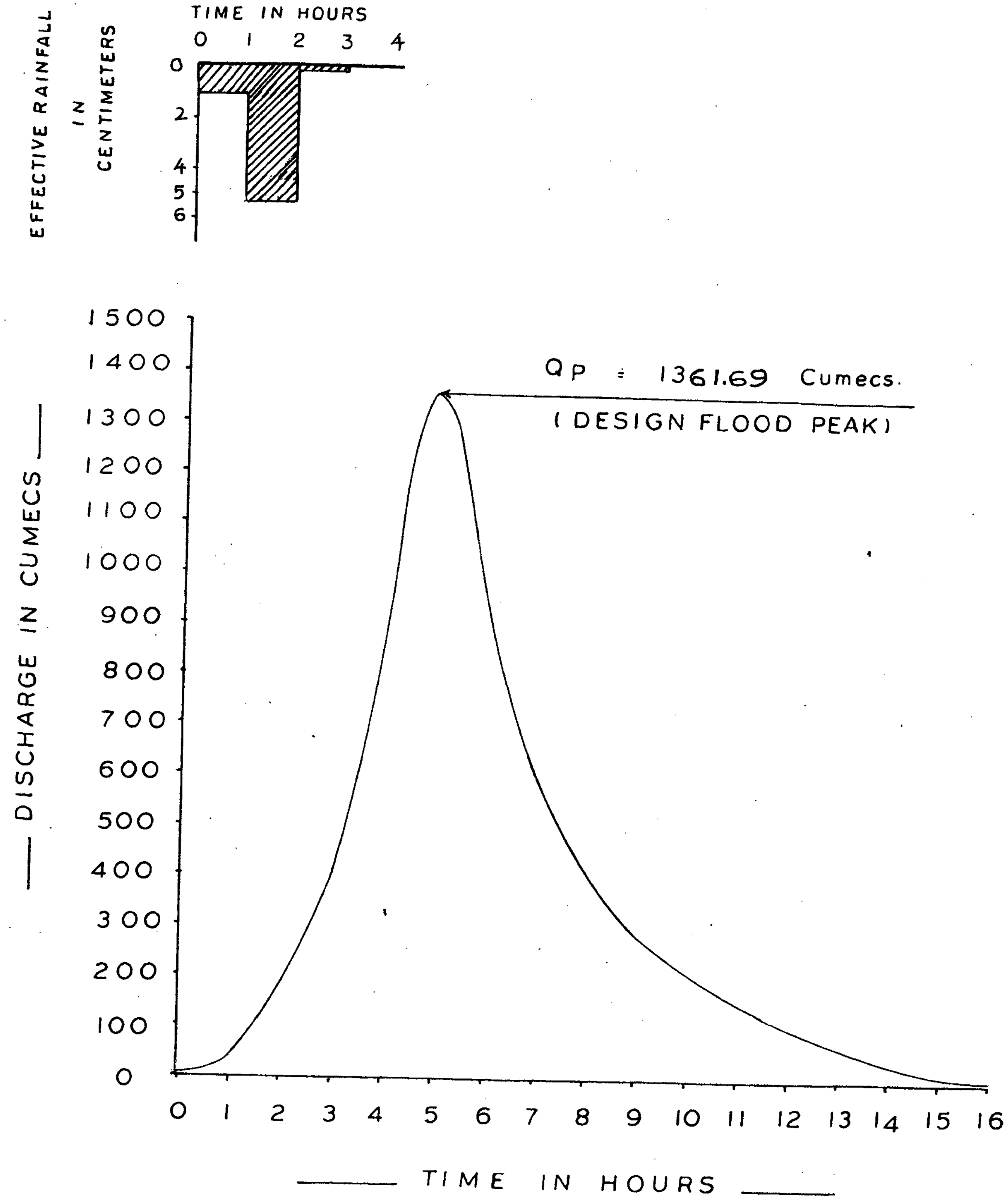
LOWER NARMADA & TAPI
SUB ZONE – 3 (b).
SYNTHETIC UNIT HYDROGRAPH.
BRIDGE NO._ 485/4

DRAWN BY — L. P. NAUTIYAL
CHECKED BY — M.R.CHAKRABORTY

FIG._A.3.



NOTE –

1. REFER ANNEXURE – 5.3 FOR COMPUTATION OF DESIGN FLOOD HYDROGRAPH.

2. CATCHMENT AREA = 285 Km^2.

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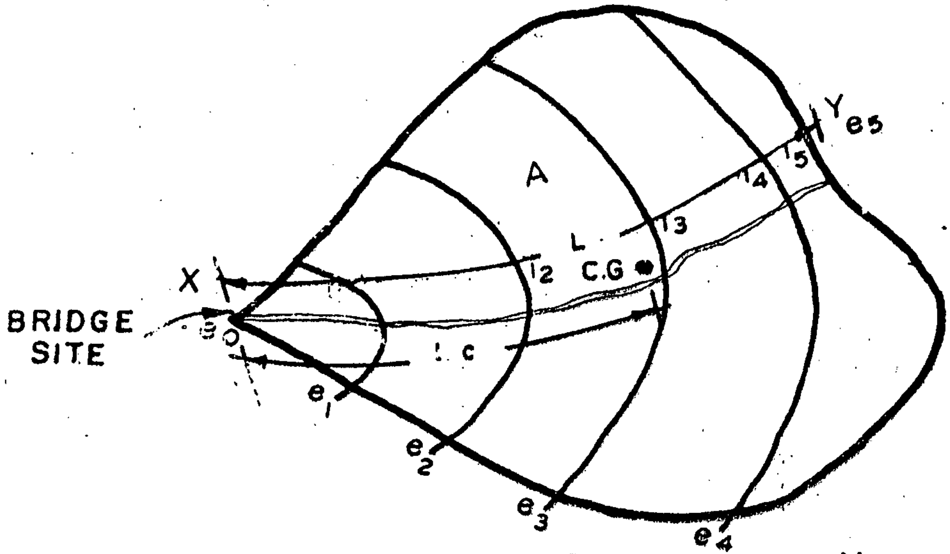
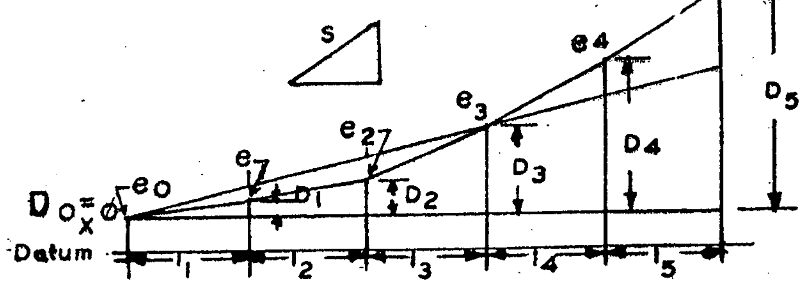
LOWER NARMADA & TAPI SUB ZONE – 3 (b) DESIGN FLOOD HYDROGRAPH BRIDGE NO. 485/4	
DRAWN BY – L. K. PANT	CHECKED BY – G. PRASAD

FIG. 1



Catchment Plan



L - Section

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

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

L = Length of longest stream course (km)

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

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

$D_i = D_0, D_1, D_2, \ldots D_n$
$= (e_0 - e_0), (e_1 - e_0), (e_2 - e_0) \ldots (e_n - e_0)$ (m)

A = Catchment area (km²)

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

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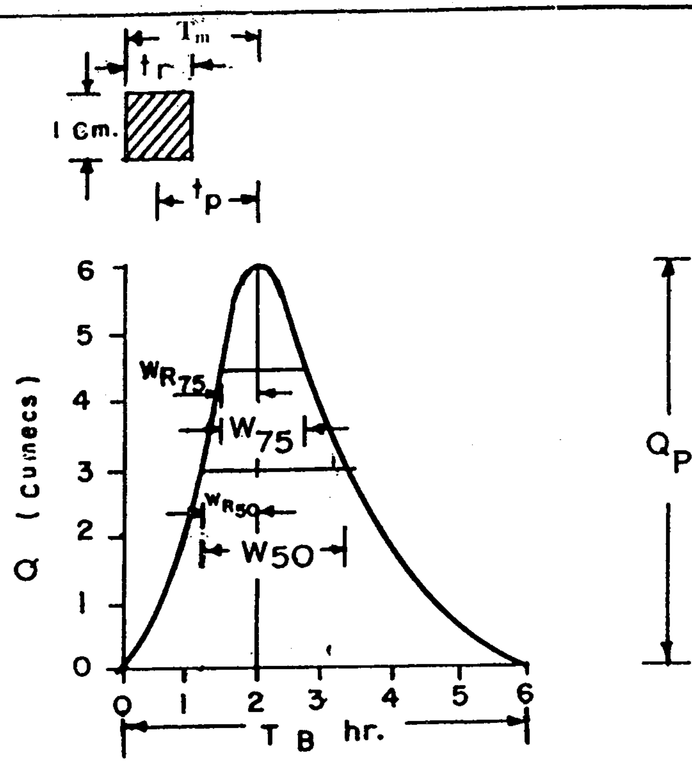
PHYSIOGRAPHIC PARAMETERS	
DRAWN	CHECKED

FIG.-2.



U. G = Unit Graph

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

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

Q_P = Peak Discharge of Unit Hydrograph (Cumecs.)

t_p = Time from the Centre of Effective Rainfall duration to the U.G Peak (hr.)

W50 = Width of the U.G measured at the 50% of peak discharge ordinate (hr.)

W75 = Width of the U.G measured at 75% of peak discharge ordinate (hr.)

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

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

T_B = Base width of Unit Hydrograph (hr.)

A = Catchment Area (Sq.km.)

q_p = Q_P / A = Cumec per sq.km.

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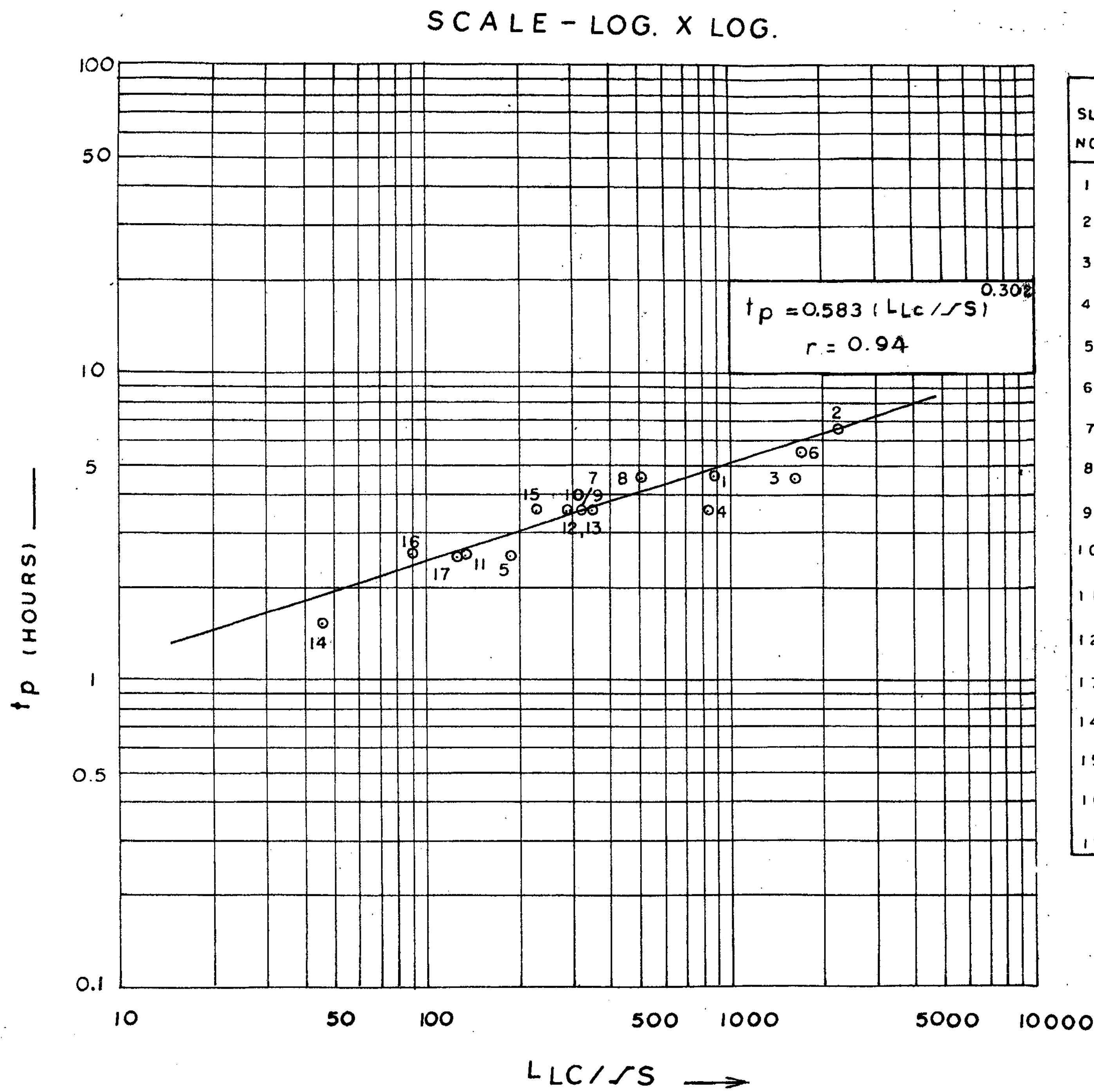
UNIT GRAPH PARAMETERS	
DRAWN BY– NAUTIYAL	CHECKED BY– Chakraborty

FIG.– 3.



SL NO.	BRIDGE NO.	$L_{LC}/\sqrt{S}$	t_p (HOURS)	
			ACTUAL	ESTI.
1	361/2	890.24	4.5	4.53
2	21	2161.86	6.5	5.93
3	523	1619.11	4.5	5.43
4	21	835.65	3.5	4.45
5	293/1	184.36	2.5	2.82
6	507	1638.83	5.5	5.45
7	485/4	322.57	3.5	3.34
8	411/1	510.84	4.5	3.83
9	479/3	348.96	3.5	3.42
10	374/1	280.89	3.5	3.19
11	666	132.99	2.5	2.55
12	50	288.61	3.5	3.23
13	86	288.79	3.5	3.23
14	502/1	46.09	1.5	1.85
15	53	227.42	3.5	3.00
16	476/1	87.59	2.5	2.25
17	497/1	127.27	2.5	2.51

GOVERNMENT OF INDIA
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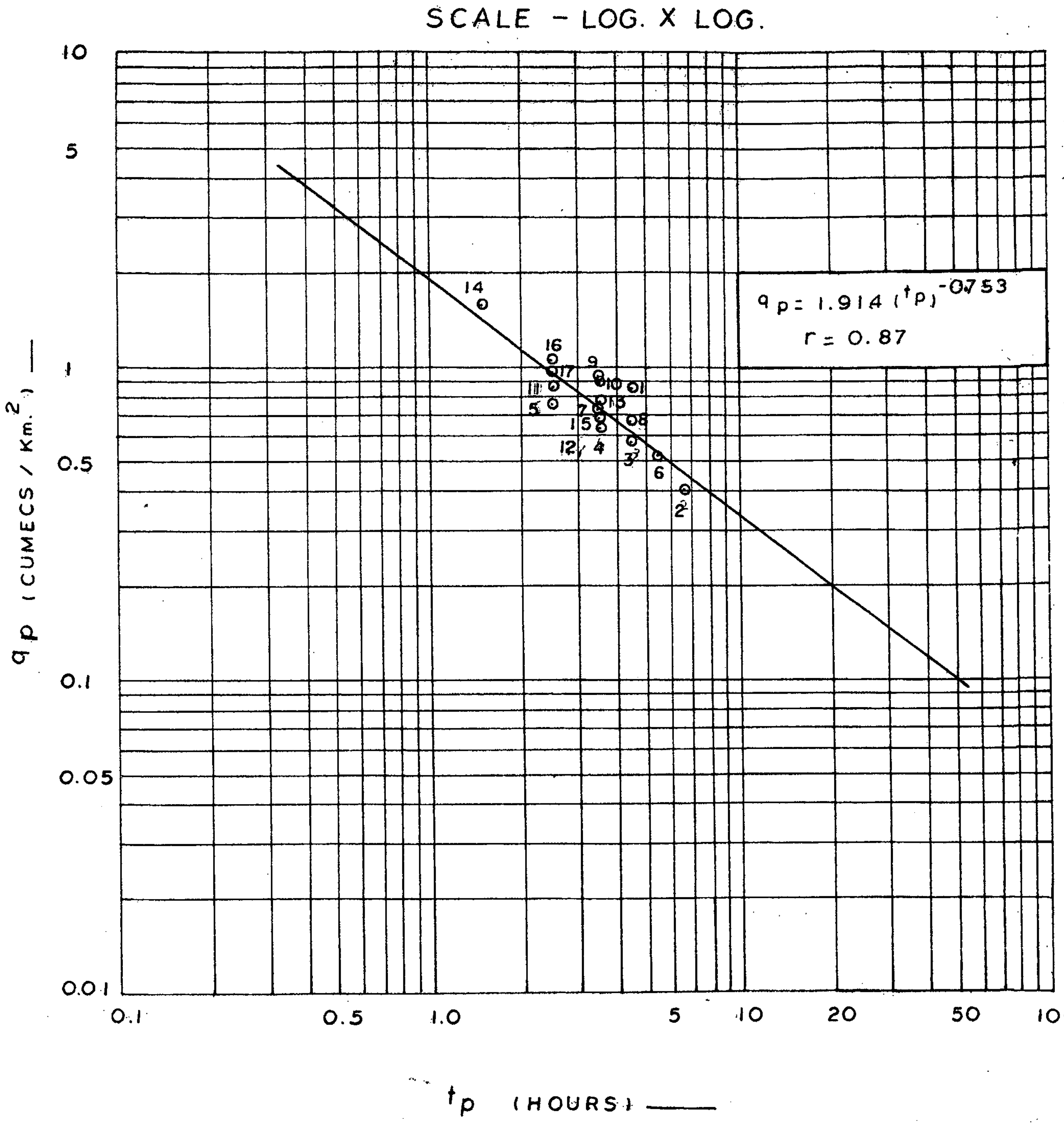
HYDROLOGY (REGIONAL STUDIES) DTE.

LOWER NARMADA & TAPI
SUB ZONE – 3 (b)
RELATION BETWEEN
$L_{Lc}/\sqrt{S}$ AND t_p

DRAWN BY —	CHECKED BY —
L.P. NAUTIYAL	M.R.CHAKRABORTY.

FIG. - 4



SL NO	BRIDGE NO.	t_p (HOURS)	q_p (Cum./Km.^{2}) ACTUAL	ESTI.
1	361/2	4.5	0.840	0.617
2	21	6.5	0.4057	0.468
3	523	4.5	0.5709	0.617
4	21	3.5	0.6300	0.745
5	293/1	2.5	0.7500	0.096
6	507	5.5	0.5225	0.530
7	485/4	3.5	0.7335	0.745
8	411/1	4.5	0.6622	0.617
9	479/1	3.5	0.9312	0.745
10	374/1	3.5	0.8800	0.745
11	666	2.5	0.8400	0.960
12	50	3.5	0.6727	0.745
13	86	3.5	0.7549	0.745
14	502/1	1.5	0.5615	1.410
15	53	3.5	0.7069	0.745
16	476/1	2.5	1.0400	0.960
17	497/1	2.5	0.9500	0.960

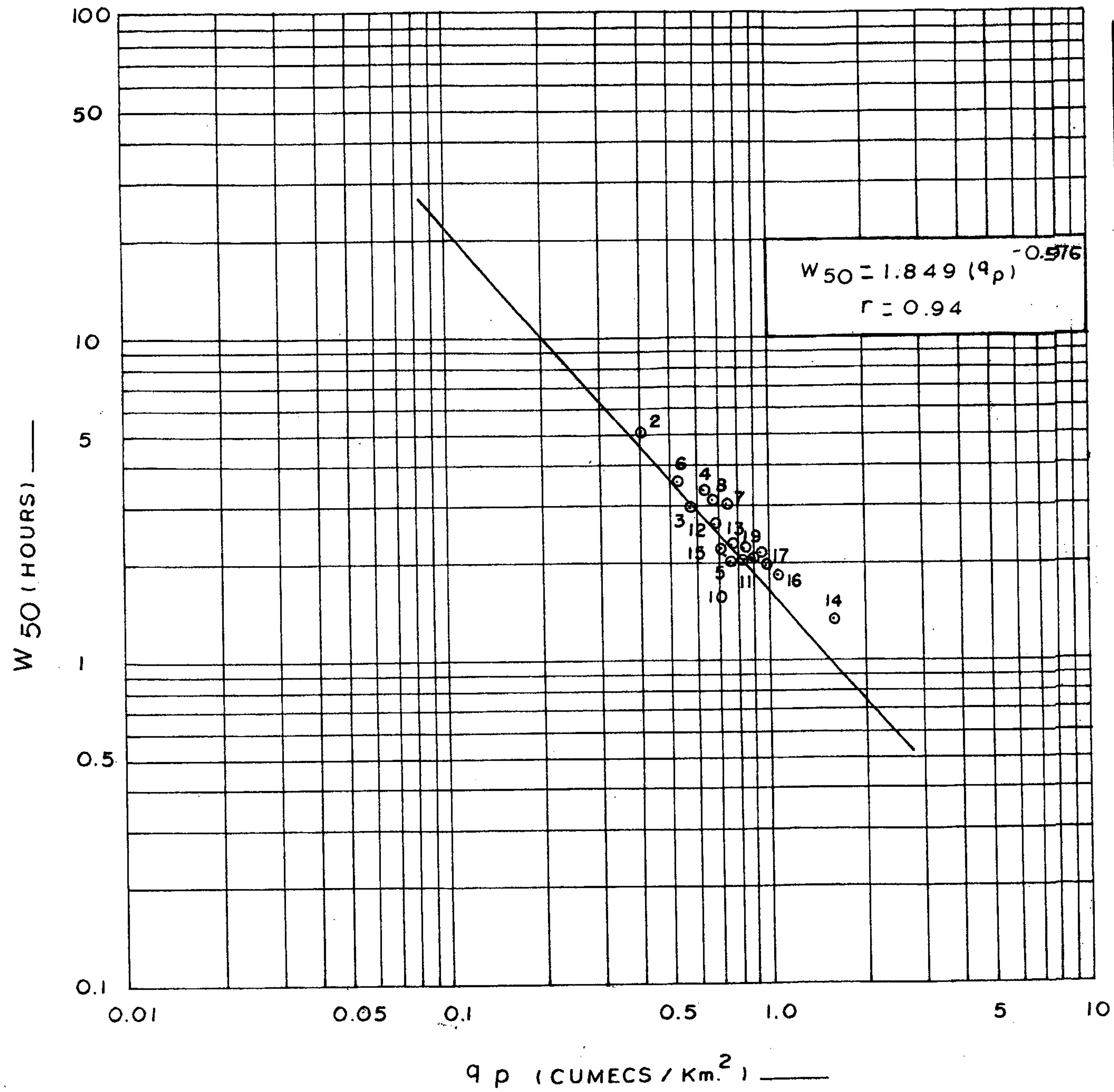
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE

LOWER NARMADA & TAPI
SUB ZONE - 3 (b)
RELATION BETWEEN t_p AND q_p

DRAWN BY-	CHECKED BY-
L. P. NAUTIYAL	M. R. CHAKRABORTY.

FIG._5.

SCALE - LOG. X LOG.



SL NO.	BRIDGE NO.	q_p (Cum./Km²)	W 50 (HOURS) ACTUAL	W 50 (HOURS) ESTI.
1	361/2	0.84	2.2	2.19
2	21	0.4057	5	4.46
3	523	0.5709	2.9	3.20
4	21	0.63	3.3	2.90
5	293/1	0.75	2	2.45
6	507	0.5225	3.5	3.48
7	485/4	0.7335	3	2.50
8	411/1	0.6622	3.1	2.76
9	479/3	0.9312	2.15	1.98
10	374/1	0.88	2	2.09
11	666	0.84	2	2.19
12	50	0.6727	2.6	2.72
13	86	0.7549	2.2	2.43
14	502/1	1.5615	1.3	1.20
15	53	0.7069	2.2	2.59
16	476/1	1.04	1.8	1.78
17	497/1	0.95	2	1.94

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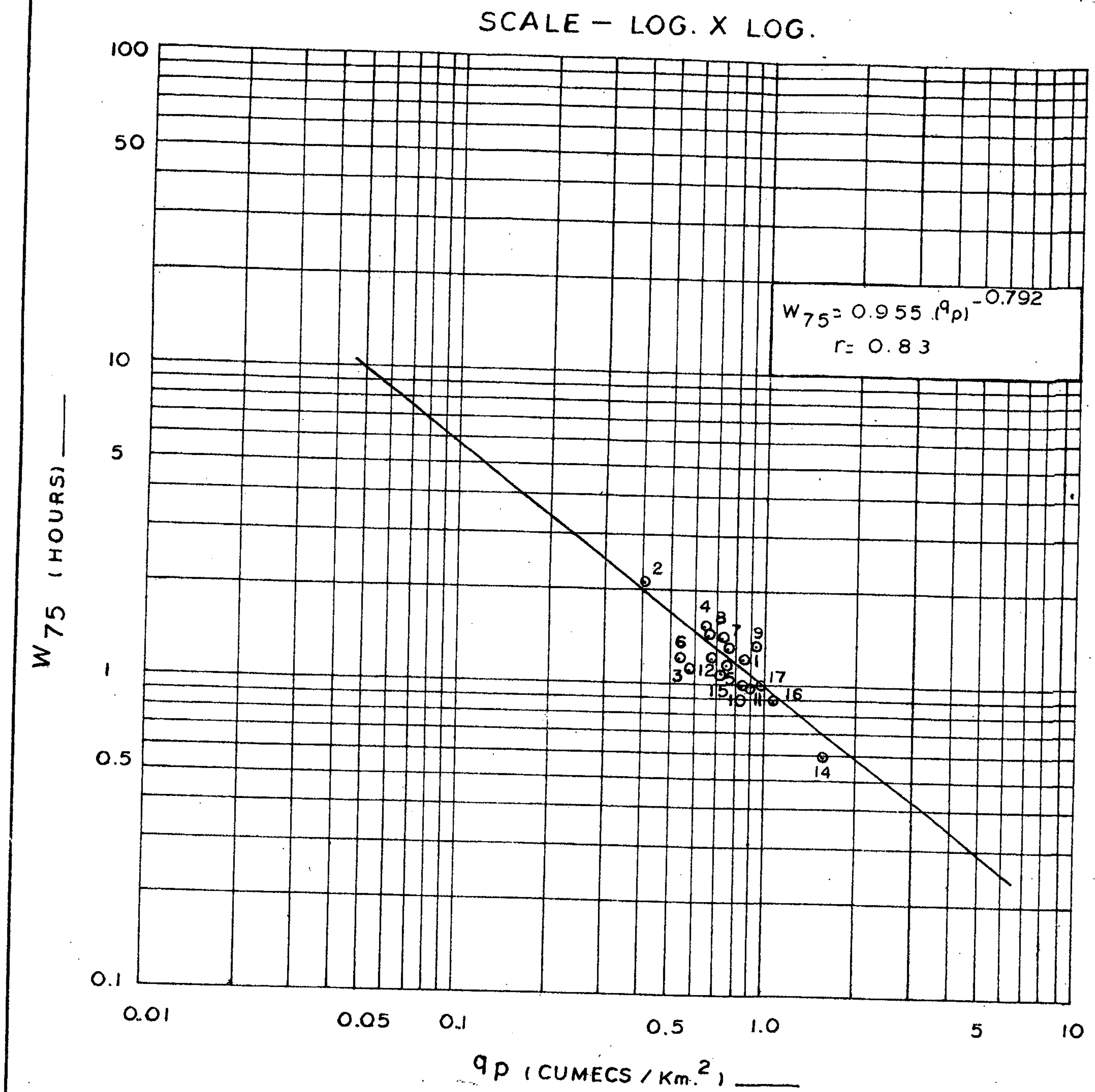
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

LOWER NARMADA & TAPI

SUB ZONE - 3 (b)
RELATION BETWEEN
q_p AND W50

DRAWN BY —	CHECKED BY —
L. P. NAUTIYAL	P. K. GUIN

FIG. _6



SL NO	BRIDGE NO.	q_p (Cum./Km.^{2})	W_{75} (HOURS) ACTUAL	ESTI.
1	36 1/2	0.8400	1.2	1.14
2	21	0.4057	2.1	2.03
3	523	0.5709	1.1	1.55
4	21	0.6300	1.5	1.43
5	293/1	0.7500	1.15	1.25
6	507	0.5225	1.2	1.66
7	485/4	0.7335	1.4	1.27
8	411/1	0.6622	1.45	1.38
9	479/3	0.9312	1.32	1.05
10	374/1	0.8800	1.0	1.10
11	666	0.8400	1.0	1.14
12	50	0.6727	1.22	1.36
13	86	0.7549	1.3	1.24
14	502/1	1.5615	0.6	0.70
15	53	0.7069	1.1	1.31
16	476/1	1.0400	0.9	0.96
17	497/	0.9500	1.0	1.04

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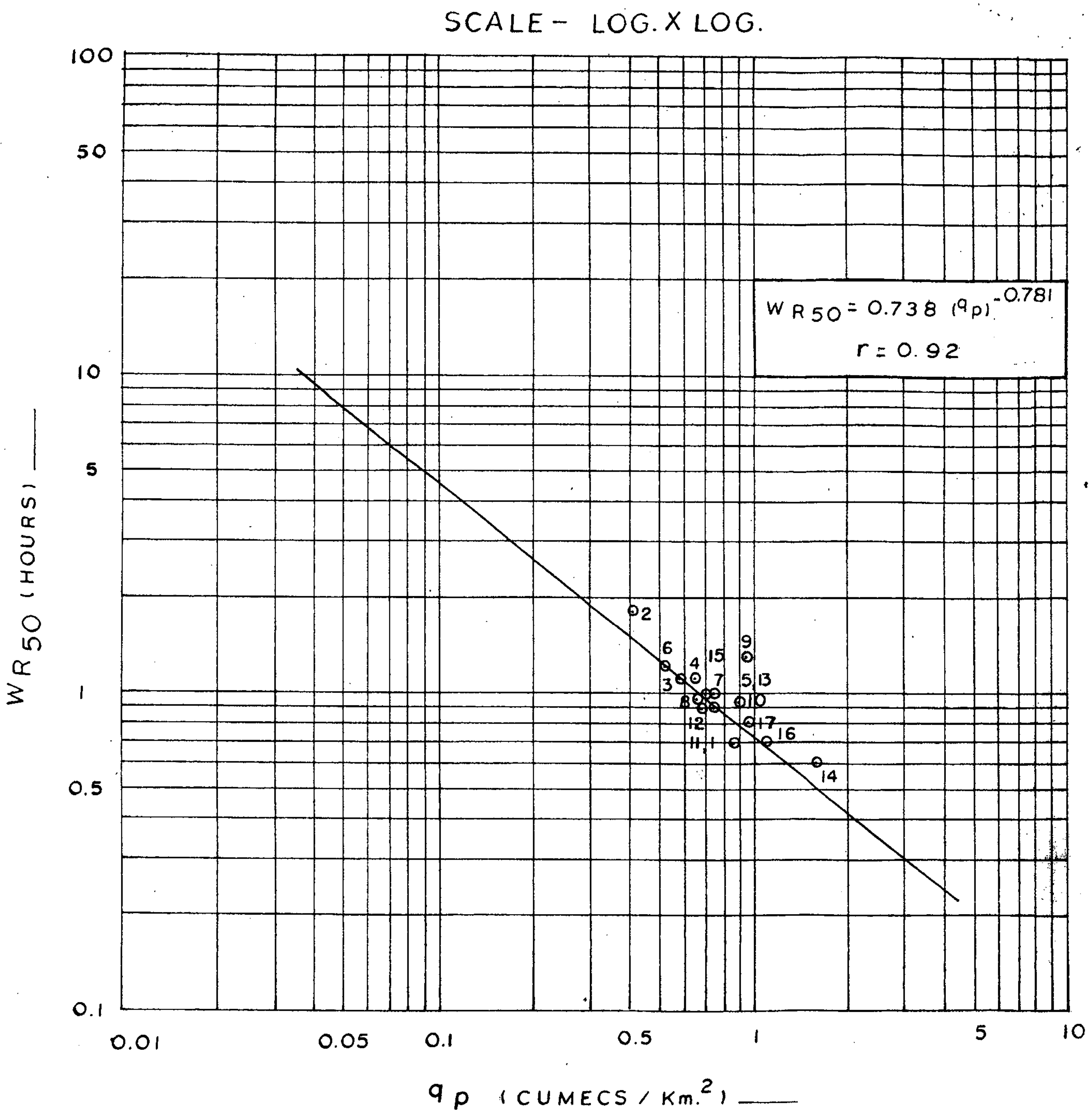
HYDROLOGY (REGIONAL STUDIES) DTE.

LOWER NARMADA & TAPI
SUB ZONE – 3(b)
RELATION BETWEEN
q_p AND W_{75}

DRAWN BY — L.K. PANT.
CHECKED BY — M.R. CHAKRABORTY.

FIG..7



SL NO.	BRIDGE NO.	q_p (Cum./Km.^{2})	WR50 (HOURS) ACTUAL	WR50 (HOURS) ESTI.
1	361/2	0.8400	0.7	0.846
2	21	0.4057	1.8	1.49
3	523	0.5709	1.1	1.14
4	21	0.6300	1.1	1.06
5	293/1	0.7500	0.9	0.924
6	507	0.5225	1.2	1.23
7	485/4	0.7335	1.0	0.94
8	411/1	0.6622	0.95	1.01
9	479/3	0.9312	1.32	0.78
10	374/1	0.8800	0.95	0.82
11	666	0.8400	0.7	0.85
12	50	0.6727	0.9	1.01
13	86	0.7549	0.9	0.92
14	502/1	1.5615	0.6	0.52
15	53	0.7069	1.0	0.97
16	476/1	1.0400	0.7	0.72
17	497/1	0.9500	0.8	0.77

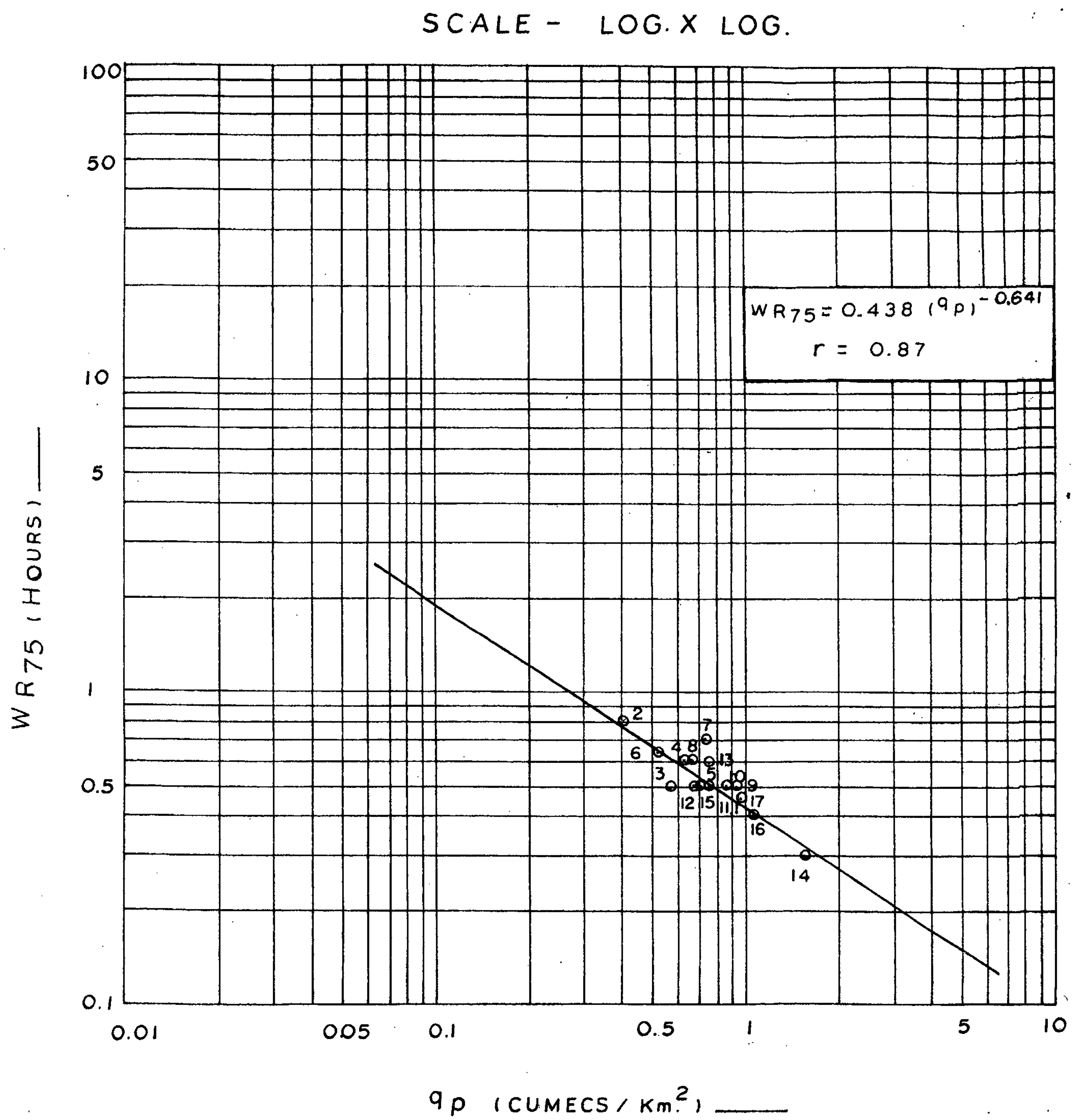
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

LOWER NARMADA & TAPI SUB ZONE - 3(b) RELATION BETWEEN q_p AND W_{R50}

DRAWN BY– L. K. PANT

CHECKED BY– B. SYAMAN

FIG.-8



SL. NO.	BRIDGE NO.	q_p (Cum/Km^2)	WR 75 (HOURS) ACTUAL	ESTI.
1	361/2	0.8400	0.5	0.491
2	21	0.4057	0.8	0.781
3	523	0.5709	0.5	0.627
4	21	0.6300	0.6	0.589
5	293/1	0.7500	0.5	0.527
6	507	0.5225	0.65	0.664
7	485/4	0.7335	0.7	0.534
8	411/1	0.6622	0.6	0.570
9	479/3	0.9312	0.5	0.459
10	374/1	0.8800	0.5	0.475
11	666	0.8400	0.5	0.490
12	50	0.6727	0.5	0.565
13	86	0.7549	0.6	0.525
14	502/1	1.5615	0.3	0.330
15	53	0.7069	0.5	0.547
16	476/1	1.0400	0.4	0.427
17	497/1	0.9500	0.45	0.452

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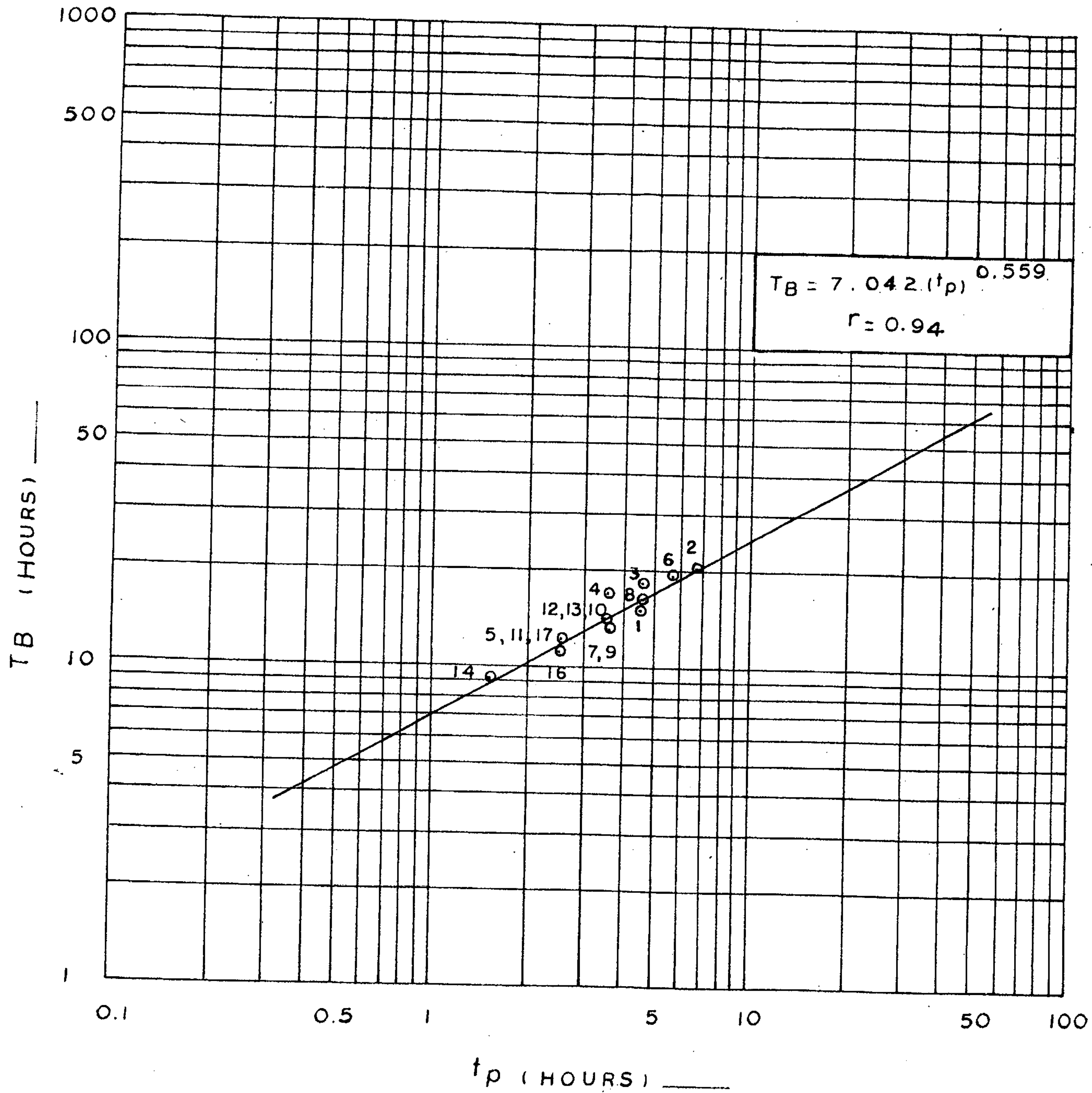
HYDROLOGY (REGIONAL STUDIES) DTE.

LOWER NARMADA & TAPI
SUB ZONE - 3 (b)
RELATION BETWEEN
q_p AND WR_{75}

DRAWN BY - L. K. PANT	CHECKED BY - P. K. GUIN

FIG._ 9

SCALE - LOG. X LOG.



SL NO	BRIDGE NO.	t_p (HOURS)	T_B (HOURS) ACTUAL	ESTI.
1	361/2	4.5	15	18.33
2	21	6.5	20	20.05
3	523	4.5	18	16.33
4	21	3.5	17	14.19
5	293/1	2.5	12	11.75
6	507	5.5	19	18.26
7	485/4	3.5	13	14.19
8	411/1	4.5	16	16.33
9	479/3	3.5	13	14.19
10	374/1	3.5	14	14.19
11	666	2.5	12	11.75
12	50	3.5	14	14.19
13	86	3.5	14	14.19
14	502/1	1.5	9	8.83
15	53	3.5	14	14.19
16	476/1	2.5	11	11.75
17	497/1	2.5	12	11.75

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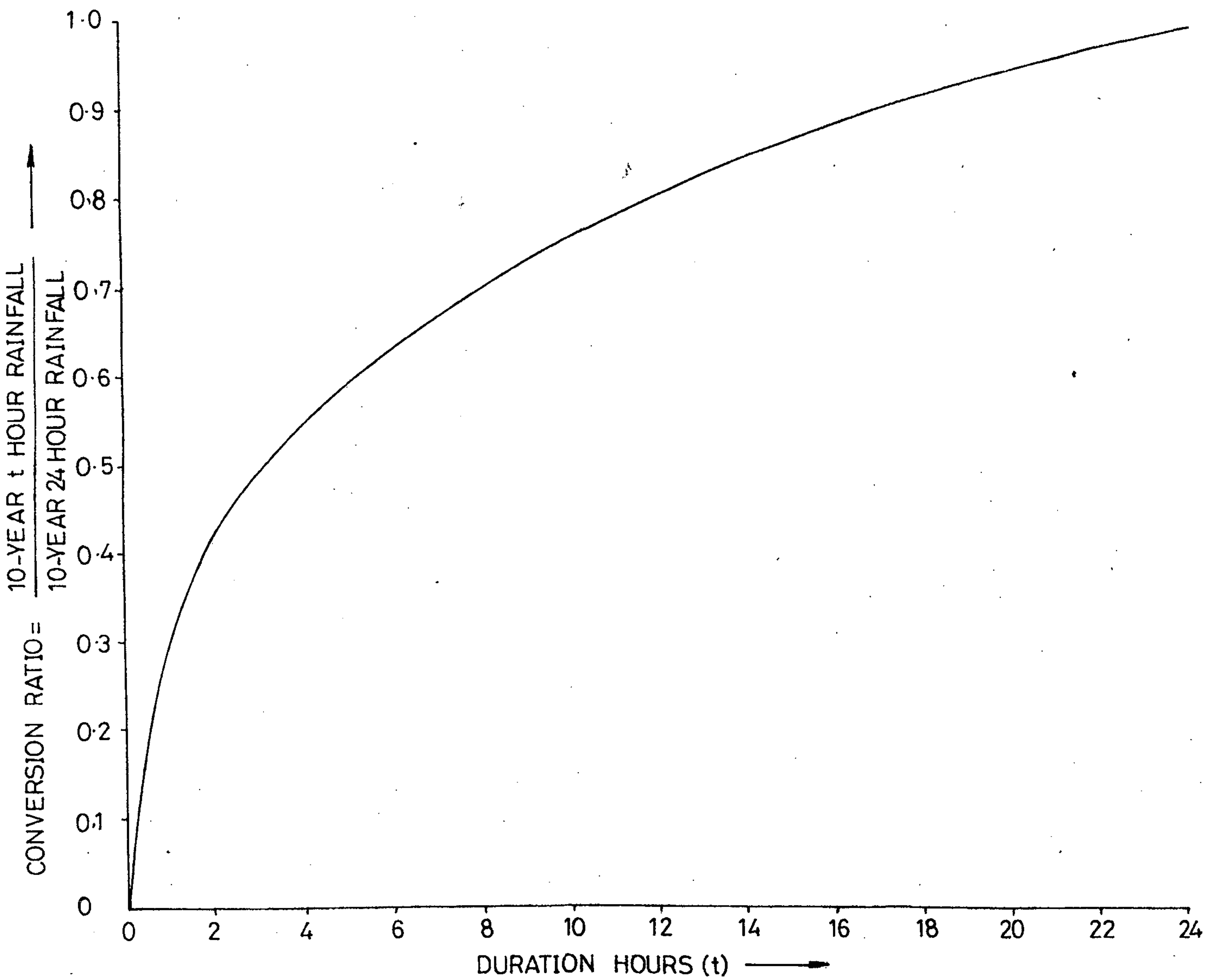
LOWER NARMADA & TAPI
SUB ZONE - 3 (b)
RELATION BETWEEN
t_p AND T_B

DRAWN BY _ L. K. PANT

CHECKED BY _ B. SYAMAN

FIG-10.



RATIOS OF 24-HOURS POINT RAINFALL TO SHORT DURATION RAINFALL

DURATION HOURS	RATIOS
1	0·31
3	0·49
6	0·63
9	0·73
12	0·81
15	0·87
18	0·92
24	1·00

NOTE
CURVE SUPPLIED BY I.M.D

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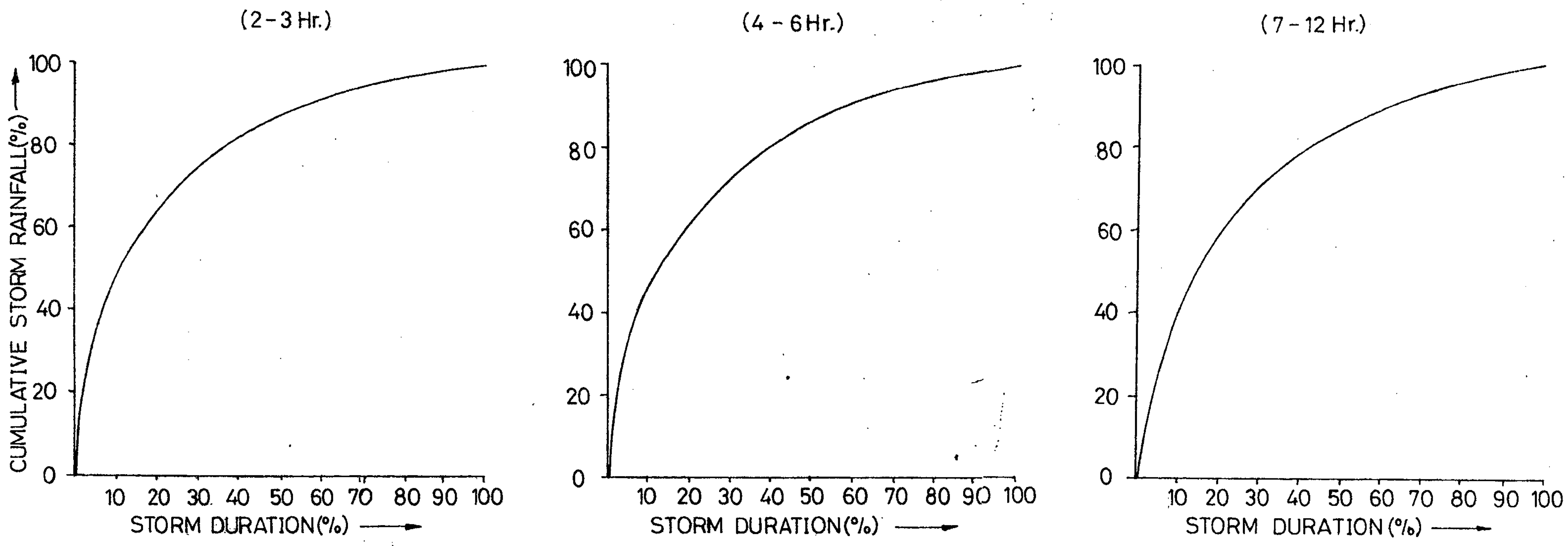
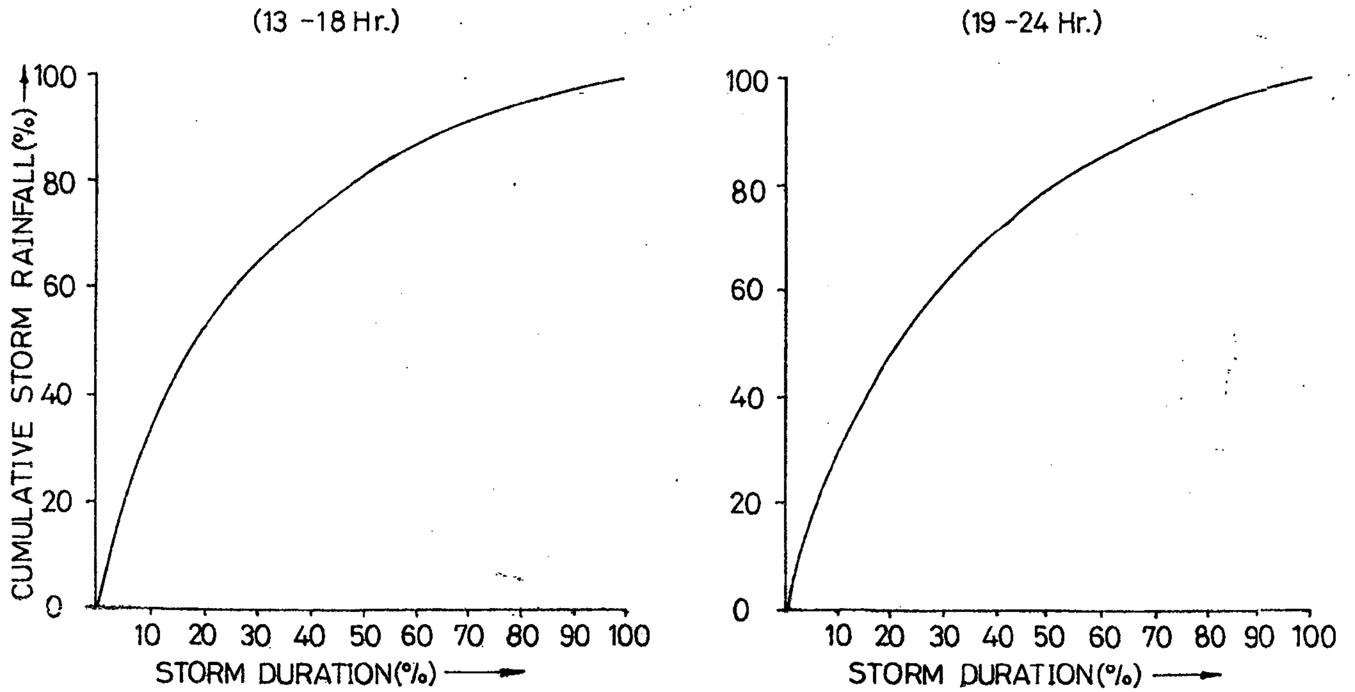
HYDROLOGY (REGIONAL STUDIES) DTE.

LOWER NARMADA & TAPI BASIN
SUB ZONE - 3(b)
DURATION Vs. CONVERSION RATIO

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

FIG._11.





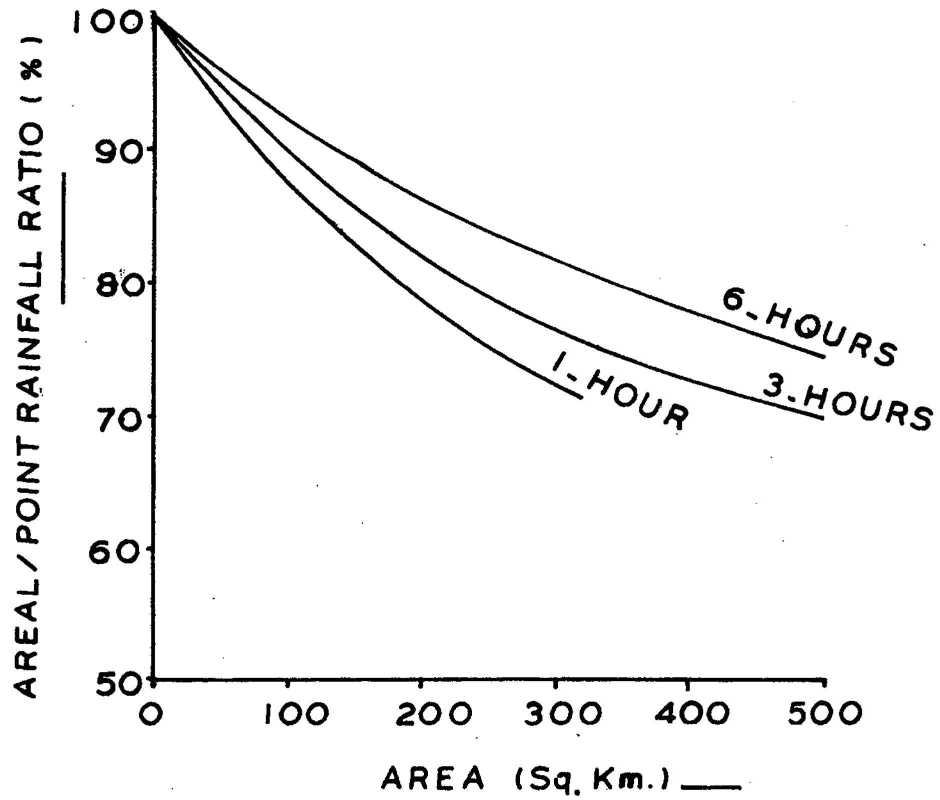
NOTE —

REFER ANNEXURE 4·3 FOR THE DISTRIBUTION CO.EFFICENTS (%) OF CUMULATIVE HOURLY RAINFALL FOR STORMS OF DURATIONS 2, 3, 4 . . . . . 23, 24 HOURS

CURVES SUPPLIED BY I. M. D

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (REGIONAL STUDIES) DTE.
LOWER NARMADA & TAPI BASIN SUB ZONE - 3 (b) MEAN AVERAGE TIME DISTRIBUTION CURVES OF STORMS OF VARIOUS DURATIONS
DRAWN BY_ L. P. NAUTIYAL — CHECKED BY_ K. K. AICH

FIG.- 12 (a).



NOTES —

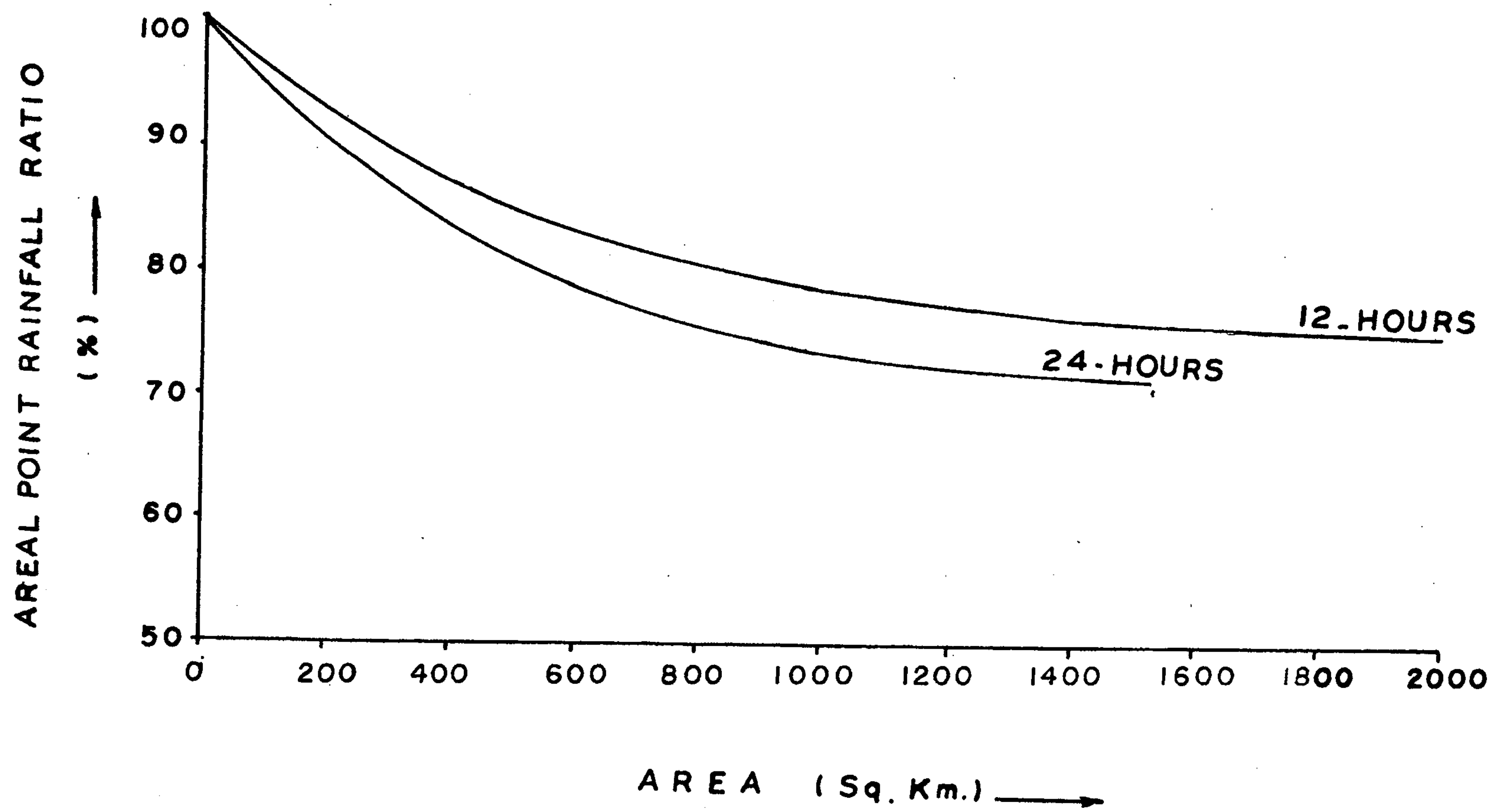
I) REFER ANNEXURE - 4.4 FOR AREAL TO POINT RAINFALL RATIOS FOR DURATION FROM 1 - 24 HOURS

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

NOTE - CURVES SUPPLIED BY I.M.D

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (REGIONAL STUDIES) DTE.	
LOWER NARMADA & TAPI SUB ZONE - 3 (b) AREAL TO POINT RAINFALL RATIO FOR 1-Hr, 3-Hrs., 6-Hrs (%)	
DRAWN BY — L. P. NAUTIYAL	CHECKED BY — M.R. CHAKRABORTY

FIG. _ 12 (b)



NOTES —

I) REFER ANNEXURE - 4.4 FOR AREAL TO POINT RAINFALL RATIOS FOR DURATION FROM 1_24 HOURS AND FOR CATCHMENT AREA UPTO 2000 Km.^{2}

II) REFER FIG._12 (a) FOR AREAL TO POINT RAINFALL RATIOS FOR DURATION 1_Hr, 3. Hrs. AND 6_Hrs.

NOTE-CURVES SUPPLIED BY I. M. D

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HYDROLOGY (REGIONAL STUDIES) DTE.

LOWER NARMADA & TAPI
SUB ZONE - 3(b).

AREAL TO POINT RAINFALL RATIO FOR 12.Hrs.& 24-Hrs. (%)

DRAWN BY —	CHECKED BY —
L. K. PANT	M.R. CHAKRABORTY