अभिकल्प कार्यालय रिपोर्ट
DESIGN OFFICE REPORT
No. LG-1(g)/R-1/23/94

केन्द्रीय जल आयोग
Central Water Commission

निचली गंगा का मैदान (उप अंचल-1 जी) का बाढ़ आकलन रिपोर्ट

FLOOD ESTIMATION REPORT FOR LOWER GANGA PLAINS SUBZONE-1(g) (REVISED)

जल विज्ञान निदेशालय
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भूतल परिवहन मंत्रालय
का एक संयुक्त कार्य

DIRECTORATE OF HYDROLOGY
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NEW DELHI -110066

A JOINT WORK OF
CENTRAL WATER COMMISSION
RESEARCH DESIGNS AND
STANDARDS ORGANISATION
INDIA METEOROLOGICAL DEPTT.
AND MIN. OF SURFACE TRANSPORT

NOVEMBER 1994

Flood Estimation Report for Lower Ganga Plains Subzone 1(g) /Revised was discussed and approved by the following members of Flood Estimation Planning and Co-ordination Committee in its 52nd meeting held on 18th January 1994 at R.D.S.O. Lucknow.

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FLOOD ESTIMATION REPORT FOR LOWER GANGA PLAINS
(REVISED)

SUBZONE 1(g)

A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE
DESIGN OFFICE REPORT NO LG-1(g)/R-1/94

HYDROLOGY(REGIONAL STUDIES) DIRECTORATE
CENTRAL WATER COMMISSION
NEW DELHI

1994

FOREWORD

Estimation of flood of various return periods for design of waterways and foundations of bridges and culverts having small and medium catchments, where hydrological data are inadequate or totally absent, is extremely difficult. In such a situation, regional method based on Hydrometeorological approach involving use of synthetic unit hydrograph and design storm of specific return period has been adopted. For this purpose, the country has been divided into 26 Hydrometeorological homogeneous subzones and 20 Flood estimation reports covering Hydrometeorological studies for 23 subzones have been published from time to time .The Flood estimation report for Western Himalayas subzone is under publication .

In addition to above, there is also periodic revision of such subzonal reports, whenever extra data sets become available and sophisticated analysis becomes due. Present report is a revision of the earlier flood estimation report of Lower Ganga Plains, subzone 1(g) published in 1974. The revisions incorporated are due to updated runoff and rainfall data and analysis procedure that is current. The report gives the method to compute design flood of 25/50/100 year return period for ungauged catchments located in Lower Ganga Plains Subzone .

The report is a joint effort of Central Water Commission (CWC), India Meteorological Department (IMD), Research Design and Standard Organisation (RDSO) of Ministry of Railways and Ministry of Surface Transport (MOST).

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

29th, July,94
New Delhi

(A.B.Joshi)
Member (Designs & Research)

PREFACE

Design engineers essentially need the design flood of a specific return period for fixing the waterway vis-a-vis the design 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 underestimation or over-estimation of design flood resulting in the loss and destruction of structure or uneconomic structure with problematic situation.

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

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

Economic constraints do not justify detailed hydrological and meteorological investigations at every new site on a large scale and on a long term basis for estimation of design flood with a desired return period. Regional flood estimation studies thus become necessary for hydro-meteorological homogeneous regions in the country. Broadly, two main regional approaches namely flood frequency and hydro-meteorological approaches are open for adoption depending on the availability of the storm rainfall and flood data. The first approach needs long term discharge observations for the representative catchments for subjecting to statistical analysis to develop a regional flood frequency model. The other approach needs concurrent storm rainfall and run-off data of the representative catchments over a period of 5 to 10 years to develop representative Unit hydrographs of the catchments located in the region, so that synthetic unit hydograph may be obtained for the region (subzone) and long term rainfall records at a large number of stations to develop design storm values. This approach has been adopted in the preparation of flood estimation reports under short term and long term plan.

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

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

Regional Hydrology Studies Dte. CWC carries out analysis of selected concurrent rainfall and flood data for the gauged catchments to derive unit hydrographs of mostly one hour duration on the basis of rainfall data, gauge and discharge data collected during the monsoon season. Representative unit hydrographs are obtained for each of the gauged catchments. The characteristics of the catchments and their unit hydrographs, prepared for several catchments in a sub-zone, are correlated by regression analysis and the equations for synthetic unit hydrograph for the subzone are derived for estimating design flood for ungauged catchments.

Studies are also carried out by the CWC to arrive at suitable recommendations for estimating loss rate and base flow for ungauged catchments.

Studies of Rainfall-Depth-Duration-Frequency, point to areal rainfall ratios and time distribution of storms are carried out by Hydro-met Cell of IMD utilising the data collected by RDSO and the long term data collected by IMD from rain-gauge stations maintained by IMD/States.

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 reports covering 24 sub zones have been published:-

1. Lower Ganga Plains subzone 1(g)* (1978)
2. Lower Godavari subzone 3(f) (1981)
3. Lower Narmada & Tapi subzone 3(b) (1982)
4. Mahanadi subzone 3(d) (1982)
5. Upper Narmada & Tapi subzone 3(c) (1983)
6. Krishna & Penner 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) (1988)
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)

* The present report is the revision of " Flood Estimation Report of Lower Ganga Plains, subzone 1(g)" and deals with estimation of the flood of 25 yr., 50 yr. and 100 yr return periods for small and medium catchments in the sub-zone 1(g). It covers Ganga plains of West Bengal, Bihar and Orissa. The revision of the Report is in accordance with recommendations of the FEPCC, made from time to time.

Hydrometeorological data of 25 small and medium catchments and 4 catchments having area less than 25 sq. km. have been collected by the Railways in the subzone for the period ranging between 2 to 13 years. On analysis of data of 20 catchments having area more than 25 sq. km. in hilly region data of 11 catchments were found suitable for UG studies. SUH equations for hilly regions are based on the data of these sites. As regards plain region, data of only 5 sites having area more than 25 sq. km. were available. This is too meagre to develop SUG relations. Hence, the hydrological studies carried out for subzone 1(f) were considered for obtaining SUG equations for the plain region of the subzone.

The storm studies have been conducted by IMD for entire Subzone. The rainfall data of 173 O.R.G stations maintained by IMD and State Governments, 49 S.R.R.G stations maintained by IMD in and around the subzone and short duration data (hourly/ half hourly rainfall) of 24 stations in 7 bridge catchments of the subzone maintained by RDSO have also been utilised for the storm studies conducted by IMD.

Part 1 of the report - " Introduction" gives the summary of the earlier studies and need to revise them. Description of the subzone detailing river system , rainfall , temperature and types of the soil is given in Part II . Part III brings out the SUH relations to be used for ungauged catchments in the sub-zone. The storm studies carried out by the IMD are dealt in Part IV of the report. Criteria 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 illustrative example each for hilly and plain Region. Part VI highlights the limitations, assumptions and conclusions.

The report on sub zone 1(g) is recommended for estimation of design flood for small and medium catchments varying in areas from 25 to 1000 sq km. This report may also be used for catchments having areas upto 2500 sq. km. judiciously after comparing the neighboring catchments having more or less similar characteristics. For catchments of areas less than 25 sq Km , the method given in the Report No. RBF- 16 published by RDSO may be used .

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

This report is a joint effort of Hydrology (Regional Studies) Dte, Central Water Commission of Ministry of Water Resources, India Mateorological Department of Ministry of Science and Technology. Research Design Standard Organisation, Ministry of Railways and Roads and Bridges Wing of Ministry of Surface Transport.

(R.V. Godbole)
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9th, Jan, 94.

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SYMBOLS

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

A	Catchment Area in km^2.
ARF	Areal Reduction Factor.
C.G.	Centre of Gravity
Cumecs	Cubic metres per second
cms	Centimetres
D_{i-1}, D_i	Depths between the river bed profile (L-section) based on the levels of (i-1) and ith contours at the inter-section points and the level of the base line (datum) drawn at the point of study in metres.
E.R.	Effective Rainfall in cms.
Hr	Hour
H(RS),CWC	Hydrology (Region Studies) Directorate, Central Water Commission, New Delhi.
I.M.D.	India Meteorological Department
In	Inches
Km	Kilometres
L	Length of longest main stream along the river course in km.
L_c	Length of the longest main stream from a point opposite to centroid of the catchment area to the gauging site along the main stream in km.
L_i	Length of the ith segment of L-section in km.
M.O.S.T.	Ministry of Surface Transport (Roads Wing).
M	Metres
Min	Minutes

mm	Millimetres
Q_p	Peak Discharge of Unit Hydrograph in cubic metres per second.
Q_{25}, Q_{50} and Q_{100}	Flood Discharge with return periods of 25-yr, 50-yr and 100-yr respectively in cumecs
q_p	Peak Discharge of Unit Hydrograph per unit area in cumecs per sq. km.
R_{25}, R_{50} and R_{100}	Point Storm Rainfall Values for 25-yr,24-hour 50-yr 24-hour and 100-yr 24-hour return periods respectively in cm.
R.D.S.O	Research Designs & Standards Organisation (Ministry of Railways),Lucknow.
S	Equivalent stream slope in m/km.
S.U.G	Synthetic Unit Hydrograph
S.R.H	Surface Runoff Hydrograph
D.R.H	Direct Runoff Hydrograph
Sec	Seconds
Sq	Square
Sq.km	Square Kilometres, Km2
T	Time Duration of Rainfall in hours
T_B	Base Width of Unit Hydrograph in hours
T_D	Design Storm Duration in hours
T_m	Time from the start of rise to the peak of Unit Hydrograph in hours

PART -I

INTRODUCTION

The present report is the revision of the Flood Estimation Report of Lower Ganga Plains, subzone 1(g) ,the first report published under long term plan as per recommendations of the Committee of engineers, headed by Dr. A.N.Khosla. The report originally brought-out in the year 1974 (Design Office Report No.2/1974),gave the method to compute design flood of 50 year return period by SUG approach. The studies incorporated in the earlier report and in the revised report are summarized below:

1.1 Earlier studies :

1.1.1 Hydrological studies : The hydrological studies were based on the hydromet data of 15 catchments observed during the years 1958-1969 . Out of these, 2 catchments have area less than 25 sq. km. Representative unit hydrographs of 0.25 hour , 0.50 hour and 1 hour duration were derived depending on the value of tp. From these RUGs the unit hydrograph parameters were obtained and equations were developed correlating unit hydrograph parameters and basin parameters for derivation of synthetic unit hydrograph for ungauged catchments in the subzone.

1.1.2 Storm Studies: Storm studies were conducted by IMD . The report contains i) Isopluvial maps of 50- year return period and for duration 15,30 and 45 minutes and 1,3,6,9,12, 15 and 24 hours, which were extracted from the relevant maps of India contained in Short Term Report - 1/73, ii) Areal distribution relations and iii) Time distribution curve for obtaining distribution of a storm of any duration .

1.2 Need to revise earlier studies:

1.2.1 The Flood Estimation Planning And Coordination Committee (FEPCC) in its 43rd meeting decided to demarcate the subzone 1(g) into hilly and plain regions and recommended to adopt SUG relations developed for subzone 1(f) for the plain region of the subzone 1(g) as indicated in the flood estimation report of 1(f). For the hilly region , the equations given in the flood estimation report for 1(g) were recommended .

The FEPCC in the 51st meeting decided to revise the report incorporating separate equations correlating unit hydrograph and basin parameters of gauged catchments in the region for deriving SUG in plain as well as hilly region based on revised hydrological studies with available data . It was also decided that the revised report should also contain the design storm components based on longterm available data in the form of i) 25, 50 and 100 - year 24 hour isopluvial maps ii) short duration ratios iii) time distribution curves and iv) point to areal rainfall ratios.

1.3 Present Studies:

In persuasion of the decision taken by FEPCC in various meetings , the hydrological and storm studies as detailed below have been carried out.

1.3.1 Hydrological studies

There are 25 gauged catchments spread over the subzone. For bifurcating the subzone , the catchments having slopes more than 2 mts/km. have been considered to be in hilly region . It is seen that such catchments are situated in the upper portion of the subzone and accordingly the subzone has been demarcated as hilly and plain region .

SUG equations for hilly region have been obtained using hydromet data available during the period 1956-1967 for 10 catchments and data available during the period 1960-1991 of one catchment, the observation on which is being continued as key gauging site. The catchments considered have area more than 25 sq. km.

Due to inadequate data in the plain region of the subzone , the SUG equations could not be derived . Six hourly RUGs of gauged catchments in subzone 1(f) have been converted in to one hourly RUGs and unit hydrograph parameters were obtained . The relationships between one hour unit graph parameters and basin parameters of gauged catchments in subzone 1(f) have been developed and recommended for derivation of SUG in plain region as the region resembles the subzone 1(f) .

Simplified regression equations for the quick estimation of flood peak for different return period have also been developed for hilly region by correlating flood peaks obtained applying design storm of specific return period on SUG of a gauged catchments in this region with basin parameters and 24 hour rainfall.

The hydrological studies carried out by CWC have been given in Part -III of the report .

1.3.2 Storm studies

The India Meteorological Department (IMD) has conducted rainfall studies for the subzone utilizing the rainfall data of 173 ORG stations and 45 SRRG stations . The study covers Depth-Duration Frequency analysis of available daily/short duration rainfall data in and around the subzone. The Design storm components have been derived in the form of (i) 25, 50 and 100 year 24 hour isopluvial maps (ii) 24 hours to short duration (1 to 23 hours)rainfall ratios, (iii) Time distribution curves for storms of various durations (2 to 24 hours) and (iv) Point to areal rainfall ratios for specific durations (1, 3, 6, 12 and 24 hours).

The storm studies carried out by IMD have been covered in part- IV of the report.

1.3.3

Criteria 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 illustrative example each for hilly and plain Region. Part VI highlights the limitations, assumptions and conclusions.

In addition to above , general topography and relief and climatological features of the zone covering river system, soils, land use , rainfall, temperature and communications is given in Part - II. Maps of the zone showing topography and relief ,land use and soils have been extracted from relevant maps of India contained in the" Irrigation Atlas of India - 1978 ". The maps of the zone showing annual normal rainfall and mean daily temperature have been prepared by India Meteorological Department (IMD) on the basis of available data .

PART - II

GENERAL DESCRIPTION OF SUBZONE

2.1 Location :

The Lower Ganga Plains, subzone 1(g) lies approximately between Latitudes N 21^0 - 15' and 25^0 - 45', Longitudes E 84^0 35' and 89^0.

The subzone is bounded by subzones 1 (d) and 1(f) towards North, subzone 3(d) towards south-west and by the international boundary between India and Bangladesh towards east and south east.

The region includes the states of West-Bengal, Bihar and a small part of Orissa and drains an area of 1,30,280 Sq km. Location of the subzone on the map of India is shown at Plate - 1. Annexure 2.1 shows various subzones into which country has been divided .

2.2 River System :

Plate - 2 depicts the river system in the sub zone. The region is to a large extent covered by the Ganga river which ultimately debouches into Bay of Bengal .

During its course in subzone 1(g), the Ganga is joined by the Dwarka, the Ajay, the Mayurakshi, the Jalangi, the Damodar, the Roop Narayan and the Haldi. The other rivers which flow through the subzone and outfall into Bay of Bengal independently are the Subarnarekha and the Burha-Balang.

The break-up of the area covered by the main Ganga river and other rivers is given below :

	Name of the river	Drainage area (sq.km.)
1.	Main Ganga	40590
2.	Dwarka	8850
3.	Ajay	6050
4.	Damodar	25820
5.	Roop Narayan	8530
6.	Haldi (Kasai)	10210
7.	Subarnarekha	19296
8.	Burha-Balang	4837
9.	Other rivers and free drainage area	6097
	Total area	1,30,280

2.3 General topographical and climatological features :

2.3.1 Topography and relief

Plate -3 depicts the general topography of the subzone. The subzone has in general elevation less than 150 metres. Small areas located in the central portion of the subzone have elevation ranging between 150 to 300 metres. Towards extreme west, some areas adjoining subzone 1(d) have elevation ranging between 300 to 600 metres.

2.3.2 Soils

Plate -4 shows the types of soil found over the areas in the subzone. A large area in central part of the subzone is covered by red sandy soil. A small portion towards extreme north of the subzone, is covered by aluvial soil. Red and yellow soil is found in the western parts of the subzone. The eastern area of the subzone is almost all covered by aluvial soil along with a small region of red and loamy soil adjoining Berhampore.Mixed red, black and yellow soil, aluvial soil and laterite soil is found,in general,in the southern areas of the subzone.Deltic aluvial soil is found over the areas in the vicinity of the mouth of Bay Of Bengal.

2.3.3 Land use

Plate - 5 shows details of land use of the subzone The major portion of the area is under cultivation. Rice is the main crop of the region. Other crops grown in the area are Jute and Millets.

Forests are located in the upper reaches of Damodar,Subarnarekha and Burhabalang rivers.

2.4 Climatological features of subzone :
(As contributed by IMD)

2.4.1 Rainfall features

2.4.1.1 Annual normal rainfall : The isohyetal map of annual normal rainfall over the subzone is presented in Plate-6. The annual rainfall over the subzone is of the order of 900 mm over its extreme north west portion and gradually increases to about 1700 mm over extreme south of the subzone.

2.4.1.2 Monthly rainfall distribution: Monthly rainfall distribution at six representative stations viz., Ranchi,Berhampore,Bankura, Calcutta,Balasore and Bhagalpur is illustrated through bar charts appended to the annual normal rainfall map (Plate -6). In the bar charts alphabets along abcissa indicate names of months whereas heights of rectangles are proportional to normal rainfall of respective months. Figures at the top of each rectangle indicate the month's rainfall as percent of annual rainfall.

It is clearly brought out in the bar charts that in parts of the subzone lying in Bihar and Orissa, the main rainy season comprises of five months from June till October, whereas in parts of the subzone lying in West Bengal the rainfall in the month of May also is significant and is of the same order as that in the month of October. Total rainfall for five months from June to October at Ranchi, Berhampore, Bankura, Culcutta, Balasore and Bhagalpur is respectively 87%, 83%, 85%, 84%, 81%, and 89%, of the annual rainfall. Rainfall at these stations in the month of May is 3%, 9%, 6%, 7%, 6%, and 5% respectively.

2.4.2 Temperature Distribution.

2.4.2.1 Mean daily temperatures(annual): Mean daily temperature distribution over the subzone is shown in Plate-7. The mean daily temperatures are worked out as average of mean maximum and mean minimum temperatures over the year. It may be seen from the map that mean daily temperatures are slightly below 24°C over western parts of Hazaribagh and Ranchi districts in Bihar. The highest mean daily temperatures of magnitude slightly less than 27°C occur over Mayurbhanj district of Orissa and Howrah & Midnapore districts of West Bengal.

2.4.2.2 Monthly temperature variations at selected stations.

Monthly variations of maximum, minimum and mean daily temperatures for six representative stations viz., Berhampore Balasore, Culcutta, Ranchi Jamui and Asansol are shown graphically in Plate-7 below the map of mean daily temperatures. It may be seen from there that the highest maximum temperatures are observed in the month of April at stations Berhampore (37.6° C), Balasore(36.4° C), Calcutta (36.3° C) & Asanol (38.5° C), and in the month of May at Ranchi (37.9° c) & Jamui (40.2° C). Minimum temperatures are observed in the month of December at Ranchi and in the month of January at other five stations. Mean daily temperatures are highest in the month of April at Berhampore, Culcutta, & Asansol and in the month of May at other three stations. They are lowest in the month of January at Berhampore, Jamui and Asansol and in the month of December at other three stations.

2.5 Communications :

2.5.1 Railway sections: The Northern and Eastern Railways serve the area. The broad gauge line from Delhi to Calcutta runs almost parallel to the river Ganga for most of its length.

The following railway sections traverse the subzone partly or wholly :

1. Gaya- Dhanbad-Calcutta
2. Midnapore-Ballasore
3. Ara- Patna- Madhupur
4. Katiyar- Burdwan

2.5.2 Road sections: The basin has a good network of roads. National Highway no.2 connecting Delhi to Calcutta passes through the basin. Other National Highways are NH 31 (Patna to Purnea), NH 6, 35(all connecting Calcutta to different parts of West Bengal and beyond).

The following road sections traverse the subzone partly or fully :

1. Aurangabad- Calcutta
2. Purnea- Dumka
3. Daulatgang- Ranchi
4. Cuttack- Midnapore
5. Malda- Calcutta

The Ganga is navigable in the subzone down to the sea. Small and medium sized crafts ply on the river.

PART - III

SYNTHETIC UNIT HYDROGRAPH STUDIES

3.1 Synthetic Unit Hydrograph (SUG) :

Hydrometeorological approach has been adopted for developing a regional method for estimating design flood for small and medium catchments in various hydrometeorologically homogeneous subzones. In this approach, the design storm after converting it into effective rainfall (input) is applied to the unit hydrograph (transfer function) to obtain a design flood (basin response). It is possible to develop unit hydrograph if site specific concurrent rainfall runoff data is available for 3-4 years. Collection of adequate concurrent rainfall runoff data for every site, is however neither practicable nor economically feasible. In such a situation the regional method for developing Synthetic Unit Hydrograph (SUG) is resorted to. The SUG in the present study is a unit hydrograph of unit duration for a catchment developed from relations established between physiography and unit hydrograph parameters of the representative catchments in hydrometeorologically homogenous region (subzone). Data collected and analysed for obtaining subzonal SUG equations are discussed in succeeding paragraphs.

3.2 Data Required:

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

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

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

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

The following catchment details are also required .

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

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

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

3.3 Data Collected:

The Eastern and South - Eastern railways under the supervision and guidance of Research Designs and Standards organisation (RDSO) has observed and collected the data for 29 catchments . The size of the gauged catchments varies from 9 sq.km to 3632 sq.km.

Locations of the gauging sites at road and railway bridges in the subzone 1(g) are shown in Plate-2. Annex.3.1 shows the names of streams, railway/road bridge numbers with railway sections, road sections, catchment areas, number of raingauge stations and the period of availability of concurrent rainfall-runoff data.

4 sites namely Bridge No. 101(s), 27, 12 and 23 have catchment area less than 25 sq.km.These were,therefore not considered for the present study.After the scrutiny of data and consistency checks, it was found that out of 25 remaining sites, data of 14 catchments was found suitable for unit hydrograph studies. Concurrent rainfall and discharge data for 80 bridge catchment years for 14 catchments were available for the studies. This includes additional data of 3 catchments (Bridge number 160 , 286 and 436) collected susquently and not utilised in earlier studies .

3.4 Development of one hour synthetic unitgraph equations:

The Lower Ganga plain sub zone broadly consists of two regions hilly and plain. The area comprising Chota Nagpur plateau and foothills , varying in height from 150 to 1375 metres, are situated on the western side of the subzone. These areas and upper reaches of Damodar and Subarnarekha rivers lying in the south western part of the sub zone form a part of hilly region. Remaining area comprising a narrow strip on the northern boundary of the region adjoining the Ganga and eastern parts of Damodar and Subarnarekha area form the plain region and resemble the plain area of Middle Ganga sub zone 1(f).

On studying the slopes of 29 catchments, it was found that 24 catchments have slopes varying from 2.0 m/km to 9.37 m/km . These catchments have been considered to be lying in the hilly region. Slopes of remaining 5 sites (Bridge no. 181,237,436 236 and 42) have been found to be less than 2 m/km. These catchments resemble with the catchments of Subzone 1(f) and are considered to be lying in the plain area. The subzone has been bifurcated as plain and hilly region considering the location of the gauged catchments as shown in Plate II.

Equations correlating unit hydrograph and physiographic parameters of gauged catchments for derivation of SUG for hilly and plain regions are discussed in following paras.

3.4.1 SUG equations for hilly region

For derivation of SUG equations, the unit hydrograph studies have been carried out for 11 sites lying in hilly region as detailed in Annexure 3.1 .

Various steps to derive one hour SUG equations for an ungauged catchment are briefly described as under:

3.4.1.1 Physiography parameters of the catchment:

Physiography parameters indicated in Fig. 1 are discussed in the following paragraphs

a) 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 is measured .

b) Length of the Main Stream (L)

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

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

For finding the centre of gravity of the catchment, usually the boundary of the catchment is cut on a card board, which is then hung in three different directions in vertical planes and the plumb lines are drawn from the point of hanging. The point of intersection of these lines gives the centre of gravity of the catchment. The main 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 stream from the centre of gravity to the point of study (Lc).

d) Equivalent Stream Slope (S)

Slope is also one of the physiography parameters . The slope may be equivalent slope or statistical slope. In this report equivalent stream slope has been used for developing the SUG relation. This can be computed by the following methods.

i) Analytical Method

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

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

where L_i = Length of the ith segment in km.

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

L = Length of the longest stream as defined in section 3.4.1.1 in km.

ii) Graphical Method:

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

Physiography parameters A, L, Lc and S obtained for 11 catchments are shown in Annexure 3.2

3.4.1.2 Unit hydrograph Parameters of the catchments

A. Scrutiny of data and finalization of gauge and discharge rating curve

The data was scrutinized through arithmetical checks and gauge and discharge rating curve(s) were drawn either on linear scale or on log-log scale. The stages for conceivable floods were converted into discharges initially identified with reference to rise and fall in the stages of the river.

B. Selection of flood and corresponding storm events

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

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

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

Based on the above criteria, 46 flood events were selected for UG studies.

C. Computation of hourly catchment rainfall

Thiessen network was drawn for the raingauge stations on the catchment map and Thiessen Weights were computed.One hour point rainfall at each station was multiplied by its respective Thiessen Weight and added to obtain the catchment rainfall for each hour duration during the storm period.

D. Computation of Infiltration loss (0-index) and 1-hour effective rainfall units

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

E. Separation of base flow

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

F. Derivation of 1-Hour Unitgraph

The unit duration of 1-hour was adopted for derivation of unitgraphs. The 1-hour unitgraphs were derived from the rainfall excess hyetographs and their corresponding direct runoff hydrographs by iterative method. The iterations were carried out till the observed and estimated direct runoff hydrographs compared favorably. 46 unitgraphs were derived for 11 catchments .

G. Drawing of representative Unitgraphs and measuring their parameters

Set of Unitgraphs as obtained above for a catchment were superimposed and an average/representative Unitgraph (RUG) was derived and tested on observed flood events . The parameters of RUH i.e .t_p q_p , W_{50} , W_{75} , WR_{50} , WR_{75} and T_B (as illustrated in Fig.2) for 11 catchments are given in Annexure 3.3 . Annexure 3.4 shows hourly ordinates of RUGs of 11 catchments .

3.4.1.3 Estâblishing relationships between physiography and Representative Unitgraph Parameters

Linear and non-linear equations were tried for establishing the relationships between RUG parameters (Annexure 3.3) and physiography parameters (Annexure 3.2) of the catchments . Various combinations of physiography and RUG parameters studied for arriving at the best fit equations are given in Annexure 3.5

Relationship between physiography factor ($LL_c/\sqrt{S}$) and U.G. parameter tp was found to be significant. UG parameter tp was related to other U.G parameters, q_p W_{50} ,W_{75} WR_{50} , WR_{75} and T_B

Following relationships given in Table 3.1 are found suitable for estimating the 1-hr unitgraph parameters of an ungauged catchment in the hilly region of subzone1(g).

TABLE - 3.1
(Recommended relationships for hilly region)

Relationships 1		"r" 2	S.E. 3	Equation No. 4	Fig.No. 5
t_p	$= 1.1808\ (LLc/\sqrt{S})^{0.285}$	0.718	1.443	3.4.1.1	3
q_p	$= 2.0972\ (t_p)^{-0.927}$	0.879	1.304	3.4.1.2	4
W_{50}	$= 1.2622\ (t_p)^{0.828}$	0.898	1.239	3.4.1.3	5
W_{75}	$= 0.7896\ (t_p)^{0.711}$	0.817	1.303	3.4.1.4	6
W_{R50}	$= 0.5357\ (t_p)^{0.745}$	0.768	1.388	3.4.1.5	7
W_{R75}	$= 0.3825\ (t_p)^{0.647}$	0.681	1.444	3.4.1.6	8
T_B	$= 5.5830\ (t_p)^{0.824}$	0.899	1.236	3.4.1.7	9
T_m	$= t_p + t_r/2$	-	-	3.4.1.8	
Q_p	$= A * q_p$	-	-	3.4.1.9	

Relations developed are shown in Figures 3 to 9

Relationships given in Table 3.1 are recommended to estimate the parameters of 1-hour synthetic unitgraph for an ungauged catchment having steep slope similar to the slopes considered in the hilly region of the subzone with its known physiography parameters A, L, Lc and S.

3.4.2 SUG equations for plain region

The hydrological data of 5 sites (Bridge Nos 42 181, 237, 436 and 236) lying in this region are available for study , out of which data of Bridge number 236, 237 and 181 was found suitable for UG studies . This is inadequate for deriving the equations of SUG. Hence,the hydrological studies carried out for deriving SUG for ungauged catchments in 1(f) subzone have been considered for derivation of SUG of ungauged catchments in the plain region as recommended in the Flood estimation report of 1(f) subzone (para 7 at page 50).Equations furnished in the Report of 1(f) subzone are for derivation of six hourly unit hydrograph.

Six hourly RUGs of 22 catchments lying in the subzone 1(f) have been converted to 1 hour RUG and equations have been derived afresh for development of relationships based on physiography parameters of gauged catchments of subzone 1(f) (Annexure 3.5) and one hour U.G parameters of RUGs of gauged catchments of subzone 1(f) (Annexure 3.6). Table 3.2 shows recommended relationships for plain region .

Table 3.2
(Recommended relationships for plain region)

Relationships 1	Equation No. 2
$q_p = 0.6617\ (L / \sqrt{S})^{-0.515}$	3.4.2.1
$t_p = 1.8833\ (q_p)^{-0.940}$	3.4.2.2
$W_{50} = 1.7897\ (q_p)^{-1.006}$	3.4.2.3
$W_{75} = 0.8955\ (q_p)^{-1.061}$	3.4.2.4
$W_{R50} = 0.5524\ (q_p)^{-1.012}$	3.4.2.5
$W_{R75} = 0.2984\ (q_p)^{-1.012}$	3.4.2.6
$T_B = 12.4755\ (t_p)^{0.721}$	3.4.2.7
$T_m = t_p + t_r /2$	3.4.2.8
$Q_p = q_p \times A$	3.4.2.9

Using the equations given in Table 3.1 and 3.2, two sets of U.Gs were developed for few catchments in hilly region and on reproduction of 4-5 flood events it is seen that the flood obtained using UGs derived from hilly equations are comparable with observed flood events.

Similar studies were carried out for ascertaining suitability of equations for plain region.

Relationships given in Table 3.1 are recommended to estimate the parameters of 1-hour synthetic unitgraph for an ungauged catchment having steep slope similar to the slopes considered in the hilly region of the subzone with its known physiography parameters A, L, Lc and S.

Relationships given in Table 3.2 are recommended to obtain the parameters of 1-hour SUG for an ungauged catchment in plain region having flatter slope.

3.4.3 Derivation of S.U.G of ungauged catchment

The steps for derivation of 1-hour unitgraph are

i) Determine physiography parameters of the ungauged catchment viz A , L,Lc and S from the catchment area plan.

ii) Decide the equations to be adopted, from the set of equations given in Tables 3.1 and 3.2 considering slope of the catchment .

iii) Obtain the value of the unit hydrograph parameter which is related to physiography parameters (tp in case of hilly region and qp in case of plain region) .

iv) Obtain the values of other parameters of unit hydrograph from the computed value of unit hydrograph parameter(tp/qp) from the appropriate equations .

v) Obtain the values of Tm and Qp

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

Sum of discharge ordinates of tr-hr Unitgraph is obtained and compared with the estimates by the following equation:

$$\sum Q_i = \frac{2.78 * A * d}{tr}$$

Where Q_i = discharge ordinates at 1-hour interval (cumecs)
A = catchment area in sq.km.
d = depth of rainfall (1 Cm in present study)
tr = unit duration in hours. (1 hour in present study)

Suitable modifications can be made in falling limb below W_{50} points so that volume of unit hydrograph equals 1cm volume and a smooth unitgraph be drawn.

3.5 Design Loss Rate:

Direct surface runoff is the end product of storm rainfall after infiltration into surface soils, sub-surface and ground besides abstractions like evaporation, evapotranspiration, soil moisture and filling up of surface depressions. It is difficult, rather impossible, to record these various parameters at various representative locations in the catchment except by the analysis of observed storm rainfall and flood events. Conversion of gross storm rainfall units into effective rainfall units for application to unitgraph is normally done by subtraction of constant loss rate (0-index) for the catchment, even though the loss rates in the catchments, a complex phenomena, vary due to soil conditions, soil cover complex and topography alongwith temporal and spatial variations of storm rainfall.

Loss rate (cm/hr) values computed for 46 flood events analysed for 11 bridge catchments are tabulated in Annexure 3.7. The model value of loss rate has been computed as 0.27 cm/hr. It is not possible to compute reliable model value of loss rate for plain region for want of adequate data. The model value of loss rate , 0.30 cm/hr. was obtained on the basis of loss rate values computed for 151 flood events analysed for 23 catchments in subzone - 1(f).

The loss rate of the order of 0.27 cm/hr may be adopted for all the catchments in the subzone. This may, however be modified suitably as per site conditions .

3.6 Design Base Flow :

Base flow values for 46 flood events analysed for 11 catchments in Hilly region tabulated in different ranges are shown in Annex 3.8. Out of 49 flood events, 40 flood events fall under the range of 0.00 - 0.10 cumecs/sq.km. An average value of base flow works out to be 0.05 cumecs/sq.km.

Base flow values of 87 flood events out of 151 flood events of 23 catchments in subzone 1(f) fall in the range of 0.01 tc 0.09 cumecs/sq km, giving an average value of base flow as 0.04 cumecs/sq km.

Base flow value of 0.05 cumecs/sq km is recommended for adoption for ungauged catchments in the subzone.

PART IV

RAINFALL STUDIES

4.1 Introduction :

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

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

4.2 Data collected :

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

4.2.1 Ordinary raingauge (ORG) data (Daily rainfall) of 173 stations, 7 maintained by IMD and 166 maintained by the State Governments, in 20 districts(8 in Bihar,10 in West Bengal and 2 in Orissa) covering the subzone with 9 districts partly outside the subzone. Of these , 129 and 44 stations have respectively 51-70 years and 40-50 years record.

4.2.2 Self recording raingauge (SRRG) data (Hourly rainfall) of 49 stations maintained by IMD in 14 districts (7 in Bihar,5 in West Bengal and 2 in Orissa) with 8 districts partly outside the subzone. Of these 21,8 and 20 stations have respectively 8-19 years (229 stations-years) ,5-7 years (43 station-years) and 1-4 years (43 station- years) record. The upper Damodar Valley (DV) area covered by the subzone provides well distributed SRRG data of 26 stations in 4 districts of Bihar. Of these 15, 6 and 5 stations have respectively 8 - 12 years (153 station-year), 5-7 years(32 station-years) and 1-4 years (12 station-years) record.

4.2.3 Short duration data(Hourly/half Hourly rainfall) of 24 stations in 7 bridge catchments of the subzone specially maintained by RDSO during the period from late fifties to mid sixties.

4.3 Data Used :

The ORG/SRRG data mentioned in paras 4.2.1 and 4.2.2 above available from IMD's National Data Centre have been extensively utilised for analysis. However, the bridge catchment data mentioned in para 4.2.3 procured from RDSO specifically for deriving point to areal rainfall ratios were not usable because these data were not recorded in proper formàt so as to organise and synchronise for obtaining concurrent data series.

4.4 Depth - Duration - Frequency Analysis :

4.4.1 Isopluvial maps

For each of the 173 ORG stations in and around the subzone, a series of annual maximum one-day rainfall was generated. The 173 station series thus formed were subjected to frequency analysis using Gumbel~s extreme value distribution for computing one-day rainfall estimates for 25, 50 and 100-year return periods. These daily rainfall estimates (173 x 3) were converted into any 24-hour rainfall estimates by using the conversion factor of 1.15. For each return period, the 24-hour rainfall estimates for 173 stations were plotted on a base map and isopluvials were drawn. The isopluvial maps of 25,50 and 100- year 24-hour rainfall are shown in Plates 8 ,9 & 10 respectively, which can be used to derive 24 -hour rainfall estimates for specific return periods at any point in the subzone.

4.4.2 Short duration ratios

For each of the 21 SRRG stations having at least 8 years record, the hourly rainfall data were subjected to frequency analysis using partial duration series for computing T-year t-hour rainfall estimates for T= 2,5,10,.25 and 50 years and t = 1,3,6,9,12,15,18 and 24 hours. These estimates (21x8x5) were converted into ratios with respect to the corresponding 24-hours estimates. Average ratios (8x5) for the subzone as a whole (mean of 21 station ratios) were then computed for each T-year t-hour pair. It was noticed that for a specified duration t, the average ratios beyond T = 5 years were comparable in magnitude. As such the average ratios (8) corresponding to 10- year t-hour rainfall have been recommended to be adopted uniformly for converting 24-hour rainfall into t-hour rainfall. These 8 conversion ratios for t =1, 3, 6, 9, 12, 15, 18 and 24 hours given below were plotted on a graph and a smooth curve was drawn as shown in graph at Fig. 10, which can be used to derive conversion ratios for any duration t in general, including the intermediate durations (see Table alongside graph).

Rainfall Duration (t) hours	Conversion ratio = 10-year t-hour rainfall / 10-year 24-hour rainfall
1	0.350
3	0.515
6	0.640
9	0.735
12	0.800
15	0.860
18	0.915
24	1.000

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

4.4.3 Time Distribution Curves

Based on hourly rainfall data of 29 SRRG stations having at least 5 years' record,a total of 4258 rainstorms of durations ranging from 2 to 24 hours were analysed and grouped stationwise into the following 5 categories:

1) rainstorms of 2 to 3- hour duration (1308 of all stations)
2) rainstorms of 4 to 6- hour duration (1208)
3) rainstorms of 7 to 12- hour duration (1072)
4) rainstorms of 13 to 18- hour duration (352)
5) rainstorms of 19 to 24 -hour duration (318)

For each station, 5 different graphs corresponding to each group of rainstorms were prepared by plotting the cumulative percentage of the total storm rainfall against the percentage of the storm duration and the average time distribution curves (29x5)were drawn. Average time distribution curves (5) for the subzone as a whole were then drawn by plotting 29 station curves on the same graph and these are shown in Fig 11, which can be used to derive the time distribution co-efficients of storm rainfall in the subzone for rain storm of any duration. (see Annexure 4.1).

4.4.4 Point to Areal Rainfall Ratios

In all the earlier subzonal studies, on account deficient SRRG network , the short duration bridge data of RDSO was being used to derive the point to areal rainfall ratios. For subzone 3(g), even RDSO had not observed any bridge data and so an alternate method was developed to compute these ratios by making conjunctive use of ORG and SRRG data. In the present study, the availability of a very good SRRG network in the upper Damoder Valley (DV) area made it possible to adopt the best scientific procedure by making use of SRRG data in preference to bridge data .

The hourly rainfall records of 26 SRRG stations in the upper DV area were scanned for storm durations T= 1, 3, 6, 12 and 24 hours to select t-hour representative rainstorms based on considerations of a maximum central value and the available concurrent data indicating an appreciable gradient. Isohyetal maps of 5 representative storms described hereunder were then prepared using concuurrent rainfall values of stations corresponding to the date and time of each representative storm.

Duration (hours)	Representative Storms: Station	Rainfall (mm)	Date & time of occurrence (clock hour)	Concurrent data(no of stations)
1	Dumri	55	3.7.72 (18 - 19)	13
3	Barkhagaon	108	3.6.69 (15 - 18)	14
6	Barkhagaon	123	3.6.69 (15 - 21)	14
12	Konar	119	3.9.70 (11 - 23)	21
24	Padma	208	3-4.9.70 (09 - 09)	21

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

4.5 Heaviest rainfall records :

4.5.1 ORG data The highest ever recorded one-day station rainfall (24 hours rainfall ending 0830 hrs of date) along with date of occurrence in each of the twenty districts covering the subzone 1(g) have been compiled from the ORG data and presented in Annexure 4.3. However, in case of districts with stations recording >/ 35 cm.all such stations have been included. Normal annual rainfall for each selected station is also given in the Annexure 4.3 .

4.5.2 SRRG Data The heaviest storm rainfall in durations of 24, 12 , 6, 3 and 1 hour along with date and time of occurrence in each of the 14 districts covering all the 49 SRRG stations have been compiled from the available autographic records and are presented in Annexure 4.4

4.6 Procedure for design storm rainfall estimation :

For a specified design storm duration T_D hours (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 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 TD from Fig 10 and multiply the 50- year 24-hour point rainfall in step -1 to obtain 50 year TD hour point rainfall.

Step -3 Read the areal reduction factor corresponding to storm duration TD and the given area of catchment from Fig 12 or annexure 4.2 and multiply the 50-year TD- hour point rainfall in Step 2 by this factor to obtain the 50 year TD hour areal rainfall over the catchment.

Step-4 Read the time distribution coefficients for 1, 2........(TD-1) hours correspomding to storm duration TD from relevant graph in Fig. 11 or Ann-4.1 and multiply the 50-year TD - hour areal rainfall in step-3 by these coefficients to obtain the cumulative depths of 1,2,......(TD-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,...... (TD-1) and TD 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:

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

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

a) Indian Railway Standard Bridges substructures and foundation Code revised in 1985 stipulates that all bridges shall be designed with adequate waterway for design discharge. This shall normally be the computed flood with probable recurrence interval of 50 years however at discretion of Chief Engineer/Chief Bridge Engineer,If the bridge damage is likely to have severe consequences,the bridge may be designed for flood with a probable recurrence interval of more than 50 years, while bridges on less important lines of sidings may be designed for floods with a proable 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 water way of a bridge is to be designed for a maximum flood of 50-yr return period. To provide for adequate margin of safety, the foundation and protection works should be designed for larger discharge. The recommended percentage increase over the design discharge specified in clause 103 is same as suggested by the committee of Engineers.

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

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

e) Indian Standards 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 Millon cubic meter or hydraulic head between 7.5 m. and 12 m.

5.2 Estimation of Design Flood by SUG approach :

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:

a) Computation of design flood peak

Step-1 Synthetic unit hydrograph

Derive the synthetic unit hydrograph as per section 3.5 and tabulate 1 hour U.G. ordinates.

Step-2 Design storm duration

The duration of storm,which causes maximum flow in a river at a specified location is called "Design Storm Duration". To obtain Design storm duration for the catchments in the Hilly region of the subzone, flood peaks of 25,50,and 100 year return period for all of the 11 gauged catchments in the Hilly region were computed using different values of TD, ranging between TD=1.1*tp to TD=TB. The computed values of flood peaks are shown in Annexure 5.1. From the Annexure it can be seen that for all the catchments, flood computed flood peaks using TD=1.1*tp were on the higher side than the computed flood peaks using TD=TB.

The value of Design storm Duration for the ungauged catchments located in the catchments of subzone1(f) has been taken to be equal to 1.1 * Tp. As SUG equations developed for subzone 1(f) have been recommended to be applied for the plain region of subzone (1g) also,it is proposed that value of Design Storm Duration for ungauged catchments in the plain region may also be taken to be equal to 1.1 * tp.

Based on the above criteria it is suggested to adopt TD= 1.1 * tp for all the catchments in the subzone.

Step-3 Design storm rainfall :

i) Adopt suitable design storm duration (TD) as explained above.

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

iii) Adopt design loss rate as recommended in section 3.5

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

Step-4

(a) Design flood peak

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

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

(iii) Obtain total surface runoff by summing the product of unit hydrograph ordinates as tabulated in Step 1 and the effective rainfall values as tabulated in Step 3 (iv)

(iv) Obtain flood peak by adding base flow to total surface runoff as per step 4 (111)

b) Design Flood Hydrograph

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

Step-5 Reverse the sequence of effective rainfall units obtained in Step 4(i) to get the critical sequence of the effec- tive rainfall units.

Step-6 Multiply the first 1-hr effective rainfall with the ordinates of U.G. to get the corresponding direct runoff ordinates. Likewise, repeat the procedure with the rest of the hourly effective rainfall values giving a lag of 1-hr to successive direct runoff ordinate.

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

Step-8 Add the base flow as given in Step 4(ii) to the direct runoff ordinates at 1-hr interval in Step-7 to get the 50-yr flood hydrograph.

5.3 Estimation of Design Flood by Simplified Approach:

Simplified approach has been developed for the quick estimation of design flood of 25 ,50,100 year return period. This method is based on the multiple regression correlation of return flood peaks with the physiography parameters which can be directly measured from the topographic maps and T year 24 hrs Point Rainfall. The return period - 24 hour point rainfall for the location in question can be obtained from the isopluvial maps supplied by IMD and appended in the Report. The general form of the equations is given below:

$$Q_T = K * A^a * L^b * S^c * R^d_T \qquad \text{.....................5.3.1}$$

Where,

Q_T	=	T- year flood peak in cumecs
A	=	Catchment area in sq.km
S	=	Equivalent slope in m/km
L	=	Length of longest stream in km
R_T	=	T- year,24 hour point rainfall in cm.
K,a,b,c,and d	=	Constants

5.3.1 Hilly Region

The simplified equations for the hilly region of the subzone have been developed by correlating 25,50 and 100 year flood peaks with the physiography parameters A, S, L and 25, 50 and 100 year - 24 hour point rainfall.The equations are given below:

$$Q_{25} = 0.831 * (A)^{0.883} * (L)^{-0.389} * (S)^{0.132} * (R_{25})^{1.117} \;..$$

r = 0.998 S.E. = 1.059

$$Q_{50} = 1.320 * (A)^{0.871} * (L)^{-0.359} * (S)^{0.106} * (R_{50})^{0.968} \;..$$

r = 0.999 S.E.= 1.046

$$Q_{100} = 0.614 * (A)^{0.889} * (L)^{-0.405} * (S)^{0.109} * R_{100})^{1.220} \;..$$

r = 0.999 S.E. = 1.039

The results of computation of flood peaks by SUG approach and simplified approach for all the 11 bridge catchments are given in the Annexure 5.2

5.3.2 Plain region

There are only 5 gauged catchments in the plain region . This is inadequate for deriving equations for obtaining flood peaks for different return periods .

5.4 Illustrative examples:

For illustrating the procedure to compute 50 yr design flood in hilly and plain regions, two examples one each for hilly and plain region have been worked out and given below

5.4.1 Computation of design flood for hilly region

5.4.1.1 By SUG approach

Particulars of the catchment (Bridge No. 110 , refer Fig. A-1) under study treated as ungauged are given below

i) Name of sub-zone	:	Ganga Plains (1g)
ii) Name of Tributary	:	saphi
iii) Name of Road Section	:	Garwa Rd-Barkakana
iv) Shape of catchment	:	Fan
v) Location	:	Lat 23° 39' 45"
		Long 85° 02' 30"
vi) Topography	:	Steep Slope

Procedure is explained stepwise

Step-1:- Physiography parameters

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

From the catchment area plan, the area of the catchment(A) in sq km and the length of the longest mainstream(L) in km from the farthest catchment boundary to the point of study was measured. Lc, The length of river from the centre of gravity to the point of study was also measured in Km.

Centre of gravity of the catchment was determined at the point of intersection of the plumb lines by holding freely the catchment area plan cut on a card-board. Length of the longest stream opposite to the centre of gravity to the point of study(Lc) was measured in km.

Equivalent stream slope(S) was obtained by graphical method as shown in fig-1 and by analytical method as shown in Annex-5.3

Physiography parameters of the catchment as described in para 3.4.1 were obtained and are given below

1) Area (A)	:	389.76 sq km
2) Length of the longest stream (L)	:	38.29 km
3) Length of the longest stream from a point opposite to C.G. of catchment to point of study (Lc)	:	18.50 km
4) Equivalent stream slope (S) (Refer Annexure 5.3)	:	9.37 m/km

Step-2 1-hr Synthetic Unitgraph

Synthetic Unitgraph Parameters as given below were computed using equations in para 3.4.1.3 and physiography parameters given above.

t_p = 5.5 hour

q_p = 0.432 cumecs/sq.km.

W_{50} = 5.18 hour

W_{75} = 2.65 hour

W_{R50} = 1.91 hour

W_{R75} = 1.15 hour

T_B = 23 hour

T_m = 6 hour

Q_p = 168.38 cumecs/sqkm

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 <Qi x ti = 1082.7 m /s as shown in Fig A-2 and compared with the volume of 1.00 cm Direct Runoff Depth over the catchment, computed from the formula:

$$Q = Axd/ti \times 0.36$$

Where A = Catchment area in Sq. Km.

d = 1.0 cm depth

ti = tr (the unit duration of the UG) = 1 Hr.

$$Q = \frac{A * d}{0.36 * tr} = \frac{389.76 * 1}{0.36 * 1} = 1082.7 \text{ cum/sec}$$

Note - (In case, <Qiti for the unitgraph drawn is higher or lower than the volume of 1 cm, the falling limb of hydrograph may be suitably modified without altering the points of synthetic parameters.)

Step-3 Estimation of Design Storm

(a) Design storm duration

The Design Storm Duration (TD) has been adopted as 1.1 * tp as this value of storm duration gave higher value of flood peak (refer Section 5.2). Rounding of the design storm duration to nearest hour, its value came as 6 hrs.

(b) Estimation of Point Rainfall and Areal Rainfall for storm duration

Catchment under study was located on Plate -9 showing 50-yr 24-hr point rainfall. The point rainfall was found to be 24.00 cm. The Conversion factor of 0.640 was read from Fig - 10 to convert the 50-yr 24-hr point rainfall to 50-yr 6-hr point rainfall (since TD = 6 hrs). 50-yr 6-hr point rainfall was 15.36 cm.

Areal reduction factor of 0.846 corresponding to the catchment area of 389.76 sq.km for TD = 6-hr. was interpolated from Annex.4.2 or Fig 12(a) for conversion of point rainfall to areal rainfall. 50-yr 6-hr areal rainfall thus worked out to be 12.99 cm. The 50-yr, 6-hr areal rainfall was split in to 1-hour rainfall increments using time distribution coefficients given in Annexure 4.1 or Fig 11.

A design loss rate of 0.27 cm /hr as recommended in para 3.5 was applied to get effective rainfall hyetograph.

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

Table -5.1
(Hourly rainfall Increments)

Duration 1	Distribution coefficient 2	Storm rainfall 3 (cm)	Rainfall increments 4 (cm)	Effective rainfall increments 5 (cm)
1	0.57	7.40	7.40	7.13
2	0.74	9.61	2.21	1.94
3	0.86	11.17	1.56	1.29
4	0.93	12.08	0.91	0.64
5	0.97	12.60	0.52	0.25
6	1.00	12.99	0.39	0.12

Step-4 Estimation of Base Flow

Taking design base flow of 0.05 cumecs per sq km as recommended in para 3.6, the base flow was estimated to be 19.49 cumecs for the catchment area of 389.76 sq.km.

Step-5 Estimation of 50-yr Flood

(a) Computation of flood peak

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

Table 5.2
(computation of flood peak)

Time (hrs)	U.G. ordinate (cumecs)	1-hr effec, rainfall (cms)	Direct Runoff (cumecs)
4	74.00	0.12	8.88
5	135.00	1.29	174.15
6	168.40	7.13	1200.69
7	141.00	1.94	273.54
8	113.00	0.64	72.32
9	87.50	0.25	21.87
		Total	1751.45
		Base Flow	19.49
		50-yr Flood Peak	1770.94

(b) **Computation of Design Flood Hydrograph**

Effective rainfall increments shown in col. (3) of Table 2 in Step-5 were reversed to obtain critical sequence as shown in Table-5.3 given below:

Table -5.3
(Critical sequence of rainfall)

Time in hrs	Critical 1-hr effective rainfall sequence cms
1	0.25
2	0.64
3	1.94
4	7.13
5	1.29
6	0.12

For computation of design flood hydrograph, the U.G ordinates were tabulated in col(2) of Annex. 5.4. The critical sequence of effective rainfall increments were entered in col.3 to 8 horizontally. Direct runoff resulting from each of the effective rainfall increments was obtained by multiplying effective rainfall depths with the synthetic U.G. ordinate in col. (2) and direct runoff values were entered in columns against each unit with a successive lag of 1-hr since the unit duration of S.U.G. is 1-hr. Direct runoff values are shown in col (3) to (8). Direct runoff values were added horizontally and total direct runoff is shown in col. (9). Adding total base flow of 19.49 cu. m /sec. (col. 10), design flood hydrograph ordinates as given in (col.11) were obtained with a peak of 1770.94 cu.m/sec. The ordinates given in col. (11) were plotted against time (col. 1) to get the design flood hydrograph as shown in Fig A-3

5.4.1.2 Computation of design flood by simplified approach

Physiography parameters of the bridge No. 110, treated as ungauged, are given below

A = 389.76 sq.km
L = 38.29 km
S = 9.37 mt/km.

The value of point rainfall of 50 year return period is 23.5 cm.

The simplified equation for computing 50 year design flood peak is :

$$Q_{50} = 1.320 * (A)^{0.871} * (L)^{-0.359} * (S)^{0.106} * (R_{50})^{0.968}$$

(Refer para 5.3.1)

Substituting the values of A,L S and R_{50} in the above equation, the value of 50 year design flood peak comes out to be 1772.89 cumecs against the value of 1770.94 cumecs computed by SUG approach.

5.4.2 Computation of design flood for plain region by SUG approach

Particulars of the catchment (bridge no. 237,refer Fig. A-4) under study treated as ungauged are given below

i) Name of sub-zone	Ganga Plains 1(g)
ii) Name of Tributary	Birai
iii) Name of Road Section	Kharagpur - Adra
iv) Shape of catchment	Leaf
v) Location	Lat 23° 05' 24"
	Long 87° 17' 38"
vi) Topography	Flat Slope

Procedure is explained stepwise:

Step-1 determination of physiography parameters

Using method given above to compute design for hilly catchments, following Physiography Parameters were obtained

1) Area (A) 224.29 sq km

2) Length of the longest stream (L) 29.30 km

3) Equivalent stream slope (S) (Refer Annexure 5.6) 1.46 m/km

Synthetic unitgraph parameters computed using equations in para 3.4.2, are given below in Table 5.4

Relationship		value of SUG parameter
q_p	=	0.128 cumecs/Km
t_p	=	13.01 say 13.50 hr
W_{50}	=	15.80 hr
W_{75}	=	7.94 hr
W_{R50}	=	4.43 hr
W_{R75}	=	2.38 hr
T_B	=	81.39 hr say 81 hr
T_m	=	14.0 hr
Q_p	=	28.71 cumecs

Estimated parameters of unitgraph in step-2 were plotted on a graph paper as shown in Fig A-5. 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 <Qi x ti = 28.71 cu. m /s as shown in Fig A-5 and compared with the volume of 1.00 cm Direct Runoff Depth over the catchment, computed from the formula Q = Axd/ti x 0.36

Where A = Catchment area in Sq. Km.

d = 1.0 cm depth

ti = tr (the unit duration of the UG) = 1 hr.

$$Q = \frac{A * d}{0.36 * tr} = \frac{224.29 * 1}{0.36 * 1} = 623.03 \ m^3 /s$$

Note:- (In case, <Qiti for the unitgraph drawn is higher or lower than the volume of 1 cm, the falling limb of hydrograph may be suitably modified without altering the points of synthetic parameters.)

Step-3 Estimation of design storm

(a) Design storm duration

The Design Storm Duration (TD) has been adopted as 1.1 * tp (as this value of storm duration has been used in subzone Report Report 1 (f), refer para 5.2.1). Rounding of the design storm duration to nearest hour, its value came as 15 hrs.

(b) Estimation of point Rainfall and Areal Rainfall for storm duration:

Catchment under study was located on Plate -9 showing 50-yr 24-hr point rainfall. The point rainfall was found to be 29.50 cm. The Conversion factor of 0.86 was read from Fig - 10 to convert the 50-yr 24-hr point rainfall to 50-yr 15-hr point rainfall (since TD = 15 hrs). 50-yr 15-hr point rainfall was 25.37 cm.

Areal reduction factor of 0.931 corresponding to the catchment area of 224.29 sq.km for TD = 15-hr. was interpolated from Annex.4.2 or Fig 12(b) for conversion of point rainfall to areal rainfall. 50-yr 15-hr areal rainfall thus worked out to be 23.62 cm. The 50-yr, 15-hr areal rainfall was split in to 1-hour rainfall increments using time distribution coefficients given in Annexure 4.1 or Fig 11.

A design loss rate of 0.27 cm /hr as recommended in para 3.5 was applied to get effective rainfall hyetograph.

The Table-5.4 given below gives the hourly effective rainfall increments.

Table - 5.4
(Hourly rainfall Increments)

Duration 1	Distribution coefficient 2	Storm rainfall 3 (cm)	Rainfall increments 4 (cm)	Effective rainfall increments 5 (cm)
1	0.28	6.62	6.62	6.35
2	0.44	10.39	3.77	3.50
3	0.56	13.23	2.84	2.57
4	0.63	14.88	1.65	1.38
5	0.69	16.30	1.42	1.15
6	0.74	17.48	1.18	0.91
7	0.79	18.66	1.18	0.91
8	0.82	19.36	0.70	0.43
9	0.85	20.08	0.72	0.45
10	0.88	20.78	0.70	0.43
11	0.91	21.49	0.71	0.44
12	0.94	22.20	0.71	0.44
13	0.96	22.67	0.47	0.20
14	0.98	23.15	0.48	0.21
15	1.00	23.62	0.47	0.20

Step-4 Estimation of Base Flow

Taking design base flow of 0.05 cumecs per sq km as recommended in para 3.6, the base flow was estimated to be 11.21 cumecs for the catchment area of 224.29 sq.km.

Step-5 Estimation of 50-yr Flood

(a) Computation of flood peak

For estimation of the peak discharge, the effective rainfall increments were re-arranged against ordinates such that the maximum effective rainfall is placed against the maximum U.G. ordinate, next lower value of effective rainfall against next lower value of U.G. ordinate and so on, as shown in col. (2) and (3) in Table-5.5. Sum of the product of U.G. ordinates and effective rainfall increments gives total direct surface runoff to which base flow is added to get total peak discharge.

Table -5.5
(50 year flood peak)

Time (hrs)	U.G. ordinate cumecs	1-hr effec. rainfall (cms)	Direct Runoff (cumecs)
11	18.40	0.43	7.91
12	22.30	0.91	20.29
13	26.20	1.38	36.16
14	28.71	6.35	182.31
15	28.40	3.50	99.40
16	27.00	2.57	69.39
17	25.60	1.15	29.44
18	23.00	0.91	20.93
19	22.20	0.45	9.99
20	20.80	0.44	9.15
21	19.40	0.44	8.54
22	18.40	0.43	7.91
23	17.20	0.21	3.61
24	16.20	0.20	3.24
25	15.20	0.20	3.04
		50-yr Flood Peak	511.31
		Add Base flow	11.21
		Total	522.52

(b) Computation of Design Flood Hydrograph:

Effective rainfall increments shown in col. (3) of Table 6 in Step-5 were reversed to obtain critical sequence as shown below in Table 5.6

Table -5.6
(Critical sequence of rainfall)

Time in hrs	Critical 1-hr effective rainfall sequence cms
1	0.20
2	0.20
3	0.21
4	0.43
5	0.44
6	0.44
7	0.45
8	0.91
9	1.15
10	2.57
11	3.50
12	6.35
13	1.38
14	0.91
15	0.43

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

Add the base flow of 11.21 cumecs /km^2 as given in Step 4 to the total direct runoff ordinates at 1-hr interval to get the 50-yr flood hydrograph.

The flood hydrograph thus obtained with a peak of 522.52 cumecs is given in annexure 5 . 6 and shown in Figure A - 6 .

5.5 Computation of design HFL :

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

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

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

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

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

The above procedure pertains to determination of design HFL corresponding to design flood of a river under natural conditions. With the type of structures in position there will generally be a constriction in the waterway. The affect of the constriction by way of raising the design HFL under natural conditions has to be evaluated in the water elevations to arrive at the revised design HFL under constricted conditions. The difference between upstream and downstream water levels corresponding to design flood due to constriction in the waterway may be termed as afflux. There are hydraulic methods for working out the final design HFL due to constriction by the structure. The weir formula or 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/drain in the unfavorable reach i.e. not complying with the usual requirements of gauge site, the design flood elevation may be computed in a straight reach downstream of the crossing and design flood elevation may be worked out by undertaking backwater studies.

PART VI

ASSUMPTIONS, LIMITATIONS AND CONCLUSIONS

6.1 Assumptions:

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

6.1.2 A generalized value of loss rate and base flow is assumed for the hilly and plain region of the subzone 1(g).

6.2 Limitations:

6.2.1 The data of 11 catchments have been considered for developing relationship between unit hydrograph and physiography parameters for deriving SUG of catchments in hilly areas of the subzone.

For want of adequate data, the relations established for subzone 1(f) are recommended for adoption for driving SUG in the plain area of the subzone.

For more reliable relationships the data of more suitable catchments in plain as well as hilly areas of subzone would be desirable.

The base flow and loss rate values for the subzone may have to be suitably modified due to the assumptions explained above. The designer may adopt other suitable values as per site conditions.

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.

6.3 Conclusions :

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

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

6.3.3 25-yr, 50-yr and 100-yr flood may be estimated using design loss rate of 0.27 cm/hr.

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

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ANNEXURE 2.1

LIST OF HYDRO-METEOROLOGICAL SUB-ZONE

SUBZONE	NAME OF SUBZONE (designated earlier)	Name of sub-zone (designated now)	River Basins included in the subzone
1(a)	Luni basin & thar (Luni & other rivers of Rajasthan and Kutch)	Luni	Luni river. Thar (Luni & Other rivers of Rajasthan and Kutch and Banas river)
1(b)	Chambal Basin	Chambal	Chambal river
1(c)	Betwa Basin & Other Tributaries	Betwa	Sind, Betwa and Ken rivers and other South Tributaries of Yamuna
1(d)	Sone Basin and Right Bank Tributaries.	Sone	Sone and Tons rivers and other South Bank Tributaries of Ganga.
1(e)	Punjab Plains including parts of Indus, Yamuna, Ganga and Ramganga Basins.	Upper Indo-Ganga Plains	Lower portion of Indus Ghaggar Sahibi Yamuna, Ganga and Upper portion of Sirsa, Ramganga, Gomti and Sai rivers.
1(f)	Ganga Plains including Gomti, Ghagra, Gandak, Kosi and other.	Middle Ganga Plains	Middle Portion of Ganga, Lower portion of Gomti, Ghagra, Gandak, Kosi and middle portion of Mahanadi
1(g)	Lower Ganga Plains including Subarnarekha and other east-flowing rivers between Ganga and Baitarani.	Lower Ganga Plains	Lower portion of Ganga, Hoogli river system and Subarnarekha.
2(a)	North Brahmaputra Basin	North Brahmaputra	North Bank Tributaries of Brahmaputra river and Balason river.
2(b)	South Brahmaputra Basin	South Brahmaputra	South Bank Tributaries of Brahmaputra river.
2(c)	Barak and others	Barak	Barak, Kalden and Manipur rivers.
3(a)	Mahi, including the dhadhar, Sabarmati and rivers of Saurashtra.	Mahi and Sabarmati	Mahi and Sabarmati including Rupen & Mechha Bandar, Ozat Shetaranji rivers of Kathiawad Peninsula.

3(b)	Lower Narmada and Tapi Basin	Lower Narmada & Tapi	Lower portion of Narmada, Tapi and Dhadhar rivers.
3(c)	Upper Narmada and Tapi Basin	Upper Narmada & Tapi	Upper portion of Narmada 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 penner Basin except coastal region	Krishna	Krishna & Pennner 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 & Godavari rivers.
4(b)	Coromandal Coast including east flowing rivers between Godavari and Kaveri	Lower Eastern Coast	East flowing coastal rivers, Manimukta, South Pennar, Cheyyar, Palar, North Pennar, Munneru, Palleru, Cundalakama and Krishna Delta.
4(c)	Sandy Coroman Belt (east flowing rivers between Cauvery & Kanyakumari).	South Eastern Coast	East flowing coastal rivers, Manimuther, Vaigani, Arjuna, Tamraparni.
5(a)	Konkan coast (west flowing river between Tapi and Panaji)	Konkan Coast	West flowing coastal rivers between Tapi and Maudavi rivers
5(b)	Malabar Coast (west flowing rivers between Kanyakumari and Panaji)	Malabar Coast	West flowing coastal rivers between Mandavi and Kanyakumari
6	Andaman and Nicobar	Andaman & Nicobar	
7	J & K Kumaon Hills (indus Basin).	Western Himalayas	Jhelum, Upper portion of Indus, Ravi and Beas rivers

LIST OF BRIDGE CATCHMENTS

Sl.No.	Name of Stream	Name of Section	Bridge No	Location Deg.	Min.	Sec.	Deg.	Min.	Sec.	Catchment Area Sq.Km.	No. of rain gauges	Data Availability	No. of years
(A)	BRIDGES IN HILLY REGION												
i)	BRIDGES CONSIDERED FOR REGRESSION ANALYSIS												
1	Barsati	Grand Chord	167	85	50	48	24	13	00	569.80	5	57-69	13
2	Saphi	Garwa Rd_Barkakana	110	85	02	30	23	39	45	389.76	3	66-67	2
3	Kupan Nadi	Kharagpur Tatanagar	94	86	52	29	29	32	30	336.70	4	61-66	6
4	Katra	Rupsa	101	86	36	00	22	09	23	244.24	3	59,66	2
5	Khera	Grand Chord	160	85	52	20	24	11	40	164.18	2	60-66,82-91	17
6	Sanhua	Rajkherswan-Rourkela	286	85	48	00	22	43	24	133.38	2	66-67,75	3
7	Bamni	Sini-Adra	656	86	37	50	24	32	30	83.48	2	61-66	7
8	Darua	Main-Line	114	87	05	28	22	24	30	28.90	2	61-64	4
9	Kasai	Kharagpur-Tata	150	85	54	51	24	07	54	27.38	1	58,60-66	8
10	Bakra	Grand Chord	676	86	33	50	24	41	20	92.38	2	66,70-75	7
11	Bamni	Sini- Adra	348	86	07	00	22	58	00	87.41	2	67	1
ii)	BRIDGES NOT CONSIDERED FOR REGRESSSION												
12	Jamunia	Barkakana-Loop	10	86	12	00	23	45	00	853.56	5	66-67,69	3
13	Hingla	Ondal-Sainthia Chord	49	87	20	00	23	45	00	393.68	4	60-62,65-67	6
14	Bhera	Muri-Barkakana	562	85	41	58	23	32	47	147.09	2	65-66	2
15	Saphi	Garwa-Rd-	155	84	50	00	23	39	00	127.78	1	66-67	2
16	Bakereshwar	Barkakana	75	87	26	00	23	49	00	116.34	2	66-67	2
17	Nainikhal	Barabani Loop	35							70.20	1	58-60-61,63-66,68	8
18	Chandrengd	Ondal Sainthia	94(s)							64.38	1	66-67	2
19	Jhapri	Sahibganj - Loop	294							34.84	1	65	1
20	Kasai	Adra - Asansol	502	86	47	25	23	35	26	28.68	1	61-65	5
B)	BRIDGES IN PLAIN REGION												
21	Torai	Sahibganj Loop	236	87	51	00	24	39	00	492.10	5	58,60-68	10
22	Birai	Kharagpur-Adra	237							224.29	3	58,61	2
23	Tamal	Kharagpur-Adra	181	87	19	30	22	38	10	212.90	5	58,65-67	4
24	Singharin	Rani Ganj-Waria	436	87	13	14	23	33	40	154.08	3	66-68	3
25	Ajoy	OndalSainthia Chord	42										
C)	BRIDGES HAVING CATCHMENT AREA <25 sq.km. in Hilly Region.												
26	Joucery	Kastha Branch	101	87	05	40	23	49	08	20.02	1	60-66	7
27	Kursa	Barkakana Loop	27	85	20	25	23	38	45	15.16	1	60-66	7
28	Kursa	Giridih Branch	12							10.79	1	62,65	2
29	Lakhanpur	Giridih Branch	23	86	25	32	24	14	30	8.58	1	62-64	3

SUBZONE 1(g) ANNEXURE 3.2

BASIN CHARACTERISTICS OF SELECTED CATCHMENTS IN HILLY REGION

Sl.No.	Bridge No.	Area Sq.km.	L Km.	Lc Km.	S m/Km.
1	167	569.80	54.00	24.94	2.01
2	110	389.76	38.29	18.50	9.37
3	94(b)	336.70	33.47	17.70	2.61
4	101(b)	244.24	45.05	20.11	5.93
5	160	164.18	31.86	15.45	4.80
6	286	133.38	35.40	16.57	7.40
7	676	92.38	18.99	6.84	3.86
8	348	87.41	19.71	10.46	9.29
9	656	83.48	20.19	9.65	2.54
10	114	28.90	9.25	3.22	5.45
11	150	27.38	10.57	5.63	5.29

SUBZONE-1(g)

ANNEXURE-3.3

1-Hr RUG parameters of catchments in hilly region

SL.No.	Bridge No.	tp Hr.	qp Cumec/S	Qp Cumecs	TB Hr.	W50 Hr.	W75 Hr.	WR50 Hr.	WR75 Hr.
1	167	8.50	0.25	144.80	34	9.4	4.8	3.4	2.1
2	110	4.50	0.43	166.20	24	4.6	2.5	1.4	0.9
3	94b	9.50	0.27	92.00	28	9.0	4.6	3.6	2.3
4	101b	5.50	0.58	141.30	20	3.5	1.6	1.0	0.6
5	160	7.50	0.45	73.80	26	4.8	2.4	1.6	0.8
6	286	6.50	0.27	35.60	35	7.1	3.4	2.8	1.8
7	676	2.50	0.93	85.50	11	2.4	1.3	1.2	0.8
8	340	5.50	0.41	35.60	27	5.4	2.5	2.2	1.1
9	656	2.50	0.66	55.40	15	2.7	1.4	0.8	0.6
10	114	3.50	0.59	17.00	14	3.8	2.3	1.7	1.1
11	150	2.50	1.31	36.90	9	3.2	2.0	1.3	0.8

SUBZONE1(g) ANNEXURE - 3.4

PHYSIOGRAPHY AND UNIT HYDROGRAPH PARAMETERS STUDIED TO ESTABLISH THEIR RELATIONS

Sl.No	Dependant Variable	Independant Variable	A	B	R
1	*tp	$L*Lc/S^{0.5}$	1.1808	0.285	0.72
2	tp	A	0.82	0.36	0.70
3	qp	$L*Lc/^{0.5}$	2.05	-0.29	0.59
4	qp	A	3.09	0.38	0.70
5	*qp	tp	2.0972	-0.927	0.88
6	W50	$L*Lc/S^{0.5}$	2.05	0.29	0.59
7	W50	A	1.16	0.28	0.63
8	*W50*	tp	1.2622	0.828	0.90
9	W75	$L*Lc/S^{0.5}$	1.06	0.17	0.71
10	W75	A	0.80	0.22	0.57
11	*W75	tp	0.7896	0.711	0.82
13	WR50	$L*L^{c0.5}$	2.05	0.29	0.59
14	WR50	A	0.65	0.20	0.43
15	*WR50	tp	0.5357	0.745	0.77
17	WR75	$L*L^{c0.5}$	0.54	0.14	0.41
18	WR75	A	0.42	0.19	0.43
19	*WR75	tp	0.3825	0.647	0.68
22	*TB	tp	5.5830	0.824	0.90

NOTE - "A" stands for Constant

"B" stands for Regreesion Coefficient

"R" stands for Corelation Coefficient

* Relations recommended for adoption

subzone 1(f)

ANNEXURE - 3.5

Basin characteristics of selected catchments

Sl. No.	Bridge No.	C.A. Sq.Km.	L. Km.	S m/km.	$\frac{L}{\sqrt{S}}$
1	2	3	4	5	6
1	6	4479.10	286.58	0.62	363.96
2	79A	2472.40	227.20	0.126	640.06
3	177	712.25	66.00	0.140	176.39
4	7	673.40	110.50	0.125	312.54
5	187	670.39	53.43	0.145	140.31
6	30	447.76	56.83	1.79	42.48
7	152	299.53	27.03	0.048	123.37
8	48	234.11	40.63	5.099	17.99
9	33	192.40	35.82	0.258	70.52
10	18	180.40	43.47	0.144	114.55
11	3(i)	146.70	34.00	0.344	57.97
12	85	136.70	20.53	0.276	39.08
13	20	130.00	45.00	0.70	53.79
14	9	122.24	28.96	0.319	51.27
15	66	72.26	14.89	0.65	18.47
16	24	69.75	15.00	0.78	16.98
17	141	59.83	41.06	0.31	73.75
18	59	54.39	18.02	0.583	23.60
19	459	48.07	10.14	1.36	8.69
20	23	47.91	12.33	0.467	18.04
21	31	39.30	7.75	1.37	6.62
22	4	34.05	13.06	0.35	22.08
23	3	32.89	6.84	0.53	9.40
24	55	32.37	13.15	0.72	15.50
25	63	30.56	9.65	1.203	8.80

ONE HOUR R U G PARAMETERS Of CATCHMENTS OF SUBZONE 1(f)

Sl.no	Bridge No.	C. A. (sq.km)	Qp (cumecs)	tp (hrs)	TB (hrs)	W50 (hrs)	W75 (hrs)	WR50 (hrs)	WR75 (hrs)
1	6	4479.10	300.00	43.5	140	32.5	18.5	14.0	7.5
2	79(A)	2472.40	49.80	75.5	360	117.0	60.0	39.0	21.0
3	177	712.25	38.80	71.5	211	36.5	19.0	14.0	6.5
4	7	673.40	26.80	43.5	204	59.0	28.0	22.0	12.0
5	187	670.39	15.20	67.5	282	108.0	57.0	32.0	21.0
6	30	447.76	60.00	9.5	72	12.2	6.0	4.7	2.5
7	152*	299.53	-	-	-	-	-	-	-
8	48	234.11	141.00	5.5	17	3.5	1.7	1.5	0.7
9	33	192.40	11.40	7.5	140	37.0	15.5	4.5	2.5
10	18	180.40	13.50	13.5	122	18.5	9.5	2.5	1.5
11	3(i)	146.70	14.00	15.5	114	17.5	8.5	3.5	2.0
12	85	136.70	17.10	9.5	110	12.2	6.0	3.0	1.5
13	20	130.00	8.00	24.5	98	42.5	23.5	12.5	6.5
14	9	122.24	4.98	49.5	164	62.5	27.0	18.5	7.8
15	66	72.26	8.30	24.5	115	19.1	10.0	6.0	4.8
16	24 *	69.75	-	-	-	-	-	-	-
17	141	59.83	3.06	26.5	150	47.0	23.5	7.0	3.0
18	59	54.39	5.50	24.5	115	18.1	9.2	5.6	2.7
19	459	48.07	9.50	6.5	33	12.6	7.8	4.3	3.0
20	23	47.90	6.30	18.5	120	13.0	6.2	3.7	2.0
21	31	39.30	10.00	10.5	36	8.0	3.8	2.8	1.2
22	4 *	34.05	-	-	-	-	-	-	-
23	3	32.89	3.54	12.5	92	18.5	10.5	6.5	4.0
24	55	32.37	4.88	6.5	50	15.2	7.2	2.8	1.4
25	63	30.56	12.00	2.5	23	5.3	2.5	1.1	0.7

Note * Bridges not considered for development of SUG equations

SUBZONE - 1(g) ANNEXURE - 3.7

Loss Rate (cm/hr) ranges for observed floods in hilly region

SL.No.			Bridge No.	167	110	94	101	160	286	348	656	114	150	
			C.A sq.Km.	589.70	389.76	336.70	244.24	164.18	133.38	87.41	83.48	28.90	27.38	
Loss Rate Ranges				Number of flood events										Total
SL	LB	UB												
1	0	0.10												
2	0.11	0.30			7			1	2			3		13
3	0.31	0.50		3	2					2		1		8
4	0.51	0.70			1	1		1			1		1	5
5	0.71	0.90				1				1			1	3
6	0.91	1.10					1			1	1	1		4
7	1.11	1.30						1		1			1	3
8	1.31	1.50					2					1		3
9	1.51	1.70					1		2			1		4
10	1.71	1.90												
11	1.91	2.10												
12	2.11	2.30									2			2
13	2.31	2.50												
14	2.51	2.70												
15	2.71	2.90												
16	2.91 & above						1							1
				3	10	2	5	3	4	5	4	7	3	46

$$\text{Modal Loss Rate} = \frac{Li+(FM - F1) * (W)}{(2FM - F1 - F2)} = 0.27 \text{ Cumecs/sq.km.}$$

Where

Li = Lower limit of the modal class

FM = Frequency of the modal class

F1 = Frequency of the class preceeding the modal class

F2 = Freuency of the class succeeding the modal class

W = Width of the modal class

SUBZONE - 1(g) ANNEXURE - 3.8

Base Flow (cumec/sq.km.) ranges for observed floods in hilly region

SL.No.	Bridge No.	167	110	94	101	160	286	348	656	114	150	
	C.A sq.Km.	589.70	389.76	336.70	244.24	164.18	133.38	87.41	83.48	28.90	27.38	
Base Flow Ranges SL . LB UB		Number of flood events										Total
1 0 0.10		3	9	2	4	3	4	1	4	7	3	40
2 0.11 0.20			1					4				5
3 0.21 0.30												-
4 0.31 0.40										1		1
5 0.40 & above												
Col. Total		3	10	2	4	3	4	5	4	8	3	46

$$\text{Modal Base flow} = \frac{Li+(FM - F1) * (H)}{(2FM - F1 - F2)} = 0.05 \text{ Cumecs/sq.km.}$$

Where
Li = Lower limit of the modal class
FM = Frequency of the modal class
F1 = Frequency of the class preceeding the modal class
F2 = Freuency of the class succeeding the modal class
H = Width of the modal class

ANNEXURE..4·I

TIME DISTRIBUTION CO-EFFICIENTS OF CUMULATIVE HOURLY RAINFALL - SUBZONE 1(g)

INTER-MEDIATE HOURS	DESIGN STORM DURATION (HOURS)																							INTER-MEDIATE HOURS
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1	0.88	0.79	0.66	0.61	0.57	0.50	0.47	0.44	0.42	0.40	0.38	0.31	0.30	0.28	0.27	0.25	0.24	0.22	0.22	0.22	0.21	0.20	0.20	1
2	1.00	0.94	0.86	0.79	0.74	0.68	0.63	0.61	0.60	0.55	0.53	0.48	0.46	0.44	0.43	0.41	0.40	0.38	0.35	0.34	0.33	0.32	0.31	2
3		1.00	0.95	0.91	0.86	0.79	0.75	0.72	0.69	0.66	0.63	0.59	0.57	0.56	0.53	0.52	0.50	0.46	0.44	0.42	0.42	0.41	0.40	3
4			1.00	0.96	0.93	0.86	0.83	0.80	0.77	0.74	0.72	0.66	0.64	0.63	0.62	0.60	0.58	0.53	0.51	0.50	0.50	0.47	0.46	4
5				1.00	0.97	0.92	0.89	0.85	0.83	0.80	0.79	0.72	0.70	0.69	0.67	0.65	0.64	0.59	0.58	0.56	0.55	0.54	0.52	5
6					1.00	0.96	0.93	0.90	0.88	0.85	0.83	0.79	0.76	0.74	0.72	0.70	0.69	0.65	0.63	0.61	0.60	0.59	0.57	6
7						1.00	0.97	0.94	0.92	0.89	0.87	0.82	0.80	0.79	0.76	0.75	0.73	0.69	0.67	0.66	0.64	0.63	0.61	7
8							1.00	0.97	0.95	0.92	0.90	0.86	0.84	0.82	0.80	0.79	0.77	0.73	0.71	0.70	0.68	0.67	0.65	8
9								1.00	0.98	0.95	0.93	0.90	0.88	0.85	0.84	0.82	0.81	0.76	0.75	0.74	0.72	0.71	0.69	9
10									1.00	0.98	0.96	0.93	0.91	0.88	0.87	0.85	0.84	0.79	0.78	0.77	0.75	0.74	0.72	10
11										1.00	0.98	0.96	0.94	0.91	0.90	0.88	0.87	0.82	0.81	0.80	0.78	0.77	0.75	11
12											1.00	0.98	0.96	0.94	0.92	0.91	0.89	0.85	0.84	0.83	0.81	0.80	0.79	12
13												1.00	0.98	0.96	0.94	0.93	0.91	0.88	0.87	0.85	0.84	0.82	0.81	13
14													1.00	0.98	0.96	0.95	0.93	0.90	0.89	0.87	0.86	0.84	0.83	14
15														1.00	0.98	0.97	0.95	0.92	0.91	0.89	0.88	0.86	0.85	15
16															1.00	0.99	0.97	0.94	0.93	0.91	0.90	0.88	0.87	16
17																1.00	0.99	0.96	0.95	0.93	0.92	0.90	0.89	17
18																	1.00	0-98	0-97	0-95	0-94	0-92	0.91	18
19																		1.00	0.99	0.97	0.96	0.94	0.93	19
20																			1.00	0.99	0.98	0.96	0.95	20
21																				1.00	0.99	0.98	0.97	21
22																					1.00	0.99	0.98	22
23																						1.00	0.99	23
24																							1.00	24

ANNEXURE-4.2

AREAL REDUCTION FACTORS (%) FOR POINT TO AREAL RAINFALL

SUBZONE - 1(g)

CATCHMENT AREA (sq.km.)	DESIGN STORM DURATION (HOURS)																								CATCHMENT AREA (sq.km.)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0000	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0000
50	94.00	95.25	96.50	96.92	97.33	97.75	97.79	97.83	97.87	97.92	97.96	98.00	98.06	98.12	98.19	98.25	98.31	98.38	98.44	98.50	98.56	98.62	98.69	98.75	50
100	89.00	91.25	93.50	94.25	95.00	95.75	95.83	95.92	96.00	96.08	96.17	96.25	96.38	96.50	96.62	96.75	96.88	97.00	97.12	97.25	97.37	97.50	97.62	97.75	100
150	85.50	88.00	90.50	91.58	92.67	93.75	93.92	94.08	94.25	94.42	94.58	94.75	94.92	95.08	95.25	95.42	95.58	95.75	95.92	96.08	96.25	96.42	96.58	96.75	150
200	82.75	85.38	88.00	89.25	90.50	91.75	91.96	92.17	92.37	92.58	92.79	93.00	93.23	93.46	93.69	93.92	94.15	94.37	94.60	94.83	95.06	95.29	95.52	95.75	200
250	80.00	82.75	85.50	86.92	88.33	89.75	90.08	90.42	90.75	91.08	91.42	91.75	92.00	92.25	92.50	92.75	93.00	93.25	93.50	93.75	94.00	94.25	94.50	94.75	250
300	77.75	80.38	83.00	84.58	86.17	87.75	88.21	88.67	89.12	89.58	90.04	90.50	90.77	91.04	91.31	91.58	91.85	92.12	92.40	92.67	92.94	93.21	93.48	93.75	300
350			80.75	82.50	84.25	86.00	86.58	87.17	87.75	88.33	88.92	89.50	89.79	90.08	90.38	90.67	90.96	91.25	91.54	91.83	92.12	92.42	92.71	93.00	350
400			78.75	80.58	82.42	84.25	84.96	85.67	86.37	87.08	87.79	88.50	88.81	89.12	89.44	89.75	90.06	90.37	90.69	91.00	91.31	91.62	91.94	92.25	400
450			76.75	78.67	80.58	82.50	83.33	84.17	85.00	25.83	86.67	87.50	87.83	88.17	88.50	86.83	89.17	89.50	89.83	90.17	90.50	90.83	91.17	91.50	450
500			75.00	77.00	79.00	81.00	81.92	82.23	83.75	84.67	85.58	86.50	86.88	87.25	87.62	89.00	88.37	88.75	89.12	89.50	89.87	90.25	90.62	91.00	500
600												85.00	95.42	85.83	86.25	86.67	87.08	87.50	87.92	88.33	88.75	89.17	89.58	90.00	600
700												83.50	83.96	84.42	84.87	85.33	85.79	86.25	86.71	87.17	87.62	88.08	88.54	89.00	700
800												82.50	82.98	83.46	83.94	84.42	84.90	85.37	85.85	86.33	86.81	87.29	87.77	88.25	800
900												81.50	82.00	82.50	83.00	83.50	84.00	84.50	85.00	85.50	86.00	86.50	87.00	87.50	900
1000												80.50	81.02	81.54	82.06	82.58	83.10	83.62	84.15	84.67	85.19	85.71	86.23	86.75	1000
1100												79.50	80.04	80.58	81.12	81.67	82.21	82.75	83.29	83.83	84.37	84.92	85.46	86.00	1100
1200												78.50	79.06	79.62	80.19	80.75	81.31	81.87	82.44	83.00	83.56	84.12	84.69	85.25	1200
1300																								84.75	1300
1400																								84.25	1400
1500																								83.75	1500
2000																								81.75	2000

ANNEXURE-4.3.

Statistics of Heaviest Daily Rainfall & annual normal rainfall in subzone 1 (g).

State/ District.		Station	Heaviest ≥35 cm	Rainfall <35 cm	Date of occurrence	Annual Normal R/F in cm
1		2	3	4	5	6
	WEST BENGAL					
1.	Birbhum	1. Suri	67.3	-	01.07.1866	140.9
		2. Murarai	42.2	-	10.09.1902	137.0
		3. Hetampur	39.0	-	13.06.1875	135.2
		4. Labpur	36.0	-	25.09.1956	119.5
2.	Bankura	5. Taldangra	59.9	-	10.08.1950	153.7
3.	Midnapore	6. Contai	44.7	-	03.09.1967	170.2
4.	Purulia	7. Purulia	43.9	-	18.06.1898	135.8
5.	24-Parganas	8. Diamond-Harbour	42.5	-	20.09.1900	161.8
		9. Dum Dum	38.3	-	06.06.1984	157.8
		10.Barrackpore	37.8	-	22.09.1878	150.3
		11.Sandheads	37.4	-	14.07.1972	117.2
		12.Alipore	37.0	-	28.09.1978	160.6
		13.Sagar Islands	35.9	-	05.06.1927	180.9
6.	Hoogly	14.Serampore	42.3	-	21.09.1900	155.6
7.	Burdwan	15.Mangalkot	39.1	-	26.09.1956	120.1
8.	Howrah	16.Howrah	35.7	-	20.09.1900	153.5
9.	Murshidabad	17.Lalbagh	-	30.4	19.08.1902	146.2
10.	Nadia	18.Krishnagar	-	29.4	20.10.1900	143.9
	ORISSA					
11.	Balasore	19.Balasore	39.9	-	18.07.1987	158.6
		20.Jaleswar	39.4	-	23.07.1894	137.4
		21.Balipal	37.2	-	18.10.1946	150.8
12.	Mayur Bhanj	22.Rairangpur	-	27.4	30.07.1927	164.7

1	2	3	4	5	6
BIHAR					
13. Santhal Parganas	23.Mahagama	39.7	-	24.09.1899	108.4
14. Monghyr	24.Jamalpur	37.1	-	29.08.1914	126.8
	25.Gidhaur	36.8	-	13.06.1949	127.9
	26.Monghyr	35.2	-	22.08.1870	112.9
15. Hazaribagh	27.Bagodar	36.0	-	09.07.1974	124.7
16. Singhbhum	28.Majhgaon	35.7	-	30.07.1927	147.8
17. Bhagalpur	29.Bhagalpur	35.3	-	25.09.1965	109.3
18. Palamau	30.Balumath	-	31.6	19.07.1949	138.6
19. Dhanbad	31.Dhanbad	-	27.2	08.08.1913	128.9
20. Ranchi	32.Silli	-	23.6	18.06.1898	134.9

Note: Districts underlined are partly outside the subzone.

ANNEXURE..4.4

Heaviest 24 hours' & shorter durations' rainfall recorded in Subzone 1(g)

State/ District		SRRG Station	Highest Storm Rainfall (mm) & Duration (hrs.)	Date & Time of Occurence (Clock hr.)
(1)		(2)	(3)	(4)
BIHAR				
1. Palamau (2)	1.	Chandwa	389 (24)	16-17.9.76 (01-01)
			230 (12)	(15-03)
			140 (6)	16.9.76 (18-24)
	2.	Khalari	97 (3)	15.6.77 (16-19)
			60 (1)	(16-17)
2. Hazaribagh (16)	3.	Sillaichak	332 (24)	16-17.9.76 (23-23)
			231 (12)	(22-10)
			164 (6)	(22-04)
	4.	Tialiya	127 (3)	9.8.70 (07-10)
	5.	Palganj	100 (1)	18.9.78 (09-10)
3. Dhanbad (7)	6.	Rajdaha	285 (24)	16-17.7.75 (23-23)
	7.	Dhanbad	187 (12)	27.9.75 (00-12)
			162 (6)	26.9.78 (18-24)
	8.	Panchet Hill	154 (3)	9.8.69 (02-05)
	9.	Chandankiary	80 (1)	16.6.77 (13-14)
4. Bhagalpur (1)	10.	Sabour*	208 (24)	21-22.4.71 (07-07)
			197 (12)	(15-03)
			160 (6)	21.4.71 (15-21)
			98 (3)	(18-21)
			52 (1)	19.5.71 (15-16)
5. Ranchi (2)	11.	Mandar	194 (24)	5-6.8.71 (22-22)
			182 (12)	(20-08)
			176 (6)	(23-05)
			171 (3)	6.8.71 (01-04)
			99 (1)	(01-02)
6. Singhbhum (4)	12.	Jamshedpur(A)	193 (24)	4-5.8.77 (14-14)
			176 (12)	(21-09)
			169 (6)	5.8.77 (03-09)
			184 (3)	(03-06)
	13.	Ghatsila*	100 (1)	25.7.79 (17-18)
7. Monghyr (1)	14.	Jamui	67 (24)	11-12.9.72 (07-07)
			47 (12)	(17-05)
			37 (6)	(23-05)
			35 (3)	12.7.72 (12-15)
			35 (1)	(12-13)

Contd.....

(1)		(2)	(3)	(4)
	WEST BENGAL			
8.	24-Parganas (2)	15. Dum Dum	417 (24)	5-6.6.84 (06-06)
			271 (12)	(19-07)
			207 (3)	25-26.8.84 (23-02)
			100 (1)	24.8.87 (06-07)
		16. Alipore	236 (6)	27.9.78 (04-10)
9.	Burdwan (3)	17. Durgapur	388 (24)	26-27.9.78 (09-09)
			308 (12)	(20-08)
			202 (6)	(21-03)
			121 (3)	26.9.78 (21-24)
			86 (1)	29.7.75 (18-19)
10.	Birbhum (1)	18. Shanti Niketan	356 (24)	26.9.78 (00-24)
			268 (12)	26-27.9.78 (21-02)
			190 (6)	27.9.78 (01-07)
			135 (3)	15.4.75 (17-20)
			100 (1)	9.12.71 (00-01)
11.	Bankura (1)	19. Bankura*	185 (24)	29.9.71 (00-24)
			128 (12)	28-29.9.71 (22-10)
			124 (6)	29.9.71 (00-06)
			89 (3)	(00-03)
			45(1)	7.8.71 (08-09)
12.	Purulia (1)	20. Purulia*	97 (24)	16-17.7.71 (03-03)
			76 (12)	6.7.71 (05-18)
			66 (6)	(07-13)
			51 (3)	30.5.71 (15-18)
			43(1)	15.8.71 (00-01)
	ORISSA			
13.	Balasore (3)	21. Akhuapada	232 (24)	26-27.8.78 (16-16)
			225 (12)	27.8.78 (03-15)
			200 (6)	(08-14)
			200 (3)	26.7.76 (04-07)
			100 (1)	(05-06)
14.	Mayurbhanj (5)	22. Baripada*	187 (24)	11-12.9.76 (01-01)
			150 (12)	11.9.76 (09-21)
			136 (6)	(10-16)
		23. Bangriposhi*	100 (3)	8.7.77 (08-11)
			100 (1)	(08-09)

Note:-

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

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

SUBZONE 1(g)

ANNEXURE 5.1

COMPUTED FLOOD PEAKS (CUMECS) USING TD = TB and TD= 1.1 * tp

Sl.No.	Bridge No.	TD = 1.1*tp			TD = TB		
		Q25	Q50	Q100	Q25	Q50	Q100
1	167	1502.64	1843.06	2195.24	1473.61	1841.80	2212.26
2	110	1731.71	1770.94	2055.71	1680.22	1721.14	2012.42
3	94 (B)	1281.60	1503.33	1618.15	1238.67	1466.80	1584.61
4	101 (B)	1003.42	1209.77	1330.35	955.33	1163.66	1284.85
5	160	679.40	829.80	980.80	617.57	764.00	910.44
6	286	561.80	685.80	795.10	506.73	626.46	731.22
7	676	634.30	663.00	763.70	614.28	643.17	744.28
8	348	548.10	619.10	715.40	484.83	600.65	697.17
9	656	491.20	513.20	591.20	448.88	470.48	546.07
10	114	233.10	273.00	329.00	230.66	271.70	310.45
11	150	216.14	262.40	308.30	213.37	259.88	306.40

SUBZONE - 1(g) ANNEXURE - 5.2

Flood peaks computed by SUG approach and simplified approach

SL.No.	Bridge No.	Q25		Q50		Q100	
		SUG eqns.	simple eqns.	SUG eqns.	simple eqns.	SUG eqns.	simple eqns.
1	167	1502.64	1480.41	1843.06	1852.67	2195.24	2168.45
2	110	1731.71	1776.50	1770.94	1772.89	2055.71	2058.29
3	94	1281.60	1323.68	1503.33	1545.09	1618.15	1681.42
4	101	1003.42	1024.38	1209.77	1209.77	1330.35	1345.39
5	160	679.40	679.94	829.80	830.12	980.80	976.26
6	286	561.80	575.51	685.80	698.65	795.10	798.05
7	676	634.30	582.79	663.80	603.91	763.70	705.16
8	656	491.20	492.39	513.20	517.36	591.20	600.51
9	348	548.10	507.32	619.10	611.08	715.40	712.14
10	114	243.20	248.47	273.00	286.46	329.00	333.49
11	150	216.14	217.93	262.40	261.81	308.30	313.79

SUBZONE - 1(g) ANNEXURE 5.3

COMPUTAION OF EQUIVALENT SLOPE OF BRIDGE CATCHMENT NO-110
IN HILLY REGION

SL. No.	REDUCED DISTANCE RD (Mile)	REDUCED LEVEL RL (feet)	LENGTH OF EACH SEGMENT Li (Mile)	HEIGHT ABOVE DATUM Di (feet)	(Di-1+Di) (feet)	Li*(Di-1+Di) Mile*feet
1	0.00	1250.00	0.00	0.00	0.00	0.00
2	3.00	1400.00	3.00	150.00	150.00	450.00
3	4.00	1450.00	1.00	200.00	350.00	350.00
4	7.20	1750.00	3.20	500.00	700.00	2240.00
5	9.00	1800.00	1.80	550.00	1050.00	1890.00
6	10.20	1850.00	1.20	600.00	1150.00	1380.00
7	11.50	1900.00	1.30	650.00	1250.00	1625.00
8	13.10	1950.00	1.60	700.00	1350.00	2160.00
9	15.30	2000.00	2.20	750.00	1450.00	3190.00
10	18.10	2050.00	2.80	800.00	1550.00	4340.00
11	19.30	2100.00	1.20	850.00	1650.00	1980.00
12	20.70	2150.00	1.40	900.00	1750.00	2450.00
13	21.80	2200.00	1.10	950.00	1850.00	2035.00
14	23.50	2250.00	1.70	1000.00	1950.00	3315.00
15	23.80	2260.00	0.30	1010.00	2010.00	603.00
						28008.00

$$S = \frac{Li*(Di-1+Di)}{L^2} = \frac{28008.00}{566.44} = 49.45 \text{ ft./mile}$$

$$= 9.37 \text{ Mt/Km}$$

DATUM = 236.28M , i.e. R.L of river bed at point of study.

Subzone - 1(g) ANNEXURE 5.4

Computation of Design Flood Hydrograph Using SUG Equations of Bridge No. 110 (Hilly Region)

TIME HRS.	S.U.G ORDINATES CUMECS	RAINFALL EXCESS IN CMS 0.25	0.64	1.94	7.13	1.29	0.12	TOTAL D.S.R.O. IN CUMECS	BASE FLOW IN CUMECS	TOTAL FLOW IN CUMECS
		DIRECT RUNOFF (CUMECS)								
1	2	3	4	5				6	7	8
1	0.00	0.00						0.00	19.49	19.49
2	5.00	1.25	0.00					1.25	19.49	20.74
3	13.00	3.25	3.20	0.00				6.45	19.49	25.94
4	28.00	7.00	8.32	9.70	0.00			25.02	19.49	44.51
5	74.00	18.50	17.92	25.22	35.65	0.00		97.29	19.49	116.78
6	135.00	33.75	47.36	54.32	92.69	6.45	0.00	234.57	19.49	254.06
7	168.40	42.10	86.40	143.56	199.64	16.77	0.60	489.07	19.49	508.56
8	141.00	35.25	107.78	261.90	527.62	36.12	1.56	970.23	19.49	989.72
9	113.00	28.25	90.24	326.70	962.55	95.46	3.36	1506.56	19.49	1526.05
10	87.50	21.88	72.32	273.54	1200.69	174.15	8.88	1751.46	19.49	1770.95
11	70.00	17.50	56.00	219.22	1005.33	217.24	16.20	1531.49	19.49	1550.98
12	54.50	13.63	44.80	169.75	805.69	181.89	20.21	1235.96	19.49	1255.45
13	44.50	11.13	34.88	135.80	623.88	145.77	16.92	968.37	19.49	987.86
14	36.00	9.00	28.48	105.73	499.10	112.88	13.56	768.75	19.49	788.24
15	29.00	7.25	23.04	86.33	388.59	90.30	10.50	606.01	19.49	625.50
16	23.00	5.75	18.56	69.84	317.29	70.31	8.40	490.14	19.49	509.63
17	18.50	4.63	14.72	56.26	256.68	57.41	6.54	396.23	19.49	415.72
18	14.30	3.58	11.84	44.62	206.77	46.44	5.34	318.59	19.49	338.08
19	11.00	2.75	9.15	35.89	163.99	37.41	4.32	253.51	19.49	273.00
20	8.00	2.00	7.04	27.74	131.91	29.67	3.48	201.84	19.49	221.33
21	5.00	1.25	5.12	21.34	101.96	23.87	2.76	156.29	19.49	175.78
22	2.80	0.70	3.20	15.52	78.43	18.45	2.22	118.52	19.49	138.01
23	1.20	0.30	1.79	9.70	57.04	14.19	1.72	84.74	19.49	104.23
[illegible]	0.00	0.00	0.77	5.43	35.65	10.32	1.32	53.49	19.49	72.98
25			0.00	2.33	19.96	6.45	0.96	29.70	19.49	49.19
26				0.00	8.56	3.61	0.60	12.77	19.49	32.26
27					0.00	1.55	0.34	1.88	19.49	21.37
28						0.00	0.14	0.14	19.49	19.63
29							0.00	0.00	19.49	19.49

SUBZONE 1(g) ANNEXURE- 5.5

COMPUTATION OF EQUIVALENT SLOPE OF BRIDGE NO 237 IN PLAIN REGION

SL.NO	REDUCED DISTANCE. (from point of study.) (Mile)	REDUCED LEVEL (Ft)	LENGTH OF EACH SEGMENT (Li) (Mile)	HEIGHT ABOVE DATUM (Ft)	$(D_{i-1}+D_i)$ (Ft)	$Li*(D_{i-1}+D_i)$
1	2	3	4	5	6	7
1	0.00	165	0.00	0	0	0
2	4.70	200	4.70	35	35	164.5
3	11.20	250	6.50	85	120	780.0
4	17.00	300	5.8	135	220	1276.0
5	18.20	310	1.2	145	280	336.0
						2556.5

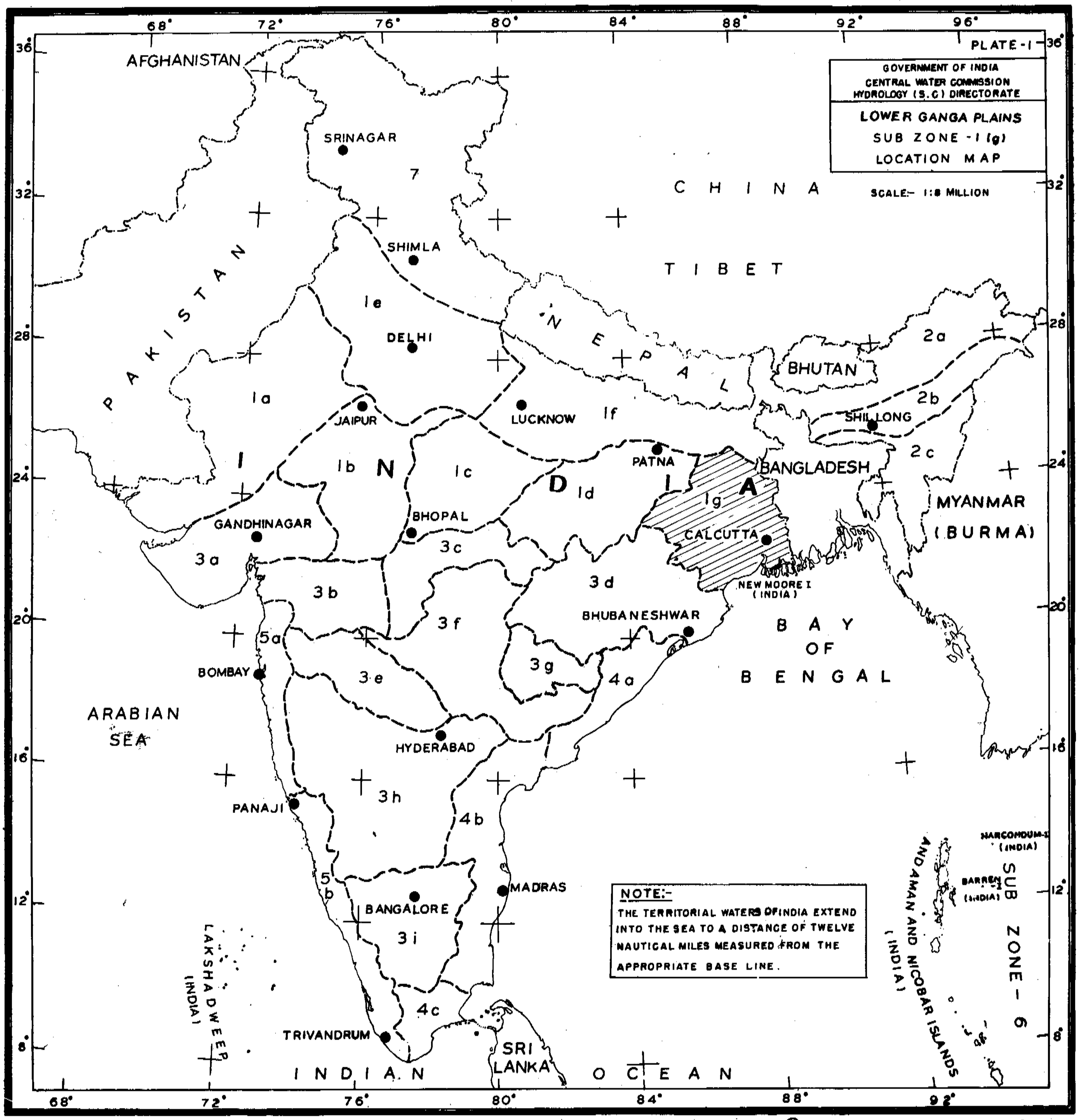
$$S = \frac{(Li * (D_{i-1} + D_i))}{L^2} = \frac{2556.5}{331.2} = 7.71 \text{ ft/mile}$$

$$= 1.46 \text{ m/km}$$

Computation of Design Flood Hydrograph Using SUG Equations of Bridge No. 237 (Plain Region)

TIME HRS.	S.U.G ORD. CUMEC	TOTAL D.S.R.O. CUMECS	BASE FLOW CUMECS	TOTAL FLOW IN CUMECS
0.00	0.00	0.00	11.21	11.21
1.00	0.50	0.10	11.21	11.31
2.00	1.40	0.38	11.21	11.59
3.00	2.20	0.83	11.21	12.04
4.00	3.20	1.59	11.21	12.80
5.00	4.40	2.80	11.21	14.01
6.00	5.80	4.49	11.21	15.70
7.00	7.20	6.71	11.21	17.92
8.00	9.10	9.83	11.21	21.04
9.00	11.60	14.33	11.21	25.54
10.00	15.00	21.15	11.21	32.36
11.00	18.40	31.52	11.21	42.73
12.00	22.30	47.47	11.21	58.68
13.00	26.20	68.20	11.21	79.41
14.00	28.71	91.46	11.21	102.67
15.00	28.40	118.14	11.21	129.35
16.00	27.00	147.82	11.21	159.03
17.00	25.60	180.79	11.21	192.00
18.00	23.00	216.56	11.21	227.77
19.00	22.20	258.44	11.21	269.65
20.00	20.80	306.27	11.21	317.48
21.00	19.40	359.12	11.21	370.33
22.00	18.40	411.26	11.21	422.47
23.00	17.20	459.90	11.21	471.11
24.00	16.20	496.31	11.21	507.52
25.00	15.20	511.31	11.21	522.52
26.00	14.40	503.04	11.21	514.25
27.00	13.40	481.31	11.21	492.52
28.00	12.60	454.87	11.21	466.08
29.00	11.80	423.81	11.21	435.02
30.00	11.00	400.37	11.21	411.58
31.00	10.40	375.61	11.21	386.82
32.00	9.80	352.40	11.21	363.61
33.00	9.40	322.02	11.21	333.23
34.00	8.80	311.60	11.21	322.81
35.00	8.30	293.11	11.21	304.32
36.00	7.80	275.45	11.21	286.66
37.00	7.40	259.11	11.21	270.32
38.00	7.10	242.83	11.21	254.04
39.00	6.80	228.03	11.21	239.24
40.00	6.40	214.11	11.21	225.32
41.00	6.00	201.15	11.21	212.36
42.00	5.80	190.03	11.21	201.24
43.00	5.60	179.56	11.21	190.77
44.00	5.30	170.22	11.21	181.43
45.00	5.00	160.56	11.21	171.77
46.00	4.80	151.84	11.21	163.05
47.00	4.60	143.75	11.21	154.96

48.00	4.30	136.58	11.21	147.79
49.00	4.10	130.15	11.21	141.36
50.00	3.80	123.81	11.21	135.02
51.00	3.60	117.41	11.21	128.62
52.00	3.40	111.55	11.21	122.76
53.00	3.10	106.65	11.21	117.86
54.00	2.90	101.76	11.21	112.97
55.00	2.60	96.59	11.21	107.80
56.00	2.40	91.68	11.21	102.89
57.00	2.20	87.13	11.21	98.34
58.00	2.00	82.53	11.21	93.74
59.00	1.90	77.61	11.21	88.82
60.00	1.80	73.11	11.21	84.32
61.00	1.60	68.35	11.21	79.56
62.00	1.40	63.98	11.21	75.19
63.00	1.30	59.61	11.21	70.82
64.00	1.20	54.89	11.21	66.10
65.00	1.10	50.64	11.21	61.85
66.00	1.00	46.24	11.21	57.45
67.00	0.90	42.50	11.21	53.71
68.00	0.80	39.06	11.21	50.27
69.00	0.70	35.94	11.21	47.15
70.00	0.60	33.34	11.21	44.55
71.00	0.52	30.65	11.21	41.86
72.00	0.42	27.67	11.21	38.88
73.00	0.35	24.95	11.21	36.16
74.00	0.30	22.79	11.21	34.00
75.00	0.25	20.73	11.21	31.94
76.00	0.20	18.78	11.21	29.99
77.00	0.15	16.90	11.21	28.11
78.00	0.10	15.05	11.21	26.26
79.00	0.08	13.23	11.21	24.44
80.00	0.05	11.48	11.21	22.69
81.00	0.00	9.80	11.21	21.01
82.00	0.00	8.30	11.21	19.51
83.00	0.00	6.87	11.21	18.08
84.00	0.00	5.69	11.21	16.90
85.00	0.00	4.70	11.21	15.91
86.00	0.00	3.80	11.21	15.01
87.00	0.00	2.96	11.21	14.17
88.00	0.00	2.20	11.21	13.41
89.00	0.00	1.54	11.21	12.75
90.00	0.00	1.04	11.21	12.25
91.00	0.00	0.58	11.21	11.79
92.00	0.00	0.18	11.21	11.39
93.00	0.00	0.08	11.21	11.29
94.00	0.00	0.02	11.21	11.23
95.00	0.00	0.00	11.21	11.21

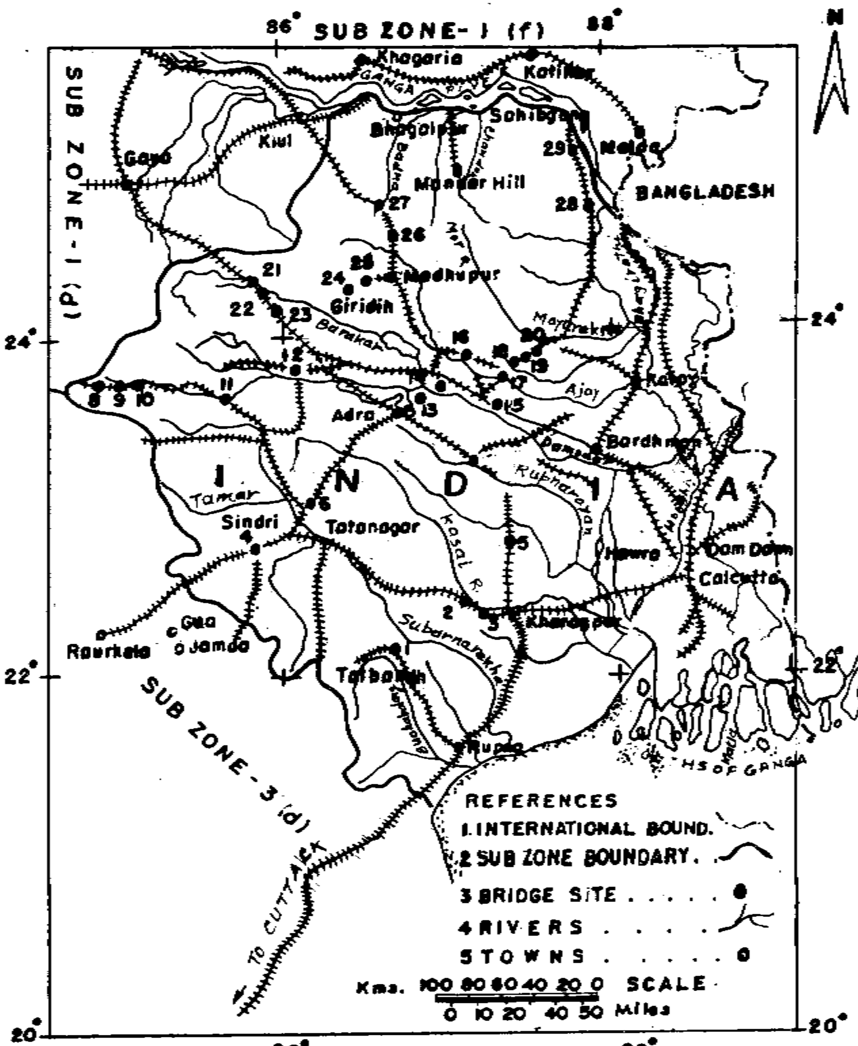


NOTES:- i) BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.

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

L. P. NAUTIYAL, L.K. PANT

PLATE-2



The Territorial Waters of India Extend in to the sea to a distance of Twelve Nautical Miles Mesured from the appropriate base line.

Sl. NO.	BRIDGE NO.	C.A. Km^2	LOCATION LONG.	LOCATION LATI.
1.	101(b)	244.24	86°36'00"	22°09'23"
2	114	28.90	87°05'22"	22°24'30"
3	94(b)	336.70	86°52'29"	29°32'30"
4	286	133.38	85°48'00"	22°43'24"
5	181	212.90	87°19'30"	22°38'10"
6	348	87.41	86°07'00"	22°58'60"
7.	237	224.29	87°17'38"	23°05'24"
8	155	127.78	84°50'00"	23°39'00"
9	27	15.16	85°20'25"	23°38'45"
10	110	389.76	85°02'30"	23°39'45"
11	562	147.09	85°41'58"	23°32'47"
12	10	853.56	86°12'00"	23°45'00"
13	502	28.68	86°47'25"	23°35'26"
14	35	70.20	86°55'00"	23°39'00"
15	436	154.08	87°13'14"	23°43'40"
16	101	20.02	87°05'40"	23°49'08"
17	42	3631.50	87°17'00"	23°43'30"
18	49	393.68	87°20'00"	23°45'00"
19	94(S)	64.38	87°21'00"	23°47'00"
20	75	116.34	87°26'00"	23°49'00"
21	167	568.80	85°50'48"	24°13'00"
22	160	164.18	85°52'20"	24°11'40"
23	150	27.38	85°54'51"	24°07'54"
24	23	8.58	86°25'32"	24°14'30"
25	12	10.79	86°30'00"	24°18'00"
26	656	83.48	86°37'50"	24°32'30"
27	676	92.38	86°33'50"	24°41'20"
28	236	492.10	87°51'00"	24°39'00"
29	294	34.84	87 48 00	25 08 00

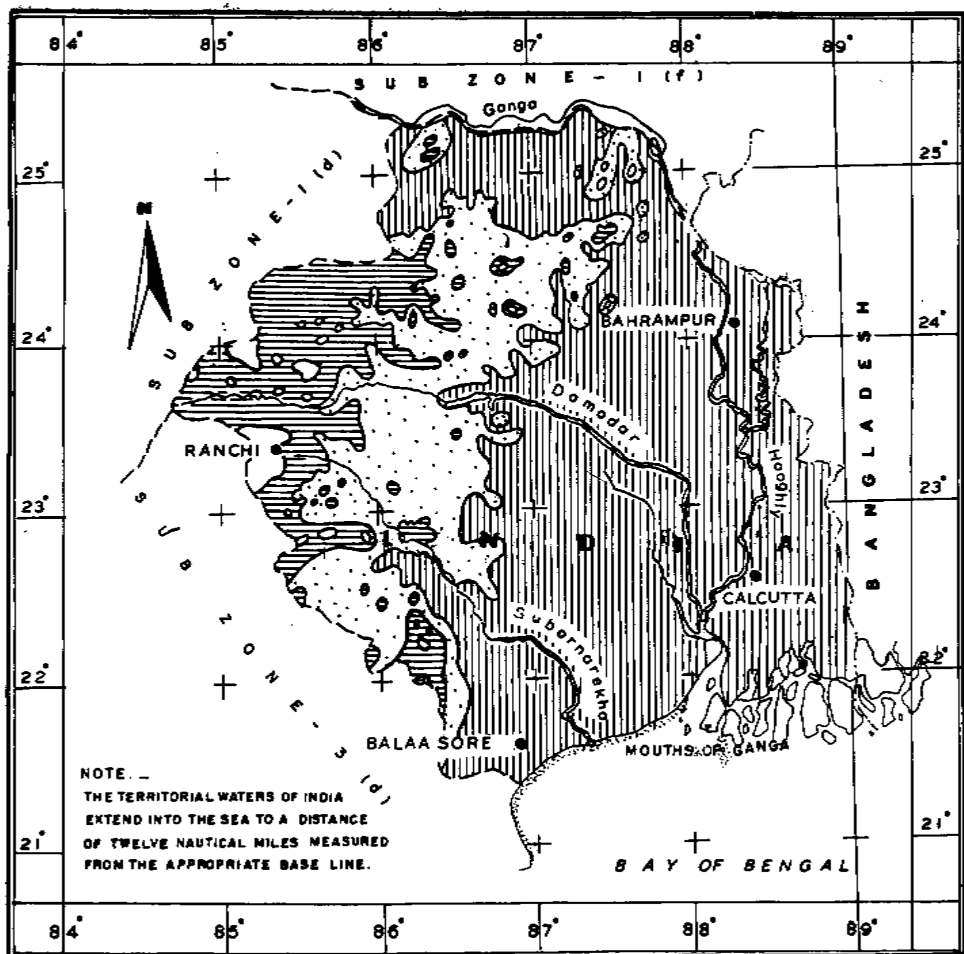
Government of India
Central Water Commission
Hydrology (R.S.) Directorate

LOWER GANGA PLAINS
SUB ZONE-1(g)
INDEX MAP SHOWING RIVER SYSTEM AND G&D SITES

DRAWN - L.K. PANT | CHECKED - C.S. AGARWAL

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

PLATE - 3.



REFERENCES

1. 0 – 150
2. 150 300
3. 300 – 600
4. 600 – 900
5. INTERNATIONAL BOUNDARY
6. SUB ZONE BOUNDARY . . .
7. RIVERS . . . . .
8. TOWNS . . . . . .

SCALE

Kms. 50 0 50 100 150 Kms.

भारत सरकार
केन्द्रीय जल आयोग
जल विज्ञान (क्षेत्रीय अध्ययन) निदेशालय

निचली गंगा के मैदान
उप क्षेत्र - (1जी)
भू - आकृति

उद्रेखित एस० एन० मुखोपा एल० मी० मोटियाल	सर्वीक्षित सी० एम० अग्रवाल

NOTES–

THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1989 - EDITION) PLATE NO.–18.

NOTES– I) BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.

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

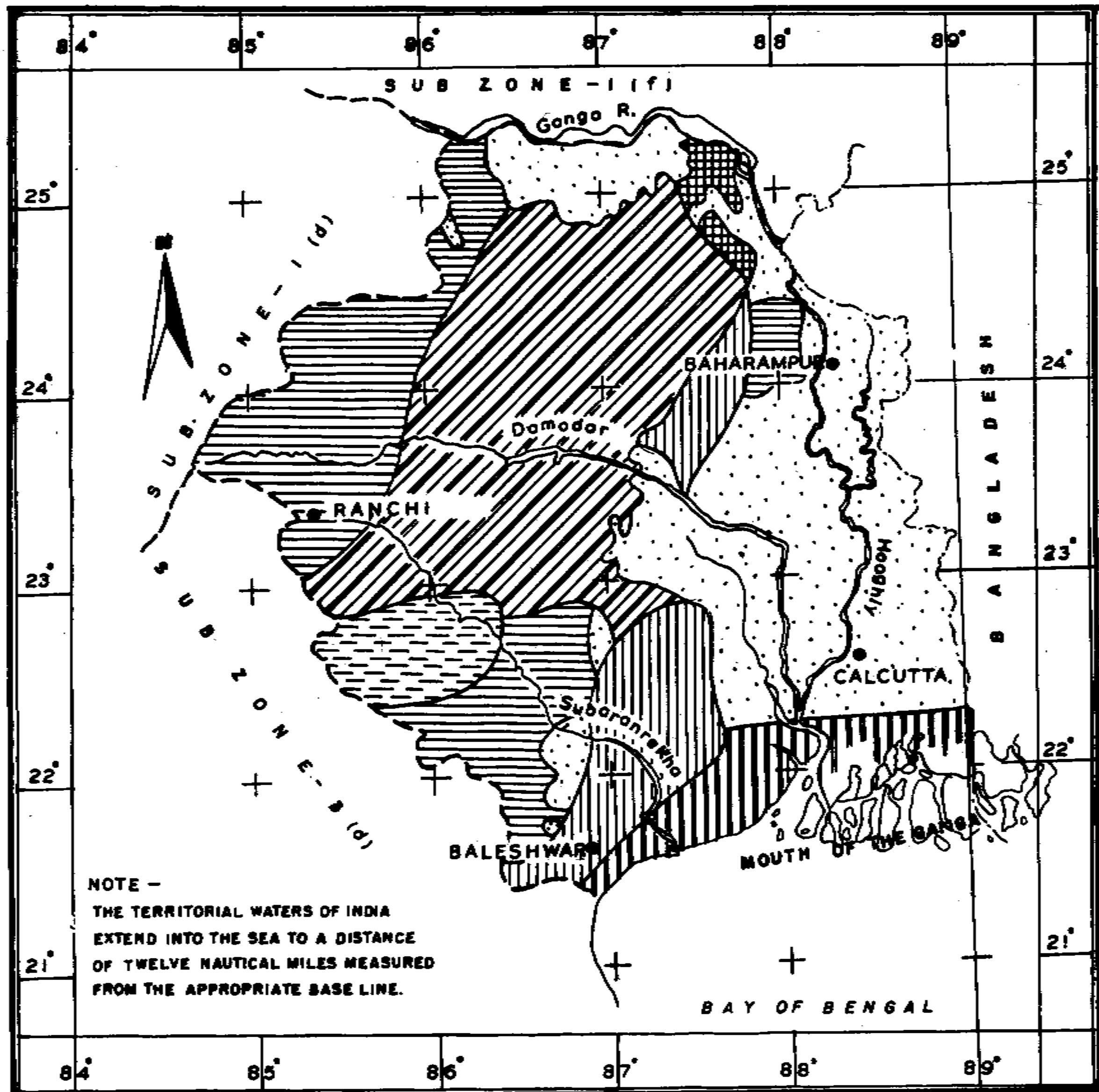


PLATE – 4.

REFERENCES

1. ALLUVIAL SOIL
2. RED AND YELLOW SOIL
3. MIXED RED AND BLACK SOIL
4. RED SANDY SOIL
5. LATERITE SOIL
6. DELTAIC ALLUVIAL SOIL
7. RED LOAMY SOIL
8. INTERNATIONAL BOUNDARY
9. SUB ZONE BOUNDARY
10. RIVERS
11. TOWNS

SCALE

Kms. 50 0 50 100 150 Kms.

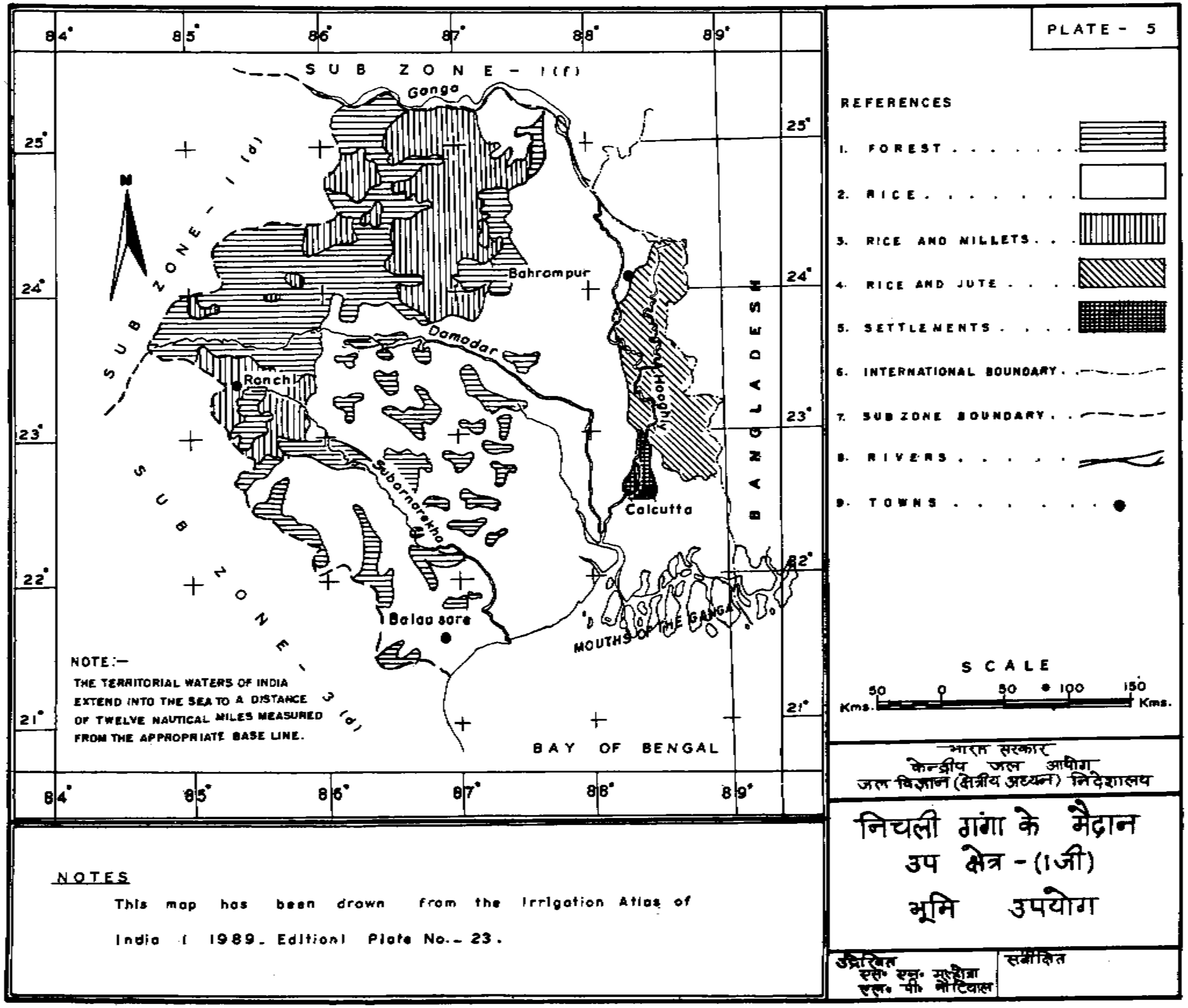
भारत सरकार
केन्द्रीय जल आयोग
जल विज्ञान (क्षेत्रीय अध्ययन) निदेशालय

निचली गंगा के मैदान
उप क्षेत्र – (1जी)
मृदा का वर्गीकरण

उत्रेखित एस० एन० सुखीजा एस० पी० नौटियाल	संवीक्षित

NOTE :-
THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1972 EDITION), PLATE NO.– 8.

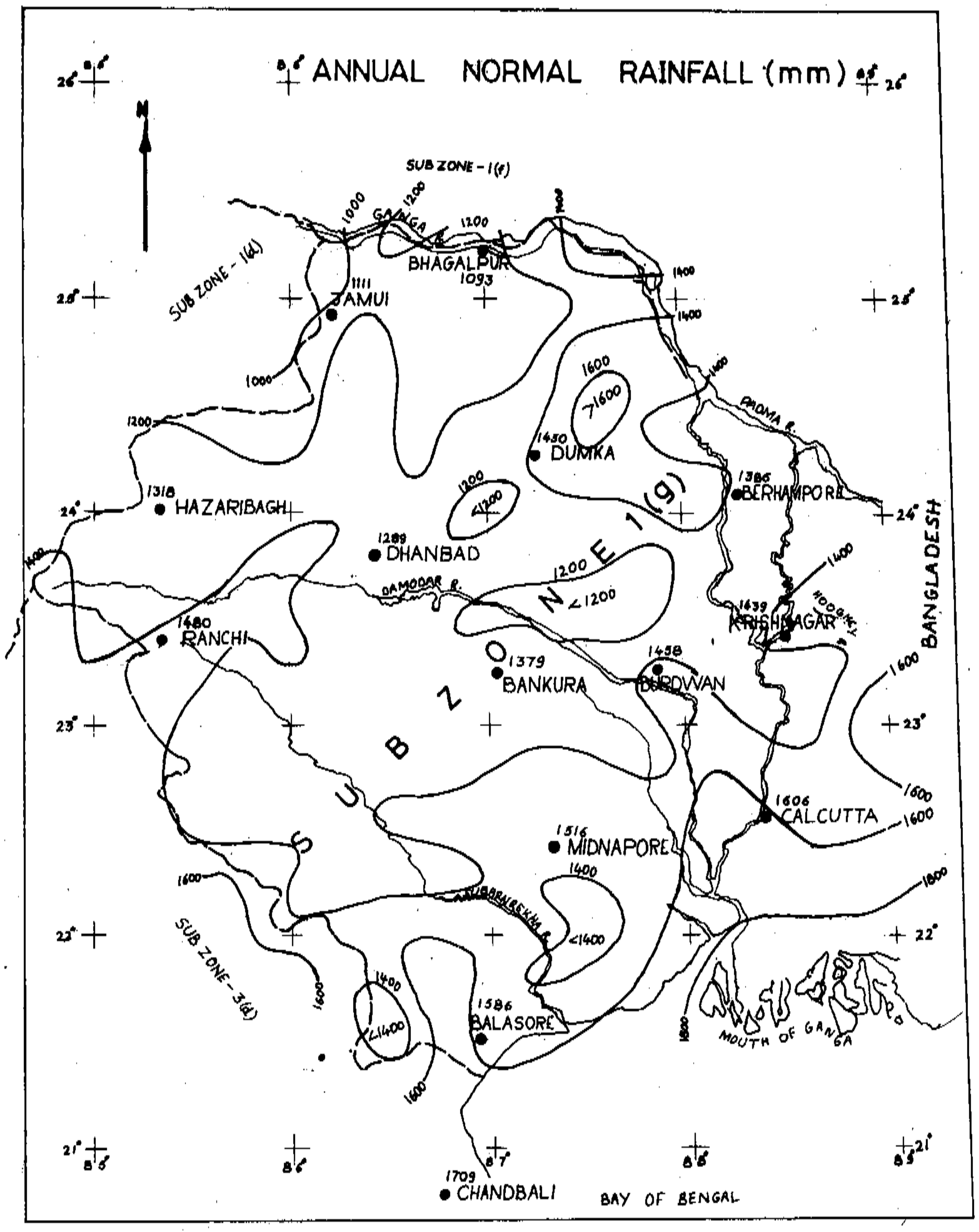
NOTES.– i) BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.
ii) RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS SHOWN ON THE MAP RESTS WITH PUBLISHER.



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

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

PLATE - 6.



REFERENCES

1. SUB ZONE BOUNDARY
2. TOWNS
3. ISOHYETES IN mm. (NORMAL ANNUAL)
4. RIVERS

NOTES

1. THE ALPHABETS ALONG ABCISSA INDICATE NAME OF MONTHS.
2. COLUMN HEIGHTS REPRESENT RAINFALL IN mm.
3. FIGURES ABOVE COLUMN INDICATE MONTHLY RAINFALL AS PERCENT OF ANNUAL RAINFALL.

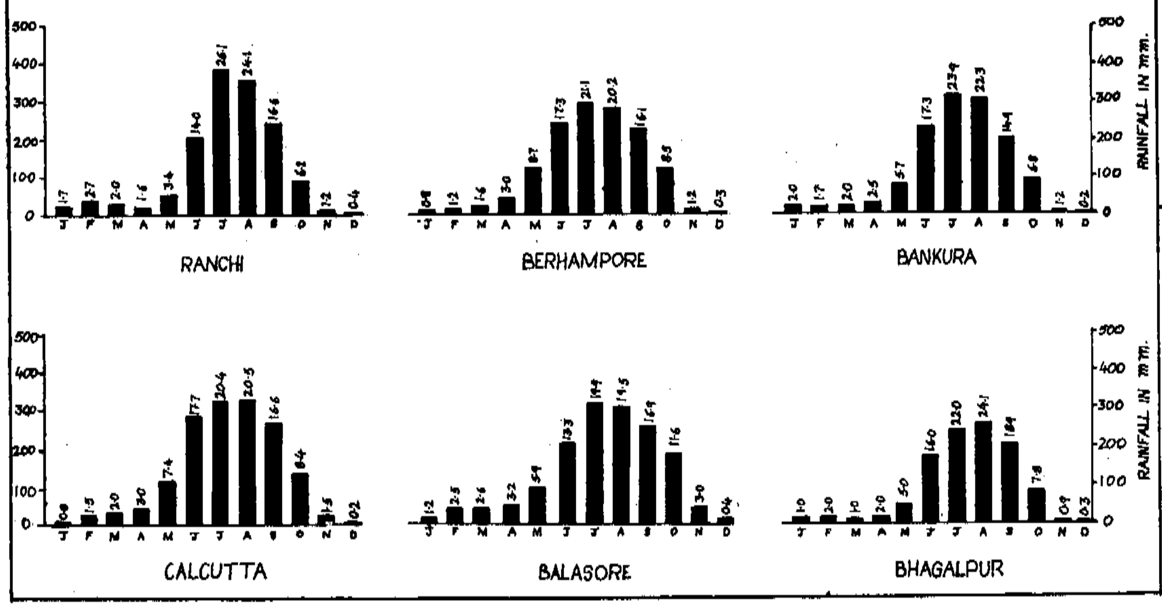
MAP SUPPLIED BY I.M.D

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

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 WITH PERMISSION OF THE SURVEYOR GENERAL OF INDIA.

MONTHLY RAINFALL DISTRIBUTION



SCALE

Kms. Kms.

भारत सरकार
केन्द्रीय जल आयोग
जल विज्ञान (क्षेत्रीय अध्ययन) निदेशालय

निचली गंगा के मैदान
उप क्षेत्र - (1- जी)
सामान्य वार्षिक वर्षा

उद्रेखित एल॰पी॰ नौटियाल | संवीक्षित आर॰के॰ गुप्ता

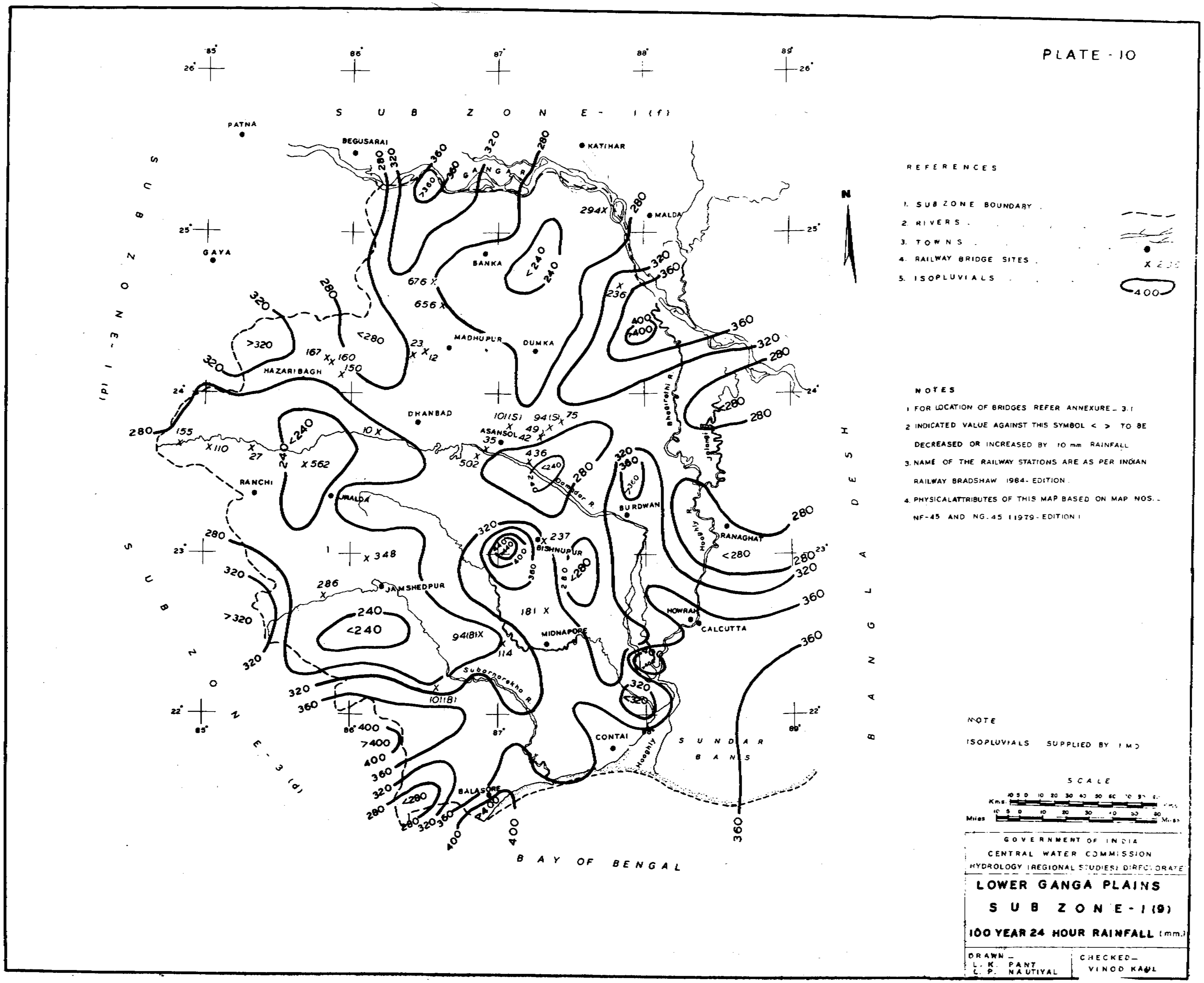
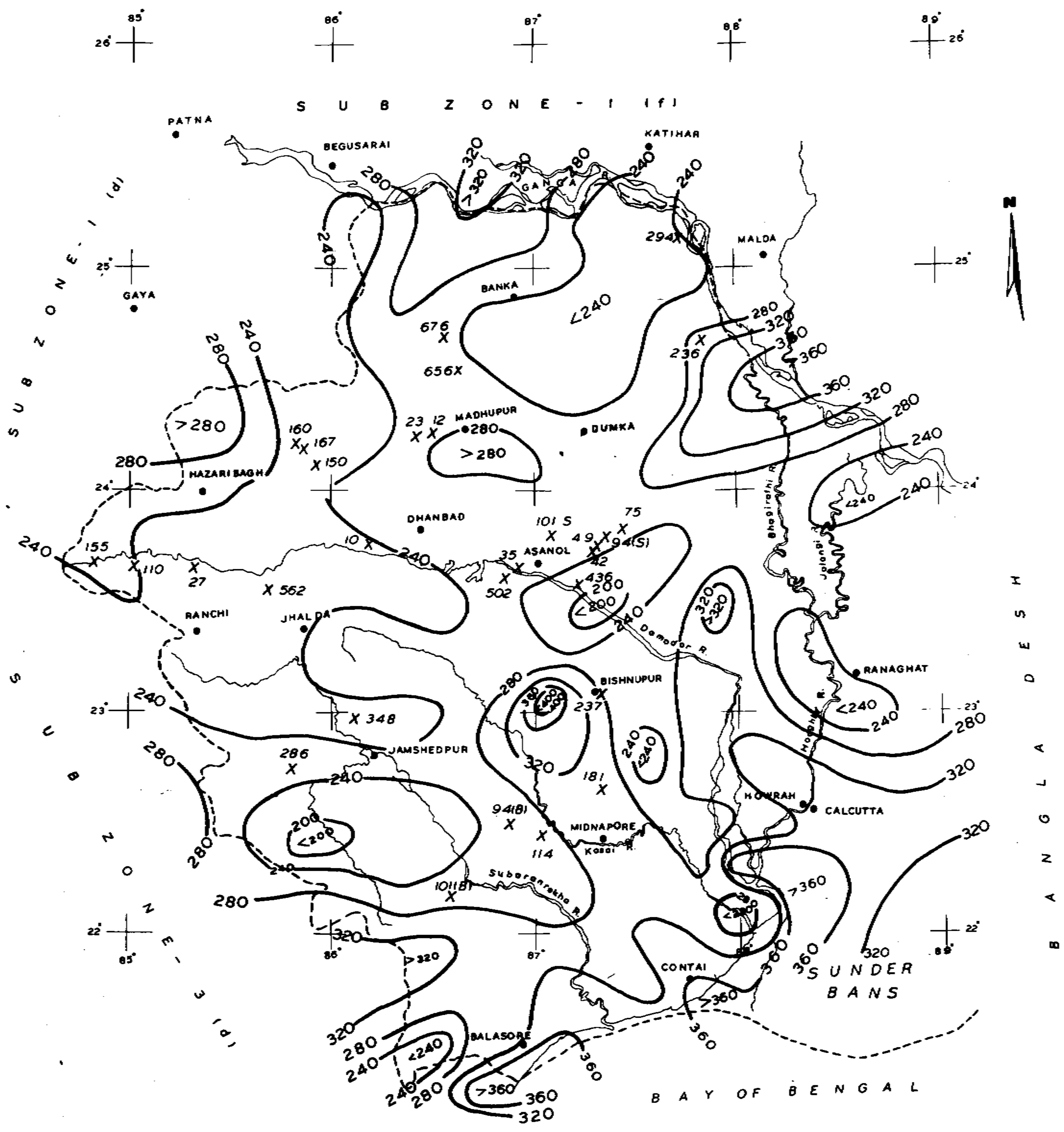


PLATE - 10
SUB ZONE - 1 (f)
SUB ZONE - 1 (d)
SUB ZONE - 3 (d)
BANGLADESH
BAY OF BENGAL
SUNDAR BANS
PATNA
BEGUSARAI
KATIHAR
GAYA
MALDA
BANKA
MADHUPUR
DUMKA
HAZARIBAGH
DHANBAD
ASANSOL
RANCHI
PURULIA
BURDWAN
RANAGHAT
BISHNUPUR
JAMSHEDPUR
MIDNAPORE
HOWRAH
CALCUTTA
CONTAI
BALASORE
GANGA R.
Damodar R.
Subarnarekha R.
Bhagirathi R.
Jalangi R.
Hooghly R.
REFERENCES
1. SUB ZONE BOUNDARY
2. RIVERS
3. TOWNS
4. RAILWAY BRIDGE SITES
5. ISOPLUVIALS
NOTES
1 FOR LOCATION OF BRIDGES REFER ANNEXURE - 3.1
2 INDICATED VALUE AGAINST THIS SYMBOL < > TO BE DECREASED OR INCREASED BY 10 mm RAINFALL
3. NAME OF THE RAILWAY STATIONS ARE AS PER INDIAN RAILWAY BRADSHAW 1984 - EDITION.
4. PHYSICAL ATTRIBUTES OF THIS MAP BASED ON MAP NOS. - NF-45 AND NG.45 (1979 - EDITION)
NOTE
ISOPLUVIALS SUPPLIED BY I M D
SCALE
Kms
Miles
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DIRECTORATE
LOWER GANGA PLAINS
SUB ZONE - 1 (g)
100 YEAR 24 HOUR RAINFALL (mm)
DRAWN -
L. K. PANT
C. P. NAUTIYAL
CHECKED -
VINOD KAUL



REFERENCES

1. SUB ZONE BOUNDARY
2. RIVERS
3. TOWNS
4. RAILWAY BRIDGE SITES . . . X 23
5. ISOPLUVIALS . . . 240

NOTES

1. FOR LOCATION OF BRIDGES REFER ANNEXURE - 3.1.
2. INDICATED VALUE AGAINST THIS SYMBOL < > TO BE DECREASED OR INCREASED BY 10 mm RAINFALL
3. NAME OF THE RAILWAY STATIONS ARE AS PER INDIAN RAILWAY BRADSHAW (1984 - EDITION)
4. PHYSICAL ATTRIBUTES OF THIS MAP BASED ON MAP NOS. NF-45 AND NG-45 (1979 - EDITION)

NOTE

ISOPLUVIALS SUPPLIED BY I.M.D.

SCALE

Kms. 10 5 0 10 20 30 40 50 60 70 80 90

Miles 10 5 0 10 20 30 40 50 60

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

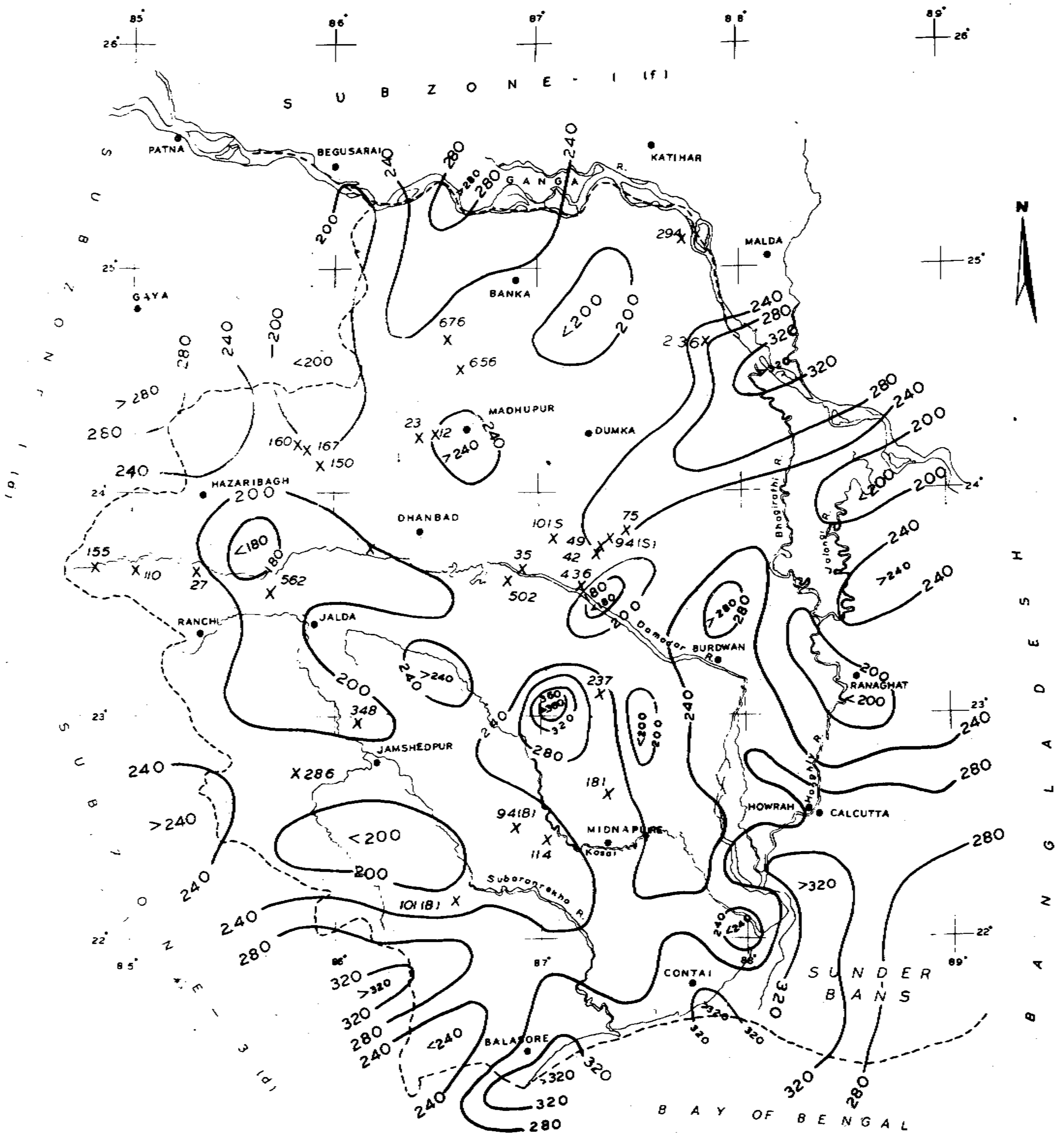
LOWER GANGA PLAINS

SUB ZONE - 1 (g)

50 YEAR 24 HOUR RAINFALL (mm)

DRAWN -	CHECKED -
L. K. PANT L. P. NAUTIYAL	VINOD KAUL

PLATE - 8.



REFERENCES

1. SUB ZONE BOUNDARY
2. RIVERS
3. TOWNS
4. RAILWAY BRIDGE SITES — X 236
5. ISOPLUVIALS — 200

NOTES

1. FOR LOCATION OF BRIDGES REFER ANNEXURE - 3.1
2. INDICATED VALUE AGAINST THIS SYMBOL < > TO BE DECREASED OR INCREASED BY 10 mm. RAINFALL.
3. NAME OF THE RAILWAY STATIONS ARE AS PER INDIAN RAILWAY BRADSHAW (1984-EDITION.)
4. PHYSICAL ATTRIBUTES OF THIS MAP BASED ON MAP NOS. NF-45 AND NG-45 (1979. EDITION)

NOTES -

ISOPLUVIALS SUPPLIED BY IMD.

SCALE

Kms. 10 5 0 10 20 30 40 50 60 70 80 90 Kms.

Miles 10 5 0 10 20 30 40 50 60 Miles

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

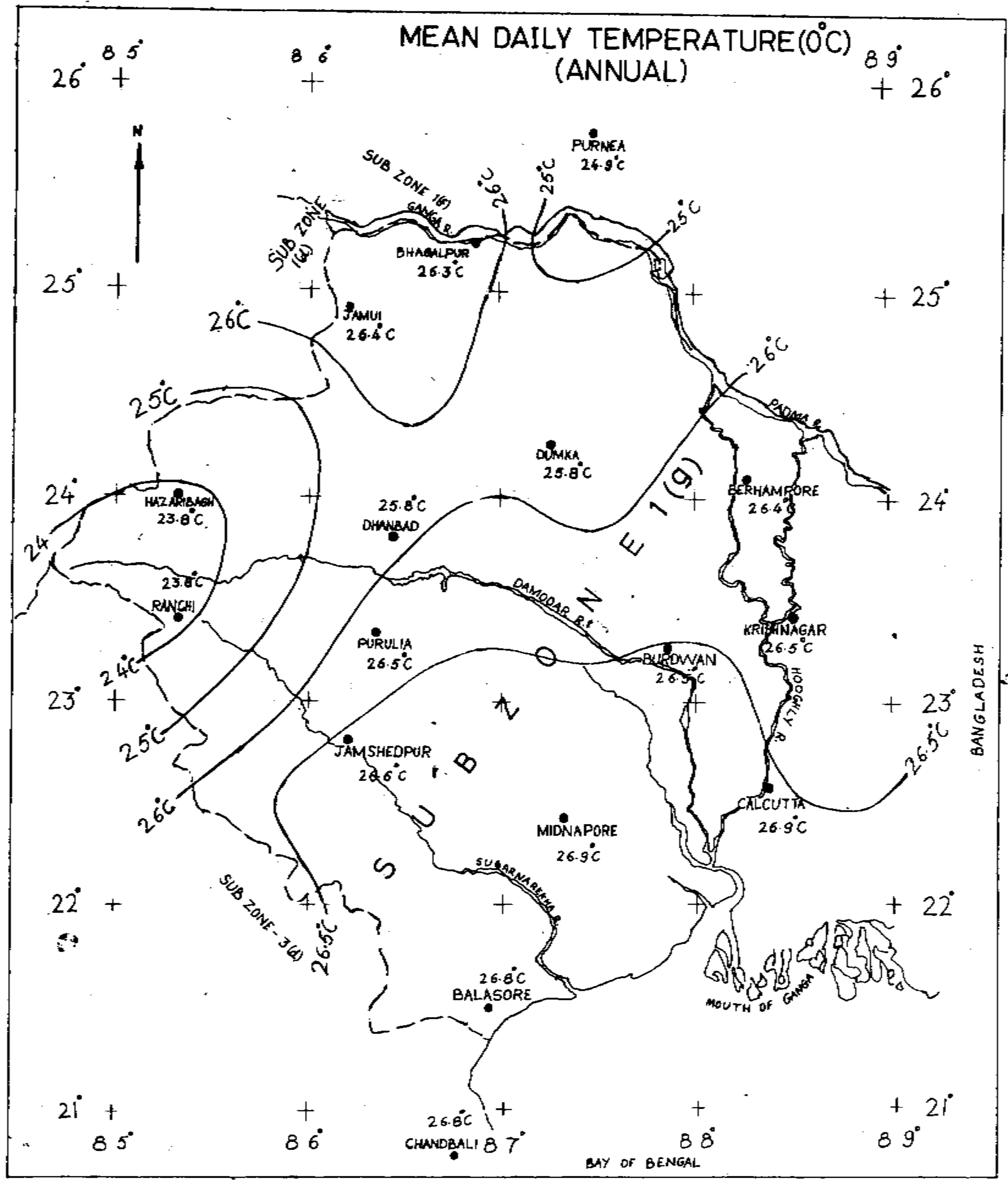
LOWER GANGA PLAINS

SUB ZONE - I (g)

25 YEAR 24 HOUR RAINFALL (mm.)

DRAWN - L. K. PANT, L. P. NAUTIYAL	CHECKED - VINOD KAUL

PLATE - 7



REFERENCES

1. ISOTHERMS (DEGREES CELSIUS).
2. SUB ZONE BOUNDARY
3. TOWNS
4. RIVERS

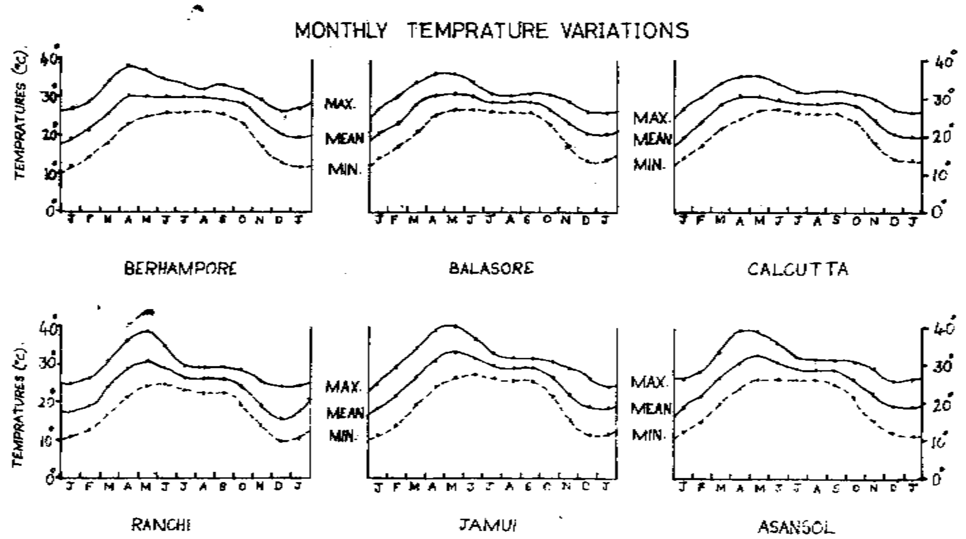
NOTES

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

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

MAP SUPPLIED BY I.M.D

SCALE

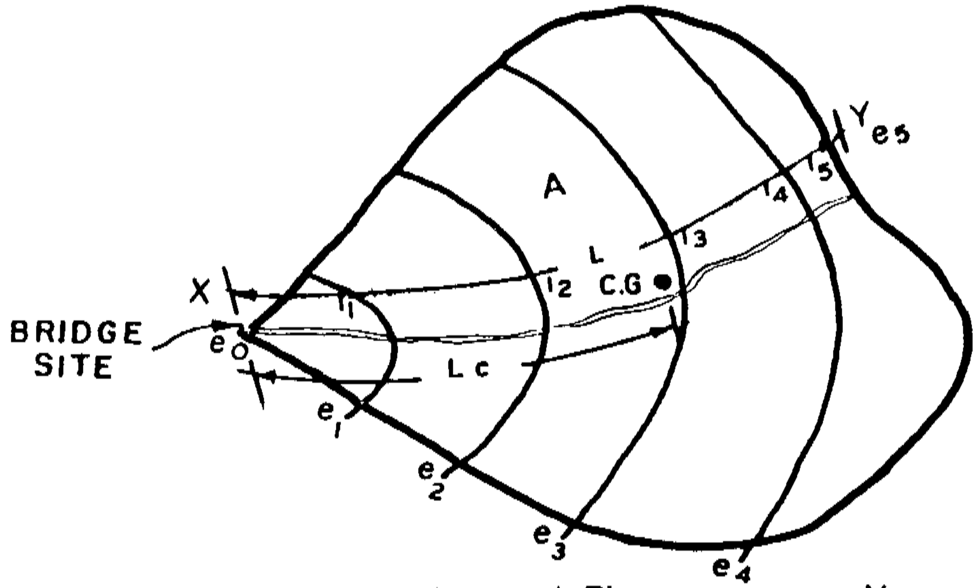


भारत सरकार
केन्द्रीय जल आयोग
जल विज्ञान (क्षेत्रीय अध्ययन) निदेशालय

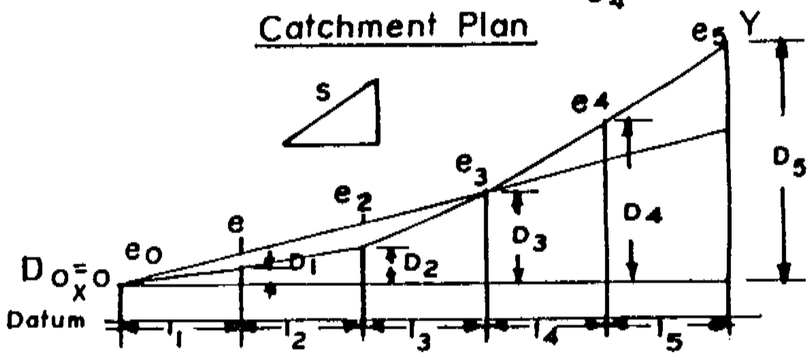
निचली गंगा के मैदान
उप क्षेत्र 1-जी
सामान्य वार्षिक तापमान

उद्रेखित एल० के० पँत	संवीक्षित आर० के० गुप्ता

FIG. I



Catchment Plan



L - Section

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

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

L = Length of longest stream course (km)

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

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

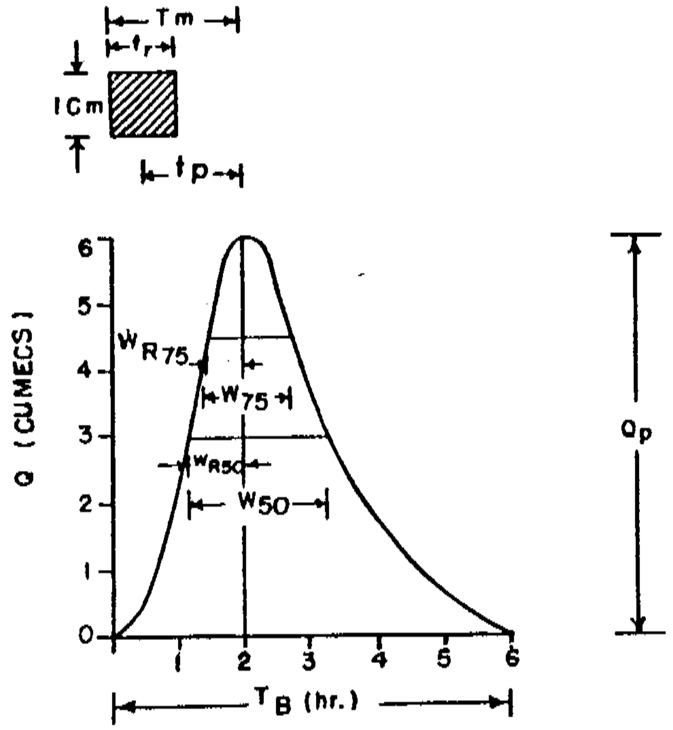
$D_i = D_0, D_1, D_2, \ldots D_n$
$= (e_0 - e_0), (e_1 - e_0), (e_2 - e_0) \ldots (e_n - e_0)$ (m)

A = Catchment area (km²)

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

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (REGIONAL STUDIES) DTE.	
PHYSIOGRAPHIC PARAMETERS	
DRAWN L.P. NAUTIYAL	CHECKED VINOD KAUL

FIG. – 2



U.G. = Unit Graph

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

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

Qp = Peak Discharge of Unit Hydrograph (cumecs)

t_p = Time from the centre of effective rainfall duration to the U.G peak (hr.)

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

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

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

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

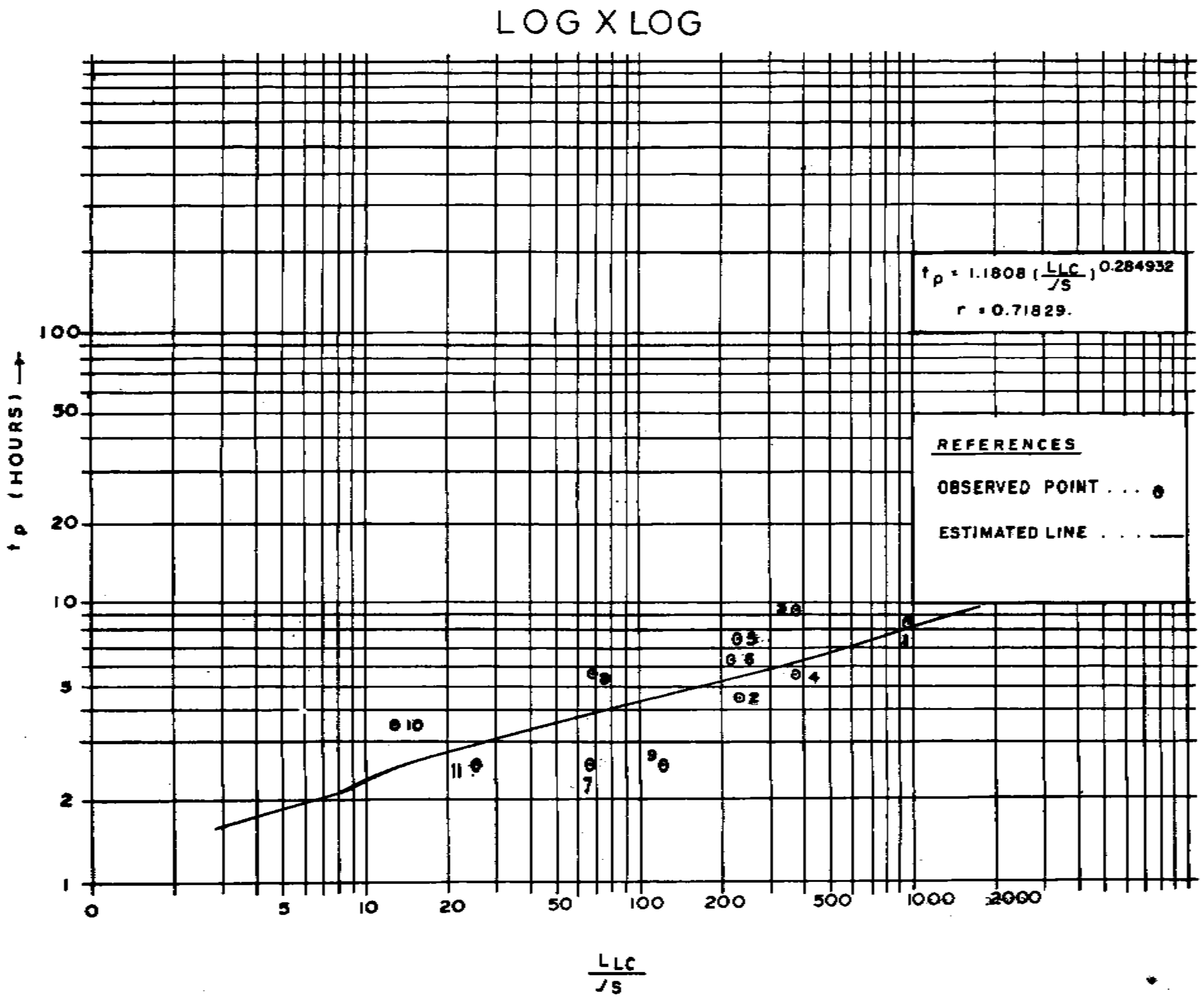
T_B = Base width of Unit Hydrograph (hr.)

A = Catchment Area (Sq. km.)

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

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (SMALL CATCHMENT) DTE.	
UNIT GRAPH PARAMETERS	
DRAWN BY– L.K. PANT	CHECKED BY– VINOD KAUL

FIG.– 3.



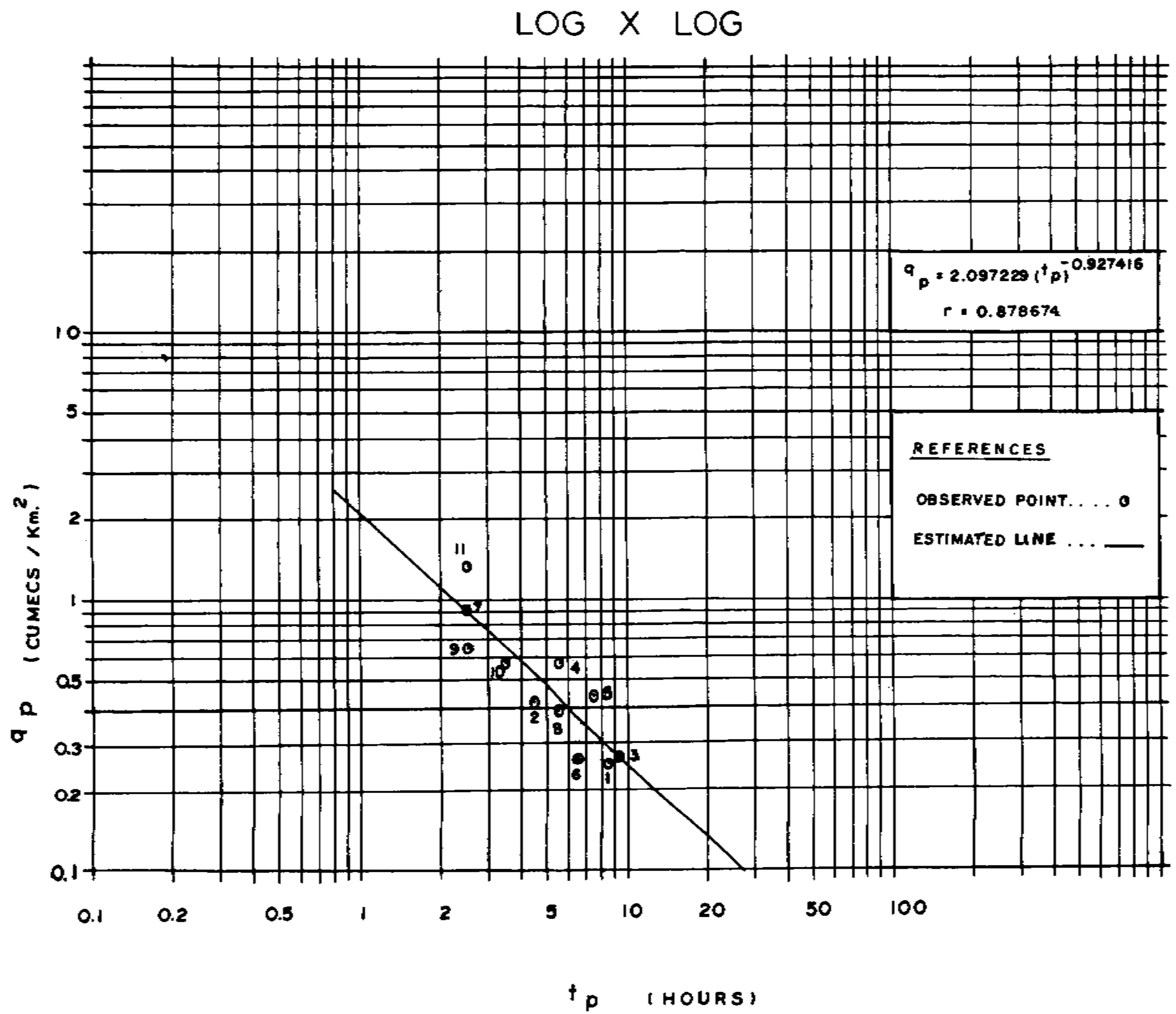
SL NO.	BRIDGE NO.	OBSERVED VALUE $\frac{L_{LC}}{\sqrt{S}}$	t_p (HOURS)
1	167	949.93	8.50
2	110	231.41	4.50
3	94(B)	366.70	9.50
4	101(B)	372.03	5.50
5	160	224.67	7.50
6	286	215.63	6.50
7	676	66.11	2.50
8	348	67.64	5.50
9	656	122.25	2.50
10	114	12.76	3.50
11	150	25.87	2.50

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

LOWER GANGA PLAINS
(HILLY REGION)
SUB ZONE – 1(9)
RELATION BETWEEN
$L_{LC}/\sqrt{S}$ AND t_p

DRAWN — S. N. MALHOTRA, L. P. NAUTIYAL
CHECKED — R. K. GUPTA.

FIG. — 4.



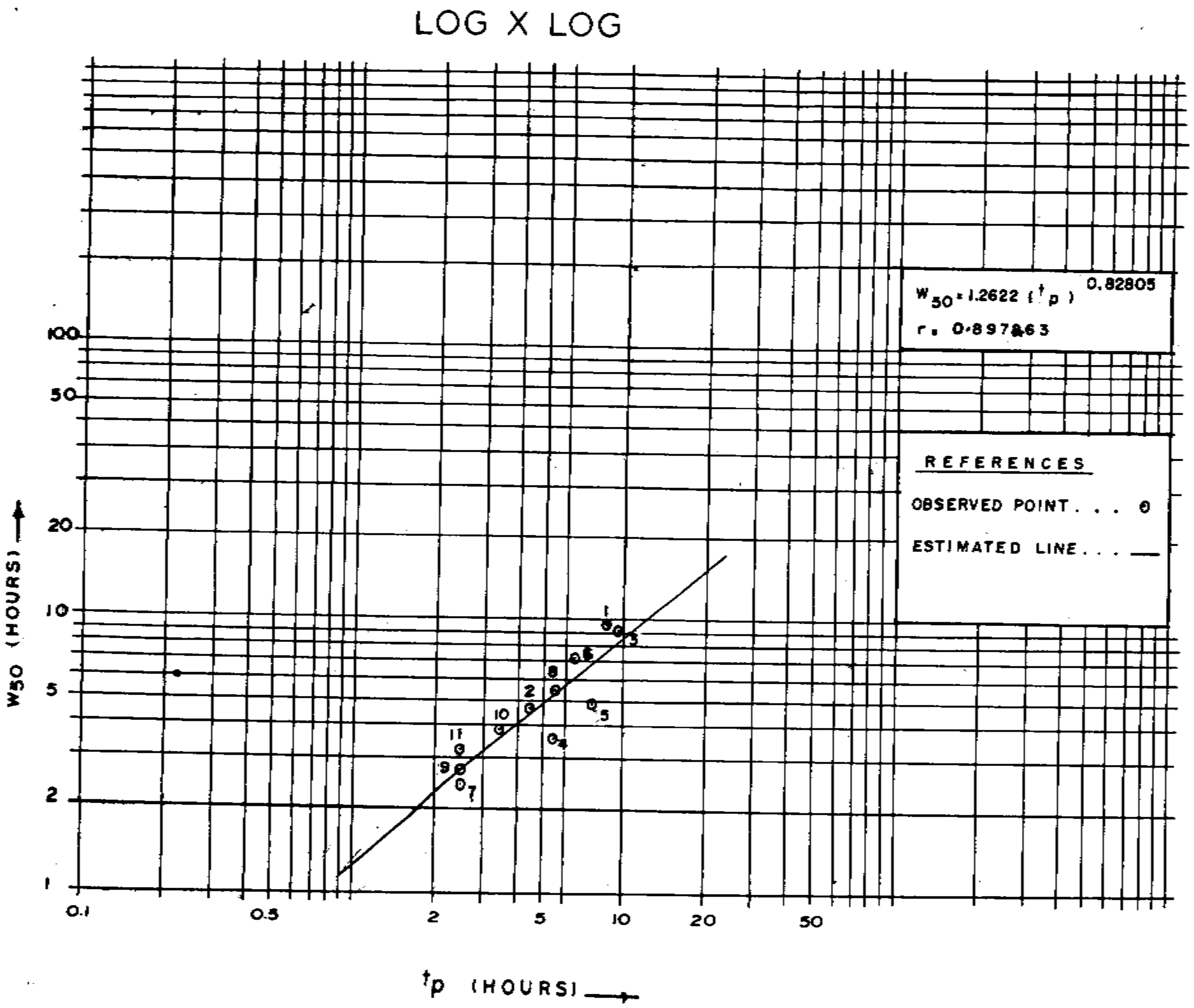
SL. NO.	BRIDGE NO.	OBSERVED VALUE t_p (HOURS)	OBSERVED VALUE q_p (CUMECS/Km.^{2})
1	167	8.50	0.254
2	110	4.50	0.426
3	94(B)	9.50	0.273
4	101(B)	5.50	0.578
5	160	7.50	0.450
6	286	6.50	0.267
7	676	2.50	0.925
8	348	5.50	0.407
9	656	2.50	0.664
10	114	3.50	0.588
11	150	2.50	1.350

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

LOWER GANGA PLAINS
(HILLY REGION)
SUB ZONE - 1(g)
RELATION BETWEEN
t_p AND q_p

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

FIG. – 5.



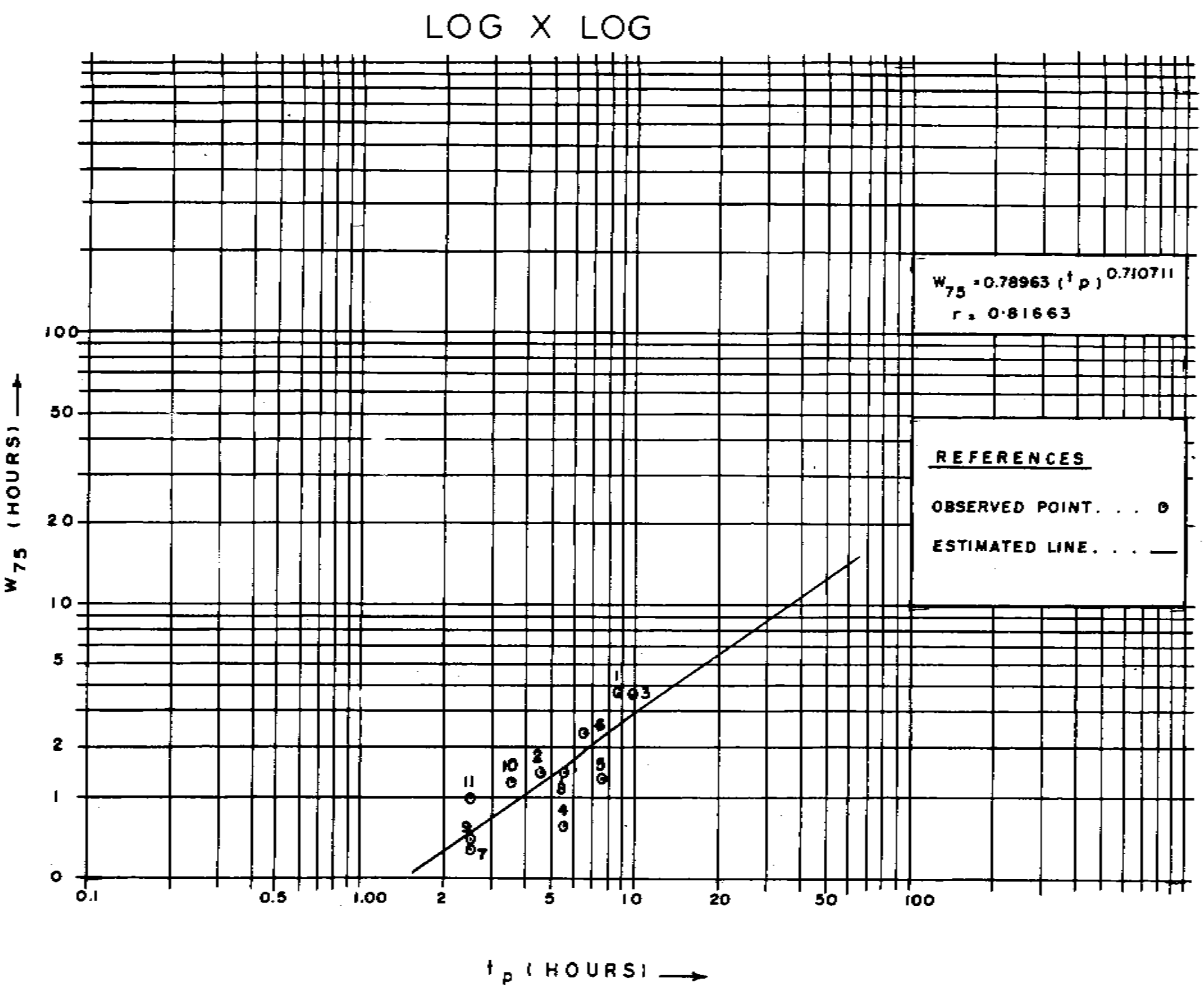
SL. NO.	BRIDGE NO.	OBSERVED VALUE tp (HOURS)	W50 (HOURS)
1	167	8.50	9.40
2	110	4.50	4.60
3	94(B)	9.50	9.00
4	101(B)	5.50	3.50
5	160	7.50	4.80
6	286	6.50	7.10
7	676	2.50	2.40
8	348	5.50	5.40
9	656	2.50	2.70
10	114	3.50	3.80
11	150	2.50	3.20

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

LOWER GANGA PLAINS
(HILLY REGION)
SUB ZONE – 1(g)
RELATION BETWEEN
t_p AND W_{50}

DRAWN – S. N. MALHOTRA, L. P. NAUTIYAL
CHECKED – R. K. GUPTA

FIG. — 6.



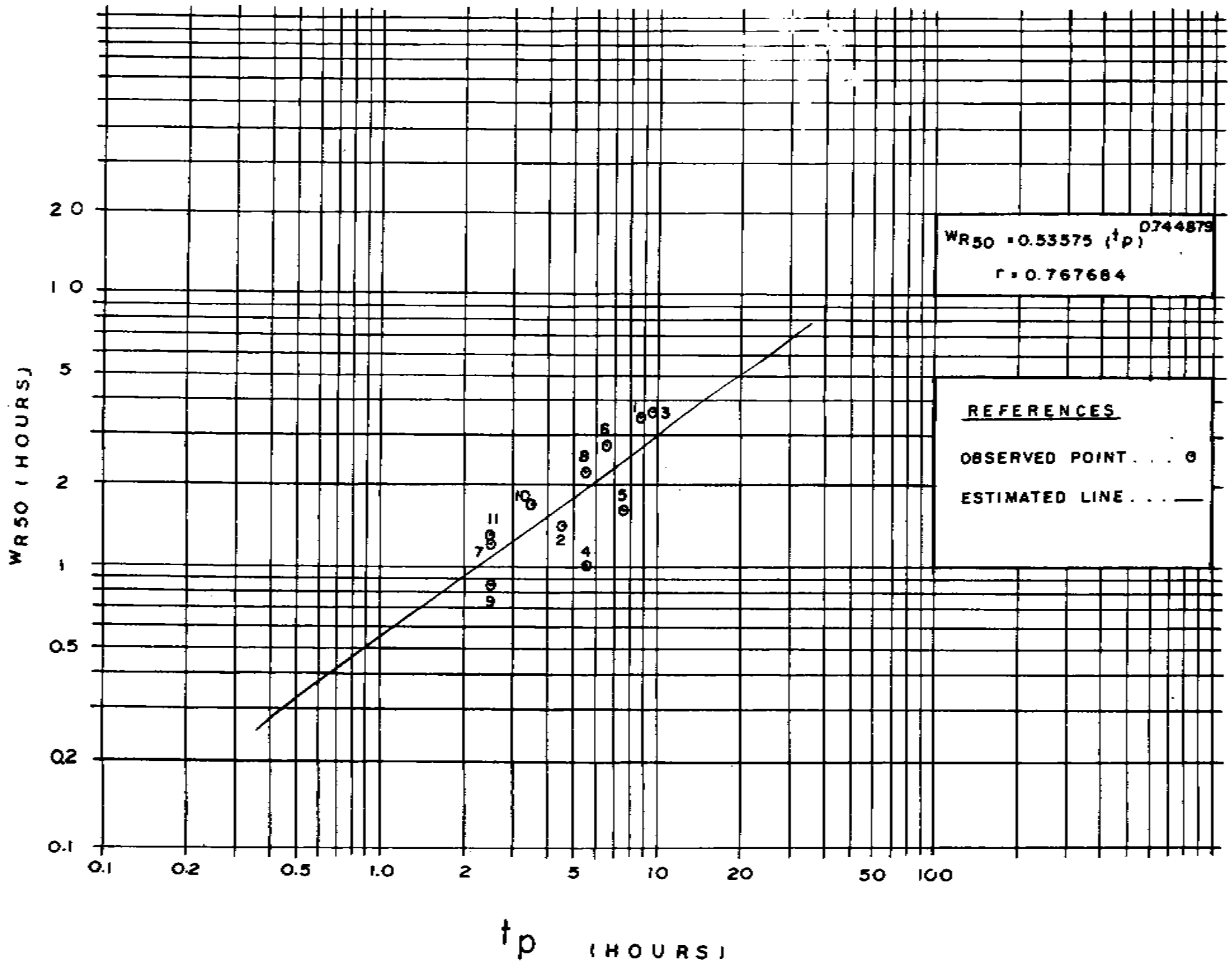
SL NO.	BRIDGE NO.	OBSERVED VALUE t_p (HOURS)	W_{75} (HOURS)
1	167	8.50	4.80
2	110	4.50	2.80
3	94(B)	9.50	4.60
4	101(B)	5.50	1.60
5	160	7.50	2.40
6	286	6.50	3.40
7	676	2.50	1.30
8	348	5.50	2.50
9.	656	2.50	1.40
10	114	3.50	2.30
11	150	2.50	2.00

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

LOWER GANGA PLAINS
(HILLY REGION)
SUB ZONE - 1(9)
RELATION BETWEEN
t_p AND W_{75}

DRAWN — S. N. MALHOTRA, L. P. NAUTIYAL.
CHECKED — R. K. GUPTA

FIG.— 7.



SL NO.	BRIDGE NO.	OBSERVED VALUE t_p (HOURS)	OBSERVED VALUE W_{R50} (HOURS)
1	167	8.50	3.40
2	110	4.50	1.40
3	94(B)	9.50	3.60
4	101(B)	5.50	1.00
5	160	7.50	1.60
6	286	6.50	2.80
7	676	2.50	1.20
8	348	5.50	2.20
9	656	2.50	0.85
10	114	3.50	1.70
11	150	2.50	1.30

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

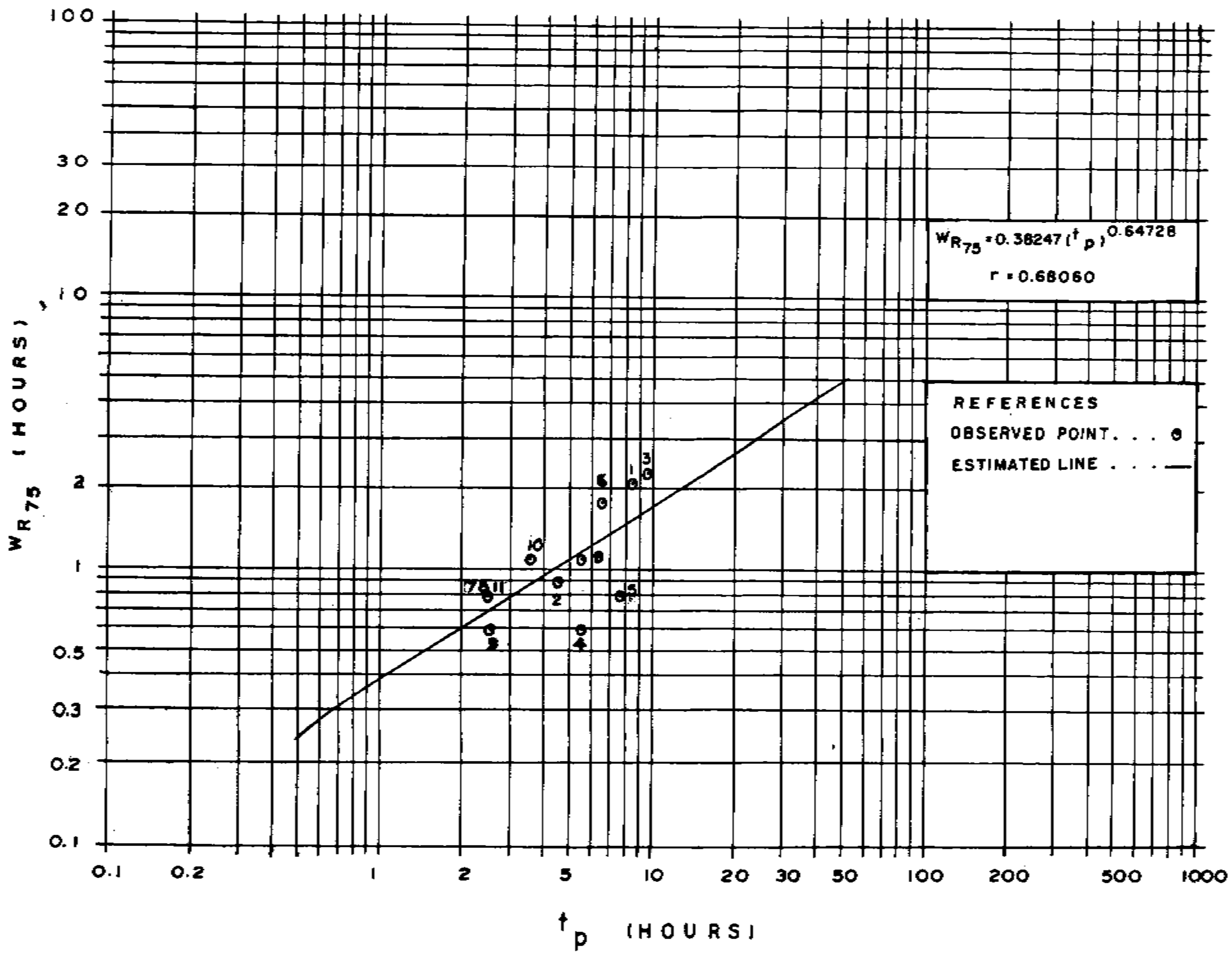
LOWER GANGA PLAINS
(HILLY REGION)
SUB ZONE – 1 (g)

RELATION BETWEEN
t_p AND W_{R50}

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

FIG. — 8.

LOG X LOG



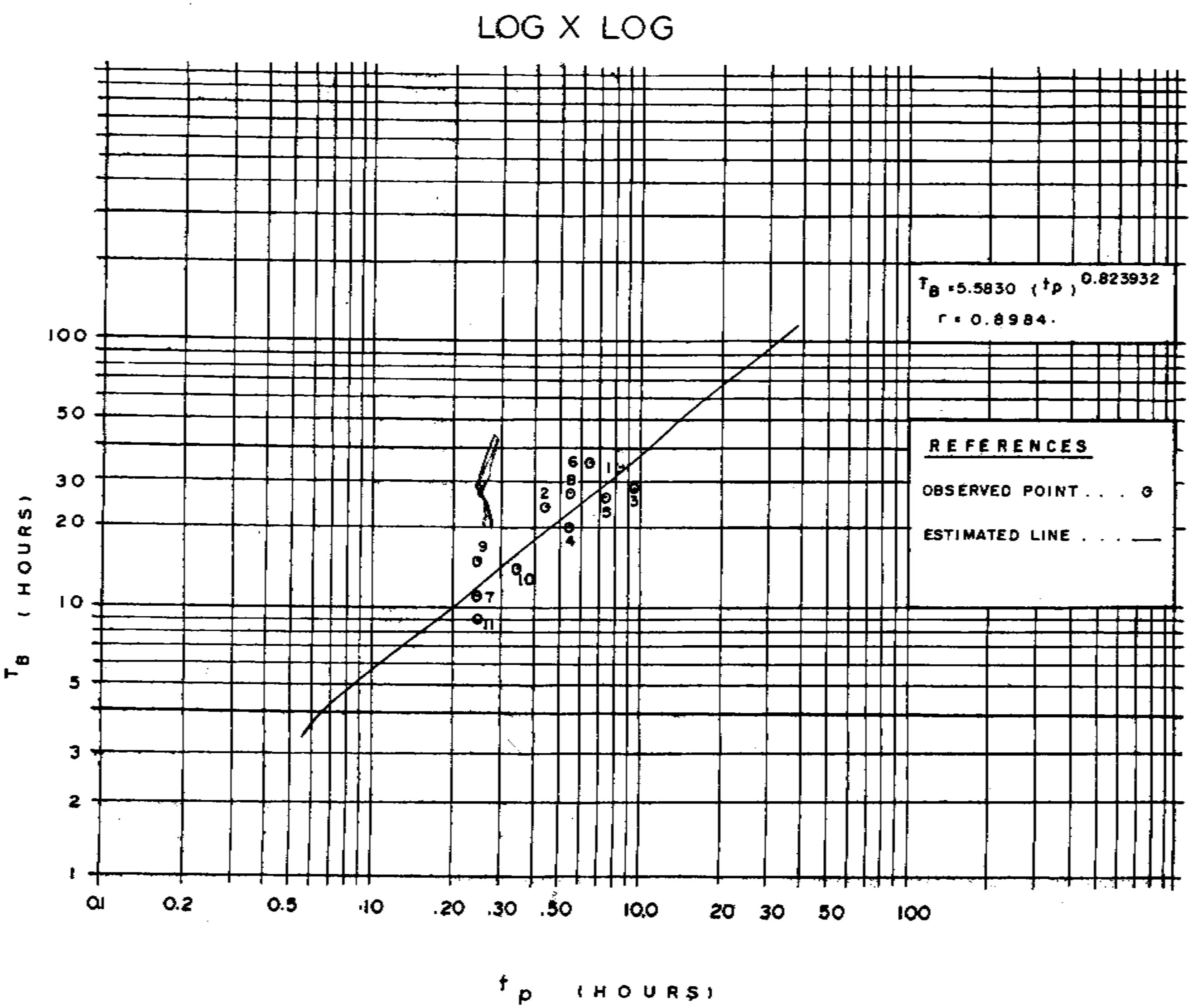
SL. NO.	BRIDGE NO.	OBSERVED VALUE t_p (HOURS)	OBSERVED VALUE W_{R75} (HOURS)
1	167	8.50	2.10
2	110	4.50	0.90
3	94(B)	9.50	2.30
4	101(B)	5.50	0.60
5	160	7.50	0.80
6	286	6.50	1.80
7	676	2.50	0.80
8	348	5.50	1.10
9	656	2.50	0.60
10	114	3.50	1.10
11	150	2.50	0.80

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

LOWER GANGA PLAINS
SUB ZONE – 1(g)
RELATION BETWEEN
t_p AND W_{R75}
(HILLY REGION)

DRAWN — S. N. MALHOTRA L. P. NAUTIYAL	CHECKED — R.K. GUPTA

FIG. — 9.



SL. NO.	BRIDGE NO.	OBSERVED VALUE	
		t_p (HOURS)	TB (HOURS)
1	167	8.50	34
2	110	4.50	24
3	94(B)	9.50	28
4	101(B)	5.50	20
5	160	7.50	26
6	286	6.50	35
7	676	2.50	11
8	348	5.50	27
9	656	2.50	15
10	114	3.50	14
11	150	2.50	9

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

LOWER GANGA PLAINS
(HILLY REGION)
SUB ZONE - I(g)
RELATION BETWEEN t_p AND T_B

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

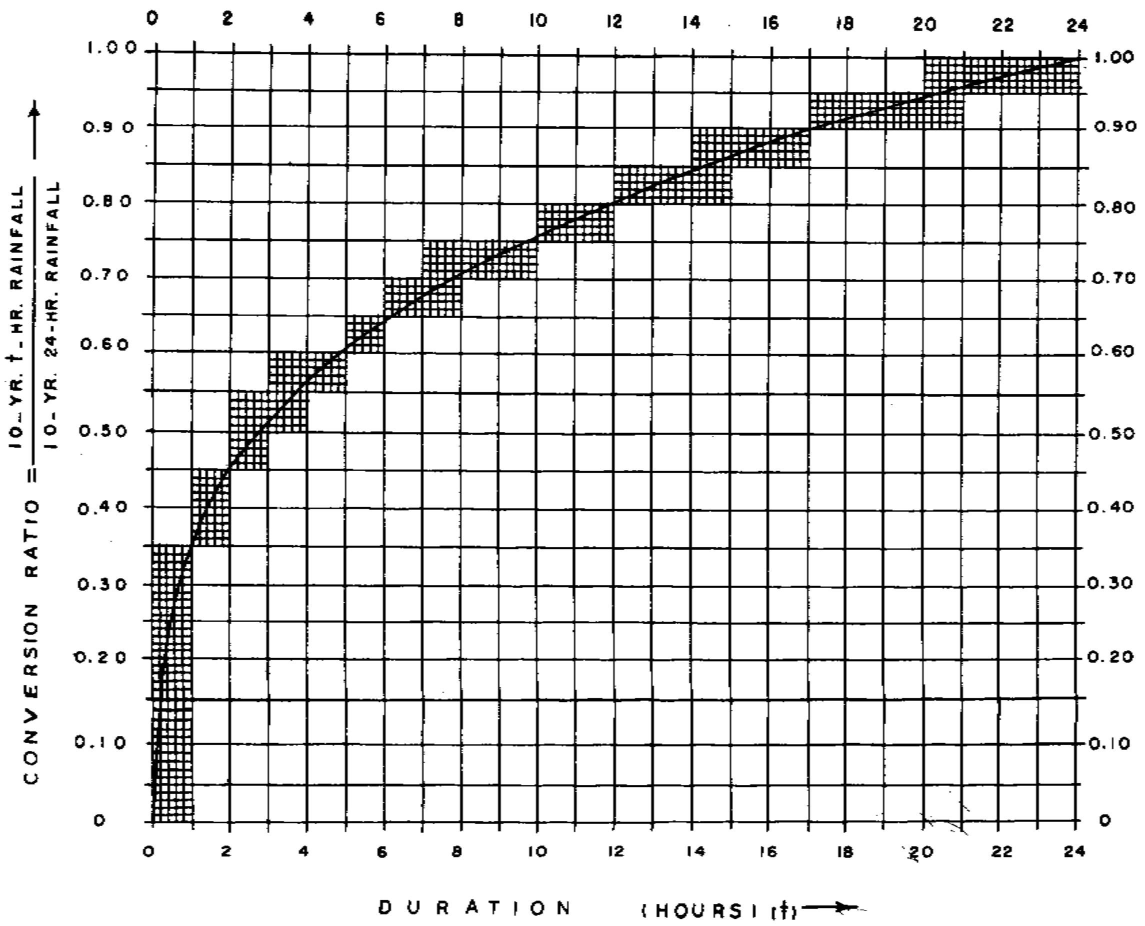


FIG.— 10

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

DURATION (HRS.)	RATIO
1	0.350
2	0.450
3	0.515
4	0.560
5	0.605
6	0.640
7	0.675
8	0.705
9	0.735
10	0.760
11	0.780
12	0.800
13	0.825
14	0.845
15	0.860
16	0.880
17	0.900
18	0.915
19	0.930
20	0.945
21	0.960
22	0.975
23	0.990
24	1.000

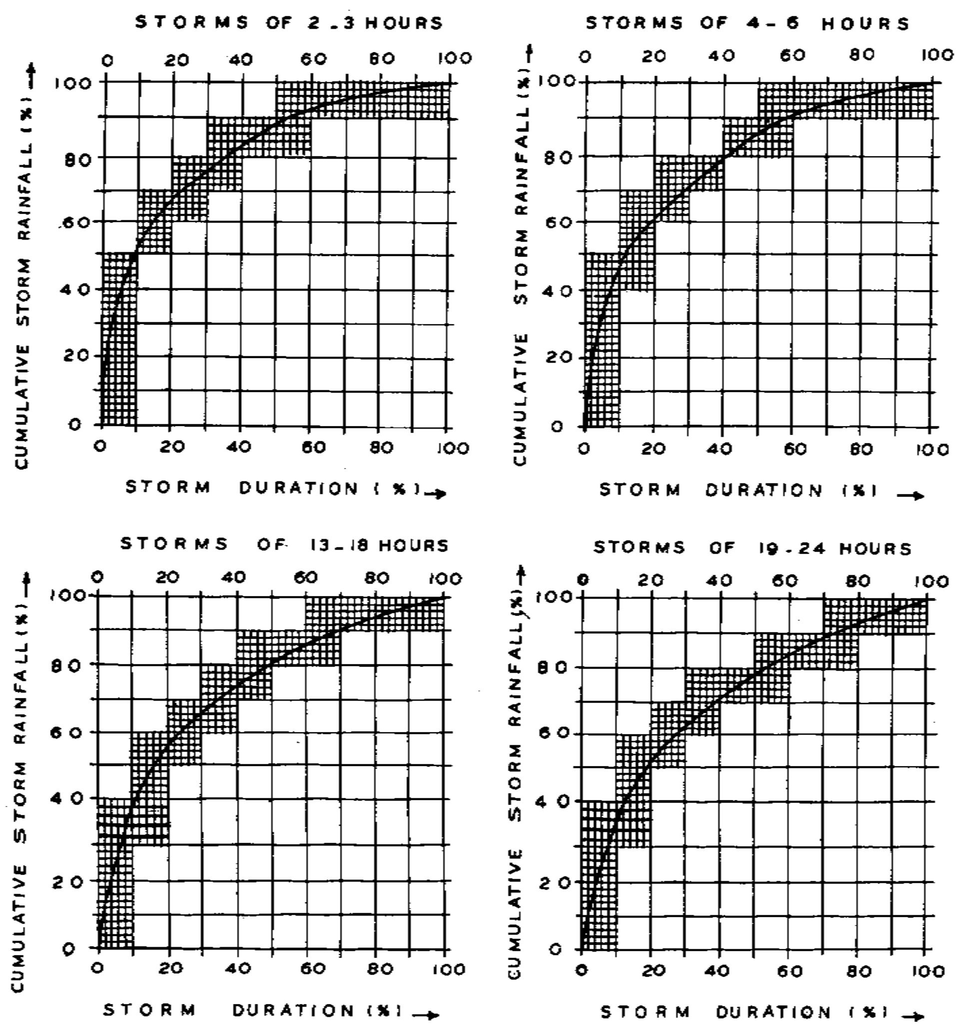
NOTE :- CURVE SUPPLIED BY I.M.D

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

LOWER GANGA PLAINS
SUB ZONE - 1 (9)
DURATION VS. CONVERSION RATIO

DRAWN	CHECKED—
S.N. MALHOTRA L. P. N AUTIYAL	R. K. GUPTA

FIG. – 11.



NOTE –

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

NOTE :- CURVES SUPPLIED BY I.M.D.

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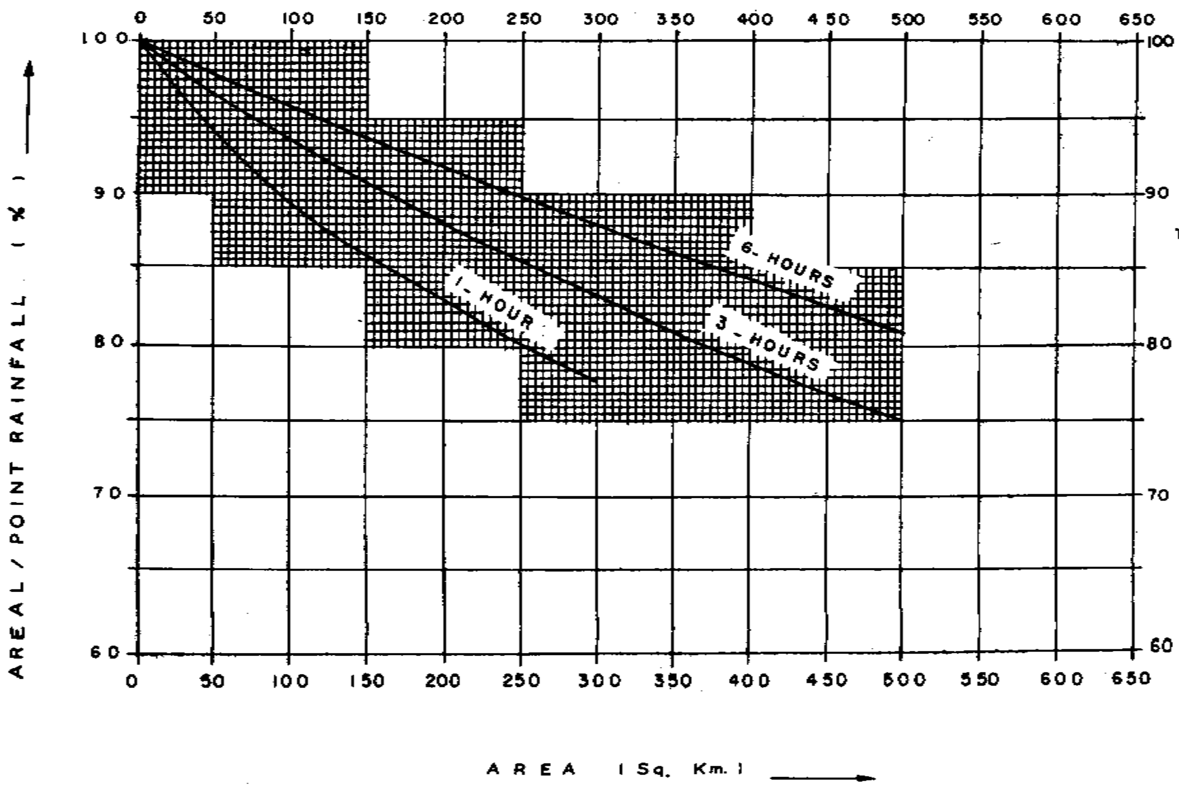
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

LOWER GANGA PLAINS
SUB ZONE – 1 (g)
MEAN AVERAGE TIME DISTRIBUTION CURVES OF STORMS OF VARIOUS DURATIONS

DRAWN –	CHECKED –
S. N. MALHOTRA L. P. NAUTIYAL	R. K. GUPTA

FIG. – 12 (a).



NOTE –

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

II) REFER FIG.– 12 (b) FOR AREAL TO POINT RAINFALL RATIOS FOR DURATION 12– HOURS AND 24– HOURS

NOTE :–
CURVES SUPPLIED BY I.M.D

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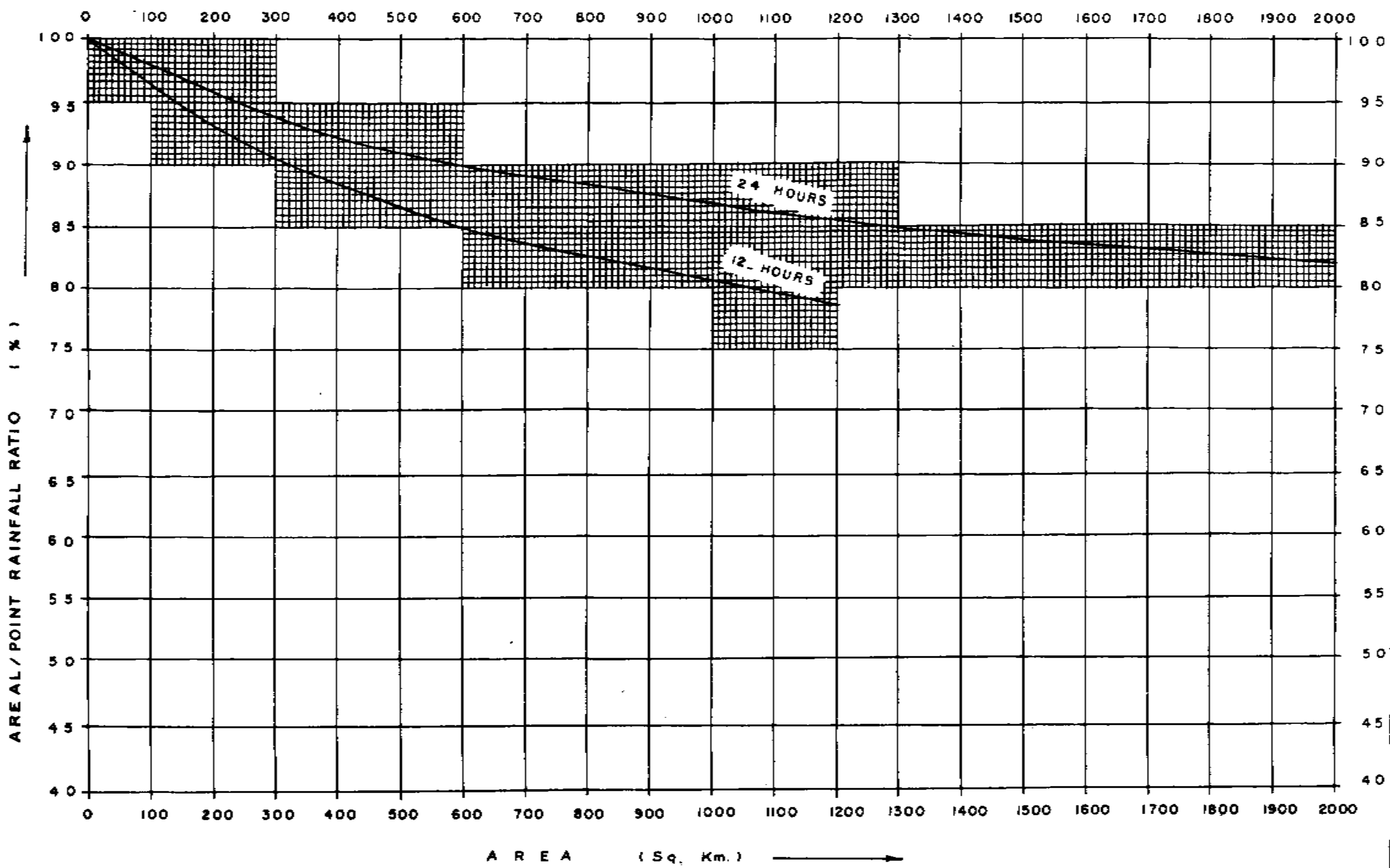
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

LOWER GANGA PLAINS
SUB ZONE – I (g)
AREAL TO POINT RAINFALL RATIO (%)
FOR 1, 3 AND 6 HOURS

DRAWN –
S. N. MALHOTRA
L. P. NAUTIYAL

CHECKED –
R. K. GUPTA

FIG. – 12(b)



NOTE –

i) REFER ANNEXURE-4.2 FOR AREAL TO POINT RAINFALL RATIOS FOR DURATION FROM 1 TO 24 Hrs. AND FOR CATCHMENT AREAS UP TO 2000 Sq. Km.

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

NOTE:-

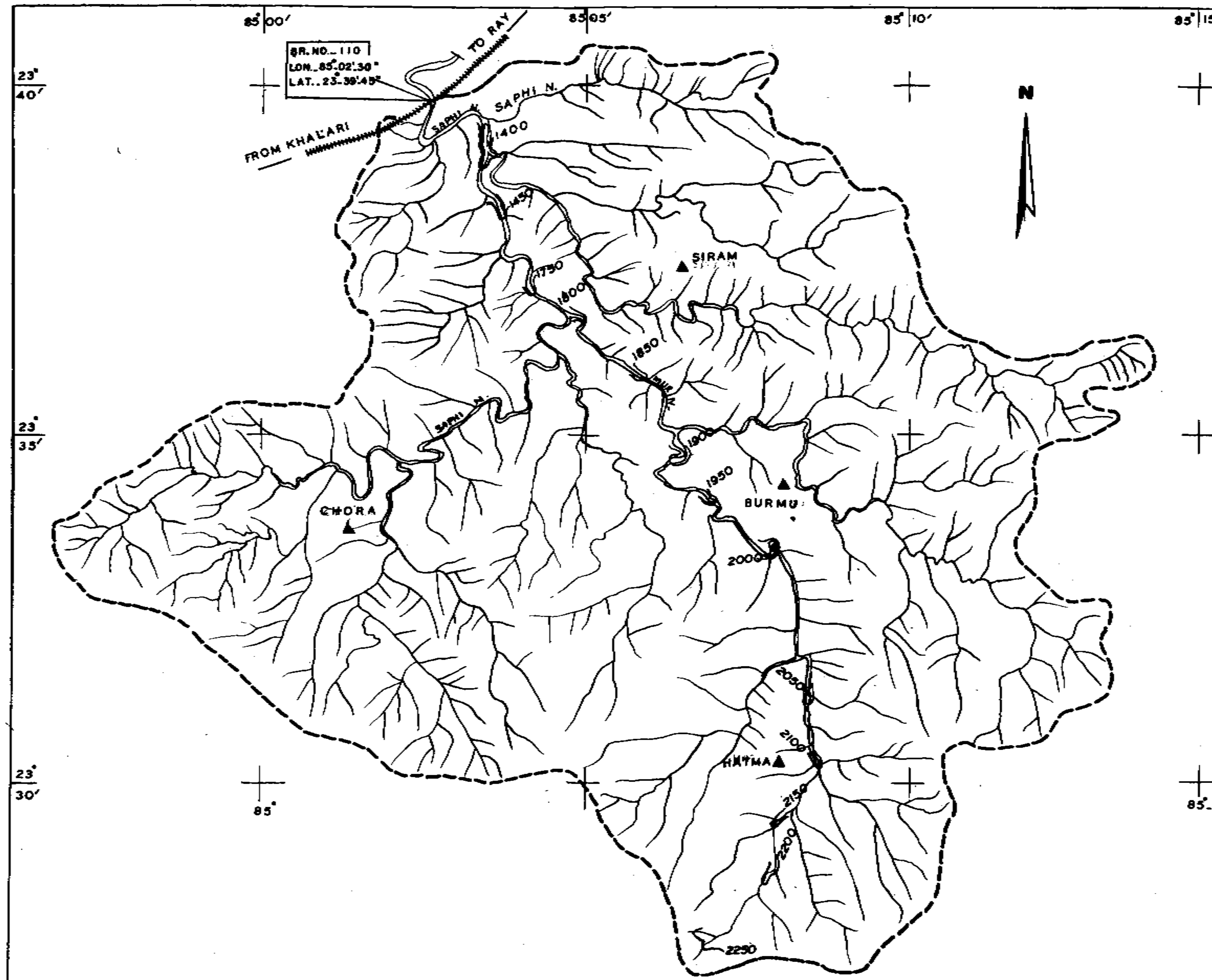
CURVES SUPPLIED BY I.M.D

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

LOWER GANGA PLAINS
SUB ZONE - 1(g)
AREAL TO POINT RAINFALL RATIO (%) FOR 12-HOURS & 24-HOURS

DRAWN –	CHECKED –
S. N. MALHOTRA L. P. NAUTIYAL	R.K. GUPTA

FIG.-A-1.



REFERENCES

1. CATCHMENT BOUNDARY . . . . . .
2. RIVER & IT'S TRIBUTARIES . . . .
3. RAINGAUGE STATIONS . . . . . .
4. CONTOURS . . . .

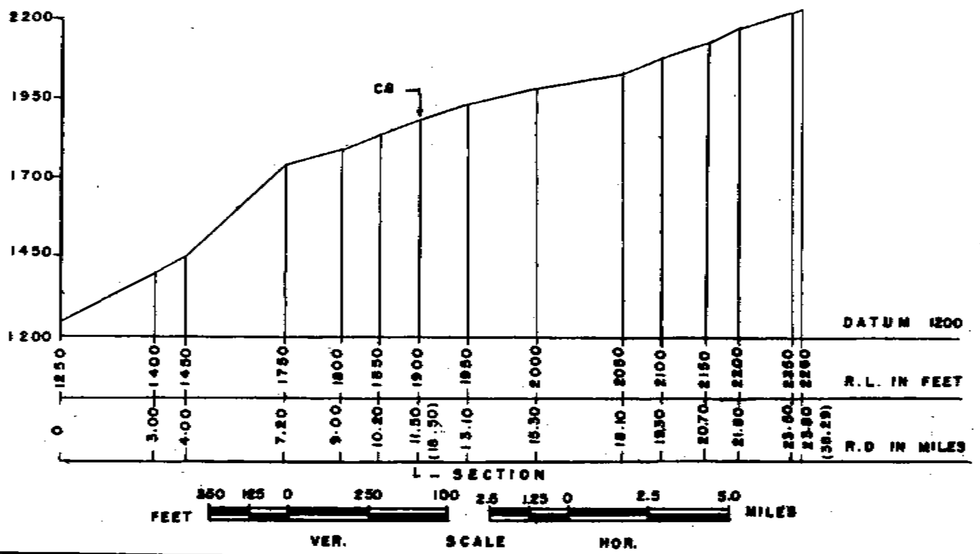
DETAILS OF THE CATCHMENTS

1. CATCHMENT AREA , (A) . . . . . 389.76 Km.^{2}
2. SHAPE OF THE CATCHMENT FAN
3. LENGTH OF THE MAIN RIVER (L) . . . 38.29 Km.
4. L_c . . . . 18.50 Km.
5. EQUIVALENT SLOPE (S) . . . . . 9.37 M/km.
6. TOPOSHEET NO.- 73 A/14, 73E/2,3

NOTE

ALL DIMENTIONS IN FPS HAVE BEEN CONVERTED TO MKS UNITS FOR USE IN REPORT.

SL. NO.	NAME OF RAIN GAUGE STATIONS	STATION WEIGHTAGE 1966	1967	REMARKS
1.	HATMA	0.257	0.349	
2.	BURMU	0.217	0.266	
3.	CHORA	0.279	0.385	
4.	SIRAM	0.247	-	



SCALE

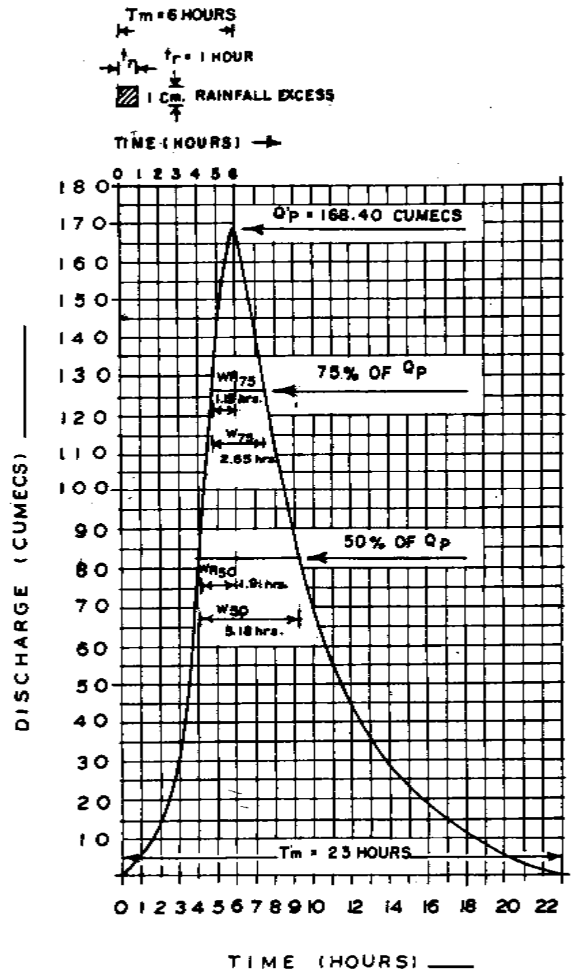
MILES 1.0 0.5 0 1 2 3 MILES

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

CATCHMENT AREA PLAN OF BRIDGE NO.- 110, 1-(9), AT MILE 281/4 ON BARKAKANA LOOP OF EASTERN RAILWAY

DRAWN-	CHECKED-
S. S. JHAS L. K. PANT	K. K. AICH.

FIG. – A – 2.



TIME IN (HOURS)	1- HOUR SYNTHETIC U.G ORDINATES (Cumecs)
0	0
1	5.00
2	13.00
3	28.00
4	74.00
5	135.00
6	168.40
7	141.00
8	113.00
9	87.50
10	70.00
11	54.50
12	44.50
13	36.00
14	29.00
15	23.00
16	18.50
17	14.30
18	11.00
19	8.00
20	5.00
21	2.80
22	1.20
23	0
TOTAL	1082.70 Cumecs.

SYNTHETIC U.G. PARAMETERS

C. AREA = 389.76 Km^2

t_p = 5.50 HOURS

T_B = 23.00 HOURS

Q_p = 168.40 CUMECS

W_{50} = 5.18 HOURS

W_{75} = 2.65 HOURS

W_{R50} = 1.91 HOURS

W_{R75} = 1.15 HOURS

q_p = 0.432 Cums./Km^2

T_m = 6.00 HOURS.

t_r = 1.00 HOUR

$$\Sigma Q_i t_i = \frac{A \times d}{t_r \times 0.36} = \frac{389.76 \times 1.00}{1.00 \times 0.36} = 1082.70 \text{ CUMECS}$$

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

LOWER GANGA PLAINS

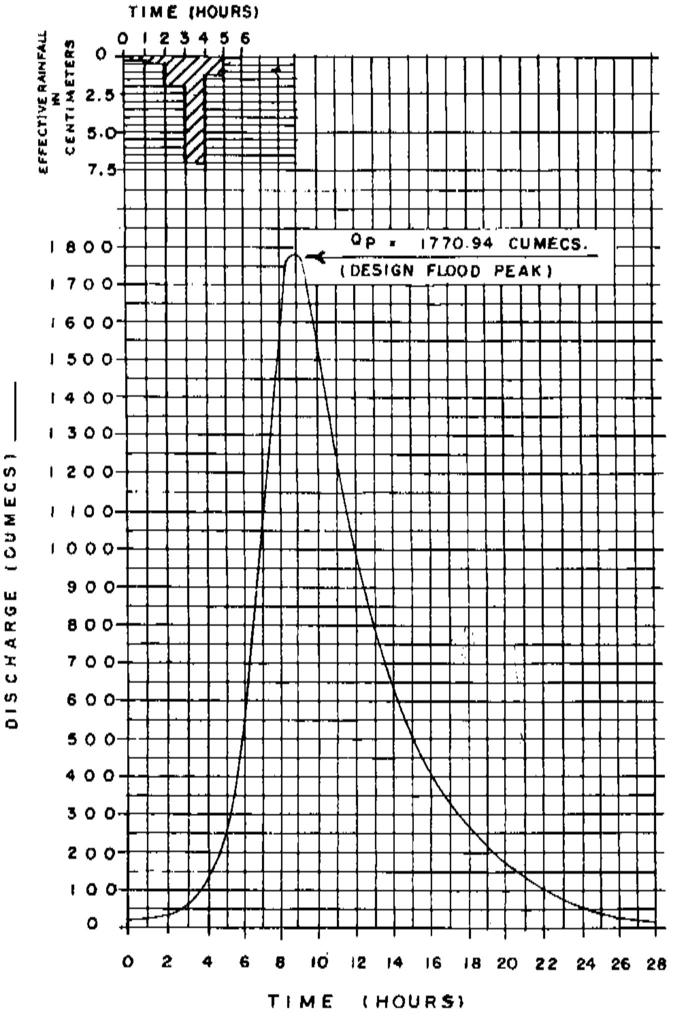
SUB ZONE – 1(9)

SYNTHETIC UNIT HYDROGRAPH

BRIDGE NO.. 110, ON RIVER SAPHI

DRAWN –	CHECKED –
S. N. MALHOTRA L. P. NAUTIYAL	R. K. GUPTA

FIG. - A _ 3.



NOTE: -

REFER ANNEXURE 5.3 FOR COMPUTATION OF DESIGN FLOOD HYDROGRAPH.

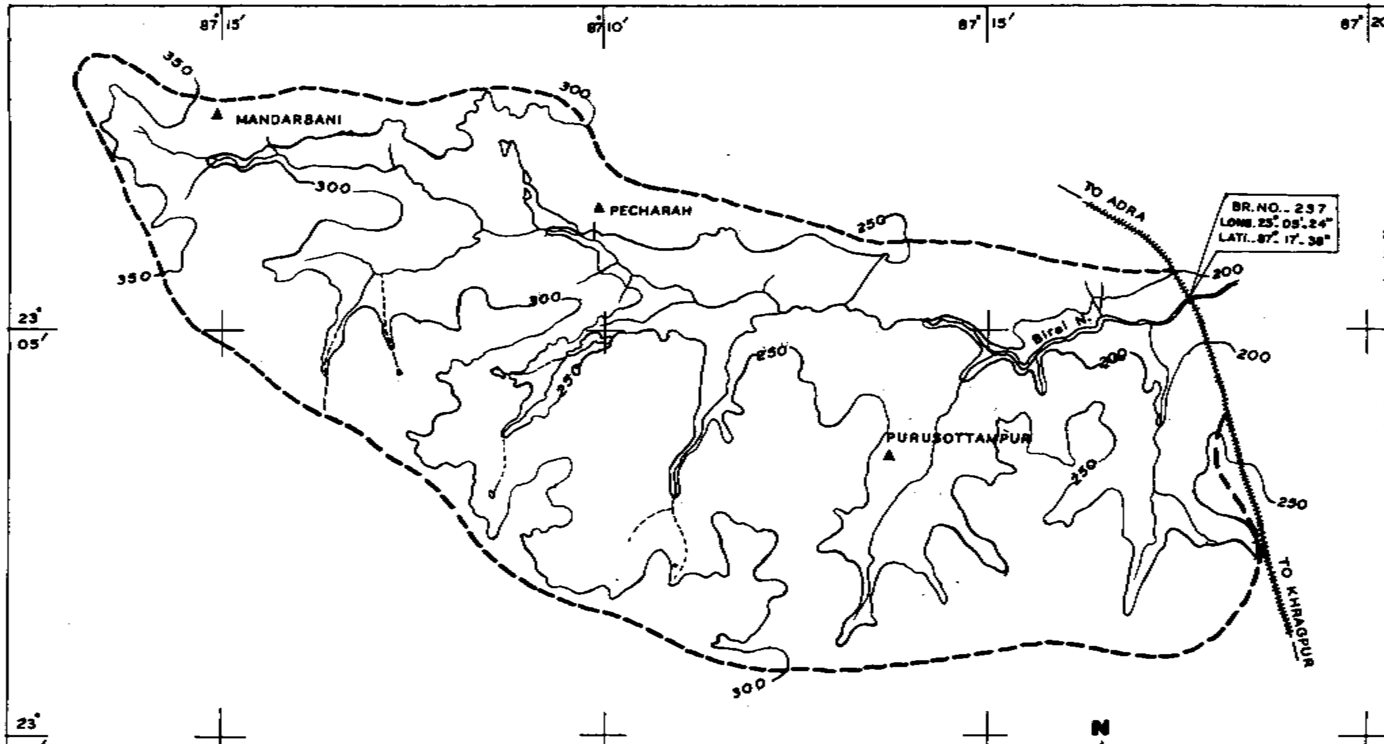
CATCHMENT AREA = 389.76 Sq. Km.

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

LOWER GANGA PLAINS
SUB ZONE - 1 (g)
DESIGN FLOOD HYDROGRAPH
BR NO - 110 ON RIVER SAPHI

DRAWN —	CHECKED —
L. P. NAUTIYAL S. N. MALHOTRA	R. K. GUPTA

FIG. A-4.



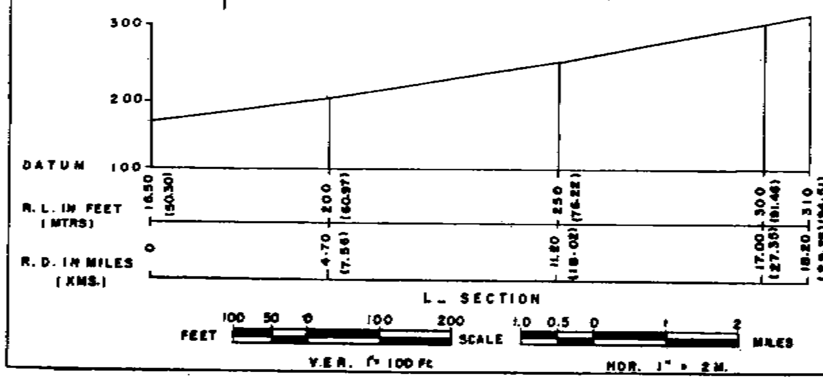
REFERENCES

1. CATCHMENT BOUNDARY
2. RIVER & ITS TRIBUTARIES
3. CONTOURS
4. RAINGAUGE STATIONS ▲

DETAILS OF THE CATCHMENT.

1. AREA OF THE CATCHMENT (A) . . 224.29 Km.²
2. LENGTH OF THE MAIN RIVER (L) . . 29.30 Km.
3. EQUIVALENT SLOPE (S) . . 1.46 M/km.
4. SHAPE OF THE CATCHMENT . . LEAF
5. TOPO SHEET NO. . . NO. 73 M/4&8

SCALE: 1.0 0.5 0 1 2 3 MILES — 1″ = 1 MILES



SL. NO.	NAME OF R.G. STATION	STATION WTS. 1960-1964	REMARKS
1.	MANDARBANI	0.191	
2.	PECHARAH	0.289	
3.	PURUSOTTAMPUR	0.520	

GOVERNMENT OF INDIA
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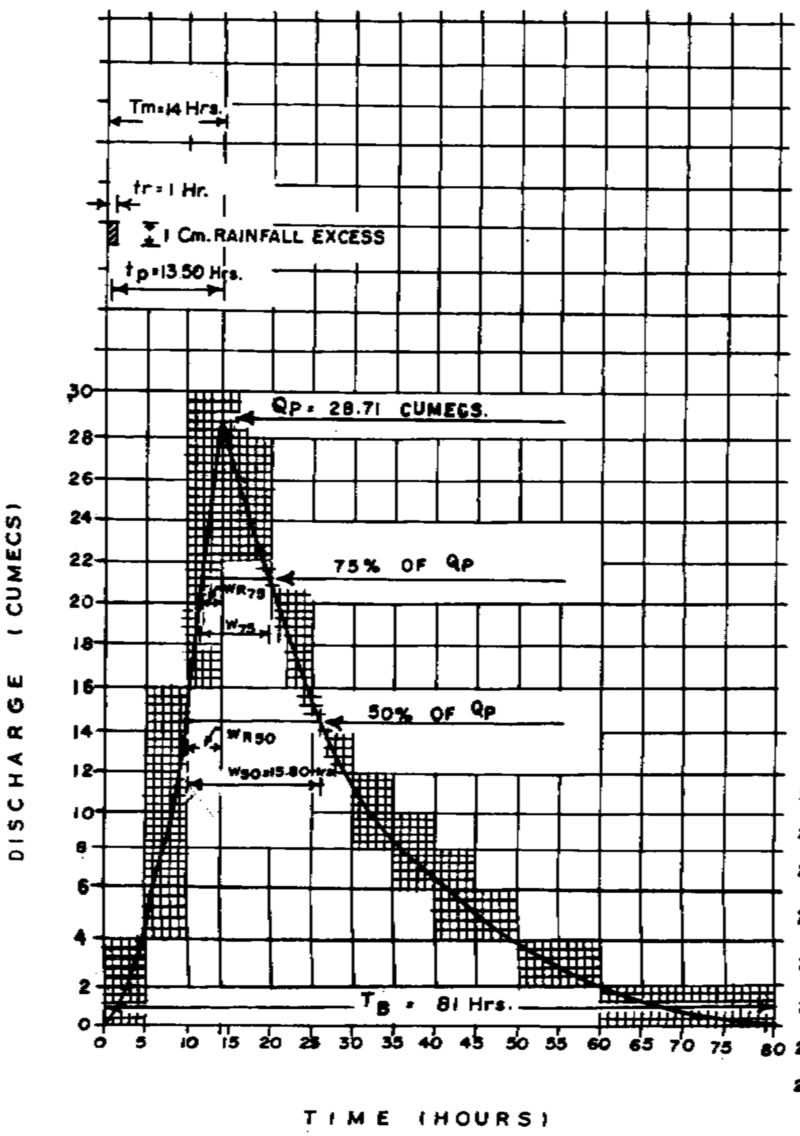
CATCHMENT AREA PLAN OF BRIDGE NO. 237, 1-(B) AT MILE 126.286 ON KHARAGPUR - ADRA SECTION OF SOUTH EASTERN RAILWAY.

DRAWN –	CHECKED –
S. S. JHAS L. P. NAUTIYAL	VINOD KAUL

FIG. A- 5.



1 - HOUR SYNTHETIC U.G. ORDINATES

TIME IN HOURS	ORDINATES (Cumecs)	TIME IN HOURS	ORDINATES (Cumecs)	TIME IN HOURS	ORDINATES (Cumecs)
0	0.00	28	12.60	56	2.40
1	0.50	29	11.80	57	2.20
2	1.40	30	11.00	58	2.00
3	2.20	31	10.40	59	1.90
4	3.20	32	9.80	60	1.80
5	4.40	33	9.40	61	1.60
6	5.80	34	8.80	62	1.40
7	7.20	35	8.30	63	1.30
8	9.10	36	7.80	64	1.20
9	11.60	37	7.40	65	1.10
10	15.00	38	7.10	66	1.00
11	18.40	39	6.80	67	0.90
12	22.30	40	6.40	68	0.80
13	26.20	41	6.00	69	0.70
14	28.71	42	5.80	70	0.60
15	28.40	43	5.60	71	0.52
16	27.00	44	5.30	72	0.42
17	25.60	45	5.00	73	0.35
18	23.00	46	4.80	74	0.30
19	22.20	47	4.60	75	0.25
20	20.80	48	4.30	76	0.20
21	19.40	49	4.10	77	0.15
22	18.40	50	3.80	78	0.10
23	17.20	51	3.60	79	0.08
24	16.20	52	3.40	80	0.05
25	15.20	53	3.10	81	0.00
26	14.40	54	2.90		
27	13.40	55	2.60		

SYNTHETIC U.G. PARAMETERS

C. AREA = 224.29 Km^2

t_r = 1.00 HOUR

Q_p = 28.71 CUMECS

q_p = 0.128 CUMECS/Km^2

t_p = 13.50 HOURS

T_m = 14.00 HOURS

T_B = 81.00 HOURS

W_{50} = 15.80 HOURS

W_{75} = 7.94 HOURS

W_{R50} = 4.43 HOURS

W_{R75} = 2.38 HOURS

R_{R75} = 2.38 HOURS

d = 1.00 Cm.

$$\Sigma Q_i = \frac{A \times d}{t_r \times 0.36} = \frac{224.29 \times 1.00}{1.00 \times 0.36}$$

= 623.03 CUMECS

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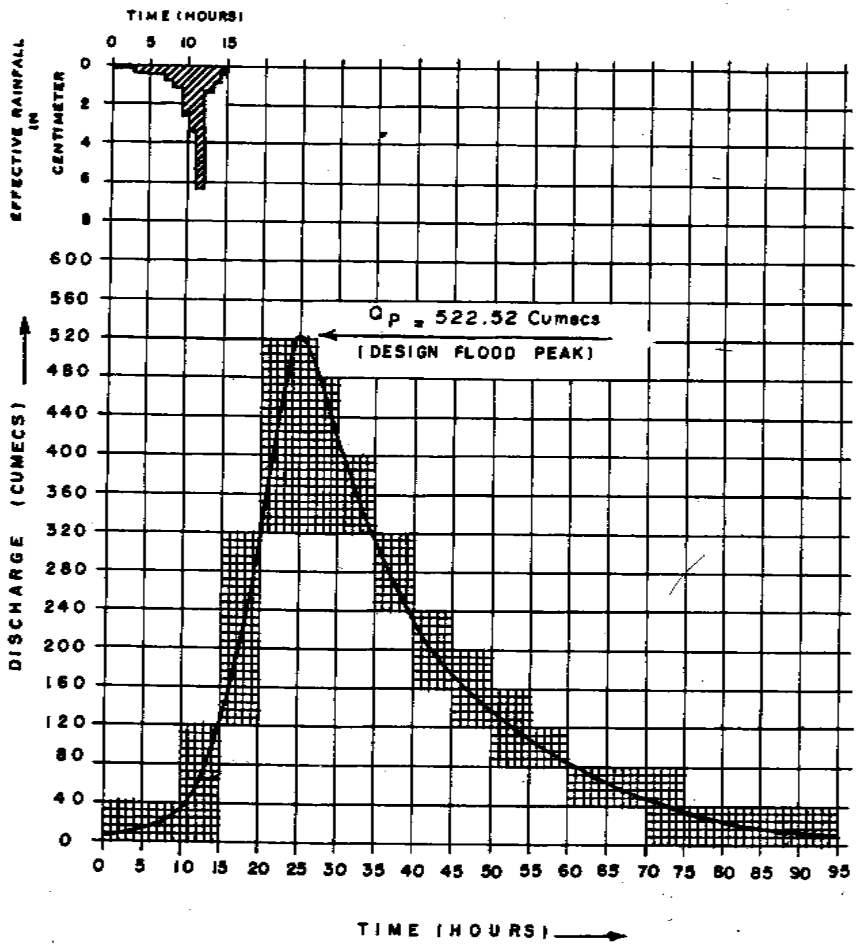
HYDROLOGY (REGIONAL STUDIES) DTE.

LOWER GANGA PLAINS
SUB ZONE - 1(g)
SYNTHETIC UNIT HYDROGRAPH
BR. NO.- 237 ON RIVER BIRAI

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

FIG.. A _ 6.



NOTE _

REFER ANNEXURE _4.2 FOR COMPUTATION OF DESIGN FLOOD HYDROGRAPH.

CATCHMENT AREA = 224.29 Sq. Km.

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

LOWER GANGA PLAINS
SUB ZONE - 1 (g)
DESIGN FLOOD HYDROGRAPH
BRIDGE NO.. 237 ON RIVER BIRAI.

DRAWN_	CHECKED_
S. N. MALHOTRA L. P. NAUTIYAL	K. K. AICH.

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13. Sh.	L.K.Pant	--------do--------

LIST OF FLOOD ESTIMATION REPORTS PUBLISHED

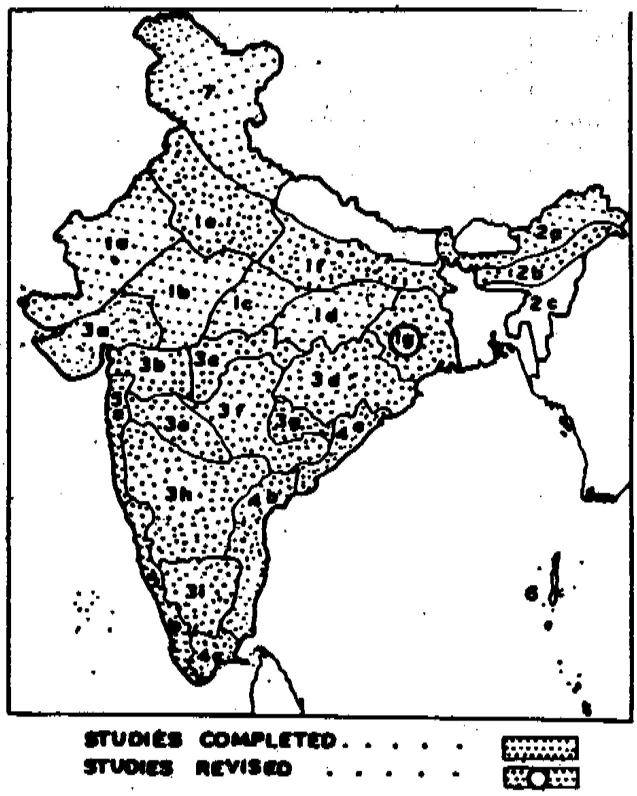
A. UNDER SHORT TERM PLAN

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 & Tapi subzone 3(b) (1982)
4. Mahanadi subzone 3(d) (1982)
5. Upper Narmada & Tapi subzone 3(c) (1983)
6. Krishna & Penner 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) (1988)
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)

* Present reprt is the revision of this Report



Designed & Printed at Publication Division of Central Water Commission
R.K. Puram, New Delhi-110066. Publication No. 24/94