अभिकल्प कार्यालय विवरण
DESIGN OFFICE REPORT
NO.SB-2(b)/R-4/44/99

केन्द्रीय जल आयोग
CENTRAL WATER COMMISSION

दक्षिणी ब्रह्मपुत्र (उप अंचल - 2 बी)
का बाढ़ ऑकलन विवरण
(परिशोधित)
FLOOD ESTIMATION REPORT FOR SOUTH BRAHMAPUTRA SUBZONE - 2(b)
(REVISED)

जल विज्ञान निदेशालय
क्षेत्रीय अध्ययन
जल विज्ञान अध्ययन संगठन
नई दिल्ली- 110066

DIRECTORATE OF HYDROLOGY
(REGIONAL STUDIES)
HYDROLOGY STUDIES ORGANISATION
NEW DELHI -110066

केन्द्रीय जल आयोग
भारत मौसम विभाग
अनुसंधान अभिकल्प एवं मानक संगठन
भूतल परिवहन मंत्रालय
का संयुक्त कार्य

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

मार्च, 2000
MARCH, 2000

Revised Flood Estimation Report for South Bramhaputra Subzone 2 (b) was discussed and approved by the following members of Flood Estimation Planning and Co-ordination Committee in its 55th Meeting held on 13.3.2000 at Central Water Commission, New Delhi.

(R.K. Gupta)
Director Hydrology (RS)
Central Water Commission
New Delhi.

(B. Lal)
Deputy Director General (HM)
India Meteorological Deptt.
New Delhi.

(M.B. Vijay)
Director (B & S)
Research Design & Standards Organisation
Lucknow - 226011.

(I.K. Pandey)
Superintending Engineer(Bridges)
Ministry of Surface Transport
New Delhi.

DESIGN OFFICE REPORT
SB-2(b)/R-4/44/99

CENTRAL WATER COMMISSION

FLOOD ESTIMATION REPORT FOR SOUTH BRAHMAPUTRA BASIN SUBZONE -2(b) (REVISED)

HYDROLOGY (REGIONAL STUDIES) DIRECTORATE
HYDROLOGY STUDY ORGANISATION
NEW DELHI.

MARCH, 2000

FOREWORD

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

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

In addition to above, there is also periodic revision / updation of such subzonal reports, whenever additional data sets become available and sophisticated analysis becomes due. The flood estimation reports of Lower Ganga Plains subzone 1(g), Lower Godavari subzone 3 (f), Mahanadi subzone 3(d), published in 1975, 1981 and 1982 respectively have already been revised and published. The present report is the revision/updation of flood estimation report of South Brahmaputra Basin Subzone 2 (b) published in the year 1984. It gives the method to compute design flood of 25,50, and 100-year return period for ungauged catchments located in South Brahmaputra basin Subzone 2 (b).

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

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

New Delhi,
December, 1999.

(Dr.B.K.Mittal)
Member (D&R) CWC

PREFACE

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

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

Recognising the need to evolve a method for estimating design flood peak of desired frequency, the committee of engineers headed by Dr. A.N. Khosla have recommended in their report in the year 1959 that the design discharge for bridges should be the maximum flood on record for a period of not less than 50 years. Where adequate records are available, extending over a period not much less than 50 years, the design flood should be the 50-years flood determined from the probability curve prepared on the basis of the recorded floods during that period. In case, where the requisite data as above are not available, the design flood should be decided based on the ground and meteorological characteristics obtained on the basis of design storms necessitating the systematic and sustained collection of hydro-meteorological data at selected catchments in different climatic zones of India.

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

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

Under long-term plan, country has been divided into 26 hydro-meteorologically-homogeneous subzones. For preparing the flood estimation reports for these subzones, systematic and sustained collection of hydrometeorological data at the representative catchments, numbering 10 to 30, for a period of 5 to 10 years in different subzones has been carried out in a phased manner by different zonal railways since 1965 under the supervision and guidance of Bridges and Flood Wing of Research Designs and Standards Organisation (RDSO) of Ministry of Railways. Similarly, the Ministry of Transport (MOT) had undertaken the collection of data for 45 catchments through Central Water Commission (CWC) since 1979.

Hydrology (Regional Studies) Directorate, Central Water Commission carried out analysis of collected concurrent rainfall and flow data for the gauged catchments to derive unit hydrographs of mostly one-hour duration.. Representative unit hydrographs are prepared for each of the gauged catchments from the selected flood events. The characteristics of the catchments and the unit hydrographs, characteristics for each catchment studies in a subzone are correlated and the equations for synthetic unit hydrograph for the subzone are derived for developing the response function for an ungauged catchment. This response function on convolution with the storm input as studied and provided by IMD gives the estimated design flood for that ungauged catchment. Studies are also carried out by the CWC to arrive at suitable recommendations for estimating loss rate and base flow for ungagued catchments.

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

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

So far, following 21-Flood Estimation Reports (FERs) covering 24 Subzone have been published :

1. Lower Ganga Plains Subzone 1 (g) (1978)
2. Lower Godavari Subzone 3 (f) (1981)

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

Hydrometeorological inputs in the FERs at serial number 1 to 7 were based on Self Recording Raingauges (SRRGs) data alone and consisted :

(i) Isopluvial maps for 24 hour and / or shorter duration corresponding to 50 year return period period only,
(ii) Time of storm rainfall, and
(iii) Point to areal rainfall ratios.

However, in the subsequent reports, IMD modified the methodology and prepared the hydrometeorological inputs based on conjunctive use of ordinary raingauges (ORG) and SRRG data. It was accordingly recommended and desired by the FEPCC to revise the FERs at serial No. 1 to 7, so that all the reports are uniform so far as methodology is concerned. It was further decided while updating the meteorological component, the validation of hydrological studies must also be carried out to find if significant changes are there. The hydrological study was to be revised based on the additional hydrological data, collected subsequent to the preparation of the original reports. The FER for Lower Ganga Plains Subzone 1(g), published in 1978, Lower Godavari Subzone 3(f), published in 1981 and Mahanadi Subzone 3 (d) published in 1982 have already been revised where the hydrometeorological input has been included as per revised methodology.

Present report is the revision/validation of the flood estimation report of South Brahmaputra basin Subzone 2(b) (report No.SB/8/1984) and deals with the estimation of flood of 25 years, 50 year and 100 year return period for small and medium catchments in the Subzone. It covers the areas of the Right Bank of River Brahmaputra, which is one of the biggest rivers in the world and flows through Himalayas, Assam, Garo Hills and enters Bangladesh.

The rainfall-runoff data of 25 catchments having catchment area more than 25 Sq.km. for a period of 1 to 11 years during 1961 to 1983 was collected by the Railways. Data of 14 catchments for 71 bridge years found suitable were utilised in study carried out earlier. In the present study, additional data of 29 bridge years for 5 catchments, collected subsequently along with the earlier data, thus totaling 100 bridge years has been used for unit hydrograph study.

IMD while updating the storm studies has used the rainfall data of 74 O.R.G. stations maintained by IMD and State Governments and 6 S.R.R.G. stations maintained by IMD in and around the Subzone as no short duration data has been collected by RDSO at or around the discharge observation stations. As an alternate method, data of 6 SRRG Stations in and around the Subzone were used along with the ORG data.

The report covers six parts. Part-I of the report "Introduction" gives the summary of the earlier and revised studies. Description of the Subzone detailing river systems, rainfall, temperature and soil type etc. is given in Part-II. Part-III brings out the Synthetic Unit Hydrograph (SUH) relations to be used for ungauged catchments in the Subzone. The storm studies carried out by IMD are dealt in Part-IV of the report. Criterion and standards in regard to design flood of structures and procedures to compute the design flood of ungauged catchments are described in Part - V along with an illustrative example. Part-VI highlights the limitations, assumptions and conclusions.

The report on Subzone 2 (b) is recommended for estimation of design flood for small and medium catchments varying in areas from more than 50 Sq.km. upto 1500 Sq.km. This report may also be used for catchments having areas up to 5000 Sq.km. judiciously after comparing the neighbouring catchments having more or less similar characteristics. The method adopted and conclusions arrived at, are subject to periodical review and revision in the light of adequate data being collected and analysed and also the advancements in theory and technique.

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

(R.K. GUPTA)
DIRECTOR
Hydrology (RS) Dte.

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SYMBOLS AND ABBREVIATIONS

Symbols

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

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

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

ABBREVIATIONS

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

PART – I

INTRODUCTION

1.1 GENERAL

The Committee of Engineers headed by Dr. A.N. Khosla recommended to develop regional methodology for estimating design flood for small and medium catchments. On the recommendations of the Committee, the country was divided into 26 hydrometeorologically homogeneous subzones. The various Subzone into which the country has been divided are listed in Annexure 1.1. South Brahmaputra subzone 2(b) is one of the 26 hydrometeorologically homogeneous subzones.

The flood estimation report of South Brahmaputra Subzone 2(b), (Design Office Report No.SB/8/1984) was published in 1984. The present report is validation/revision of the earlier report.

The report published in 1984 contained inputs for estimating the design flood of 50 year return period only whereas the present report provides inputs for estimating design floods of 25, and 100 year in addition to 50 year return period.

1.2 NEED FOR REVISION OF REPORT

Rainfall maps of 50 year return period for duration of 1, 3, 6, 9, 12, 15 and 24 hours were furnished in flood estimation reports, published till 1984. These reports were based on data of sparse self-recording raingauges network. After bringing out these subzonal reports, IMD upgraded the methodology, of storm study, for preparing the rainfall maps using rainfall data of ORG and SRRG in and around the Subzone in addition to the data with in the subzone.

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

1.3 REVISED STUDY

Hydrological and storm studies contained in the earlier report and in the revised/validated report are as follows:

1.3.1 Hydrological study

The hydrological study carried out in 1984 was based on rainfall-runoff data of 14 atchments observed for a period varying from of 1 to 11 years during the period 1961-1983. Representative unit hydrograph of 1-hour duration were derived from the selected flood events from the available data. The equations relating unit hydrograph parameters and basin parameters were developed for deriving 1-hr. synthetic unit hydrograph.

Subsequent to the preparation of the earlier report, additional data in respect of 5 bridge sites (463, 414, 3-MOT, 4-MOT and 6-MOT) for a period varying from 2-8 years was made available by RDSO. These data have now been utilised and integrated with the earlier studies.

The parameter of Statistical Slope used in the earlier report has been replaced with equivalent slope. Recommendations regarding the suitable values of loss rate and base flow have also been revised considering additional data.

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

1.3.2 Storm Study

The earlier report contained isopluvial maps of 50-year return period for different duration, time distribution curves and areal to point rainfall ratios. The present report contains:

(i) Isopluvial maps of 25, 50 and 100 year for 24-hours based on available rainfall data of ORG and SRRG in and around the Subzone.
(ii) Short duration rainfall ratios for converting 24 hours rainfall to short duration rainfall.
(iii) Time distribution curves for storms of various duration.
(iv) Point to areal ratios for different duration.

In the present study, IMD has utilised the rainfall data of 74 ORG stations maintained by IMD and State Governments and 6 SRRG stations maintained by IMD. Besides this data, RDSO has also made available hourly/half hourly concurrent rainfall data in selected bridge catchments for conducting point to areal rainfall study. However, in the present study, SRRG data from a network of IMD's stations in and around the Subzone are used. The storm studies carried out by IMD are given in Part-IV of the report.

1.4 PROCEDURE TO ESTIMATE DESIGN FLOOD

The flood estimation report for Subzone 2(b) can be used for estimation of design flood (25-year, 50-year and 100-year) for ungauged or inadequately gauged catchments in the Subzone. Part-V explains procedure for obtaining the design flood of specified return period along with an illustrative example.

PART-II

GENERAL DESCRIPTION OF SUBZONE

2.1 LOCATION

The Brahmaputra also known as Tsangpo in Tibet rises at Tamchok Khamdet Chorten in the Chemayung-dung glacier. It has a long course through the comparatively dry and flat region of Southern Tibet, before breaking through the Himalayas below the peak of Nancha Barwa. It is known as the Dihang in the Arunachal Himalayas before it enters the Assam plains. The Dibang and the Lohit join the Dihang from the east near Sadija. After traversing the Assam valley for 720 km, the Brahmaputra sweeps round the Garo hills and enters the Rangpur District of Bangladesh near Dhubri. It flows southwards to join the Ganga at Goalundo. The Brahmaputra with a total catchment of 0.74 million Sq.km. is one of the biggest rivers in the world. The total length of the river in India is about 885 km. The drainage area of the Brahmaputra basin in India is about 1,95,000 Sq.km.

A number of tributaries drain into the Brahmaputra from North and South, in its course through the state of Assam. Of the 25 principal north bank tributaries, the Subansiri, the Jia-Bhareli and the Manas are fairly large ones. There are 15 principal south bank tributaries, the most important among them being the Burhi-Dehing, the Kopili and the Dhansiri. The north bank tributaries are generally large, since their catchments lie in the heavy rainfall zone of the Himalayas. The south bank tributaries of the Brahmaputra in the Assam State are generally smaller as compared to those of the north bank, as their catchments in the Assam hills are smaller and get less rain. The Brahmaputra, in its course through the Assam plains divides into many channels and forms numerous braids of which an important islands is Majuli island which has area of about 1250 sq. km. in area.

2.2 RIVER SYSTEM

The course of the Brahmaputra river in the plains divides the Brahmaputra basin in India into two subzones viz.; Northern and Southern Subzone. The main tributaries in Southern Subzone are Belang, Noa-dihing, Dibru, Burhi-dihing, Jhanji, Dhansiri, Diphu, Kopili, Umium, Dudhnai or Krishnai. The drainage area of major tributaries in South Brahmaputra basin are given in Table 2.1. The river system of Subzone 2(b) is given at Plate - 2.

Table 2.1
(Drainage Area)

Sl. No.	Basin/Sub-basin	Drainage area (Sq.km)
1	Belang	3004.74
2	Kulsi	5007.90
3	Dibru	2704.26
4	Burhidihing/Noadihing	13671.55
5	Jhanji	5909.32
6	Disai (Dhansiri)	14162.33
7	Sonai	3154.97
8	Kopili	18679.45
9	Dudhnai or Krishnai	2904.58
10	OtherMinor Tributaries	4356.87
Total Area of South Brahmaputra Subzone		**73555.97**

Say 73556.0 Sq.km

2.3 GENERAL TOPOGRAPHICAL FEATURES

2.3.1 Physiography

The South Brahmaputra Basin Subzone 2(b) lies between longitude 89^0 45' to 97° 15' East and latitude 25° 15' to 28° North approximately. The shape of the sub-zone 2(b) is elongated with its northern boundary falling along the main course of the Brahmaputra river. The northern ranges of Garo, Khasi, and Jaintia hills fall along the southern boundary of the sub-zone. The South Brahmaputra Subzone is bounded on the north by the north Brahmaputra Subzone 2 (a), on the south by Barak Subzone 2 (c) on the East by Burma and West by Bangladesh. The Subzone comprises of large parts of Assam and areas of Meghalaya, Nagaland and Arunachal Pradesh. The physiographic map of subzone is appended at Plate-3.

The South Brahmaputra Subzone comprises of number of hills having altitudes varying from 150 m to more that 1350 m. The main hills are the Manipur Hills, Patkai Bum, Dapple Bum and Khasi Jaintia Hills have altitudes of 1350 m and above. The altitude of Garo Hills range from 300 m to 600 m while Mikir Hills have altitude range of 150 m to 300 m. The flat area, which lies along the river Brahmaputra, varies between 75 m to 150 m. The important towns in the Subzone are Goalpara, Guwahati, Nowgong, Mariani and Dibrugarh. Towns situated at altitude between 600 m to 1350 m are Haflong and Kohima whereas Shillong is situated at still higher elevation of more than

1350 m. Some other important towns in the Subzone are Lumding, Tura, Dhubri, Dispur, Jorhat and Sadiya.

2.3.2 Soils

The Subzone 2(b) has a variety of soils as shown at Plate-4. Broadly they can be classified as red loamy soil, red and yellow soil, laterite soils and alluvial soil of recent origin. The red loamy soil is found towards the northeast and a small belt continues upto lower half of the Subzone and upto Shillong in the southwest. The flood plains covering the Dibrugarh, Mariani, Nowgong, Guwahati and Goalpara districts represent alluvial soils of recent origin. There is a small belt of laterite soils towards southeast. The laterite soils are also found in the southern corner and towards the southwest of the Subzone. The red and yellow soils are normally found towards the south and towards the south western corner of the Subzone between Tura and boundary of Bangladesh. At micro level this broad classification may not hold good.

2.3.3 Land Use

The land use map is appended at plate-5. The map has been prepared from Irrigation Atlas of India, 1989. It can be seen from the map that about 85% area of the Subzone is under forest. Along the bank of river Brahmaputra the area which at one time was all covered by shrubs and grassland is now cultivable area. The major crops grown are rice and wheat.

2.4 CLIMATOLOGICAL FEATURES

2.4.1 Rainfall Features

The rainfall is generally spread over a period of eight months, i.e. from March to October. From May to October, the Subzone gets both southwest monsoon and cyclonic rain, and about 90 percent of the total rainfall occur in these months. The winter season from December to March is practically dry.

2.4.1.1 Annual normal rainfall features

The isohyetal map of annual normal rainfall for the subzone 2(b) is shown in plate 6. The annual rainfall can be seen to be highly variable in space. The highest annual normal rainfall is recorded at Wakchong Station in the Subzone is 3204 mm. The eastern part of the subzone receives highest annual rainfall greater than 3000 m.m. Major parts of the subzone receive annual rainfall in the range of 1250-2500 mm. The annual rainfall of station Lanka in Nowgong district of Assam is barely 1242 mm. The annual rainfall is lowest in Central parts of the Brahmaputra Valley.

2.4.1.2. Monthly rainfall distribution

Monthly rainfall distribution at two representative station viz.; Guwahati and Nowgong is illustrated through bar charts appended to the annual normal rainfall map. In the bar charts, alphabets along abscissa indicate names of months whereas heights of rectangles are proportional to the normal rainfall of respective months. It can be seen from the bar charts of these 2 station that thunderstorms activity in the months of April and May cause good rainfall activity. It increases in the month of June with the onset of southwest monsoon, which persists till October. Also, the bar chart reveals that in general, May rainfall is more than the September rainfall. Similarly, April rainfall is more than October rainfall. The total rainfall during the south west monsoon season (June-September) at the 2 selected station ranges between 61.1 to 72.2% of the annual rainfall.

2.4.2 Temperature Distribution

The variation of the mean annual temperature in the Central and extreme Western portions of the Subzone is between 22.5° to 25° C. Towards the North East the mean annual temperature falls down to a range of 20° to 22.5° C and towards the far end of the North East the temperature is below 20° C. Towards the South West in the Khasi Hills adjoining Shillong the temperature is below 20° C which increases to a range of 20° to 22.5° C as one proceeds down towards plains. Plate 5 shows the variation of normal annual temperature in Subzone along with the bar graphs of minimum mean and maximum monthly temperature at Guwahati and Dibrugarh.

2.4.2.1 Mean Daily Temperature (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 temperature over the year. It may be seen from the map that mean daily temperature (annual) are lowest over Khasi-Jaintia hills of Meghalaya, station Shillong having the lowest mean daily temperature of 16.7° C. Central parts of Brahmaputra Valley, extreme western part and some parts of Tripura have higher mean daily temperature (>24 ° C), station Guwahati recorded the mean daily temperature of 24.6 ° C. Another area of low mean daily temperature (< 20°C), runs along extreme eastern boundary of this Subzone.

2.4.2.2 Monthly Temperature Variation at Selected Stations

Monthly variation of mean maximum, mean minimum and mean daily temperatures for 4 representative stations viz.; Guwahati, Tezu, Goalpara and Mokokchung are shown graphically in plate 7. below the map of mean daily temperatures. It may be seen from these that the highest maximum temperature are observed in the month of April at Mokokchung (29.1° C) and in the month of August at the other three stations viz., Guwahati (32.2 ° C), Tezu (33.7° C), and Goalpara (32.8° C). Minimum temperature are observed at all the four selected stations in the month of January; mean minimum temperature at individual stations being Guwahati (11.0° C), Tezu (7.1° C), Goalpara (8.5° C) and Mokokchung (9.5° C).

Mean daily temperature is highest in the month of June at Mokokchung (22.9° C) and in the month of August at Guwahati (29.0° C), Tezu (28.5° C) and Goalpara (26.7° C).They are lowest in the month of January at all the four stations when the mean daily temperatures are Guwahati (17.5° C), Goalpara (16.7° C), Mokokchung (13.1° C) and Tezu (15.2 C).

2.5 COMMUNICATION

2.5.1 Railways

The important Railway sections of North East Frontier Railways exist in the Subzone are given in Table 2.2

Table 2.2
(Railway section)

Sl. No.	Railway Sections
1.	Guwahati - Dangari
2.	Makum- Lekhapani
3.	Tinsukia- Dibrugarh Town
4.	Moranghat- Simalguri- Nagimmora
5.	Mariani- Jorhat- Neamati(Jorhat-Neamati)
6.	Jorhat - Furkating
7.	Lumding- Haflong
8.	Chaparmukh- Senchoa- Silghat Town
9.	Senchoa – Mairabari

2.5.2. Roads

The National highways in the Subzone are given in Table 2.3 as follows:

Table 2.3
(National Highways)

Sl. No.	Highway	Section
1.	N H- 51	Dalu-Golpara
2.	NH - 37	Golpara-Guwahati-Silghat-Jorhat-Sibsagar-Dibrugarh-Danguri
3.	NH - 40	Nangpoh-Shillong-Dawki
4.	NH - 39 & 36	Nowgong – Kohima
5.	NH - 39	Kohima –Dhansiri

PART III

SYNTHETIC UNIT HYDROGRAPH STUDIES

3.1 SYNTHETIC UNIT HYDROGRAPH (SUG)

SUG is a unit hydrograph of unit duration for a catchments developed from relations established between physiographic and unit hydrograph parameters of the representative gauged catchments in hydrometeorologically homogeneous region (Subzone).

Hydrometeorological approach has been adopted for developing a regional method for estimating design flood for small and medium catchments in various hydrometeorologically homogeneous subzones. In this approach, the design storm after converting it into effective rainfall (input) is applied to the unit hydrograph (transfer function) to obtain a design flood (basin response). It is possible to develop unit hydrograph if site-specific concurrent rainfall-runoff data is available for 5-8 years. Collection of adequate concurrent rainfall- runoff data for every site, is however neither practicable nor economically feasible. In such a situation, the regional method for developing Synthetic Unit Hydrograph (SUG) is resorted to. Data collected and analysed for obtaining subzonal SUG equations are discussed in succeeding paragraphs.

3.2 DATA REQUIRED

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

i) Hourly gauge data at the gauging site (bridge site).
ii) Gauge and discharge data observed 2 to 3 times a day at the gauging site.
iii) Hourly rainfall data of raingauge stations in the catchments. Raingauge stations may be self- recording and or/manually operated.

The following catchment details are also required.

iv) Catchment area plans showing the river network, location of raingauge stations and gauge and discharge sites, storages, habitations, forests agricultural and irrigated areas, soils etc.
v) Cross-sections of the river at bridge site (gauging site), upstream and downstream of the bridge site,
vi) Longitudinal section of the river upstream and downstream of the bridge site.

3.3 DATA COLLECTED

North-East Frontier Railways, under the overall guidance and supervision of RDSO had collected data of 21 bridge catchments. Besides, 4 bridge catchments are being gauged by Central Water Commission on behalf of M.O.T. since 1981. The rainfall-runoff data of 25 catchments having catchment area more than 25 Sq.km. for a period of 1 to 11 years during 1961-83 was collected by the Railways. Data of 14 catchments for 71 bridge years found suitable were utilised in a study carried out earlier. Additional data for 29 bridge years for 5 bridge sites shown in Table 3.1 was collected subsequent to the preparation of the earlier report. Thus, a total of 100 bridge year data has been used for developing co-relation between unit hydrograph and physiographic parameters for derivation of SUG.

Table 3.1
(Additional data for 5 bridge sites)

Sl.No.	Site	Additional Data	Bridge Years
1	463*	1984-91	8
2	414*	1984-91 & 93	9
3	3-MOT	1984-85	2
4	4-MOT	1984-88	5
5	6-MOT	1984-88	5
Total			29 Years

*Key G&D sites, where observations are continuously made.

Annexure 3.1 shows the name of the stream, railway bridge No. Railway section, catchment area, No. of rain gauge stations and period of availability of rainfall runoff data of 25 bridge catchments having catchment areas more than 25 Sq.km. This also includes additional data of 5 catchments, collected subsequent to the preparation of the report. It can be seen from Annexure 3.1 that the catchment area of gauge sites lie between 25 to 1270 Sq.km.

3.4 DERIVATION OF SYNTHETIC UNIT HYDROGRAPH

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

3.4.1 Physiographic parameters

The physiographic parameters considered in the present study are catchment area (A), length of main stream (L), length of the main stream from a point near the centre of gravity of catchment to the observation site (Lc) and equivalent stream slope (S). The parameters are indicated in Figure-1. Estimation of these are explained in the following paragraphs.

3.4.1.1 Catchment Area (A)

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

3.4.1.2 Length of the Main Stream (L)

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

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

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

3.4.1.4 Equivalent stream slope (S)

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

(a) Graphical method

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

(b) Analytical method

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

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

Where

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

Physiographic parameters A, L, Lc and S are obtained for 14 catchments used for analysis are shown in Annexure 3.2.

3.4.2 UNIT HYDROGRAPH PARAMETERS

3.4.2.1 Scrutiny of data and finalisation of gauge discharge rating curve

Out of the 25 gauged catchments, data of 14 catchments (71 bridge years) was found suitable for the unit hydrograph study contained in the earlier report. The additional data of 5 catchments, viz., 463, 414, 3 MOT, 4 MOT and 6 MOT (29 bridge years) was scrutinized through arithmetical checks and gauge and discharge rating curve(s) were drawn on log-log scale. The hourly discharges for the duration of the selected floods were obtained from the rating curves.

3.4.2.2 Selection of floods and corresponding storm events

In the previous study 81 flood events of 14 catchments were found suitable for U.G. studies. The general guidelines followed earlier for selecting flood events from the additional data are given below:

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

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

Flood events shown in Table 3.2 were found suitable from the additional data collected at 5 bridge catchments. These catchments were amongst 14 catchments considered in the previous study. The catchments considered in the present study are the same catchments that were found suitable in the previous study. Guidelines followed for selecting flood events in the previous study are adopted for identifying flood events from the additional data.

Table 3.2
(Selected flood events)

Sl. No.	Site	Events		Total Events
		Utilised earlier	Additional events	
1.	463	9	4	13
2.	414	6	3	9
3	3-MOT	4	3	7
4	4-MOT	10	5	15
5	6-MOT	11	4	15
			19 Flood events	

3.4.2.3 Computation of hourly catchment rainfall

Out of 5 catchments viz.; 463, 414, 3-MOT, 4-MOT and 6-MOT for which additional data was received there is no change in raingauge network of 3 catchments viz.; 463, 414 and 3-MOT and the station weights computed earlier were used. For the remaining 2-bridge catchments viz. 4 -MOT and 6-MOT there is a change in raingauge network. Station weights have been computed again for these catchments for obtaining weighted rainfall for different flood events.

3.4.2.4 Separation of base flow

The selected flood events of 5 Bridge catchments were plotted on the normal graph paper. The base flow was separated through the normal procedure to obtain direct surface runoff hydrograph and the direct runoff depth over the catchment was computed for each flood event.

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

With the known values of 1-hour catchment rainfall and the direct runoff depth for each flood event, the infiltration loss (constant loss rate) by trials was estimated for selected flood events of 5 Bridge catchments viz. 463, 414, 3-MOT, 4-MOT and 6-MOT.

3.4.2.6 Derivation of 1-hour unit hydrograph

The studies to derive 1-hour unit hydrograph were confined to only those flood events found suitable in the additional data of 5 bridge catchments. The 1-hour unit-hydrographs were derived from the rainfall excess hyetograph, obtained by subtracting loss rate from 1-hour rainfall and their corresponding direct runoff hydrograph.

3.4.2.7 Drawing of representative unitgraph and measuring their parameters

The Representative Unit Hydrograph (RUG) of 5 catchments were derived utilising UGs obtained from the additional data and unit hydrograph derived earlier. Integrated RUGs of 5 sites have been tested on observed floods. RUGs of remaining 9 sites developed earlier were utilised as such without any modifications. Following parameters of RUGs as indicated in Figure-2, for 14 catchments were obtained and are furnished at Annexure 3.3.

a) Time from the centre of unit rainfall duration to the peak of unit hydrograph in hours (tp)
b) Peak discharge of unit hydrograph in cubic meters per second (Q_p). This is the product of peak discharge per sq. km(q_p) and catchment area (A).
c) Base width of unit hydrograph in hours (T_B)
d) Width of unit hydrograph measured at discharge ordinate equal to 50% of Q_p in hours (W_{50}).
e) Width of U.G. measured in hours at discharge ordinate equal to 75% of Qp (W_{75}).
f) Width of the rising side of U.G. measured in hours at discharge ordinates equal to 50% of Q_p (WR_{50}).
g) Width of the rising side of U.G. measured in hours at discharge ordinates equal to 75% of Qp (WR_{75}).

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

3.4.3 Establishing relationships between physiographic and unit hydrograph parameters

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

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

Where

Y = Dependent variable
X = Independent variable
C = A constant
P = An exponent

Various relationships attempted are shown in Annexure 3.4. The relationship between estimated physiographic parameter A and U.G. parameter Q_p was found to be significant. Time to peak discharge of the UG (t_p) was related to q_p. UG parameters W_{50}, W_{75}, WR_{50}, WR_{75} were related to q_p. The UG parameter T_B is significantly correlated to t_p. The principle of least square errors was used in the regression analysis to establish the relationship in the form of equation 3.4.3.1 to obtain the parameters of the Synthetic unitgraph in an unbiased manner.

The following relationships have been derived for estimating the 1-hr unitgraph parameters for an ungauged catchment in the Subzone 2(b).

Table 3.3
(Recommended SUG relations)

Sl. No.	Relationship	Equation No.
1	$Q_p = 0.905\ (A)^{0.758}$	3.4.3.2
2	$t_p = 2.87\ (q_p)^{-0.839}$	3.4.3.3
3	$W_{50} = 2.304\ (q_p)^{-1.035}$	3.4.3.4
4	$W_{75} = 1.339\ (q_p)^{-0.978}$	3.4.3.5
5	$W_{R50} = 0.814\ (q_p)^{-1.018}$	3.4.3.6
6	$W_{R75} = 0.494\ (q_p)^{-0.966}$	3.4.3.7
7	$T_B = 2.447\ (t_p)^{1.157}$	3.4.3.8
8	$T_m = t_p + t_r/2$	3.4.3.9
9	$Q_p = q_p \times A$	3.4.3.10

Relations developed are shown in Figures 3 to 9. Details of physiographic and unit hydrograph parameters used to establish relationships and their co-efficients of correlation is given in Annexure 3.4. The 25, 50 and 100 year flood peaks for 14 selected bridges have been computed using the recommended relations given in Table 3.3 and also from the RUGs of these bridges taking storm duration as $T_d = 1.1 * t_p$, as explained in para 5.2. Annexure 3.5 shows the comparison of flood peaks using SUGs and corresponding RUGs. As can be seen from the Annexure, the maximum variation for 50 year flood peak lies between + 40.72% - 57.84% and for 25 year flood from + 41.30% to 68.10%. From the variation data we see that very small catchments have larger variation as compared to catchments of moderate size.

In the particular case of Bridge No.MOT-4 / MOT-6, the slope of the catchments are very steep. The average slope of other catchments is of the order of 2.5 m/km whereas the slope of these catchments are 6.5 m/km. This may be one of the factor for large variations.

In case of Bridge No.184/186, the average RUG parameters of these bridges are different than all other bridges. Therefore, the reproduced values have large variations. Considering the wide range of sample catchments, the report is applicable to all types of catchments.

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

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

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

The steps for derivation of 1-hour unitgraph are:

i) Physiographic parameters of the ungauged catchment viz. A, L, L_c and S are determined from the catchment area plan.
ii) Obtain t_p, q_p W_{50}, W_{75} WR_{50} WR_{75} and T_B substituting appropriate basin/unit hydrograph parameters given in equations 3.4.3.2 to 3.4.3.10.
iii) Plot the parameters of 1-hour unitgraph viz.; T_m, T_B, Q_p, W_{50}, W_{75}, WR_{50} and WR_{75} on a graph paper as shown in illustrative Figure 2 and sketch the unitgraph through these points.

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

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

Where

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

Suitable modifications can be made in falling limb upto W_{50} points and a smooth unitgraph be drawn to make the two volumes equal.

3.5 SIMPLIFIED APPROACH

In the simplified approach, only flood peak of the 25-year, 50 year and 100 year is estimated on the basis of regression relationship. The physiographic parameters and corresponding 25 year, 50 year and 100 year 24-hr. point rainfall as read from the isopluvial maps (plates 8,9,10) supplied by IMD are obtained and substituted in the empirical relation developed on the basis of regression analysis using 25 year, 50 year and 100 year flood values for each of the 14-gauged catchment for different sizes as computed by detailed approach. The values of Q_{25}, Q_{50} and Q_{100}, for the 14 catchments so obtained are treated as dependent variables were related to their respective physiographic parameters A, S and 24 hour point rainfall values at that observation site for 25,50 and 100 years (R_{25}, R_{50} and R_{100}) as independent variables using multiple regression analysis and using method of least square for fitting. The derived flood formulae for Q_{25}, Q_{50} and Q_{100} and their respective coefficient of correlation 'r' are as under:

$$Q_{25} = 1.9194\,(A)^{0.4240}\,(S)^{0.0917}\,(L)^{0.9965}\,(Lc)^{-0.5092}\,(R_{25})^{0.3789}, \quad r = 0.9466$$

$$Q_{50} = 1.1368\,(A)^{0.4846}\,(S)^{0.0540}\,(L)^{0.8915}\,(Lc)^{-0.5012}\,(R_{50})^{0.6107}, \quad r = 0.9540$$

$$Q_{100} = 0.5160\,(A)^{0.5226}\,(S)^{0.0552}\,(L)^{0.7010}\,(Lc)^{0.3961}\,(R_{100})^{0.9286}, \quad r = 0.9535$$

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

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

R_{25}, R_{50} and R_{100} are the point storm rainfall values for 25 years, 24-hour, 50-yr, 24-hour and 100 year, 24 hour return periods respectively in cm. The rainfall values are found after locating the catchment on the isopluvial maps (Plates 8,9 & 10).

3.6 DESIGN LOSS RATE

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

In the pre-revised report, the loss rate based upon φ index approach using the actually observed data of 81 flood events was adopted as 0.35 cm/hr. In the present report, due to additional data of 5 bridge catchments a total of 100 flood events have been considered. In Annexure 3.6 the variations of loss rate have been represented by a class interval against the number of events falling in each of these class intervals. There are two alternatives, one is to adopt a lowest value of loss rate and the other to adopt a modal value of the loss rate. Since this report is intending at providing 25 years, 50 years and 100 years return period flood which may not be a very rare event when considered from design point of view, a modal value of loss rate of 0.35 cm/hr as adopted in the pre-revised report has been recommended for computing the loss rate values for ungauged catchments in the Subzone. The designer can adopt any other suitable value as per site conditions.

3.7 DESIGN BASE FLOW

Base flow values for 100 flood events inclusive of additional flood events of 5 catchments tabulated in different ranges are shown in Annexure 3.7. Out of 100 flood events, 68-flood events fall under the range of 0.01 -0.09 cumec/Sq.km. The average base flow rate of 0.05 cumec/Sq.km. is recommended for estimating base flow for a catchment in the Subzone. The designer may, however, adopt any other suitable value as per site condition.

PART-IV

STORM STUDIES

4.1 INTRODUCTION

The India Meteorological Department (IMD) has conducted detailed rainfall studies for South Brahmaputra subzone 2(b). The study covers depth-duration-frequency analysis of available daily /short duration rainfall data in and around the subzone. The design storm components have been derived in the form of:

(i) 25, 50 and 100-year 24-hour isopluvial maps,
(ii) 24 hours to short duration (1 to 23 hours) rainfall ratios,
(iii) Time distribution curves for storm of different durations (2 to 24 hours), and
(iv) Point to areal rainfall ratios for specified duration (1,3,6,12 and 24 hours).

The methodology for analysis of each component and the procedure for design storm estimation are discussed in section 4.5. The results of the study serve as basic input for design flood estimation for small and medium catchments.

4.2 DATA

The rainfall data for a large number of stations in and around the subzone for as long a period as possible have been used. Ordinary raingauge (ORG) data of 74 stations- (53 inside the subzone and 21 around the subzone) and self recording raingauge (SRRG) data of 6 stations have been utilised.

4.3 DEPTH DURATION FREQUENCY ANALYSIS

4.3.1 Isopluvial Maps

For each of the 74 ORG stations in and around the Subzone, a series of annual maximum one-day rainfall was generated. The 74 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 (74 * 3) were converted into any 24-hour rainfall estimates by using the conversion factor of 1.15. For each return period, the 24-hour estimates for 74 stations were plotted on the base map and isopluvial were drawn. The isopluvial maps of 25,50 and 100-year 24-hour rainfall are shown in Plates 8, 9 and 10 respectively, which can be used to derive 24-hour rainfall estimates for specific return periods at any desired location in the Subzone.

4.3.2 Short Duration Ratios

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

Table 4.1
(Conversion Ratios)

Rainfall Duration (t) In Hours	Conversion Ratio 10-Year t-Hour Rainfall/10 year-24-Hour Rainfall
1	0.48
3	0.62
6	0.74
9	0.81
12	0.87
15	0.91
18	0.95
24	1.00

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

4.3.3. Time Distribution Curves

Based on hourly rainfall data of all the 6 SRRG stations a total of 1040 rainstorms of duration ranging from 2 to 24 hours were analysed and grouped station wise into the following 5 categories.

a) rainstorms of 2 to 3 - hour duration (229 for 6 stations)
b) rainstorms of 4 to 6 - hour duration (286 for 6 stations)

c) rainstorms of 7 to 12 - hour duration (322 for 6 stations)
d) rainstorms of 13 to 18 - hour duration(116 for 6 stations)
e) rainstorms of 19 to 24 - hour duration (87 for 6 stations)

For each station, 5 different graphs corresponding to each group of rainstorms were prepared by plotting the cumulative percentage of the total storm duration and the average time distribution curves (6 x 5) were drawn. Average time distribution curves (5) for the zone as a whole were then drawn by plotting 6 station curves on the same graph and these are shown in Fig.11, which can be used to derive the time distribution co-efficient of storm rainfall in the zone for the rainstorms of any duration.

4.3.4 Point To Areal Rainfall Ratios

In this Subzone, sufficient bridge data (collected by RDSO) was not available, an alternate method based on concurrent data from network of ORG/SRRG stations was used, as in the case of Subzone 3(g), Subzone 1(g) and zone 7 for determining point to areal curves. The data of 6 SRRG stations in and around the catchment were used. SRRG data of 6 stations were scrutinized to collect the rainstorms of various duration (t=1,3,6,12 & 24 hrs) and about 250 rainstorms were selected. The hourly rainfall records of SRRG's and daily rainfall data of surrounding ORG's were carefully examined for various storm duration (5) to select t-hour representative rainstorms based on the following consideration:

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

About 25 representative rainstorms were selected for analysis. For each representative rainstorm the ratio of rainstorm rainfall to corresponding 24-hour rainfall was computed and the daily rainfall values of surrounding ORG stations were reduced in the same proportion. Isohyetal maps of 25 representative rainstorms were then prepared using concurrent rainfall values of SRRG stations and surrounding ORG stations (reduced values) corresponding to the date and time of each representative rainstorm. By planimetering each isohyetal map around the rainstorm centre and plotting the ratios of areal rainfall depth to point rainfall against the areas, the best fit curves (5) were drawn as shown in the graph at Figs 12(a) and 12(b), which can be used to derive the percentage areal reduction factors for converting point rainfall of any duration in the zone into corresponding areal rainfall for any particular small catchment in the zone.

4.4 HEAVIEST RAINFALL RECORDS

4.4.1 ORG Data

The highest ever recorded one day station rainfall (24 hours rainfall ending 0830 hrs of date) along with date of occurrence in each of the 11 districts covering Subzone 2(b) have been compiled from the ORG data and presented in Annexure 4.1 and, in case of districts with stations recording ≥ 35 cm all such stations have been included. Normal annual rainfall for each selected station is also shown in the Annexure No. 4.1.

4.4.2 SRRG Data

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

4.5 PROCEDURE FOR DESIGN STORM RAINFALL ESTIMATION

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

Step -1: Locate the bridge catchment under study on the 50-year, 24-hour isopluvial map in plate 9 and obtain the 50-year 24-hour point rainfall value in cm. For a catchment covering more than one isopluvial, compute the average point rainfall.

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

Step- 3: Read the areal reduction factor corresponding to storm duration T_D and the given area of catchment from fig.12 (a) & 12(b) or Annexure 4.3 and multiply the 50-year T_D-hour point rainfall in step-2 by this factor to obtain the 50-year T_D-hour areal rainfall over the catchment.

Step -4: Read the time distribution co-efficient for 1,2 ... ..., (T_D-1) hours corresponding to storm duration T_D from relevant graph in Fig.11 or Annexure 4.4. and multiply the 50-year T_D-hour areal rainfall in Step-3 by these co-efficient to obtain the cumulative depths of 1,2 ... ..., (T_D-1) hour catchment rainfall.

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

PART – V

DESIGN FLOOD ESTIMATION

5.1 CRITERIA AND STANDARDS IN REGARD TO DESIGN FLOOD OF STRUCTURES OF SMALL AND MEDIUM CATCHMENTS

Khosla Committee of Engineers had recommended a design flood of 50-year return period for fixing the waterway of the bridges. The committee had also recommended to design the foundation and protection work for larger discharge by increasing the design flood for waterways by 30 % for small catchments upto 500 Sq.km., 25 to 20% for medium catchments upto 500 to 5000 Sq.km., 20 to 10% for large catchments upto 5000 to 25000 Sq.km. and less than 10% for very large catchments above 25000 Sq.km. Criteria and standards followed for design flood for bridges, cross-drainage structures and small dams are given below:

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

b) Indian Road Congress - IRC 5-1985, clause 103 of Section-I "General Features of Design" Specifies that the waterway of a road bridge is to be designed for a maximum flood of 50-yr return period. To provide for adequate margin of safety, the foundation and protection works should be designed for larger discharge as computed under clause 103. The recommended percentage increase over the design discharge specified in clause 103 is given under clause 110.1.2 of IRC-5-1985. These recommendations are the same as given in the report of the Committee of Engineers and are reproduced in Table no. 5.1 as follows :

Table 5.1
(Recommended Increase In Design Discharge)

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

c) Indian Standard Code of "Practice for design of cross drainage works - IS; 7784 Part-I, 975" recommends that the waterway for cross drainage works should be designed for a 25 yr. return period flood. To provide adequate margin of safety, the foundation and protections 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 and reproduced in para (b) above.

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

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

5.2 ESTIMATION OF DESIGN FLOOD

To obtain design flood of required return period the effective rainfall for design storm duration is to be applied to the unit hydrograph of a catchment. Procedure for computing design flood peak and design flood hydrograph for T-year return period by SUG approach is as under.

Step -1: Synthetic unit hydrograph

Derive the synthetic unit hydrograph as per section 3.4 .4 and tabulate 1-hour U.G. ordinates.

Step -2: Design storm duration

The duration of storm, which causes maximum flow in a river at a specified location, is called "Design Storm Duration". The SUG of 14 catchments have been derived using the parameters computed from recommended equations given in Table-3.3. Annexure 5.1 shows the computed UG parameters. It has been studied that the critical storm duration, which causes severe floods in small and medium catchments, as used in this subzone is equal to 1.1tp. The flood peaks of 25 yrs, 50 yrs and 100 yrs return period is computed for this storm duration.

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

Step -3 : Design storm rainfall

i) Adopt suitable design storm duration (T_D) as explained in Step-2.
ii) Obtain design storm rainfall and hourly areal rainfall units vide section 4.6.
iii) Adopt design loss rate as recommended in section 3.5.
iv) Obtain hourly effective rainfall increments by subtracting the design loss rate.

Step -4:

(a) Design flood peak

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

ii) Obtain the base flow for the catchment area under study vide section 3.7.
iii) Obtain total surface runoff by summing the product of unit hydrograph ordinates and effective rainfall consecutively.
iv) Obtain the total flow by adding the base flow to the computed total surface runoff in step (iii) above this will give the peak value of the flood.

b) Design flood hydrograph.

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

Step-5:

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

Step –6:

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

Step –7:

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

Step –8:

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

5.2.1 Illustrative Example

Bridge No.160 at mile 370/8-9 on Lumding-Guwahati section, Northeast Frontier Railway has been marked out as ungauged catchment for illustrating the procedure to compute 50-year design Flood. The catchment plan is enclosed at fig. A-1.

The particulars of the catchment under study are as follows:

(i) Name of Subzone	:	South Brahmaputra Basin.
(ii) Name of Tributary	:	Longpher
(iii) Name of Railway Section	:	Lumding - Guwahati
(iv) Shape of catchment	:	Fan shape.
(v) Location	:	Lat 25°-47'-00" Long 93°-04'-48"
(vi) Topography	:	Moderate slope.

Procedure is explained as below:

Step-1 : Physiographic Parameters

Physiographic parameters obtained are given below.

1) Area (A)-Refer fig. A-1.	= 470.00 Sq.km.
2) Length of the longest stream (L)	= 56.35 km.
3) Length of the longest stream from a point opposite to C.G. of catchment to point of study (Lc)	= 31.40 km.
4) Equivalent stream slope (S_{eq})	= 2.02 m/km.

The computation of equivalent Slope is shown at Annexure 5.2.

Step 2 : 1 hr Synthetic Unitgraph

Synthetic unitgraph parameters as given below were computed using equation in para 3.4.3

1) $Q_P = 0.905\,(A)^{0.758} \qquad = 0.905 \times (470)^{0.758}$
$= 95.96$ rounded off to 96.00 cumec.

2) $q_p = \dfrac{Qp}{A} = \dfrac{96.00}{470} \qquad = 0.20$ cumec/km^2

3) $tp = \dfrac{2.87}{(q_p)^{0.839}} \qquad = 11.07$ adjusted to 11.50

(when tr = 1 hour)

4) $W_{50} = \dfrac{2.304}{(q_p)^{1.035}} \qquad = 12.19$ hours

5) $W_{75} = \dfrac{1.339}{(q_p)^{0.978}} \qquad = 6.46$ hours.

6) $WR_{50} = \dfrac{0.814}{(q_p)^{1.018}} \qquad = 4.19$ hours.

7) $WR_{75} = \underline{0.494} \qquad = 2.34$ hours.

8) T_B = $2.447(t_p)^{1.157}$ = 41.29 rounded off to 41.00 hours.

9) T_m = tp + tr/2 = 11.50 + 0.50 = 12.00 hours.

Estimated parameters of unitgraph in Step 2 were plotted on a graph paper as shown in Fig. A-2. The plotted points were joined to draw synthetic unitgraph. The discharge ordinates (Qi) of the unitgraph at ti = tr=1 hr interval were summed up and multiplied by tr=1 i.e. $Q_1 \times t_i$ = 1305.6 cumec and compared with the theoretical volume of 1.00 cm. direct run off depth over the catchment, computed from the formula Q = (A x d)(t_i x 0.36).

Where A = catchment area in Sq.km.

d = 1.0 cm. depth.

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

$$Q = \frac{A \times d}{0.36 \times tr} = \frac{470 \times 1}{0.36 \times 1} = 1305.6 \text{ cumec.}$$

Note: In case, $\sum Qi*ti$ for the unitgraph drawn is higher or lower than the volume of 1 cm, the falling limb of hydrograph may be suitably modified without altering the points of synthetic parameters such that the sum of all the ordinates under the UG is equal to theoretical value as computed above.

Step 3: Estimation of design storm

a) Design storm duration

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

1.1 tp = 1.1 x 11.5
= 12.65 hrs.

Rounded off to nearest full hour = 13.00 hrs.

∴ Design Storm Duration (T_D) = 13.00 hrs.

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

The site under study was located on plate 9 showing 50 year, 24 hr point rainfall. The point rainfall was found to be 22.5 cm. The conversion factor of 0.88 was read from Fig 10 to convert the 50 year-24 hour point rainfall to 50 year, T_D(13) hrs point rainfall. 50 yrs, 13 hr point rainfall thus worked out to be 0.88 x 22.5 cm = 19.80 cm.

Areal reduction factor of 0.8406 corresponding to the catchment area of 470 Sq.km. for TD = 13 hour was interpolated from Annexure 4.3 or Fig.12 (b) for conversion of point rainfall to areal rainfall. 50 yr., 13 hr. areal rainfall thus works out to be 0.8406 x 19.80 cm = 16.64 cm.

The 50 yr., 13 hour areal rainfall has been split into 1-hour rainfall increments using time distribution coefficients given in Annexure 4.4 or Fig.11. The hourly ordinates are given in Table 5.2

A design loss rate of 0.36 cm/hr, as recommended in Para 3.6 was applied to get effective rainfall hyetograph.

Table 5.2
(Hourly effective rainfall increments)

Duration (Hr) (1)	Distribution Co-efficient (2)	Storm Rainfall (Cm) (3)	Rainfall Increments (Cm) (4)	Loss Rate/Hour (Cm) (5)	Effective Hourly Rainfall (Cm) (6)
1	0.26	4.33	4.33	0.35	3.98
2	0.43	7.15	2.82	0.35	2.47
3	0.56	9.32	2.17	0.35	1.82
4	0.64	10.65	1.33	0.35	0.98
5	0.70	11.65	1.00	0.35	0.98
6	0.76	12.65	1.00	0.35	0.65
7	0.82	13.64	0.99	0.35	0.64
8	0.87	14.48	0.84	0.35	0.49
9	0.90	14.98	0.50	0.35	0.15
10	0.94	15.64	0.66	0.35	0.31
11	0.96	15.97	0.33	0.35	-
12	0.98	16.31	0.34	0.35	-
13	1.00	16.64	0.33	0.35	-

Step 4: Estimation of base flow

Adopting a design base flow of 0.05 cumec per Sq.km. as recommended in para 3.7 the base flow for the catchment under study was estimated to be 0.05 x 470 = 23.50 cumecs for the catchment under study.

Step 5 : Estimation of 50 year flood peak

(a) Computation of Flood Peak

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

Table 5.3
(50 year Flood Peak)

Time In Hours. (1)	S.U.G. Ordinates (Cumec) (2)	1-Hour Effective Rainfall (Cm) (3)	Direct Runoff (Cumec) (4)
9	64.00	0.31	19.84
10	76.00	0.65	49.40
11	92.00	1.82	167.44
12	96.00	3.98	382.08
13	92.00	2.47	227.24
14	86.00	0.98	84.28
15	80.00	0.65	52.00
16	72.08	0.64	46.59
17	68.00	0.49	33.32
18	60.08	0.15	9.12
		Total	1071.31
		Base Flow	23.50
		Q_{50}	1094.81

(b) Computation of design flood hydrograph

Effective hourly rainfall shown in col. (3) of Table 5.2 in Step 5 was reversed to obtain critical sequence as shown in Table 5.4

Table 5.4
(Critical Sequence of Rainfall)

Time (Hrs) (1)	Critical 1-Hr. Effective Rainfall Sequence (Cm) (2)
1	0.15
2	0.49
3	0.64
4	0.65
5	0.98
6	2.47
7	3.98
8	1.82
9	0.65
10	0.31

For computation of design flood hydrograph, the U.G. ordinates were tabulated in Col.2 of Annexure 5.3. The critical sequence of effective rainfall increments was entered in Col.3 to Col.12 horizontally. Direct run off resulting from each of the effective rainfall depths with the U.G. ordinates in Col. 2 were entered in columns against each unit with a successive lag of 1 hour. Direct runoff values were added horizontally and total direct runoff is shown in Col.14.Total hydrograph ordinates were obtained by adding base flow of 23.5 m3/s to Col.14 and are given in Col.15. Design Flood Hydrograph was plotted against time as shown in Fig. A-3. The peak of the flood hydrograph obtained was 1094.81 m3/sec which tallies with the Peak shown in Table 5.3

5.3 COMPUTATION OF FLOOD PEAK USING FLOOD FORMULAE

For estimation of 25 yr., 50 yr., and 100 yr., the same bridge catchment No.160 is considered for selection of the problem by flood formulae. The physiographic and meteorologic parameters for the catchment under study are:

Catchment area (A)	= 470 Sq.km.
Length of the longest stream (L)	= 56.35 km.

Length of the longest stream from a point
opposite to C.G. of catchment to point of study (Lc) = 31.40 km.
Equivalent slope (S_{eq}) = 2.02 m/km.

25 yr., 24 hr point rainfall (R_{25}) = 19.00 cm
50 yr., 24 hr point rainfall (R_{50}) = 22.50 cm
100 yr., 24 hr point rainfall (R_{100}) = 26.00 cm

$$Q_{25} = 1.9194(A)^{0.4240} (S)^{0.0917} (L)^{0.9965} (Lc)^{-0.5092} (R25)^{0.3789}$$

$$= 1.9194(470)^{0.4240} (2.02)^{0.0917} (56.35)^{0.9965} (31.40)^{-0.5092} (19.00)^{0.3789}$$
$$= 815.18 \text{ cumec}$$

$$Q_{50} = 1.1368(A)^{0.4846} (S)^{0.0540} (L)^{0.8915} (Lc)^{-0.5012} (R_{50})^{0.6107}$$

$$= 1.1368(470)^{0.4846} (2.02)^{0.0540} (56.35)^{0.8915} (31.40)^{-0.5012} (22.50)^{0.6107}$$
$$= 1008.28 \text{ cumec}$$

$$Q_{100} = 0.5160(A)^{0.5226} (S)^{0.0552} (L)^{0.7010} (Lc)^{-0.3961} (R_{100})^{0.9286}$$

$$= 0.5160(470)^{0.5226} (2.02)^{0.0552} (56.35)^{0.7010} (31.40)^{-0.3961} (26.00)^{0.9286}$$
$$= 1186.82 \text{ cumec}$$

The percentage variations in the values of Q_{25}, Q_{50} and Q_{100} as estimated by the detailed approach and as estimated by the flood formulae for the catchment under study are 8.02, 7.90 and 9.63% respectively. This variation is within acceptable limit. Therefore, the flood values for 25 yr., 50 yr. and 100 yr. return periods estimated by the respective flood formulae are reasonable for adoption in preliminary designs.

5.4 COMPUTATION OF DESIGN H.F.L.

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

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

The permanent stage discharge relation is a straight line or a combination of straight lines on a logarithmic plotting depending on the channel configuration; a single straight line for a single well defined channel and a combination of two straight lines for the main channel with its firm portions. The stage discharge relation may be considered more accurate depending on the reliable and adequate observed gauge and discharge data of the river at the point of study. The gauge discharge rating curve so determined may be used for fixing the design HFL corresponding to design flood by extrapolation if necessary.

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

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

The various values of the roughness co-efficient for different types of channel can be obtained from any standard textbook on channel hydraulic. The above procedure pertains to determination of design HFL corresponding to design flood of a river under natural conditions. With the type of structures in position there will generally be a constriction in the waterway. The effect of the constriction by way of raising the design HFL under natural conditions has to be evaluated in the water elevation to arrive at the revised H.F.L under constricted conditions. The difference between upstream and downstream water levels corresponding to design flood due to constriction in the waterway may be termed as afflux. There are hydraulic methods for working out the final design HFL due to constriction by the structure. The weir formula or orifice formula of hydraulics is generally used depending on the upstream and downstream depths to estimate the revised design HFL under constricted conditions.

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

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

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

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

PART VI

ASSUMPTIONS, LIMITATIONS AND CONCLUSIONS

6.1 ASSUMPTIONS

It is assumed that 50-yr. return period storm rainfall produces 50-yr. flood. Similar is the case for 25 yr. and 100-yr. flood.
A generalised conclusion regarding the base flow and loss rate is assumed to hold good during the design flood event. The catchments used in the analysis are treated as homogeneous.

6.2 LIMITATIONS

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

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

3. The data of only 14 catchments have been considered for developing a generalised approach. However, for more reliable results, the data of more catchments uniformly distributed would be desirable.

6.3 CONCLUSIONS

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

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

The report is applicable for the catchment areas ranging from 50 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 neighbouring catchments also. However, individual site conditions may necessitate special study. Engineer-in-charge at site is advised to take a pragmatic view while deciding the design discharge of a bridge.

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ANNEXURES

Annexure 1.1

LIST OF HYDRO-METEOROLOGICAL SUB ZONES

Sub-zone	Name Of Subzone (Designated Earlier)	Name Of Subzone (Designated Now)	River Basins Included In The Subzone
1(a)	Luni basin and Thar (Luni and other rivers of Rajasthan and Kutch).	Luni	Luni river and Thar (Luni &other rivers of Rajasthan and Kutch and Banas rivers)
1 (b)	Chambal Basin	Chambal	Chambal river.
1 (c)	Betwa Basin & other Tributaries.	Betwa	Sind, Betwa and Ken rivers and other South tributaries of Yamuna.
1 (d)	Sone Basin and Right Bank tributaries.	Sone	Sone & Tons rivers and other South Bank tributaries of Ganga.
1 (e)	Punjab Plains including parts of Indus, Yamuna, Ganga and Ramganga Basins.	Upper-Indo Ganga Plains.	Lower portion of Indus, Ghaggar, Sahibi Yamuna, Ganga and Upper portion of Sirsa, Ramganga, Gomti and Sai rivers.
1 (f)	Ganga plains including Gomti, Ghagra, Gandak, Kosi and others.	Middle Ganga Plains.	Middle portion of Ganga, Lower portion of Gomti, Ghagra, Gandak, Kosi and middle portion of Mahanadi.
1 (g)	Lower Ganga Plains including Subarnarekha and other east-flowing rivers between Ganga and Baitarani.	Lower Ganga Plains.	Lower portion of Ganga, Hoogli river system and Subarnarekha.
2 (a)	North Brahmaputra Basin	North Brahmaputra	North Bank tributaries of Brahmaputra rivers and Balason river.
2 (b)	South Brahmaputra Basin	South Brahmaputra	South Bank tributaries of Brahmaputra river.
2 (c)	Barak and others	Barak	Barak, Kalden and Manipur rivers.
3 (a)	Mahi, including the Dhadhar, Sabarmati and rivers of Saurashtra.	Mahi and Sabarmati.	Mahi and Sabarmati including Rupen and Machhu, Bhadar, Ozat, Shetranji rivers of Kathiawad Peninsula.

Sub-zone	Name Of Subzone (Designated Earlier)	Name Of Subzone (Designated Now)	River Basins Included In The Subzone
3 (b)	Lower Narmada and Tapi Basin	Lower Narmada and Tapi.	Lower portion of Narmada, Tapi and Dhadhar rivers.
3 (c)	Upper Narmada and Tapi Basin	Upper Narmada & Tapi	Upper portion of Narmada and Tapi rivers.
3 (d)	Mahanadi Basin including Brahmani and Baitarani rivers.	Mahanadi	Mahanadi, Baitarani and Brahmani rivers.
3 (e)	Upper Godavari Basin.	Upper Godavari	Upper portion of Godavari Basin.
3 (f)	Lower Godavari Basin except coastal region.	Lower Godavari	Lower portion of Godavari Basin.
3 (g)	Indravati Basin	Indravati	Indravati river.
3 (h)	Krishna Subzone including Pennar Basin except coastal region.	Krishna & Pennar	Krishna and Pennar rivers except coastal region.
3 (i)	Kaveri & East flowing rivers except coastal region.	Kaveri	Kaveri, Palar and Ponnaiyar rivers except coastal region.
4 (a)	Circars including east flowing rivers between Mahanadi and Godavari.	Upper Eastern Coast.	East flowing coastal rivers between Deltas of Mahanadi and Godavari rivers.
4 (b)	Coromandal Coast including east flowing rivers between Godavari and Kaveri.	Lower Eastern Coast.	East flowing coastal rivers, Manimukta, South Pennar, Cheyyar, Palar, North Pennar, Munneru, Palleru, Cundalakama and Krishna Delta.

Annexure 3.1

LIST OF RAILWAY/ROAD BRIDGE CATCHMENTS IN SUBZONE - (2b) (SOUTH BRAHMAPUTRA BASIN) AND AVAILABILITY OF GAUGE, DISCHARGE AND RAINFALL DATA

Sl.No.	Name of the Stream	Railway/ Road Section	Railway/ Road Bridge Site No	Bridge Site Location		Catchment Area (Km^2)	No. of Rain Gauge Stations	Data Availability	No.of Years	Remarks
				Latitude Deg - min - Sec	Longitude Deg- min- Sec					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	JHANZI	MARIANI-TINSUKIA	463*	26-48-40	94-31-40	875	7	1970-72, 1974 -76 & 83-91	15	
2	DESAI	MARIANI-TINSUKIA	414*	26-54-00	94-19-00	554	4	1975-79, 84 - 91 & 93	14	
3	LANGPHER	LUMDING-GAUHATI	160	25-47-00	93-04-48	470	4	1966-69 & 83	5	
4	SAFRAI	MARIANI-TINSUKIA	526	27-00-53	94-55-25	304	4	1975-79	5	Floods not suitable for analysis
5	LUMDING	LUMDING-BADARPUR	8	25-44-55	93-08-00	284	2	1966-67,70-71 & 83	5	
6	LANKAJAN	GAUHATI-LUMDING	146	25-52-37	92-50-00	216	5	1962 & 64	2	
7	BARTIMAN	MARIANI-TINSUKIA	539	27-06-00	95-08-36	188	3	1961,65 & 67-68	4	-do-
8	TINGRAI	MARIANI-TINSUKIA	574	27-27-48	95-21-15	182	3	1961-62 & 1969-71	5	-do-
9	BARLONG-FER	LUMDING-FURKATING	184	26-14-00	93-45-00	171	4	1962 & 65-74	11	
10	DIPHU	LUMDING-FURKATING	215	25-50-24	93-26-36	136	4	1961-62,66 & 1968-69	5	
11	DARIKAJAN	MARIANI-TINSUKIA	507	26-56-35	94-46-55	89	2	1962	1	Data inadequate
12	DAYANG	LUMDING-BADARPUR	269	25-14-32	93-10-05	77	4	961-62, 64 - 66 & 1974 -75	7	Floods not suitable for analysis

Contd. Annexure A 3.1

Sl.No.	Name of the Stream	Railway/ Road Section	Railway/ Road Bridge Site No	Bridge Site Location Latitude Deg-min-Sec	Longitude Deg-min-Sec	Catchment Area (Km^2)	No. of Rain Gauge Stations	Data Availability	No.of Years	Remarks
13	TEOK OR MAMSOSHJAN	MARIANI-TINSUKIA	446	26-45-25	94-27-32	54	2	1971-72 & 1974-76	5	
14	HUGREJAN	MARIANI-TINSUKIA	566	27-23-22	95-18-35	47	2	1961-62, 64, 65 & 1968-70	7	-do-
15	MUPA	LUMDING-BADARPUR	130	25-21-48	93-08-00	46	2	1962,74-78 & 1983	7	
16	PUTINAI	MARIANI-TINSUKIA	440	26-40-00	94-26-00	46	1	1961-62,65 & 1969-70	5	
17	LANGCHOLIET	LUMDING-FURKATING	192	25-45-24	93-18-48	38	3	1961- 62 & 1966-68	5	
18	DESAM	MARIANI-TINSUKIA	556	27-13-48	95-20-12	33	1	1961- 62 1964-65&1967	5	-do-
19	BHIDING	LUMDING-BADARPUR	170	25-13-20	93-07-25	32	2	1961-62,64,67 & 1974	7	-do-
20	BARHAPJAN	DANGARI-MAKUM	70	27-32 00	95-29-50	31	2	1975-79	5	
21	NAGADULIAJAN	KHARIKHATIA -MARIANI	408	26-37-55	94-17-05.	26	2	1971-73	3	Floods not suitable for analysis
22	DIGRU	SONAPUR-JORHAT	4(MOT)	26-06-55	91-59-05	1270	8	1981-88	8	
23	DUDHNAI	KRISHANAI DUDHNAI	6(MOT)	25-58-45	90-47-40	476	4	1981-88	8	
24	KOHORA	KAZIRANGA-KOHORA	3(MOT)	26-35-25	93-24-20	29	1	1981-85	5	
25	KHUR-KHURI	CHHAVGAON-BAMUNI	5(MOT)	26-01-50	26-01-50	25	1	1981-83	3	Floods not suitable for analysis

* Key G & D sites, where observations are continuously made

Annexure 3.2

PHYSIOGRAPHIC PARAMETERS OF SELECTED CATCHMENTS

Sl.No.	Br. No.	Catchment Area (A) (Sq Km)	Length (L) (Km)	Length from Centroid of the Catchment to the Outlet (L_c) .(Km)	Equivalent Slope (Seq)
1	4 (MOT)	1270	84.47	41.19	6.34
2	463	875	86.45	49.63	3.71
3	414	554	51.49	22.53	1.06
4	6 (MOT)	476	60.18	27.35	6.98
5	160	470	56.35	31.39	2.02
6	8	284	49.90	19.30	4.51
7	146	216	49.75	25.68	2.42
8	184	171	25.68	12.20	2.78
9	215	136	20.00	9.50	3.55
10	446	54	19.70	9.63	2.05
11	130	46	17.23	10.06	10.83
12	440	46	27.40	22.70	3.57
13	70	31	13.68	6.90	0.38
14	3 (MOT)	29	9.65	5.23	23.86

Annexure 3.3

ONE HOUR REPRESENTATIVE UNIT-HYDROGRAPH PARAMETERS OF SELECTED CATCHMENTS FOR SOUTH BRAHMAPUTRA BASIN

Sl.No.	Br. Catchment No.	t_p (Hour)	Q_p (Cumec)	q_p (Cumec/Sq.km.)	t_r (Hour)	T_B (Hour)	W_{50} (Hour)	W_{75} (Hour)	W_{R50} (Hour)	W_{R75} (Hour)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	4(MOT)*	17.50	123.00	0.10	1	73	26.75	13.00	8.00	4.25
2	463*	9.50	172.00	0.20	1	34	14.30	8.10	5.75	3.80
3	414*	9.50	123.78	0.22	1	31	11.95	5.85	4.30	2.10
4	6(MOT) *	19.50	64.50	0.14	1	88	17.00	10.50	9.75	5.75
5	160	9.50	100.50	0.21	1	38	10.90	6.00	1.30	1.00
6	8	9.50	105.40	0.37	1	30	5.20	2.20	1.60	0.80
7	146	4.50	84.00	0.39	1	16	6.55	3.20	2.25	1.30
8	184	4.50	76.00	0.44	1	17	5.00	3.45	1.60	0.90
9	215	14.50	27.40	0.20	1	53	10.00	5.00	4.20	2.00
10	446	8.50	13.00	0.24	1	30	9.80	5.00	3.25	1.70
11	130	6.50	18.66	0.40	1	18	6.35	4.20	3.20	2.40
12	440	7.50	15.45	0.34	1	19	8.05	5.25	3.30	2.15
13	70	7.50	8.65	0.28	1	23	9.20	4.20	3.30	1.40
14	3(MOT) *	6.50	13.65	0.47	1	23	5.00	2.65	1.70	0.95

* (Integrated using additional data)

RELATION BETWEEN PHYSIOGRAPHIC AND UNIT HYDROGRAPH PARAMETERS STUDIED

Sl.No.	X	Y	A	B	R
1	A	Q_p	0.905	0.758	0.94
2	q_p	t_p	2.870	(-) 0.839	0.88
3	q_p	W_{50}	2.304	(-) 1.035	0.97
4	q_p	W_{75}	1.339	(-) 0.978	0.91
5	q_p	WR_{50}	0.814	(-) 1.018	0.77
6	q_p	WR_{75}	0.494	(-) 0.966	0.74
7	t_p	T_B	2.447	1.157	0.96

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

Annexure 3.5

COMPARISON OF FLOOD PEAKS BASED ON RUGs and SUGs EQUATIONS

Sl.No.	Br.No.	Q_{25} in cumec			Q_{50} in cumec			Q_{100} in cumec		
		RUG	SUG	% Diff	RUG	SUG	% Diff	RUG	SUG	% Diff
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	4(MOT)	1340.00	2153.49	(-) 60.71	1751.31	2764.37	(-)57.84	1994.64	3128.92	(-)56.87
2	463	1312.75	1140.16	(+) 13.15	1439.11	1276.49	(+)11.30	1603.41	1425.24	(+)11.11
3	414	1030.32	939.81	(+) 8.77	1394.56	1251.63	(+)10.25	1565.12	1440.14	(+)7.98
4	6(MOT)	844.99	1194.59	(-) 41.37	1072.97	1561.89	(-)45.57	1208.15	1749.08	(-)44.77
5	160	907.19	886.25	(+) 2.31	1118.04	1094.81	(+)2.08	1327.51	1313.36	(+)1.06
6	8	843.27	584.41	(+) 30.70	1014.51	706.99	(+)30.31	1242.69	870.48	(+)29.95
7	146	1096.10	772.17	(+) 29.55	1281.38	911.50	(+)28.86	1513.40	1085.13	(+)28.30
8	184	697.87	409.62	(+) 41.30	814.91	483.08	(+)40.72	1003.39	596.10	(+)40.59
9	215	245.60	354.57	(-) 44.37	291.08	416.15	(-)42.97	365.23	514.86	(-)40.97
10	446	131.10	180.90	(-) 37.99	144.49	199.55	(-)38.11	153.59	211.97	(-)38.01
11	130	260.32	200.00	(+) 23.17	290.30	236.40	(+)18.57	346.38	283.11	(+)18.27
12	440	157.88	163.27	(-) 3.41	174.36	179.65	(-)3.03	196.12	201.63	(-)2.81
13	70	108.09	181.70	(-) 68.10	138.57	189.85	(-)37.00	162.58	222.22	(-)36.68
14	3(MOT)	141.25	123.31	(+) 12.70	151.60	132.34	(+)12.70	185.98	164.07	(+)11.78

Annexure 3.6

LOSS RATE RANGES - NUMBER OF FLOOD EVENTS
(In cm. per hour)

Sl.No.	Br. No.	C.A. (km^2)	Upto 0.2	0.2 to 0.4	0.4 to 0.7	0.7 to 1.00	1.00 to 2.00	above 2.00	Total
1	4(MOT)	1270	9	3	3	-	-	-	15
2	463	875	6	3	3	1	-	-	13
3	414	554	5	2	1	-	-	-	9
4	6(MOT)	476		5	4	-	1	-	15
5	160	470	2	-	2	-	-	-	4
6	8	284	-	-	6	-	-	-	6
7	146	210	-	1	1	-	1	-	3
8	184	171	1	-	1	1	-	-	3
9	215	136	-	2	2	1	-	-	5
10	446	54	-	2	-	1	-	-	3
11	130	46	3	2	1	-	-	-	6
12	440	46	1	2	1	1	-	-	5
13	70	31	-	3	1	2	-	-	6
14	3(MOT)	29	1	1	2	1	2	-	7
	Total		33	26	28	9	4	-	100

Annexure 3.7

OBSERVED BASE FLOW RANGES-NUMBER OF FLOOD OCCASION OBSERVED
(In cumec per square kilometer)

Sl.No.	Bridge No.	0.001 to0.005	0.005 to 0.009	0.009 to 0.01	0.01 to 0.09	0.09 to 0.10	0.10 to 0.20	Above 0.20	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	4(MOT)	-	3	-	12	-	-	-	15
2	463	-	-	-	10	2	-	1	13
3	414	-	-	-	7	-	-	2	9
4	6(MOT)	-	-	-	14	-	-	1	15
5	160	2	1	-	1	-	-	-	4
6	8	1	3	1	1	-	-	-	6
7	146	-	1	-	2	-	-	-	3
8	184	-	-	-	3	-	-	-	3
9	215	-	1	3	1	-	-	-	5
10	446	-	-	-	-	-	1	2	3
11	130	-	-	-	5	1	-	-	6
12	440	-	-	-	2	2	-	1	5
13	70	-	-	-	3	-	1	2	6
14	3(MOT)	-	-	-	7	-	-	-	7
	Total	3	9	4	68	5	2	9	100

Annexure 3.8

FLOOD VALUES BY SYNTHETIC UNIT GRAPH AND FLOOD FORMULAE

Sl.No.	Br.No.	C.A. (Km^2)	By S.U.G.			By Flood Formulae			Variation with respect to S.U.G. (%)		
			Q_{25} (Cumec)	Q_{50} (Cumec)	Q_{100} (Cumec)	Q_{25} (Cumec)	Q_{50} (Cumec)	Q_{100} (Cumec)	Q_{25}	Q_{50}	Q_{100}
1	4(MOT)	1270	2153.49	2764.37	3128.92	1933.73	2484.28	2984.36	10.20	10.13	4.62
2	463	875	1140.16	1276.49	1425.24	1319.13	1478.36	1533.40	(-)15.70	(-)15.81	(-)7.59
3	414	554	939.81	1251.63	1440.14	882.82	1164.55	1336.10	6.06	6.96	7.22
4	6(MOT)	476	1194.59	1561.89	1749.08	1166.96	1469.19	1765.46	2.31	5.94	(-)0.94
5	160	470	886.25	1094.81	1313.36	815.18	1008.28	1186.82	8.02	7.90	9.63
6	8	284	584.41	706.99	870.48	788.02	905.53	1023.85	(-)34.84	(-)28.08	(-)17.62
7	146	216	772.17	911.50	1085.13	656.74	824.07	1044.13	14.95	9.59	3.78
8	184	171	409.62	483.08	596.10	391.88	466.10	554.13	4.33	3.51	7.04
9	215	136	354.57	416.15	514.86	321,99	383.43	461.76	9.24	7.86	10.31
10	446	54	180.90	199.55	211.97	202.46	225.94	229.69	(-)11.92	(-)13.22	(-)8.36
11	130	46	200.00	236.40	283.11	206.28	238.37	302.63	(-) 3.14	(-)0.83	(-)6.89
12	440	46	163.27	179.65	201.63	178.68	188.08	204.49	(-) 9.43	(-)4.69	(-)1.42
13	70	31	181.70	189.85	222.22	129.31	163.01	201.66	28.83	14.13	9.25
14	3(MOT)	29	123.31	132.34	164.07	134.14	141.54	173.85	(-) 8.78	(-)6.95	(-) 5.96

Annexure 3.9

NUMBER OF FLOOD EVENTS

Sl.No.	Br. No.	No. Of Flood Events
1	4(MOT)	15
2	463	13
3	414	9
4	6(MOT)	15
5	160	4
6	8	6
7	146	3
8	184	3
9	215	5
10	446	3
11	130	6
12	440	5
13	70	6
14	3(MOT)	7
	Total	100

Annexure - 4.1

STATISTICS OF HEAVIEST DAILY RAINFALL & ANNUAL NORMAL RAINFALL

State / District	Station	Heaviest Rainfall		Date Of Occurrence	Annual Normal Rainfall (Cm)
		>35cm	<35 cm		
MEGHALAYA					
1. Khasi & Jaintia Hills	1. Upper Shillong	43.7	-	20.06.1934	242.5
	2. Shillong (Obsy)	41.5	-	20.06.1934	225.3
2. Garo Hills	3. Dalu	-	32.0	13.06.1956	273.4
ASSAM					
3. Dhubri	4. Lakhimpur	49.0	-	05.05.1959	244.4
	5. Dhúbri	36.8	-	11.06.1909	258.7
4. Goalpara	6. Bijni	48.6	-	02.07.1895	317.6
	7. Goalpara	35.7	-	12.05.1958	244.2
	8. Damra	35.4	-	08.07.1946	235.8
5. Kamrup	9. Barduar	41.7	-	20.06.1934	249.6
6. N.C. Hills	10. Jattinga Valley	40.0	-	10.07.1915	476.7
7. Nowgong	11. Kampur	38.6	-	05.08.1966	202.0
8. Dibrugarh	12. Dibrugarh	-	31.1	25.08.1896	279.6
9. Jorhat	13. Golaghat	-	25.4	02.06.1889	221.0
10. Sibsagar	14. Sibsagar	-	21.8	18.07.1929	253.9
NAGALAND					
11. Nagaland	15. Wokha	-	27.7	12.02.1906	294.6

Annexure 4.3

HEAVIEST 24-HOURS & SHORTER DURATIONS RAINFALL RECORDED IN SUBZONE 2(b)

State/ District	SRRG Station	Highest Observed Storm Rainfall (mm)	Duration (Hr)	Date & Time Of Occurrence	Clock Hour
MEGHALAYA					
1.Khasi & Jaintia Hills	1.Shillong	347	24	14-5thSept'60	(01-01)
		223	12		(13-01)
		165	6		(19-01)
		110	3		(22-01)
		48	1	15th Sept'60	(00-01)
ASSAM					
2. Nowgong	2. Nowgong	427	24	03-04th Sept'78	(02-02)
		280	12		(13-01)
		184	6		(19-01)
		107	3	8th August'84	(05-08)
		89	1	8th October'85	(18-19)

State/ District	SRRG Station	Highest Observed Storm Rainfall (mm)	Duration (Hr)	Date & Time Of Occurrence	Clock Hour
3.Dibrugarh	3.Dibrugarh	207	24	26-27th Aug'77	(23-23)
		189	12	27th Aug'77	(02-14)
		132	6	23rd Sept'73	(01-07)
		121	3	03-04th Aug'70	(09-12)
		95	1	3rdAug70	(09-10)
4.Kamrup	4. Guwahati	187	24	18-19th July'78	(04-04)
		186	12	18th July'78	(04-16)
		179	6		(06-12)
		163	3		(08-11)
		93	1	17th May'70	(04-05)
5.Jorhat	5. Chabua	129	24	05-06th July'74	(02-02)
		103	12	26-27th July'71	(22-10)
		102	6		(22-04)
		81	3	27th July'71	(00-03)
		50	1		(01-02)
	6. Jorhat	121	24	09-10 Oct'75	(01-01)
		121	12	09th Oct'75	(01-13)
		121	6		(01-07)
		87	3	12th Aug'76	(03-06)
		77	1		(03-04)

AREAL REDUCTION FACTORS (%) FOR POINT TO AREAL RAINFALL

Catchment Area (Sq Km)	Design Storm Duration (Hours)				
	1	3	6	12	24
00	100.00	100.00	100.00	100.00	100.00
50	93.75	94.25	95.50	97.00	98.00
100	88.00	90.00	91.75	94.50	96.50
150	83.00	86.00	89.00	92.00	95.25
200	78.50	82.00	85.50	90.00	94.00
250	74.50	78.50	82.50	88.50	93.00
300	71.00	75.50	80.00	87.50	92.00
350		72.25	77.25	86.00	91.50
400		69.50	75.50	85.00	90.50
450		66.75	73.00	84.00	89.50
500		64.50	71.25	83.00	88.50
600				81.50	87.25
700				79.50	85.50
800				78.00	84.50
900				77.00	83.75
1000				76.00	83.00
1100				75.00	82.25
1200					81.50
1300					80.50
1400					79.50
1500					79.50
2000					77.50

Annexure 4.4

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

HOURS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	HOURS
1	100	86	75	65	58	54	45	40	38	36	34	32	26	25	23	21	20	19	17	16	15	14	13	12	1
2	-	100	94	85	79	73	66	63	59	56	53	51	43	41	40	38	37	35	31	29	28	27	26	24	2
3	-	-	100	95	90	85	78	74	71	68	65	63	56	54	52	51	48	47	41	39	37	36	35	34	3
4	-	-	-	100	96	92	87	83	80	77	74	72	64	62	61	59	57	55	50	48	46	45	43	42	4
5	-	-	-	-	100	96	92	89	86	83	80	78	70	68	66	64	62	61	57	55	53	52	50	49	5
6	-	-	-	-	-	100	97	94	91	88	85	83	76	74	72	70	68	66	63	61	60	58	57	55	6
7	-	-	-	-	-	-	100	97	95	92	89	87	82	80	77	75	73	71	68	66	65	64	62	60	7
8	-	-	-	-	-	-	-	100	98	95	92	90	87	85	82	80	78	76	72	70	69	68	66	64	8
9	-	-	-	-	-	-	-	-	100	98	96	94	90	88	85	83	81	80	75	74	73	71	69	68	9
10	-	-	-	-	-	-	-	-	-	100	98	96	94	92	90	87	85	83	80	77	76	74	73	71	10
11	-	-	-	-	-	-	-	-	-	-	100	98	96	94	92	90	88	85	83	80	79	77	76	75	11
12	-	-	-	-	-	-	-	-	-	-	-	100	98	97	95	93	91	89	87	84	83	81	80	77	12
13	-	-	-	-	-	-	-	-	-	-	-	-	100	99	97	95	93	92	89	87	85	83	82	80	13
14	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	97	95	93	91	90	88	86	85	83	14
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	97	95	94	92	90	89	87	86	15
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	97	95	94	92	91	89	88	16
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	97	96	95	94	92	90	17
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	97	96	95	93	92	18
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	98	97	95	94	19
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	98	97	96	20
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		100	99	98	97	21
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	98	22
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	23
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	24

Annexure 5.1

LIST OF SUG PARAMETERS OBTAINED FROM EQUATIONS

SL.NO.	BR.NO.	C.A. (KM^2)	Q_p (CUMEC)	q_p CUMEC PER SQ.KM	tp HRS	W_{50} HRS	W_{75} HRS	WR_{50} HRS	WR_{75} HRS	T_B	1 CM VOLUME (CUMEC)
1	4(MOT)	1270	203.86	0.16	13.50	15.35	8.03	5.26	2.90	50	3527.28
2	463	875	153.71	0.18	12.50	13.59	7.16	4.66	2.59	45	2430.55
3	414	554	108.71	0.20	11.50	12.19	6.46	4.19	2.34	41	1538.89
4	6(MOT)	476	96.89	0.20	11.50	12.19	6.46	4.19	2.34	41	1322.22
5	160	470	95.96	0.20	11.50	12.19	6.46	4.19	2.34	41	1305.55
6	8	284	65.50	0.23	9.50	10.55	5.64	3.63	2.04	33	788.89
7	146	216	53.23	0.25	9.50	9.67	5.20	3.34	1.89	33	600.00
8	184	171	44.59	0.26	8.50	9.29	5.00	3.20	1.81	29	475.00
9	215	136	37.49	0.28	8.50	8.60	4.65	2.97	1.69	29	377.78
10	446	54	18.61	0.34	7.50	7.04	3.85	2.44	1.40	25	150.00
11	130	46	16.48	0.36	6.50	6.63	3.64	2.30	1.32	21	127.78
12	440	46	16.48	0.36	6.50	6.63	3.64	2.30	1.32	21	127.78
13	70	31	12.22	0.39	6.50	6.10	3.36	2.12	1.23	21	86.11
14	3(MOT)	29	11.62	0.40	6.50	5.95	3.28	2.07	1.20	21	80.55

Annexure 5.2

COMPUTATION OF EQUIVALENT SLOPE OF BRIDGE CATCHMENT NO. 160

Sl.No.	Reduced Distance		Reduced level		Length of Each segment (Li) (Km)	Height above the datum (Di) (m)	$D_{i-1}+D_i$ (m)	Li (D_{i-1} + D_i) (Km.m)
	RD (Miles)	RD (Km)	RL (Feet)	RL (Metres)				
1	0	0	255.0	77.70	0	0	0	0
2	5.75	9.26	300.0	91.50	9.26	13.80	13.80	127.79
3	7.75	12.48	334.0	101.80	3.22	24.10	37.90	122.04
4	12.50	20.12	350.0	106.70	7.64	29.00	53.10	405.68
5	16.25	26.16	400.0	122.00	6.04	44.30	73.30	442.73
6	19.50	31.40	438.0	133.50	5.24	55.80	100.10	524.52
7	25.00	40.25	500.0	152.40	8.85	74.70	130.50	1154.92
8	35.00	56.35	750.0	228.70	16.10	151.00	225.70	3633.77
							ΣSum	6411.45

$$\text{Slope} = \frac{\Sigma\, Li\,(Di - 1 + Di)}{L^2}$$

$$\text{Slope} = \frac{6411.45}{(56.35)^2} = 2.02 \text{ m/Km}$$

Datum (i.e. R.L. of river bed at point of study) = 77.70 m

COMPUTATION OF DESIGN FLOOD HYDROGRAPH OF BRIDGE CATCHMENT NO. 160

Time (Hours)	S.U.H Ordi-nates (m^3/s)	Rainfall Excess In Cm										Total DSRO (m^3/s)	Base Flow (m^3/s)	Total Flow (m^3/s)
		0.15	.49	0.64	0.65	0.98	2.47	3.98	1.82	0.65	0.31			
		Direct Runoff (m^3/s)												
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
0	0.0	0										0	23.50	23.50
1	2.4	0.36	0.00									0.36	23.50	23.86
2	6.4	0.96	1.18	0.00								2.14	23.50	25.64
3	10.0	1.50	3.14	1.54	0.00							6.17	23.50	29.67
4	14.0	2.10	4.90	4.10	1.56	0.00						12.66	23.50	36.16
5	19.2	2.88	6.86	6.40	4.16	2.35	0.00					22.65	23.50	46.15
6	25.6	3.84	9.41	8.96	6.50	6.27	5.93	0.00				40.91	23.50	64.41
7	36.8	5.52	12.54	12.29	9.10	9.80	15.81	9.55	0.00			74.61	23.50	98.11
8	50.0	7.50	18.03	16.38	12.48	13.72	24.70	25.47	4.37	0.00		122.66	23.50	146.16
9	64.0	9.60	24.50	23.55	16.64	18.82	34.58	39.80	11.65	1.56	0.00	180.70	23.50	204.20
10	76.0	11.40	31.36	32.00	23.92	25.09	47.42	55.72	18.20	4.16	0.74	250.02	23.50	273.52
11	92.0	13.80	37.24	40.96	32.50	36.06	63.23	76.42	25.48	6.50	1.98	334.18	23.50	357.68
12	96.0	14.40	45.08	48.64	41.60	49.00	90.90	101.89	34.94	9.10	3.10	438.65	23.50	462.15
13	92.0	13.80	47.04	58.88	49.40	62.72	123.50	146.46	46.59	12.48	4.34	565.22	23.50	588.72
14	86.0	12.90	45.08	61.44	59.80	74.48	158.08	199.00	66.98	16.64	5.95	700.35	23.50	723.85
15	80.0	12.00	42.14	58.88	62.40	90.16	187.72	254.72	91.00	23.92	7.94	830.88	23.50	854.38

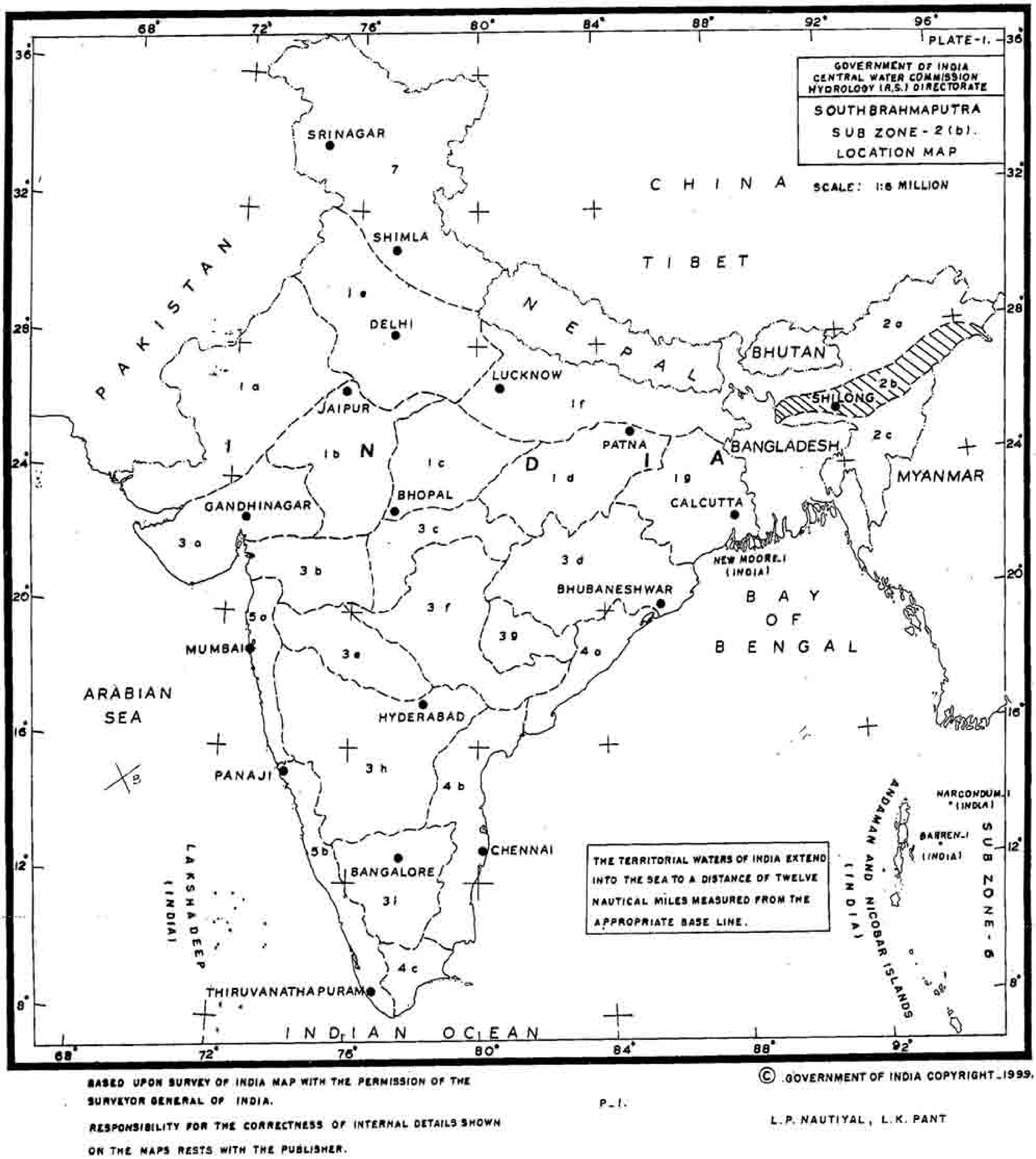
COMPUTATION OF DESIGN FLOOD HYDROGRAPH OF BRIDGE CATCHMENT NO. 160 (Contd..)

Time (Hours)	S.U.H Ordi-nates (m^3/s)	Rainfall Excess In Cm										Total DSRO (m^3/s)	Base Flow (m^3/s)	Total Flow (m^3/s)
		0.15	.49	0.64	0.65	0.98	2.47	3.98	1.82	0.65	0.31			
16	72.8	10.92	39.20	55.04	59.80	94.08	227.24	302.48	116.48	32.50	11.41	949.15	23.50	972.65
17	68.0	10.20	35.67	51.20	55.90	90.16	237.12	366.16	138.32	41.60	15.50	1041.83	23.50	1065.33
18	60.8	9.12	33.32	46.59	52.00	84.28	227.24	382.08	167.44	49.40	19.84	1071.31	23.50	1094.81
19	56.0	8.40	29.79	43.52	47.32	78.40	212.42	366.16	174.72	59.80	23.56	1044.09	23.50	1067.59
20	48.8	7.32	27.44	38.91	44.20	71.34	197.60	342.28	167.44	62.40	28.52	987.46	23.50	1010.96
21	44.0	6.60	23.91	35.84	39.52	66.64	179.82	318.40	156.52	59.80	29.76	916.81	23.50	940.31
22	36.6	5.49	21.56	31.23	36.40	59.58	167.96	289.74	145.60	55.90	28.52	841.99	23.50	865.49
23	32.0	4.80	17.93	28.16	31.72	54.88	150.18	270.64	132.50	52.00	26.66	769.47	23.50	792.97
24	26.0	3.90	15.68	23.42	28.60	47.82	138.32	241.98	123.76	47.32	24.80	695.61	23.50	719.11
25	22.0	3.30	12.74	20.48	23.79	43.12	120.54	222.88	110.66	44.20	22.57	624.27	23.50	647.77
26	18.0	2.70	10.78	16.64	20.80	35.87	108.68	194.22	101.92	39.52	21.08	552.21	23.50	575.71
27	16.0	2.40	8.82	14.08	16.90	31.36	90.40	175.12	88.82	36.40	18.85	483.15	23.50	506.65
28	12.0	1.92	7.84	11.52	14.30	25.48	79.04	145.67	80.08	31.72	17.36	414.93	23.50	438.43
29	10.0	1.50	6.27	10.24	11.70	21.56	64.22	127.36	66.61	28.60	15.13	353.19	23.50	376.69
30	8.0	1.20	4.90	8.19	10.40	17.64	54.34	103.48	58.24	23.79	13.64	295.82	23.50	319.32
31	6.4	0.96	3.92	6.40	8.32	15.68	44.46	87.56	47.32	20.80	11.35	246.77	23.50	270.27
32	5.4	0.75	3.14	5.12	6.50	12.54	39.52	71.64	40.04	16.90	9.92	206.07	23.50	229.57
33	3.2	0.48	2.45	4.10	5.20	9.80	31.62	63.68	32.76	14.30	8.06	172.44	23.50	195.94
34	2.4	0.36	1.57	3.20	4.16	7.84	24.70	50.94	29.12	11.70	6.82	140.41	23.50	163.91

COMPUTATION OF DESIGN FLOOD HYDROGRAPH OF BRIDGE CATCHMENT NO. 160 (Contd..)

Time (Hours)	S.U.H Ordi-nates (m^3/s)	Rainfall Excess In Cm										Total DSRO (m^3/s)	Base Flow (m^3/s)	Total Flow (m^3/s)
		0.15	0.49	0.64	0.65	0.98	2.47	3.98	1.82	0.65	0.31			
35	2.0	0.30	1.18	2.05	3.25	6.27	19.76	39.80	23.30	10.40	5.58	111.88	23.50	135.38
36	1.6	0.24	0.98	1.54	2.08	4.90	15.81	31.84	18.20	8.32	4.96	88.86	23.50	112.36
37	1.0	0.15	0.78	1.28	1.56	3.14	12.35	25.47	14.56	6.50	3.97	69.76	23.50	93.26
38	0.80	0.12	0.49	1.02	1.30	2.35	7.90	19.90	11.65	5.20	3.10	53.04	23.50	76.54
39	0.6	0.09	0.39	0.64	1.04	1.96	5.93	12.74	9.10	4.16	2.48	38.53	23.50	62.03
40	0.4	0.06	0.29	0.51	0.65	1.57	4.94	9.55	5.82	3.25	1.98	28.63	23.50	52.13
41	0.0	0.00	0.20	0.38	0.52	0.98	3.95	7.96	4.37	2.08	1.55	21.99	23.50	45.49
42			0.00	0.26	0.39	0.76	2.47	6.37	3.64	1.56	0.99	16.46	23.50	39.96
43				0.00	0.26	0.59	1.98	3.98	2.91	1.30	0.74	11.76	23.50	35.26
44					0.00	0.39	1.48	3.18	1.82	1.04	0.62	8.54	23.50	32.04
45						0.00	0.99	2.39	1.46	0.65	0.50	5.98	23.50	29.48
46							0.00	1.59	1.09	0.52	0.31	3.51	23.50	27.01
47								0.00	0.73	0.39	0.25	1.37	23.50	24.87
48									0.00	0.26	0.19	0.45	23.50	23.95
49										0.00	0.12	0.12	23.50	23.62
50											0.00	0.00	23.50	23.50

PLATES

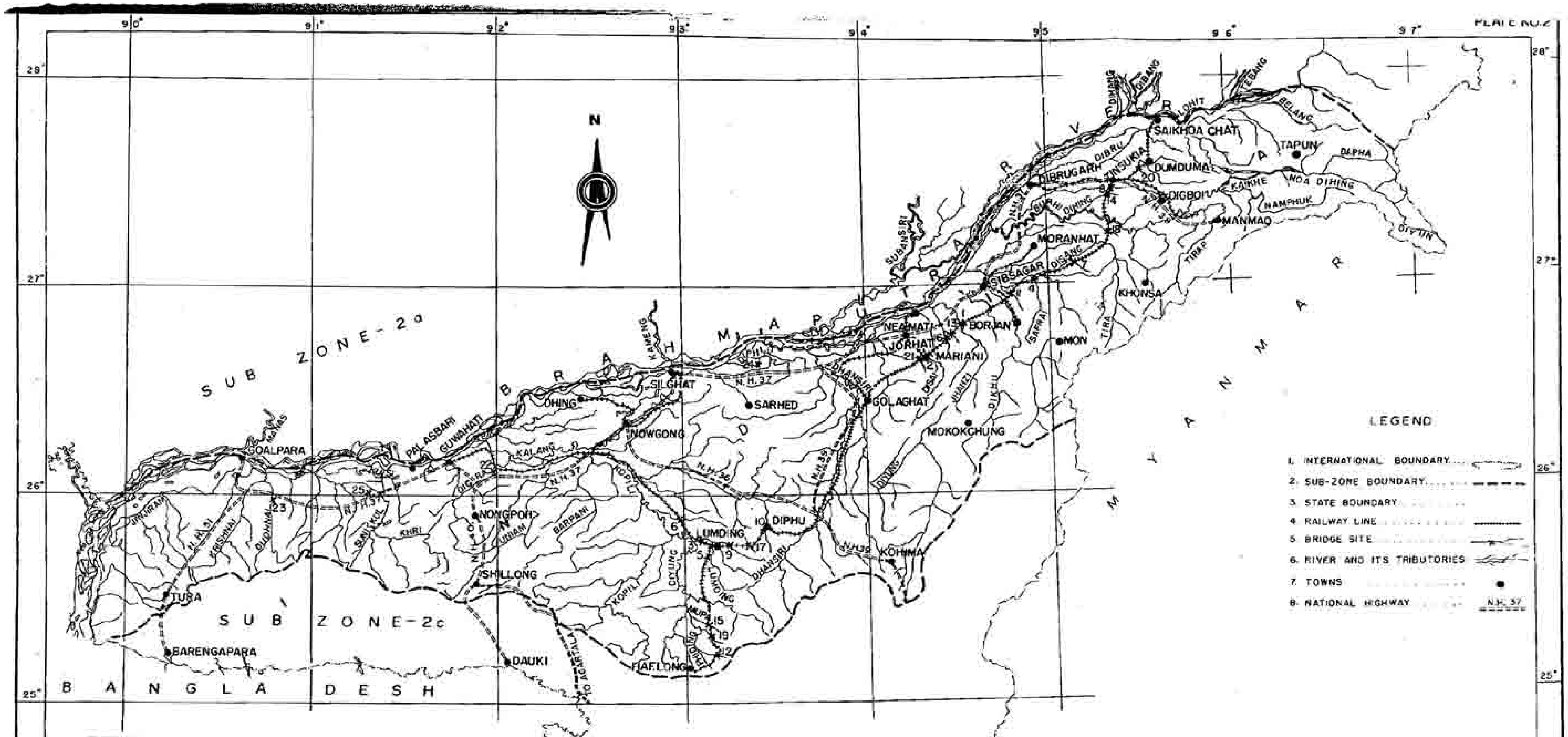


BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.

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

P_I.

L.P. NAUTIYAL, L.K. PANT



Sl.NO	B/SITE NO.	RAILWAY SECTION	STREAM	C.A. IN SQ. KM.	DATA AVAILABILITY
1	463	MARIANI- TINSUKIA	JHANZI	875.00	1970, 71, 72, 74-76, 83, 91
2	414	MARIANI - TINSUKIA	DESAI	554.00	1975-79, 84-91, 93
3	160	LUMDING-GUWAHATI	LANGPHER	470.00	1966-69 AND 83
4	526	MARIANI- TINSUKIA	SAFRAI	304.00	1975-79
5	8	LUMDING-BADARPUR	LUMDING-N.	284.00	1966-67, 70-71 AND 83
6	146	GUWAHATI-LUMDING	LANKAJAN	216.00	1962 AND 64
7	539	LUMDING-TINSUKIA	BARTIMAN	188.00	1961, 65 AND 67-68
8	574	LUMDING-TINSUKIA	TINGRAI	182.00	1961-62 AND 69-71
9	184	LUMDING-FURKATING	BARLONGFER	171.00	1962 AND 65-74
10	215	LUMDING-FURKATING	DIPHU	136.00	1961, 62, 66, 68 AND 69
11	507	MARIANI - TINSUKIA	DARIKAJAN	89.00	1962
12	269	LUMDING-BADARPUR	DIYUNG	77.00	1961-62, 64-66, 74-75
13	446	MARIANI- TINSUKIA	TEOK	54.00	1971-72 AND 74-76.

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

Sl.NO.	B/SITE NO.	RAILWAY/ROAD SECTION.	STREAM	C.A. IN SQ. KM.	DATA AVAILABILITY
14	566	LUMDING-TINSUKIA	HUGREJAN	47.00	1961-62, 64-65 AND 68-70
15	130	LUMDING-BADARPUR	MUPA	46.00	1962, 1974-78 AND 83
16	440	MARIANI- TINSUKIA	PUTINAI	46.00	1961, 62, 65 AND 69-70
17	192	LUMDING-TINSUKIA	LANGCHOLIET	38.00	1961-62 AND 66-68
18	556	MARIANI-TINSUKIA	DESAM	33.00	1961-62, 64-65 AND 67
19	170	LUMDING-BADARPUR	PHIDING	32.00	1961, 62, 64-67 AND 74
20	70	DANGARI-MAKUM	BARHAPJAN	31.00	1975-79
21	408	KHARIKHATIA-MARIANI	NAGADULIAJAN	26.00	1971-73
22	4MOT	SONAPUR- JORBAT C.W.C.(M.O.S.T.)	DIGRA	1270.00	1981-88
23	6MOT	KRISHNAI-DUDHNAI C.W.C.(M.O.S.T.)	DUDHNAI	476.00	1981-88
24	3MOT	KAZIRANGA-KOHORA C.W.C.(M.O.S.T.)	KOHORA	29.00	1981-88
25	5MOT	CHHAYGAON-BAMUNI C.W.C.(M.O.S.T.)	KHUR-KHURI	25.00	1981-83

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

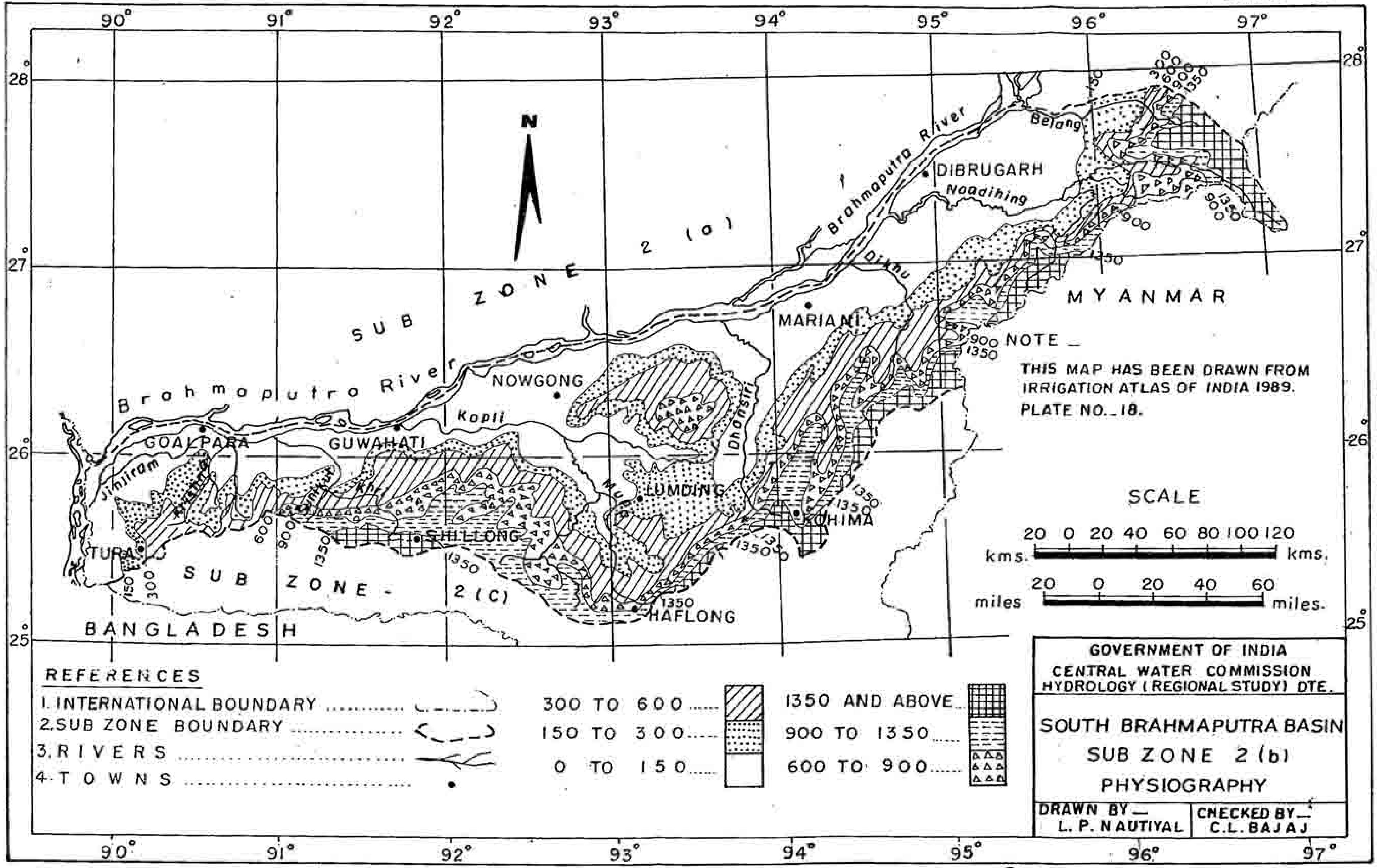
P. 2.

GOVT. OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (SMALL CATCHMENTS) DIRECTORATE

SOUTH BRAHMAPUTRA BASIN
(SUB-ZONE 2b)
RIVER SYSTEM, LOCATION OF RAILWAY AND M.O.T. BRIDGES

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

DRG. NO. HSC/0-2/2b



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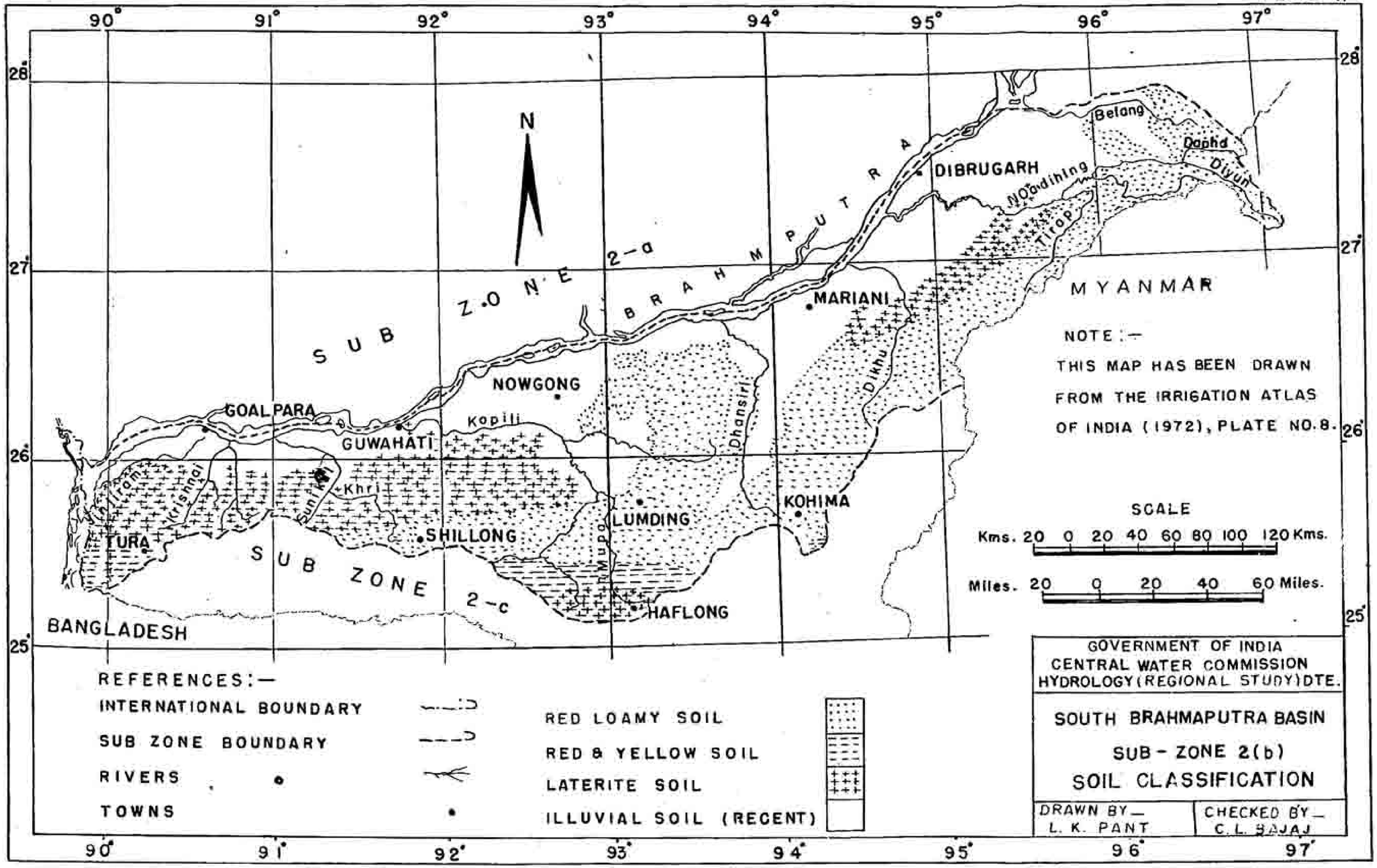
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS REST WITH THE PUBLISHER.



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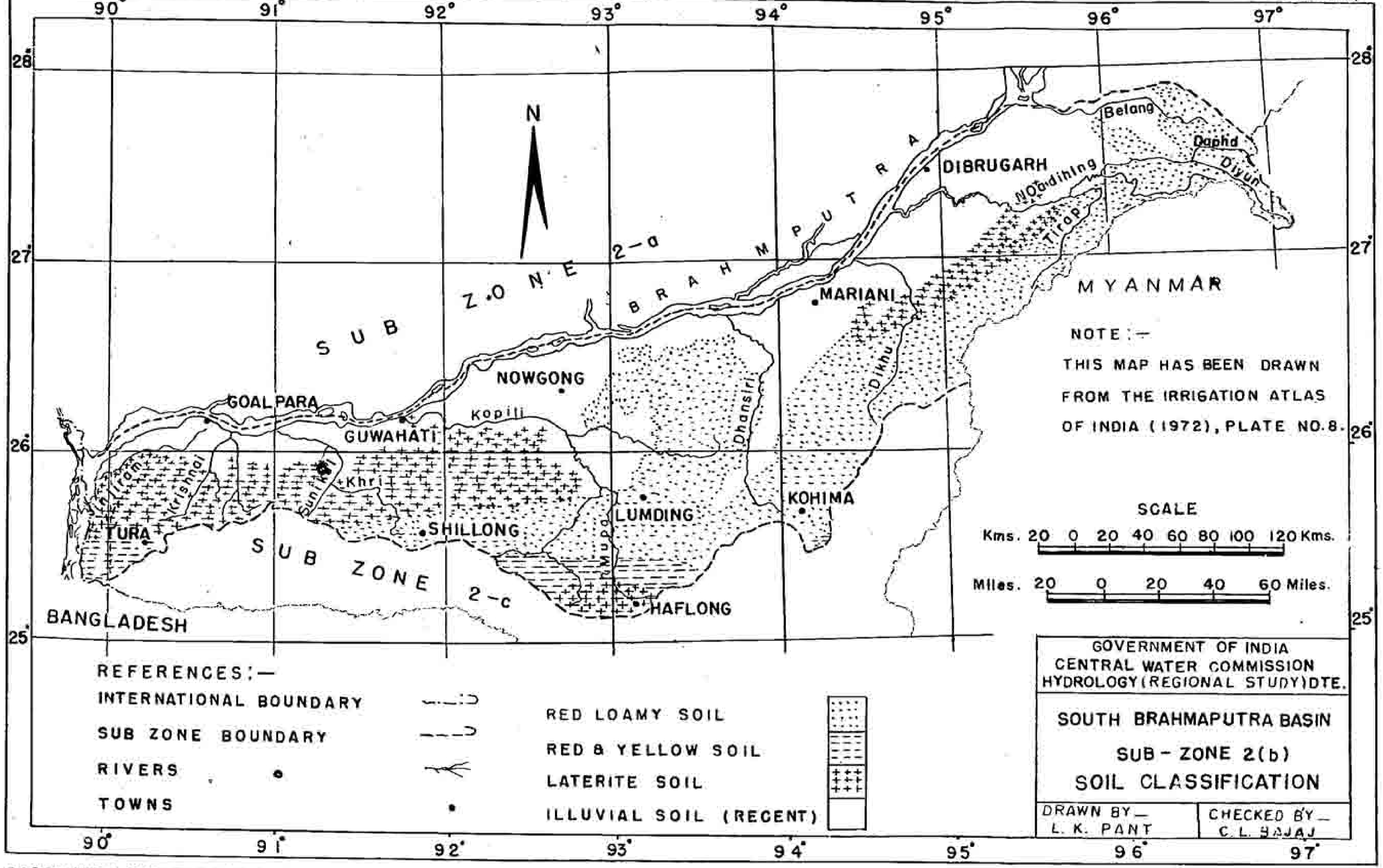
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS REST WITH THE PUBLISHER.

PLATE-4.



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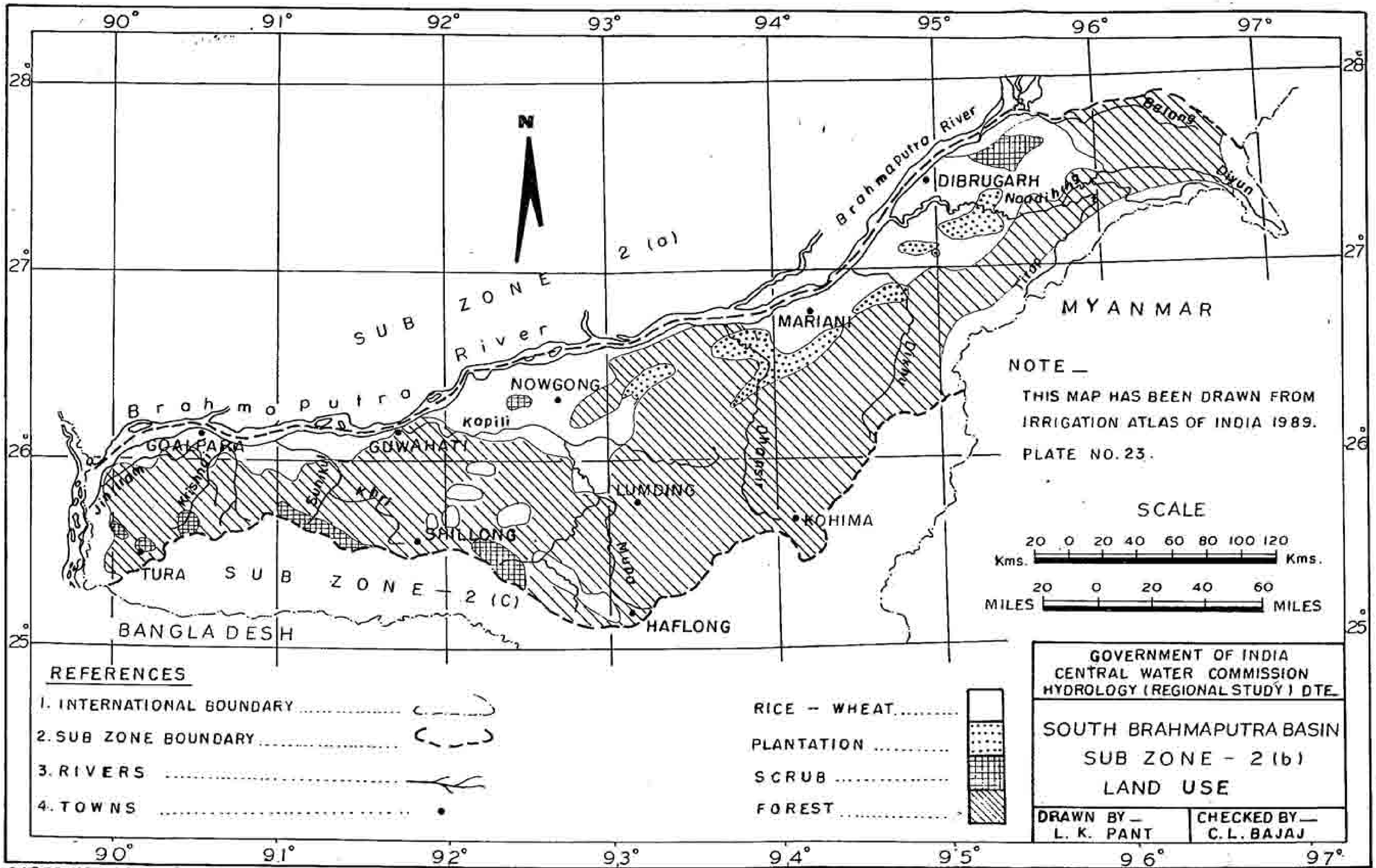
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS REST WITH THE PUBLISHER.



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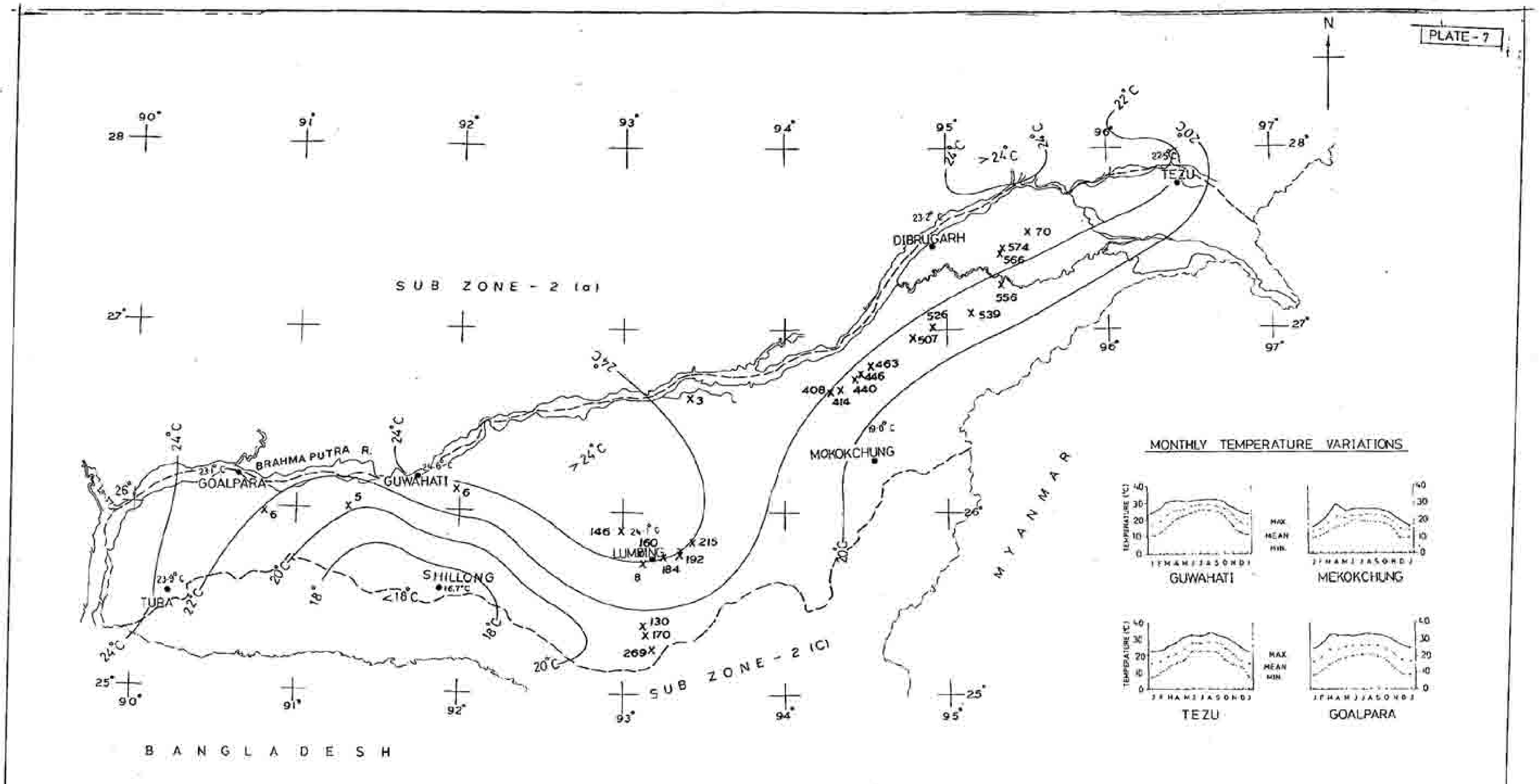
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS REST WITH THE PUBLISHER.

PLATE - 7



REFERENCES

1. INTERNATIONAL BOUNDARY
2. SUBZONE BOUNDARY
3. TOWNS
4. ISOTHERMS (°C)
5. RIVERS
6. BRIDGE SITES x 269

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.

MAP SUPPLIED BY I.M.D

SCALE

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

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

SOUTH BRAHMAPUTRA BASIN
SUB ZONE - 2 (b).
MEAN DAILY TEMPERATURE (ANNUAL) (°C)

DRAWN BY - L. P. NAUTIYAL. | CHECKED BY - K. K. AICH.

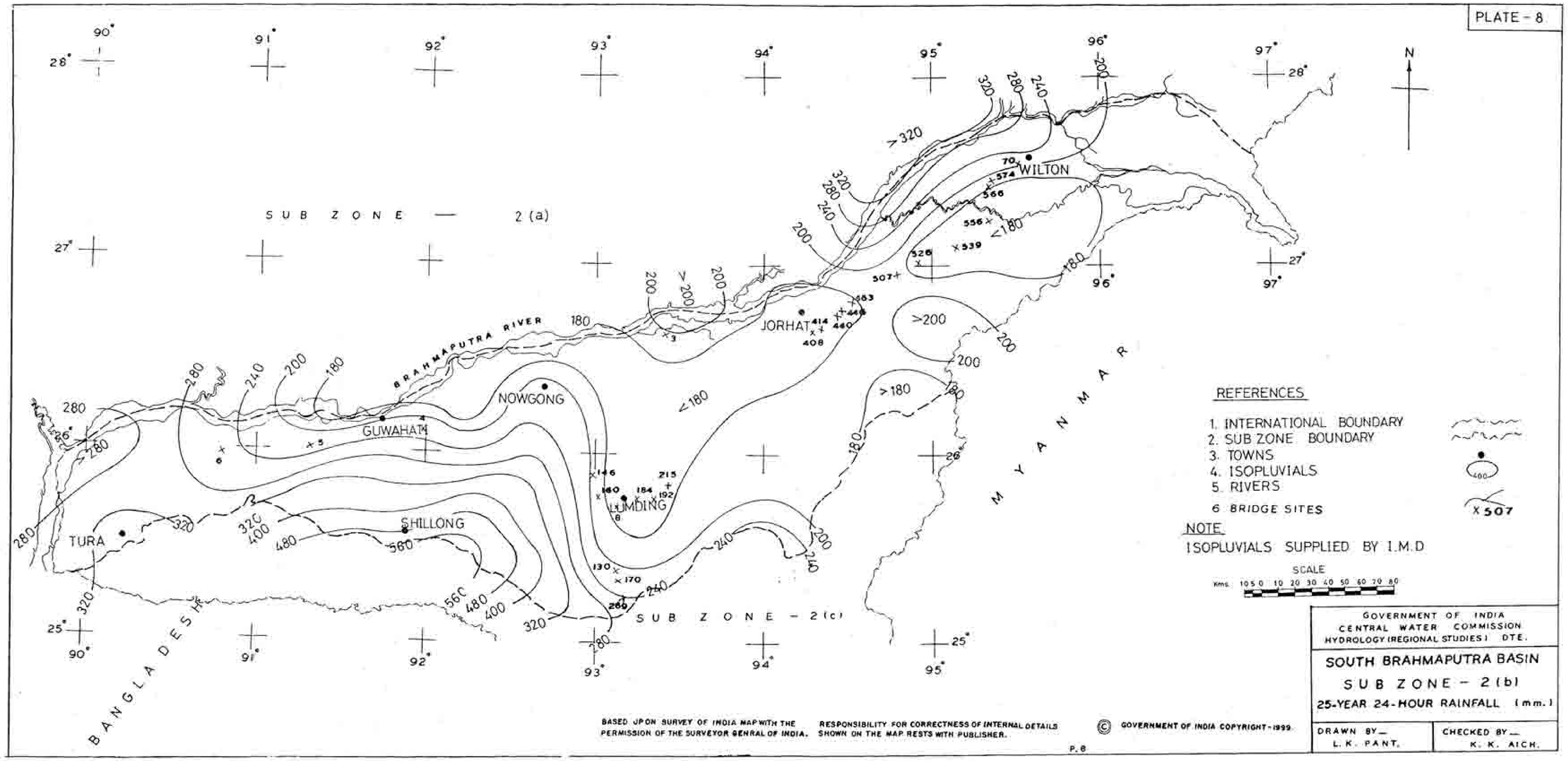


PLATE - 8
SUB ZONE — 2 (a)
BRAHMAPUTRA RIVER
GUWAHATI
NOWGONG
JORHAT
WILTON
LUMDING
SHILLONG
TURA
MYANMAR
BANGLADESH
SUB ZONE - 2(c)
REFERENCES
1. INTERNATIONAL BOUNDARY
2. SUB ZONE BOUNDARY
3. TOWNS
4. ISOPLUVIALS
5. RIVERS
6 BRIDGE SITES
NOTE
ISOPLUVIALS SUPPLIED BY I.M.D
SCALE
GOVERNMENT OF INDIA
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HYDROLOGY (REGIONAL STUDIES) DTE.
SOUTH BRAHMAPUTRA BASIN
SUB ZONE - 2(b)
25-YEAR 24-HOUR RAINFALL (mm.)
DRAWN BY_ L.K. PANT.
CHECKED BY_ K.K. AICH.
BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENRAL OF INDIA.
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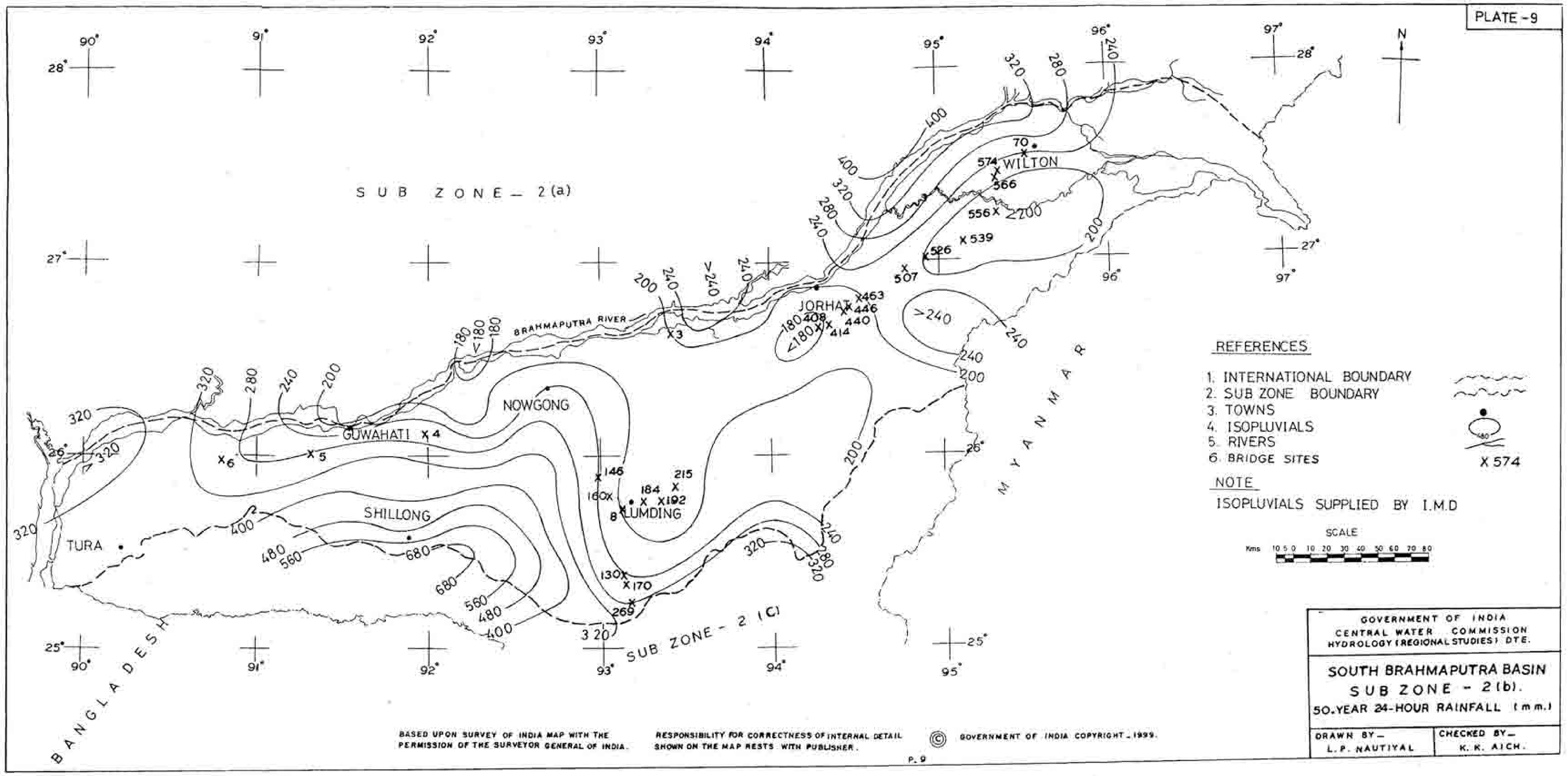
PLATE - 9
SUB ZONE - 2 (a)
SUB ZONE - 2 (C)
BRAHMAPUTRA RIVER
GUWAHATI
NOWGONG
SHILLONG
TURA
LUMDING
JORHAT
WILTON
BANGLADESH
MYANMAR
N
REFERENCES
1. INTERNATIONAL BOUNDARY
2. SUB ZONE BOUNDARY
3. TOWNS
4. ISOPLUVIALS
5. RIVERS
6. BRIDGE SITES
X 574
NOTE
ISOPLUVIALS SUPPLIED BY I.M.D
SCALE
Kms
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SOUTH BRAHMAPUTRA BASIN
SUB ZONE - 2 (b).
50-YEAR 24-HOUR RAINFALL (mm.)
DRAWN BY - L. P. NAUTIYAL
CHECKED BY - K. K. AICH.
P. 9

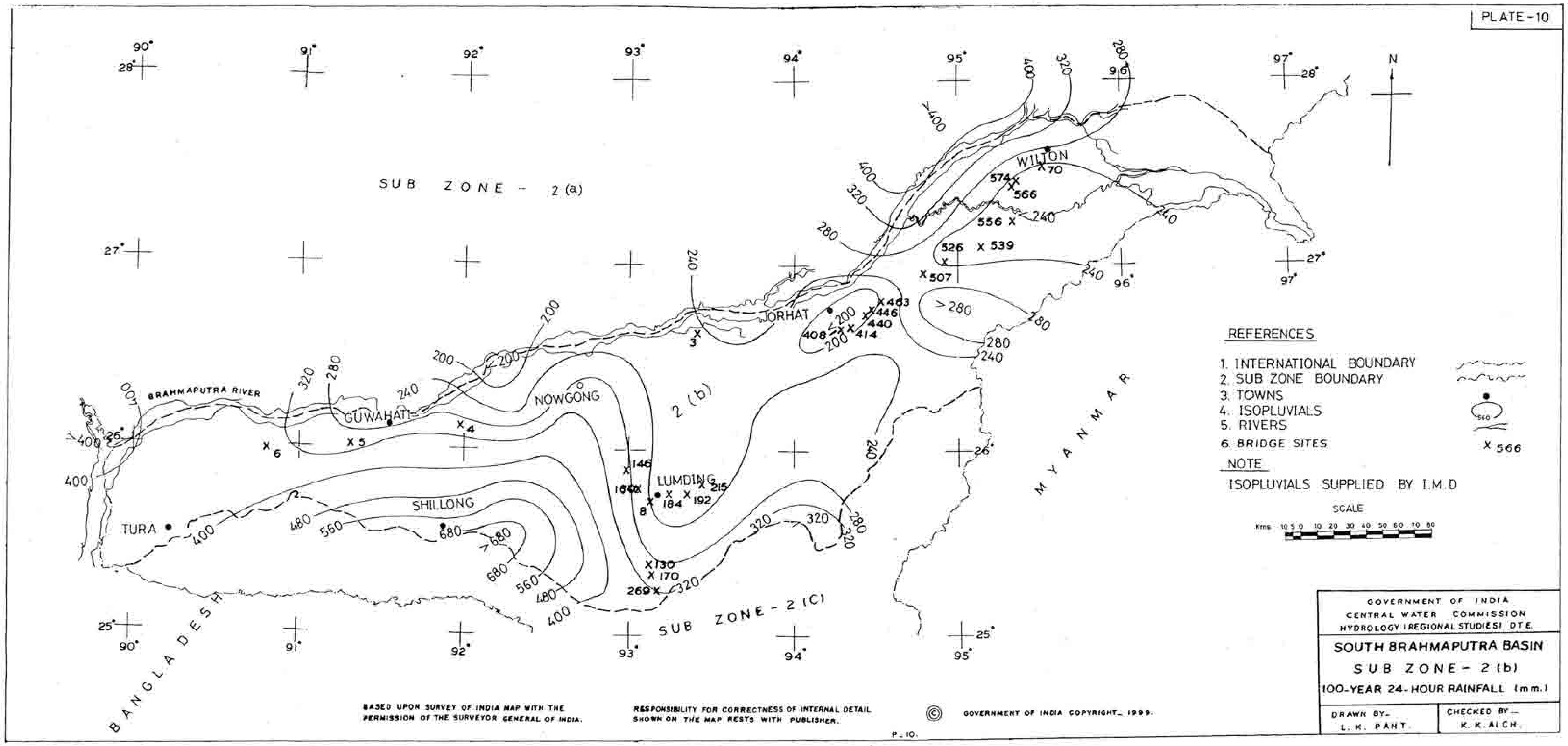
PLATE - 10
SUB ZONE - 2 (a)
2 (b)
SUB ZONE - 2 (C)
BRAHMAPUTRA RIVER
GUWAHATI
NOWGONG
JORHAT
WILTON
LUMDING
SHILLONG
TURA
MYANMAR
BANGLADESH
N
REFERENCES
1. INTERNATIONAL BOUNDARY
2. SUB ZONE BOUNDARY
3. TOWNS
4. ISOPLUVIALS
5. RIVERS
6. BRIDGE SITES
NOTE
ISOPLUVIALS SUPPLIED BY I.M.D
SCALE
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HYDROLOGY (REGIONAL STUDIES) DTE.
SOUTH BRAHMAPUTRA BASIN
SUB ZONE - 2 (b)
100-YEAR 24-HOUR RAINFALL (mm.)
DRAWN BY- L. K. PANT.
CHECKED BY- K. K. AICH.
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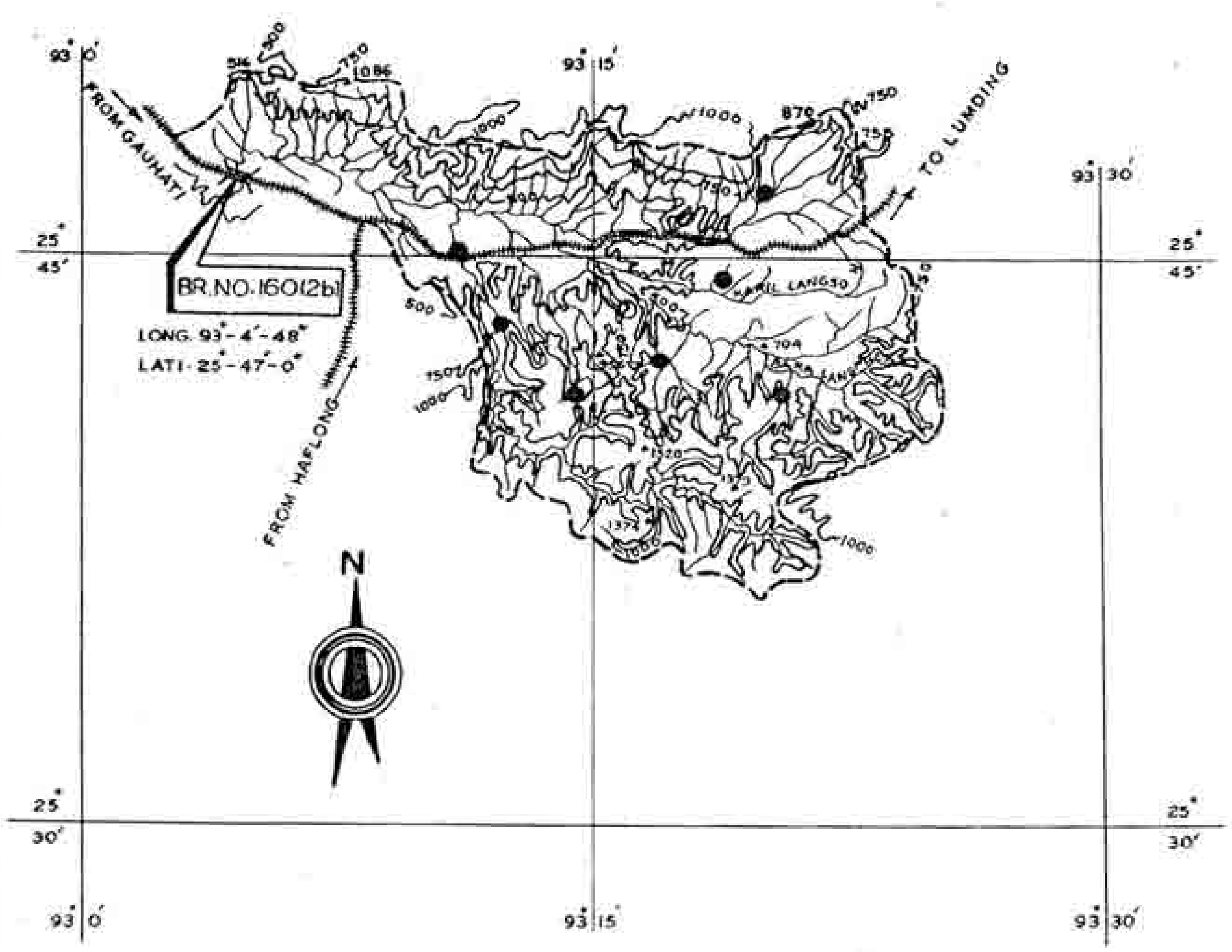
FIG. A. 1



NOTES:-

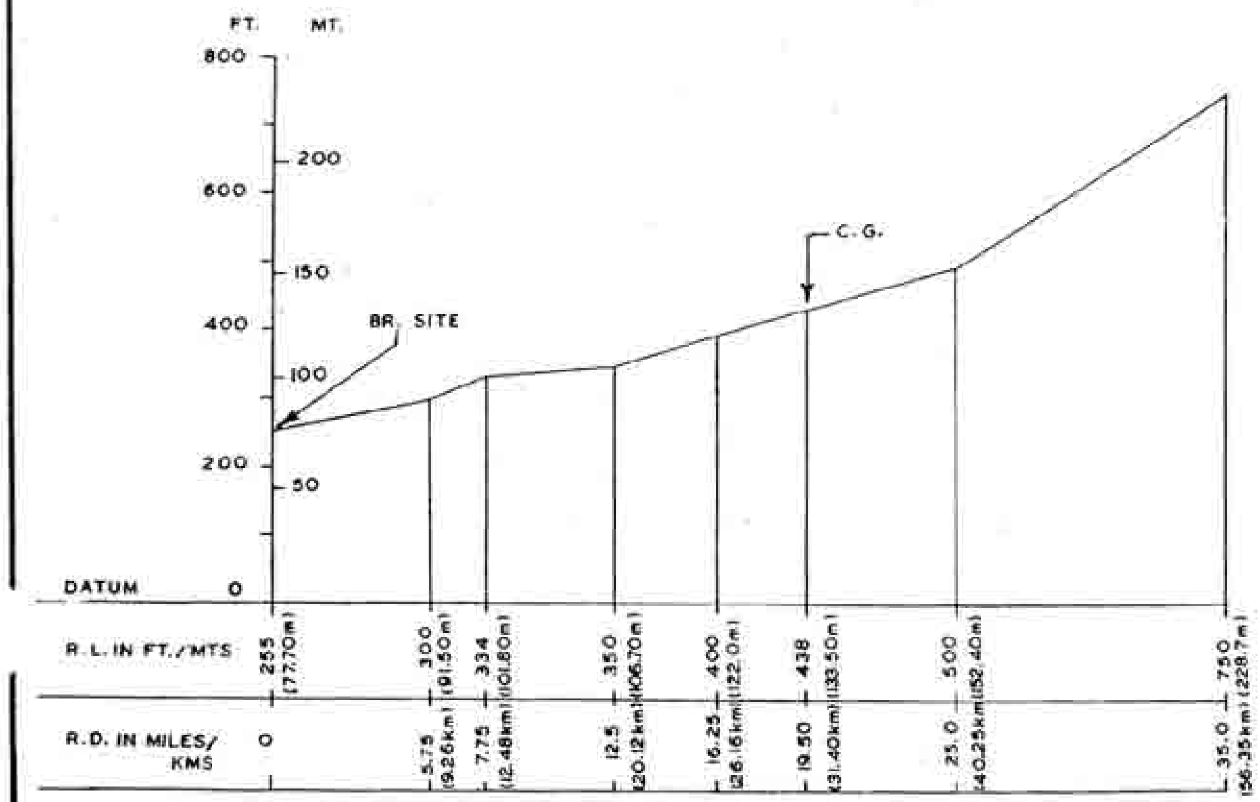
1. ALL LEVELS CORRESPOND TO G.T.S. DATUM.
2. H.F.L. AT GAUGE SITE, (490 ft U/S OF ¢ OF Br) = 320·28 FT.

REFERENCES

1. CATCHMENT BOUNDARY
2. RAILWAY LINE
3. RIVER AND ITS TRIBUTARIES
4. RAINGAUGE STATIONS ●
5. CONTOURS (500)
6. SPOT LEVELS ▲755
7. CONTOUR INTERVALS — 250 FT.
8. TOPO SHEET NO. — 83 G
9. CENTRE OF GRAVITY — ○ C.G.

DETAILS OF CATCHMENT

1. AREA OF THE CATCHMENT = 469·80 SQ. KMS.
2. SHAPE OF CATCHMENT = FAN SHAPE
3. TOTAL LENGTH OF RIVER & ITS TRIBUTARIES = 468·51 KMS
4. L = 56·35 KMS.
5. Lc = 31·39 KMS.
6. Wc = 18·35 KMS.
7. D = 0·997 KM/KM²
8. Seq. = 2·02 M/KM



L - SECTION OF BARA LANGPHER RIVER

SCALE

MILES 5 4 3 2 1 0 5 10 — HORIZONTAL

200 0 200 400 FEET — VERTICAL

F. I.

SCALE:-

KMS. 5 4 3 2 1 0 5 10 15 KMS.

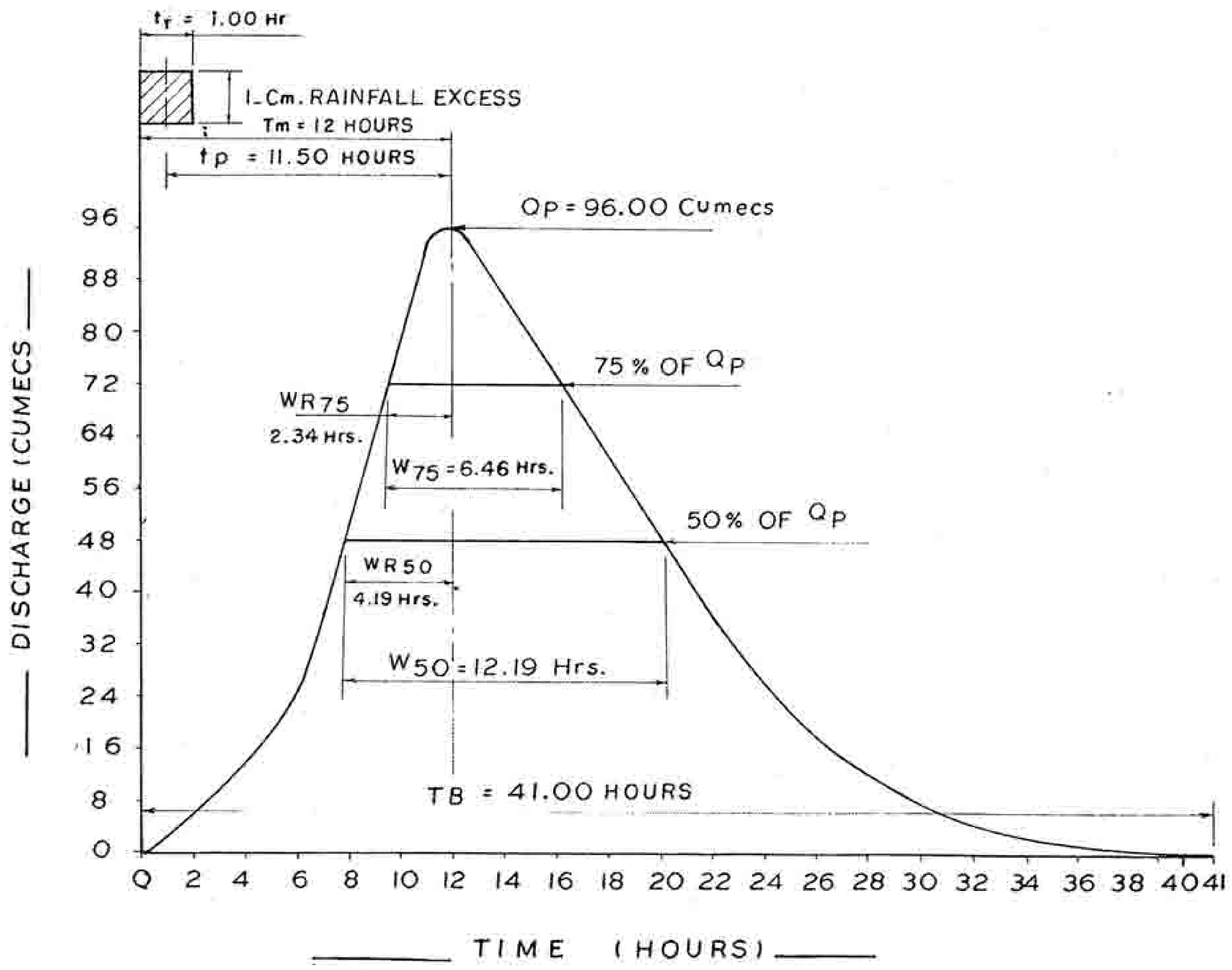
MILES 4 3 2 1 0 4 8 MILES

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

CATCHMENT AREA PLAN FOR BR. NO.160 AT K.MTS 370/8-9 ON LUMDING - GAUHATI SEC. N.F. RLY. SUB - ZONE 2(b)

DRAWN BY	CHECKED BY
L. K. PANT.	C. L. BAJAJ

FIG. _ A-2.



SYNTHETIC U.G. PARAMETERS

1.	C. AREA	=	470 Km^2
2.	t_r	=	1.00 Hr.
3.	Q_p	=	96.00 Hrs.
4.	t_p	=	11.50 Hrs.
5.	q_p	=	0.20 Cums./Km^2
6.	T_m	=	12.00 Hrs.
7	T_B	=	41.00 Hrs.
8.	W50	=	12.19 Hrs.
9.	W75	=	6.46 Hrs.
10.	W_{R50}	=	4.19 Hrs.
11.	W_{R75}	=	2.34 Hrs.
12.	d	=	1.00 Cm.

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

$$\Sigma Q_i = \frac{470 \times 1.00}{1.00 \times 0.36}$$

$$= 1305.60 \text{ Cumecs.}$$

1_HOUR SYNTHETIC U.G ORDINATES

0	0	16	72.80	32	5.40
1	2.40	17	68.00	33	3.20
2	6.40	18	60.80	34	2.40
3	10.00	19	56.00	35	2.00
4	14.00	20	48.80	36	1.60
5	19.20	21	44.00	37	1.00
6	25.60	22	36.60	38	0.80
7	36.80	23	32.00	39	0.60
8	50.00	24	26.00	40	0.40
9	64.00	25	22.00	41	0.00
10	76.00	26	18.00		
11	92.00	27	16.00		
12	96.00	28	12.80		
13	92.00	29	10.00		
14	86.00	30	8.00		
15	80.00	31	6.40		

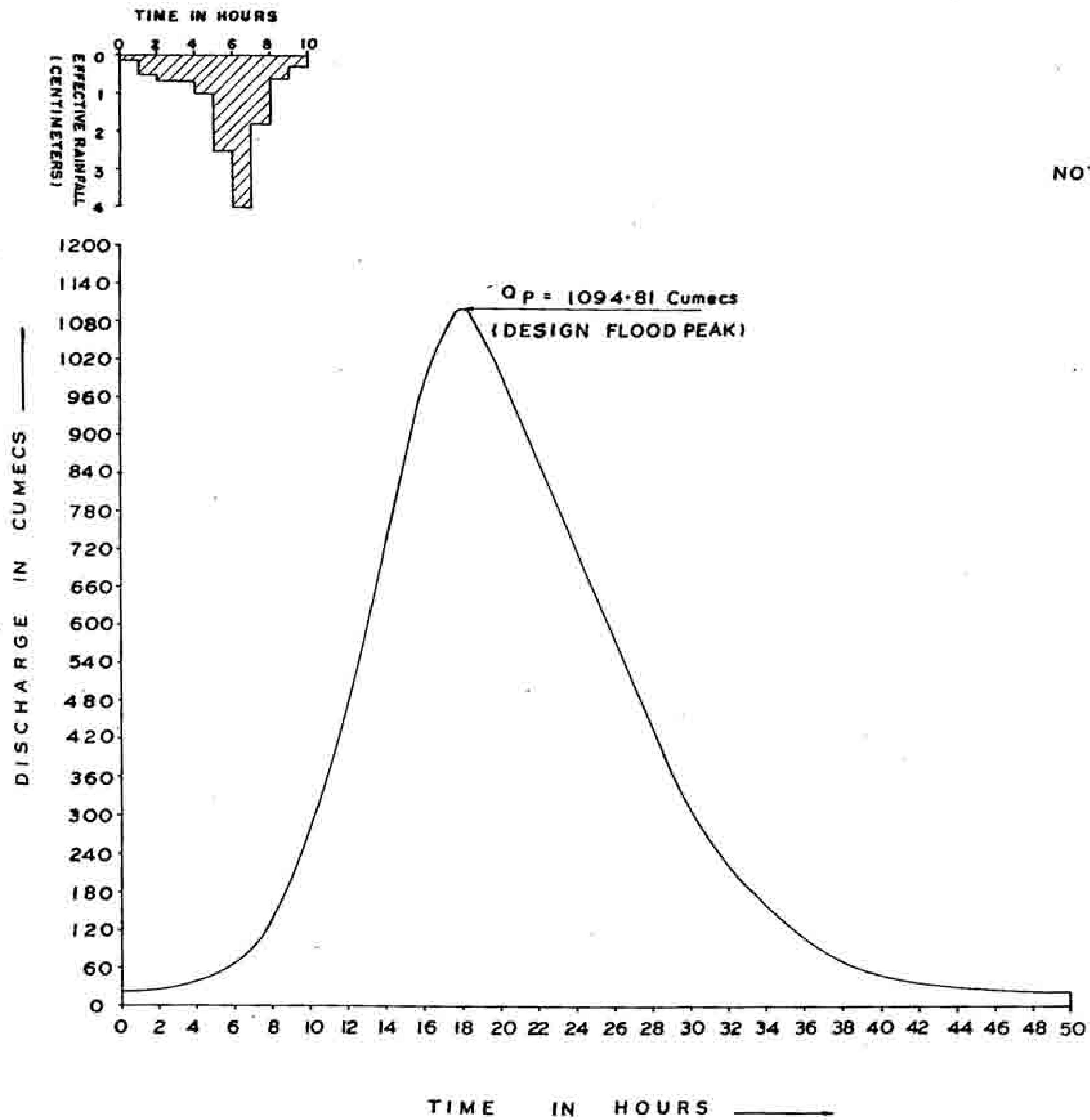
TOTAL = 1305.60 CUMECS

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

SOUTH BRAHMAPUTRA BASIN
SUB ZONE - 2 (b)
SYNTHETIC UNIT HYDROGRAPH OF BRIDGE NO. _ 160.

DRAWN BY_	CHECKED BY_
L. P. NAUTIYAL.	K. K. AICH.

FIG. _ A.3



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

CATCHMENT AREA = 470.00 Km^2

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CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

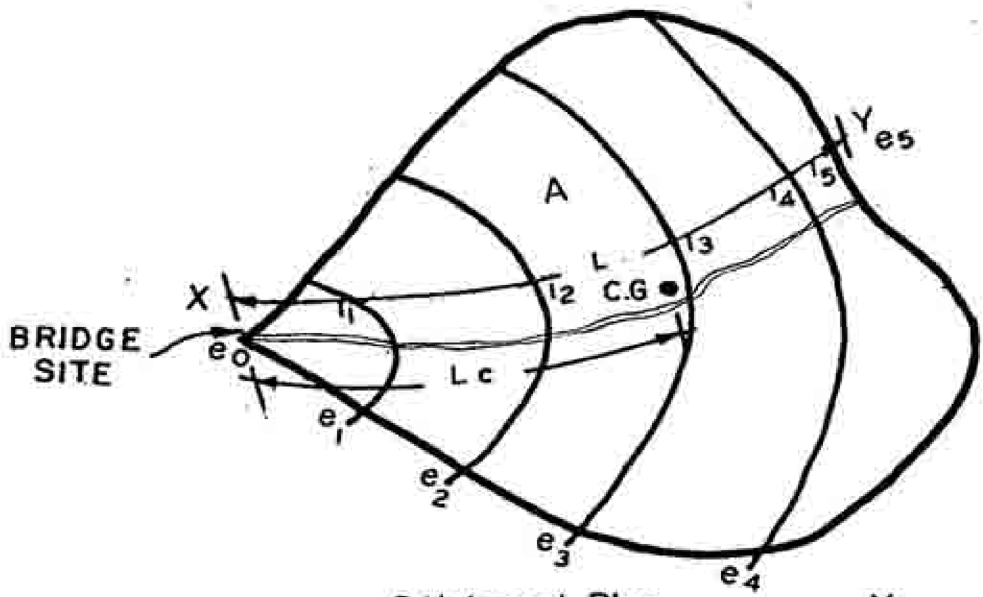
SOUTH BRAHMAPUTRA SUB ZONE-2(b)

DESIGN FLOOD HYDROGRAPH

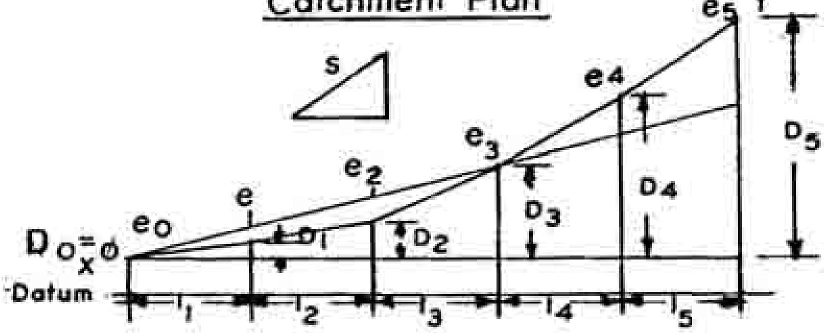
BRIDGE NO. _ 160.

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

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)

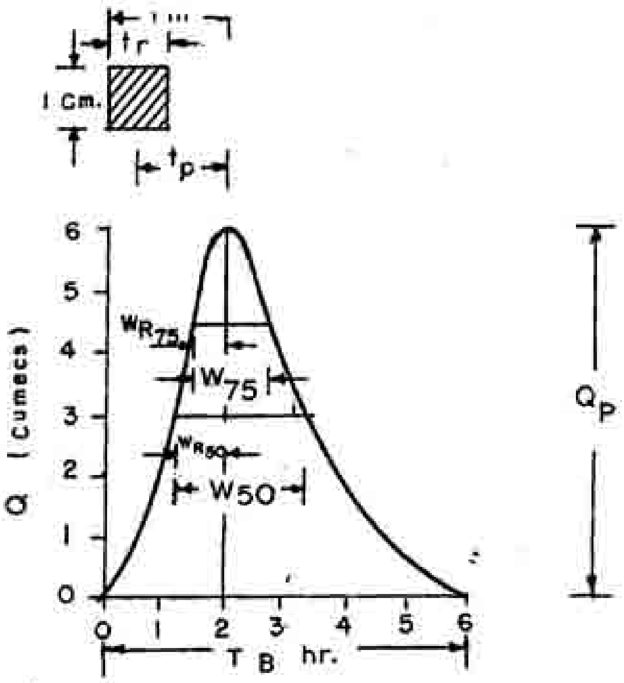
Lc = Length of longest stream course from a point opposit the centre of gravity of the catchment to the point of study (Km.)

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

PHYSIOGRAPHIC PARAMETERS

DRAWN

CHECKED
VINOD KAUL



U. G = Unit Graph

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

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

Q_P = Peak Discharge of Unit Hydrograph (Cumecs.)

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

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

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

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

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

T_B = Base width of Unit Hydrograph (hr.)

A = Catchment Area (Sq.km.)

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

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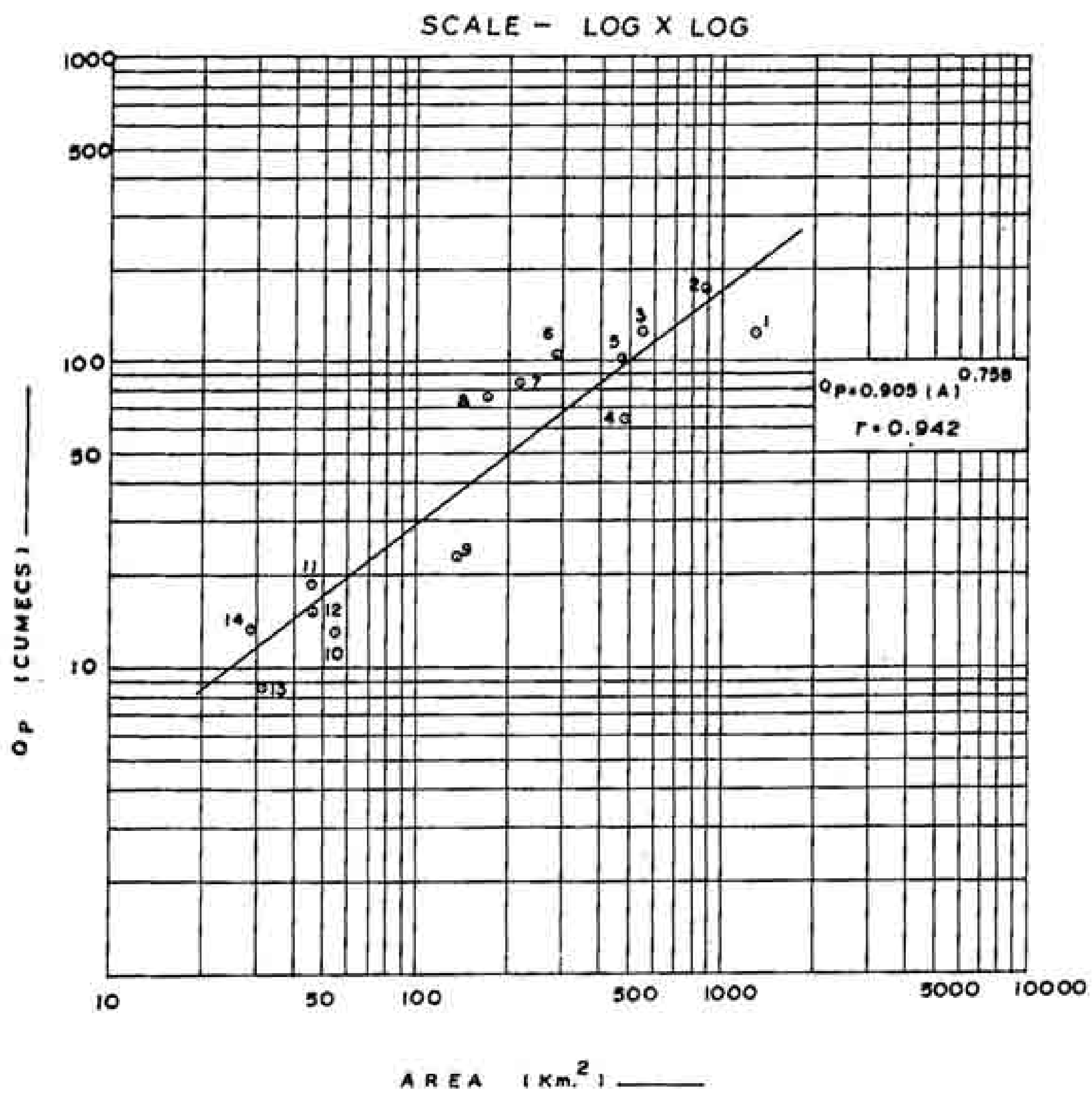
UNIT GRAPH PARAMETERS	
DRAWN BY- NAUTIYAL	CHECKED BY-

FIG. - 3



Sl. NO.	BRIDGE NO	A (Km.²)	Qp (CUMECS)
1	4-MOT	1270	123
2	463	875	172
3	414	554	123.78
4	6-MOT	476	64.50
5	160	470	100.50
6	8	284	105.40
7	146	216	84.00
8	184	171	76.00
9	215	136	27.40
10	446	54	13.00
11	130	46	18.66
12	440	46	15.45
13	70	31	8.66
14	3. MOT	29	13.65

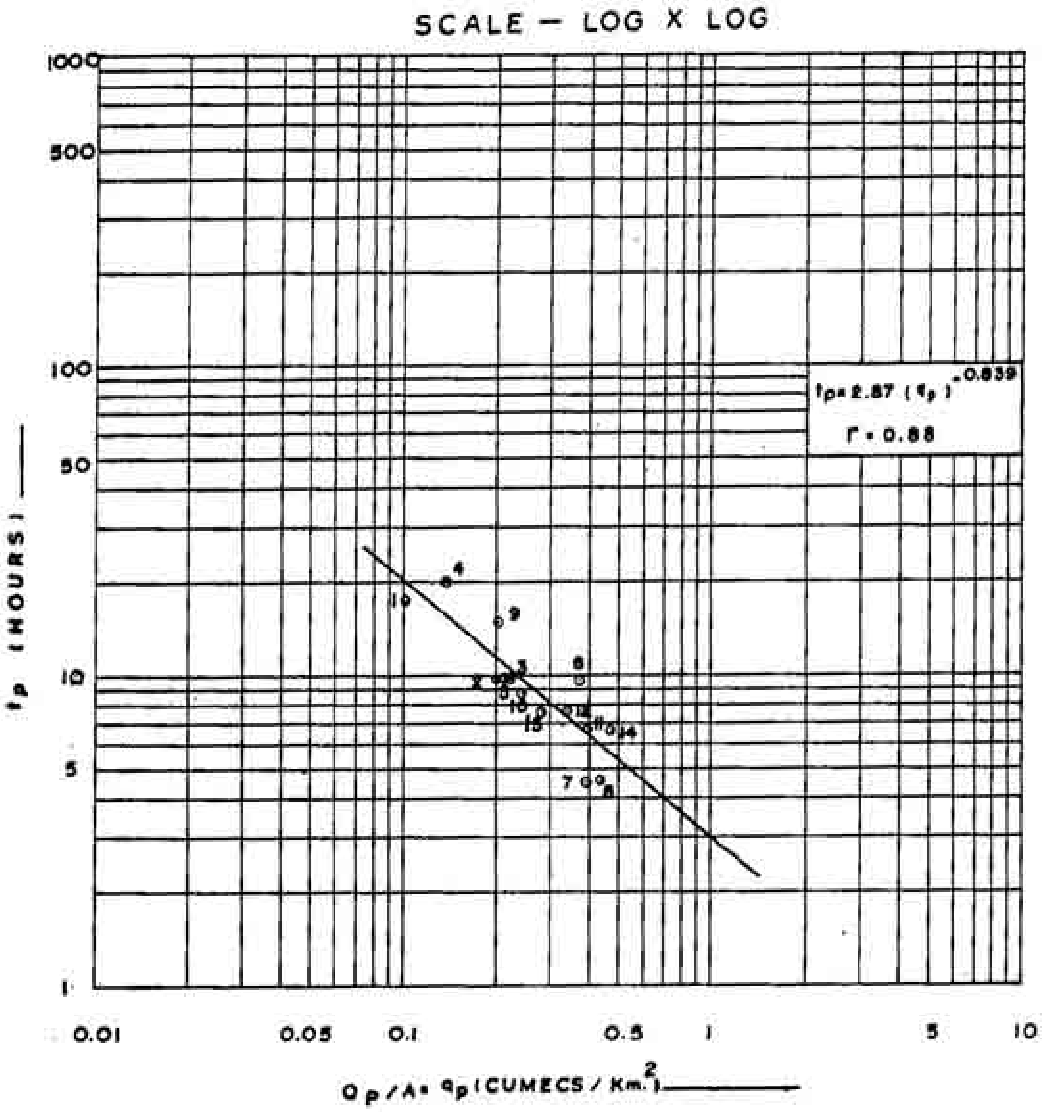
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

SOUTH BRAHMAPUTRA BASIN
SUB ZONE - 2 (b)
RELATION BETWEEN
A AND Qp

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

F. 6.

FIG. - 4



Sl. NO.	BRIDGE NO.	q_p (Cum./Km.^{2})	t_p (HOURS)
1	4-MOT	0.10	17.50
2	463	0.20	9.50
3	414	0.22	9.80
4	6-MOT	0.14	19.50
5	160	0.21	9.30
6	8	0.37	9.50
7	146	0.39	4.50
8	184	0.44	4.50
9	216	0.20	14.50
10	446	0.24	8.50
11	130	0.40	6.50
12	440	0.34	7.50
13	70	0.28	7.80
14	3-MOT	0.47	6.50

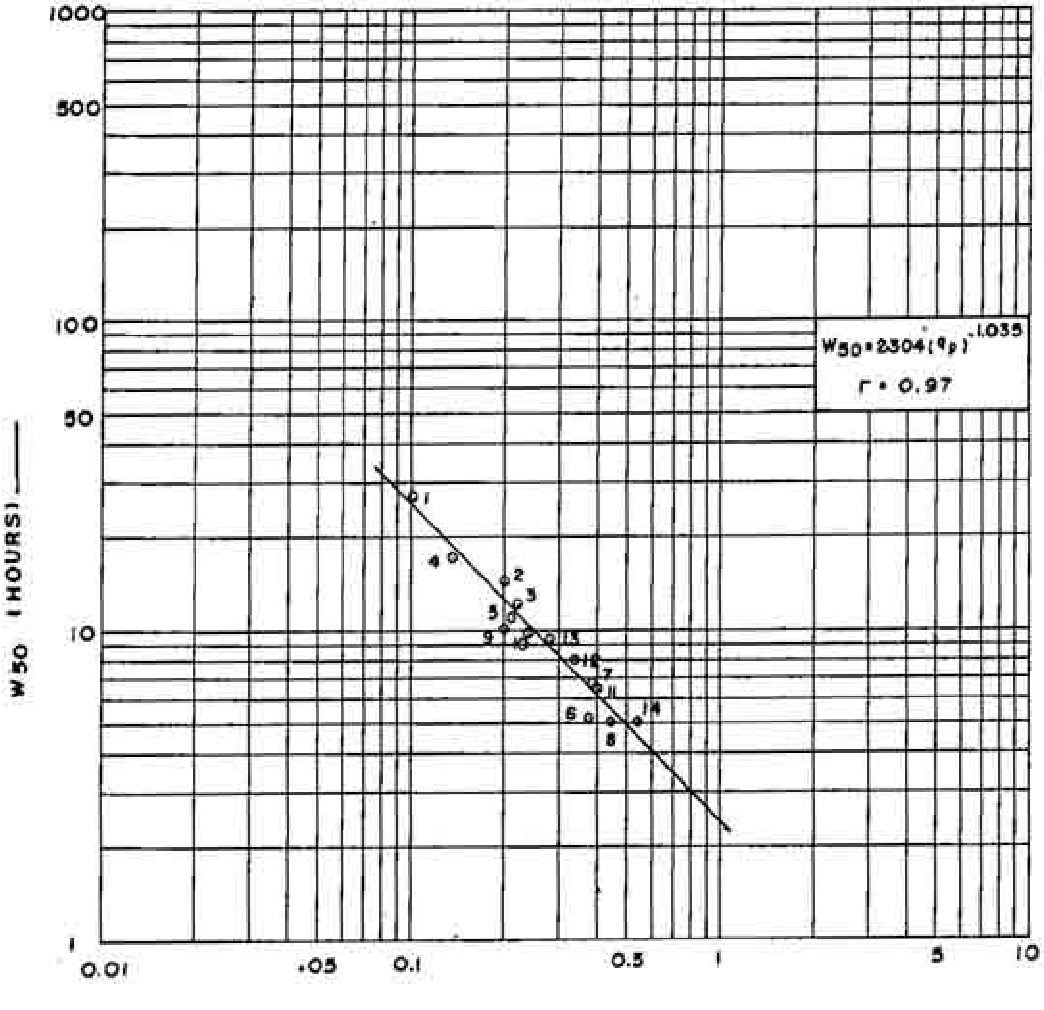
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

SOUTH BRAHMAPUTRA BASIN
SUB ZONE - 2(b)
RELATION BETWEEN
q_p AND t_p

DRAWN BY — L. P. NAUTIYAL | CHECKED BY — K. K. AICH.

FIG. – 5.

SCALE – LOG X LOG



F.-8.

Sl. No	Bridge No.	q_p (Cum/Km²)	W_{50} (Hours)
1	4-MOT	0.10	26.75
2	463	0.20	14.30
3	414	0.22	11.95
4	6.MOT	0.14	17.00
5	160	0.21	10.90
6	8	0.37	5.20
7	146	0.39	6.55
8	184	0.44	5.00
9	215	0.20	10.00
10	446	0.24	9.80
11	130	0.40	6.35
12	440	0.34	8.05
13	70	0.28	9.20
14	3-MOT	0.47	5.00

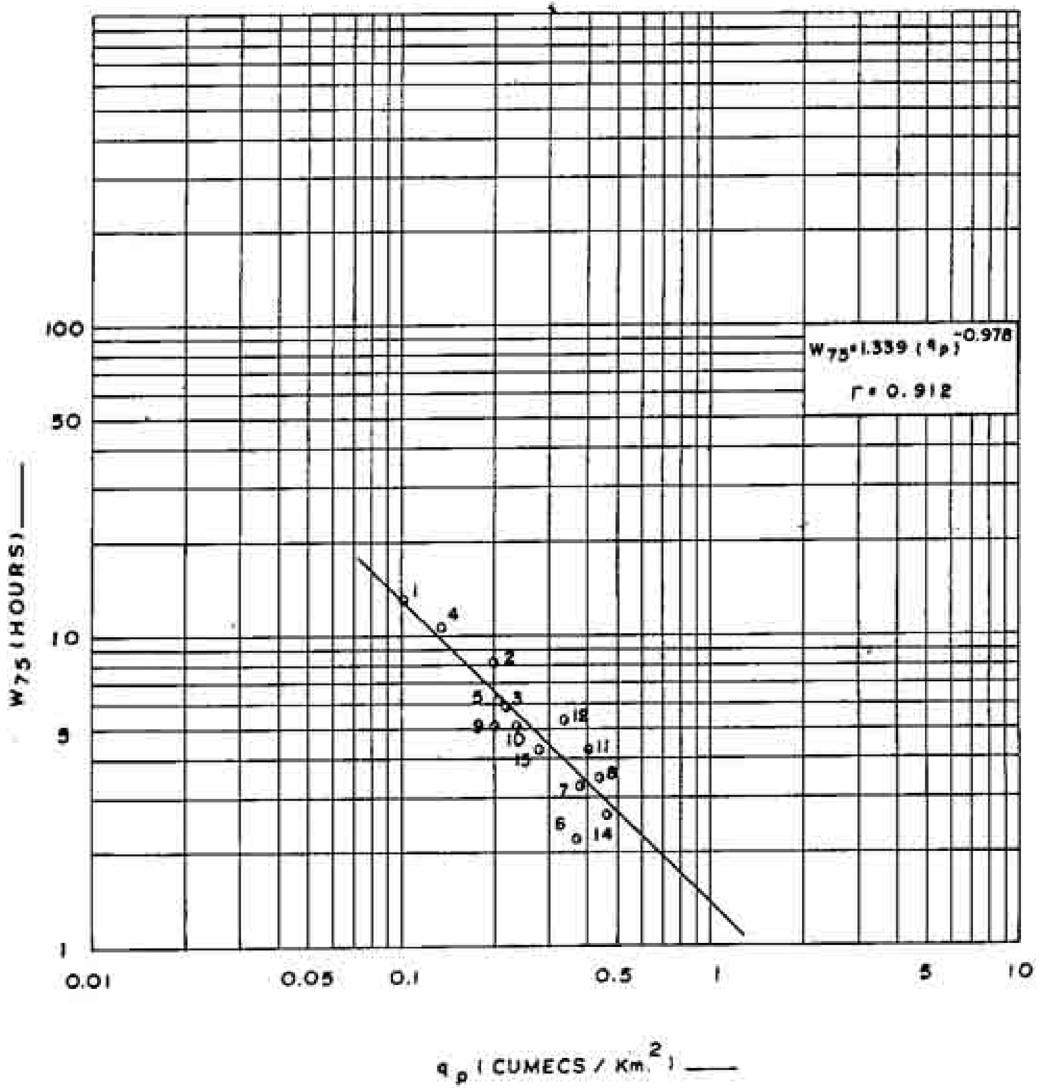
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

SOUTH BRAHMAPUTRA BASIN
SUB ZONE – 2 (b)
RELATION BETWEEN
q_p AND W_{50}

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

FIG. – 6.

SCALE – LOG X LOG



F-9.

Sl. No.	BRIDGE NO.	q_p Cum./Km.^{2}	W_{75} HOURS
1	4.MOT	0.10	13.00
2	483	0.20	8.10
3	414	0.22	5.85
4	6.MOT	0.14	10.50
5	160	0.21	6.00
6	8	0.37	2.20
7	146	0.39	3.20
8	184	0.44	3.45
9	215	0.20	5.00
10	446	0.24	5.00
11	130	0.40	4.20
12	440	0.34	5.25
13	70	0.28	4.20
14	3.MOT	0.47	2.65

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

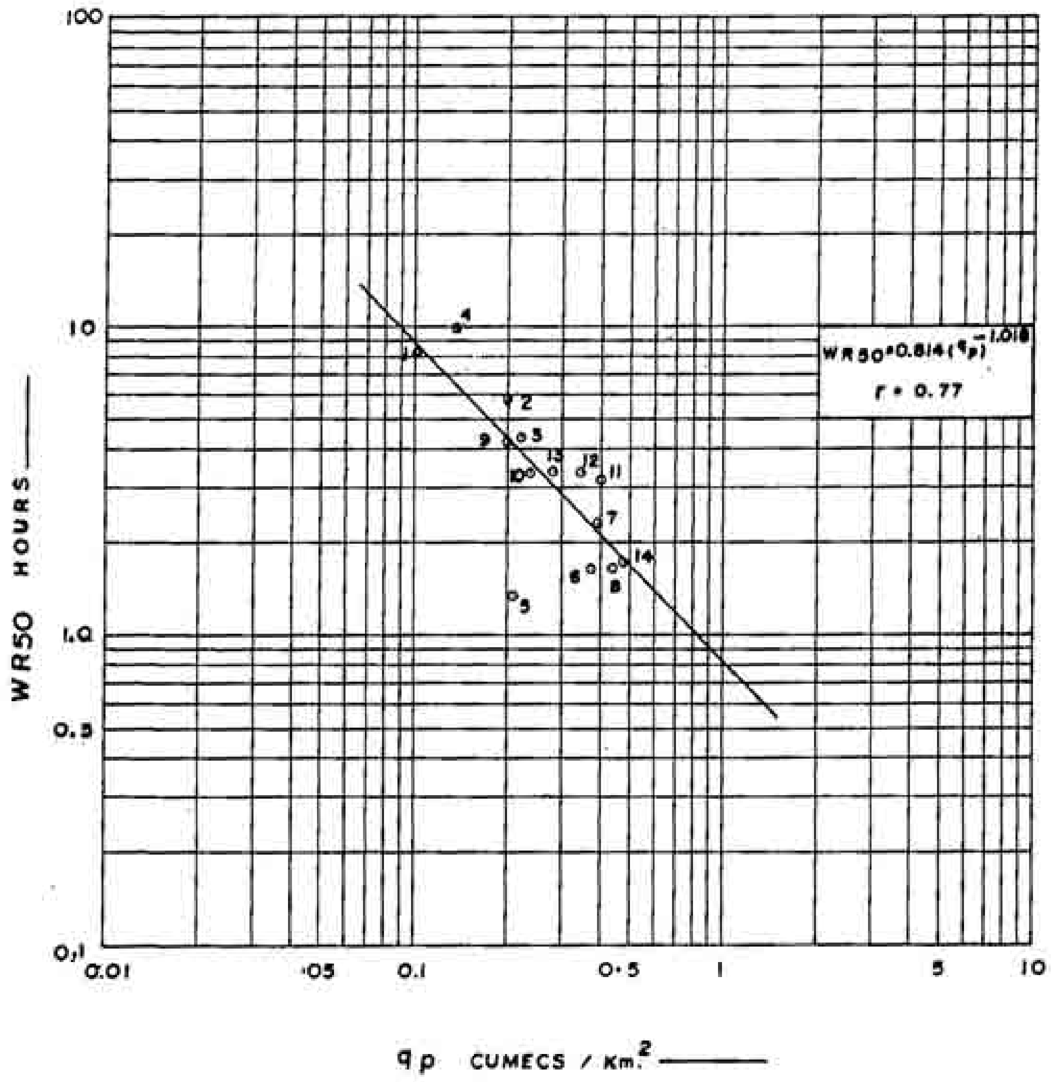
SOUTH BRAHMAPUTRA BASIN
SUB ZONE – 2(b)
RELATION BETWEEN
q_p AND W_{75}

DRAWN BY— L. K. PANT.

CHECKED BY— K. K. AICH.

FIG.-7.

SCALE - LOG X LOG



F-10.

Sl. No.	BRIDGE NO.	qp Cum./Km.^{2}	W_{R50} HOURS
1	4-MOT	0.10	8.00
2	463	0.20	5.75
3	414	0.22	4.30
4	6-MOT	0.14	9.75
5	160	0.21	1.30
6	8	0.37	1.60
7	146	0.39	2.25
8	184	0.44	1.60
9	215	0.20	4.20
10	446	0.24	3.25
11	130	0.40	3.20
12	440	0.34	3.30
13	70	0.28	3.30
14	3-MOT	0.47	1.70

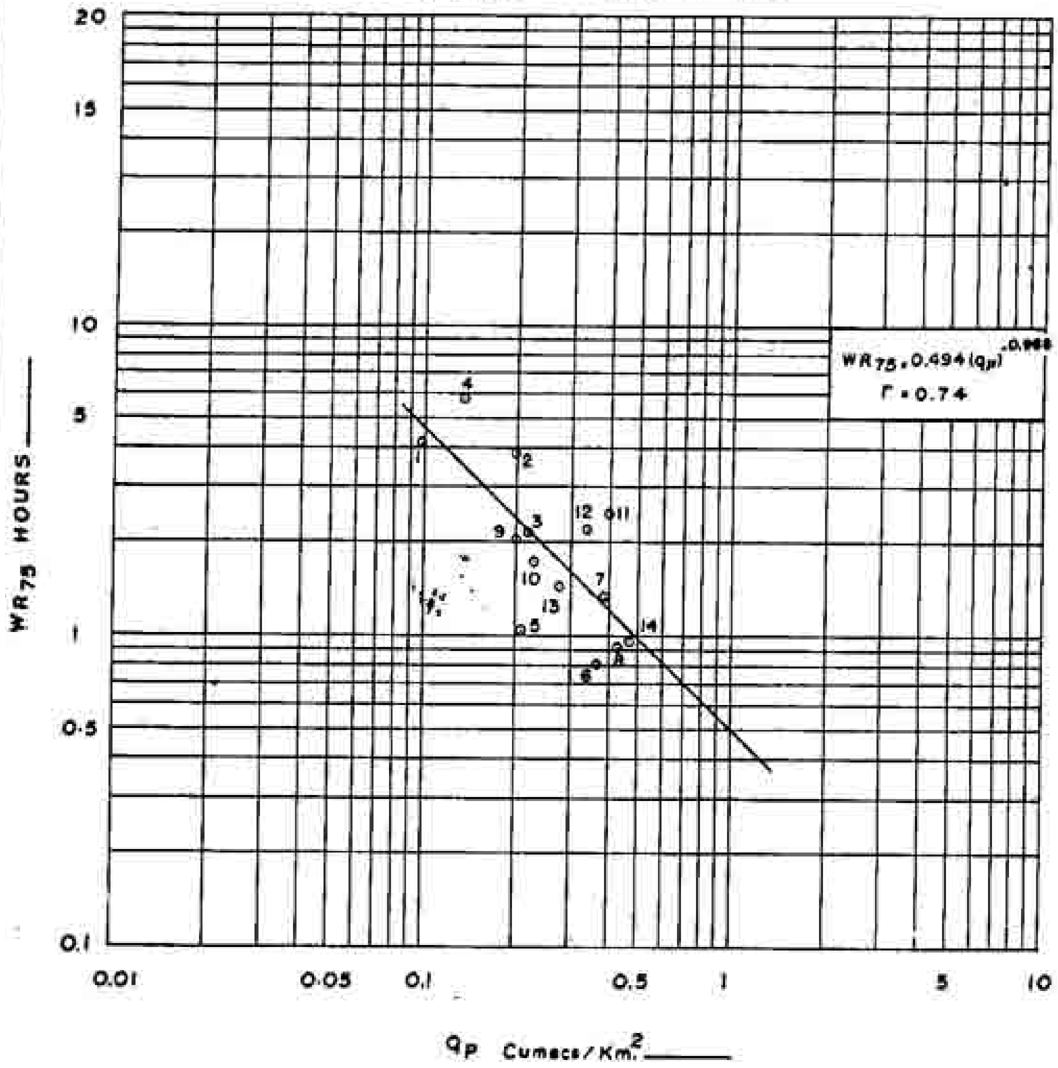
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

SOUTH BRAHMAPUTRA BASIN
SUB ZONE - 2 (b)
RELATION BETWEEN
qp AND WR50

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

FIG. - 8.

SCALE - LOG X LOG



Sl. No.	BRIDGE NO.	qp Cum./Km²	WR75 (HOURS)
1	4 MOT	0.10	4.25
2	463	0.20	3.80
3	414	0.22	2.10
4	6 MOT	0.14	5.75
5	160	0.21	1.00
6	8	0.37	0.80
7	146	0.39	1.30
8	184	0.44	0.90
9	215	0.20	2.00
10	446	0.24	1.70
11	130	0.40	2.40
12	440	0.34	2.15
13	70	0.28	1.40
14	3 MOT	0.47	0.95

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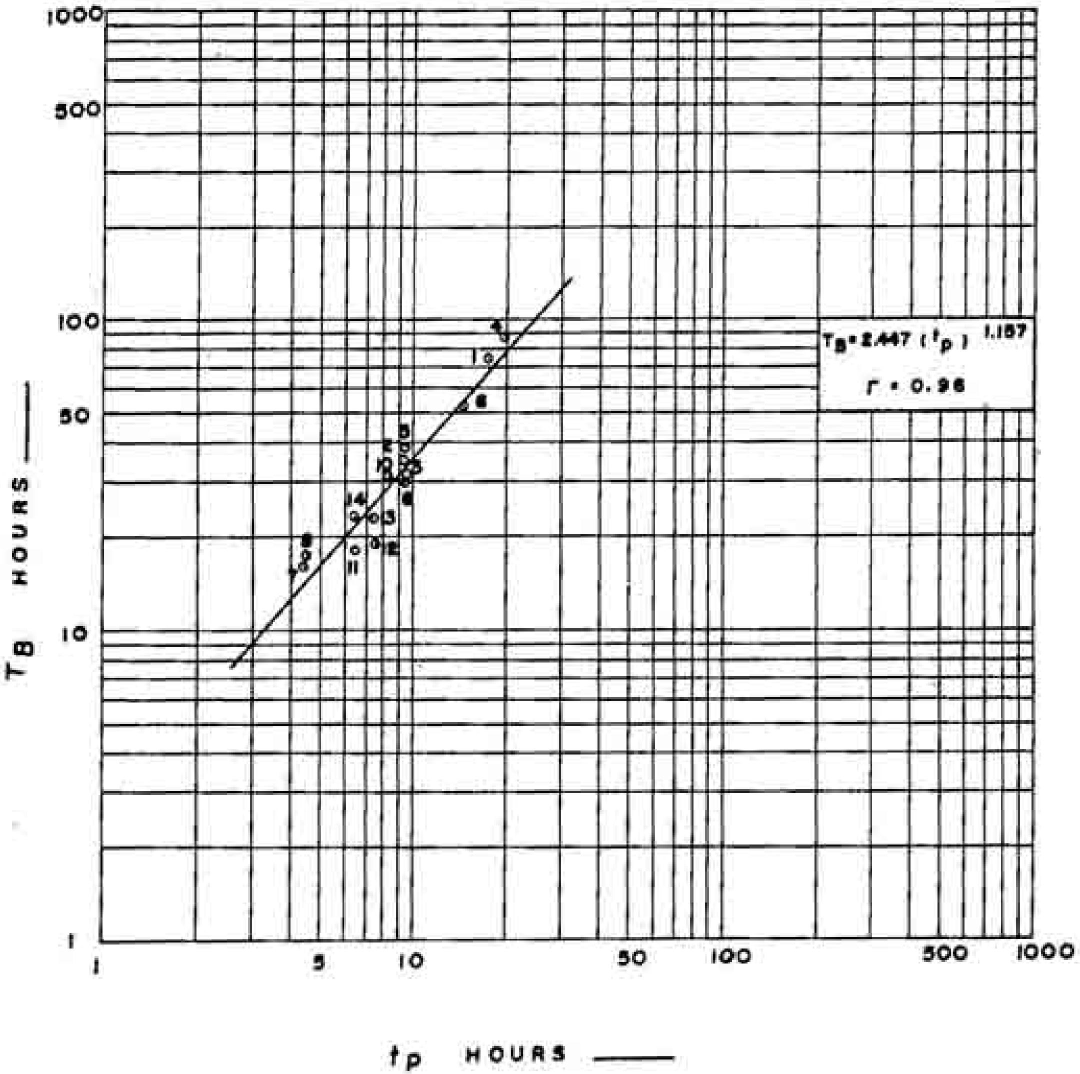
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

SOUTH BRAHMAPUTRA BASIN
SUB ZONE - 2(b)
RELATION BETWEEN
q_p AND WR_{75}

DRAWN BY -	CHECKED BY -
LALIT KUMAR	K. K. AICH

FIG. – 9.

SCALE – LOG X LOG



F-12.

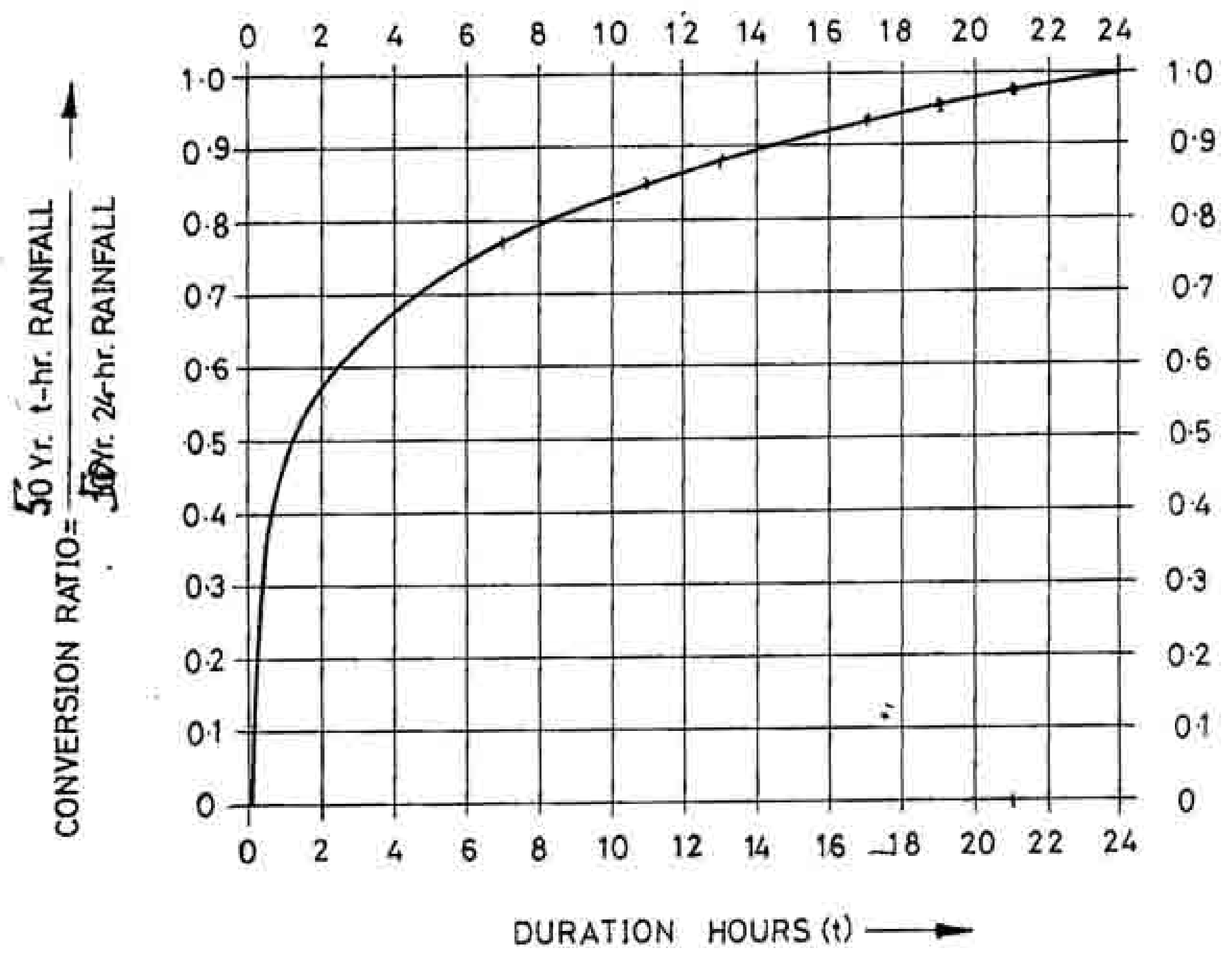
Sl. NO.	BRIDGE NO.	t_p (HOURS)	T_B (HOURS)
1	4-MOT	17.50	73.00
2	463	9.50	34.00
3	414	9.50	31.00
4	5-MOT	19.50	88.80
5	160	9.50	38.00
6	6	9.50	30.00
7	146	4.50	16.00
8	184	4.50	17.00
9	215	14.50	53.00
10	446	8.50	30.00
11	130	6.50	18.00
12	440	7.50	19.00
13	70	7.50	23.00
14	3-MOT	6.50	23.00

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

SOUTH BRAHMAPUTRA BASIN
SUB ZONE – 2 (b)
RELATION BETWEEN
t_p AND TB

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

FIG.- 10.



F- 13.

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

DURATION (hrs.)	RATIO
1	0·48
3	0·62
6	0·74
9	0·81
12	0·87
15	0·91
18	0·95
24	1·00

NOTE- CURVE SUPPLIED BY I.M.D

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
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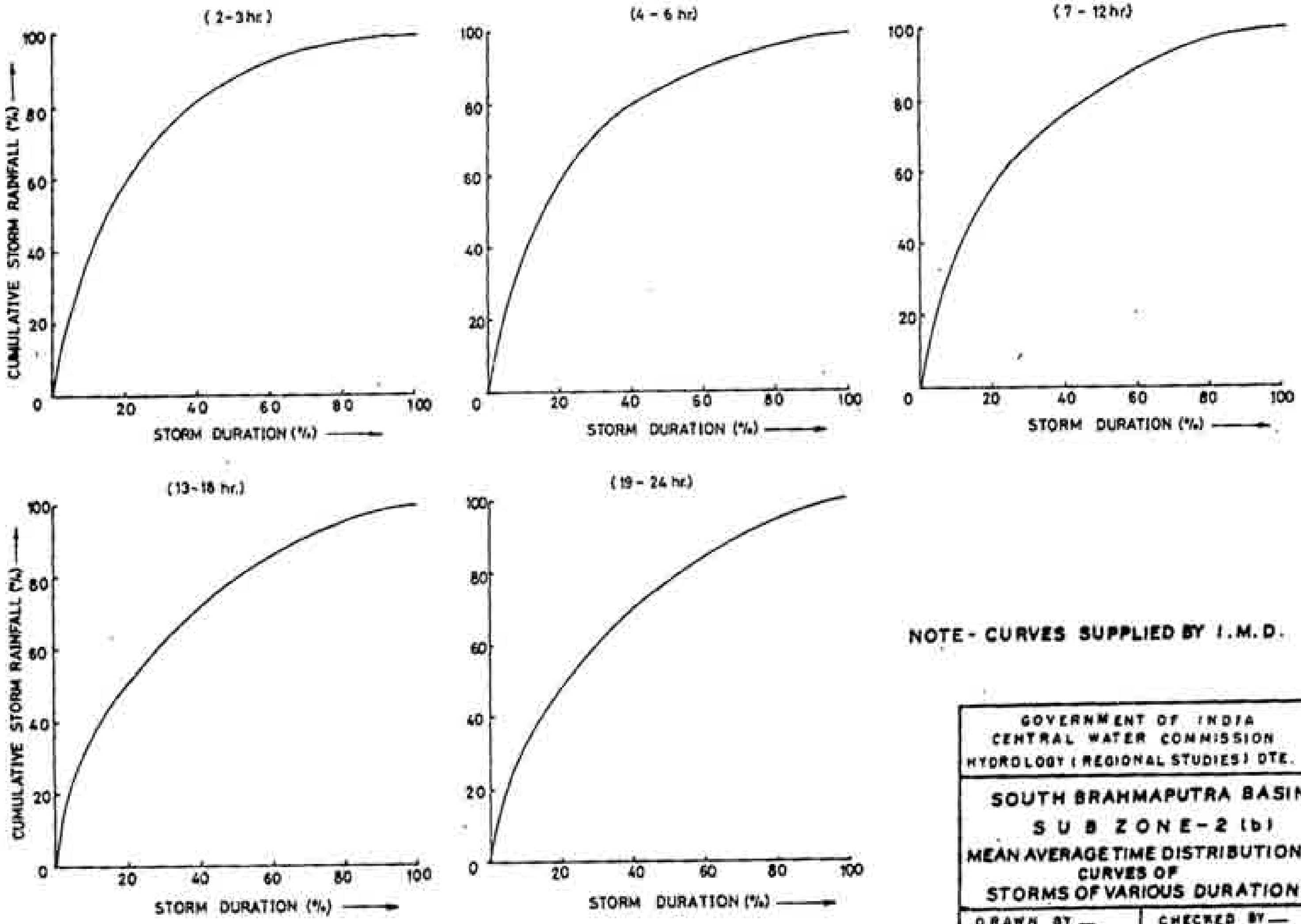
SOUTH BRAHMAPUTRA BASIN
SUB ZONE - 2 (b)
DURATION Vs CONVERSION RATIO

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

SUB ZONE 2 (b)

FIG. – 11.



NOTE - CURVES SUPPLIED BY I.M.D.

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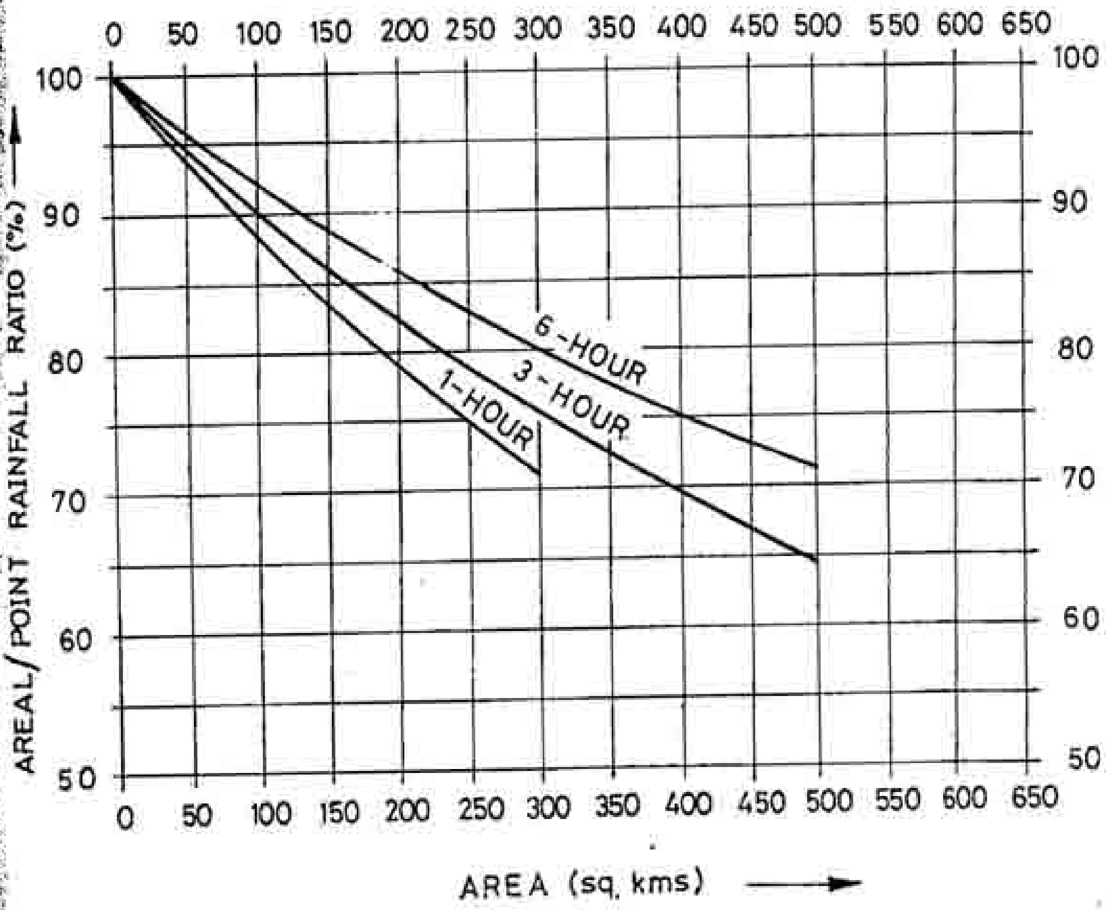
SOUTH BRAHMAPUTRA BASIN
SUB ZONE-2 (b)
MEAN AVERAGE TIME DISTRIBUTION CURVES OF STORMS OF VARIOUS DURATIONS

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

F-14.

FIG. - 12 (a)



NOTE - CURVES SUPPLIED BY I.M.D

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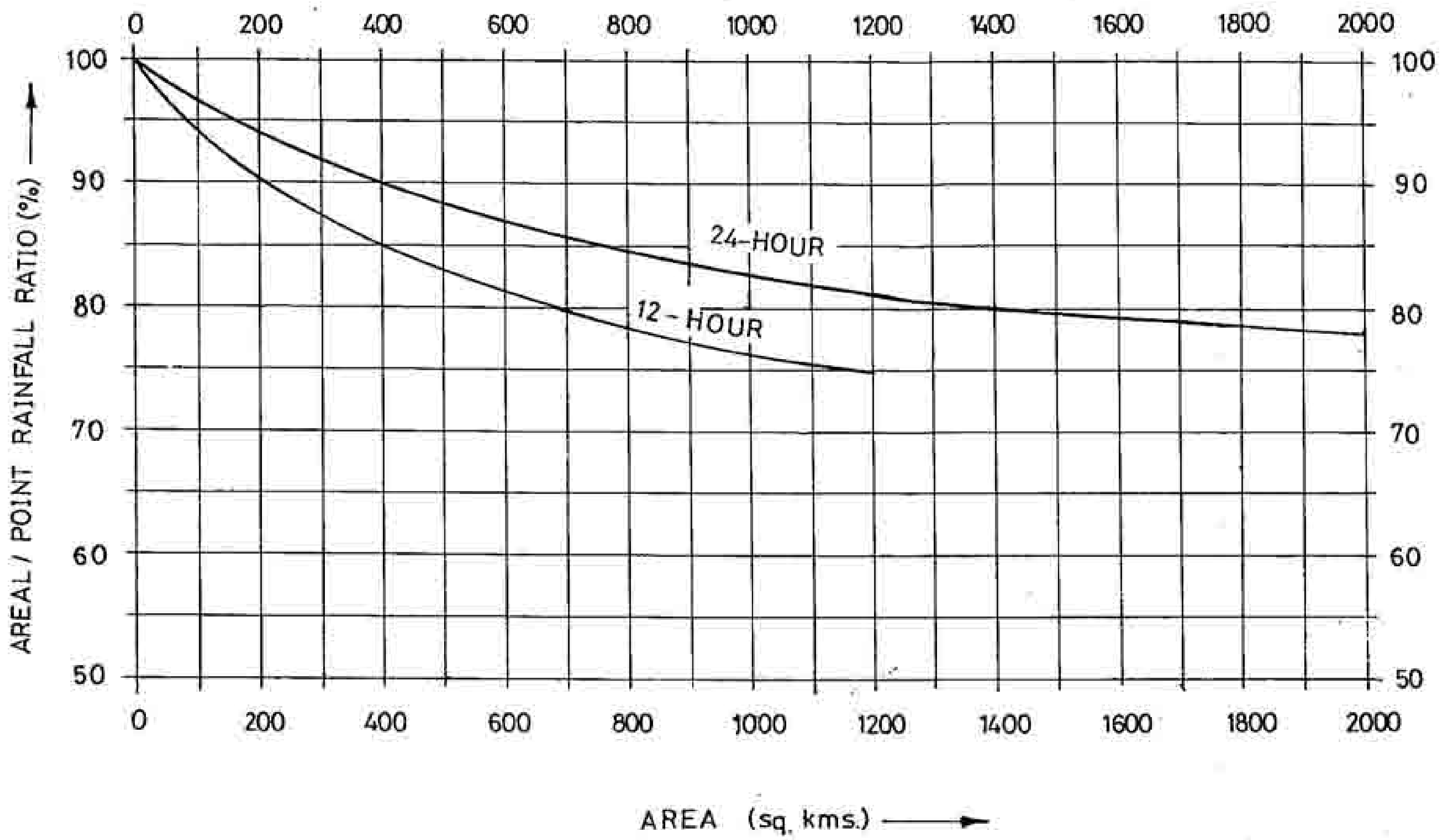
SOUTH BRAHMAPUTRA BASIN
SUB ZONE - 2 (b)
AREAL TO POINT RAINFALL RATIO
FOR 1-Hr. 3-Hrs. 6-Hrs (%)

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

FIG.- 12 (b)



NOTE - CURVE SUPPLIED BY I. M. D.

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CENTRAL WATER COMMISSION
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SOUTH BRAHMAPUTRA BASIN
SUB ZONE - 2 (b)
AREAL TO POINT RAINFALL RATIO
FOR 12-Hrs. & 24-Hrs. (%)

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

ERRATA SLIP

Page No.	Item No.	Line No.	Read	Read as
6	2.4.2	-		omit paragraph, "The variation .... Guwahati and Dibrugarh"
	2.4.2.1	6	-	omit "and some parts of Tripura" from this line.
27	-	Last line	$W_{R75} = 0.494$	$W_{R75} = \frac{0.494}{(q_p)^{0.966}}$
29	-	9	0.36cm/hr	0.35cm/hr
29	Table 5.2	5, col.6	0.98 cm	0.65 cm
31		1	Table 5.2	Table 5.3
31		8	Col. 14	Col.13
31		9	Col. 14	Col.13
A-4	Annexure 3.1	Location Longitutude (S.No.25)	26° 01' 50"	91° 26' 25"
A-13	4.1	Station No.11	Kampur	Kamrup
A-14	4.2	Station No.1	14 - 5th Sept. '60	14-15th Sept.'60
A-15	4.2	Station No.3	03-04th Aug. '70	03rd Aug.'70
A-16	4.3	last but one line	79.50	79.00

NAMES OF THE OFFICIALS ASSOCIATED

A) Research Designs and Standards Organisation (Guidance and Supervision of data Collection)

1.	Shri B.M. Gupta	Director (B & S)
2.	Shri A.K.D. Chowdhary	Chief Design Assistant
3.	Shri A.K. Roy	Chief Design Assistant
4.	Shri Samay Singh	Inspector of Works

B) India Meteorological Department (Storm Studies)

1.	Dr. (Smt.) Surinder Kaur	Director
2.	Shri V.A. Rustogi	Meteorologist Gr.-I
3.	Smt. H.P. Dutta	Asstt. Meteorologist Gr-I
4.	Shri P.K. Sharma	Asstt. Meteorologist Gr-II
5.	Shri Greesh Kumar	Scientific Assistant
6.	Shri P.K. Panchal	Senior Observer
7.	Smt. Indu	Senior Observer
8.	Shri Raju Bhargava	D'man

C) Central Water Commission (Hydrological Studies and Preparation of Report)

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2.	Shri Vinod Kaul	Deputy Director
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4.	Shri K.K. Aich	Estra Asstt. Director
5.	Shri A.P. Khanna	Extra Asstt. Director
6.	Shri L.P. Nautiyal	D/man Gr-II
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9.	Smt. Raj Kumari	Sr. Computor
10.	Smt. Sudesh Sharma	Jr.Computor
11.	Shri V.K. Banga	P.A.
12.	Smt. Shashi Gupta	Stenographer

LIST OF FLOOD ESTIMATION REPORTS PUBLISHED

A. UNDER SHORT TERM PLAN

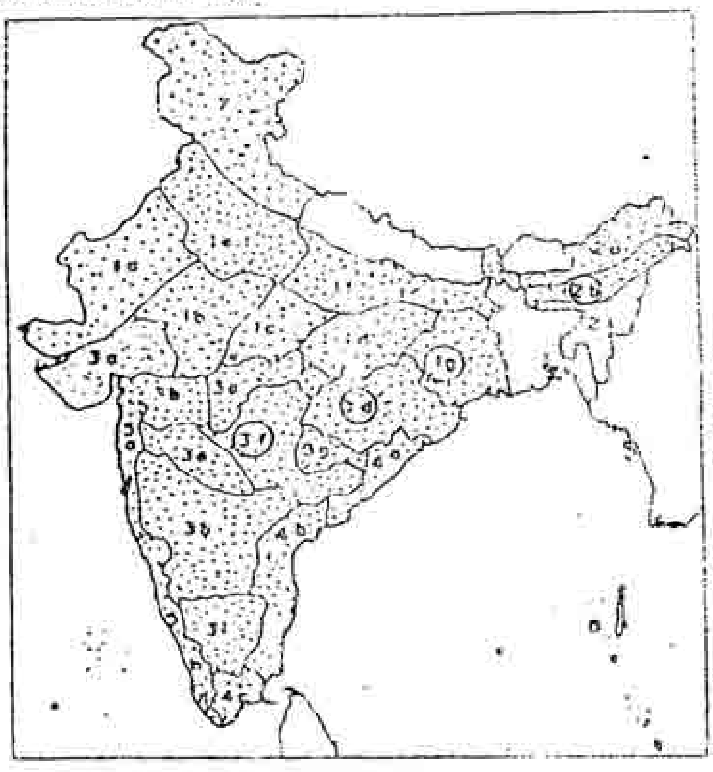
1.	Estimation of Design Flood peak	(1973)

B. UNDER LONG TERM PLAN

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

C. REVISED UNDER LONG TERM PLAN

1.	Lower Ganga Plains subzone - 1(g)	(1994)
2.	Lower Godavari subzone - 3 (f)	(1995)
3.	Mahanadi subzone - 3(d)	(1997)



STUDIES COMPLETED . . . . .

STUDIES REVISED . . . . .

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