अभिकल्प कार्यालय विवरण
DESIGN OFFICE REPORT
नं.:केपी-3(एच)/आर-5/45/2000
NO. KP-3(h)/R-5/45/2000

केन्द्रीय जल आयोग
CENTRAL WATER COMMISSION

कृष्णा एवं पेन्नार (उप अँचल - 3 एच)
का बाढ़ ऑकलन विवरण
(परिशोधित)
FLOOD ESTIMATION REPORT FOR KRISHNA AND PENNAR SUBZONE - 3(h)
(REVISED)

जल विज्ञान निदेशालय
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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
AND MINISTRY OF TRANSPORT

सितम्बर 2000
September, 2000

Draft of Revised Flood Estimation Report for Krishna & Pennar Subzone 3(h) was discussed in the 55[th] Meeting of FEPCC held on 13.3.2000 at Central Water Commission, New Delhi. The final report after incorporating the comments received is approved by the following Members.

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सितम्बर 2000
September, 2000

डा० बिपिन किशोर मित्तल
DR. B.K. MITTAL

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Dated, the ....

MESSAGE

The starting point for any activity related to any Water Resources Project is the study of its hydrology. The success of a project lies in the safe and economic design of hydraulic structures. The vagaries of the nature render it very difficult to estimate the magnitude and proneness of flood at any site and more so at ungauged sites. The reliable estimation of hydrological parameters depends on the vastness and quality of the past hydrometeorological data available at and around the project site.

The economic and time constraints do not justify the collection of hydrometeorological data at all locations in small and medium catchments. For an ungauged catchment, no scientific procedures are available for the estimation of flood of desired frequency. The empirical formulae such as Inglis, Ryves, Dickens have the inherited limitations that these estimate only the peak flood and that the risk associated with this estimated flood is not known in terms of its return period.

Central Water Commission in association with Ministry of Railways, India Meteorological Department and Ministry of Transport has developed the methodology for estimation of25-yr, 50-yr and 100-yr return period floods for small and medium catchments on regional basis and brought out in the form of subzonal reports in a planned manner.

The present report is the revision of the flood estimation report for Krishna & Pennar Subzone 3 (h) which was published in 1983. The technology developed has been transferred to Water Resources Departments of many states by organizing workshops at their locations by Central Water Commission.

I would like to place on record my appreciation for good work done by the officers of these four organizations in bringing out this report.

(B.K. MITTAL)

FOREWORD

In the past, the estimation of flood for various return periods for design of waterways and foundations of Railways and Road bridges, culverts, cross drainage works, spillways of minor tanks having small and medium catchments have generally been based on empirical formulae. These formulae were evolved with a small data base for a particular region as available at various points of time. The estimation is extremely difficult where the hydrological data are inadequate or totally absent. There was, therefore, a need for evolving the design flood of small and medium ungauged catchment.

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

In addition to the above, there is also periodic revision of such subzonal reports, whenever additional data sets become available and sophisticated analysis becomes due. The flood estimation reports of Lower Ganga Plain Subzone 1 (g), Lower Godavari Subzone 3 (f), Mahanadi Subzone 3 (d) and South Brahmaputra Subzone 2 (b) published in 1978, 1981, 1982 and 1984 respectively have already been revised and published. The present report is the revision of flood estimation report of Krishna and Pennar Subzone 3(h) published in the year 1983. It gives the method to compute design flood of 25, 50 and 100 year return period for ungauged catchment located in Krishna and Pennar Subzone 3 (h).

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

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

New Delhi, September, 2000

(V.V. BADAREENARAYANA)
CHIEF ENGINEER (HSO)
Central Water Commission

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 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 since 1979.

Hydrology (Regional Studies) Directorate, Central Water Commission (CWC) carried out analysis of collected concurrent rainfall and flow data for the gauged catchments to derive unit hydrographs of mostly one-hour duration. Representative unit hydrographs are prepared for each of the gauged catchments from the selected flood events. The characteristics of the catchments and the unit hydrographs, prepared for several catchments in a subzone are correlated by regression analysis and the equations for synthetic unit hydrograph for the subzone are derived for estimating design flood for ungauged catchments. The response functions on correlation 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 Subzones have been published :

1. Lower Ganga Plains Subzone 1 (g) (1978)
2. Lower Godavari Subzone 3 (f) (1981)
3. Lower Narmada and Tapi Subzone 3 (b) (1982)
4. Mahanadi Subzone 3(d) (1982)
5. Upper Narmada & Tapi Subzone 3 (c) (1983)
6. Krishna & Pennar Subzone 3 (h) (1983)

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

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

(i) Isopluvial maps for 24 hour and/or shorter duration corresponding to 50 year return period only

(ii) Time distribution of storm rainfall and

(iii) Point to areal rainfall ratios.

However, in the subsequent reports, IMD modified the methodology and prepared the hydrometeorological inputs based on conjunctive use of ordinary raingauges (ORG) and SRRG data. It was accordingly, recommended and desired by the FEPCC to revise the FERs at serial No. 1 to 7, so that all the reports are uniform so far as methodology is concerned. It was further decided while updating the meteorologoical component of 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 and South Bramhaputra subzone 2(b) published in 1984 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 Krishna and Pennar Subzone 3 (h) and deals with the estimation of flood of 25 year, 50 year and 100 year return period for small and medium catchment in the Subzone. The Subzone covers about 95% area of Krishna river basin and 65% of the area of Pennar basins covering part of the States of Maharashtra, Karnataka and Andhra Pradesh.

The flood estimation report of Subzone 3 (h) was prepared and published in 1983. The rainfall-runoff data of 29 catchments having catchment area between 25 Sq.km.to1700 Sq.km. for a period of 5 to 10 years during the period from 1958 to 1979 have been collected from Railways. Out of 178 bridge years data available for 29 catchments, 134 bridge years data of 21 catchments was found suitable and was utilised for the study carried out earlier. In the present study additional data of 36 bridge years for 3 catchments was collected subsequent to the preparation of earlier report. Thus, a total of 170 bridge year data has been used for unit hydrograph study.

IMD while updating the storm studies used the rainfall data of 456 O.R.G. stations (292 inside the subzone and 164 around the subzone) and 24 Self Recording Raingauge (S.R.R.G.) stations in the study.

The report covers six parts. Part-I of the report "Introduction" gives the summary of the earlier and revised studies. Physiographic, climatic and hydrometeorological features of the subzone have been explained in Part-II. Part-III brings out the Synthetic Unit Hydrograph (SUH) relations to be used for ungauged catchments in the Subzone.

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

The report on Subzone 3 (h) is recomn..nded for estimation of design flood for small and medium catchments varying in areas from 25 Sq.km. to 2000 Sq.km. This report may also be used for catchments having areas up to 5000 Sq.km. judiciously after comparing the neighbouring catchments having more or less similar characteristics.

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

(R.K. GUPTA)
DIRECTOR
Hydrology (RS) Dte
Central Water Commission

CONTENT

PLATES

FIGURES

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}, Q_{100}	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_{eq}	Equivalent stream slope (m/km)
S_1, S_2	Slope of Individual Channel Segment (m/km)
T_B	Base period of Unit Hydrograph in hours.
T_D	Design Storm Duration (hr)
T_m	Time from start of rise to the peak of unit hydrograph ($T_m = t_p + t_r/2$)
t_p	Time lag from centre of unit rainfall duration to the peak of Unit hydrograph in hours
t_r	Unit rainfall duration in hours
U.G.	Unit Hydrograph
W_c	Minimum width of catchment area through the centre of gravity of the catchment

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

ABBREVIATIONS

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

PART - I

INTRODUCTION

1.1 GENERAL

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

Krishna and Pennar Subzone 3 (h) is one of the 26 hydrometeorologically homogeneous subzones into which the country has been divided, for developing the regional methodology for assessing the design flood of small and medium catchments.

The flood estimation report of Krishna & Pennar Subzone 3(h), (Design Office Report No.K/6/1982) was published in 1983. The present report is revision of the earlier report. The earlier report contained the inputs for estimating the design flood of 50 year return period only where as the present report provides inputs for estimating design floods of 25, 50 and 100 years 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, India Meteorological Department (IMD) upgraded the methodology of storm study, for preparing the isopluvial maps using rainfall data of ORG and SRRG in and around the subzone in addition to the data within the subzone.

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

1.3 REVISED STUDY

Hydrological and Storm Studies as carried out in preparing the report of 1983 and the supplementary/additional studies carried out to revise that report is brought out in this revised report. The brief of these studies is as under.

1.3.1 Hydrological study

The hydrological study carried out earlier in 1982-83 was based on rainfall-runoff data of 21 Catchments observed for a period of 5 to 10 years during the period 1958-79. Representative Unit Hydrograph (RUG) of 1-hour duration was 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 1983 report, additional data in respect of three key gauging sites (bridge No. 601, 98 and 353) for a period of 36 bridge years from 1979-96 was made available by Research Design and Standards Organisation (RDSO). These data have now been utilised and integrated with the earlier studies.

Equivalent Slope has been considered as one of the physiographic parameters in the revised study in place of the Statistical Slope. Attempts have also been made to introduce additional parameters P (Perimeter) and Wc (Width of the Catchment at the Centroid). 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 durations.
(iv) Point to areal ratios for different duration.

In the present study, IMD has utilised the rainfall data for a large number of stations in and around the subzone for as long a period as possible. Ordinary Raingauge (ORG) data of 456 stations (292 inside the subzone and 164 around the subzone) and Self-Recording Raingauge (SRRG) data of 24 stations have been utilised. The storm studies carried out by IMD are given in Part-IV of the report.

1.4 PROCEDURE TO ESTIMATE DESIGN FLOOD

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

PART-II

GENERAL DESCRIPTION OF KRISHNA & PENNAR SUBZONE

2.1 LOCATION

The Krishna & Pennar Subzone 3 (h) lies between longitude 73°21' to 80°25' East and latitude 13°7' to 19°25' North. The subzone is bounded on the north by Upper Godavari Subzone 3 (e) and Lower Godavari Subzone 3 (f), on the South by Cauvery Basin 3 (i), on the east by Lower Eastern Coast 4 (b) and on the west by Konkan Coast 5 (a) and Malabar Coast 5 (b). The subzone comprises part of Maharashtra, Karnataka and Andhra Pradesh. Plate-1 shows location of Krishna & Pennar Subzone on map of India.

2.2 RIVER SYSTEM

Krishna & Pennar basins excluding their deltaic strip along the eastern coast cover the Krishna & Pennar Subzone. About 95% of the total areas of Krishna and 65% of Pennar basin are included in this subzone. The Krishna river is the largest east flowing river of peninsular India. It rises on the eastern side of Western ghat about 60 km. south of Pune at an altitude of 1337 metres. The Krishna flows for a length of about 1400-km through the states of Maharashtra, Karnataka and Andhra Pradesh to outfall into the Bay of Bengal. The right bank tributaries of Krishna are Koyna, Varna, Panchganga, Dudhganga, Ghataprapha, Malaprabha and Tungabhadra. The left bank tributaries of Krishna are Yarla, Bhima and Musi. Average bed slope of Krishna from its source to confluence with Bhima and from Bhima confluence to Tungabhadra confluence are 1.43 metres per km and 0.55 metre per km. respectively. The bed slope of Krishna from Tungabhadra confluence to its outfall is flat.

The Pennar rises in the Chenna Kesabir hill of Nandidurg range in Karnataka State. It flows for about 61 km in Karnataka and about 53 km in Andhra Pradesh before it outfalls into the Bay of Bengal.

The total drainage area of the subzone is 2,80,881 Sq.km. out of which catchment area of Krishna Basin is 2,45,026 Sq.km., which is about 87% of the total area. The drainage area of Krishna and its tributaries and Pennar basin is given in Table 2.1 as follows:

Table 2.1
(DRAINAGE AREA)

Sl.No.	Basin/Sub-basin	Drainage Area (Km^2)
1	Koyana - Right Bank Tributary	1,752
2	Varna- Right Bank Tributary	2,003
3	Panchganga – Right Bank Tributary	2,604
4	Dudhganga – Right Bank Tributary	2,554

Sl.No.	Basin/Sub-basin	Drainage Area (Km^2)
5	Ghataprabha – Right Bank Tributary	8,763
6	Malaprabha – Right Bank Tributary	11,818
7	Tungabhadra - Right Bank Tributary	73,113
8	Yarla - Left Bank Tributary	3,204
9	Bhima - Left Bank Tributary	70,108
10	Musi - Left Bank Tributary	11,017
11	Other Areas (Krishna)	58,090
12	Area of Krishna Basin in the subzone	2,45,026
13	Total Area of Krishna Basin	2,58,948
14	Area of Pennar Basin in subzone	35,855
15	Total Area of Pennar Basin	55,213
16	Total Area of Subzone	2,80,881

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

2.3 GENERAL TOPOGRAPHICAL FEATURES

2.3.1 Physiography

The basin is sloping towards East in general. The altitude varies from 600m along the North to 150 m along the East. Important cities and towns in the subzone are Pune, Sholapur, Satara, Bijapur, Raichur, Hyderbad, Nalgonda, Kurnool, Kolhapur, Belgaum, Bellary etc. The physiography of the subzone is shown at Plate- 3.

2.3.2 Soils

The subzone 3 (h) has a variety of soils as shown at Plate- 4. Two broad soil groups in the subzone are red soils and black soils. Areas from Pune to Sholapur and Bijapur are having black type of soil. There are small pockets of shallow black soil with very small pockets of mixed red and black soil and red loamy soil. The portion along northeastern side of the subzone consists of red soil. In addition, there are small pockets of laterite soil, skeletal soil and medium black soil. The soil group has further been classified as deep black, medium black, red, sandy and red loamy soil etc. At micro level, this broad classification has not been reflected properly.

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 only about 20% area of the subzone is under scrub and forest and the remaining is cultivable area. The main crops in the subzone are paddy, cotton, groundnuts, sugarcane, wheat millets and pulses. There are large number of minor and medium irrigation projects besides hydropower projects in the subzone. Tungabhadra, Nagarjunasagar and Srisailam are some of the main projects.

2.4 CLIMATOLOGICAL FEATURES.

2.4.1 Rainfall features

2.4.1.1 Annual normal rainfall

The isohyetal map of annual normal rainfall for the subzone 3(h) is shown in plate-6. The subzone receives about 75 to 80% of the annual rainfall from SW monsoon during the monsoon season from mid June to mid October. The amount of rainfall varies from 50 cm. in SouthEastern part of the subzone to more than 300 cm. in the western parts. The rainfall from the Central part of the subzone increases towards NE subzone and is of the order of 100 cm. The western boundary receives the heaviest rainfall, Mahabaleshwar in Maharashtra and Belgaum in Karnataka receives maximum rainfall during July in the South West monsoon season.

2.4.1.2 Monthly rainfall distribution

Monthly rainfall distribution at six representative stations, viz, Belgaum, Gulbarga, Jamalamadugu. Nalgonda, Mahabaleshwar and Pavagada is illustrated through bar charts appended to the annual normal rainfall maps (Plate-6). In the bar charts, alphabets along abscissa indicate names of months whereas heights of rectangles are proportional to normal rainfall of respective months.

It can be seen from the bar charts that the period June to October constitutes the main rainy season over the subzone. The months of April & May are also the months of good rainfall activity. The rainfall in the months of July & August is considerable at Belgaum & Mahabaleshwar and constitute 54% and 69% of the annual rainfall respectively. Normal rainfall for the five months (June to October) at Belgaum, Gulbarga, Jamalamadugu, Nalgonda, Mahabaleshwar and Pavagada is 86%, 85%, 77%, 85%, 98% & 70% respectively of the annual rainfall. It shows that these stations receive 70% to 98% of the annual rainfall during these five months.

2.4.2 TEMPERATURE DISTRIBUTION

2.4.2.1 Mean daily temperature (annual)

Mean daily temperature distribution over the subzone is shown in plate-7. The Mean daily temperature are worked out as average of mean maximum and mean minimum temperature over the year. It may be seen from the map that mean daily temperature (annual) are lowest (< 24°C) over NW portion of the subzone. Extreme western part of Maharashtra and some parts of Karnataka have higher mean temperature (>25°C). It increases towards eastern side of the subzone. Area of highest mean daily temperature

(>28°C) runs along eastern side of the subzone. Khammam recorded the mean daily temperature 28.5°C.

2.4.2.2 Monthly Temperature variations at selected stations

Monthly variations of mean maximum, mean minimum and mean daily temperature for six representative stations viz., Anantpur, Kurnool, Khammam, Ahmednagar, Miraj and Sholapur are shown graphically in plate-7 below the map of mean daily temperature. It may be seen from these graphs that the highest maximum temperatures are observed in the months of April or May. At Khammam, Sholapur, Kurnool and Ahmednagar highest maximum temperature is observed in the month of May and in the month of April at Miraj and Anantpur. Minimum temperature is observed in the month of December for the five stations except at Miraj where it is observed in January. Mean daily temperatures are highest in the month of May at all the stations except Anantpur at which it is observed in the month of April. Mean daily temperatures are found lowest in the month of December at all the six stations.

2.5 COMMUNICATION

2.5.1 Railways

The important railway sections of Southern Railways, south central Railways and Central Railways exist in the subzone are given in Table 2.2 as follows:

Table 2.2
(Railway Section)

Sl.No.	Railway – Section	Railway
1	Bellary-Rayadurg	South-Central Railway
2	Wadi-Secunderabad	South-Central Railway
3	Gadag-Hospet	South-Central Railway
4	Hospet-Guntakal	South-Central Railway
5	Bangalore-Dharmavaram	Southern Railway
6	Renigunta-Guntakal	Southern Railway
7	Pune-Miraj	South-Central Railway
8	Kazipet-Vijayawada	Central Railway
9	Hubli-Arsikere	Southern Railway
10	Birur-Talaguppa	Southern Railway
11	Kurduwadi-Miraj	South-Central Railway
12	Hubli-Guntakal	South-Central Railway
13	Pune-Wadi	Central Railway
14	Londa-Miraj	South-Central Railway
15	Guntakal-Vijayawada	South-Central Railway
16	Gadak-Sholapur	South-Central Railway
17	Dhond-Raichur	Central Railway
18	Dhond-Ahmednagar	Central Railway
19	Pune-Raichur	Central Railway
20	Secunderabad-Kazipet	Central Railway
21	Dharamavaram-Guntakal	South-Central Railway

2.5.2 Roads

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

Table 2.3
(National Highway)

Sl.No.	Highway	Section
1	NH-4	Pune-Bangalore
2	NH-4A	Belgaum-Panaji
3	NH-7	Nizamabad-Bangalore
4	NH-9	Pune-Vijayawada
5	NH-13	Sholapur-Chitradurga
6	NH-50	Pune-Nasik

PART III

SYNTHETIC UNIT HYDROGRAPH STUDIES

3.1 SYNTHETIC UNIT HYDROGRAPH (SUG)

SUG is a unit hydrograph of unit duration for a catchment developed from relations established between physiographic and unit hydrograph parameters of the representative gauged catchments in 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 carrying out the unit hydrograph studies for development of equations for derivation of Synthetic UG parameters following concurrent rainfall and runoff data for a number of catchments of small and medium size representatively located in a Subzone are required for a period of 5 to 8 years during the monsoon season.

i) Hourly gauge data at the gauging site (bridge site).
ii) Gauge and discharge data observed preferably 2 to 3 times a day at the gauging site. In the absence of this, even daily discharge data at these stations can be used.
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

South-Central Railways, Central Railways and Southern Railways under the overall guidance and supervision of Research Design and Standards Organisation, Lucknow had collected rainfall, gauge and discharge data of 29 bridge catchments for a period of 2 to 12 years during 1958-1979. Data of 21 bridge catchments for 134 bridge years found suitable were utilised in the study carried out during 1983. Additional data for 36 bridge years for 3 bridge sites shown in Table 3.1 was collected subsequent to the preparation of the report. Thus, a total of 170 bridge year data has been used for developing co-relation between unit hydrograph and physiographic parameters for developing of Synthetic Unit Hydrograph (SUG).

Table 3.1
(Additional data for 3 bridge sites)

Sl.No.	Site	Additional Data	Bridge Years
1	601	1980-96	17
2	98	1980-81	2
3	353	1979-95	17
		Total	36 Years

Annexure 3.1 shows the name of the stream, railway bridge number, Railway section, and catchment area, No. of rain gauge stations and period of availability of rainfall runoff data of 29 bridge catchments having catchment areas more than 25 Sq.km. This also includes additional data of 3 catchments, collected subsequent to the preparation of the report. It can be seen from Annexure 3.1 that the catchment area of gauge sites lie between 29 to 2382 Sq.km.

3.4 DERIVATION OF SYNTHETIC UNIT HYDROGRAPH

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

3.4.1 Physiographic parameters.

The physiographic parameters considered in the present study are catchment area (A), length of main stream (L), length of 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 replaced with 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):

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

Where,

L_i = Length of the ith segments in km.

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

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

Physiographic parameters A, L, Lc and S are obtained for 21 catchments used for analysis and are shown in Annexure 3.2.

3.4.2 UNIT HYDROGRAPH PARAMETERS

3.4.2.1 Scrutiny of data and finalisation of gauge discharge rating curve

Out of the 29 gauged catchments, data of 21 catchments (134 bridge years) was found suitable for the unit hydrograph study contained in the earlier report. The additional data of 3-catchment viz. 601, 98 and 353 (36-bridge years) was scrutinized through arithmetical checks and gauge and discharge rating curve(s) were developed. The hourly discharges for the duration of the selected floods were obtained from the rating curves.

3.4.2.2 Selection of floods and corresponding storm events

In the previous study 157 flood events of 21 catchments were found suitable for U.G. studies. The general guidelines followed for selecting a flood event are given below.

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

28 Flood events shown in Table 3.2 were found suitable from the additional data collected at 3 bridge catchments. The catchments considered in the present study are the same catchments that were found suitable in the previous study.

Table 3.2
(Selected flood events)

SL.NO.	SITE	EVENTS		TOTAL EVENTS
		Utilised Earlier	Additional Events	
1	601	7	26	33
2	98	4	2	6
3	353	3	No suitable flood	3

3.4.2.3 Computation of hourly catchment rainfall

The 3-catchment viz.; 601, 98 and 353 for which additional data was received the raingauge network remains the same and the station weights computed earlier were used.

3.4.2.4 Separation of base flow

The selected flood events of 3 Bridge catchments were plotted on the 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) was estimated for selected flood events of 3 Bridge catchments viz. 601, 98 and 353.

3.4.2.6 Derivation of 1-hour unit hydrograph

The studies to derive 1-hour unit hydrograph were confined to only those flood events found suitable from the additional data of 3 bridge catchments. The 1-hour unitgraph 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 3 catchments were derived utilising UGs obtained from the additional data and unit hydrograph derived earlier. Integrated RUGs of 3 sites have been tested on observed floods. RUGs of remaining 18 sites developed earlier were utilised as such without any modifications. Following parameters of RUGs as indicated in Figure-2 for 21 catchments were obtained and are furnished at Annexure 3.3.

(a) Time from the centre of unit excess rainfall duration to the peak of unit hydrograph in hours (tp).
(b) Peak discharge of unit hydrograph in cubic meters per second (Q_p). This is the product of peak discharge per sq. km. (q_p) and catchment area (A).
(c) Base width of unit hydrograph in hours (T_B).
(d) Width of unit hydrograph measured at discharge ordinate equal to 50% of Q_p in hours (W_{50}).
(e) Width of unit hydrograph measured in hours at discharge ordinate equal to 75% of Qp (W_{75}).
(f) Width of the rising side of unit hydrograph measured in hours at discharge ordinates equal to 50% of Q_p (WR_{50}).
(g) Width of the rising side of unit hydrograph measured in hours at discharge ordinates equal to 75% of Qp (WR_{75}).
(h) Time from the start of rise to the peak of the unit hydrograph (T_m). This is the summation of t_p and 0.5*tr where tr is the unit duration of unit hydrograph.

3.4.3 Establishing relationships between physiographic and representative unitgraph parameters.

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

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

Where

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

Various relationships attempted are shown in Annexure 3.4. The relationship between $Llc/\sqrt{S}$ as some of the physiographic parameters and t_p as one of the U.G. parameter was developed and found to be significant. Similarly, q_p was related to time to peak discharge of the UG (t_p). UG parameters W_{50}, W_{75}, WR_{50}, WR_{75} were related to q_p. The UG parameter T_B is correlated to t_p. The principle of least square errors was used in the regression analysis to establish the relationship in the form of equation 3.4.3.1 to obtain the parameters of the Synthetic unitgraph in an unbiased manner.

The following relationships have been derived for estimating the 1-hr unitgraph parameters for an ungauged catchment in the Subzone 3 (h) as shown in Table 3.3 as follows:

Table 3.3
(Recommended SUG relations)

Sl. No.	Relationship		Equation No.
	Based on Report of 1983	Revised Relationship	
1	$t_p = 0.258 (LLc/\sqrt{s})^{0.49}$ $r = 0.90$	$t_p = 0.325 (LLc/\sqrt{s})^{0.447}$ $r = 0.750$	3.4.3.2
2	$q_p = 1.017 (t_p)^{-0.52}$ $r = 0.87$	$q_p = 0.996 (t_p)^{-0.497}$ $R = 0.733$	3.4.3.3
3	$W_{50} = 2.396 (q_p)^{-1.08}$ $r = 0.99$	$W_{50} = 2.389 (q_p)^{-1.065}$ $R = 0.973$	3.4.3.4
4	$W_{75} = 1.427 (q_p)^{-1.08}$ $r = 0.94$	$W_{75} = 1.415 (q_p)^{-1.067}$ $R = 0.861$	3.4.3.5
5	$W_{R50} = 0.750 (q_p)^{-1.25}$ $r = 0.78$	$W_{R50} = 0.753 (q_p)^{-1.229}$ $R = 0.597$	3.4.3.6
6	$W_{R75} = 0.557 (q_p)^{-1.12}$ $r = 0.73$	$W_{R75} = 0.558 (q_p)^{-1.088}$ $r = 0.510$	3.4.3.7
7	$T_B = 7.193 (t_p)^{0.53}$ $r = 0.93$	$T_B = 7.392 (t_p)^{0.524}$ $r = 0.860$	3.4.3.8
8	$T_m = t_p + t_r/2$	$T_m = t_p + t_r/2$	3.4.3.9
9	$Q_p = q_p \times A$	$Q_p = q_p \times A$	3.4.3.10

Relations developed are shown in Figures 3 to 9. Details of physiographic and unit hydrograph parameters used to establish relationships and their co-efficient of correlation is given in Annexure 3.4. The 25, 50 and 100 year flood peaks for 21 selected bridges have been computed using the new relations given in Table 3.3 and also from the RUGs of these bridges taking critical storm duration as $T_D = 1.1 * t_p$, as explained in para 5.2. Annexure 3.5 shows the comparison of flood peaks using SUGs and corresponding RUGs.

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

Sl. No.	Bridge No. 601 (C.A. - 398.60 Km²)				Bridge No. 98 (C.A. - 348.40 Km²)		
	As Per Earlier Report (1974-79)	Validation Data (1980-93)	Additional Data (1994-96)	Integrated Data	As Per Earlier Report (1978-79)	Additional Data (1980-81)	Integrated Data
Q_p	153.92	209.00	156.5	173.1	204.00	191.00	198.00
q_p	0.39	0.52	0.39	0.43	0.58	0.55	0.57
t_p	5.5	6.5	6.5	6.5	2.5	3.5	2.5
T_B	18	19	24	20	10	17	14
W_{50}	6.8	4.2	5.6	5.53	4.5	3.5	4.0
W_{75}	3.9	2.1	3.45	3.15	2.8	1.6	2.2
W_{R50}	2.8	1.7	2.3	2.27	1.5	1.3	1.4
W_{R75}	1.8	0.9	1.55	1.42	1.0	0.7	0.85

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

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

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

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

The steps for derivation of 1-hour unitgraph are:

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

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

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

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

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

Where

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

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

3.5 TESTING OF EQUATIONS

An attempt was made to verify the equations recommended in this report by applying on a gauged WARNA catchment (Long. 73° 52' and Lat 17° 7') where a data based unit hydrograph is also available. As recommended in the report the unit hydrograph parameters of the gauged catchment used in developing a synthetic unit graph should be used if they match with the physiographic properties of the catchment in sub basin. In case no such representative catchment is available Synthetic Unit Graph may be developed using equations. In this particular case physiographic parameters of bridge No.16 matches closely with WARNA catchment. So the unit graph for Bridge No. 16 was transposed to the WARNA catchment. The physiographic parameters of WARNA and Bidge No. 16 are given as below:

Physiographic Parameters	**Warna Catchment**	**Bridge No. 16**
Catchment Area (Km^2)	301.41	270.60
L (Km)	31.30	35.40
Lc (Km)	12.40	13.84
S (m/Km)	1.81	1.29

The unit hydrograph so developed is compared with the data based unit hydrograph. The UG parameters are given as below:

UG Parameters	**As Per Transposed UG Of Bridge No.16 Over Warna Catchment**	**As Per Data Based Studies**
tp (Hrs)	2.5	2.5
Qp (m^3/s)	217	200
T_B (Hrs)	9	13

The result of the two catchments is not very significantly different and thus the synthetic relation so developed is valid for Ungauged Catchments in this region.

3.6 SIMPLIFIED APPROACH

To quickly assess the peak of 25 year, 50 year and 100 year return period flood, a simplified approach has been developed. The physiographic parameters and corresponding 25 year, 50 year and 100 year 24-hr. point rainfall as read from the isopluvial maps (plates 8,9,10) supplied by IMD are obtained and substituted in the empirical relation developed on the basis of regression analysis using 25 year, 50 year and 100 year flood peaks for each of the 21 gauged catchment for different sizes as computed by detailed approach. The values of Q_{25}, Q_{50} and Q_{100}, for the 21 catchments so obtained are treated as dependent variables were related to their respective physiographic parameters A, L, Lc and 24 hour point rainfall values at that observation site for 25, 50 and 100 years as (R_{25}, R_{50} and R_{100}) as independent variables using multiple regression analysis and using method of least square for fitting. The derived flood formulae for Q_{25}, Q_{50} and Q_{100} and their respective coefficient of correlation 'r' are as under. The correlation of dependent variables Q_{25}, Q_{50} and Q_{100} with independent variables were studied and it was found that slop was not having any significant correlation. Hence, slope was not considered in the simplified formula.

$$Q_{25} = 0.4285\,(A)^{0.733}\,(L)^{-0.272}\,(Lc)^{0.264}\,(R_{25})^{1.426}, \quad r = 0.980$$

$$Q_{50} = 1.69432\,(A)^{0.753}\,(L)^{-0.338}\,(Lc)^{0.304}\,(R_{50})^{0.934}, \quad r = 0.980$$

$$Q_{100} = 8.33458\,(A)^{0.794}\,(L)^{-0.422}\,(Lc)^{0.313}\,(R_{100})^{0.416}, \quad r = 0.981$$

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

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

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

3.7 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 annexure 3.6, the variation of the loss rate can be seen. There is a wide variation in the loss rate ranging from 0.1 mm/hr to a high of 30 mm/hr. The loss so assessed is a complex phenomenon as the estimation of catchment rainfall depends on many hydrological factors such as antecedent moisture condition, size of the catchment, soil type etc, but also the estimation of catchment rainfall depends upon the location of the raingauge stations, which also affects the estimation of the rainfall with respect to runoff observed at the outlet of the catchment.

As the flood potential of a catchment will depend on the loss rate, we can see from the table that as many as 25 flood events fall under the category of 0.1-2 mm/hr. An average of this range i.e. 1 mm/hr can therefore be recommended as the loss rate for any ungauged catchment in this subzone.

However, the user can assess any loss rate value based on the information available to him.

3.8 DESIGN BASE FLOW

Base flow values for 188 flood events inclusive of additional flood events of 3 catchments tabulated in different ranges are shown in Annexure 3.7. Out of 188 flood events, 111 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 Krishna & Pennar Basin, Subzone 3(h) and prepared this chapter as Storm Studies. The study covers Depth-Duration-Frequency analysis of available daily/short duration rainfall data in and around the subzone. The design storm components have been derived in the form of (i) 25,50 and 100-year 24-hour isopluvial maps, (ii) 24 hours to short duration (1 to 23 hours) rainfall ratios (iii) Time distribution curves for storm of different durations (2 to 24 hours) and (iv) point to areal rainfall ratios for specified durations (1,3,6,12 and 24 hours). The methodology for analysis of each component and the procedure for design storm estimation is discussed in Section-4.5. The results of the study serve as basic input for design flood estimation for small and medium catchments. Subzone 3(h) covers parts of Maharashtra, Andhra Pradesh and Karnataka. Six districts of Maharashtra, eight districts of Karnataka and five districts of Andhra Pradesh are fully inside the subzone, whereas, nine districts (two in Maharashtra, three in Andhra Pradesh and four in Karnataka) are partially inside/outside the subzone.

4.2 DATA USED

The rainfall data for a large number of stations in and around the subzone for as long a period as possible have been used. Ordinary raingauge (ORG) data of 456 stations (292 inside the subzone and 164 around the subzone) and self recording raingauge (SRRG) data of 24 stations have been utilised.

4.3 DEPTH DURATION FREQUENCY ANALYSIS

4.3.1 ISOPLUVIAL MAPS

For each of the 456 ORG stations in and around the subzone, a series of annual maximum one-day rainfall was generated. The 456 stations series thus formed were subjected to frequency analysis using Gumbel's extreme value distribution for computing one day rainfall estimates for 25, 50 and 100-year return periods. These daily rainfall estimates (456 x 3) were converted into any 24 - hour rainfall estimates by using the conversion factor of 1.15. For each return period, the 24-hour estimates for 456 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 24 SRRG stations in the subzone and most of the stations are having data more than 7 years. The hourly rainfall data were subjected to frequency analysis using partial duration series for computing T - year t- hour rainfall estimates for T = 2, 5, 10, 25 and 50 years and t = 1, 3, 6, 9, 12, 15, 18 and 24 hour. These estimates (24 x 8 x 5) were converted into ratio with respect to the corresponding 24 - hour estimates. Average ratios (8 x 5) for the zone as a whole (mean of 24 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 25-year t-hour rainfall have been recommended to be adopted uniformly for converting 24 - hour rainfall into t - hour rainfall. These 8 conversion ratios for t = 1, 3, 6, 9, 12, 15, 18 and 24 hours given below were plotted on graph and a smooth curve was drawn as shown in graph at Fig.10, which can be used to derive conversion ratios for any duration (t) in general, including the intermediate durations.

Duration (t) In Hours	Conversion Ratio $\frac{\text{25 - Year t - Hour Rainfall}}{\text{25 - Year 24 Hour Rainfall}}$
1	0.44
3	0.63
6	0.72
9	0.79
12	0.84
15	0.89
18	0.93
24	1.00

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

4.3.3 TIME DISTRIBUTION CURVES

Based on hourly rainfall data of all the 24 SRRG stations a total of 4552 rainstorms of durations 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 (957 of all stations)
b) rainstorms of 4 to 6 - hour duration (1187 of all stations)
c) rainstorms of 7 to 12 - hour duration (1215 of all stations)
d) rainstorms of 13 to 18 -hour duration (568 of all stations)
e) rainstorms of 19 to 24 -hour duration (625 of all stations)

For each station, 5 different graphs corresponding to each group of rainstorms were prepared by plotting the cumulative percentage of the total storm duration and the average time distribution curves (24 x 5) were drawn. Average time distribution curves (5) for the sub zone as a whole were then drawn by plotting 24 station curves on the same graph and average curves are drawn which are given in Fig.11. These curves can be used to derive the time distribution co-efficient of storm rainfall in the sub zone for the rainstorms of any duration (Annexure 4.3)

4.3.4 POINT TO AREAL RAINFALL RATIOS

In the present study, the availability of a fairly dense network of SRRGs in the subzone made it possible to adopt the best scientific procedure for deriving point to areal relationship based on SRRG data and concurrent ORG data in preference to bridge data. The data of 24 SRRG stations in and around the catchment were used. SRRG data of 24 stations were scrutinized to collect the rainstorms of various durations (t = 1,3,6,12 & 24 hrs) and about 40 rainstorms were selected. The hourly rainfall records of SRRG's and daily rainfall data of surrounding ORG's were carefully examined for various storm durations (5) to select t - hour representative rainstorms based on the following considerations:

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

About 40 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 40 representative rainstorms were then prepared using concurrent rainfall values of SRRG stations and surrounding ORG stations (reduced values) corresponding to the date and time of each representative rainstorm. By planimetering each isohyetal map around the rainstorm centre and plotting the ratios of areal rainfall depth to point rainfall against the areas, the best fit curves (5) were drawn as shown in the graph at Figs. 12(a) and 12(b) which can be used to derive the percentage areal reduction factors for converting point rainfall of any duration in the subzone into corresponding areal rainfall for any particular small catchment in the subzone (Annexure 4.4)

4.4 HEAVIEST RAINFALL RECORDS

4.4.1 ORG Data

The highest ever recorded one day station rainfall (24 hours rainfall ending 0830 hrs. of date) along with date of occurrence in each of the 28 districts covering subzone 3(h) have been compiled from the ORG data and presented in Annexure 4.1. Normal annual rainfall for each station is also given in the Annexure.

4.4.2 SRRG Data

The heaviest storm rainfall in duration of 24, 12, 6, 3 and 1 hour along with date and time of occurrence at the 18 SRRG stations have been compiled and presented in Annexure 4.2.

4.5 PROCEDURE FOR DESIGN STORM RAINFALL ESTIMATION

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

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

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

Step- 3 : Read the areal reduction factor corresponding to storm duration T_D and the given area of catchment from fig.12 a and 12 b or Annexure - 4.4 and multiply the 50-year T_D -hour point rainfall in step-2 by this factor to obtain the 50-year T_D -hour areal rainfall over the catchment.

Step- 4 : Read the time distribution co-efficient for 1,2 ... ... T_D hours corresponding to storm duration T_D from relevant graph in fig. 11 or Annexure 4.3 and multiply the 50 yr. T_D -hour areal rainfall in Step-3 by these co-efficient to obtain the cumulative depths of 1,2... ... ... T_D -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 -hours in Step-4.

For a 6-hr storm, the time distribution coefficients obtained from fig.11 or Annexure 4.3 are given in col.(2) of Table 4. These values are multiplied by 50-yr 6-hour areal rainfall to obtain the cumulative depths, col. (3). Hourly storm rainfall depths are obtained by successive differences of cumulative storm rainfall depths as given in Table 4.

Table 4

Hour	Time Distribution Coefficient (%)	Cumulative Rainfall Depth (Cm)	Hourly Rainfall Depth (Cm)
1	2	3	4
1	59	5.6	5.6
2	76	7.2	1.6
3	86	8.2	1.0
4	94	8.9	0.7
5	98	9.3	0.4
6	100	9.5	0.2

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., 2(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 should be designed with adequate waterway for design discharge. This shall normally be the computed flood with probable recurrence interval of 50 years. However, at the discretion of Chief Engineer/Chief Bridge Engineer, if a bridge is likely to have severe consequences, it may be designed for floods with a probable recurrence interval of more than 50 years, while bridges on less important lines or sidings may be designed for floods with a probable recurrence interval of less than 50 years.

b) Indian Road Congress - IRC 5-1985, clause 103 of Section-I "General Features of Design" Specifies that the waterway of a road bridge is to be designed for a maximum flood of 50-yr return period. To provide for adequate margin of safety, the foundation and protection works should be designed for larger discharge as computed under clause 103. The recommended percentage increase over the design discharge specified in clause 103 is given under clause 110.1.2 of IRC-5-1985. These recommendations are the same as given in the report of the Committee of Engineers and are reproduced as under :

Sl. No.	Catchment Area	Increase In Design Discharge
1	Upto 500 Km^2	30 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, 1975" recommends that the waterway for cross drainage works should be designed for a 25 yr. return period flood. To provide adequate margin of safety, the foundation and 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.

.'rocedure for computing design flood peak and design flood hydrograph for T-year return period by SUG approach is as under.

Step -1: Synthetic unit hydrograph

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

Step -2: Design storm duration

The duration of storm, which causes maximum flow in a river at a specified location, is called "Design Storm Duration". The SUG of 21 catchments have been derived using the parameters computed from recommended equations given in Table-3.3. Annexure 5.1 shows the computed UG parameters. It has been studied that the critical storm duration which causes severe floods in small and medium catchments as used in this subzone is equal to 1.1*tp. The flood peaks of 25 yrs, 50 yrs and 100 yrs return period is computed for this storm duration.

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

Step -3 : Design storm rainfall

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

ii) Obtain design storm rainfall and hourly areal rainfall units vide section 4.5.

iii) Adopt design loss rate as recommended in section 3.7.

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 38.

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

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

b) Design flood hydrograph.

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

Step-5:

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

Step –6:

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

Step –7:

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

Step –8:

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

5.2.1 Illustrative example.

1. Bridge No.16 at mile 11/12-13 on Hubli-Arsikere section, Southern Railway has been marked out as ungauged catchment for illustrating the procedure to compute 50-year design Flood. The catchment plan is enclosed at figure A-1.

   The particulars of the catchment under study are as follows:

(i) Name of Subzone : Krishna & Pennar.
(ii) Name of Tributary : Bennihallah

(iii) Name of Railway Section	:	Hubli - Arsikere
(iv) Shape of catchment	:	Normal.
(v) Location	:	Lat 15°-13' Long 75°-18'
(vi) Topography	:	Moderate slope.

Procedure is explained below:

Step-1 : Physiographic Parameters

Physiographic parameters obtained are given below:

1) Area (A)-Refer fig. A-1.	= 270.60 Sq.km
2) Length of the longest stream (L)	= 35.40 km
3) Length of the longest stream from a point opposite to C.G.(Lc) =	13.84 km
4) Equivalent stream slope (S_{eq})	= 1.29 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:

Table 5.1
(Synthetic UG Parameters)

Sl.No.	SUG Parameters	
1	$q_p = 0.996(t_p)^{-0.497}$	= 0.472 cumecs/sq.km
2	$t_p = 0.325(LLc/\sqrt{S})^{0.447}$	= 4.895 hrs rounded to 4.5 hrs
3	$W_{50} = 2.389\ (q_p)^{-1.065}$	= 5.32 hrs
4	$W_{75} = 1.415\ (q_p)^{-1.067}$	= 3.16 hrs
5	$WR_{50} = 0.753(q_p)^{-1.229}$	= 1.89 hrs
6	$WR_{75} = 0.558(q_p)^{-1.088}$	= 1.26 hrs
7	$T_B = 7.392(t_p)^{0.524}$	= 16hrs
8	T_m = tp + tr/2	= 5.00 hrs where tr =1.0 hr
9	$Q_P = q_p \times A$	= 127.7 cumecs

Estimated parameters of unitgraph in Step 2 were plotted on a graph paper as shown in Fig.A.2 The plotted points were joined to draw synthetic unitgraph. The discharge ordinates (Qi) of the unitgraph at ti = tr=1 hr interval were summed up and multiplied by tr=1 i.e. $Q_i \times t_i$ = 751.7 cumecs and compared with the theoretical volume of 1.00 cm. direct run off depth over the catchment, computed from the formula as below:

$Q = (A \times d)(t_i \times 0.36)$.

Where, A = Catchment area in Sq.km.

d = 1.0 cm. depth.

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

$$Q = \frac{A \times d}{0.36 \times tr} = \frac{270.60 \times 1}{0.36 \times 1} = 751.7 \text{ cumec.}$$

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 x t_p	= 1.1 x 4.5
	= 4.95
Rounded off to nearest full hour	= 5.00 hrs.
∴ Design Storm Duration (T_D)	= 5.00 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 15.50 cm. The conversion factor of 0.69 was read from Fig.10 to convert the 50 year-24 hour point rainfall to 50 year, T_D (5.00) hrs point rainfall. 50 yrs, 5 hr point rainfall thus worked out to be 0.69 x 15.50 cm = 10.70 cm.

Areal reduction factor of 0.7746 corresponding to the catchment area of 270.60 Sq.km. for T_D = 5.00 hour was interpolated from Annexure 4.4 or fig.12(a) for conversion of point rainfall to areal rainfall. 50 yr, 5.00 hr. areal rainfall thus works out to be 0.7746 x 10.70 cm = 8.29 cm.

The 50 yr., 5.00 hour areal rainfall has been split into 1-hour rainfall increments using time distribution coefficients given in Annexure 4.3 or figure 11. The hourly ordinates are given in Table 5.2.

A design loss rate of 0.1 cm/hr, as recommended in para 3.7 was applied to get effective rainfall hyetograph.

Table 5.2
(Hourly effective rainfall increments)

Duration	Distribution Co-efficient	Storm Rainfall	Rainfall Increments	Loss Rate/Hour	Effective Hourly Rainfall
(hr)		(cm)	(cm)	(cm)	(cm)
1	2	3	4	5	6
1	0.62	5.14	5.14	0.10	504
2	0.81	6.71	1.57	0.10	1.47
3	0.91	7.54	0.83	0.10	0.73
4	0.97	8.04	0.50	0.10	0.40
5	1.00	8.29	0.25	0.10	0.15

Step 4: Estimation of base flow

Adopting a design base flow of 0.05 cumec per Sq.km. as recommended in para 3.8 the base flow for the catchment under study was estimated to be 0.05 x 270.60 = 13.53 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 anu 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 (Hours)	S.U.G. Ordinates (Cumec)	1-Hour Effective Rainfall (Cm)	Direct Runoff (Cumec)
1	2	3	4
4	109.00	0.73	79.57
5	127.60	5.04	643.10
6	114.00	1.47	167.58
7	93.00	0.40	37.20
8	71.50	0.15	10.72
		Total	938.17
		Add Base Flow	13.53
		Peak discharge $(Q)_{50}$=	951.7 0 cumec

(b) Computation of design flood hydrograph

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

Table 5.4
(Critical Sequence of Rainfall)

Time (Hrs)	Critical 1-Hr. Effective Rainfall Sequence (Cm)
1	2
1	0.15
2	0.40
3	1.47
4	5.04
5	0.73

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.7 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.8. Total hydrograph ordinates were obtained by adding base flow of 13.53 m3/s to col.8 and are given in col.10. Design Flood Hydrograph was plotted against time as shown in Fig.A-3. The peak of the flood hydrograph obtained was 951.70 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.16 is considered for selection of the problem by flood formulae. The physiographic and meteorologic parameters for the catchment under study are:

Catchment area (A) = 270.60 Sq.km.

Length of the longest stream (L) = 35.40 km.

Length of the longest stream from a point opposite to C.G. of catchment to point of study (Lc) = 13.84 km.

Equivalent slope (S_{eq}) = 1.29 m/km.

25 yr., 24 hr point rainfall (R_{25}) = 15.00 cm
50 yr., 24 hr point rainfall (R_{50}) = 15.50 cm
100 yr., 24 hr point rainfall (R_{100}) = 19.00 cm

$Q_{25} = 0.4285\,(A)^{0.733}\,(L)^{-0.272}\,(Lc)^{0.264}\,(R_{25})^{1.426}$
$= 0.4285(270.60)^{0.733}\,(35.40)^{-0.272}\,(13.84)^{0.264}\,(15.0)^{1.426}$
$= 937.67$ cumec

$Q_{50} = 1.69432\,(A)^{0.753}\,(L)^{-0.338}\,(Lc)^{0.304}\,(R_{50})^{0.934}$
$= 1.69432\,(270.60)^{0.753}\,(35.40)^{-0.338}\,(13.84)^{0.304}\,(15.5)^{0.934}$
$= 990.03$ cumec

$Q_{100} = 8.33488\,(A)^{0.794}\,(L)^{-0.422}\,(Lc)^{0.313}\,(R_{100})^{0.416}$, $r = 0.981$
$= 8.33488\,(270.60)^{0.794}\,(35.40)^{-0.422}\,(13.84)^{0.313}\,(19)^{0.416}$
1223.26 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 shown in Table no.5.5.

Table No. 5.5
(Comparison of Results)

Br. no.	Catchment Area (Km²)	By SUG			By Flood Formula			Variation With Respect to SUG (%ge)		
		Q_{25}	Q_{50}	Q_{100}	Q_{25}	Q_{50}	Q_{100}	Q_{25}	Q_{50}	Q_{100}
16	270.6	919.24	951.70	1174.50	937.67	990.03	1223.26	-2.00	-4.03	-4.15

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

5.4 COMPUTATION OF DESIGN H.F.L

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

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

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

Computation of 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 atleast 300 m. upstream and downstream of the crossing site.

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

PART VI

ASSUMPTIONS, LIMITATIONS,CONCLUSIONS & RECOMMENDATION

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 21 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 25 Sq. km. to 1500 Sq. km. Further the report may be used for large catchments upto 5000 Sq. km. based on sound judgement and considering the data of neighbouring catchments also. However, individual site conditions may necessitate special study. Engineer-in-charge at site is advised to take a pragmatic view while deciding the design discharge of a bridge.

6.4 RECOMMENDATION

1. In case the physiographic parameters of the ungauged catchment matches with any the gauged catchment the unit hydrograph parameters of the gauged catchments can be proportionately transposed to the ungauged catchment and UG so derived be adjusted.
2. When the parameters of ungauged catchment do not match with any of the gauged catchment preference can be given to gauged catchment close to location of ungauged catchment.
3. When none of the above two conditions are fulfilled go in for the use of recommended relations.

REFERENCES

1. Engineering Hydrology : Wilson E.M.
2. Estimation of Design Flood "Recommended Procedures" (September 1972) : Central Water Commission, New Delhi.
3. Guide to Hydrological Practices (Third Edition): World Meteorological Organisation No.168, 1994.
4. IRC: 5 - 1985 - Standard specifications and code of practice for Road Bridges, Section - 1, General Features of Design ($6^{th\ Revision}$) 1985, Indian Roads Congress.
5. IRC: SP: 13 - 1973 - Guidelines for the Design of Small Bridges and Culverts.
6. Indian Railway standard code of Practice for Structures and Foundation of Bridges (Revised - 1985 Edition).
7. Irrigation Atlas of India (Revised 1989).
8. Report of Irrigation Commission (1972).
9. Report of the Khosla Committee of Engineers (October 1959) Government of India, Ministry of Railways.

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.
4 (c)	Sandy Coromandal Belt (east flowing rivers between Cauvery and Kanyakumari)	South Eastern Coast.	East flowing coastal rivers, Manimuthar, Vaigai, Arjuna, Tamraparni.
5 (a)	Konkan Coast (west flowing river between Tapi and Panaji)	Konkan Coast.	West flowing coastal rivers between Tapi and Mandavi rivers.
5 (b)	Malabar Coast (west flowing rivers between Kanyakumari and Panaji)	Malabar Coast.	West flowing coastal rivers between Mandavi and Kanyakumari.
6	Andaman & Nicobar	Andaman and Nicobar.	
7	J & K, Kumaon Hills (Indus Basin)	Western Himalayas.	Jhelum, Upper portion of Indus, Ravi and Beas rivers).

Annexure 3.1

LIST OF RAILWAY/ROAD BRIDGE CATCHMENTS IN SUBZONE - (3h) (KRISHNA AND PENNER 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		Catch-Ment Area (Km^2)	No. of Rain Gauge Stations	Data Availa-bility	No.of Years	Remarks
				Latitude Deg - min	Longitude Deg- min					
1	2	3	4	5	6	7	8	9	10	11
A: BRIDGES CONSIDERED FOR REGRESSION ANALYSIS										
1	KAGNA	WADI-SECUNDERABAD, S.C.R.	53(ii)	17-14	77-34	1689.92	9	1966-74	9	
2	HIREHALLAH	GADAG-HOSPET, S.C.R.	63	15-20	76-11	1357.15	9	1973-77	5	
3	NARIHALLAH	HOSPET-GUNTAKAL, S.R.	200	15-12	76-40	555.37	6	1966-73	8	
4	PINAKINI	BANGALORE-DHARMAVARAM, S.R.	328	13-37	77-31	437.60	4	1967-74	8	
5	PAGERU	RENIGUNTA-GUNTAKAL, S.R.	601	14-38	78-43	398.60	4	1974-96	23	
6	KHARA	PUNE-MIRAJ, S.C.R.	98	18-18	74-09	348.40	4	1978-81	4	
7	BENNIHALLAH	HUBLI-ARSIKERA, S.R.	16	15-13	75-18	270.60	6	1961-66	6	
8	MANJARI	KHURDWADI-MIRAJ S.C.R.	169	17-30	75-14	230.87	3	1970-74	5	

Sl. No.	Name of the Stream	Railway/ Road Section	Railway/ Road Bridge Site No	Bridge Site Location		Catch-Ment Area (Km^2)	No. of Rain Gauge Stations	Data Availa-bility	No.of Years	Remarks
				Latitude	Longitude					
				Deg - min	Deg- min					
1	2	3	4	5	6	7	8	9	10	11
9	PEDDAVANKA	HUBLI-GUNTAKAL S.C.R.	313	15-10	77-18	220.45	3	1974-77	4	
10	SOGAON	PUNE-WADI, C.R.	202	18-16	75-02	171.70	4	1958-59	2	
11	VODDI	LONDA-MIRAJ, S.C.R.	215(i)	16-50	74-42	167.32	3	1966-74	9	
12	HIRENH-ALLAH	GADAG-SOLAPUR, S.C.R.	18	16-04	75-42	131.52	2	1966-73	8	
13	MARTUR (TEGNOOR)	DHOND-RAICHUR, C.R.	365	17-11	76-58	119.60	3	1958-66,69	10	
14	JAM	DHOND-AHMEDNAGAR, C.R.	353	19-07	74-42	118.25	3	1975-95	21	
15	TILATI-NALLAH	PUNE-RAICHUR, S.C.R.	771	17-30	76-04	118.23	2	1969-74	6	
16	THOLENHALLA N	BIRUR-TELAGUPPA, S..R.	53(i)	13-50	75-47	102.45	3	1961-65	5	
17	ANGARN-ALLAH	DHOND-RAICHUR, C.R.	253	17-58	75-26	100.98	4	1958-66	9	
18	BIRNAL	LONDA-MIRAJ, S.C.R.	166	16-30	74-523	91.27	2	1971-79	9	
19	MOOSI	WADI-SECUNDERABAD, S.C.R.	123	17-31	77-55	64.75	7	1958-65	8	
20	SUKHIRA-NALLAH	MIRAJ-PUNE, S.C.R.	384	17-36	74-10	62.16	2	1961,62, 1964-65	4	
21	DUGGI	MIRAJ-PUNE, S.C.R.	404	17-38	74-10	29.78	3	1961-62, 66-70	7	

Sl. No.	Name of the Stream	Railway/ Road Section	Railway/ Road Bridge Site No	Bridge Site Location		Catch-Ment Area (Km^2)	No. of Rain Gauge Stations	Data Availa-bility	No.of Years	Remarks
				Latitude	Longitude					
				Deg - min	Deg- min					
1	2	3	4	5	6	7	8	9	10	11
B: BRIDGES NOT CONSIDERED FOR REGRESSION ANALYSIS										
22	CHANNAHAGARI	BELLARY-RAYADURG, S.C.R	56	14-50	76-52	2382.20	8	1966-69	4	
23	BHOOGA	KAZIPET-VIJAYAWADA, C.R.	642	17-23	80-11	326.08	5	1959, 1961-62	3	
24	KUMUDAVATI	BIRUR-TALAGUPPA, S.R.	179	14-01	75-25	251.17	3	1970-74	5	
25	KANIKALAVAGM	GUNTAKAL-VIJAYAWADA, S.C.R	215(ii)	15-30	78-28	139.08	3	1961-62, 1965-74	12	
26	ERIMULLIVAGU	SECUNDERABAD KAZIPET, C.R	291	17-29	78-45	108.57	4	1962, 1968-69	3	
27	AGRAHARAHALLA	ARSIKERA-HUBLI, S.R.	66	14-05	76-08	70.84	2	1972-78	7	
28	KOTAPALLIVAKA	DHARMAVARAM-GUNTAKAL, S.C.R	61	14-43	77-36	56.51	2	1970-73	4	
29	BANJAL	GADAG-SOLAPUR, S.C.R	83	17-49	76-58	48.28	-	1970-74	5	

Annexure- 3.2

PHYSIOGRAPHIC PARAMETRS OF SELECTED CATCHMENTS

Sl.No.	Br. No.	Catchment Area (A) (Sq.Km.)	Length (L) (Km)	Length from Centroid of the Catchment to the Outlet (L_c) (Km)	Equivalent Slope (Seq) m/km
1	2	3	4	5	6
1	53(ii)	1689.92	54.06	22.53	2.34
2	63	1357.15	56.32	27.35	1.92
3	200	555.37	41.83	20.91	5.13
4	328	437.60	37.00	19.30	5.52
5	601	398.60	36.20	16.73	2.12
6	98	348.40	31.38	15.29	6.95
7	16	270.60	35.40	13.84	1.29
8	169	230.87	26.96	12.88	3.30
9	313	220.45	26.72	13.68	1.96
10	202	171.70	19.30	9.85	5.08
11	215(i)	167.32	23.25	11.26	3.32
12	18	131.52	23.74	10.46	3.01
13	365	119.60	16.00	7.00	4.94
14	353	118.25	26.54	15.69	4.12
15	771	118.23	18.10	8.85	1.92
16	53(i)	102.45	21.24	8.61	9.21
17	253	100.98	16.49	8.05	2.78
18	166	91.27	16.89	7.24	6.07
19	123	64.75	16.09	7.24	3.23
20	384	62.16	14.96	9.65	9.91
21	404	29.78	10.70	6.44	11.83

ONE HOUR REPRESENTATIVE UNIT-HYDROGRAPH PARAMETERS OF SELECTED CATCHEMNTS FOR KRISHNA AND PENNAR 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	53(ii)	7.5	496.70	0.294	1	24	9.0	5.8	3.7	2.5
2	63	7.5	533.88	0.393	1	22	6.8	4.0	2.8	1.6
3	200	4.5	312.00	0.562	1	15	4.2	2.2	2.4	1.4
4	328	6.5	133.98	0,306	1	21	8.6	4.8	2.8	1.9
5	601	6.5	173.1	0.434	1	20	5.53	3.15	2.27	1.42
6	98	2.5	198	0.568	1	14	4.0	2.20	1.4	0.85
7	16	4.5	117.00	0.432	1	15	6.1	4.0	2.9	2.1
8	169	2.5	116.58	0.505	1	12	5.0	3.5	1.4	0.9
9	313	3.5	108.70	0.493	1	15	4.9	2.4	0.8	0.5
10	202	2.5	115.70	0.674	1	10	3.95	2.5	1.6	1.1
11	215(i)	2.5	112.00	0.669	1	11	3.85	2.5	1.5	1.1
12	18	2.5	87.59	0.666	1	11	3.8	2.4	1.5	1.1
13	365	1.5	86.89	0.727	1	9	3.6	2.0	1.2	0.8
14	353	2.5	107.00	0.905	1	10	2.8	1.6	0.8	0.5
15	771	4.5	72.38	0.612	1	15	4.2	2.6	1.8	1.2
16	53(i)	2.5	58.94	0.575	1	13	4.0	2.5	1.6	1.2
17	253	1.5	72.54	0.718	1	11	3.3	1.8	0.8	0.6
18	166	2.5	61.00	0.668	1	14	3.3	1.9	0.7	0.5

Annexure 3.3 Contd...

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
19	123	2.5	46.00	0.710	1	10	3.3	2.0	1.2	1.0
20	384	1.5	54.27	0.873	1	9	2.8	2.0	1.2	1.0
21	404	1.5	22.42	0.753	1	10	3.2	1.6	0.8	0.6

Annexure 3.4

RELATION BETWEEN PHYSIOGRAPHIC AND UNIT HYDROGRAPH PARAMETERS STUDIED

Sl.No.	X	Y	A	B	R
1	$LLc/\sqrt{S}$	t_p	0.325	0.447	0.750
2	t_p	q_p	0.996	(-) 0.497	0.733
3	q_p	W_{50}	2.389	(-) 1.065	0.973
4	q_p	W_{75}	1.415	(-) 1.067	0.861
5	q_p	WR_{50}	0.753	(-) 1.229	0.597
6	q_p	WR_{75}	0.558	(-) 1.088	0.510
7	t_p	T_B	7.392	0.524	0.860

NOTE : Equation is of the form of $\mathbf{Y = A * X^B}$

Annexure 3.5

COMPARISON OF FLOOD PEAK BASED ON RUGs and SUGs

Sl.No.	Bridge No.	Q_{25}(Cumec)			Q_{50} (Cumec)			Q_{100}(Cumec)		
		RUG	SUG	% Diff	RUG	SUG	% Diff.	RUG	SUG	% Diff.
1	53 (ii)	3932.17	4799.50	-22.06	4877.95	5946.30	-21.90	5553.50	6765.37	-19.24
2	63	4150.59	3881.30	6.49	4288.2	3992.60	6.89	4838.63	4505.62	6.11
3	200	2084.63	1836.70	11.89	2152.37	1896.60	11.89	2558.85	2255.70	10.00
4	328	1051.57	1467.20	-39.53	1363.19	1897.30	-39.18	1536.32	2136.18	-34.76
5	601	1362.11	1477.10	-6.24	1572.15	1668.20	-6.11	1656.17	1756.64	-5.80
6	98	1206.45	1208.20	-0.14	1247.75	1249.90	-0.17	1536.81	1542.16	-0.14
7	16	867.80	919.24	-5.93	898.00	951.70	-5.98	1109.34	1174.50	-4.84
8	169	909.47	1005.50	-10.56	1101.10	1219.00	-10.70	1183.23	1310.45	-9.96
9	313	765.06	844.55	-10.39	791.36	873.69	-10.40	949.18	1048.57	-8.67
10	202	926.6	862.70	6.90	1038.21	966.44	6.91	1149.82	1070.18	6.24
11	215 (i)	822.29	768.42	6.55	876.73	819.19	6.56	1040.05	971.50	5.53
12	18	641.89	607.16	5.41	729.69	690.08	5.43	795.54	752.27	4.98
13	365	635.28	708.71	-11.56	797.27	888.68	-11.47	898.15	1001.16	-10.18
14	353	859.28	546.91	36.35	992.32	632.16	36.29	1072.15	683.31	33.59
15	771	592.54	572.46	3.39	731.04	704.70	3.60	750.83	723.60	3.51
16	53(i)	479.63	520.99	-8.62	510.28	554.26	-8.62	571.58	620.81	-7.69
17	253	541.19	514.80	4.88	609.82	580.55	4.80	644.14	613.43	4.54

Annexure 3.6

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

Sl. No.	Br. No.	CA (Km^2)	0.1 to 2	2 to 4	4 to 6	6 to 8	8 to 10	10 to 12	12 to 14	14 to 16	16 to 18	18 to 20	20 to 22	22 to 24	24 to 26	26 to 28	28 to 30	Total	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	53(ii)	1689.92	1	1	1	-	-	-	1	-	1	-	-	-	-	-	-	5	Loss
2	63	1357.15	3	3	1	-	-	-	-	-	-	-	-	-	-	-	-	7	rates
3	200	555.37	-	1	-	1	1	-	2	-	-	-	-	1	-	-	-	6	in
4	328	437.60	-	-	-	-	1	1	-	1	-	-	-	-	-	-	-	3	mm/
5	601	398.60	1	6	5	8	2	1	4	1	4	-	1	-	-	-	-	33	hr.
6	98	348.40	1	3	1	-	-	1	-	-	-	-	-	-	-	-	-	6	
7	16	270.60	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	4	
8	169	230.87	-	-	1	1	-	-	1	1	1	-	-	-	-	-	-	5	
9	313	220.45	-	5	3	2	2	-	1	1	-	-	-	-	-	-	-	14	
10	202	171.70	1	2	-	1	-	-	-	-	-	-	-	-	-	-	-	4	
11	215(i)	167.32	-	1	1	1	1	-	-	-	-	-	1	1	1	-	-	7	
12	18	131.52	2	2	6	-	1	-	-	1	-	-	-	-	-	-	-	12	
13	365	119.60	6	6	4	1	1	-	1	1	1	-	2	-	-	1	1	25	
14	353	118.25	1	-	-	1	-	-	1	-	-	-	-	-	-	-	-	3	
15	771	118.23	-	1	2	-	-	1	-	-	1	-	-	-	-	-	1	6	
16	53(i)	102.45	2	2	2	2	-	1	-	-	-	-	-	-	-	-	-	9	
17	253	100.98	1	4	1	2	-	-	-	-	-	-	1	-	-	-	-	9	
18	166	91.27	-	-	2	-	-	-	-	1	1	2	1	-	-	-	-	7	
19	123	64.75	2	6	-	1	4	-	-	-	-	-	-	-	-	-	-	13	
20	384	62.16	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	4	
21	404	29.78	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	
	Total		25	48	31	22	13	5	11	7	9	2	6	2	1	1	2	185	

Annexure - 3.7

AVERAGE BASE FLOW RANGES FOR STUDIED FLOOD EVENTS

(In Cumec per sq. Km.)

SL. NO.	BRIDGE NO.	0.001 TO 0.005	0.0051 TO 0.009	0.01 TO 0.09	0.10 TO 0.19	0.20 AND ABOVE	TOTAL
1	2	3	4	5	6	7	8
1	53(ii)	2	1	2	-	-	5
2	63	4	3	-	-	-	7
3	200	5	1	-	-	-	6
4	215(i)	4	-	3	-	-	7
5	328	-	2	1	-	-	3
6	601	18	1	14	-	-	33
7	98	-	1	3	-	-	4
8	16	2	1	1	-	-	4
9	169	-	1	5	1	-	7
10	313	9	3	1	-	-	13
11	202	1	1	2	-	-	4
12	18	-	-	10	2	-	12
13	365	1	2	22	1	-	26
14	353(i)	-	-	4	-	-	4
15	771	-	-	7	1	-	8
16	53(i)	-	-	9	-	-	9
17	253	-	-	5	3	1	9
18	166	-	-	6	-	1	7
19	123	-	-	11	1	1	13
20	384	-	-	3	1	-	4
21	404	-	-	2	-	1	3
	Total	46	17	111	10	4	188

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	53(ii)	1689.92	4799.50	5946.30	6765.37	3815.35	4190.64	5044.24	20.50	29.52	25.44
2	63	1357.15	3881.30	3992.60	4505.62	3538.18	4240.00	4712.49	8.84	-6.20	-4.59
3	200	555.37	1836.70	1896.60	2255.70	1856.18	1932.59	2320.60	-1.06	-1.90	-3.88
4	328	437.60	1467.20	1897.30	2136.18	1577.78	2012.27	2112.90	-7.54	-6.06	1.09
5	601	398.60	1477.10	1668.20	1756.64	1556.11	1726.68	1804.95	-5.35	-3.50	-2.75
6	98	348.40	1208.20	1249.90	1542.16	1197.41	1285.77	1622.82	0.89	-2.87	-5.23
7	16	270.60	919.24	951.70	1174.50	937.67	990.03	1223.26	-2.00	-4.03	-4.15
8	169	230.87	1005.50	1219.00	1310.45	1054.35	1223.61	1257.25	-4.91	-0.38	4.03
9	313	220.45	844.55	873.69	1048.57	868.45	929.80	1153.50	-2.83	-6.42	-10.00
10	202	171.70	862.70	966.44	1070.18	865.88	941.15	1032.08	-0.37	2.62	3.56
11	215(i)	167.32	768.42	819.19	971.50	733.41	790.21	945.12	4.56	3.41	2.71
12	18	131.52	607.16	690.08	752.27	572.05	658.97	739.84	5.78	4.51	1.65
13	365	119.60	708.71	888.68	1001.16	585.78	722.18	775.25	17.34	18.73	22.56
14	353	118.25	546.91	623.16	683.31	654.58	735.11	768.73	-19.69	-16.29	-12.50
15	771	118.23	572.46	704.70	723.60	571.13	702.94	739.44	0.23	0.25	-2.19
16	53(i)	102.45	520.99	554.26	620.81	511.31	534.33	605.03	1.86	3.59	2.54
17	253	100.98	514.80	580.55	613.43	532.51	595.08	651.68	-3.44	-2.50	-6.23

Annexure 3.9

NUMBER OF FLOOD EVENTS

Sl.No.	Br. No.	No. of Flood Events
1	53(ii)	5
2	63	7
3	200	6
4	328	3
5	601	33
6	98	6
7	16	4
8	169	5
9	313	14
10	202	4
11	215(i)	7
12	18	12
13	365	25
14	353	3
15	771	6
16	53(ii)	9
17	253	9
18	166	7
19	123	13
20	384	4
21	404	3
	Total	185

Annexure 4.1

STATISTICS OF HEAVIEST DAILY RAINFALL & ANNUAL NORMAL RAINFALL IN SUBZONE 3 (h).

Sl.No.	State/District	Station	Heaviest Rainfall (Cm)	Date Of Occurrence	Annual Normal Rainfall (Cm)
1	2	3	4	5	6
MAHARASHTRA					
1	Pune	Khandala	51.6	19.07.1958	470.6
2	Kolhapur	Gaganbawada	49.9	24.07.1989	621.2
3	Satara	Mahabaleshwar	45.9	03.06.1882	622.6
4	Ahmednagar	Kopargaon	33.0	15.10.1951	51.2
5	Sangli	Sangli	30.0	11.06.1959	56.9
6	Sholapur	Pandharpur	25.5	07.09.1895	61.1
7	Bhir	Mominabad	25.4	24.06.1951	80.0
8	Osmanabad	Osmanabad	24.7	07.09.1895	81.0
KARNATAKA					
9	Shimoga	Nagar (Hosnagar)	45.7	22.07.1969	287.5
10	Gulbarga	Yadgir	37.5	25.06.1983	67.5
11	Chickmagalur	Sringeri	29.6	21.07.1945	369.5
12	Belgaum	Khanapur	30.7	05.08.1914	168.4
13	Dharwar	Nargund	29.0	02.07.1959	51.7
14	Kolar	Malur	25.4	01.05.1872	73.3
15	Hassan	Saklespur	22.9	16.07.1924	234.9

Sl.No.	State/District	Station	Heaviest Rainfall (Cm)	Date Of Occurrence	Annual Normal Rainfall (Cm)
1	2	3	4	5	6
16	Bijapur	Indi	21.6	07.09.1895	56.4
17	Chitradurg	Challakere	21.6	12.05.1888	45.5
18	Tumkur	Kunigal	20.9	30.09.1925	76.5
19	Raichur	Rajulbanda	20.0	23.11.1958	65.9
20	Bellary	Sirguppa	19.6	17.08.1905	63.5
ANDHRA PRADESH					
21	Kurnool	Nandyal	38.9	23.05.1952	76.5
22	Warangal	Hanamkonda	30.5	27.09.1908	92.4
23	Khammam	Khammam	30.0	10.07.1954	91.1
24	Anantpur	Madakasira	29.1	21.05.1879	59.4
25	Cuddapah	Rajampet	26.7	24.10.1874	77.3
26	Mehboobnagar	Nagarkurnool	26.7	23.05.1952	63.4
27	Nalgonda	Palliwada Project	21.6	19.07.1956	59.0
28	Hyderabad	Begumpet	19.1	11.09.1950	77.2

Annexure 4.2

HEAVIEST 24-HOURS & SHORTER DURATIONS RAINFALL RECORDED IN SUBZONE 3 (h)

State/District	SRRG Station	Highest Observed Storm Rainfall (mm)	Duration (Hr)	Date & Time Of Occurrence	Clock Hour
1	2	3	4	5	6
KARNATAKA					
1. Shimoga	1. Agumbe	443	24	22.7.76	(20-20)
		282	12	-do-	(08-20)
		172	6	-do-	(08-14)
		123	3	25.9.75	(16-19)
		100	1	12.8.87	(11-12)
2. Bangalore	1. Bangalore	131	24	4-5.10.77	(20-20)
		131	12	-do-	(20-08)
		118	6	-do-	(23-05)
		100	3	20.9.80	(21-24)
		82	1	5.10.77	(01-02)
3. Belgaum	1.Belgaum	225	24	27-28.6.83	(06-06)
		125	12	27.6.83	(02-14)
		122	6	14.6.79	(06-12)
		114	3	-do-	(06-09)
		77	1	6.4.84	(15-16)
4.Bellary	1.Bellary	110	24	12-13.7.84	(23-23)
		89	12	3-4.10.83	(15-03)
		80	6	11-12.9.83	(21-03)
		72	3	11.9.83	(21-24)
		59	1	4.8.87	(20-21)
	2.Hospet	147	24	11-12.9.79	(23-23)
		147	12	-do-	(23-11)
		122	6	12.9.79	(00-06)
		80	3	1.6.86	(02-05)
		54	1	19.9.89	(22-23)
5.Chitradurg	1.Chitradurg	84	24	24-25.9.80	(22-22)
		74	12	-do-	(22-10)
		74	6	-do-	(22-04)
		74	3	-do-	(22-01)
		64	1	24.9.80	(23-24)

State/District	SRRG Station	Highest Observed Storm Rainfall (mm)	Duration (Hr)	Date & Time Of Occurrence	Clock Hour
1	2	3	4	5	6
6.Dharwar	1.Gadag	135	24	4-5.6.73	(03-03)
		76	12	-do-	(20-08)
		75	6	-do-	(02-08)
		70	3	14.9.70	(02-05)
		59	1	4.6.73	(20-21)
7.Tumkur	1. Gubbi	144	24	1-2.10.84	(04-04)
		139	12	-do-	(14-02)
		108	6	1.10.84	(17-23)
		91	3	29.9.80	(20-23)
		51	1	28.5.82	(23-24)
8.Hassan	1. Hassan	89	24	26-27.9.78	(15-15)
		85	12	7-.8.10.89	(15-03)
		85	6	7.10.89	(16-22)
		76	3	-do-	(16-19)
		59	1	-do-	(17-18)
9.North Kanara	1.Honawar	307	24	15-16.6.86	(13-13)
		262	12	2.10.88	(03-15)
		195	6	-do-	(06-12)
		121	3	-do-	(09-12)
		100	1	7.9.84	(03-04)
10. Bijapur	1. Hungud	109	24	26-27.09.89	(07-07)
		85	12	5-6.08.87	(16-04)
		77	6	3-4.09.81	(20-02)
		70	3	25.06.87	(02-05)
		61	1	-do-	(02-03)
MAHARASHTRA					
1.Pune	1.Dhond	107	24	27-28.6.74	(19-19)
		95	12	-do-	(19-07)
		87	6	do-	(19-01)
		67	3	24.10.74	(18-21)
		60	1	6.6.74	(14-15)
2.Sangli	1.Sangli	114	24	17-18.10.75	(22-22)
		103	12	23-24.9.80	(17-05)
		103	6	23.9.80	(17-23)
		94	3	-do-	(18-21)
		59	1	-do-	(18-19)

State/District	SRRG Station	Highest Observed Storm Rainfall (mm)	Duration (Hr)	Date & Time Of Occurrence	Clock Hour
1	2	3	4	5	6
ANDHRA PRADESH					
1. Anantpur	1.Anantpur	164	24	25-26.9.74	(23-23)
		164	12	26.9.74	(11-23)
		163	6	-do-	(17-22)
		135	3	-do-	(18-21)
		100	1	10.6.78	(18-19)
2.Cuddapah	1.Cuddapah	93	24	13-14.9.76	(22-22)
		76	12	10.6.82	(01-13)
		76	6	-do-	(01-07)
		70	3	-do-	(01-04)
		64	1	22.9.78	(05-06)
3.Mehboobnagar	3.Mehboobnagar	239	24	12-13.5.79	(22-22)
		173	12	13.5.79	(10-22)
		114	6	22.9.81	(17-23)
		92	3	-do-	(17-20)
		54	1	3.8.74	(00-01)
4.Raichur	1.Raichur	169	24	6-7.10.75	(15-15)
		162	12	-do-	(15-03)
		121	6	6.10.75	(15-21)
		91	3	23.4.77	(03-06)
		87	1	-do-	(03-04)
5.Guntur	1.Rentachintala	80	24	7-8.3.75	(16-16)
		80	12	-do-	(16-04)
		80	6	7.3.75	(16-22)
		80	3	-do-	(16-19)
		65	1	31.5.71	(17-18)

Annexure 4.3

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

Inter-Mediate Hours	Design Storm Duration (Hours)																							Inter-Mediate Hours
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1	100	89	78	67	62	59	44	41	39	37	35	34	33	32	31	30	29	29	20	20	19	19	18	17	1
2	-	100	95	86	81	76	64	61	57	55	52	50	45	43	42	41	40	38	35	34	33	32	31	29	2
3	-	-	100	96	91	86	77	73	70	67	62	61	55	52	51	50	49	44	42	41	40	39	38	37	3
4	-	-	-	100	97	94	85	81	78	75	72	70	63	61	60	57	56	54	49	48	47	46	44	43	4
5	-	-	-	-	100	98	91	87	84	81	78	76	70	68	65	63	61	60	56	54	53	52	51	50	5
6	-	-	-	-	-	100	97	92	89	86	83	81	76	74	72	70	67	65	62	60	59	57	56	55	6
7	-	-	-	-	-	-	100	97	94	91	87	85	82	79	77	75	72	70	66	65	63	61	60	59	7
8	-	-	-	-	-	-	-	100	97	95	94	89	86	84	81	79	77	75	70	69	67	66	65	63	8
9	-	-	-	-	-	-	-	-	100	98	96	93	90	87	85	83	81	79	73	72	71	70	68	67	9
10	-	-	-	-	-	-	-	-	-	100	98	96	94	91	89	87	85	83	77	75	74	73	71	70	10
11	-	-	-	-	-	-	-	-	-	-	100	98	96	94	92	89	87	85	80	78	76	75	74	73	11
12	-	-	-	-	-	-	-	-	-	-	-	100	98	96	94	92	91	89	82	81	80	78	77	75	12
13	-	-	-	-	-	-	-	-	-	-	-	-	100	98	96	95	93	91	85	84	82	81	80	78	13
14	-	-	-	-	-	-	-	-	-	-	-	-	-	100	98	97	96	94	89	87	85	83	82	80	14
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	98	96	93	90	88	86	84	83	15
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	98	95	93	91	89	87	85	16
17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	97	95	93	91	89	88	17
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	97	95	94	92	90	18
19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	97	95	94	93	19
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	98	96	95	20
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		100	99	98	97	21
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	[illegible]	98	22
23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	99	23
24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	24

Annexure 4.4

AREAL REDUCTION FACTORS (%) FOR POINT TO AREAL RAINFALL

CATCH MENT AREA (KM²)	Design Storm Duration (Hours)																								CATCH-MENT AREA (KM²)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
00	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	'00	100	100	00
50	89.75	90.75	91.75	92.25	92.75	93.25	93.83	94.42	95.00	95.58	96.17	96.75	96.83	96.92	97.00	97.08	97.17	97.25	97.33	97.42	97.50	97.58	97.67	97.75	50
100	83.50	85.25	87.00	87.58	89.17	88.75	89.54	90.33	91.12	91.92	92.71	93.50	93.67	93.83	94.00	94.17	94.33	94.50	94.67	94.83	95.00	95.17	95.33	95.50	100
150	78.00	80.12	82.25	83.25	84.25	85.25	86.21	87.17	88.12	89.08	90.04	91.00	91.21	91.42	91.62	91.83	92.04	92.25	92.46	92.67	92.87	93.08	93.29	93.50	150
200	73.75	76.12	78.50	79.83	81.17	82.50	33.54	84.58	85.62	86.67	87.71	88.75	89.00	89.25	89.50	89.75	90.00	90.25	90.50	90.75	91.00	91.25	91.50	91.75	200
250	70.25	72.75	75.25	76.83	78.42	80.00	81.12	82.25	83.37	84.50	85.62	86.75	87.04	87.33	87.62	87.92	88.21	88.50	88.79	89.08	89.37	89.67	89.96	90.25	250
300	67.25	70.00	72.75	74.42	76.08	77.75	79.00	80.25	81.50	82.75	84.00	85.25	85.56	85.88	86.19	86.50	86.81	87.12	87.44	87.75	88.06	88.37	88.69	89.00	300
350			70.50	72.33	74.17	76.00	77.33	78.67	80.00	81.33	82.67	84.00	84.33	84.67	85.00	85.33	85.67	86.00	86.33	66.67	87.00	87.33	87.67	88.00	350
400			68.50	70.58	72.67	74.75	76.08	77.42	78.75	80.08	81.42	82.75	83.08	83.42	83.75	84.08	84.42	84.75	85.08	85.42	85.75	86.08	86.42	86.75	400
450			67.00	69.17	71.33	73.50	74.83	76.17	77.50	78.83	80.17	81.50	81.88	82.25	82.62	83.00	83.37	83.75	84.12	84.50	84.87	85.25	85.62	86.00	450
500			65.75	67.92	70.08	72.25	73.62	75.00	76.37	77.75	79.12	80.50	80.88	81.25	81.62	82.00	82.37	82.75	83.12	83.50	83.87	84.25	84.62	85.00	500
600												78.75	79.17	79.58	80.00	80.42	80.83	81.25	81.67	82.08	82.50	82.92	83.33	83.75	600
700												77.50	77.92	78.33	78.75	79.17	79.58	80.00	80.42	80.83	81.25	81.67	82.08	82.50	700
800												76.50	76.92	77.33	77.75	78.17	78.58	79.00	79.42	79.83	80.25	80.67	81.08	81.50	800
900												75.75	76.19	76.62	77.06	77.50	77.94	78.37	78.81	79.25	79.69	80.12	80.56	81.00	900
1000												75.00	75.44	75.88	76.31	76.75	77.19	77.62	78.06	78.50	78.94	79.37	79.81	80.25	1000
1100												74.50	74.96	75.42	75.87	76.33	76.79	77.25	77.71	78.17	78.62	79.08	79.54	80.00	1100
1200												74.00	74.46	74.92	75.37	75.83	76.29	76.75	77.21	77.67	78.12	78.58	79.04	79.50	1200
1300																								79.25	1300
1400																								79.20	1400
1500																								78.75	1500
2000																								78.00	2000

LIST OF SUG PARAMETERS OBTAINED FROM EQUATIONS

Sl.No.	Br.No.	C.A. (Km^2)	Q_P Cumec	q_p Cumec per sq.km	Tp Hrs	W_{50} Hrs	W_{75} Hrs	WR_{50} Hrs	WR_{75} Hrs	T_B Hrs.	1 Cm Volume (Cumec)
1	2	3	4	5	6	7	8	9	10	11	12
1	53(ii)	1689.92	663.9	0.393	6.50	6.46	3.83	2.36	1.54	20	4694.2
2	63	1357.15	496.6	0.366	7.50	6.97	4.14	2.58	1.67	21	3769.9
3	200	555.37	261.9	0.472	4.50	5.32	3.16	1.89	1.26	16	1542.7
4	328	437.60	206.4	0.472	4.50	5.32	3.16	1.89	1.26	16	1215.6
5	601	398.60	188.0	0.472	4.50	5.32	3.16	1.89	1.26	16	1107.2
6	98	348.40	186.2	0.534	3.50	4.66	2.76	1.62	1.10	14	967.8
7	16	270.60	127.6	0.472	4.50	5.32	3.16	1.89	1.26	16	751.7
8	169	230.87	123.4	0.534	3.50	4.66	2.76	1.62	1.10	14	641.3
9	313	220.45	117.8	0.534	3.50	4.66	2.76	1.62	1.10	14	612.4
10	202	171.70	108.5	0.632	2.50	3.90	2.31	1.32	0.92	12	476.9
11	215(i)	167.32	105.7	0.632	2.50	3.90	2.31	1.32	0.92	12	464.8
12	18	131.52	83.1	0.632	2.50	3.90	2.31	1.32	0.92	12	365.3
13	365	119.60	97.4	0.814	1.50	2.97	1.76	0.97	0.70	9	332.2
14	353	118.25	63.2	0.534	3.50	4.66	2.76	1.62	1.10	14	328.5
15	771	118.23	74.7	0.632	2.50	3.90	2.31	1.32	0.92	12	328.4
16	53(I)	102.45	64.7	0.632	2.50	3.90	2.31	1.32	0.92	12	284.6
17	253	100.98	63.8	0.632	2.50	3.90	2.31	1.32	0.92	12	280.5
18	166	91.27	57.7	0.632	2.50	3.90	2.31	1.32	0.92	12	253.5
19	123	64.75	40.9	0.632	2.50	3.90	2.31	1.32	0.92	12	179.9
20	384	62.16	50.6	0.814	1.50	2.97	1.76	0.97	0.70	9	172.7
21	404	29.78	24.2	0.813	1.50	2.97	1.76	0.97	0.70	9	82.7

Annexure 5.2

COMPUTATION OF EQUIVALENT SLOPE OF BRIDGE CATCHMENT NO. 16

Sl. No.	Reduced Distance		Reduced Level		Length of Each segment (Li) (Km)	Height above the datum (Di) (m)	Di-1+Di (m)	Li (Di-1 + Di) (Km.m)
	RD (Miles)	RD (Km)	RL (Feet)	RL (Metres)				
1	2	3	4	5	6	7	8	9
1	0	0	2000.0	609.60	0	0	0	0
2	8.50	13.68	2050.0	624.84	13.68	15.24	15.24	208.48
3	15.50	24.94	2100.0	640.08	11.26	30.48	45.72	514.81
4	20.00	32.18	2150.0	655.32	7.24	45.72	76.20	551.69
5	22.00	35.40	2180.0	664.46	3.22	54.86	100.58	323.87
							ΣSum	1598.85

Datum (i.e. R.L. of river bed at point of study) = 609.60 m

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

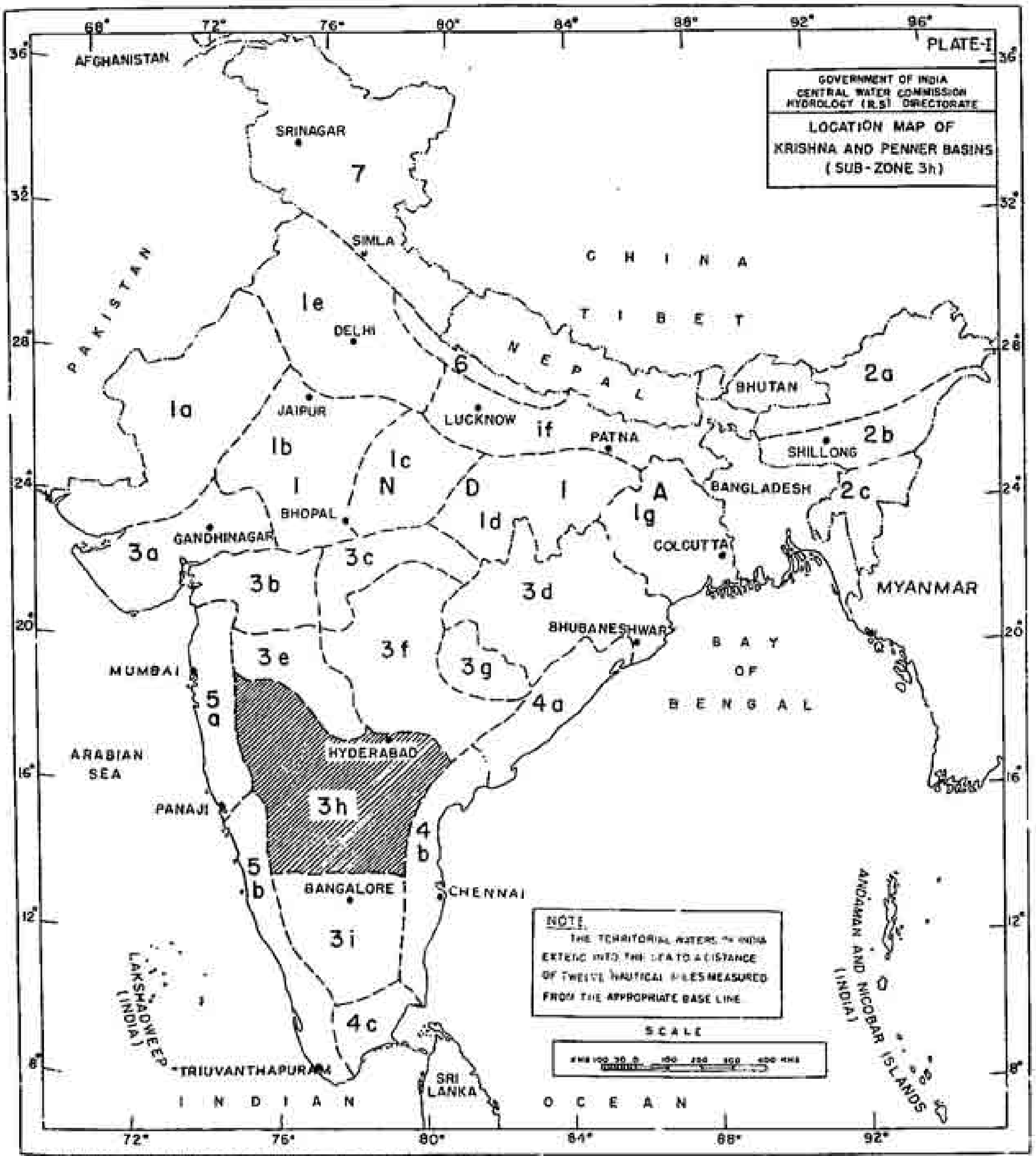
$$= \frac{1598.85}{(35.40)^2}$$

$$= 1.29 \text{ m/Km}$$

Annexure 5.3

COMPUTATION OF DESIGN FLOOD HYDROGRAPH OF BRIDGE CATCHMENT NO. 16

Hours	SUH Ordinates (m^3/s)	Rainfall Excess in Cm 0.15	0.40	1.47	5.04	0.73	Total DSRO (m^3/s)	Base Flow (m^3/s)	Total Flow (m^3/s)
		Direct Runoff (m^3/s)							
1	2	3	4	5	6	7	8	9	10
0	0.00	0.00					0.00	13.53	13.53
1	6.00	0.90	0.00				0.90	13.53	14.43
2	18.00	2.70	2.40	0.00			5.10	13.53	18.63
3	59.50	8.93	7.20	8.82	0.00		24.95	13.53	38.48
4	109.00	16.35	23.80	26.46	30.24	0.00	96.85	13.53	110.38
5	127.60	19.14	43.60	87.47	90.72	4.38	245.31	13.53	258.84
6	114.00	17.10	51.04	160.23	299.88	13.14	541.39	13.53	554.92
7	93.00	13.95	45.60	187.57	549.36	43.43	839.92	13.53	853.45
8	71.50	10.72	37.20	167.58	643.10	79.57	938.17	13.53	**951.70**
9	53.00	7.95	28.60	136.71	574.56	93.14	840.97	13.53	854.50
10	36.50	5.48	21.20	105.11	468.72	83.22	683.72	13.53	697.25
11	25.50	3.83	14.60	77.91	360.36	67.89	524.59	13.53	538.12
12	17.30	2.60	10.20	53.66	267.12	52.19	385.77	13.53	399.30
13	11.30	1.70	6.92	37.49	183.96	38.69	268.75	13.53	282.28
14	6.70	1.01	4.52	25.43	128.52	26.64	186.12	13.53	199.65
15	2.80	0.42	2.68	16.61	87.19	18.61	125.52	13.53	139.05
16	0.00	0.00	1.12	9.85	56.95	12.63	80.55	13.53	94.08
17			0.00	4.12	33.76	8.25	46.13	13.53	59.66
18				0.00	14.11	4.89	19.00	13.53	32.53
19					0.00	2.04	2.04	13.53	15.57
20						0.00	0.00	13.53	13.53



THE EXTERNAL BOUNDARY AND COAST LINE OF INDIA ON THE MAPS AGREE WITH THE RECORD COPY CERTIFIED BY THE SURVEY OF INDIA.

P.I.

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

PLATE No- 3.

REFERENCES:-

ALTITUDE IN METRES

- 0 TO 150
- 150 TO 300
- 300 TO 600
- ABOVE 600

NOTE:- THIS MAP HAS BEEN DRAWN FROM IRRIGATION ATLAS OF INDIA (YEAR 1989) PLATE No- 18.

SCALE

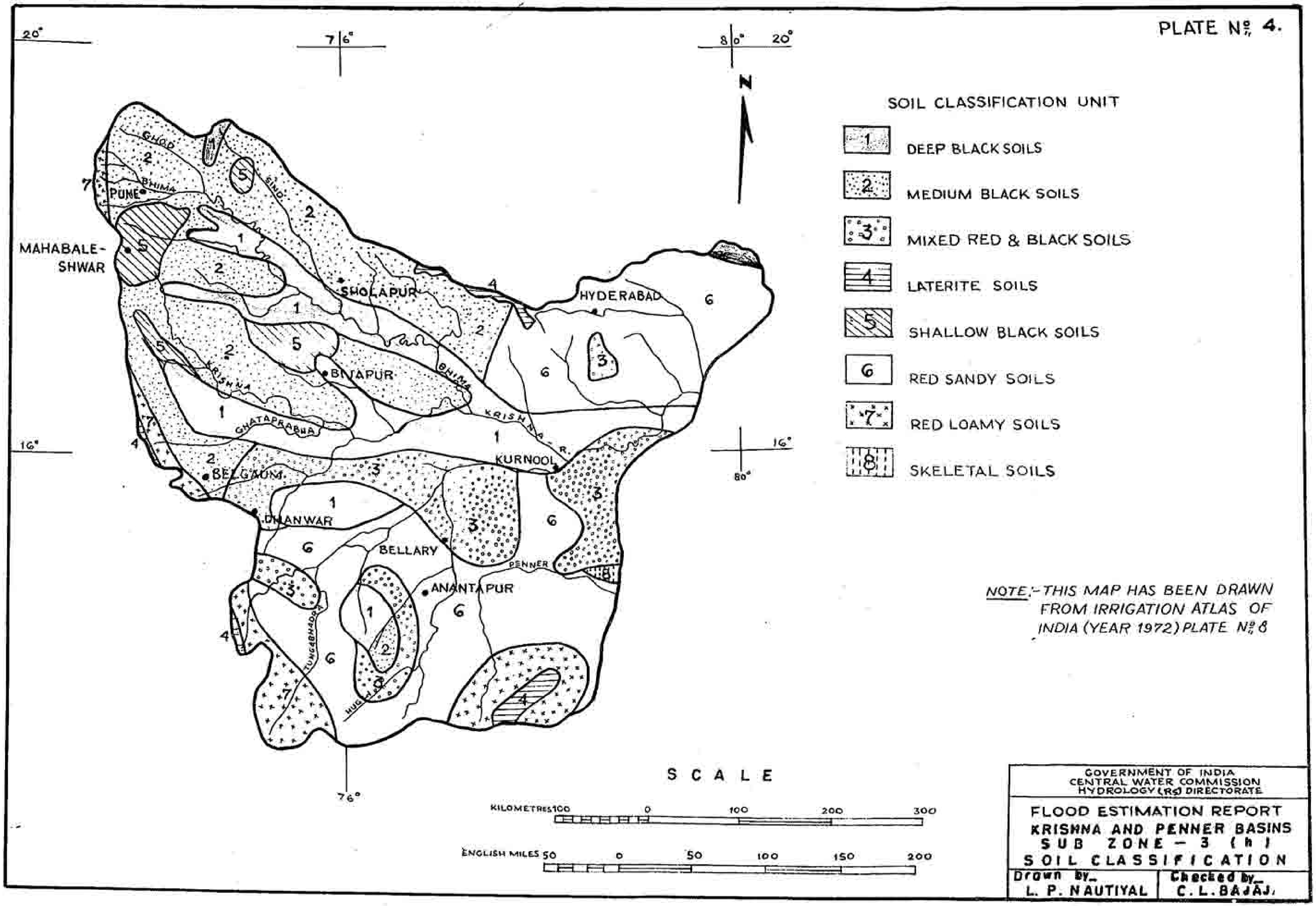
KILOMETRES 100 40 0 100 200 300

ENGLISH MILES 50 0 50 100 150 200

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

FLOOD ESTIMATION REPORT
KRISHNA AND PENNER BASINS
SUB ZONE - (3(h)
PHYSIOGRAPHY

DRAWN_ PANT	CHECKED_ BAJAJ

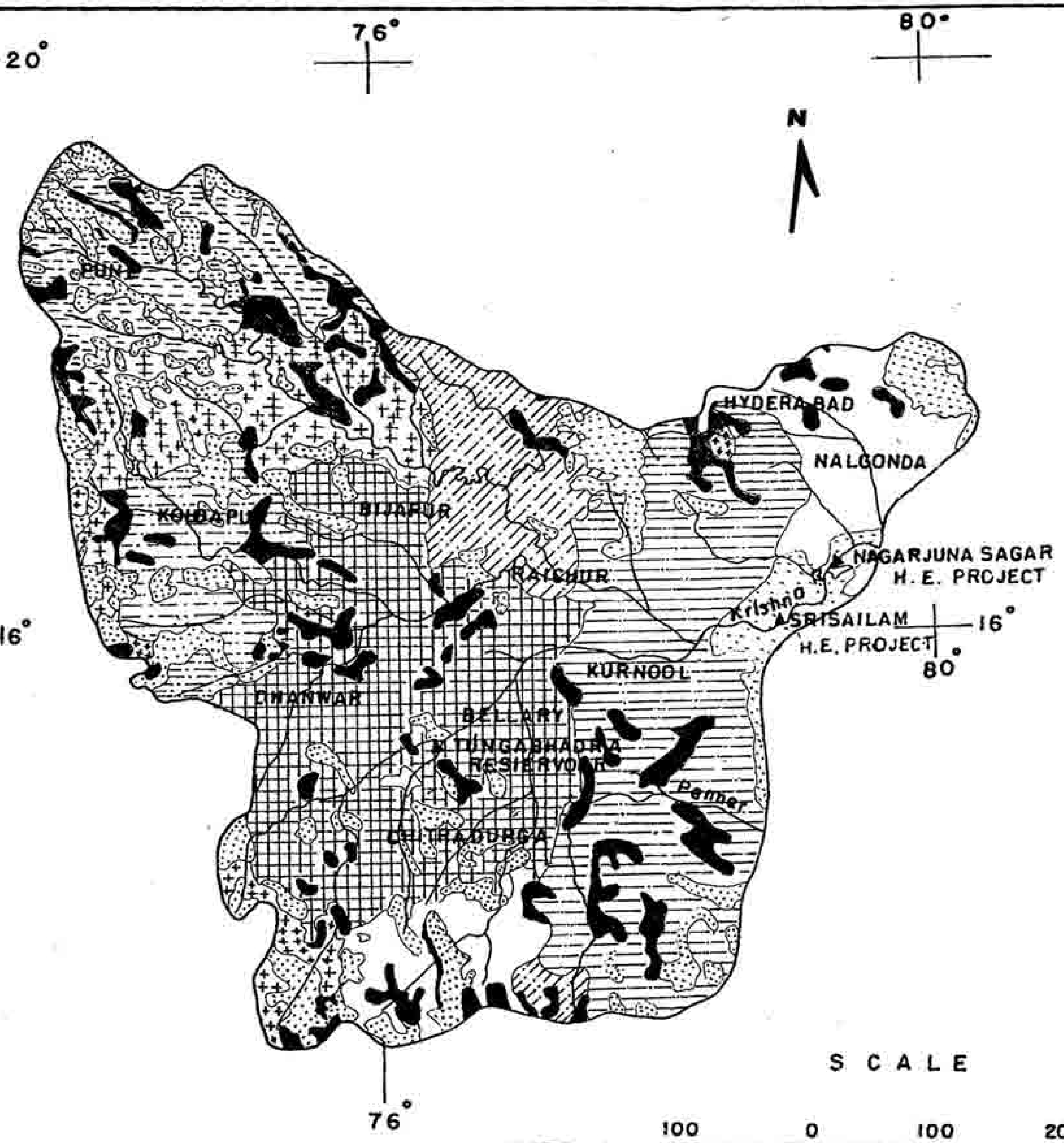


GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (RS) DIRECTORATE

FLOOD ESTIMATION REPORT
KRISHNA AND PENNER BASINS
SUB ZONE - 3 (h)
SOIL CLASSIFICATION

Drawn by_	Checked by_
L. P. NAUTIYAL	C. L. BAJAJ.

PLATE – 5



REFERENCES –

- SCRUB
- FOREST
- MILLETS & COTTON
- MILLETS–OILSEEDS
- WHEAT – SUGARCANE
- MILLETS
- MILLETS – PULSES
- RICE – MILLETS

NOTE – THIS MAP HAS BEEN DRAWN FROM IRRIGATION ATLAS OF INDIA(YEAR.1989) PLATE – 23.

SCALE

KILOMETRES 100 0 100 200 300

ENGLISH MILES 50 0 50 100 150 200

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

FLOOD ESTIMATION REPORT
KRISHNA & PENNER BASINS
SUB ZONE - 3 (h)
LAND USE

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

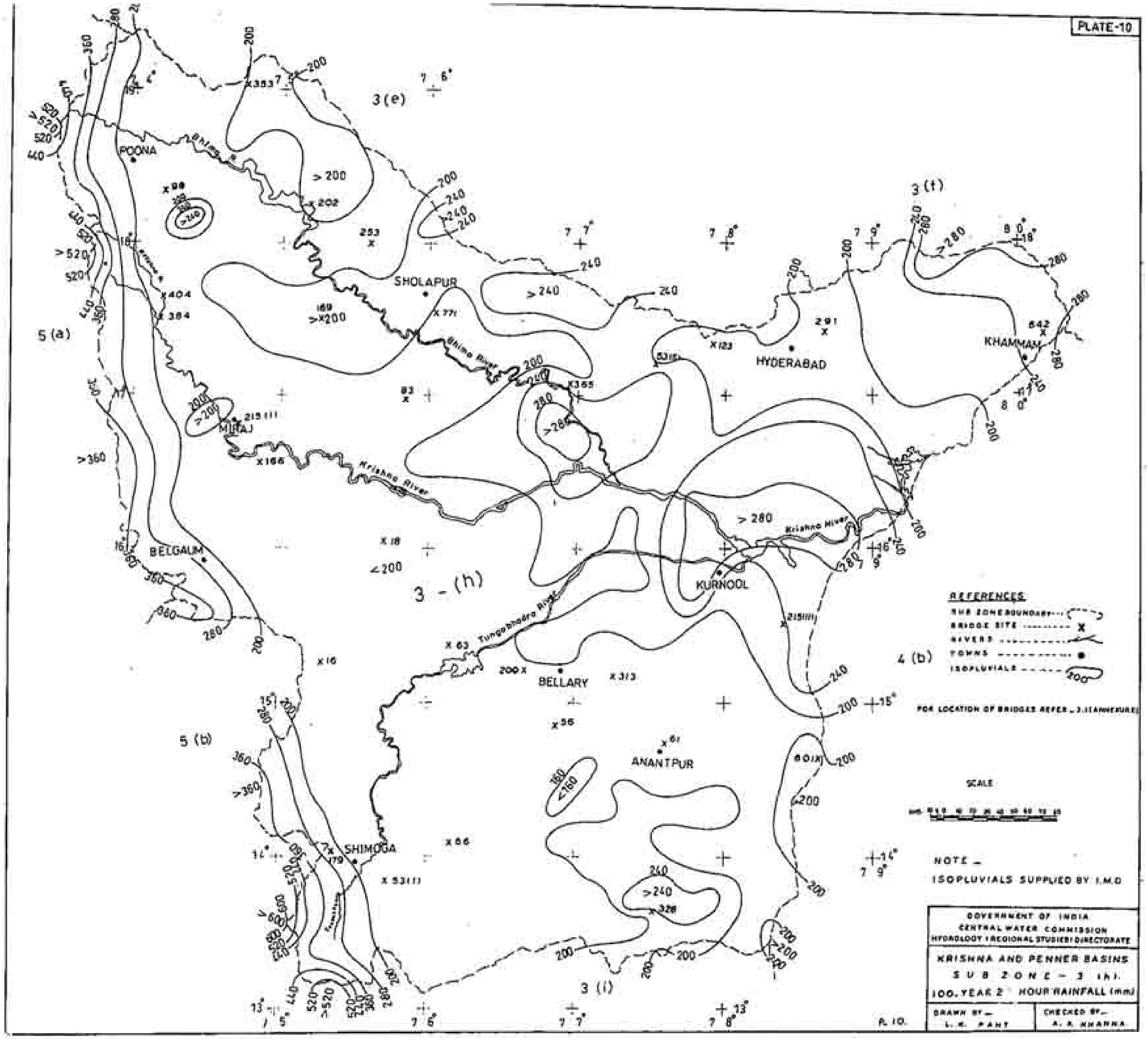
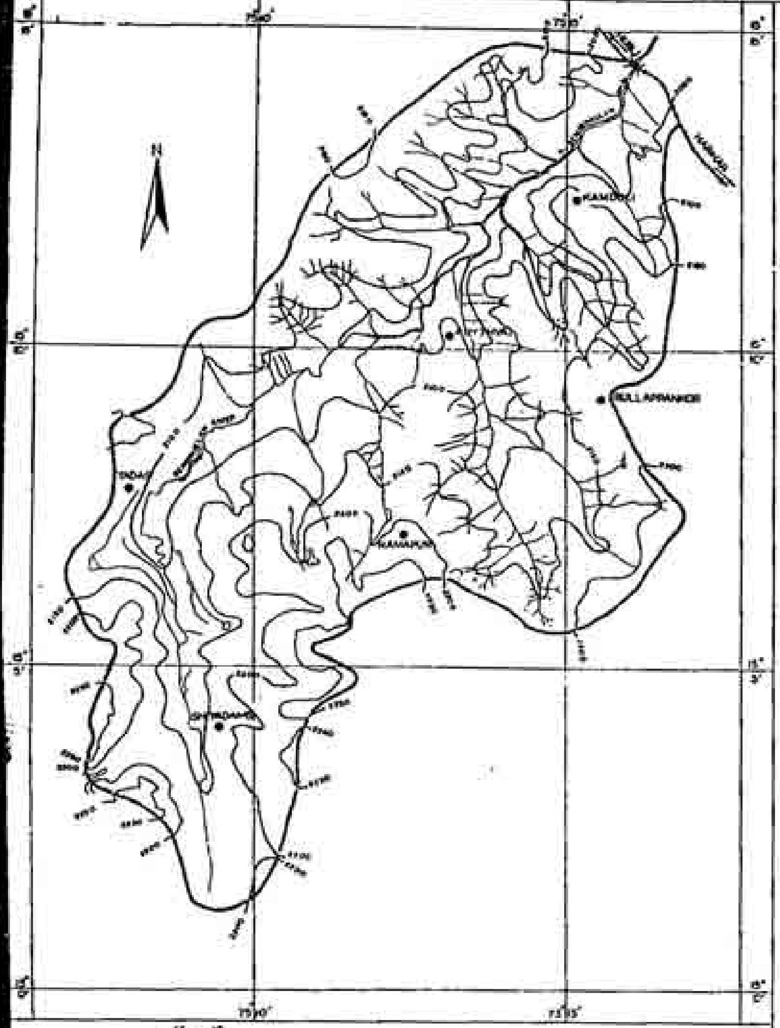


PLATE-10
3 (e)
3 (f)
3 - (h)
3 (i)
4 (b)
5 (a)
5 (b)
POONA
SHOLAPUR
HYDERABAD
KHAMMAM
MIRAJ
BELGAUM
KURNOOL
BELLARY
ANANTPUR
SHIMOGA
Bhima River
Krishna River
Tungabhadra River
REFERENCES
SUB ZONE BOUNDARY
BRIDGE SITE
RIVERS
TOWNS
ISOPLUVIALS
FOR LOCATION OF BRIDGES REFER - 3.1(ANNEXURE)
SCALE
NOTE -
ISOPLUVIALS SUPPLIED BY I.M.D
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DIRECTORATE
KRISHNA AND PENNER BASINS
SUB ZONE - 3 (h).
100-YEAR 24 HOUR RAINFALL (mm)
DRAWN BY -
L. K. PANT
CHECKED BY -
A. K. KHANNA
PL 10.

FIG. - A.I



NOTES:- टिप्पणी

1. ALL LEVELS CORRESPOND TO G.T.S. DATUM.
2. H.F.L. AT GAUGING SITE [illegible]

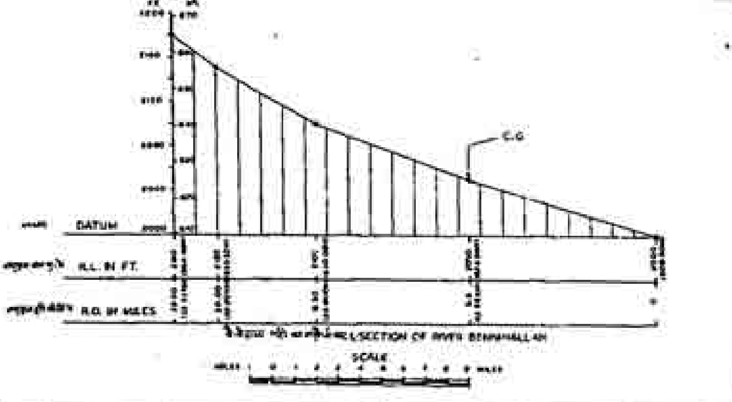
REFERENCES

1. CATCHMENT BOUNDARY
2. RAILWAY LINE
3. RIVER AND ITS TRIBUTARIES
4. RAINGAUGE STATIONS
5. CONTOURS
6. CONTOURS INTERVAL .... 50 FT.

DETAILS OF THE CATCHMENT

1. CATCHMENT AREA .... [illegible]
2. SHAPE OF THE CATCHMENT AREA .... NORMAL
3. L ...... [illegible]
4. Lc ...... [illegible]
5. [illegible]
6. [illegible]

SL. NO.	NAME OF THE R.G. STATIONS	LONG.	LAT.	STATION WEIGHT
1	[illegible]	[illegible]	[illegible]	[illegible]
2	TADAS	[illegible]	[illegible]	[illegible]
3	RAMAPUR	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]
6	KAMDOLI	[illegible]	[illegible]	[illegible]



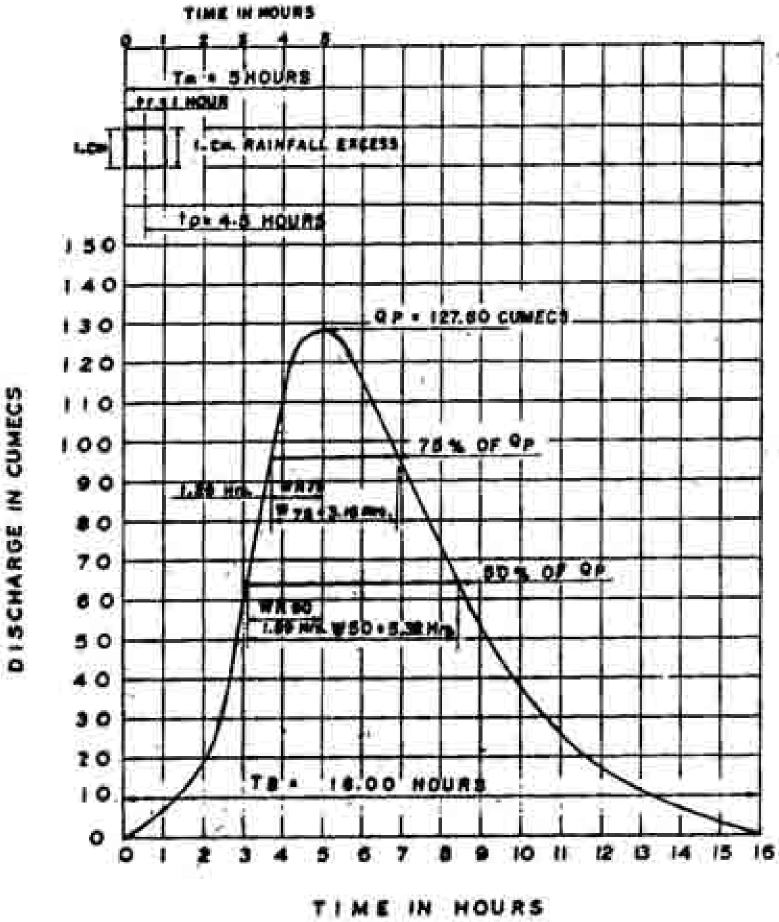
SCALE

CATCHMENT AREA PLAN FOR BRIDGE [illegible]
AT MILE [illegible] ON HUBLI - HARIHAR SEC-
TION SOUTHERN RAILWAY
SUB ZONE - 3A

TRACED | CHECKED

F-1

FIG.- A.2.



SYNTHETIC U.G. PARAMETERS

1.	C. AREA	= 270.6 SQ.KM.
2.	t_r	= 1.00 HOUR
3.	Q_p	= 127.6 CUMECS
4.	t_p	= 4.5 HOURS
5.	q_p	= 0.472 CUM./KM.^{2}
6.	T_m	= 5.0 HOURS
7.	T_B	= 16.0 HOURS
8.	W_{50}	= 5.32 HOURS
9.	W_{75}	= 3.16 HOURS
10.	W_{R50}	= 1.89 HOURS
11.	W_{R75}	= 1.28 HOURS
12.	d	= 1.00 Cm.

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

$$\Sigma Q_i = \frac{270.6 \times 1.00}{1.00 \times 0.36}$$

$$= 751.70 \text{ CUMECS}$$

1. HOUR S.U.G ORDINATES

HOURS	ORDINATES
0	0
1	8.00
2	18.00
3	59.50
4	109.00
5	127.60
6	114.00
7	93.00
8	71.50
9	53.00
10	36.50
11	25.60
12	17.30
13	11.30
14	6.70
15	2.80
16	0
TOTAL	751.70 CUMECS

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

KRISHNA & PENNER BASINS
SUB ZONE - 3 (h)
SYNTHETIC UNIT HYDROGRAPH
BRIDGE NO.- 16.

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

FIG. – A.3.

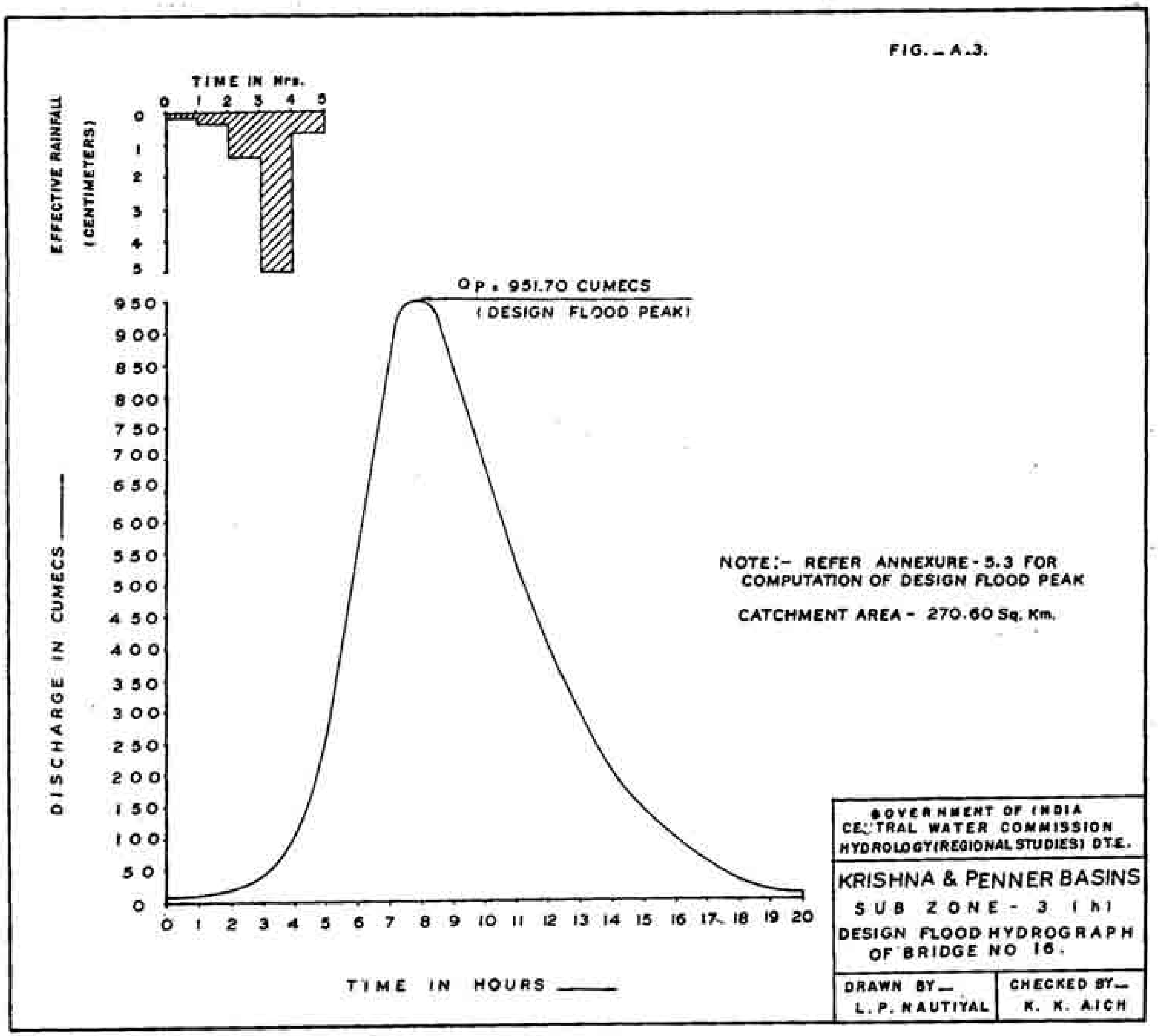
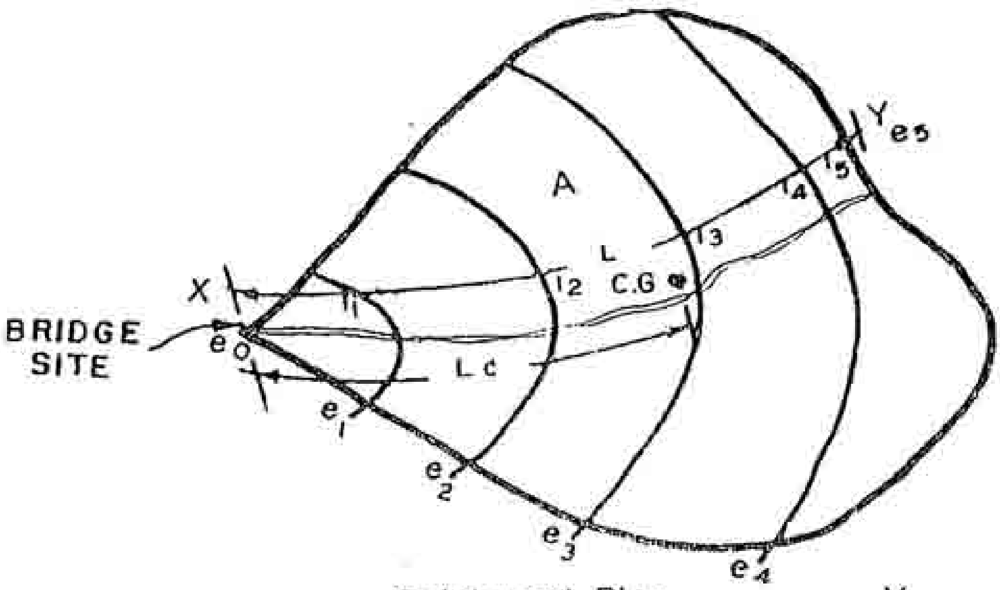
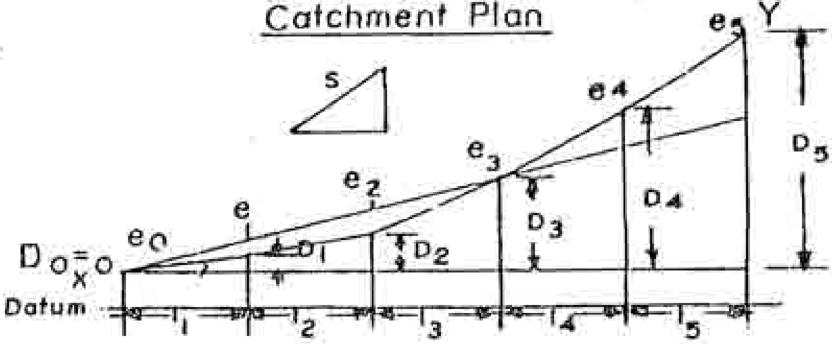

TIME IN Hrs.
0 1 2 3 4 5
EFFECTIVE RAINFALL (CENTIMETERS)
0 1 2 3 4 5
Qp = 951.70 CUMECS
(DESIGN FLOOD PEAK)
DISCHARGE IN CUMECS
950 900 850 800 750 700 650 600 550 500 450 400 350 300 250 200 150 100 50 0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
TIME IN HOURS
NOTE:- REFER ANNEXURE - 5.3 FOR COMPUTATION OF DESIGN FLOOD PEAK
CATCHMENT AREA - 270.60 Sq. Km.
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.
KRISHNA & PENNER BASINS
SUB ZONE - 3 (h)
DESIGN FLOOD HYDROGRAPH OF BRIDGE NO 16.
DRAWN BY — L. P. NAUTIYAL
CHECKED BY — 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)

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

A = Catchment area (km^2)

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

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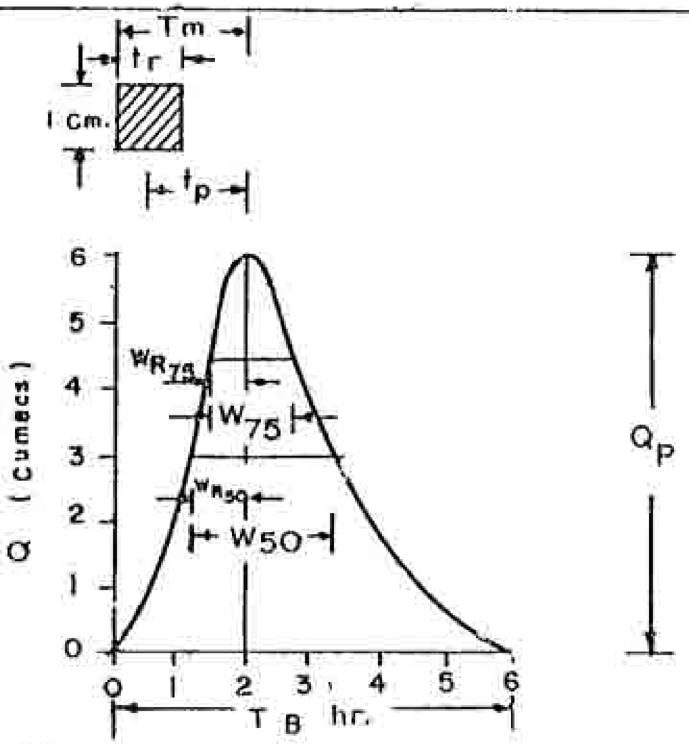
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

PHYSIOGRAPHIC PARAMETERS

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

FIG. - 2.



U.G = Unit Graph

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

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

Q_P = Peak Discharge of Unit Hydrograph (Cumecs.)

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

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.)

TB = Base width of Unit Hydrograph (hr.)

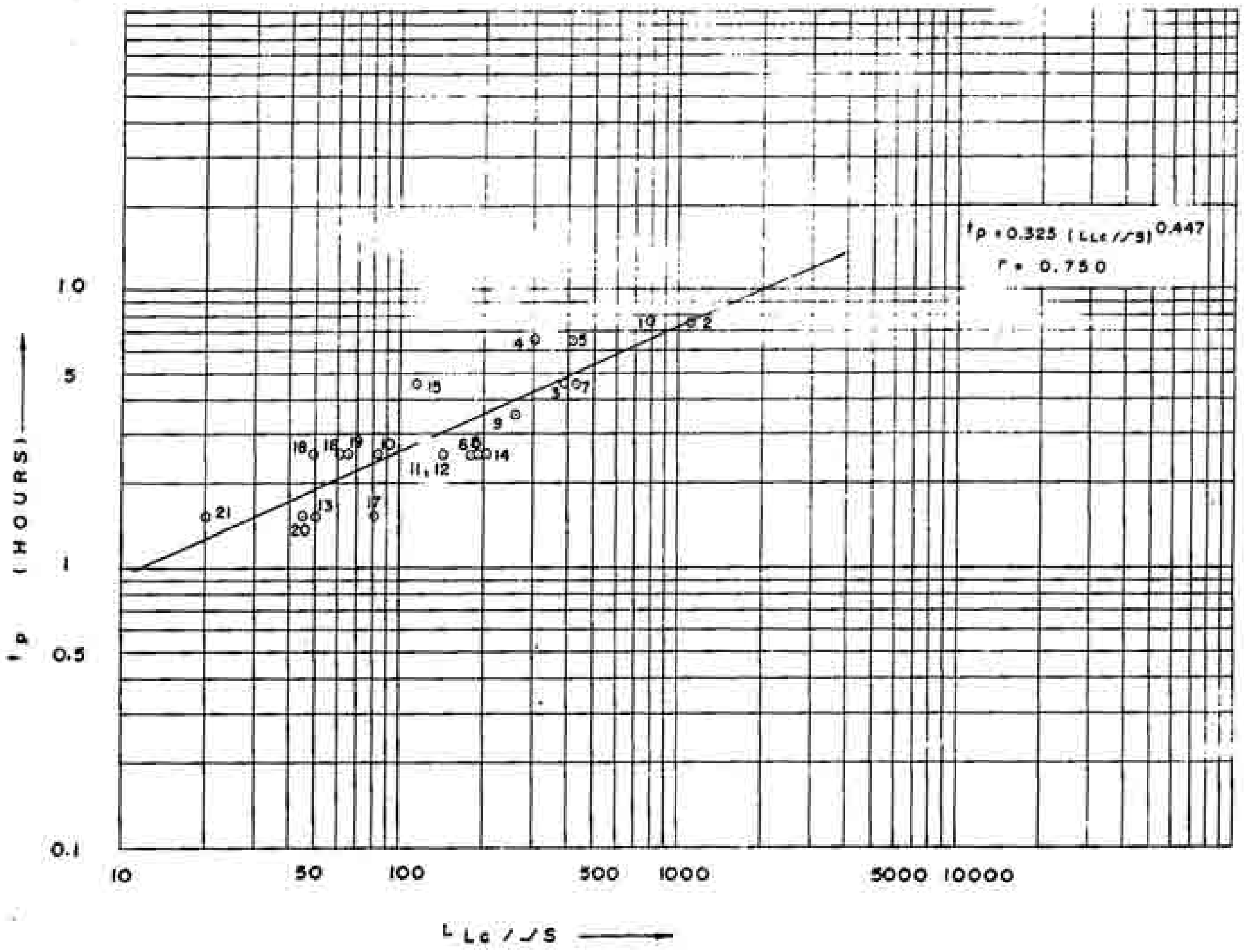
A = Catchment Area (Sq.km.)

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

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (R.S.) DIRECTORATE
UNIT GRAPH PARAMETERS
DRAWN BY- NAUTIYAL / CHECKED BY- C.L. BAJAJ

FIG. 3.

SCALE - LOG X LOG



SL. NO.	BRIDGE NO.	$L_{LC}/\sqrt{S}$	ACTUAL t_p (HOURS)	ESTT. t_p (HOURS)
1	53(II)	796.21	7.5	6.44
2	62	1111.65	7.5	7.47
3	200	388.17	4.5	4.68
4	528	303.94	6.5	4.18
5	601	415.93	6.5	4.81
6	98	182.00	2.5	3.33
7	16	433.08	4.5	4.90
8	169	191.15	2.5	3.40
9	313	261.09	3.5	3.91
10	202	84.35	2.5	2.38
11	2/5(I)	143.68	2.5	2.99
12	18	143.13	2.5	2.99
13	365	50.39	1.5	1.87
14	393	205.15	2.5	3.51
15	771	115.60	4.5	2.72
16	53(I)	80.28	2.5	2.03
17	253	79.61	1.5	2.30
18	166	49.63	2.5	1.86
19	123	64.82	2.5	2.10
20	384	45.66	1.5	1.80
21	404	20.03	1.5	1.24

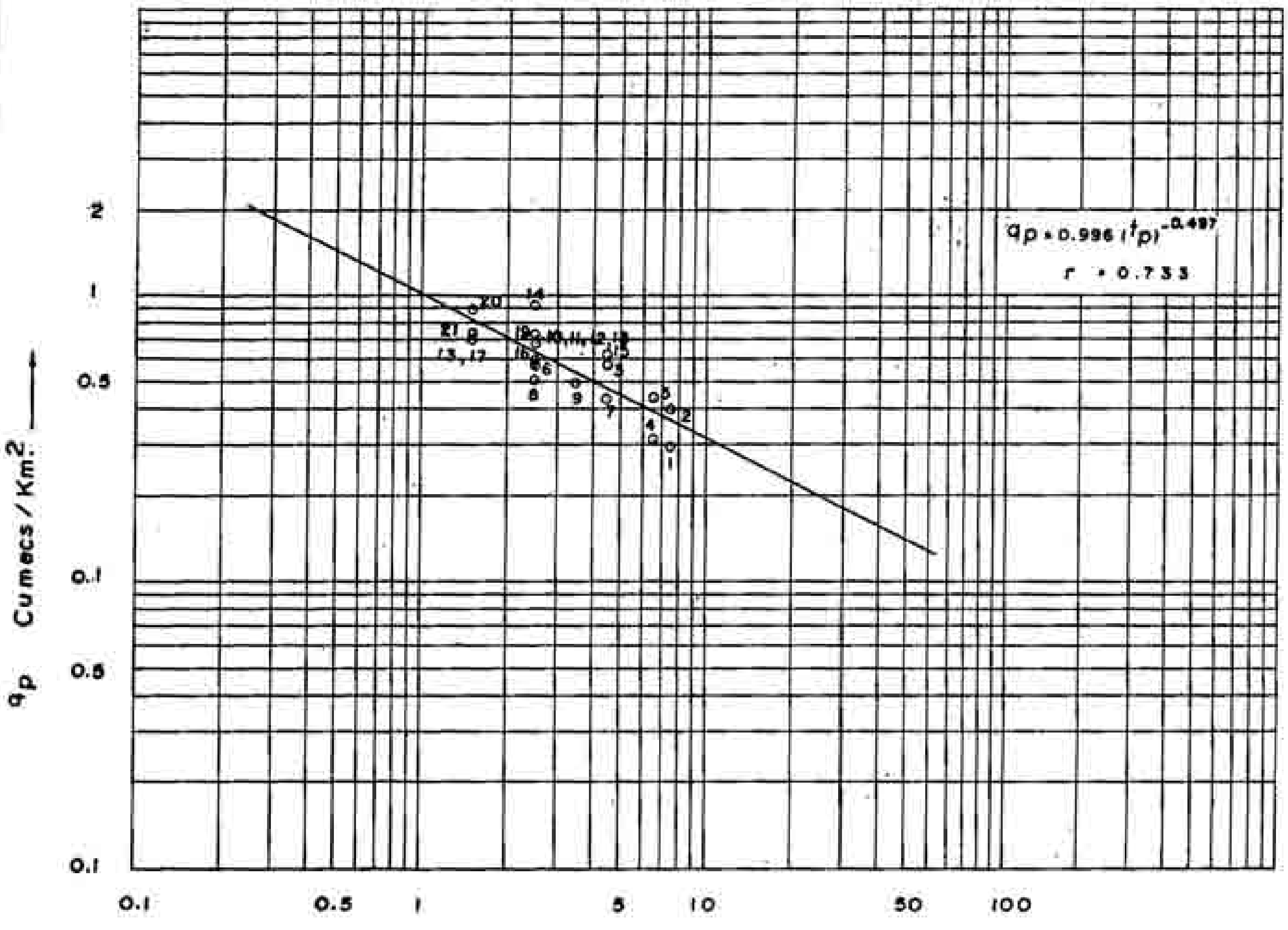
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

KRISHNA & PENNER BASINS
SUB ZONE - 3 (h)
RELATION BETWEEN
t_p AND $L_{LC}/\sqrt{S}$

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

FIG.-4.

SCALE - LOG X LOG



SL. NO.	BRIDGE NO.	t_p (HOURS)	ACTUAL q_p (Cu./Km^2)	ESTI. q_p (Cu./Km^2)
1	53(II)	7.5	0.2939	0.37
2	62	7.5	0.3933	0.37
3	200	4.5	0.5618	0.47
4	328	6.5	0.3082	0.39
5	601	6.5	0.4343	0.39
6	98	2.5	0.5883	0.63
7	16	4.5	0.4324	0.47
8	169	2.5	0.5050	0.63
9	313	3.5	0.4631	0.53
10	202	2.5	0.6738	0.63
11	215(I)	2.0	0.6694	0.63
12	18	2.5	0.6880	0.63
13	366	1.5	0.7285	0.81
14	353	2.5	0.9049	0.63
15	771	4.5	0.6122	0.47
16	53(I)	2.0	0.5753	0.63
17	25-3	1.5	0.7164	0.81
18	166	2.5	0.6682	0.63
19	123	2.5	0.7101	0.63
20	384	1.5	0.6731	0.81
21	404	1.5	0.7529	0.81

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

KRISHNA & PENNER BASINS
SUB ZONE - 3 (h)
RELATION BETWEEN q_p AND t_p

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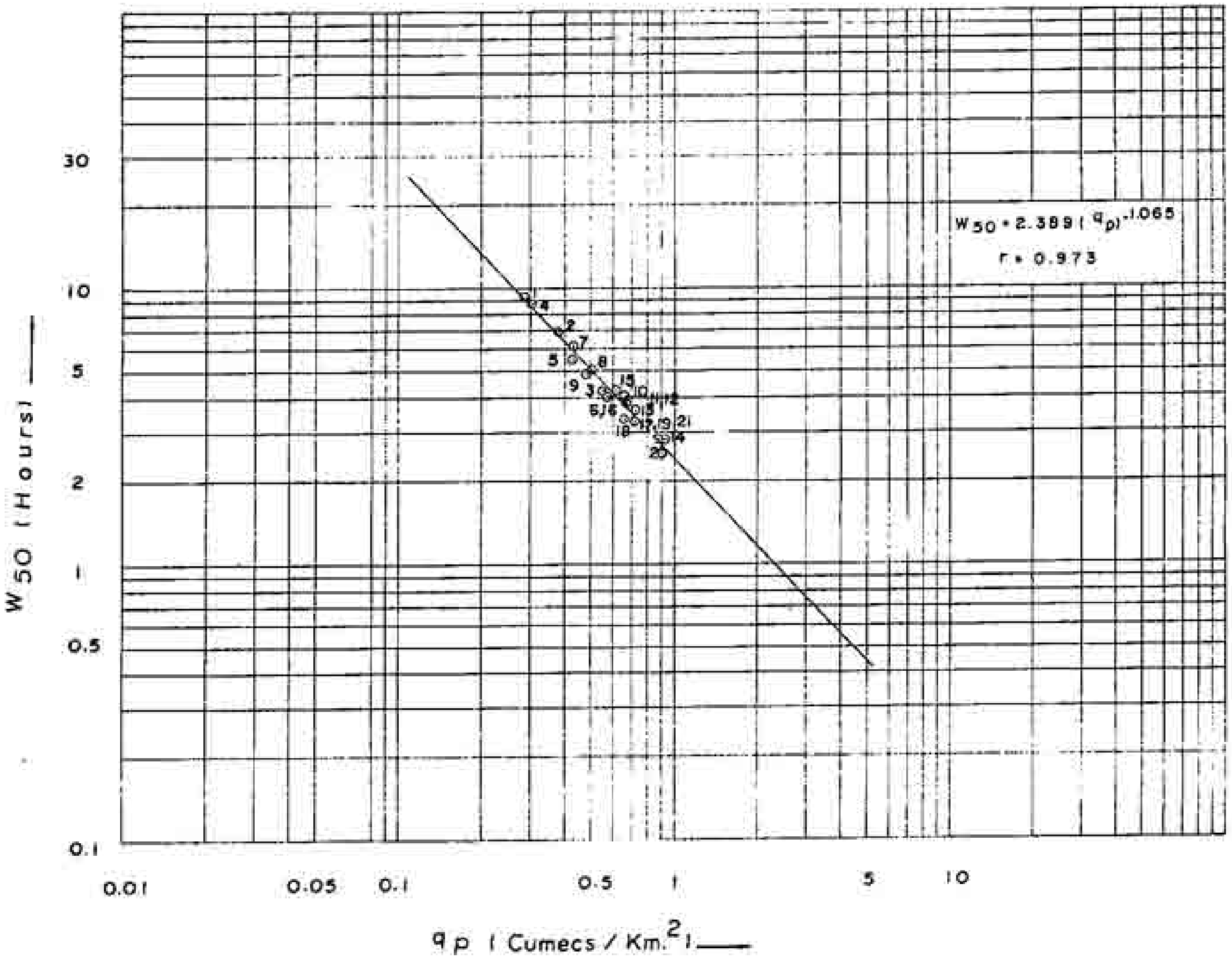
L. K. PANT	C. L. BAJAJ

FIG._5.

SCALE - LOG X LOG



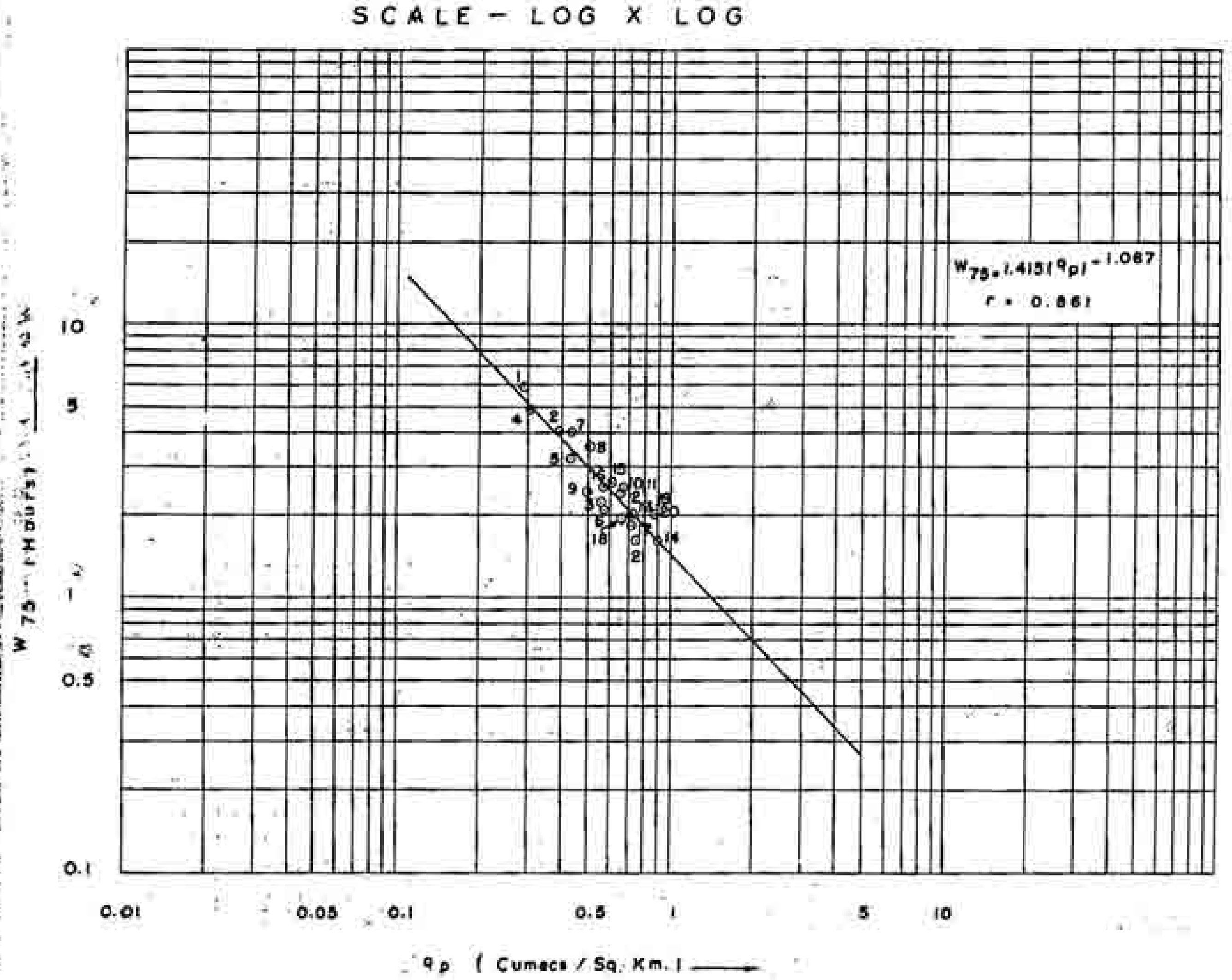
SL. NO.	BRIDGE NO.	qp Cu./Km.²	ACTUAL W50 (HOURS)	ESTI. W50 (HOURS)
1	53(II)	0.2939	9.00	8.80
2	62	0.3933	6.80	6.45
3	200	0.3618	4.20	4.41
4	328	0.3062	8.60	8.43
5	601	0.4343	5.33	5.82
6	98	0.5583	4.00	4.36
7	16	0.4324	6.10	5.83
8	169	0.5050	5.00	4.95
9	313	0.4931	4.90	5.07
10	202	0.6738	3.95	3.64
11	215(I)	0.6594	3.85	3.66
12	18	0.6660	3.80	3.88
13	365	0.7265	3.60	3.36
14	353	0.9049	2.90	2.66
15	771	0.6182	4.20	4.03
16	53(I)	0.5753	4.00	4.30
17	253	0.7184	3.30	3.41
18	166	0.6682	3.30	3.67
19	123	0.7101	3.30	3.44
20	384	0.8731	2.80	2.78
21	404	0.7529	3.20	3.23

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

KRISHNA & PENNER BASINS
SUB ZONE - 3(h)
RELATION BETWEEN
qp AND W50

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

FIG. _ 6.



SL NO.	BRIDGE NO.	q_p C/ Km^2	ACTUAL W_{75} HOURS	ESTI. W_{75} HOURS
1	53(II)	0.2939	5.80	5.23
2	62	0.3933	4.00	3.83
3	200	0.5818	2.20	2.62
4	326	0.3062	4.80	5.00
5	601	0.4343	3.15	3.45
6	38	0.5683	2.20	2.59
7	18	0.4324	4.00	3.46
8	169	0.5030	3.30	2.93
9	313	0.4931	2.40	3.01
10	202	0.6738	2.30	2.18
11	215(II)	0.6694	2.30	2.17
12	18	0.6668	2.40	2.18
13	365	0.7265	2.00	1.98
14	353	0.9048	1.60	1.57
15	771	0.6162	2.60	2.39
16	53(I)	0.5753	2.30	2.55
17	253	0.7164	1.80	2.02
18	166	0.6682	1.90	2.18
19	123	0.7101	2.00	2.04
20	384	0.8731	2.00	1.64
21	404	0.7529	1.60	1.92

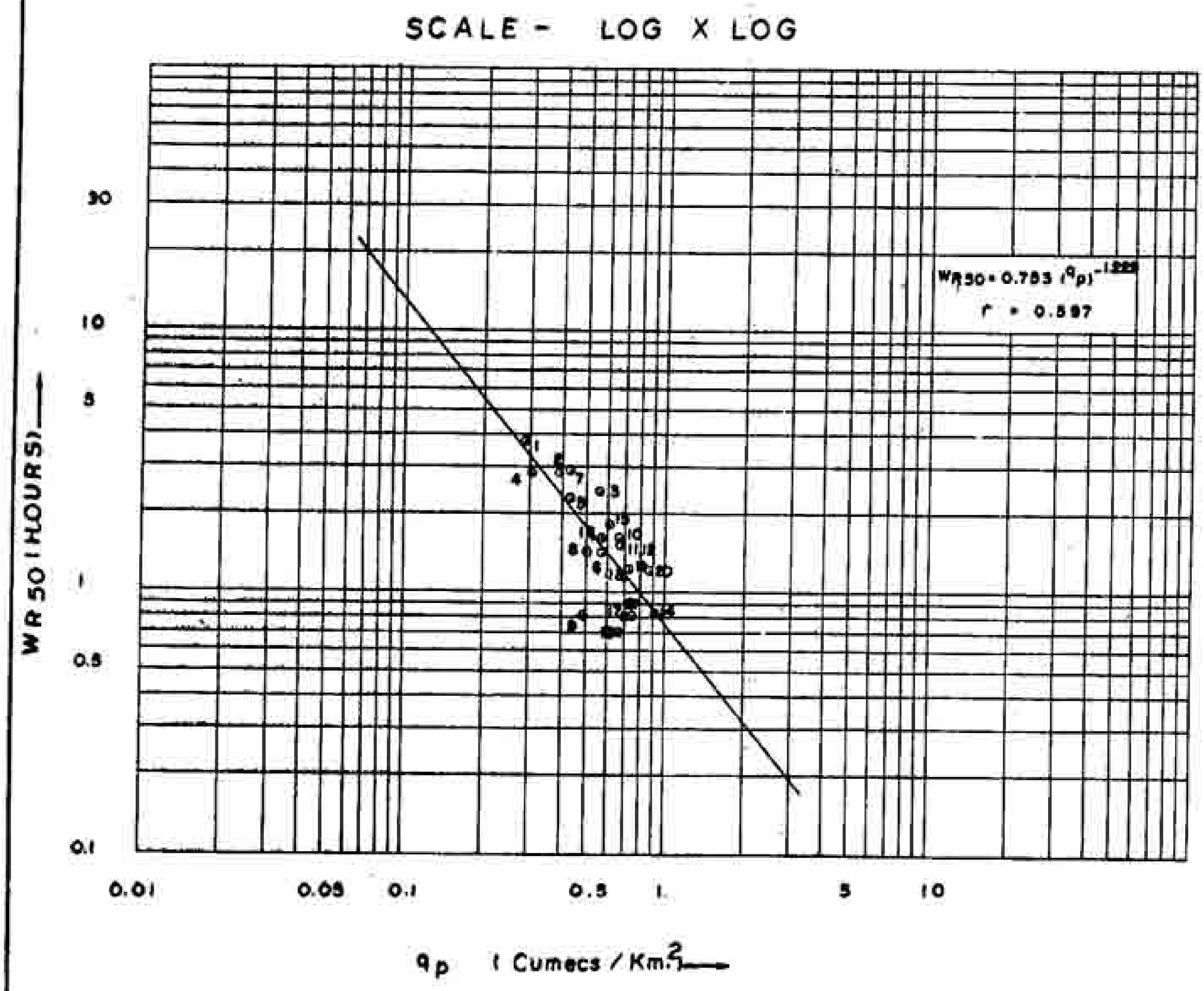
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

KRISHNA & PENNER BASINS
SUB ZONE – 3 (h)
RELATION BETWEEN q_p AND W_{75}

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

F-9.

FIG. — 7.



F. 10.

SL. NO	BRIDGE NO.	q_p (Cum/Km^2)	ACTUAL WR50 HOURS	ESTI. WR50 (HOURS)
1	53(II)	0.2939	3.70	3.39
2	62	0.3933	2.80	2.37
3	200	0.5618	2.40	1.53
4	328	0.3062	2.80	3.22
5	601	0.4345	2.27	2.10
6	98	0.6883	1.40	1.81
7	10	0.4324	2.90	2.11
8	169	0.5080	1.40	1.74
9	313	0.4831	0.80	1.80
10	202	0.6738	1.80	1.22
11	215(I)	0.6694	1.50	1.23
12	18	0.6680	1.50	1.24
13	368	0.7285	1.20	1.12
14	353	0.9049	0.60	0.85
15	771	0.6122	1.80	1.38
16	53(I)	0.5733	1.80	1.49
17	253	0.7184	0.80	1.13
18	188	0.6682	0.70	1.24
19	123	0.7101	1.20	1.15
20	384	0.8731	1.20	0.89
21	404	0.7529	0.80	1.07

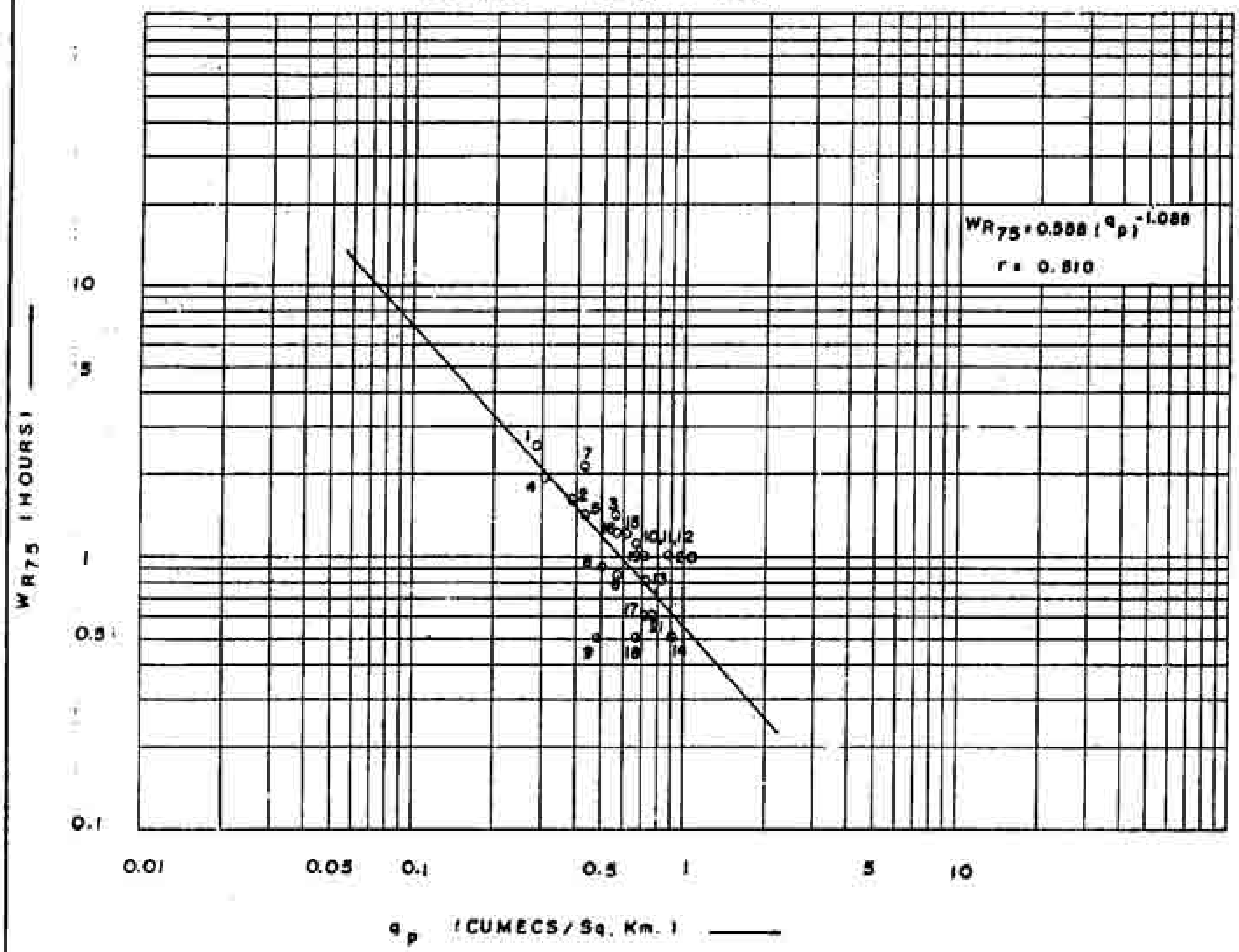
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

KRISHNA & PENNER BASINS
SUB ZONE - 3 (h)
RELATION BETWEEN
q_p AND W_{R50}

DRAWN BY —	CHECKED BY —
L. P. NAUTIYAL	C. L. BAJAJ

FIG. - 8.

SCALE - LOG X LOG



SL. NO.	BRIDGE NO.	q_p C/Km²	ACTUAL WR_{75} HOURS	ESTI. WR_{75} HOURS
1	53(II)	0.2939	2.50	2.11
2	92	0.3933	1.80	1.64
3	200	0.5619	1.40	1.04
4	328	0.3062	1.90	2.02
5	601	0.4343	1.42	1.39
6	98	0.5683	0.85	1.03
7	16	0.4324	2.10	1.39
8	169	0.5060	0.90	1.17
9	313	0.4631	0.50	1.20
10	202	0.6739	1.10	0.86
11	215(I)	0.6694	1.10	0.86
12	18	0.6660	1.10	0.87
13	368	0.7268	0.80	0.79
14	353	0.9049	0.50	0.62
15	771	0.6162	1.20	0.95
16	53(I)	0.5793	1.20	1.02
17	253	0.7164	0.60	0.80
18	148	0.6688	0.50	0.87
19	123	0.7101	1.00	0.81
20	384	0.8731	1.00	0.63
21	404	0.7529	0.60	0.76

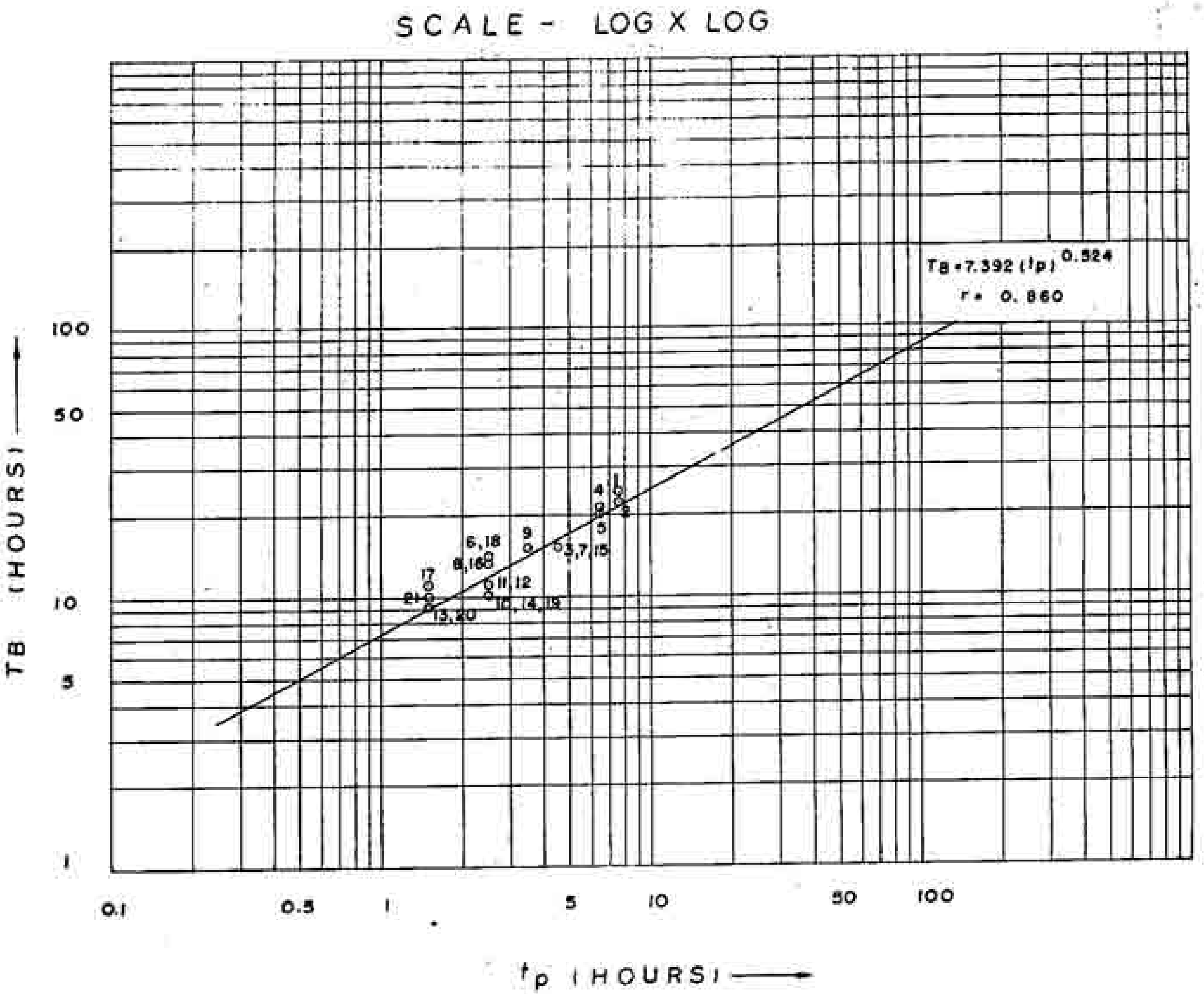
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

KRISHNA & PENNER BASINS
SUB ZONE - 3 (h)
RELATION BETWEEN q_p AND WR_{75}

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

F-11.

FIG. - 9.



Sl. NO.	BRIDGE NO.	t_p (HOURS)	ACTUAL T_B (HOURS)	ESTIM. T_B (HOURS)
1	53(1)	7.5	24	21.25
2	62	7.5	22	21.25
3	200	4.5	15	16.26
4	328	6.5	21	19.71
5	601	6.5	20	19.71
6	98	2.5	14	11.95
7	16	4.5	15	16.26
8	189	2.5	13	11.95
9	313	3.5	15	14.25
10	202	2.5	10	11.95
11	215(1)	2.5	11	11.95
12	18	2.5	11	11.95
13	360	1.5	9	9.14
14	353	2.5	10	11.95
15	771	4.5	15	16.26
16	53(1)	2.5	13	11.95
17	253	1.5	11	9.14
18	168	2.5	14	11.95
19	123	2.5	10	11.95
20	384	1.5	9	9.14
21	404	1.5	10	9.14

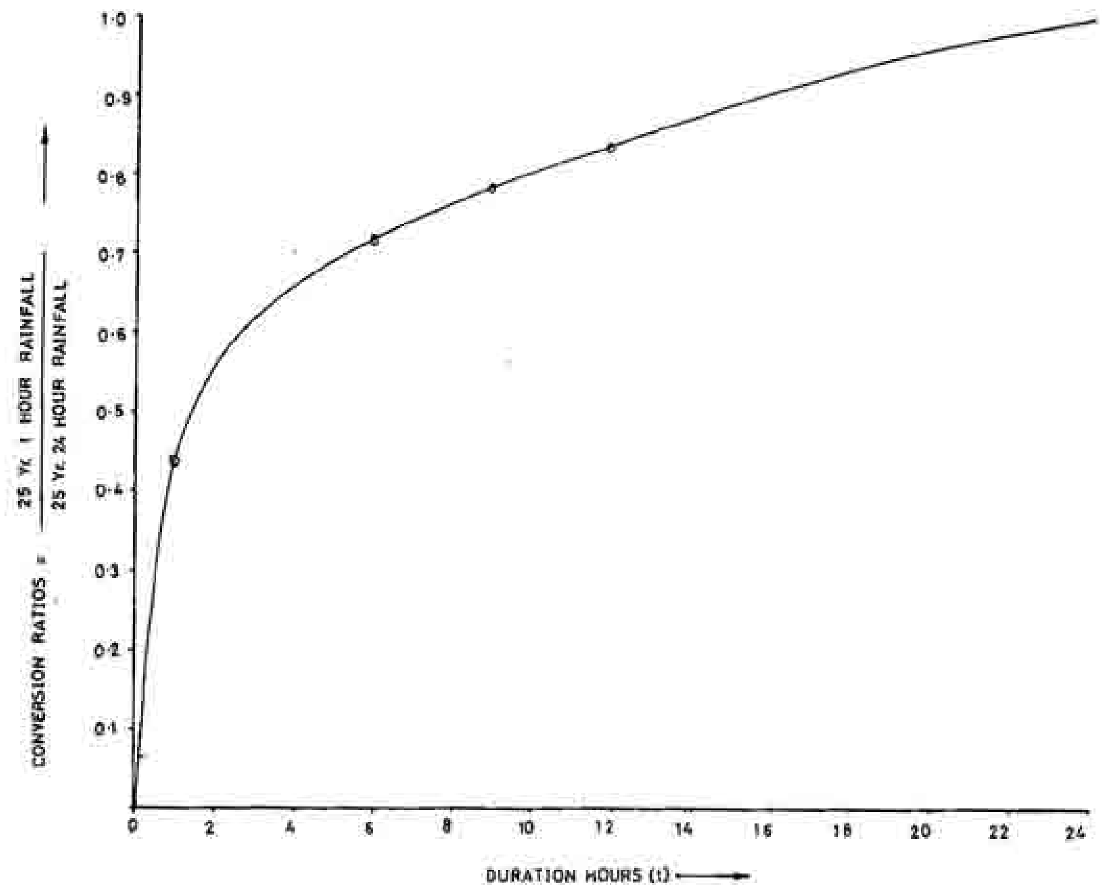
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

KRISHNA & PENNER BASINS
SUB ZONE - 3(h)
RELATION BETWEEN
t_p AND T_B

DRAWN BY — LALIT KUMAR PANT	CHECKED BY — C. L. BAJAJ

F-12

FIG. – 10.



NOTE – CURVE SUPPLIED BY I. M. D

RATIOS OF 24 HOUR POINT RAINFALL TO SHORT DURATION RAINFALL

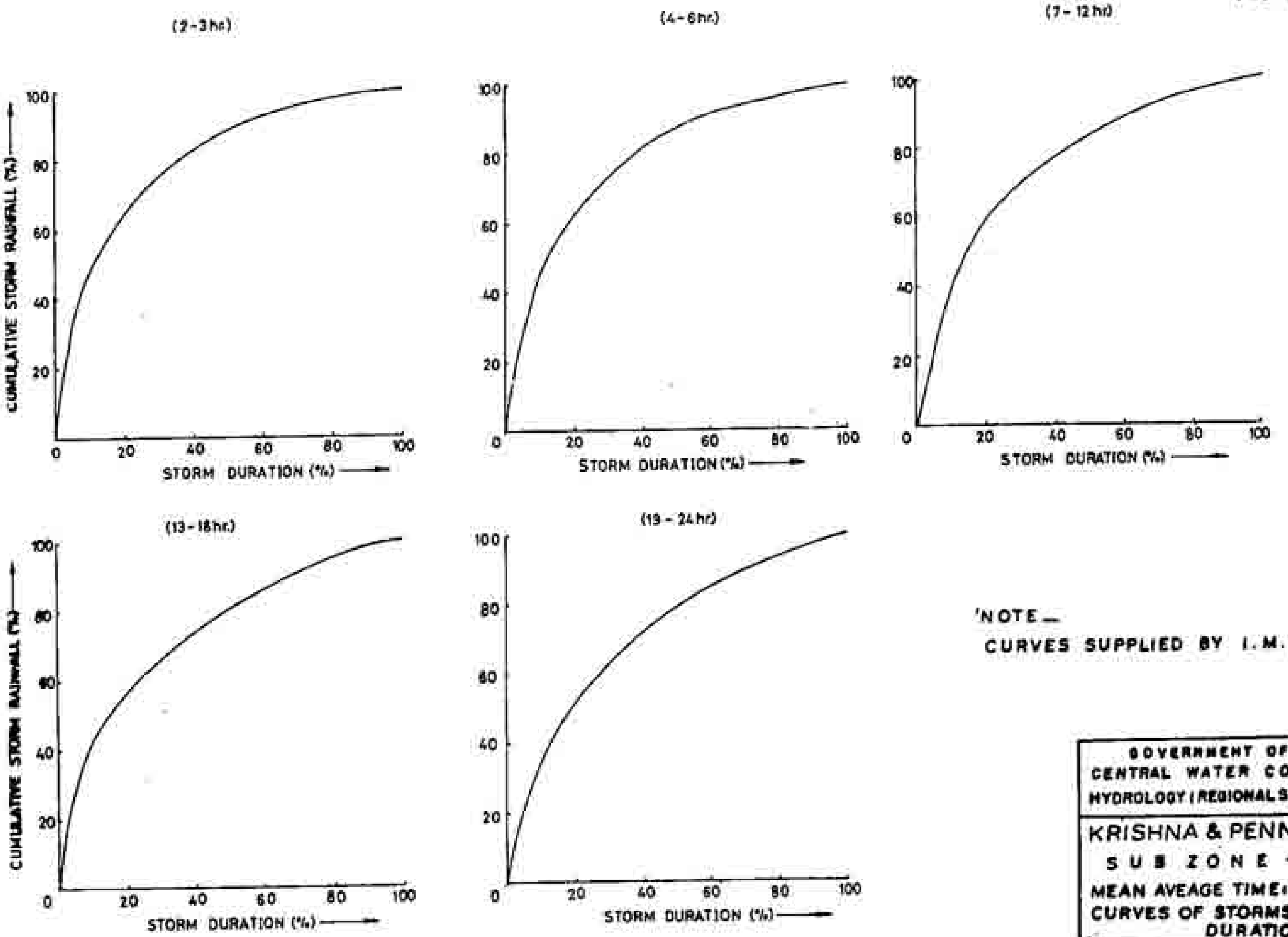
DURATION (HOURS)	RATIOS
1	0·44
2	0·57
3	0·64
4	0·68
5	0·69
6	0·72
7	0·74
8	0·77
9	0·79
10	0·81
11	0·82
12	0·84
13	0·86
14	0·87
15	0·89
16	0·91
17	0·92
18	0·93
19	0·95
20	0·96
21	0·97
22	0·98
23	0·99
24	1·00

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

KRISHNA & PENNER BASINS
SUB ZONE – 3 (h)
DURATION Vs. CONVERSION RATIO

DRAWN BY –	CHECKED BY –
L. P. NAUTIYAL	C. L. BAJAJ

FIG.-11.



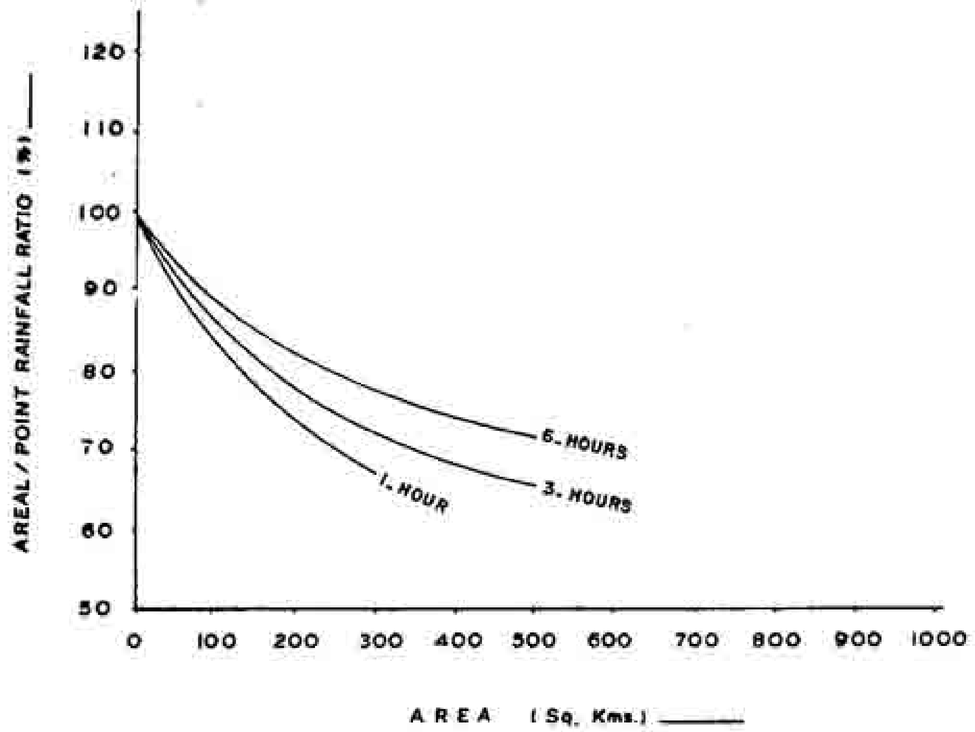
NOTE—
CURVES SUPPLIED BY I. M. D.

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

KRISHNA & PENNER BASINS
SUB ZONE - 3 (h)
MEAN AVEAGE TIME: DISTRIBUTION CURVES OF STORMS OF VARIOUS DURATION

DRAWN BY—	CHECKED BY—
L. P. NAUTIYAL	[illegible]

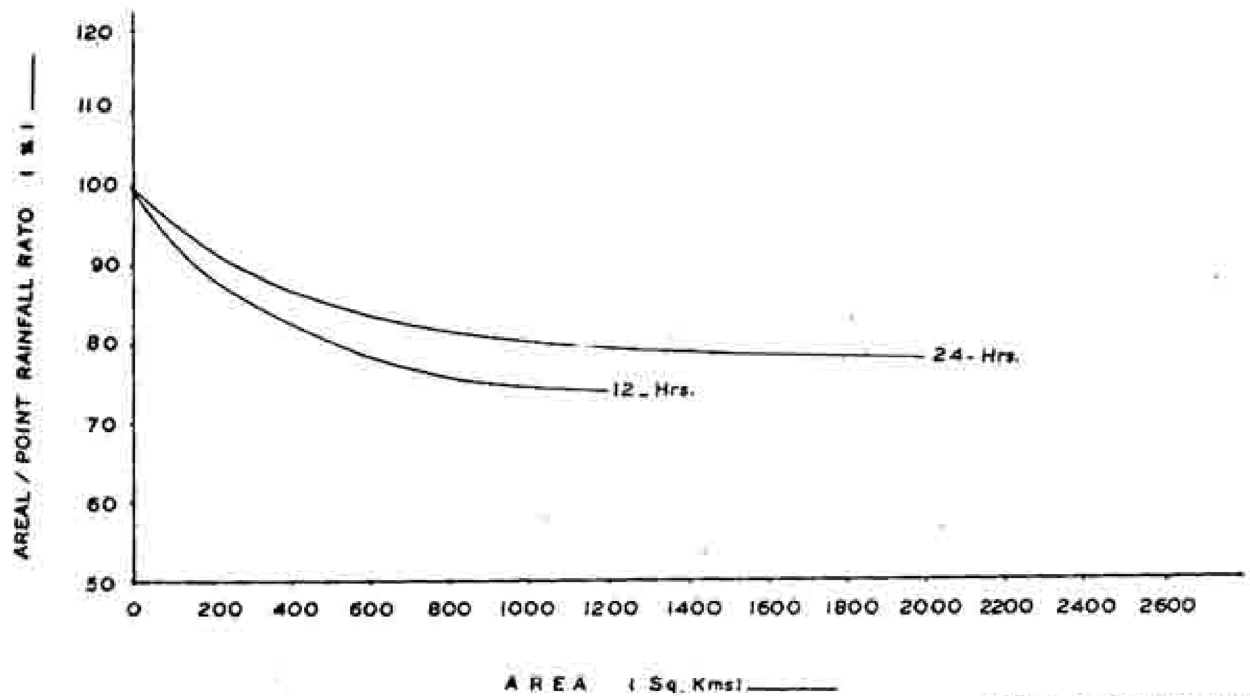
FIG.- 12 (a)



NOTE - CURVES SUPPLIED BY I. M. D.

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (REGIONAL STUDIES) DTE	
KRISHNA & PENNER BASINS SUB ZONE - 3 (h) AREAL TO POINT RAINFALL RATIO FOR 1.Hr. 3.Hrs. & 6.Hrs. (%).	
DRAWN BY_ L. P. NAUTIYAL	CHECKED BY_ C. L. BAJAJ

FIG. – 12 (b).



NOTE - CURVES SUPPLIED BY I. M. D.

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION HYDROLOGY (REGIONAL STUDIES) DTE	
KRISHNA & PENNER BASINS SUB ZONE - 3 (h) AREAL TO POINT RAINFALL RATIO FOR 12 Hrs. & 24-Hrs. (PERCENTAGE)	
DRAWN BY- L. K. PANT	CHECKED BY- K. K. AICH

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3.	Shri A.K. Roy	Chief Design Assistant
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11.	Smt. Shashi Gupta	Stenographer

LIST OF FLOOD ESTIMATION REPORTS PUBLISHED

A. UNDER SHORT TERM PLAN

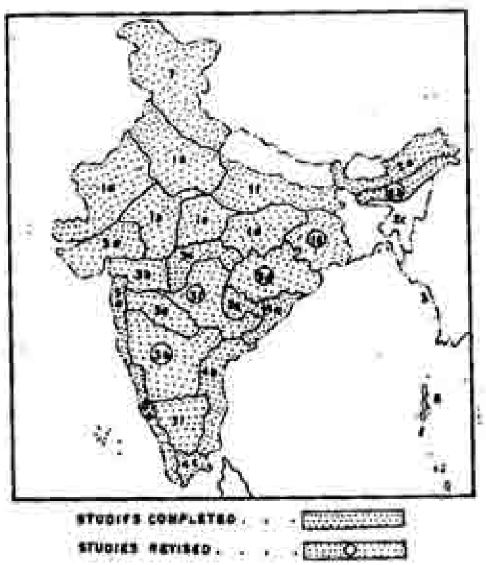
1. Estimation of Design Flood Peak (1973)

B. UNDER LONG TERM PLAN

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

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)
4. South Brahmaputra Subzone 2(b) (2000)



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