# estimation of design flood peak

## A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE

**REPORT NO. 1/73**

(REVISED)

HYDROLOGY FOR SMALL CATCHMENTS DIRECTORATE
CENTRAL WATER COMMISSION
GOVERNMENT OF INDIA, NEW DELHI-110022

FOREWORD

It gives me great pleasure to know that the report, "Estimation of Design Flood Peak" - A method based on unit hydrograph principle, has been very well received by the various Engineering Organisations and Institutions in the country, and the increasing demand for it has called for the second reprint.

The report, first published in 1973, has utilized the stage-discharge and rainfall data of 60 railway bridge catchments spread all over the country. The initial effort put in to bring out this publication deserves appreciation, as it has for the first time, given a rational method of computing design flood discharge for drainage areas between 25 to 500 sq.kms., thereby dispensing with the empirical approach.

With the passage of time, gauge-discharge and short duration rainfall data has become available for more than 400 bridge catchments. By utilising this data, the Hydrology Directorate (Small Catchments) of the Central Water Commission is endeavouring to bring out, under a Long Term Plan, a series of reports on the method of design flood estimation in hydro-meteorologically homogeneous regions of the country. Twenty Six such regions have been identified, and upto now, reports for the lower Gangetic Plains (Sub-Zone 1(g)), Lower Godavari. Sub-Zone (sub-zone 3(f)), Lower Narmada and Tapi Sub-Zone (Sub-Zone 3(b)) and Mahanadi Sub-Zone (Sub-Zone 3(d)) have been published. It is desirable that for drainage areas in the regions for which such regional reports have been published, the methods suggested therein are adopted.

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# PREFACE

The later half of the last century witnessed the first impact of industrial revolution in this country. This brought in its wake considerable improvement in the communication systems. There are many thousands of bridges built at this time on these communication media. Some of them are standing for over a century now - bearing testimony to the intuition, skill and sound judgement of the Engineers in India who did pioneering work in the design and construction of these bridges. However, the multiplicity of authority and multifarious control without coordination of efforts naturally had their limitations and the bridges constructed suffered from lack of standardisation and uniformity. After independence, when most of these communication links became the responsibility of the Union Government, it was considered profitable to review the methods of design of bridges in the light of the latest knowledge and experience gained and to formulate standards which should generally guide the design of bridges in future.

Government of India appointed a Committee of Engineers under the Chairmanship of Dr. A.N. Khosla who considered the various aspects of bridge design and submitted their report in 1959. The Committee made valuable recommendations. It has been recognised that the basic factor in the design of a bridge is the assessment of flood discharge to be safely passed through the structure. The necessity of systematic and sustained collection of hydro-meteorological data has been stressed. Short Term and Long Term plans for achieving the objectives have been suggested. For implementing these plans, the Committee recommended the setting up of specialist cells, on a permanent basis, in Ministry of Railways, Ministry of Transport, India Meteorological Department and Central Water and Power Commission. In pursuance of the recommendations of the Committee of Engineers, Flood Estimation Directorate in C.W.& P.C. has been established in 1965. The Planning and Coordinating Committee was constituted for planning and allocating the work and for reviewing and approving for publication the results of the studies of the various cells.

The work under the Short Term Plan has since been completed. The method evolved for estimating the design flood peak for small drainage basins of areas from 25 to 500 sq. km. is presented in this report. The Planning and Coordinating Committee during the 21st Meeting held in August, 1972 have given their approval and recommended the method for application pending development of better and improved methodology under the Long Term Plan.

This report is based on the studies carried out by Flood Estimation Directorate of C.W. & P. C. in respect of Unit Hydrograph Analysis, Rainfall-Runoff relations and general methodology to be adopted for estimating the design flood. Rainfall depth-duration frequency studies made by Hydromet Cell of India Meteorological Department have also been included in this report in a summary form. The basic data for analysis has been supplied by Bridges & Flood Wing fo Research Designs and Standards Organisation of Ministry of Railways. The report constitutes Chapter VI of the comprehensive report being brought out by Ministry of Railways. The views expressed and the conclusions arrived at are subject to periodical review and revision in the light of further data being collected and analysed. The views expressed in this report do not necessarily represent the views of Central Water and Power Commission.

Strenuous work done by the Officers and staff of Flood Estimation Directorate for bringing out this report is acknowledged. Considerable effort put in by Shri P. Ramakrishna Rao, Dy. Director in carrying out the studies and in drafting the report needs special mention.

Sd/-

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C O N T E N T S

## 1. INTRODUCTION

The flood peak and the time distribution of run-off from a drainage basin during a rainfall storm depend on the meteorological conditions and on the physical characteristics of the basin. To find a formula or to evolve a method that makes it possible to predict, with reasonable accuracy, the flood peak knowing the meteorological features of a rainfall storm and the physical characteristics of the drainage basin is a task engaging the attention of hydrologists all over the world.

For determining the waterway and foundation design floods of desired frequencies for bridges and cross drainage works across innumerable number of small streams, economic considerations do not justify, even on a moderate scale, detailed hydrological and meteorological investigations at every individual site. It would be of immense value if formulae of general validity could be evolved in which only significant parameters of limited number appear characterising the basin system (such as area of the basin, slope and length of the main stream) and the rainfall storm (such as depth, duration and frequency) that could be easily evaluated.

Earlier attempts in India resulted in the empirical formulae developed on the basis of limited experience or study made with liberal assumptions.

<u>Dickens</u>

$$Q = CA^{3/4} \quad \text{with} \quad C = 400 \text{ to } 1400$$

This formula is used widely in North and Central India.

Ryves

$$Q = CA^{2/3} \text{ for maximum flood peak}$$

This formula is widely used in South India with the value of C varying from 450 to 2700.

Inglis

$$Q = CA/(A+4)^{1/2} \text{ for fan-shaped basins with}$$

$$C = 7000.$$

This formula is used in Western Ghat region.

Nawab Ali Nawaz Jung

$$Q = CA^{(a-b \log A)}$$

Where a = 0.89 to 0.92 and b = 1/14 to 1/16

For Tunga Bhadra River Basin, a = 0.92, b = 1/14 and C = 1750.

These formulae made use of only one parameter viz. the area A of the drainage basin in sq. miles. The constant connecting the maximum flood peak and the area of the basin is manipulated in an attempt to account for the host of inter-related factors which impart different flood producing potential. Judgement involved in the evaluation of these co-efficients imposed a serious limitation on the scope of these formulae.

In view of the complex nature of the conditions obtaining in drainage basins and rainfall storms, the relationships with area alone as a parameter will not be adequate. The problem is two-fold:

i) to select a minimum number of parameters that truly represent the basin response to the storm,

ii) to account for the complexities of the patterns of the rainfall storms.

Unit hydrograph represents the response of the drainage basin to a storm of unit rainfall excess. in this report, a method of estimating the flood peak from small drainage basins based on the unit hydrograph principle is described.

## 2. DESIGN FLOOD DEFINED

The estimation of flood peak of a given frequency due to a design rainfall storm is difficult to achieve due to the fact that each element in the estimation procedure introduces some joint probability making the frequency of the flood different from that of the rainfall storm. If average values of all except one parameter are used to estimate the design flood, it is considered reasonable to expect that the flood will have more or less the same frequency as that of the parameter. Thus, the design flood is defined (Chow V.T.,1964*) as the maximum peak rate of runoff that would occur under the average physiographic conditions of the drainage basin due to a rainfall storm of a given frequency and of various durations.

The Khosla Committee of Engineers designated the flood with a 50-year return period as the design flood to be adopted for the design of waterway of bridges. Hence, the storm rainfall with a 50-year return period is taken as the design storm.

For the design of foundations, however, the Committee felt that it will be prudent to provide an adequate margin of safety and suggested the adoption of a higher flood which is 30% over the design flood for waterway for small catchments upto 200 sq. miles.

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*Chow V.T.:- Handbook of Applied Hydrology, Mc Graw Hill Inc. 1964 Section 25, page 24.

## 3. OUTLINE OF THE METHOD

The unit hydrograph method assumes that the basin response to the storm is linear and hence the flood hydrographs produced by storms of fixed duration but varying volumes of rainfall are substantially similar. The method has the intrinsic advantage in that the runoff from any design storm could be obtained by simple super-position principle.

The steps involved in the estimation of flood peak utilising the unit hydrograph principle are schematically shown in Fig.1. knowing the point rainfall ($R_p$) of desired duration and frequency, the corresponding areal rainfall (Ra) is obtained by multiplying with areal to point rainfall ratio (p) and the rainfall excess is obtained by applying the loss rate. The maximum flood discharge (Qmax) is then equal to the base flow (Qo) plus the product of the volume of rainfall excess and the peak value of unit hydrograph (Qtc) of the same duration (tc) as the rainfall excess. To allow for the effect of non-uniform distribution of rainfall excess in time and space, a factor could be introduced at the end.

Thus, for estimation of peak rate of runoff, the following factors are to be determined or estimated:

a) Unit hydrograph parameters :

   i) Qtc, the peak value of tc hours U.G.

   ii) tc, the duration of rainfall excess of design storm.

b) Design rainfall storm parameters:

i) Point rainfall of desired frequency and of duration of tc hours.

ii) Areal to point rainfall ratio, p.

iii) Loss rate or runoff factor.

c) Base flow.

The procedure for evaluating the above factors for basins for which rainfall and runoff data is available is described in the following paragraphs. Correlations have been developed for use in estimation of design flood peaks in case of ungauged basins.

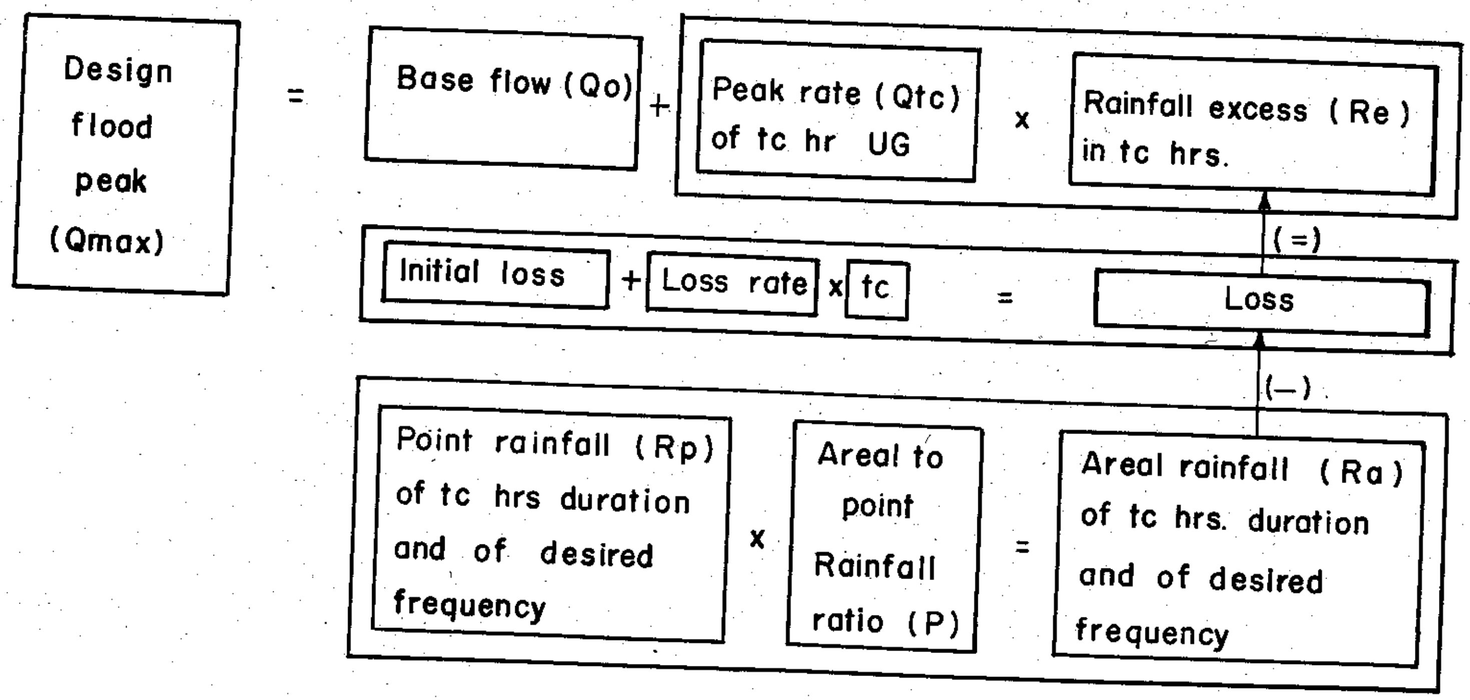



FIG. 1: ESTIMATION OF DESIGN FLOOD

## 4. UNIT HYDROGRAPH PARAMETERS

Unit hydrograph (UG) is to be derived from the Short Term observed rainfall-runoff data as per the standard procedures. In the absence of observed data, synthesis of unit hydrograph or estimating the required U.G. parameters using the empirical relationships derived on the basis of the analysis of gauged basins may be resorted to.

Sixty drainage basins of different shapes and areas (from 10 to 200 sq. miles) have been analysed. The basins selected represent different climatic conditions and do not contain any major-tank or flood control structures. The location of these basins is shown in Fig. 2. The characteristics of the basins analysed and the U.G. parameters are given in Table 1. As the rainfall data were available at one hour interval, it has been possible to derive unit hydrographs of one hour duration.

The U.G. parameters selected are defined as under:

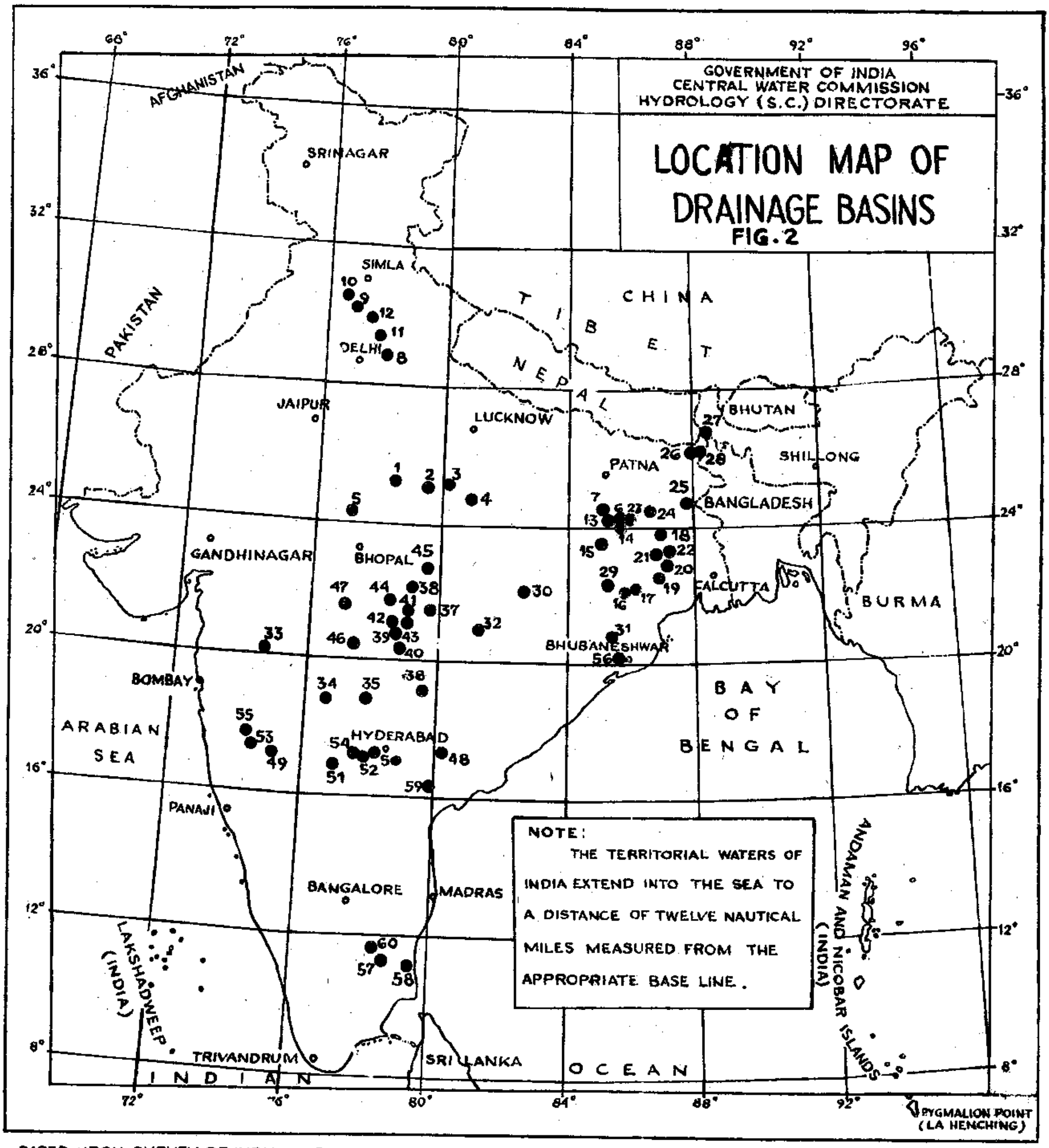
i) tp is the time measured in hours from centroid of rainfall excess to the peak of hour U.G.

ii) Qp is the peak rate of 1 hour U.G. in cusecs.

iii) Qtp is the peak rate of tp hour U.G. in cusecs.

iv) qp = Qp/A in cusecs/sq. miles.

v) qtp =Qtp/A in cusecs/sq. mile, where A is the area of the drainage basin in sq. miles.




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



NOTE: NUMBERS REFER TO BASIN NOS. SHOWN IN TABLE - 1

TABLE 1 :- THE DRAINAGE BASIN CHARACTERISTICS & UG PARAMETERS

| S. No. | Bridge No. | Rly. | Section | Drainage Basin Characteristics | | | | | | | 1 Hour U.G. Parameters | | | tp Hour U.G. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | A SQ. MILES | L MILES | Lc MILES | W MILES | Sst % | Slc % | Sl % | tp HOURS | qp CFS/SQ.M. | Qp CFS. | Qtp CFS. | qtp CFS/SQ.M. |
| BETWA BASIN (SUB-ZONE 1c) | | | | | | | | | | | | | | | |
| 1 | 687 | C | JHANSI - BINA | 106.00 | 22.5 | 10.20 | 8.10 | 0.25 | 0.19 | 1.32 | 4.50 | 87.00 | 9225 | 8109 | 76.50 |
| 2 | 744/1 | C | ITARSI - ALLAHABAD | 131.00 | 20.0 | 10.60 | 6.97 | 0.428 | 0.15 | 1.877 | 5.00 | 60.46 | 7920 | 7128 | 54.41 |
| 3 | 803/1 | C | BHOPAL - BINA | 38.60 | 19.0 | 12.00 | 3.75 | 0.086 | 0.056 | 1.15 | 10.00 | 51.30 | 1980 | 1662 | 43.05 |
| 4 | 820 | C | BHIMSEN - KHAIRAR | 118.93 | 40.8 | 15.60 | 10.50 | 0.074 | 0.049 | 0.97 | 20.50 | 25.22 | 3000 | 2446 | 20.58 |
| 5 | 761/2 | C | JHANSI - MANIKPUR | 59.70 | 15.0 | 7.00 | 5.50 | 0.14 | 0.075 | 1.16 | 4.00 | 124.80 | 7450 | 6689 | 112.04 |
| SONE BASIN (SUB ZONE 1d) | | | | | | | | | | | | | | | |
| 6 | 171 | E | BARKAKANA - LOOP | 144.00 | 32.5 | 13.75 | 7.99 | 0.21 | 0.14 | 3.73 | 6.00 | 79.70 | 11477 | 9637 | 66.92 |
| 7 | 345 | E | GRAND - CHORD | 115.00 | 24.9 | 11.75 | 6.50 | 0.683 | 0.28 | 3.66 | 3.25 | 136.70 | 15720 | 13467 | 117.10 |
| PUNJAB PLAINS (SUB-ZONE 1e) | | | | | | | | | | | | | | | |
| 8 | 89 | N | MORADABAD - GAZIABAD | 313.00 | 51.75 | 31.00 | 7.00 | 0.027 | 0.021 | 0.25 | 27.00 | 14.85 | 4650 | 3998 | 12.77 |
| 9 | 229 | N | DELHI - AMBALA | 72.50 | 29.00 | 13.30 | 6.65 | 0.107 | 0.074 | 0.985 | 6.50 | 62.06 | 4500 | 3842 | 52.99 |
| 10 | 325 | N | AMBALA - LUDHIYANA | 85.00 | 28.00 | 13.25 | 4.10 | 0.16 | 0.10 | 0.764 | 9.50 | 49.53 | 4210 | 3940 | 46.35 |
| 11 | 166 | N | GAZIABAD - SAHARANPUR | 64.00 | 16.00 | 9.50 | 4.60 | 0.104 | 0.030 | — | 4.50 | 57.19 | 3660 | 3230 | 50.47 |
| 12 | 294 | N | SAHARANPUR - AMBALA | 160.00 | 32.75 | 22.00 | 5.20 | 0.201 | 0.137 | — | 7.00 | 82.30 | 13150 | 9793 | 61.21 |
| LOWER GANGETIC PLAINS (SUB-ZONE 1g) | | | | | | | | | | | | | | | |
| 13 | 150 | E | GRAND - CHORD | 10.57 | 6.56 | 3.50 | 2.30 | 0.438 | 0.30 | 2.915 | 1.50 | 340.60 | 3600 | 3110 | 294.22 |
| 14 | 167 | E | GRAND CHORD | 220.00 | 33.56 | 15.50 | 12.40 | 0.210 | 0.18 | 3.86 | 7.00 | 69.09 | 15200 | 11674 | 53.06 |
| 15 | 110 | E | BARKAKANA LOOP | 150.50 | 23.80 | 11.50 | 13.69 | 0.45 | 0.40 | 4.261 | 3.25 | 116.90 | 17893 | 14215 | 94.45 |
| 16 | 286 | SE | RAJKHERWAR - ROURKELA | 51.50 | 23.00 | 10.30 | 5.15 | 0.65 | 0.33 | 7.86 | 8.00 | 48.50 | 2498 | 2066 | 40.12 |
| 17 | 348 | SE | SINI - ADRA | 33.75 | 12.25 | 6.50 | 4.0 | 0.521 | 0.52 | 8.807 | 5.50 | 113.50 | 3831 | 2590 | 76.74 |
| 18 | 101 B | SE | RUPRA - TALBAND | 94.30 | 23.00 | 12.50 | 7.6 | 0.514 | 0.40 | 10.076 | 4.90 | 134.00 | 12636 | 9022 | 95.67 |
| 19 | 114 | SE | KHARAGPUR - TATA | 11.16 | 5.75 | 2.00 | 2.9 | 0.53 | 0.41 | 1.203 | 4.12 | 145.50 | 1624 | 1234 | 110.57 |
| 20 | 181 | SE | ADRA - KHARAGPUR | 82.20 | 20.09 | 10.09 | 6.8 | 0.16 | 0.11 | 1.269 | 7.50 | 76.60 | 6296 | 4655 | 56.63 |
| 21 | 237 | SE | KHARAGPUR - ADRA | 86.60 | 17.20 | 7.70 | 6.0 | 0.18 | 0.16 | 0.712 | 5.25 | 60.60 | 5250 | 4650 | 53.70 |
| 22 | 94 | SE | KHARAGPUR - TATA | 130.00 | 20.80 | 11.00 | 10.75 | 0.277 | 0.17 | 1.73 | 8.50 | 44.60 | 5800 | 5166 | 39.74 |
| 23 | 160 | E | GRAND - CHORD | 63.4 | 19.80 | 9.60 | 6.0 | 0.43 | 0.25 | 3.142 | 5.25 | 104.00 | 6650 | 4700 | 74.13 |
| 24 | 656 | E | JASIDIH - LAHABON | 32.23 | 12.55 | 6.00 | 3.7 | 0.208 | 0.208 | 3.263 | 2.50 | 180.58 | 5820 | 3980 | 123.49 |
| 25 | 236 | E | SAHABGANG - LOOP | 190.00 | 36.50 | 22.50 | 14.0 | 0.10 | 0.064 | 4.413 | 15.00 | 44.11 | 8380 | 6304 | 33.18 |
| NORTH BRAHMAPUTRA BASIN (SUB-ZONE 2a) | | | | | | | | | | | | | | | |
| 26 | 8 | NF | KATIHAR - SILIGURI | 136.8 | 25.50 | 16.8 | 4.60 | 1.913 | 1.37 | 1.630 | 4.00 | 93.93 | 12800 | 11487 | 83.97 |
| 27 | 91 | NF | SILIGURI - ALIPURDUAR | 51.4 | 20.75 | 9.0 | 4.00 | 3.636 | 1.85 | 2.321 | 3.50 | 177.82 | 9140 | 6600 | 128.40 |
| 28 | 29 | NF | SILIGURI - ALIPURDUAR | 35.1 | 11.12 | 6.4 | 5.30 | 2.961 | 1.43 | 2.455 | 3.50 | 170.94 | 6000 | 4786 | 136.35 |
| MAHANADI BASIN (SUB ZONE 3d) | | | | | | | | | | | | | | | |
| 29 | 139 | SE | RAJKHARSA - BLANGUA | 144.5 | 32.00 | 15.25 | 6.40 | 0.43 | 0.351 | 1.452 | 4.50 | 105.88 | 15300 | 11490 | 79.52 |
| 30 | 59 | SE | JHARSUGUDA - BILASPUR | 52.4 | 18.50 | 7.00 | 3.20 | 0.333 | 0.147 | 1.136 | 5.50 | 95.41 | 5000 | 3142 | 59.96 |
| 31 | 46 | SE | NERGUNDI - TALCHER | 41.9 | 12.40 | 4.83 | 6.28 | 0.343 | 0.21 | 0.610 | 8.50 | 47.73 | 2000 | 1722 | 41.10 |
| 32 | 332/555 | SE | KHARAGPUR - BHADRAK | 90.6 | 19.00 | 7.80 | 8.00 | 0.191 | 0.118 | 1.33 | 4.50 | 83.88 | 7600 | 6464 | 71.35 |
| UPPER GODAVARI BASIN (SUB-ZONE 3e) | | | | | | | | | | | | | | | |
| 33 | 51 | SC | MANMAD - SECUNDRABAD | 23.9 | 9.92 | 4.55 | 3.00 | 0.545 | 0.254 | 4.43 | 1.75 | 354.60 | 8475 | 6465 | 270.50 |
| 34 | 55 | SC | PARBHANI - PURLI | 12.1 | 12.71 | 6.00 | 1.00 | 1.04 | 0.529 | 5.709 | 1.00 | 466.11 | 5640 | 5640 | 466.11 |
| 35 | 4 | SC | MUDKHED - ADILABAD | 19.59 | 7.62 | 3.30 | 3.90 | 0.750 | 0.60 | 5.491 | 1.75 | 433.89 | 8500 | 5680 | 289.94 |
| 36 | 214 | SC | KAZIPET - BALHARSHAH | 13.62 | 10.04 | 4.60 | 1.40 | 0.88 | 0.72 | 5.979 | 1.25 | 417.32 | 5684 | 4300 | 315.71 |
| 37 | 59 | SE | TIMSAR - TIRODI | 25.25 | 12.00 | 6.00 | 2.60 | 0.28 | 0.14 | 2.637 | 3.00 | 190.09 | 4800 | 3516 | 139.24 |
| 38 | 20 | SE | NAINPUR - BARKUKI | 23.35 | 10.90 | 5.25 | 2.25 | 0.49 | 0.30 | 2.844 | 2.75 | 205.56 | 4800 | 3506 | 150.14 |
| 39 | 491/1 | CR | BADNERA - NAGPUR | 16.32 | 9.20 | 4.80 | 2.20 | 0.54 | 0.35 | 4.062 | 1.75 | 287.00 | 4684 | 3500 | 214.46 |
| LOWER GODAVARI BASIN (SUB-ZONE 3f) | | | | | | | | | | | | | | | |
| 40 | 494/1 | CR | WARDHA - BALHARSHAH | 46.30 | 11.40 | 6.26 | 5.20 | 0.19 | 0.16 | 0.731 | 2.50 | 110.88 | 5134 | 4792 | 103.50 |
| 41 | 57 | SE | NAGPUR - GONDARAIPUR | 55.94 | 17.20 | 7.75 | 5.30 | 0.16 | 0.091 | 0.739 | 5.50 | 79.63 | 4455 | 3957 | 70.73 |
| 42 | 604 | CR | ITARSI - NAGPUR | 131.48 | 26.50 | 12.70 | 10.00 | 0.260 | 0.174 | 2.108 | 3.50 | 144.51 | 19000 | 15188 | 115.52 |
| 43 | 51 | SE | NAGPUR - RAIPUR | 31.43 | 11.50 | 6.50 | 3.30 | 0.15 | 0.105 | 1.102 | 3.00 | 95.45 | 3000 | 2791 | 88.60 |
| 44 | 228 | SE | CHHINDWARA - NAGPUR | 194.34 | 27.75 | 15.80 | 13.16 | 0.369 | 0.272 | 2.487 | 3.50 | 101.26 | 19680 | 17432 | 89.70 |
| UPPER NARMADA AND TAPTI BASIN (SUB ZONE 3c) | | | | | | | | | | | | | | | |
| 45 | 253 | SE | GONDIA - JABALPUR | 44.10 | 19.20 | 8.65 | 3.85 | 0.38 | 0.219 | 7.049 | 2.50 | 113.38 | 5000 | 4218 | 95.65 |
| 46 | 394 | C | BHUSAVAL - BADNERA | 134.72 | 27.00 | 11.20 | 7.00 | 0.35 | 0.264 | 2.102 | 2.50 | 95.01 | 12800 | 12260 | 91.00 |
| 47 | 615 | C | KHANDWA - ITARSI | 57.00 | 21.50 | 10.50 | 4.41 | 0.15 | 0.145 | 0.681 | 7.50 | 75.44 | 4300 | 3249 | 57.00 |
| KRISHNA BASIN (SUB-ZONE 3h) | | | | | | | | | | | | | | | |
| 48 | 642 | C | VIJAYAWADA - KAZIPET | 125.90 | 25.00 | 11.50 | 6.40 | 0.268 | 0.19 | 0.878 | 5.50 | 55.60 | 7000 | 5995 | 47.62 |
| 49 | 16 | S | HUBLI - HARIHAR | 104.50 | 23.50 | 9.40 | 8.50 | 0.342 | 0.13 | 1.821 | 3.50 | 133.97 | 14000 | 10671 | 102.11 |
| 50 | 215 | SC | LONDA - MIRAJ | 48.90 | 17.50 | 10.50 | 6.80 | 0.109 | [illegible] | 1.022 | 6.50 | 65.44 | 3200 | 2557 | 52.29 |
| 51 | 365 | SC | DHONIAT - RAIDHUR | 46.00 | 9.00 | 4.00 | 6.20 | 0.403 | 0. | 2.50 | 3.50 | 205.17 | 9438 | 6698 | 145.60 |
| 52 | 123 | SC | WADI - SECUNDRABAD | 28.00 | 10.00 | 4.00 | 4.20 | 0.439 | 0. | 4.046 | 1.00 | 240.00 | 6000 | 6000 | 240.00 |
| 53 | 384 | SC | POONA - MIRAJ | 25.00 | 9.25 | 5.00 | 3.25 | 0.91 | 0.70 | 8.333 | 1.00 | 480.00 | 12000 | 12000 | 480.00 |
| 54 | 53 | SC | BIRUR - TALAGUPPA | 40.00 | 13.50 | 5.75 | 4.80 | 0.711 | 0.585 | 2.216 | 4.00 | 170.50 | 6820 | 4705 | 117.62 |
| 55 | 404 | SC | MIRAJ - POONA | 11.50 | 6.70 | 4.00 | 2.50 | 1.099 | 0.87 | 4.381 | 1.50 | 304.34 | 3500 | 3077 | 287.57 |
| EAST COAST (SUB ZONE 4 a,b) | | | | | | | | | | | | | | | |
| 56 | 702 | SE | NANPADA - GUNUPUR | 209.34 | 34.00 | 12.00 | 13.00 | 0.19 | 0.116 | 0.37 | 17.50 | 22.55 | 4720 | 4113 | 19.65 |
| 57 | 172 | S | CUDDALUR - SALEM | 51.18 | 15.00 | 7.00 | 6.20 | 0.62 | 0.453 | 3.614 | 2.50 | 259.86 | 13300 | 10192 | 199.14 |
| 58 | 60 | S | CUDDALUR - SALEM | 37.30 | 10.00 | 5.50 | 4.50 | 0.34 | 0.293 | 1.811 | 4.50 | 133.78 | 4990 | 3726 | 99.89 |
| 59 | 49 | E | GUMTI - MACHADA | 36.00 | 16.00 | 7.40 | 3.88 | 0.21 | 0.168 | 1.463 | 3.50 | 122.78 | 4420 | 3596 | 99.89 |
| 60 | 157 | E | JALARPET - SALEM | 47.80 | 12.00 | 3.70 | 2.40 | 0.84 | 0.391 | 2.303 | 3.50 | 148.54 | 7100 | 6063 | 126.85 |

The basin characteristics chosen are defines as under:

i) A is the area of the drainage basin in sq. miles.

ii) L is the length of the main stream in miles from the upstream water divide to the bridge site.

iii) Lc is the length of the main stream in miles from the bridge site to a point on the main stream near the Centre of gravity (CG) of the catchment area.

iv) W is the minimum width of the catchment in miles measured at C.G. of the catchment.

v) Sst is the weighted mean slope of the main stream as a ratio given by the relation:

$$Sst = \left( \frac{L}{l_1/s_1^{\frac{1}{2}} + l_2/s_2^{\frac{1}{2}} + \ldots} \right)^2$$

Where $s_1$, $s_2$, $s_3$ are the slopes of the main stream in the reaches of lengths $l_1$, $l_2$, $l_3$.......... into which the length, L of the main stream is divided.

vi) SLC is the weighted mean slope of the main stream as a ratio given by the relation:

$$SLC = \left( \frac{Lc}{l_1/s_1^{\frac{1}{2}} + l_2/s_2^{\frac{1}{2}} + \ldots} \right)^2$$

Where $s_1$, $s_2$, $s_3$, are the slopes of the main stream in reaches of lenghts $l_1$, $l_2$, $l_3$............ into which the length, Lc of the main stream is divided.

The results of the attempts to correlate the U.G. parameters viz., tp( time measured from the centroid of rainfall excess to the peak of a short duration U.G.), and Qtp (peak of tp hr U.G.) with the catchment characteristics are discussed below.

## 4.1 Estimation of Qtp

A plot of Qtp vs. A with SLC as parameter is shown in Fig. 3. It is seen that the effect of SLC on Qtp is not significant for catchments with high stream slopes viz., SLC gtreater than 0.0028 (or 16 ft/ mile). However, for catchments with SLC less than 0.0028, the stream slope is a significant factor. The parameter SLC is preferred to Sst for the reason that the estimates of the former are comparatively more reliable.

The different equations, fitted by regression analysis, are given in Table 2. Data of catchments with area less than 30 sq. miles have not been utilised for developing the relations, as rainfall and runoff data at short durations required for deriving a reliable unit hydrograph are not available. A few bridge data, which do not follow the general trend, have also been excluded from the analysis. A critical examination of data of these catchments would be necessary to enable to find the reason for their deviation from the general trend.

The following equations may be adopted for estimating Qtp:

i) For catchments with SLC less than 0.0028

$$Qtp = 16{,}000A^{3/4} (SLC)^{2/3} \quad \ldots\ldots\ldots (1)$$

ii) For catchments with SLC greater than 0.0028

$$Qtp = 320\ A^{3/4} \quad \ldots\ldots\ldots (2)$$

The constants and indices as obtained by regression analysis have been rounded off such that the final results do not materially change.

A plot of the observed vs. estimated values of Qtp for all the 60 bridge catchments is shown in Fig. 4. The scatter of plotted positions is large. However, such scatter is not uncommon in similar hydrological studies.

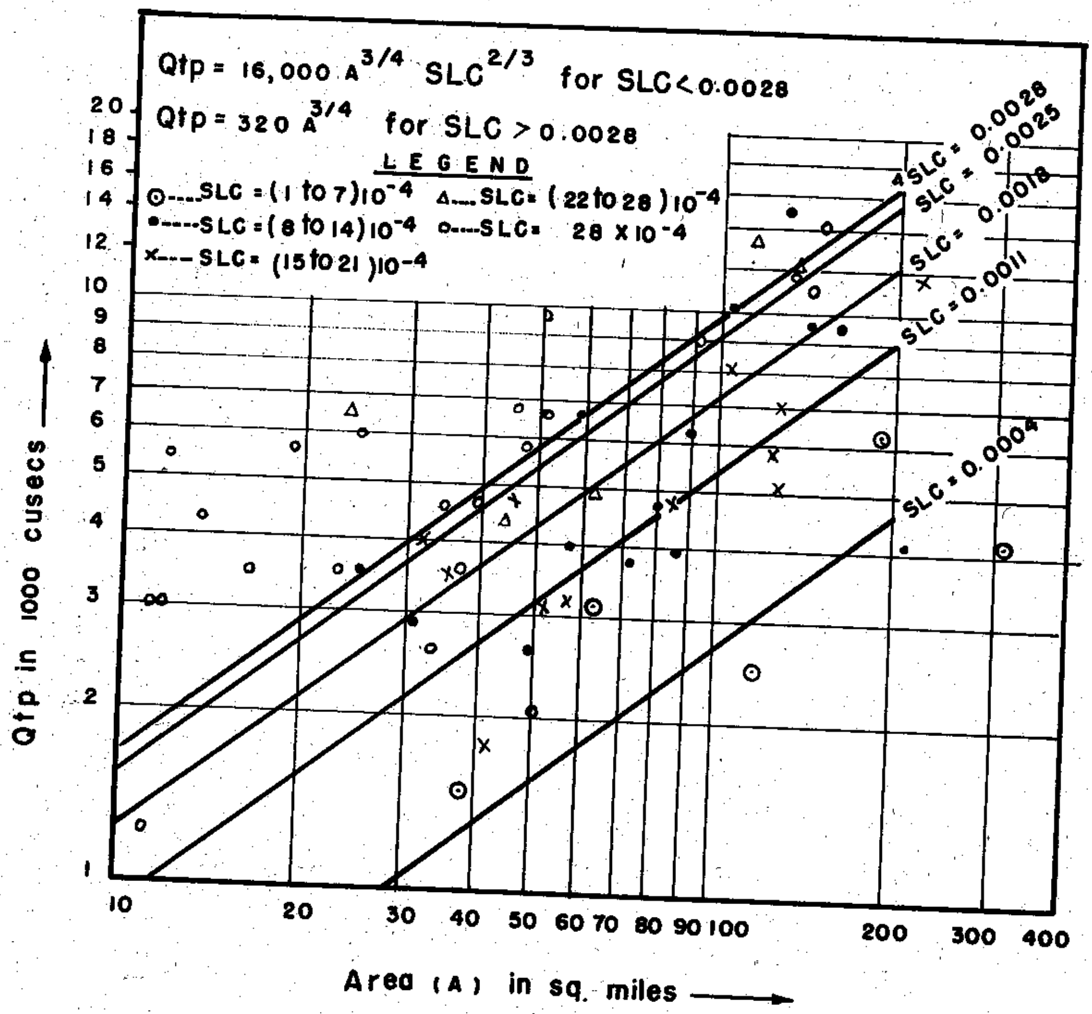



FIG. 3: RELATION OF Qtp vs A & SLC

TABLE - 2

ESTIMATION OF Qtp - RELATIONS OBTAINED BY REGRESSION ANALYSIS

| Sl. No. | No. of Bridge Catchments | Sample Size N | Equation representing the relationship | Corr. Coefficient | Standard (log σ) | Deviation (σ) |
|---|---|---|---|---|---|---|
| 1. | <u>Catchments with SLC Greater than 0.0028</u> | | | | | |
| | 7,15,18,26,27,28,29,37, 38,44,46,51,54 & 60. | 14 | $Qtp = 274\ A^{0.7728}$ | 0.934 | 0.090 | 1.230 |
| 2. | <u>Catchments with SLC less than 0.0028</u> | | | | | |
| | 1,2,3,6,7,8,9,10,12,14,20, 21,23,24,25,30,32,37,40,43, 44,45,46,47,48,50,58,59. | 28 | $Qtp = 11{,}415\ A^{0.7472}\ SLC^{0.6213}$ | 0.94 | 0.0843 | 1.214 |
| 3. | Catchments of both the above groups. | 38 | $Qtp = 1432\ A^{0.7326}\ SLC^{0.3739}$ | 0.90 | 0.1051 | 1.275 |

The scatter cannot be entirely attributed to the errors in data. The main reason for such high variation may be due to the fact that the man's activities resulting in different degrees of interference against free drainage such as the existence of (i) minor irrigation tanks (iii) bridges and culverts with inadequate waterway or with embanked roadways and railways across the tributaries and main stream,(iii ) bunding for irrigation of areas in the catchment etc. These obstructions would be responsible for different degrees of attenuation of the peaks of the hydrographs . Further, some catchments are drained by shallow stream with flood plains. A detailed study of the effects of these factors is beyond the scope of this report.

The relations derived are valid for catchments in which the flood is contained within the banks of the stream. For streams with significant flood plains, these relations tend to overestimate the design flood peak.

## 4.2 Estimation of tp

The plot of tp vs. qtp is shown in Fig. 5. It is seen that the following equation, found by regression analysis, is the best representation of the data of the 60 bridge catchments:

$$tp = 233/qtp^{0.9} \quad \ldots \quad \ldots \quad (3)$$

Corr. coeff. $r = 0.94$ TO $0.97$

Standard deviation: $\log \sigma = 0.0744$

$\sigma = 1.19$

The reason for the scatter may be attributed to the fact that the estimates of tp are not unbiased as the beginning of direct surface runoff or the rainfall excess for measuring tp are not well defined. Since the observations are taken at 1 hr. interval, an error of 1 hour in the estimates is possible.

The equation (3) is preferred to other normal types of relations in vogue (correlating tp with basin characteristics) for the reason that the errors in the estimation of qtp and tp would be compensatory in nature. The effect of

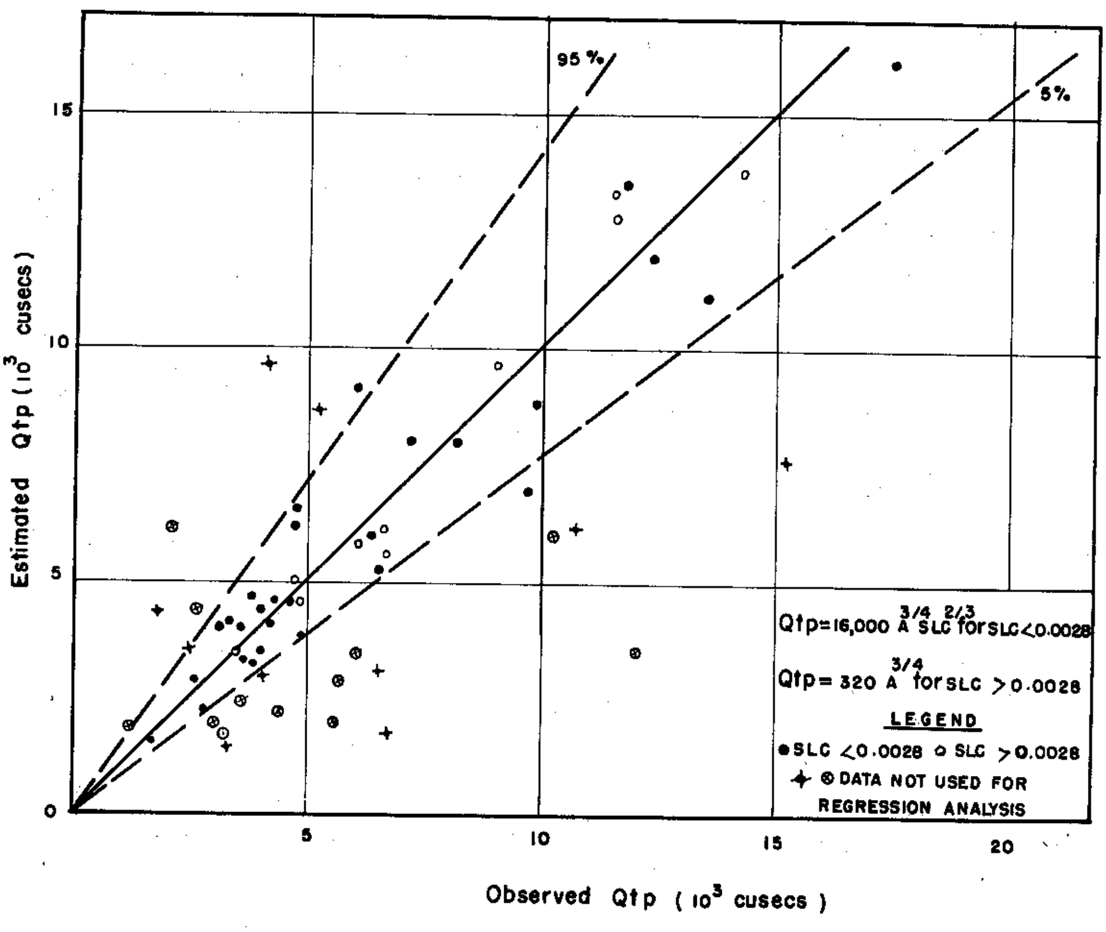



FIG. 4: OBSERVED Vs ESTIMATED Qtp VALUES

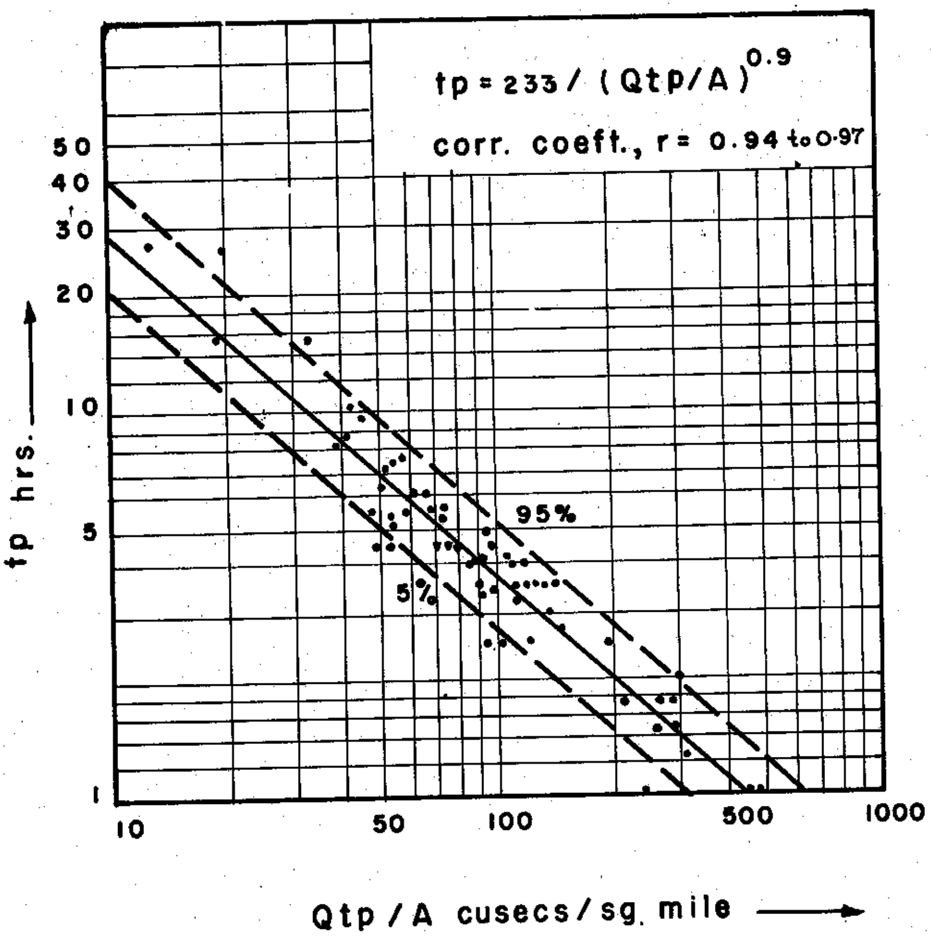



FIG. 5 RELATION OF tp vs Qtp/A

over-estimation of qtp is to under-estimate the value of tp. Further, the equation (3) gave high correlation with minimum standard error.

## 4.3 Duration of Rainfall Excess

The duration of rainfall excess (tc) that produces the design flood peak depends on the shape of the U.G. or U.G. Parameters, on the meteorological characteristics and on the soil complex and soil moisture conditions of the basin. Studies revealed that the duration (tc) varies from tp to 1.2. tp and can be taken as equal to 1.2 tp without appreciable error for conditions obtaining in Indian catchments. The error in estimating tc is less important since the rainfall value varies approximately as $(tc)^n$, n varying from 0.2 to 0.5. The error in the estimated flood peak would be of the order of ± 10% due to the error of ± 30% in tc.

Thus, the duration of rainfall excess (tc) can be estimated using the equation:

$$tc = 1.2\ tp = 280/qtp^{0.9} \quad \ldots \quad \ldots \quad (4)$$

As the reduction in peak rate (qtc) of tc hr. U.G. over the peak rate (qtp) of tp hr. U.G. is insignificant, it can be assumed that:

$$qtc = qtp$$

## 5. POINT RAINFALL VALUES

The India Meteorological Department, New Delhi, have evaluated the extreme point rainfall values of different durations for different return periods and have prepared isopluvial maps covering the entire country.

One hour extreme rainfall values corresponding to return periods of 2,5,10,25 and 50 years have been computed based on a fairly long series of data from about 100 self-recording raingauge stations. Maximum rainfall amounts in 1 hour from each year of record for a particular station were listed. The annual maximum series thus formed was treated by Gumbel's extreme value technique for obtaining the rainfall extreme values for different return periods. Similarly, rainfall values for durations of 15 min, 30 min, 45 min. 3 hrs, 6 hrs, 9 hrs, 12 hrs and 15 hrs for return periods of 2, 5, 10, 25 and 50 years have been computed from the autographic data of rainfall from about 60 stations distributed over the country and having data for at least 5 years. Observational day maximum rainfall for return periods of 2,5,10,25,50 and 100 years has been computed using records of about 1600 raingauge stations having daily data for at least 50 years.

For intermediate durations, the maximum rainfall values can be picked up from depth-duration-frequency curves. The maximum rainfall values, for different durations and for different return periods estimated from the isopluvial maps, may be plotted on logorithmic paper and smooth curves may be drawn through these points. While drawing the smooth curves, much weight may not be given to the points representing the maximum rainfall values for 12 hrs and 15 hrs durations.

Isopluvial maps for return periods of 50 years have been appended for ready reference. Maps for other return periods can be had from India Meteorological Department.

5.1 Adjustment Factors for Point Rainfall

The values given by India Meteorological Department on the isopluvial map for 24 hrs. duration are observational day rainfall amounts. For obtaining the maximum consecutive 1440 minutes rainfall amounts, the values given on this map need to be increased by 15% as per the results of detailed study made by I.M.D. No such adjustment is to be made to the values read from the isopluvial maps for durations of 15 min, 30 min, 45 min, 1 hr, 3 hrs, 6 hrs, 9 hrs, 12 hrs and 15 hrs.

Further, the data for the frequency analysis of point rainfall considered has been based on the annual maximum for each duration. These maxima for any year may belong to different storms with the result that a rainfall intensity-duration frequency curve constructed from these data show greater amounts for all durations than the corresponding within-storm amounts for total storm depths of the same frequency.*

From a study of the rainfall-runoff data for a large number of drainage basins of areas upto 200 sq. miles it is seen that the maximum flood peaks are invariably produced by storms of long duration of over 12 hrs. containing high intensity spells, whereas low peaks are produced by short duration storms though the intensity may be higher. Thus, the design rainfall value of the required duration and frequency should be the within-storm rainfall value.

India Meteorological Department made a study to estimate the adjustment factors for converting the point rainfall values read from IMD maps to within storm values utilising the available data of selected self-recording stations situated in different climatic zones of India. The adjustment factor (ratios of within storm values to among storm values) are calculated for return periods of 2, 5, 10, 25 and 50 years. The results of study, given in

* U.S. Weather Bureau: "Rainfall Intensity - frequency regime" Tech. Paper No. 29 (pt.3) --1957-58.

Table 3, show that the return period has significant effect on the adjustment factor. The adjustment factor varies from 0.70 to 1.0 depending on the duration and the return period. However, for a 50-year return period, the factor is nearly 1.0 for all durations. Further, it is also observed that the highest maximum rainfall values at each station are the within storm values. As the design storm is of 50 year return period, the adjustment factor is 1.0 for purposes of design flood estimation. Thus, the depth-duration curve based on the maximum point rainfall values read from the isopluvial maps for different durations and for a return period of 50-years represents the cumulative rainfall depth-duration curve of the design storm.

TABLE - 3

AVERAGE PERCENTAGE RATIO OF WITHIN-STORM TO AMONG STORM RAINFALL VALUES

| Within | Return periods | DURATION | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 15 min | 30 min | 45 min | 1 hr. | 3 hrs. | 6 hrs. | 9 hrs. | 12 hrs. | 15 hrs. | 24 hrs. |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 24 hrs storm | 2 yrs | 73.7 | 78.3 | 78.8 | 80.0 | 91.6 | 94.3 | 96.3 | 98.8 | 98.5 | 100.00 |
| | 5 yrs | 83.4 | 87.7 | 87.8 | 89.0 | 96.9 | 97.6 | 98.1 | 97.9 | 99.1 | 100.00 |
| | 10 yrs | 87.7 | 91.8 | 91.6 | 92.8 | 99.0 | 98.9 | 98.8 | 97.5 | 99.4 | 100.00 |
| | 25 yrs | 91.9 | 95.9 | 95.2 | 96.2 | 100.9 | 100.1 | 99.4 | 97.1 | 99.7 | 100.00 |
| | 50 yrs | 94.4 | 98.1 | 97.2 | 98.1 | 101.9 | 100.8 | 99.7 | 96.9 | 99.8 | 100.00 |
| 15 hrs storm | 2 yrs | 73.3 | 78.7 | 79.5 | 81.1 | 92.6 | 96.1 | 97.8 | 100.1 | 100.0 | |
| | 5 yrs | 83.3 | 88.1 | 88.3 | 90.0 | 97.7 | 98.5 | 98.6 | 98.3 | 100.0 | |
| | 10 yrs | 87.9 | 92.1 | 91.9 | 93.7 | 99.7 | 99.4 | 98.9 | 97.6 | 100.0 | |
| | 25 yrs | 92.3 | 96.1 | 95.4 | 97.2 | 101.5 | 100.3 | 99.0 | 96.9 | 100.0 | |
| | 50 yrs | 94.8 | 98.3 | 97.3 | 99.1 | 102.5 | 100.7 | 100.9 | 96.5 | 100.0 | |
| 12 hrs storm | 2 yrs | 75.1 | 80.4 | 80.9 | 82.1 | 94.3 | 97.2 | 99.2 | 100.0 | | |
| | 5 yrs | 83.8 | 88.6 | 88.9 | 90.3 | 98.1 | 98.3 | 99.0 | 100.0 | | |
| | 10 yrs | 88.0 | 92.2 | 92.4 | 93.8 | 99.7 | 98.7 | 99.0 | 100.0 | | |
| | 25 yrs | 91.9 | 95.7 | 95.6 | 97.1 | 101.0 | 99.2 | 98.9 | 100.0 | | |
| | 50 yrs | 94.2 | 97.8 | 97.4 | 98.6 | 101.8 | 99.4 | 98.8 | 100.0 | | |
| 9 hrs storm | 2 yrs | 76.4 | 82.4 | 83.1 | 85.1 | 95.9 | 98.6 | 100.0 | | | |
| | 5 yrs | 86.3 | 91.5 | 91.5 | 93.4 | 98.9 | 99.3 | 100.0 | | | |
| | 10 yrs | 90.8 | 95.3 | 94.8 | 96.7 | 100.1 | 99.6 | 100.0 | | | |
| | 25 yrs | 95.2 | 99.1 | 98.1 | 99.8 | 101.2 | 99.8 | 100.0 | | | |
| | 50 yrs | 97.6 | 101.3 | 100.0 | 101.5 | 101.7 | 99.9 | 100.0 | | | |

Table 3 (Contd.)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 hrs storm | 2 yrs | 77.2 | 83.9 | 84.3 | 87.0 | 98.0 | 100.0 | | | | |
| | 5 yrs | 87.2 | 92.3 | 91.9 | 94.4 | 99.3 | 100.0 | | | | |
| | 10 yrs | 91.7 | 95.9 | 95.3 | 97.4 | 99.9 | 100.0 | | | | |
| | 25 yrs | 96.1 | 99.5 | 98.4 | 100.2 | 100.4 | 100.0 | | | | |
| | 50 yrs | 98.6 | 101.5 | 100.1 | 101.8 | 100.7 | 100.0 | | | | |
| 3 hrs storm | 2 yrs | 79.9 | 87.0 | 87.9 | 89.7 | 100.0 | | | | | |
| | 5 yrs | 89.7 | 93.8 | 93.6 | 95.1 | 100.0 | | | | | |
| | 10 yrs | 94.4 | 96.7 | 96.0 | 97.3 | 100.0 | | | | | |
| | 25 yrs | 98.9 | 99.6 | 98.3 | 99.3 | 100.0 | | | | | |
| | 50 yrs | 101.6 | 101.3 | 99.6 | 100.5 | 100.0 | | | | | |
| 1 hr storm | 2 yrs | 87.6 | 93.3 | 93.8 | 100.0 | | | | | | |
| | 5 yrs | 92.5 | 95.7 | 94.8 | 100.0 | | | | | | |
| | 10 yrs | 94.6 | 96.8 | 95.3 | 100.0 | | | | | | |
| | 25 yrs | 96.6 | 97.9 | 95.8 | 100.0 | | | | | | |
| | 50 yrs | 97.8 | 98.5 | 96.1 | 100.0 | | | | | | |
| 45 min. storm | 2 yrs | 91.4 | 99.1 | 100.0 | | | | | | | |
| | 5 yrs | 94.5 | 99.3 | 100.0 | | | | | | | |
| | 10 yrs | 96.2 | 99.5 | 100.0 | | | | | | | |
| | 25 yrs | 97.5 | 99.7 | 100.0 | | | | | | | |
| | 50 yrs | 98.4 | 99.8 | 100.0 | | | | | | | |
| 30 min. storm | 2 yrs | 94.3 | 100.0 | | | | | | | | |
| | 5 yrs | 96.7 | 100.0 | | | | | | | | |
| | 10 yrs | 97.7 | 100.0 | | | | | | | | |
| | 25 yrs | 98.9 | 100.0 | | | | | | | | |
| | 50 yrs | 99.5 | 100.0 | | | | | | | | |

## 6. AREAL TO POINT RAINFALL RATIO

Data of 12 dense networks have been studied. The networks selected are for drainage basins with areas varying from 40 to 300 sq. miles. Number of raingauge stations and the length of record available are given in Table 4. The locations of networks are shown in Fig.6.

For each raingauge station, hourly rainfall data are available. Annual series of maximum 3 hrs and 6 hrs point rainfall recorded by each of the raingauge stations in the network are formed and treated by Gumbel's extreme values technique for obtaining the rainfall extreme values for a 2-year return period. When the length of the record is less than 4-years, partial series have been formed. The mean of the 2-year point rainfalls of all raingauges within the basin will be the representative point rainfall for the network.

Areal rainfall values have been computed by Theissen Polygon method. Annual series of maximum 3 hrs and 6 hrs areal rainfalls for each drainage basin are formed and the extreme values for a 2-year return period are obtained.

The ratios of Areal rainfall of 2-year return period to the representative point rainfall of 2-year return period for durations of 3 hours and 6 hours are computed for each network (Tables 4 & 5) and plotted against the area of the basin. These plots are shown in Fig. 7 & 8. Mean curves are drawn through the plotted positions. It is possible to fit the following single equation to the mean curves representing the relationship between the ratio and the area:

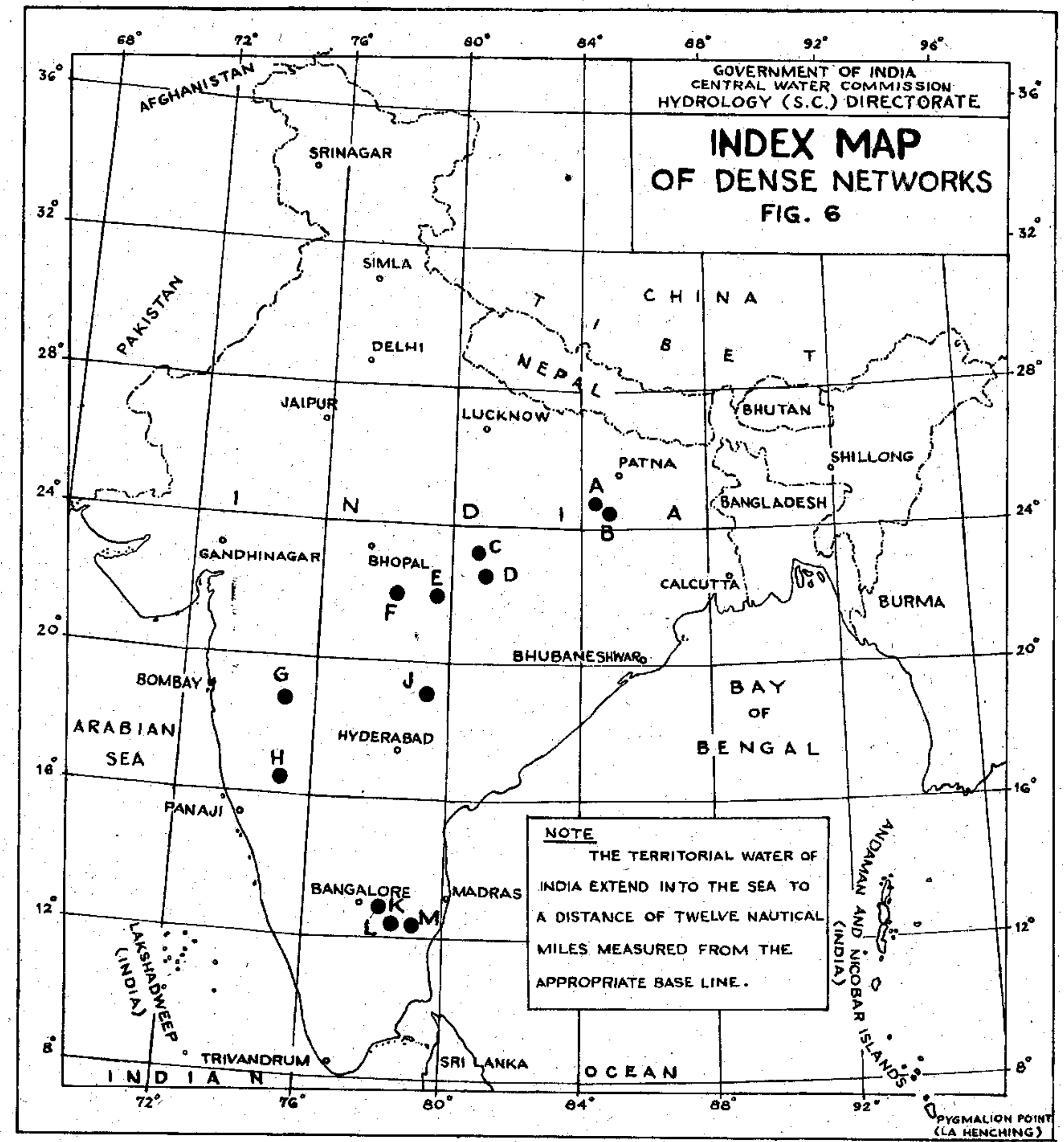
$$P = \exp\left(-A^{1/3}/8T^{1/2}\right) \quad \ldots \quad \ldots \qquad (5)$$

TABLE - 4

AREAL TO POINT RAINFALL RATIOS

Rainfall Duration = 3 hours

| Network and sub-zone | Area (sq. miles) | No. of rain-gauges | Length of records (yrs.) | Point rainfall 2 year return period (inches) | | | | | | | Areal Rainfall 2 year return period (inches) | Areal/point rainfall ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | Mean | | |
| A/I-d | 115 | 3 | 7 | 2.40 | 2.35 | 1.95 | - | - | - | 2.23 | 1.30 | 0.583 |
| B/I-g | 220 | 5 | 12 | 2.05 | 2.15 | 1.60 | 2.38 | 1.60 | - | 1.96 | 1.35 | 0.689 |
| C/III-D | 59 | 5 | 5 | 2.00 | 1.82 | 2.01 | 2.45 | 2.30 | - | 2.12 | 1.62 | 0.764 |
| D/III-d | 257 | 5 | 5 | 2.70 | 2.95 | 3.20 | 3.40 | 2.20 | - | 2.89 | 1.90 | 0.657 |
| E/III-f | 158 | 4 | 4 | 3.58 | 3.30 | 2.82 | 3.00 | - | - | 3.18 | 2.45 | 0.772 |
| F/III-f | 131 | 4 | 6 | 2.4 | 1.95 | 2.20 | 2.20 | - | - | 2.18 | 1.85 | 0.849 |
| G/III-h | 44 | 3 | 8 | 1.60 | 1.85 | 1.60 | - | - | - | 1.68 | 1.37 | 0.815 |
| H/III-h | 104 | 6 | 6 | 1.45 | 1.32 | 1.82 | 1.35 | 0.83 | 0.90 | 1.26 | 0.75 | 0.595 |
| J/III-h | 126 | 4 | 6 | 1.60 | 1.60 | 2.10 | 2.95 | - | - | 2.06 | 1.35 | 0.664 |
| K/IV-b | 48 | 5 | 3 | 2.25 | 2.58 | 2.02 | 2.65 | 1.75 | - | 2.25 | 2.00 | 0.889 |
| L/IV-b | 51 | 4 | 6 | 2.95 | 2.35 | 4.00 | 2.75 | - | - | 3.01 | 2.10 | 0.698 |
| M/IV-b | 152 | 6 | 6 | 2.10 | 2.40 | 2.30 | 2.26 | 2.01 | 2.41 | 2.25 | 1.50 | 0.667 |




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

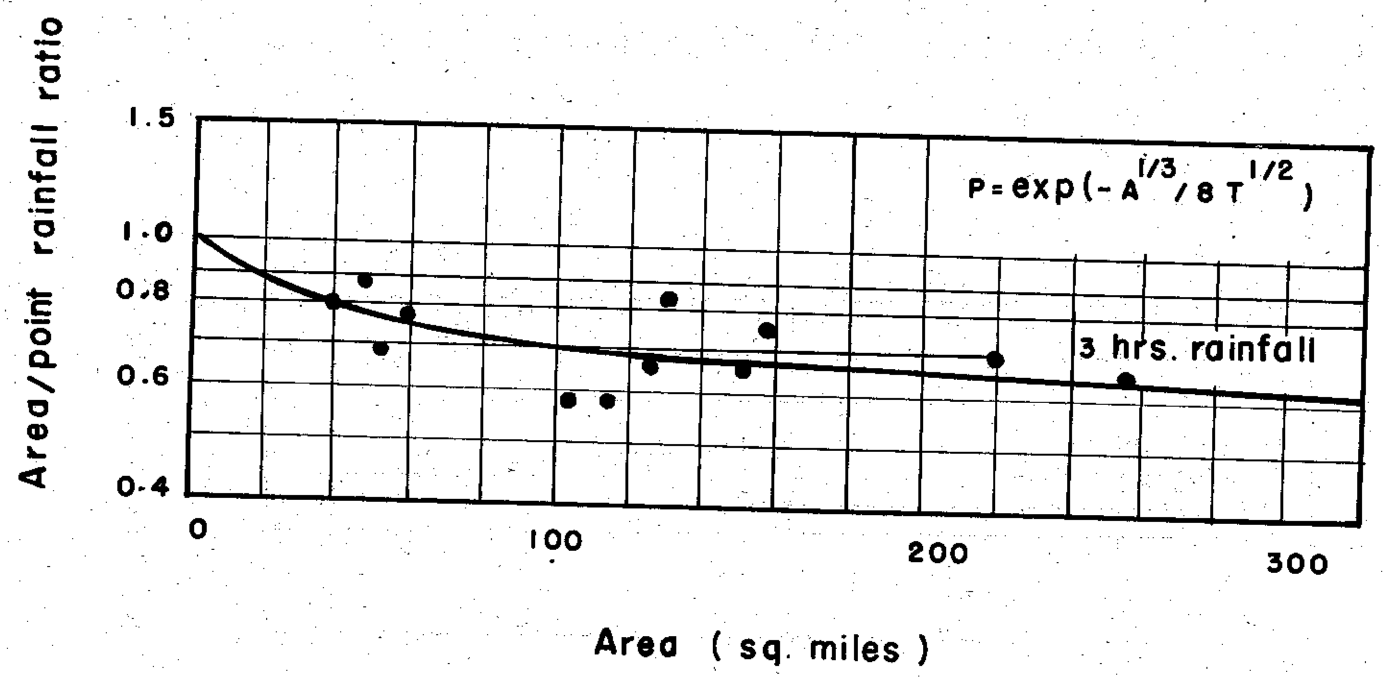



FIG. 7: AREAL / POINT RAINFALL RATIOS FOR 3 Hr. DURATION

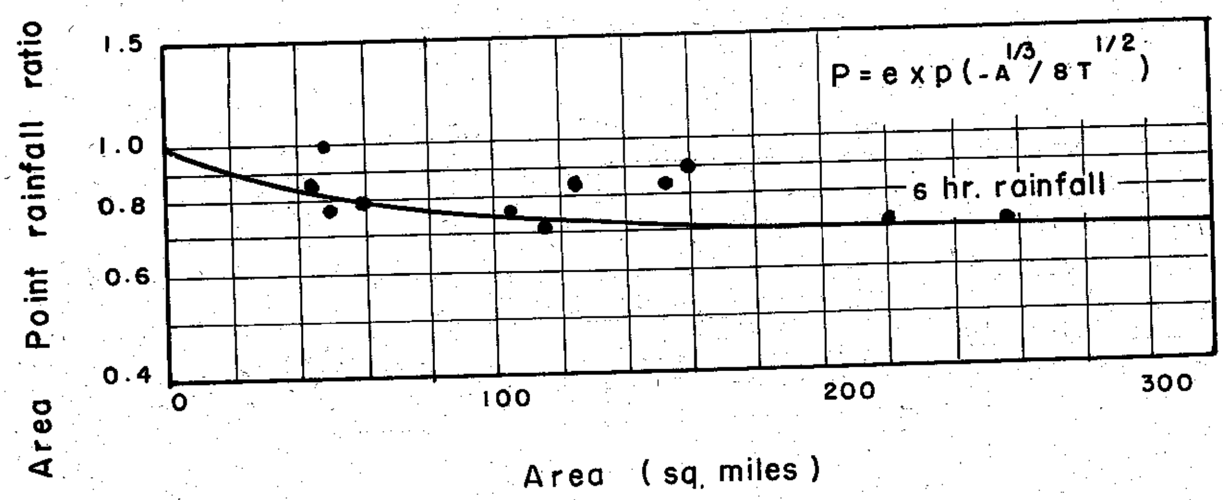



FIG. 8 AREAL / POINT RAINFALL RATIOS FOR 6 Hr. DURATION

## TABLE - 5

## AREAL TO POINT RAINFALL RATIOS

Rainfall Duration = 6 hours

| Network and sub-zone | Area in sq. miles | No. of rain-gauges | Length of record (yrs) | Point rainfall 2 yr. return period | | | | | | | Areal rainfall 2-yr return period (inches) | Areal/point rainfall ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | Mean | | |
| A/I-d | 115 | 3 | 7 | 2.50 | 2.90 | 2.25 | - | - | - | 2.55 | 1.82 | 0.714 |
| B/I-g | 220 | 5 | 12 | 2.77 | 2.62 | 2.40 | 3.30 | 2.00 | - | 2.62 | 1.85 | 0.706 |
| C/III-d | 59 | 5 | 5 | 2.90 | 1.80 | 2.25 | 2.60 | 2.10 | - | 2.33 | 1.90 | 0.815 |
| D/III-d | 257 | 5 | 5 | 3.80 | 4.40 | 3.55 | 4.00 | 2.75 | - | 3.70 | 2.60 | 0.703 |
| E/III-f | 158 | 4 | 4 | 4.12 | 4.80 | 4.38 | 3.28 | - | - | 4.14 | 3.58 | 0.864 |
| G/III-h | 44 | 3 | 8 | 1.95 | 2.35 | 2.23 | - | - | - | 2.18 | 1.85 | 0.849 |
| H/III-h | 104 | 6 | 6 | 1.30 | 1.75 | 2.25 | 1.07 | 1.05 | 1.43 | 1.47 | 1.11 | 0.755 |
| J/III-h | 126 | 4 | 6 | 2.20 | 2.35 | 2.50 | 1.90 | - | - | 2.24 | 1.90 | 0.848 |
| K/IV-b | 48 | 5 | 3 | 5.10 | 3.16 | 3.08 | 3.12 | 2.27 | - | 2.95 | 2.85 | 0.966 |
| L/IV-b | 51 | 4 | 6 | 2.65 | 2.56 | 3.60 | 3.15 | - | - | 2.99 | 2.30 | 0.769 |
| M/IV-b | 152 | 6 | 6 | 2.28 | 1.95 | 2.20 | 2.26 | 2.00 | 2.20 | 2.15 | 1.78 | 0.828 |

Where p = areal to point rainfall ratio.

A = area of the basin in sq. miles and

T = duration of storm in hours.

The scatter of the plotted positions with respect to the mean curves is considerable. Reliable estimates would require a greater number of networks with reasonable length of record and synchronised continuous readings of a closer network of raingauges.

It is assumed that the time of the year, return period and magnitude of storm, shape and orientation of the area etc. have no significant effect on the relationship. Detailed studies have been taken up by India Meteorological Department and pending completion of these studies, equation (5) or Table A prepared on the basis of equation 5 may be used to estimate the areal to point rainfall ratio.

TABLE A. AREAL TO POINT RAINFALL RATIOS (%)

| Area (Sq.miles) | Duration (Hrs) 0.50 | 1.00 | 2.00 | 3.00 | 4.00 | 5.00 | 6.00 |
|---|---|---|---|---|---|---|---|
| 10.0 | 68.33 | 76.39 | 82.66 | 85.60 | 87.40 | 88.65 | 89.59 |
| 20.0 | 61.89 | 71.23 | 78.67 | 82.21 | 84.40 | 85.92 | 87.06 |
| 30.0 | 57.74 | 67.81 | 75.98 | 79.91 | 82.35 | 84.05 | 85.34 |
| 40.0 | 54.63 | 65.21 | 73.91 | 78.13 | 80.76 | 82.60 | 83.99 |
| 50.0 | 52.14 | 63.10 | 72.21 | 76.65 | 79.43 | 81.39 | 82.86 |
| 60.0 | 50.05 | 61.30 | 70.75 | 75.39 | 78.30 | 80.34 | 81.89 |
| 70.0 | 48.26 | 59.74 | 69.47 | 74.27 | 77.29 | 79.42 | 81.03 |
| 80.0 | 46.69 | 58.36 | 68.33 | 73.27 | 76.39 | 78.59 | 80.26 |
| 90.0 | 45.28 | 57.11 | 67.29 | 72.37 | 75.57 | 77.84 | 79.56 |
| 100.0 | 44.02 | 55.98 | 66.35 | 71.54 | 74.82 | 77.15 | 78.91 |
| 110.0 | 42.87 | 54.94 | 65.47 | 70.77 | 74.12 | 76.50 | 78.31 |
| 120.0 | 41.81 | 53.98 | 64.66 | 70.05 | 73.47 | 75.90 | 77.75 |
| 130.0 | 40.84 | 53.09 | 63.91 | 69.38 | 72.86 | 75.34 | 77.22 |
| 140.0 | 39.94 | 52.25 | 63.19 | 68.75 | 72.29 | 74.81 | 76.72 |
| 150.0 | 39.09 | 51.47 | 62.52 | 68.15 | 71.74 | 74.30 | 76.25 |
| 160.0 | 38.30 | 50.73 | 61.89 | 67.58 | 71.23 | 73.82 | 75.80 |
| 170.0 | 37.56 | 50.03 | 61.28 | 67.05 | 70.74 | 73.37 | 75.38 |
| 180.0 | 36.86 | 49.37 | 60.71 | 66.53 | 70.27 | 72.93 | 74.97 |
| 190.0 | 36.19 | 48.74 | 60.16 | 66.04 | 69.82 | 72.52 | 74.57 |
| 200.0 | 35.57 | 48.14 | 59.64 | 65.57 | 69.38 | 72.11 | 74.20 |
| 210.0 | 34.97 | 47.57 | 59.13 | 65.12 | 68.97 | 71.73 | 73.84 |
| 220.0 | 34.40 | 47.02 | 58.65 | 64.68 | 68.57 | 71.36 | 73.49 |
| 230.0 | 33.85 | 46.49 | 58.18 | 64.26 | 68.19 | 71.00 | 73.15 |
| 240.0 | 33.33 | 45.99 | 57.74 | 63.86 | 67.81 | 70.65 | 72.82 |
| 250.0 | 32.84 | 45.50 | 57.30 | 63.47 | 67.45 | 70.32 | 72.51 |
| 260.0 | 32.36 | 45.03 | 56.88 | 63.09 | 67.11 | 69.99 | 72.20 |
| 270.0 | 31.90 | 44.58 | 56.48 | 62.72 | 66.77 | 69.68 | 71.90 |
| 280.0 | 31.46 | 44.14 | 56.09 | 62.37 | 66.44 | 69.37 | 71.62 |
| 290.0 | 31.03 | 43.72 | 55.71 | 62.02 | 66.12 | 69.07 | 71.34 |
| 300.0 | 30.62 | 43.31 | 55.34 | 61.69 | 65.81 | 68.78 | 71.06 |

Table A (Contd.)

| Area (Sq.miles) / Duration (hrs) | 9.00 | 12.00 | 15.00 | 18.00 | 21.00 | 24.00 |
|---|---|---|---|---|---|---|
| 10.0 | 91.41 | 92.52 | 93.28 | 93.85 | 94.29 | 94.65 |
| 20.0 | 89.31 | 90.67 | 91.61 | 92.31 | 92.86 | 93.31 |
| 30.0 | 87.86 | 89.39 | 90.46 | 91.25 | 91.87 | 92.38 |
| 40.0 | 86.72 | 88.39 | 89.55 | 90.41 | 91.09 | 91.64 |
| 50.0 | 85.77 | 87.55 | 88.79 | 89.71 | 90.44 | 91.03 |
| 60.0 | 84.95 | 86.83 | 88.13 | 89.11 | 89.87 | 90.49 |
| 70.0 | 84.22 | 86.18 | 87.55 | 88.57 | 89.37 | 90.02 |
| 80.0 | 83.57 | 85.60 | 87.02 | 88.08 | 88.91 | 89.59 |
| 90.0 | 82.97 | 85.07 | 86.53 | 87.63 | 88.49 | 89.19 |
| 100.0 | 82.42 | 84.58 | 86.09 | 87.22 | 88.11 | 88.83 |
| 110.0 | 81.90 | 84.12 | 85.67 | 86.83 | 87.75 | 88.49 |
| 120.0 | 81.42 | 83.70 | 85.28 | 86.47 | 87.41 | 88.17 |
| 130.0 | 80.97 | 83.29 | 84.92 | 86.14 | 87.09 | 87.87 |
| 140.0 | 80.55 | 82.91 | 84.57 | 85.81 | 86.79 | 87.59 |
| 150.0 | 80.14 | 82.55 | 84.24 | 85.51 | 86.51 | 87.32 |
| 160.0 | 79.76 | 82.21 | 83.93 | 85.22 | 86.24 | 87.06 |
| 170.0 | 79.39 | 81.88 | 83.63 | 84.94 | 85.98 | 86.82 |
| 180.0 | 79.04 | 81.57 | 83.34 | 84.67 | 85.73 | 86.58 |
| 190.0 | 78.70 | 81.27 | 83.07 | 84.42 | 85.49 | 86.36 |
| 200.0 | 78.37 | 80.98 | 82.80 | 84.17 | 85.26 | 86.14 |
| 210.0 | 78.06 | 80.70 | 82.54 | 83.94 | 85.03 | 85.93 |
| 220.0 | 77.76 | 80.43 | 82.30 | 83.71 | 84.82 | 85.72 |
| 230.0 | 77.47 | 80.16 | 82.06 | 83.48 | 84.61 | 85.53 |
| 240.0 | 77.19 | 79.91 | 81.83 | 83.27 | 84.41 | 85.34 |
| 250.0 | 76.91 | 79.67 | 81.60 | 83.06 | 84.21 | 85.15 |
| 260.0 | 76.65 | 79.43 | 81.38 | 82.86 | 84.02 | 84.97 |
| 270.0 | 76.39 | 79.20 | 81.17 | 82.66 | 83.84 | 84.80 |
| 280.0 | 76.14 | 78.97 | 80.97 | 82.47 | 83.66 | 84.63 |
| 290.0 | 75.90 | 78.75 | 80.76 | 82.28 | 83.48 | 84.46 |
| 300.0 | 75.66 | 78.54 | 80.57 | 82.10 | 83.31 | 84.30 |

## 7. ESTIMATION OF RUNOFF

### 7.1 Initial Loss

Initial loss may be defined as that portion of a storm which is intercepted by vegetation held in depression storage, infiltration at a high rate or is lost through the stream bed and banks prior to the commencement of surface runoff. Snyder has defined initial loss as the "maximum amount of precipitation that can occur under specific conditions without producing runoff". As design storm is expected to be a long duration storm that occurs during rainfall season only, it is considered reasonable to assume that the initial loss is met by the spells of rainfall prior to the high intensity spells. Thus, initial loss for these high intensity spells of design storm may be assumed to be zero.

### 7.2 Loss Rate

The factors affecting runoff in a drainage basin vary from storm to storm considerably. Hence, a direct plotting of rainfall versus runoff of the individual storms results in a wide scatter of the plotted points giving no satisfactory correlation. The relation may improve by considering factors such as initial soil moisture condition, storm duration, soil type and vegetal cover. Such detailed analyses are, however, beyond the scope of the study envisaged under the short term plan of the Khosla Committee of Engineers and have been deferred for the Long Term plan.

From a study of the rainfall-runoff data for a large number of drainage basins of areas from 10 to 200 sq. miles, it is observed that:

i) Maximum flood peaks are invariably produced by storms of long duration of over 12 hrs containing high intensity spells, whereas low peaks are produced by short duration storms though the intensity is higher. Even in the case of long duration storms, higher peaks are produced if high intensity spells are preceded by low intensity spells. It may be reasoned that most of the initial rainfall is absorbed in wetting the soil and that rainfall immediately preceding the high intensity spells is significant for small basins in producing high flood peaks.

ii) The plots of total rainfall of long duration storms against the runoff with soil type as a parameter showed good correlation. The reason for good correlation may be attributed to the fact that the time of the year (flood season) as a parameter is implied in the analysis. It would be reasonable to assume that such conditions exist at the time of occurrence of the design storm.

Rainfall runoff data of three drainage basins with clayey type of soils are given in Table 6 and of three drainage basins with loamy soils in Table 7. Only storms which produced flood peaks of the magnitude of the mean annual flood peak and above have been selected. As the number of storms producing high peaks in small for individual basins, the data of basins of similar soil characteristics have been combined to enable derivation of relationship between rainfall and runoff.

The relationships obtained by regression analysis are as under:

Clayey soils, $R = 0.47\ H^{1.22}$

Corr. Coeft, r = 0.98

Sandy-loam soils, $R = 0.33\ H^{1.18}$

Corr. Coeft., r = 0.85

Where R = Total direct surface runoff in inches.

H = Total storm rainfall in inches.

TABLE - 6

RAINFALL RUNOFF RELATIONS FOR CLAYEY SOILS

| Bridge No. and subzone | Soil type and topography | Vegetal cover | Date of storm | Storm pattern | Duration (hrs) | Total rainfall (H-in.) | Total runoff (R-in.) | Runoff factor Ø=R/H | Flood peak cs. | Mean annual flood peak(cs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 604/III-f | Clayey black soil-undulating country with steep slopes | Forests 20% | 27.7.60 | L.H. | 5 | 2.602 | 1.140 | 0.44 | 22,400 | 24,500 |
| | | Irrigated 30% | 23/25.8.61 | L.H.L. | 45 | 8.516 | 6.614 | 0.78 | 35,000 | |
| | | Fallow 50% | 20/21.7.64 | L.H. | 4 | 1.763 | 1.220 | 0.69 | 19,600 | |
| 603/I-c | Black cotton soil plains | Cultivated | 14/17.8.64 | H.L. | 33 | 8.49 | 6.90 | 0.81 | 8,200 | 6,000 |
| | | | 25/27.8.64 | L.H.L. | 16 | 4.19 | 3.02 | 0.71 | 5,400 | |
| | | | 30.7.66 to 2.8.66 | L.H. | 31 | 6.99 | 5.33 | 0.76 | 5,540 | |
| | | | 19/21.8.66 | H.L. | 17 | 5.06 | 3.15 | 0.62 | 8,430 | |
| 110/I-g | Clayey soil hilly | Forests and Fallow land | 23/24.8.67 | H.L. | 17 | 2.144 | 1.087 | 0.51 | 15,725 | |
| | | | 25/26.8.67 | H.H.L. | 12 | 2.553 | 1.499 | 0.59 | 22,900 | |
| | | | 2/4.9.67 | H.H.L. | 15 | 4.148 | 2.621 | 0.63 | 27,200 | |

NOTATION FOR STORM PATTERN:

L.H. Light showers followed by high intensity rainfall.
L.H.L. High intensity rainfall preceded and succeeded by light showers.
H.L. High intensity rainfall succeeded by light showers.
L.H., L.H.L., H.H.L. One storm followed by another with a short period of no rain.

TABLE - 7

RAINFALL RUNOFF RELATIONS FOR SANDY LOAM SOILS

| Bridge No. and subzone | Soil type and topography | Vegetal cover | Date of storm | Storm pattern | Duration (hrs) | Total rainfall (H-in.) | Total runoff (R-in.) | Runoff factor $\phi = R/H$ | Flood peak (cusecs) | Mean annual flood peak(cs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 181/I-g | Loamy soil plains | Forests 35% | 4/5.9.61 | H.L. | 14 | 3.50 | 1.50 | 0.42 | 6,344 | 3,650 |
| | | Farmland 55% | 2/4.10.62 | H.L. | 22 | 4.11 | 1.733 | 0.44 | 5,450 | - |
| | | Fallow 10% | 21.9.62 | H.L. | 30 | 4.196 | 1.220 | 0.29 | 3,460 | - |
| 167/I-g | Loamy soils Hilly | Forests 64% | 1/2.10.61 | L.H.L. | 44 | 9.480 | 4.270 | 0.45 | 36,910 | - |
| | | Irrigated 26% | 29/30.9.63 | L.H.L. | 32 | 4.960 | 3.265 | 0.66 | 45,000 | - |
| | | Fallow 10% | 29/30.7.65 | L.H. | 24 | 3.822 | 2.130 | 0.55 | 22,100 | - |
| | | | 24/25.9.65 | L.H. | 29 | 4.422 | 1.727 | 0.39 | 18,000 | - |
| 656/I-g | Loamy soils plains | Cultivated 54% | 24/25.9.66 | L.H.L. | 9 | 3.632 | 1.402 | 0.39 | 7,600 | 5,000 |
| | | Fallow 46% | 18.8.66 | L.H. | 4 | 3.555 | 1.341 | 0.38 | 7,130 | - |
| | | | 21/23.9.62 | L.H.L. | 31 | 5.780 | 2.860 | 0.49 | 6,325 | - |

NOTATION FOR STORM PATTERN:- Same as given in Table 6.

For other types of soils, the relationship may be obtained by judicious interpolation and extrapolation based on relative permeabilities. The following relationships (Table-B) for different soil types may be considered as acceptable.

TABLE - B

ESTIMATION OF RUNOFF

| | Type of Soils | Runoff |
|---|---|---|
| 1. | Sandy soils<br>Sandy loam | $0.30\ H^{1.2}$ |
| 2. | Coastal alluvium<br>Silty loam | $0.40\ H^{1.2}$ |
| 3. | Red soils<br>Clayey loam<br>Grey & Brown alluvium | $0.50\ H^{1.2}$ |
| 4. | Black cotton soils<br>Clayey soils | $0.55\ H^{1.2}$ |
| 5. | Hilly soils | $0.60\ H^{1.2}$ |

Ø-Index approach to runoff estimation is a simple tool and it represents the combined effects of interception, depression storage and infiltration. The loss rate represented by Ø-Index will be lower than the actual rate in the initial stages and will be higher than the loss rate reached at the end of the storm. It is assumed that high intensity spell producing the design flood peak is preceded and succeeded by low intensity spells and it is considered reasonable to take the loss rate for the high intensity spell as equal to Ø-Index for purposes of estimation of runoff from the high intensity spell responsible for design flood peak.

As discussed in para 5.1 the depth-duration curve for a return period of 50-years represents the cumulative rainfall of the design storm. Hence, the difference between the maximum rainfall values for durations of 2 hours and 1 hour gives the rainfall during the 2nd hour; similarly the differences of rainfall values of 3 hours and 2 hours durations gives the contribution during the 3rd hour and so on. By keeping the high intensity spell at the middle, the rainfall hyetograph of the design storm can be constructed. Knowing the runoff from the relationship given in Table B, appropriate to the type of the soil, Ø-Index can be estimated.

It is seen from Tables 6 and 7 that the duration of rainfall storm producing high flood peaks is generally over 15 hours for sub-humid regions. Further, it is observed from depth-duration curves for on return period of 50-years that out of the rainfall of 24 hrs duration over 80% occurs in 12 hrs in sub-humid and humid regions and over 90% in arid and semi-arid regions. Hence, the estimated Ø-Index value reduces only slightly with the increase in the duration of the design storm beyond 12 hours and thus, it would suffice if an approximate estimate of the duration of the design storm is made. For purposes of the estimation of Ø-Index, the duration of the design storm may be taken as 24 hrs as the maximum rainfall estimates for this duration are statistically more reliable.

## 8. EFFECT OF TEMPORAL DISTRIBUTION OF RAINFALL EXCESS

The temporal distribution of rainfall excess is assumed to be rectangular. However, if the rainfall excess is distributed in such a way as to give the maximum peak rate, then the increase in flood peak over that with rectangular distribution would be of the order of 2% to 20% depending on the duration of rainfall excess and the shape of the unit hydrograph. On the basis of studies on drainage basis with different U.G. shapes it is concluded that the following multiplying factors (Table C) would take into account the effect of non-uniform distribution of rainfall excess in time:

TABLE - C

ADJUSTMENT OF DESIGN FLOOD PEAK FOR TEMPORAL DISTRIBUTION OF RAINFALL EXCESS

| Duration of rainfall excess | Upto 3 hrs | 3 hrs to 6 hrs | 6 hrs to 9 hrs | 9 hours to 12 hours |
|---|---|---|---|---|
| Adjustment factor | 1.05 to 1.10 | 1.10 to 1.15 | 1.15 to 1.20 | 1.20 to 1.25 |

9. BASE FLOW

A study of a large number of small drainage basins in India revealed that the base flow during the flood season is varying from 5 to 40 cusecs/sq.mile depending on the meteorological zone in which the basins are located. However, when compared to the peak of the high floods, base flow constitutes a amall percentage. Hence an approximate estimate of base flow would be adequate. The following estimates for base flow (Table-D) based on the observed data on various basins, are considered reasonable:

TABLE - D

RECOMMENDED BASE FLOW ESTIMATES

| | Sub-Zones | | Recommended base flow estimates (cusecs/sq.miles) |
|---|---|---|---|
| 1. | I-a | (Luni basin) | |
| | I-b | (Chambal basin) | |
| | I-d | (Sone basin) | |
| | I-e | (Punjab plains) | |
| | I-f & g | (Gangetic plains) | |
| | III-c | (Upper Narmada and Tapi basins) | 5 |
| | III-e | (Upper Godavari Basin) | |
| | III-h | (Krishna basin) | |
| | III-i | (Cauvery basin) | |
| | VII | (J&K, Kumaon Hills) | |
| 2. | I-c | (Betwa basin) | |
| | III-a | (Mahi and Sabarmati basin) | |
| | III-b | (Lower Narmada and Tapi basin) | 10 |

Table D (Contd.)

| | Sub-Zones | | Recommended base flow estimates (cusecs/sq. miles) |
|---|---|---|---|
| | III-f | (Lower Godavari basin) | |
| | III-g | (Indravati basin) | |
| | IV-a, b & c | (East Coast) | |
| | VI | (Tarai) | |
| 3. | III-d | (Mahanadi basin) | |
| | V-a & b | (West coast) | 20 |
| 4. | II-a b & c | (Brahmaputra basin) | 40 |

## 10. CONCLUSION

For the estimation of design flood peak, the empirical formulae in vogue in different regions of the country have serious limitations in that the frequency concept is completely absent and hence, the risk involved in accepting the flood estimate is indeterminate. Further, these formulae made use of only one parameter viz. the area (A) of the catchment. The constant connecting the maximum flood peak and the area (A) of the catchment has to account for a host of inter-related factors involved in the complex process of the transformation of rainfall into runoff by the basin system. Judgement involved in selecting the constant vitiates the utility of these formulae for general use.

The standard procedure outlined in this chapter has been evolved on a rational basis taking into account the various aspects of the rainfall runoff process. The method may be adopted for estimating the flood peak of desired frequency for small drainage basins from 10 to 200 sq.miles in area. However, in the statistical sense, the sample size utilised for estimating the rainfall parameters and the parameters representing the basin response is too small to ensure adequate reliability in the estimates. Hence, it is essential to check whether the results obtained by this procedure are reasonable

The crest gauges giving the maximum flood levels are being observed systematically since 1958 for some bridge catchments for which reliable stage-discharge curves have been developed. With the help of these crest gauges, it would be possible to form annual series of maximum flood peaks and to estimate the flood peak of 50-year return period by frequency analysis after the data for over 20 years is collected. The estimate thus obtained can be compared with the estimate obtained by the procedure outlined in this report and a review of the procedure, if necessary can be made in due course of time.

The procedure is recommended, as an interim measure for adoption till such time a better method is evolved under long term plan.

Note:

Subsequent to this publication the following reports for estimation of 50 year flood under Long Term Plan have been brought out, which is recommended for application for respective sub-zones, I-g and 3-f shown in the map of India at appendix IV.

1. Report on Hydrometeorological studies for Lower Gangetic Plains (sub-zone I-g)

2. Flood Estimation Report for Lower Godavari sub-zone (sub-zone 3-f)

Further the following subzonal reports under Long Term Plan have been finalised and are expected to be published which is also shown in the map of India at appendix IV.

1. Flood Estimation Report for Lower Narmada and Tapi Basin (sub-zone 3b)

2. Flood Estimation Report for Mahanadi sub-zone (sub-zone 3-d)

## APPENDIX - I

### ILLUSTRATIVE EXAMPLE

<u>Problem</u>

It is required to estimate the design flood peak of 50-year return period for the design of waterway of railway bridge No.604 (Itarsi-Nagpur Section, Sub-zone 3-f) across the Jam river. The drainage basin plan is shown in Fig.9.

<u>Data</u>

(a) Area of the drainage basin upto the location of the bridge No. 604 (measured from Survey of India Topo Sheet 1" = 1 mile), A = 131.48 sq. miles.

(b) Length of the main stream from the centroid of the drainage basin to the bridge site (measured from Survey of India Topo Sheet 1" = 1 mile), Lc = 12.7 miles.

(c) Weighted mean slope of the stream, SLC

$$= \left[ \frac{Lc}{l_1/s_1^{\frac{1}{2}} + l_2/s_2^{\frac{1}{2}} + ..} \right]^2$$

Where $s_1$, $s_2$ ...................... are the slopes of the main stream in the reaches of lengths $l_1$, $l_2$.......... into which the length Lc of the main stream is divided. From the survey of India Topo Sheet (1" = 1 mile), the lengths of the reaches of the stream between the contours crossing the stream have been measured. The details of calculation for arriving at the value of SLC are given in the table (i). It is assumed that the bed slope in the reach between two successive contours is uniform.

TABLE (i)

SLOPE PARAMETER

| RD (miles) (1) | EL (feet) (2) | Length of reach (miles) (3) | Difference in elevation (feet) (4) | Slope (%) (5) = $\frac{(4)\times 100}{(3)\times 5280}$ | $1/S^{\frac{1}{2}}$ (6) |
|---|---|---|---|---|---|
| 0 | 1297.80 | | | | |
| 5.9 | 1350.00 | 5.9 | 52.20 | 0.1676 | 14.00 |
| 11.9 | 1400.00 | 6.0 | 50.00 | 0.1578 | 15.08 |
| 12.7 | (1414.8) | 0.8 | 14.80 | 0.3433 | 1.37 |
| 14.6 | 1450.00 | 1.9 | | | |
| | | | | Total: | 30.45 |

$SLC = (12.7/3045)^2 = 0.174\% = 0.00174$

(d) Soil type and topography: Clayey black Cotton soil; Undulating country with steep slopes.

Unit Hydrograph Parameters

(a) Since SLC is less than 0.0028, equation (1) would give:

$$Qtc = 16000A^{3/4} \quad (SLC)^{2/3}$$
$$= 16{,}000\ (131.48)^{3/4} \times (0.00174)^{2/3}$$
$$= 8986 = 9000 \text{ cusecs (say)}$$

(b) $tc = 280 / (Qtc/A)^{0.9}$ from equation (4)

$$= 280\ (68.345)^{0.9}$$
$$= 280/44.79$$
$$= 6.2513 = 6.3 \text{ hrs (say)}$$

## Design Rainfall Storm

From the isopluvial maps of I.M.D., the point rainfall values of 50 year return period for various durations are read. The value for duration of 24 hours is to be increased by 15% for obtaining the consecutive 1440 min. maximum point rainfall value. A log plot of these values is shown in Fig. 10. A smooth curve representing the depth-duration curve is drawn. Areal to point rainfall ratios are taken from Table A and areal to point rainfall hyetograph for the design storm is then constructed. The computations are shown in Table (ii).

## Loss Rate

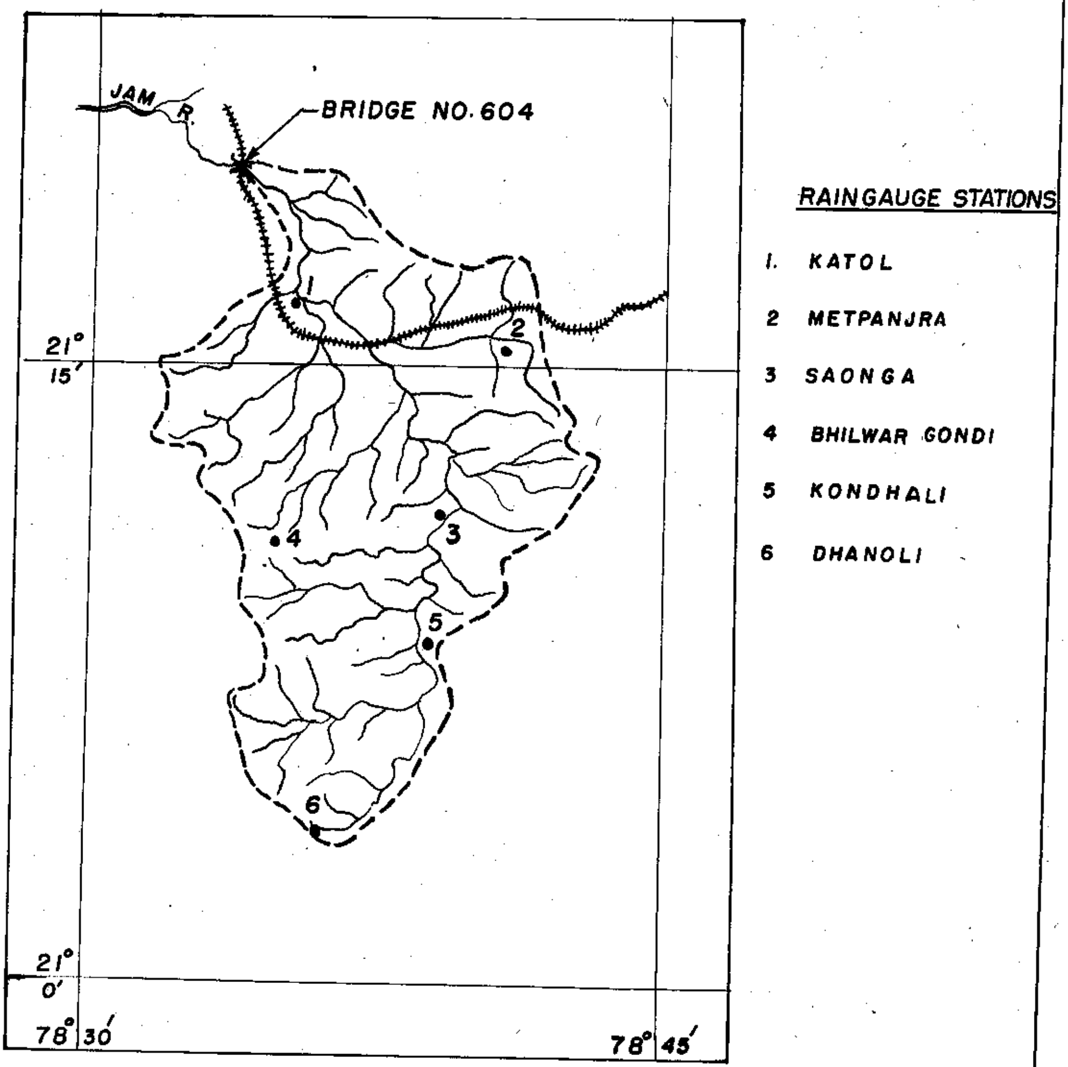
As the type of soil obtaining in the catchment is clayey black cotton soil, the following relationship may be adopted for estimating the runoff from a long duration storm :

$$R = 0.55\ H^{1.2}$$

From Table (ii) areal rainfall of 24 hours duration and 50 years return period, H = 180.19 mm = 7.094 inches.

$$\text{Runoff, } R = 0.5\ (7.094)^{1.2} = 5.773 \text{ inches} = 146.65 \text{ mm.}$$

A uniform loss rate is applied to the design storm hyetograph given in Col. 6 of the Table (ii) such that the rainfall excess obtained is equal to the estimated runoff of 146.65 mm (5.773 inches). The hyetograph of the design storm and the rainfall excess hyetograph obtained are shown in Fig. 11. It is seen that the duration of rainfall excess is 24 hrs. and that the uniform loss rate = 1.398 mm /hr = 0.055 inch/hr.




Based upon Survey of India mapwith the permission of the Surveyor General of India



FIG. 9 CATCHMENT PLAN

TABLE (ii)

DESIGN STORM HYETOGRAPH

| Duration | Point rainfall volume (mm) of 50-yr. ret. period: Read from IMD maps | Point rainfall volume (mm) of 50-yr. ret. period: Read from depth duration curve (fig. 10) | Areal to point rain-fall ratio from Table A | Areal rain-fall (mm) | Hourly areal rainfall of design storm (MM) |
|---|---|---|---|---|---|
| 15 Min. | 50 | 50 | - | - | - |
| 30 " | 70 | 70 | 0.408 | 28.56 | - |
| 45 " | 80 | 80 | - | - | - |
| 1 hr | 90 | 90 | 0.531 | 47.79 | 47.79 |
| 2 " | - | 110 | 0.639 | 70 .29 | 22.50 |
| 3 " | 125 | 125 | 0.694 | 86.75 | 16.46 |
| 4 " | - | 135 | 0.729 | 98.42 | 11.67 |
| 5 " | - | 142.5 | 0.753 | 107.30 | 8.88 |
| 6 " | 140 | 150 | 0.772 | 115.80 | 8.50 |
| 6.3 " | - | - | - | 117.585 | - |
| 7 " | - | - | - | (121.75)* | 5.95 |
| 8 " | - | - | - | (127.70) | 5.95 |
| 9 " | 140 | 165 | 0.810 | 133.65 | 5.95 |
| 10 hr | - | - | - | (137.97) | 4.32 |
| 11 " | - | - | - | (142.29) | 4.32 |
| 12 " | 150 | 176 | 0.833 | 146.61 | 4.32 |
| 13 " | - | - | - | (150.10) | 3.49 |
| 14 " | - | - | - | (153.59) | 3.49 |
| 15 " | 160 | 185 | 0.849 | 157.07 | 3.48 |
| 16 " | - | - | - | (160.11) | 3.04 |
| 17 " | - | - | - | (163.14) | 3.03 |
| 18 " | - | 193 | 0.861 | 166.17 | 3.03 |
| 19 " | - | - | - | (168.85) | 2.68 |
| 20 " | - | - | - | (171.53) | 2.68 |
| 21 " | - | 200 | 0.871 | 174.20 | 2.67 |
| 22 " | - | - | - | (176.20) | 2.00 |
| 23 " | - | - | - | (178.20) | 2.00 |
| 24 " | 195x1.15 | 205 | 0.879 | 180.19 | 1.99 |

* Values shown in brackets are interpolated values.

Estimation of Design Flood Peak

(a) Duration of high intensity spell, responsible for design flood peak, tc = 6.3 hrs.

(b) From Col. 5 of Table (ii), areal rainfall volume of 50 year return period and of duration of 6 hrs. 115.80 and of duration of 7 hrs = 121.75 mm. By interpolation, areal rainfall volume of 6.3 hrs = 115.80 + (121.75 - 115.80) 0.3 = 115.80 + 1.785 = 117.585 mm.

(c) Applying a loss rate of 1.398 mm/hr, max. rainfall excess volume of 6.3 hrs duration.

= 117.585 - 6.3 x 1.398

= 117.585 - 8.807

= 108.78 mm = 4.283 inches

(d) Peak value of unit hydrograph of 6.3 hrs duration, Qtc = 9000 cusecs.

(e) Peak of the flood hydrograph due to a rainfall excess of 4.283 inches and of duration of 6.3 hrs. = 9000 x 4.283 = 38,547 cusecs.

(f) Adjustment factor to account for the effect of temporal distribution of rainfall excess = 1.15 (from Table C). Hence, peak of the design flood hydrograph excluding base flow = 1.15 x 38,547 = 44,329 cusecs.

(g) Adding base flow @ 10 cusecs/sq. mile (vide Table D) the design flood peak works out to:

Q = 44,329 + 1,310 = 45,639 cusecs.

= say 45,600 cusecs.

Results

(i) Flood peak for design of waterway of the bridge = 45,600 cusecs.

(ii) Flood peak for design of foundations of the bridge = 30% over 45,600 cusecs as recommended by the Committee of Engineers = 59,280 cusecs.

Check

The catchment is being systematically gauged since 1959. The annual maximum flood peaks observed are tabulated below:

| Date | Flood Peak Discharge (cfs) |
|---|---|
| 13-9-59 | 14,500 |
| 27-7-60 | 13,600 |
| 24-8-61 | 34,870 |
| 8-8-62 | 22,200 |
| 25-8-63 | 16,500 |
| 6-8-64 | 20,600 |
| 21-9-65 | 10,250 |

The annual series of the maximum observed flood discharge is treated by Gumbel's extreme value technique for obtaining the design flood peak of 50-year return period. The Gumbel's plot is shown in Fig. 12. It is seen that the flood peak of 50-year return period is 38,000 cusecs which is somewhat lesser order as the one estimated by the method evolved in this report. This appears to be more reasonable for the fact that already a value of 34,870 cfs in 1961 within a small sample of seven observations.

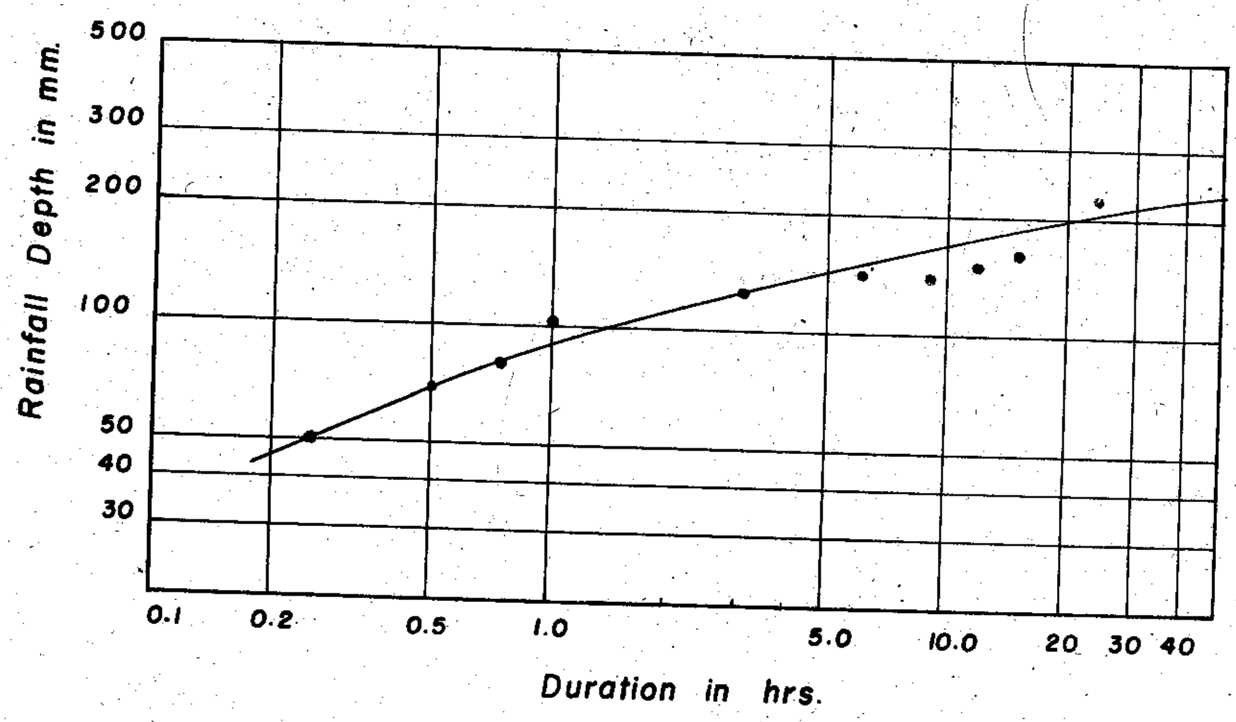



FIG. -: 10 DEPTH - DURATION CURVE

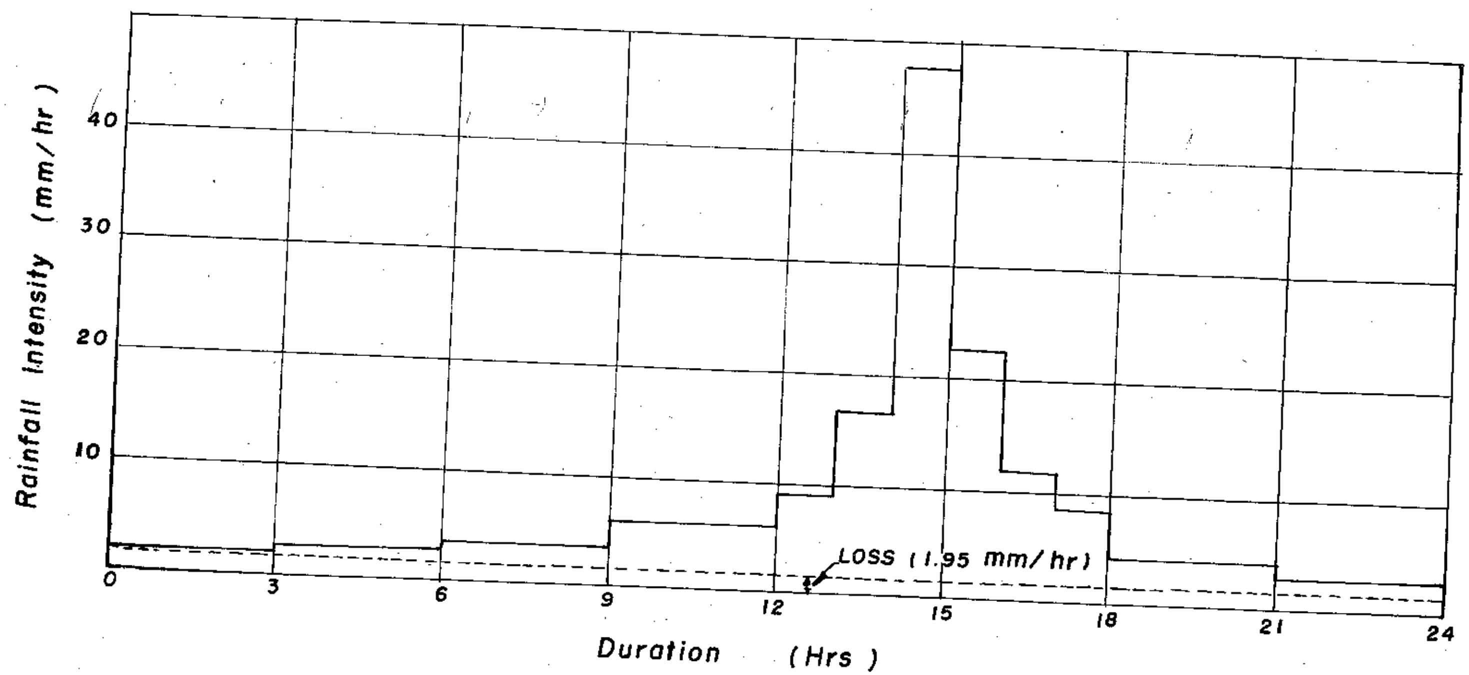



FIG.-: 11 DESIGN STORM RAINFALL

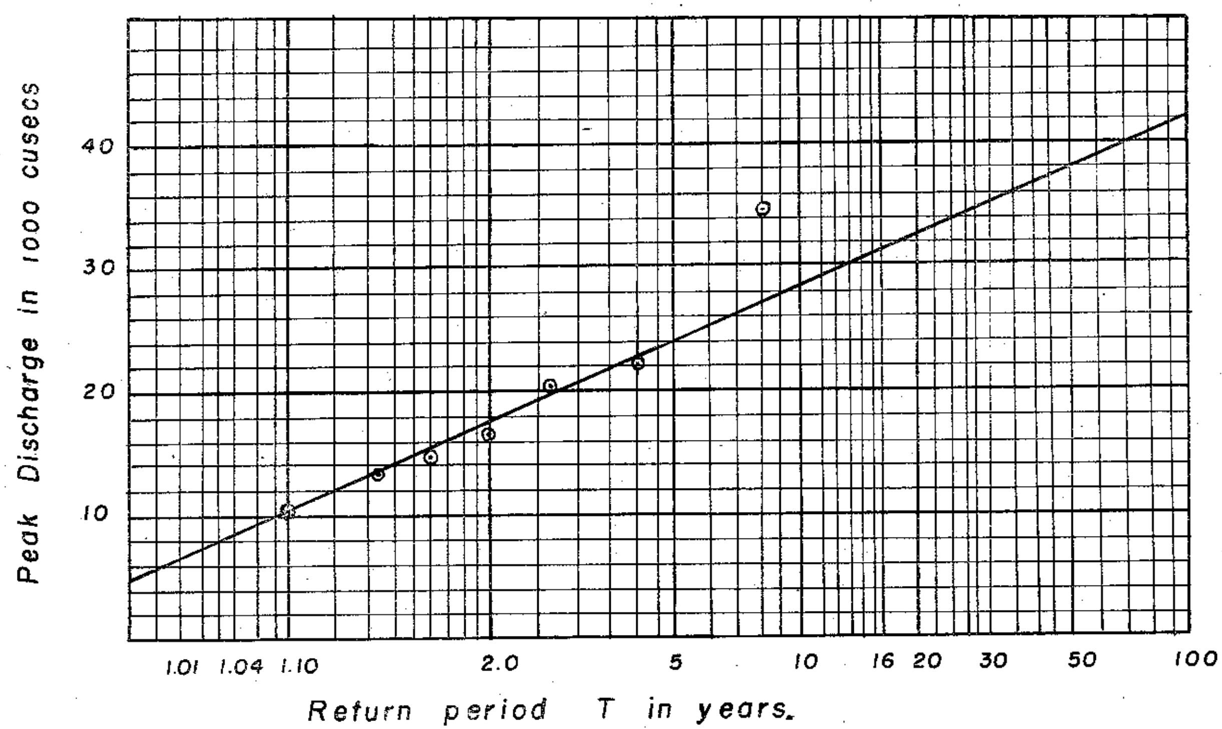
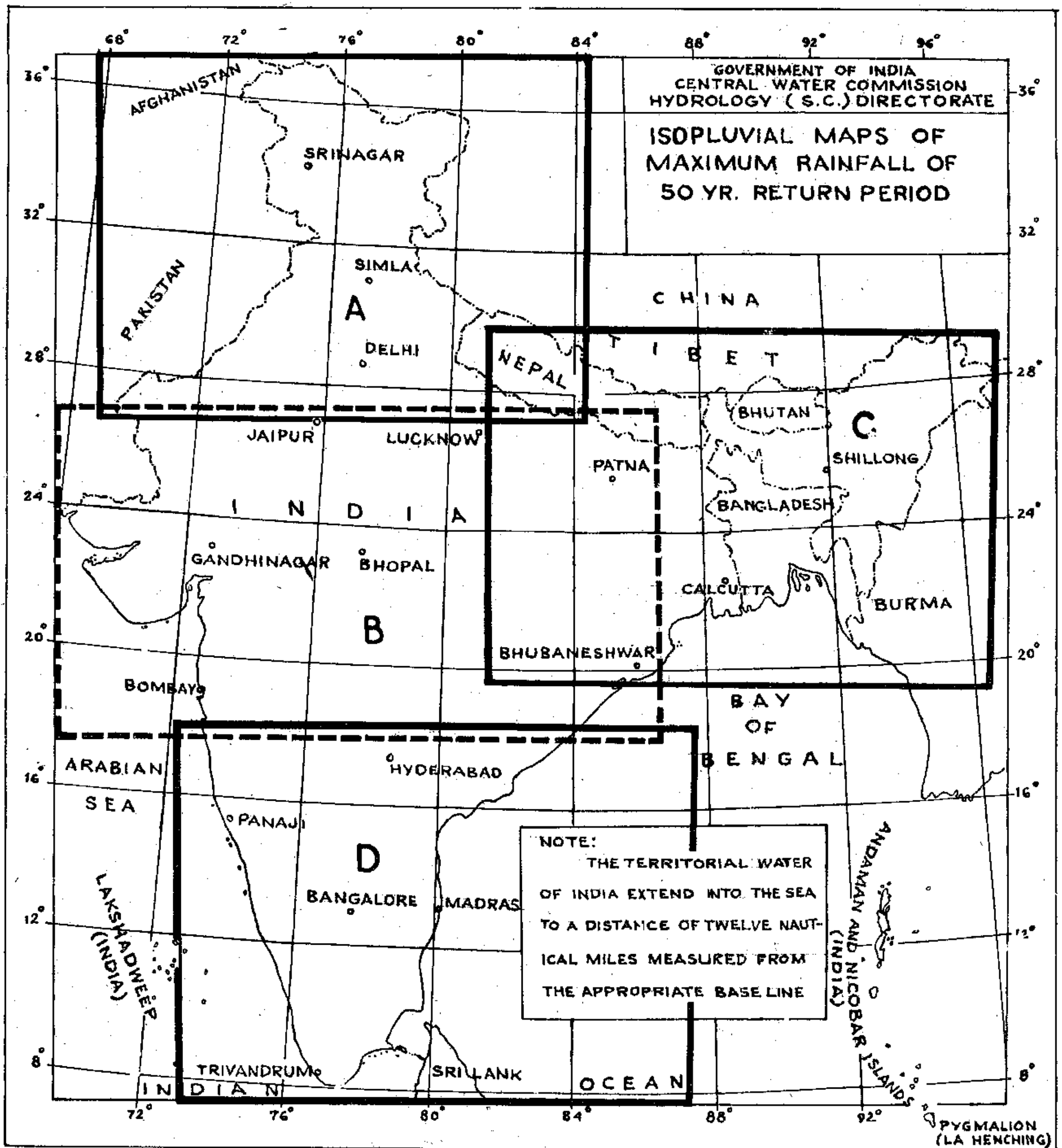


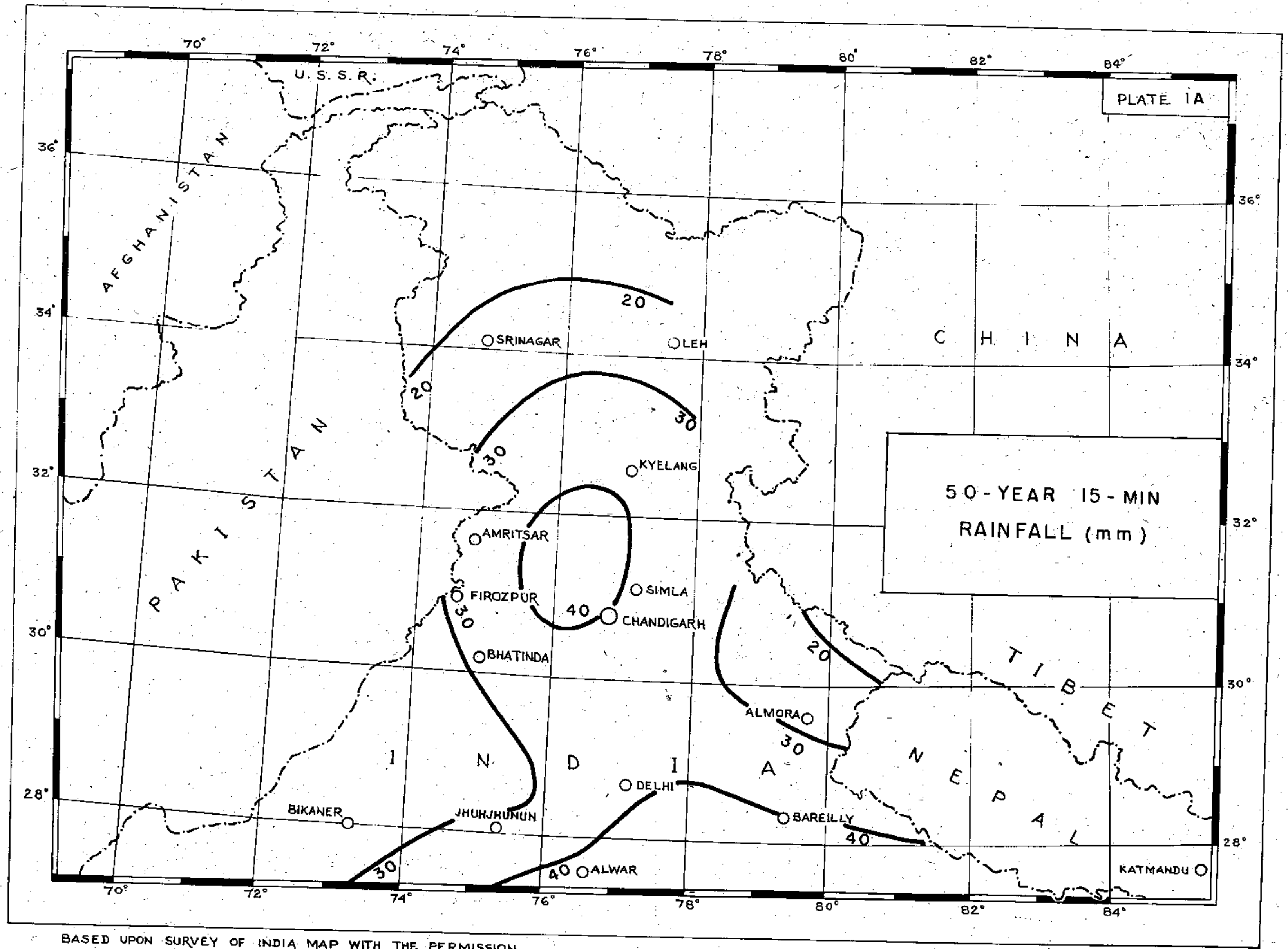

FIG. 12: FLOOD FREQUENCY ANALYSIS




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



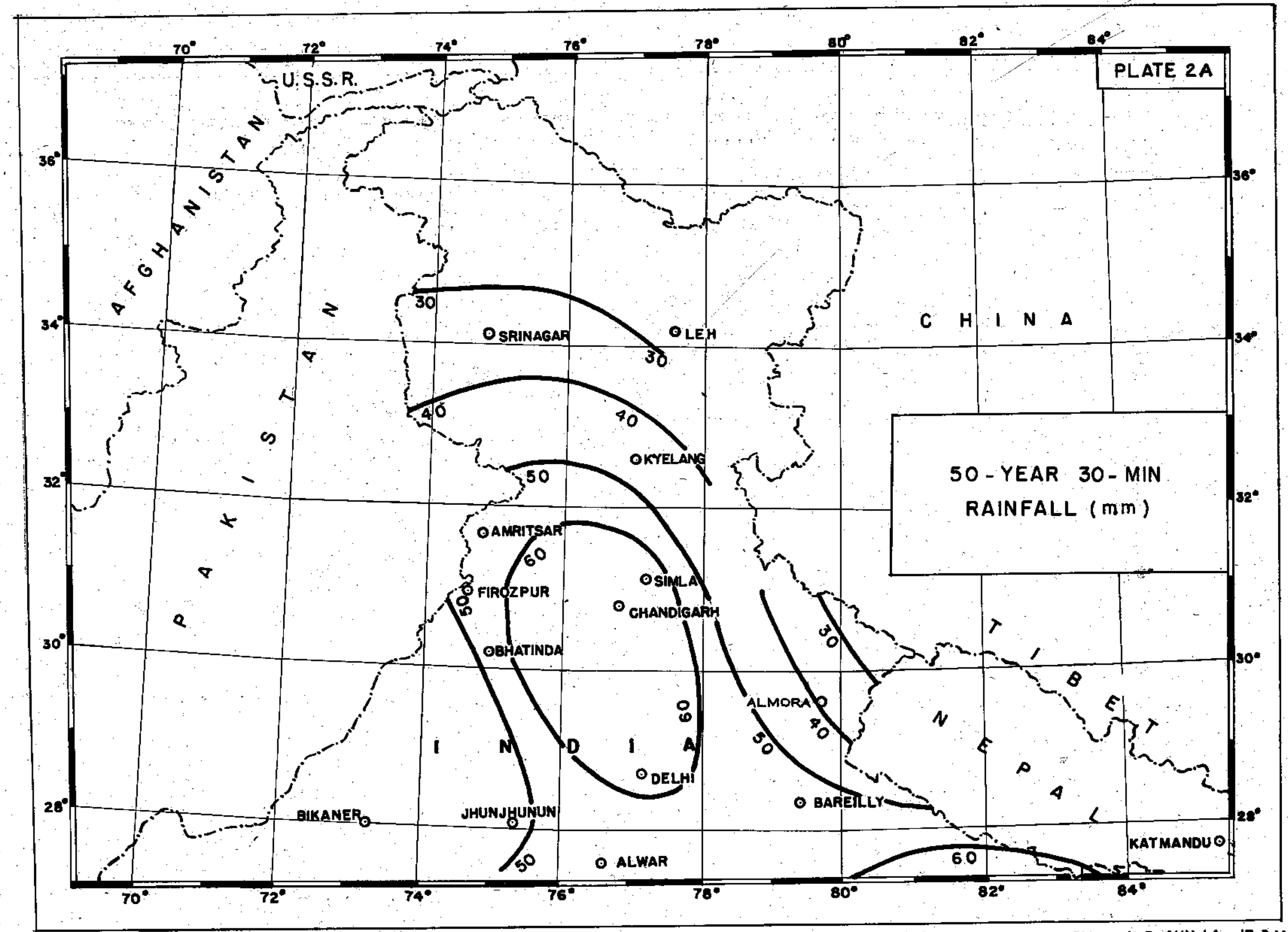
EACH MAP GIVEN IN 4 PARTS (A, B, C & D) AS SHOWN ABOVE




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



TRACED BY—K.B. AHUJA. JR.D.MAN
CHECKED BY—A. K. GHOSH, A.D.

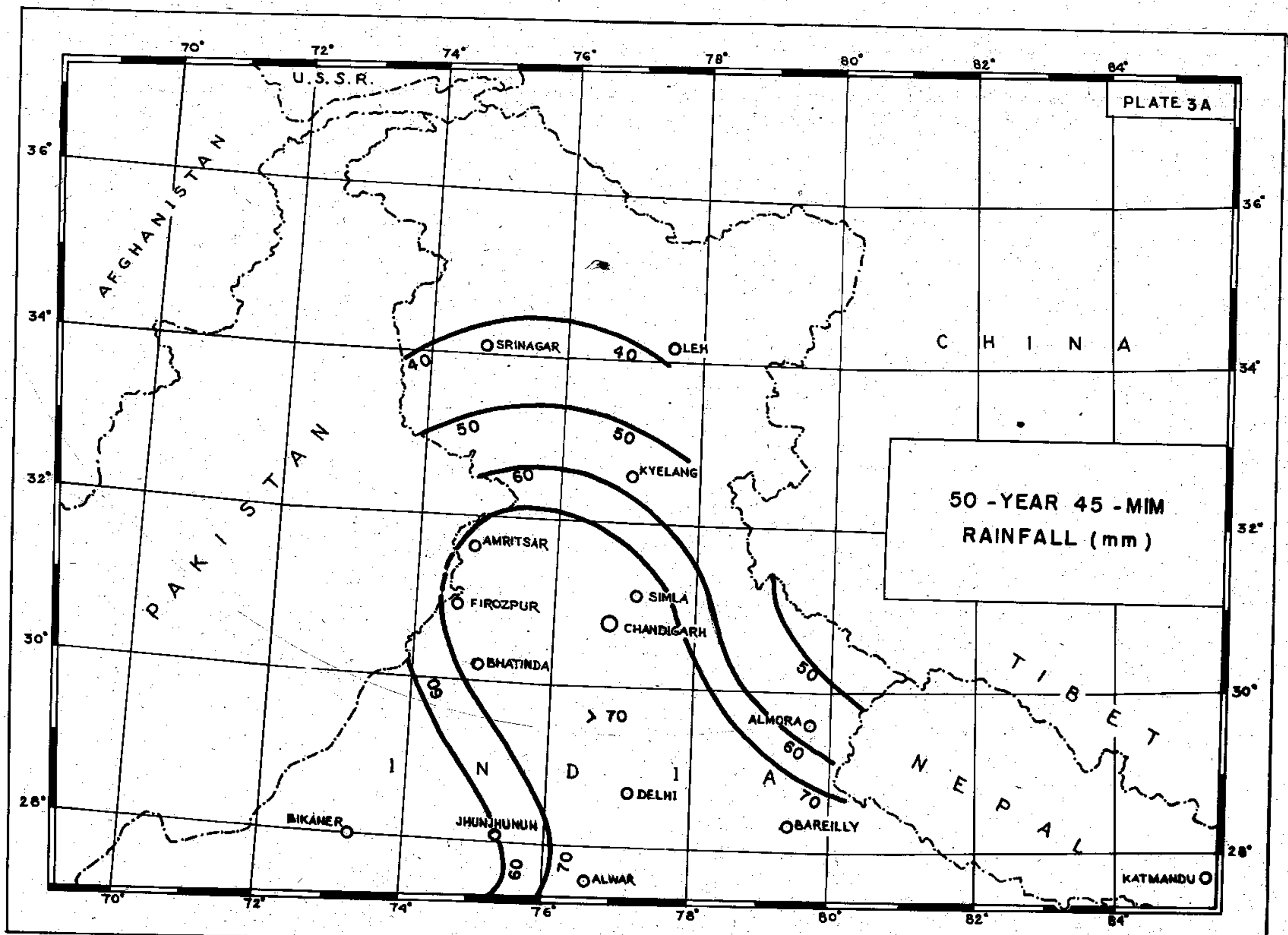



BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.



TRACED BY — K.B. AHUJA. JR. D.MAN

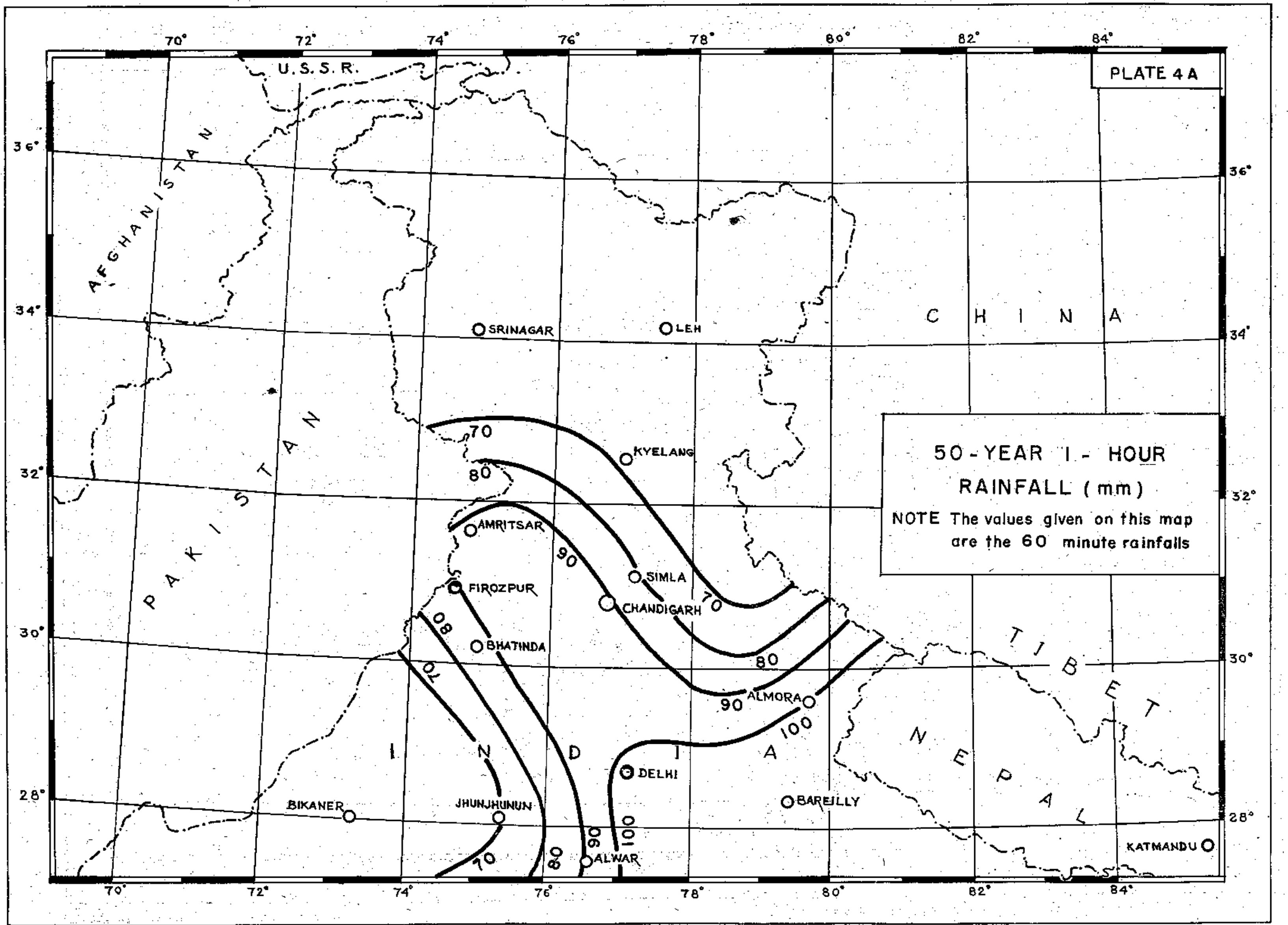
CHECKED BY — A.K. GHOSH, A.D.




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



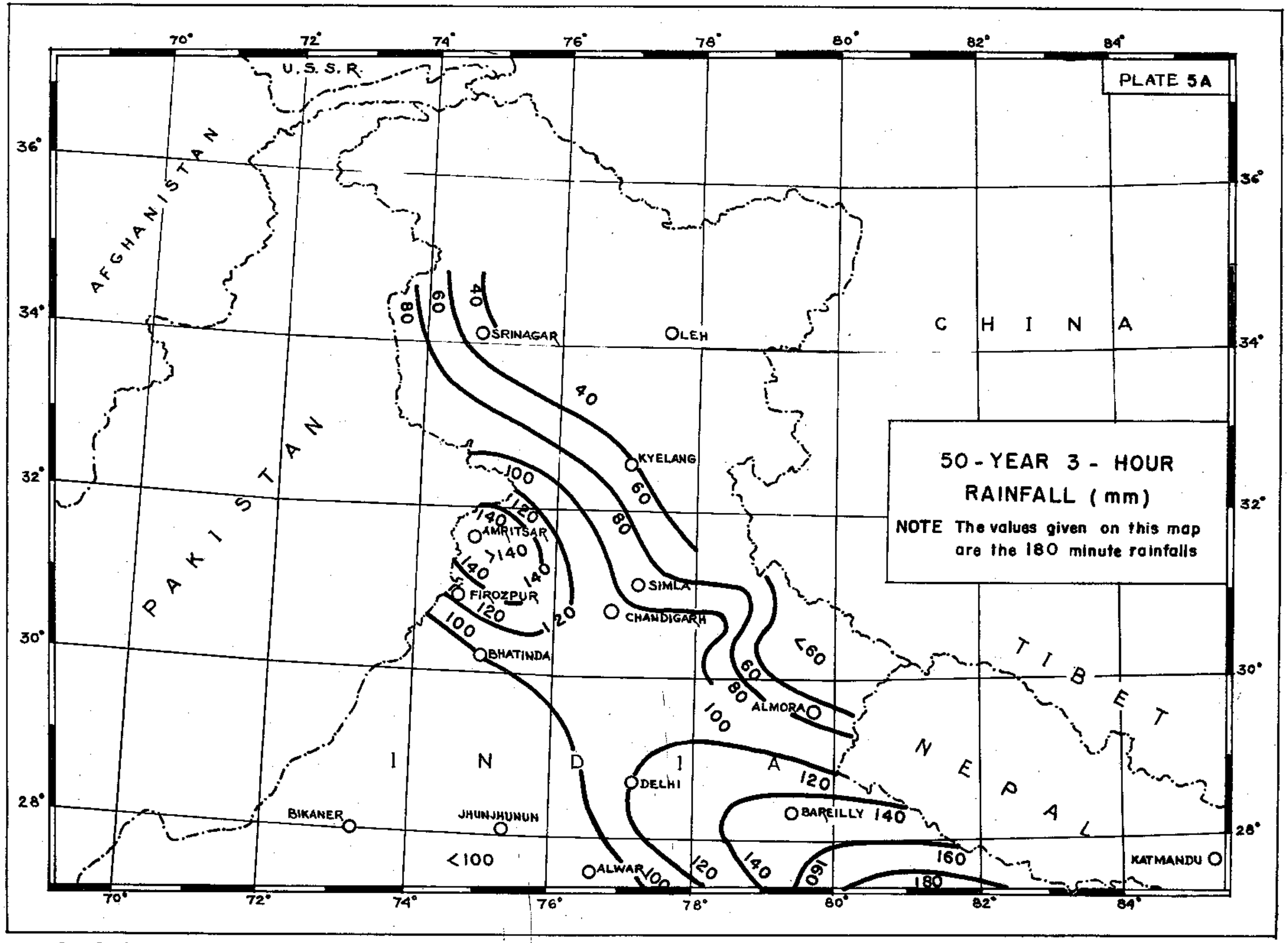
TRACED BY- K.B. AHUJA, JR. D.MAN
CHECKED BY- A.K. GHOSH (A.D.)




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



TRACED BY — K.B. AHUJA, JR. D. MAN.
CHECKED BY — A.K.GHOSH (A.D.)




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



TRACED BY - K. B. AHUJA. JR. D. MAN
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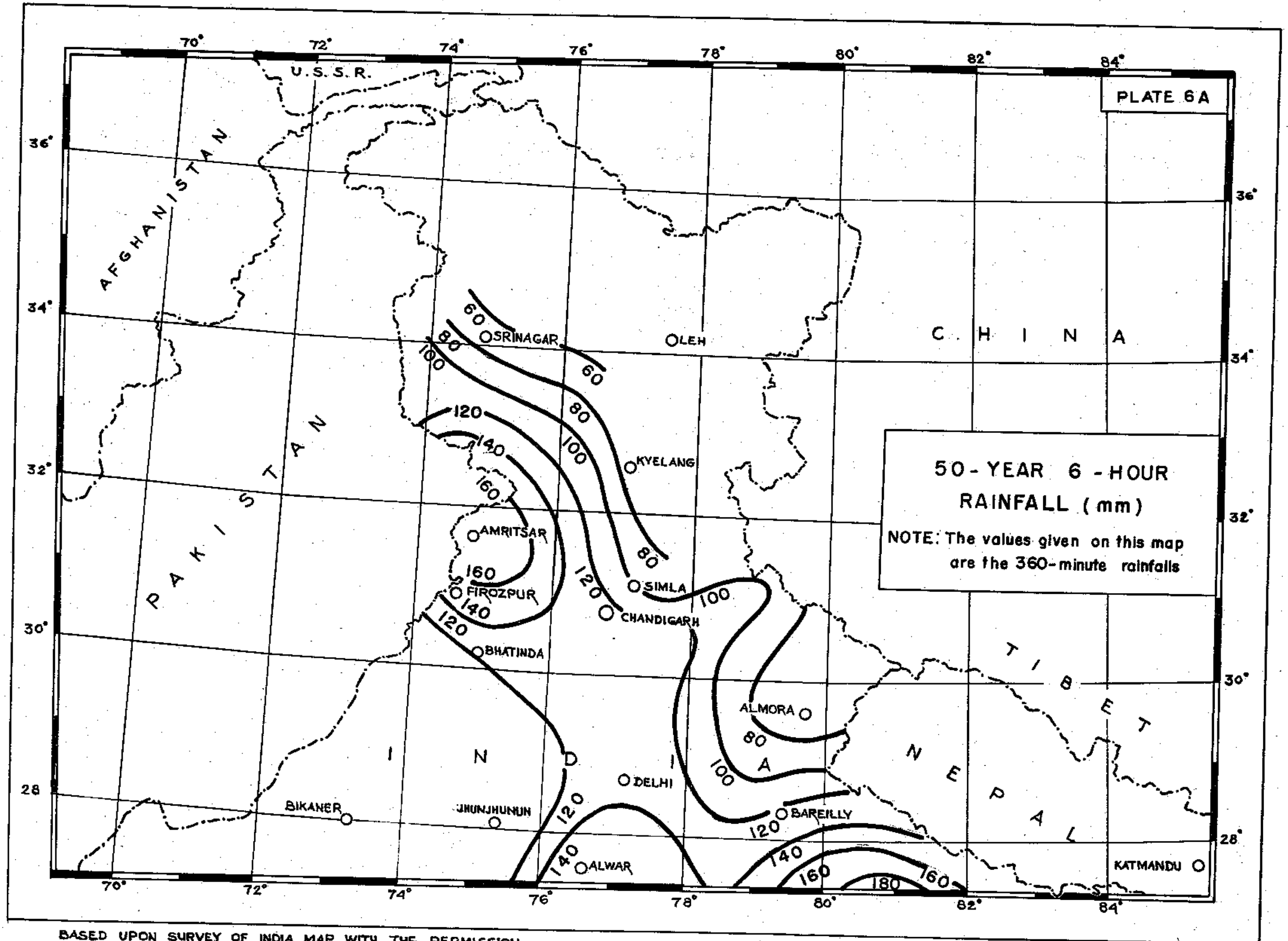


BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.



TRACED BY — K.B. AHUJA. JR. D.MAN
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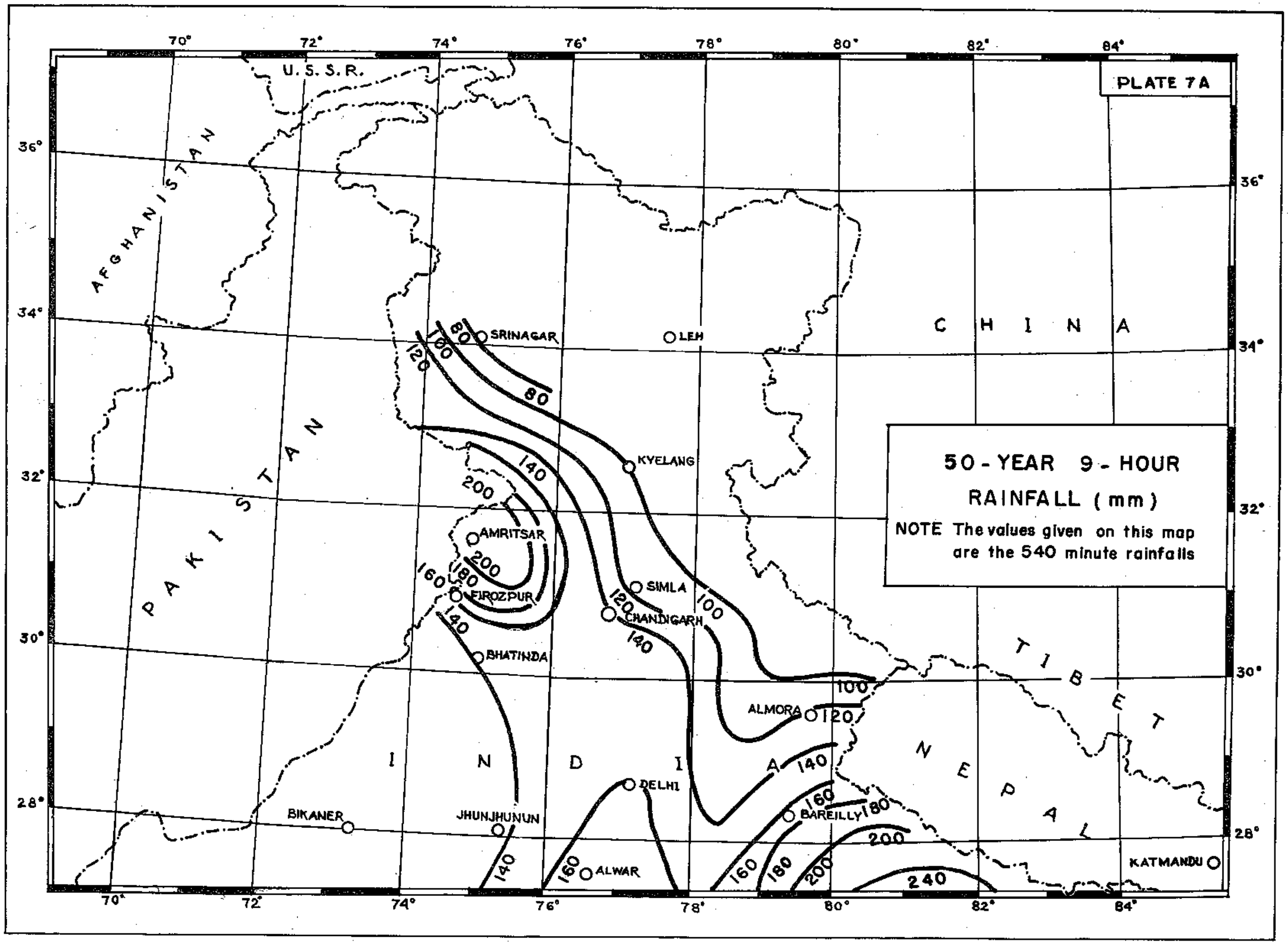


BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.



TRACED BY — K.B. AHUJA. JR. D. MAN.
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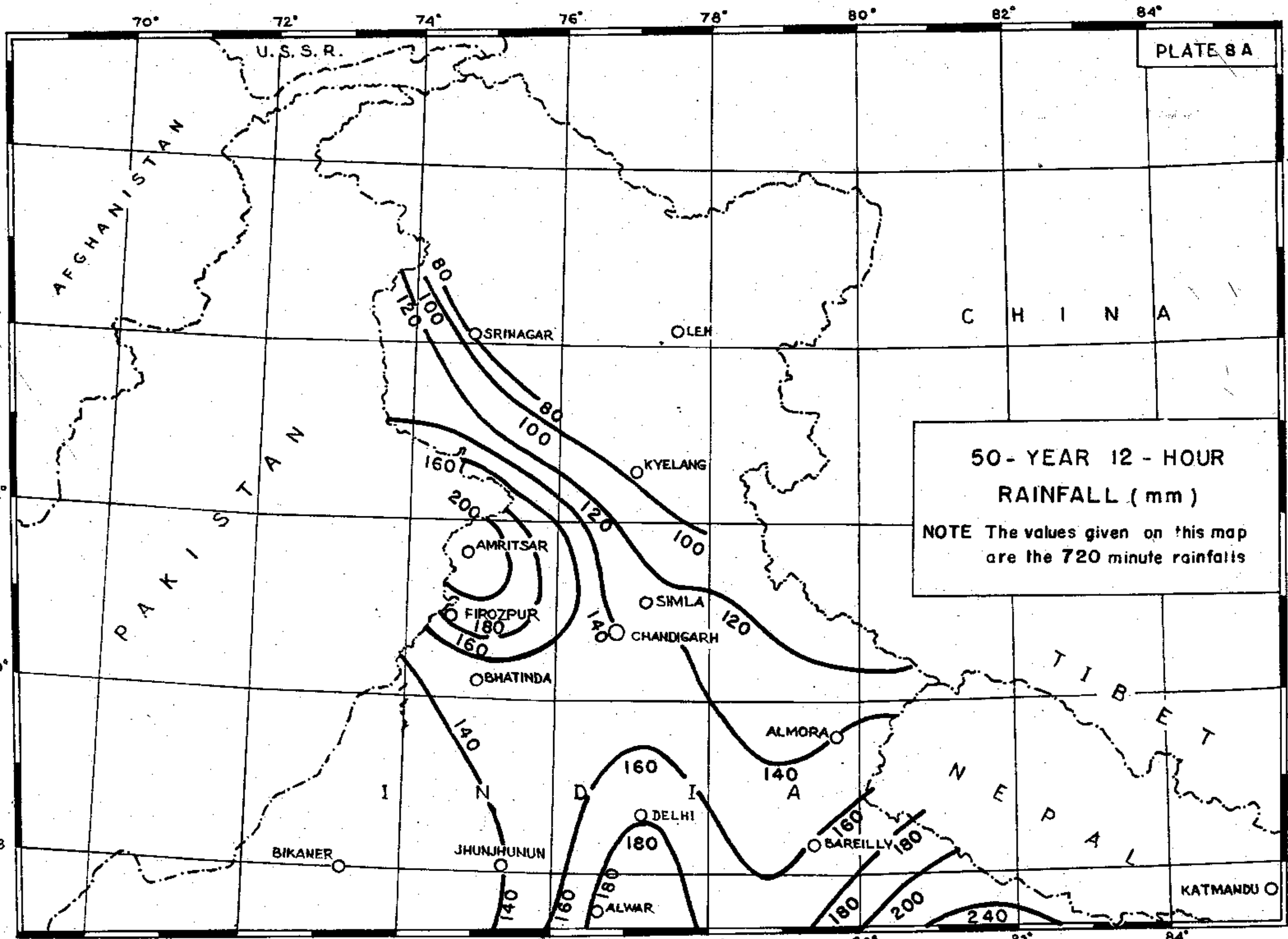
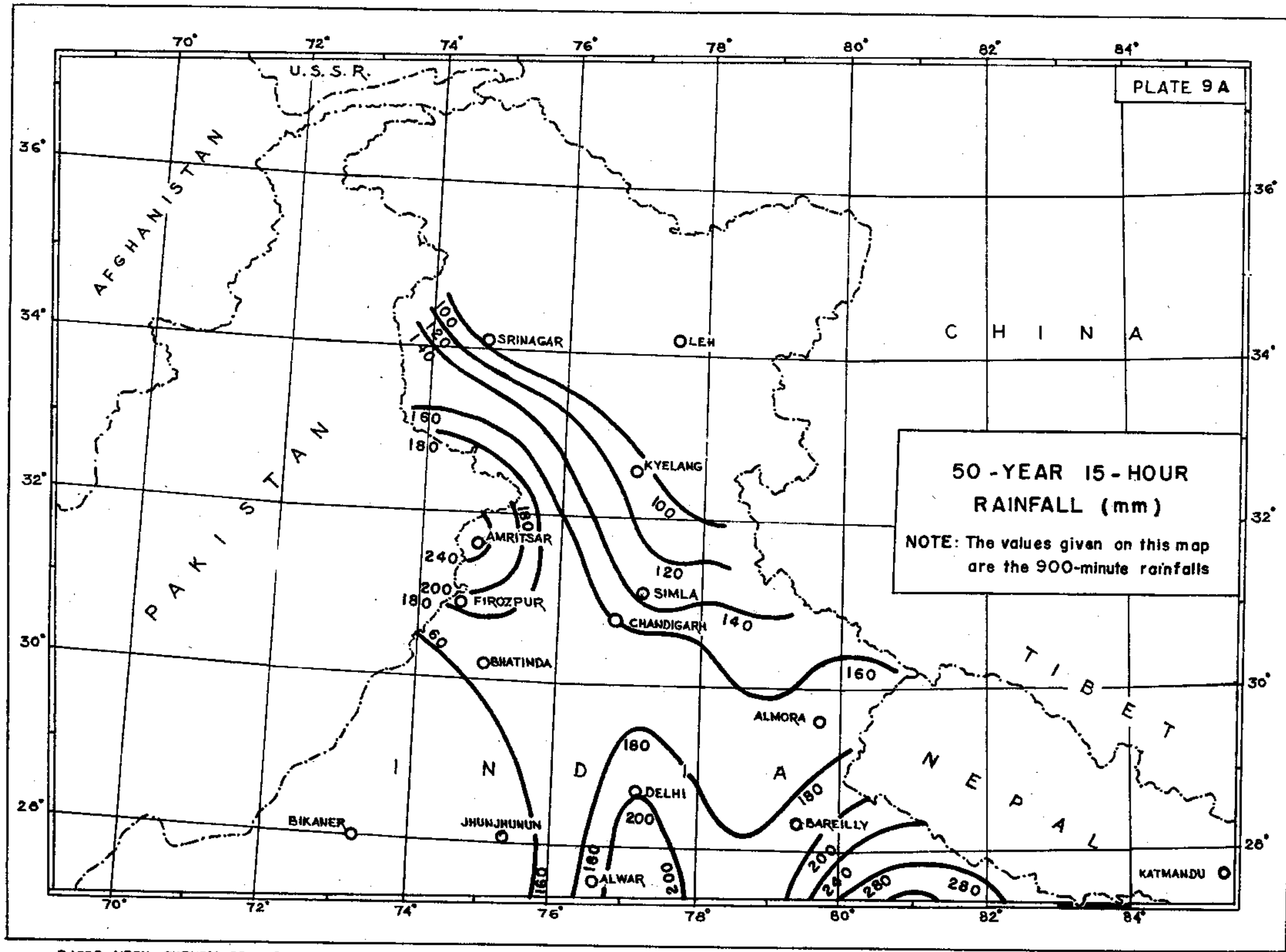





TRACED BY — K. B. AHUJA. JR. D. MAN
CHECKED BY — A. K. GHOSH (A.D)

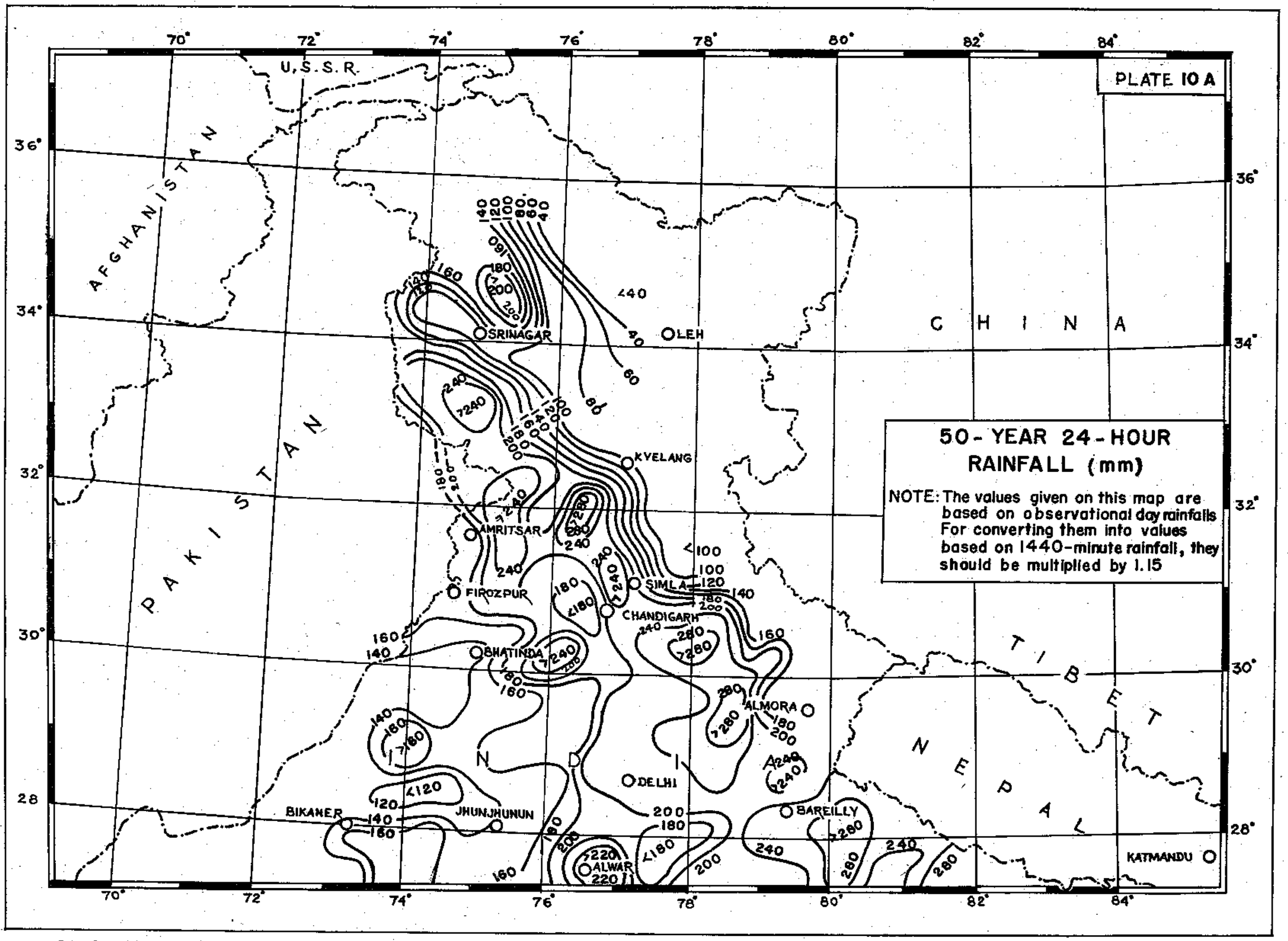



BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA



TRACED BY K.B.AHUJA. JR.D.MAN

CHECKED BY A.K.GHOSH. A.D.

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TRACED BY— K.B. AHUJA, JR. D. MAN

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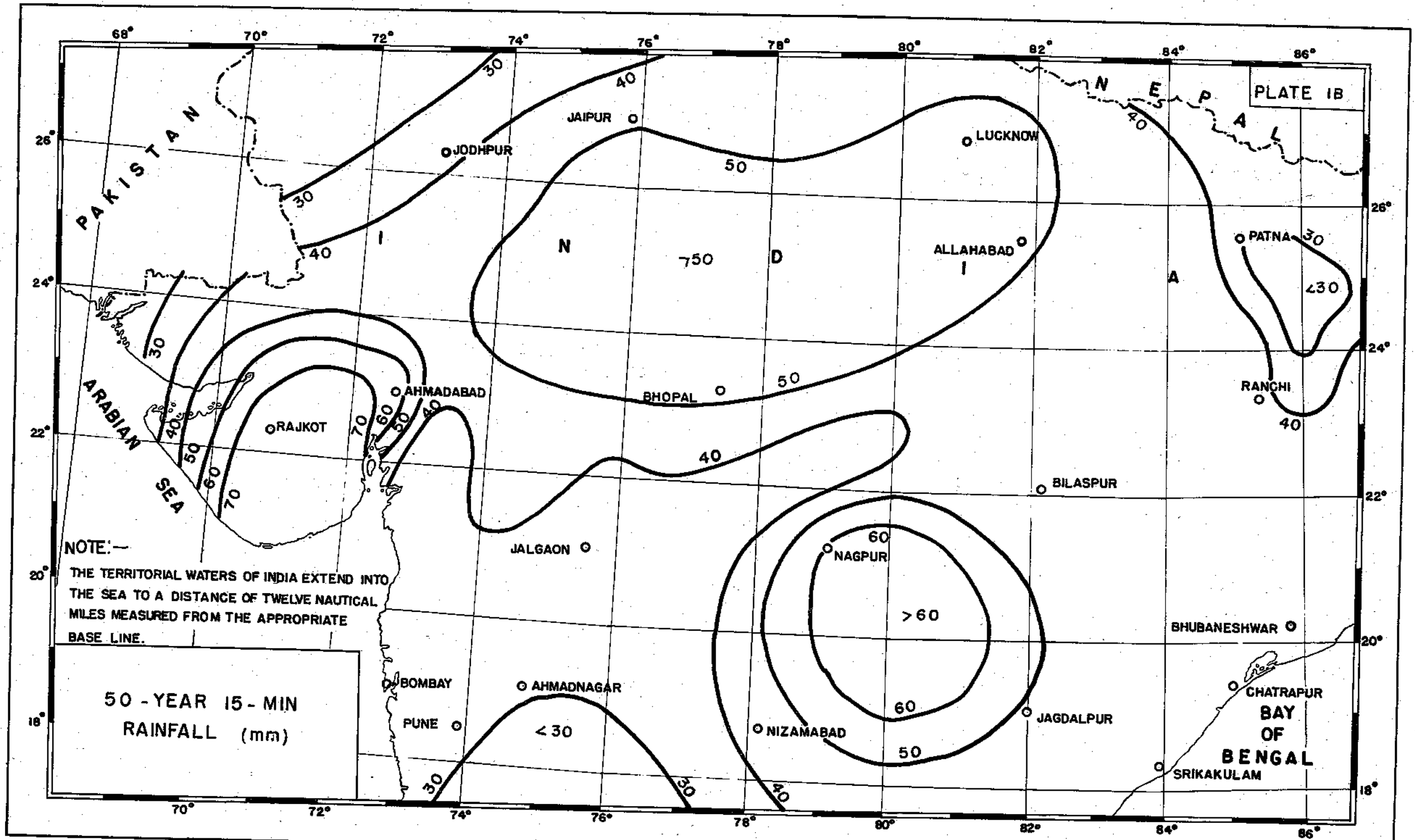
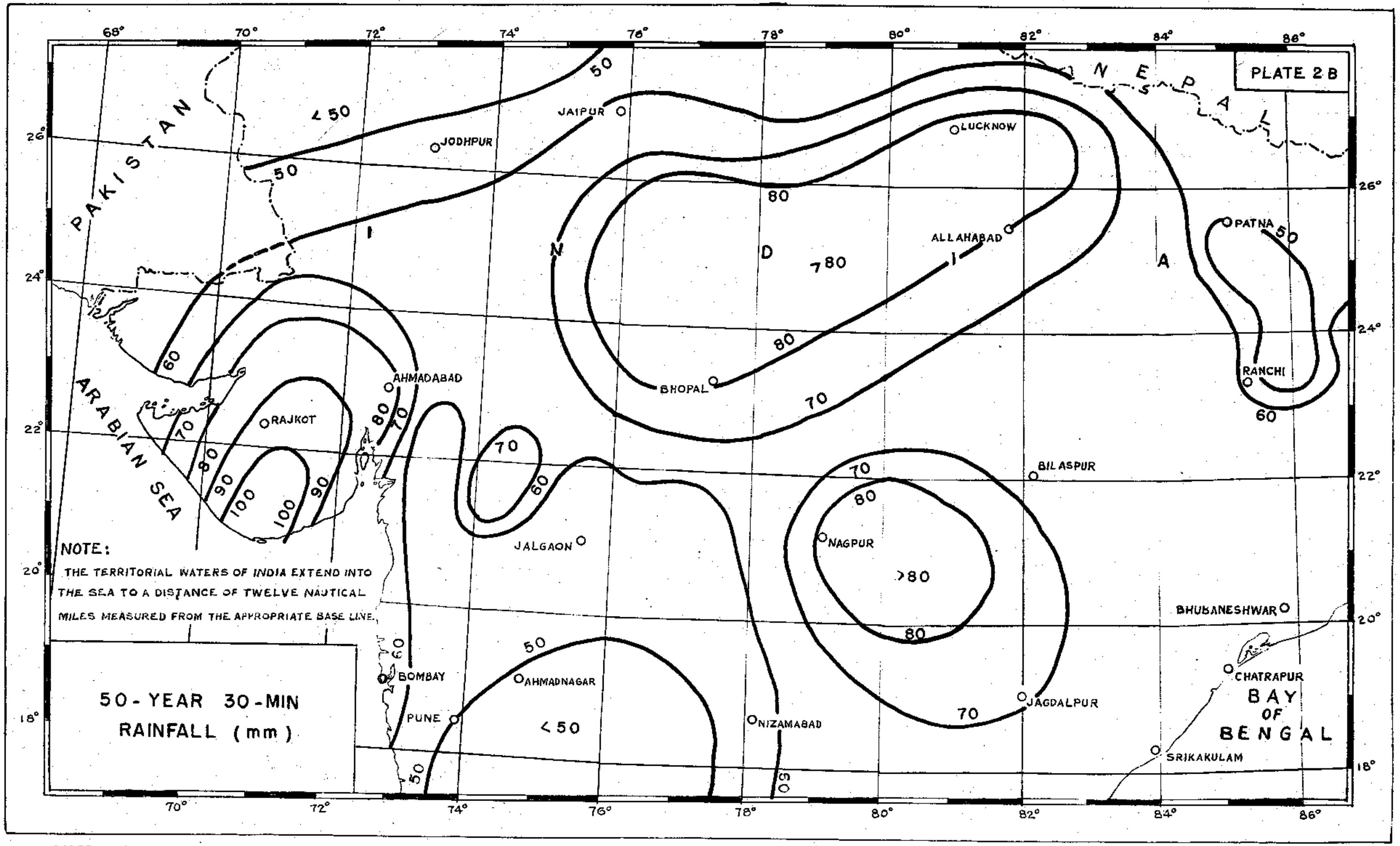



BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.



TRACED BY: R. S. SINGH.
CHECKED BY: A. K. GHOSH. A.D.

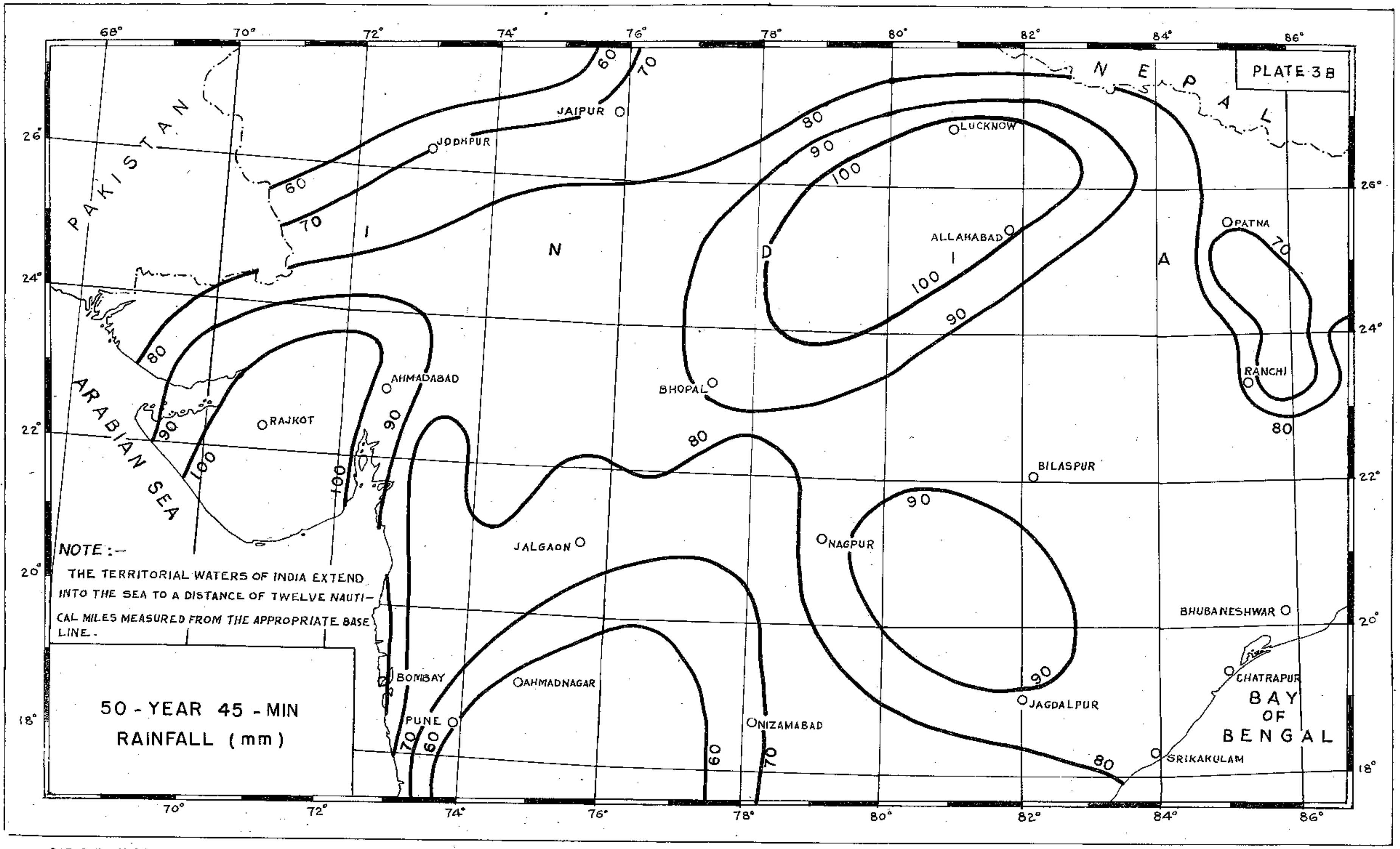



50-YEAR 30-MIN RAINFALL (mm)

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



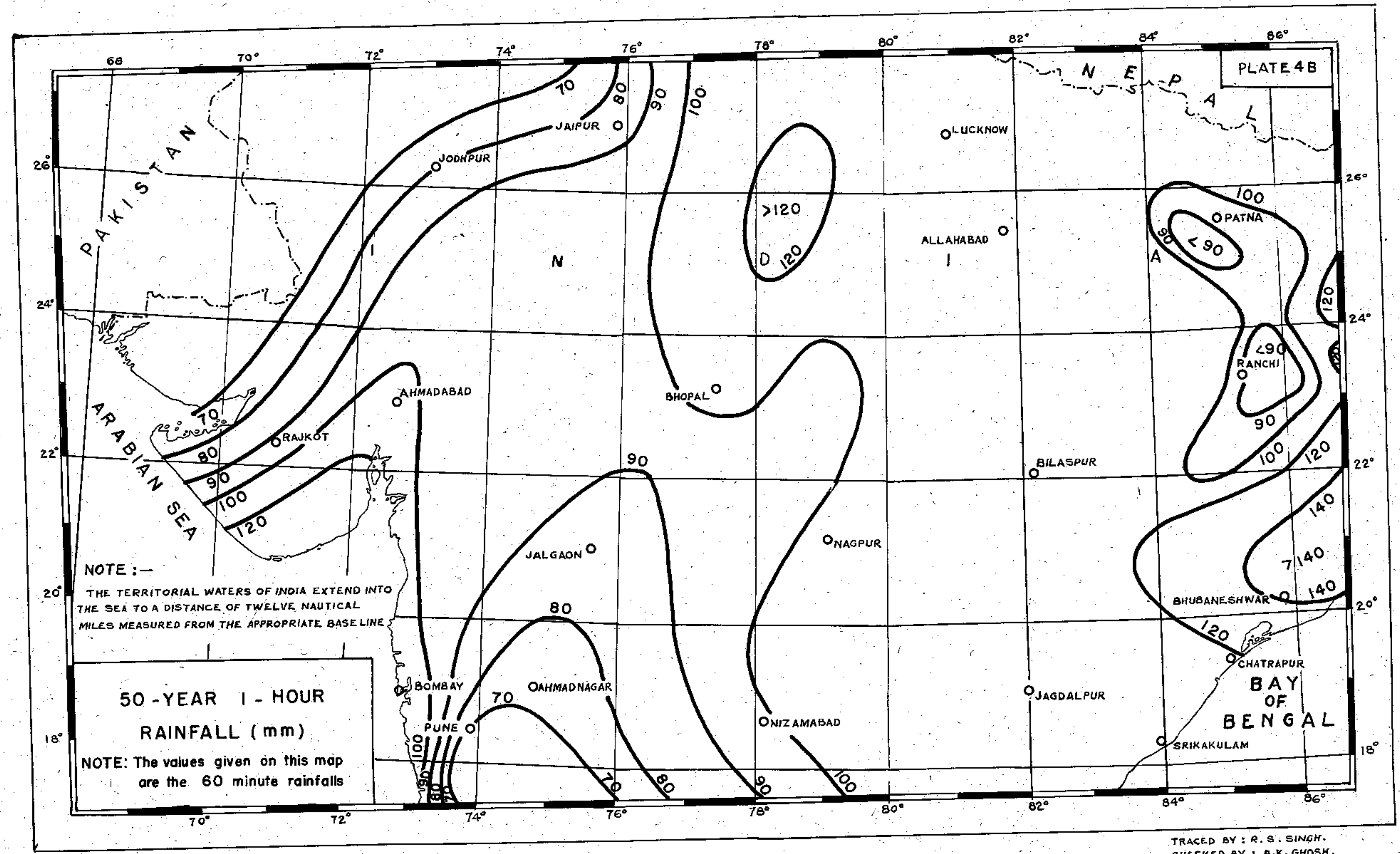
TRACED BY: R.S. SINGH.
CHECKED BY: A.K. GHOSH A.D.




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

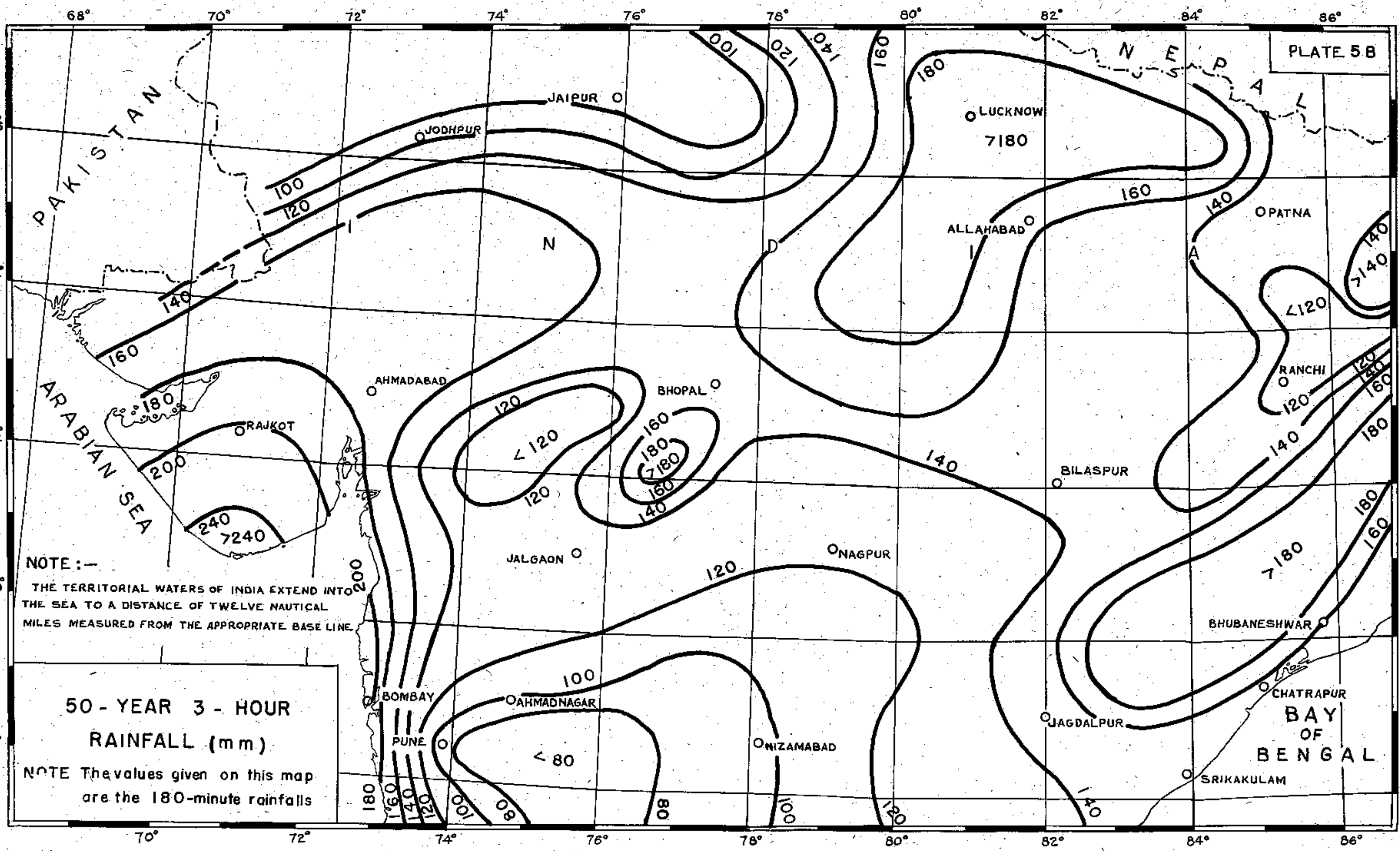


TRACED BY : R. S. SINGH.
CHECKED BY : A. K. GHOSH
A. D.




TRACED BY : R. S. SINGH.
CHECKED BY : A.K. GHOSH. A.D.

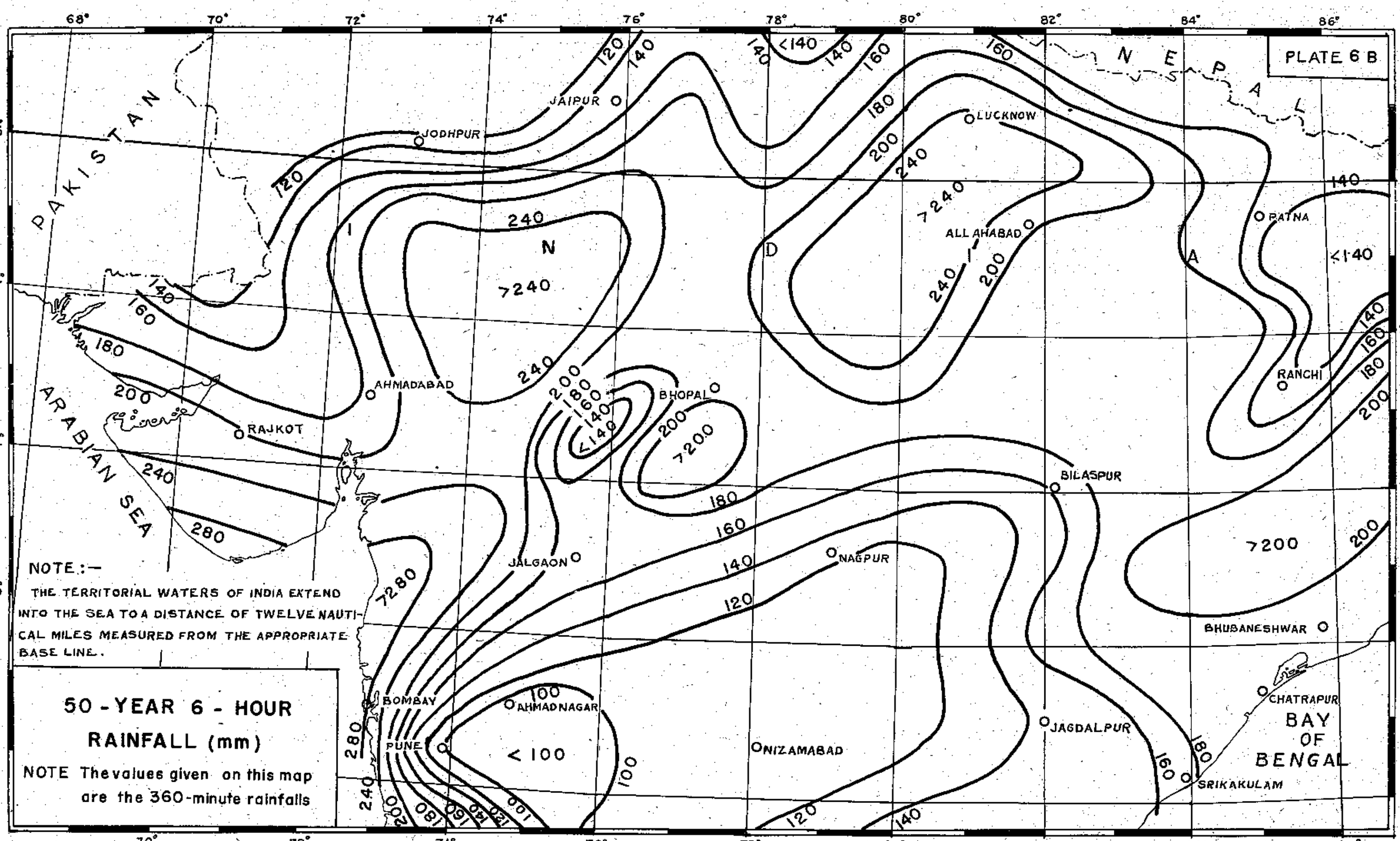
BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.




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



TRACED BY: R.S. SINGH.
CHECKED BY: A.K. GHOSH. A.D.



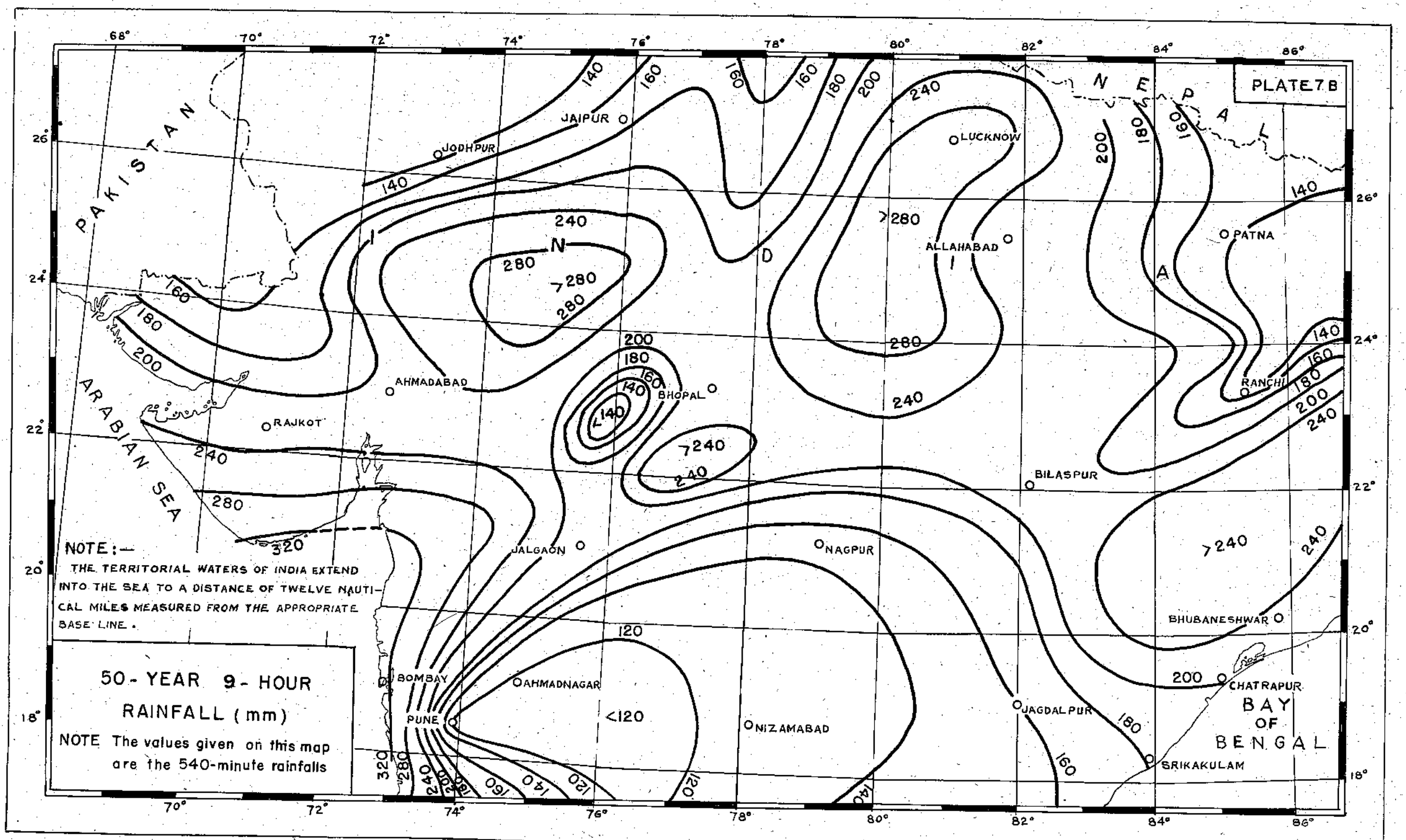

**50 - YEAR 6 - HOUR RAINFALL (mm)**

NOTE The values given on this map are the 360-minute rainfalls

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



TRACED BY : R. S. SINGH.
CHECKED BY : A. K. GHOSH. A.D.

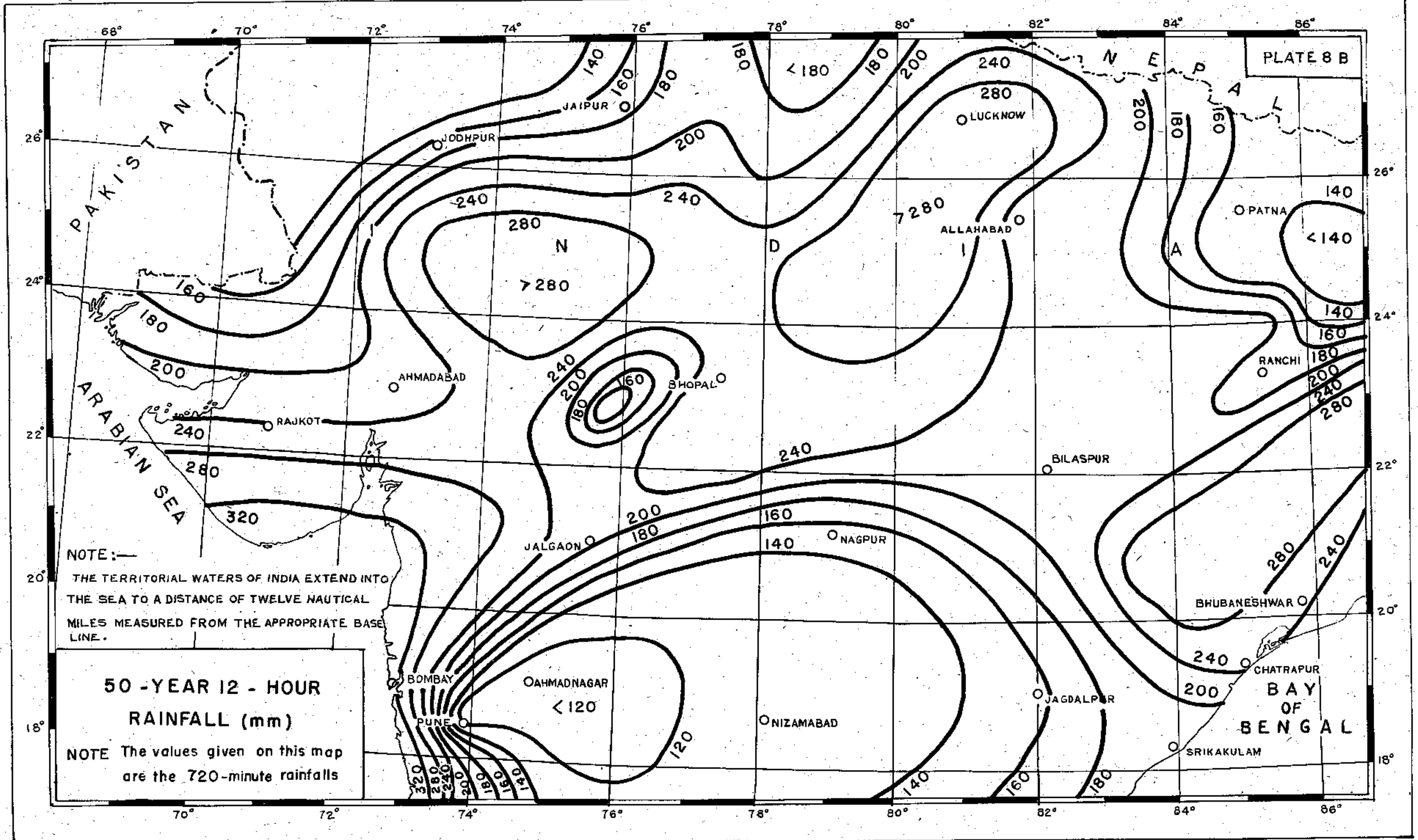



BASED UPON THE SURVEY OF INDIA WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.



TRACED BY: R. S. SINGH
CHECKED BY: A. K. GHOSH A.D.

MAP OF INDIA FIG. 2/SHORT TERM PLAN - 2

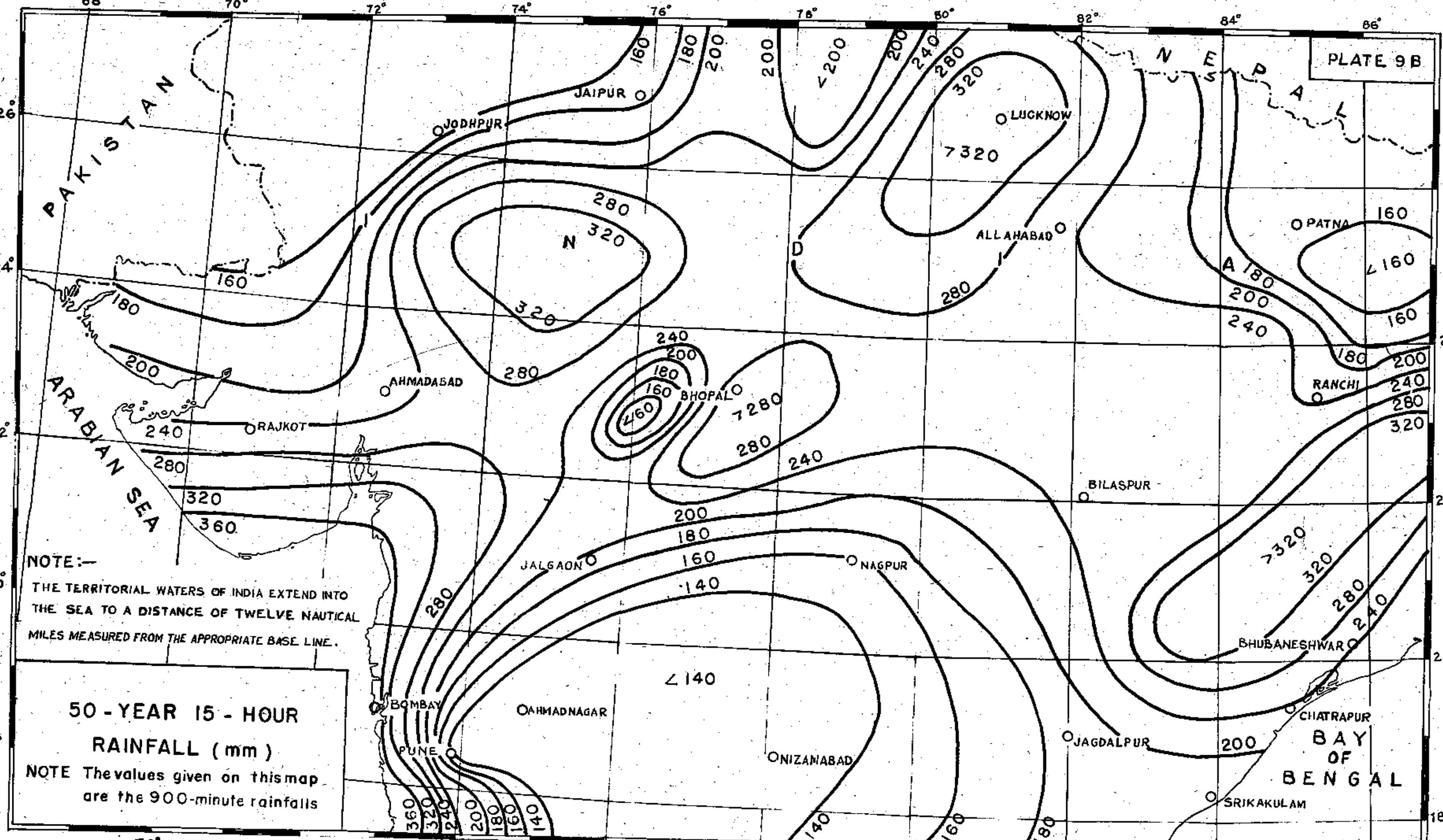



BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.



TRACED BY: R.S. SINGH.
CHECKED BY: A.K. GHOSH. A.D.

MAP OF INDIA. FIG. 2/SHORT TERM PLAN - 2




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

**50-YEAR 15-HOUR RAINFALL (mm)**

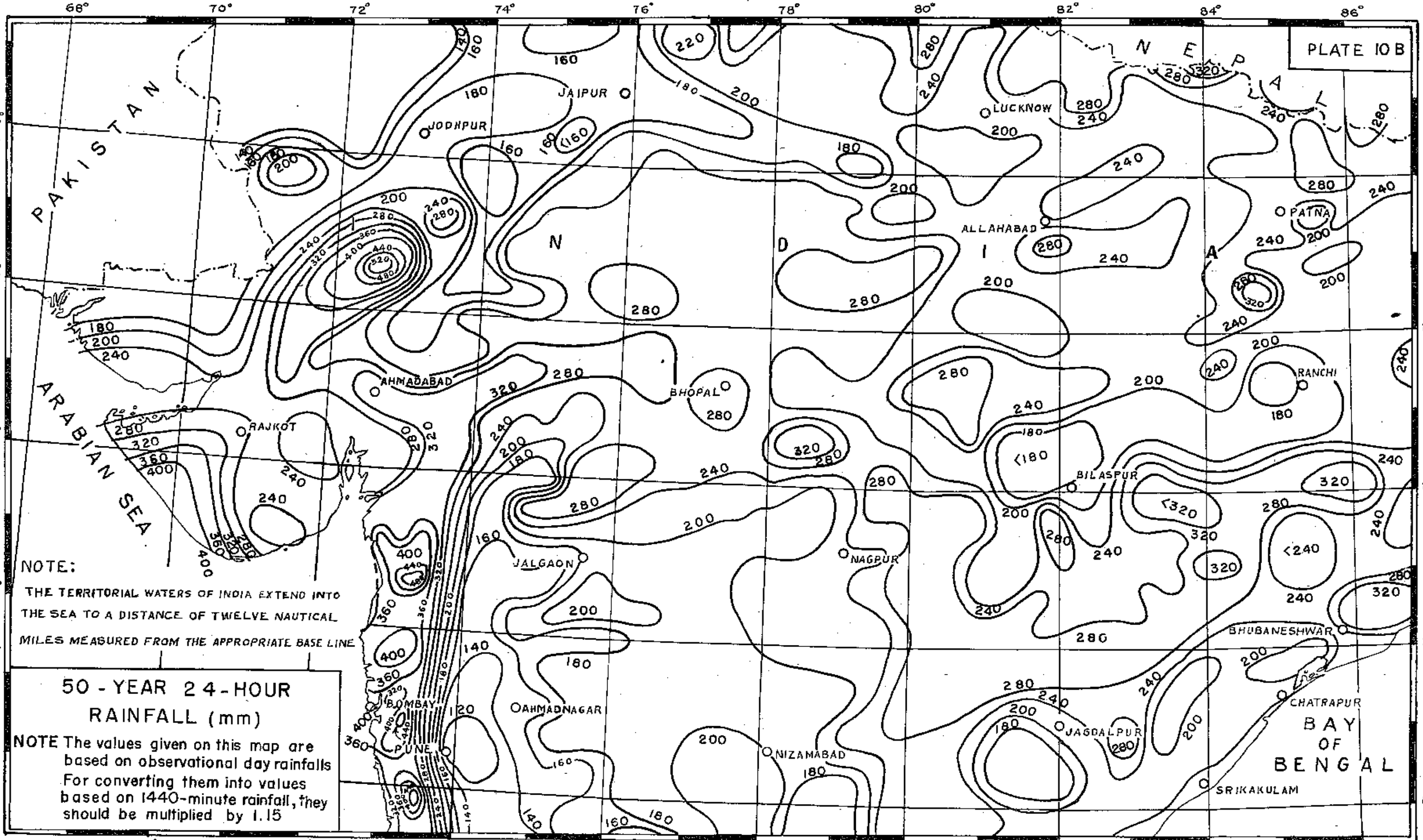
NOTE The values given on this map are the 900-minute rainfalls

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



TRACED BY: R.S. SINGH.
CHECKED BY: A.K. GHOSH. A.D.

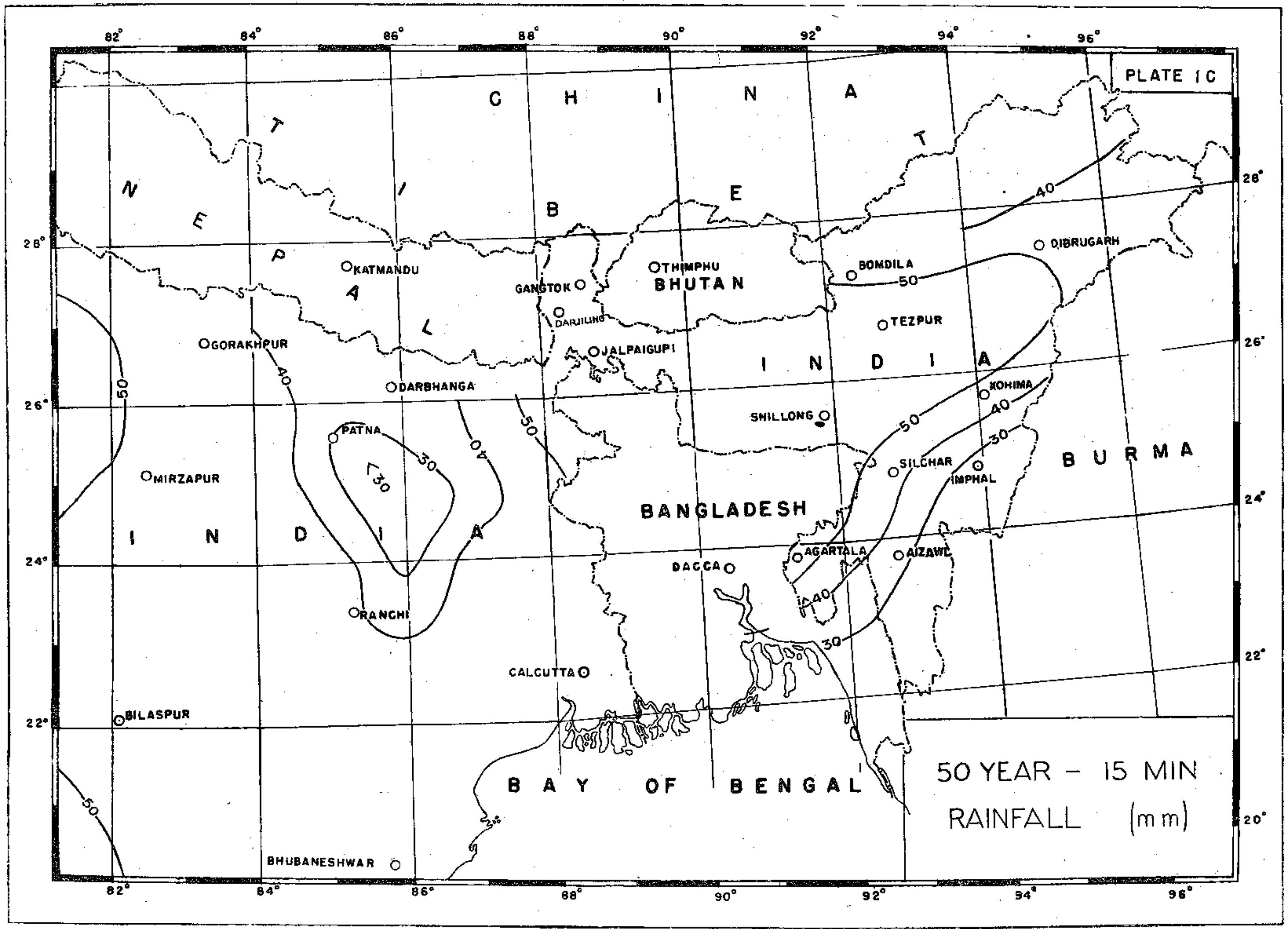
MAP OF INDIA FIG. 2/SHORT TERM PLAN – 2




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



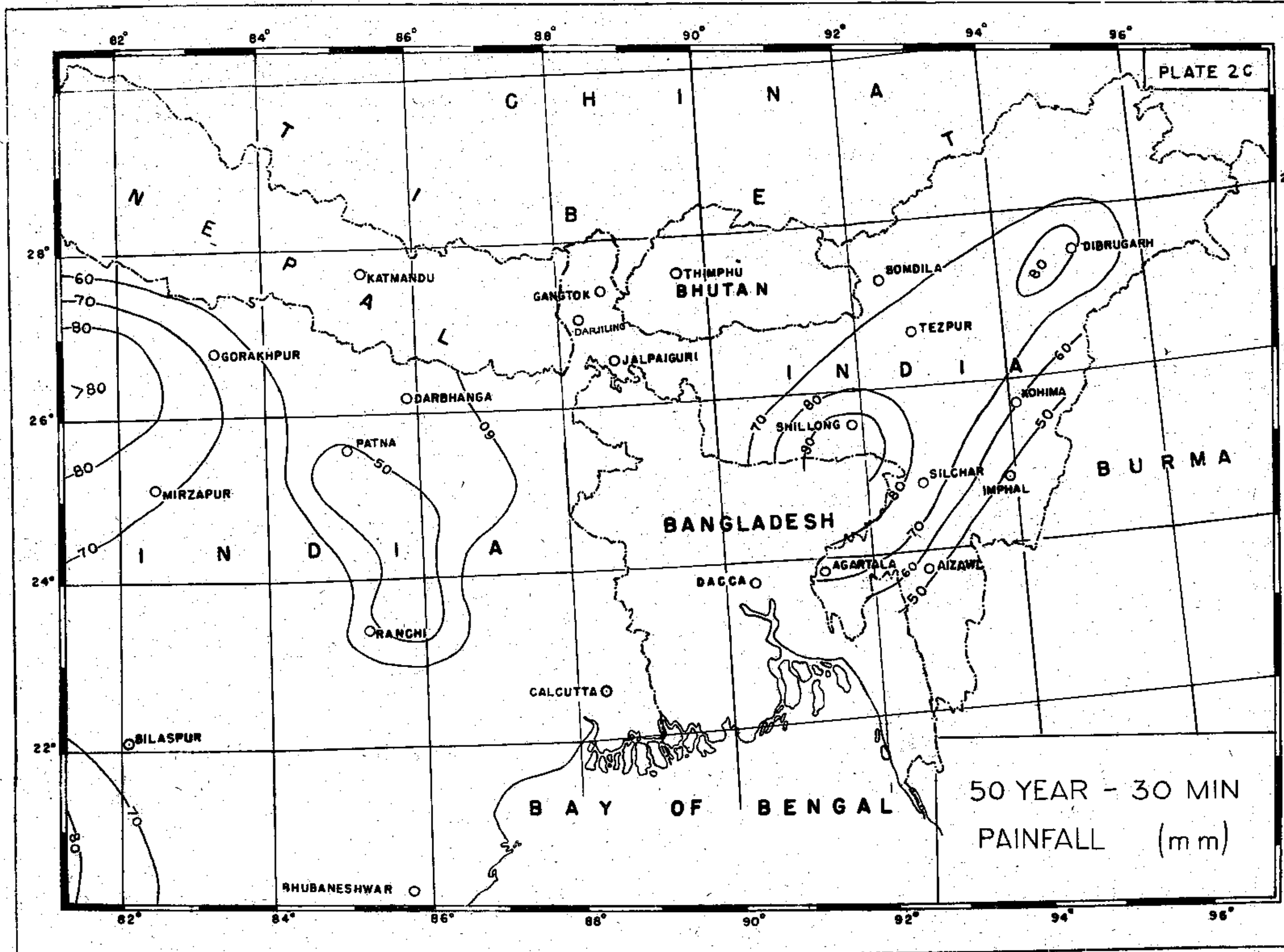
TRACED BY: R.S. SINGH.
CHECKED BY: A.K. GHOSH. A.D.




Based upon Survey of India map with the permission of the Surveyor General of India.
The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.



Traced by: S.N. Malhotra.
Checked by: A.K. Ghosh.

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Traced by : S. N. Malhotra.
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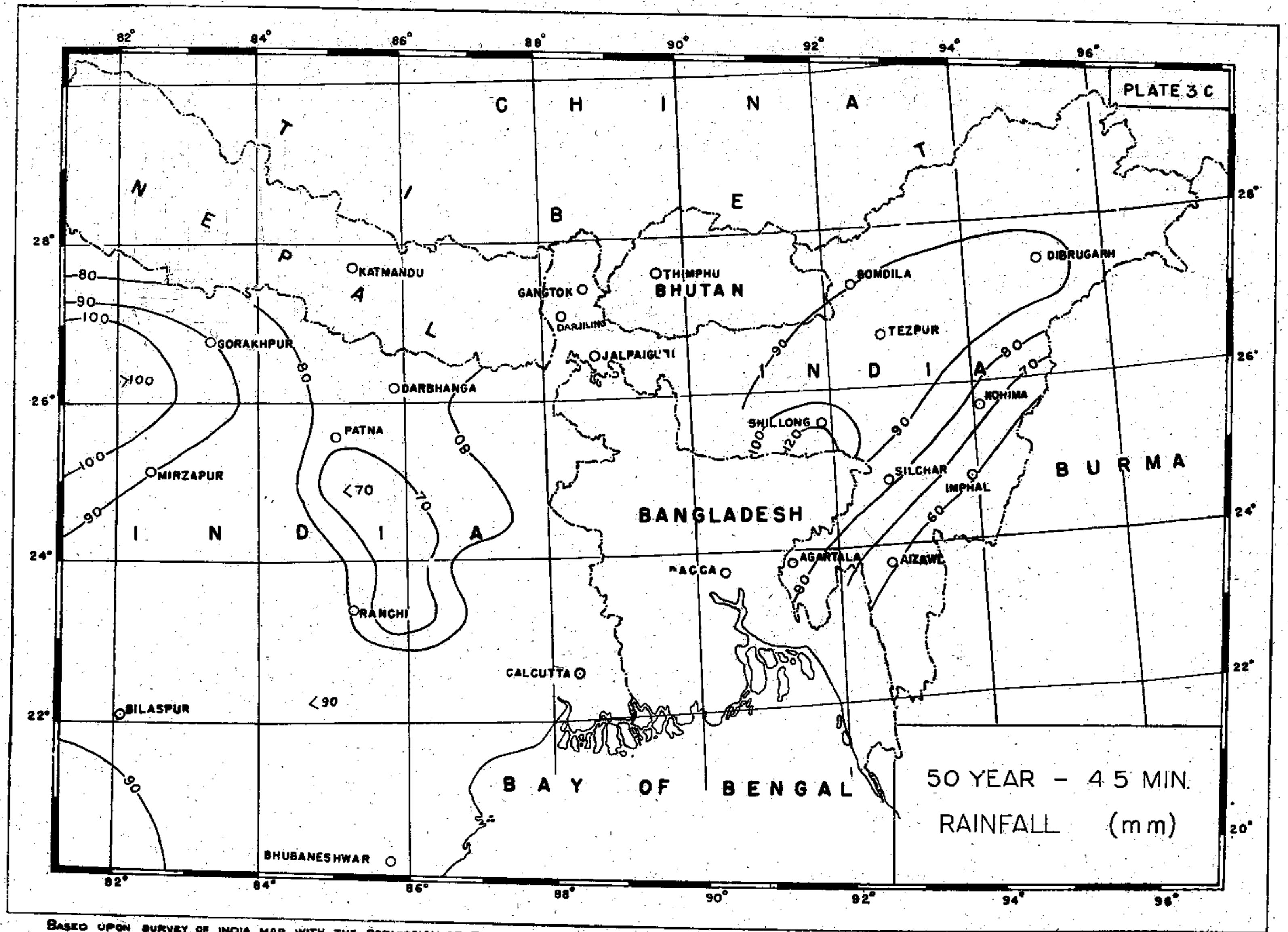


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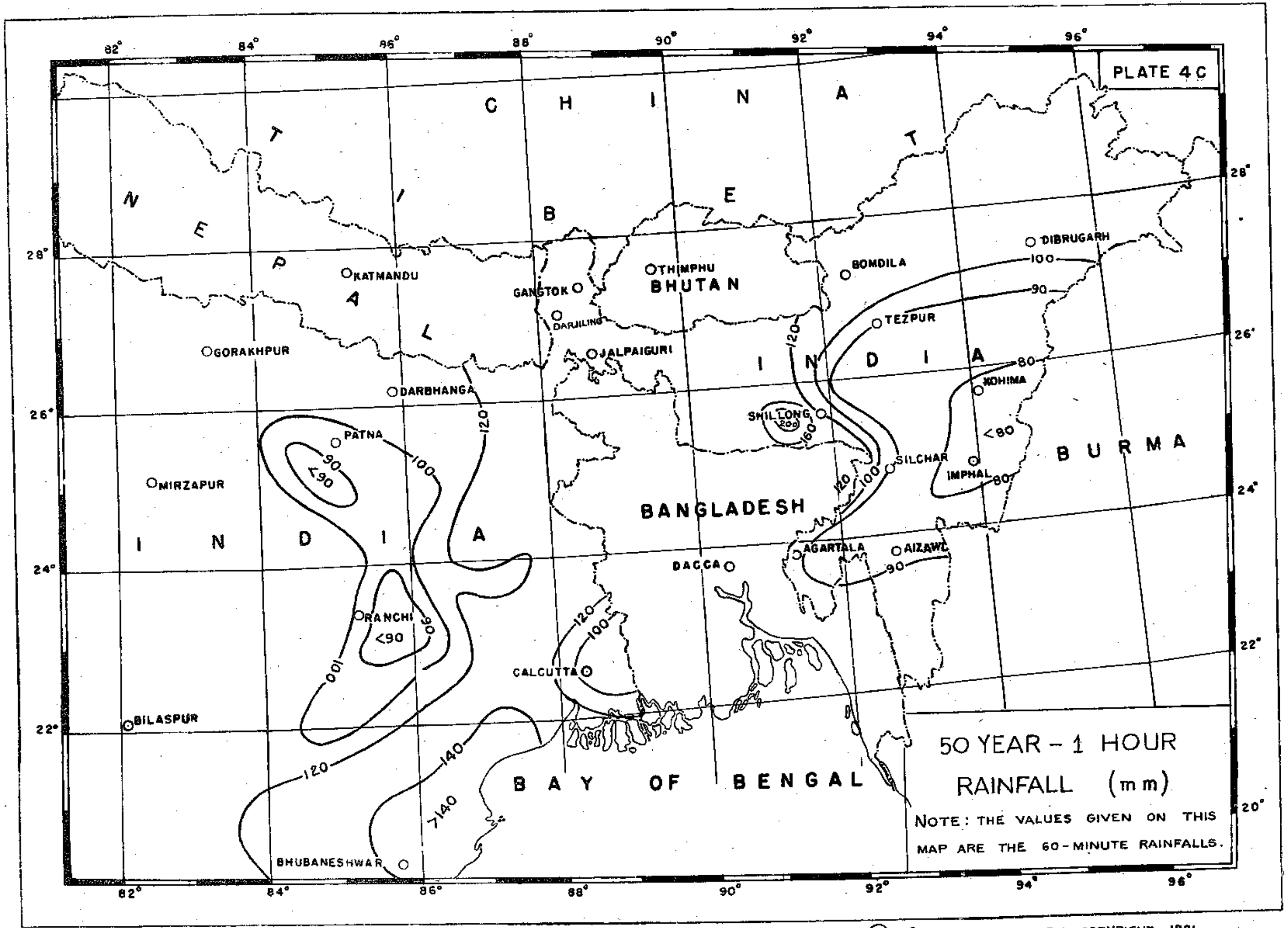


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Traced by : S.N. Malhotra.
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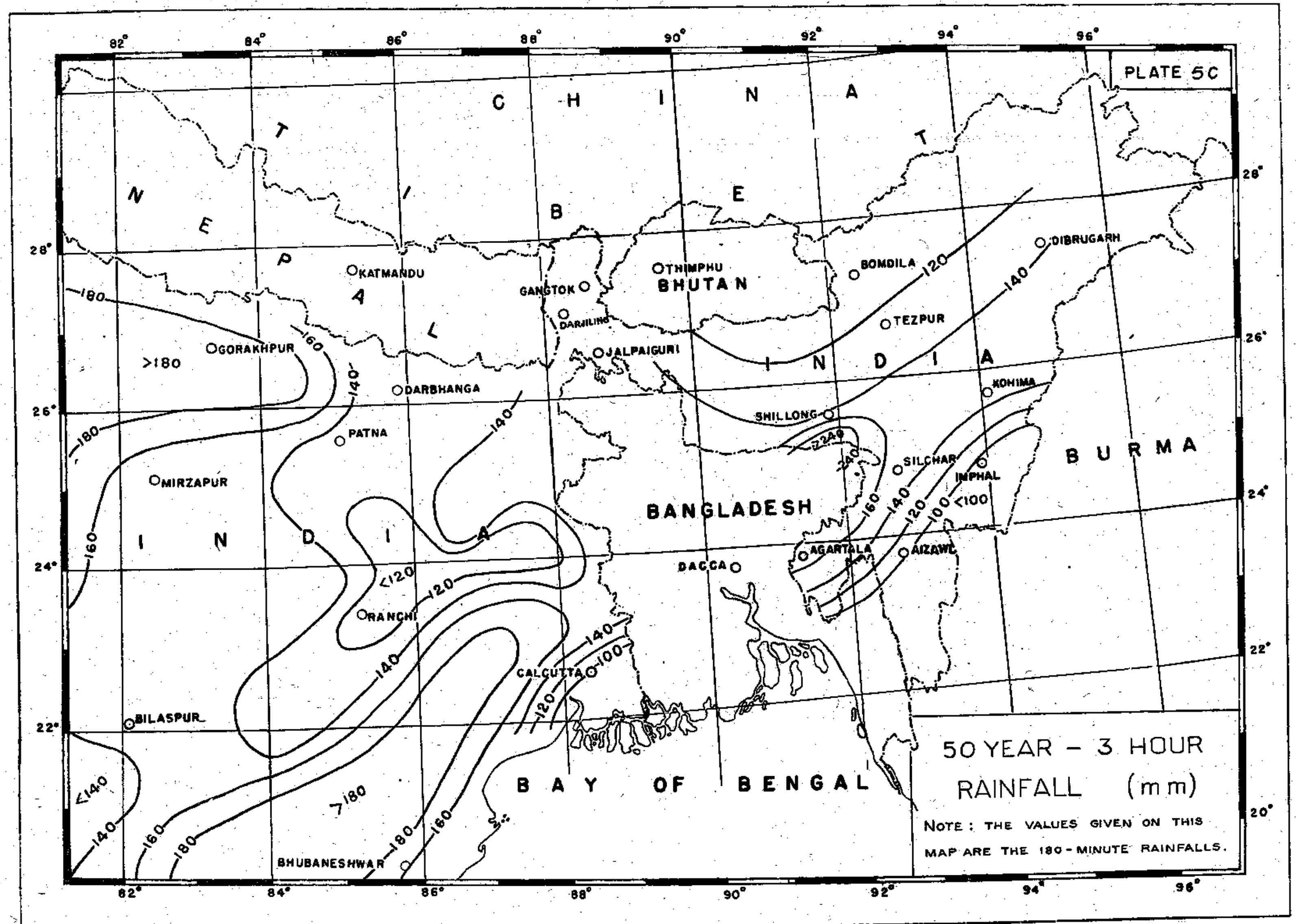
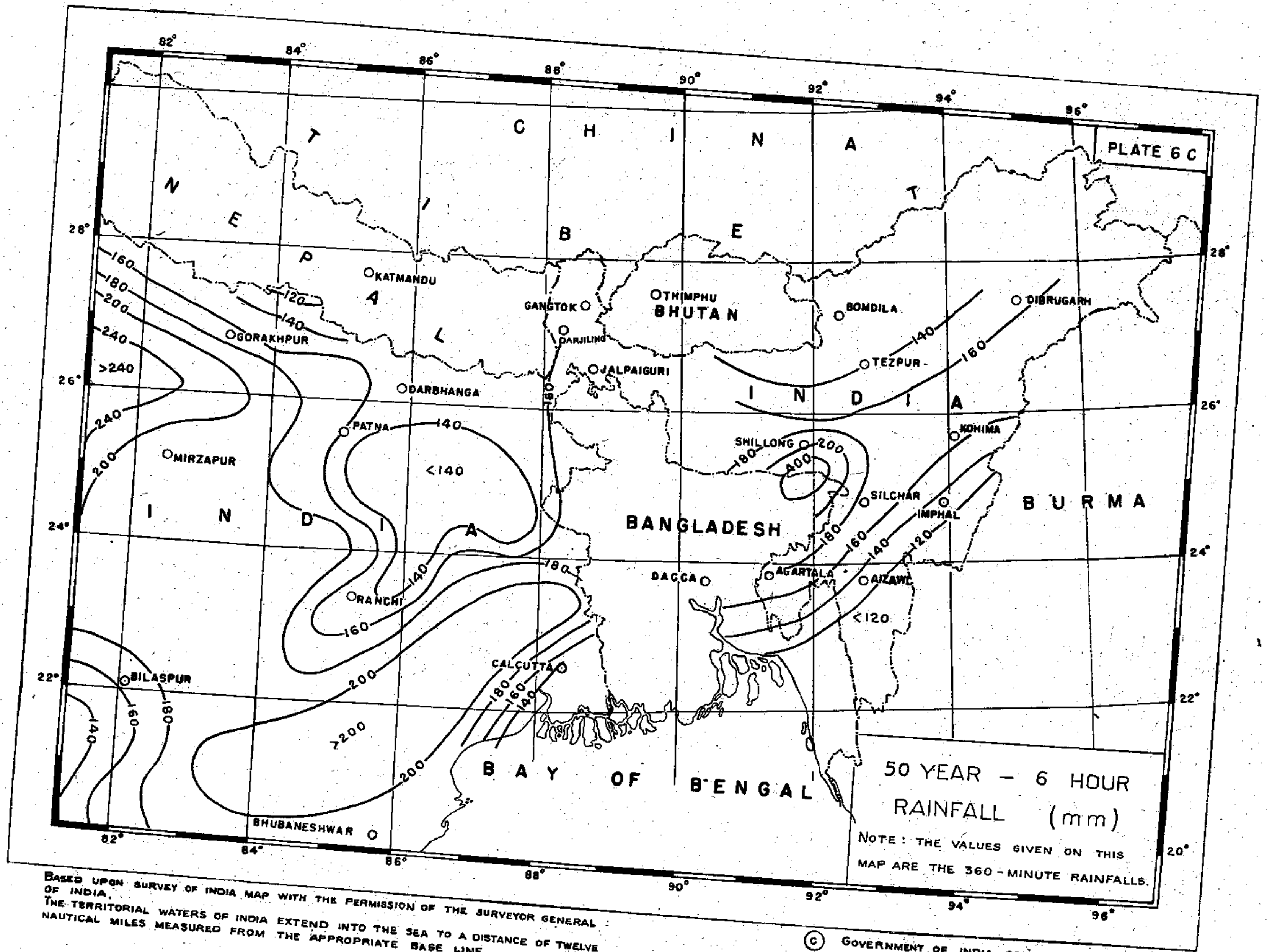



BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.
THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.



TRACED BY : S. N. MALHOTRA
CHECKED BY : A. K. GHOSH




BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.
THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.



TRACED BY : S. N. MALHOTRA.
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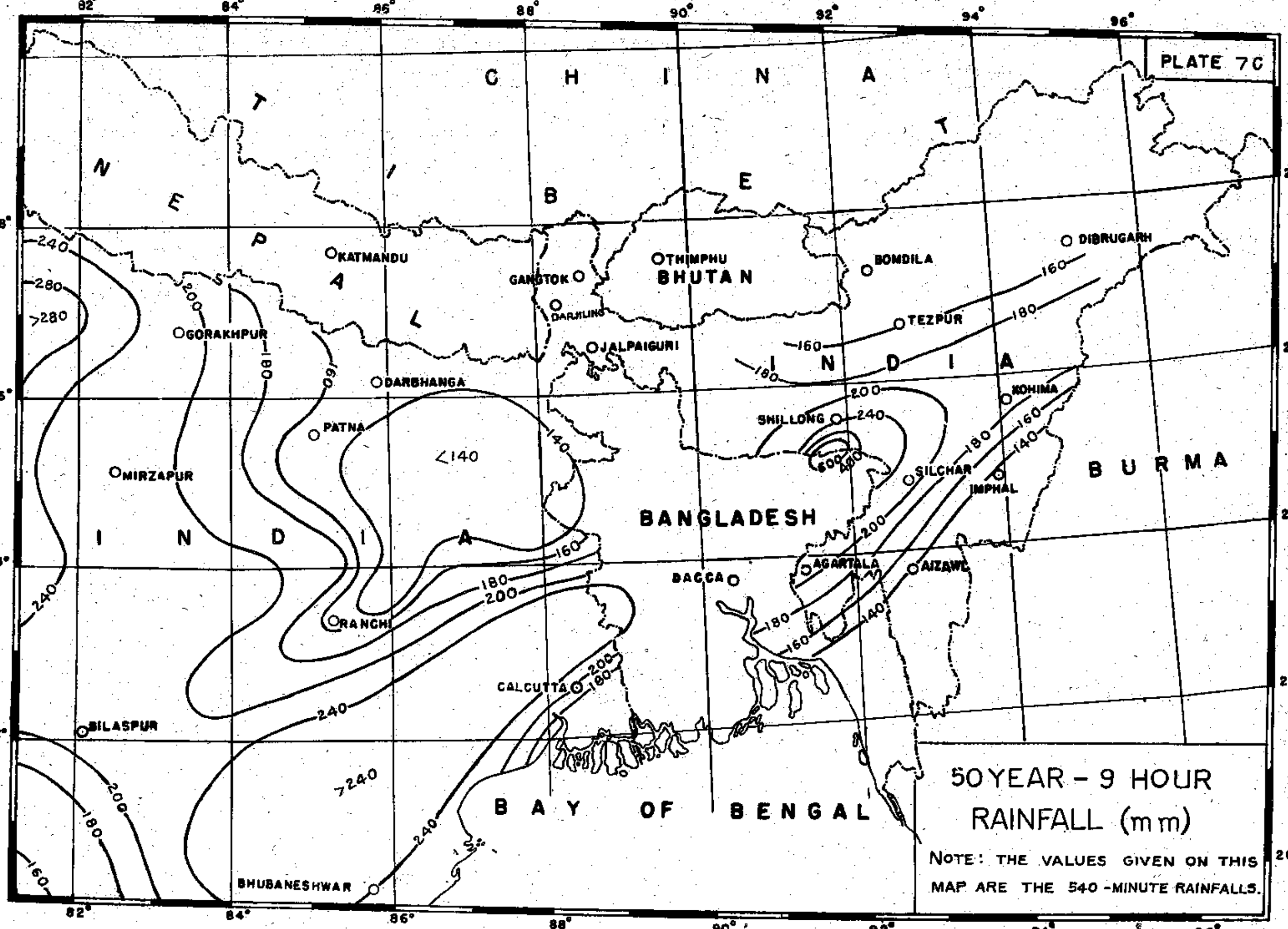


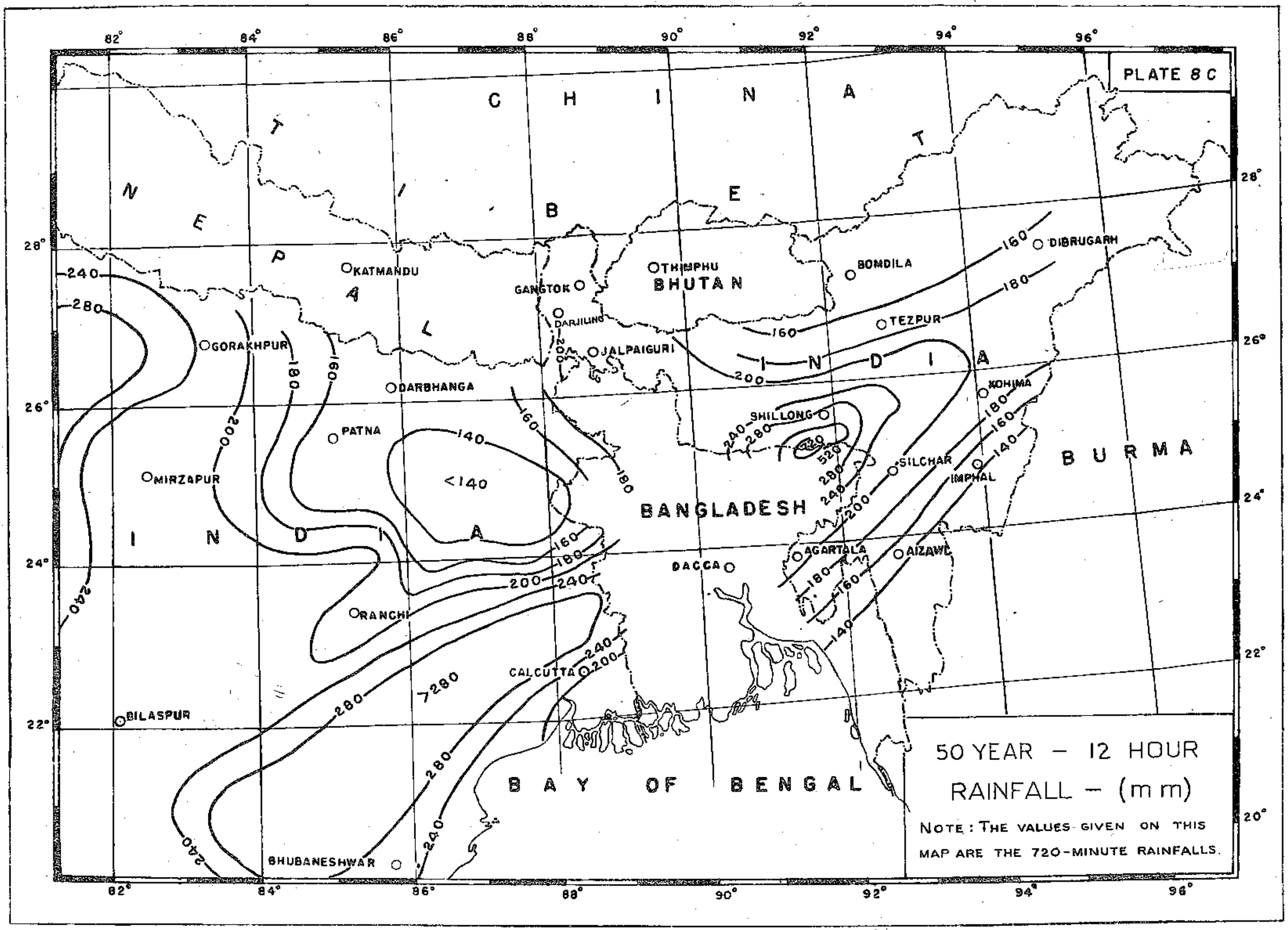

50 YEAR - 9 HOUR RAINFALL (mm)

NOTE: THE VALUES GIVEN ON THIS MAP ARE THE 540-MINUTE RAINFALLS.

Based upon Survey of India map with the permission of the Surveyor General of India.
The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.



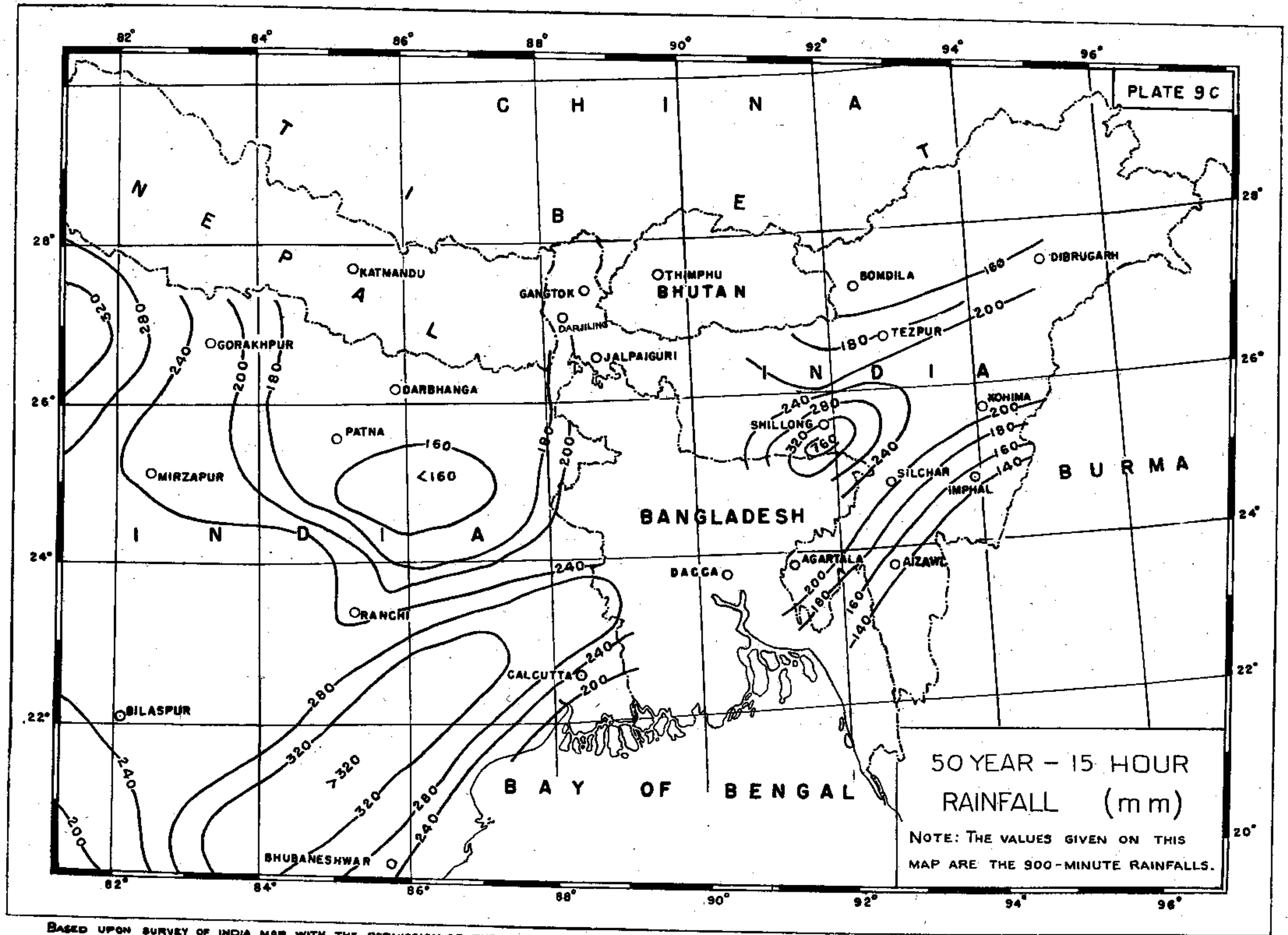
TRACED BY : S. N. MALHOTRA.
CHECKED BY : A. K. GHOSH.




Based upon Survey of India map with the permission of the Surveyor General of India.
The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.



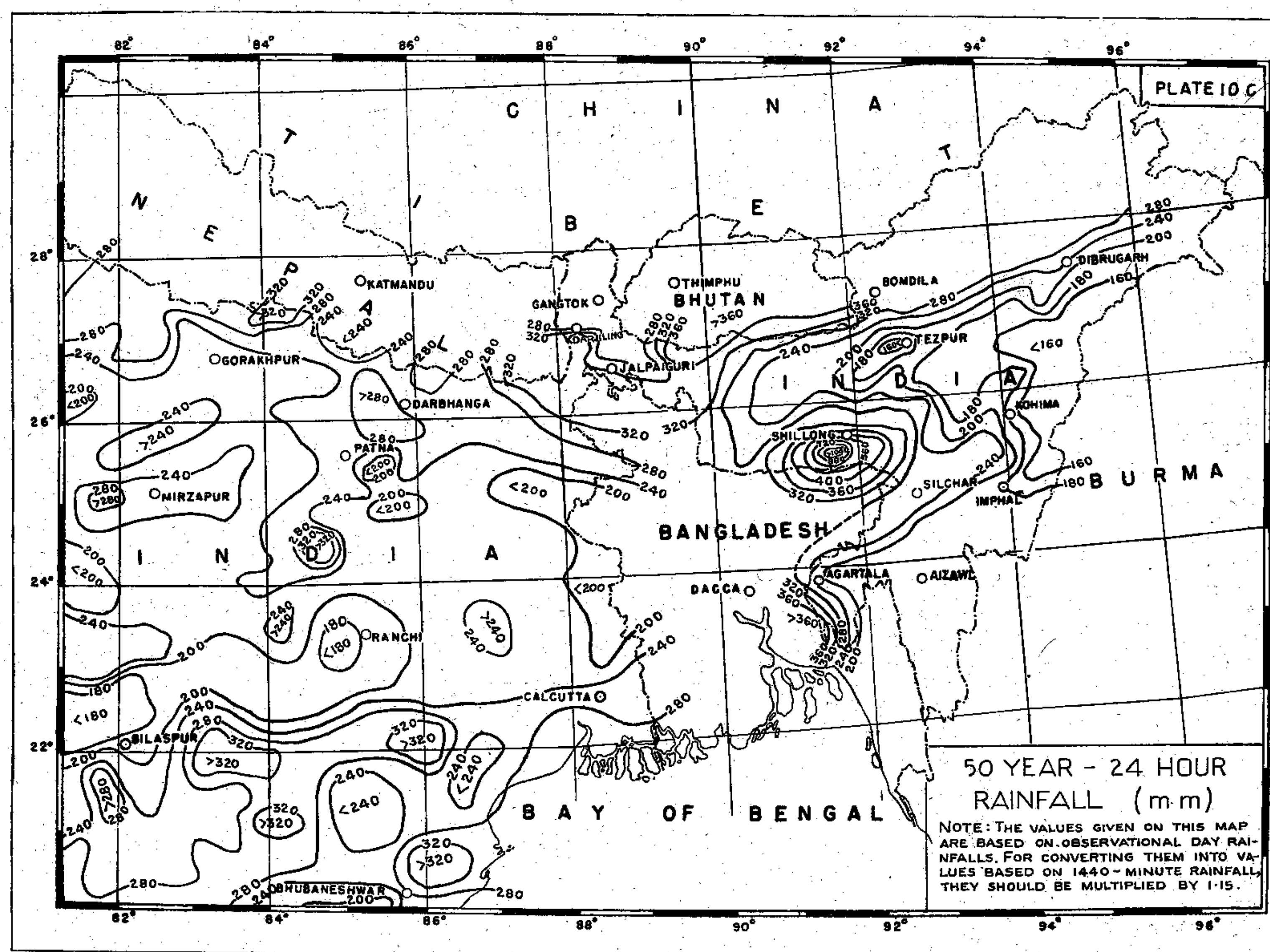
Traced by : S. N. Malhotra.
Checked by : A. K. Ghosh.




Based upon Survey of India map with the permission of the Surveyor General of India.
The territorial waters of India extend into the sea to a distance of twelve nautical miles measured from the appropriate base line.



Traced by : S. N. Malhotra
Checked by : A. K. Ghosh.



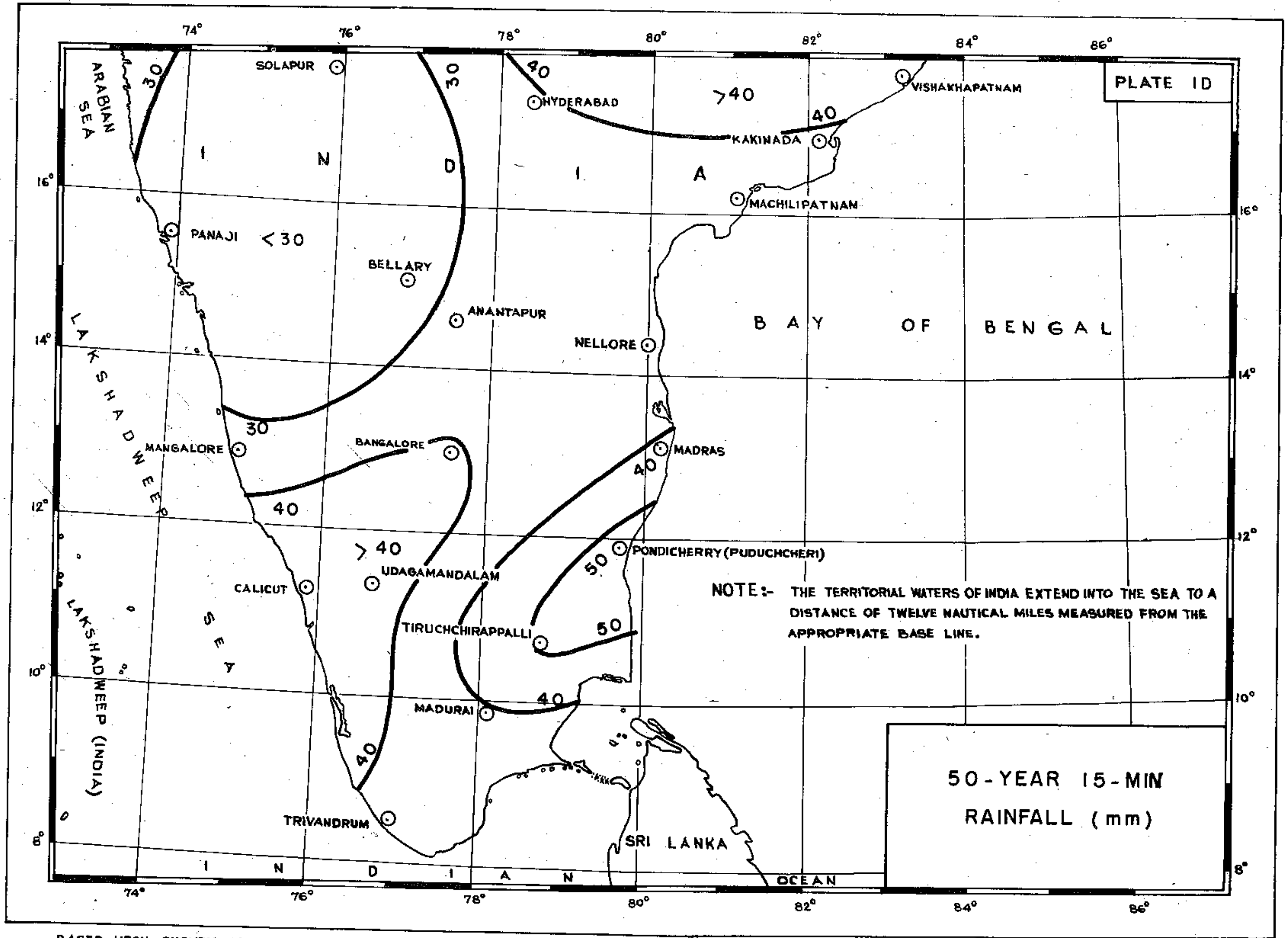

50 YEAR - 24 HOUR RAINFALL (m m)

NOTE: THE VALUES GIVEN ON THIS MAP ARE BASED ON OBSERVATIONAL DAY RAINFALLS. FOR CONVERTING THEM INTO VALUES BASED ON 1440-MINUTE RAINFALL, THEY SHOULD BE MULTIPLIED BY 1·15.

BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.
THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.



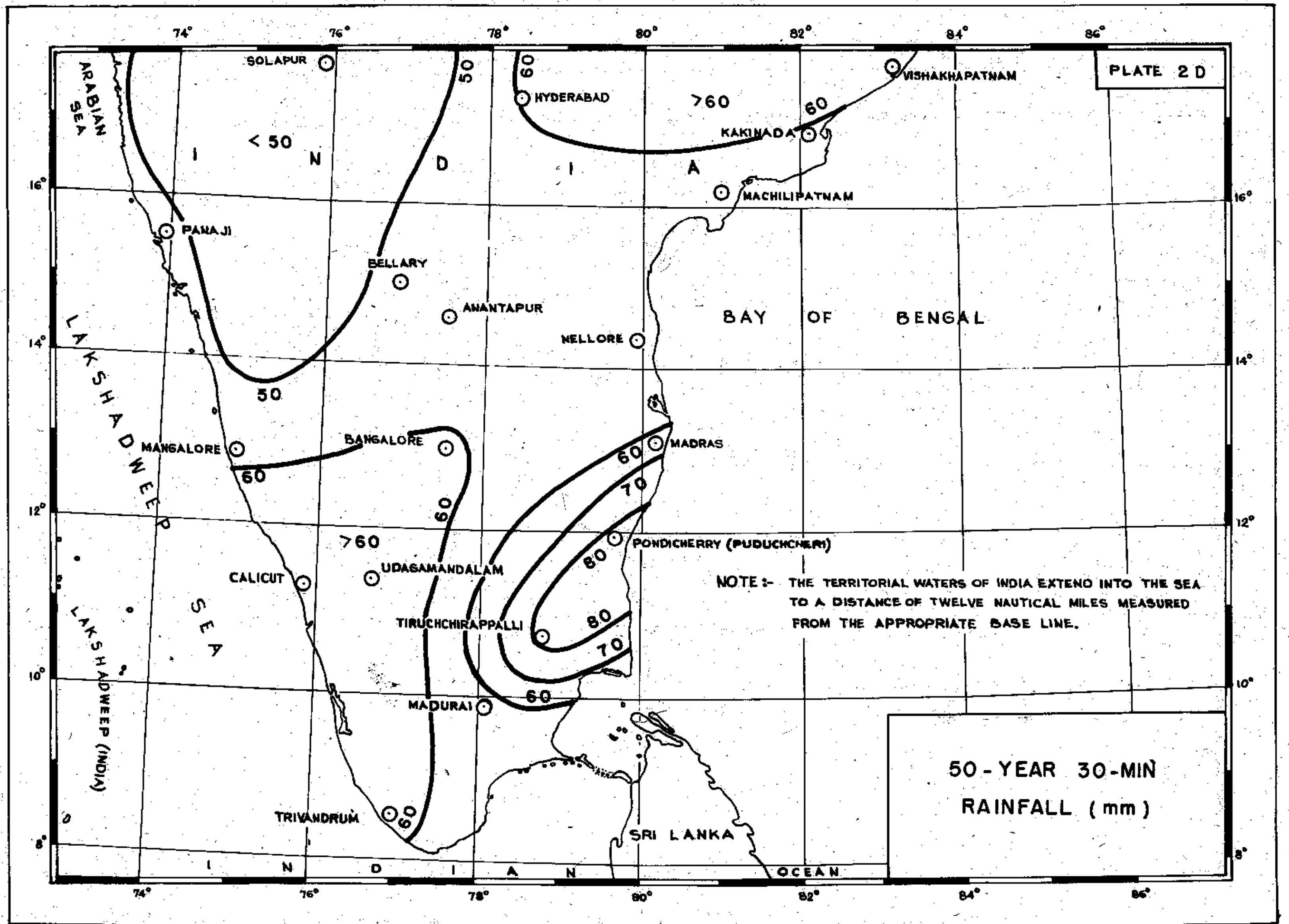
TRACED BY : S.N. MALHOTRA.
CHECKED BY : A. K. GHOSH.




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



TRACED BY- MURARI LAL
CHECKED BY- A. K. GHOSH
A.D.

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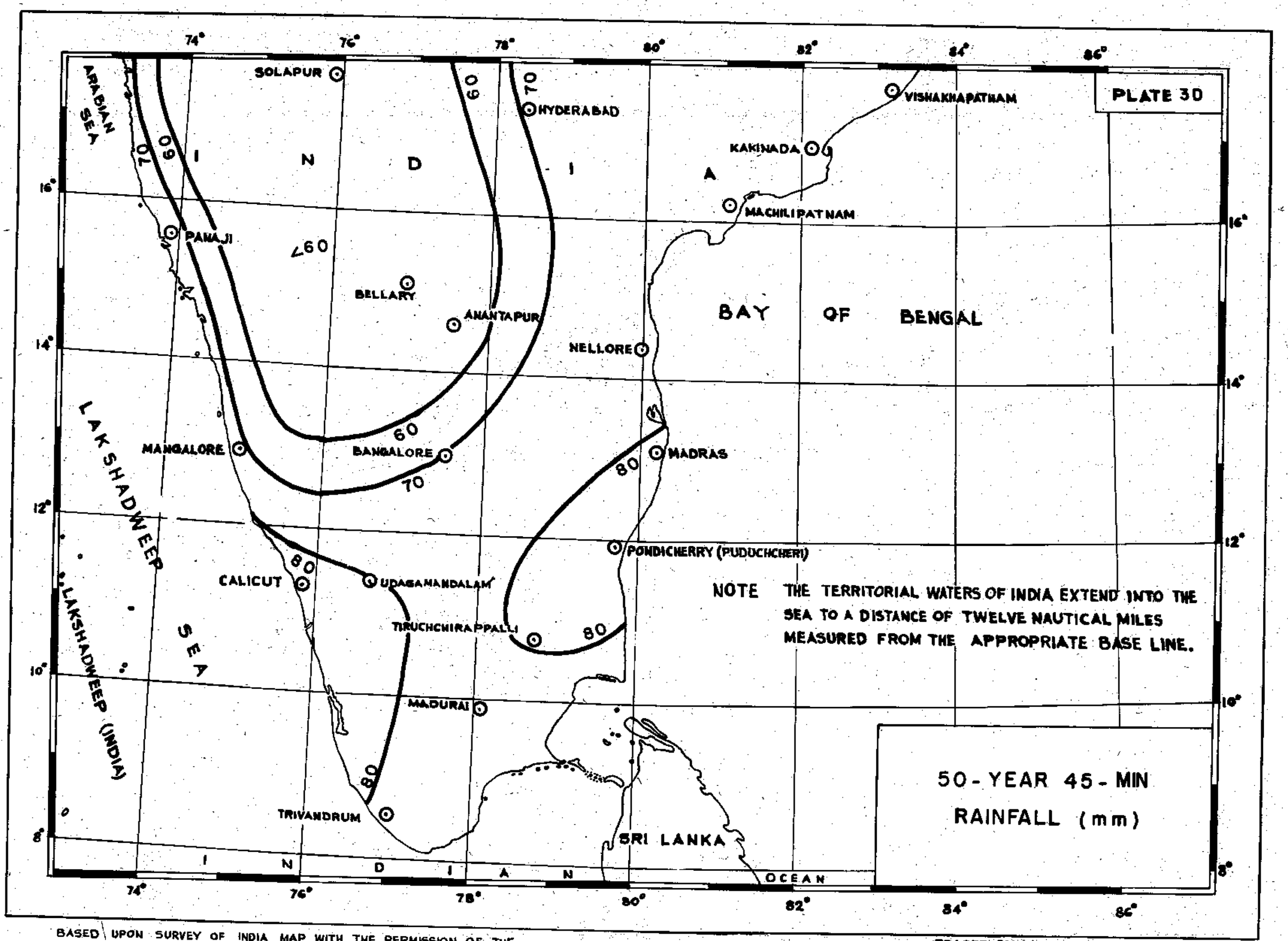
TRACED BY:- MURARI LAL
CHECKED BY:- A. K. GHOSH A.D.

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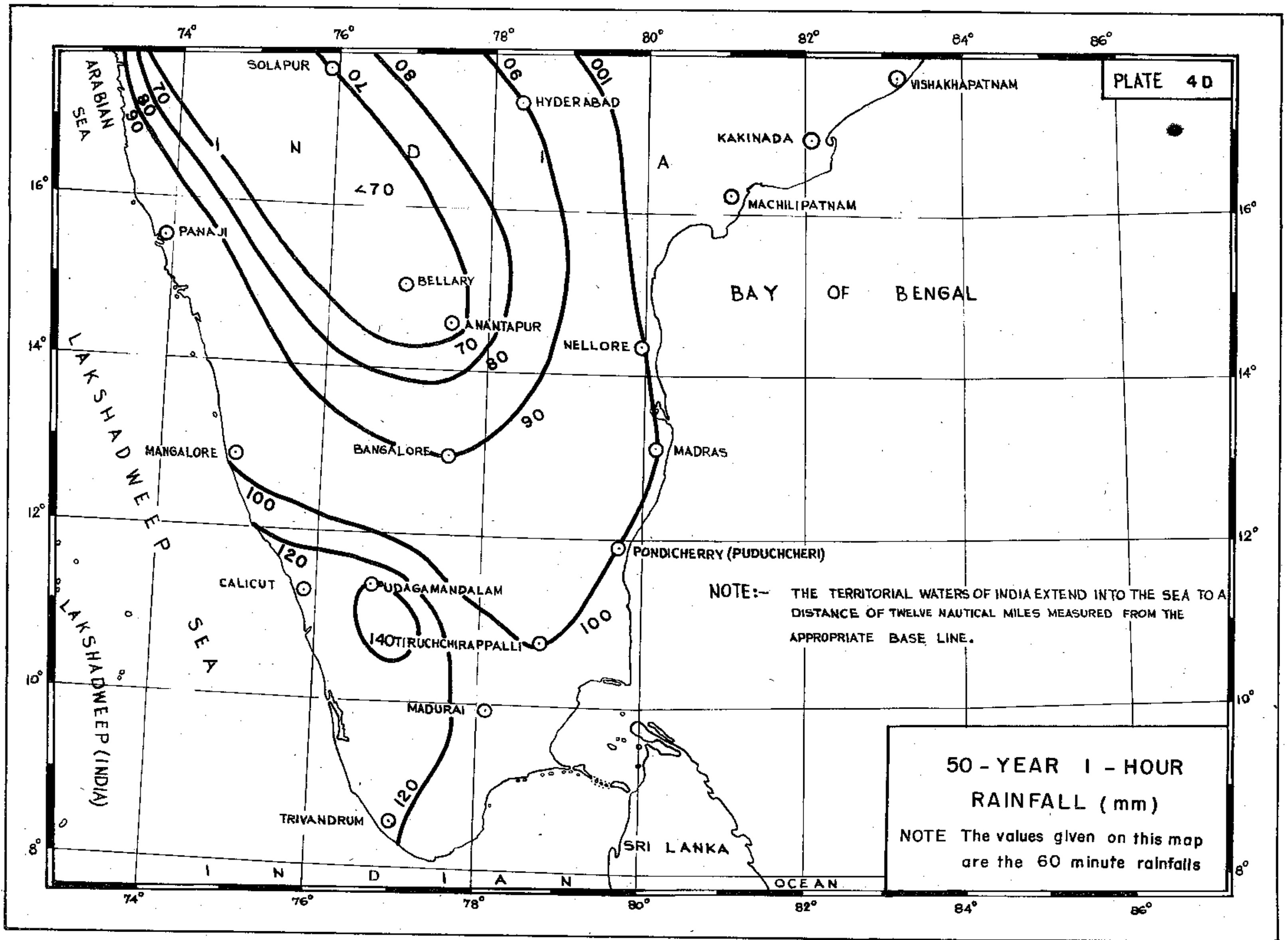
CHECKED BY - A. K. GHOSH
A.D.

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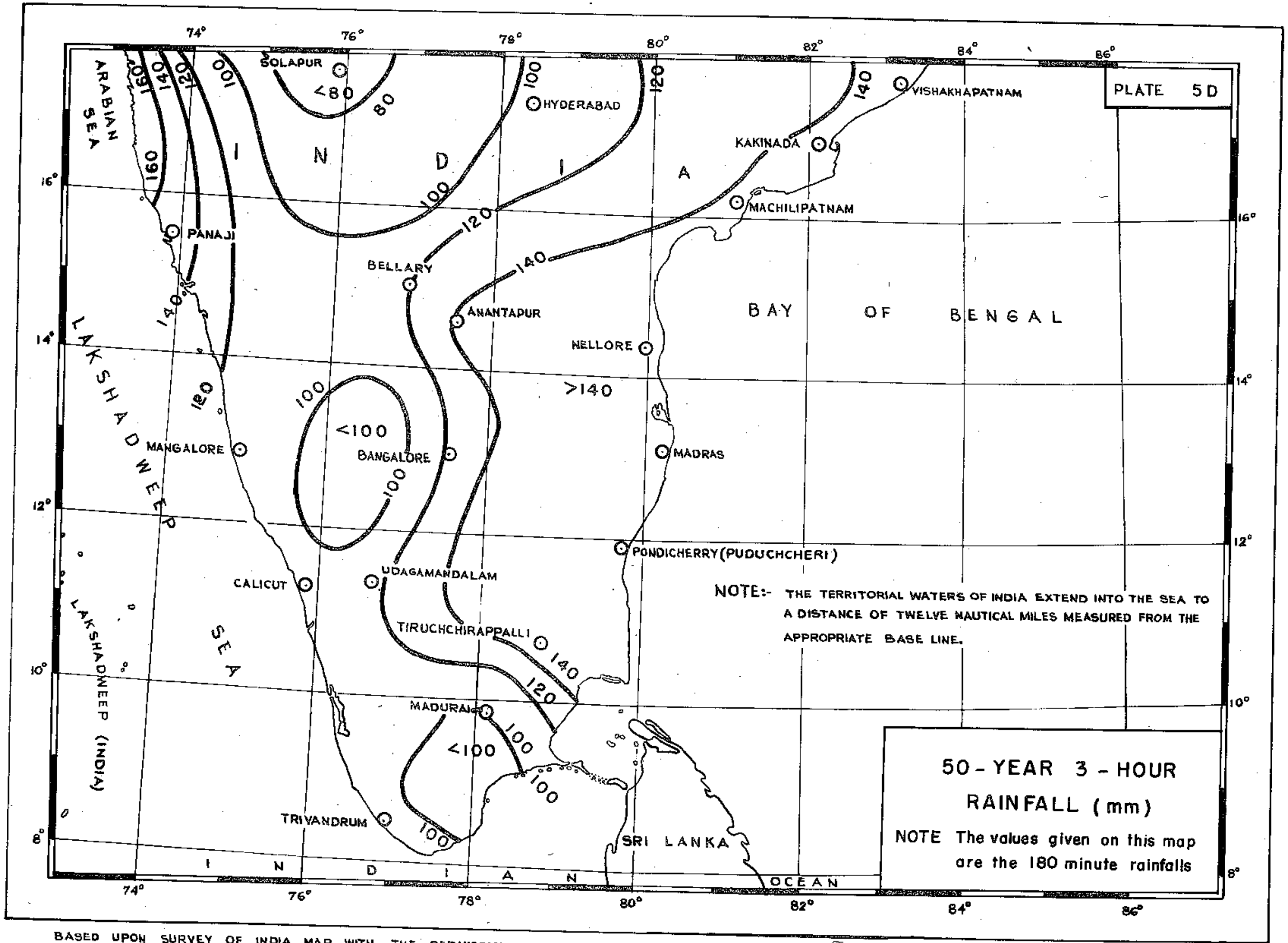
CHECKED BY:- A.K. GHOSH A.D.

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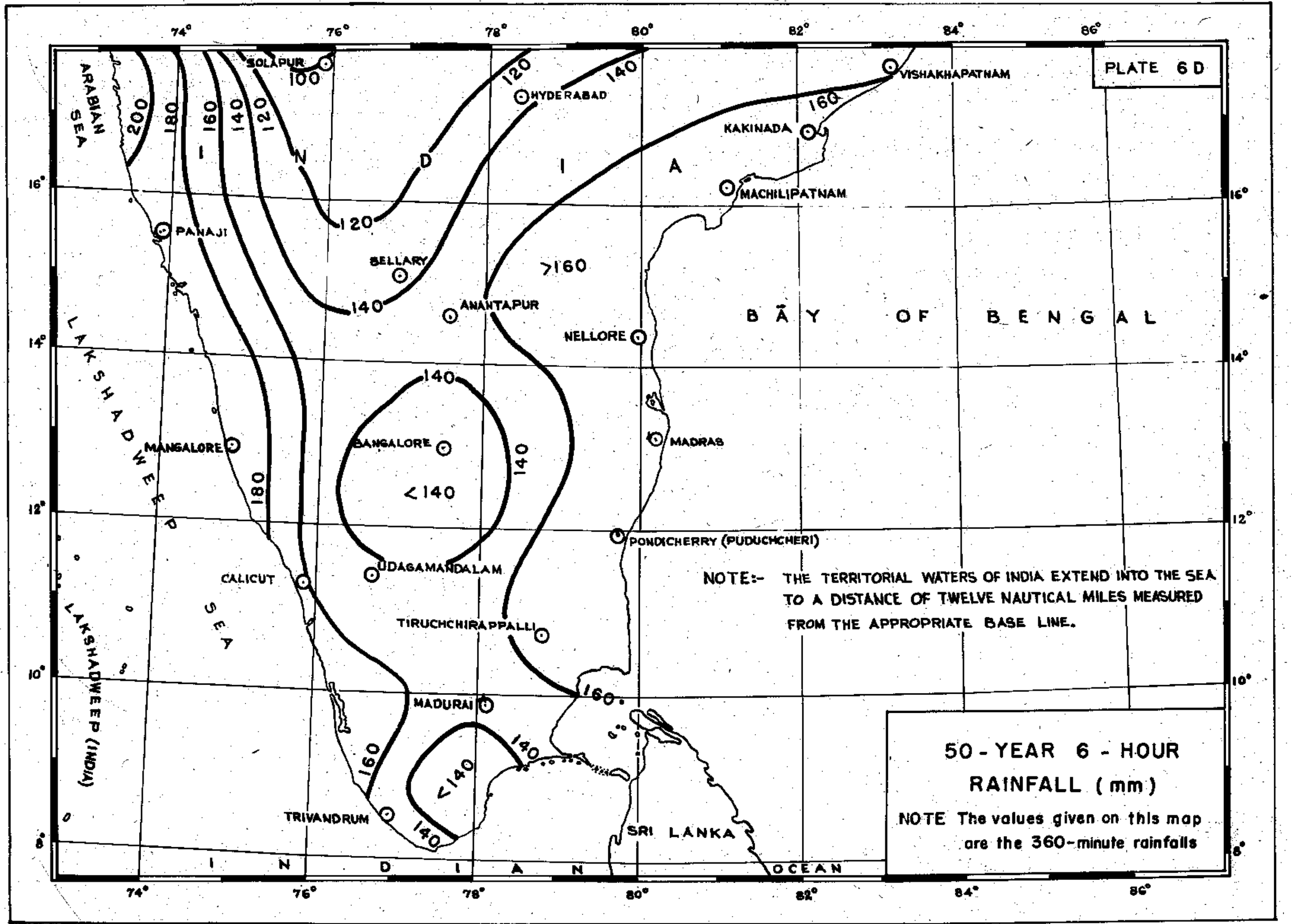


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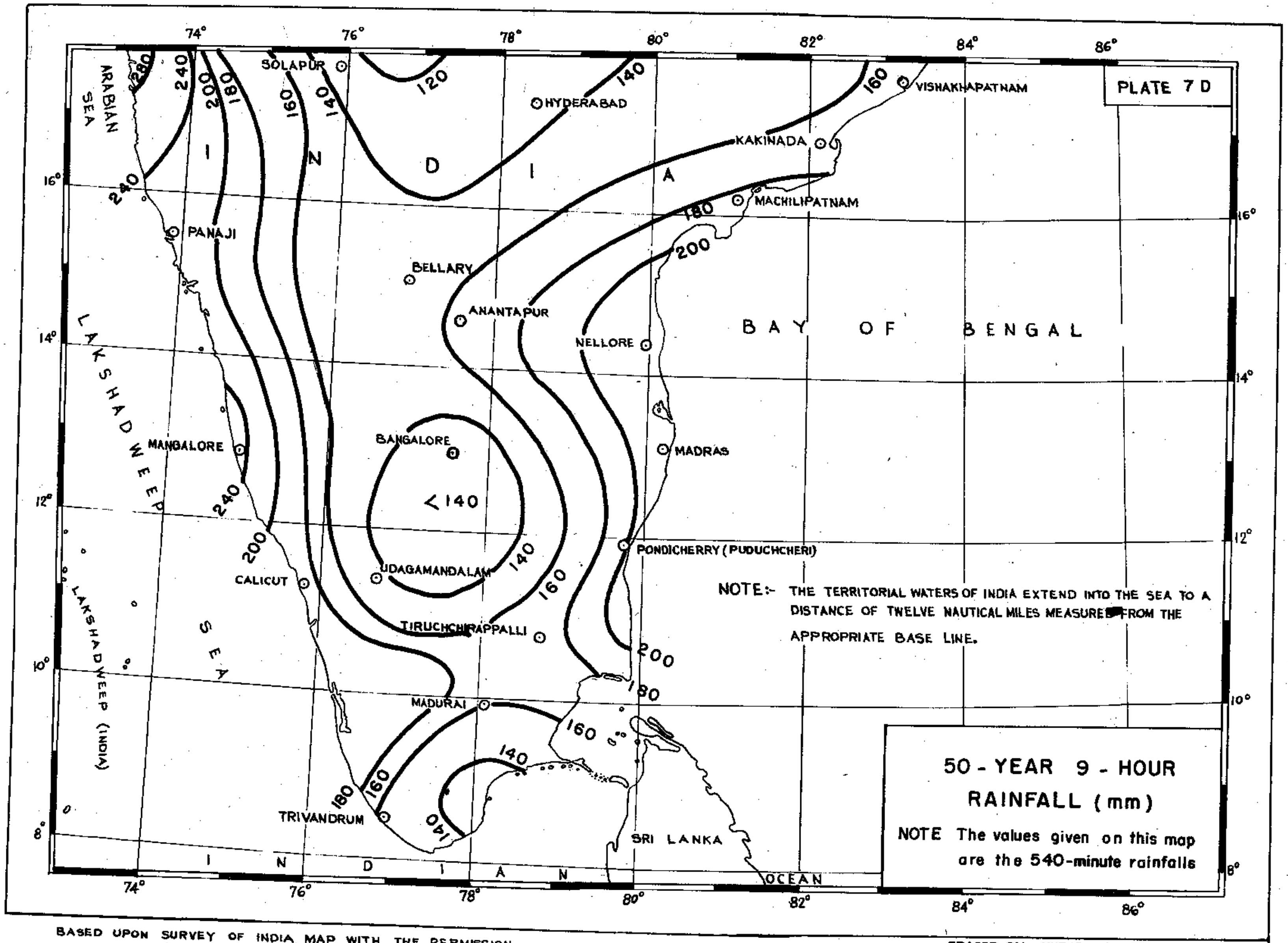


BASED UPON SURVEY OF INDIA MAP WITH THE PERMISSION OF THE SURVEYOR GENERAL OF INDIA.



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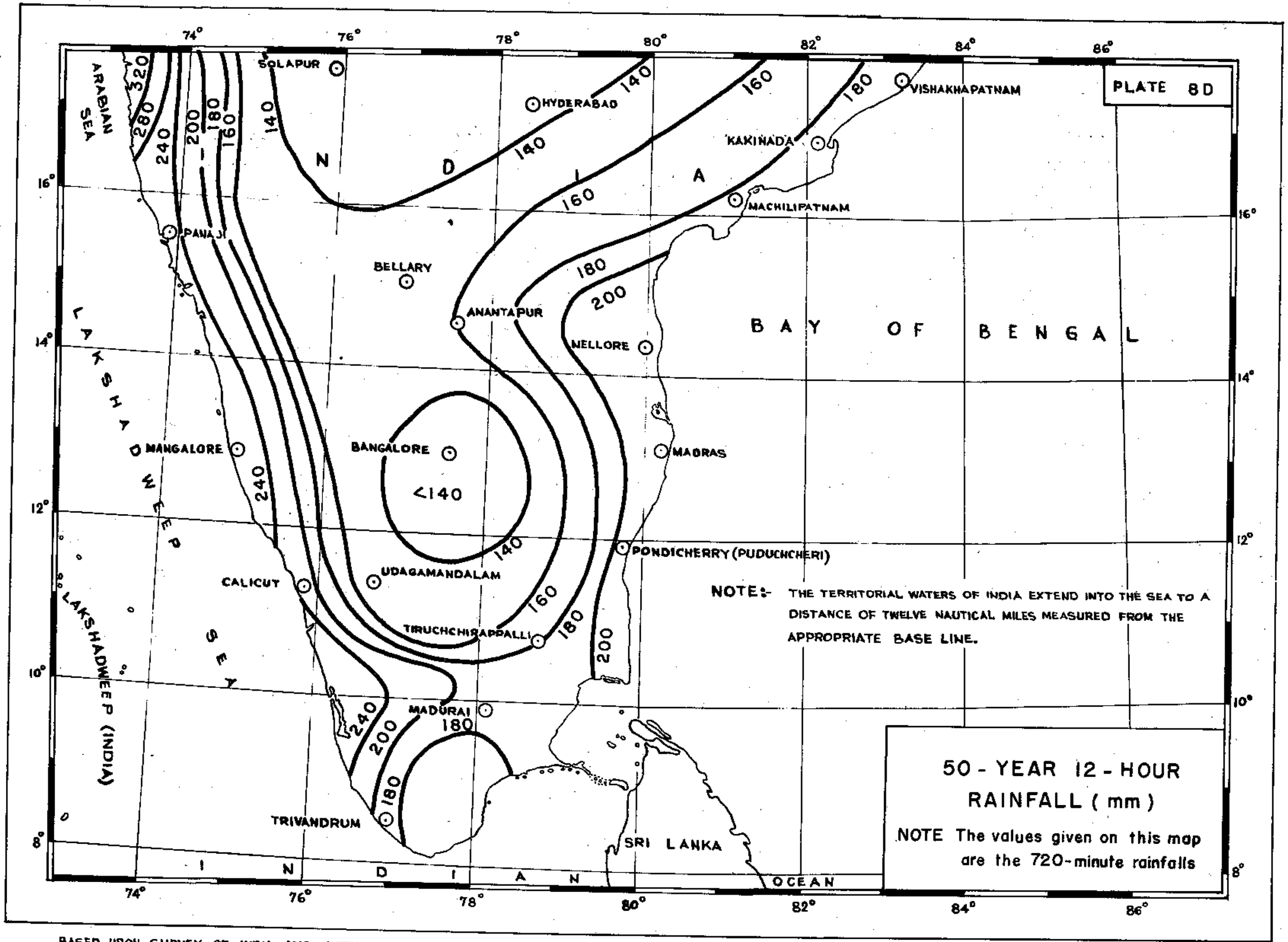


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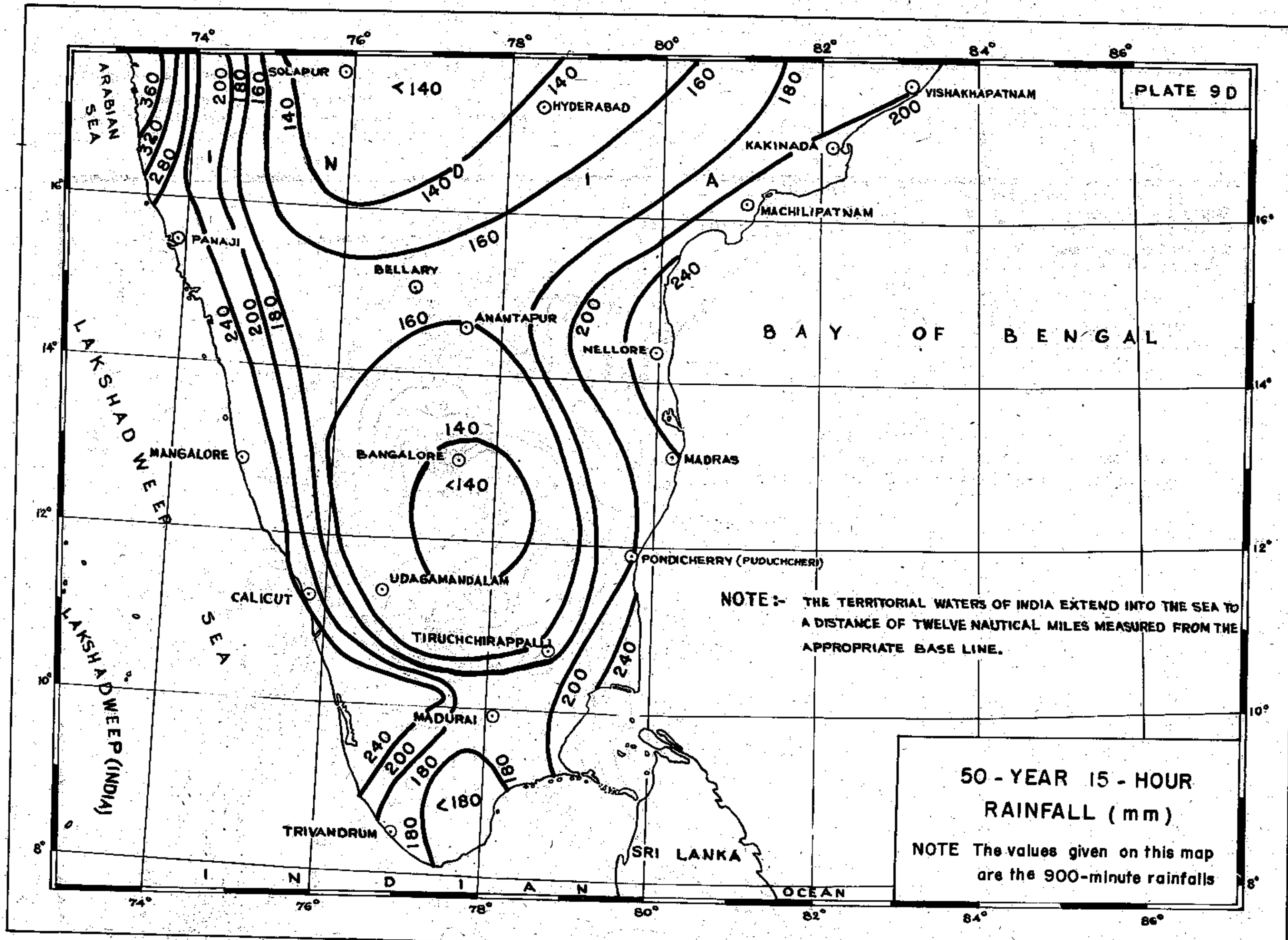
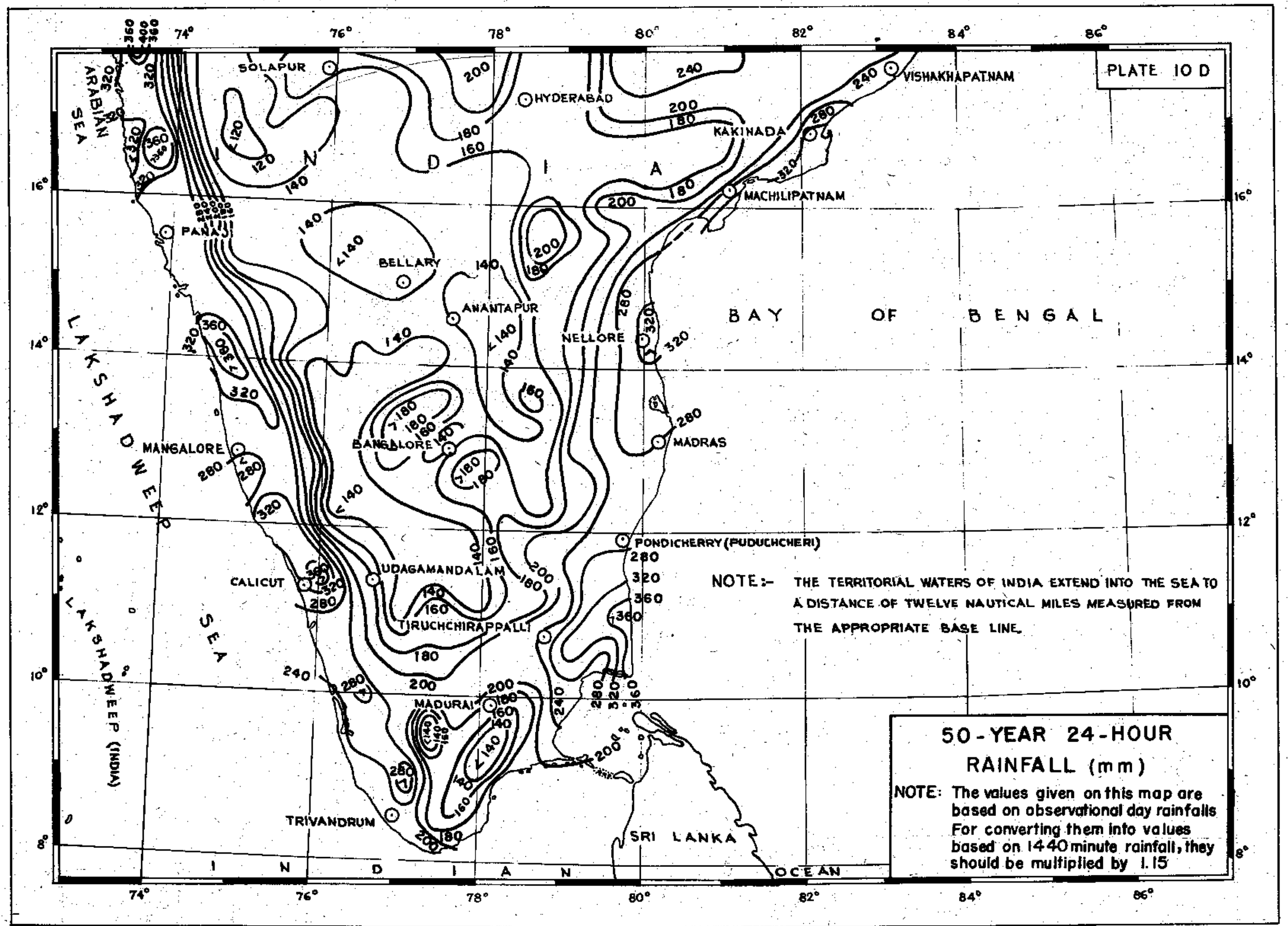





TRACED BY:- MURARI LAL
CHECKED BY:- A. K. GHOSH A.D.




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



TRACED BY:- MURARI LAL
CHECKED BY:- A. K. GHOSH A.D.

# CONVERSION OF VARIOUS EQUATIONS USED IN THE REPORT INTO METRIC SYSTEM

| F.P.S. SYSTEM (1" U.G.) — Equation No. as in the report | | METRIC SYSTEM (1 cm. UG) |
|---|---|---|
| Eq. 1 | $Q_{tp} = 16000\ A^{3/4}\ S_{LC}^{2/3}$ | $87.368\ A^{3/4}\ S_{LC}^{2/3}$ |
| Eq. 2. | $Q_{tp} = 320\ A^{3/4}$ | $1.7474\ A^{3/4}$ |
| Table 2. (i) | $Q_{tp} = 274\ A^{0.7728}$ | $1.464\ A^{0.7728}$ |
| " (ii) | $Q_{tp} = 11415\ A^{0.7472} S_{LC}^{0.6213}$ | $62498\ A^{0.7472} S_{LC}^{0.6213}$ |
| " (iii) | $Q_{tp} = 1432\ A^{0.7326} S_{LC}^{0.3739}$ | $7.95\ A^{0.7326} S_{LC}^{0.3739}$ |
| Eq. 3. | $t_p = \frac{233}{q_{tp}^{0.9}}$ | $\frac{1.729}{q_{tp}^{0.9}}$ |
| Eq. 4 | $t_e = 1.2\,t_p = \frac{280}{q_{tp}^{0.9}}$ | $1.2\,t_p = 2.078\ q_{tp}^{-0.9}$ |
| Page 26 (i) | $R = 0.47\ H^{1.22}$ | $0.38285\ H^{1.2}$ |
| (ii) | $R = 0.33\ H^{1.18}$ | $0.279\ H^{1.18}$ |
| Table 3 (i) | $R = 0.3\ H^{1.2}$ | $0.249\ H^{1.2}$ |
| " | $R = 0.4\ H^{1.2}$ | $0.332\ H^{1.2}$ |
| " | $R = 0.5\ H^{1.2}$ | $0.415\ H^{1.2}$ |
| " | $R = 0.55\ H^{1.2}$ | $0.456\ H^{1.2}$ |
| " | $R = 0.6\ H^{1.2}$ | $0.498\ H^{1.2}$ |

**F.P.S. System:**

"$t_p$" is the time measured in hours from centroid of rainfall excess to the peak of 1 hr. U.G.

"$Q_{tp}$" is the peak rate of $t_p$ hr. U.G. in cusecs.

"$q_{tp}$" = $Q_{tp}/A$ in cusecs/sq. mile

"A" is the area of drainage basin in sq. miles.

"$S_{LC}$" is the weighted mean slope of the main stream in ft/ft.

"R" Total direct surface runoff in inches

"H" Total storm rainfall in inches.

"$t_e$" the duration of rainfall excess of design storm. (in Hours)

**Metric System:**

"$t_p$" is the time measured in hours from centroid of rainfall excess to the peak of 1 cm. U.G.

"$Q_{tp}$" is the peak rate of $t_p$ hr. U.G. in cumecs.

"$q_{tp}$" = $Q_{tp}/A$ in cumecs/sq. km.

"A" is the area of drainage basin in Sq. km.

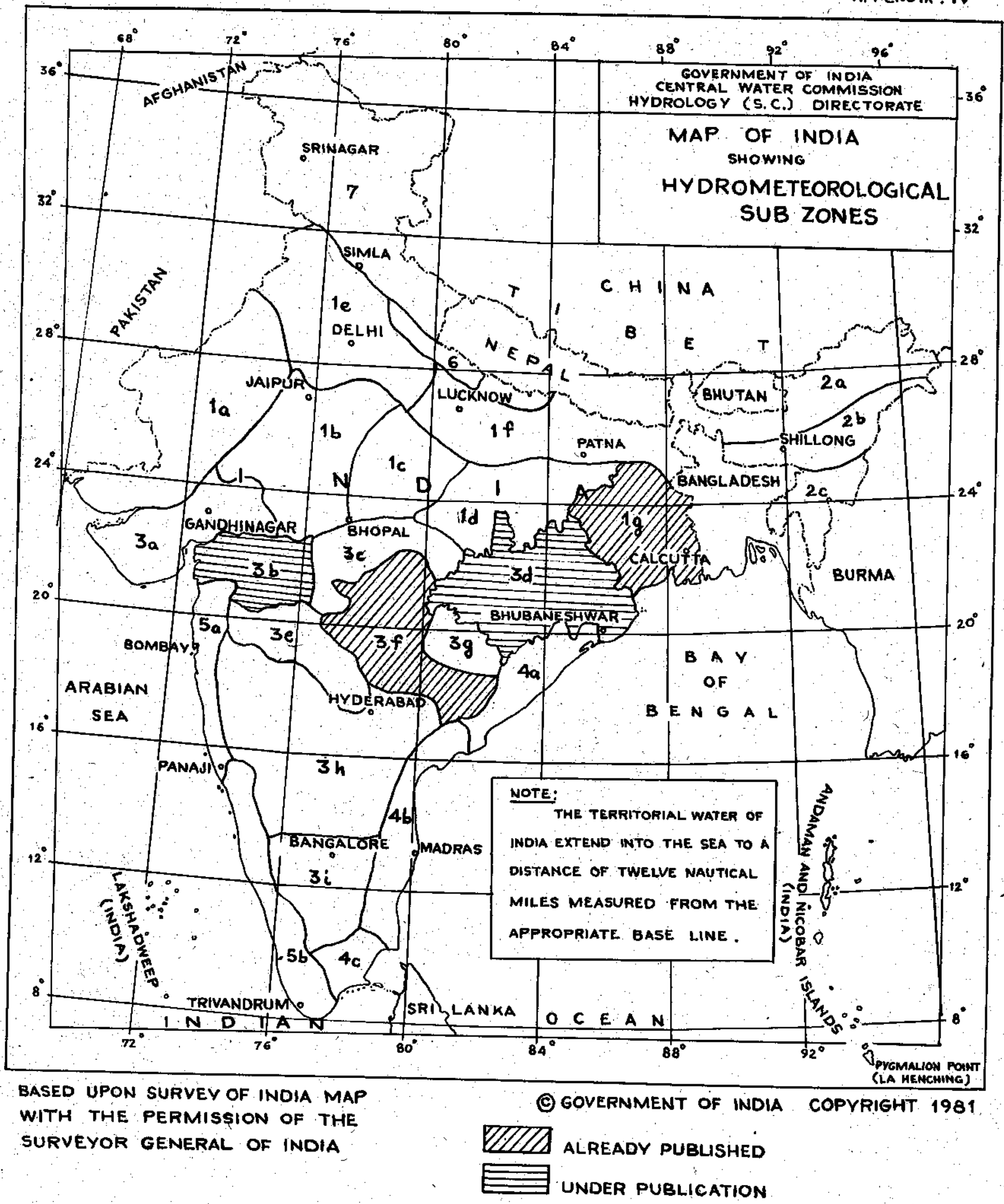
"$S_{LC}$" is the weighted mean slope of the the main stream in meter/meter

"R" Total direct surface runoff in cms.

"H" Total storm rainfall in cms.

"$t_e$" the duration of rainfall excess of design storm (in Hours)

APPENDIX. IV




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