DESIGN OFFICE REPORT
No. L - 20/1993

केन्द्रीय जल आयोग
Central Water Commission

लूनी का बाढ़ आकलन विवरण
(उप अंचल - १ ए)

FLOOD ESTIMATION REPORT FOR LUNI SUB ZONE - 1(a)

DIRECTORATE OF HYDROLOGY
(REGIONAL STUDIES)
CENTRAL WATER COMMISSION
NEW DELHI -110066

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

NOVEMBER 1993

FLOOD ESTIMATION REPORT OF LUNI BASIS SUB ZONE 1(a) WAS APPROVED BY THE FOLLOWING MEMBERS OF THE FLOOD ESTIMATION PLANNING AND COORDINATION COMMITTEE IN ITS 50TH MEETING HELD ON 17-1-1992 AT R.D.S.O, LUCKNOW.

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FLOOD ESTIMATION REPORT OF LUNI

SUBZONE 1(a)

A METHOD BASED ON UNIT HYDROGRAPH PRINCIPLE
DESIGN OFFICE REPORT NO. L/20/1992

HYDROLOGY (REGIONAL STUDIES) DIRECTORATE
CENTRAL WATER COMMISSION
NEW DELHI

1993

FOREWORD

Estimation of flood of various return periods for design of waterways and foundations of bridges and culverts having small and medium catchments, where hydrlogical data are inadequate or totally absent, is extremely difficult. In such a situation, regional method based on hydrometeorological approach involving use of design storm for specified return period and synthetic unit hydrograph has been adopted as recommended by the Committee of Engineers under the Chairmanship of Dr. A.N. Khosla set up by the Government of India in 1959. For this purpose, the country has been divided into 26 hydrometeorological homogenous subzones. The hydro meteorological and storm studies for 21 subzones have been completed and 18 flood estimation reports covering 21 subzones have been published.

The present report is 19th in the series and deals with the estimation of design flood of small and medium catchments in Luni subzone 1(a) covering the Luni River Basin, Thar desert and Rann of Kachchh. The report recommends a methodology for estimation of design flood with return period 25, 50 and 100 years for structures having small and medium catchments in the Luni subzone, till such time rainfall-runoff data are available for evolving a better and more rational method of arriving at the design flood.

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

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

New Delhi

Dated March, 1993

MSReddy

(M.S.REDDY)
Member (WP)

PREFACE

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

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

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

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

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

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

Regional Hydrology Studies Dte. (formerly Hydrology (SC) Directorate) of CWC carries out analysis of selected concurrent rainfall and flood data for the gauged catchments to derive unit hydrographs of mostly one hour duration on the basis of rainfall data, gauge and discharge data collected during the monsoon season. Representative unit hydrographs are obtained for each of the gauged catchments. The characteristics of the catchments and their unit hydrographs, prepared for several catchments in a 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.

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

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

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

So far, following 18 reports covering 21 subzones have been published:-

1. Lower Gangetic 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 & Penner subzone	3(h)	1983
7. South Brahmaputra Basin 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 Basin subzone	2(a)	1991
18. West coast subzones	5(a) & (b)	1992

The present report deals with the estimation of design flood of 25 yr, 50 yr., 100 yr., return period for small and medium catchments in subzone 1(a) which covers parts of Rajasthan and Gujrat.

For preparing the report, the data of four bridge catchments observed by the Western Railways under the guidance of RDSO and six catchments observed by Central Water Commission on behalf of Ministry of Surface Transport, varying for a period of 2 to 9 years have been collected. The Report is based on hydrological studies carried out considering the hydrometeorological data of 7 catchments found suitable and storm studies carried out with the rainfall data of 142 ordinary raingauge stations and 34 self recording raingauges maintained by State Governments/IMD/Railway/CWC.

Part I of the report deals with the summary of the synthetic unit hydrograph approach of design flood estimation alongwith an illustrative example. General description of the subzone detailing location of gauging sites, river system, rainfall, temperature and types of soil is given in Part II. Part III brings out the SUH relations to be used for ungauged catchments in the subzone. It also covers the UG(s) derived for 48 flood events and RUG of each catchment. The storm studies carried out by the IMD are dealt in Part IV of the report. The procedures to compute the design flood of ungauged catchments by deriving the SUG obtained from various equations correlating UG parameters and physiographic parameters and from RUG of adjoining catchments are described in Part V. Part VI highlights the limitations, assumptions and conclusions.

The report on subzone 1(a) is recommended for estimation of design flood for small and medium catchments varying in areas from 25 to 1000 km^2. This report may also be used for catchments of areas upto 5000 km^2. Judiciously after comparing loss-rate values in the neighboring catchments having more or less similar characteristics. For catchments of areas less than 25 km^2. the method given in the Report No. RBF published by RDSO may be used.

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

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

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NEW DELHI

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SYMBOLS AND ABBREVIATIONS

SYMBOLS

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

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

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

t_p	Time from the centre of Unit Rainfall Duration to the Peak of Unit Hydrograph in hours
t_r	Unit Rainfall Duration adopted in a specific study in hours
U.G.	Unit Hydrograph
W_{50}	Width of U.G. measured at 50% peak Discharge Ordinate (Qp) in hours.
W_{75}	Width of the U.G. measured at 75% peak Discharge Ordinate (Qp) in hours.
W_{R50}	Width of the rising side of U.G. measured at 50% of peak Discharge Ordinate (Qp) in hours.
W_{R75}	Width of the rising side of U.G. measured at 75% of peak Discharge Ordinate (Qp) in hours.
%	Percent.
<	Summation

PART-1

SUMMARY OF S.U.H APPROACH

The Flood Estimation report for Luni sub-Zone 1(a) may be used for estimation of design flood (25-yr, 50-yr and 100-yr) for ungauged and inadequately gauged catchments in the subzone. The method adopted in this report is explained in following parts :-

Part-III explains the procedure to obtain Synthetic Unit Hydrograph for catchments in the subzone.

Part-IV explains the procedure to obtain design storm rainfall and its temporal distribution.

Part-V explains steps to be followed for obtaining the design flood of 25 yr/ 50 yr/ 100 yr return period.

1.1 Steps necessary to estimate the design flood peak/design flood hydrograph are as under :

i) Preparation of catchment area plan of the ungauged catchment in question.

ii) Determination of physiographic parameters viz: catchment area (A), Length of the longest stream (L), equivalent stream slope (S) and length of stream from centre of gravity (Lc).

iii) Determination of 1-hr. SUG parameters i.e. q_p, Q_p, t_p, T_m, W_{50}, W_{75}, WR_{50}, WR_{75} & T_B.

iv) Drawing of SUH.

v) Estimation of design storm duration (TD)

vi) Estimation of point rainfall and areal rainfall for design storm duration (TD) and to obtain areal rainfall increments for unit duration intervals.

vii) Estimation of effective rainfall increments by subtracting the prescribed design loss rate from the areal rainfall increments.

viii) Estimation of base flow.

ix) Computation of design flood peak.

x) Computation of design flood hydrograph.

1.2 An example of ungauged Catchment has been worked out for illustrating the procedure to compute 50 yr design flood. The particulars of the catchment under study are as follow:

i)	Name of sub-zone	Luni
ii)	Name of Tributary	Mithi
iii)	Name of Road Section	Kherwa - Bhumadra
iv)	Shape of catchment	Fan
v)	Location	Lat 25°-45'-15" Long 73-27'-20"
vii)	Topography	Moderate slope

Procedure is explained stepwise:

Step-1:- Determation of physiographic parameters:

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

From the catchment area plan, the area of the catchment(A) in sq km and the length of the longest mainstream(L) in km from the farthest catchment boundary to the point of study was measured. Centre of gravity of the catchment was determined at the point of intersection of the plumb lines by holding freely the catchment area plan cut on a card-board. Length of the longest stream opposite to the centre of gravity to the point of study(Lc) was measured in km.

Equivalent stream slope(S) was obtained by graphical method as shown in fig-1 and by analytical method as shown in Annex-1.1

Physiographic parameters obtained are given below:

1)	Area (A)	414.00 sq km
2)	Length of the longest stream (L)	52.80 km
3)	Length of the longest stream from a point opposite to C.G. of catchment to point of study (Lc)	28.00 km
4)	Equivalent stream slope (S)	3.178m/Km

Step-2:- Derivation of 1-hr Synthetic Unitgraph:

Synthetic Unitgraph Parameters were computed using equations in para 3.4.3.

$t_p = 0.257\ (A)^{0.409}\ (S)^{0.432}$ =4.98 say 4.5 hrs

$q_p = 2.165\ (t_p)^{-0.893}$ = 0.565 cumecs

$W_{50} = 2.654\ (q_p)^{-0.921}$ = 4.487 hrs

$W_{75} = 1.672\ (q_p)^{-0.816}$ = 2.664 hrs

$W_{R50} = 1.245\ (q_p)^{-0.571}$ = 1.727 hrs

$W_{R75} = 0.816\ (q_p)^{-0.559}$ = 1.122 hrs

$T_B = 6.299\ (t_p)^{0.612}$ =15.92 say 16 hrs

$T_m = t_p + t_r/2$ = 5.0 hrs

$Q_p = q_p \times A$ = 233.91 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 <Qi x ti=1150 m^3/s as shown in Fig A-2 and compared with the volume of 1.00 cm Direct Runoff Depth over the catchment,computed from the formula Q = Axd/ti x 0.36

Where A = Catchment area in Sq. Km.

d = 1.0 cm depth

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

$$Q = \frac{A * d}{0.36 * tr} = \frac{414.00 * 1}{0.36 * 1} = 1150 \text{ cum/sec}$$

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

Step-3: Estimation of Design Storm:

(a) Design storm duration:

The Design Storm Duration (TD) has been adopted as 1.1 * tp as this value of storm duration gave higher value of flood peak (refer Section 5.2.1). Rounding of the design storm duration to nearest hour, its value came as 5 hrs.

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

Catchment under study was located on Plate -9 showing 50-yr 24-hr point rainfall. The point rainfall was found to be 25.00 cm. The Conversion factor of 0.680 was read from Fig - 10 to convert the 50-yr 24-hr point rainfall to 50-yr 5-hr point rainfall (since TD = 5 hrs). 50-yr 5-hr point rainfall was 17.00 cm.

Areal reduction factor of 0.664 corresponding to the catchment area of 414.00 sq.km for TD = 5-hr. was interpolated from Annex.4.1 or Fig 11(a) for conversion of point rainfall to areal rainfall. 50-yr 5-hr areal rainfall thus worked out to be 11.28 cm.

The 50-yr, 5-hr areal rainfall was split in to 1-hour rainfall increments using time distribution coefficients given in Annexure 4.2 or Fig 12.

A design loss rate of 0.50 cm /hr as recommended in para 3.5 was applied to get effective rainfall hyetograph. These hourly effective rainfall values are given in Table-1.

Table - 1
(Hourly rainfall Increments)

Duration 1	Distribution coefficient 2	Storm rainfall 3 (cm)	Rainfall increments 4 (cm)	Effective rainfall increments 5 (cm)
1	0.56	6.32	6.32	5.82
2	0.76	8.58	2.26	1.76
3	0.88	9.93	1.35	0.85
4	0.95	10.72	0.79	0.29
5	1.00	11.28	0.56	0.06

Step-4: Estimation of Base Flow:

Taking design base flow of 0.05 cumecs per sq km as recommended in para 3.6, the base flow was estimated to be 20.70 cumecs for the catchment area of 414.00 sq.km.

Step-5: Estimation of 50-yr Flood.

(a) Computation of flood peak

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

Table - 2

(50 year flood peak)

Time (hrs)	U.G. ordinate cumecs	1-hr effec. rainfall (cms)	Direct Runoff (cumecs)
1	2	3	4
1	186.00	0.85	158.10
2	233.00	5.82	1361.30
3	204.00	1.76	359.04
4	154.00	0.29	44.66
5	106.00	0.06	6.36
		Total	1929.46
		Base Flow	20.70
		50-yr Flood Peak	1950.16

(b) Computation of Design Flood Hydrograph:

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

Table - 3
(Critical sequence of rainfall)

Time in hrs	Critical 1-hr effective rainfall sequence cms
1	0.06
2	0.29
3	1.76
4	5.82
5	0.85

For computation of design flood hydrograph, the U.G. ordinates were tabulated in col(2) of Annex. 1.2. The critical sequence of effective rainfall increments were entered in col.3 to 7 horizontally. Direct runoff resulting from each of the effective rainfall increments was obtained by multiplying effective rainfall depths with the synthetic U.G. ordinate in col. (2) and direct runoff values were entered in columns against each unit with a successive lag of 1-hr since the unit duration of S.U.G. is 1-hr. Direct runoff values are shown in col (3) to (7). Direct runoff values were added horizontally and total direct runoff is shown in col. (8). Adding 3 total base flow of 20.70 m^3/sec. (col. 9), design flood hydrograph ordinates as given were plotted against time (col. 1) to get the design flood hydrograph as shown in Fig A-3.

1.3 Computation of design flood using RUG of the gauged catchment:-

The SUG equations have been developed using limited data of only seven catchments which are also not distributred uniformily over the entire subzone Synthetic unit hydrograph derived using these equations may not be reliable.It is therefore suggested to derive SUG of ungauged catchment using alternative method based on the RUGs developd for seven catchments and the unknown physiography parametres of the ungauged catchment and seven gauged catchments. Few approaches can be as under:

a) Synder's approach: The values of Synder's coefficents, C^p and C^t can be obtained from the known unit hydrograph parameters and physiography parametes of the catchment which is similar to the ungauged cathment. The unit hydrograph of the ungauged cathment can be obtained using the coefficents and physiography parameters in Synder's equations and unit hydrograph can be derived.

b) Dimensionless unit hydrograph approach: The physiography parameters of the catchment(s) which resembles the physiography of the .gauged catchment is/are identified The unit hdrograph(s) of selected catchment(s) is converted to dimensionles unit hydrograph In case of selected catchments more than one, dimensionless unit hydrograph can be averaged. This dimensionless unit hydrograph can be coverted to synthetic unit hydrograph by using appropriate values of lag and volume.

PART II

GENERAL DESCRIPTION OF THE SUBZONE

2.1 Location:

The Luni basin subzone 1(a) lies approximately between East longitudes 68° and 76° and North latitudes 22° 45 and 30°. Plate I shows location of Luni subzone in map of India. Annex 2.1 shows the list of subzones in India.

The subzone 1(a) is bounded by international boundary between India and Pakistan in the west, subzone 1(e) in the north, sub zone 3(a) in the south and sub zone 1(b) in the east.

2.2 River System:

The area covered by the subzone is shown in Plate - 2. The sub zone comprises of the Luni river basin covering 20% of the sub zonal area, Thar desert in the north region covering about 60% of the sub zonal area and "Rann of Kachch" in the south region covering remaining 20% of the sub zonal area. The sub zone being mostly arid, river channels in the region are generally small and shallow. All the rivers flowing through the sub zone either disappear in the sandy waters or the marshy land in "Runn of Kutch".

The sub zone 1(a) has a total area of 2,05,624 Km2, out of which 202422 Km2 lies in Rajasthan State and the remaining area of 3,202 Km2 lies in Gujarat State.

The Luni river is the only major river in the sub zone. It originates in Aravali hills and flows through the deserts of Western Rajasthan. It has the total basin area of 36,527 Km2.This constitutes approximately 20% of the sub zonal area and the rest of the area (80%) comprises of Thar desert and marshy land. It covers a length of 482 km and flowing towards east, disappears in the "Great Rann of Kachch".

The catchment areas of major tributaries of the Luni river and its free drainage area are as under :-

Sl. No.	Tributary	Catchment area in Km2
1.	Jojri	1,453
2.	Gunai Mata-Khari	3,150
3.	Sagi	940
4.	Guhiya	3,652
5.	Khari- Hemawas	1,124
6.	Mithri	1,075
7.	Jawai	3,499
8.	Bandi	1,373
9.	Sukri	1,787
	Sub Total	18,053
	Free Catchment	18,474
	Total	36,527

2.3 Topography and Relief

Plate 3 depicts the general topography of the sub zone. The extreme north-west portion of sub zone has an elevation less than 150 meters. It increases towards east and the middle portion of the north east sector has an elevation ranging between 150 and 300 meters. It continues to increase further towards north-east and south-east, where the elevation varies between 300 and 600 meters. Towards extreme south-west fringe of the sub zone, where the "Great Runn of Kutch" is located, the elevation decreases and becomes less than 150 meters.

2.4 Rainfall:

Plate 4 shows the annual rainfall of the sub zone and the histograms of normal monthly rainfall at Bikaner,Jaisalmer, Jodhpur, Barmer, Ajmer and Bhuj. The southwest monsoon causes the rainfall in the sub zone from July to October. The normal annual rainfall varies from 175 to 800 mm.

2.5 Temperature:

Plate 5 shows the normal annual temperature in the sub zone along with the histograms showing the minimum, maximum and the mean annual temperatures at Bikaner,Jodhpur,Barmer,Ajmer and Bhuj. The variation of the mean annual temperature in the sub zone is not much. The mean annual temperature in the sub zone is of the order of 26.5 ^{0}C with slightly lower at Ajmer where it is around 25^{0}C.

2.6 Soils

Plate 6 shows the different types of soils in the region. The Thar desert contains mainly Rhegosolic soils with small pockets of Lithosolic soils in the areas adjoining Bikaner and Jaisalmer districts.

The Luni catchment mainly contains submotane soils and a strip of old alluvial soils from Alor to "Rann of Kachch".

The marshy land of the Rann of Kutch basically covers deltaic alluvial soils and a small area of red sandy soils and deep black soils towards south of the Kachch.

2.7 Land Use:

The land use map at Plate 7 has been prepared from the "Irrigation Atlas of India - 1972". The sub zone 1(a) has considerable area of waste land. It has a small area of forests where the annual rainfall is of the order of 400 mm. The area adjoining Pakistan is most fertile with wheat as the major crop in addition to little areas of rice fields. Other major crops grown are millets and pulses.

2.8 Communications

2.8.1 Railways Sections

Following railway sections traverse partly or fully through the sub zone.

1.	Bhuj-Gandhidham	WR
2.	Gandhidham- Maliya	WR
3.	Bhildi-Palanpur	WR
4.	Bhildi-Sanderi	NR
5.	Palanpur-Marwar	WR
6.	Marwar-Munabad	NR
7.	Marwar-Amet	WR
8.	Chawan-Jaisalmer	NR
9.	Jodhpur-phuleru	NR
10.	Marwar-Phuleru	WR
11.	Salwa-Bilara	NR
12.	Merta-Kolayat	NR
13.	Bikaner-Hanumangarh	NR
14.	Hanumangarh-Anupgarh	NR
15.	Bikaner=Sadulpur	NR
16.	Samarhiali-Bhildi	WR
17.	Jaipur - Rajagarh	WR

2.8.2 Highways:

Following National Highways partly pass through the sub zone.

1.	Gandhidham-Maliya	8A
2.	Samarhali-Ganganagar	15
3.	Bikaner-Jaipur	11.
4.	Jaipur-Kankroli	8

PART - III

SYNTHETIC UNIT HYDROGRAPH STUDIES

3.1 Synthetic Unit Hydrograph (SUH) :

Hydrometeorological approach has been adopted for developing a regional method for estimating design flood for small and medium catchments in various hydrometeorologically homogeneous sub-zones. 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 (output). It is possible to develop unit hydrograph if site specific concurrent rainfall runoff data is available for 3-4 years. Collection of adequate concurrent rainfall runoff data for every site, however is neither practicable nor economically feasible.In such a situation the regional method for developing SUH is resorted to. The SUH in the present study is a unit hydrograph of unit duration for a catchment developed from relations established between physiographic and unit hydrograph parameters of the representative catchments in hydrometeorologically homogenous regions (sub- zones). Data collected and analysed for obtaining sub-zonal SUH equations are discussed in succeeding paragraphs.

3.2 Data Required:

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

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

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

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

The following catchment details are also required .

iv) Catchment area plans showing the river net-work, location of raingauge stations and gauge and discharge sites, contours, highways and railway network, natural and man made sto-rages, habitations, forests, agricultural and irrigated areas, soils etc.

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

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

3.3 Data Collected :

The Western and Northern railways under the supervision and guidance of Research Designs and Standards organisation (RDSO) has observed and collected the data for 4 catchments including one catchment having area less than 25 sq. km for a period ranging from 1 to 4 years. The Central Water Commission on behalf of the Ministry of Transport (Surface) has also observed and collected the required data since 1980 for 6 catchments for a period of 2 to 7 years. The size of the gauged catchments varies from 18 sq.km to 682 sq.km. Concurrent rainfall, gauge and discharge data for 41 bridge catchment years from 10 catchments were available for the studies.

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

3.4 Analysis of data for obtaining sub-zonal synthetic unit hydrograph equations (one hour):

To obtain a synthetic unitgraph, following steps are followed:

i) Analysis of physiographic parameters of the catchments.

ii) Scrutiny of data and finalisation of gauge and discharge rating curves.

iii) Selection of floods and corresponding storm events.

iv) Computation of 1-hour catchment rainfall.

v) Separation of base flow and computation of direct runoff-depth.

vi) Computation of infiltration loss (0-index) and 1-hour rainfall excess units.

vii) Derivation of 1-hour unitgraph.

viii) Drawing of representative unitgraphs and measuring the parameters.

ix) Establishing relationships between physiographic and representative unitgraph parameters.

x) Derivation of 1-hour synthetic unitgraph using such equations for an ungauged catchment.

The above steps are briefly described as under:

3.4.1 Physiographic parameters of the catchment:

Physiographic parameters indicated in Fig. 1 are discussed 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 longest length of the main river from the farthest 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 bridge site (Lc) :

For finding the centre of gravity of the catchment, usually the boundary of the catchment is cut on a card board, which is then hung in three diffrent 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 slope or statistical slope. In this report equivalent stream slope has been used for developing the SUH relation. This can be computed by the following methods.

(a) Graphical Method:

Longitudinal section (L-sectión) of the main stream was prepared from the values of the contours across the stream or the spot levels near the banks with respect to their distances from the point of interest/gauging site. A line is so drawn by trials from the 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 to 4 segments representing the broad ranges of the slopes of the segments and the following formula is used to calculate the equivalent slope (S) :

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

where L_i = Length of the ith segment in km.

D_{i-1}, D_i = Elevations of river bed at ith intersection points of contours reckoned from the bed elevation at points of interest considered as datum and D(i-1) and 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 obtained for 7 catchments , found suitable for analysis are shown in Annex.3.2 and are also indicated on catchment area plans of 7 sites at Fig.A-4.1 to A-4.7.

3.4.2 Unit hydrograph Studies:

3.4.2.1 Scrutiny of data and finilisation of gauge discharge rating curve:

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

3.4.2.2 Selection of flood and corresponding storm events:

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

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

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

3.4.2.3 Computation of hourly catchment rainfall:

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

3.4.2.4 Computation of Infiltration loss (0-index) and 1-hour effective rainfall units:

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

3.4.2.5 Separation of base flow:

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

3.4.2.6 Derivation of 1-Hour Unitgraph:

A unit duration of 1-hour was adopted for derivation of unitgraphs. The 1-hour unitgraphs were derived from the rainfall excess hyetographs and their corresponding direct runoff hydrographs by iterative method. The iterations were carried out till the observed and estimated direct runoff hydrographs compared favourably. 37 unitgraphs were derived for 7 catchments considered.

3.4.2.7 Drawing of representative Unitgraphs and measuring their parameters:

Set of Unitgraphs as obtained vide para 3.4.2.6 above were superimposed and an average/representative Unitgraph (RUG) was derived and tested to check weather observed hydrograph peak discharges can be reasonably reproduced. Annex. 3.3 show the details of RUG of these 7 sites. The parameters of these RUH i.e tp, qp , W50 , W75 , WR50 , WR75 and TB (as illustrated in Fig.2) were measured for each Catchment.

List showing these parameters for 7 catchments is given in Annex.3.4 :

3.4.3 Establishing relationships between Physiographic and Representative Unitgraph Parameters:

Two models (linear and non-linear) were tried for establishing the relationship between RUH parameters and physiographic characteristics of the catchments and non-linear modal as described below found to be the best fit model.

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

where

Y = Dependent variable
X = Independent variable
C = A constant
P = An exponent
From above equation, it follows that
Log Y = Log C + P log X

Thus if Y and X are plotted on a log-log paper, one may expect a straight line relationship.

Various trials of relationship between the physiographic parameters (Annex.3.2) and one of the unitgraph parameter (Annex. 3.5) for 7 gauged catchments considered suitable for the studies were made. The relationship between physiographic parameters and U.G. parameter tp was found to be significant. Afterwards tp was related to unit peak discharge of the U.G. (qp) and qp was related to various U.G. parameters like W50 ,W75 , WR50 , WR75 . The TB could be significantly correlated to tp. The principle of least squares was used in the regression analysis to get 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 in the subzone1(a).

Relationships	Equation No.	Fig.No.
1	2	3
$t_p = 0.257 (A)^{0.409} (S)^{0.432}$	3.4.3.2	3
$q_p = 2.165 (t_p)^{-0.893}$	3.4.3.3	4
$W_{50} = 2.654 (q_p)^{-0.921}$	3.4.3.4	5
$W_{75} = 1.672 (q_p)^{-0.816}$	3.4.3.5	6
$W_{R50} = 1.245 (q_p)^{-0.571}$	3.4.3.6	7
$W_{R75} = 0.816 (q_p)^{-0.559}$	3.4.3.7	8
$T_B = 6.299 (t_p)^{0.612}$	3.4.3.8	9
$T_m = t_p + t_r /2$	3.4.3.9	
$Q_p = q_p \times A$	3.4.3.10	

Relations developed are shown in Figures 3 to 9. List of catchment and unit hydrograph parameters studied to establish relationships and co-effecients of correlations is given in Annexure-3.5

The above relationships are recommended to estimate the parameters of 1-hour synthetic unitgraph for an ungauged catchment with its known physiography characteristics A and S.

3.4.4 Derivation of 1-Hour Synthetic Unitgraph for an Ungauged catchment:

Considering the hydro-meteorological 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 and S are determined from the catchment area plan.

ii) Substitute A and S in the equation 3.4.3.2 to obtain tp and this tp in equation 3.4.3.3 to get qp in cumecs/ sq.km.

iii) Substitute the value of q_p or t_p in the equations 3.4.3.4 to 3.4.3.8 to obtain W_{50}, W_{75}, W_{R50}, W_{R75} and T_B in hours.

iv) Plot the parameters of 1-hour unitgraph viz. T_m, T_B, Q_p, W_{50}, W_{75}, W_{R50}, and W_{R75}, on a graph paper as shown in illustrative Fig.A2 and sketch the unitgraph through these points.

Sum of discharge ordinates of tr-hr Unitgraph is obtained by using the following equation:

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

Where Q_i = discharge ordinates at 1-hour interval (cumecs)

A = Catchment area in sq.km.

tr = Unit duration in hours.

Suitable modifications can be made in falling limb upto W_{50} points, and a smooth Unitgraph be drawn.

3.5 Design Loss Rate:

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

The loss rate (cm/hr) values computed for 48 flood events analysed for 7 bridge catchments are tabulated in Annexure 3.6. The model value of loss rate has been computed as 0.41 cm/hr.However, a loss rate of 0.5 cm/hr has been recommended as design loss rate, considering the variation observed in the loss rates in the analysed flood events.

The designer can modify this value as per local conditions.

3.6 Design Base Flow :

Base flow values for 48 flood events tabulated in different ranges are shown in Annex 3.7 Out of 48 flood events, 39 flood events fall under the range of 0.00 - 0.10. Base flow rate of 0.05 cumecs/sq..km may be adopted for estimating base flow for a catchment.

PART IV

RAINFALL STUDIES

4.1 Introduction:

4.1.1 The India Meteorological Department (IMD) has conducted detailed rainfall studies for Luni Basin - Subzone 1(a). The study covers Depth-Duration Frequency analysis of rainfall data from 142 ordinary raingauge stations of IMD/States and 40 self recording raingauge stations of IMD/Railways. The Design storm components have been derived in the form of (i) 25, 50 and 100 year- 24 hour isopluvial maps (ii) 24 hours of short duration (1 to 23 hours)rainfall ratios, (iii) Time distribtion curves for storms of various durations (2 to 24 hours), and (iv)Point to areal rainfall ratios for specific durations (1, 3, 6, 12 and 24 hours). The methdology applied for analysis of each component and the procedure for design storm estimation is discussed in the subsequent paras.

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

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 has been collected for the purpose of this study and the following data utilised for analysis.

4.2.1 Daily Rainfall Data of 142 ordinary raingauge (ORG) stations - 12 maintained by IMD and 130 maintained by the State Governments of Rajasthan, Haryana, Madhya-Pradesdh and Gujarat Of these 106 stations have 50-90 years- record while 36 stations have 25-50 years record. This was necessary in order to cover the areas where the network of raingauges is very sparse, particularly over the north-western parts of the subzone.

4.2.2 Hourly rainfall data of 18 self recording raingauge (SRRG) stations maintained by IMD. Of these 12 stations have 8-14 years- record while 6 stations have 4-6 years record.

4.2.3 Hourly/half hourly rainfall data of 22 raingauge stations in 6 bridge catchments maintained by the Railways and CWC on behalf of MOST. The Research Designs and Standards Organisation (RDSO) of Ministry of Railways and CWC have collected and supplied data from a network of 28 stations maintained by them temporarily in 8 bridge catchments in the subzone for a period of 4-5 years. But the data of 2 bridge catchments could not be utilised, being not concurrently available for at least 4 years at all stations in these bridge catchments.

4.3 Depth-Duration-Frequency Analysis:

4.3.1 Analysis of ORG Data - Isopluvial maps

For each of the 142 ORG stations in and around the subzone, a series of annual maximum one-day rainfall was generated. The 142 station series thus formed was subjected to frequency analysis using Gumbel~s extreme value distributionn for computing one-day rainfall estimates for 25, 50 and 100-year return periods. These daily rainfall estimates (142 * 3) were converted into any 24-hour rainfall estimates by using the conversion factor of 1.15. For each return period, the 24-hour rainfall estimates for 142 stations were plotted on a base map and isopluvials were drawn. The isopluvial maps of 25,50 and 100- year 24-hour rainfall are shown in Plates 8,9 & 10. respectively, which can be used to derive 24- hour rainfall estimates for specific return period at any point in the subzone.

4.3.2. Analysis of SRRG Data

4.3.2.1 Short Duration Ratio

For each of the 12 SRRG stations having at least 8 years record, the hourly rainfall data were subjected to frequency analysis using partial duration series for computing t = 1,3,6,9,12,15,18 and 24-hour and T = 2,5,10 and 25-year return periods. These estimates (12*8*4) were converted into ratios with respect to the corresponding 24-hours estimates. Average ratios (8x4) for the subzone as a whole (mean of 12 station ratios) were then computed for each T-year t-hour pair. It was noticed that for a specified duration t, the average ratios beyond T = 5 years were comparable in magnitude. As such the average ratios (8) corresponding to 10-year t-hour rainfall have been recommended to be adopted uniformly for converting 24-hour rainfall into t-hour rainfall. These 8 conversion ratios for t =1, 3, 6, 9, 12, 15, 18 and 24 hours given below were plotted on a graph and a smooth curve was drawn as shown in graph at Fig.10, which can be used to derive conversion ratios for any duration t in general, including the intermediate durations (see Table alongside graph).

Rainfall Duration (t) in hours	Conversion ratio = 10 year t-hour rainfall / 10-year 24-hour rainfall
1	0.36
3	0.58
6	0.72
9	0.79
12	0.85
15	0.89
18	0.94
24	1.00

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

4.3.2.2 Time Distribution Curves

Based on 156 station-year data of all the 18 SRRG stations, a total of 814 rainstorms of durations ranging from2 to 24 hours were analysed and grouped stationwise into the following 5 categories :

1) rainstorms of 2 to 3- hour duration

2) rainstorms of 4 to 6- hour duration

3) rainstorms of 7 to 12- hour duration

4) rainstorms of 13 to 18- hour duration

5) rainstorms of 19 to 24 -hour duration

For each station, 5 different graphs corresponding to each group of rainstorms were prepared by plotting the cumulative percentage of the total storm rainfall against the percentage of the storm duration and the average time distribution curves (18x5)were drawn. Average time distribution curves (5) for the sub-zone as a whole were then drawn by plotting 18 station curves on the same graph and these are shown in Fig 12,which can be used to derive the time distribution co-efficients of storm rainfall in the subzone for rain storm of any duration. (see Annex 4.1).

4.3.3 Analysis of bridge catchment data-point to Areal rainfall ratios.

For each raingauge station in a particular bridge catchment, the available short duration rainfall data were subjected to frequency analysis using partial duration method for computing t = 1, 3, 6, 12, and 24-hour rainfall estimates for 2- year return period. For each duration t, the mean of station estimates was taken to be the t-hour representative point rainfall for the catchment. As a second step, on the basis of simultaneous occurrence of rainfall at all stations in the catchment, the event of maximum average depth for duration in each year were subjected to frequency analysis for computing 2 year t-hour areal rainfall depths for the catchment. The percentage ratio of 2-year t-hour areal rainfall values to 2-year t-hour representative point rainfall value for the catchment were then calculated. This exercise was repeated to obtain percentage ratios (5) corresponding to short durations t for each of the 6 bridge catchments. Finally, for each duration t, the best fit curve was drawn by plotting the percentage ratios(6) against the catchment areas as shown in the graph at Fig. 11(a) and 11(b) which can be used to derive the percentage areal reduction factors for converting point rainfall of any duration in the subzone into corresdponding areal rainfall for any particular size of the small catchment in the subzone. (see Ann. 4.2).

4.4 Heaviest daily rainfall records

The highest ever recorded one-day station rainfall(24-hour rainfall ending 0830 hrs of date) alongwith date of occurrence in each of the 18 districts covering the sub-zone 1(a) have been compiled from the ORG data and presented in Annex.4.3, However, in the case of districts with stations recording rainfall >/ 35 cm, all such stations have been included.

4.5 Procedure for Design Storm Rainfall Estimation

For a specified design storm duration TD hours (time of concentration) for a particular bridge catchment in the sub-zone, 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 TD from Fig 10 and multiply the 50- year 24-hour point rainfall in step -1 to obtain 50 year TD hour point rainfall.

Step-3 Read the areal reduction factor corresponding to storm duration TD and the given area of catchment from Fig 11 or Ann 4.2,and multiply the 50 year TD hour point rainfall in step 2 by this factor to obtain the 50 year TD hour areal rainfall over the catchment.

Step-4 Read the time distribution coefficients for 1, 2........(TD-1) hours correspomding to storm duration TD from relevent graph in Fig.12 or Annex-4.1 and multiply the 50-year TD - hours areal rainfall in step-3 by these coefficients to obtain the cumulative depths of 1,2,......(TD-1) hour catchment rainfall.

Step-5 Obtain the depths of storm rainfall occuring every hour in the bridge catchment by subtraction of successive cumulative values in step-4.

PART-V

DESIGN FLOOD ESTIMATION

5.1. Criteria and Standards in regard to Design Flood of Structures of small and Medium Catchments.

The Khosla Committee of Engineers had recommended a design flood of 50-yr return period for fixing the water way of the bridges. The commitee had also recommended to design the foundation and protection work for larger discharge by increasing the design flood for waterways by 30 % for small catchments up to 500 sq km., 25 to 20 % for medium catchments upto 500 to 5000 sq km. , 20 to 10 % for large catchments upro 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 Substrucures and Foudation Code revised in 1985 stipulates that all bridges shall be designed with adequate waterway for design discharge. This shall normally be the computed flood with probable recurrence of 50 years. However at the discreation of Chief Bridge Engineer, bridge damage to which is likely to have severe consequences may be designed for flood with a probable recurrenece interval of more than 50 years, while bridges on less important lines of sidings may be designed for floods with a proable recurrence interval of less than 50 years.

b) Indian Road Congress-IRC 5-1985, clause 103 of Section I "General Features of Design" Specifies that the water way of a bridge is to be designed for a maximum flood of 50-yr return period. To provide for adequate margin of safety, the foundation and protection works should be designed for larger discharge. The recommended percentage increase over the design discharge specified in clasue 103 is same as suggested by the committee of Engineers.

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

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

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

It is not possible to recommend adoption of design storm duration due to scanty data of 7 bridge catchments available for the entire sub zone. Hence it is suggested that the alternative studies to compute the flood be carried out for different storm durations and the one which gives the higher discharges may be adopted as design storm duration.

The hourly effective rainfall unit for design storm duration can be obtained using various map and curves as explained in Part IV. For deriving the unit hydrographs of ungauged catchments the method explained in Part III may be adopted.

5.2.1 Procedure for computing design flood peak and design flood hydrograph for T yr return period by SUH approach is as under:

a) Computation of Design Flood Peak

Step-1 Synthetic Unit Hydrograph

Derive the synthetic unit hydrograph as per section 3.4.4 and tabulate 1 hour U.G. ordinates.

Step-2 Design Storm Duration

The duration of storm which causes the maximum discharge in a drainage area is called " Design storm duration (TD)". Alternative studies are to be carried out by estimating flood peak assuming various values of TD ranging between TD = 1.1* TP and TD = TB. The value which gives maximum discharge may be rounded off to the full hour and considered as design storm duration of the catchment.

Step-3 Design storm rainfall.

i) Adopt suitable Design storm durartion (TD) as explained above.

ii) Obtain hourly areal rainfall incements vide section 4.5

iii) Obtain hourly effective rainfall increments by subtrating the design loss adopted vide secton 3.5.

Step-4 Design flood peak:-

(i) Arrange 1 hour effective areal rainfall values against the 1- hour U.G. ordinates such that the maximum value of effective rainfall against the maximum ordinate of

U.G., the next lower value of effective rainfall value against the next lower U.G. ordinate and so on upto T D hour duration.

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

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

(iv) Obtain flood peak by adding base flow to total surface runoff.

(b) Design Flood Hydrograph

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

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

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

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

Step-8 Add the base flow in Step 4(ii) to the direct runoff ordinates at 1-hr interval in Step-7 to get the total flow at one hour interval and plot these flows to get 50-yr flood hydrograph.

5.3 Computation of Design H.F.L. Corresponding to Design Flood:

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

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

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

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

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

The above procedure pertains to determination of design HFL corresponding to design flood of a river under natural conditions. With the type of structures in position there will generally be a constriction in the waterway. The effect of the constriction by way of raising the design HFL under natural conditions has to be evaluated in the water elevations to arrive at the revised design HFL under constricted conditions. The difference between upstream and downstream water levels corresponding to design flood due to constriction in the waterway may be termed as afflux. There are hydraulic methods for working out the final design HFL due to constriction by the structure. The weir formula or orifice formula of hydraulics is generally used depending on the upstream and downstream depths to estimate the revised design HFL under constricted conditions.

Sometimes it happens that the cross section of river or nalla on the downstream side of a cross drainage structure may be narrow than the cross section at the location of a crossing site. The flood levels at the proposed structure may also be affected by the high flood levels in the main river joining downstream in proximity of the stream. In such cases, there will be backwater effect due to the narrow gorge of the river as the design flood for the crossing site will not be able to pass through the narrow gorge in the downstream and hene there will 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 back water study may be carried out.

In the absence of any observed levels of water profiles for computing hydraulic gradient, bed gradient of nalla shall 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 unfavourable reach i.e. not complying with the usual requirements of gauge site, the design flood elevation may be computed in a straight reach downstream of the crossing and design flood elevation may be worked out by undertaking backwater studies.

PART VI

ASSUMPTIONS, LIMITATIONS AND CONCLUSIONS

6.1.0 Assumptions:

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

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

6.2.0 Limitations:

6.2.1 The data of 7 catchments including one cachment having area less than 25 sq. km has been considered for developing a generalised approach. However, for more reliable relationships the data of more suitable catchments would be desirable.

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

6.2.3 The approach developed mostly covers the catchment with flat to moderate slopes.

6.3.0 Conclusions:

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

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

6.3.3 25-yr, 50-yr and 100-yr flood may be estimated using design loss rate of 0.50 cm/hr.

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

REFERENCES:

1. Report of the Khosla Committee of Engineers (October, 1959) Government of India, Ministry of Railways.

2. "Hand Book of Hydrology", Ven Te Chow

3. "Open Channel Hydraulics", Ven Te Chow

4. Guide to Hydrological Practices (Third Edition) World Meteorological Organisation No. 168, 1974.

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

6. "Engineering Hydrology" Wilson E.M.

7. Code of Practice by Indian Railways (Revised 1985).

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

9. IRC : SP : 13 - 1973 - Guidelines for the Design of Small Bridges and Culverts.

10. Flood Studies Report. Vol. 1 Hydrological Studies, Natural Environment Research Council, 27, Charing Cross Road, London, 1975.

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12. IRS: 1985: Indian Railway Standard Bridge sub structures and foundation code.

ANNEXURE - 1.1

SUB ZONE 1(a) UNGAUGED CATCHMENT

COMPUTATION OF EQUIVALENT SLOPE

CA = 414.00 sq.km , L = 52.8 Km.

Sl.NO	REDUCED DISTANCE. (from point of study.) (Km)	REDUCED LEVEL (m)	LENGTH OF EACH SEGMENT Li (Km)	HEIGHT ABOVE DATUM (m)	$(D_{i-1} + D_i)$ (m)	$Li*(D_{i-1} + D_i)$
1	2	3	4	5	6	7
1	0.000	236.280	0.000	0.000	0.000	0.000
2	3.220	243.900	3.220	7.620	7.620	24.536
3	14.450	259.150	11.230	22.870	30.490	342.403
4	20.110	274.390	5.660	38.110	60.980	345.147
5	25.740	289.630	5.630	53.350	91.460	514.920
6	30.570	304.880	4.830	68.600	121.950	589.019
7	35.400	320.120	4.830	83.840	152.440	736.285
8	39.420	335.370	4.020	99.090	182.930	735.379
9	41.830	350.610	2.410	114.330	213.420	514.342
10	43.440	365.850	1.610	129.570	243.900	392.679
11	44.250	381.100	0.810	144.820	274.390	222.256
12	48.270	431.300	4.020	195.020	339.840	1366.157
13	49.070	533.540	0.800	297.260	492.280	393.824
14	51.49	609.76	2.420	373.480	670.740	1623.191
15	52.80	670.73	1.310	434.450	807.930	1058.388
						8858.525

$$S = \frac{\sum (Li * (D_{i-1} + D_i))}{L^2} = \frac{8858.525}{2787.840} = 3.178 \text{ m/km}$$

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

ANNEXURE - 1.2

COMPUTATION OF FLOOD HYDROGRAPH
(Using SUG equations, refer para 3.4.3)

UNGAUGED CATCHMENT

SUB-ZONE : 1(a)

TIME IN HOURS	S.U.H. ORDINATES IN CUMECS	RAINFALL EXCESS IN CMS 0.06	0.29	1.76	5.82	0.85	TOTAL D.S.R.O. IN CUMECS	BASE FLOW IN CUMECS	TOTAL FLOW IN CUMECS	
		DIRECT RUNOFF (CUMECS)								
1	2	3	4	5	6	7	8	9	10	
0	0.00	0.00					0.00	20.70	20.70	
1	8.00	0.48	0.00				0.48	20.70	21.18	
2	24.00	1.44	2.32	0.00			3.76	20.70	24.46	
3	95.60	5.74	6.96	14.08	0.00		26.78	20.70	47.48	
4	186.00	11.16	27.72	42.24	46.56	0.00	127.68	20.70	148.38	
5	233.90	14.03	53.94	168.26	139.68	6.80	382.71	20.70	403.41	
6	204.00	12.24	67.83	327.36	556.39	20.40	984.22	20.70	1004.92	
7	154.00	9.24	59.16	411.66	1082.52	81.26	1643.84	20.70	1664.54	
8	106.00	6.36	44.66	359.04	1361.30	158.10	1929.46	20.70	1950.16	--->PEAK
9	67.00	4.02	30.74	271.04	1187.28	198.82	1691.90	20.70	1712.60	
10	35.00	2.10	19.43	186.56	896.28	173.40	1277.77	20.70	1298.47	
11	17.00	1.02	10.15	117.92	616.92	130.90	876.91	20.70	897.61	
12	5.00	0.30	4.93	61.60	389.94	90.10	546.87	20.70	567.57	
13	9.50	0.57	1.45	29.92	203.70	56.95	292.59	20.70	313.29	
14	3.00	0.18	2.76	8.80	98.94	29.75	140.43	20.70	161.13	
15	2.00	0.12	0.87	16.72	29.10	14.45	61.26	20.70	81.96	
16	0.00	0.00	0.58	5.28	55.29	4.25	65.40	20.70	86.10	
17	0.00	0.00	0.00	3.52	17.46	8.08	29.06	20.70	49.76	
18	0.00	0.00	0.00	0.00	11.64	2.55	14.19	20.70	34.89	
19	0.00	0.00	0.00	0.00	0.00	1.70	1.70	20.70	22.40	
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.70	20.70	
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.70	20.70	
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.70	20.70	
23			0.00	0.00	0.00	0.00	0.00	20.70	20.70	
24				0.00	0.00	0.00	0.00	20.70	20.70	
25					0.00	0.00	0.00	20.70	20.70	
26						0.00	0.00	20.70	20.70	

ANNEXURE 2.1

LIST OF HYDRO-METEOROLOGICAL SUB-ZONE

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

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

ANNEXURE 3.1

SUB ZONE 1(a)

LIST OF RAILWAY BRIDGE/M.O.T. CATCHMENTS AND AVAILABIGAUGE, DISCHARGE AND RAINFALL DATA

Sl.No	Name of Stream	Name of Section where bridge is located with Railway zone/Road Section	Railway bridge No./ site No.	G.Site Location						Catch-ment area (sq.km)	No of rain-gauges	Data availability	No. of years
				Longitude			Latitude						
				Deg.	Min.	Sec.	Deg.	Min.	Sec.				
(A) BRIDGES CONSIDERED FOR REGRESSION ANALYSIS													
1	LUNI	GOVINDGARH - RIAN	MOT-2	74	19	03	26	31	21	682.00	5	1980-85	6
2	MITRI	PALI-SANDERAV	MOT-5	73	11	05	25	19	50	600.00	5	1980-85	6
3	SUKRI	BEAWAR-PALI	MOT-3	73	43	51	25	56	09	380.00	5	1980-85	6
4	UNGTI	PALI - SANDERAV	MOT-4	73	13	00	25	21	15	82.00	2	1980-85	6
5	GAURIANDI	AJMER-PALANPUR	527	73	57	35	25	58	55	70.55	3	1962,64-66	4
6	UNGTI	AJMER-PALANPUR	639	73	17	12	25	18	36	39.25	1	1962	1
7	BALWANA	AJMER-PALANPUR	672	73	08	40	25	06	40	18.49	3	1964-66	3
BRIDGES NOT CONSIDERED FOR REGRESSION ANALYSIS													
8	SAKARA	BHACHAUTUNA	MOT-6	70	15	00	23	13	00	373.00	4	1980-86	7
9	MENDHA	JAIPUR-SIKAR	MOT-1	73	37	00	27	22	00	153.00	3	1980-86	6
10	Tri of Mendha	JAIPUR-RINGAS	120	75	36	00	27	18	00	94.48	2	1962	1

ANNEXURE. 3.2

Subzone-1(a)

BASIN CHARACTERISTICS OF SELECTED CATCHMENTS

Sl.NO	Bridge	Area (sq.km)	L (km)	Lc (km)	S (m/km)
1	2	3	4	5	6
1	MOT-2	682.00	19.00	7.75	6.18
2	MOT-5	600.00	55.99	25.74	4.11
3	MOT-3	380.00	60.33	30.57	2.96
4	MOT-4	82.00	22.84	11.58	2.47
5	527	70.55	15.78	5.31	3.80
6	639	39.25	13.04	7.00	3.28
7	672	18.49	7.08	3.38	5.01

Subzone 1(g) ANNEXURE-3.3

HOURLY REPRESENTATIVE UNITGRAPH ORDINATES
(in cumecs)

Hours	Bridge No.						
	MOT-2	MOT-5	MOT-3	Mot-4	527	639	672
0	0	0	0	0	0	0	0
1	6	6	23	10.0	31.4	1.9	5.0
2	13	13	69	22.0	130.5	7.2	36.8
3	25	22	165	23.1	22.3	22.3	5.5
4	39	37	280	22.3	9.0	47.6	2.4
5	60	75	170	20.6	2.2	19.9	1.2
6	78	160	113	19.0	0.6	7.4	0.4
7	102	240	88	17.6	0.0	1.7	0.1
8	128	260	64	16.0		1.0	0.0
9	155	210	42	14.3		0.0	
10	170	160	25	12.8			
11	164	126	11	11.1			
12	151	96	5.5	9.8			
13	137	73	0.0	8.3			
14	124	55		7.0			
15	108	40		5.6			
16	96	30		4.2			
17	78	22		2.6			
18	66	17		1.5			
19	54	12		0.0			
20	43	8					
21	34	4.7					
22	26	0.0					
23	20						
24	12						
25	5.4						
26	0.0						

SUB ZONE 1(a)

ANNEXURE. 3.4

REPRESENTATIVE 1-HR UNIT GRAPH PARAMETERS

Sl.NO	Bridge	tp hrs	qp cumecs/km	Qp cumecs	tr hrs	TB hrs	W50 hrs	W75 hrs	WR50 hrs	WR75 hrs
1	2	3	4	5	6	7	8	9	10	11
1	MOT-2	9.50	0.25	170.00	1.00	26.00	10.20	5.60	3.70	2.00
2	MOT-5	7.50	0.43	260.00	1.00	22.00	5.10	2.80	2.30	1.60
3	MOT-3	3.50	0.74	280.00	1.00	13.00	2.40	1.40	1.20	0.70
4	MOT-4	2.50	0.28	23.10	1.00	19.00	9.50	5.50	1.70	1.30
5	527	1.50	1.85	130.49	1.00	7.00	1.35	0.80	0.70	0.40
6	639	3.50	1.38	47.60	1.00	9.00	3.60	2.50	1.90	1.40
7	672	1.50	1.98	36.76	1.00	8.00	1.20	0.90	0.70	0.50

ANNEXURE - 3.5

Subzones-1(a)

LIST OF PHYSICAL AND UNIT HYDROGRAPH PARAMETERS STUDIED TO ESTABLISH RELATIONSHIPS

Sl. No.	Independent variables Physiographic Parameters/unit graph parameters	Dependent variables Unitgraph parameter	a	b		Correlati coefficen
1	2	3	4	5		6
1	A	qp	0.651	-0.448		0.720
2	A	tp	0.421	0.427		0.840
3	A & S	qp	3.944	-0.466,	0.440	0.740
4 *	A & S	tp	0.257	0.409,	0.433	0.860,
5	L ,lc,S	qp	7.332	0.323,	-0.998, -0.759	0.570
6	L,Lc,S	TP	0.132	-0.892,	1.593, 1.744	0.830
7 *	Tp	qp	2.165	-0.893		0.730
8 *	W50	qp	2.654	-0.921		0.930
9 *	W75	qp	1.672	-0.816		0.890
10 *	WR50	qp	1.245	-0.571		0.810
11 *	WR75	qp	0.816	-0.589		0.790
12 *	TB	Tp	6.299	0.612		0.840

* Relations adopted for derivation of SUG.

Subzone-1(a)

LOSS RATE RANGES(cm/hr.)-NO. OF FLOOD OCCASIONS

SL. NO.	BRIDGE NO --->		WOT-2	WOT-5	WOT-3	WOT-4	527	639	672	WOT-6	WOT-1	128	
	CATCHMENT AREA---> IN sq.Km		602.00	680.00	380.00	82.00	78.55	39.25	18.49	373.00	153.00	94.00	
	LOSS RATE RANGES		NUMBER OF OBSERVED FLOODS										ROW-TOTAL
	LO	HI											
1	0.0	0.1		1	2	1	1		2				7
2	0.1	0.3			1	1		2					4
3	0.3	0.5		1	1		1		1				6
4	0.5	0.7		1		2				1			4
5	0.7	0.9	1			1	1		1		1		6
6	0.9	1.1		1	2		1						4
7	1.1	1.3	1			1	1				1		4
8	1.3	1.5							1				1
9	1.5	1.7				1	1				1		3
10	1.7	1.9	1							1			2
11	1.9	2.1	1								1		2
12	2.1	2.3							1	1			2
13	2.3	2.5									1		1
14	2.5	2.7								1			1
15	2.7	2.9	1										1
16	2.91	and above.											
		COL.TOTAL	5	6	6	3	6	2	6	5	5		G.TOTAL 48

$$\text{MODEL LOSS RATE} = Li + \frac{(FM - F1) * (W)}{(2FM - F1 - F2)} = 0.41 \text{ cm/hr.}$$

WHERE ,

Li ---> Lower limit of the modal class. (0.31)
FM ---> Frequency of the modal class. (6)
F1 ---> Frequency of the class preceding the modal class. (4)
F2 ---> Frequency of the class succeeding the modal class. (4)
W ---> Width of the modal class. (0.2)

----> Note :- The mode) value of loss rate has been computed rejecting the floods having loss rate upto 0.1 cm/hr and more than 1.7 cm/hr

Subzones-1(a)

ANNEXURE 3.7

BASE FLOW RANGES(cumec/sqkm.)-NO. OF FLOOD OCCASIONS

SL. NO.	BRIDGE NO ---->		MOT-2	MOT-5	MOT-3	MOT-4	527	639	672	MOT-6	MOT-1	120	
	CATCHMENT AREA---> IN sq.Km		682.00	680.00	380.00	82.00	70.55	39.25	18.49	373.00	153.00	94.48	
	BASE FLOW RANGES		NUMBER OF OBSERVED FLOODS										ROW-TOTAL
	LB	RB											
1	0.000	0.100	5	6	5	5	5	0	3	6	4	0	39
2	0.110	0.200	0	0	1	2	1	2	1	0	0	0	7
3	0.210	0.300	0	0	0	0	0	0	0	0	1	0	1
4	0.310	0.400	0	0	0	0	0	0	0	0	1	0	1
5	0.410	above .41	0	0	0	0	0	0	0	0	0	0	0
		COL.TOTAL	5	6	6	7	6	2	4	6	6	0	G.TOTAL 48

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

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		0.84	0.72	0.62	0.55	0.52	0.42	0.40	0.36	0.35	0.32	0.29	0.24	0.23	0.21	0.19	0.18	0.15	0.14	0.13	0.12	0.12	0.11	0.10	1
2		1.0	0.91	0.83	0.76	0.71	0.64	0.60	0.56	0.53	0.50	0.48	0.42	0.40	0.38	0.36	0.33	0.32	0.24	0.24	0.22	0.21	0.20	0.20	2
3			1.00	0.93	0.88	0.83	0.77	0.73	0.69	0.66	0.63	0.60	0.55	0.51	0.50	0.48	0.46	0.43	0.34	0.32	0.30	0.29	0.28	0.27	3
4				1.00	0.95	0.91	0.85	0.82	0.78	0.75	0.72	0.69	0.63	0.61	0.59	0.57	0.55	0.53	0.42	0.40	0.38	0.37	0.35	0.34	4
5					1.00	0.96	0.91	0.88	0.84	0.82	[illegible]	0.77	0.70	0.68	0.66	0.64	0.62	0.60	0.49	0.47	0.45	0.44	0.41	0.40	5
6						1.00	0.97	0.93	0.89	0.87	0.84	0.82	0.77	0.74	0.72	0.70	0.67	0.66	0.55	0.53	0.51	0.49	0.47	0.46	6
7							1.00	0.97	0.94	0.91	0.89	0.86	0.82	0.79	0.77	0.75	0.72	0.71	0.60	0.58	0.57	0.54	0.52	0.51	7
8								1.00	0.97	0.94	0.92	0.89	0.86	0.83	0.81	0.79	0.77	0.75	0.65	0.63	0.62	0.59	0.57	0.56	8
9									1.00	0.57	0.55	0.92	0.89	0.87	0.85	0.83	0.81	0.79	0.70	0.68	0.66	0.64	0.62	0.60	9
10										1.00	0.58	0.95	0.92	0.90	0.88	0.86	0.84	0.83	0.74	0.72	0.70	0.68	0.66	0.64	10
11											1.00	0.98	0.95	0.93	0.91	0.89	0.87	0.86	0.78	0.76	0.74	0.72	0.70	0.68	11
12												1.00	0.98	0.96	0.94	0.92	0.90	0.88	0.81	0.80	0.77	0.75	0.73	0.71	12
13													1.00	0.98	0.96	0.94	0.92	0.90	0.84	0.83	0.80	0.78	0.76	0.74	13
14														1.00	0.98	0.96	0.94	0.92	0.87	0.86	0.83	0.81	0.79	0.77	14
15															1.00	0.98	0.96	0.94	0.90	0.89	0.86	0.84	0.82	0.80	15
16																1.00	0.98	0.96	0.53	0.92	0.89	0.87	0.85	0.83	16
17																	1.00	0.98	0.96	0.94	0.92	0.90	0.88	0.85	17
18																		1.00	0.99	0.96	0.94	0.92	0.90	0.88	18
19																			1.00	0.98	0.96	0.94	0.92	0.91	19
20																				1.00	0.98	0.96	0.94	0.93	20
21																					1.00	0.98	0.96	0.95	21
22																						1.00	0.98	0.97	22
23																							1.00	0.99	23
24																								1.00	24

ejp

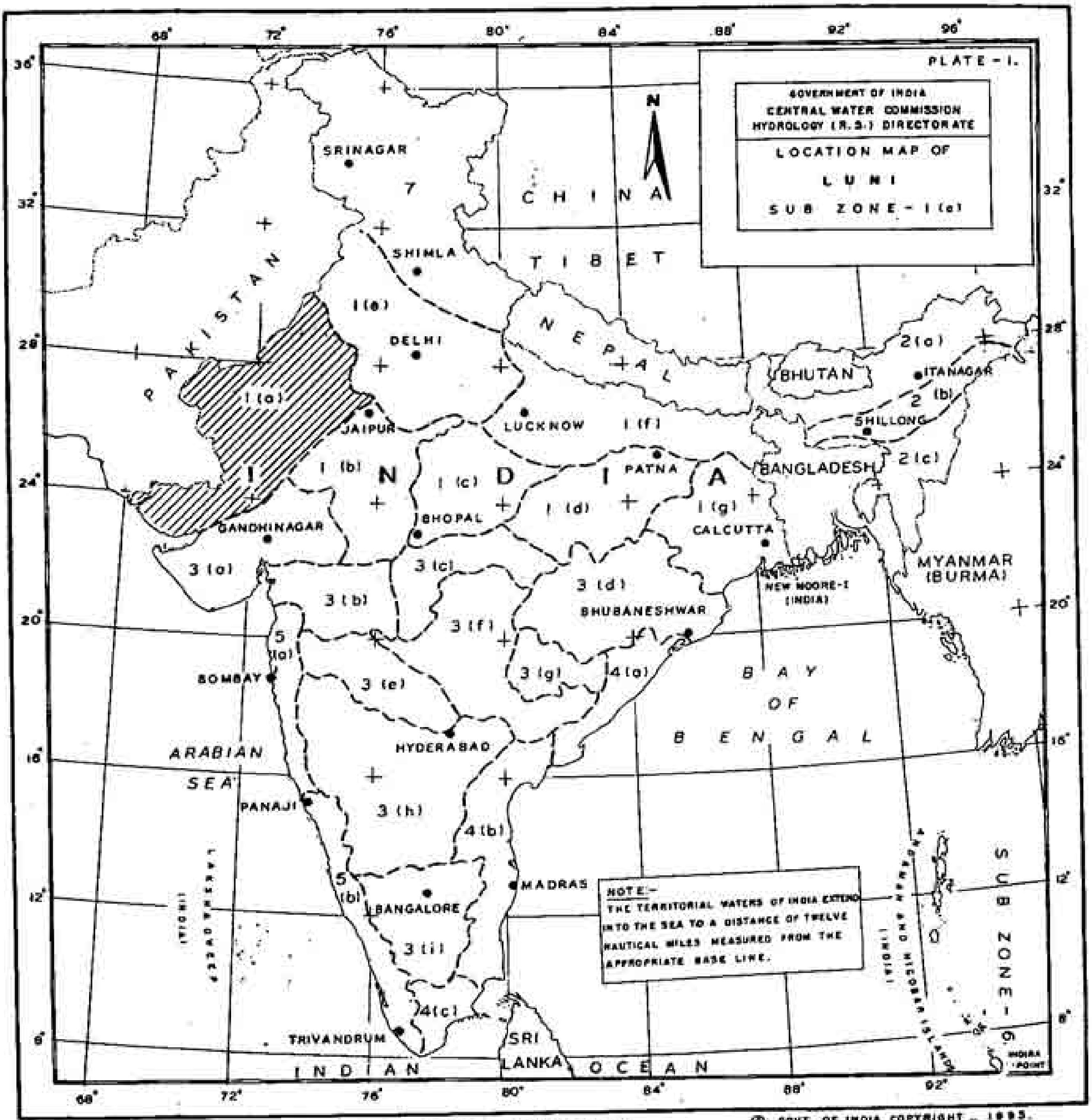
AREAL REDUCTION FACTORS (%) FOR POINT TO AREAL RAINFALL – SUBZONE 1 (a).

CATCHMENT AREA (Sq. Km.)	DESIGN STORM DURATION (HOURS)																								CATCHMENT AREA (Sq. Km.)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
0	1 00	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	.100	100	100	100	100	100	0
50	81.50	83.75	86.00	87.50	89.00	90.50	90.67	90.84	91.00	91.17	91.34	91.50	91.67	91.84	92.00	92.17	92.34	92.50	92.67	92.83	93.00	93.17	93.34	93.50	50
100	74.25	76.87	79.50	81.00	82.50	84.00	84.58	85.16	85.75	86.33	86.91	87.50	87.75	88.00	88.25	88.50	88.75	89.00	89.25	89.50	89.75	90.00	90.25	90.50	100
150	69.00	72.13	75.25	76.83	78.41	80.00	80.83	81.66	82.50	83.33	84.17	85.00	85.25	85.50	85.75	86.00	86.25	86.50	86.75	87.00	87.25	87.50	87.75	88.00	150
200	65.25	68.63	72.00	73.66	75.32	77.00	78.00	79.00	80.00	81.00	82.00	83.00	83.30	83.60	83.90	84.20	84.50	84.80	85.10	85.40	85.70	86.00	86.30	86.50	200
250	62.00	65.50	69.00	70.92	72.84	74.75	75.87	76.99	78.11	79.23	80.35	81.50	81.79	82.09	82.37	82.66	82.95	83.24	83.53	83.87	84.12	84.40	84.76	85.00	250
300			66.50	68.50	70.50	72.60	73.75	75.00	76.25	77.50	78.70	80.00	80.33	80.67	81.00	81.33	81.67	82.00	82.33	82.67	83.00	83.33	83.67	84.00	300
350			64.00	66.16	68.32	70.50	71.83	73.16	74.49	75.82	77.15	78.50	78.87	79.24	79.61	79.99	80.35	80.72	81.09	81.46	81.83	82.20	82.57	83.00	350
400			62.50	64.66	66.82	69.00	70.42	71.84	73.26	74.68	76.10	77.50	77.88	78.25	78.63	79.00	79.37	79.75	80.13	80.50	80.88	81.25	81.68	82.00	400
450			61.00	63.16	65.32	67.50	69.00	70.50	72.00	73.50	75.00	76.50	76.80	77.25	77.63	78.00	78.37	78.75	79.13	79.50	79.88	80.75	80.58	81.00	450
500			60.00	62.16	64.32	66.50	68.10	69.60	71.10	72.60	73.10	75.50	75.87	76.24	75.61	76.90	76.85	77.22	77.39	77.56	78.33	78.70	79.07	80.00	500
600												74.50	74.80	75.25	75.63	76.00	76.37	76.75	77.13	77.50	77.88	78.25	78.58	79.00	600
700												73.50	73.88	74.26	74.64	75.02	75.39	75.78	76.15	76.52	76.90	77.27	77.64	78.00	700
800												73.00	73.35	73.70	74.05	74.40	74.75	75.10	75.45	75.80	76.15	76.50	76.85	77.75	800
900												72.50	72.83	73.16	73.49	73.82	74.15	74.48	74.81	75.14	75.47	75.80	76.13	76.50	900
1000												72.00	72.31	72.65	72.93	73.24	73.55	73.86	74.17	74.48	74.79	75.10	75.41	75.80	1000
1100												71.50	71.80	72.10	72.40	72.70	73.00	73.30	73.60	73.90	74.70	74.50	74.80	75.10	1100
1200												71.25	71.52	71.79	72.06	72.33	72.60	72.87	73.14	73.41	73.58	73.85	74.12	74.50	1200
1300																								74.00	1300
1400																								73.50	1400
1500																								73.00	1500
2000																								72.50	2000

ANNEXURE - 4.3

HEAVIEST DAILY RAINFALL RECORDED IN SUBZONE-1(a).

STATE/ District	Station	Heaviest Raintall >/ 35-Cm.	< 35 Cm.	Date of Occurrence
(1)	(2)	(3)	(4)	(5)
RAJASTHAN STATE				
Sirohi	1. Mount Abu	560.0	-	01.09.1973
Jalora	2. Sachar	511.8	-	16.09.1893
Jaipur	3. Dausa	424.9	-	10.09.1924
	4. Samodh	393.7	-	27.07.1920
	5. Moramabad	352.0	-	29.06.1971
Ajmer	6. Dooli	413.8	-	01.09.1908
Pali	7. Desuri	391.0	-	31.07.1952
Barmer	8. Chotah	355.6	-	26.08.1944
Nagora	9. Parbatsar	-	306.8	24.07.1929
Jodhpur	10. Shargarh	-	298.5	02.09.1908
Jhunjhunu	11. Khetri	-	281.4	13.07.1908
Jaislmer	12. Bap	-	266.7	08.08.1933
Bikaner	13. Palana	-	265.9	07.08.1933
Udaipur	14. Bhim	-	261.6	22.08.1944
Ganganagar	15. Ganganagar	-	251.7	31.08.1928
Churu	16. Sardarshahar	-	226.1	09.07.1960
Sikar	17. Srimadhopur	-	188.0	12.07.1912
GUJRAT STATE				
Kutch	18. Bhuj	467.9	-	15.07.1959
Mehsana	19. Radhanpur	418.8	-	25.07.1905
	20. Kalol	369.6	-	17.09.1950
Banaskantha	21. Palanpur	409.7	-	16.09.1893
	22. Tharad	370.3	-	25.07.1905



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

S. N. MALHOTRA, L. P. NAUTIYAL.

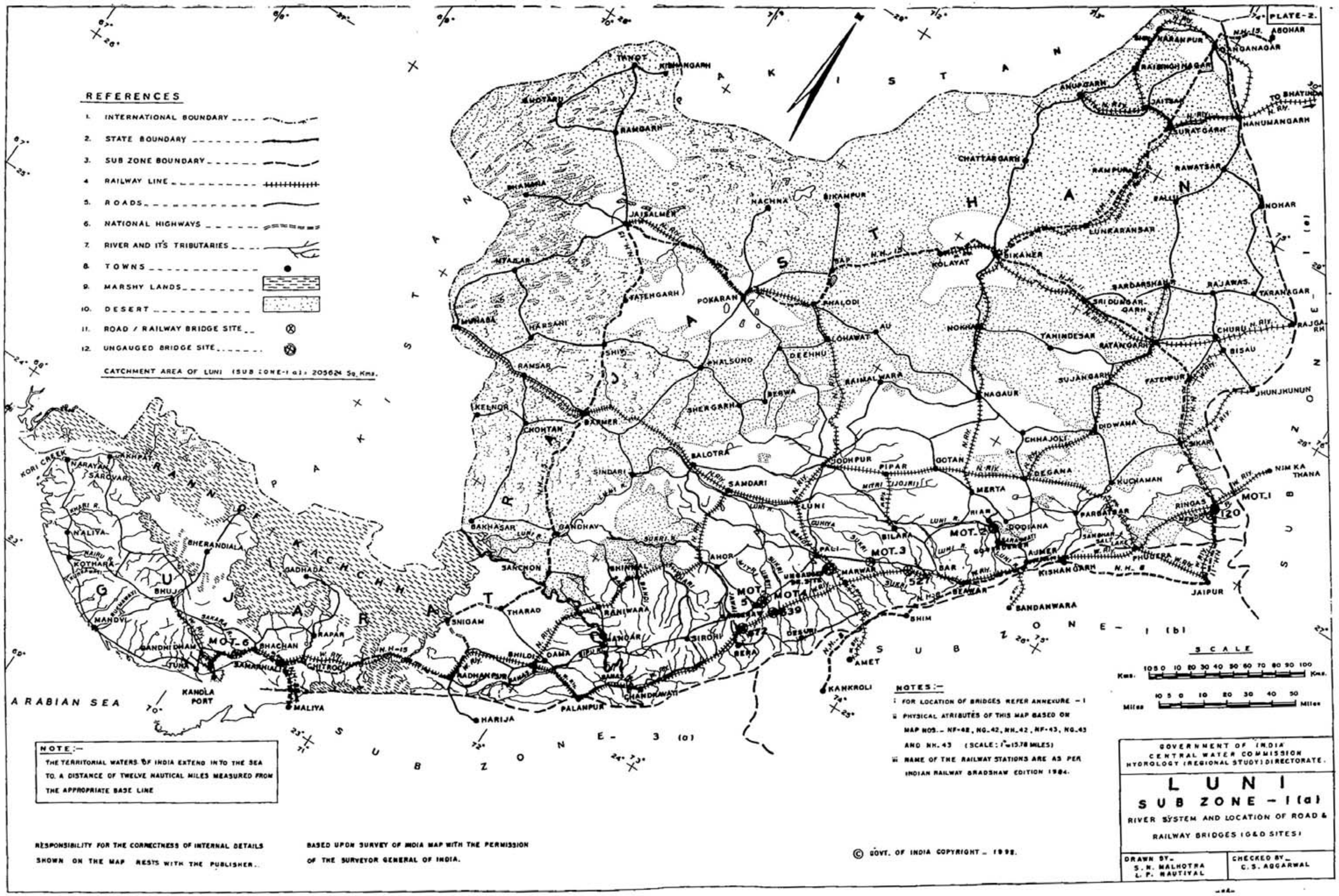


PLATE-2.
REFERENCES
1. INTERNATIONAL BOUNDARY
2. STATE BOUNDARY
3. SUB ZONE BOUNDARY
4. RAILWAY LINE
5. ROADS
6. NATIONAL HIGHWAYS
7. RIVER AND IT'S TRIBUTARIES
8. TOWNS
9. MARSHY LANDS
10. DESERT
11. ROAD / RAILWAY BRIDGE SITE
12. UNGAUGED BRIDGE SITE
CATCHMENT AREA OF LUNI (SUB ZONE-I (a)) : 205624 Sq. Kms.
PAKISTAN
RAJASTHAN
GUJARAT
RANN OF KACHCHH
ARABIAN SEA
SUB ZONE - I (b)
SUB ZONE - 3 (a)
MOT.1
MOT.2
MOT.3
MOT.4
MOT.5
MOT.6
SCALE
Kms. 10 5 0 10 20 30 40 50 60 70 80 90 100 Kms.
Miles 10 5 0 10 20 30 40 50 Miles
NOTES:-
i FOR LOCATION OF BRIDGES REFER ANNEXURE - I
ii PHYSICAL ATRIBUTES OF THIS MAP BASED ON MAP NOS.- NF-42, NG-42, NH-42, NF-43, NG-43 AND NH-43 (SCALE: 1"=15.78 MILES)
iii NAME OF THE RAILWAY STATIONS ARE AS PER INDIAN RAILWAY BRADSHAW EDITION 1984.
NOTE:-
THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS SHOWN ON THE MAP RESTS WITH THE PUBLISHER.
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GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDY) DIRECTORATE.
LUNI
SUB ZONE - I (a)
RIVER SYSTEM AND LOCATION OF ROAD & RAILWAY BRIDGES (G&D SITES)
DRAWN BY.- S. N. MALHOTRA L. P. NAUTIYAL
CHECKED BY.- C. S. AGGARWAL

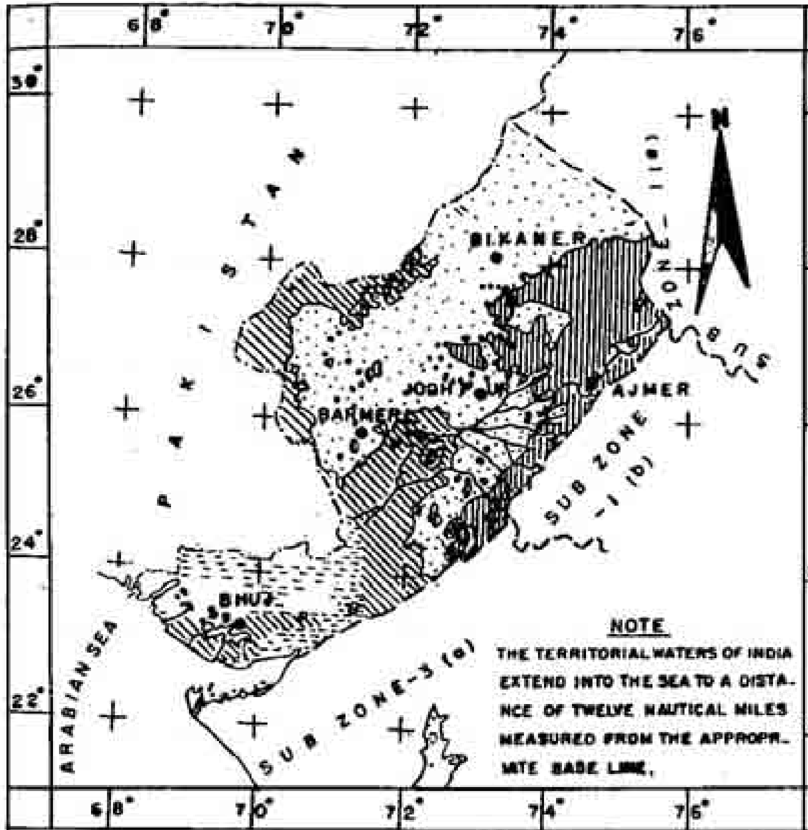


PLATE - 3.

LEGEND

ALTITUDE IN METERS SYMBOL

1. 0 — 150
2. 150 — 300
3. 300 — 600
4. 600 — 900

REFERENCES

1. INTERNATIONAL BOUNDARY
2. SUB ZONE BOUNDARY
3. RIVERS
4. TOWNS

SCALE

100 50 0 100 200 300 400
KMS. KMS.

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDY) DIRECT.

LUNI

SUB ZONE - 1(a)

PHYSIOGRAPHY

NOTE :—

THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1989 EDITION) PLATE_18.

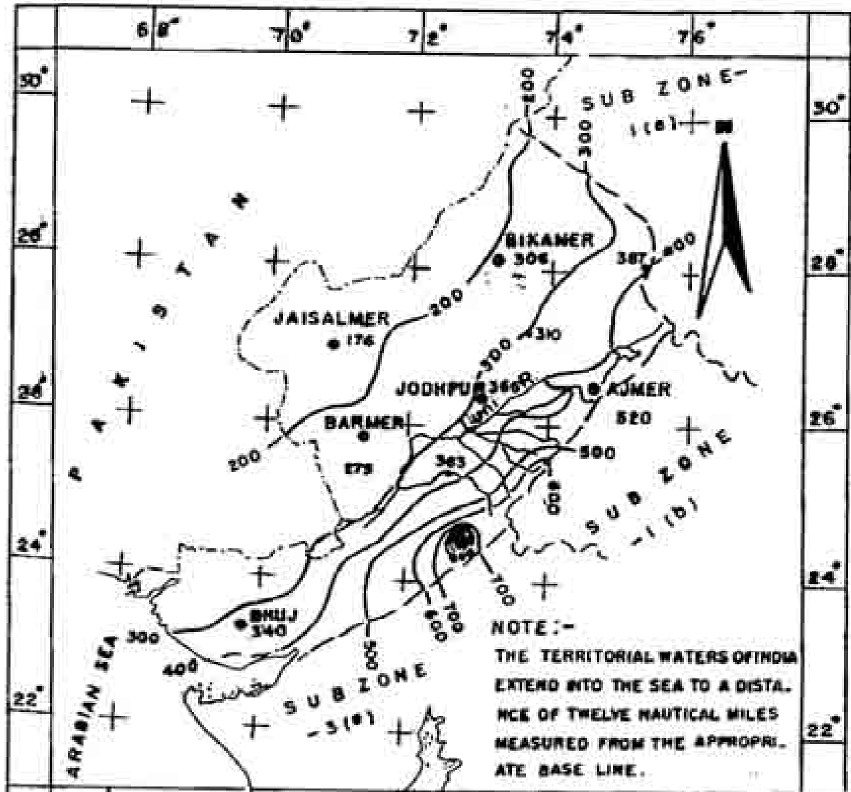
DRAWN — S. N. MALHOTRA, L. P. NAUTIYAL

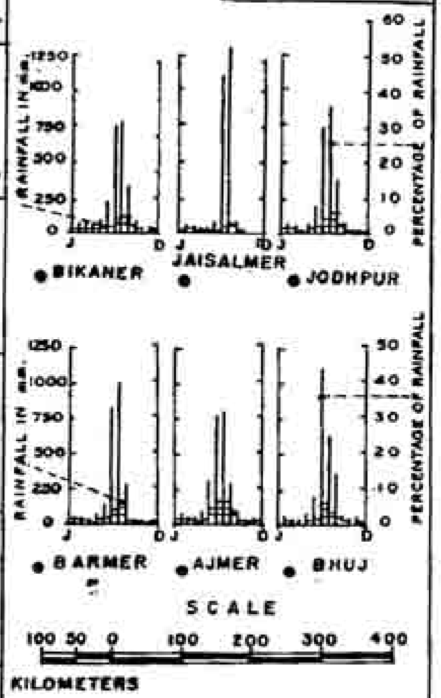
CHECKED — R. K. GUPTA

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

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

PLATE - 4.





NOTES -

1. HISTOGRAMS FOR SIX STATIONS WITH NAMES
2. EACH VERTICAL COLUMN REPRESENT THE MEAN MONTHLY RAINFALL FOR EACH MONTH (FROM JANUARY TO DECEMBER).
3. THE THICK VERTICAL LINES AT THE CENTRE OF EACH COLUMN INDICATES THE PERCENTAGE OF RAINFALL IN THE MONTH TO THE MEAN ANNUAL TOTAL.
4. THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1989) PLATE - 20.

REFERENCES

1. ISOHYETAL LINES WITH VALUE IN mm (NORMAL ANNUAL)
2. INTERNATIONAL BOUNDARY
3. SUB ZONE BOUNDARY
4. RIVERS.
5. TOWNS.
6. SPOT RAINFALL (mm).

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LUNI

SUB ZONE - 1(a)

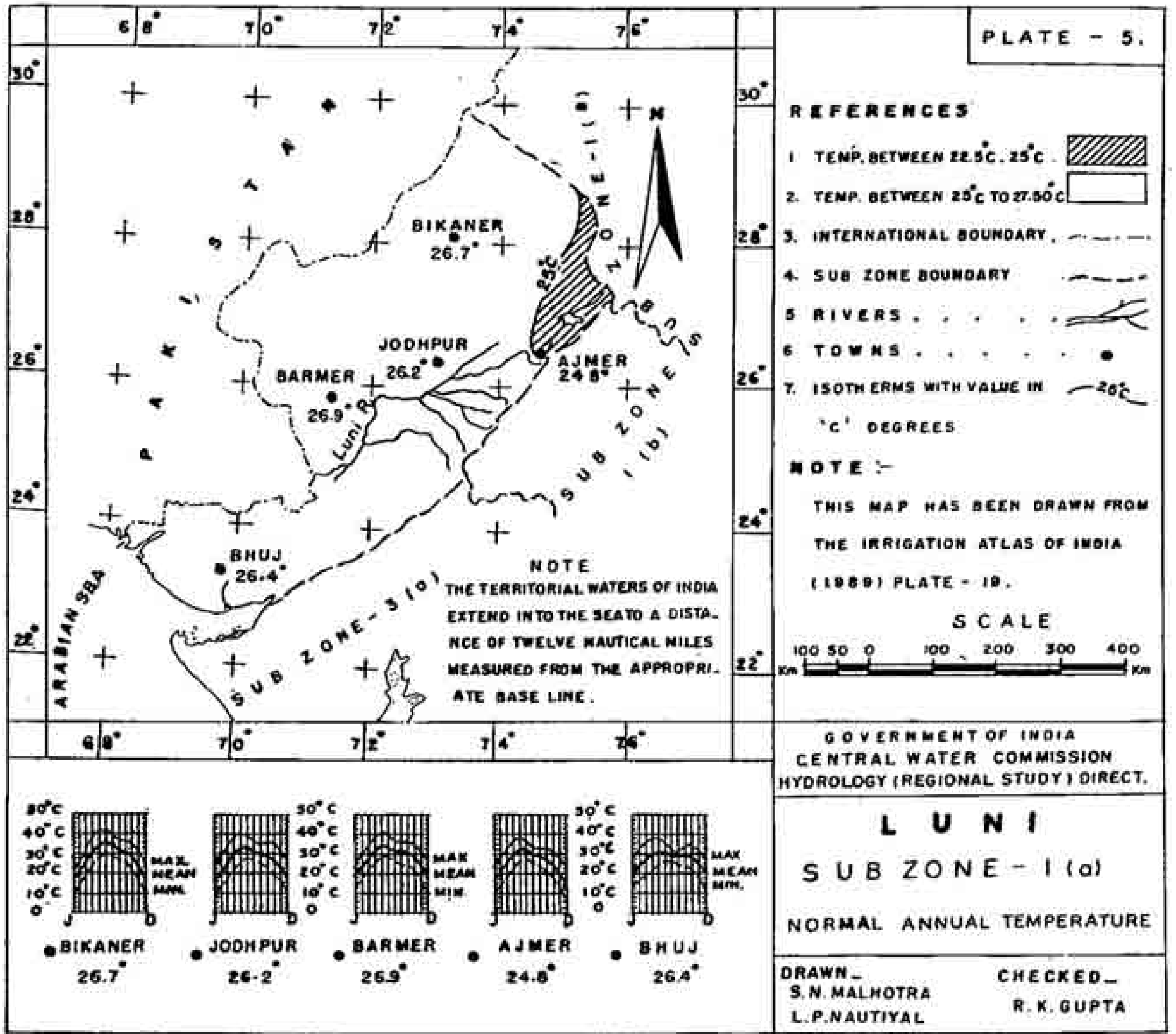
NORMAL ANNUAL RAINFALL

DRAWN_
S. N. MALHOTRA
L. P. NAUTIYAL

CHECKED_
R. K. GUPTA

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

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

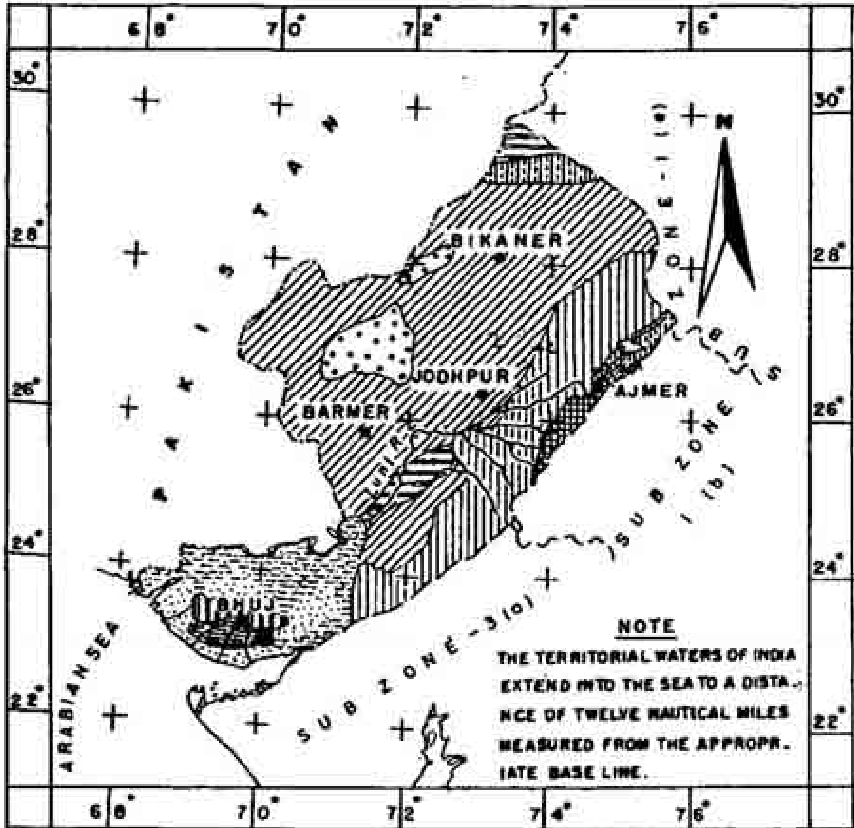


NOTES:-

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

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

PLATE - 6.



SOIL CLASSIFICATION UNIT

1. OLD ALLUVIAL SOILS . . .
2. RED SANDY SOIL . . . . .
3. RED AND YELLOW SOIL. .
4. DESERT SOIL (RHEGOSOLIC).
5. DESERT SOIL (LITHOSOLIC)
6. GRAY BROWN SOIL . . .
7. CALCAREOUS SIEROZEMIC - SOIL
8. DEEP BLACK SOIL . . . .
9. MEDIUM BLACK SOIL . . .
10. MIXED RED AND BLACK . . SOIL.
11. ALLUVIAL SOIL (RECENT) .
12. DELTAIC ALLUVIAL SOIL . . .

SCALE

100 50 0 100 200 300 400

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

L U N I

SUB ZONE - I (a)

SOIL CLASSIFICATION

DRAWN_	CHECKED_
S. N. MALHOTRA L. P. NAUTIYAL	C. S. AGGARWAL.

REFERENCES

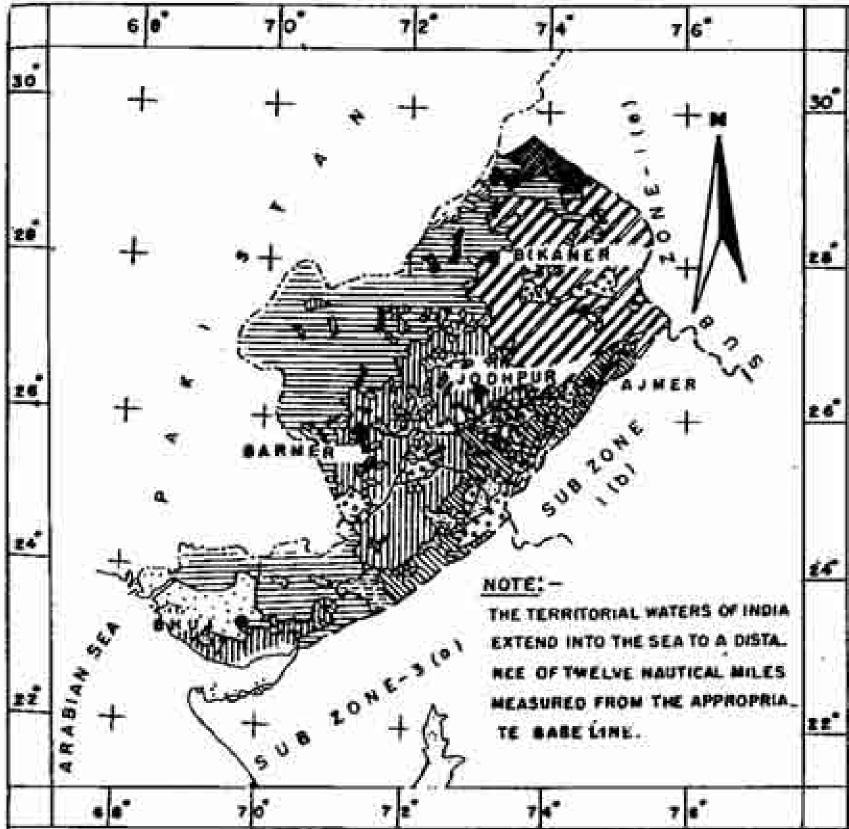
1. INTERNATIONAL BOUNDARY
2. SUB ZONE BOUNDARY . . .
3. RIVERS . . . . . .
4. TOWNS . . . .
5. MARSHY LAND . . .
6. SAMBHER LAKE . . . .

NOTE:- THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA. (1971) PLATE NO. - 8.

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

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

PLATE - 7.



REFERENCES

1. WASTE LAND
2. FOREST
3. SCRUB
4. WHEAT - PULSES
5. MILLETS - PULSES
6. MILLETS
7. WHEAT - MILLETS
8. RICE
9. MILLETS AND COTTON
10. INTERNATIONAL BOUNDARY
11. SUB ZONE BOUNDARY
12. RIVERS
13. TOWNS

SCALE

Km 100 50 0 100 200 300 400 Km

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDY) DIREC.

LUNI

SUB ZONE - I (a)

LAND USE

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

NOTE -

THIS MAP HAS BEEN DRAWN FROM THE IRRIGATION ATLAS OF INDIA (1989 EDITION). PLATE NO. 23.

NOTES

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

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

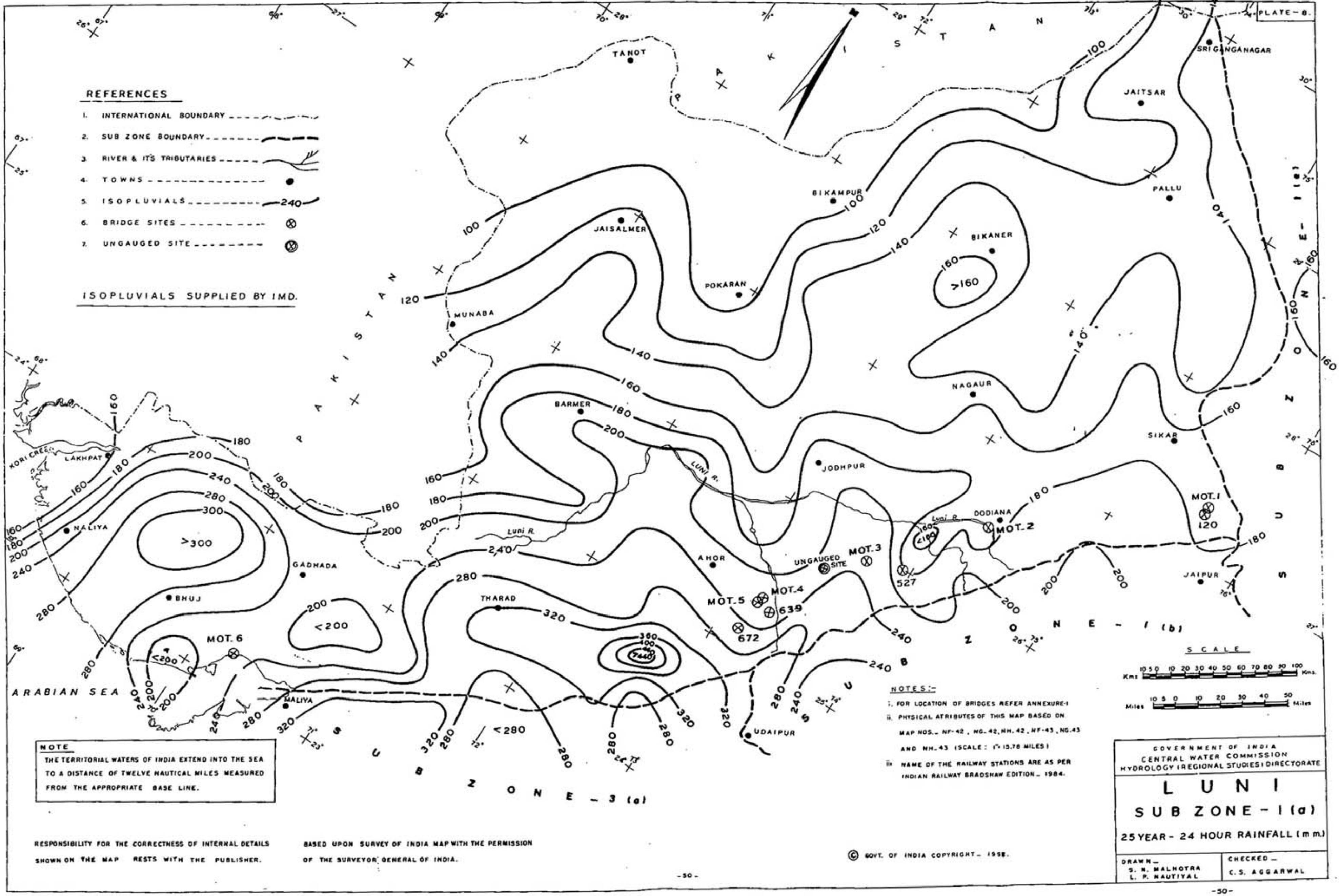


PLATE - 8.
REFERENCES
1. INTERNATIONAL BOUNDARY
2. SUB ZONE BOUNDARY
3. RIVER & ITS TRIBUTARIES
4. TOWNS
5. ISOPLUVIALS
6. BRIDGE SITES
7. UNGAUGED SITE
ISOPLUVIALS SUPPLIED BY IMD.
PAKISTAN
SRI GANGANAGAR
JAITSAR
PALLU
TANOT
JAISALMER
BIKAMPUR
POKARAN
BIKANER
>160
MUNABA
NAGAUR
BARMER
SIKAR
JODHPUR
Luni R.
DODIANA
MOT.1
MOT.2
MOT.3
MOT.4
MOT.5
MOT.6
UNGAUGED SITE
527
639
672
AHOR
JAIPUR
THARAD
UDAIPUR
LAKHPAT
KORI CREEK
NALIYA
BHUJ
GADHADA
MALIYA
>300
<200
<280
ARABIAN SEA
SUB ZONE - 1 (b)
SUB ZONE - 3 (a)
NOTE
THE TERRITORIAL WATERS OF INDIA EXTEND INTO THE SEA TO A DISTANCE OF TWELVE NAUTICAL MILES MEASURED FROM THE APPROPRIATE BASE LINE.
RESPONSIBILITY FOR THE CORRECTNESS OF INTERNAL DETAILS SHOWN ON THE MAP RESTS WITH THE PUBLISHER.
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NOTES:-
i. FOR LOCATION OF BRIDGES REFER ANNEXURE-I
ii. PHYSICAL ATRIBUTES OF THIS MAP BASED ON MAP NOS. - NF-42, NG-42, NH-42, NF-43, NG-43 AND NH-43 (SCALE: 1"=15.78 MILES)
iii. NAME OF THE RAILWAY STATIONS ARE AS PER INDIAN RAILWAY BRADSHAW EDITION - 1984.
SCALE
Kms
Miles
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DIRECTORATE
LUNI
SUB ZONE - 1 (a)
25 YEAR - 24 HOUR RAINFALL (mm)
DRAWN -
S. K. MALHOTRA
L. P. NAUTIYAL
CHECKED -
C. S. AGGARWAL
-50-

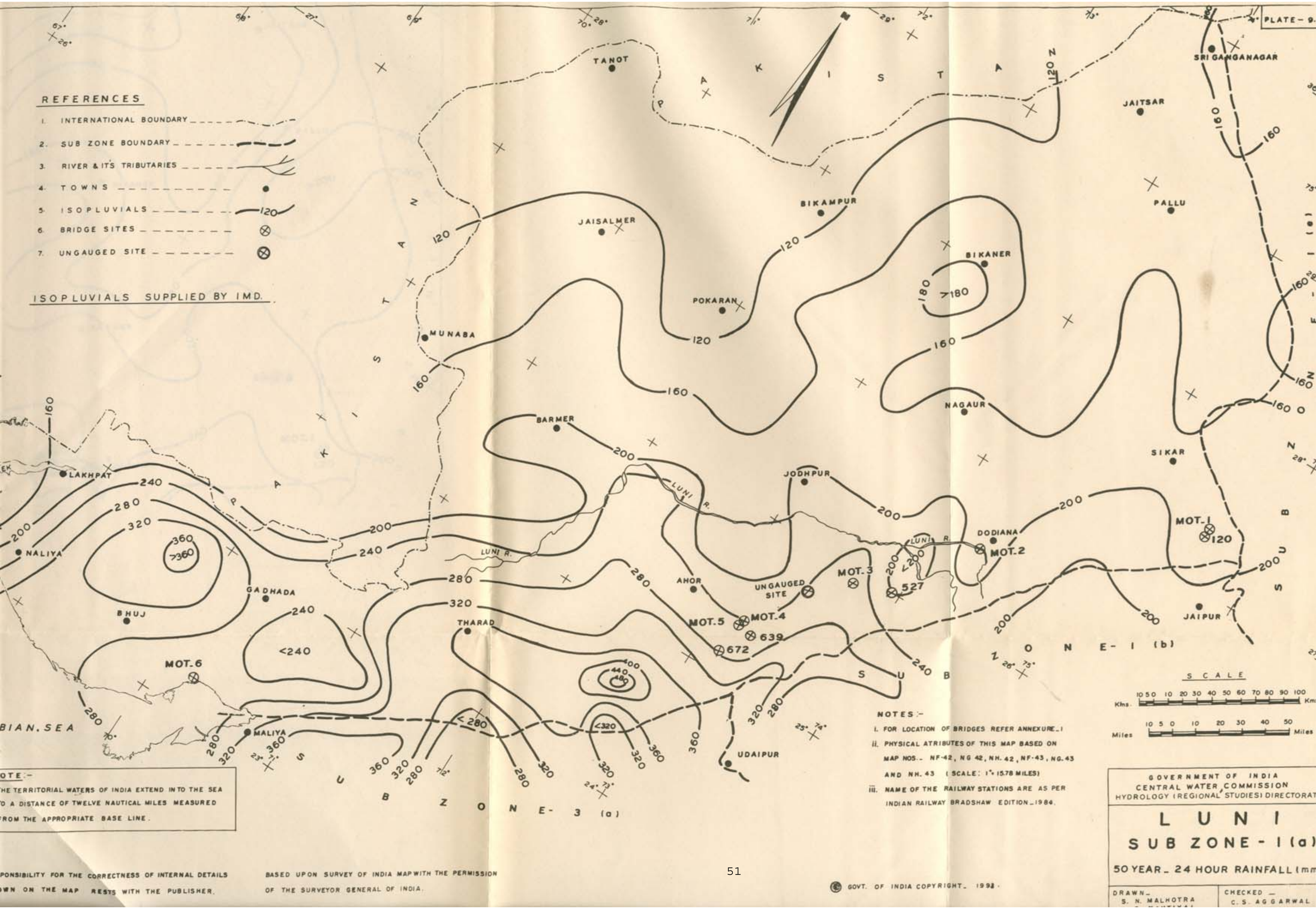
PLATE - 9.
REFERENCES
1. INTERNATIONAL BOUNDARY
2. SUB ZONE BOUNDARY
3. RIVER & IT'S TRIBUTARIES
4. TOWNS
5. ISOPLUVIALS
6. BRIDGE SITES
7. UNGAUGED SITE
ISOPLUVIALS SUPPLIED BY IMD.
PAKISTAN
SRI GANGANAGAR
JAITSAR
PALLU
TANOT
BIKAMPUR
JAISALMER
BIKANER
POKARAN
MUNABA
NAGAUR
SIKAR
BARMER
JODHPUR
LUNI R.
DODIANA
MOT.1
MOT.2
MOT.3
MOT.4
MOT.5
MOT.6
UNGAUGED SITE
527
639
672
AHOR
THARAD
JAIPUR
UDAIPUR
LAKHPAT
NALIYA
BHUJ
GADHADA
MALIYA
ARABIAN SEA
SUB ZONE - 1 (b)
SUB ZONE - 3 (a)
SCALE
Kms.
Miles
NOTES:-
i. FOR LOCATION OF BRIDGES REFER ANNEXURE_I
ii. PHYSICAL ATRIBUTES OF THIS MAP BASED ON MAP NOS.- NF-42, NG 42, NH. 42, NF-43, NG. 43 AND NH. 43 (SCALE: 1"= 15.78 MILES)
iii. NAME OF THE RAILWAY STATIONS ARE AS PER INDIAN RAILWAY BRADSHAW EDITION_1984.
NOTE:-
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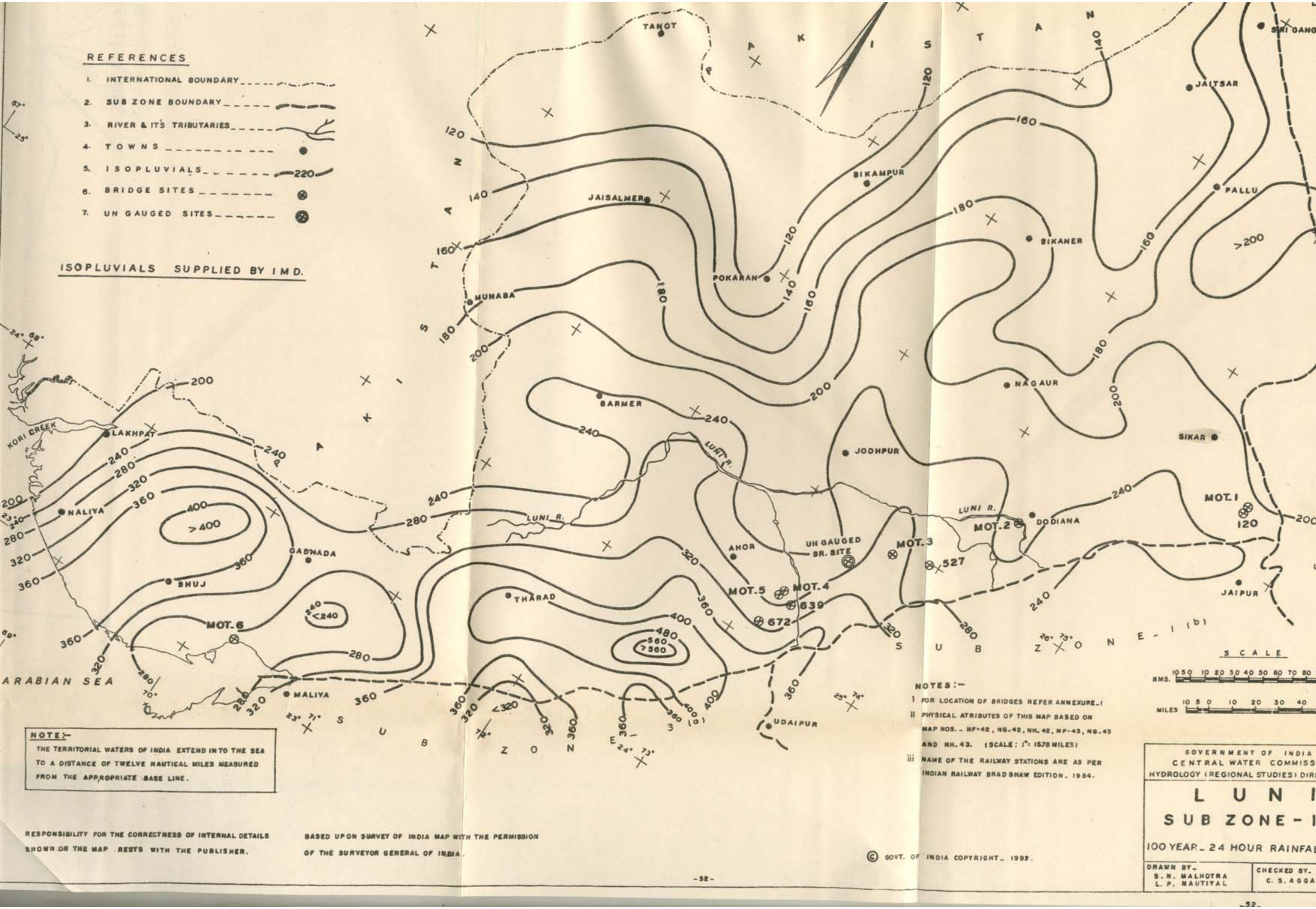
HYDROLOGY (REGIONAL STUDIES) DIRECTORATE
LUNI
SUB ZONE - I (a)
50 YEAR_ 24 HOUR RAINFALL (mm)
DRAWN_ S. N. MALHOTRA
CHECKED _ C. S. AGGARWAL



REFERENCES

1. INTERNATIONAL BOUNDARY
2. SUB ZONE BOUNDARY
3. RIVER & IT'S TRIBUTARIES
4. TOWNS
5. ISOPLUVIALS (220)
6. BRIDGE SITES
7. UN GAUGED SITES

ISOPLUVIALS SUPPLIED BY IMD.

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

NOTES:-
i FOR LOCATION OF BRIDGES REFER ANNEXURE-I
ii PHYSICAL ATRIBUTES OF THIS MAP BASED ON MAP NOS. - NF-42, NG-42, NH-42, NF-43, NG-43 AND NH-43. (SCALE: 1" = 15.78 MILES)
iii NAME OF THE RAILWAY STATIONS ARE AS PER INDIAN RAILWAY BRADSHAW EDITION. 1984.

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

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

GOVERNMENT OF INDIA
CENTRAL WATER COMMISS
HYDROLOGY (REGIONAL STUDIES) DIR

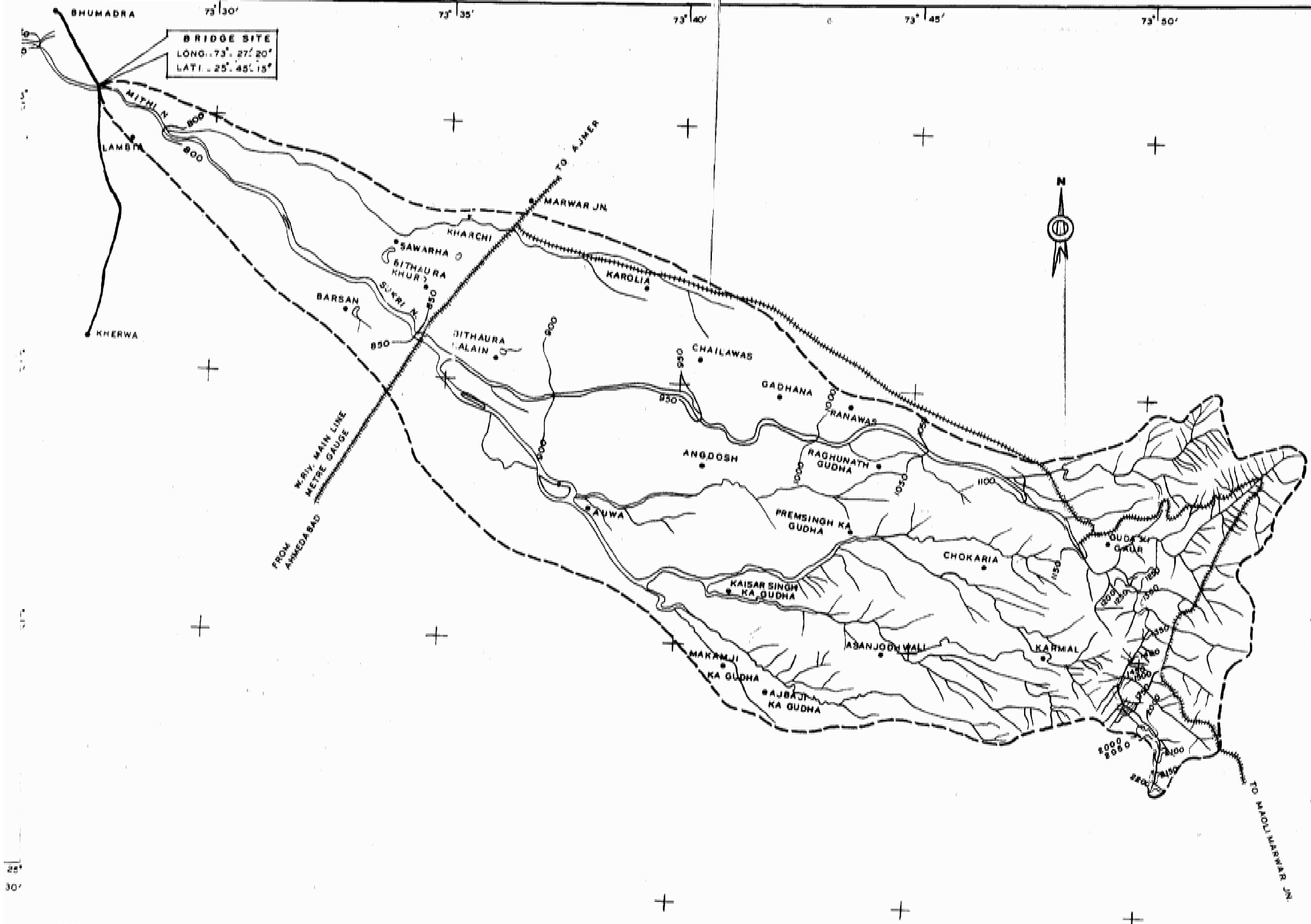
LUNI

SUB ZONE - I

100 YEAR - 24 HOUR RAINFAL

DRAWN BY - S. N. MALHOTRA, L. P. NAUTIYAL | CHECKED BY - C. S. AGGA

FIG. A-1



NOTES :-

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

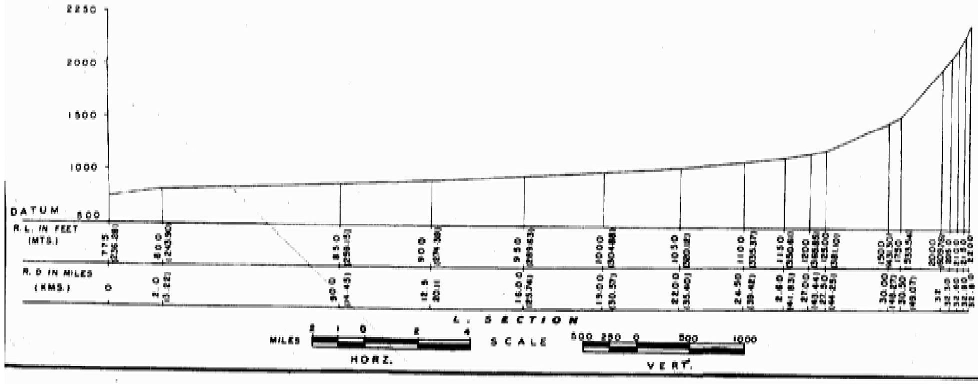
REFERENCES

1. CATCHMENT AREA
2. RAILWAY LINE
3. RIVERS AND IT'S TRIBUTARIES
4. ROADS
5. CONTOURS
6. TOPO SHEET NO. . . . . . 45 G/5,6,10 & 14

DETAIL OF CATCHMENT AREA

1. AREA OF CATCHMENT . . . . . 414.00 Km²
2. SHAPE OF CATCHMENT . . . . FAN
3. L . . . . 52.8 Kms.
4. Lc . . . . 28.0 Kms.
5. SLOPE (EQU) . . . . . . 3.43 Mt./Km

SCALE
MILES 1.0 0.5 0 1 2 3



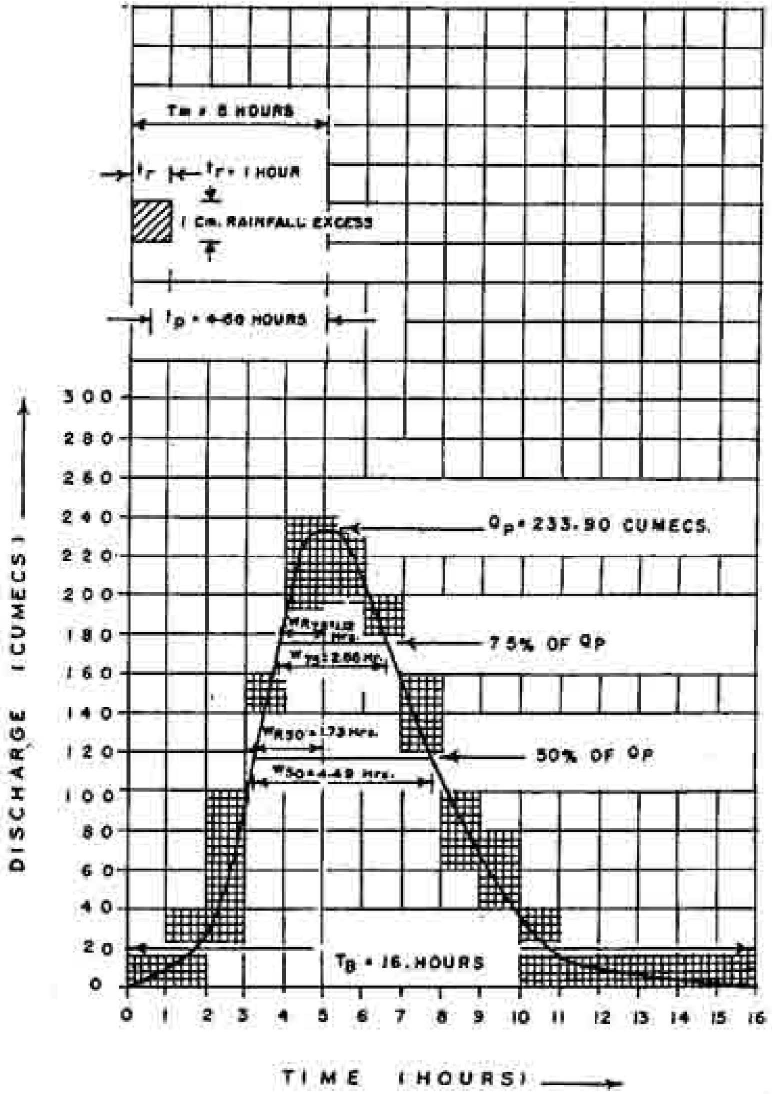
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (R.S) DIRECTORATE

CATCHMENT AREA PLAN OF UNGAUGED SITE ON RIVER MITHI ON KHERWA - BHUMADRA ROAD SEC.

SUB ZONE - 1 (a).

DRAWN BY - S.S. JHAS. L.P. NAUTIYAL.	CHECKED BY - R.K. GUPTA.

FIG. — A. 2.



SYNTHETIC U.G. PARAMETERS

1	C. AREA	=	414.00 Sq. Km.
2	t_r	=	1.00 HOUR
3	Q_p	=	233.90 CUMECS
4	q_p	=	0.565
5	t_p	=	4.50 HOURS
6	T_m	=	5.00 HOURS
7	T_B	=	16.00 HOURS
8	W_{50}	=	4.49 HOURS
9	W_{75}	=	2.66 HOURS
10	WR_{50}	=	1.73 HOURS
11	WR_{75}	=	1.12 HOURS
12	d	=	1.00 Cm.

$$\Sigma Q_i = \frac{A \times d}{t_r \times 0.36} = \frac{414 \times 1.00}{1.00 \times 0.36} = 1150.00 \text{ CUMECS}$$

1. HOUR SYNTHETIC U.G. ORDINATES

0	0
1	8.00
2	24.00
3	95.60
4	186.00
5	233.90
6	204.00
7	154.00
8	106.00
9	67.00
10	35.00
11	17.00
12	9.50
13	5.00
14	3.00
15	2.00
16	0
TOTAL	1150.00 CUMECS

GOVERNMENT OF INDIA
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HYDROLOGY (REGIONAL STUDIES) DTE.

LUNI

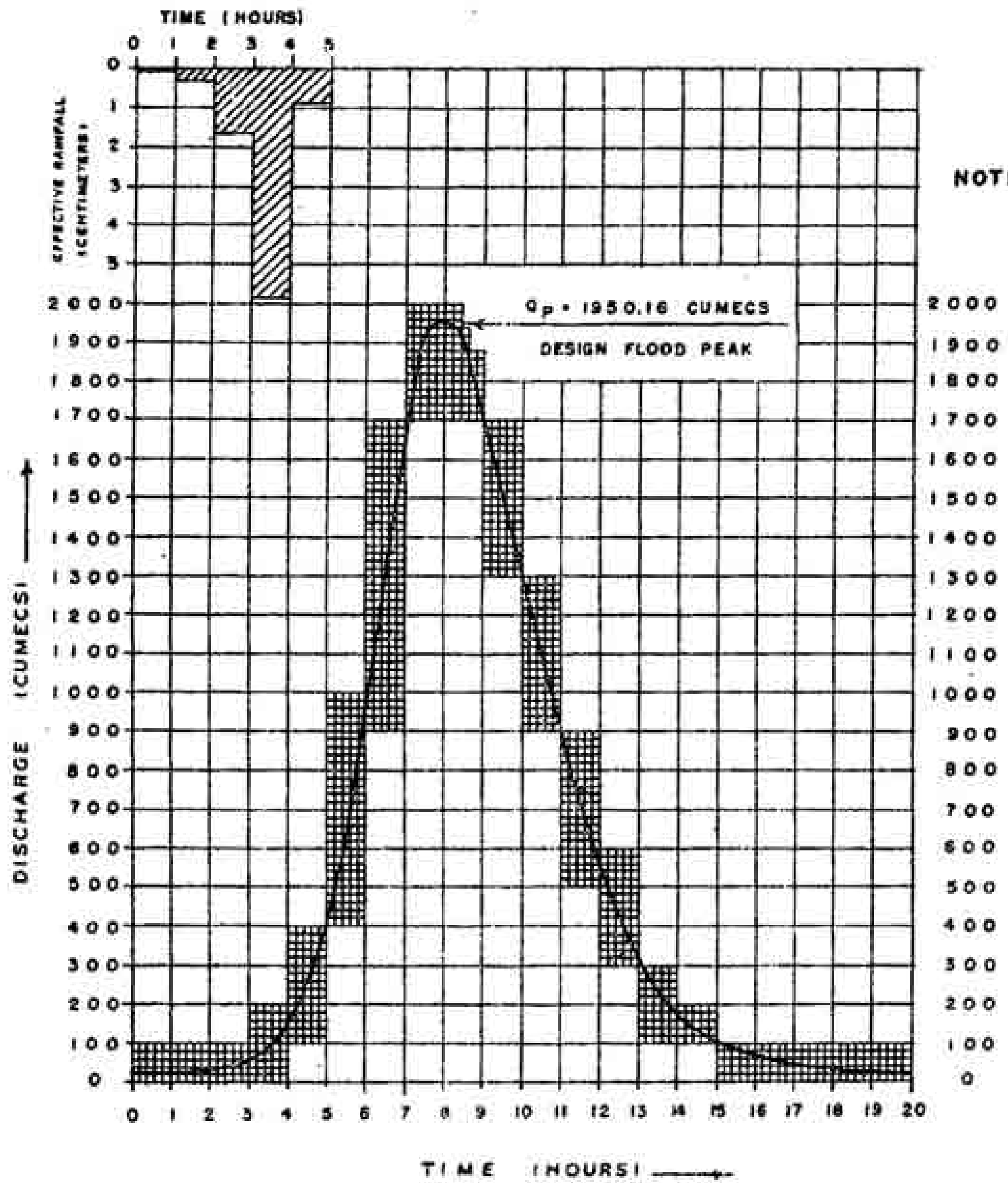
SUB ZONE - I (a)

SYNTHETIC UNIT HYDROGRAPH OF UNGAUGED CATCHMENT

DRAWN — S. N. MALHOTRA, L. P. NAUTIYAL

CHECKED — C. S. AGGARWAL

FIG. A – 3.



NOTE :– REFER ANNEXURE_1.2 FOR COMPUTATION OF DESIGN FLOOD PEAK.

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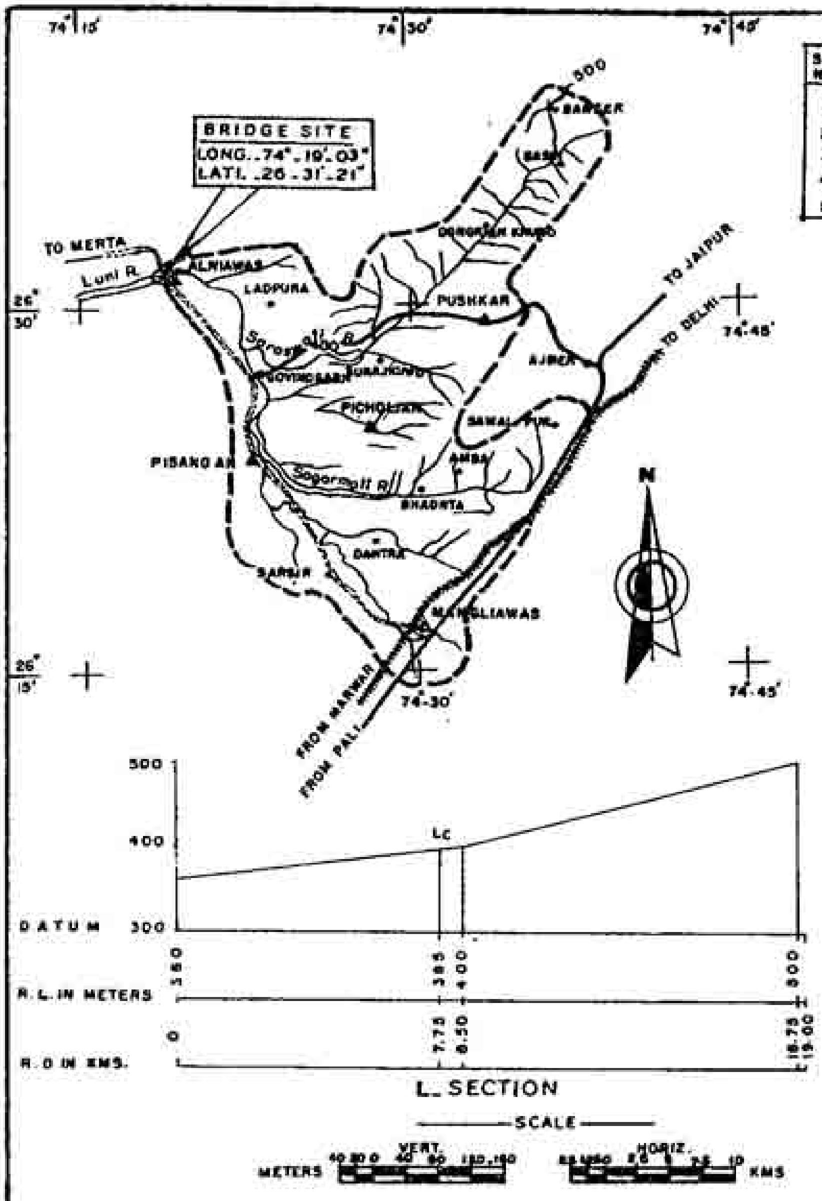
LUNI
SUB ZONE – 1 (a)
DESIGN FLOOD HYDROGRAPH
OF UNGAUGED CATCHMENT

DRAWN – S. N. MALHOTRA	CHECKED – C. S. AGGARWAL

FIG. A.4.1

SL. NO.	NAME OF R. G. STATION	LOCATION LONG.	LOCATION LATI.	WEIGHTAGE 1981 - '85
1.	ALNIAWAS	74°-19'-08"	[illegible]	0.092
2.	PISANGAN	74°-22'-45"	26°-23'-15"	0.132
3.	PICHOLIAN	74°-25'-06"	[illegible]	0.322
4.	PUSHKAR	74°-33'-40"	26°-29'-06"	0.278
5.	MANGLIAWAS	74°-30'-00"	[illegible]	0.176



L_SECTION

SCALE
VERT. METERS 40 20 0 40 80 120 160
HORIZ. 2.5 1.25 0 2.5 5 7.5 10 KMS

LEGEND

1. RIVER & ITS TRIBUTARIES
2. CATCHMENT BOUNDARY
3. RAINGAUGE STATIONS
4. CONTOURS
5. ROAD
6. IMPORTANT TOWNS
7. TOPO SHEET NO. . . . 45 J.
8. G & D SITE

DETAIL OF CATCHMENT

1. CATCHMENT AREA . . . 682.0 Sq. Km.
2. SHAPE OF CATCHMENT . . FAN
3. LENGTH OF MAIN RIVER . . 19.00 Kms.
4. BASIN LENGTH . . . 15.00 Kms.
5. LC . . . . . . 7.75 Kms.
6. Seq . . . . . . 6.18 M/Km.

SCALE - 1 Cm. = 2.5 Km.
KMS. 2.5 1.25 0 2.5 5 7.5 10 12.5 15 17.5

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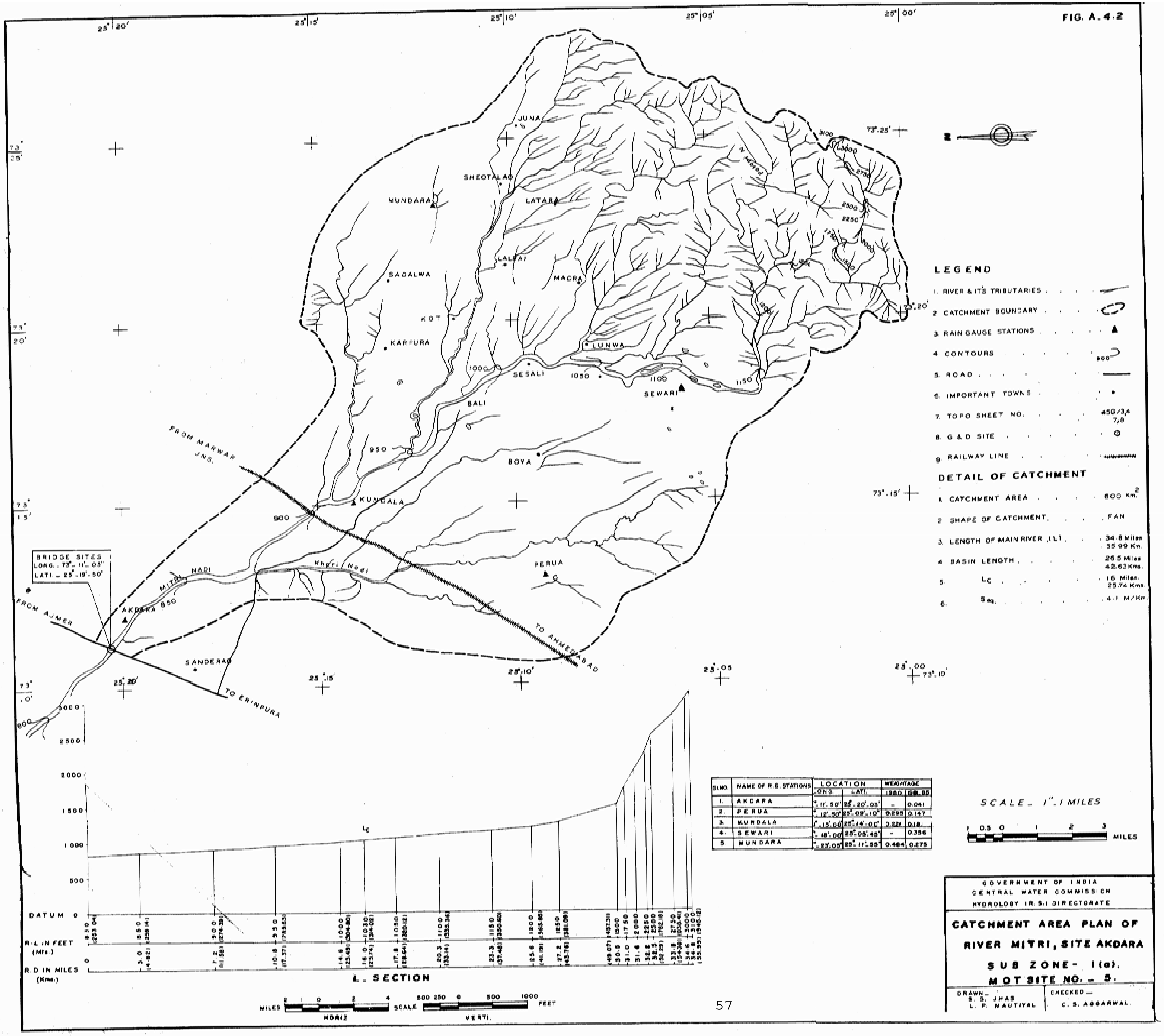
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DIRECTORATE

CATCHMENT AREA PLAN OF RIVER LUNI, SITE ALNIAWAS
MOT SITE. NO. _ 2
SUB ZONE - 1 (a)

DRAWN BY - SANTOKH SINGH, L. P. NAUTIYAL.
CHECKED BY - C. S. AGGARWAL

FIG. A.4.2



Sl.NO.	NAME OF R.G. STATIONS	LOCATION		WEIGHTAGE	
		LONG.	LATI.	1980	19[illegible]-85
1.	AKDARA	°-11'-50'	25°-20'-03"	-	0.041
2.	PERUA	°-12'-50"	25°-09'-10"	0.295	0.147
3.	KUNDALA	°-15'-00'	25°-14'-00'	0.221	0.181
4.	SEWARI	°-18'-00'	25°-05'-45"	-	0.356
5.	MUNDARA	°-23'-05"	25°-11'-55"	0.484	0.275

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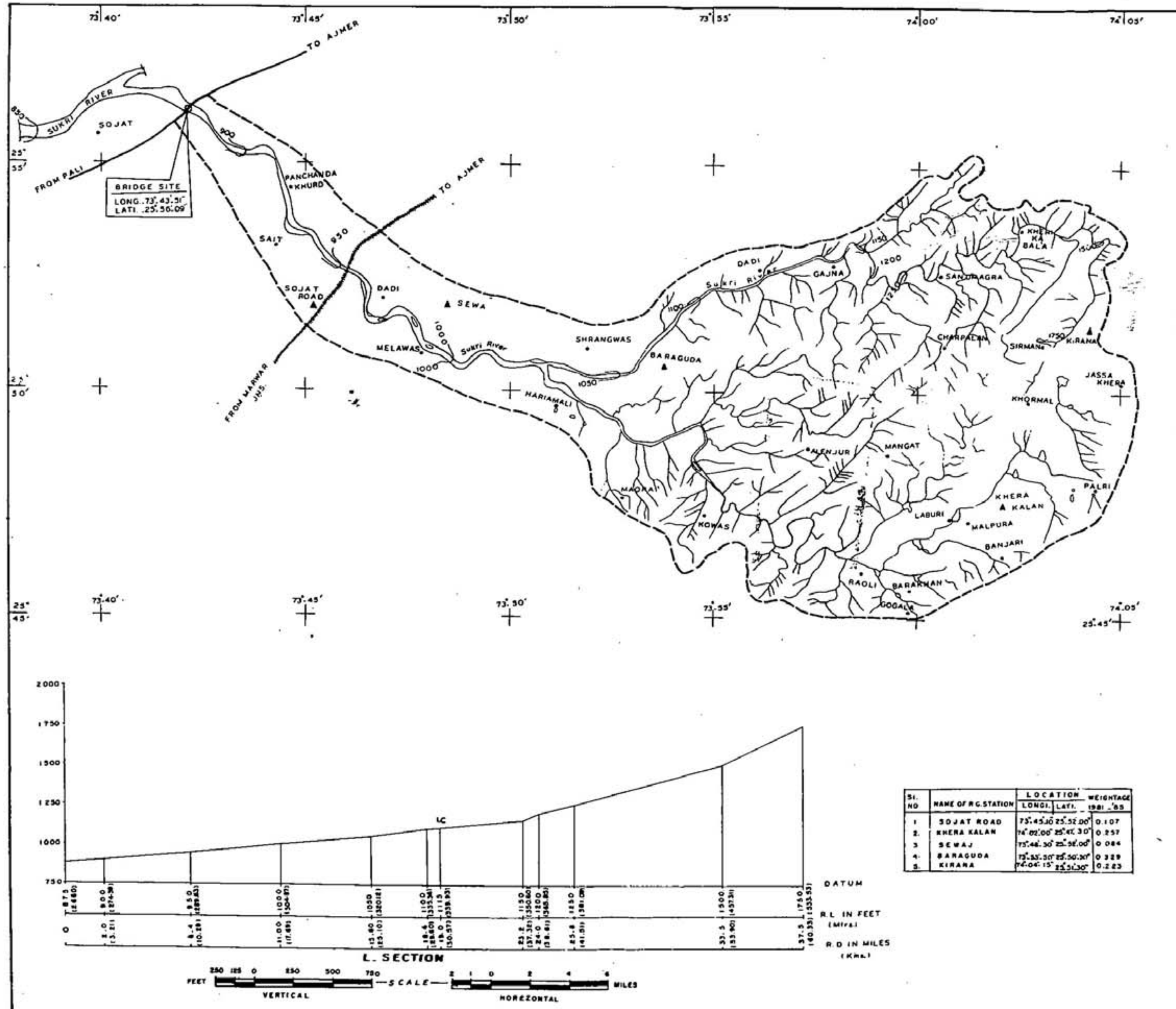
CATCHMENT AREA PLAN OF RIVER MITRI, SITE AKDARA
SUB ZONE - 1(a).
MOT SITE NO. - 5.

DRAWN - S. S. JHAS, L. P. NAUTIYAL | CHECKED - C. S. AGGARWAL.

FIG. A.4.3



SI. NO	NAME OF R.G. STATION	LOCATION LONGI.	LATI.	WEIGHTAGE 1981-'85
1	SOJAT ROAD	73°.45'.30"	25°.52'.00"	0.107
2.	KHERA KALAN	74°.02'.00"	25°.47'.30"	0.257
3	SEWAJ	73°.46'.30"	25°.56'.00"	0.084
4.	BARAGUDA	73°.55'.30"	25°.50'.30"	0.329
5.	KIRANA	74°.04'.15"	25°.51'.30"	0.223

LEGEND

1. RIVER & ITS TRIBUTARIES
2. CATCHMENT BOUNDARY
3. RAIN GAUGE STATION
4. CONTOUR
5. ROAD
6. IMPORTANT TOWN
7. TOPO SHEET NO — 45G/9,13 45K/1
8. GAUGE AND DISCHARGE SITE
9. RAILWAY LINE

DETAIL OF CATCHMENT

1. CATCHMENT AREA — 380.00 Km²
2. SHAPE OF CATCHMENT — FAN
3. LENGTH OF MAIN RIVER — 37.50 Miles, 60.33 Kms
4. LC — 19.0 Miles, 30.57 Kms
5. S_{eq} — 2.96 M/Km.

SCALE 1" = 1 Miles

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

CATCHMENT AREA PLAN OF RIVER-SUKRI, SITE-SOJAT

SUB ZONE-1 (a). MOT SITE NO. 3.

DRAWN — SANTOSH SINGH JHAS, L. P. NAUTIYAL
CHECKED — C. S. AGGARWAL

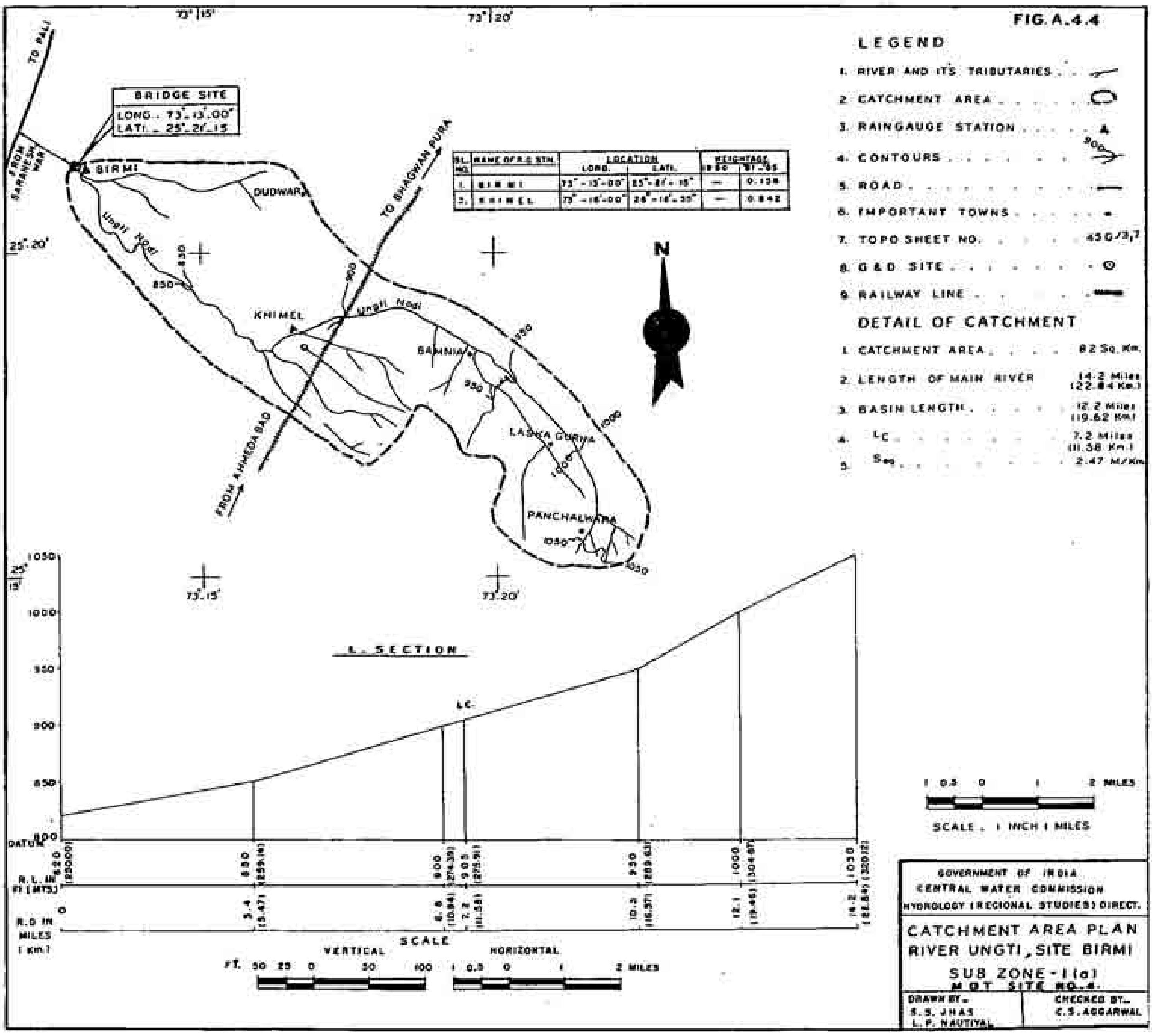
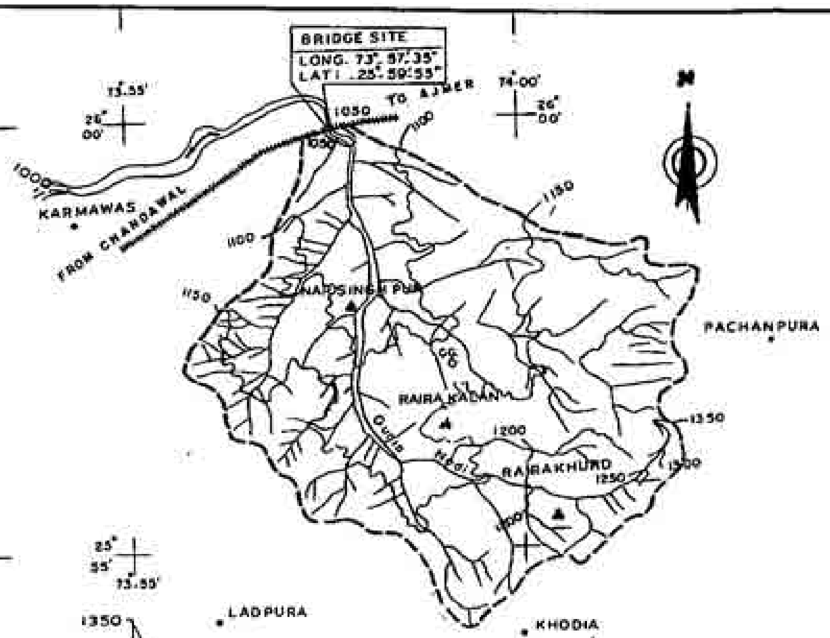


FIG. A.4.4
LEGEND
1. RIVER AND IT'S TRIBUTARIES
2. CATCHMENT AREA
3. RAINGAUGE STATION
4. CONTOURS
5. ROAD
6. IMPORTANT TOWNS
7. TOPO SHEET NO.
8. G & D SITE
9. RAILWAY LINE
DETAIL OF CATCHMENT
1. CATCHMENT AREA 82 Sq. Km.
2. LENGTH OF MAIN RIVER 14.2 Miles (22.84 Km.)
3. BASIN LENGTH 12.2 Miles (19.62 Km)
4. Lc 7.2 Miles (11.58 Km.)
5. Seq 2.47 M/Km.
BRIDGE SITE
LONG. 73°-13'-00"
LATI. 25°-21'-15
TO PALI
FROM SARANESHWAR
BIRMI
DUDWARA
TO BHAGWAN PURA
FROM AHMEDABAD
KHIMEL
BAMNIA
LASKA GURHA
PANCHALWARA
Ungti Nadi
LOCATION
LONG.
LATI.
WEIGHTAGE
0.158
0.842
N
L. SECTION
LC
DATUM
R.L. IN FT (MTS)
R.D IN MILES (Km)
SCALE
VERTICAL
HORIZONTAL
SCALE 1 INCH 1 MILES
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DIRECT.
CATCHMENT AREA PLAN
RIVER UNGTI, SITE BIRMI
SUB ZONE - 1 (a)
MOT SITE NO. 4.
DRAWN BY
S. S. JHAS
L. P. NAUTIYAL
CHECKED BY
C. S. AGGARWAL

FIG. A.45



NOTE

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

REFERENCES

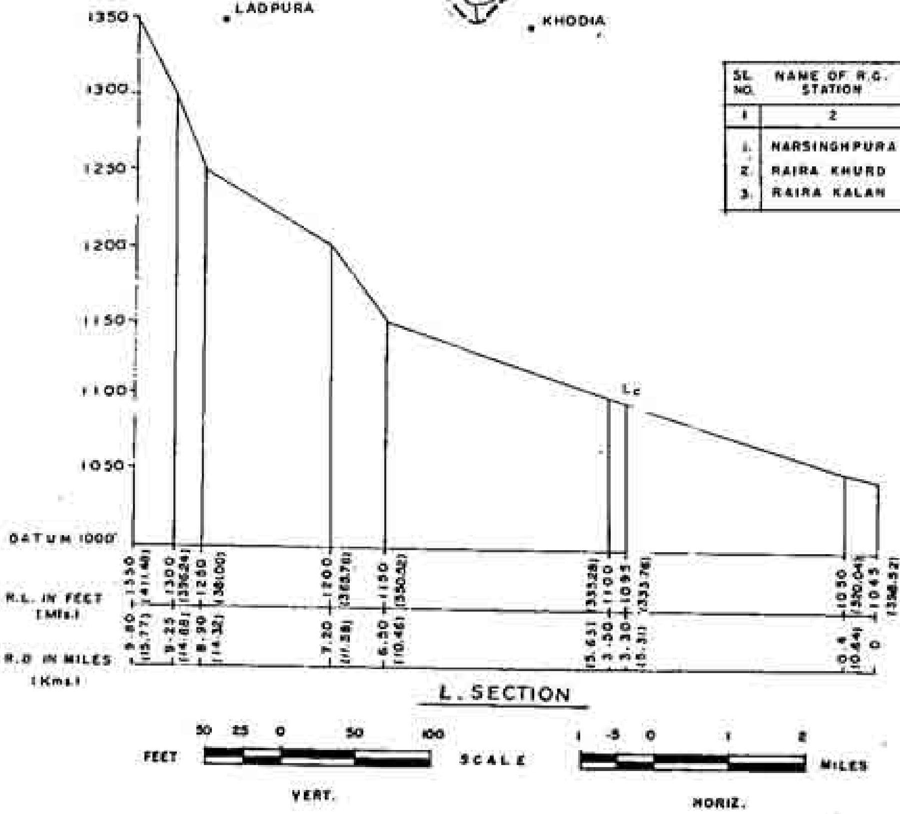
1. CATCHMENT BOUNDARY
2. RAILWAY LINE
3. RIVER AND TRIBUTARIES
4. RAINGAUGE STATIONS
5. CONTOUR
6. TOPO SHEET NO. . . . 45G/13, 45K/1.

DETAIL OF CATCHMENT

1. CATCHMENT AREA . . . 77.50 Sq. Km.
2. LENGTH OF MAIN RIVER . . . 15.78 Km.
3. L_c . . . 5.31 Km.
4. W_c . . . 7.41 Km.
5. S_{eq} . . . 3.80 M/Km.
6. SHAPE OF CATCHMENT . . . FAN

SL. NO.	NAME OF R.G. STATION	LONG	LATI.	STATION WEIGHTAGE 1962, 64	1965	1966
1	2	3	4	5	6	7
1.	NARSINGHPURA	73°.57'.50"	25°.57'.50"	0.578	0.400	–
2.	RAIRA KHURD	74°-25'.00"	25°.55'.20"	0.422	–	–
3.	RAIRA KALAN	73°.59'.00"	25°.56.30"	–	0.600	1.000

SCALE
MILES 1 0.5 0 1 2

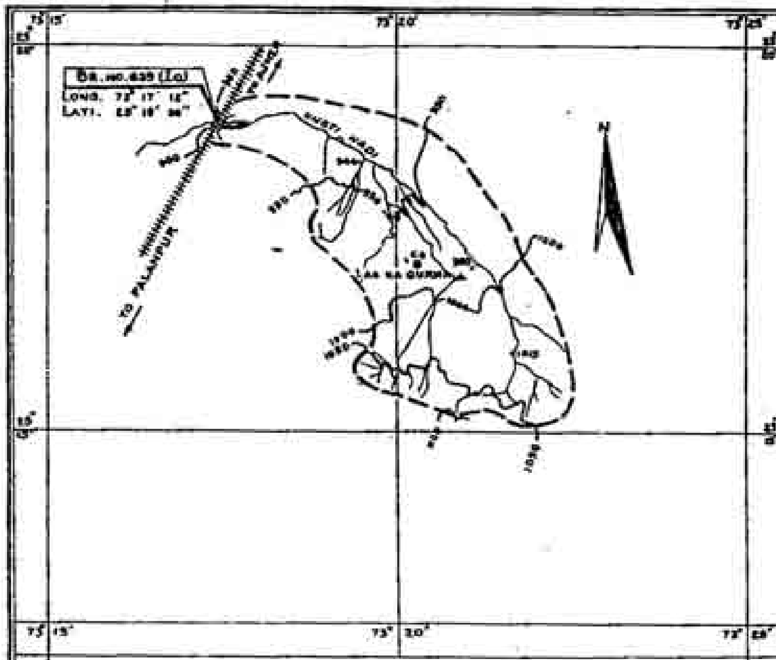


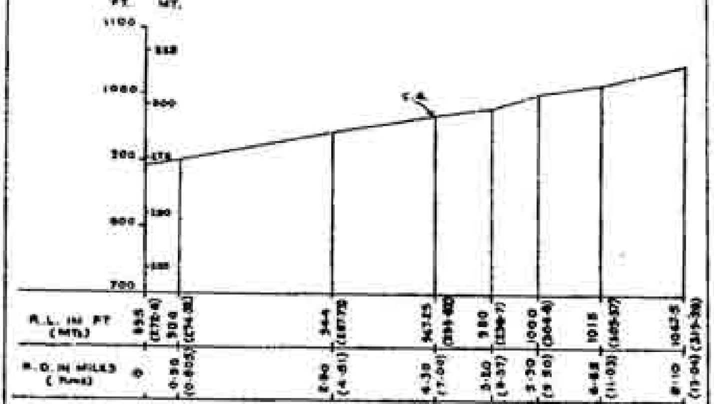
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

CATCHMENT AREA PLAN OF BR. NO. 527 (9 KESABI) AT MILE 292/8.9 AT AJMER - PALANPUR SECTION AJMER DIVISION. WESTERN RAILWAY
SUB ZONE - 1(a)

DRAWN	CHECKED
S.S. JHAS L.P. NAUTIYAL	C.S. AGGARWAL

FIG. A-4-8





L- SECTION OF UNGTI NADI

SCALE

NOTE

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

REFERENCES

1. CATCHMENT BOUNDARY
2. RAILWAY LINE
3. RIVER & ITS TRIBUTARIES
4. RAINGAUGE STATIONS
5. SPOT LEVEL ·250
6. CENTRE OF GRAVITY ·C.G.
7. TOPO SHEET (1" = 1 MILE) NO. 45 G/7 (1934 EDITION)

DETAILS OF CATCHMENT AREA

1. CATCHMENT AREA .... 33.23 SQ. Kms.
2. SHAPE OF THE CATCHMENT AREA .... FAN
3. L .... 13.04 Kms
4. L_C .... 7.00 "
5. W_C .... 3.80 "
6. S_{eq} .... 5.28 M/Km

S NO.	NAME OF R.G. STATION	LOCATION		STATION WTS.
		LONG	LATI.	1SCE
1.	LAS KA GURHA	73° 20' 37"	25° 17' 00"	1.00

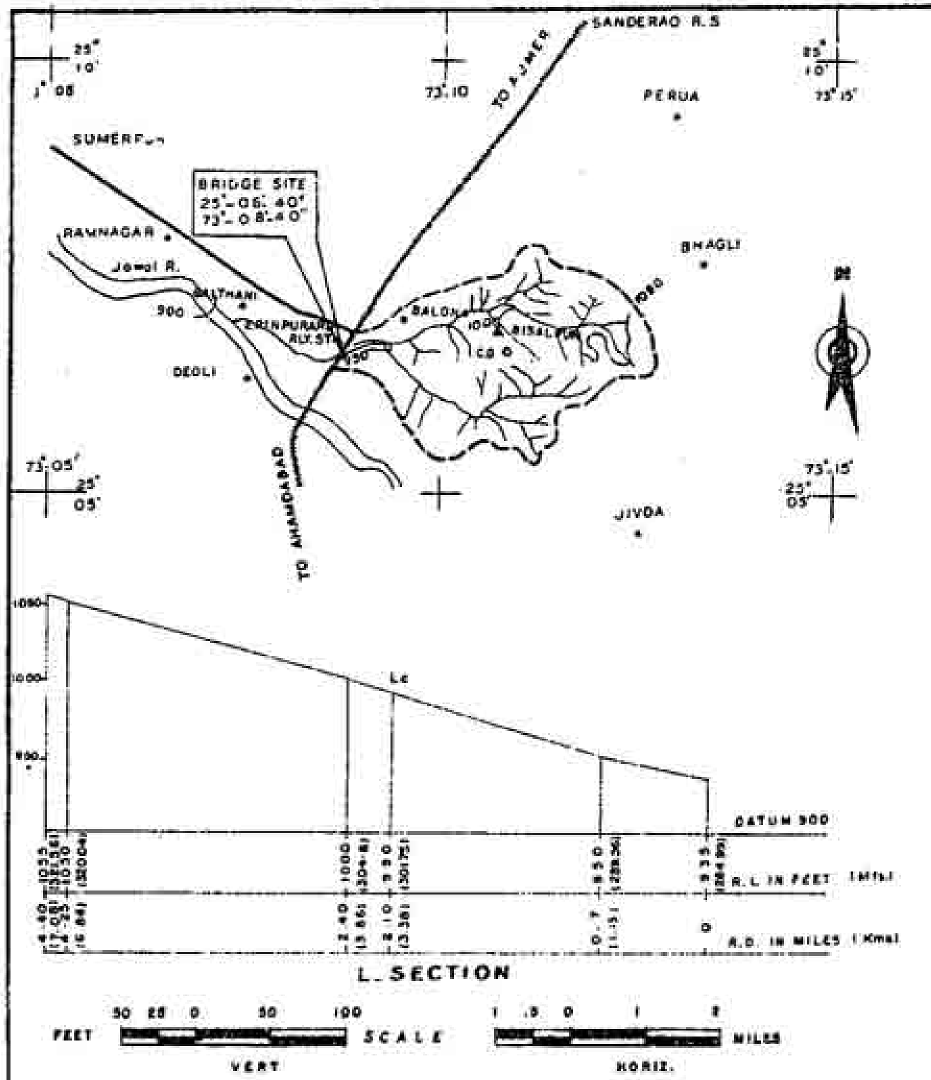
SCALE

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (R.3) DTE.

CATCHMENT AREA PLAN FOR BR. NO. 635 AT MILE 394/5-6 ON AJMER-PALANPUR SEC., W. RLY., SUB ZONE-1(a)

DRAWN BY: S.N. MALHOTRA
CHECKED BY: C.S. AGARWAL

FIG. A.4.7



NOTE

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

REFERENCES

1. CATCHMENT BOUNDARY
2. RAILWAY LINE
3. RIVER AND IT'S TRIBUTARIES
4. ROAD
5. CONTOUR
6. CENTRE GRAVITY
7. TOPO SHEET NO. . . . 45 G/4

DETAIL OF CATCHMENT

1. CATCHMENT AREA . . . 18.49 Sq. Km.
2. SHAPE OF CATCHMENT . . . FAN
3. LENGTH . . . 7.08 Km.
4. Lc . . . 3.38 Km.
5. Wc . . . 3.70
6. EQUIVALENT SLOPE . . . 5.01 / Km.
7. MAXIMUM STRAIGHT LENGTH OF CATCHMENT . . . 6.52 Km.
8. Seq. . . . 5.01 M/Km.

SL. NO.	NAME OF R.G. STATION	LONG.	LATI.	STATION of 1964-65
1.	BILAS PUR	73°.10'.45"	25°.06'.30"	1

SCALE

1 .5 0 1 2 MILES

GOVERNMENT OF INDIA
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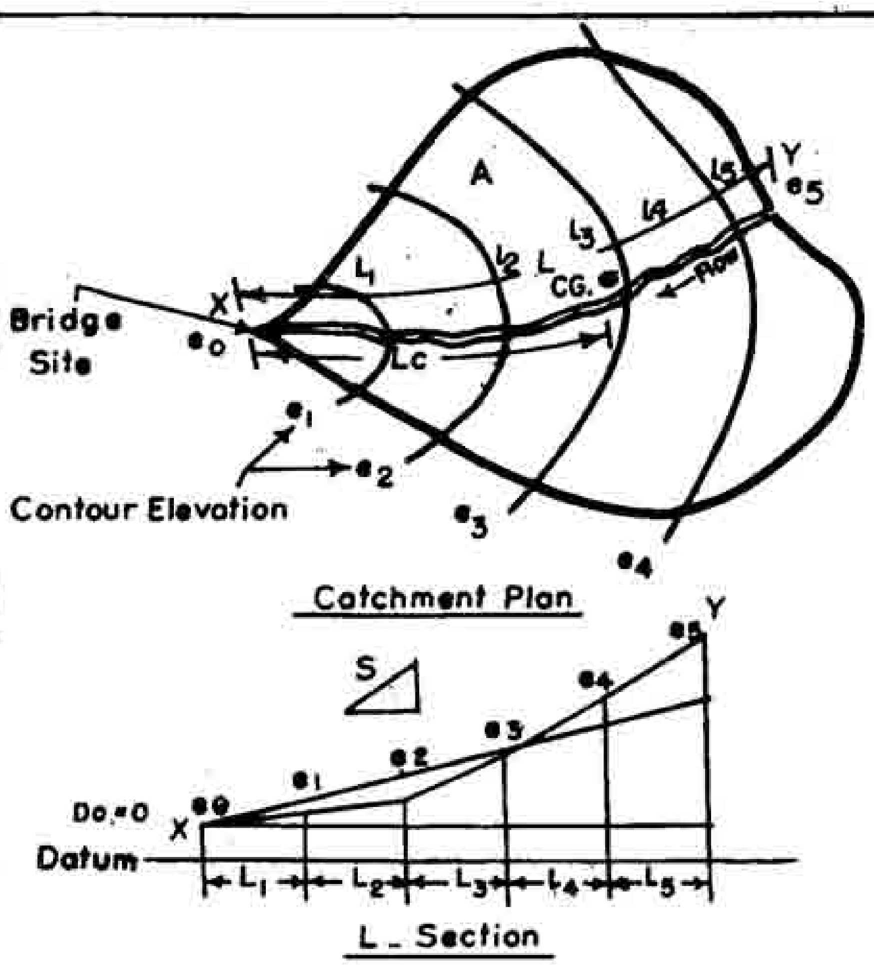
HYDROLOGY (REGIONAL STUDIES) DTE.

CATCHMENT AREA PLAN OF Br. NO. 672 (3 x 60GB) AT MILE 373 / 2.3
BALWANA RIVER AJMER DIVISION
AJMER - PALANPUR SECTION
WESTERN RAILWAY, SUB ZONE - 1(a).

DRAWN -	CHECKED -
S. S. JHAS L. P. NAUTIYAL	C. S. AGGARWAL

FIG. - I.



S = Statistical stream slope (m/km.)

L = Length of longest stream course (km.)

L_C = Length of longest stream course from a point opposite the centre of gravity of the catchment to the Bridge site (km.)

A = Catchment Area (km.^{2})

$$S = \left\{ \frac{L}{\frac{L_1}{\sqrt{S_1}} + \frac{L_2}{\sqrt{S_2}} + \cdots} \right\}^2$$

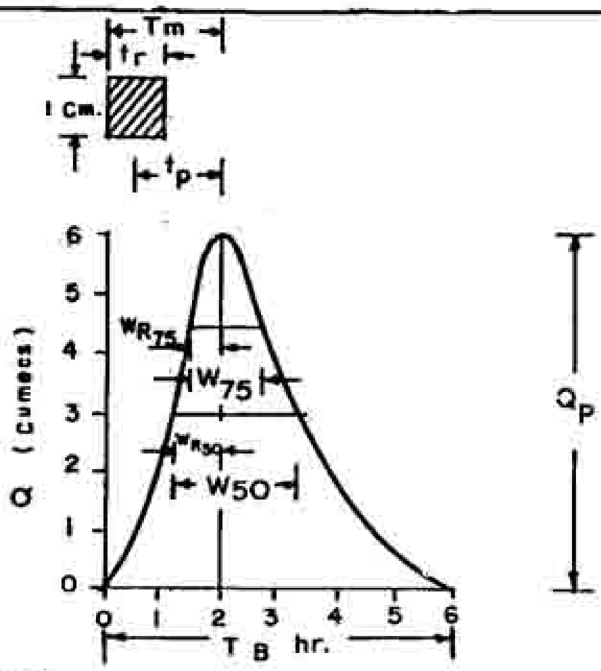
Where -

L_1, L_2 . . . Segment Lengths (km.)

S_1, S_2 . . . Segment Slopes (mt./km.)

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

FIG. - 2.



U.G = Unit Graph

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

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

Q_P = Peak Discharge of Unit Hydrograph (Cumecs.)

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

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

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

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

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

T_B = Base width of Unit Hydrograph (hr.)

A = Catchment Area (Sq.km.)

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

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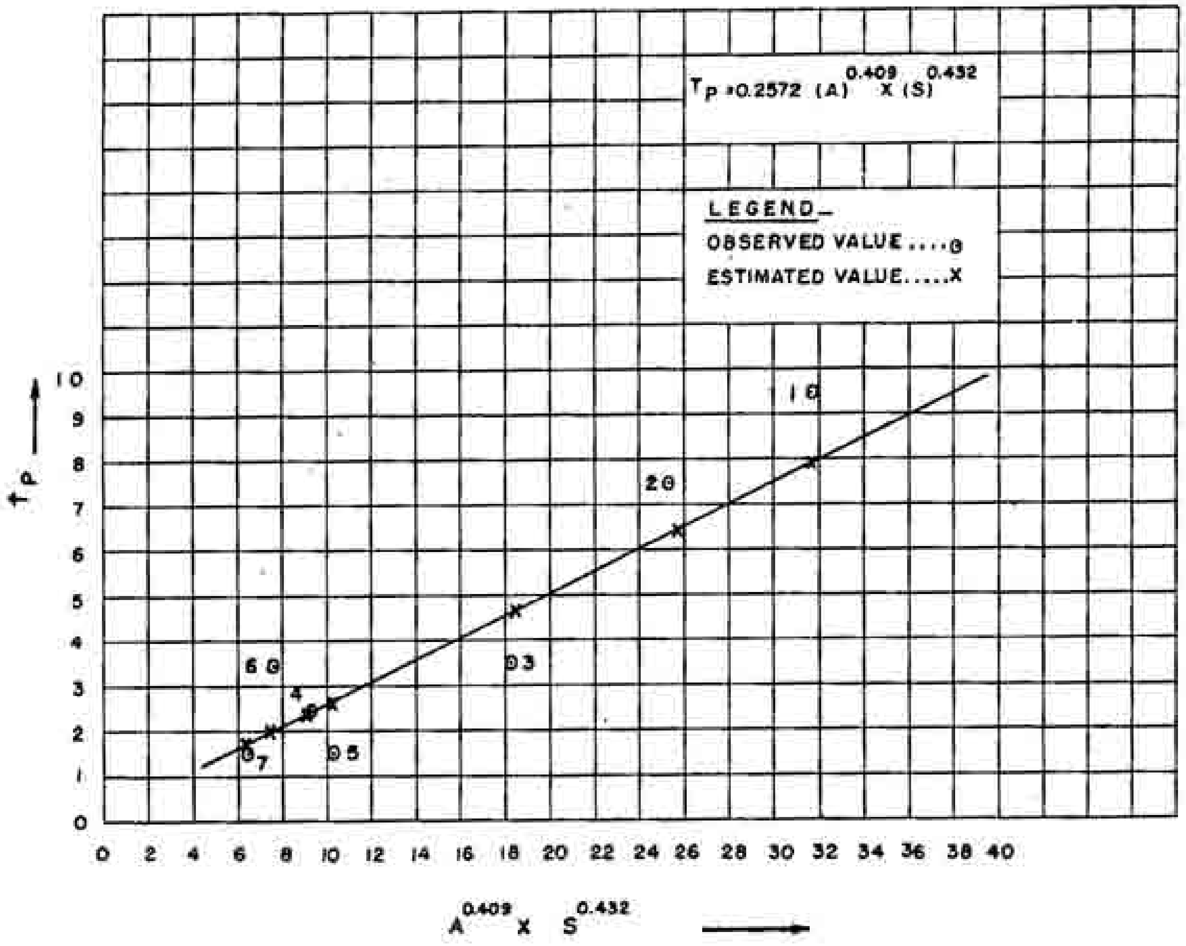
UNIT GRAPH PARAMETERS	
DRAWN BY- BHATIA, NAUTIYAL	CHECKED BY- A. K. GHOSH

FIG._3.



Sl. NO.	BRIDGE NO.	A (km^2)	S (Mt./Km)	t_p (Hrs.) Obs. Value	t_p (Hrs.) Est. Value
1.	MOT.2	682.00	6.18	9.50	8.16
2.	MOT.5	600.00	4.11	7.50	6.49
3.	MOT.3	380.00	2.96	3.50	4.67
4.	MOT.4	82.00	2.47	2.50	2.31
5.	527	77.55	3.80	1.50	2.61
6.	639	39.25	3.28	3.50	1.93
7.	672	18.49	5.01	1.50	1.74

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HYDROLOGY (REGIONAL STUDIES) DIRECT.

LUNI

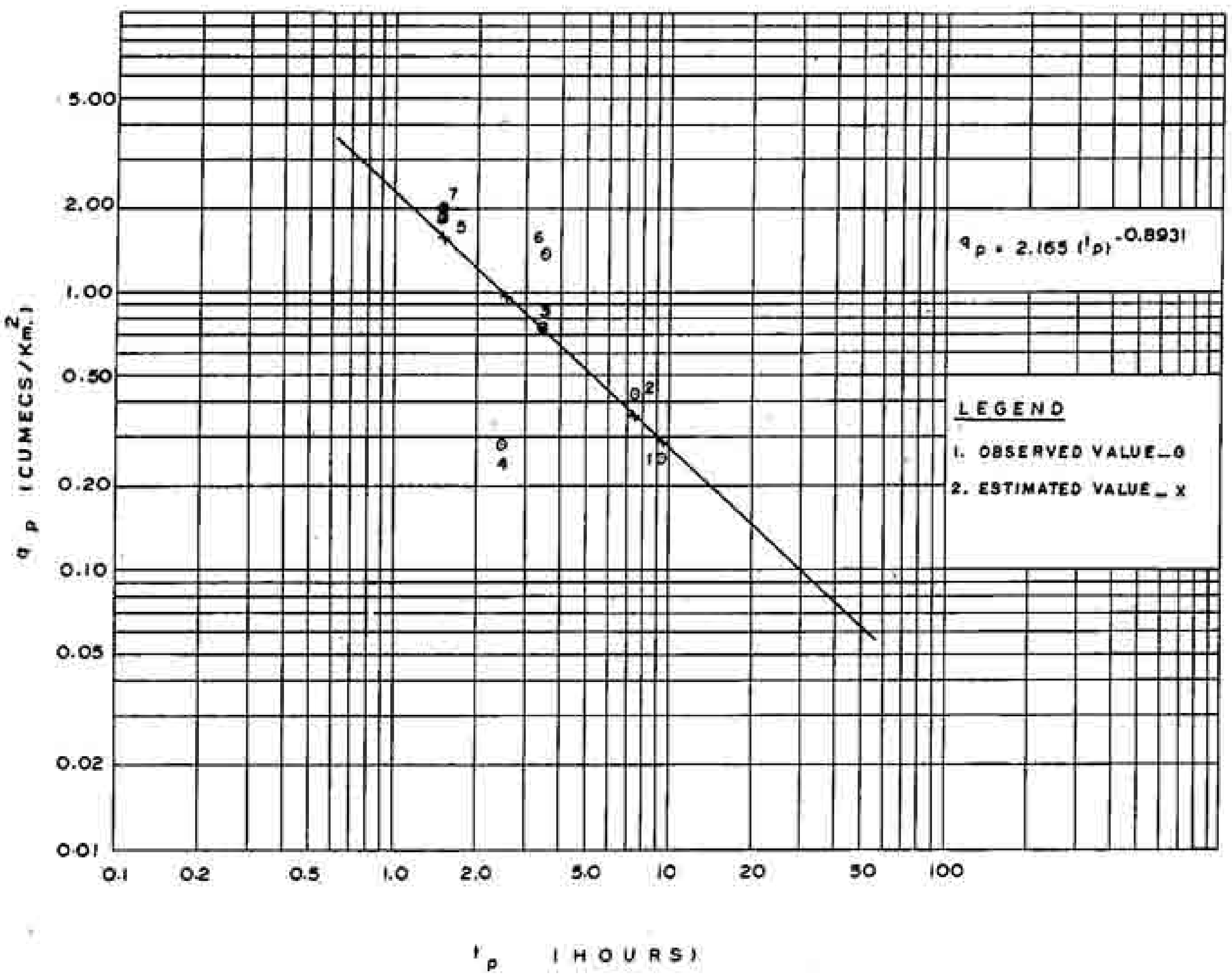
SUB ZONE - I (a)
RELATION BETWEEN
A, S AND t_p

DRAWN _ L. K. PANT, L. P. NAUTIYAL

CHECKED _ VINOD KAUL

FIG. - 4.

SCALE - LOG. X LOG.



SL. NO.	BRIDGE NO.	t_p (HOURS)	q_p (CUMECS/Km^2)	
			OBSERVED VALUE	ESTIMATED VALUE
1.	MOT_2	9.50	0.25	0.29
2.	MOT_5	7.50	0.43	0.36
3.	MOT_3	3.50	0.74	0.71
4.	MOT_4	2.50	0.28	0.98
5.	527	1.50	1.85	1.51
6.	639	3.50	1.38	0.71
7.	672	1.50	1.98	1.51

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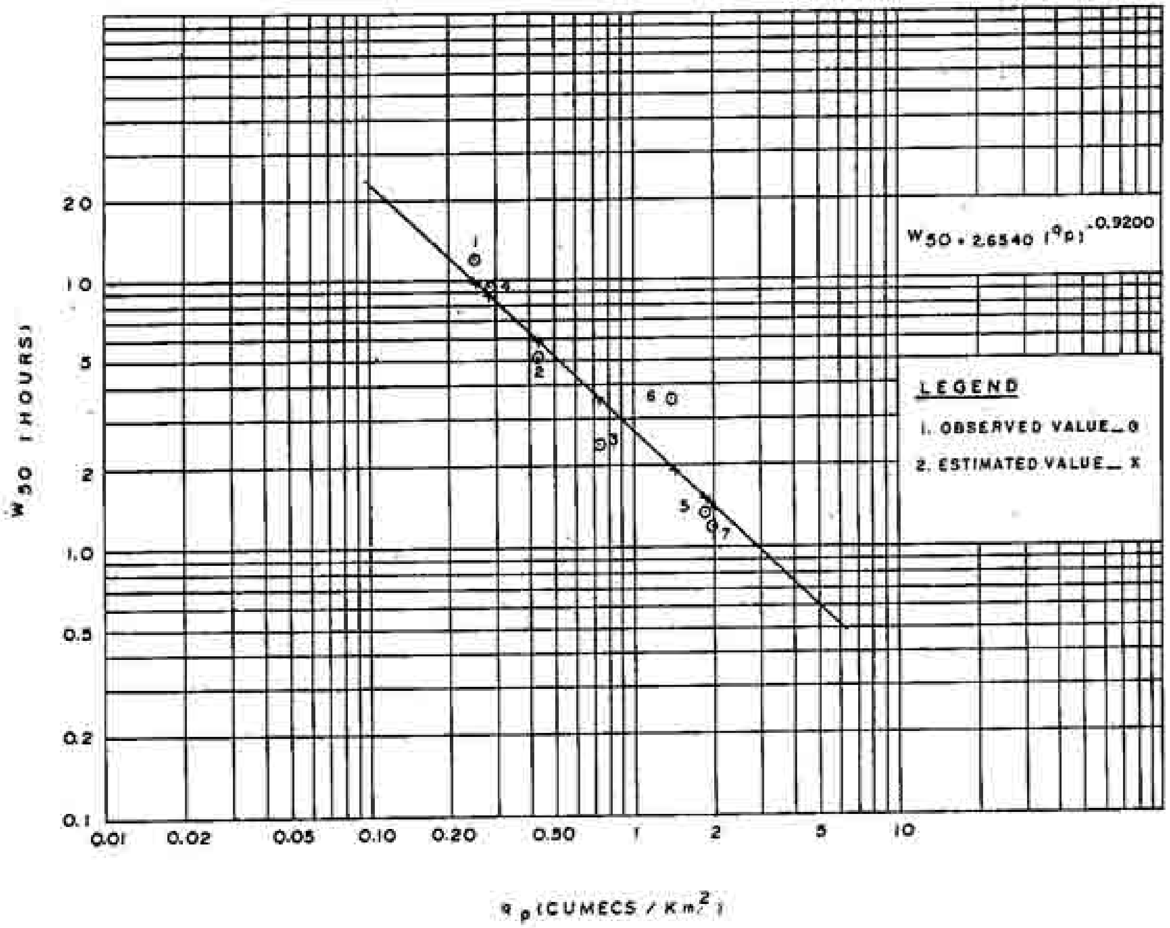
L U N I

SUB ZONE - 1(a)
RELATION BETWEEN
t_p AND q_p

DRAWN _	CHECKED _
L. P. NAUTIYAL.	VINOD / KAUL

FIG. - 5.

SCALE - LOG. X LOG



Sl. No.	BRIDGE NO.	q_p CUMECS/Km^2	W_{50} (HOURS) OBSERVED VALUE	ESTIMATED VALUE
1.	MOT.2	0.25	10.20	9.50
2.	MOT.5	0.43	5.10	5.78
3.	MOT.3	0.74	2.40	3.50
4.	MOT.4	0.28	9.50	8.56
5.	527	1.85	1.35	1.51
6.	639	1.38	3.60	1.97
7.	672	1.98	1.20	1.42

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

L U N I

SUB ZONE - 1(a)

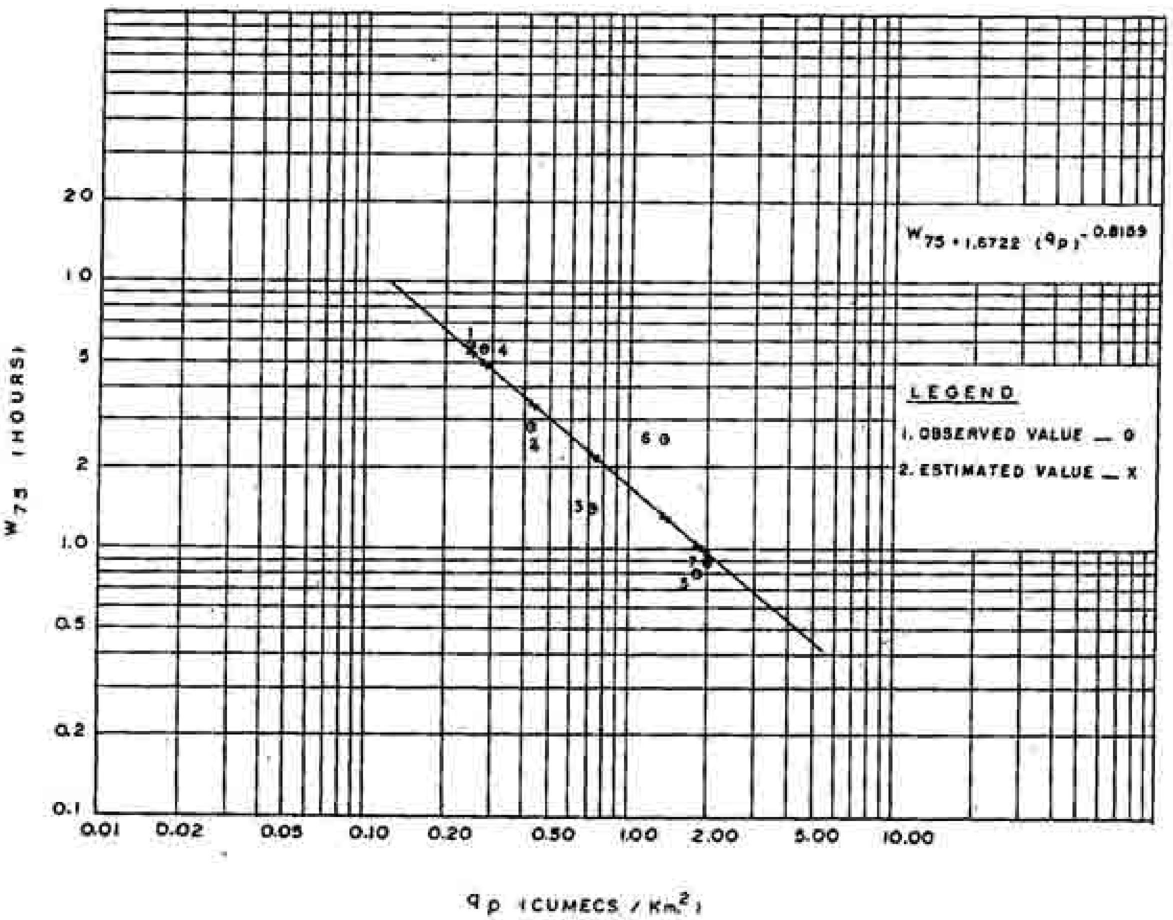
RELATION BETWEEN q_p AND W_{50}

DRAWN — L. K. PANT

CHECKED — VINOD KAUL

FIG. – 6.

SCALE – LOG. X LOG.



SL. NO.	BRIDGE NO.	q_p (CUMECS/Km^2)	W_{75} (HOURS) OBSERVED VALUE	W_{75} (HOURS) ESTIMATED VALUE
1.	MOT.2	0.25	5.60	5.18
2.	MOT.5	0.43	2.80	3.33
3.	MOT.3	0.74	1.40	2.14
4.	MOT.4	0.28	5.50	4.72
5.	527	1.85	0.80	1.01
6.	639	1.36	2.50	1.29
7.	672	1.98	0.90	0.96

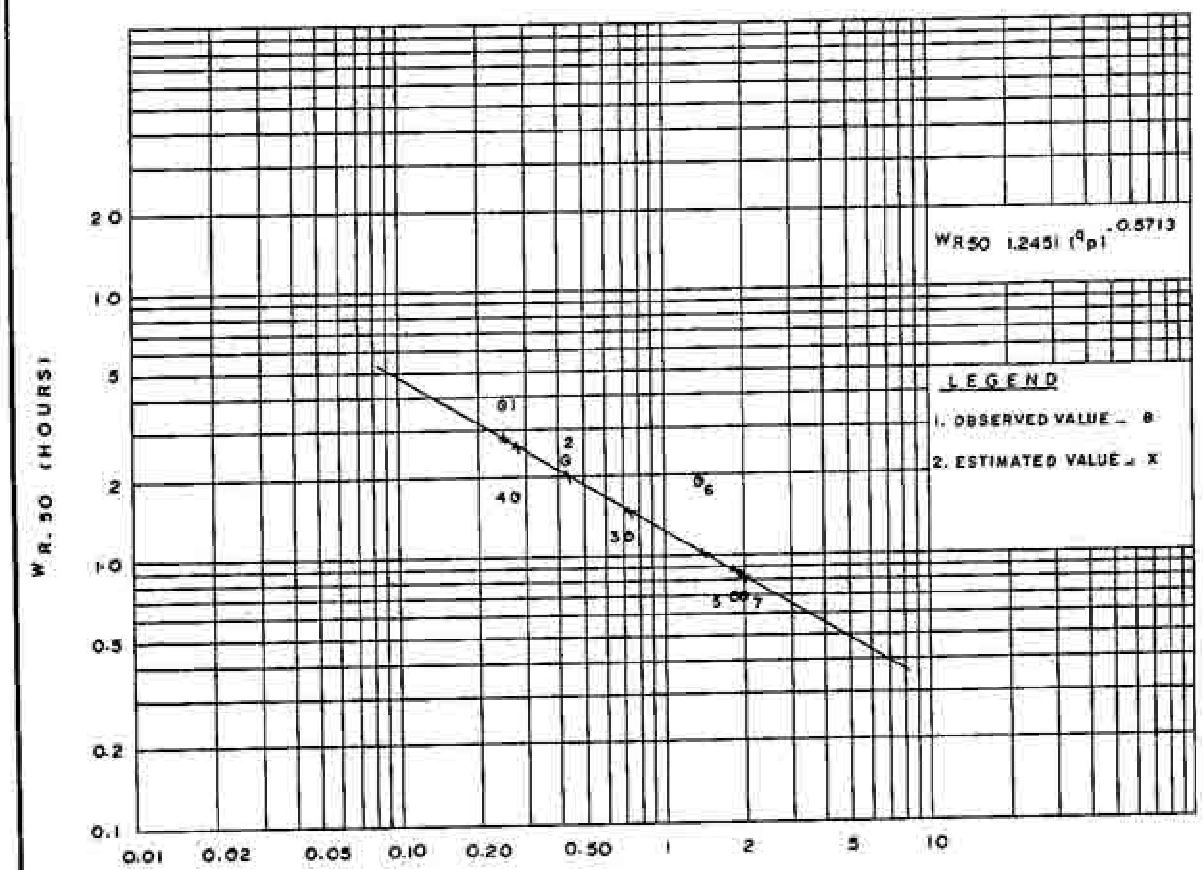
GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

LUNI
SUB ZONE - 1 (a)
RELATION BETWEEN q_p AND W_{75}

DRAWN –	CHECKED –
L. P. NAUTIYAL	VINOD KAUL

FIG. - 7.

SCALE - LOG X LOG



SL. NO.	BRIDGE NO.	q_p (Cumecs/Km²)	W_{R50} (HOURS) OBSERVED VALUE	ESTIMATED VALUE
1.	MOT. 2	0.25	3.70	2.75
2.	MOT. 5	0.43	2.30	2.02
3.	MOT. 3	0.74	1.20	1.48
4.	MOT. 4	0.28	1.70	2.58
5.	527	1.85	0.70	0.88
6.	639	1.38	1.90	1.04
7.	672	1.98	0.70	0.84

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CENTRAL WATER COMMISSION
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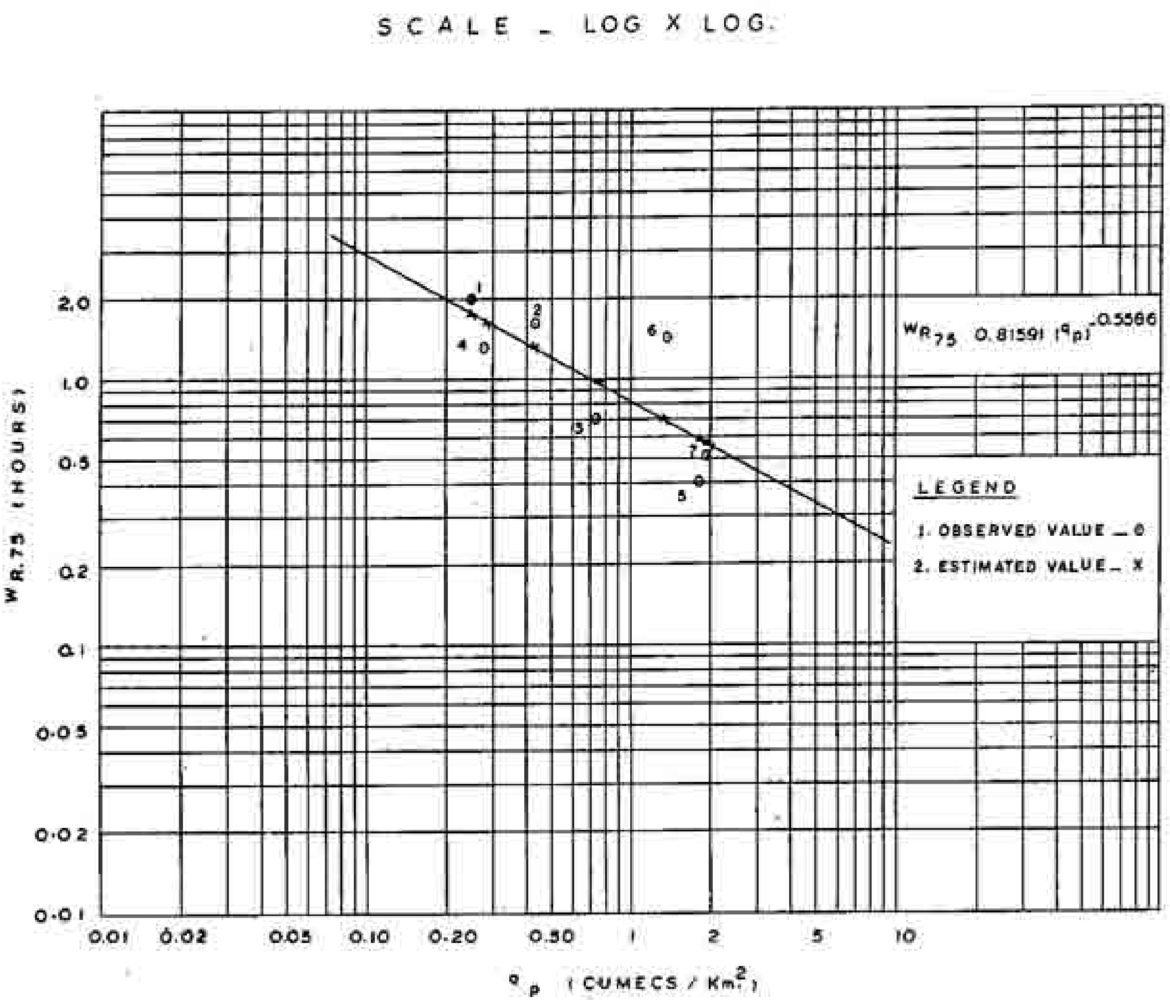
LUNI
SUB ZONE - 1(a)
RELATION BETWEEN q_p AND WR50

DRAWN - L. K. PANT	CHECKED - VINOD KAUL

FIG. - 8.



SL. NO.	BRIDGE NO.	q_p (CUMECS/Km^2)	W_{R75} (HOURS) OBSERVED VALUE	ESTIMATED VALUE
1.	MOT.2	0.25	2.00	1.77
2.	MOT.5	0.43	1.60	1.31
3.	MOT.3	0.74	0.70	0.96
4.	MOT.4	0.28	1.30	1.66
5.	527	1.88	0.40	0.58
6.	639	1.38	1.40	0.68
7.	672	1.98	0.30	0.56

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CENTRAL WATER COMMISSION
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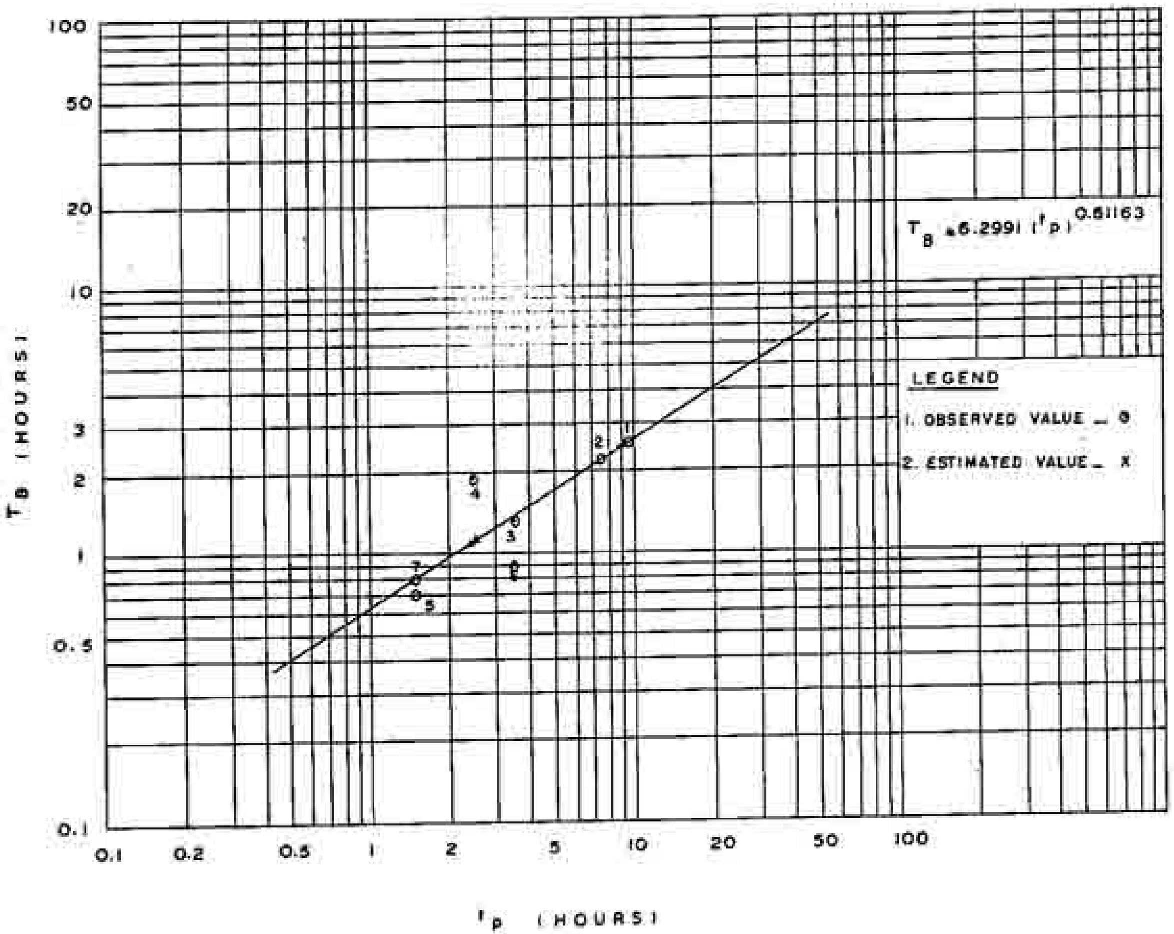
LUNI
SUB ZONE - 1(a)
RELATION BETWEEN
q_p AND W_{R75}

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

FIG. - 9.

SCALE - LOG. X LOG.



SL. NO.	BRIDGE NO.	t_p (HOURS)	T_B (HOURS) OBSERVED VALUE	T_B (HOURS) ESTIMATED VALUE
1.	MOT.2	9.50	26.00	24.96
2.	MOT.3	7.50	22.00	21.60
3.	MOT.3	3.50	13.00	13.55
4.	MOT.4	2.50	19.00	11.03
5.	527	1.50	7.00	8.07
6.	639	3.50	9.00	13.85
7.	672	1.50	8.00	8.07

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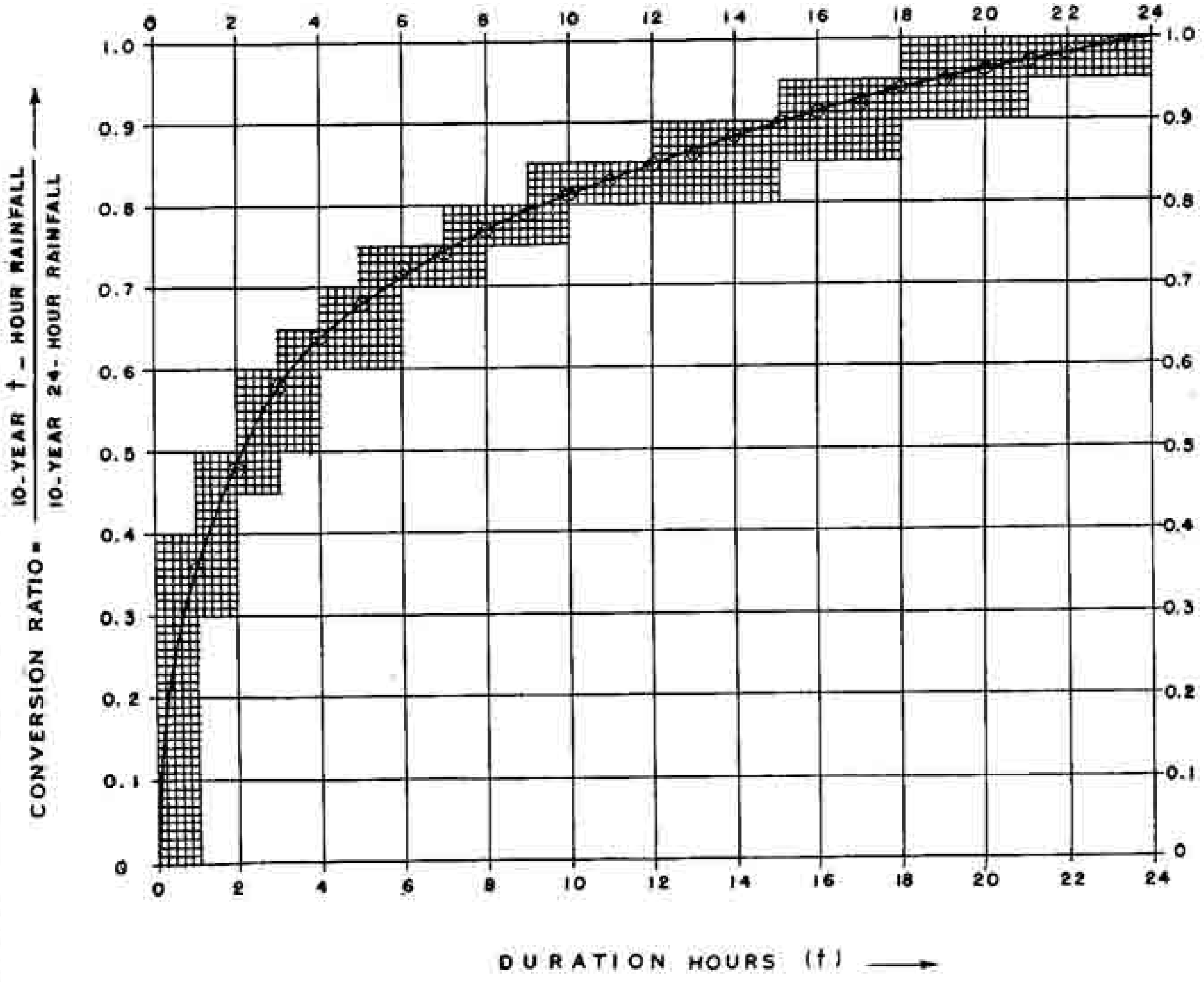
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

LUNI
SUB ZONE - 1(a)
RELATION BETWEEN
t_p AND T_B

DRAWN - L. K. PANT.

CHECKED - VINOD KAUL

FIG. – 10.



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

DURATION (Hrs.)	RATIO
1	0.360
2	0.490
3	0.580
4	0.640
5	0.680
6	0.713
7	0.742
8	0.770
9	0.794
10	0.810
11	0.830
12	0.848
13	0.865
14	0.880
15	0.898
16	0.910
17	0.925
18	0.940
19	0.950
20	0.960
21	0.970
22	0.980
23	0.990
24	1.000

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

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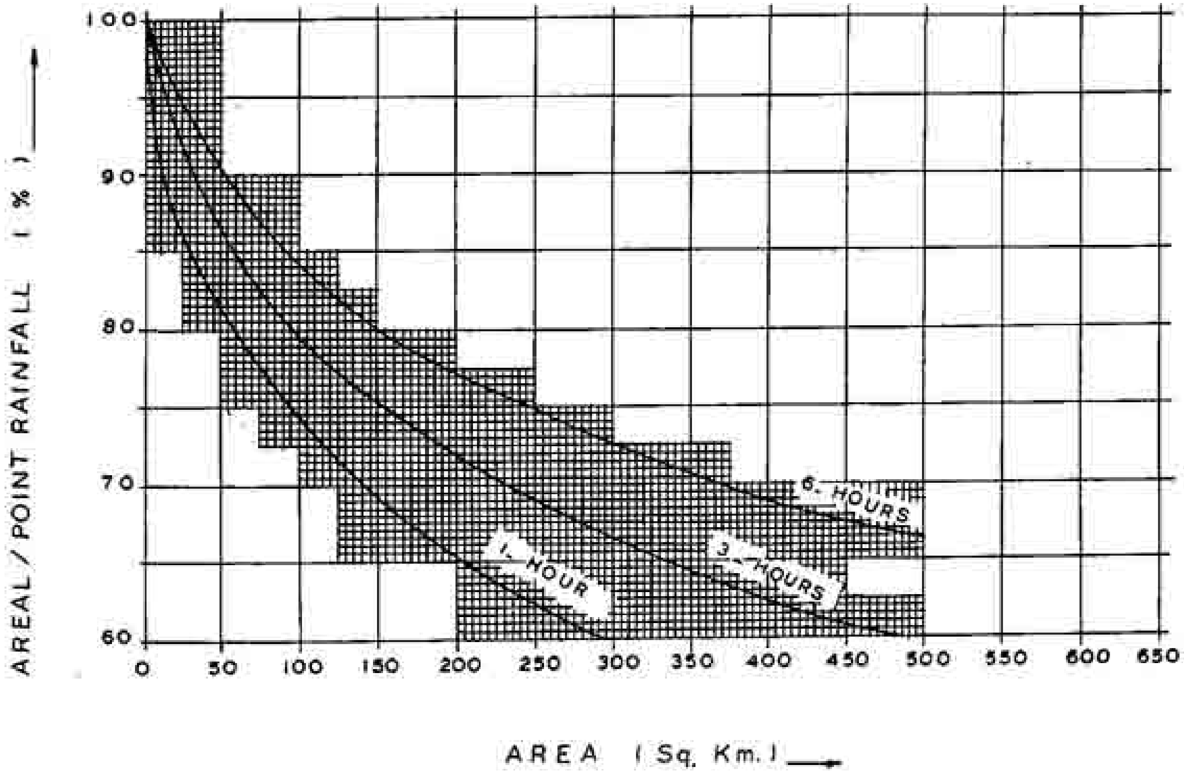
LUNI
SUB ZONE - 1 (a)
DURATION VS. CONVERSION RATIO

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

FIG. - 11 (a).



NOTE:-

i) REFER ANNEXURE - 4-1 FOR AREAL TO POINT RAINFALL RATIOS FOR DURATION FROM 1-24 HOURS.

ii) REFER FIG.- 11 (b) FOR AREAL TO POINT RAINFALL RATIOS FOR DURATION 12-HOURS AND 24- HOURS.

NOTE :-
CURVES SUPPLIED BY I M D.

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HYDROLOGY (REGIONAL STUDY) DIRECT.

L U N I

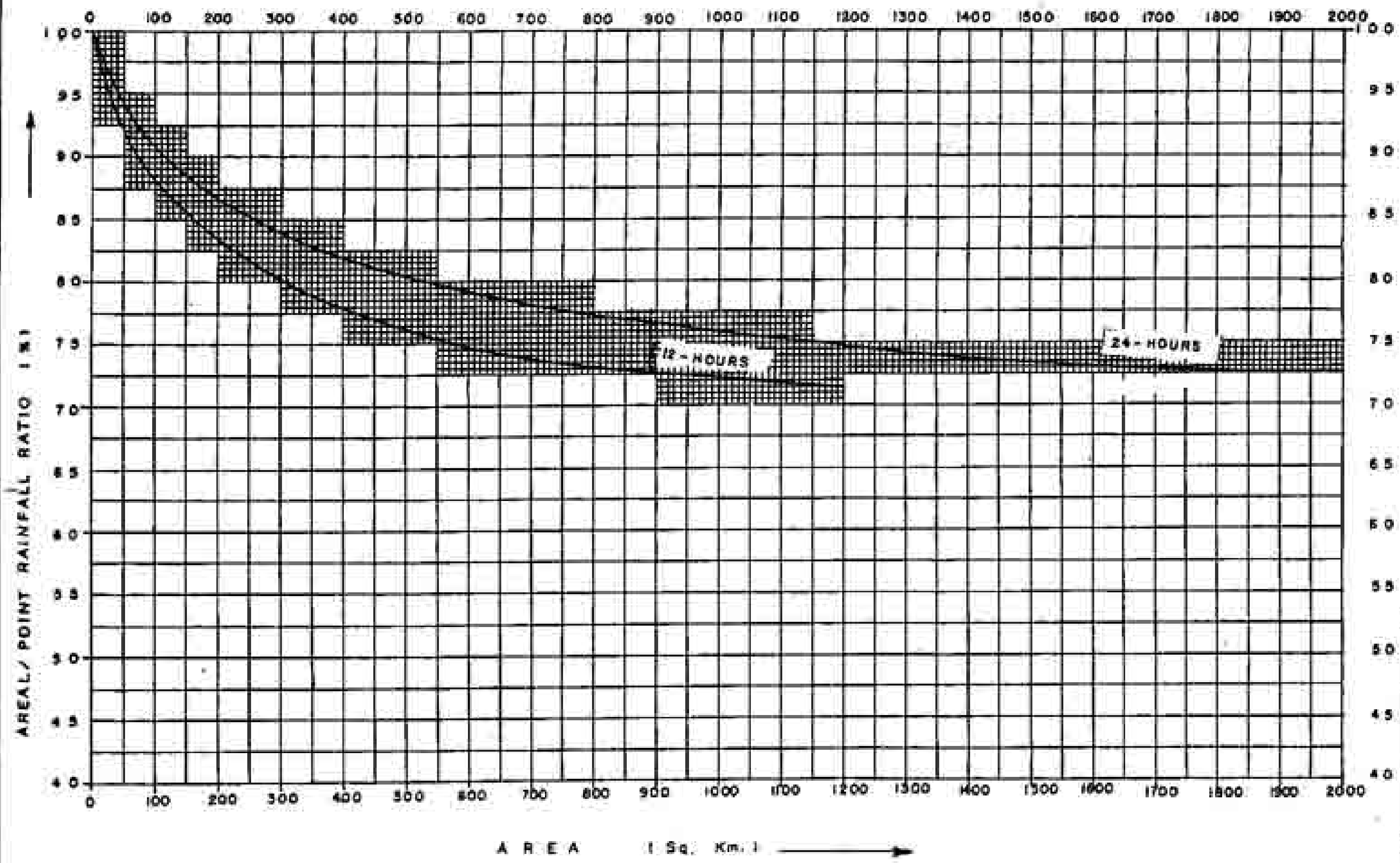
S U B ZONE - I (a)

AREAL TO POINT RAINFALL RATIO

FOR 1 Hr., 3 Hrs.& 6 Hrs.
(%)

DRAWN -	CHECKED -
S. N. MALHOTRA L. P. NAUTIYAL.	C. S. AGGARWAL

FIG.- 11 (b)



NOTE:-

i) REFER ANNEXURE_4-I FOR AREAL TO POINT RAINFALL RATIOS FOR DURATION FROM 1 TO 24 HRS. AND FOR CATCHMENT AREAS UPTO 2000 SQ. KM.

ii) REFER FIG.- 11 (a) FOR AREAL TO POINT RAINFALL RATIOS FOR DURATION 1-HOUR, 3-HOURS & 6-HOURS.

NOTE

CURVES SUPPLIED BY IMD.

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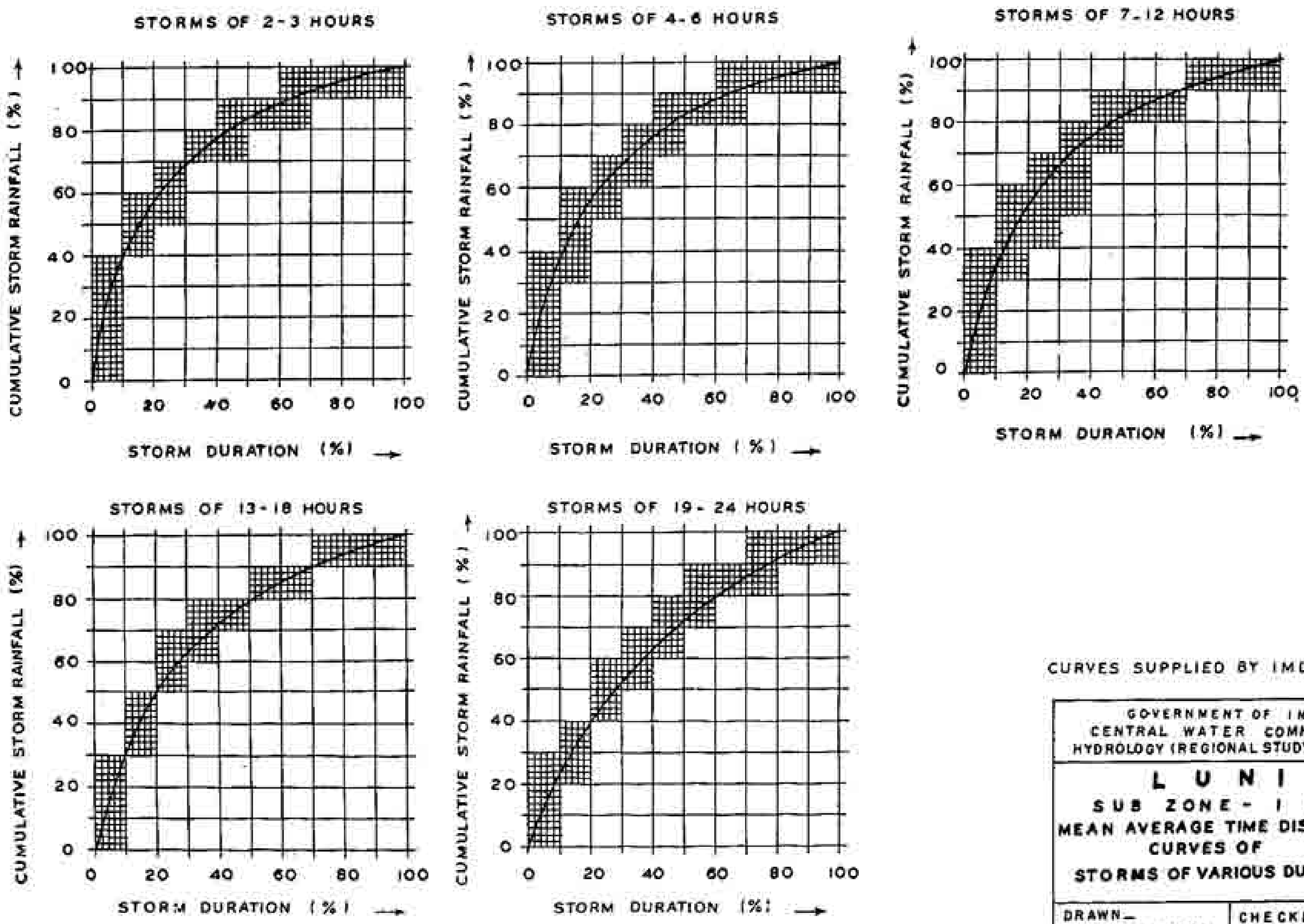
LUNI

SUB ZONE - 1 (a)

AREAL TO POINT RAINFALL RATIO FOR 12 & 24 HOURS (%)

DRAWN —	CHECKED —
S. N. MALHOTRA L. P. NAUTIYAL	VINOD KAUL

FIG. — 12.



CURVES SUPPLIED BY IMD.

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L U N I

SUB ZONE - I (a)
MEAN AVERAGE TIME DISTRIBUTION CURVES OF STORMS OF VARIOUS DURATION

DRAWN—	CHECKED—
S. N. MALHOTRA L. P. NAUTIYAL	C. S. AGGARWAL.

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A. UNDER SHORT TERM PLAN

1.	Estimation of Design Flood Peak	(1973)

B. UNDER LONG TERM PLAN

1.	Lower Gangetic Plains subzone-1(g)	(1978)
2.	Lower Godavari subzone-3(f)	(1981)
3.	Lower Narmada & Tapi subzone-3(b)	(1982)
4.	Mahanadi subzone-3(d)	(1982)
5.	Upper Narmada & Tapi subzone-3(c)	(1983)
6.	Krishna & Penner subzone-3(h)	(1983)
7.	South Brahmaputra Basin subzone-2(b)	(1984)
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9.	Middle Ganga Plains subzone-1(f)	(1985)
10.	Kaveri Basin subzone-3(i)	(1986)
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18.	West coast Region subzone 5(a) & (b)	(1992)

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