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SAHARANPUR, U.P., INDIA

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glacier and thus does not contribute to floods as far as spillway design of Dam is concerned.

With this areal rainfall values obtained are :

ONE DAY DURATION

Return Period	Critical Design Storm value (including snow-melt) in mm.
100	259.7
500	374.0
1000	398.6

TWO DAY DURATION

100	462.6
500	569.5
1000	599.9

CONCLUSIONS

This objective method is suitable when simultaneous record of all stations in the catchment is not available. The Critical Storm thus generated will lead to Probable Maximum Storm if suitable Return Period is adopted. As the probability of occurrence of heavy rainfall at all the stations heavier than that at key station is less, the calculated risk of Critical Design Storm computed from the Return Period is higher than the actual risk. Still designer can select the design value depending on the calculated risk, computed from the Return Period.

ACKNOWLEDGEMENT

The authors express their gratitude to Dr. D.V.L.N. Rao, Director (Hydrometeorology) for his encouragement and guidance for completion of the paper. Thanks are also due to Shri Raveendran. G. and Shri V.K. Bhalla for their help for typing the paper and preparation of diagram.

The authors also express their gratitude to Dr. P.K. Das, Director General of Meteorology for his keen interest in this study, and for permission to present this paper.

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1. WMO Operation Hydrology Report No.1 (1973) WMO No. 332.

Design Storm Studies for Beas Catchment Upto Pandoh Dam Site

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ABSTRACT

In this paper an attempt has been made to determine the design storm for Beas Catchment upto Pandoh dam using physical approach. It is a mountainous watershed having an area of 5300 Sq. Kms. A detailed study of rainstorms which affected the region was carried out and major rainstorms were finally selected for Design Storm evaluation taking into consideration the region of influence of storm type and topographic controls. Time distribution of 24 hr and 48 hr rainstorm has also been carried out to understand the storm characteristics of the area and the results discussed in detail.

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1. INTRODUCTION

Pandoh dam has since been constructed in Himachal Pradesh under Beas-Sutlej link project mainly for the diversion of the Beas waters into Govind Sagar, the lake created on the Sutlej river by the constructions of Bhakra Dam. This project was conceived for harnessing the irrigation and power potential of Beas and Sutlej rivers. Pandoh dam has been so designed that it can not absorb any flood water. In the background of unprecedented and disastrous flood that occurred in the Machhu river in Gujrat during the second week of August, 1979, causing Machhu Dam burst, Bhakra Beas Management Board (BBMB) desired to have detailed study of Probable Maximum Flood that could occur in Pandoh dam catchment and work out some emergency plan for safety of dam and to cater for such flood. This study in a sequel to an investigation undertaken at the request of the Bhakra Beas Management Board to India Meteorological Department to look into the problem of Probable Maximum Precipitation over Pandoh Catchment as the Probable Maximum flood to be adopted for a particular project or any or its hydraulic structures is interdependent on the maximum probable storm or probable maximum precipitation that can occur over the project area in the given duration.

2. PHYSICAL FEATURES

The catchment area of river Beas upstream of Pandoh dam is spread in an average length of 69 Kms and width 77 Kms, comprising a total area of about 5300 Sq. Kms. The famous valley of Kulu which is known for its scenic beauty and grandeur of Himalayan ranges lies in this catchment. The catchment is hilly and its high peaks remain covered with snow for nine months in a year but the snow covered area in the catchment is negligible as compared with the total catchment area.

The source of river Beas is said to be "Beas Kund", a small spring near Rotang Pass. The gradient of the river in upper reaches is very steep and in this portion it encounters many falls. As we descend to lower elevations, river becomes more and more in stable condition and the flow is comparatively uniform, straight and less turbulent. Main river is fed by tributeries from both sides. Some of the major tributories which join upstream of Pandoh dam are :

a) Sarbari Khad near Kulu
b) Parbati river near Bhuntar
c) Hurla Nala about 5 Kms below Bhuntar
d) Tirathan and Sainj Khads join together and meet river Beas near Largi.
e) Bakhli Khad about 1 Km upstream of Pandoh dam.

All these tributeries have got parennial flow which varies considerably during different months of the year. In the initial stage, the river is a small stream with a humble discharge. On its way, different tributaries join one by one from both sides and enrich the discharge of the river so that ultimately Beas becomes a violent river by the time it reaches Pandoh.

3. RAINGAUGE NETWORK

There are 9 raingauge stations including 3 I. Met.D. observatory stations within the catchment for which daily rainfall data are available. In other words, one raingauge station roughly represents about 600 Sq. Kms. of the catchment area. It may, however, be mentioned that the rainfall data prior to 1951 is inadequate for the studies as there were only 3 raingauge stations at Kulu, Nagar and Banjer in the catchment prior to 1951. The remaining raingauge stations including I.Met.D. observatory stations have been established in phased manner during the last 30 years.

Hourly rainfall data in respect of 5 self recording raingauge (SRRG) stations maintained by the project authorities are available since 1969. Fig. 1 shows the locations of the raingauges in and around the catchment.

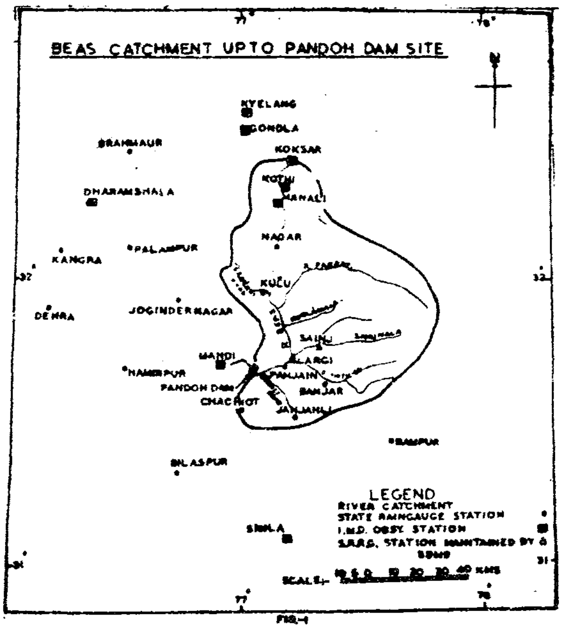

FIG.-1

4. DATA UTILISED

The daily rainfall tables of Punjab and Himachal Pradesh for the period 1951 to 1979 have been examined and the daily rainfall data of raingauge stations in and around the catchment have been utilised in the present study. The daily rainfall data of I.Met.D. observatory stations not published in the state rainfall tables have also been used. Discharge data for the catchment as supplied by the project authorities have also been examined for preliminary storm selection. The highest 1 - day rainfall recorded at different stations in the catchment is given in Table 1.

5. DESIGN STORM STUDY

WMO guide to hydrological practices (1974) and operational Hydrology Report No.1, WMO No. 332 (1973) recommend i) Depth-Duration (D-D), ii) Depth-Area-Duration (DAD) & iii) Storm transposition techniques for the derivation of the Standard Project Storm (SPS) for a basin. The conventional method of moisture maximisation is applied to the SPS value to obtain the corresponding Probable Maximum Precipitation (PMP) value for that basin. However, the choice of the above mentioned methods for design storm evaluation depends mainly on the catchment characteristics, meteorological/climatological features of the region and the quantity as well as quality of the rainfall data available for the study.

Normally Depth-Duration (D-D) analysis is best suited for Design Storm evaluation in mountainous catchments. However, this method needs judicious application in the present study as the rainfall data in respect of bulk of stations in the catchment are not available for a sufficiently long period. Attempt has been made in this paper to evaluate PMP values for the catchment by adopting a modified procedure as described in the later paragraphs. Rainstorms upto 3 days' durations have been considered to meet the requirements of the design engineers in the estimation of the design flood for the catchment upto Pandoh dam.

TABLE - 1

Highest observed one-day rainfall at raingauge stations in Pandoh catchment.

S.No.	Station	Date & Yr. of occurrence	Highest one-day rainfall (cm)	Data available from	Remarks if any
1.	Manali (Obsy)	14.8. 1970	88.3	1968	
2.	Koksar (Obsy)	05.10. 1955	167.6	1951	
3.	Kothi (Obsy)	12.5. 1957	110.5	1951	
4.	Kulu	04.10. 1888	236.2	1869	
5.	Nagar	16.02. 1913	183.4	1884	Data not published since 1965
6.	Panjain	15.09. 1963	206.2	1955	
7.	Banjar	11.01. 1885	213.4	1869	
8.	Janjheli	28.06. 1961	129.5	1955	
9.	Chachiot	21.08. 1951	228.6	1951	

6. SELECTION & ANALYSIS OF HEAVY RAINSTORMS

In order to obtain quantitative estimates of design storm for the catchment under study, a comprehensive study of all major rainstorms that occurred in the past over the catchment was carried out by Depth-Duration (D-D) method on the basis of available daily rainfall data of raingauge stations in and around the catchment. Due consideration was given to the topographical features of the catchment while drawing the isohyets. The study revealed that the rainstorm of 3-5 October, 1955 contributed the maximum average depths of precipitation over the catchment for 1-day, 2-day & 3-day durations for all the rainstorms which were experienced by the catchment during the period considered i.e. 1951 to 1979. The average rainfall depths caused by 1955 rainspell over the catchment for different durations are :

Duration	Rainfall depths (cm)
1-day (4 Oct., 1955)	7.9
2-day (4-5 Oct., 1955)	15.6
3-day (3-5 Oct., 1955)	19.6

Storm of 3-5 October, 1955 which was centred near Batala is in fact the heaviest recorded storm over Punjab and Himachal Pradesh and it gave very heavy precipitation over areas upto 50,000 Sq. Kms. for duration of 3 days. A depression centred over east Rajasthan which ultimately broke over Punjab hills was responsible for this intense rainfall activity over Punjab and Himachal Pradesh.

Since the available data in the catchment under study does not cover a sufficiently long period, the D-D values of the highest recorded rainspell of 3-5 October, 1955 may not be adopted as Standard Project Storm (SPS) values for the catchment for obvious reasons.

In order to assess the flood potentialities of the catchment, the major rainstorms that occurred in close proximity of the catchment where meteorological influence and topography were sufficiently alike to that of the catchment under study were picked up and the following severe rainstorms were finally selected for detailed isohyetal analysis :

i) Rainstorm of 2-4 August, 1953 centred at Dharamsala.

ii) Rainstorm of 30 August - 1 Sep. 1960 centred at Mandi.

1-day, 2-day & 3-day isohyetal patterns of 2-4 August, 1953 rainstorm are shown in figs. 2, 3 & 4 respectively. It may be seen from the figures that the storm had good areal extent vis-a-vis the size of the catchment under study and the rainfall was also well distributed in the storm. DAD analysis was carried out taking the rainstorm itself as the unit of study and DAD curves for various durations for this rainstorm are presented in fig. 5.

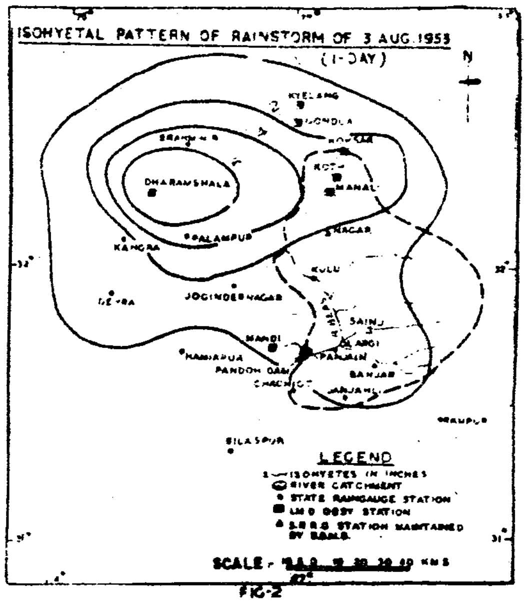

FIG-2

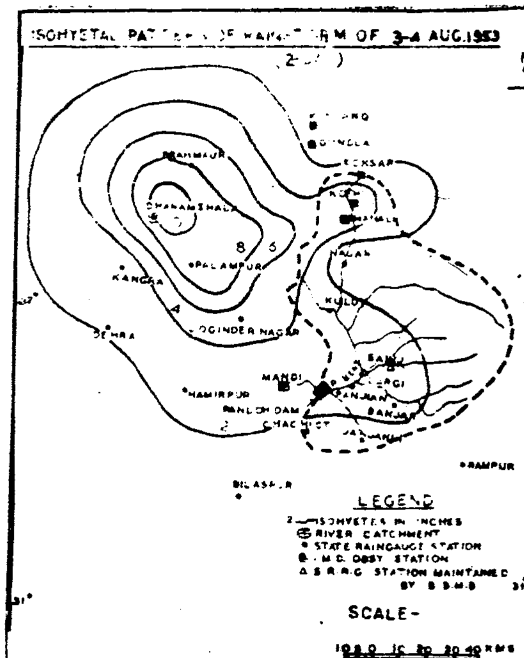

FIG-3

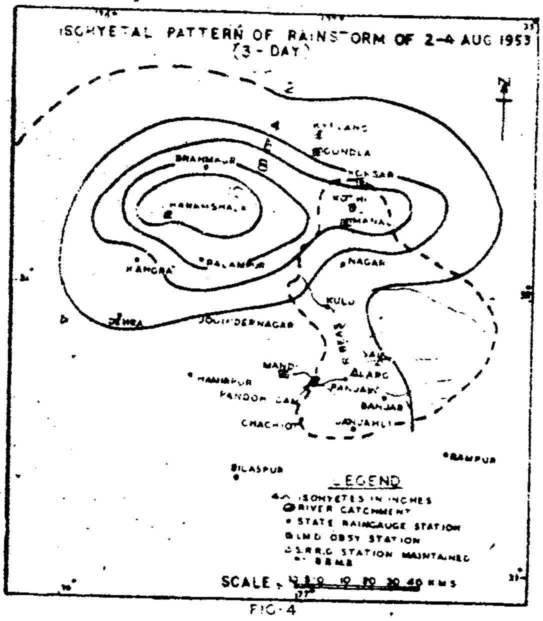

FIG-4

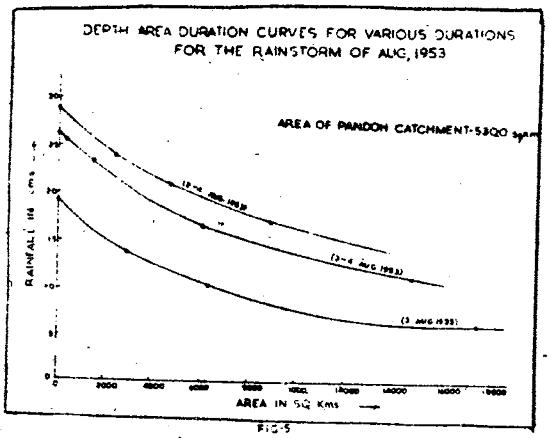

FIG-5

The following maximum raindepths were obtained from these curves corresponding to the area of catchment.

Duration	Maximum depths of rain (Cm)
1 - day(3Aug., 1953)	11.6
2 - day(3-4 Aug., 1953)	17.7
3 - day(2-4 Aug., 1953)	20.5

The storm pattern was transposed over the catchment under study in the most critical manner so as to realise the maximum average raindepths from the storm taking care that change in orientation affected was in confirmity with the meteorological and topographical considerations. After fixing the storm pattern over the basin, the average raindepths for various durations were worked out by planimetering the catchment area between that transposed isohyets. The D-D values obtained for various durations are as follows :

Duration	Average depth of rainfall (Cm)
1-day (3 Aug., 1953)	11.4
2-day (3-4 Aug., 1953)	16.7
3-day (2-4 Aug.; 1953)	18.5

The depths of precipitation in storm centre in 30 August - 1 September, 1960 rainstorm were much higher when compared to rainstorm of 2-4 August, 1953 but its areal extent was limited and the catchment under study could not be covered by the storm isohyets. Storm of 30 August - 1 September, 1960 was, therefore, not considered for D-D analysis.

Using the envelope curve method for D-D analysis the following depths of rain as given in Table - 2 were finally obtained for the catchment and may be considered as Standard Project Storm (SPS) values for different durations for Pandoh catchment.

TABLE - 2

Standard Project Storm (SPS) values for Pandoh Catchment obtained from enveloping curves for various durations.

Durations	Standard Project Storm (SPS) Values (Cm)
1 - day	11.4
2 - day	16.7
3 - day	19.6

7. ESTIMATION OF PROBABLE MAXIMUM PRECIPITATION (P M P)

According to the Glossary of American Meteorological Society (1959), Probable Maximum Precipitation (PMP) has been defined as that greatest depth of precipitation for a given duration that is physically possible over a drainage basin. The main aim of PMP is, therefore, to obtain such an estimate of rainfall which will guide a design engineer in designing the spillway capacity of a dam which under all circumstances precludes the possibility of endangering the structure of the proposed dam.

The PMP values for the catchment under study were derived from conventional method applying moisture maximisation to the SPS values. On the basis of available surface dew point data of observatory stations considered representative for these rainstorms, the maximisation factor works out to 50% and 45% for rainstorms of 2-4 August, 1953 and 3-5 October, 1955 respectively. The M.A.Fs thus obtained were applied to the Standard Project Storm (SPS) values and the corresponding PMP values for different durations are given in Table 3.

TABLE - 3

Probable Maximum Precipitation (PMP) values for Pandoh Catchment obtained after Moisture maximisation.

Duration	PMP Values (Cms)
1 - day	17.1
2 - day	25.1
3 - day	28.4

8. AN ALTERNATE TECHNIQUE FOR THE ESTIMATION OF DESIGN DEPTHS

As already pointed out earlier, the Depth-Duration (D-D) method is best suited for design storm evaluation in mountainous watersheds. Storm transposition technique is normally not applied in such catchments. As the rainfall data for studies in the present case were not available for a sufficiently long period, there is a doubt as to what constitutes a realistic estimate of design storm in relation to Depth-Duration method, under the circumstances, the major storm of 1953 which occurred in proximity of the catchment and yielded the maximum depths for 1-day and 2-day durations was also considered for a further examination of design values with the available data. This methodology has also its limitations, but no other method is known by which design storm values can be estimated with insufficient data in mountainous catchments. An alternate method has also been suggested in this paper to evaluate design storm values, the procedure of which is outlined below.

The detailed examination of 30 August - 1 September, 1960 rainstorm centred at Mandi revealed that there was very concentrated rainfall around the storm centre but its areal extent was limited. Considering the close proximity of this storm to the project catchment, the gradient of 1953 storm was transposed to 1960 storm for evaluation of design storm values for the catchment on the assumption that the type of variation of rainfall with distance associated with 1953 rainstorm could as well have occurred in 1960 storm. Table 4 gives the Areal Reduction Factor (ARF) of 1953 storm corresponding to Pandoh catchment area for various durations.

TABLE - 4

AREAL REDUCTION FACTOR (ARF) of 2-4 Aug. 1953 Storm for various durations corresponding to Pandoh Catchment area.

Duration	Central Value(Cm)	Average rainfall depth corresponding to catchment Area	A.R.F.
1-day	19.4	11.6	0.59
2-day	26.2	17.7	0.69
3-day	28.8	20.5	0.71

The depths of precipitation recorded at the storm centre of 30 August - 1 September, 1960 storm were as follows :

Date	Duration	Central Rain-depth value (Cm)
31 Aug., 1960	1-day	27.1
31 Aug.-1-Sep.1960	2-day	37.0
30 Aug.-1 Sep.1960	3-day	39.3

The design storm values worked out for various durations by applying ARF of 1953 storm (Table -4) to the corresponding central rainfall values of 1960 storm are given in Table 5.

TABLE - 5

Design storm values for Pandoh Catchment for various durations

Duration	Design Values (Cm)
1 - day	16.0
2 - day	25.5
3 - day	27.9

Since a certain amount of inherent maximisation has already been effected on the storm of 1960 by transposing the gradient of 1953 storm no further maximisation due to moisture charge is considered necessary and the design values given in Table 5 may be taken as PMP values for the catchment.

It may be seen from Tables 3 & 5 that the design storm values given in Table 5 are comparable to the values (Table 3) obtained by applying conventional moisture maximisation procedure to the Standard Project Storm (SPS) values given in Table 2.

The one-day design value may further be increased by 15% to convert it to any 24-hr. value for design purposes.

9. TIME DISTRIBUTION OF STORM RAINFALL

One of the most inportant factors affecting the peak discharge is the variability of precipitation in time. For this purpose a break-up of storm rainfall into small time units is essential according to the unit period chosen for unit hydrograph. Normally 3-hourly time distribution of 24-hr. storm rainfall and 6-hourly time distribution of 48-hr. storm rainfall meets most of the requirements of the design engineers.

Five self-recording raingauge (SRRG) stations maintained by the project authorities are located in this catchment. The locations of these raingauges are given in the map of the catchment (fig.1). The list of stations and the period of data used for each station is given in Table 6.

TABLE - 6

List of Self Recording Raingauge Stations with period of hourly data available.

S.No.	Station	Period of Record	No. of Yr.
1.	Sainj	1969 to 1979	11
2.	Larji	1969 to 1979	11
3.	Banjar	1969 to 1979	11
4.	Janjhali	1969 to 1979	11
5.	Pandoh	1969 to 1979	11

The criterion adopted for selection of 24-hr. and 48-hr. rainspells for time distribution analysis was as under :

i) 24-hr. rainspell

A minimum rainfall of 5 cm. in 24 hours with at least 15 rainy clock hours and break between successive spells not exceeding 3 consecutive hours at any stage within the rainspell duration.

ii) 48-hr. rainspell

A minimum rainfall of 7 cm. in 48 hours with at least 33 rainy clock hours and break between successive spells not exceeding 6 consecutive hours at any stage within the rainspell duration.

For selection of these rainspells, clock hour data of 2 to 3 calender days were scanned in each case and any consecutive 24-hr. and 48-hr. rainspells which satisfied the above criteria were finally selected for time distribution studies.

Time distribution analysis was carried out on the basis of 3 consecutive clock hour durations rainfall data in respect of each rainspell of 24-hr. and 48-hr. period. 3 hourly values of rainfall in each storm was arranged in such a fashion that the maximum 3-hr. rainfall in a particular storm was placed in the initial time period and cumulative maximum raindepth values of 6,9.....21-hr. durations in respect of 24-hr. rainstorms and similar values of 6,9,12... 45-hr. durations in respect of 48-hr. rainstorms were worked out using the rainfall values in the adjacent time period without disterbing the sequence relationship between the successive hour values. These cumulative values were converted into percentages of total storm rainfall. The percentages thus obtained for each 24-hr. storm at a particular station were plotted on a graph as dimensionless curves with cumulative percentage of total rainfall along Y-axis against percentage of storm duration along the X - axis. Similarly time distribution curves were drawn seperately for each station in respect of 48-hr. storms. These curves were enveloped for each SRRG station considered for the study and finally a single mean envelope time distribution curve was derived by plotting the envelope time distribution curves of different stations on a single graph. The mean envelope time distribution of 24-hr. and 48-hr. storm rainfall computed on the basis of hourly rainfall data of SRRG stations listed in Table 7 are given below :

TABLE - 7

Time distribution values (%) of 24-hr. and 48-hr. storm rainfall recommended for Pandoh Project in Himachal Pradesh.

Duration (Hrs)	% of 24-hr. storm rainfall	% of 48-hr. storm rainfall
3-hr.	37	22
6-hr.	53	34
9-hr.	68	44
12-hr.	81	52
15-hr.	90	61
18-hr.	96	69
21-hr.	99	75
24-hr.	100	80
30-hr.		89
36-hr.		96
42-hr.		100
48-hr.		100

This time distribution is recommended for Pandoh dam project for 24-hr. and 48-hr. storm rainfall.

10. CONCLUSIONS

From this study the following broad conclusions may be drawn :

a) From the examination of all heavy rainspells that occurred over this mountainous catchment during the period 1951-1979, it is observed that the rainstorm of 3-5 October, 1955 has contributed the highest average depths of 7.9, 15.6 & 19.6 cm for 1,2 & 3-day durations over this project area. It is likely that higher depths may be obtained if the rainfall data for a sufficiently long period were available.

b) The two methods have been discussed in this paper which may be suitable on occasions with inadequate data as it usually happens in mountainous catchments. The Probable Maximum Precipitation (PMP) values as evaluated by both these methods for Pandoh Catchment are noted below :

Duration	PMP Values evaluated by Conventional Method	PMP Values evaluated by Proposed Alternate Method
1 - day	17.1	16.0
2 - day	25.1	25.5
3 - day	28.4	27.9

From the above figures it appears that the alternate method of converting the highest recorded point rainfalls in and around the catchment to areal rainfalls on the basis of Depth-Area relations derived for various durations from analysis of major rainstorms that occurred in the close proximity of the catchment where the topographical features and storm characteristics are sufficiently alike to that of the catchment under study gives fairly good agreement with the conventional technique. Hence, it is tentatively concluded, subject to further application to different catchments, that the alternate method proposed in section 8 is quite suitable for PMP estimates.

c) Time distribution values of 24-hr. and 48-hr. storm rainfall to be adopted for Pandoh dam project have been worked out and are given in Table 7.

11. ACKNOWLEDGEMENT

The authors are grateful to Dr. P.K. Das, Director General of Meteorology for his encouragement in research and his kind permission to present the paper. The authors are also grateful to Dr. D.V.L.N. Rao Director (Hydrometeorology) for going through the paper and offering valuable suggestions. Thanks are also due to S/Shri. Praveen Kumar & A.S. Dabas for their assistance in compilation and computation of the data and to Shri Devender Sharma for typing the manuscript.

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Estimation of Probable Maximum Precipitation Depth for Ravi Catchment Upto Thein Dam Site

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ABSTRACT

In this paper an attempt has been made to evaluate Probable Maximum Precipitation estimate for the hilly catchment of River Ravi upto Thein Dam site. Major rainstorms which affected the region have been studied in detail and the heaviest storm depths for different durations estimated. The heaviest rainstorm has been maximised for moisture charge for obtaining maximum probable precipitation values.

Time distribution studies of storm rainfall have also been carried out and the results discussed in detail.

INTRODUCTION

The river Ravi rises in Kulu hills in Himachal Pradesh and enters the plains near Madhopur. It has a catchment area of about 6,000 sq. km. in India. The river is being guaged at Thein since 1962, ten miles down stream at the Punjab/Himachal Pradesh border in connection with the proposed dam at Thein.

The river flows in Himachal Pradesh for about 160 km. after which it enters the Punjab territory where it forms a boundary line between Jammu and Kashmir and Punjab state. The catchment map of river Ravi upto Thein Dam Site is shown in Fig. 1.

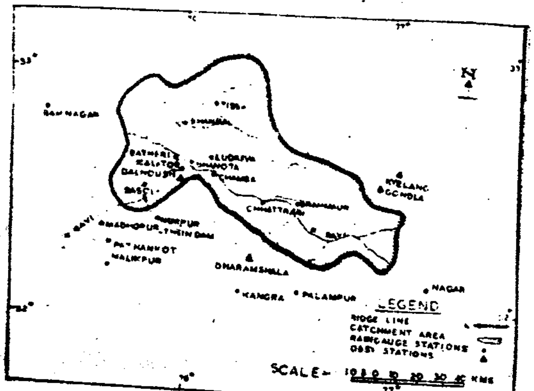

FIG. I RAVI CATCHMENT UPTO THEINDAM

There are 11 raingauge stations in the catchment for which daily rainfall data are available. Rainfall data in the catchment was inadequate prior to 1951 as there were only two stations at Dalhousie and Basohli. Thereafter the number has increased to eleven. There are two observatory stations one at Chamba and other at Dalhousie in the catchment. Self-recording raingauge exists at Dalhousie.

The raingauge station at Madhopur which does not fall in the catchment of River Ravi upto Thein Dam site represents the rainfall conditions of the dam site, being near to it and is equipped with self-recording raingauge as well. In the present study the daily rainfall data for the period 1951-'79 have been utilised. The average annual rainfall in the basin on the basis of available rainfall data works out to 150 cms. About 50% of this rainfall occurs during southwest monsoon season.

DESIGN STORM STUDY

The choice of the method for design storm evaluation depends mainly on the catchment characteristics, its location and the amount and quality of available rainfall data. In the present case, the catchment under study has a well marked topography and also rainfall data were not available for a sufficiently long period so as to follow the usual statistical technique for obtaining design depths. The choice has, therefore, been restricted to physical approach only by duly considering the high ridges between the adjacent catchments.

In this context an exhaustive study of all the major rainstorms which occurred in and near the basin was carried out and the available daily rainfall data were examined. All those rain spells during which a number of stations recorded heavy rainfall on one or more of the days were picked up from the rainfall volumes available with I.M.D. and analysed in detail. The flood records for river Ravi were were also duly considered for preliminary selection of rainstorms. The following three major storms were further picked up for detailed isohyetal analysis for estimating design depths for different durations.

(1) 03 to 05 October, 1955
(2) 08 to 10 August, 1973
(3) 15 to 17 July, 1975

The study revealed that the storm of 3-5 October, 1955 is the heaviest on record so far and yielded maximum rainfall depths for one day, two day and three day duration.

The isohyetal pattern for the rainstorm of 3-5 October, 1955 for one day, two day, three day durations are given in figures 2 to 4 and Depth-Duration curves in figure 5.

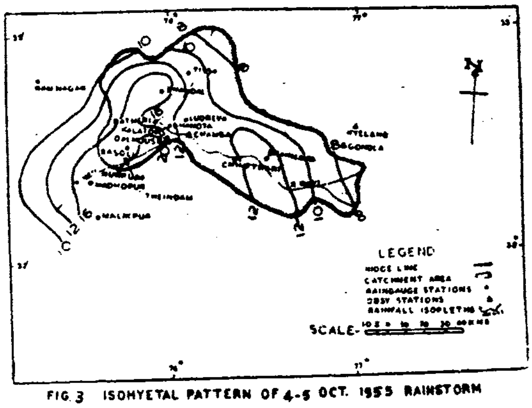

FIG. 3 ISOHYETAL PATTERN OF 4-5 OCT. 1955 RAINSTORM

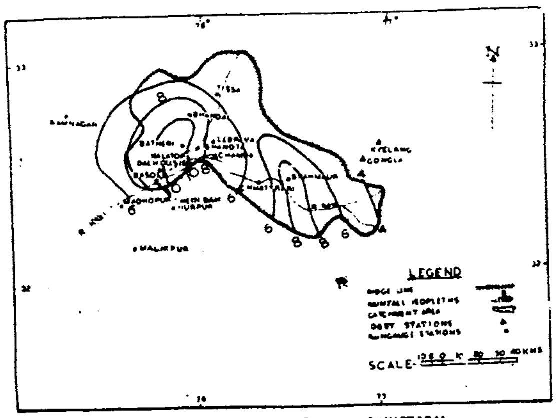

FIG. 2 ISOHYETAL PATTERN OF 4 OCT. 1955 RAINSTORM

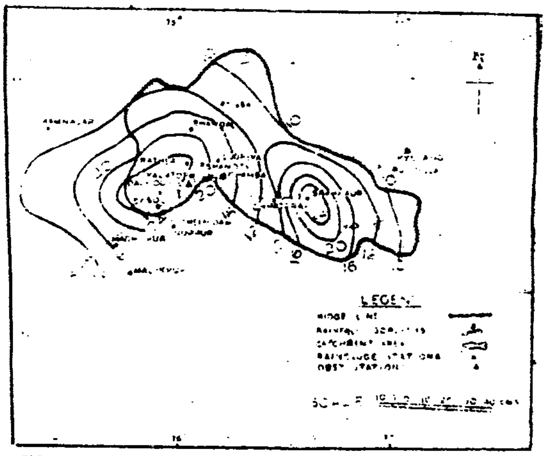

FIG. 4 ISOHYETAL PATTERN OF 3-5 OCT 1955 RAINSTORM

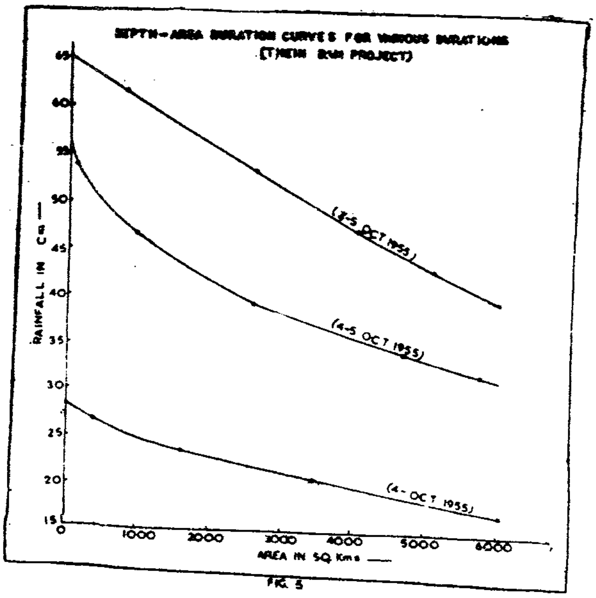

FIG. 5

Isohyetal analysis of this rainstorm was carried out by judiciously considering the topography and behaviour of rainfall. The normal procedure of drawing isohyetals has not been followed in this particular case. The isohyetals have been drawn in such a way that they do not cut the high ridges due to the fact that ridges break the continuity of rainfall on either side. Isohyetal depths for different durations, as worked out by considering the catchment as unity, were adopted as standard project storm (SPS) values for the catchment and are given below:

Storm Period	Duration	Standard Project Storm Value
4 October, 1955	1-day	17.0 cm.
4-5 October, 1955	2-day	31.4 cm.
3-5 October, 1955	3-day	39.7 cm.

ESTIMATION OF PROBABLE MAXIMUM PRECIPITATION (PMP)

The Probable Maximum Precipitation (PMP) which represents the physical upper limit to storm rainfall can be estimated by multiplying the highest recorded depth over a basin by a factor which represents the most effective combination of dynamic efficiency inflow winds and maximum moisture charge. Bruce (1959) assumed that the highest rainfall recorded over a basin represents the most effective combination of storm efficiency and inflow winds and for obtaining PMP values. The moisture adjustment factor (MAF) is defined as the ratio of maximum total moisture in an atmospheric column of unit cross section in the region to the total moisture in a similar column prevailing during the storm period. In order to compute MAF, the maximum precipitable water and the precipitable water prevalent duing the storm period were picked up from the modified U.S. weather, diagram prepared by Parnanpik and Hariharan (1951) on the basis of highest and the prevalent surface dew point temperatures. The MAF in this case works out to be 1.45 for the highest storm. The M.A.F. thus obtained was applied to the Standard Project Storm values to compute the PMP values for different durations and are given below:

Duration	Probable Maximum Precipitation (PMP) Value
1-day	24.7 Cm.
2-day	45.5 Cm.
3-day	57.6 Cm.

A conversion factor of 15% is applied to one-day value given above for obtaining any 24-hour value.

Storm transposition technique has not been applied to this catchment for the well-known reason that the rainstorms of the mountainous regions having height more than one Km. cannot be transposed as the magnitude and the areal distribution of precipitation are conditioned by the topography and no other satisfactory procedure is available. In order to check that the PMP values obtained above are consistent with the requirements of the design criterion, these values were compared with the areal depths obtained by using the highest ever recorded point rainfall values of all the raingauge stations in and around the catchment and the values were found to be quite comparable.

A statement showing the heaviest 24-hour rainfall recorded at all the raingauge stations in the Project Catchment is given in Table 1.

TABLE - I

HIGHEST 24-HOUR (OBSERVATIONAL DAY) RAINFALL AT THE STATIONS OF RAVI CATCHMENT UPTO THEIN DAM SITE

Station	Rainfall (mm)	Date	Date available from
Tissa	230.4	17-02-1964	1951
Bhandal	203.0	09.02.1966	1951*
Ludreva	200.0	12.09.1961	1951
Batheri	284.5	04.10.1955	1951
Bhanota	223.5	05.10.1955	1952@
Chamba	157.5	04.10.1955	1951
Dalhousie	287.0	05.10.1955	1870
Chhatrari	275.0	05.03.1979	1951
Bharmour	226.1	04.10.1955	1951@
Basoli	228.6	04.10.1955	1901
Kalatop	279.0	08.09.1966	1951

* Out of order in October, 1955.
@ Data received from Project authorities.

SYNOPTIC SITUATION RESPONSIBLE FOR THE RAINSTORM OF 3-5 OCTOBER, 1955

The project catchment is situated in the Western Himalayas with a large area lying above about 1,500 meters. The catchment generally receives heavy rainfall during post monsoon season, i.e., during the late September or early October although heavy rainfall also occurs during south west monsoon season (June-September). The synoptic situation associated with the October, 1955 storm is given below.

Southwest monsoon started withdrawing from Punjab and adjoining North-west India from 15th September, 1955 but started reviving again later in association with a Bay of Bengal depression which moved towards the region. This depression became deep and was centred near Jhalawar in east Rajasthan on 3.10.1955. On 4th October, 1955 it intensified further and remained stationary causing exceptionally heavy rain at some places in Punjab and Himachal Pradesh. The intense rainfall activity continued in this region when this depression became weak and lay over Punjab on 5th October, 1955. On the next day it filled up and caused fairly wide spread rainfall in the region. Torrential rain occurred in the region, of the catchment during the first week of October, 1955 not only due to this depression, but also due to the movement of Westerly Wave across the Himalayas. The southwest monsoon withdrew from this region during the middle of October, 1955.

The design engineers generally require 3-hourly or 6-hourly time distribution of storm rainfall of one-day and two-day rainstorms for determining storm hydrograph characteristics. An attempt has been made to compute time distribution of storm rainfall for the Ravi catchment on the basis of available clock hour rainfall data of four stations, viz., Pathankot and Madhopur for plain area of the catchment and Dalhousie and Dharamshala for hilly area of the catchment.

The procedure adopted for selection of rainstorms for time distribution analysis was that break in rainfall should not ordinarily exceed 3 consecutive hours and there are at least 15 to 18 rainy hours in 24-hour storms and not more than 6 consecutive hour break and at least 33 to 36 rainy hours in case of 48-hour storms. For selection of these storms clock hour data of 2 to 3 observational days were scanned in each case and any consecutive 24-hour and 48-hour spells during which maximum rainfall was recorded, were selected.

Time distribution analysis was carried out on the basis of 3 consecutive clock-hour durations rainfall data in respect of each rainstorms of 24-hour and 48 hour periods. In each rainstorm any 3-hour duration in which maximum rainfall was recorded, was selected. This maximum rainfall value of each storm was expressed as percentage of 24-hour and 48-hour rainfall value as the case may be. The same procedure was followed for obtaining corresponding percentage ratios for 6-hour, 9-hour, 12-hour, 18-hour and 21-hour durations maximum rainfall in respect of 24-hour rainstorms and the same procedure was followed in respect of 48-hours storms. The percentage thus estimated for each duration for each storm were plotted against durations and time distribution curves obtained separately for all the 24-hour and 48-hour storms of the four stations considered representative for the Ravi catchment.

Since the catchment is mostly hilly, separate time distributions for 24-hour and 48-hour storms for plain and hilly areas have been computed on the basis of available clock hour rainfall data of four stations.

The percentage time distribution for 24-hour and 48-hour storms on the basis of available clock hour data for plains based on Madhopur and Pathankot as well as hilly areas based on Dalhousie and Dharamshala are given in Table 2 and Table 3 respectively.

TABLE - 2

ENVELOPING TIME DISTRIBUTION OF STORM RAINFALL BASED ON PATHANKOT AND MADHOPUR SELF RECORDING RAINGAUGE DATA
(Plain Area)

Duration (hours)	Percentage of 24-hour storm rainfall	Percentage of 48-hour storm rainfall
3	54	29
6	69	43
9	83	55
12	93	65
15	97	73
18	100	80
21	100	86
24	100	91
27		94
30		96
33		97
36		98
39		98
42		99
45		100
48		100

TABLE - 3

ENVELOPING TIME DISTRIBUTION OF STORM RAINFALL BASED ON DALHOUSIE AND DHARAMSHALA SELF RECORDING RAINGAUGE DATA
(Hilly Area)

Duration (hours)	Percentage of 24-hour storm rainfall	Percentage of 48-hour storm rainfall
3	51	45
6	70	55
9	82	63
12	89	69
15	95	75
18	99	80
21	99	84
24	100	87
27		91
30		94
33		96
36		98
39		99
42		99
45		100
48		100

CONCLUSIONS

The average annual rainfall of the Ravi Basin upto Thein Dam Site is of the order of 150 cm. out of which about 50% occurs during the southwest monsoon season, i.e., from June to September.

The foregoing study revealed that the storm of 3-5 October, 1955 was the severemost for this hilly catchment so far and contributed highest depths for various durations.

The moisture maximisation factor computed on the basis of surgace dew point temperature data for the haviest storm of 3-5 October, 1955 worked out to be 1.45.

The time distribution values obtained for plain as well as hilly region separately are of great importance to the design Engineers for the purpose of evaluation of design flood by Unit Graph method depending on the locations of storm centre

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The authors are grateful to Dr. P.K. Das, Director General of Meteorology for his encouragement in research and for kind permission to present this paper. The authors are thankful to Dr. D.V.L.N. Rao, Director (Hydrometeorology) and Shri S.C. Sharma, Meteorologist, for their encouragement and interest in the study. They are also thankful to S/Shri A.S. Dabas and P.K. Kapoor for their valuable assistance and Shri Raveendran. G. for typing this paper.

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Distribution of Rainfall in the Himalayan and Sub-Himalayan Regions During 'Breaks' in Monsoon

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ABSTRACT

The distribution of rainfall over the Kosi Himalayas and its submontane area to the south has been studied for all the 'break' monsoon situations which occurred during the 21-year period from 1949 to 1969. Only those 'break' situations were considered whose duration was 3 days or more. In this study it was found that during a 'break' situation, besides the axis of monsoon trough remaining close to the foot-hills of Himalayas, there were other weather systems which affected the region. Considering these, rainfall distribution was also studied for different categories of 'breaks'. Besides the Kosi Himalayas, a preliminary rainfall study was made in respect of Sikkim Himalayas and its submontane area, in order to see whether the results obtained for the Kosi Himalayas also hold good for this section of the Himalayas.

INTRODUCTION

During the southwest monsoon season (June-September) the seasonal monsoon trough axis normally lies over the Indo-Gangetic plains and passes through Sriganganagar-Kanpur-Allahabad-Calcutta. On certain occasions, this trough axis gets shifted northwards from its normal position to the foot-hills of Himalayas causing a considerable decrease in the rainfall activity over most parts of the country. This particular synoptic situation is known as the 'break' monsoon condition, to the Indian meteorologists.

Althouth rainfall activity over most parts of the country decreases during 'breaks', it has been noticed that the incidence of rainfall considerably increases over the Himalayan and sub-Himalayan regions. As such, during these 'break' periods rivers in North Indian plains, which rise in the Himalayas, experience severe flooding.

The meteorology of 'break' situations and the distribution of rainfall during 'breaks' over the country have been studied by several workers [Koteswaram(1950), Parthasarathy (1958), Ramaswamy(1962), Ramamurthy (1969), Raghavan(1973), Raman & Rao (1980), Pant(1980)] but the incidence of rainfall over the Himalayas visa-vis these 'breaks' could not be studied due to paucity of a good network of rainfall stations in this region. In recent years, rainfall data of a fairly good network of rainfall stations has become available for the Kosi Himalayas and neighbourhood. With the help of this data an attempt has been made in this paper to study the distribution of rainfall in the Kosi section of the Himalayas and the submontane area to its south, during 'break' situations.

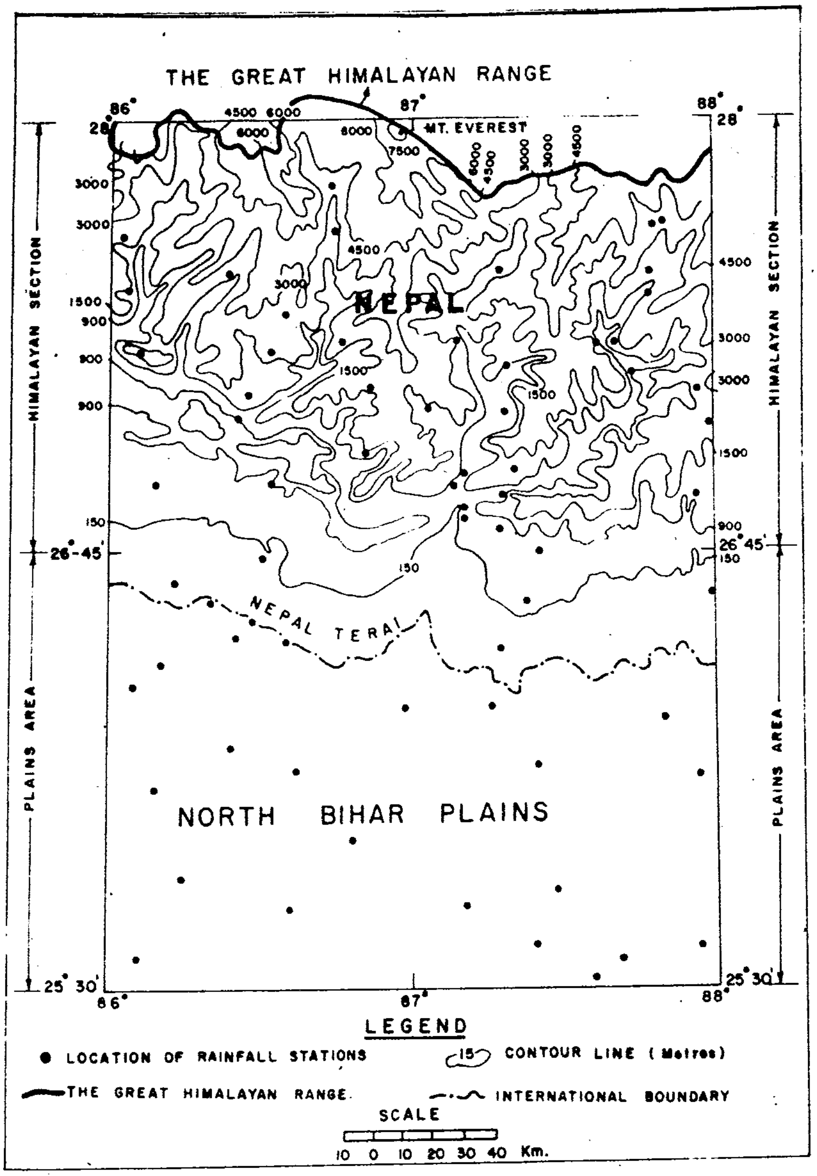
HIMALAYAN AND SUB-HIMALAYAN SECTIONS CONSIDERED

(a)Himalayan section: The Kosi Himalayas lying between Lat.26°-45'N to 28° N and Long.86° E to 88° E. was considered in this study. There are 37 rainfall stations located in this section of the Himalayas whose heights vary from about 150 metres to 3500 metres asl.
(b)Sub-Himalayan section: This area lies between Lat.25°-30'N to 26°-45'N & Long.86° E to 88° E. In other words, this section lies exactly south of the Kosi Himalayan section and is comprised of the plain areas of Nepal Terai and North Bihar. There are 30 rainfall stations in this area.

Thus, the Himalayan and sub-Himalayan(or submontane) sections considered in this study lie between Lat. 25°-30'N to 28° N and Long.86° E to 88° E and contain in all 67 rainfall stations(see Fig.1)

'BREAKS' CONSIDERED

All the major 'break' situations which lasted for 3 days and more were considered for this study, for the 21-year period from 1949 to 1969. It



THE HIMALAYAN AND PLAINS AREAS CONSIDERED FOR 'BREAK' MONSOON RAINFALL STUDY.

FIG. 1

was found that there were 26 such 'break' situations during this period. The list of these 'breaks' is given in Table 1. It can be seen from this table that there were in all 149 'break' days for this study.

CATEGORIES OF 'BREAKS'

It was noticed from an examination of daily weather reports and synoptic weather charts that on some 'break' days when the axis of the seasonal monsoon trough was close to the foot-hills of Himalayas, there were other weather systems which also affected the area under consideration. According to these weather systems, the sample of 149 'break' days was divided into the following categories :-

(a) 'break' days when westerly waves/western disturbances moved eastwards across the Himalayas. Out of a total of 149 'break' days there were 28 such days.

(b) 'Break' days when surface lows appeared in the neighbourhood of the areas considered in this study. There were 22 such days.

(c) 'Break' days when the eastern portion of the monsoon trough axis got shifted southwards from the foot-hills. This situation was present on 17 days.

(d) 'Break' days when the Arabian Sea branch of the monsoon current was weak. This situation was there on 6 days, viz. 4th to 9th July, 1966 as the circulation pattern during these 6 days was similar to that of the month of May (Ramamurthy, 1972).

(e) 'Break' days when there was no other synoptic situation present except the monsoon trough axis lying close to the foot-hills of Himalayas. There were 82 such days.

Taking the above categories of 'break' days into consideration, rainfall distribution over the Kosi Himalayas as well as the submontane area south of it, was studied.

PROCEDURE FOLLOWED

Using the monthly total rainfall data of 10-year period from 1956 to 1965, mean daily rainfall for each of the 67 stations were worked out for the principal monsoon months of July and August, during which 'break' monsoon situations mostly occur. With the help of average daily rainfall data of individual stations, mean daily rainfall of the Himalayan as well as the submontane areas were then worked out.

In the same manner, using rainfall data of individual stations on 'break' days, average daily rainfall for the two areas were calculated for each of the 149 'break' days. On the basis of this data, average daily rainfall for each category of the 'breaks' was calculated for the two areas and these averages were expressed as percentages of the respective mean daily rainfall of the two areas. Table 2 gives these rainfall percentages for different categories of 'break' situations.

RESULTS OBTAINED

It is seen from Table 2 that if all the 149 'break' days were considered together, the rainfall on a 'break' day was 190% and 211% of the mean daily rainfall over the Himalayan and the submontane areas respectively.

A study of Table 2 also shows the following :-

(a) On occasions when a westerly wave/western disturbance happened to move eastwards across the Himalayas, the average rainfall over the Himalayan and the submontane areas were 232% and 312% of their respective mean daily rainfall,

(b) When low pressure areas were present over or near the region under study during 'break' situations, the Himalayan area received 171% while the submontane area received 178% of their respective mean daily rainfall,

(c) On 'break' days when eastern end of the monsoon trough axis shifted slightly south of the foothills, the Himalayan and the submontane areas experienced rainfall which was 168% and 174% respectively of their mean daily rainfall,

(d) When the Arabian Sea branch of the monsoon current was weak during the 'breaks' the Himalayan area received 103% and the submontane area received 54% of their respective mean daily rainfall and

(e) When 'break' days were free from other synoptic weather systems mentioned earlier, the rainfall over the Himalayan area was 186% while over the submontane area it was 192% of their respective mean daily rainfall.

STUDY FOR THE SIKKIM HIMALAYAS

In order to see whether the results obtained for the Kosi Himalayas were also valid for other neighbouring sections of the Himalayas, the same type of study was also carried out for the Sikkim Himalayas and its submontane area. This region of the Himalayas is to the east of the Kosi Himalayas and in connection with North Bengal floods of 1955 & 1956, a good network of rainfall stations was installed in this region. At the time of this study, for this area rainfall data were available for only a few 'breaks'. This study was therefore carried out for 36 break days, for which data were readily available. It was seen that in this region also an increase in rainfall was experienced during the 'break' periods. The Sikkim Himalayas received 162% of its mean daily rainfall while the submontane area to its south experienced 221% of its respective mean daily rainfall. In other words the increases in rainfall over the two areas in this section of the Himalayas was comparable to that over the Kosi Himalayas and its submontane area. A more detailed study for this region is being carried out.

SUMMARY AND CONCLUSIONS

Broad conclusions from this study are as follows :-

(a) During 'break' monsoon situations the rainfall over the Himalayan as well as the submontane areas increases considerably and it is observed that percentage increase in rainfall is generally more over the submontane area,

(b) On a 'break' day in general and on a 'break' day when there are no other synoptic weather systems present, both the areas receive almost double of their respective mean daily rainfall,

(c) When other synoptic weather systems are present on a 'break' day, the distribution of rainfall gets modified as mentioned below :-

(i) When a westerly wave/western disturbance happens to be present on a 'break' day, the Himalayan area gets more than double and submontane area experiences more than three times their respective mean daily rainfall. In other words, the sub-Himalayan area is affected far more than the Himalayan area in this particular situation.

(ii) When low pressure areas are present in the neighbourhood or when the axis of the monsoon trough gets shifted southwards on a 'break' day, both the Himalayan and submontane areas are equally affected. Both these areas receive about 175% of their respective mean daily rainfall.

(iii) During a 'break' situation when the Arabian Sea branch of the monsoon current is weak, the Himalayan area appears to be not affected and receives almost its mean daily rainfall. In this particular situation, the submontane area experiences deficit rainfall which can be half of its mean daily rainfall, during this particular situation.

(d) It has been noticed that during 'break' periods Sikkim Himalayas and its submontane area also experience considerable increase in rainfall which is quite comparable with the results obtained for the Kosi Himalayas and its submontane area.

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TABLE 1 'Break' Monsoon Periods Considered

No.	Year	'Break' Period	No. of days
1	1949	19-23 July	5
2	1949	21-25 August	5
3	1950	15-24 August	10
4	1951	1-3 July	3
5	1951	11-17 July	6
6	1951	24-29 August	6
7	1952	9-12 July	4
8	1953	24-26 July	3
9	1954	18-29 July	12
10	1954	21-25 August	5
11	1955	22-29 July	8
12	1956	20-26 August	7
13	1957	27-31 July	5
14	1957	5-7 August	3
15	1958	10-14 August	5
16	1959	16-18 August	3
17	1960	16-21 July	6
18	1962	18-22 August	5
19	1963	10-13 July	4
20	1963	17-21 July	5
21	1964	14-18 July	5
22	1965	6-8 July	3
23	1965	4-15 August	12
24	1966	2-11 July	10
25	1966	23-27 August	5
26	1967	7-10 July	4
Total number of 'break' days = 149			

TABLE 2 Average Rainfall on a 'Break' Day Expressed as a Percentage of Mean Daily Rainfall

Category of 'breaks'	No. of days	Area considered	Average rainfall* as % of mean daily rainfall
General: All 'break' days considered together during 1949-1969.	149	Himalayan area	190
		Submontane area	211
a: 'Break' days when, westerly waves/ western disturbances were moving along the Himalayas.	28	Himalayan area	232
		Submontane area	312
b: 'Break' days when surface lows were present over or near the area under study.	22	Himalayan area	171
		Submontane area	178
c: 'Break' days when eastern end of the monsoon trough axis shifted south of the foot-hills of Himalayas.	17	Himalayan area	168
		Submontane area	174
d: 'Break' days when the Arabian Sea branch of monsoon current was weak.	6	Himalayan area	103
		Submontane area	54
e: 'Break' days with no other synoptic situations were present except the trough axis lying near the foot-hills.	82	Himalayan area	186
		Submontane area	192

* Rainfall averages over the two areas were worked out by both the Arithmetic and isohyetal average methods. It was, however, noticed that with the present network of stations in these areas both the methods gave almost identical values of average areal rainfall.

A Case Study of Rain Storm in the Eastern Mountainous Catchments of Brahmaputra Leading to Highest Ever Recorded Flood Level at Dibrugarh

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ABSTRACT

Dibrugarh recorded the highest ever flood level of 346.5 ft. on 16th August 1977. The rainfall over the eastern mountainous catchment between 11th and 17th August 1977 is analysed. Isohyetal analysis for - periods of one day to seven days were made. Depth area curves for heaviest one day and heaviest two days are presented. The Horton constants 'K' and 'n' in the formula giving the Depth Area Curve

$$\frac{\overline{P}}{P_0} = e^{-KA^n}$$

are 0.004972 and 0.599 for one day and .009152 and 0.50683 for two day storm. Comparison of the two days envelope curve for the 103 storms in Brahmaputra plains with the two day curve of August 1977 storm, shows that August 1977 storm yield is higher and storms of greater depth on this region cannot be ruled out.

The higher flood level reached is greatly due to the rainstorm and the part played by aggredation of river bed needs study and co-ordination in assessing the return period of high flood level in future. Synoptic situation leading to the rainstorm is discussed.

1. INTRODUCTION

1.1 The river Brahmaputra is the mightiest of the Himalayan rivers in the Indian subcontinent, causing floods every year in various regions of its catchment. The river has its origin in the great glacier in the northern most chain of the Himalayas in the Kailash range, at an elevation of 5150 metres, south of lake Kanggya Tsho in Tibet. After flowing about 1700km in easterly direction in Tibet, at elevations about 3600 m., the river abruptly turns northeast in a hair-pin bend, cuts the Himalayas, at a few kilometres east of Namcha Barwa (7756 m.) then turns south and southwest and emerges from the foot hills as Siang, and then Dihang. The river crosses the Sadia frontier and enters Assam valley in the west of Sadia town. It receives two other tributaries from the eastern hilly tracks; Dibing and Lohit. From the confluence of all the three, it is named Brahmaputra, flows in a westerly direction for about 720 km before turning south towards Bay of Bengal through Bangladesh. Dibrugarh is situated in a short distance of about 100 km from the beginning of the Brahmaputra, all the waters of the main river and the two tributaries flow along this city. The catchment to the east of Dibrugarh is a large part of elevations, higher than a kilometre. In 1950, the entire region experienced a severe earthquake which caused many land slides, river bed aggradation etc. the region is in the Seismic belt experiencing shocks of minor nature for a long time.

1.2 At Dibrugarh the river recorded highest ever recorded flood level of 346.5 ft. on 16th August 1977 as a result of a two day rainstorm that occurred on 15/16 Aug. 1977. The present study gives the salient features of this storm.

2. Synoptic Situation

2.1 Major rainfall in the Brahmaputra basin takes place in the monsoon season. The axis of the monsoon trough normally runs from Rajasthan to Head Bay of Bengal. It meanders about the mean position in relation to the development of low pressure over the Head Bay. When the eastern part of the monsoon trough shifts to the foot of the Himalayas, the basin gets copious rainfall. The continued duration of this situation is called the Break monsoon situation.

2.2 On 10th August, 1977, the axis of the seasonal trough on sea level chart lay from Bikaner to Gwalior thence to Ambikapur to Northwest Bay. On the 11th the axis shifted northwards and was running through Ferozepur, Meerut, Sultanpur, Purnea and Khonsa, when a western disturbance (which originate in the mid latitudes over Mediterranean) moved away eastwards across extreme north of the country. (The further movements of these disturbance are not seen in the Indian weather charts, but on many occasions, they reappear just north of the eastern region over Tibet and give rise to copious rainfall in the Tibetan part and adjoining Arunachal Pradesh of Brahmaputra catchment). The monsoon axis remained there till 14th and shifted further north to the foot hills of Himalayas on 15th. An upper air trough was seen over West Bengal on 15th and 16th between 0.9 and 2.1 km a.s.l. Eastern end of the monsoon trough shifted southwards to Head Bay from 18th onwards. This synoptic situation is most frequent and is most favourable for heavy rainfall

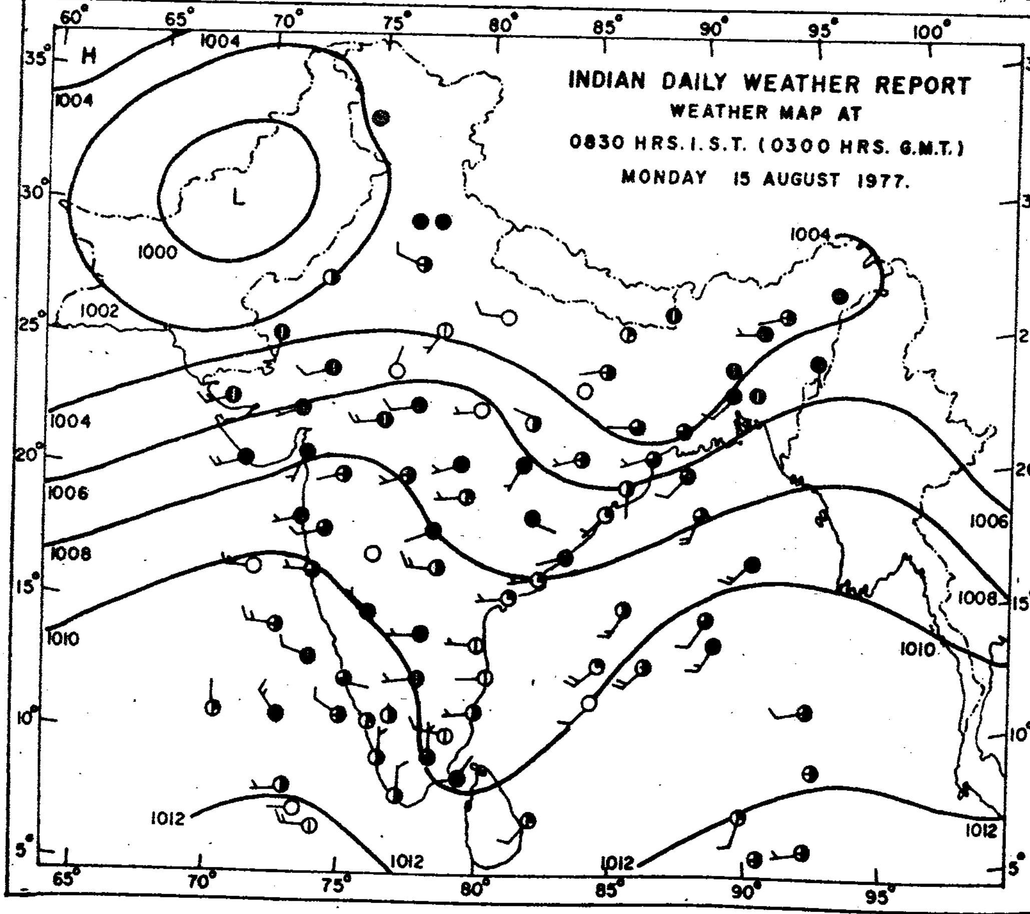

FIG:-1

and flood in this area. The surface analysis of weather chart on 15th August 1977 is shown in figure 1.

3. Rain Storm Analysis

3.1 The river Brahmaputra started rising at Dibrugarh from 11th August 1977 and reached a peak flood level of 346.5 ft. a.m.s.l. on 16th August 1977, the highest ever recorded flood level at Dibrugarh. The level then started receding fast. All the available rainfall records in the region for this period were analysed. Rainfall in this area was the heaviest on 16th August 1977 (rainfall from 0830 hrs. IST of 15th Aug. to 0830 hrs IST of 16th August recorded at 0830 hrs IST of 16th August 1977), considerably heavy on 15th and appreciable rainfall was received on other days from 11th to 17th Aug. 1977 - Isohytel analysis was carried out for one

BRAHMAPUTRA BASIN
ONE DAY STORM 15 AUGUST 1977

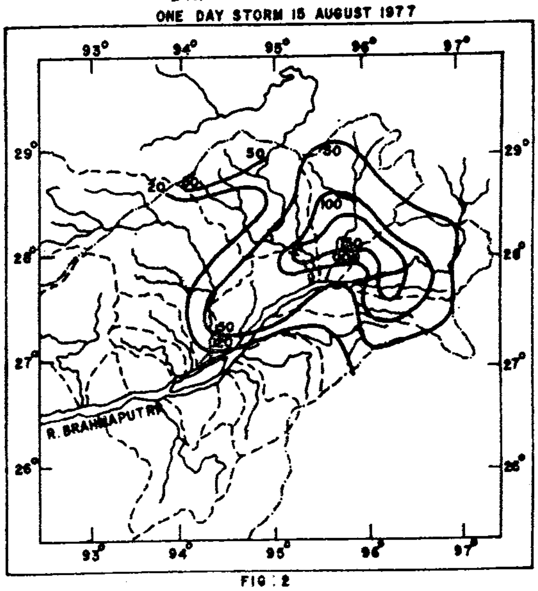

FIG : 2

BRAHMAPUTRA BASIN
ONE DAY STORM 16 AUGUST 1977

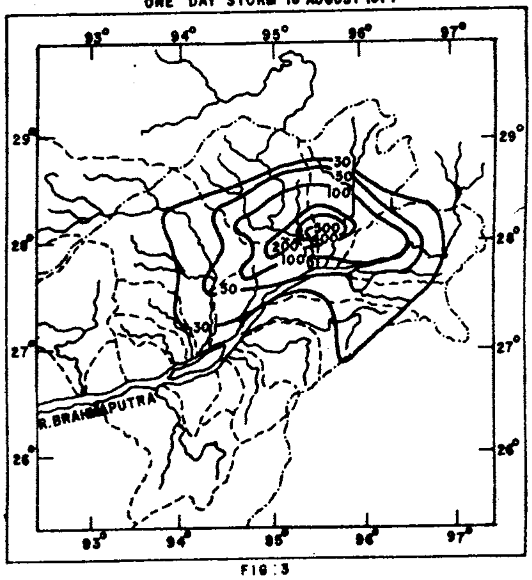

FIG : 3

BRAHMAPUTRA BASIN
TWO DAYS STORM 15-16 AUGUST 1977

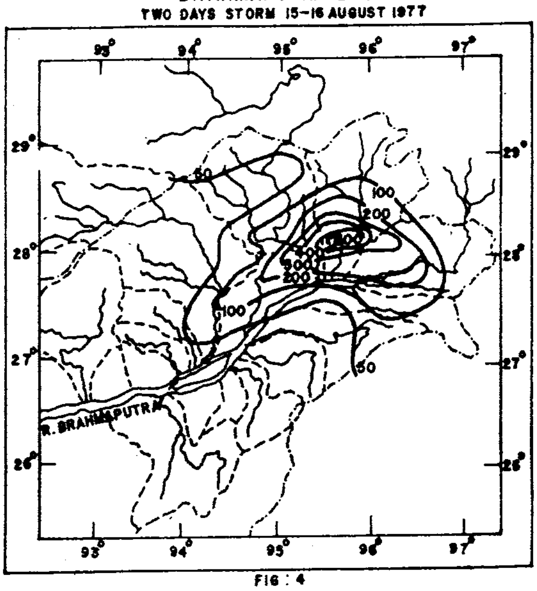

FIG : 4

BRAHMAPUTRA BASIN
THREE DAYS STORM 14-16 AUGUST 1977

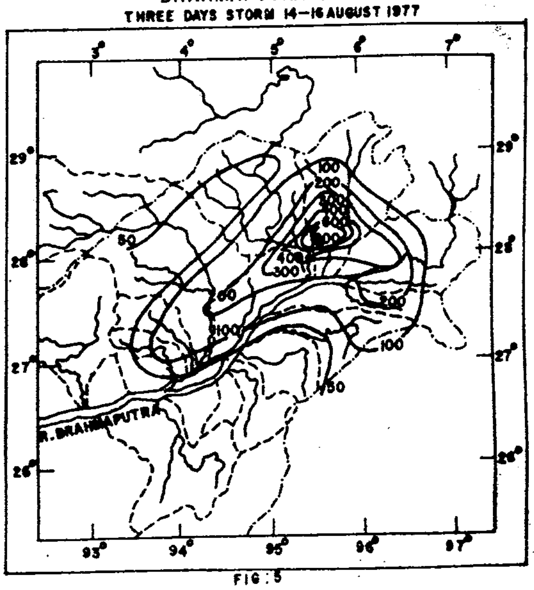

FIG : 5

day storm on 16th August, and 15th August and for durations of two days (15-16), three days (14-16), four days (14-17), five days (13-17), six days (12-17) and seven days (11-17) and given in figures 2 to 9 respectively. From these, the data for depth area curve was tabulated for all the 8 charts. The relevant data for the one-day depth area curve on 16th August 1977 and two days 15th and 16th August, 1977 are given in Table 1.

3.2 The rainstorm occurred in southeastern Arunachal Pradesh and adjoining north-eastern Assam with its centre near Roing and axis of maxima along the foothills. The rainstorm is situated in the region of eastern cell of annual rainfall maxima of the Brahmaputra catchment. On 16th, Roing reported daily rainfall of 74.5 cm heaviest in four years 1974 to 1977 (for which the data of this station are available), while the second highest is 23.3 cms. It is reasonable to presume that extreme heavy rainfall experienced on 16th has a return period of at least ten years. However, rainfall data of stations around reveal that a sharp decrease to less than 20 cms., as we move away from Roing. Central maximum of rainstorm on 16th was more than three

BRAHMAPUTRA BASIN
FOUR DAYS STORM 14-17 AUGUST 1977

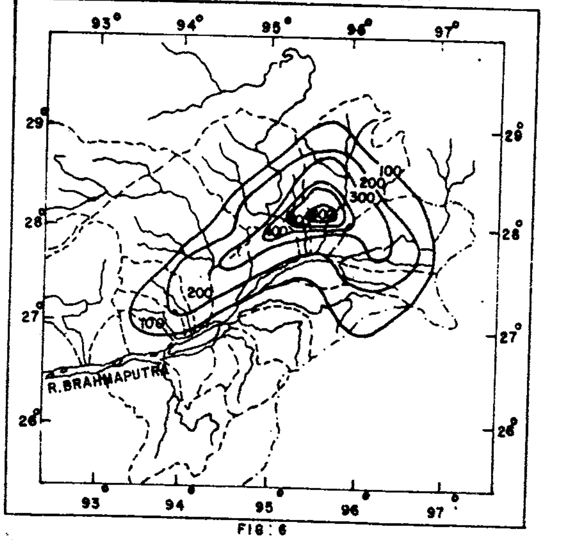

FIG: 6

BRAHMAPUTRA BASIN
FIVE DAYS STORM 13-17 AUGUST 1977

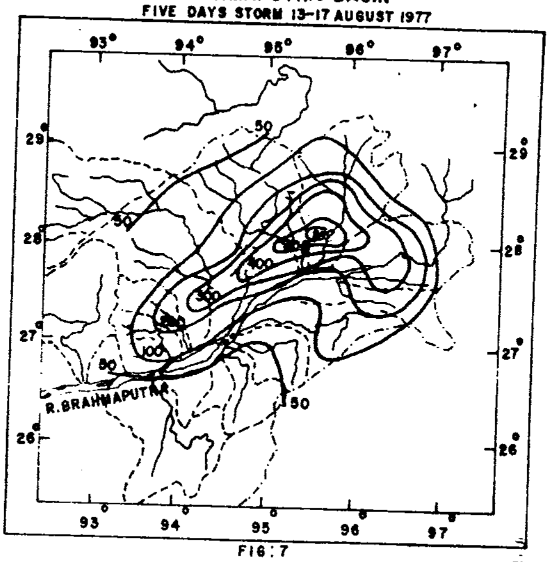

FIG: 7

BRAHMAPUTRA BASIN
SIX DAYS STORM 12-17 AUGUST 1977

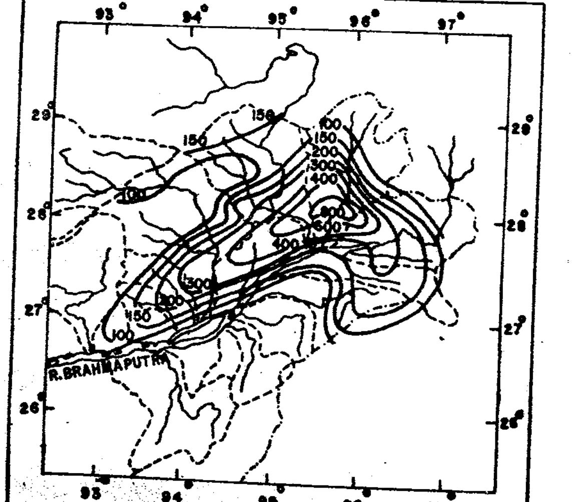

FIG: 8

BRAHMAPUTRA BASIN
SEVEN DAYS STORM 11-17 AUGUST 1977

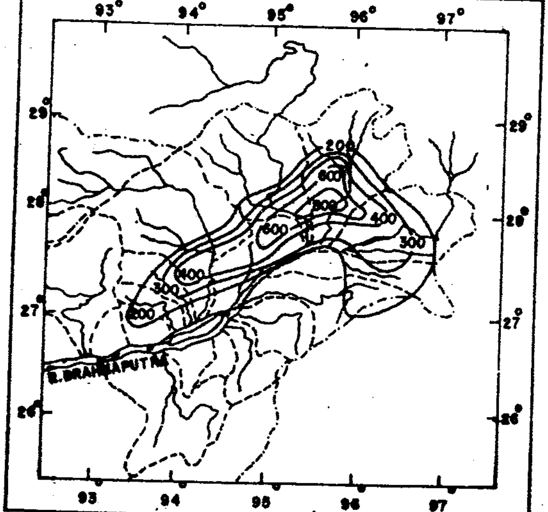

FIG: 9

Table 1

Value of peripheral Isohyet (mms)	Area enclosed by the Isohyet (sq.kms)	Mean rainfall for the segment (mms)	Area of the Segment (sq.kms)	Amount of water received by the segment area x 10^6 cum.	Amount of water received by the area enclosed by P. Isohyet x 10^6 cum.	Average precipitation for the area in col.2 (mms)	Calculated average precipitation for area on the basis of Horton formula
16th August 1977 (one day)							
745.0	-	-	-	-	-	-	-
600.0	220	670	220	147.4	147.4	670.0	704
400.0	780	500	560	280.0	427.4	548.0	585
200.0	2750	300	1970	591.0	1018.4	370.3	441
100.0	11000	150	8250	1237.5	2255.9	205.0	229
050.0	21630	075	10630	797.3	3053.2	141.1	128
Horton constant K = .004472 n = .599							
15th & 16th August 1977 (two day)							
945.0	-	-	-	-	-	-	-
800.0	120	870	120	104.4	104.4	870.0	852
600.0	480	700	360	252.0	356.4	742.5	767
400.0	1840	500	1360	680.0	1036.4	563.3	625
300.0	3910	350	2550	892.5	1928.9	493.3	516
200.0	9730	250	7180	1795.0	3723.9	328.7	381
100.0	22240	150	15060	2259.0	5982.9	269.0	219
Horton constant K = .009152 n = .50683							

times that on 15th. Over an area of 8000 sq.kms. around the storm centre the average depth of precipitation on 16th was one and a half time that on 15th. But there was little difference when 30,000 sq.kms. around the storm centre was taken into consideration. It appears that heavy rainfall for two consecutive days must have been from a rainstorm of severity not commonly experienced by that area.

3.3 Horton (1924) found that depth area curve could be represented by -

$$\bar{P} = P_o \, e^{-KA^n}$$

in which $\bar{P}$ is the average depth of rainfall for given duration over an area A, P_0 is the highest amount at the centre of the storm, 'K' and 'n' are constants for a given storm.

3.4 The 'K' and 'n' constants for this storm for maximum one day rainfall (16th August 1977) and two days rainfall (15th and 16th August 1977) were evaluated by least square technique and are given in Table 1.

3.5 The average precipitation for the diffrent isohytels were also computed using the constants and given in the last column on Table 1. They appear to compare reasonably well with the actuals.

3.6 Considering such a heavy storm is not of an common nature, the 'K' and 'n' values evaluated could be used for other storms in the area for the extrapolation purposes.

4. Comparison with the earlier study

4.1 Pant et al (1970) have examined 103 major rain storms occurring in the plains of Brahmaputra from 1901-1960 and presented enveloping depth area curves for 2, 3, 4 days and depth area curves of heaviest 2 days storm and 3 days storm. The D.A.D. curves for 15th August 1977, 16th August 1977 and 15th-16th August 1977 are shown in figure 10 by solid lines. Envelopes of two days storms as obtained from the study of 103 storms and the heaviest two day storm as experienced on 6-7 October

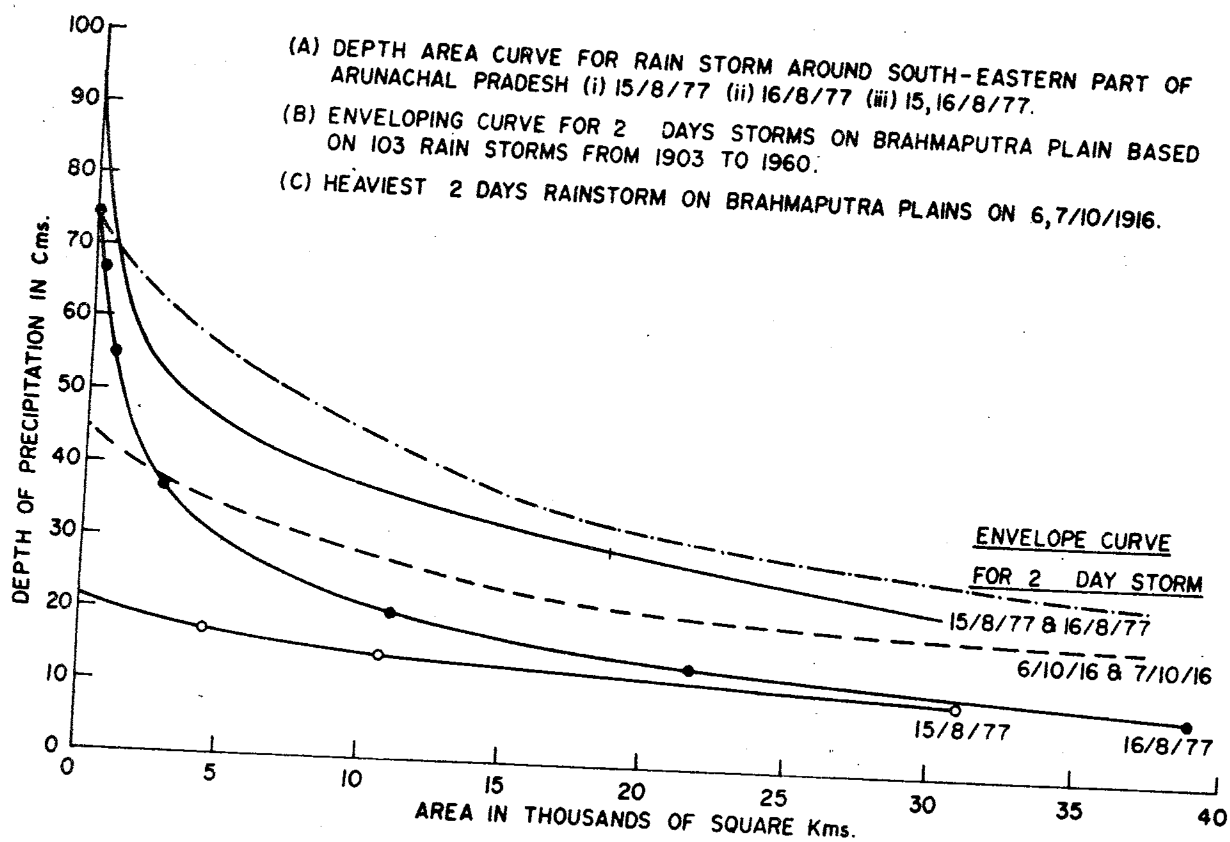

FIG. 10

1976 are shown by dash-dot lines and broken lines respectively.

It is seen that average precipitation over an area of 30,000 sq.kms during 15-16th August 1977 was about 20 percent higher than that experienced on 6-7 October 1916 over Brahmaputra plains. For assessing heaviest rainstorms experienced over the hilly terrains during 1901 to 1960, it appears reasonable to increase central rainfall by 80% and rainfall for 30,000 sq.kms. by 20%, keeping in view the effect of the orography and mean annual rainfall distribution over the basin where the rainstorm of 15-16 August 1977 was situated.

The above also leads to the conclusion that the rainstorm of August 1977 had a great contribution towards recording of highest ever recorded flood level on the 16th August 1977. The aggredation of the river bed has therefore a lesser role at the recording of highest flood level. Comparing with the envelope curve for two days storm in Brahmaputra plains and with modification for transposition to the region, indicate the occurrence of rainfall with heavier contribution can not be ruled out; since the depth of precipitation over different areas upto 30,000 sq.kms. were atleast 25% below the envelope curve values.

5. Conclusion

a) The 15-16 August 1977 rain storm in the hilly northeastern part of the Brahmaputra catchment is one of the heaviest.

b) The Horton's constants 'K' and 'n' for one day storm is '0.004472' & '0.599' and for two days storm '0.009152' & '0.50683' over this region.

c) The storm yield is higher than the highest two day storm in the plains recorded during 1901-1960. For getting the maximum two day storm, therefore the central value may be increased by 80% and 30,000 sq.km average by 20%.

d) Comparing with two day storm envelope of plains, occurrence of higher storm than this can not be ruled out.

e) The rainstorm contributed significantly towards recording of highest flood level at Dibrugarh with perhaps lesser role for the aggredation of river bed.

6. Acknowledgement : Grateful thanks are due to Mr.D.Sinha for collaboration in this study.

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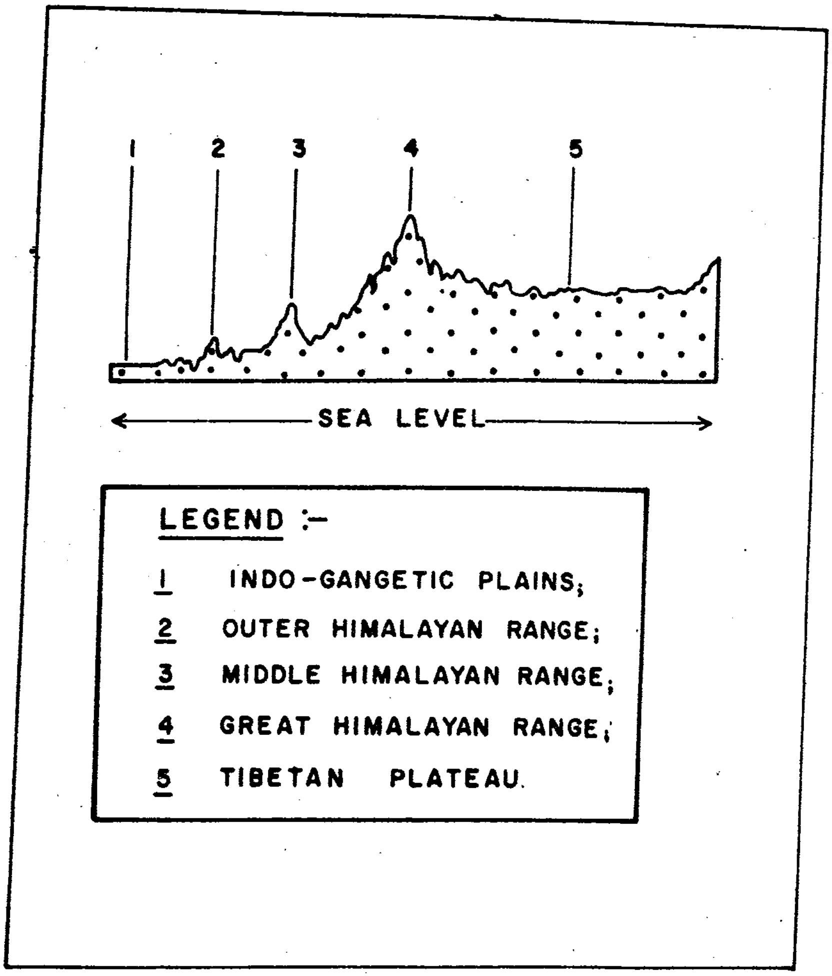

LONGITUDINAL CROSS SECTION OF THE HIMALAYAS.

FIG.1

On Some Hydrometeorological Aspects of Precipitation in Himalayas

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ABSTRACT

The paper deals with hydrometeorological aspects of precipitation in western Himalayas. 50 years data have been analysed to bring out (i) altitude effects (ii) windward and leeward pattern (iii) correlation structure of precipitation field (iv) storm characteristics and (v) specific water yields from mountainous catchment.

1. Introduction

The Himalayan mountain system may be divided into three parallel longitudinal ranges

i) The outer Himalayas or Siwalik ranges with height from 1000-1300 m and width from 10 to 50 kms.

ii) The lesser or middle Himalayas with altitude between 2000 to 3300 m and width between 60 to 80 km.

iii) The greater Himalayas with average height of 6100 m and average width of about 200 km.

The width of Himalayas is maximum in western region. This part of mountains comprises of several parallel ranges viz. Siwalik, Pir Panjal, Dhaula Dhar, Zanskar, Ladhak and Karakoram which run from NW to SE and are interspersed with valleys of Kashmir, Lahul, Kulu, Kangra and Doon. Based on an approximate estimation, the coefficient of variation of the elevation field in this area has been found to be slightly over 50%.

In this paper an attempt has been made to bring out salient features of orographic precipitation such as windward leeward effects and altitude variations. Rainfall data for a period of over 50 years (1901-50) have been studied for the regions of Himachal Pradesh, Jammu and Kashmir, Pakistan and eastern Afghanistan. Isohyetal maps for different climatic seasons and for annual precipitations have been prepared to study the spatial variations. For study of altitudinal variations in western Himalayas rainfall data of seven subregions having homogeneous topographic aspects were studied. The pattern of variations are not alike in all cases. A regression equation has also been developed which describes the variation of snow to rainfall ratio with altitude.

The precipitation in mountain regions are generally characterised with larger spatial variability than in flat terrains. As a result the correlation between precipitation fields in mountains at various distances converges to zero more rapidly.

Variation of precipitation amount with altitude in different seasons is markedly affected by the wind fluctuations. Other controlling factors being constant, the gradient of precipitations with respect to elevation may be regarded as a function of changes in wind vectors. It has been observed that precipitation gradients decrease or even become negative when considerable increase of wind speed with elevation occurs. This may partly explain the decreasing trend of precipitation in Himalayas in very high altitudes (say about 6 kms).

2. Variability of precipitation in western Himalayas

Himalayas and other highlands of central Asia favour the development of SW monsoon in three ways (i) they serve as important higher level heat source and hence play important role in deepening and locating low pressure area and associated monsoon trough over north India, (ii) with the reversal of thermal gradient between

equator and Tibetan Plateau, easterly jet is formed near tropopause between latitudes 10° to 15°N over peninsular India. This causes north-ward deflection of westerly jet stream beyond 40°N and (iii) the hill features over NE India and Burma act like a box which deflect monsoon currents north and eastwards to the plains of north India.

NE monsoon of winter is also affected by Himalayas as it prevents the polar air masses to invade plains of India from north.

Low pressure systems induced from extratropical cyclones during their eastward passage are obstructed by western Himalayas and most of the precipitation is released there. Their contribution to winter precipitation reduces markedly over central and eastern Himalayas.

The spatial variation of seasonal and annual precipitation in western Himalayas and adjoining areas are presented in fig. 1 to 3. The salient features of the distribution are as follows :

i) Winter (Dec.-March)

In Indian regions, a gradual increase in winter precipitation is observed from Siwaliks towards northwest upto the foot of Pir Panjal range. On the windward side of this range the precipitation amount increases rather rapidly. Gulmarg and Muzzafarabad which lie on the extension of Pir Panjal record more than 50 cm. of precipitation in terms of water equivalent. In Kashmir valley which lies between Pir Panjal and Greater Himalayas, a marked decrease in winter precipitation is recorded. This region has been covered in a low precipitation field marked by 40 cm. isohyetal. Further westwards, on the windward side of Greater Himalayas, appreciable increase in precipitation amount is recorded which reaches a maximum of more than 80 cm. around longitude 76°E. The regions around Sonamarg, Gurez and Haddan receive maximum winter snowfalls in whole of Himalayas.

A striking feature of winter precipitation distribution is the abrupt fall in precipitation amounts on the leesides of Greater Himalayas west and northwards in Ladakh regions The areas beyond line joining Gilgit, Sakardu and Leh receive less than 3 cm. of normal winter precipitation resulting into extreme cold desert conditions.

The isohyetal pattern of western Himalayas present an excellent example of this effect. Physical reason of this influence mainly lies in orographic lifting of moist air. Vertical velocity component generated by hill ranges is given by $\vec{V}\cdot\nabla z$, where $\vec{V}$ is velocity vector of airflow and ∇z is the gradient of mountain range. The vertical velocity caused by a hill range depends on the wind speed and the angle with which it strikes the slope. It is maximum when wind is perpendicular to the orientation of the range. The orientation of Pir Panjal and Greater Himalayas are from NW to SE in Northwest India. Whenever an induced low persists over Pakistan and adjoining areas, the lower tropospheric winds become southwesterly i.e. almost perpendicular to these ranges. This flow, besides accelerating the lifting effect over windward side, brings fresh moisture from north east Arabian sea and causes further increase in precipitation.

ii) Pre-Monsoon(April-June)

Western disturbances continue to affect this region but with lower intensities as the season advances. The isohyetal pattern follows more or less the same distribution characteristics as that of winter season except that the region of mixima gets more localised in the premonsoon season. It is also characterised by more thunderstorm activities in which the mechanism of orographic lifting plays a very important role. It has been observed in western Himalayas that the solid precipitation continues at altitudes higher than 3000 m even upto the end of June.

iii) SW Monsoon(July-Sept.)

During this season, the southern slopes become windward side as the monsoon currents arrive from southeasterly direction, The windward-leeward effect is clearly brought out in the precipitation map. The precipitation maximum in Kangra valley is intensified under 220 cm. isohyet during these three months. The highest precipitation normal of 260 cm. is recorded at Dharamsala (1211 m; 32°, 16' N, 76° 23' E). Beyond the Siwalik hills in Jammu, the currents grow weaker and cause very little precipitation; in Kashmir region similarly, the areas of Himachal Pradesh and Ladhak situated north of Pir panjal range receive very scanty rainfall of less than 20 cm. Disappearance of winter precipitation maxima cells in Gulmarg and Sonamarg sectors could be taken as an excellent example of leeward effect.

iv) Postmonsoon(Oct.-Nov.)

This is a period of cyclonic storms in Indian seas and the regions of western Himalayas generally remain cut off from these pressure systems. Occassionally, the induced Lows arriving from west cause significant precipitation in western Himalayas. Thus the precipitation field is very weak. Isohyetal map shows the precipitation distribution during this period. Maxima over Kashmir and Kangra valleys are well marked though in very weak form.

The seasonal effects of orographic precipitation is very clearly reflected in annual precipitation distribution over western Himalayas. Indian part of this region can be distinctly divided into two areas (i) north H.P., Kashmir and Ladhak - where winger precipitation is dominant, (ii) Jammu - Kangra - Kulu - Doon-Kumaon valleys where the monsoon precipitation is higher.

It is also evident that the precipitation maxima and minima are aligned more or less parallel to the orientation of mountain ranges. The wavy pattern of isohyets over H.P. and hills of west U.P. suggest small scale orographic influences.

3. Precipitation and altitude

The characteristics of precipitation are influenced by increasing altitude in three ways.

i) The quantity of precipitation increases with altitude upto a certain level and decreases thereafter. The level of maximum varies greatly from place to place depending on local topography. It is generally observed between altitudes of 1.5 to 2.5 km. a.s.l.

ii) Average variability of precipitation generally increases with altitudes.

iii) On higher altitudes, the period of maximum precipitation is generally earlier than that on foot hills.

Rainfall of stations grouped with similar orographic features in H.P. and west U.P. given in table 1. These data exhibit the altitude variations of precipitation amounts.

4. Correlation structure of precipitation field in mountains

One of the most important characteristics of mountain precipitation is a very high degree of spatial variability. For n stations, $(n,2)$ correlation coefficients between precipitation series taking $(n,2)$ pairs of stations can be computed. In Dehang catchment in Brahmaputra basin, the graph between correlation and distances between stations follows an exponential relation $r = 0.72 \, Exp(-5/26.5)$. This relation shows that in mountain regions, a correlation converges to zero vary rapidly. In the present sample study r becomes insginificant after 35 kms, suggesting that the precipitation patterns become almost independent after this range of distance. This is very important factor to be considered while estimating areal precipitation in mountaineous catchments. Obviously the density of desirable precipitation network would be higher than that required for flat terrain for the same area.

The correlation coefficient is described above may be considered as an estimate of multiple eorrelation $(R_{p.xh})$ between precipitation (p) and altitude (h) and base distance (x). Base distance may be defined as the component of actual distance on a herizontal plane. If r_{hx} represents the correlation between altitude and distances, r_{xp} between distance and precipitation and r_{hp} between altitude and precipitation then

$$(1-r^2_{xh}) R^2_{p.xh} = (1-r^2_{px})(1-r^2_{px.h}),$$

where $r_{px.h}$ is partial correlation between p and x when the effects of h has been eliminated.

This relation assumes a linear variation of p with x and h i.e. $p = A + Bx + Ch$. From (i) r_{ph} may be estimated. For evaluation of the precipitations, only those stations may be taken into account which are situated approximately on the same level.

TABLE 1 Variation of precipitation with altitude

Station	Latitude (N)	Longitude (E)	Height (m)	Annual precipitation (cms)
(a)	(b)	(c)	(d)	(e)
		Kangra Valley		
Dehra	31° 50'	76° 13'	436	131.8
Kangra	32° 06'	76° 15'	733	196.6
Palampur	32° 07'	76° 32'	1250	263.7
Dharamsala	32° 13'	76° 19'	1387	300.9
		Doon Valley		
Ambari	30° 30'	77° 49'	489	183.7
Dehradun	30° 19'	78° 02'	679	207.5
Raipur	30° 18'	78° 05'	750	209.7
Rajpur	30° 24'	78° 05'	914	300.7
Mussouree	30° 27'	78° 05'	2042	247.0
		Almora Hills		
Almora	29° 36'	79° 40'	1572	105.4
Ranikhet	29° 38'	79° 26'	1810	133.7
Mukteshwar	29° 28'	79° 39'	2311	132.5
		Nainital		
Haldwani	29° 13'	79° 31'	440	199.5
Kathgodam	29° 17'	79° 32'	513	209.2
Nainital	29° 23'	79° 27'	1934	253.9
		Joshimath		
Karanoparyag	30° 16'	79° 15'	769	142.3
Ukhimath	30° 30'	79° 15'	1220	201.1
Birangkhal	30° 15'	69° 15'	1520	122.8
Joshimath	30° 33'	79° 35'	1840	95.4
		Kulu and Lahaul Valley		
Kulu	31° 57'	77° 7'	1215	100.6
Banjar	31° 38'	77° 20'	1524	110.6
Kathoi	31° 18'	77° 32'	1608	101.2
Kasauli	30° 53'	76° 58'	1844	163.7
Kotgarh	31° 18'	77° 29'	1949	115.3
Simla	31° 06'	77° 10'	2202	159.0
Keylong	32° 35'	77° 4'	3166	61.4

TABLE 2 Approximate increase in precipitation with altitude

S.No.	Location	Elevation Range (m)	Increase in precipitation (mm/100m)
1	2	3	4
1.	Central Asia(USSR)	2000–4000	37.5 – 102.5
2.	Alps (Italian)	2000–3500	21.2 – 57.1
3.	Central Europe(Poland)	a) 850–1400	44 – 272
		b) 500–2000	43 – 142
4.	Eastern Europe(Yogoslavia)	700–2100	11 – 117
5.	Rockies(Canada)	1600–2500	9.4 – 63.6
6.	Rockies(USA)	2100–2800	9.1 – 88.5

1	2	3	4
7.	Scandinavia	a) 0 - 600	126
8.	India	b) 300- 2000	18
	a) Western Himalayas	a) 400- 3200	3-200
	b) Central Himalayas	b) 700- 2000	30-300
	c) Eastern Himalayas	c) 2000-2400	80
	d) Western Ghats	d) 400-2000	60-100

TABLE 3

Basin	Glaciated area(%)	Sp. yield (m) basin	Glacier
Indus	12	0.41	1.92
Jhelum	1	0.84	34.08*
Chenab	13	1.04	4.32
Ravi	1	0.98	50.16*
Beas	5	1.03	11.68*
Sutlej	11	0.35	1.68
Jamuna	3	0.87	16.96*
Average		0.53	2.47

*Probably increased figures are due to rain contribution and demands further investigations.

5. Estimation of areal precipitation

For the estimation of areal precipitation in mountain regions if we attempt at working out a theoretical model, there can be two approaches possible (i) based on meteorological parameters such as vertical interaction of wind vector $\vec{V}$ with the gradient of hill ranges(∇z), stability conditions and precipitable water. The time derivatives of these quantities are also very important to be considered (ii) working out a regression equation and expressing precipitation field entirely as function of topographic factors such as elevation, slope, forest indices etc. and aspects (in terms of azimuth) of the barrier.

But if a method combining both the approaches can be developed, the estimate, probably may be more reliable. Let us consider the factors as described below :

x_1 : $\vec{V}\cdot\nabla z$ where $\vec{V}$ is the surface wind recorded at the time of precipitation and ∇z is the gradient of the elevation field.

x_2 : Mean precipitable water $(q/g)\cdot\Delta p$ where q is specific humidity, Δp=(500-surface pressure) in mbs and g, the acceleration due to gravity.

x_3 : Mean lapse rate of vertical temperature distribution up to 500 mbs.

x_4 : Elevation.

x_5 : Forest indices, which may be considered as follows :

Forest conditions	x_5
Dense forest	1
Forest	2
Open forest	3
Open area with forest	4
Open-terrain	5

x_6 : Aspects, which may be expressed as x_6 = cos (180 + A), A being the azimuth of the slope aspects.

Thus the precipitation quantity P(in terms of water equivalent may be expressed as

$$P = f(x_1, x_2 \ldots x_6)$$

For determining the nature of relationship with each of the independent (assumed) variables the following two points are desirable.

(i) to compute partial correlation coefficicnts of P with each of x_i and test their significance.

(ii) to plot scatter diagram in p and x_i plane and determine the nature of relationship

$$p = G(x_i) .$$

In general, mountain precipitation is greatly influenced by physiographic features e.g. elevation, landslope, aspect, distance to barrier, barrier height, shield effect etc. The physiographic features play an important role in controlling atmospheric circulation, storm occurrence and also the amount of precipitation. Evaluation of physiographic effects on individual storms is complicated by insufficient data on wind vectors, stability and other storm characteristics and by great variability in storm characteristics. The areal pattern of individual storms in mountaneous regions may be effectively expressed in terms of the ratio of storm precipitation to the mean, seasonal or annual, provided that the storms are of the type predominant in determining the mean pattern.

The distribution of orographic precipitation depends mainly on two process : the distribution of the three dimensional motion field, caused by the mountains, and the effectiveness of the precipitation releasing machanisms. A quantitative prediction of precipitation of mountaneous areas would depend upon our ability to simulate both processee numerically. Generally speaking, it the motion field whcih is the most critical factor of the two, and orographic precipitation is therefore primarily a problem in atmospheric dynamics. The effect of mountains upon air currents represents a fascinating area in dynamic meteorology with a number of unsolved problems. It has therefore been fully realised that these difficulties constitute the main obstacle to progress in numerical weather prediction.

The precipitation in mountain areas reflect great spatial and temporal variability. Although earlier investigators referred to a decrease in accumulation at certain elevation but none of the works reviewed by Meiman (3) indicated such an effect. In general, there is an increase in precipitation with rise in elevation but the interaction between land surface and atmospheric factors is complex.

6. Specific yields from some of the mountain catchments of western Himalayas

For arriving the glacier yields, it has been assumed that 80% of flow is contributed by glacier melt during the months of June to Sept as has been observed for glaciers in scandinavia and elsewhere. The average figure of 0.53 m for the specific yield for the mountain basins (table 3) is smaller as compared to 0.78 m i.e. the yield

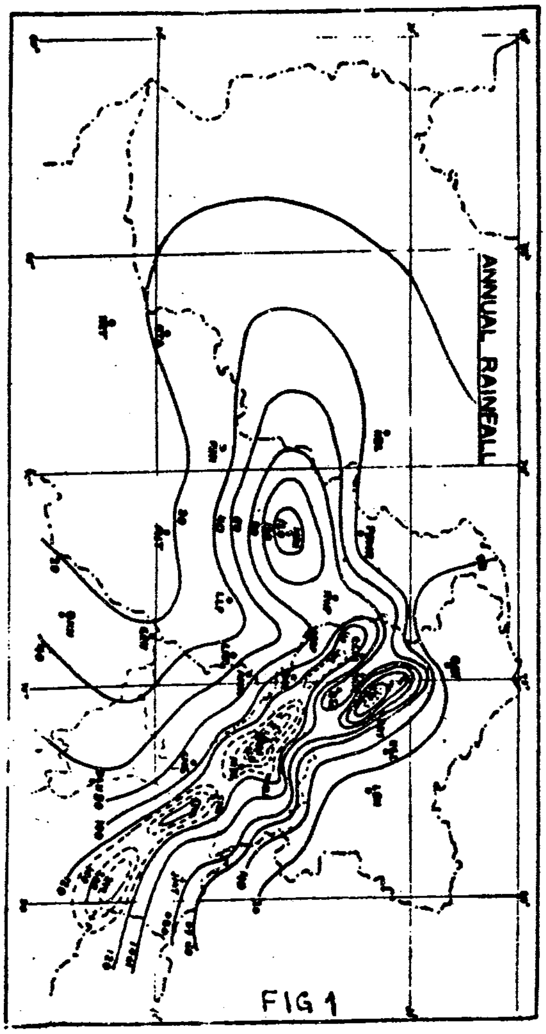

FIG 1

from mountain basin of KOSI (Eastern Himalayas) which also gives an yield of 4.6 m from the glacier area. If we account for some water losses by evapo/ration/sublimation and infiltration, we could add about 2 m on this account to get an average value of 4500 mm precipitation in western Himalayas. This further exceed by about 2000 mm from that of Eastern Himalayas.

It may be stated here the scientific studies undertaken during the 1963 American Mt. Everest Expedition showed that a high net positive accumulation in Khumbu glacier region at 6160 m. Enviromental tritium profile of the snowpack showed that there is average net

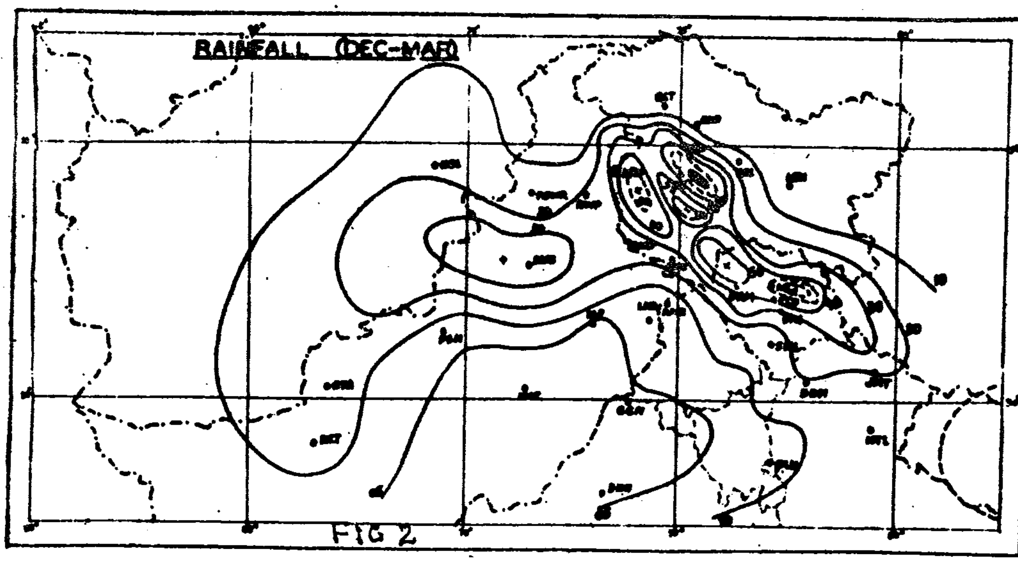

FIG 2

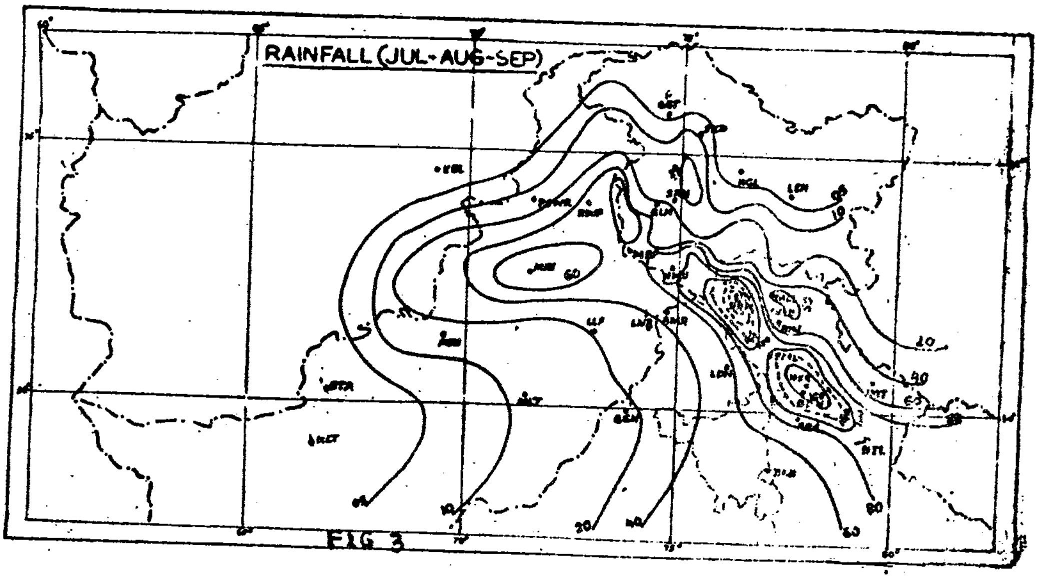

FIG 3

accumulation of 1.7 m per year. The accumulation and ablation are irregular and shows that there is deposition in the accumulation zone corresponding to precipitations in winter and summer seasons (4). Recently, the Tibetan Scientific Expendition has reported that the precipitation of 6000-7000 m altitude on Mt. Everest is more than twice that enjoyed by areas at around 5000 m. An increase in precipitation with altitude is observed by the Japanese Glaciological Expedition to Nepal 1974 (5). It has also been confirmed that the monsoon season is both accumulation and ablation period for Himalayan glaciers and this is the reason that the snow pack at around 6000 m becomes wet and grannular.

As a general physical rule, it is observed that the level of maximum precipitation is located fairly close to glacier equilibrium line and annual sums of precipitation are great even under the conditions of extreme continental climate (6). Globally, it has been observed that the permanent snow line lie at sea level at the poles, 1.2 km for Scandinavia, 2.5 to 3 km for Alps and Pyrenees and 5 to 6 km for equatorial locations. A gradual increase in precipitation with height takes place in Alps upto 2.6 km. and thereafter it is assumed as constant. In East Pamirs, the precipitation increase upto an elevation of 5.5 km. In a recent paper, on snow and glacier contributions in a western Himalayan catchment it has been shown that the average annual yield (discharge per unit area of the catchment) increases with the percentage of glaciated area. It is interesting to note that the Meteorologists and Hydrologists in India have believed for a long time that the maximum precipitation in Himalayas is obtained near about m but the recent studies conducted by Dhar et. al (7) show that there exist no linear relationship between elevation and mean precipitation and the two could be best related by a polynomial of the 4th degree. A maximum of rainfall occurs near the foothills of the Himalayas as one proceeds northwards, Rain fall decrease until an elevation of 0.6 to 0.8 km is reached. It has been observed that this low rainfall region is located just on the lee side of the Siwalik mountain ranges. Rainfall again increases northwards until an elevation of 2.0 to 2.4 km is reached (Middle Himalayas). Thereafter precipitation decreases on the lee side of these ranges and probably a third maximum occurs on the windward side of Great Himalayan Range (average height 6100 m.). The greater precipitation in this range is self evidently supported by the physical presence of a multitude of glaciers in this range. Hence, it is presumed that the areas of maximum precipitation in Himalayas lie in the Great Himalayan Range.

7. Acknowledgement

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Comparative Intensity-Duration Studies of Severe Rainstorms in Mountainous and Plain Areas of Western Uttar Pradesh

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ABSTRACT

For the western region of the province Uttar Pradesh in India, a comparative study of intensity duration analysis was carried out for the historic six severe rainstorms registered between the year 1880 and 1974. For the purpose, the area was split in to three regions. Region-I consisted off Roorkee-Hardwar Dehradun and Chakrota. Region-II comprised of Nagina, Dhampur Lansdown and Pauri where as Region-III included Moradabad, Nainital, Almora and Ranikhet. The enveloping curves for 1 day, 2 day and 3-day durations were drawn and presented in Figure-1. The analysis has indicated that that maximum intensities for these durations were recorded in the foot-hill region of the Himalayan belt in the Western Uttar Pradesh. However, quite high intensity-duration values were observed at the southern periphery of the mountainous ranges where annual rainfall values were also found out to be very high.

INTRODUCTION

Orography is one of the major factors influencing the rainfall distribution in in any region. The present paper describes the intensity-duration aspect of precipitation considering the cases of severe rainstorms. The region of western Uttar Pradesh has been selected as study area for its wide topographical diversities.

Severe rainstorms in western Uttar Pradesh are most likely during the monsoon or post monsoon season. Hence the major meteorological system responsible for the spatial and time distribution of precipitation is the south-west (summer) monsoon circulation (5). Generally either of the two types of meteorological situations (a)monsoon depression/trough or tropical cyclone and (b) 'Monsoon break' or westerly current, are responsible for the heavy and widespread rainfall in the region Particularly for the region under consideration, the former situation plays the major role for the occurance of severe rainstorms (1,5).

The monsoon advances almost from east to west in the region under study. Hence the influence of the monsoon is more in the estern sector leading to the higher values of normal annual as well as seasonal rainfall amount than in the western sector of the region. In case of the north south variation, the rainfall normals are higher in the mountainous belt which acts as a direct barrier to moisture laiden monsoon winds. There is fall in the values of rainfall normals in northward as well as southward directions of this belt (5).

DATA USED

For obtaining the cases of maximum rainfall in different stations of the region, some major rainstorms were selected. Selection of the storms were made with a general review of the whole data of past 84 years (1891 to 1974) available in the India Meteorological Department and also on the basis of severe floods in the region which are mentioned in some published literatures (2,3,4). The daily rainfall data available for all the selected representative raingauge stations were extracted directly from the published rainfall tables of India. Mostly, the storm period was limited for three days, the daily rainfalls for three days were collected in most of the cases.

The self recording rain gauges in the region under study have been established only recently, no self recording data were available for the historical storms selected for the analysis. Hence, only the 24 hour rainfall intensities have been used to carry out the intensity duration analysis.

MOUNTAINOUS AND PLAIN AREAS

The region of western Uttar Pradesh has a gradual change in topography from southern part to northern part, the southern part being plain and the northern part hilly and mountainous. The elevation above mean sea level varies from 152 m to 7316 m (Nanda Devi).

Terai, Siwaliks (Sub Himalayan tract), Himachal (Lower Himalyas) and Himadri (Greater Himalyas) are the major physiographic groups of the region, out of which the terai belt is almost a featureless plain lacking topographical prominees. The siwaliks is a long chain of narrow and low hills where as the Himanchal range is a massive mountainous tract.

INTENSITY-DURATION ANALYSIS

The local 24 hour rainfall intensity durations during the selected severe rainstorms, worked out for different representative stations of mountainous and plain areas in the region of western Uttar Pradesh, are presented in Table-1. This table has been worked out to give the maximum rainfall intensity values with one day interval for the 1 day, 2 day and 3 day durations. The maximum intensity-duration curves are also obtained for all the stations selected or study with the help of enveloping curve drawn by plotting the maximum intensity values of 1 day, 2 day and 3 day durations for each stations. The curves thus obtained are displayed in Figure-1.

DISCUSSIONS

Among all the storms, the rainfall intensity value for 1 day as well as 2 day duration is found to be the heighest in case of the September 1880 storm at all the selected stations. Similarly, out of the entire rainfall records of the region the intensity of 823 mm/day is distinctly the highest intensity for one day and 521 mm/day for two days which were recorded at Nagina in Bijnor district on 18th and 19th September 1880 respectively. These values are followed by the values of 772 mm/day for one day and 497 mm/day for two days recorded at Dhampur in the same district (Bijnor). The Bijnor district is located near the foothills of the Central sector of western Uttar Pradesh.

Table 1 shows that the severity of rain-

TABLE - 1 INTENSITY-DURATION VALUES FOR DIFFERENT RAINSTORMS

MAXIMUM INTENSITY (mm/day)

Storms			1 day value				2 day value				3 day value			
(A) Western Sector														
			Chakrata	D' Dun	Hardwar	Roorkee	Chakrata	D' Dun	Hardwar	Roorkee	Chakrata	D.' Dun	Hardwar	Roorkee
Storm of	Sept.	1880			495	272			400	238				
''	''	1924	182	158	305	204	143	153	279	197	130	151	237	164
''	''	1937	129	117	116	173	68	67	73	97	49	45	49	65
''	Aug.	1951	72	27	267	73	42	206	191	56	32	152	134	38
''	Oct.	1956	192	143	173	231	123	78	93	123	105	53	81	102
''	Sept.	1963	139	75	91	165	77	45	67	112	55	35	56	75
(B) Central Sector														
			Pauri	Lansdowne	Nagina	Dhampur	Pauri	Lansdowne	Nagina	Dhampur	Pauri	Lansdowne	Nagina	Dhampur
Storm of	Sept.	1880			823	772			521	497				
''	''	1924	99	323	226	223	98	297	189	202	88	258	164	100
''	''	1937	88	220	100	87	51	123	50	46	35	90	38	34
''	Aug.	1951	51	47	312	43	38	42	188	31	28	31	145	28
''	Oct.	1956	173	175	122	148	108	143	104	146	85	129	79	98
''	Sept.	1963	125	114	128	120	93	88	100	99	88	65	68	67
(C) Eastern Sector														
			Almora	Ranikhet	Nainital	Moradabad	Almora	Ranikhet	Nainital	Moradabad	Almora	Ranikhet	Nainital	Moradabad
Storm of	Sept.	1880	165	305	315	158	156	199	272	127				
''	''	1924	221	172	175	229	175	152	175	161	129	102	151	108
''	''	1937	81	89	259	50	55	59	158	37	39	41	24	27
''	Aug.	1951	24	64	67	23	20	38	43	16	17	34	48	16
''	Oct.	1956	75	140	280	75	65	98	219	53	60	80	185	43
''	Sept.	1963	89	85	253	106	77	75	206	104	65	53	156	70

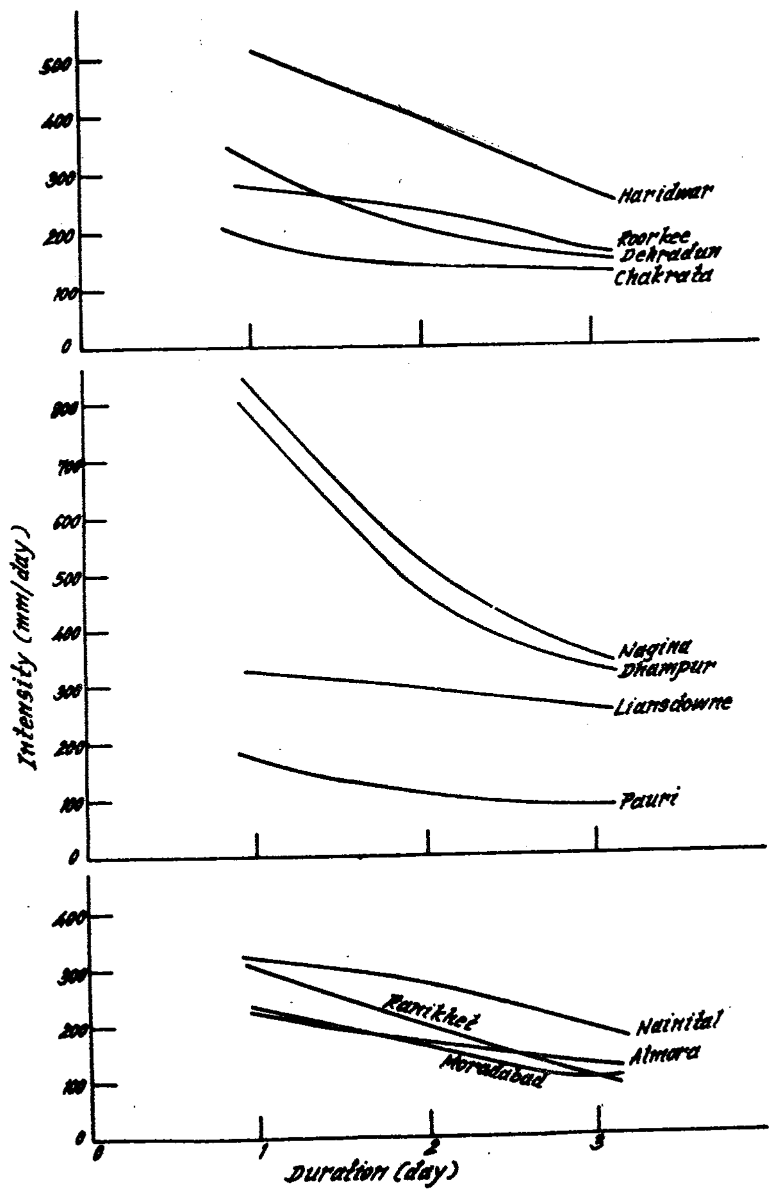

Fig. 1. _Maximum (Enveloping) Intensity-Duration Curves.

fall intensity during September 1880 storm is confined mainly in the central sector of region.

In comparison to other storms under study, the storm of September 1924 follows the September 1880 storm in terms of the severity of intensity.

The maximum (enveloping intensity duration curves of different station in different sectors show that Hardwar, Nagina and Nainital in western, central and eastern sector respectively have the upper most position in the Figure-1. Here the raingauge stations at Hardwar and Nagina are close to the foot hills. Stations such as Dehradun, Lansdowne and Ranikhet, lying windwards in western central and eastern sector of the region respectively are in the second highest position in the Figure-1. Out of the stations of mountainous region studied here, the enveloping maximum intensity-duration curve of Lansdowne situated in the central sector gives the highest value, which is followed by the curve of Nainital. Except in the case of September 1880 storm, which was confined mainly in the district of Bijnor, Nainital has recorded comparatively higher intensities in most of the cases. It may mainly due to the windward location of the place and favourable local conditions such as the existence of lakes and high mountains.

CONCLUSION

The studies made here have revealed that the maximum intensities for different durations (1,2 and 3 day) has been recorded in the plain areas near the foothills. Comparatively higher rainfall intensity values are also observed in the southern periphery of the mountainous range where the annual as well as seasonal rainfalls are also high.

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A Study of Heavy Rainfall Over the Ganga Basin Upto Hardwar

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ABSTRACT

In this study analysis of 70 to 80 years' rainfall data of about 60 long-period stations in and around the Ganga basin upto Hardwar has been carried out. Mean annual rainfall of this basin has been estimated and found to be about 150 cm. It has also been seen that 72% of this rainfall is received during the monsoon months of June to September. The highest observed one-day point rainfall within the basin has been found to be of the order of 49 cm. Generalized charts of maximum one-day point rainfall of 10,25,50 and 100-year return periods have also been prepared on the basis of past rainfall records. Estimation of probable maximum point rainfall (PMP) of the basin shows that one-day PMP estimates range from 50 to 70 cm. Analysis of heavy rainspells over the basin has shown that 28-30th September,1924 rainstorm was the severemost rainstorm of the basin which contributed the highest average raindepths for durations of 1 to 3 days.

INTRODUCTION

The Ganga is one of the major rivers of our country, whose length is about 1600 miles from its source in the Himalayas to the point where it falls into the Bay of Bengal. The Ganga has numerous tributaries which drain the north Indian area bounded by Long. 73°35'E to 89°E and Lat.22°26'N to 31°26'N. Its main tributaries from the Himalayas in the north are the Yamuna, the Ghagra, the Gandak and the Kosi. The important tributaries from the Central Indian Plateau in the south are the Betwa, the Ken and the Sone which drain the Vindhyas, the Amarkantak and the Chota Nagpur plateaus. Its main tributaries from the western part of the country are the Banas and the Chambal which drain the Aravalli Hills. Before falling into the Bay of Bengal, the Ganga is joined by the Mayurakshi, the Ajay and the Damodar in West Bengal.

In this note an attempt has been made to study the heavy rainfall over the portion of its catchment in the Himalayas, that is,its Himalayan catchment upto Hardwar where it debouches into the north Indian plains. Its catchment area upto Hardwar is of the order of about 8950 sq.miles (i.e.23180 sq. km.). Using the long-period rainfall data(i.e. from 1891 to 1970) of all the available rainfall stations within the basin and its surrounding neighbourhood, the following studies have been carried out :-

(i)Preparation of a map of the basin showing the highest observed one-day point rainfall that has actually occurred at stations in the basin during the last 80 years,
(ii)Estimation and preparation of generalized charts of maximum point rainfall of different probabilities or return periods (i.e. 10,25,50 and 100 years),
(iii)Estimation of probable maximum point rainfall(PMP)using the latest statistical technique and preparation of a generalized PMP chart, and
(iv)Analysis of the severemost rainstorms which contributed maximum raindepths over the basin.

In addition to the above studies, mean monsoon and annual rainfall of the basin has also been worked out to give an idea of the magnitude of rainfall that the basin receives in the monsoon season as well as during the year as a whole.

The above studies were carried out so that the results obtained here may be useful for the planning of various water resources projects in the Himalayan reaches of this basin for generation of hydropower, flood control and irrigation in the plain reaches of the basin.

DATA USED

There are in all about 23 rainfall stations in the Ganga basin upto Hardwar This network of rainfall stations is not adequate enough to assess the distribution of rainfall over this Himalayan catchment. As such, due to this lacuna, the studies carried out in this paper may be considered as tentative till more data are available from a denser network of stations.

Rainfall data of the stations within the basin and its neighbourhood, numbering about 60, were extracted from the published rainfall records of the India Meteorological Department. This data formed the basic input for the present study.

RAINFALL FEATURES OF THE BASIN

Broadly speaking, the southwest (or the summer) monsoon rainfall is the main contributing factor to the runoff of the most of the Indian rivers. The Ganga basin(upto Hardwar) gets 72% of its mean annual rainfall during the monsoon months of June to September. However, during the winter season from December to March the basin also receives about 15% of its mean annual rainfall in association with the passage of weather disturbances known as "Western Disturbances". During this season (i.e. Dec. to March) in the higher reaches of the basin, precipitation occurs in the form of snow which on melting in the summer months of April and May contributes substantially to the river flow in the premonsoon months. Normally monsoon sets in over this region by about the last week of June. Annual rainfall of the basin upto Hardwar has been worked out by the isohyetal method and found to be about 150 cm. Rainfall distribution during the monsoon season as well as year as a whole over this basin are shown in Figs. 1 and 2.

HIGHEST OBSERVED ONE+DAY POINT RAINFALL

Information about the highest observed one-day point rainfall is required by the designers and hydrologists for planning hydraulic structures of medium and minor nature. Keeping this in view, highest observed one-day rainfall for each of the stations in & near the basin were picked out from a careful acrutiny of past rainfall records. Fig.3 shows the distribution of the highest one-day rainfall over the basin. It is seen from Fig.3 that the highest recorded one-day point rainfall has been of the order of 49 cm. This magnitude of rainfall was recorded by two stations, viz., Dehradun(48.7 cm) & Hardwar(49.5 cm) on 25th July,1966 and 18th September,1880 respectively. From an examination of Fig.3, it can be seen that the highest observed one-day rainfall for stations in this basin varies from 10 to 49 cm.

ESTIMATION OF MAXIMUM RAINFALL OF DIFFERENT RETURN PERIODS

Design engineers normally require maximum one-day point rainfall of different return periods or probabilities for the economic planning and design of small and medium hydraulic structures such as bridges, culverts, storm drainage works etc.

Annual maximum one-day rainfall data of each of the stations was picked out for each year of the 80-year period from 1891. This data was then subjected to Gumbel's(1954) extreme value analysis as modified by Chow (1964).

According to Chow(1964) the value of maximum rainfall X_T corresponding to the return period T years is obtained with the help of the following two equations :-

$$X_T = A+BK_T \quad \text{-----(1)}$$

$$K_T = -\left[1.100 + 1.795 \log_{10} \log_{10}\left(\frac{T}{T-1}\right)\right] \text{-(2)}$$

Where A and B are constants which can be obtained by the method of least squares.

By applying the procedure mentioned above to the annual maximum rainfall data series of each of the stations considered, estimates of maximum one-day point rainfall for return periods of 25,50 and 100 years were worked out.

By using the annual maximum rainfall series, slightly less values are obtained for low return periods upto 10 years. As such, estimates of maximum one-day rainfall for 10-year return period were worked out using the conversion factor as obtained by Dhar & Kulkarni(1973) for obtaining partial duration series from the annual series. Generalized charts of maximum point rainfall of 10,25,50 and 100-year return periods were then prepared and these charts are shown at Figs.4 to 7.

From an examination of the generalized charts of different return periods, the maximum point rainfall for stations in the basin were found to vary as follows :-

Return period	Range of maximum point rainfall over the Himalayan portion of the Ganga basin upto Hardwar.
10-year	10 to 30 cm
25-year	15 to 35 cm
50-year	20 to 40 cm
100-year	20 to 45 cm

PROBABLE MAXIMUM POINT RAINFALL(PMP)

Probable maximum rainfall (PMP) is defined as the highest or the extreme rainfall which nature can produce over a given point or a specified area in a given duration of time. PMP estimates are used for the design of those hydraulic structures in whose case no risks due to their failure can ever be taken. Estimates of PMP are normally required for the design of spillway capacities of those dams and reservoirs which are to be built upstream of large towns and industrial areas.

In the present study Hershfield's (1961,1965) statistical technique,which is based upon the analysis of long-period rainfall data of a station or an area, is used. In tropical countries where long-period rainfall data are available, this technique appears to be more suitable than the moisture maximization technique which is not suitable for these regions. In the past Dhar & Kamte(1969) and Dhar & Kulkarni(1974) have used this technique for different regions of this country. In brief the technique is as follows :-

$$X_{pmp} = \overline{X}_n + S_n \cdot K \quad \cdots (3)$$

Where X_{pmp} = The extreme rainfall for a station, $\overline{X}_n$ and S_n = mean and standard deviation of the annual maximum rainfall series and,
K = Frequency factor which depends upon the number of years of data and the return period. Hershfield obtained the value of K by using an emperical equation and found its value to be 15. But it was later found by him(Hershfield, 1965) that the value of K = 15 was high for areas of generally heavy rainfall and low for arid area(WMO,1973).He also observed that K has a tendency to decrease with increase of $\overline{X}_n$ values. Using the revised technique of Hershfield (1965),PMP estimates have been worked out for different regions of the country by Dhar and his co-workers(Dhar and Kamte,1973, Dhar et al 1975).Using the same technique for the long-period stations in the Ganga basin, PMP estimates were determined and these have been given in Fig.8. It is seen from this Fig. that one-day PMP estimates for stations over the basin range from about 50 to 70 cm. It is also observed that PMP values are quite high in the foothill regions of the basin when compared to stations in the higher regions.

RAINSTORM ANALYSIS OVER THE BASIN

For the design of water resources projects, rainstorm analysis forms an essential part of the basin hydrological studies. For this purpose, all the major rainspells that the basin experienced during the past 80-year period from 1891 were examined. On scrutiny of the data the following heavy rainspells were selected :-(i)2-3 October,1910, (ii)15-17 August,1912,(iii)18-19 Sept., 1914,(iv)17-18 August,1921,(v)28-30 Sept. 1924,(vi)21-22 August,1951,(vii)8-10 Oct.,1956 and(viii)15-16 September,1963.

Employing the technique of isohyetal analysis, weighted rainfall of maximum 1,2, and 3 days were then worked out for the basin upto Hardwar. Analysis of the above heavy rain-spells over the basin revealed that maximum raindepths were experienced by the basin during the rainstorm of 28-30 September,1924. A general study of this rainstorm has been carried out by Ramamurthy(1959).Isohyetal pattern of 3-day duration of this rainstorm is shown in Fig.9. It is seen from this figure that the centre of this rainstorm was located at a station called Lansdowne in the Garhwal district of Uttar Pradesh. The basin(upto Hardwar) experienced 15.5 cm,28.5 cm and 35.1 cm of rain during 1,2, and 3-day durations of this rainstorm.

In Sept.,1880 a very severe rainstorm occurred over the plain areas south of this basin(Dhar et al,1975).It caused flash floods in the foothill region of this catchment which was responsible for causing death and destruction in the districts of Bijnor, Moradabad, Shaharanpur, Pilibhit, Nainital & Almora in northwest Uttar Pradesh. Both the September, 1880 and 1924 rainstorms occurred towards the end of the monsoon season and were associated with the passage of monsoon depressions from the Bay of Bengal.

SUMMARY AND CONCLUSIONS

(i) Mean annual rainfall of the Ganga basin upto Hardwar was estimated to be of the order of 150 cm and 72% of this rainfall is received during the southwest monsoon months of June to September,

(ii) The chart showing the highest observed one-day rainfall over this basin shows that rainfall of the order of 49 cm occurred at two stations, viz. Dehradun and Hardwar, on 25th July, 1966 and 18th Sept., 1880 respectively,

(iii) Examination of generalized charts of maximum one-day point rainfall of 10, 25, 50 and 100-year return periods shows that over this basin rainfall of 10-year return period varies from about 10 to 30 cm, for 25-year it ranges from 15 to 35 cm, for 50-year 20 to 40 cm and for 100-year from 20 to 45 cm.,

(iv) The generalized PMP chart of the basin shows that point PMP over the basin ranges from about 50 to 70 cm. It is also observed that magnitudes of PMP are higher in the foothill region of the catchment,

(v) Analysis of heavy rainspells over the basin during the last 80-year period (i.e. 1891 to 1970) has shown that 28-30th September, 1924 rainstorm was the most severe one which contributed greatest average raindepths over the basin for durations of 1 to 3 days. The basin received about 35 cm of rain for a duration of 3 days during this rainstorm.

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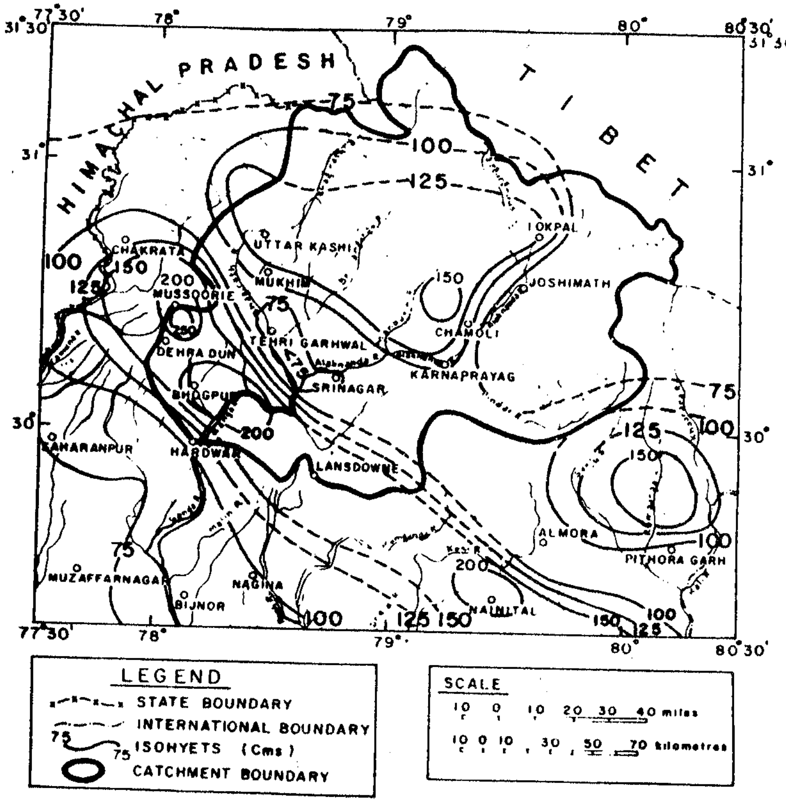
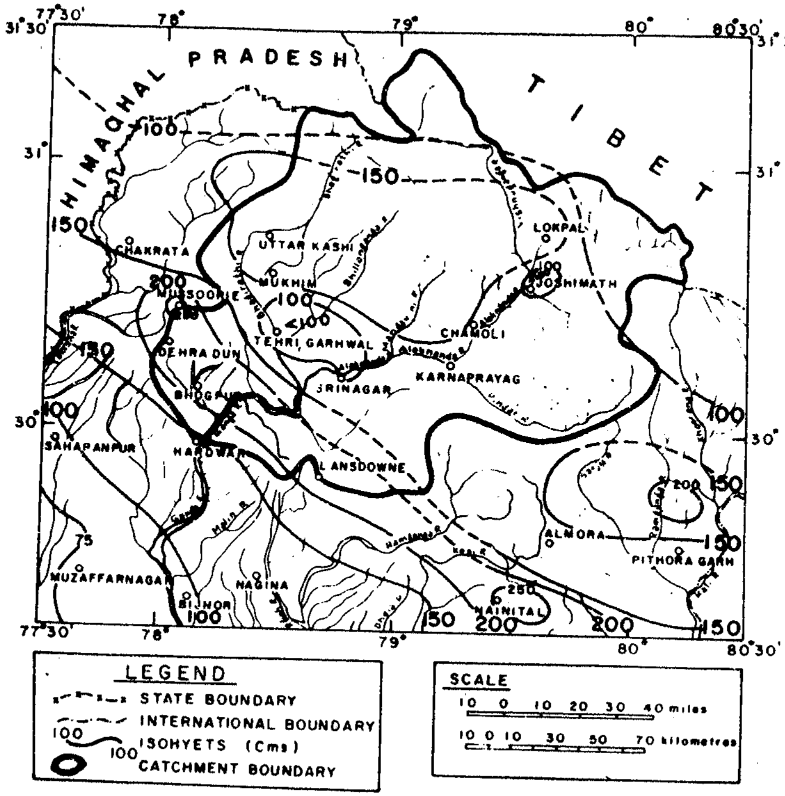


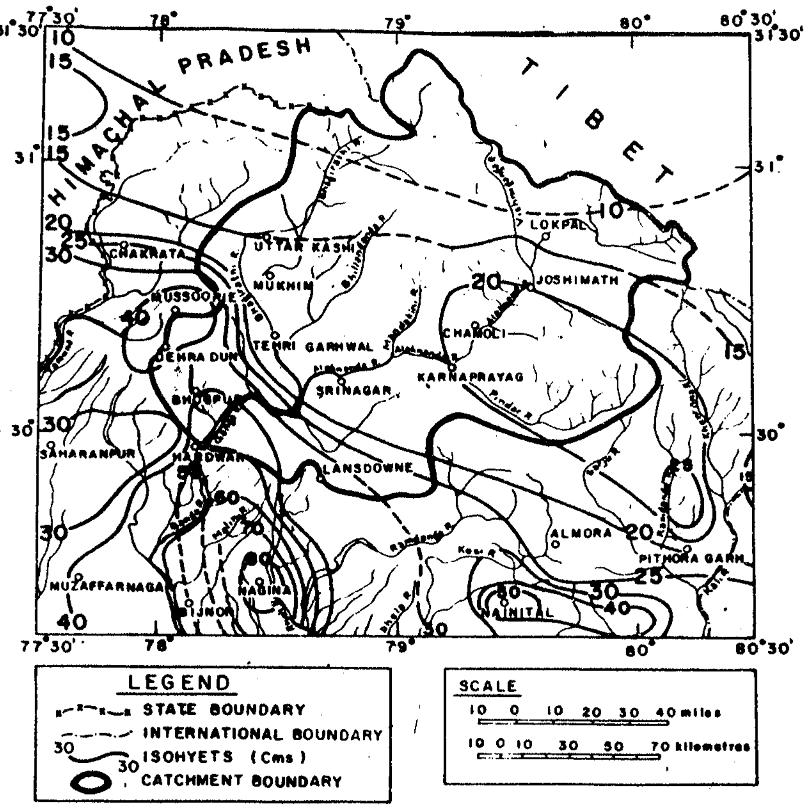
MEAN MONSOON (JUNE TO SEPTEMBER) RAINFALL OVER THE GANGA BASIN (UPTO HARDWAR)

FIG.1



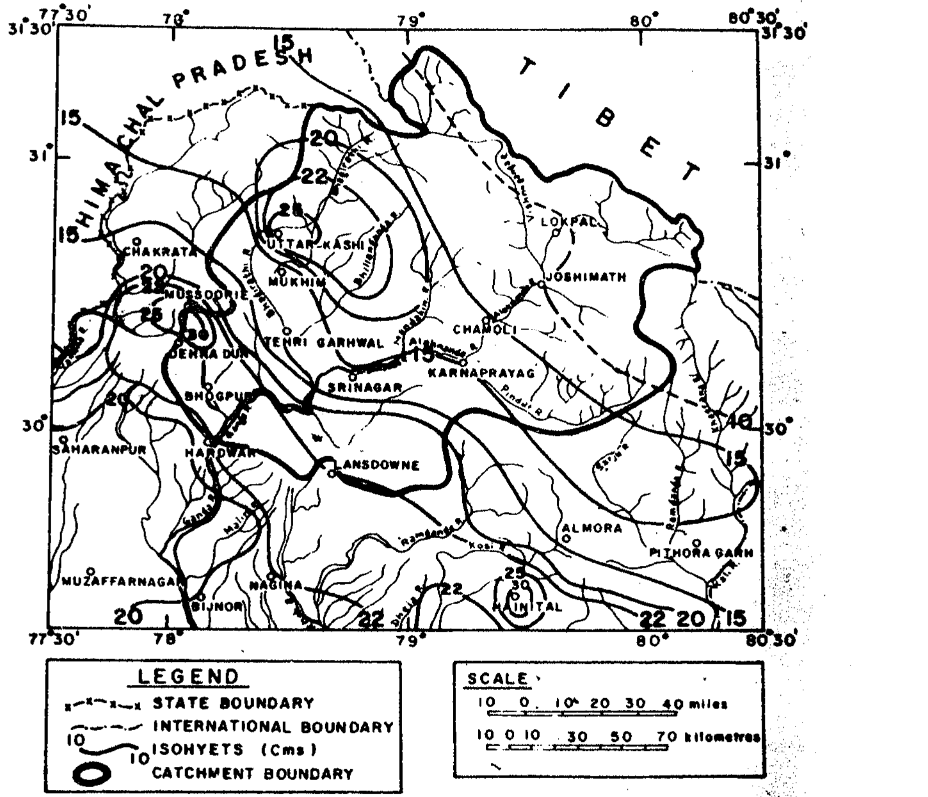
MEAN ANNUAL RAINFALL OVER THE GANGA BASIN (UPTO HARDWAR)

FIG.2



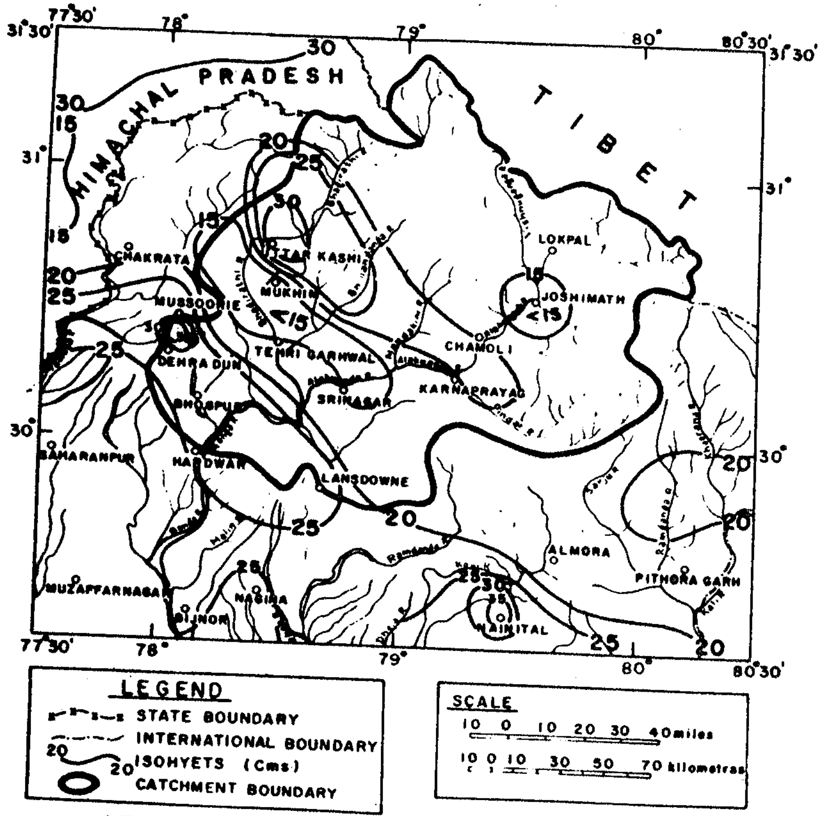
HIGHEST OBSERVED ONE-DAY RAINFALL OVER THE GANGA BASIN (UPTO HARDWAR)

FIG.3



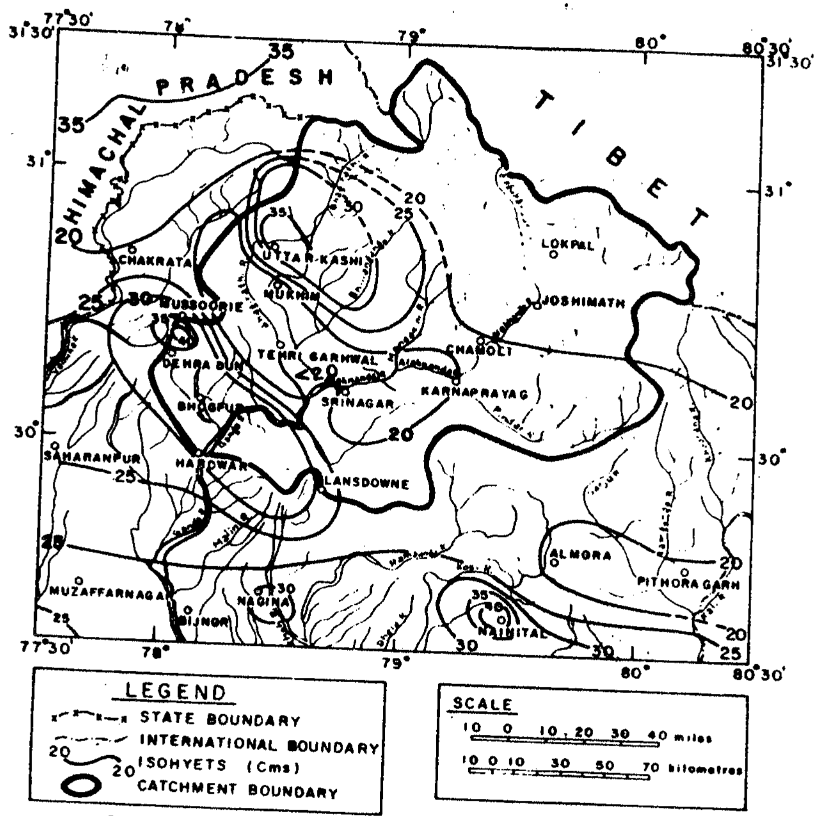
GENERALIZED CHART OF 10-YEAR ONE-DAY MAXIMUM RAINFALL OVER THE GANGA BASIN (UPTO HARDWAR)

FIG.4



GENERALIZED CHART OF 25-YEAR ONE-DAY MAXIMUM RAINFALL OVER THE GANGA BASIN (UPTO HARDWAR)

FIG.5

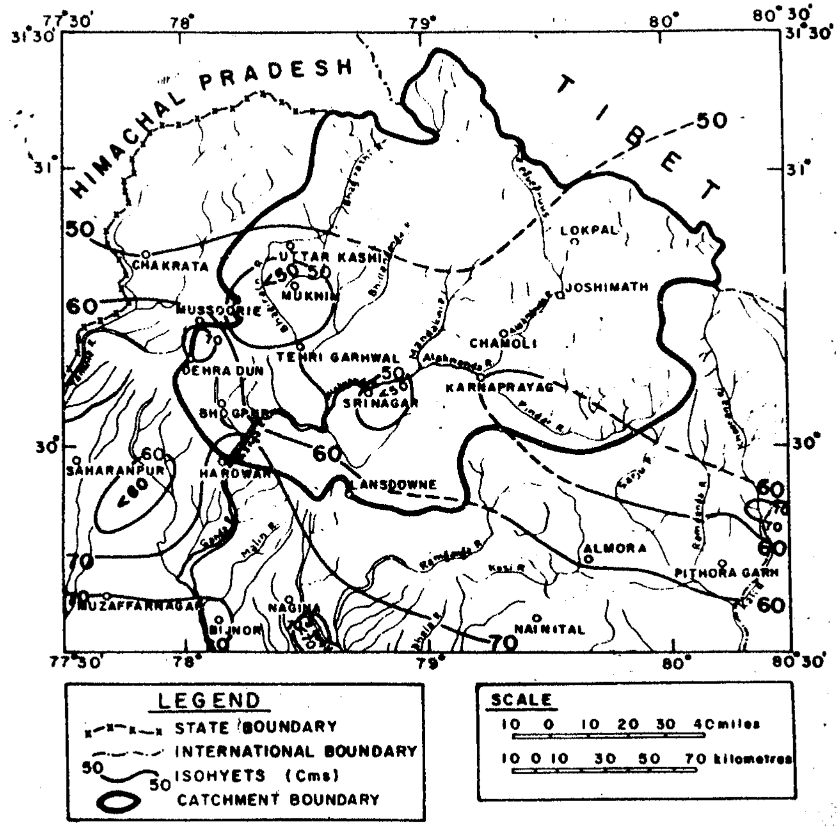


GENERALIZED CHART OF 50-YEAR ONE-DAY MAXIMUM RAINFALL OVER THE GANGA BASIN (UPTO HARDWAR)

FIG.6

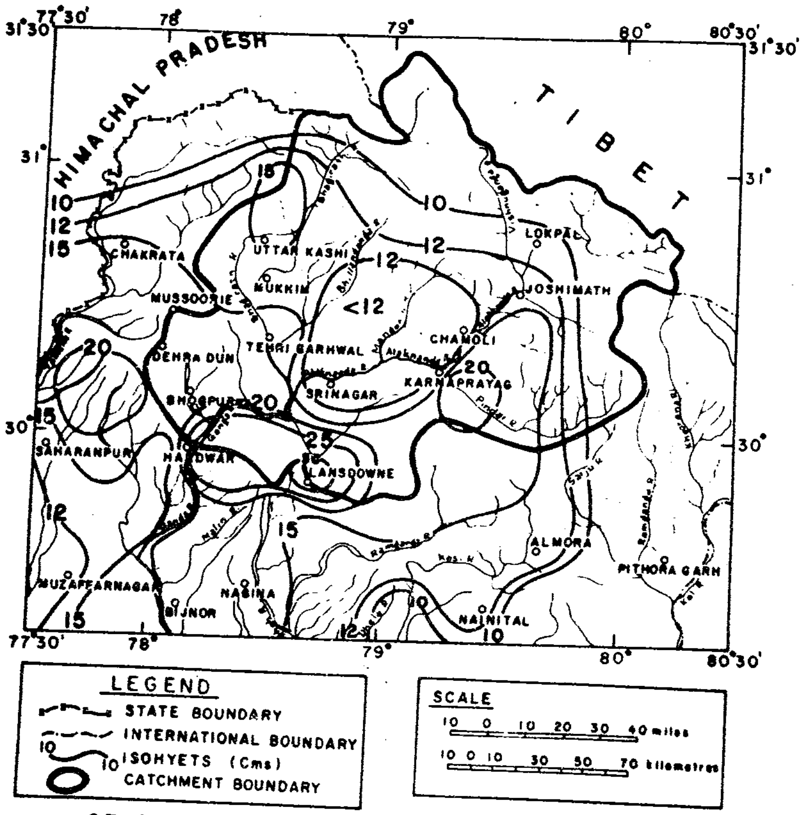
GENERALIZED CHART OF 100-YEAR ONE-DAY MAXIMUM RAINFALL OVER THE GANGA BASIN (UPTO HARDWAR)

FIG.7



EXTREME ONE-DAY RAINFALL (PMP) OVER THE GANGA BASIN (UPTO HARDWAR)

FIG.8



SEVEREMOST RAINSTORM OF 28th - 30th SEPTEMBER, 1924 OVER THE GANGA BASIN (UPTO HARDWAR)

FIG. 9

Soil Moisture Retention Model in Rainfall Disposition for Flood and Drought Moderation

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ABSTRACT

Soil holds moisture with varying force and perform the functions both of recepticle as well as passage for flow. The types of soil moisture storage and their volumes are important in rainfall disposition studies in the context of flood and drought. A simple computerised mass water balance model for working out continuous rainfall disposition centering around variations in soil moisture has also been offered. The model requires the data on rainfall and mean temperature besides the soil moisture estimation equations. The characteristics points of the equations along with a few soil characteristics have been used to explain variable hydrologic response under different management practices. With the help of data from four different management fields in the Nilgiris feasibility of developing extensive defence against drought & flood by altering hydrologic responses through manipulation of soil moisture storage has been demonstrated.

INTRODUCTION

Flood and drought are the events of considerable departures from the normal and represent unfavourable and undesirable hydrologic response of an area. The interaction of 'Land Cycle' with the 'Water Cycle' is the key to the understanding of the hydrologic response variations and, therefore, onset, extent and intensity of the flood and drought hazards.

Man has no control on water input i.e. rainfall and other climatic associates whereas he has very restricted ability to increase the useful land base. It is, however, possible to make adjustment in the ways how he deploys these resources. Soil moisture storage, besides influencing watershed retention and thus stream flow, also profoundly affects the energy and biological balance of watershed. This in turn modifies the hydrologic balance (Dooge, et al, 1973). The endeavour in this paper is to demonstrate this significant role of soil moisture and offer a simple computerised model for working out continuous rainfall disposition or water balance centering around the variation in soil moisture. The importance of soil moisture and the model in developing extensive defence against both flood and drought has been explained.

SOIL MANTLE AND HYDROLOGY

Soil is well known as the most vital natural medium for producing bulk of our requirements. But it is also the primary storage for the most critical production input i.e. water as well as the permeable medium to replenish the supply of water either to the channel system or ground water after the prime supplier rain has stopped. This dual ability of the soil mantle is its core or characteristics. It is again the combined effect of infiltration and percolation rate, volumes and direction of drainage through soil profile.

Physical Characteristics

It is well known that the ability of soil to intake the water and to hold it basically rests on its texture and structure or aggregation., These also regulate the transmission by controlling the hydraulic conductivity. But even a soil mantle with all favourable characteristics to hold and utilise large volume of rainfall, and has a shallow profile, will result in large runoff. Thus, besides all these basic characteristics, the most important single factor which affects the hydrologic response is the soil depth.

SOIL MOISTURE STORAGE

Storage Types

Water in the soil profile is held with

variable tensions and moisture held in between identified tensions are called different types of hydrological storage. This can be divided in three parts: (i) firstly, detention storage which reflects the amount of water held between field capacity and the maximum water holding capacity (MWH) (Fig.1). This volume of water finds its way through the soil profile and gets absorbed by the soil profile or released into the channel system or ground water storage much after the rain has stopped; (ii) secondly, the retention storage which is defined by the difference between permanent wilting point or moisture equivalent and field capacity. Water from this storage does not flow out of profile but gets utilised through the process of evapotranspiration; and (iii) thirdly, the storage below permanent wilting point is, however, not generally available for any of the two purposes indicated above.

For a hydrologist the detention and retention storages are of special interests. More the detention storage greater is the possibility to ensure larger release of water to the streams and the ground water storages over a longer duration. When the retention storage is more, it is likely to utilise larger bulk of water held in detention storage and, therefore, likely to reduce the flow out of profile. Marked variations in these storages with the changes in land-use management were reported earlier (Das, et al, 1970) and also can be seen from Fig. 1.

Retention Storage Opportunity

Retention Opportunity (RO) is defined as the difference between the soil moisture storage for the antecedent period say a week (SM_a) and field capacity (F.C) vide Fig.1. Again the availability of this opportunity at a particular time is not of all importance. Its availability over the weeks and the cummulative totals play very significant role in the disposition of incident rainfall. The incidence of rainfall coinciding the retention opportunity is another factor regulating the utilisation of incident rainfall on land and thus the flow out of it. (Das, et al, 1967, 1970).

SOIL MOISTURE STORAGE IN RAINFALL DISPOSITION OR WATER BALANCE

Models for rainfall disposition or water balance are many. These obviously differ in emphasis and form as the objectives differ. In Watershed Management Programmes, variations in disposition of incident rainfall with the changes in land use management, is an important factor. Thus the component in the model which can reflect such changes and provide a basis to quantify the same is considered as the Key. Examination of various hydrologic phases after rain falls on ground reveal that many of storages on a watershed such as surface detention, depression storage, crown and floor interception are temporal. The water, thus stored, gets transformed to soil storage and evapotranspiration.

The basic mass water balance as given in equation (1) has been taken as the base (Hewlett and Nutter, 1969).

$$P = E_t + Q \pm \Delta SM + L + U \;........ \quad (1)$$

Where

P = Gross Precipitation

E_t = Total Evapotranspiration

Q = Stream flow

ΔSM = Change in Soil Moisture Storage within basin

L = Leak in or out of basin

U = Under flow

Assuming no leak and no under flow the water balance or disposition becomes:

$$P_g - E_r - Q \pm \Delta SM = 0 \;........... \quad (2)$$

The problem was then to choose a method for keeping continuous record of SM over selected time interval. Because SM at any moment is a deal between the volume of soil profile in operation and its attributes in one hand and the depleting forces of gravity drainage and evapotranspiration on the other hand (Baver, 1956). It is highly site specific, highly variable with time and thus complex. It is extremely difficult to be simulated. Thus, out of four main approaches, namely: (i)

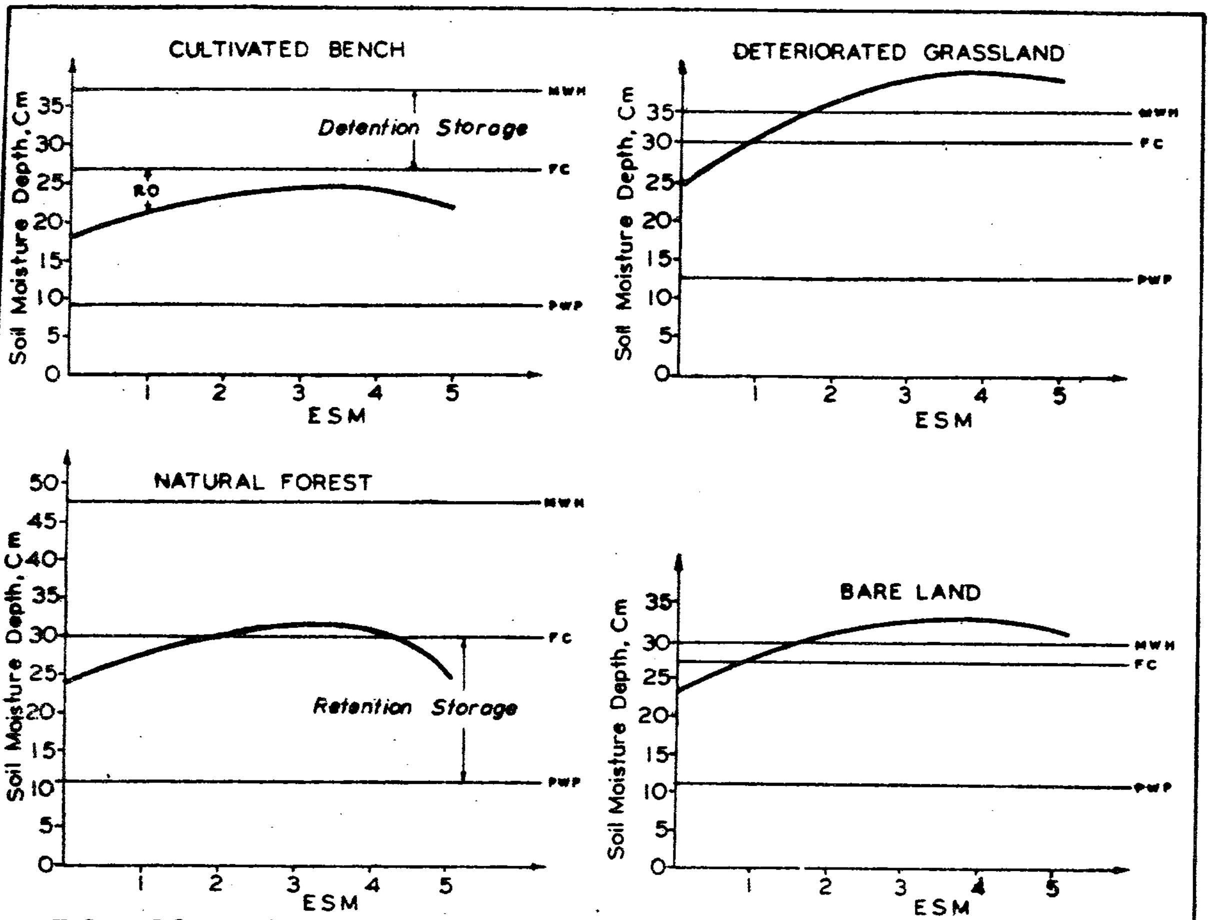

FIG.1 SOIL MOISTURE - ESM CURVES WITH CHARACTERISTIC POINTS

Table 1 - ESM-SM Estimation Models for Different Management Fields with Important Characteristics, Ootacamund, the Nilgiris, India

All depths are in Cm.

S. No.	Management Field or Land Use Practice	Estimation Model $SM = a + bx - Cx^2$	Critical dryness*	Critical wetness**	PWP	FC	MWH	Maximum Expansion
1	2	3	4	5	6	7	8	9
1.	Bench Terrace (Non-Paddy) cultivated	$SM=17.83+3.63x-0.48x^2$	17.83	24.67	9.37	26.60	36.96	9.04
2.	Shola - Submountane Evergreen forest	$SM=23.37+37+4.67x-0.68x^2$	23.37	31.42	10.69	29.90	47.65	20.90
3.	Deteriorated Grass-land	$SM=24.56+7.19x-0.89x^2$	24.56	39.06	12.72	30.48	34.34	5.61
4.	Bare land	$SM=22.99+5.26x-0.71x^2$	22.99	32.82	11.62	27.28	29.69	3.63

* Least retention ** Peak retention SM = Soil Moisture
X = ESM = Effective Soil Moisture Factor, PWP = Permanent Wilting Point,
F.C = Field Capacity, MWH = Maximum Water Holding Capacity.

Lysimeter; (ii) Paired Watershed; (iii) Soil Moisture plots; and (iv) Meteoro- logical approach of Thoruthwaite - Mather, carefully designed natural soil moisture plots have been used. These plots were considered to be capable of offering additional useful information which would help in understanding the physical process concerning the dispo- sition of the incident rainfall (Hewlett and Nutter, 1969).

DESCRIPTION OF THE MODEL

The model was developed for the Nilgi- ris. Though basin leakage (in or out) could be neglected here too, the under- flow, such as deep percolation (D_p) has to be considered as the lateritic soil profile is characterised by deep weathering.

Equation (2) has, therefore, been modi- fied as follows with all values in cm. depths.

$$P = E_t + Q + D_p \pm \Delta SM \text{ .... } (3)$$

In this ($Q + D_p$) has been taken as water lost from the basin while ($E_t \pm$ Δ SM) as the amount utilised on the basin. Thus the computation of uti- lisation under different land manage- ment practices has been taken as the main measurable parameters.

$$\text{Now, } RO = (FC - SM_a), \text{ Cm .... } (4)$$

$$\text{Where, if } SM_a \geq FC, \text{ then } RO = 0$$

$$\text{and } WL = (p - RO), \text{ CM .... } (5)$$

$$\text{where, if } P \leq RO, \text{ then } WL = 0$$

Retention opportunity utilised (RO_u) will, however, depend upon the inci- dence of rainfall, as in the Nilgiris surface runoff was recorded mostly around 2% and in rare occasions around 5% of the incident rainfall. (Das, et al, 1967). Thus, it was assumed that

$$RO_u = RO - P \text{ .... } (6)$$

$$\text{Where if } RO \geq P, \text{ then } RO_u = P$$

$$\text{and if } RO < P, \text{ then } RO_u = P\text{-}WL$$

Thus all components of the model given in equation (3) becomes known. It would be seen that the model as such needs measurement of two parameters, namely rainfall (P) and soil moisture (SM) for each time interval. Other items such as soil moisture constants, depth, etc. are not to be measured during each time interval. Though it looks simple, the problem of measuring soil moisture over an extensive area and under different management practices is neither physically practicable nor financially supportable.

SOIL MOISTURE ESTIMATION EQUATIONS

An essential element for the model is, therefore, to develop reasonably relia- ble tool for estimation of soil mois- ture from easily measurable parameters under different management conditions.

A search was, therefore, made to locate such independent variate which could be physically appropriate and also easily determinable/measurable.

Indices of Soil Moisture or Antecedent Conditions

Antecedent precipitation Index (API) is possibly one of the most widely used incices and can be computed from rain- fall data alone. The constant 'K' in the computation is, however, mainly a function of soil characteristics and does not consider adequately the clima- tic associates which govern evapotrans- piration (Das, et al, 1967). This physi- cal inappropriateness was observed by Neal (1960) and Holtan et al, (1962). Again, in the Nilgiris correlation of SM was far more significant with $\sqrt{API}$ than API (Pooranchandran, et al, 1969). Low discharge Index (Q_1) is another parameter which is primarily used with reference to dry weather flow (Lawren- sen, et al, 1963). It really does not help to understand how the incoming rainfall will be distributed. Besides, determination of Q_1 is more elaborate and time consuming. A third index is Effective Soil Moisture (ESM) factor. It is a ratio of precipitation to square of mean temperature. It, there- fore, takes into account the input as well as the major depleting forces of evapotranspiration and was first advanced by Thornthwaite for climatic classification as a measure of soil moisture status. Later it was used to explain variations in runoff (Baver, 1956). ESM Factor was observed to be more significantly associated with SM as well as surface runoff as compared to API under different mana- gement practices (Das, et al, 1967).

Estimation Equations

For fields under four different management practices estimation models were obtained with ESM as the independent variate (Das, et al, 1967). Similar models were also obtained with $\sqrt{API}$ for cultivated benches in the Nilgiris (Poornachandran, et al, 1969). All these equations have the form as given in equation (7)

$$SM = a + bx - cx^2 \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

where a, b, c are constants,

$X = ESM$ or $\sqrt{API}$.

However, ESM-SM equations were more significant and had lower standard error of estimation for the regression. Thus rainfall alone and without the involvement of temperature, representing the depleting force of evapotranspiration, was not found adequate to explain changes in soil moisture over time and under different management. Thus estimation equations with ESM factor has been used in the model to determine the soil moisture storage values and therefrom retention opportunity utilised and water lost from the watershed. Measurement of the independent variates i.e. precipitation and temperature are involved which has replaced the necessity of measuring actual soil moisture on the field in subsequent computations.

OPERATION AND PERFORMANCE OF THE MODEL

Operation

The operation of the model will call for repetitive computations for the chosen time interval, here a week. Thus an IBM CPS 360 computer programme has been developed with two external entry procedures. One of the external entry procedures works out ESM & SM while the other gives sums of precipitation, RO provided, RO utilised and loss. From these values various performance characteristics of ratings could then be worked out. The operation of the computerised model will require the followings:

1) Weekly precipitation; 2) Weekly mean temperature; 3) Soil moisture status such as field capacity etc.; 4) Estimation Equation for soil moisture in depth, ESM - SM equations.

Characteristics of Soil Moisture Estimation Model

The estimation equations presented in Table 1 reveal some interesting features. It has a maximum or peak which illustrates that every field is physically limited in so far as soil moisture storage is concerned, notwithstanding the continuing or increasing supply such as rain. Soil moisture increases steadily with the increasing value of ESM due to predominance of the soil suction gradient. After the peak is reached the storage starts declining with the increasing value of ESM (Fig.1). This is primarily due to increasing hydraulic conductivity and higher transpiration rate till aeration is the limiting factor. The peak is thus the highest potential and antecedent wetness condition and, therefore, highest potential for runoff. It would be seen that according to this model highest runoff or water loss is expected from deteriorated grassland followed by bare land, shola and cultivated benches.

Similarly, the equation has got a minimum which indicates the maximum extent of depletion of soil moisture possible under normal climatic and management conditions. This is fully in line with the demonstration given by Coleman (1958) that any field will retain a part of rain in disregard of evapotranspiration demand. This incomplete depletion has been variably explained by different workers (Das, et al, 1967). This can be considered as the critical watershed/catchment dryness limit and can indicate as to when a field, under a given management schedule, may be subject to water stress conditions. The cultivated bench terraces has the minimum retention and thus highest critical dryness and, therefore, highest susceptibility to drought.

These two points by themselves speak the relative susceptibility of a watershed under a given management condition to cause flood or drought. Like the common soil moistures status limits, such as permanent wilting point, field capacity or maximum water holding capacity, these points also do not indicate the total potential of a watershed for absorption, utilisation and loss of incident rainfall. The information collated from continuous depletion and accretion of soil moisture which are complex dynamic functions of evapotranspiration demand of climate, re-distribution of absorbed moisture in the soil and physiological functioning of the plant body for utilisation of the absorbed water, would be necessary to clearly interpret the real potential of watershed either to cause runoff or result in drought.

Rainfall Disposition vis-a-vis Land Use Management

The disposition of rainfall on a watershed will have to be seen as either its ability to utilise incident rainfall on site or water loss potential. The relative performances of the four different management practices in the Nilgiris presented in Fig. 2 bear clear testimony to this. The highest cumulative retention was offered by the benches under cultivation followed by shola, deteriorated grassland and bare land (Fig. 2a). Similar trend was also observed in respect of utilisation of cumulative retention storage (Fig.2b). Bench terraces helped in large total absorption and utilisation of 61% of annual rainfall as compared to 41% under natural forest, 29% under degraded grassland and 28% under bare land. The greater ability of the benches in utilising large portion of incident rainfall rests on continuous depletion of retention storage through raising crops and favourable distribution of rainfall coinciding with retention opportunities created.

Insofar as efficiency of utilisation of retention opportunity is concerned the difference amongst the management practices are not very great (Fig.2d). The cultivated benches which utilised the highest portion of rainfall did not have significantly higher efficiency as bulk of the opportunities created in such fields were not utilised due to non-availability of supply that is rainfall. In other words such management practice is capable of holding and utilising still larger amount of water and, therefore, has the potential to increase the watershed retention capacity and reduce water loss further.

Insofar as water loss is concerned the maximum portion of rain water goes out of watershed from bare land and deteriorated grassland (Fig.2c). In case of forest land even though large volume of rain water infiltrates into the profile the bulk of it could be retained in detention storage and disposed of slowly over a long period. Grasslands absorbed about 71% of the incident rainfall, as inspite of grazing the minimum cover was available on the surface. But due to compaction it did not promote voluminous vertical movement through percolation to deeper layers. Similarly, due to excessive wetness conditions, depletion by evapotranspiration was also minimum. Therefore, along the compacted shallow sloping profile voluminous interflow resulted.

Flood Moderation

It is well accepted that flood occurs if there is excessive rainfall and the watershed cannot retain bulk of it. It is also argued that with incidence of high intensity heavy rainfall or rainfall over a long period, watershed gets saturated and, therefore, its ability to retain and utilise rain water falls. As a result, notwithstanding the management practices, including forest vegetation, watershed will be unable to moderate the flood to any significant extent. Neither of these contentions can be supported by unqualified explanation of the physical processes involved and actual data available from the field. Besides we are concerned with relative performance of the land use or management practices in respect of water loss and water utilisation, so that appropriate landuse practices could be adopted to moderate either flood or drought. In case of a catchment the hydrologic responses such as, watershed retention, peak and yield, as had been reported elsewhere (Raghunath, <u>et al</u>, 1970), are determined by the manner how the land surface is distributed amongst land use practices such as forest, grass land and cultivated benches. Examining the variations in landuse statistics over three decades, the same authors showed that large scale conversion of sloping grasslands to cultivated benches and plantations of <u>Eucalyptus globulous</u> and <u>Acacia Mollisima</u> in 17 watersheds of the Nilgiris enhanced annual watershed retention by 28 cms. The information obtained in respect of four management practices in the Nilgiris have confirmed the feasibility of such changes. The results showed that there are land management practices, such as cultivated benches,/help in providing continuous retention opportunity to intake,

/which

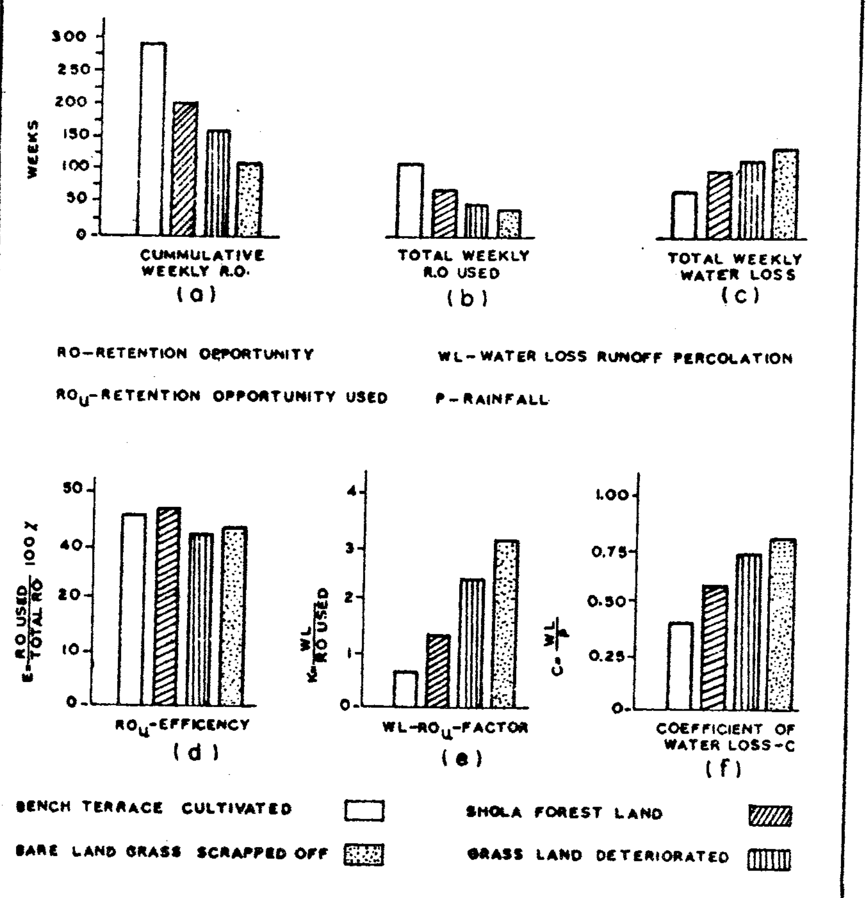

FIG.2 PERFORMANCE CHARACTERISTICS OF FOUR LAND-USE PARCTICES IN RESPECT OF RAINFALL DISPOSITION IN THE NILGIRIS

absorb and utilise bulk of incoming rainfall. This continuous process of depletion, therefore, help in retarding the chance of saturating the large tract of area simultaneously. On the other hand the large detention storage created through adoption of a particular land management such as forests help in absorbing and holding the rain water temporarily and then dispose of the same slowly and over a long period.

The wide expansion ability of a profile gives dynamism to the system of soil moisture storage and in a real sense increases the total volume of hydrologic soil depth and thus total storage. The management practices such as forest offers large expansion capability, therefore, provide a best cushion against flood by holding the water temporarily and reducing the danger of quick accumulation of flow.

The peaks of the ESM-SM curves in conjunction with maximum water holding capacity (Fig.1) and expansion percentage abilities (Table 1) indicate that both in deteriorated grassland and bare land the peaks far exceed the field capacity and even maximum water holding capacity. These fields, therefore, get thoroughly soaked following continuous rains. Therefore, these are prone to cause quick accumulation of runoff. On the other hand, in the natural forest land it remains far below the maximum water holding capacity. Besides, the expansion is as high as 20.90 cms for forest land against 5.61 and 3.63 cms for grassland and bare land respectively. Therefore, forest lands do not pose any risk in causing heavy runoff. In cultivated benches the peak remains below field capacity and expansion ability is 12.70 cms. It has, therefore, least runoff producing potential. These details establish the possibility of reducing an event due for a long return period to that is expected at a shorter return period.

The differential role of these management practices can also be visualised from the flow characteristics of water. It is commonly known that channel flow is faster than overland flow and the later is again faster than interflow. Therefore, the formation of runoff will be quickest and rise to the peak will be the steepest if bulk of runoff accumulation is in the form of channel flow. This will be closely followed by situation when accumulation is by and large through excessive overland flow. The peak will be moderated as well as time of flow will be extended if the runoff formation mostly depends on interflow, and further if the interflow is not along the shallow profile. From this angle too natural forest has got greatest influence in inducing the incident rainfall into the profile and then move out as interflow through a long line of percolation and seepage. On the other hand, compacted grassland, though absorb considerable amount, had to part with it at a much shorter time following the rain, as was observed from voluminous collection of interflow in protected surface pits (Das, et al, 1970). It may, therefore, be necessary to have immediate catchments of the reservoirs under somewhat grazed grassland (but free of excessive erosion) to effect quick and large water inflow at crucial period. Voluminous evidences obtained in the country and abroad on such differential roles have been reviewed and published elsewhere (Das & Singh, 1979). Thus, there is considerable possibility to reduce the runoff producing potential of a watershed by manipulating the landuse management. The manner in which the outflow is desired to be regulated will guide us to choose an appropriate management. Taking into consideration the dynamic soil moisture storage and its influence on the runoff response ratings given in Fig. 2(f) have been worked out from the water balance models. These co-efficients could be utilised for rating the runoff potential of watersheds.

Drought Moderation

The problem of drought is realised firstly through significantly low rainfall, secondly due to erratic distribution of rainfall, and thirdly as a result of succession or persistence of such events. The management practice, which offer high cumulative retention opportunity and also has least retention capacity indicating greatest dryness, will be easily susceptible to droughts with slightest sub-normal indidence of rainfall. Amongst four management practices discussed the bench terrace having the most critical dryness level is exposed to this risk to the maximum. However, its ability to recreate retention storage over the weeks neutralises the risk very considerably provided the rainfall distribution remains favourable. If there is prolonged dry spell, all these practices other than forest will be subject to waterstress situation. The endeavour, therefore, should be to incorporate complementary landuse management practices in the same watershed so that entire watershed does not reach to the maximum dryness when, with the incidence of a moderate rainfall, the recovery could be quicker. This will eliminate the risk due to persistence as well. Forest and water harvesting structures with low storage capacities could be such complementary practices which could be usefully interspersed with cultivated fields. This will induce greater absorption and redistribution of water at extensive locations of the watershed and, therefore, keeping the average catchment dryness far above the critical level.

CONCLUSION

For its simplicity such as collection of data on two easily measurable parameters the model has very considerable potential. The effectiveness of the model further enhances when it helps in providing quantitative and qualitative information to explain variable responses of management practices. Using soil moisture storage as the key factor, it could give relative advantage and disadvantages of different landuse practices or ways and means to regulate the hydrologic response. The main difficulty of providing continuous data on soil moisture variations have been overcome by developing estimation tools involving only percipitation and temperature. The model has, however, assumed that with the prevailing distribution of rainfall in the Nilgiris, surface runoff is not significant. It may not be so in many cases where, the model may have to be marginally modified by incorporating a measured or determined component of surface runoff. The qualitative and quantitative variations in the hydrologic performance of the four management practices have been compared in terms of a number of coefficients or ratios and have been useful in establishing the utility of the model. The significance and application of these indices for developing composite watershed ratings and for building up extensive defence against both flood and drought, however, need to be examined more critically. Inspite of these observations, for its inherent appropriateness in the context of physical sciences of hydrology and the needs for examination of alternative management practices, the model offers great potential. The computerised programme enhances its extensive application at shorter intervals and, therefore, increases its utility.

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Flood Frequency Analysis-Comparative Study of Different Approaches

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ABSTRACT

For the design of water resources project and engineering structures, the design flood is generally estimated by frequency analysis of annual peak flood series. However, uncertainty prevails due to problems related to data such as limited data, nonhomogeneity in data, presence of outliers etc. The statistical distributions which are commonly adopted for frequency analysis in different parts of the world are Lognormal, Pearson type III, Log Pearson type III and Extreme value (Type I). Different techniques are adopted for estimating the parameters viz. method of moments, method of least squares, method of maximum likelihood and method of mixed moment. The data of annual peak flood series of four Indian rivers namely Sutlej at Bhakra, Cauvery at Chunchunakatte, Ganga at Hardwar and Pagladiya at N.T. road crossing have been used for comparative study of different statistical distributions and methods of parameter estimation for flood frequency analysis. It has been seen that the coefficient of skewness (C_S) is an important parameter for deciding suitability of a particular distribution. For river Pagladiya having highest coefficient of skewness (C_{SX} = 2.746) and negative coefficient of skewness for log transformed series (C_{SY} = -0.146) the goodness of fit of different distributions has been tested using D-Index approaches and observed that the Pearson type III distribution is most appropriate. This is in conformity with practice adopted in Federal Republic of Germany (FRG).

INTRODUCTION

Estimation of flood peak for desired return period has an important role in the hydraulic design of water resources project and engineering structures. While designing the structures, proper safeguards must be made for the safe passage of the expected maximum flood for a particular return period considered for the structure. Frequency analysis of available data are generally done to find out the expected maximum flood for a particular return period. However, uncertainty prevails in the estimation of peak floods because of availability of limited data, non-homogeneity in data due to various causes such as different methods of measurement, difference in hydraulic characteristics of flood flows, effect of man-made and natural changes, existance of observed extreme events which lie far above or far below the other values etc.

The statistical probability distributions which are commonly adopted for frequency analysis are Log Normal, Pearson type III, Log Pearson type III and Extreme value (Gumbel) distribution (Type I)

Various methods have been adopted for estimating peak flood of desired return periods such as 100 yr, 200 yr, 500 yr 1000 yr, and 10000 yr for three distributions namely, LN, LP type III and Extreme value distribution for the four rivers. Pearson type III distribution is also adopted for river Pagladiya whose C_{SY} is negative.

The methods adopted for parameter estimation are method of moment and method of least square for all the three distributions, method of mixed moment - MXM1 (Rao, DV; 1980) for log Pearson type III distribution and method of maximum likelihood (Panchang, GM; 1967) for extreme value distribution. Sample size correction for extreme value distribution (Viessman, W; 1977) is also made. The method adopted in Federal Republic of Germany (Kuratorium; 1976) for selecting the distribution between LP type III and Pearson type III depending on the coefficient of skewness of the log transformed series (C_{SY}) is also adopted here.

D-Index method (for the river Pagladiya having highest C_{SX} and negative C_{SY}) has been adopted to determine the goodness of fit of different distributions by different methods. A comparative study of different approaches are made here.

NOTATION

LN = Log normal distribution
LP = Log Pearson distribution
MM = Method of moments
MLS = Method of Least Squares
MXM1 = Method of mixed moments
MML = Method of maximum likelihood
n = number of values in data series
m = rank number in descending order
X = data series of annual peak flow
$Y = \log_e x$
P = Probability
K = frequency factor
T = return period
$\bar{X}, \mu_X$ = mean of X values
$\bar{Y}, \mu_Y$ = mean of Y values.
σ_X = standard deviation of X values
σ_Y = standard deviation of Y values
C_V = Coefficient of variation
C_S = Coefficient of skewness
C_{SX}, γ_X = Coefficient of skewness of X values
MM* = Method of Moments with sample size correction

METHODOLOGY

Generally the annual flood peak values at a given site are used f or frequency analysis. Frequency analysis considers the probability of occurence of an event with a given magnitude and uses probability theory. Annual flood peak series fits a distribution which is generally skewed and hence a three parameter distribution is generally assumed. The statistical estimates of arithmetic mean, standard deviation and coefficient of skewness for historical data are generally used to estimate the parameters of the theoritical probability distribution assumed for the annual peak flow series.

Three steps in fitting a probability distribution to a series of annual peak flow (random variables) are as follows:

i) Selection of appropriate theoretical distribution

ii) The estimation of parameters of the theoretical distribution from available data.

iii) Testing the goodness of fit of the fitted distribution on the basis of certain standard statistical criteria.

The probability distributions that are generally used in flood flow frequency analysis are :

Log Normal Distribution

This assumes that the Logarithms of the variable has a normal distribution and the value ranges from 0 to ∞

Considering $Y = \log_e X$, where X is the random variable, then x is said to have a log normal distribution if Y has a normal distribution.

The probability density function is given as

$$p(x) = \frac{1}{\sigma_Y e^Y \sqrt{2\pi}} e^{-(Y-\mu_Y)^2/2\sigma_Y^2}$$

It may be noted that

$$\mu_X = e^{\mu_Y + \sigma_Y^2/2}, \quad \sigma_X = \mu_X (e^{\sigma_Y^2} - 1)^{1/2}$$

$$C_V = (e^{\sigma_Y^2} - 1)^{1/2}, \quad C_S = 3C_V + C_V^3$$

This is a two parameter distribution where only mean and standard deviation are involved.

Log Pearson Type III Distribution

This distribution assumes that the logarithms of the variables under consideration has a Pearson type III distribution. This is usually a bell-shaped (skewed) distribution with limited range in the left direction. US Army Corps. of Engineers (HEC) has adopted this distribution for flood series particularly because this is a skewed distribution with wide range of parameters and a positive or negative C_S. Use of logarithms helps to reduce the skewness of an already skewed distribution. Foster (1924) recommended that the computed skewness for Pearson type III analysis be multiplied by a factor $(1 + \frac{8}{n})$ to obtain an adjusted skewness when dealing with small samples. This method has as a special case the log normal distribution when $C_{SY} = 0$. Beard (1962, 1967) and Benson (1968) recommended the use of regionalised skew coefficient for a reliable estimate.

This is a three parameter distribution with mean, standard deviation and coefficient of skewness. Details of this distribution is given in Chow (1967), Haan (1977).

Extreme Value Distribution Type I

The distribution of the largest and smallest value of a random variable is refered to as an extremal distribution. This distribution results from any initial distribution of exponential type which converges to an exponential function as X increases. The cumulative probability distribution function is given by

$$P(X \leq x) = e^{-e^{-(a+x)/c}}$$

Where $a = \gamma c - \mu$
$c = \frac{\sigma\sqrt{6}}{\pi}$
$\gamma = 0.57721$ = Euler's Constant.

The frequency factor K can be written as

$$K = -0.7797\left[0.57721 + \ln\ln\left(\frac{T}{T-1}\right)\right]$$

Where T is the desired return period. This distribution has a coefficient of skewness $C_{sx} = 1.139$, it this statistical population has $C_{sx} > 1.139$ then this distribution under estimates the low probability (or high return period) floods and overestimates low flood. Reverse is true when $C_{sx} < 1.139$

Plotting Position

The probability of event can be obtained by use of a plotting position. There are number of empirical formulae like California, Hazen Beard, Weibull, Chegadayev, Blom, Turkey etc. to obtain the probability of event. Chow (1953) has shown that the Weibull formula is theoritically suitable for plotting the maximum series

$$P(X > x) = \frac{m}{n+1}$$

Recurrence interval T is given by

$$T = \frac{1}{P(X > x)}$$

Recurrence interval : When annual maximum values are being analysed, the recurrence interval is defined as the mean time in years, for the m largest value among annual maximum to be exceeded once on the average.

General Equation

The general equation for hydrologic frequency analysis as proposed by Chow (1951) is

$$X(T) = \bar{X} + \sigma \cdot K(T)$$

where K(T) is the frequency factor for the return period T.

Method For Estimation Of Parameters

The parameters involved in the probability distributions can be estimated by

1. Method of moments : First, second and third moments of the data series give the statistical parameter such as mean, standard deviation and skewness, when substituted in the probability function of the given distribution gives an exact theoritical fitting but the accuracy can be substantially affected by any error involved in the data at the tail end of the distribution where the moment arms are long and the errors are thus magnified.

2. Method of least square : In this method, a regression line is fitted between the plotted values of frequency factor K and its variable X. The value of intercept (A) and slope (B) of the regression line are used to find out the predicted value for a particular return period T.

$$X(T) = A + BK(T)$$

The regression line so fitted may not represent the exact theoritical distribution but it gives a better overall fit than the method of moments. Based on the general equation for hydrologic frequency analysis, proposed by Chow (1951) least square procedure for fitting a normal, log normal or extremal distribution was developed by Brakensiek (1958)

3. Method of maximum likelihood (MML) : The parameters for which the probability of occurence of the actual observations is a maximum is known as the maximum likelihood estimate.

Let $X_1, X_2, \ldots, X_n$ be the n observations and $f(X)$ be the assumed probability density function in terms of parameters $P_1, P_2, \ldots, P_n$; then assuming independent events the probability o f outcome, P is

$$P = \prod_{i=1}^{n} f(x_i)$$

For this to be a maximum

$$\frac{\partial P}{\partial P_i} = 0 \quad \text{for } i = 1, 2 \ldots n$$

The n equations in terms of their parameters can be solved to give the maximum likelihood estimates.

Kimball (1946, 1949) has suggested this method for fitting extremal distributions, he mooted the application of this method for the purpose but concluded that one of the normal equations was as intractable of solution.

Panchang and Agarwala (1962) proceeded further and reduced a computational steps for evaluating the parameters successfully.

Peak value for any return period T is expressed as

$$X(T) = U - \left(\frac{1}{\alpha}\right) \log_e \log_e \left(\frac{T}{T-1}\right)$$

Where 'U' and 'α' are parameters. Panchang (1967) has given a workable procedure for finding the parameters 'U' and α, provided the observed number of years for which the annual maxima are on record is not too small (ordinarily not less than 30).

The MML does not require any plotting position formula for calculating the distribution parameters.

This method provides the best estimate of the parameters though the procedure is lengthy.

4. Method of mixed moments (MXM1): This is a method to find out the parameters of the Log Pearson distribution. Regional skew map is needed for Log Pearson Type III distribution for peak flow frequency analysis. Moreover, Hydrologist may wish to use L.P. in analysing other data such as precipitation, Low flows, Lake stages etc. Development of regional skews for different kinds of data is not practical. These uncertainities associated with the use of skew estimate in frequency analysis only suggests that other estimation method which are free from the use of skew should be searched. This effect of variation of skew is avoided in the method of mixed moment (MXM1) by intermixing the first two moments of data (Mean and variance) with the mean of Logarithmic data.

Objective is to estimate the parameters a, b and c so that $\mu_X = \bar{X}$, $\sigma_X^2 = S_X^2$ and $\mu_Y = \bar{Y}$ where $K_i = x_i/\bar{x}$, the dimensionless variate x_i is the data series arranged in descending order. μ_{KY} is the Mean of logarithm of dimensionless variate. σK and γ_K are the standard deviation and coefficient of skewness of dimensionless variate. The initial value of γ_K ($\gamma_K = \gamma_X$) is determined with $\sigma_K^2 = S_K^2$ and $\mu_{KY} = \bar{Y}$ from the relationship of $\mu_{KY} - \sigma_K^2 - \gamma_K$ given in table 7 of Rao (1980). The value of γ_X is then so adjusted that the value of a, b and c calculated therefrom satisfies the relation

$$\text{Mean} = c + \frac{b}{a} = \bar{Y}$$

Then the value of mean and variance of the LP Type III distribution are calculated using this set of value of a, b and c. A detailed procedure to find out the parameters of LP Type III by MXM1 has been given by Rao (1980).

FRG Method Of Selecting Distribution

In Federal Republic of Germany - FRG (Kuratorium; 1976) Pearson Type III and Log Pearson Type III distribution are commonly used for flood flow frequency analysis. The method of selecting the proper distribution adopted in FRG, depends on the value of coefficient of skewness (C_{SY}) of Log transformed series. It states

(i) If $C_{SY} \geq 0$; the distribution is LP Type III

(ii) If $C_{SY} < 0$; the distribution is Pearson Type III with following condition

a) If $C_{SX} > 0$ or $d > 0$ The distribution is Pearson type III without any modification.

b) If $C_{SX} < 0$ or $d < 0$ then C_{SX} is taken as $+2C_{VX}$ and with this vlue, Pearson type III distribution is adopted.

where $d = \bar{X}\left(1 - \frac{2C_{VX}}{C_{SX}}\right)$

Testing The Goodness Of Fit

If the observed data plot as a straight line on theprobability paper, the assumed distribution is satisfactory in a qualitative sense. But quantitatively goodness of fit test is to be done to determine which method and distribution the data series is fitting best. There are number of methods like Chi-square, D-Index etc. D-Index is considered as better representative. In the D-Index method the value of peak flow series are found out by different methods for different distributions from the plotting position of the each observed peak flow data; then the D-Index is calculated as

$$\text{D-Index} = \frac{1}{\bar{X}} \sum_{i=1}^{n} \text{ABS}\left[x_i(\text{ob.}) - x_i(\text{comp.})\right]$$

It is the sum ofabsolute vlue of differences of observed and computed annual peak flow series divided by mean of original series.

Data Used For Study

Analysis is made for ten annual peak flow series of ten Indian rivers (Table 1) representing different hydrometeorological conditions and length of data. Of these, four are in Cauvery basin representing Deccan semi-arid hydrometeorological condition, three in Brahmaputra basin representing north-east Indian humid monsoon climate with high annual rainfall and rain-forested hilly catchment area and three namely Sutlej, Yamuna and Ganga which are all Himalayan snowfed north-Indian rivers. The statistical parameters (Table-2) are found out for these rivers and shows that the coefficient of skewness varies to a great extent. Out of these ten rivers, four have been selected one from each category depending on hydrometeorological condition and coefficient of skewness - viz. 1.041 for Sutlej at Bhakra, 1.229 for Cauvery at Chunchunakatte, 1.771 for Ganga at Hardwar and 2.746 for Pagladiya at N.T. road crossing, for detailed analysis.

TABLE - 1 : Details Showing The Rivers With Site, Period And Maximum Observed Flood

Sl.	Name of river with Station of Obs.	Period of record Analysed	No. of year of record	Observed Maximum Value in M^3/Sec	Observed Maximum Year of Occur.
1.	Cauvery Basin:				
a)	Kabini at Hullahally	1918-74	57	4132	1961
b)	Hemavathy at Akki-hebbal	1918-74	57	2982	1924
c)	Cauvery at Chunchana-katta	1918-74	57	2882	1924
d)	Cauvery at K.R. Sagar	1938-72	35	6205	1961
2.	Brahmaputra Basin :				
a)	Desang at Nanglamara	1957-78	22	1059	1969
b)	Puthimari at N.T. Rd. Crossing	1955-75	21	861	1973
c)	Pagladiya at N.T. Rd. Crossing	1957-77	21	4532	1977
3.	Yamuna at Tajewala	1924-60	37	15970	1947
4.	Sutlej at Bhakra	1912-55	44	9200	1951
5.	Ganga at Hardwar	1901-65	65	19130	1924

TABLE - 2 : Statistical Parameters of Annual Peak Flow Series (Natural)

Sl. No.	Name of river with Station of obs.	Mean ($\bar{x}$) (m^3/Sec)	S.D. (σ_x) (m^3/Sec)	Coeff. of Var. (C_{vx})	Coeff. of skewness (C_{sx})
1.	Cauvery Basin :				
a)	Kabini at Hullahally	1281.29	673.19	0.5254	2.496
b)	Hemavathy at Akkihebbal	1131.28	491.21	0.4342	1.544
c)	Cauvery at Chunchanakatte	1335.35	463.56	0.3471	1.229
d)	Cauvery at K.R. Sagar	2640.91	1142.46	0.4326	1.473
2.	Brahmaputra Basin :				
a)	Desang at Nanglamara	778.73	94.89	0.1218	1.158
b)	Puthimari at N.T. Road	486.00	216.25	0.4495	0.747
c)	Pagladiya at N.T. Road	1035.66	942.92	0.9104	2.746
3.	Yamuna at Tajewala	5531.08	3849.14	0.6959	1.264
4.	Sutlej at Bhakra	3936.02	1670.39	0.4244	1.041
5.	Ganga at Hardwar	6123.23	2835.31	0.4630	1.771

RESULT AND ANALYSIS

The peak flood series of four rivers namely Sutlej at Bhakra, Cauvery at Chunchunakatta, Ganga at Hardwar and Pagladiya at N.T. Road Crossing has been utilised for flood frequency with Log normal, Log Pearson Type III and Extreme Value (Gumbel) distribution. The method of moment and method of least square has been used for parameters estimation for three distribution mentioned above. The method of mixed moment has been used for LP Type III distribution where as method of moment with sample size correction and method of maximum likelihood have been used for Extreme value distribution. The expected peak floods in m^3/sec for return periods of 100, 200, 500, 1000 and 10000 years have been computed. The results are tabulated in Tables 4,5,6 and 7.

For Sutlej at Bhakra, Cauvery at Chunchunakatte and Ganga at Hardwar the C_s for natural series is positive and varies from 1.041 to 1.771 and the C_s for log transformed series varies from 0.194 to 0.358. As per standard criteria of FRG Log Pearson Type III distribution is appropriate for these three rivers. The results in table 4,5 and 6 using different methods of parameter estimation are of same order of magnitude. The variation in expected peak values by different distributions is mostly due to basic

TABLE - 3 : Statistical Parameters Of Annual Peak Flow Series (Log Transformed - With Base E)

Sl. No.	Name of river with Station of Obs.	Mean ($\bar{Y}$)	S.D. (σ_Y)	Coeff. of var. (C_{VY})	Coeff. of skewness (C_{SY})
1.	Cauvery Basin :				
a)	Kabini at Hullahally	7.060	0.415	0.058	0.849
b)	Hemavathy at Akkihabbal	6.951	0.398	0.057	0.208
c)	Cauvery at Chunchanakatte	7.144	0.323	0.045	0.358
d)	Cauvery at K.R. Sagar	7.801	0.392	0.050	0.419
2.	Brahmaputra Basin :				
a)	Desang at Nanglamara	6.651	0.117	0.017	0.737
b)	Puthimari at N.T. Road	6.097	0.426	0.069	0.375
c)	Pagladiya at N.T.Road	6.649	0.791	0.119	-0.146
3.	Yamuna at Tajewala	8.410	0.641	0.076	0.363
4.	Sutlej at Bhakra	8.196	0.407	0.049	0.194
5.	Ganga at Hardwar	8.629	0.424	0.049	0.205

difference in two parameter distribution (Log normal and Extreme value) and Log Pearson type III distribution is a three parameter distribution and takes into account the skewness also, besides mean and standard deviation.

In the method of mixed moment (MXM1) for Log Pearson type distribution the coefficient of skewness is estimated using mean and standard devation of natural series and mean of Log transformed series, and as such the results using MXM1 tend to be somewhat different than MM & MLS. However for the selection of appropriate distribution and method amongst different combinations it is necessary that some test of goodness of fit is adopted.

For the river Pagladiya at N.T.Road Crossing for natural peak flood series $C_{VX} = 0.9104$ and $C_{SX} = 2.746$ while for log transformed series $C_{VY} = 0.119$ and $C_{SY} = -0.146$. As per FRG Criteria for this case Pearson type III is appropriate. Therefore, for the data of this river besides the three distributions adopted for other rivers, Pearson type III distribution was also tried. The results are given in table 7. In this case, as C_s for natural series is quite high in comparison to Gumbel distribution ($C_{SX} = 1.139$).

As such the expected peak flood obtained from extreme value as well as LN distribution vary significantly from those for LP type III and Pearson type III distribution. Computed flood values for different return periods, distributions and methods ofparameter estimation are also plotted in Fig. 1. The D-Index was computed for goodness of fit test by considering all 21 values as well as by considering 7 highest values which exceed the mean value of 1035.66 m^3/sec for peak flood series. These are give n in Table 8. It is seen that though on the basis of D-Index for entire series, Lognormal (MM) is a better fit, however, on the basis of seven highest values Pearson type III (MM) is the most suitable. Since Low values of peak floods are relatively less important from thepoint of view of extrapolation, the Pearson type III distribution is considered most appropriate for peak flood series for river Pagladiya.

CONCLUSIONS

The common probability distributions used for flood frequency analysis are Log normal, Extreme value type I, Pearson type III and Log pearson type III. The coefficient of skewness is an important parameter for selecting appropriate distributions. The extreme value distribution which is a two parameter distribution is suitable for peak flood series with C_{SX} approximately equal to 1.139. While the log normal distribution is appropriate for series having C_{SY} nearly equal to zero for log transformed values. For C_{SY} greater than zero, log Pearson type III is suitable. For $C_{SY} < 0$ Pearson type III distribution could be adopted with appropriate correction of C_{SX} value as per FRG practice. The method of moments, method of maximum likelihood, method of least squares and method of mixed moments (MXM1) are used for parameter estimations. The suitability of a particular method of parameter estimation could be decided by appropriate test of goodness of fit such as D-Index approach.

TABLE - 4 : Expected Peak Floods (m^3/sec) of Different Return Periods for River Sutlej At Bhakra

Sl. No.	Distribution	Method	100 yr	200 yr	500 yr	1000 yr	10000 yr
1.	Log Normal	MM	9350	10350	11700	12760	16480
		MLS	9755	10850	12355	13500	17640
2.	Log Pearson Type III	MM	9900	11100	12900	14280	19550
		MLS	10350	11705	13620	16130	21045
		MXM1	9395	10320	11530	12430	15380
3.	Extreme value Distribution	MM	9180	10080	11280	12180	15180
		MM*	9830	10200	11320	13185	-
		MLS	9690	10675	11980	12960	16230
		MML	8840	9690	10820	11670	14500

TABLE - 5 : Expected Peak Floods (m^3/sec) of Different Return Periods For River Cauvery at Chunchanakatte

Sl. No.	Distribution	Method	100 yr	200 yr	500 yr	1000 yr	10000yr
1.	Log Normal	MM	2680	2910	3210	3440	4210
		MLS	2780	3030	3355	3605	4460
2.	Log Pearson Type III	MM	2920	3240	3690	4060	5420
		MLS	3020	3370	3860	4260	5760
		MXM1	2880	3150	3500	3770	4630
3.	Extreme value Distribution	MM	2790	3040	3370	3620	4460
		MM*	2940	3040	3350	3860	-
		MLS	2910	3180	3540	3810	4700
		MML	2680	2910	3220	3450	4220

TABLE - 6 : Expected Peak Floods (m^3/sec) of Different Return Peiiods For River Ganga At Hardwar

Sl. No.	Distribution	Method	100 yr	200 yr	500 yr	1000 yr	10000 yr
1.	Log Normal	MM	14990	16670	18950	20730	27060
		MLS	15490	17280	19725	21650	28510
2.	Log Pearson Type III	MM	16000	18100	21100	23500	32720
		MLS	16570	18835	22060	24685	34755
		MXM1	16150	18030	20510	22380	28580
3.	Extreme Value Distribution	MM	15020	16560	18580	20120	25210
		MM*	15850	16460	18310	21400	-
		MLS	15490	17110	19230	20840	26170
		MML	14010	15390	17200	18570	23120

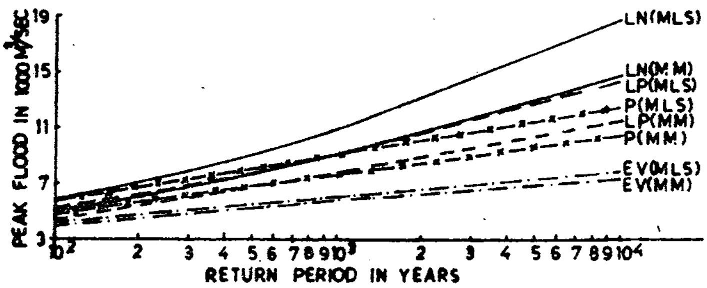

FIG.1-VARIATION OF PEAK FLOODS OF RIVER PAGLADIYA AT N.T. ROAD CROSSING FOR DIFFERENT RETURN PERIODES WITH DISTRIBUTIONS AND METHODS.

TABLE - 7 : Expected Peak Floods (m^3/sec) of Different Return Periods For River Pagladiya At N.T. Road Crossing

Sl. No.	Distribution	Method	100 yr	200 yr	500 yr	1000 yr	10000 yr
1.	Log Normal	MM	4860	5920	7520	8900	14630
		MLS	5640	6980	9040	10840	18560
2.	Log Pearson Type III	MM	4470	5320	6550	7960	11500
		MLS	5136	6200	7765	9070	14250
		MXM1	5080	6100	7480	8540	12170
3.	Extreme Value Distribution	MM	3990	4510	5180	5690	7380
		MM*	4630	4860	5540	6670	-
		MLS	4170	4700	5410	5940	7710
		MML	3040	3400	3870	4220	5400
4.	Pearson Type III	MM	4760	5570	6660	7495	10300
		MLS	5670	6660	7990	9000	12425

TABLE - 8 : D-Index Values of River Pagladiya For Different Distributions & Methods.

Distributions	For all 21 Values				For Highest 7 Values	
	MM	MLS	MXM1	MML	MM	MLS
1. LN	2.811	2.962	-	-	2.177	2.231
2. LP Ty.III	2.881	3.059	4.125	-	2.240	2.324
3. EV (Gumbel)	5.111	5.624	-	3.327	3.059	3.361
4. Pearson Ty III	3.351	3.830	-	-	2.130	2.530

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watershed is to study the orographic precipitation gradients. The model algorithm describing the variation of precipitation with elevation of precipitation with elevation and temperature is calibrated by comparing calculated snowpacks at various time intervals with the snowcourse measurements, as shown in figure 2. The complete comparision during accumulation and depletion of snowpacks requires estimation of precipitation by elevation the form of precipitation, rain or snow, and the snowmelt occurring at various times. The temperature lapse rate is therefore an importent ingredient in this part of the analysis, influencing both melt rates and orographic gradients.

Reconstitution of outflow hydrographs is the next stage of model calibration and two example which have been presented in detail.

Previously, Quick and Pipes (1975 and 1977) will be briefly outlined. The Jordan River example, fig.3, illustrates the considerable improvement which is achieved by using temperature based snowmelt equations which account for additional radiation melt and condensation melt components, For comparison, the melt calculated from only the mean air temperature is plotted. In periods of extreme snowmelt, the melt rate can be approximately double the rate that might be estimated from mean temperature alone. For the example given, plots of temperature and precipitation at a base station are presented for comparison with the outflow hydrograph.

In another example illustrated in fig. 4, for the Spillimacheen River, an earlier paper, Quick and Pipes (1977), discussed and compared the accuracy attainable using different single data station and combinations of data stations. None of the data stations were in the watershed. One valley data station exhibited far less precipitation than the mountain stations, varying in frequency, duration and amount. The study showed that the nearest station, which was also near the mid-elevation of the basin and in a similar climatic zone, gave the best results, superior even to a combination of stations. Such a mid-elevation station reduced data extrapolation errors and is more representative of amount, duration and frequency of precipitation and of the actual basin temperature regime. For the data tested, the errors of maximum peak flow, monthly volumes and hydrograph shape, measured by residual variance, were all less than 5 percent.

Conclusions

Mountain watershed modelling is simplified by orographic effects which imposes a discipline on the precipitation and snowmelt patterns.

The orographic effects are non-linear, but can be described in terms functional relationships involving temperature and saturated: and dry adiabatic lapse rates. These relationships are used to distribute point meteoro-logical data to all parts of the watershed.

The response of the watershed itself is also non-linear, but in the UBC Watershed model these non-linearities are restricted to the soil moisture budget section, which subdivides rain and snowmelt into the various components of runoff. These components of runoff are then routed to the basin outflow point using linear routing techniques. This linearisation of the routing section of the model is a great simplification and makes considerable computational economies.

The examples of model calibration are used to illustrate the flexibility and capability of the model. In particular, the snowmelt formulation, which has additional temperature terms to represent radiation and condensation effects, is shown to account for high melt rates with greater accuracy than the simple degree day method. Given representative input data, preferably at mid-elevation of the watershed, the results indicate that the modelling assumptions appear to be adequately realistic for flow forecasting purposes.

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The increase in peak discharge necessitates a general modification of the normal unit hydrograph which is arbitrarily carried out and volume adjusted for 1 cm. of runoff. The unit hydrograph so obtained has been taken as a design unit hydrograph and its ordinates are given in Table.2.

PROBABLE MAXIMUM PRECIPITATION

In mountaineous areas, transposition of storms is limited to regions of similar orographic influences. In the absence of a detailed meteorological analysis transposition of storm from outside the basin is not justifiable (CWC 258, 1972). It has been found that the highest areal rainfall for the catchment upto Tajewala was severest during 27-30th September 1924 and is the biggest storm in record. Isohyetal maps for this storm have been provided by I.M.D., the extract of which is shown in Fig. 8. Average depth of precipitation for 2 days; that is, 28-29th September 1924 has been determined by planimetering the areas between different isohyets and this works out to 35.3 cms.

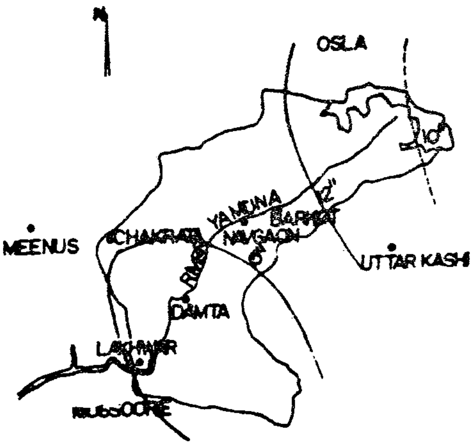

FIG.8 ISOHYETAL PATTERN 28-29th SEPT. 1924.

Storm Maximisation

The factors which affect the rainfall are : (a) the mechanical efficiency of the storm in changing water vapour and droplets of the atmosphere into rain and (b) the moisture content of the rain producing air mass involved in the storm.

As regards mechanical efficiency of the storm, it can not be evaluated. It is therefore assumed that the rainfall producing mechanism or process in these outstanding historical storms was highly efficient and is very likely near maximum efficiency. So only the account for the second effect, is done through moisture adjustment factor,MAF.

$$MAF = \frac{\text{Maximum precipitable water over the basin}}{\text{Storm precipitable water.}}$$

This factor also includes the correction due to inflow barrier.

The dew point data is available only for Chakrata station and this is taken as a representative of the whole basin.

<u>Computations Of MAF Storm Precipitable Water.</u>

Dew point temperature on 28-29th September 1924	= 11.67 P_c
Elevation of Chakrata station (Taken from survey of India maps)	= 7170 feet.
Equivalent dew point Temperature at MSL for 11.67 °C at elevation 7170 ft.	= 21.2°C
Depth of storm precipitable water at 21.2°C i.e. 1000 mb to 300 mb.	= 2.28 inch
Depth of precipitable water at inflow barrier (1000 mbs to 4000 ft.)	= 0.78 inch.
Precipitable water	= 2.28 -0.78
(4000 ft. to 300 mbs)	= 1.50 inch

<u>Maximum precipitable water</u>

Maximum dew point temperature at MSL for 17.22oc at elevation 7170 feet.	= 26.00 °C
Depth of precipitable water at 26°C	= 3.42 inch
Depth of precipitable water at inflow barrier (1000 mbs to 4000 feet)	= 1.05 "
Precipitable water (1000 mbs to 4000 feet)	= 2.37 "

$$MAF = \frac{2.37}{1.5}$$

$$= 1.58$$

Probable Maximum Precipitation

The PMF rain depths for 2-day duration is obtained by multiplying the average rainfall depth by MAF which is

Runoff Prediction of High Mountain Watersheds With Varied Landuses

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ABSTRACT

In many developing countries, the need to produce more food, fibre and shelter has caused many watersheds to undergo rapid land use changes altering drastically its hydrologic characteristics such as peak and low flows. Predicting the hydrologic characteristics of these transitional watersheds has always posed problems mainly because of the difficulties in including the land use either directly or indirectly in the rainfall-runoff modelling.

The land use changes alter mainly the volume of runoff as well as its time distribution. In order to study the effect of different land use pattern on the above characteristics, three typical watersheds-a forest, an urban and a rural-were selected in the high hills of Bhavani. The general hydrologic model proposed by Chow and Kulandaiswamy was used to model the rainfall-runoff relationship. At first the mode was applied to a paired experimental watersheds having different land use patterns.

This study revealed that the rainfall excess volume was mainly dependent upon the rainfall volume, soil moisture condition and the land use pattern, and the model parameters varied with the delay time, t_{da}, the time between the end of rainfall excess and the end of surface runoff and independent of land use pattern. Assuming that these results are equally applicable to the subwatersheds which are lying in the same hydrometeorological environs, the runoff characteristics of these watersheds were analysed with 119 storms selected from the three basins. Using the results, an attempt is made to predict as to how the hydrograph of a rural watershed for a given rainfall gets altered when it is either urbanized or afforested.

1. INTRODUCTION

Drainage basins are to-day subjected to many types of planned and unplanned changes which affect their hydrologic characteristics. A change in land use or cultural practices may have either a beneficial or an adverse effect on water resources. The hydrological effects that appear to be important as far as land use changes are concerned can be listed as follows:
a) increase or decrease in water yield,
b) increase or decrease in peak flow,
c) increase or decrease in low flow,
d) change in surface water quality,
e) increase or decrease in ground water flow and f) changes in ground water quality.

In an earlier investigation (4), hydrologic data collected from a paired experimental watersheds-one deforested and planted with blue gum trees (transitional watershed) and the other kept in original state - were analysed. The land use change caused by the growth of bluegum trees indicated an increase in the rainfall excess volume by 32% in the immediate season and this value was found to reduce with the growth of plantations in the subsequent seasons. For the watershed in transition, the rainfall excess volume was a function of rainfall volume, soil moisture condition and a transition factor representing land use change. This watershed was modelled using the 3-coefficient surface runoff model of Chow and Kulandaiswamy (1,2,3) for the surface runoff:

$$q(t) = \frac{-b_o D + 1}{a_1 D^2 + a_o D + 1} i(t) \qquad (1)$$

where q(t) is the surface runoff hydrograph ordinate (m^3/day or cm/day), i(t) is the effective rainfall rate (cm/day), a_o, a_1 and b_o are the model parameters (day, day^2 and day respectively) and D is the differential operator (d/dt). The model parameters a_o, a_1 and b_o were found to vary with the delay time, t_{da}, the time from the end of the rainfall excess to the end of the surface run-off and independent of the land use changes. This study was now extended to actual watersheds in the same hydrologic environ consisting of forest watershed (Mukurthy-25.25 Km2 EL=2150m-2700m) agricultural watershed (Kateri-54.755 Km^2 EL=1800m-2200m) and an urban watershed (Coonoor-44.03 Km2 EL=1600m-2150m). The effect of urbanization and afforestation of the agricultural water shed was investigated on the rainfall excess volume and time distribution of surface runoff, namely peak q_p and time to peak t_p.

2. DATA ANALYSIS

Five years of daily rainfall and flow data (119 storms) were subjected to analysis. The separation of baseflow is shown in Fig.1. Reproduction of flood hydrographs is made using 3-coefficient runoff model (2) as shown in Fig.2. Based upon the hydrologic features of the Bhavani basin the year

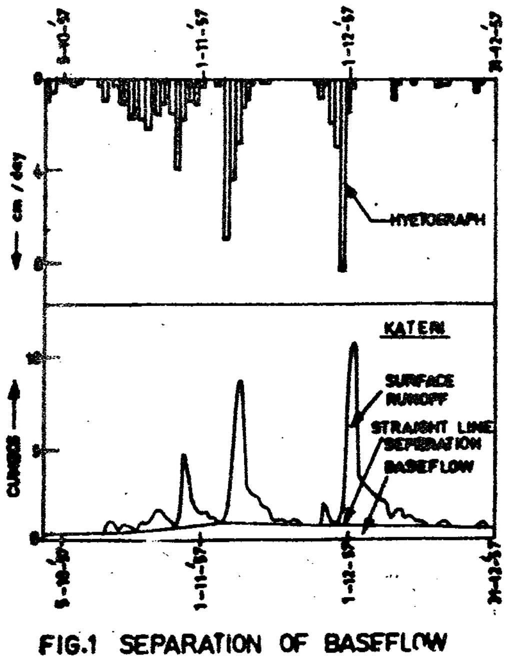


FIG.1 SEPARATION OF BASEFLOW

is divided into two workable periods as follows: (a) Non-monsoon period (January to May), (b) Monsoon period (June to December). For the storms studied, the correlation coefficient (R) varied between 0.8762 and 0.9912 for predicted flood hydrograph for the three watersheds.

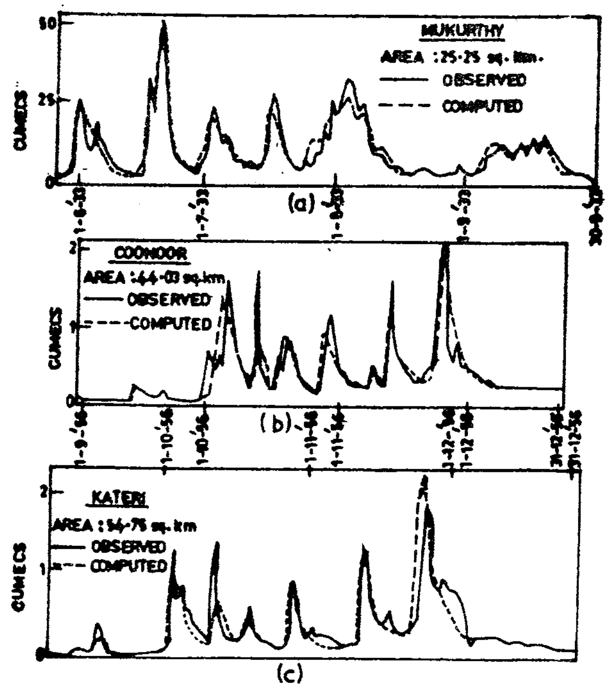


FIG.2 PLOTTING OF OBSERVED AND COMPUTED RUNOFF FOR THREE WATESHEDS

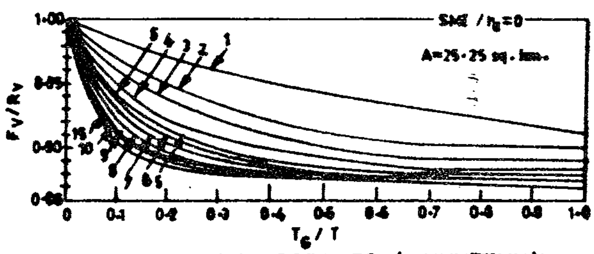


FIG.3 FOREST WATERSHED (MUKURTHY); F_V / R_V Vs. SMI / r_a AND T_G / T

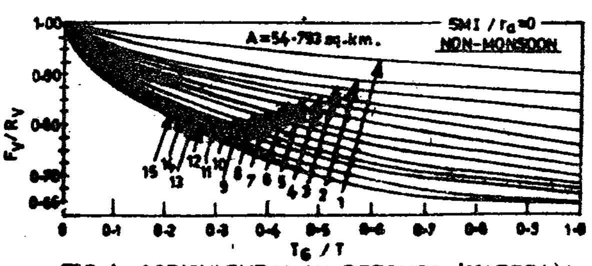


FIG.4 AGRICULTURAL WATERSHED (KATERI); GRAPH OF F_V / R_V Vs. SMI / r_a AND T_G / T

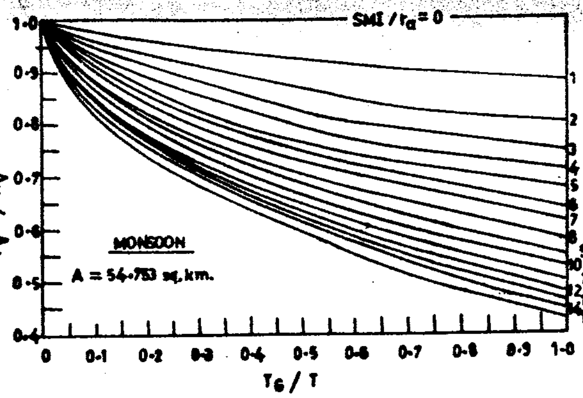


FIG.5 AGRICULTURAL WATERSHED (KATERI); GRAPH OF F_V / R_V Vs. SMI / r_a AND T_G / T

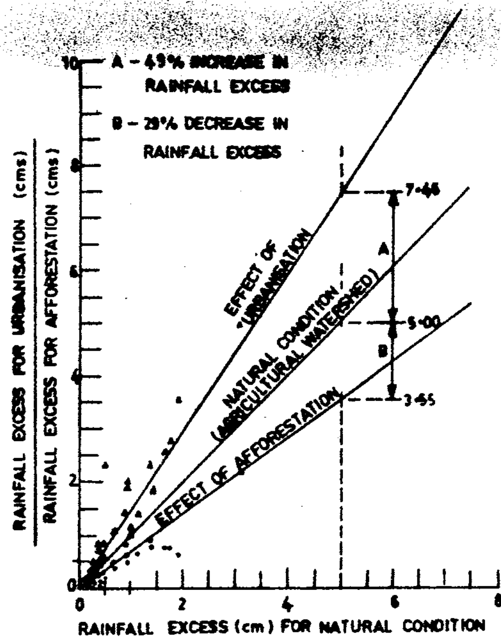


FIG.8 KATERI; EFFECT OF AFFORESTATION AND URBANISATION ON THE RAINFALL EXCESS

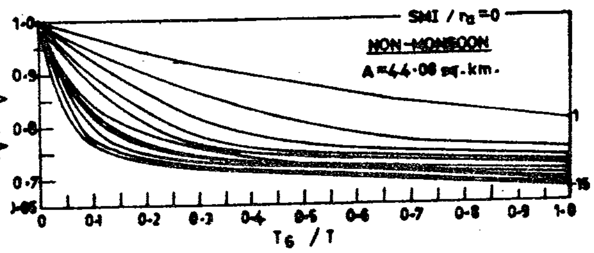


FIG.6 URBAN WATERSHED (COONOOR); GRAPH OF F_V/R_V Vs. SMI /r_o AND T_G / T

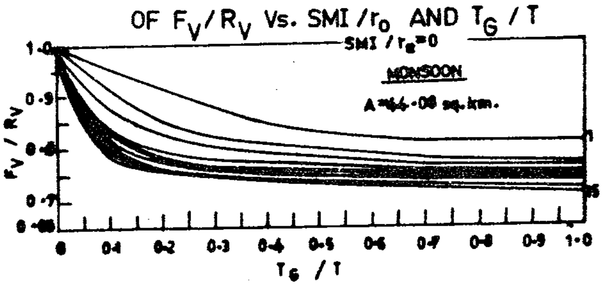
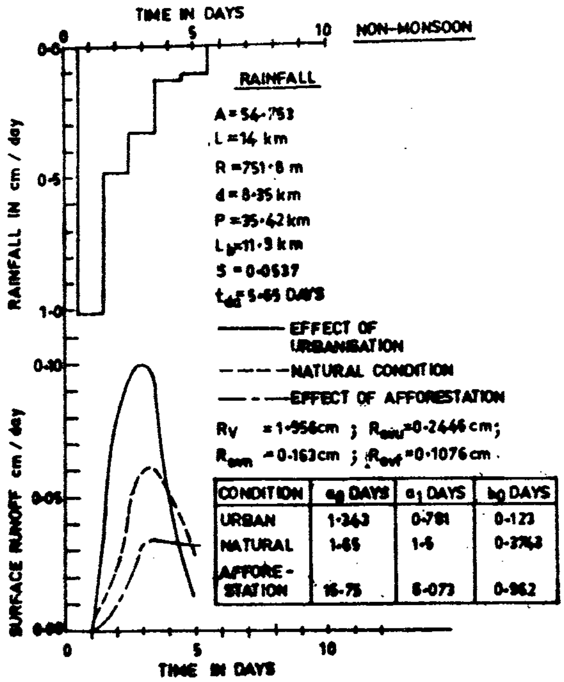


FIG.7 URBAN WATERSHED (COONOOR); GRAPH OF F_V / R_V Vs. SMI / r_o AND T_G/T



CONDITION	a_0 DAYS	a_1 DAYS	b_0 DAYS
URBAN	1·243	0·781	0·123
NATURAL	1·65	1·6	0·3743
AFFORE-STATION	16·75	8·073	0·962

FIG.9 KATERI; STORM OF 22nd APRIL 1956: STORM No.9

3. EFFECT OF AFFORESTATION OR URBANIZATION ON RAINFALL EXCESS (SURFACE RUNOFF VOLUME)

The rainfall excess of a given storm is intimately related to the storm characteristics as well as to the infiltration characteristics of the watershed. The infiltration characteristics are mainly related to the wetness of the soil prior to the storm, the type of soil and the land use to which the watershed is subjected to. This concept can be expressed by the following functional relationship:

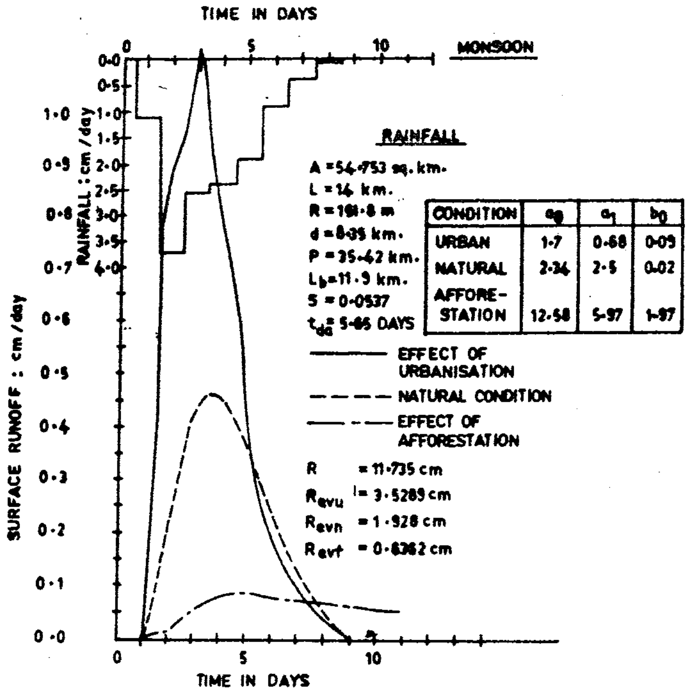


FIG.10 KATERI; STORM OF 30th SEPTEMBER 1956: STORM No.14

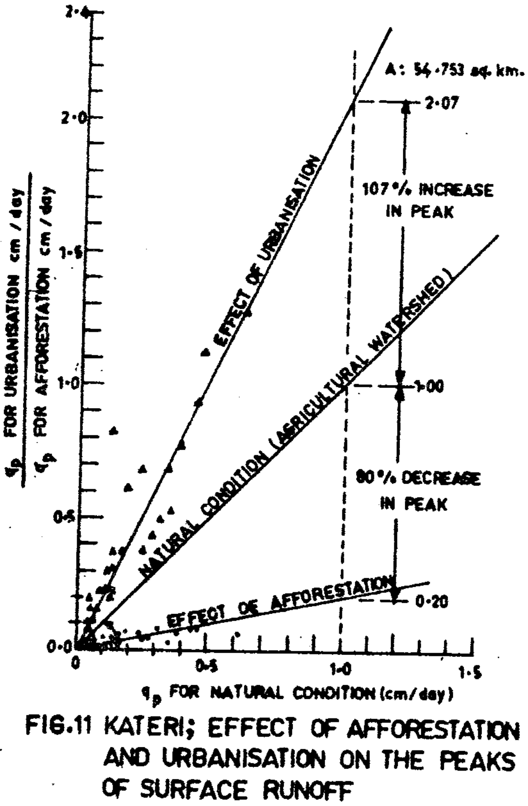


FIG.11 KATERI; EFFECT OF AFFORESTATION AND URBANISATION ON THE PEAKS OF SURFACE RUNOFF

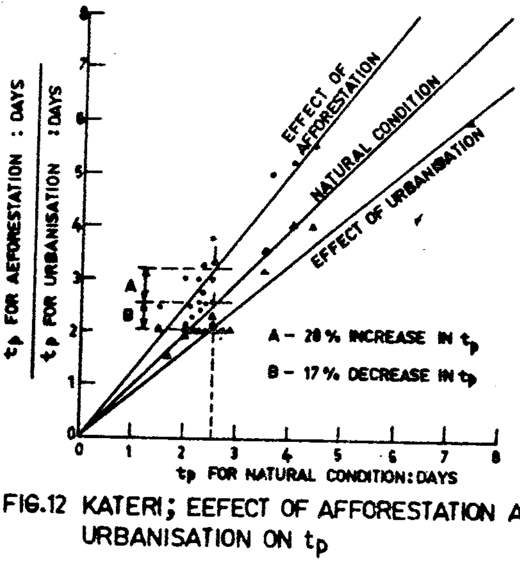


FIG.12 KATERI; EEFECT OF AFFORESTATION AND URBANISATION ON t_p

$$\frac{F_V}{R_V} = F\left(\frac{SMI}{r_a}, \frac{T_G}{T}, \text{type of land use}\right) \qquad (2)$$

where F_V represents abstractions, R_V is the volume of rainfall, SMI is the soil moisture index, r_a is the average rainfall rate, T_G is the time to the centre of gravity of the rainfall area and T is the duration of rainfall. From the observed data, curves were drawn between F_V/R_V versus T_G/T with SMI/r_a as parameters for all the three watersheds. Subtracting F_V and R_V, the volume of rainfall excess is arrived at. In the case of forest watershed (Mukurthy) a single set of curves were obtained (Fig.3) while in the case of urban (Coonoor) and rural (Kateri) watersheds two sets of curves, for monsoon and non-monsoon separately, were prepared (Figs. 4 to 7). Assuming that the rainfall excess curves obtained for one watershed can be inter-changed with the others, depending on the land use to which the watershed is subjected, the rainfall excess of the rural watershed when it is completely urbanised or afforested can be computed. For an assumed rainfall excess of 5cm in the rural watershed. (Fig.8), it is observed that there is an increase of 49% in rainfall excess, if the watershed is urbanised and a decrease of 20% in rainfall excess if the watershed is afforested as indicated in Fig.8.

4. EFFECT OF URBANIZATION OR AFFORESTATION ON TIME DISTRIBUTION OF THE RUNOFF

For obtaining the distribution of surface runoff, the 3-coefficient model (Figs. 9 and 10) is used. The coefficients a_0, a_1 and b_0 were estimated for the rural watershed for a number of storms and average values of these coefficients are computed. The model parameters a_0, a_1 and b_0, were assumed to have the following functional relationships:

$$\begin{aligned} a_0 &= f\,(A, L, \sqrt{S}, Re, t_{da}) \\ a_1 &= f\,(A, L, \sqrt{S}, Re, t_{da}) \\ b_0 &= f\,(A, L, \sqrt{S}, Re, t_{da}) \end{aligned} \qquad (3)$$

where A is the area of the watershed, L is the length of the main channel, S is the average slope of the main channel, Re is the elongation ratio of the basin and t_{da} is the average time delay of the basin. By a study of a_0, a_1 and b_0 with the watershed characteristics and the time delay, the following relationships for the three watersheds were obtained.

$$\begin{aligned} a_0 &= K_0 \frac{A\ L}{Re\ \sqrt{S}} \cdot t_{da} \\ a_1 &= K_1 \frac{A\ L}{Re\ \sqrt{S}} \cdot t_{da} \\ b_0 &= K_2 \frac{A\ L}{Re\ \sqrt{S}} \cdot t_{da} \end{aligned} \qquad (4)$$

Knowing the values of A, L, Re and S, t_{da} and a_0, a_1 and b_0, the coefficients, K_0, K_1 and K_2 in the above equations can be computed for different types of land uses. Using the values K_0, K_1 and K_2 of the urban watershed (Coonoor) the values of the parameters a_0, a_1 and b_0 were computed for the rural watershed (Kateri) in order to study the effect of urbanisation on the time distribution of surface runoff and time to peak. Similarly using the values of K_0, K_1 and K_2 of the forest watershed (Mukurthy) the values of the parameters a_0, a_1 and b_0 were computed for the rural watershed (Kateri) to study the effect of afforestation. The model parameters so evaluated were used in the 3-coefficient model (Figs. 9&10) and the time distribution of surface runoff is computed. Totally 30 storms, 18 from the monsoon period and 12 from the non-monsoon period of the rural watershed were used. From these studies, it is found that there is an increase of 107% in the surface runoff peak if the watershed is urbanised and 80% decrease in the surface runoff peak if the watershed is afforested for an assumed peak of 1.0 cm/day in the natural condition (rural) (Fig.11). Further it is found that there is a decrease of 17% in t_p time to peak if the watershed is urbanized and an increase of 28% in t_p if it is afforested, for an assumed value of 2.5 days in the natural condition (Fig.12). By using the above procedure, any mixed watershed consisting of urban, rural and forest can be modelled and the effect of land use changes on the stream-flow can be predicted.

5. CONCLUSIONS

From the modelling of the three typical watersheds - a forest watershed (Mukurthy), an urban watershed (Coonoor) and an agricultural watershed (Kateri) using Chow and Kulandaiswamy 3-coefficient model(3), the following conclusions were arrived at:

i) The three coefficient model proposed by Chow and Kulandaiswamy predicts the flood hydrographs continuously for the entire season fairly well for different types of land uses such as forest, rural and urban etc.

ii) There is an increase (49%) in rainfall excess if the rural watershed is urbanized and a decrease (20%) in rainfall excess if it is afforested.

iii) The model parameters a_o, a_1 and b_o are related to the physical characteristics of the watershed and time delay t_{da}.

iv) With the urbanization of rural watershed the surface runoff peak is found to increase (107%) and with the afforestation of the same watershed, the surface runoff peak is found to decrease (80%) for a peak of 1.0 cm/day.

v) With the urbanization of rural watershed, the time to peak (t_p) is found to decrease by 17% and with the afforestation of the same watershed, t_p is found to increase by 28%.

vi) The methodology suggested can be extended to study the effect of land use change in a mixed watershed on its hydrologic characteristics.

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Application of Remote Sensing Techniques for Hydrologic Investigations of Upper Yamuna Catchment

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ABSTRACT

The demands of water in various spheres of life, and its insufficient supply to fulfill these demands, specially in the developing countries, has become day by day a great challange to the hydrologist. In such a situation it becomes imperative to search a suitable methodology which can be used efficiently to predict the stream flows using minimum ground data, time and funds. Recently Remote Sensing techniques have become a more popular and suitable tool for such studies. Keeping in view this aspect of the problem, an analysis of Upper Yamuna Catchment, using Landsat imagery, was carried out to obtain the catchment characteristics which affect stream flows. Landsat imagery in Bands 5 and 7 on 1:1 million scale were analysed to get landuse and vegetal cover classification in categories (i) thick forest (ii) thin forest (iii) bare land & cultivation, and (iv) snow cover. Using this data, alongwith rainfall data from 20 raingauge stations and stream flow data at Dakpather and Lakhwar, the stream flows were estimated by using Lumped system and Distributed system Models based on Rational Method. The computed 10 day period stream flows of Tons sub-basin were compared with observed surface flows with the help of hydrographs, flow comparison graphs and average monsoon period and monthly flow values. Using the coefficients evaluated from Tons sub-basin, the stream flows for Yamuna sub-basin were computed and compared with the observed surface flows.

INTRODUCTION

Water is life, as it serves the living beings in different and countless ways and its demand is increasing with the increase in population, development of industries and improvement in living standards. The planning, design and management of water resources systems is getting more complex due to the conflicting demands of rapidly increasing population pressures on the limited water resources. Most of the developing countries have agricultural based economy, which is highly dependent on water. For expedient development of these countries, the development plans have to be based on proper appraisal of water resources & optimal planning for their uses. However, adequate data for hydrological studies are seldom found easily available. Non-availability of required information and limited time and funds place a hydrologist in a very difficult situation, while evaluating the water resources. In such a situation, it becomes imperative to search for a suitable methodology which can be used efficiently to predict the stream flows using minimum ground data, time and funds.

Under such circumstances, the remote sensing techniques appear to be the only tool available to the hydrologist in getting the required uptodate and reliable hydrologic information with greater speed and better accuracy. This paper deals with hydrologic study of Upper Yamuna catchment, upstream of Dakpather, with the help of remote sensing techniques, in order to evaluate the suitability of these techniques for determining the streamflows of ungauged streams, with large catchments. A number of approaches have been tried to predict the surface runoff of river Tons using aerial photographs and LANDSAT 1 imageries and precipitation data collected from the ground and then these values have been compared with observed surface runoff of river Tons at Dakpather, in form of hydrographs. Then the values of various runoff coefficients, assigned to different slope and vegetal cover response units, have been used to compute the surface runoff in the adjoining subcatchment of river Yamuna, and compared with the observed surface runoff at Lakhwar.

UPPER YAMUNA CATCHMENT

The catchment area of Upper Yamuna upstream of Dakpather Barrage, lies approximately between the Longitudes 77° 30' to 78°30' East and Latitudes 29° 19' to 31°35' North, as shown in Fig.1. The areal extent of this catchment is about 7627 sq.km., and it is divided into two main sub-catchments of river Tons upto Dakpather(area about 5443 sw. km) and river Yamuna upto Lakhwar(area about 2184 sq.km).

Tons, a major tributory of river Yamuna, springs from a height of over 5200 m from the right flank of the Bandarpunch glacier and winds its way through a narrow valley, for a distance of about 160 km, to meet the Yamuna at Kalsi, nearly 2 km upstream of the Dakpather Barrage of the Yamuna Hydel Scheme. Tons is a snowfed river and as it flows down a number of tributories join it, of which Supin, Rupin, Pabar, Shalugad and Meenas are well known. Many of these tributories are snowfed in their upper reaches and as such river Tons has a perennial flow, about twice as much as that of river Yamuna.

Yamuna originates from the south flank of Bandarpunch glacier beyond Yamnotri, and as it flows down, it is joined by a number of tributories upto Lakhwar (about 20 km from Kalsi), of which Hanumanganga, Kamala, Khutanugad Sorigad, Paligad, Badyargad, Banaligad and Aglar are well known. Like river Tons, Yamuna and some of its tributories are snowfed in their upper reaches, resulting in a perennial flow.

Both the sub-catchments of Tons and Yamuna have very steep valley slopes, with hills on both sides rising upto 500 m above the riverbed & and the pronounced orographic features favour a quick runoff. The average rainfall varies in the Tons sub-catchment between 1250 mm to 2000 mm and in the Yamuna subcatchment between 1000mm to 2000 mm, while the maximum temperature, in either case, is about 35°C. Precipitation data is available from 16 raingauge stations for the Tons subcatchment and from 5 raingauge stations for the Yamuna subcatchment, as shown in Figure-1.

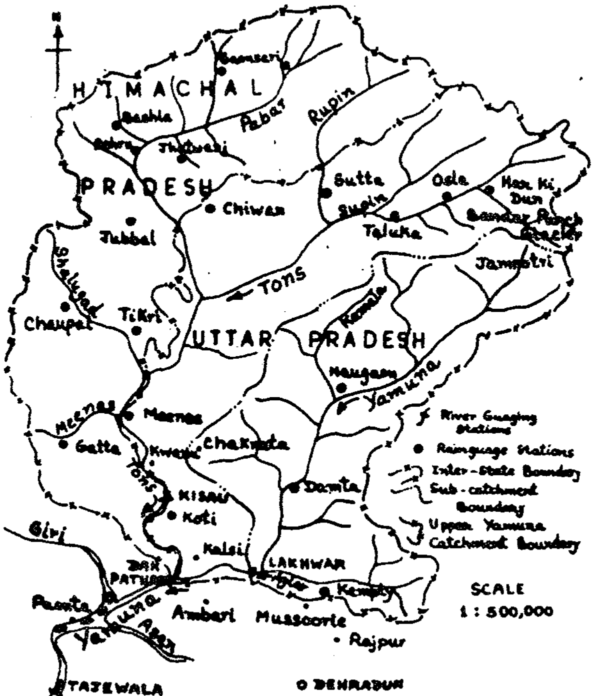

FIGURE 1 LOCATION MAP OF UPPER YAMUNA CATCHMENT

EVALUATION OF HYDROLOGICAL PARAMETERS

To get information about hydrological parameters such as vegetal cover and land use for the two subcatchments of river Tons and Yamuna, LANDSAT-1 imageries (at an enlarged scale of 1:250,000) were available.

Four categories of vegetal cover & land-use i.e. Snow cover, Thick forest, Thin forest, and Bare and Cultivated land were delineated from the LANDSAT imageries on to the base map at 1:250,000 scale. The areal extent under these categories were computed in the influence zones of each of the raingauge stations (16 nos for Tons subcatchment and 5 nos for Yamuna subcatchment) for 3 slope facets (I-above 3000 m, II-above 1200 m and III-below 1200 m) so as to include the slope facet influences on surface flows.

The overall percentage areal distribution of vegetal cover and land-use categories in the two subcatchments is given in Table-1.

Table-1 : Areal Extent (%) of Vegetal Cover and Land-use Categories (from LANDSAT Imagery)

Sub-catchment	Categories Thick Forest	Thin Forest	Bare and Cultivated land	Snow cover
TONS	41.6	34.4	6.1	17.9
YAMUNA	59.9	26.1	7.9	6.1

ESTIMATION OF STREAM FLOWS AND THEIR ANALYSIS

The stream flows for Tons sub-catchment during the monsoon period (June to September) for the year 1972 to 1975 were computed using different approaches. These results were compared with the observed stream flows at Dakpather and the methodology was tested on Yamuna sub-catchment during the monsoon period for the years 1974 and 1975, in order to test the reliability of stream flow prediction. The methodology consisted of the following steps:

1. Analysis of observed rainfall and flow data of Tons and Yamuna sub-catchment
2. Computation of runoff coefficient for different types of vegetal cover and land-use categories on different slope facets.
3. Computation of stream flows using Lumped System Model (catchment as one unit) i.e. I approach.
4. Computation of stream flows using Distributed System Model (sub-areas division by Thiessen Polygon neglecting slope facet effects) i.e. II approach.
5. Computation of stream flows using Distributed System Model (subareas division by Thiessen Polygon, considering slope facet effects) i.e. III approach.
6. Comparison of efficiency of different approaches by analysis of computed stream flows vs. observed stream flows.

a. Estimation of Stream flows in Tons Sub-catchment

(1) The adequacy of raingauge stations was determined by analysis of available 10 day period total rainfall data for the monsoon months and it was found that only 7.25 percent error may be caused in estimating the average rainfall from the data of 16 raingauge stations in the Tons sub-catchment. Further it was decided to use Thiessen-polygons method for computation of intensity of rainfall for 10 day periods, in preference to Isohyetal method or Two-axis method, mainly because of the simplicity of this method.

By analysis of hydrographs of the observed flow data at Dakpather the volume of Recharge or Base flows was determined to be about 27388800 m^3 per 10 day periods, uniformly throughout the monsoon months of June to September. Using this value, the values of Direct Observed stream flows at Dakpather were computed for the 10 day periods in the monsoon months of the years 1972 to 1975.

(2) The runoff coefficients of surface flows for various categories of vegetal cover and landuse, as well as slope facets, were computed by forming 48 observational equations for the 10-day periods of monsoon months of the years 1972 to 1975, using the well known relationship :

$$Q = \sum_{i=1}^{12} C_i I_i A_i$$

where Q = total surface runoff in a given period over the sub-catchment, C_i = runoff coefficient for a given sub-drainage area, based on the slope facet and vegetal cover and land-use category, I_i = intensity of rainfall in the given sub-drainage area, and A_i = the areal extent of the given sub-drainage area.

The values of the runoff coefficients, as obtained from the 48 observational equations, were compared with the values obtained earlier by others (Jain, S.C., Prasad, M.N., et al), and keeping into consideration the change in the

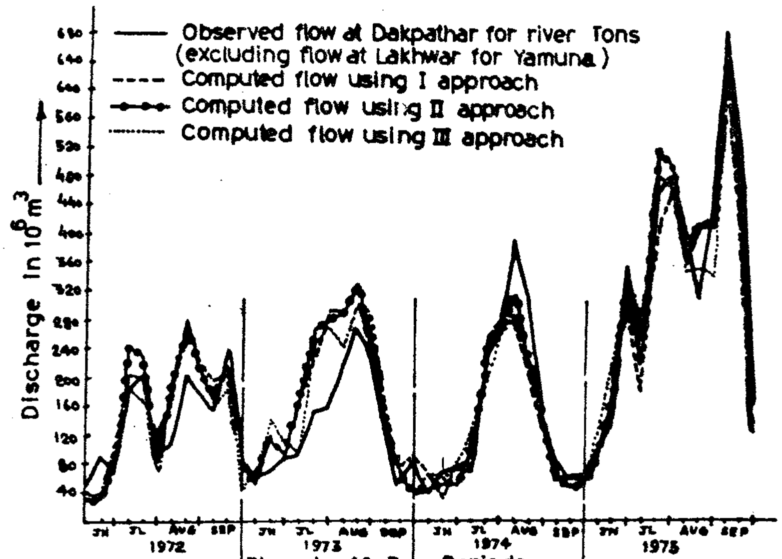

FIGURE 2 HYDROGRAPHS FOR TONS SUB-CATCHMENT

values of antacedent moisture content of the soil in various 10 day periods of June to September, as well as the contribution of slope facet factors, the following two sets of values of runoff coefficients as given in Tables 2 and 3 were adopted for computing the stream flows in the Tons sub-catchment by the 3 approaches, as discussed earlier.

Table-2: Runoff Coefficients Values for Ist and 2nd Approaches

Runoff coefficient	From Ist June to 10th June	From 11th June to 30th September
C_1	0.15	0.30
C_2	0.20	0.35
C_3	0.30	0.40
C_4	0.45	0.45

Table-3: Runoff Coefficient Values for 3rd Approach

Slope facet	Thick Forest	Thin Forest	Bare Land & Cultivation	Snow Cover
I	0.25	0.35	0.40	0.45
II	0.18	0.25	0.35	-
III	-	0.20	-	-

(3) The values of stream flows computed for 10 day periods from June to September in the year 1972 to 1975, by the 3 approaches were first compared with the Direct observed values of surface flows at Dakpather, as obtained in (1) above, with the help of Hydrographs as shown in Figure-2. Then these values were compared by drawing flow comparison graphs as shown in Figure-3. These values were also compared by computing (i) Total ten daily monsoon period surface flows, and (ii) Average ten daily monsoon period surface flows and their standard deviations, as shown in Tables 4 and 5 below.

Table-4 : Total Ten Daily Surface Flows ($10^6 m^3$) in Tons Sub-Catchment for Monsoon Period during the years 1972 to 1975.

Year	Direct Observed Surface Flows	Computed Total Surface Flows by		
		I Approach	II Approach	III Approach
1972	1629.7	1828.7	1811.5	1608.2
1973	1582.8	2147.3	2073.0	1930.3
1974	1702.8	1635.7	1600.8	1615.1
1975	4228.6	3958.0	4208.6	4124.3

Table-5 : Average Ten Daily Surface Flows ($10^6 m^3$) in Tons Sub-Catchment for Monsoon Period during the years 1972 to 1975

Year	Direct Observed		Computed Surface Flows by					
			I Approach		II Approach		III Approach	
	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
1972	135.8	63.9	152.4	77.0	150.9	86.0	134.0	71.7
1973	131.9	72.1	178.9	97.4	172.8	97.0	160.9	86.3
1974	149.4	115.5	136.3	93.4	133.4	98.7	134.6	88.2
1975	352.4	167.1	329.4	143.9	350.7	159.5	343.7	141.8

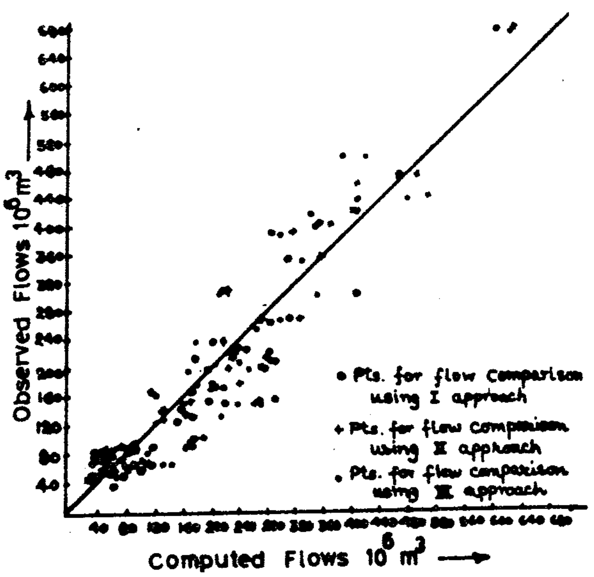

FIGURE 3 TEN-DAILY PERIODS FLOW-COMPARISON GRAPHS FOR TONS SUB-CATCHMENT

The comparison of stream flow values computed by the 3 approaches with the Direct Observed surface flow values at Dakpather, as discussed above, indicated that (i) peaks of the Hydrographs matched consistently in all the 3 approaches, but there was some inconsistency in the values computed by the 3rd approach during the periods Ist June to 10th July, probably due to the adoption of only one set of runoff coefficient values for the whole monsoon period, & (ii) the values computed by the 3rd approach were closest to the Direct Observed Surface Flow values for the Total monsoon period, as well as Average monsoon period and showed lesser fluctuations.

b. Estimation of Stream flows in Yamuna Sub-Catchment

(1) As the Yamuna and Tons-catchments are homothetic, using the same 3 approaches and runoff coefficient values for different slope facets and vegetal cover and land use categories, as for the Tons sub-catchment in (a) above, the values of stream flows for the Yamuna sub-catchment upto Lakhwar were computed for 10 day periods of monsoon months of June to September for the

years 1974 and 1975.

(2) The computed values of the stream flows, by the 3 approaches, were compared with the Direct Observed Surface Flow values at Lakhwar with the help of Hydrographs and Flow comparison graphs as shown in Figures 4 and 5, and by computing (i) Total 10 daily monsoon period surface flows and (ii) Average 10 daily monsoon period surface flows and their standard deviations, as shown in Tables 6 and 7 below.

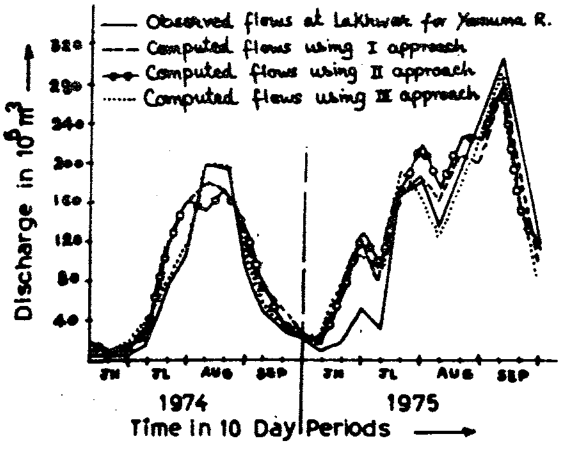

FIGURE 4 HYDROGRAPHS FOR YAMUNA SUB-CATCHMENT

Table-6: Total Ten Daily Surface Flows ($10^6 m^3$) in Yamuna Sub-Catchment for Monsoon Period during the Years 1974 and 1975

Year	Direct observed surface flows	Computed Surface Flows by		
		I Approach	II Approach	III Approach
1974	805.0	921.3	952.8	886.9
1975	1682.6	1786.9	1879.2	1744.3

Table-7: Average Ten Daily Surface Flows ($10^6 m^3$) in Yamuna Sub-Catchment for Monsoon Period during the Years 1974 and 1975.

Year	Direct Observed		Computed Surface Flows by					
			I Approach		II Approach		III Approach	
	Average	Std.Dec.	Average	Std.Dev.	Average	Std.Dev.	Average	Std.Dev.
1974	67.1	69.2	76.8	58.2	79.4	63.4	73.9	67.3
1975	140.2	95.1	148.9	70.4	156.6	75.6	145.4	68.1

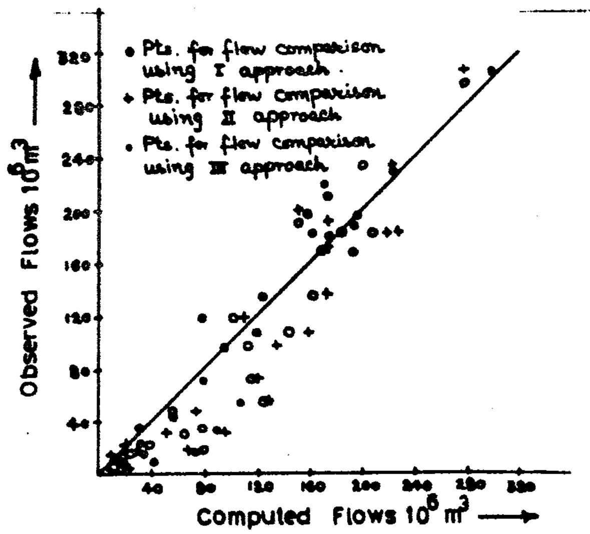

FIGURE 5 TEN-DAILY PERIODS FLOW-COMPARISON GRAPHS FOR YAMUNA SUB-CATCHMENT

(3) The comparison of the Hydrographs, Flow comparison graphs and Total Monsoon period and Average monsoon period flows, as above, again indicated that the results obtained by the 3rd approach were the closest to the Direct Observed Surface Flow values and showed comparatively lesser fluctuations.

CONCLUSIONS

On the basis of the above study with the limited precipitation & observed stream flow data, the following conclusions have been drawn:

(i) LANDSAT imageries at 1:250,000 scale, provide very good source of information for general vegetal cover and land use classification for mountaineous areas, as required for hydrological studies.

(ii) Thiessen polygon method, has been found to be quite appropriate for dealing with mountaineous areas having non-uniform rain distribution.

(iii) The 3rd approach of using a Distributed System model with subarea division by Thiessen polygon and considering the slope facet effects is quite suitable for such large sized mountaineous catchments, to estimate stream flows at sites where no stream gauge data is available.

(iv) The values of stream flows estimated by the 3rd approach can be further improved upon by (a) giving consideration to increased base flow in the later months of monsoon period, (b) evaluating the snow-melt contribution during the summer & early monsoon months and (c) evaluating substantial yearly changes in vegetal cover and land use aereal distribution with the help of time sequence LANDSAT imageries.

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Erosion and Sediment Transport in Flashy (Mountain) Streams in Punjab

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ABSTRACT

The standard techniques available for measurement of water and sediment discharges in alluvial streams can not precisely be applied to flashy streams.These limitations have been outlined in this paper and simple techniques suited to these streams have been presented.The data collected from six sandy soil flashy streams have been anal--ysed for verification of the applicability of various sediment discharge formulae, mode of sediment transport and threshold velocities for channel erosion.It has been shown that the debris flow does not take place,sediment is transported mainly as suspended load and DuBoys-Straub formula yields sediment discharge comparable to the observed value.The one percent threshold velocities which will not cause channel erosion range between 1.22 to 1.55 m/s in range of flow depth of 0.15 m to 1.53 m and are in close agreement with the Fortier-Scobey maximum permissible velocities for the non-cohesive soils.

INTRODUCTION

The Punjab State(India)is infested with numerous ephemeral(flashy)streams Fig.1,

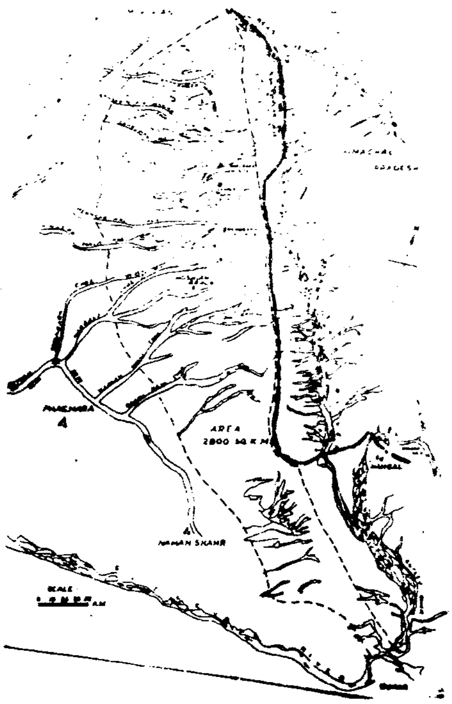

FIG.1. FLASHY STREAMS IN THE PUNJAB, INDIA

locally called Chos(bed material pre--dominantly sand)and Khads(bed material comprising,mixture of large cobbles, gravel and sand)emanating from the foot--hills of the outer Himalayas.The phys--ics of these flashy streams is quite distinct from that of alluvial streams, viz;drainage basins are small,flow only in the monsoon season(June to September) or due to winter(January-February)fre--shets otherwise these remain high and dry,short duration but instant rise in flood peaks,steep bed slopes,high rates of sediment transports causing abrupt changes in bed profile,etc.In their drainage basins the almost complete denuding of the hill slopes has caused vegetation to fall to less than 10 t/Km^2 and sediment yield to rise to about 15000 t/Km^2/year.These flashy streams fan out into plains and during times of abnormal floods these spread sand deposits on otherwise fertile lands resulting into frequent migration of settlements.Thus,in an effort to mode--rate the flood peaks and to reduce associated flood damage and also to meet the ever increasing demand for water to sustain the humanity,attempt is being made to harness these flashy streams by constructing smallreservoi--rs(capacity $\sim$ 100 Mm^3).One such reser--voir with a gross storage capacity of 31.45 Mm^3 is being created by constru--cting a 30 m high earth dam on the Dholbaha flashy stream which will prob--ably be the first of its kind in India.This will feed an irrigation channel of 1.9 m^3/s capacity.In order to determine the gross/dead storage,

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NOTATIONS

A	area of cross-section of stream at gauge station
B	width of stream
b_w	water surface width
C_*	grain concentration in volume in the static debris bed.
d	diameter of grain
d_{50}	median size of sediment
d_{35}	size for which 35 percent by weight

Hydrologic and Sediment Response Variations in Watersheds of River Valley Catchments

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ABSTRACT

Hydrologic & Sediment data pertaining to the watersheds of Damodar (DVC), Chambal (Rajasthan) and Machkund (Andhra Pradesh & Orissa), India, was analysed to establish the effectiveness of soil conservation measures in inducing reduction in peak discharge and silt load. Reduction in peak discharge was to the tune of 14% in the watersheds of Damodar catchment whereas reduction in silt inflow ranged between 28% and 75% in the watersheds of Damodar and Chambal Catchment. 9 yrs. moving average series could provide a discernible trend of silt inflow rate in Machkund catchment, thus indicating the positive role of soil conservation measures in moderating flood and sedimentation hazards.

INTRODUCTION

In India more than 900 major and medeium multi-purpose (Irrigation and Power) projects have been constructed with huge investment. These projects are expected to create irrigation potential of 42.3 m.ha. besides sizable amount of hydal power generation. Water is fed to these reservoirs by streams/rivers through a network of drainage system in the respective catchments. Due to land degradation and soil erosion large amount of sediment is carried in the streams and tributaries which ultimately find their place in reservoirs. Sediment deposit in reservoirs reduce their capacity, thereby resulting into reduction of their useful life.

Recent studies of capacity survey of selected reservoirs have revealed the alarming rate of siltation than the actual rate which was assumed while planning the projects. In the case of Nizamsagar reservoir located in Andhra Pradesh State, more than 63% of the capacity of the reservoir has been lost due to siltation there by reducing about 50% irrigable area under its command(Gupta, 1980). With a view to preventing premature siltation of reservoirs, the national programme of soil conservation in the catchments of River Valley Projects (RVP) was launched in 13 catchments (1961-66). Later on, it was extended to 31 catchments. The package of practices along with some indices for erodibility, flood, suceptibility to drought of various regions in the country has been identified (Das, 1977). /during the 3rd Five Yr. Plan

Land resource regions of India delineated by the Central Soil and Water Conservation Research and Training Institute, ICAR, India has been regrouped into 10 Soil Conservation regions. Distribution of 31 RVP catchments in different Soil Conservation Regions is shown in Table 1. 9 River Valley Projects are located in the Himalayan region of the country and these constitute about 7% of the total catchment area. The RVP catchment areas have different land use pattern which could be particularly classified as Agriculture, Forest and Waste or other lands. Out of the total catchment area of 78.6 m.ha., the agriculture, forest and waste and other lands constitute 62% 20% and 18% respectively(Das, et al, 1981). Each catchment is divided into smaller drainage unit called watershed the total area of which range between 6000 and 15000 ha comprising treatable area of 2000-4000 ha. Due to limited resources programme of soil conservation is being implemented only in selected priority/critical watersheds which produce high sediment yield (Bali, et al, 1972). Depending upon the status of land degradation, land use and works and location, appropriate soil conservation treatment viz. terracing, afforestation combined with engineering structures, silt trapping and moisture storage structures, grassland and pasture development and plantation etc. are given. The effectiveness of these treatments are being assessed through the results of flood hazards and sediment production. In the present study attempts

TABLE 1 Distribution of River Valley Projects in Different Soil Conservation Regions of India

S. No.	Soil Conservation Region of	Total geographical area m.ha.	No. of RVP catchments	State/U.T.	Total area of RVP	% area in RVP	Remarks
1.	2.	3.	4.	5.	6.	7.	8.
1.	North Himalayan	34.60	5	Jammu & Kashmir, Himachal Pradesh and Chandigarh	3.84	11.2	
2.	North Eastern Himalayan	17.70	3	Tripura, Assam and Bihar	1.32	7.5	
3.	Assam Valley and Gangetic Delta	11.18	1	Assam	0.12	1.1	
4.	Rajasthan Desert	23.85	Nil	-	Nil	Nil	
5.	Indo Gangetic Alluvial Plain	50.90	3	Uttar Pradesh, Bihar, Chandigarh, Orissa & West Bengal	1.21	2.4	
6.	Eastern Red Soils	57.45	6	Uttar Pradesh, Bihar, Orissa, West Bengal & Madhya Pradesh	21.08	36.7	
7.	Southern Red Soils	34.77	2	Kerala and Tamil Nadu	0.74	2.1	
8.	Black Soils	67.45	9	Rajasthan, Madhya Pradesh, Uttar Pradesh, Orissa, Maharashtra, Andhra Pradesh & Karnataka	47.51	70.4	
9.	Mixed Black Red and Yellow Soil	11.57	1	Uttar Pradesh Bihar and West Bengal	2.55	22.0	
10.	East West Coast	19.20	1	Maharashtra	0.18	0.9	
	Total	328.67	31	19	78.6		

have been made to establish the effectiveness of these soil conservation treatment in terms of reduction in volume and peak flow and sediment production in the selected catchment viz. Chambal (Rajasthan), Damodar-Barakar (DVC) and Machkund (Andhra Pradesh and Orissa) in India.

REVIEW OF LITERATURE

Soil Conservation measures are primarily given to induce reduction in sediment production from the watersheds and from the catchments as a whole in order to prolong the useful life of the reservoir.

The significant effect of soil conservation measures in the reduction of erosion and consequent sediment yield have been studied and reported from many parts of the world. In the Issaqueena catchment in U.S.A. the SPR was reduced by 52% in a period of 8 years by increasing the protected area from 53% to 73%. Similarly improved watershed management measures could reduce the sediment yield by 43% in the Lake-Waco Catchment (Gottschalk, et al, 1955). Jone, (1965) observed that watershed treatment could decrease the sediment yield although there was no significant change in the runoff characteristics. There was, however, a marked increase in sediment discharge during construction of terraces. Available information from experimental results, field experiences and historical evidences on the positive role of soil conservation measures on the reduction of peak discharge and sediment production have been reviewed extensively by Das & Singh (1979).

Research studies within the country on the effect of soil conservation measures in reducing sediment yield have been studied at the soil conservation Research Station(ICAR, India) at Ootacamund, Chandigarh, Dehradun and Kota. In another watersheds in Vasad treatment measures not only reduced the sediment yield but also retained large quantity of sediment received from untreated catchment (Tejwani, et al, 1975). Measures given in the watershed at Chandigarh during a period of 4 years reduced soil loss and runoff from 80.5 tonnes/ha. and 295 mm to 7.4 tonnes/ha. and 75 mm. respectively (Anon., 1976). Construction of checkdams and planting of Arundodnse grass in a forest watershed of Dehradun showed significant reduction of sediment yield between 1975 to 1977 (Anon., 1977). Experimental results have also proved that bare soil yielded more than 100 times the sediment likely to be contributed from a well vegetated area (Patnaik, 1978).

Various attempts have been made to study the hydrologic and sediment response to treatment measures in the catchments of river valley projects. The National Commission on Agriculture reported that judicious treatment measures (biological combined with engineering) resulted in reduction of sedimentation rates. This view have been supported with observed silt data for 16 small watersheds of Damodar-Barakar Catchments which indicate perceptible decrease in SPR due to treatment measures (Anon. 1976). Results from an experimental watersheds in the same catchment revealed that soil conservation measures could reduce soil erosion by 0.046 cm/ha/yr. as compared to an untreated watershed having similar size and conditions. The peak discharge from the treated watershed ranged from 4 to 4.5 cumec against 8.5 to 14.2 cumec from untreated catchment (Murthy, 1980).

Study carried out in three watersheds of Chambal catchment in Rajasthan showed that the SPR decreased with increasing coverage of area with treatment measures. The decrease was significant for the watersheds receiving continuous treatment. Trand analysis showed that treatment measures could moderate SPR to the tune of 0.62 to 1.65 ha.m./100 km^2/year. (Jose, et al, 1980 a).

Soil conservation measures are supported with construction of small structures such as silt detention dams, gully control structure etc. These structures retain considerable quantity of the incoming sediment and, therefore, provide sufficient time for stabilising the catchment. A case study revealed that 16 small structures in Orissa portion Hirakud catchment with a total watershed area of 16694 ha. could hold back sediment volume of 37.55 hectares meter in a period of twenty years (Das & Singh, 1980). Capacity survey of two silt retention structures between an interval 12 to 14 years revealed that the storage capacity of the structures were reduced by 55 to 72% through sediment deposits. Thus these structures could hold back considerable quantity of sediment, which otherwise would have been deposited in the main reservoir, (Singh and Das, 1981). Therefore, these structures also influence the hydrologic and sedimentation response of watersheds.

Effect of integrated treatment of watersheds was first noticed in the form of reduced SPR from the watershed itself. The overall effectiveness of management measures, is however, reflected through reduction in sediment production in the main reservoir, which is ascertained through repeat capacity survey in respect of outflow method. Result of reservoir sedimentation surveys in respect of Bhakra, Machkund, Maithon, Panchet and Hirakud indicate decrease in SPR vis-a-vis increasing coverage of areas by soil conservation measures (Das, et al, 1980). Treatment measures could moderate silt inflow rate into Machkund reservoir @ 0.14 ha.m. /100 sq.km /yr (Jose, et al, 1980 b). The observed rates in respect of Bhakra, Maithon and Panchet continued to be much higher than the design rates as the area treated in these catchments ranged from 16.5% to 50% of the priority area (Das, et al, 1980). This stressed the need for achieving saturation treatment with in a short time frame.

Introduction of watershed based programme in Hirakud catchment helped in setting a declining trend of SPR. The reduction in average SPR for the period 1973-77 as compared to the average SPR for 1962-66 was 28.3% inspite of the fact that only 16.4% of the priority area of the catchment was treated (Jose & Das, 1982).

MATERIALS AND METHODS

Hydrologic and Sediment monitoring of small watershed is being done (i) to identify the priority watersheds contributing high volume of sediment, (ii) develop appropriate methodology for predicting runoff and silt yield from ungauged watersheds as well as (iii) to determine the effectiveness of soil conservation measures. Therefore, monitoring of rainfall, runoff and silt load forms an integral part of the soil conservation programme. The data thus collected along with the information on physiographic factors are maintained in the watershed history sheet. For measurement of rainfall and runoff and collection of sediment samples gauging sites are installed in selected and representative watersheds. Appropriate method, equipment and trained personnells for the programme have been identified. The samples are being analysed in the silt laboratory established in different catchments. About 3% of the total treatment cost of each watershed is provided for staff and equipment under this programme (Subramaniyan, et al, 1982). In the case of rainfall the amount, distribution intensity and in the case of runoff the volume and peak flow and finally the effect of moderation of flood hazards are inferred. Similarly for erosion hazards silt samples are collected in bottles using Punjab bottle/USDA 48/USDH 49 depth integrator runoff samplers. The samples thus collected are analysed for finding of coarse, medium, fine silt and clay contents of the discharge sampled. To arrive at reliable conclusion the results obtained are cross-checked by repeating the process. Samples of each watersheds are analysised and sediment production rate (SPR) computed. So far 298 gauging sites have been/structures with head walls with a height of 0.30 to 0.45 m. above bed level of the stream are recommended for the measurement of discharge. Besides this many of these sites are also equipped with stage level recorders (Fig. 1). In other situations where putting up structures are not a practical proposition, discharge is computed by the velocity area methods.

/installed (Table 2). Lower crest

Annual rainfall, peak runoff and silt load data for Upper Sewani watershed in Damodar Catchment (Table 3). The data on progress of soil conservation alongwith corresponding SPR data in respect of 3 watersheds of Chambal catchment (Table 4) and annual progressive physical coverage with soil conservation measures along with corresponding SIR of Jalaput reservoirs (Fig. 2) have been utilised for the analysis. For Upper Sewani watershed of Damodar Catchment the hydrologic and sediment response variation of the watershed has been analysed by comparing average peak discharge and SIR for the block year 1959-63 and 1971-75. In the case of Chambal the arithemic mean SIR for the first and last 5 years.was analysed. In the light earlier results reported (Singh, et al, 1979 & Das, et al, 1980) Moving average method of

TABLE 2 Details of Hydrologic and Sediment Monitoring Sites Functioning in River Valley Project Catchments

S. No.	Name of State	Name of Catchment	No. of Hyd. & Sediment Monitoring sites opened	No. of Hyd. & Sediment Monitoring Sites functioning: Within priority water-shed	Outside priority water-shed	Total	Period of availability of data years
1.	2.	3.	4.	5.	6.	7.	8.
1.	Andhra Pradesh	i) Machkund	5	-	5	5	13
		ii) Nagarjuna-sagar	8	-	1	1	2
		iii) Nizamsagar	3	-	3	3	2
		iv) Pochampad	2	-	2	2	3
2.	Assam	i) Pagladia	-	-	-	-	-
3.	Bihar	i) Mayurakshi	27	8	6	14	8
		ii) Rengali-Mandira	-	-	-	-	-
		iii) Sone	-	-	-	-	-
4.	Gujarat	i) Damanganga	-	-	-	-	-
		ii) Dantiwada	17	-	11	11	2
		iii) Mahi	-	-	-	-	-
		iv) Ukai	-	-	-	-	-
5.	Himachal Pradesh	i) Beas	13	-	13	13	16
		ii) Sutlej	7	-	7	7	18
		iii) Giri Bata	1	-	1	1	2
6.	Jammu & Kashmir	i) Pohru	8	2	6	8	5
7.	Karnataka	i) Nagarjuna-sagar	2	2	-	2	1
		ii) Nizamsagar	3	3	-	3	1
		iii) Tungabhadra	18	18	-	18	3
8.	Kerala	i) Kundah	4	4	-	4	1
9.	Madhya Pradesh	i) Chambal	26	5	20	25	3
		ii) Hirakud	61	14	13	27	13
		iii) Matatilla	-	-	-	-	-
		iv) Rengali-Mandira	2	2	-	2	7
		v) Tawa	-	-	-	-	-
		vi) Ukai	-	-	-	-	-
		vii) Mahi	-	-	-	-	-
		viii) Sone	-	-	-	-	-
10.	Maharashtra	i) Ghod	-	-	-	-	-
		ii) Nizamsagar	-	-	-	-	-
		iii) Nagarjuna-sagar	-	-	-	-	-
		iv) Pochampad	3	-	3	3	1
		v) Ukai	-	-	-	-	-
		vi) Damanganga	-	-	-	-	-
11.	Orissa	i) Hirakud	8	5	3	8	3
		ii) Machkund	4	1	3	4	14
		iii) Rengali-Mandira	-	-	-	-	-

1.	2.	3.	4.	5.	6.	7.	8.
12.	Rajasthan	i) Chambal	47	6	29	35	17
		ii) Dantiwada	25	2	23	25	10
		iii) Mahi	30	2	8	10	10
13.	Sikkim	i) Teesta	-	-	-	-	-
14.	Tamil Nadu	i) Lower-Bhawani	2	2	-	2	2
		ii) Kundah	1	1	-	1	2
15.	Tripura	i) Gumti	-	-	-	-	-
16.	Uttar Pradesh	i) Ramganga	7	5	2	7	4
		ii) Matatilla	5	5	-	5	-
17.	West Bengal	i) Kangsabati	2	1	1	2	10
		ii) Teesta	-	-	-	-	-
18.	Chandigarh	i) Sukhna	3	3	-	3	1
19.	Damodar Valley Corporation	i) Damodar-	64	43	4	47	12
	Total :-		407	134	164	298	

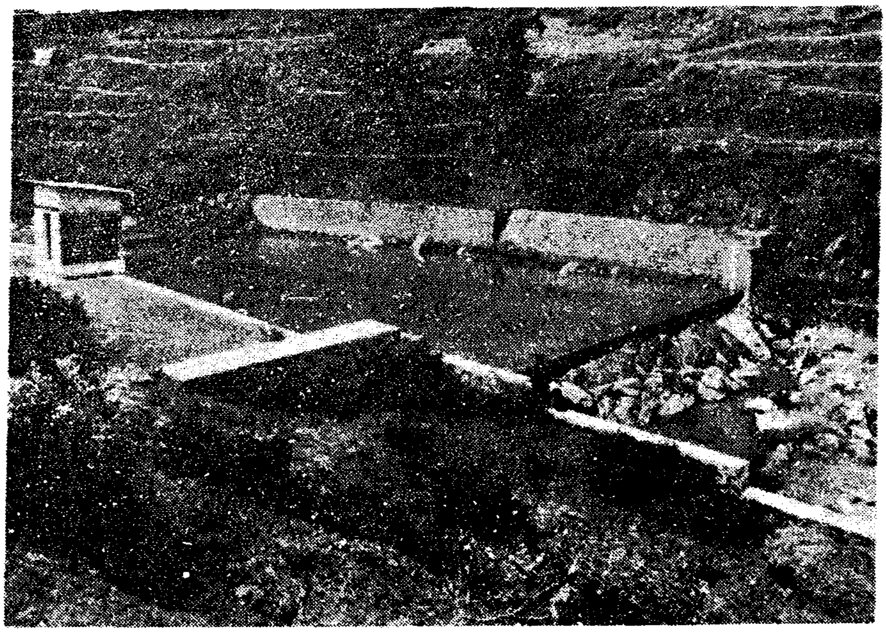

Fig. 1 Photo showing Stage Level Recorder house, hydrologic and hydraulic features, weir of sediment monitoring station, Mynalli Watershed, L.Bhavani RVP Catchment, Coonoor, Tamil Nadu State.

analysis have been followed to minimise the fluctuation in the annual data in Machkund catchment.

RESULTS AND DISCUSSION

Reduction in Peak Runoff

In the case of Upper Sewani watershed of Damodar catchment the average peak discharge for the block years 1959-63 has been observed to decrease by 14% when compared with average peak discharge for the block years 1969-73 (Table 3). This is in line with the earlier findings of reduction in peak discharge by 37% when progressive average annual series was utilised for the same watershed (Singh, et al, 1981).

TABLE 3 Rainfall, Peak Runoff and Silt Inflow Rate from Upper Sewani (7A) watershed of Damodar Catchment.

Area of Watershed : 9246 ha.

Details	Rainfall mm.	Peak discharge m^3/Sec	Annual SIR ha.m/100 km^2	SIR per Unit Runoff ha.m/100 km^2 X 10^{-3}
1.	2.	3.	4.	5.
Average 1959-63	1349.3	202.16	7.18	12.24
Average 1971-75	1191.0	173.88*	5.20	7.40
% Reduction	11.7%	14.0%	27.6%	39.5%

* Average for 1969-73

Details of Soil Conservation treatment given

Upland treatment by construction of terrace, bunds etc.	1974.0	ha.
Treatment of denuded forest and gullied land	1200.0	"
Wasteland treatment	140.0	"
Grade stabilisation structures	365	Nos.
Sediment Control structures	120	Nos.

TABLE 4 Annual Progress of Soil Conservation measures and Silt Inflow Rate for watersheds of Chambal Catchment in Rajasthan

Details	Baisakiya Nala Total Area - 5020 ha.		Karab ka Khal Total Area - 4954 ha.		Nagdara Total Area - 4136 ha.	
	1962-63 to 1978-79	SIR ha.m/100 km^2	1970-71 to 1978-79	SIR ha.m/100 km^2	1971-72 to 1978-79	SIR ha.m/100 km^2
1.	2.	3.	4.	5.	6.	7.
Area treated (ha.)	4737.5	-	4946.0	-	3254.0	-
% Area treated	94.4	-	99.8	-	78.7	-
Initial SIR average for 1964-68		7.88		4.90		19.76*
Final SIR average for 1974-78		1.98		1.42		7.70
% Reduction in SIR		74.9%		71.0%		61.0%

* Average SIR for 1970-73

SIR Moderation from Watersheds

The average SIR, SIR/unit runoff, for Upper Sewani watershed for the block years 1971-75 showed significant reduction by about 28% and 40% respectively as compared to the values for the block years 1959-63 (Table 3). Since only 36% of the area of the watershed has been treated, this could be considered as significant achievement. In the case of 3 watersheds of Chambal catchment the reduction in SIR ranged between 61% and 75% where the percentage of area treated is between 79% and 99.8%. Highest reduction has been observed in Baisakiya nala watershed in which treatment measures were continuous since 1962-63 (Table 4). Moreover, substantial reduction in SIR could be achieved in the watershed which were given saturation treatment.

Silt Inflow Rate Moderation from Catchment

The annual SIR in respect of Machkund catchment revealed marked fluctuations (Fig. 2). The major fluctuations, however, covered a period of 9 years. Therefore, the 9 years moving average series could eliminate most of these fluctuations and could provide a descernible trend line (Fig. 2). The trend line depicts a clear decreasing trend of SIR vis-a-vis coverage of area with soil conservation measures. Comparision of average SIR for the period between 1958-62 and 1973-74 revealed decrease in SIR by 47% against a coverage of 77% of the priority area of the catchment.

CONCLUSION

Hydrologic and sediment data for the watershed in the catchment of Damodar (DVC), Chambal (Rajasthan) and Machkund (Andhra Pradesh and Orissa) was analysed to identity the impact of soil conservation measures on the its response variations. The study could yield the following results:-

1) Treatment measures could induce reduction in peak discharge from the watersheds of Damodar catchment.
2) The reduction in sediment production rate was to the tune of 28% in the watershed of Damodar Catchment whereas it varied between 61% to 75% in the watersheds of Chambal catchment. The reduction in SPR was pronounced in the watersheds which received saturation treatment.
3) Moving average series could eliminate the fluctuations observed in silt inflow rate, caused due to the effect of succession and persistence, in Machkund catchment. The transformed series revealed a clear decreasing trend of SIR with progressive coverage of area.

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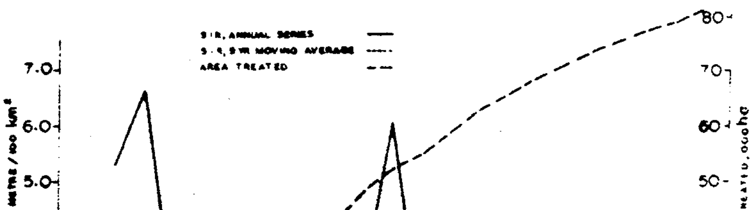

FIG. 2. SILT INFLOW RATE VIS-A-VIS PROGRESSIVE COVERAGE OF AREA WITH SOIL CONSERVATION MEASURES IN MACHKUND-CATCHMENT

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