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Sensitivity Study of a Distributed Model for Mountainous Catchment

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Abstract

In this paper, salient features of a distributed model capable of representing the spatially varied rainfall for a rain fed mountainous catchment are briefly described. It involves the development of isochronal map and then time area diagram for the catchment using information from toposheets,preferably in 1:50000 scale. The time of concentration is computed using Kirpich Formula involving determination of stream length and slopes for various sub-reaches of the river. The contours of equal time of travel are plotted on the map taking the time of interval same as that of the sampling interval of available rainfall-runoff records.

This model was applied for a typical case study for mountainous catchment of river Tons up to Kishau of area 4755 sq.km. In this study the results of sensitivity analysis of this model are presented so as to examine the effect on flood peak characteristics, magnitude as well as time due to variation in values of model parameters T_c and R. The effect on the objective function,which was evaluated as sum of squares of the deviations between observed and computed runoff vaules, was also studied. This study indicates the effect of parameter uncertaintity on the design flood hydrograph characteristics as well as stability of parameter estimates. It has been observed from the study that the model output is more sensitive to the parameter, R,particularly when it is under predicted, in comparison to the parameter,T_c.

1.0 INTRODUCTION

With rapid industrialisation and increase in population the water and electricity demands are increasing and would continue to increase. Major water resources schemes are mostly already constructed at potential sites and they also require more resources with longer gestation periods besides effects on environment. Small hydropower schemes are being planned in order to meet the growing demands of electricity particularly in mountainous catchments, which are characterised by steep slopes, well defined boundaries, thin soil, high rainfall and low evapotranspiration. In these areas hydraulic gradients are steep, and streams respond rapidly to storms. The frequent and often heavy rainfall results in a low soil moisture deficit, and a relatively large proportion of the rainfall reaches the stream network. Streams have well defined channels with an efficient cross section which helps to transmit water effectively. In many cases , there is no flood plain to store water as the hillside slope continues right down to the stream bank. Low temperatures and low evapotranspiration tend to inhibit the growth of some forms of vegetation and in many cases peat develops besides the stream channels. Elsewhere coarse grass or tree plantations are common. However, despite the high rainfall, overland flow is still rare except near the stream or in concavities in the hillsides, so that interflow dominates over much of the catchment. - Most mountainous catchments are under lain by impermeable materials giving a negligible ground water flow contribution. Consequently, the recession limb of the runoff hydrograph has to be sustained by soil through flow (interflow), which is itself a limited resource and so a relatively steep recession is to be expected.These typical characteristics make the rainfall-runoff process in mountainous catchments somewhat different in comparison to that in plains.

For planning and design of small hydropower schemes in the mountainous catchments, the spillway design flood is an important hydrologic parameter to be estimated. It involves estimation of design storm which could be a probable maximum storm (PMS) or a standard project storm (SPS), and then deriving the design flood hydrograph using an appropriate rainfall-runoff relationship. Unit hydrograph technique is one of the most widely used techniques available for the estimation of design flood. But the direct application of this technique to mountainous areas is questionable due to inherent assumption of the uniform precipitation in time as well as in space. In mountainous area, the characteristics of precipitation are influenced by orographic effects and the storms have non- uniform spatial and temporal precipitation. A distributed model, capable of representing the spatially varying precipitation, overcomes this deficiency associated with the unit hydrograph technique.

In this paper, a distributed model which transforms the spatially and temporarily varying rainfall excess hyetograph after accounting for losses into flood hydrograph is presented. Various hydrological problems and characteristics which are involved in rainfall runoff modelling studies are also highlighted and step by step procedure is given for calibration and validation of the model. The sensitivity analysis of the model is also presented.The methodology for the estimation of design flood is discussed and described.

2.0 TYPICAL HYDROLOGICAL PROBLEMS AND CHARACTERISTICS IN MOUNTAINOUS AREAS

2.1 Raingauge Network

Mountainous areas in India generally have inadequate rain gauge network due to various practical difficulties involved in taking observations. The existing network of the rain gauge stations in most cases may not be sufficient to provide the proper distribution in space for the rainfall pattern in the mountainous areas. Nevertheless the information about the rainfall at the existing rain gauge can be best utilized by representing the spatial pattern of the rainfall as isohyetal plot.

2.2 Hydrometereological Aspects

The characteristics of precipitation are influenced by increasing altitude (orographic precipitation) in three ways (Bahadur and Upadhyay, 1982):

(i) The quantity of precipitation increases with altitude up to a certain level and decreases thereafter. The level of maximum precipitation varies greatly from place to place depending on local topography.

(ii) Average variability of precipitation generally increases with altitude.

(iii) On high altitudes, the maximum precipitation occurs generally earlier than on the foothills.

The studies conducted in the neighborhood of Mount Everest have shown that the rainfall regimes have a pronounced monsoon character (Miller, 1965). The Himalayan mountain system functions as a great climatic divide which exerts a dominating influence on the meteorologic conditions of the Indian sub-continent to its south and the Central Asian areas to the north. In winter months, the Great Himalayan range serves as an effective barrier to the intensely cold continental air blowing southwards from Siberia into India. During monsoon months it forces the rain bearing winds up the mountain to deposit most of their moisture on the Indian side.

It is believed that the maximum precipitation in the Himalayas is obtained near Shiwalik ranges located at around 1200 m elevations and the higher regions have less precipitations. Dhar (1976) investigated the relationship between elevation and mean precipitation and obtained a best fit relationship by fitting a polynomial of the fourth degree.

2.3 Flow Measurement

In Indian mountainous catchments the accessibility is very poor. It makes it very difficult to monitor the mountainous streams continuously. Due to flashy nature of mountainous streams the time available for the measurement of velocity at peak is also quite short. Some times velocity is so high that the use of the sophisticated current meters is not possible for velocity measurements.Thestreamflow records available at the gauging sites of the mountainous streams are erroneous. This aspect has to be considered while carrying out calibration and validation of a rainfall runoff model.

2.4 Time of Concentration (Tc)

The time of concentration is the most important parameter used for rainfall runoff modelling of mountainous catchments. It is usually defined in terms of either the physical characteristics of a catchment or the excess rainfall hyetograph and direct surface runoff hydrograph. There are two commonly accepted definitions of Tc.First, Tc is the time required for water to travel from the most remote portion of the catchment to its outlet or design point. The methods of estimation based on this definition use catchment characteristics and a precipitation index. A number of empirical formulae based on this definition are available(Singh ,1988).The second definition of Tc is based on a rainfall hyetograph and the resulting runoff hydrograph. The excess rainfall and direct surface runoff hydrograph are computed from these observations. The time of concentration is the time from the end of excess rainfall to the point of inflection on direct runoff hydrograph recession (Singh ,1988).Neither definition yields a true value or even a reproducible value of Tc due to the difficulty of uniquely defining and then measuring the factors affecting it.Therefore,in each specific study some trial and error are optimisation technique has to be adopted to arrive at representative value of time of concentration based on observed records and physical characteristics of the catchment.

2.5 Rainfall Abstractions and Base Flow

Mountainous catchments generally have very thin soils. These catchments experience frequent occurrence of storm events as compared to the non-mountainous catchments leading to the small initial soil moisture deficit. As a result the soils of the mountainous catchments get saturated very quickly generating the overland flow more frequently together with pronounced storm runoff peaks. Thus very small and uniform loss rate is expected in the mountainous catchment during the period of storm. Since the mountainous catchments are under lain by impermeable materials, a negligible amount of base flow may be contributed to stream from the ground water.

3.0 DISTRIBUTED MODELLING APPROAOCH

3.1 Need for Distributed Modelling Approach

As discussed in section 2.0, mountainous catchments pose many typical problems for hydrologists. Lumped models such as Clark Model (Clark, 1945), Laurenson Model (Laurenson, 1964) and others are not capable of representing the transformation of spatially varying rainfall excess into the direct surface runoff. The distributed modelling approach is better suited for this purpose and also for reflecting the combined effects of translation and attenuation. Based on this approach, Mein et al (1974), Boyd et al (1979) and others developed distributed models which consider the excess rainfall direct runoff processes occurring within the boundaries of the catchment divided into sub-catchments. A distributed runoff model for use in estimation of design flood, which considers the catchment divided into various isochronous zones to represent the spatially varying rainfall was developed and its main features are presented here.

3.2 Model Structure

The schematic representation of the distributed model considering the catchment distributed into various isochronous zones is given in Fig.1 The isochronal map is prepared based on the time of concentration computed using one of the empirical approaches referred in section 2.4.The contours of equal time of travel are plotted on the map taking the time interval same as that of the sampling interval of available rainfall

TRH_1, TRH_2.....TRH_n – Average rainfall over different isochronous zones (mm)
A_1, A_2 ...... A_n — Area of different isochronous zones (Km^2)
ERH_1, ERH_2... ERH_n – Excess rainfall volume hyetograph contributed from different isochronous zones (m^3)
Δt ———— Sampling interval (hrs)
DRH ———— Direct surface runoff hydrograph (m^3/s)
BASE ———— Base flow hydrograph (m^3/s)
DIS ———— Discharge hydrograph (m^3/m)

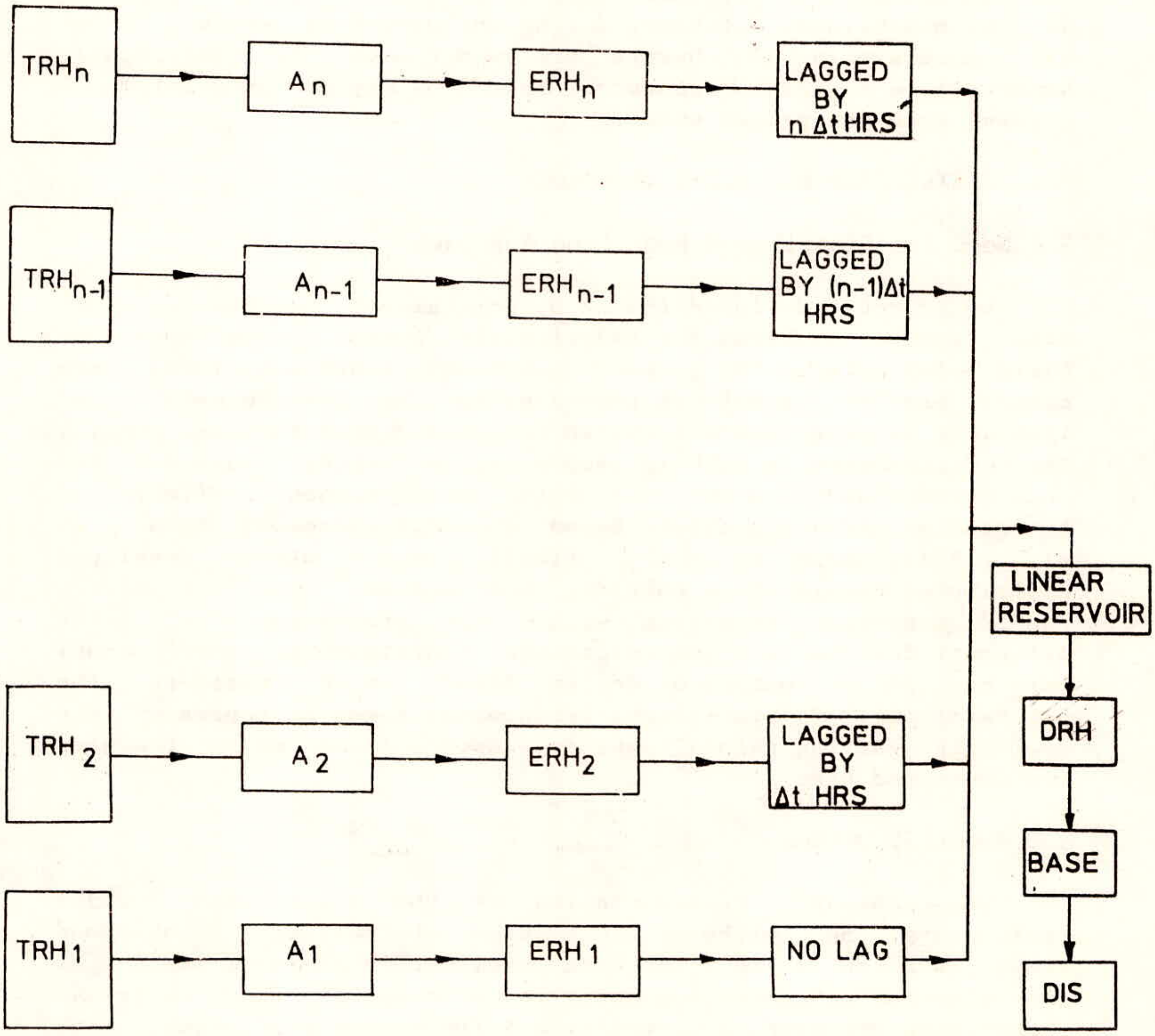

FIG. 1 – SCHEMATIC REPRESENTATION OF DISTRIBUTED MODEL

runoff records.The isochronal map for a typical mountainous catchment is shown as Fig.2. The histogram of Time-Area diagram for the catchment is illustrated as Fig.3.

The average rainfall over each isochronous zone and the discharge hydrograph observed at the catchment outlet are the required hydrometeorological inputs for the model. The excess rainfall hyetograph computed using uniform loss rate procedure for each isochronous zone is routed through a single linear reservoir with storage coefficient (R). Thus the time of concentration (Tc) and storage coefficient of linear reservoir (R) are the two parameters of the model which may be calibrated from the observed rainfall runoff events. The calibrated model can be used to estimate the design flood for known design storm specified as rainfall hyetographs for different isochronous zones.

4.0 MODEL CALIBRATION AND VALIDATION

The step by step procedures involved in calibration & validation of the proposed model and application of the model for the design flood estimation are given in the following sections.

4.1 Model Calibration

The steps involved in Model Calibration from the historical rainfall runoff records are as follows:

(i) Compute the direct surface runoff after separating the baseflow from observed discharge hydrograph using straight line technique for base flow separation.
(ii) Compute the initial estimate of the time of concentration (Tc) using one of the empirical formula (Singh, 1988).
(iii) Prepare isochronal map taking the time contour interval same as the sampling interval of the historical rainfall-runoff records for different flood events.
(iv) Plot cumulative area of consecutive isochrones against (t/Tc), where t (time in hrs) = 1,2,3... Tc and Tc is time of concentration in hours.
(v) For a historical event, prepare isohyete maps of rainfall distribution for each day.
(vi) Superimpose the isochronal map over the isohyete map of each day and compute average daily rainfall over the cumulative areas of different isochronous zones.
(vii) Plot the average daily rainfall obtained at step (v) versus cumulative area.

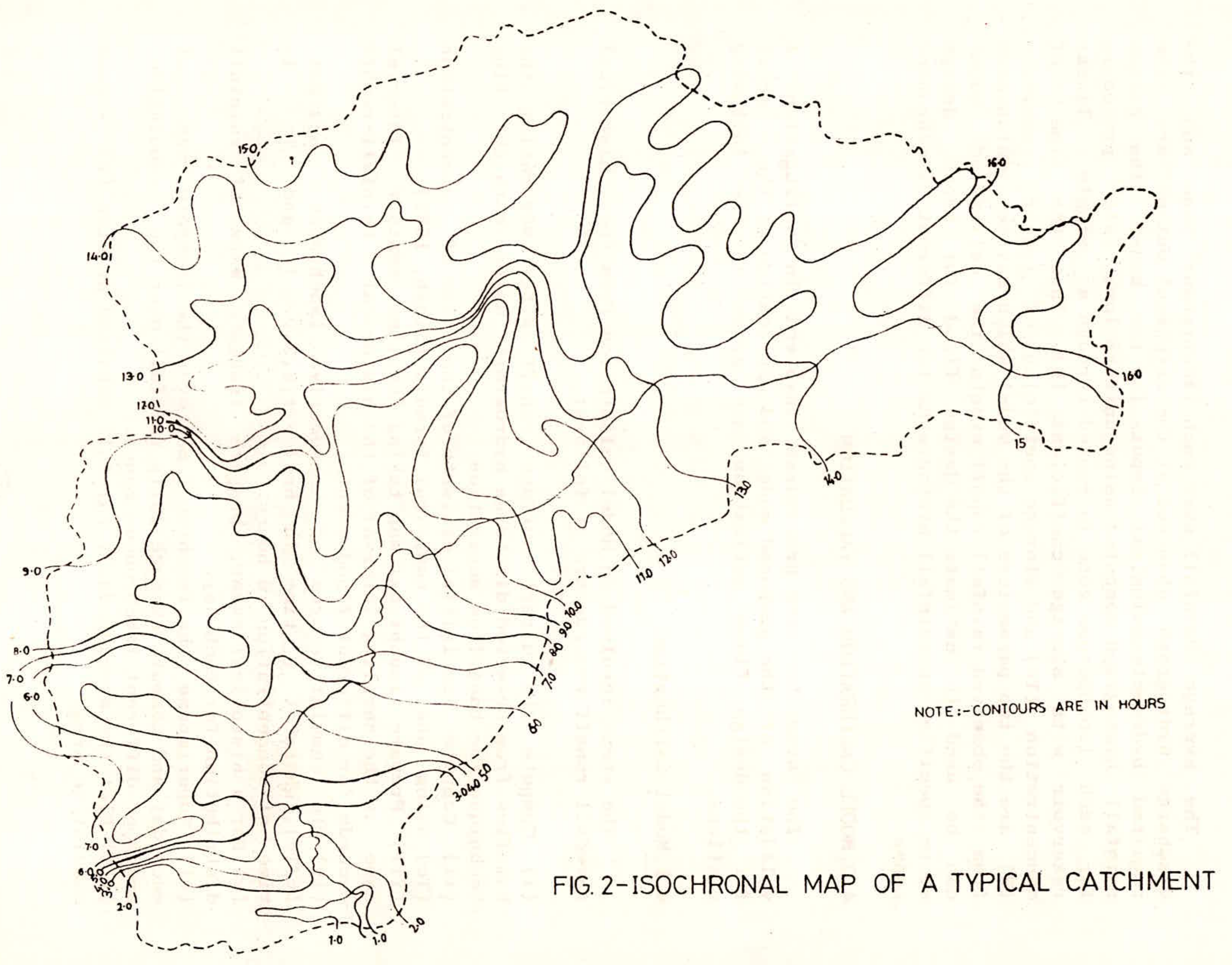

FIG. 2-ISOCHRONAL MAP OF A TYPICAL CATCHMENT

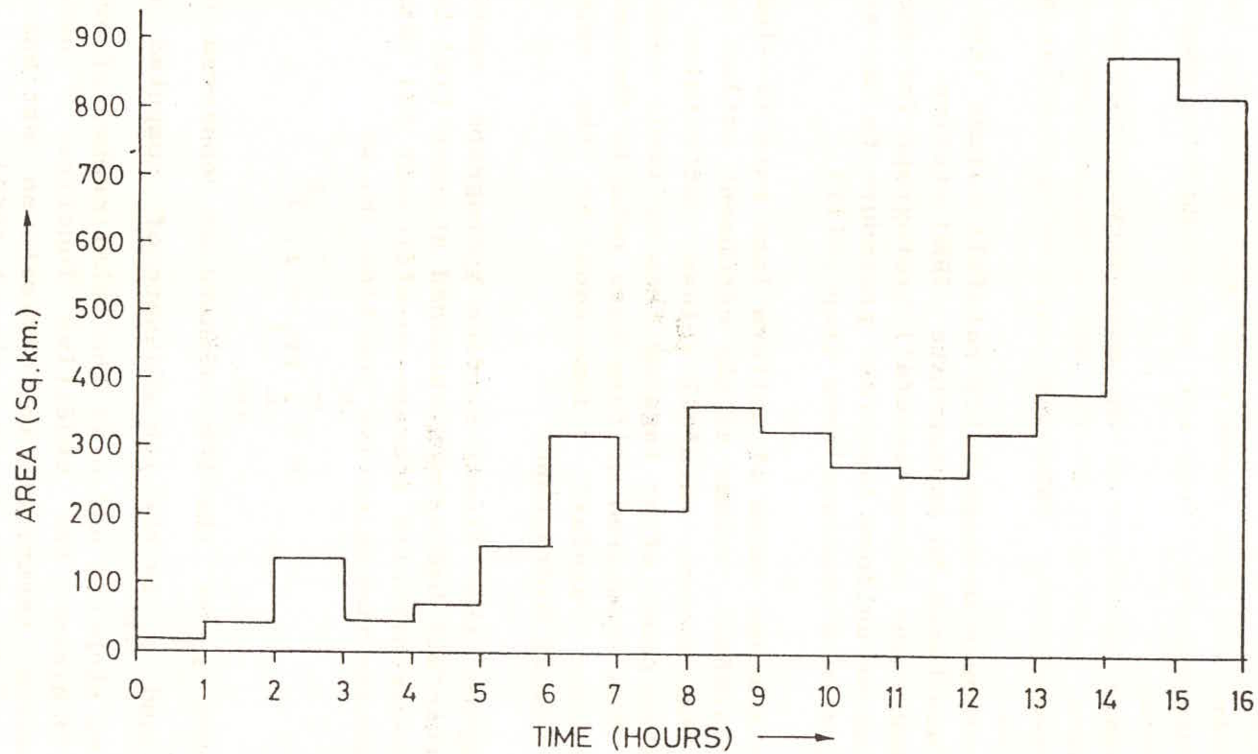

FIG. 3 - HISTOGRAM OF TIME-AREA DIAGRAM FOR THE TYPICAL MOUNTAINOUS CATCHMENT

(viii) For each area enclosed between two consecutive isochrones:

- Estimate the area enclosed using the plot developed at step (iv).
- Estimate the average daily rainfall using the plot developed at step (vii)
- Prepare the mass curve from the average daily rainfall values.
- Prepare the mass curve from the available hourly rainfall values obtained from self Recording Rain gauge (SRRG) Stations records.
- Compare the slope of the mass curve of average daily rainfall values with that of the SRRG stations and select the most representative SRRG station. having similar slope of mass curve.
- Distribute average daily rainfall values into hourly rainfall values based on appropriate SRRG station.

(ix) Compute the excess rainfall hyetograph for each isochronous zone using an uniform loss rate procedure to the average hourly rainfall values obtained from step (viii).

For a known value of uniform loss rate (Φ -index), the total excess rainfall volume at the catchment outlet is obtained by adding the excess rainfall volume contributed by different isochronous zones after lagging them by their respective time of travel. The required uniform loss rate is the one which makes total excess rainfall volume equal to the volume of direct surface runoff hydrograph.

(x) Compute the direct surface hydrograph routing the total excess rainfall hyetograph obtained at step (ix) through a single linear reservoir with storage co-efficient (R) (Singh, 1988).

(xi) Evaluate the objective function, F, as

$$F = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \qquad (1)$$

Where y_i is the ith ordinate of observed direct surface runoff and $\hat{y}_i$ is the ith ordinate of computed direct surface runoff at step (x) and n is the total number of ordinates.

(xii) Minimise the objective function F using Rosenbrock optimisation technique to estimate an optimum value of the storage co-efficient (R)(Rosenbrock,1960).

(xiii) Select another trial value of time of concentration (Tc) and repeat step (viii) to (xii) to find out another optimum value of the storage co-efficient (R).

(xiv) Based on the above procedure estimate the optimum values of Tc and R so that the objective function, F is minimized.

4.2 Model Validation

The calibrated model may be used to reproduce the direct surface runoff hydrographs of some of the independent flood events not used for calibration. The reproduction may be judged based on the following error functions evaluated using the calibrated model:

(i) Percentage Error in Peak

It is the percentage ratio of the absolute difference between observed and computed hydrograph peak and observed peak.

(ii) Percentage Error in Time to Peak

It is the percentage ratio of the absolute difference between observed and computed hydrographs time to peak and observed time to peak.

(iii) Average Absolute Error

This error function is defined as the average of the absolute value of the differences between observed and computed hydrographs.

(iv) Average Percent Absolute Error

It is defined as the average of absolute value of the differences between observed and computed hydrographs.

(iv) Average Percentage Absolute Error

It is defined as the average of absolute value of percentage difference between computed and observed hydrograph ordinates

(v) Standard Error

This error function is defined as the root mean squared sum of the difference between observed and computed hydrograph.

(vi) Efficiency

Efficiency of the model in reproducing an event is defined mathematically, as:

$$EFF = \frac{F_0 - F_1}{F_0} \times 100 \quad (2)$$

$$F_0 = \sum_{i=1}^{n} (y_i - \bar{y})^2 \quad (3)$$

$$F_1 = \sum_{i=1}^{n} (y_i - \hat{y})^2 \quad (4)$$

where EFF = Efficiency of the method , y_i = ith ordinate of observed hydrograph , $\bar{y}$ = mean of the observed hydrograph ordinates, y_i = ith ordinate of computed hydrograph and n = no. of discharge hydrograph ordinates.

4.3 Sensitivity Analysis

The model structure presented in the paper was applied to estimate the design flood for a mountainous catchment of river Tons at Kishau project site located in hills of Uttar pradesh.The model was calibrated and validated using the historical rainfall-runoff records and topographical features of the catchment. For the application results a consultancy project report entitled,'Design Flood Estimation For Kishau Dam',prepared by National Institute of Hydrology (NIH,1988) may be referred. Here sensitivity analysis is carried out using data on rainfall and runoff for one of the historical events used for calibrating the model for the simulation of the response of Kishau Catchment. The initial parameter values were considered as $T_c = 8$ hrs and R =16 hrs. The objective function was evaluated varying the values of R and keeping the value of parameter $T_c = 8$ hrs throughout constant. Fig 4 shows the variation of objective function with different values of the parameter R for the constant value of $T_c =$ 8 hrs. It is observed from the fig.4 that the values of the objective function vary in the range 10 to 260. It is also seen from the figure that the variation in objective function is pronounced in case its values are less than 16 hrs. For R greater than 16 hrs very little increase in values of the objective function is observed indicating that choosing the overestimated value of R would not provide undesirable design flood estimates. On the other hand underestimated values of R estimate the higher vaules of objective function and severely affect the peak and time to peak as observed in Fig.5 which shows variation in peak and time to peak with different values of R for the value of T_c=8 hrs remain constant.

The variations in the values of objective function are also studied for different values of T_c keeping the value of R=16 hrs throughout the computations. Fig.6 shows the variation in objective function with the different values of T_c whereas R (=16hrs) remain constant. The variation in peak and time to peak as a function of T_c is shown in Fig.7.It can be seen that the objective function is sensitive for both,under prediction as well as over prediction, but its values vary from 14 to 52. With increase in the values of T_c decrease in peak and increase in time to peak are also observed. From the study it can be concluded that the the parameter T_c should be calibrated manually and parameter R

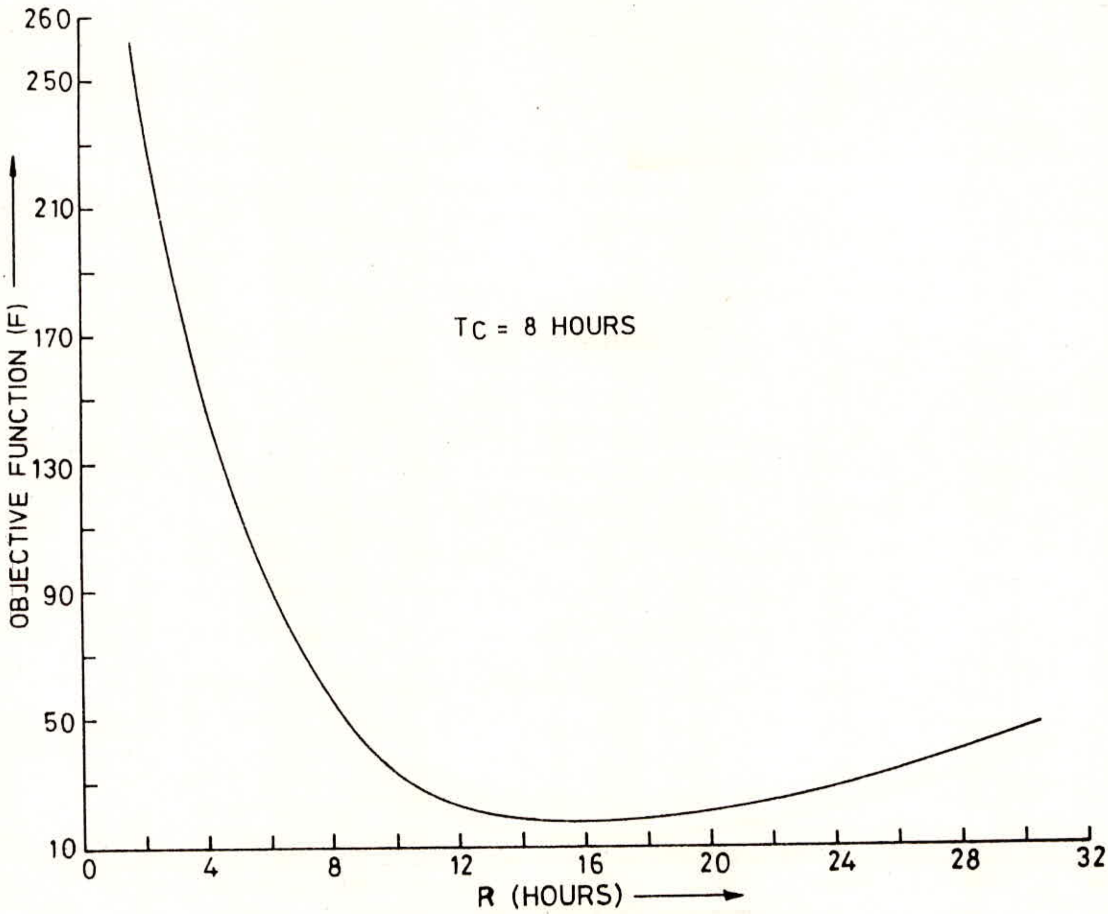

FIG: 4 - OBJECTIVE FUNCTION AS A FUNCTION OF R

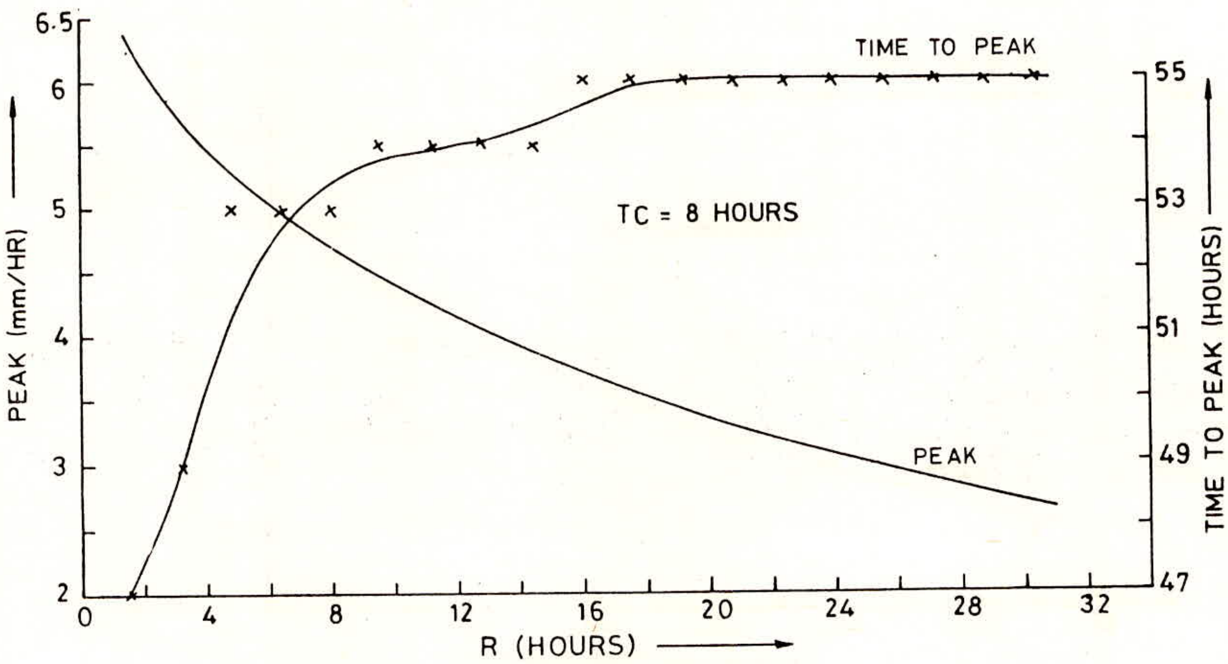

FIG : 5 - PEAK AND TIME TO PEAK AS A FUNCTION OF R

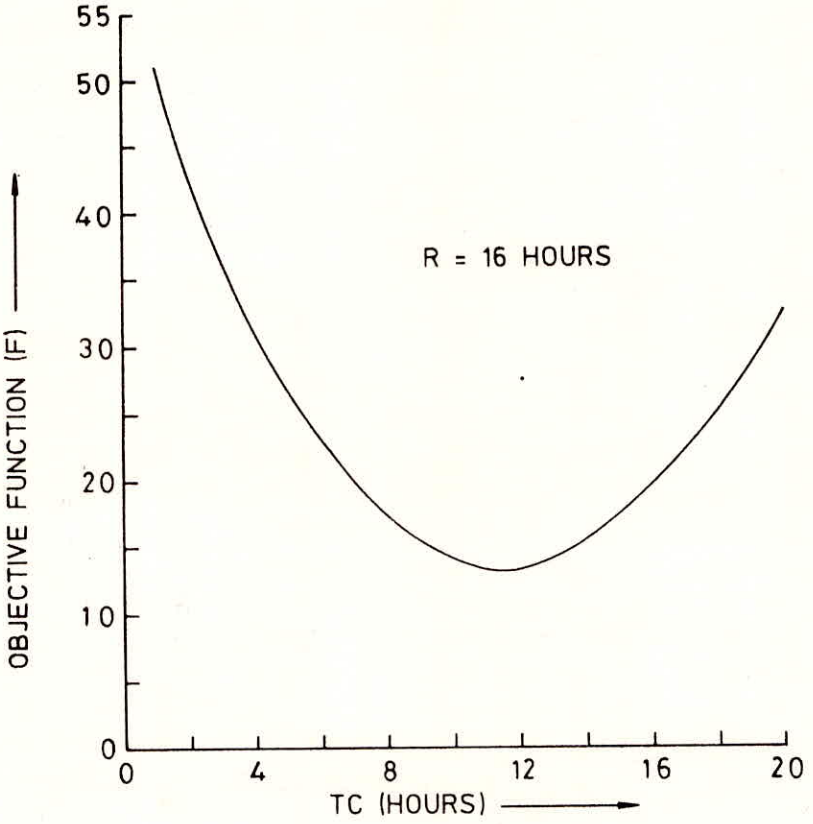

FIG: 6 - OBJECTIVE FUNCTION (F) AS A FUNCTION OF TC

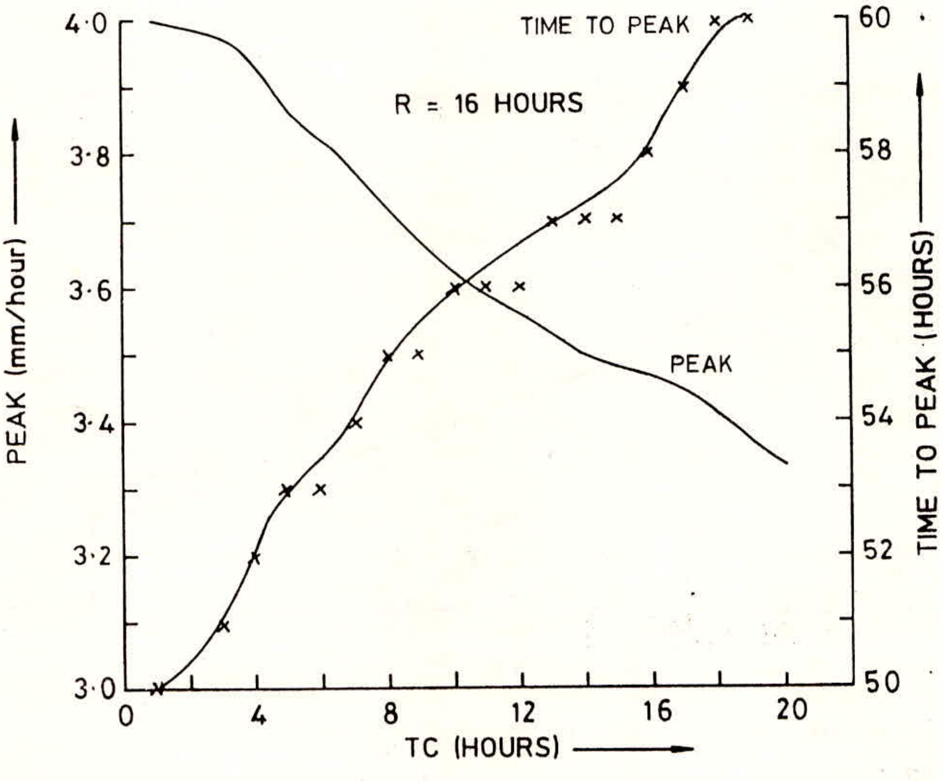

FIG: 7 - PEAK AND TIME TO PEAK AS A FUNCTION OF TC should be optimised using a suitable optimisation technique.

5.0 APPLICATION OF DISTRIBUTED MODEL FOR DESIGN FLOOD ESTIMATION

The calibrated model can be used to estimate the design flood. For this the isohytel maps for probable maximum storm (PMS) are needed. The design rainfall which may be considered as the hydrometeorological inputs to the modoel may be prepared as described in the following sections.

5.1 Estimation of PMP in Mountainous Areas

In mountainous areas involving elevations of 300 to 600 m the PMP is estimated after making appropriate adjustments for elevation and barrier where transposition of storms is involved. However, in regions of pronounced orography, the PMP is estimated using data of the problem region only as rainfall is known to exhibit wide variations in mountainous regions not only because of the elevations but also of the slope and their aspect with respect to prevailing winds in general and during the storm period in particular. Some techniques used in India and elsewhere are described here.

The WMO operational Hydrology Report No.1(WMO, 1973) has suggested two methods for estimation of PMP in orographic areas:

(i) Orographic separation method, and

(ii) Modification on non-orographic PMP for orography.

5.1.1 Orographic Separation Method

The rainfall in mountainous areas is supposed to be comprising of two parts;(i) Orographic rainfall resulting from influence of elevation and exposure, and (ii) Convergence rainfall or non-orographic processes independent of orographic influences.

The orographic separation method consists of estimating each rainfall component separately and then combining them appropriately keeping relevant details of the area under consideration.

The non-orographic component of PMP is estimated using the procedure described by WMO(1973). The orographic component is computed by using an orographic model. The application of the orographic model is, however, limited owing to the non-availability of upper air wind and dew point temperature data.

5.1.2 Modification on Non-Orographic PMP for Orography

In this method, the non-orographic PMP estimated by techniques described by WMO(1973) is adjusted for orographic effects by applying suitable modifications after studying the effect of orography on rainfall in the project region.

The steps for adjusting the non-orographic PMP to orographic effects are as given below:

(i) Determine the non-orographic PMP ignoring orography.
(ii) Examine the rainfall pattern of the region comparing the rainfall in the mountainous areas with foot hills or plain areas. Using mean seasonal or mean annual rainfall examine whether there is decreasing or increasing trend in the rainfall with increase in height.
(iii) Also examine whether the trends noticed at step (ii) are seen in extreme storm events.
(iv) If enough data of storm is available develop a regression relation between orographic and non-orographic rainfall. If storm sample not adequate use either mean seasonal or mean annual rainfall.
(v) Modify non-orographic to orographic PMP using the relation obtained at step (iv).

This method has been applied by US Weather Bureau for tropical areas in Hawaiian Islands and Mekong river basin(WMO, 1969). Dhar et al (1982) had estimated probable Maximum Precipitation for stations in western ghats using statistical techniques. Apte and Dutta Ray (1982) also used the statistical technique of frequency analysis approaoch for estimation of PMP. The limitation in these studies is the dependence on observed data which is generally, to sparse in mountainous areas.

5.2 Estimation of PMP for each Isochronous zone

The isohytes of PMP for different durations may be superimposed with the isochronal map of the catchment and the average value of PMP values may be estimated for each isochronous zone.

5.3 Time Distribution

For the estimation of Design flood, short interval increments of design storm would be required for each isochronous zone. In India, in view of the rather limited length of hourly rainfall data and the sparse network of SRRG stations, it is not possible to derive the PMP estimates of less than one observational day duration directly. As such a recourse is taken to determine the short interval design rainfall increments by applying a time distribution based on the hourly rainfall data observed at a group of self recording rain gauge stations during a severe storm in the meteorological homogeneous region study.5.3.1

Procedure for Deriving Time Distribution

The steps involved in deriving the time distribution are given below:

(i) Select all such storm spells whose 24 hour totals have exceeded at least 150 mm and 48 hour totals 200 mm.
(ii) Compute the maximum hourly rainfall totals for 1,2,3,6,9,12,15,18,21,24,....48 hours using only consecutive hourly rainfall data.
(iii) Express the maximum rainfall totals computed at step (ii) as percentage to the total rainfall amount of the 24 hour duration or 48 hour duration.
(iv) Repeat the procedure in step (ii) and step (iii) for all selected storm spells.
(v) Plot the percentages of the different durations from each spell on a graph paper and draw smooth curves. Separate graphs are plotted for 24 hour and 48 hour duration depending on need.
(vi) Draw an enveloping curve passing through the maximum percentages for each duration from out of different storm spells.

Caution: Though it is the general practice by IMD to draw envelope curve of percentages obtained at individual SRRG stations, it would be desirable if a weighted average of hourly rainfall at SRRG stations is obtained and then percentage ratios worked

5.3.2 Critical Time Distribution

The procedures described in section 5.2.1 yielded either 3 hourly or 6 hourly increments of design rainfall. In order to have the time distribution of the storm rainfall at hourly rainfall, percentage time distributions of storm rainfall are plotted against time durations. Then from the above plots percentage time distributions of storm rainfall are read at hourly interval. The PMP values for the specific durations may be distributed using the hourly percentage time distribution for the respective durations (24 hour and 48 hours). Critical sequencing may be carried out keeping the highest rainfall in the middle and next to highest rainfall values alternatively to the right and left of the highest rainfall values.

5.0 CONCLUDING REMARKS

Various water resources and hydropower development schemes are being taken up in mountainous catchments. However, typical climatic and physical characteristics of mountainous catchments make the conventional unit hydrograph based approach unsuitable for design flood estimation. Moreover,data limitations make the use of sophisticated models inappropriate. A simple distributed model has been presented and step by step procedure is given for its calibration, validation and application for design flood estimation for rain fed mountainous catchments.From the sensitivity analysis it is concluded that the model output is more sensitive to the parameter R when its value is under predicted. However,for over predicted values of R very little difference has been observed in the value of objective function ,peak and time to peak. On the other hand the model outputs are sensitive for under predicted as well as over predicted values of T_c.This model takes into account data limitations and also is capable of use with personal computers.

REFERENCES

1. Apte, N.Y. and R.K.Dutta Ray (1982),'Estimation of the Critical Design Storm Value by a New Approach for Yamuna Catchment upto Lakhwar Dam Site', Proc. of Int. Symp. on Hydrological aspects of Mountainous Watersheds, Roorkee, 4-6, November.

2. Bahadur, J. and D.S.Upadhyay (1982),' On Some Hydrometeorological Aspects of Precipitation in Himalayas', Proc. International Symposium on Hydrological Aspects of Mountainous watershed, Roorkee, 4-6 November, pp.58-65.

3. Boyd, M.J., D.H.Pilgrim and I.Cordery (1979),' A Storage Routing Model Based on Catchment Geomorphology', J.Hydrology, Vol.42, pp.209-230.

4. Dhar, O.N.(1976), Variation of rainfall with elevation in Himalayas' Ind.Journal of Power and River Valley Development, June, pp.179-186.

5. Dhar, O.N., P.R.Rakhecha, A.K.Kulkarni and G.C.Ghosh (1982),'Estimation of Probable Maximum Precipitation in the Western Ghats' Proc. International Symposium on Hydrological Aspects of Mountainous Watersheds, Roorkee, 4-6, November.

6. Mein, R.G., E.M.Laurenson, and R.A.McMohan (1974),' Simple Non-Linear Model for Flood Estimation', ASCE, HY-11, pp.1507-1518.

7. Miller, M.M.(1965), Tritium in Mt.-Everest Ice Annual Accumulation and Climatology at Great Equitorial Altitudes', Journ.Geophys. Res.70, No.6, pp.3885-3888.
8. National Institute of Hydrology (1988),'Design Flood Estimation for Kishau Dam',Consultancy Project,Final Report.
9. Rosenbrock, H.N.(1960),' An Automatic Method for finding the greatest of least value of a function', Computer Jour. Vol.3.
10. Singh, V.P.(1988),'Hydrologic Systems Vol.I, Rainfall-Runoff Modelling, Prentice Hall, Englewood Cliffs, New Jersey.
11. World Meteorological Organisation (1969),'Estimation of Maximum Flood', Tech. Note 98.
12. World Meteorological Organisation (1973), 'Manual for Estimation of Probable Maximum Precipitation Operational Hydrology, Report No.1