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# Simulation of Flood Flows in a Mountainous Catchment in Western Ghats (India)

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**Abstract**

Floods in the mountainous areas result from high intensity rains falling over steep slopes and transforming into runoff at outlet very rapidly due to less time of concentration. The rainfall runoff process in the mountainous catchment is a complex phenomenon compared to plain areas. In these areas, precipitation occurs more frequently and some times with high intensities for longer duration resulting in flash floods. For simulation of flood flows in small mountainous catchments, lumped models are convenient to use because of their simplicity. Unit hydrograph technique is one of the simple and widely used technique for simulation of flood flows.

In this paper the representative unit hydrograph is derived using Clark model. The computations are performed using one of the options for unit hydrograph derivation based on Clark's unit hydrograph approach available in the HEC-1 Flood Hydrograph Package. The rainfall runoff data for eight flood events of Hemavati sub-basin up to Sakleshpur (drainage area 600 sq. km.) are used in the study. The Clark's model parameters TC and R were calibrated using four events. The calibrated model is applied to reproduce four flood events in order to validate the model performance. It is observed from the study that the model generally reproduces the flood peak magnitudes, time to peak and overall flood hydrograph reasonably well.

**Introduction:**

Estimation of flood flows is an important component for planning, design and operation of water resources projects. Unit hydrograph technique is found to be one of the simple and widely used technique. By definition unit hydrograph is a scaling factor to convert the excess rainfall into direct surface runoff assuming the catchment as a linear, lumped and time invariant system.

There are two approaches available in literature for the derivation of unit hydrograph. These are the non-parametric system analysis approach and parametric systems synthesis approach. In non-parametric system analysis approach, the excess rainfall and direct surface runoff are related with unit hydrograph in the form of a mathematical expression. On the other hand the parametric system synthesis approach involved the use of conceptual linear models which represent the system response in the form of instantaneous unit hydrograph with the help of limited number of parameters. Under parametric system synthesis approach, Clark model is one of the versatile and widely used techniques which are often applied to derive the IUH particularly for the mountainous catchments.

The Hemavati (up to Sakleshpur) basin is selected for deriving the representative unit hydrograph using Clark's model. The conventional hydrological data such as rainfall, runoff and catchment parameters were used to derive different Clark's model parameters such as TC and storage coefficient R using HEC-1 Flood Hydrograph Package.

**Description of the Study Area:**

The present study is carried out for the catchment of Hemavati, a tributary of river Cauvery. The catchment area of Hemavati up to **WRDO** gauging site at Sakleshpur is 600 sq.km. The length of the river up to the gauging site is about 55 Km.

The HEMAVATI (up to Sakleshpur) lies between $12^{o}55'$ and $13^{o}11'$ north latitude and $75^{o}29'$ and $75^{o}51'$ east longitude in the south western part of the Karnataka covering parts of Chickmaglur and Hassan districts. The area is a hilly terrain with steep to moderate slopes. General elevation ranges from 890 m to 1240 m above mean sea level. The basin is heavily dissected by stream network.The soils of the basin can be classified broadly into two groups namely red loamy and red sandy soils. Agriculture and plantation are the chief land uses in the basin. Fig. 1 shows the study area.

**Data Preparation and Processing**

For the present study, since observed runoff data were available only at WRDO gauging site at Sakleshpur, the rainfall runoff process was simulated by considering the catchment area up to Sakleshpur as single basin.

**Identification of Flood Events**

The discharge data observed at the basins outlet at Sakleshpur were examined and events having peak flood more than 190 cumec have been identified. Out of the flood events identified those with single peaked hydrographs were separated. The different single peaked flood events along with observed peaks are given in table 1.

**TABLE 1 : OBSERVED SINGLE PEAKED FLOOD EVENTS AT WRDO GAUGING SITE AT SAKLESHPUR FROM 1978-1980**

| Sl.No. | Flood date | Equivalent depth of Observed volume (mm) | Observed peak flow (cumec) |
|---|---|---|---|
| 1. | June 16 - 18 1978 | 50.063 | 193 |
| 2. | June 24 - 26, 1978 | 106.891 | 497 |
| 3. | July 11 - 14, 1978 | 135.500 | 459 |
| 4. | July 30- August 2, 1978 | 124.445 | 393 |
| 5. | July 30- August 2, 1979 | 140.920 | 456 |
| 6. | June 20 - 24, 1980 | 202.478 | 477 |
| 7. | June 30- July 5, 1980 | 669.733 | 1390 |
| 8. | July 7 - 10, 1980 | 356.278 | 1132 |

**Processing of Runoff Records**

The observed runoff data are available at 3 hourly interval for five times a day at 0600, 0900, 1200, 1500 and 1800 hours. The data for rest of the duration are not being observed. Since for calibration of the model, a continuous series of the input data at certain regular time interval is needed, the discharge readings for 2100, 2400 and 0300 hours were interpolated for the selected events listed in table 1.

**Processing of Rainfall Data**

The rainfall data observed at Mudigere, Kotigere, Sakleshpur, Hanbal and Arehalli are being used for the study. Out of these five rain gauge stations the first three stations, namely, Mudigere, Kotigere and Sakleshpur are self recording (SRRG) stations and Hanbal and Arehalli are non recording (ORG) stations.

The rainfall pattern observed at all the stations were studied and it was found that there is considerable variation in the pattern of the rainfall observed at the stations. This is mainly due to orographic effects observed in mountainous catchments. By analysing the rainfall pattern closely, it was noticed that the rainfall pattern observed at Hanbal and Arehalli is same as of Kotigere and Mudigere respectively. To take care of the orography of the basin, the daily rainfall data observed at Hanbal and Arehalli were distributed in accordance with the hourly data observed at Kotigere and Mudigere respectively.

**Preparation of Time-area Diagram**

For preparing time-area diagram of the area, the catchment was drawn in the scale of 1:50,000. From the contour map of the area, the slope of the streams were calculated at selected points. The points of equal time of travel were marked on the streams and lines of equai time of travel were drawn. Fig.2 shows the time area relationship of the basin.

**Preparation of Input Data**

Different data files were prepared according to the requirement of the unit graph and loss rate studies by HEC-1. The computation interval is fixed at 180 minutes as the discharge records were available at 180 minutes interval. However, the rainfall data were supplied at hourly interval for each of the five stations. The HEC-1 has a in built subroutine which converts data given at other than computation interval to computation interval series. The time area ordinates of the catchment were supplied at appropriate order.

The base flow parameters were studied by plotting selected events on semi log paper and it was found that the point of inflection occurs at approximately 0.3 of the peak discharge in most of the cases. The value of RTIOR was calculated by dividing flow at the point of inflection to the flow occurring one hour later and in most of the cases it was found approximately equal to 1.01. The value of RTIOR was supplied as 1.01 .

**CALIBRATION AND VALIDATION OF THE MODEL**

Model calibration involves manipulating a specific model to reproduce the response of the catchment under study within some range of accuracy. The calibration procedure involves adjusting the values of the process parameters such as infiltration , and soil moisture capacity which can not readily be assessed by measurements. All empirical models and all lumped, conceptual models contain parameters whose value has to be fixed through calibration. The HEC-1 provides a powerful optimization technique for estimation of some of the parameters when gauged precipitation and discharge data are available. By using this technique and regionalizing the results, rainfall runoff parameters for ungauged catchments can also be estimated (HEC, 1981).

The parameter calibration option has the capability to automatically determine a set of unit hydrograph and loss rate parameters that 'best' reconstitute an observed runoff hydrograph for the basin. Data requirement for the optimization is : basin average precipitation, basin area, starting flow and base flow parameters STRTQ, QRCSN and RTIOR, and the outflow hydrograph. Unit hydrograph and loss rate parameters can be determined individually or in combination.

The automatic calibration requires selection of an explicit index of the acceptability of alternative parameters estimates, definition of the range of feasible values of the parameters, and development of some technique for correlation of the parameters estimates until the 'best' estimates are determined. Thus, the parameter estimation problem can be classified as an optimization problem, there is an objective function for which an optional value is sought, subjected to certain constraints or the decision variable. The HEC-1 program includes the capability to solve this optimization problem, thereby automatically determining optimal estimates of the parameters.

The 'best' reconstitution is considered to be that which minimizes an objective function, STDER. The objective function is the square root of the weighted squared difference between the observed hydrograph and the computed hydrograph. Presumably, this difference will be a minimum for the optimal parameter estimation. STDER is computed as follows:

$$STDER = \sqrt{\sum_{i=1}^{N} (QOBS_i - QCOMP_i)^2 \times WT_i/n}$$

Where, $QCOMP_i$ is the runoff hydrograph ordinate for time period i computed by HEC 1, $QOBS_i$ is the observed runoff hydrograph ordinate i, n is the total number of hydrograph ordinate, and $WT_i$ is the weight for the hydrograph ordinate i computed from the following equation.

$$WT_i = (QOBS_i + QAVE)/(2xQAVE)$$

Where QAVE is the average computed discharge. The weighted function emphasized accurate reproduction of peak flows rather than low flows by biasing the objective function.

**Calibration of the Model**

For the calibration of the model parameters the flood events observed from June 1978 to August 1978 were used. The events listed at Sl. No. 1 to 4 in table 1 are used for model calibration.

The Clark's unit graph parameters were optimized and for the loss rate determination, the initial and uniform loss rate option is chosen. The uniform loss rate is selected because in tropical mountainous areas the loss becomes uniform after prolonged rainfall during monsoon season.

To gain initial estimates of different parameters, for initial runs of the models, the Clark unit graph parameters TC and R and initial and constant loss rate parameters were optimized using automatic parameters optimization capability of the model. By analysing the initial results it was observed that the ratio R/TC+R is about 0.70 and the STRTL which is starting loss, is about 0.5 mm/hr.

For further calibration runs of the model, the ratio R/TC+R was fixed at 0.7 and STRTL was fixed at 0.5 mm/hr. Now with these two parameters as fixed, the constant loss rate CNSTL and TC and R were optimized. Table 2 gives the results of the calibration runs of the model.

**TABLE 2 : CALIBRATION OF THE MODEL**

| Sl. No. | Flood Event | TC (HR) | R (HR) | CNSTL (mm/Hr) | Equivalent depth of volume (mm) Obs. | Comp. | Peak flow (cumec) Obs. | Comp. | Time to peak (Hr.) Obs. | Comp. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | June 16-18,1978 | 4.23 | 9.86 | 2.49 | 50.063 | 49.625 | 193 | 200 | 21 | 24 |
| 2. | June 24-26,1978 | 5.10 | 11.89 | 1.36 | 106.891 | 105.945 | 497 | 524 | 24 | 18 |
| 3. | July 11-14,1978 | 4.17 | 9.72 | 0.66 | 135.500 | 135.496 | 459 | 512 | 30 | 33 |
| 4. | July 30-Aug.2, 1978 | 3.61 | 8.31 | 0.00 | 124.445 | 115.965 | 393 | 417 | 33 | 42 |

**The average values of TC and R were calculated from the table 2 . The average values of TC and R are 4.28 hours and 10.00 hours respectively. It can be seen from the table that the losses are highly storm dependent. They are very high at the onset of the monsoon and reduce gradually as the catchment becomes wet with continued rainfall.**

**The Clark unit graph parameters TC and R were further calibrated by trial and error. The time of concentration TC was fixed at 4.28 hours and the value of R was changed to 11, 12, 13, 14 and 15 hours. From the results of the calibration, it was observed that the volume and peak are matching more closely at the value of R equal to 14.5 hours.**

**In the next step of calibration, the value of storage coefficient R was fixed at 14.5 hours and TC was changed from 4.28 to 5 hours. From the results it was observed that at TC 4.75 hours and R 14.5 hours, the peak and volume of observed data and computed values are matching closely. Table 3 gives the results of final calibration runs for the selected events. Fig.3 shows the observed and computed hydrographs for final calibration run of the model parameters for event at Sl. No.3 in table 3**

TABLE 3 : FINAL CALIBRATION OF THE MODEL PARAMETERS

| Sl. No. | Flood Event | TC (HR) | R (HR) | CNSTL (mm/Hr) | Equivalent depth of volume (mm) | | Peak flow (cumec) | | Time to peak (Hr.) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Obs. | Comp. | Obs. | Comp. | Obs. | Comp. |
| 1. | June 16-18,1978 | 4.75 | 14.50 | 2.42 | 50.063 | 49.838 | 193 | 194 | 21 | 24 |
| 2. | June 24-26,1978 | 4.75 | 14.50 | 1.23 | 106.891 | 106.891 | 497 | 499 | 24 | 18 |
| 3. | July 11-14,1978 | 4.75 | 14.50 | 0.58 | 135.500 | 135.500 | 459 | 473 | 30 | 39 |
| 4. | July 30-Aug.2, 1978 | 4.75 | 14.50 | 0.00 | 124.445 | 110.710 | 393 | 358 | 33 | 42 |

From the table 3 it is seen that the time to peak for observed and computed hydrographs do not match for the calibrations runs. It varies from 6 hours before the actual observed peak to 9 hours after the observed peak for different events.

Similarly the constant loss rates vary considerably. The constant loss rate depends upon the storm. The constant loss rate is high for the storms observed in the month of June and reduces gradually for July and August. This is due to the fact that in the month of June, the catchment is relatively dry compared to July and August months.

From the analysis of the calibration results it is seen that the constant loss rate is as high as 2.40 mm/hour for first storm observed in June and reduce up to 1.2 mm/hour for subsequent storms observed in June. As the catchment gets more and more moisture by subsequent rains, the loss rate reduces. In the month of July it dipped further to the order of 0.5 mm/hour and goes on reducing as the catchment becomes saturated. Therefore it is evident from above that the constant loss rates can not be fixed at certain value as it varies from storm to storm.

The Summary of calibration results are given in table 4.

TABLE 4 : SUMMARY OF CALIBRATED PARAMETERS

| | | |
|---|---|---|
| TC | = | 4.75 Hours |
| R | = | 14.50 Hours |
| STRTL | = | 0.50 mm/Hour |
| RTIOR | = | 1.01 |
| CNSTL | = | Variable with event |
| Point of Inflection = 0.30 of peak | | |

**Validation of the Model**

For validation of the different model parameters, the single peaked flood events observed from July 1979 to 1980 at Sl. No. 5 to 8 in table 1 were used. For different events, data files were prepared by supplying value of model parameters TC and R as 4.75 and 14.50 hours respectively. Different loss rates were used for different events as described earlier.

For the first events observed in the month of June the loss rate was supplied as 2.5 mm/hour and for subsequent events observed in June the constant loss rate was supplied as 1.2 mm/hour. For the events observed in July the value of loss rate was given as 0.5 mm/hour and for events observed in August it was assumed as negligible. Table 5 shows the validation results.

**TABLE 5 : VALIDATION RESULTS**

| Sl No. | Flood Event | Equivalent depth of volume (mm) Obs. | Comp. | Peak flow (cumec) Obs. | Comp. | Time to peak (Hr.) Obs. | Comp. |
|---|---|---|---|---|---|---|---|
| 1. | July 30- Aug. 2,1979 | 140.920 | 184.285 | 456 | 592 | 33 | 51 |
| 2. | June 20 - 24, 1980 | 202.478 | 166.984 | 477 | 479 | 48 | 46 |
| 3. | June 30-July 5,1980 | 669.733 | 610.487 | 1390 | 1391 | 72 | 72 |
| 4. | July 7 - 10, 1980 | 356.278 | 259.910 | 1132 | 911 | 51 | 48 |

It can be seen from table 5 that observed and simulated hydrographs are matching in all cases except July-Aug 1979 event. Fig.4 shows the observed and computed hydrographs of flood events listed at Sl. No 2 in table 5 .

**CONCLUSIONS**

The present study deals with the application of HEC-1 model to a sub-basin of Hemavati river. The river Hemavati (up to Sakleshpur) drains an area of about 600 sq.km. Based on this study the following conclusions are drawn.

1. The HEC-1 has been successfully used for modeling rainfall runoff response of Hemavati (up to Sakleshpur) sub-basin within the constraints of data availability. The simulation results show good reproduction of stream flow volumes, peaks and hydrographs.
2. Recording and non-recording rain gauge network, though, adequate, is not well distributed within the catchment to represent orographic effects observed in mountainous areas, therefore, the rainfall input is not properly represented.

**References**

Feldman, A.D.; (1981) HEC models for Water Resources System Simulation: Theory and Experience. In advances in Hydrosciences ed. Ven Te Chow, Vol.12, Academic Press. pp. 297-423.

Hydrologic Engineering Center (1981)"HEC-1 Flood Hydrograph Package" Generalized computer program, User's Manual U.S. Army Corps of Engineers, California.

Hydrological Engineering Center (1982)" Hydrologic Analysis of Ungauged watersheds using HEC-1", Training Document No.12, U.S. Army Corps of Engineers, California.

Ramasastri, K.S.; S.M. Seth (1984), "Application of HEC-1 for flood forecasting" Proceedings of National Seminar on Real-time Hydrological Forecasting. 31 Oct.- 1 Nov. 1984, New Delhi. pp. 217-226.

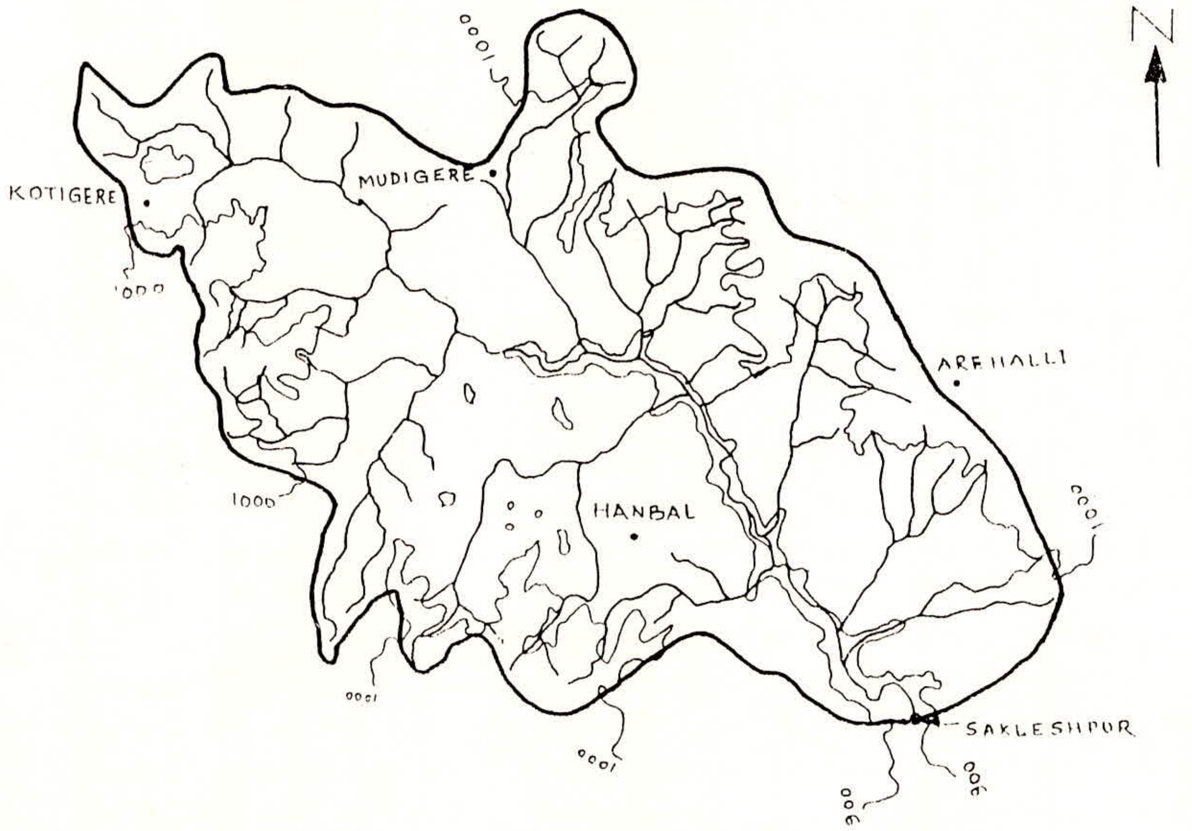



Fig. 1 : Map of Hemavathy (Upto Sakleshwar) Basin

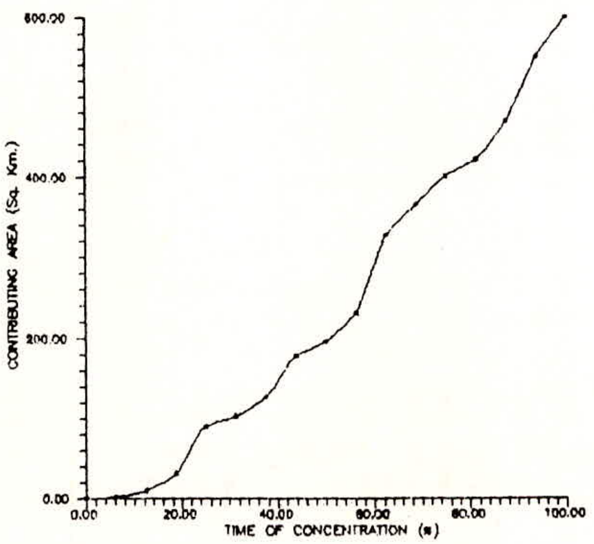
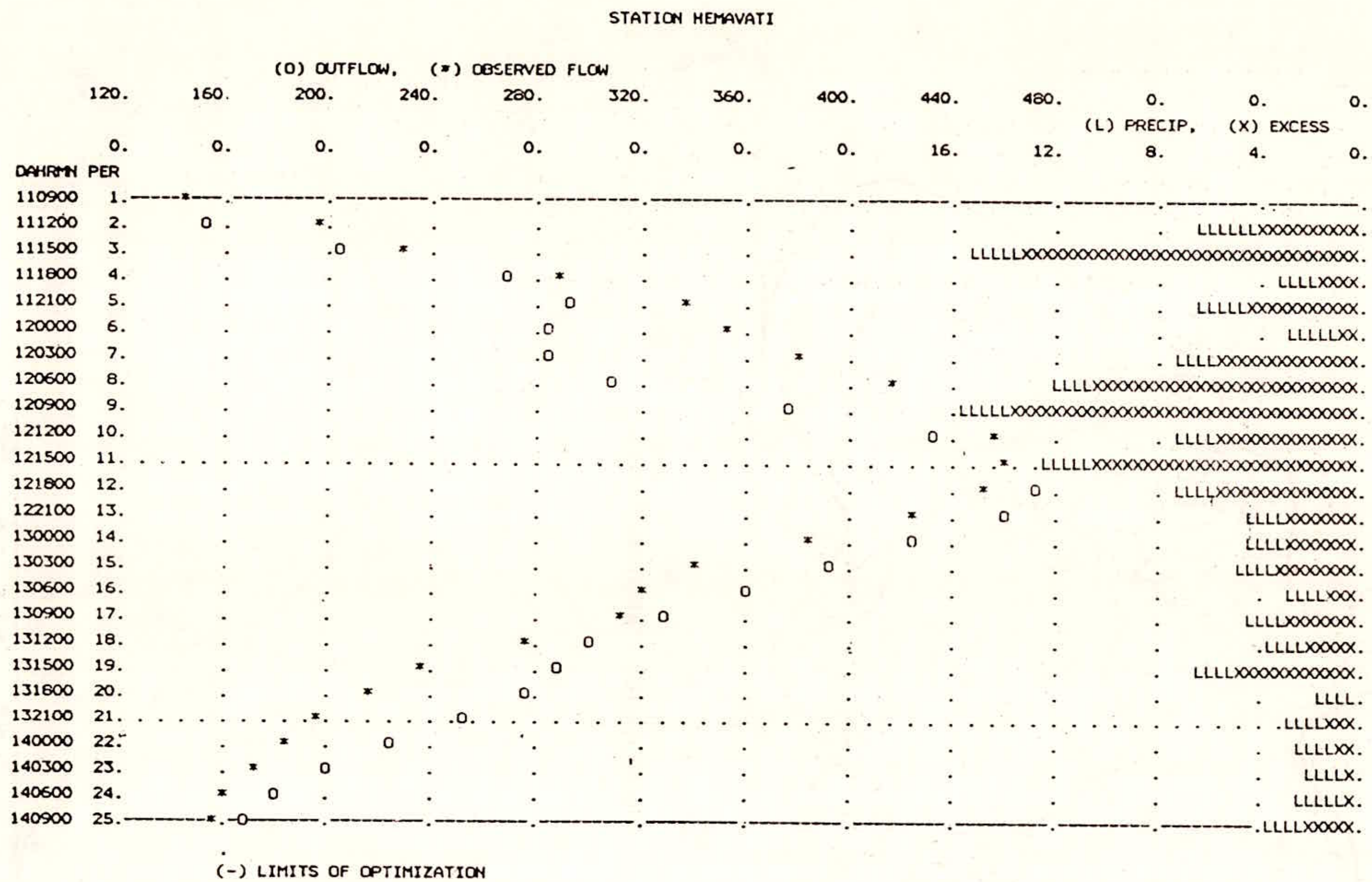



Fig 2 : TIME-AREA DIAGRAM OF HEMAVATI BASIN




** STATION HEMAVATI **          DRAINAGE AREA = 600.00

| ..DATE... | .......PERCENT ERROR...... | | | | ..................... OPTIMIZATION | | | | | | RESULTS ..................... | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DA MON YR | AVG | VOL | LAG | PEAK | TC | R | TC+R | R/(TC+R) | TP | CP | QP | STRTL | CNSTL |
| 11 JUL 78 | 14.2 | .0 | 35.7 | 3.1 | 4.75 | 14.50 | 19.25 | .75 | 6.40 | .35 | 35. | .50 | .58 |

FIG. 3. FINAL CALIBRATION RUN FOR EVENT JULY 11-14, 1978

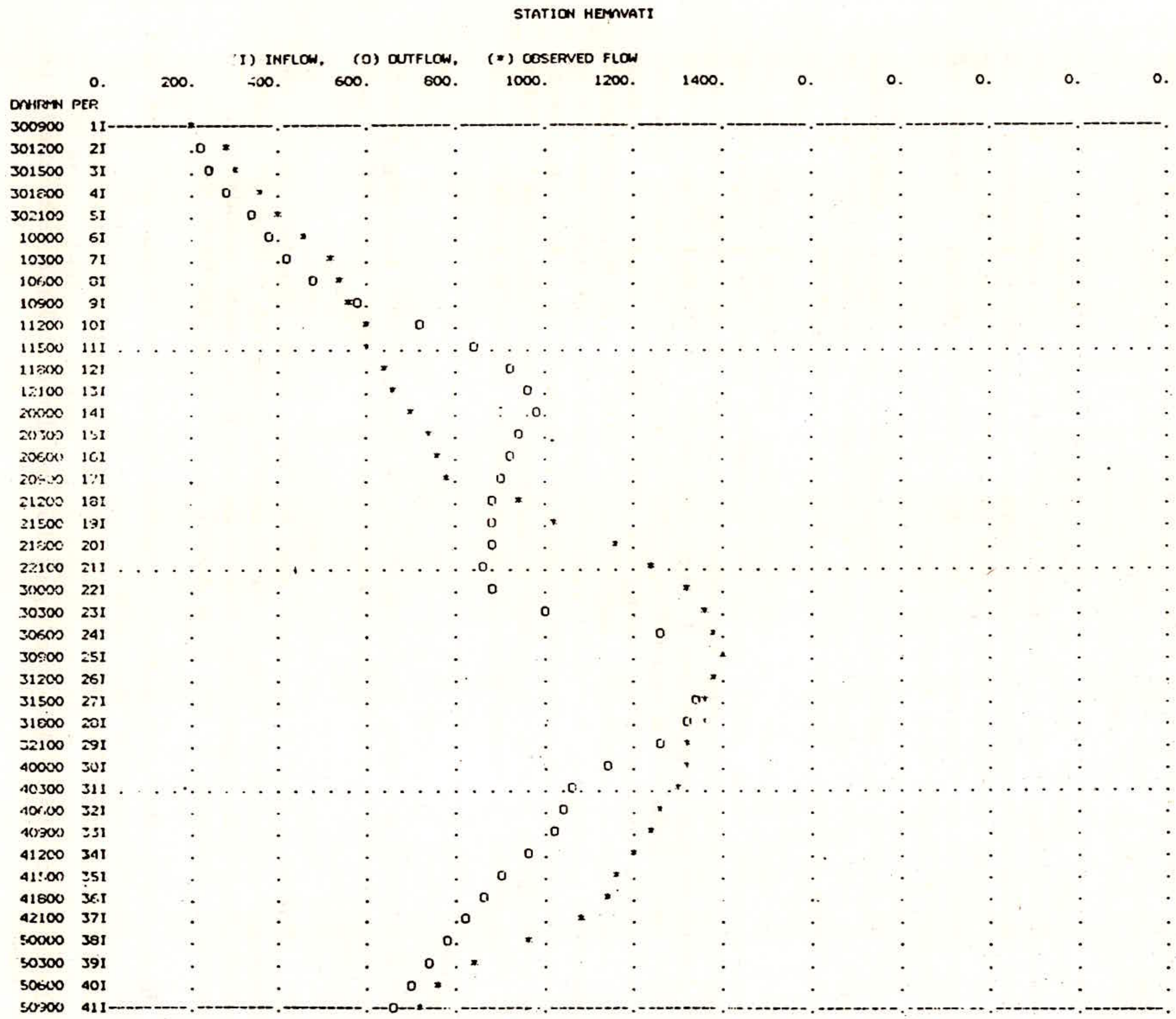



FIG. 4. COMPARISON OF OBSERVED AND SIMULATED HYDROGRAPH FOR EVENT JUNE 20-24 , 1980

DISCUSSION

S. M. SETH : Are there any tanks or reservoirs upstream of Sakleshpur ? How such depression could be accounted for in similar studies ?

AUTHOR(S) : To the best of the knowledge of the authors there are neither any tanks nor any man made reservoirs in the catchment of Hemavathi upstream of Sakleshpur.

The HEC model has no provision for dealing with the depression storage loss. All losses are dealt in a lumped way by either uniform loss,exponential loss or SCS curve technique. In case of large storages due to tanks or reservoirs the storage routing could be carried out in case relationships indicating elevation - storage are available.

COMMENT BY GENERAL REPORTER : Application of unit Hydrograph technique is questionable due to inherent assumption of the temporal and spatial variability of the precipitation.

AUTHOR(S) : The authors are aware of the limitation of the use of a lumped model like HEC1 which is based in the Unit Hydrograph approach. It may, however be mentioned that where the rainfall could be properly represented the limitation does not come in the way of satisfactory simulation. The attention of the General Reporter is invited to a study by Kite (1991) where a lumped model has been used for simulation of flood in a mountainous catchment in Canada. In the case of Hemavathi the non recording and recording raingauges are well distributed in the catchment thereby enabling a proper representation of rainfall input to the model. The results obtained also amply vindicate this point.

REFERENCE

Kite G W (1991) A watershed model using Satellite data applied to a mountain basin in Canada. Journal of Hydrology Vol.128 No.1-4, pp 157-169.

D. K. SHARMA : (1) In what way it has been found that the performance of Clark's model for computing design flood is better compared to other methods. Has some studies been conducted to compare performance of Clark's model with other methods ?

(2) Has the model parameters $T_c$ and R been verified by taking actual observations in the field ?

(3) Our experiences while working with Clark's method using HEC 1 has been that the model provides lower flood values compared to other methods.

AUTHOR(S) : For the same catchment a study carried out in NIH by C. P. Kumar and K. S. Ramasastri using the physically based and distributed SHE model has given comparable results of simulation of flood flows. The performance of the models depends to a large extent on the availability of data and its representativeness for the catchment. It may be mentioned in both the cases only flows are simulated and no design flood studies have been carried out.

The HEC 1 model has been used by the National Institute of Hydrology for the estimation of design flood Narmada Sagar and Sardar Sarovar dams. They have given design flood peaks which could not be rated as under estimates.

(2) To the best of the knowledge of the authors the parameters $T_C$ and R can only be estimated and calibrated but not measured in the field .