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APPLICATION OF HEC-1 TO HEMAVATI (UP TO SAKLESHPUR) BASIN

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PREFACE

The mountainous areas are sources of water, food and energy for millions of people the world over. In India out of a total geographical area of 328 million hectares, about 93.06 million hectares are mountainous. These mountainous regions are sources of major rivers in the country. Past experiences on harnessing of water resources in the mountains have indicated that a scientific understanding of the complex hydrological processes in the mountainous regions would be necessary to achieve the desired objectives.

Inspite of rapid advances in hydrology particularly in modelling it is not always possible to make universal use of such models because local problems predominate over other factors. The last decade has seen the widespread use of watershed models for simulation and forecasting of stream flows in India. Their use for the mountainous areas has been rather limited partly due to non availability of data and partly due to problems typical of mountainous areas in the country.

A comprehensive modelling of precipitation runoff process is offered through the Hydrclogic Engineering Centre (HEC-1) Flood Hydrograph Package . The HEC-1 package is a comprehensive, single event lumped model intended to simulate discrete storm events. It uses spatially and temporally lumped or averaged parameters to simulate the precipitation-runoff process. The result of this modelling process is the computation of stream flow hydrographs at desired locations.

The Hemavati (upto Sakleshpur) basin is selected for model application. The present study consists of data processing, evaluation of model parameters, carrying out simulation runs, formulating approach for calibration, and validation of results. The study has been carried out by Mr. M.K.Jain, Scientist 'B' under the guidance of Mr.K.S.Ramasastri, Scientist 'F'.

SATISH CHANDRA

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The present study deals with the application of the HEC-1 model to the Hemavati basin (upto Sakleshpur) of the river Cauvery. The study basin lies between $12^{O}55''$ and $13^{O}11''$ north latitude and $75^{O}29''$ and $75^{O}51''$ east longitude in the south west part of the Karnataka covering parts of Chickmanglur and Hassan district. The river Hemavati drains an area of 600 sq.km. **upto** WRDO gauging site at Sakleshpur and length of the main river upto the gauging site is about 55.5 km.

The conventional hydrological data such as daily and hourly rainfall data and 3 hourly discharge data from 1978 to 1980 were readily available and are used for the model calibration and validation. Topographic details were drawn from Survey of India toposheets.

In this application study, the HEC-1 model has been successfully used for simulation of peak floods. Various model parameters such as Time of concentration, storage coefficient, loss rate and other parameters were evaluated and fixed for the basin. The simulation results show good reproduction of stream flow volumes, peaks and hydrographs.

1.0 INTRODUCTION

Development of water resources of a basin involves quantification and proper utilization of water resources of a river basin. In the pre-computer era quantification was tedious work as the amount of calculations involved is very large. With the advent of computers and development of many sophisticated watershed models it is comparatively easy to compute basin water resources provided we know the mathematics of the physical processes involved and reliable data base to support the model.

Hydrological cycle of mountainous river basins is a complex interaction of the processes influenced both by regional peculiarity of climate, soil, geological conditions and vertical zonal variability together with slope exposition. Runoff estimation in mountainous areas requires thorough understanding of runoff processes in these areas. The rain and snowmelt runoff processes in mountainous catchment is relatively a complex phenomenon than that in plain areas, primarily because of rapid variation of hydrometeorological, geomorphological and other catchment characteristics in the mountainous area.

Runoff processes in mountainous areas differ from those in plain areas primarily because of differences in meteorological and physiographical factors in plain and mountainous areas. Meteorological parameters like rain, snow, temperature and physiographic factors like soils, rocks and their composition in a watershed are highly variable at different elevations.

In mountainous areas, precipitation occurs more frequently and some times with high intensities for longer durations. Interception losses are significant due to forest type of vegetation. Interception losses are high at the beginning of a storm and are reduced gradually to a constant rate. Similarly infiltration rates depend upon nature of soil, depth of soil and slope of surface.

Runoff in mountainous regions results from rainfall, snowmelt and glacier melt. The rain or snow falling in a catchment undergoes a number of transformation and abstractions through various component processes such as interception, detention, evapotranspiration, overland flow, infiltration, interflow, percolation, subsurface flow, base flow etc. and emerges as runoff at catchment outlet.

Numerous models have been developed and tested on many watersheds. Models are generally developed for a specific geographical location as it is very difficult to develop a universally applicable model due to the complexity of the hydrological processes. However, model developed for a particular location can as well be applied for other locations with or without modifications.

Keeping in view of the above, the present study is undertaken. An attempt is being made to simulate rainfall run-off response of a sub-catchment of Hemavati (catchment area 600 sq.km.) using HEC-1 flood hydrograph package developed by Hydrologic Engineering Centre (HEC) of US Army Corps of Engineers.

2.0 HEC-1 MODEL

2.1 General

Computer program HEC-1 is a comprehensive, "single event" precipitation-run-off model intended to simulate discrete storm events. The HEC-1 watershed model uses spatially and temporally lumped or averaged parameters to simulate the precipitation and run-off process. The program was developed by Hydrologic Engineering Center (HEC) of US Army Corps of Engineers.

In the HEC-1 model , the transformation of rainfall excess to stream flow is accomplished either by Unit hydrograph or by Kinematic wave routing procedure. A variety of procedures can be used to calculate watershed interception and infiltration referred to as loss rate.

The main purpose of the HEC-1 Flood Hydrograph package is to simulate the hydrological processes during flood events. The precipitation (rainfall,snowfall/melt) to run-off process can be simulated for large complex watersheds.

2.2 SALIENT FEATURES

The HEC-1 has several major capabilities which are used in the development of a watershed simulation model and analysis of flood control measures. These capabilities are as follows

Automatic estimation of unit graph, interception infiltration and STREAM FLOW routing parameters.

Simulation of complex river basin run-off and stream flow.

River basin simulation using a precipitation depth versus area function

Computation of modified frequency curves and expected annual damages for any location in the stream systems and automatically for several flood control plans throughout the watershed.

Simulation of flow through a reservoir and spillway for dam safety analysis.

Simulation of dam breach hydrographs.

Optimization of flood control system components

The automatic parameter estimation capability relates to the determination of the sub-basin run-off parameters by a universal search procedure. The unit hydrograph loss rate and stream flow routing parameters may be optimized for individual storm events based upon observed precipitation, stream flow data for a sub-basin. Stream flow parameters may also be optimized for known inflow and outflow in a river reach.

Watershed precipitation and run-off simulation is the main function of the program and the basis for other capabilities. The model may be used to simulate run-off in a simple, single basin watershed or in a highly complex basin with a virtually unlimited number of sub-basins and routing reaches in which interconnections may or may not exist.

2.3 Model Philosophy

The HEC-1 is designed as event based watershed model. The single event model simulates only single storm events and does not usually maintain a continuous accounting of soil moisture between flood events. The HEC-1 model is designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an inter connected system of hydrologic and hydraulic components. Each component models an aspect of precipitation runoff process within a portion of the basin, commonly referred to as sub-basin. A component may represent a surface run-off entity, a stream channel, or a reservoir.

Representation of a component requires a set of parameters which specify the particular characteristics of the component and mathematical relations which describe the physical processes. The result of the modelling process is the computation of stream flow hydrograph at desired location in the river basin.

2.4 Model description

HEC-1 is a lumped parameter model. It uses spatially and temporally lumped (or averaged) parameters to simulate precipitation and run-off process. The HEC-1 model components are used to simulate rainfall run-off process as it occurs in an actual river basin. The model component function based on simple mathematical relationships which are intended to represent individual meteorological, hydrological and hydraulic processes which comprises the precipitation run-off process. A typical watershed with subbasins and routing reach components is shown in Fig.1a. The HEC-1 simulates the precipitation, precipitation loss, and run-off process in each subbasin, routes streamflow downstream and combines tributary inflows.

In subsequent paragraphs different model components will be discussed in brief.

Precipitation

A precipitation hyetograph is used as input for all run-off calculations. Any of the options used to specify precipitation produce a hyetograph. The hyetograph represents subbasin average precipitation depths over a computation interval. Two methods are available to supply precipitation data of an observed storm. They are (1) Basin average precipitation and (ii) weighted precipitation gauges.

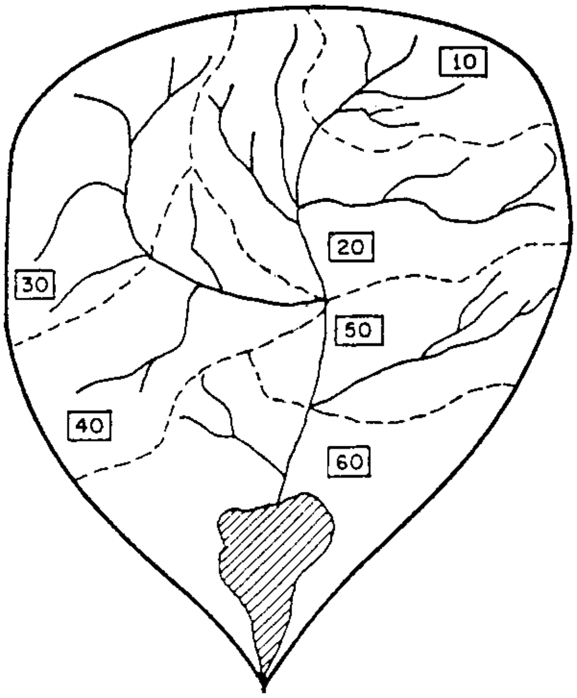


Figure 1 a Example River Basin

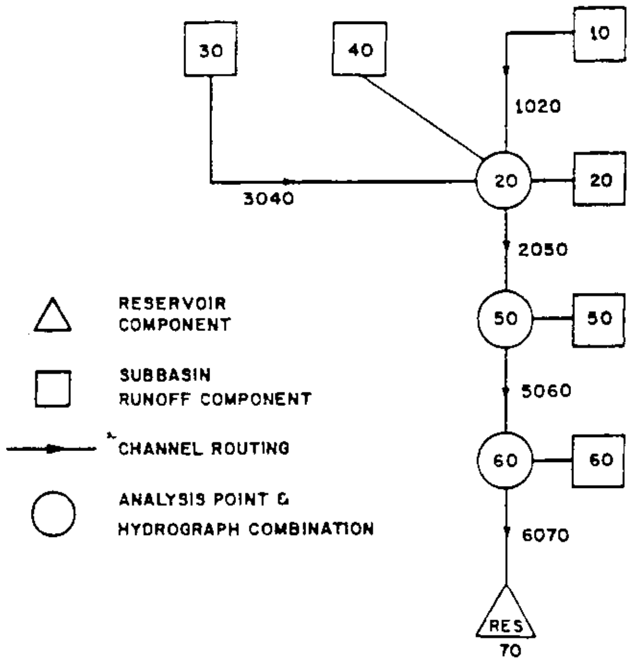


Figure 1 b Example River Basin Schematic

All time series precipitation data are input as end of interval values. The date, time interval and length of the input precipitation series must be specified, also desired beginning of simulation and the simulation time interval. If the desired computation time interval is different from the input data time interval, the programme will interpolate (using a three point spline function) the input precipitation series in order to determine the precipitation for the required computation intervals. The simulation is performed at a constant time interval but the data may be given at any time interval.

Loss rate Analysis

Precipitation losses to interception, depression storage and infiltration may be simulated by one of the four loss rate functions: Initial and constant loss rate function, HEC exponential loss rate, SCS curve number and Holton loss rate function.

The initial and constant loss rate function is the simplest form of all loss rate functions. An initial loss, STRTL (units of depth), and constant loss rate, CNSTL (units of depth/hour), are specified for this method. After the initial loss is satisfied, rainfall is lost at the constant loss rate, CNSTL.

The HEC exponential loss rate function simulates the losses as a function of accumulated soil moisture (losses not available for run-off). It is an empirical method which relates losses to rainfall intensity and accumulated losses.

In SCS curve number method, soil group type is related to curve number as a function of soil cover, land use type and antecedent moisture conditions. Precipitation loss is calculated based on supplied value of curve number and initial surface moisture capacity in the unit of depth.

In Holtan method the loss rate is expressed as a function of 'growth index', representing the relative maturity of ground cover, the infiltration capacity per unit of available storage, available storage in units of water equivalent; constant rate of percolation of water through the soil profile below the surface layer, and an empirical exponent, typically taken equal to 1.4.

The portion of the rainfall/snowmelt not lost to soil moisture etc. is referred to as precipitation excess. The next step in HEC-1 simulation is to convert a hyetograph of rainfall/snowmelt excess into a run-off hydrograph from the subbasins.

Surface run-off

The HEC-1 program simulates direct surface run-off by convoluting the rainfall/snowmelt excesses through a unit hydrograph or by the kinematic wave transformation. Rainfall/snowmelt excesses are computed for each time interval by subtracting infiltration losses from incoming precipitation. The rainfall excess hyetograph is transformed to a subbasin outflow by utilizing the general equation :

$$Q(i) = \sum_{i=1}^{n} \sum_{J=1}^{i} U(j) \times X(i-j+1)$$

Where Q(i) is the subbasin outflow at the end of computation interval i, U(j) is the j th ordinate of the unit hydrograph, X(i) is the average rainfall excess for computation interval i and, N is the number of rainfall ordinates.

Several alternative approaches for specifying unit hydrograph may be used in the watershed simulation. If unit graph ordinates are known, they may be input directly. The three unit graph functions in the program are based on methods developed by Clark (1945), Synder (1938) and SCS (1972).

The Clark method requires three parameters to calculate a unit hydrograph: TC, the time of concentration for the basin; R, a storage coefficient; and a time-area curve. In the event of time-area curve is not supplied, the program utilizes a dimensionless time-area curve.

The Synder method determines the unit graph peak discharge, time to peak and width of the unit graph at 50 and 75% of peak discharge. The initial Clark parameters are estimated from the given Synder coefficients Tp and Cp, which defines the peak of the unit graph.

The SCS dimensionless unit hydrograph techniques uses a single parameter, TLAG, which is equal to the lag (Hrs) between centre of mass of rainfall excess and the peak of unit hydrograph to define the shape of hydrograph by calculating peak flow and time to peak.

Because the Synder coefficients used in HEC-1 define the coordinates of only the peak of unit hydrograph, the clark method is used as a curve fitting mechanism to produce a complete unit hydrograph that has peak coordinates that are constant with the user specified Synder coefficients. The Clark method is used to compute a unit graph and then the corresponding Synder parameters Tp and Cp are determined. The derived Tp and Cp are compared to the input Synder data and adjustments are made to the clark parameters until the desired Synder coefficients are obtained. After the unit graph coefficients are determined, direct run-off at the basin outlet is calculated.

The kinematic wave (Woolhiser, 1975) run-off transformation in HEC-1 has been specially developed for simulation of run-off in urban areas. The kinematic wave method produces a non linear run-off response to rainfall excess as compared to linear response of unit graph. The objective of HEC's utilization of kinematic wave technique was to associate parameters as closely as possible with measurable watershed characteristics such as slope, land use and storm drains. Such an approach is desired to reduce ambiguities in calibration process and to enable parameter estimation for future land use conditions.

Base flow

The model employs a logarithmic decay function to simulate base flow. The effect of base flow on streamflow hydrograph is incorporated as a function of three input parameters; STRTQ, -Starting flow, QRCSN - a recession threshold and RTIOR - recession rate. The relationship between stream flow hydrograph and these variable is given in fig.2.

The program adjusts RTIOR to the time steps of the particular simulation and computes the recession flow Q as :

$$Q = Q_o \, (\mathrm{RTIOR})^{-n\Delta t}$$

Where Q_o is STRTQ or QRCSN and $n\Delta t$ is time in hours since recession was initiated.

The rising limb of the stream flow hydrograph is adjusted for base flow by adding recessed starting flow to the computed direct run-off flows. The falling limb is determined in the same manner until the computed flow is determined to be less than QRCSN. At this point, from this time on the stream flow hydrograph is computed using the recession equation until the computed flow rises above the baseflow recession.

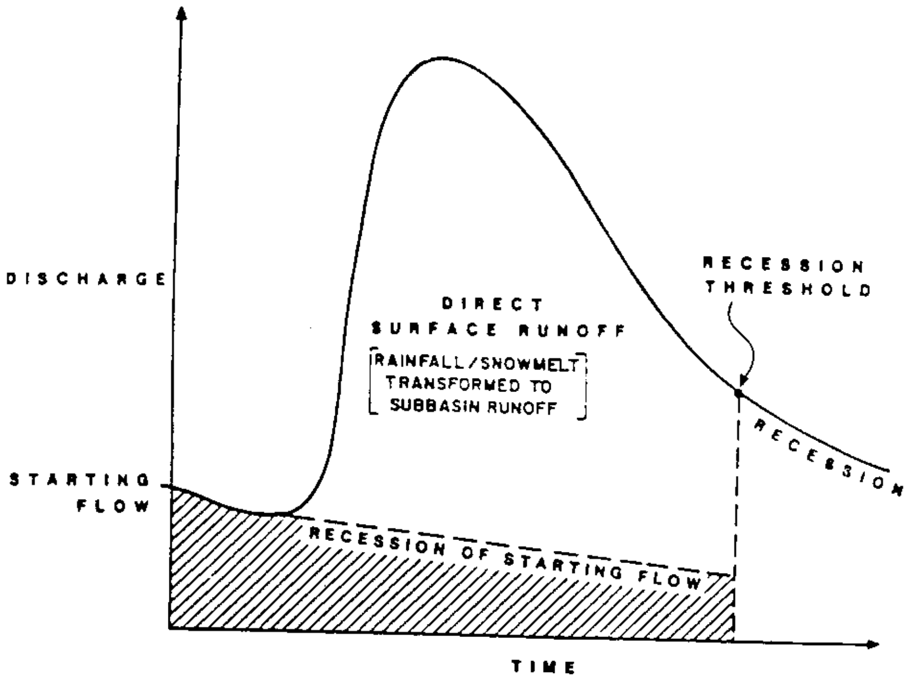


Figure 2 Base Flow Diagram

Streamflow routing

There are several types of flood routing functions available in HEC-1 watershed simulation method. Most of the method available are based on continuity equation and some relation between flow and storage or stage. These are Muskingum, modified pulse and kinematic wave methods. Besides these methods working R&D, level-pool reservoir, Talum and Straddle-stagger routing methods are also available. Parameters are automatically calibrated for Muskingum, working R&D, straddle-stagger and Talum methods.

River network

The watershed simulation in HEC-1 is accomplished in a converging tree network as shown in fig.1b. The simulation must begin at the uppermost basin of a stream branch. The connectivity of watershed subbasins and routing reaches is implied by the order of these elements in the data deck. Streamflow diversions may be performed at any point in the stream network. The diverted flows may be treated as normal hydrographs and routed and combined through a new branch of stream network. The diverted flows may be returned to virtually any point of the channel network.

2.5 DATA REQUIREMENT

Precipitation runoff simulation with HEC-1 requires data describing precipitation, loss rate surface runoff, base flow and channel routing. The specific data requirement depends upon type of study, purpose of study, accuracy required etc. The general structure of the input data is a series of input blocks which proceeds from upstream to down stream. The input block specify parameters that controls subbasin runoff, routing, combining, diversions, etc. The data may be supplied in Metric or English units.

3.0 DESCRIPTION OF THE STUDY AREA AND DATA AVAILABILITY:

The HEMAVATI river is one of the main tributaries of the river Cauvery. It rises in Ballalarayanadurga in the western ghats in the Mudigere taluk of Chickmaglur district of Karnataka. The western ghats region is mountainous covered with thick vegetation. The HEMAVATI tributary joins the river Cauvery on its left bank after traversing a length of 193 Km. in Hassan and Mudigere districts of Karnataka in the water spread of Krishnarajasagar reservoir near Akkihebbal. Fig. 3 shows Hemavati sub-basin in the Cauvery basin.

The HEMAVATI river, in its early reaches, passes through a very heavy rainfall region in the vicinity of the Kotigere and Mudigere. Important tributaries to the HEMAVATI are Yagachi and Algur. The river Yagachi flows in a meandering course along NNW-SSE to SSE-NNE directions, and joins the river HEMAVATI at Gorur. The river Algur joins the Hemavati from south near Algur. Numerous small streams also join the river Hemavati all along its course. The river Hemavati drains an area of 5,200 Sq. Km. The annual rainfall of the area varies from 762 to 5080 mm with an average annual of 2972 mm.

Study area:

For the present study the Hemavati up to WRDO gauging site at Sakleshpur is selected. The river drains 600 Sq.Km. of the catchment area up to WRDO gauging site at Sakleshpur. 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 covered in Survey of India topo

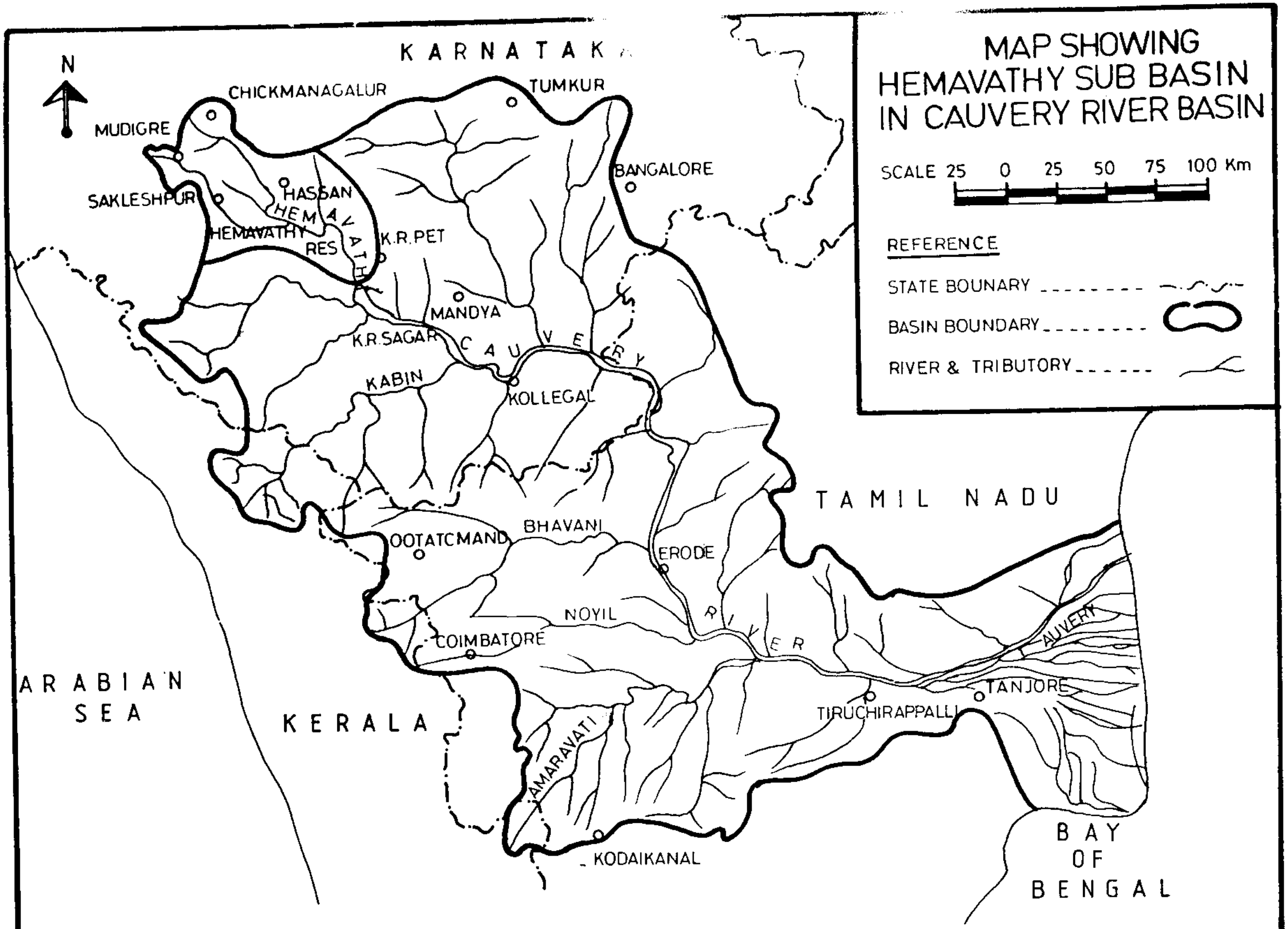


FIG.3. HEMAVATHY SUB BASIN IN CAUVERY RIVER BASIN

sheets No. 480/8, 480/12, 480/16, 48P/9 and 48P/13. Fig. 4 shows the map of study area.

Climate and rainfall

In the study area summer season persists from March to May. Heavy to very heavy rain storms are experienced in the rainy season which extends from June to October. November to February are winter months. Severe cold is experienced during this period.

Topography

The area under study is a hilly catchment with steep to moderate slope. The entire basin can be classified as hilly lands, moderately sloping and low lands (valley lands). General elevation of the area ranges from 890 m to 1240 m above mean sea level. Contour map of the basin is given in figure 5.

River network

The basin has a hilly terrain and is heavily dissected by stream network. The length of largest tributary is approximately 20 Km. The total length of the Hemavati river upto WRDO gauging site Sakleshpur is about 55 Km. Fig.4 shows the river network of the study area.

Land use

Agriculture and plantation is the chief land use in the basin. Coffee, paddy, and cardamom are grown. Coffee is grown on hill slopes and paddy cultivation is practiced in valley land. Cardamom is grown in all parts of the basin.

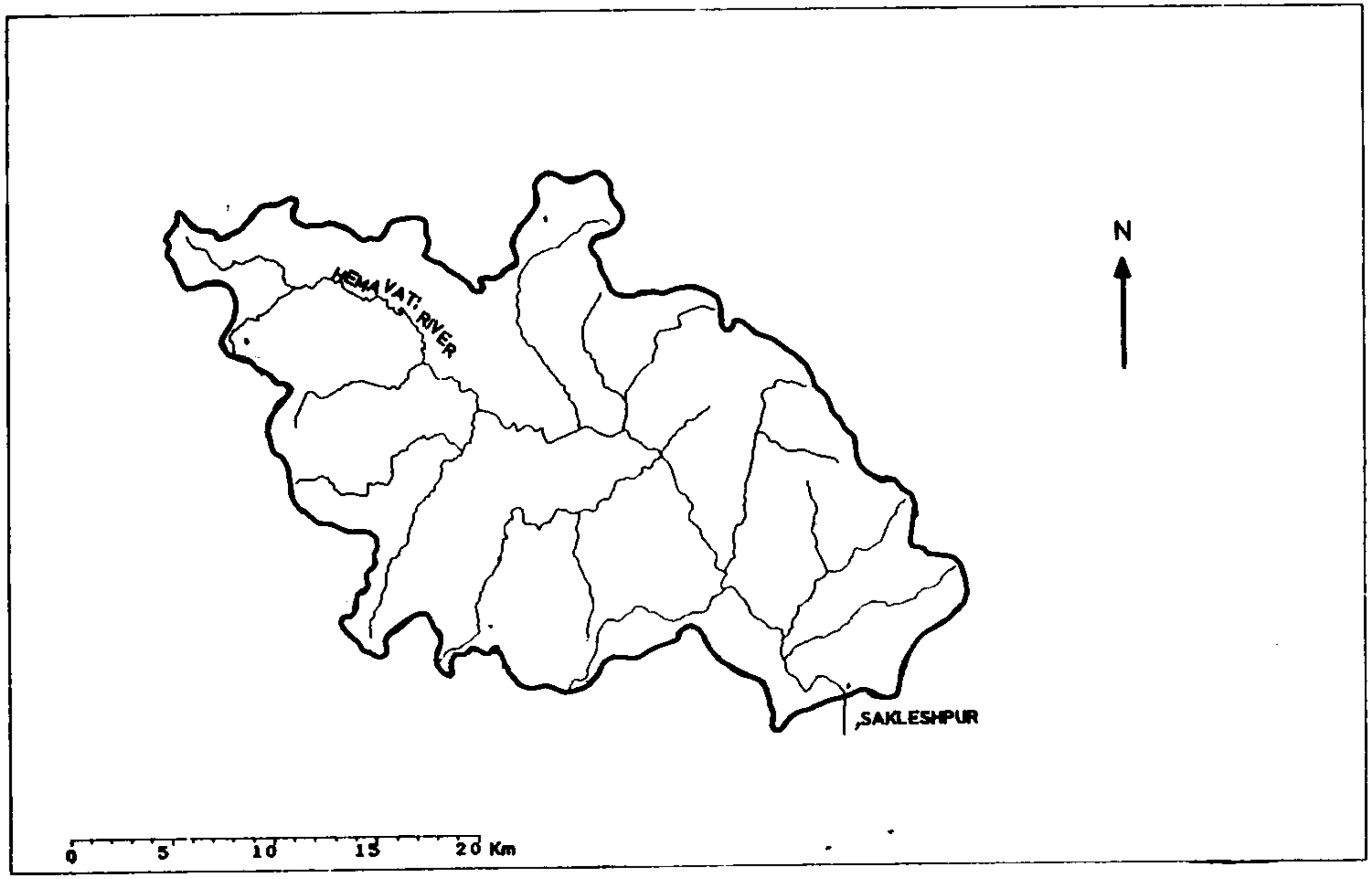


FIG. 4 MAP OF STUDY AREA

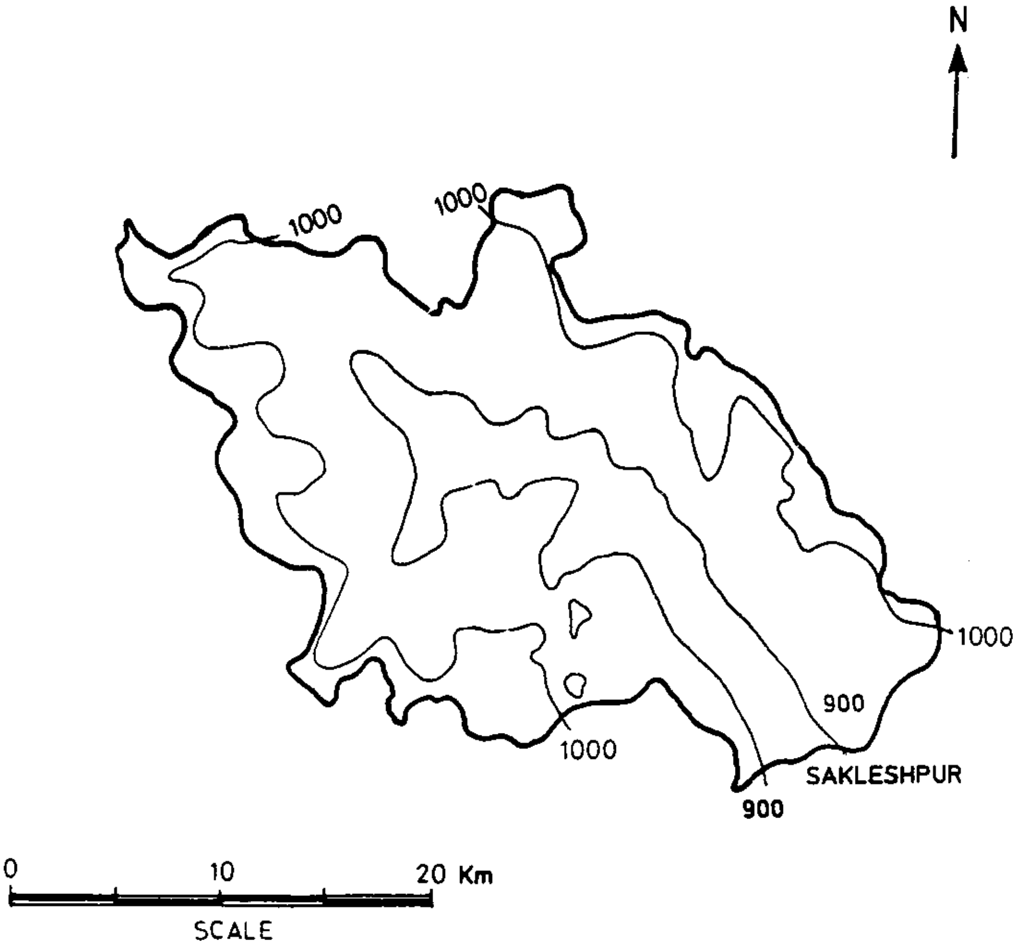


FIG. 5 TOPOGRAPHIC MAP OF AREA

Soil

Broadly the soils in the basin can be classified into two groups viz. red loamy and red sandy soils. Soil texture is very fine . The water retention capacity of the soil is less compared to black soils. The soils are suitable to grow a wide variety of crops.

Data availability.

For the present study the rainfall and runoff data from 1978 to 1980 were collected. There are five raingauge stations lies with in or just outside the basin. The rainfall stations are Arehalli, Hanbal, Mudigere, Kotigere and Sakleshpur. The gauging stations Mudigere, Kotigere and Sakleshpur are recording raingauge stations and Arehalli and Hanbal are non-recording stations. Hourly rainfall data of the three recording stations from 1978-80 are available. Rainfall behaviour of all the five raingauges was studied and it was found that rainfall pattern at Hanbal and Kotigere are same. Similarly pattern at Mudigere and Arehalli is also same. For the present study the daily data at Arehalli and Hanbal was distributed into hourly records according to rainfall patterns observed at Mudigere and Kotigere respectively. The runoff data at WRDO gauging site at Sakleshpur were only available. The gauge and discharge readings at three hourly interval for five times a day 0600, 0900, 1200, 1500 and 1800 hours are available. Readings for remaining period are not available. Since the model requires a continuous time series, the readings for 2100, 2400 and 0300 hours were interpolated for selected events. Topographic information were collected from Survey of India toposheets no. 480/8, 480/12, 480/16, 48P/9 and 48P/13. The land and channel elevations for drawing time area diagram was taken from above mentioned toposheets.

4.0 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 upto Sakleshpur as single basin.

4.1 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 these identified flood events a search was made to separate single peaked hydrographs. The different identified single peaked flood events alongwith observed peaks are given in table 4.1.

TABLE 4.1 : 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

4.2 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 4.1.

4.3 Processing of rainfall data

The rainfall data observed at Mudigere, Kotigere, Sakleshpur, Handball and Arehalli are being used for the study. Out of these five raingauge 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 hourly rainfall data at all three SRRG's for most of the study duration i.e. 1978-1980 are available.

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 the 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. The Theissen weights for each raingauge stations were calculated. Table 4.2 shows the theissen weights for the gauges. Fig.6 shows the location of raingauges alongwith the area represented by each gauge.

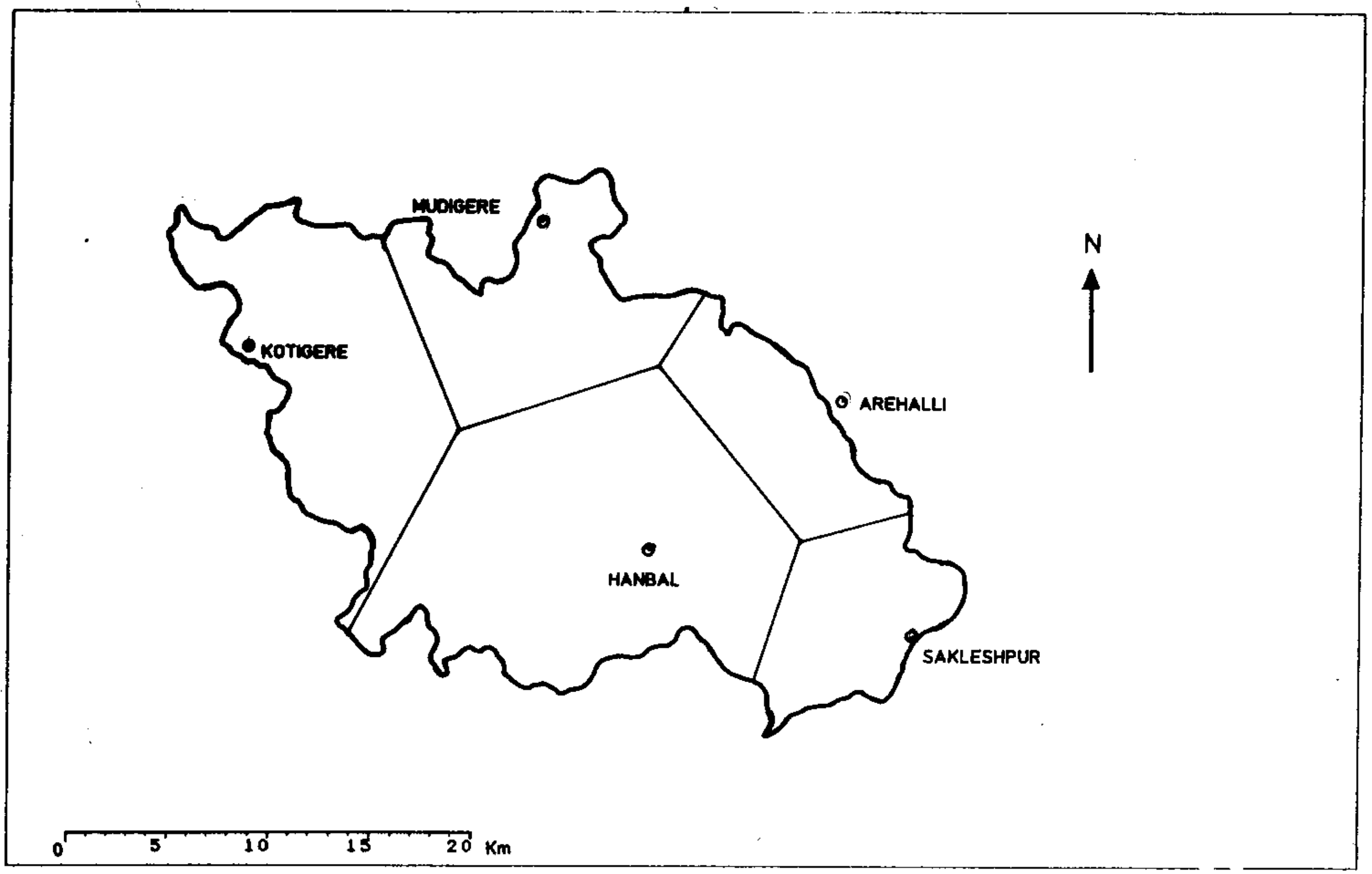


FIG. 6 THEISSEN POLYGONS OF RAINGAUGE STATIONS

TABLE 4.2 : THEISSEN WEIGHTS OF THE RAINGAUGES

Sl.No.	Station name	Weight
1.	Arehalli	0.33
2.	Hanbal	0.16
3.	Kotigere	0.17
4.	Mudigere	0.25
5.	Sakleshpur	0.09

4.4 Preparation of time-area diagram

For preparing time-area diagram of the area, the catchment was drawn from Survey of India toposheets no. 480/8, 480/12, 480/16, 48P/9 and 48P/30 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 equal time of travel were drawn.

Table 4.3 gives the per cent of the travel time and cumulative area contributing to the outlet. These data are used for routing the flow to the outlet by clark method to produce the hydrograph. Fig.7 shows the time area relationship of the basin.

4.5 Preparation of the Data Files

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 3 hourly 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. Theissen weights were supplied to the model to calculate basin average precipitation.

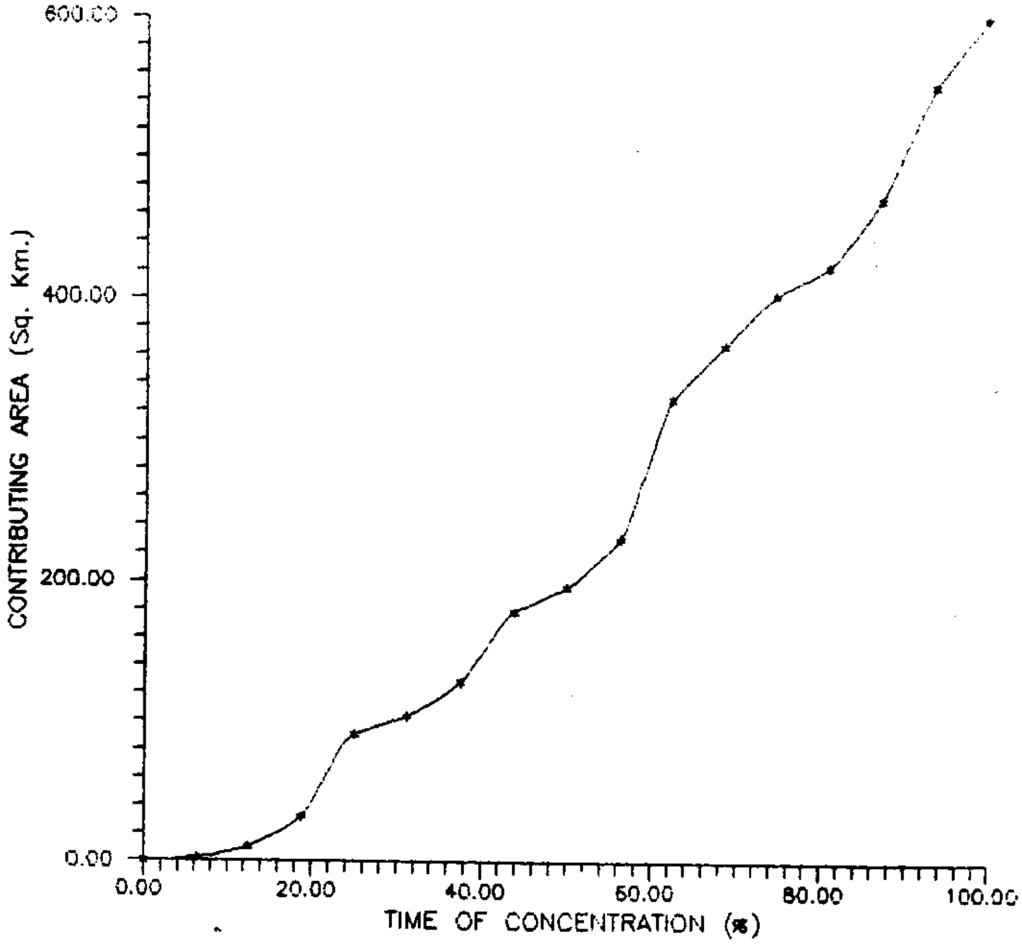


Fig. 7 TIME-AREA DIAGRAM OF HEMAVATI BASIN

TABLE 4.3 : TIME AREA DATA OF THE BASIN

Sl.No.	Time in % of TC	Contributing Area (sq.km.)
1.	0.00	0.000
2.	6.25	2.325
3.	12.50	10.450
4.	18.75	31.575
5.	25.00	90.575
6.	31.25	103.700
7.	37.50	127.775
8.	43.75	178.345
9.	50.00	196.220
10.	56.25	230.845
11.	62.50	328.095
12.	68.75	366.220
13.	75.00	401.920
14.	81.25	422.470
15.	87.50	470.270
16.	93.75	551.270
17.	100.00	600.000

The time area ordinates of the catchment were supplied at appropriate order.

The base flow parameters were studied by plotting selected events on semilog 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 in the data files.

5.0 CALIBRATION AND VALIDATION OF THE MODEL

5.1 GENERAL

Model calibration involves manipulating a specific model to reproduce the response of the catchment under study within some range of accuracy. The fitting or 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.

$$WT_i = (QOBS_i + QAVE)/(2 \times QAVE)$$

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.

5.2 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 used for the calibration of the model are listed in table 5.1.

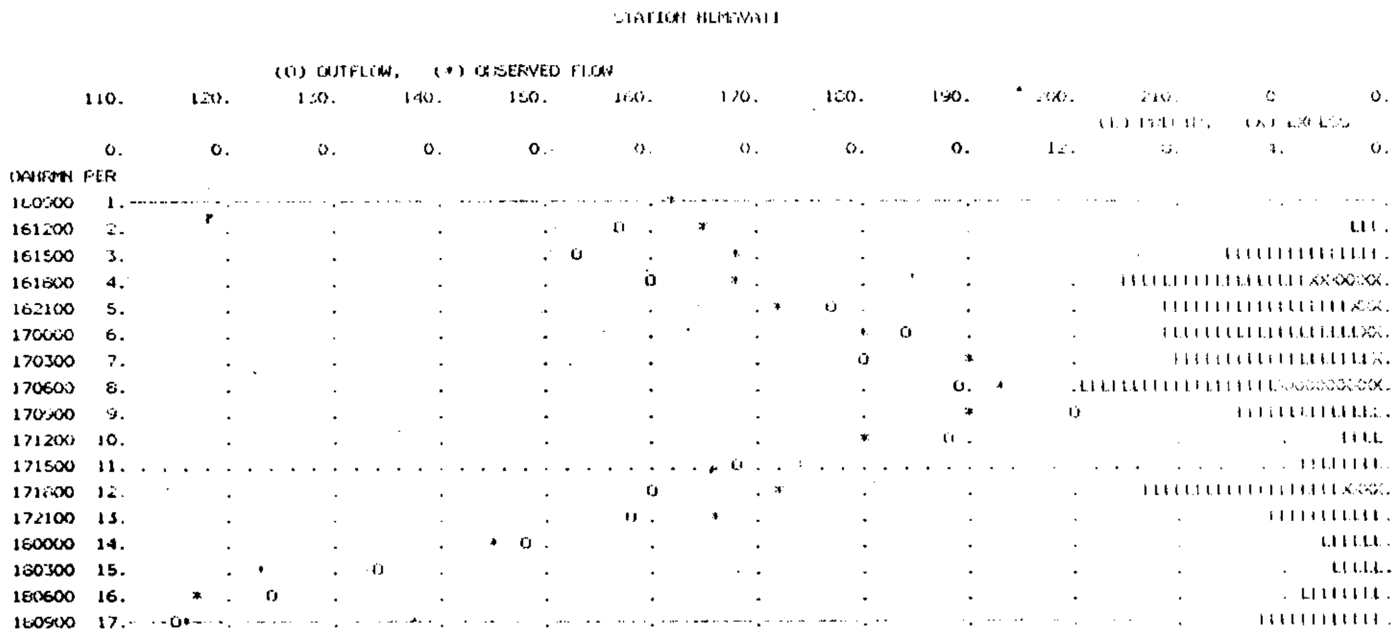
TABLE 5.1 : LIST OF THE EVENTS USED FOR MODEL CALIBRATION

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

For the present study, the clark 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 mountainous areas the loss becomes uniform after prolonged rainfall.

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 5.2 gives the results of the calibration runs of the model. The observed and computed hydrographs for the calibration runs of the model are given in figures 8a to 8d.

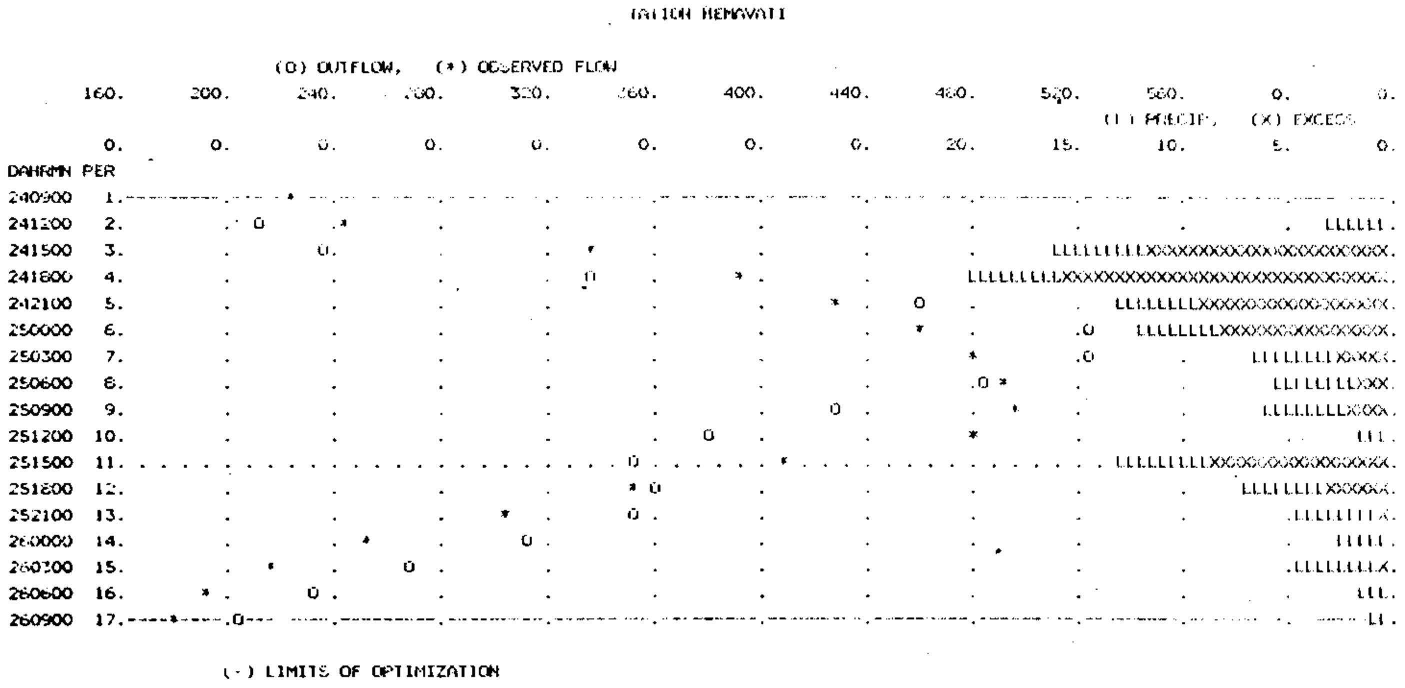


(-) LIMITS OF OPTIMIZATION

** STATION HEMAVATI **　　DRAINAGE AREA = 600.00

..DATE...	......PERCENT ERROR......				....................O P T I M I Z A T I O N					R E S U L T S			
DA MON YR	AVG	VOL	LAG	PEAK	TC	R	TC+R	R/(TC+R)	TP	CP	QP	STRTL	CNSTL
16 JUN 78	4.4	-.9	5.8	3.8	4.23	9.86	14.09	.70	5.47	.33	45.	.50	2.49

FIG. 8 a OPTIMIZATION RUN FOR EVENT JUNE 16-18, 1978

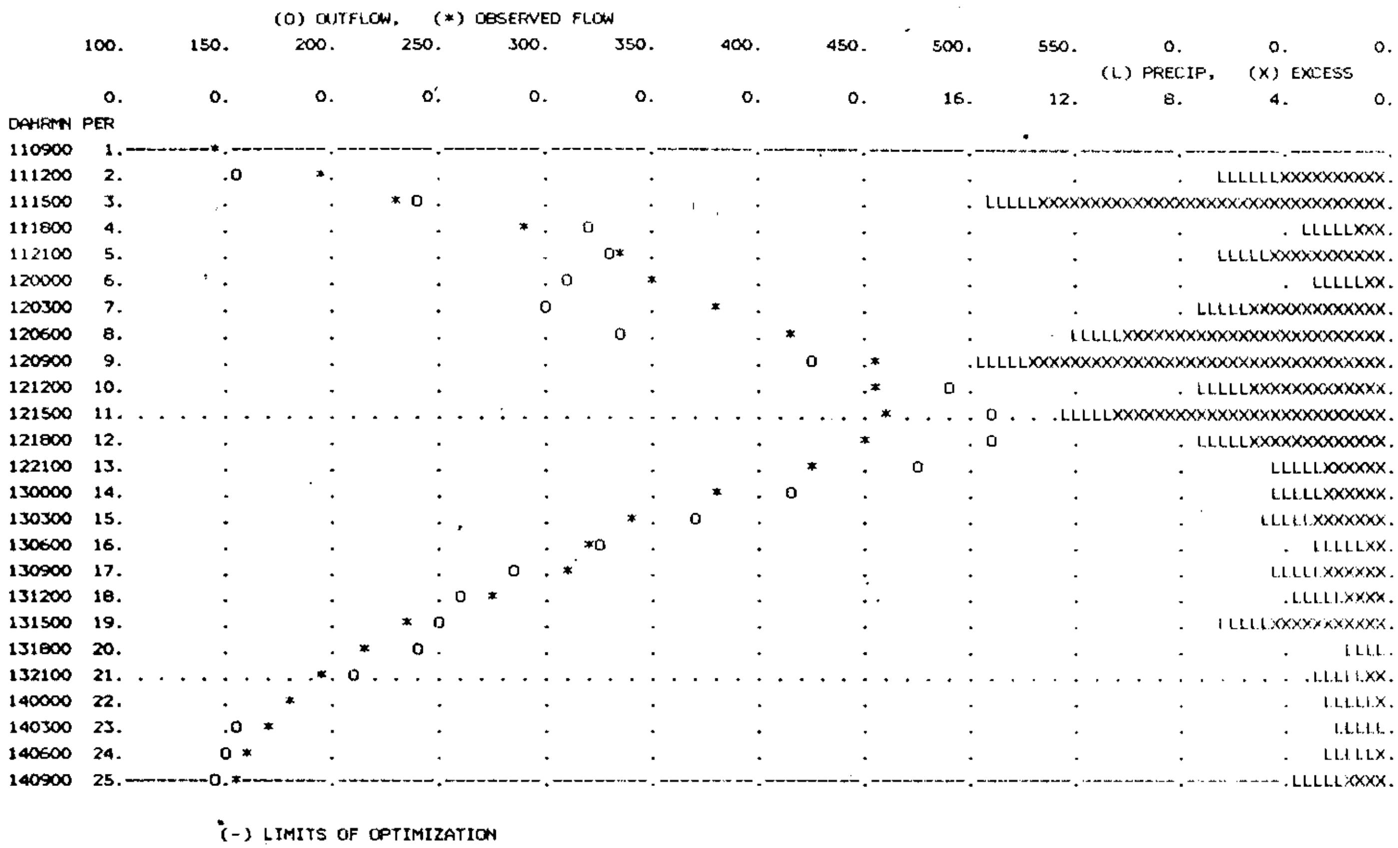


** STATION HEMAVATI ** DRAINAGE AREA = 600.00

..DATE...	.......PERCENT ERROR......				......................O P T I M I Z A T I O N						R E S U L T S		....
DA MON YR	AVG	VOL	TMG	PEAK	TC	R	TC+R	R/(TC+R)	TP	CP	QP	STRTL	CNSTL
24 JUN 78	14.0	-.9	12.4	5.8	5.10	11.89	16.99	.70	6.58	.42	41.	.50	1.33

FIG. 8 b OPTIMIZATION RUN FOR EVENT JUNE 24-26 , 1978

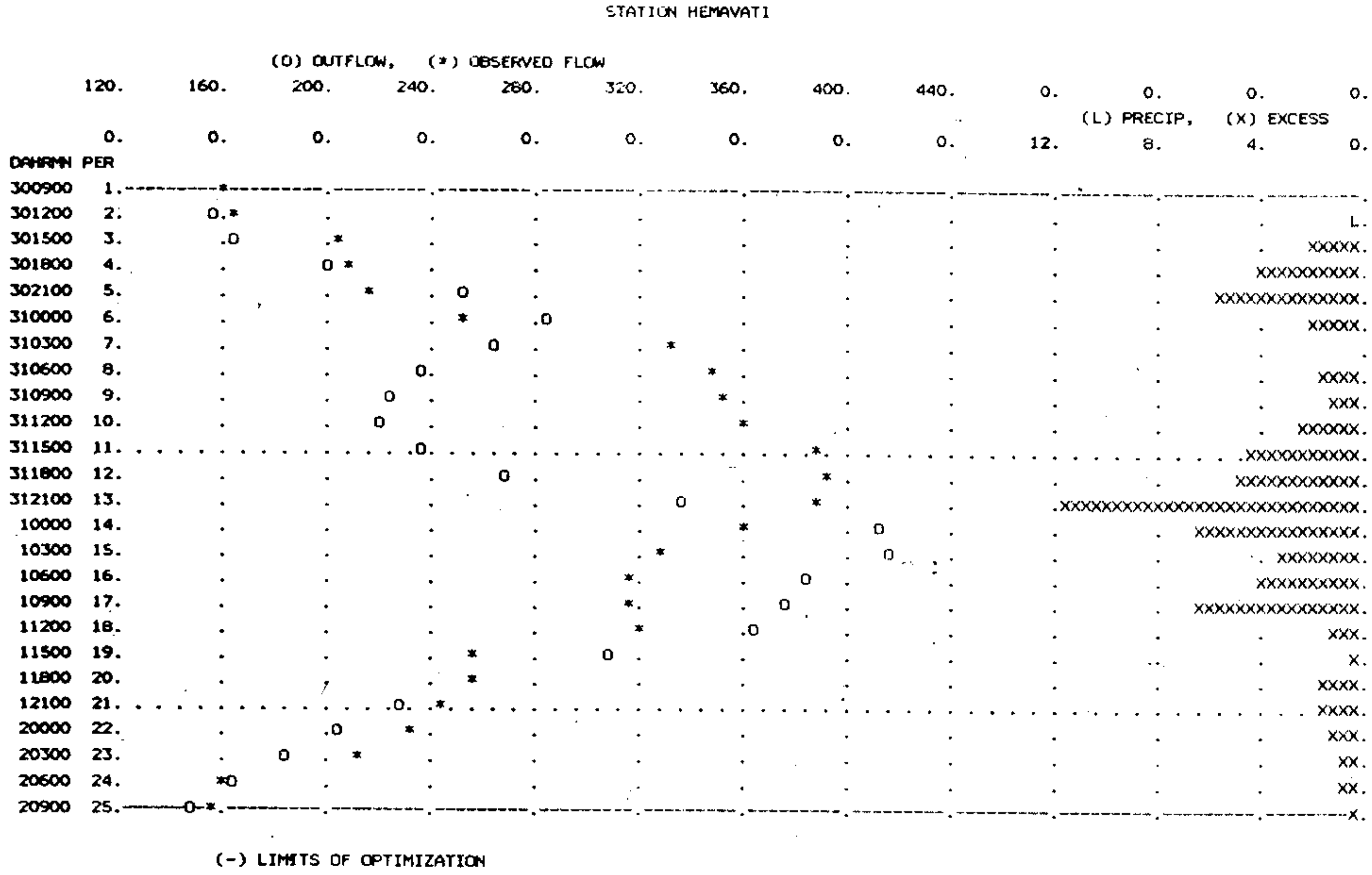
STATION HEMAVATI



** STATION HEMAVATI ** DRAINAGE AREA = 600.00

..DATE...			.......PERCENT ERROR......				...................., O P T I M I Z A T I O N					R E S U L T S		....
DA	MON	YR	AVG	VOL	LAG	PEAK	TC	R	TC+R	R/(TC+R)	TP	CP	QP	STRTL	CNSTL
11	JUL	78	8.7	.0	6.1	11.5	4.17	9.72	13.89	.70	5.44	.39	46.	.50	.66

FIG. 8 c OPTIMIZATION RUN FOR EVENT JULY 11-14 , 1978



** STATION HEMAVATI **   DRAINAGE AREA = 600.00

..DATE...	.......PERCENT ERROR......				.... O P T I M I Z A T I O N						R E S U L T S	....	
DA MON YR	AVG	VOL	LAG	PEAK	TC	R	TC+R	R/(TC+R)	TP	CP	QP	STRTL	CNSTL
30 JUL 78	17.2	-6.8	102.8	6.1	3.61	8.42	12.04	.70	5.13	.43	53.	.50	.00

FIG. 8 d OPTIMIZATION RUN FOR EVENT JULY 30,-AUG. 2 , 1978

TABLE 5.2 : CALIBRATION OF THE MODEL

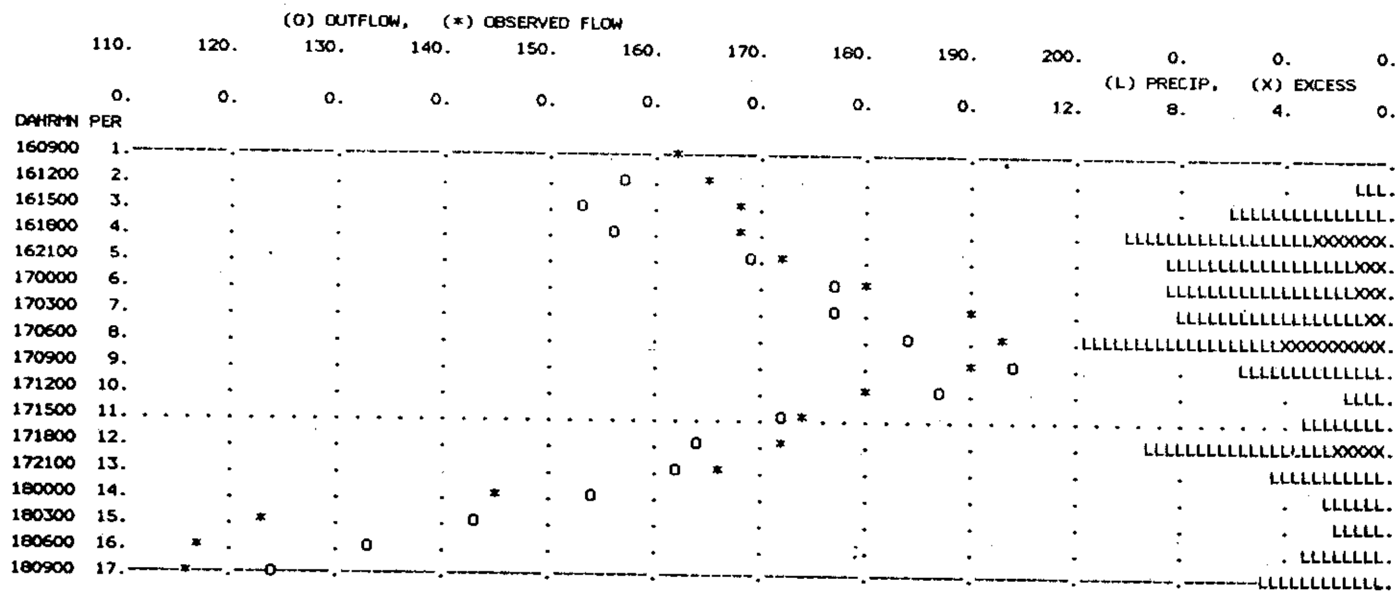
Sl. No.	Flood Event	TC (HR)	R (HR)	CNSTL (mm/Hr)	Equivalent depth of volume (mm) Obs.	Comp.	Peak flow (cumec) Obs.	Comp.	Time to peak (Hr.) Obs.	Comp.
1.	June 16-18,1978	4.23	9.86	2.49	50.063	49.625	193	200	21	24
2.	June 24-26,1978	5.10	11.89	1.36	106.891	105.945	497	524	24	18
3.	July 11-14,1978	4.17	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 5.2. 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 time of concentration TC 4.75 hours and storage coefficient R 14.5 hours, the peak and volume of observed data and computed values are matching closely. Table 5.3 gives the results of final calibration runs for the selected events. Fig.9a to 9d shows the observed and computed hydrographs for final calibration run of the model parameters.

STATION HEMAVATI



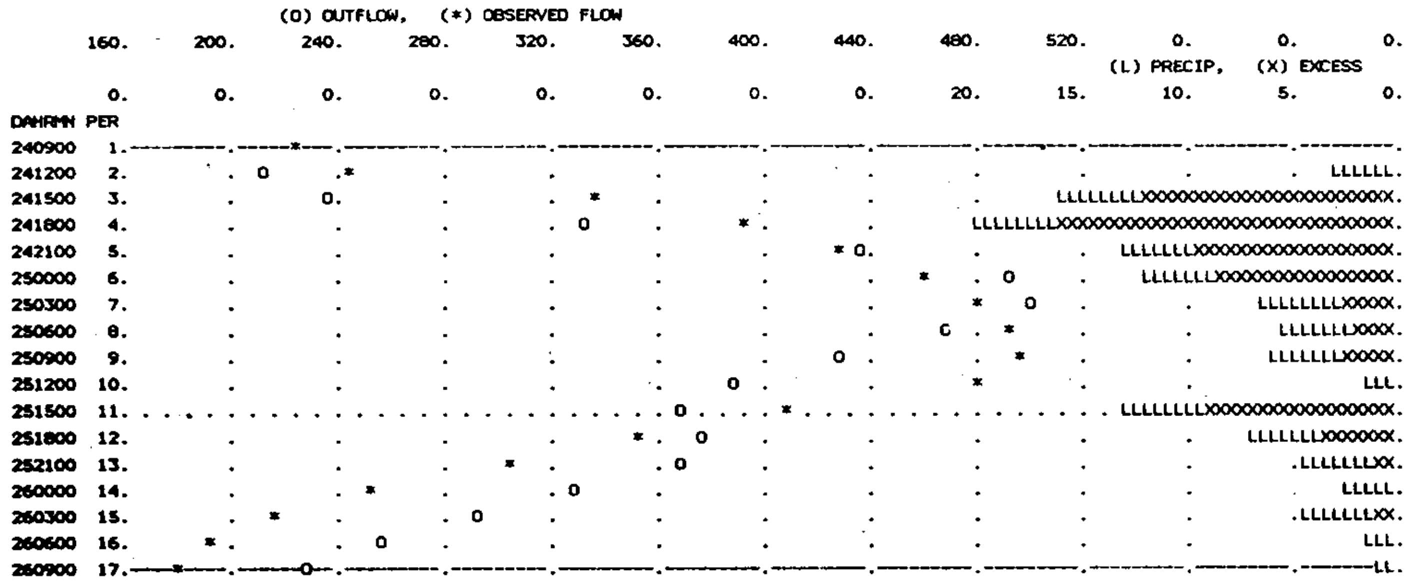
(-) LIMITS OF OPTIMIZATION

** 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
16 JUN 78	5.5	-.4	14.5	.3	4.75	14.50	19.25	.75	6.40	.35	35.	.50	2.42

FIG. 9 a FINAL CALIBRATION RUN FOR EVENT JUNE 16-18 , 1978

STATION HEMAVATI



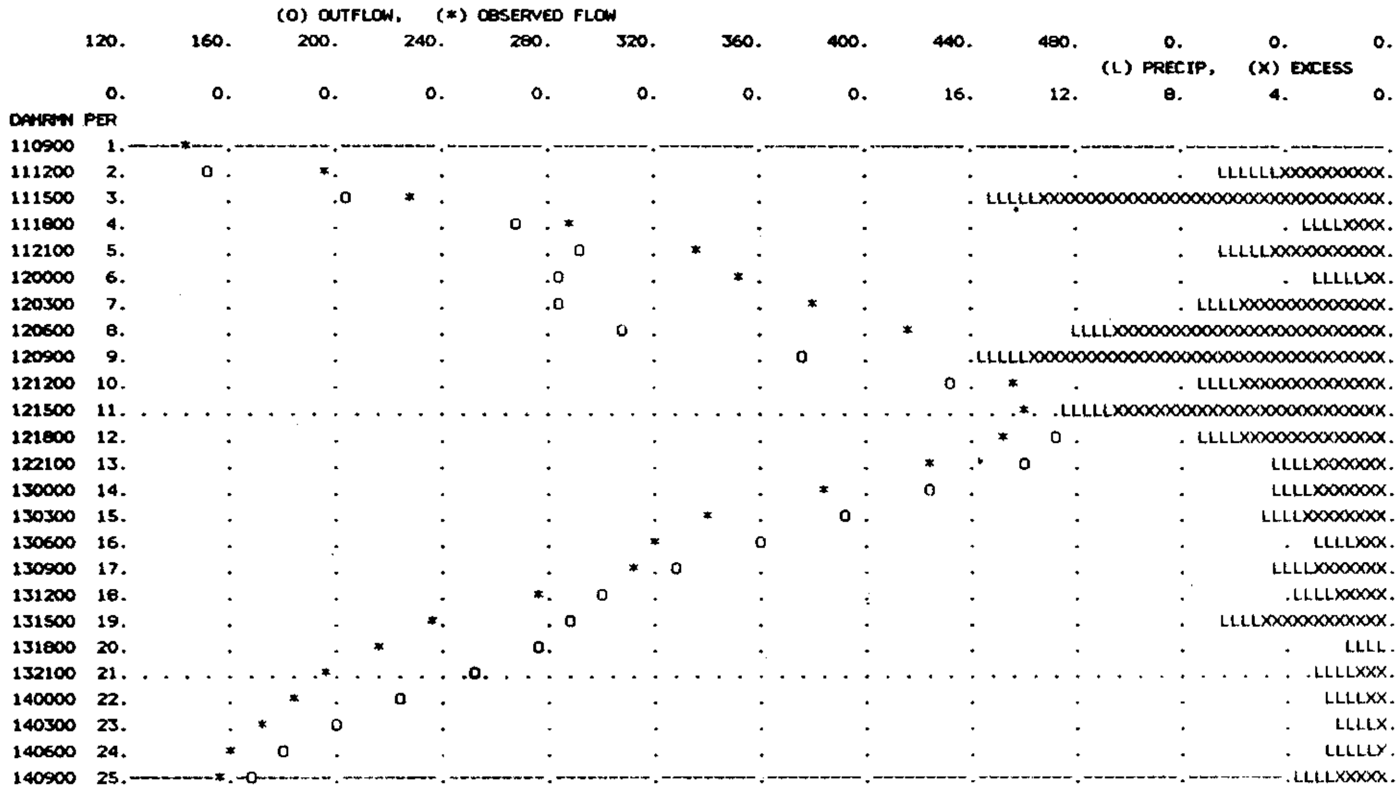
(-) LIMITS OF OPTIMIZATION

** STATION HEMAVATI ** DRAINAGE AREA = 600.00

..DATE...			.......PERCENT ERROR......				....................O P T I M I Z A T I O N						R E S U L T S		
DA	MON	YR	AVG	VOL	LAG	PEAK	TC	R	TC+R	R/(TC+R)	TP	CP	QP	STRTL	CNSTL	
24	JUN	78	16.0	.0	20.9	.5	4.75	14.50	19.25	.75	6.40	.35	35.	.50	1.23	

FIG. 9 b FINAL CALIBRATION RUN FOR EVENT JUNE 24-26 , 1978

STATION HEMAVATI



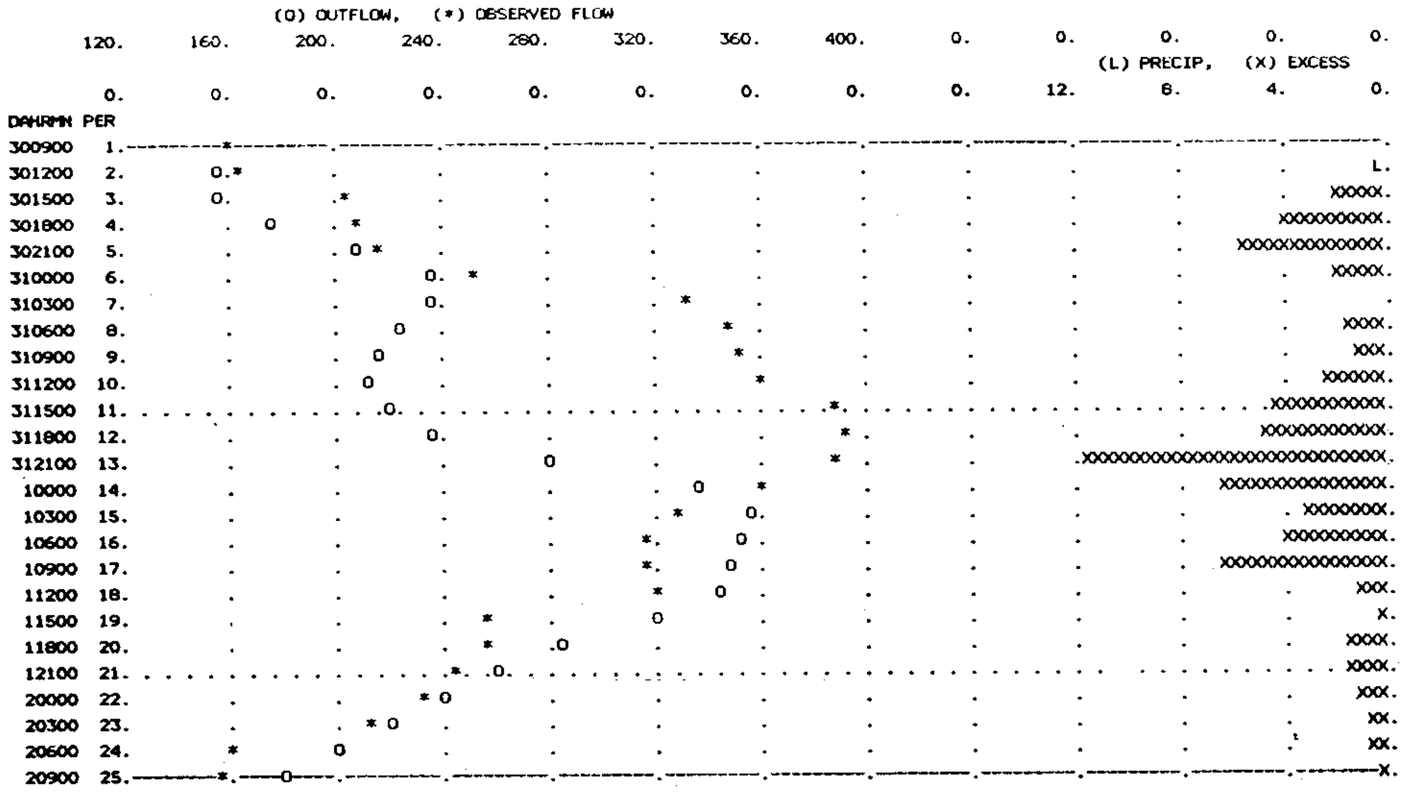
(-) LIMITS OF OPTIMIZATION

** STATION HEMAVATI ** DRAINAGE AREA = 600.00

..DATE...	.......PERCENT ERROR......				....................O P T I M I Z A T I O N						R E S U L T S		
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. 9 c FINAL CALIBRATION RUN FOR EVENT JULY 11-14, 1978

STATION HEMAVATI



(-) LIMITS OF OPTIMIZATION

** STATION HEMAVATI ** DRAINAGE AREA = 600.00

..DATE...			.......PERCENT ERROR......				.... O P T I M I Z A T I O N						R E S U L T S		
DA	MON	YR	AVG	VOL	LAG	PEAK	TC	R	TC+R	R/(TC+R)	TP	CP	QP	STRTL	CNSTL
30	JUL	78	18.0	-11.0	210.6	-8.9	4.75	14.50	19.25	.75	6.40	.35	35.	.50	.00

FIG. 9 d FINAL CALIBRATION RUN FOR EVENT JULY 30-AUG. 2 , 1978

TABLE 5.3 : 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	33
4.	July 30-Aug.2, 1978	4.75	14.50	0.00	124.445	110.710	393	358	33	42

From the table 5.3 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 upto 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 5.4.

TABLE 5.4 : 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 79 to 1980 were used. Table 5.5 shows the list of events used for the validation. For different events, data files were prepared by supplying value of model parameters TC and R as 4.75 and 14.50 hours. The loss rates were supplied event wise as described earlier.

TABLE 5.5 : EVENTS USED FOR VALIDATION OF THE MODEL

Sl.No.	Flood date	Equivalent depth of Observed volume (mm)	Observed peak flow (cumec)
1.	July 30- August 2, 1979	140.920	456
2.	June 20 - 24, 1980	202.478	477
3.	June 30- July 5, 1980	669.733	1390
4.	July 7 - 10, 1980	356.278	1132

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 5.6 shows the validation results.

TABLE 5.6 : VALIDATION RESULTS

Sl. No.	Flood Event	Equivalent depth of volume (mm)		Peak flow (cumec)		Time to peak (Hr.)	
		Obs.	Comp.	Obs.	Comp.	Obs.	Comp.
1.	July 30- Aug.2,1979	140.920	164.285	456	592	33	51
2.	June 20 - 24, 1980	202.478	166.984	477	479	48	48
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 5.6 that observed and simulated hydrographs are matching. Fig.10a to 10d shows the simulated hydrograpns and Fig.11a to 11d shows the comparison of observed and simulated hydrographs of flood events used for model validation.

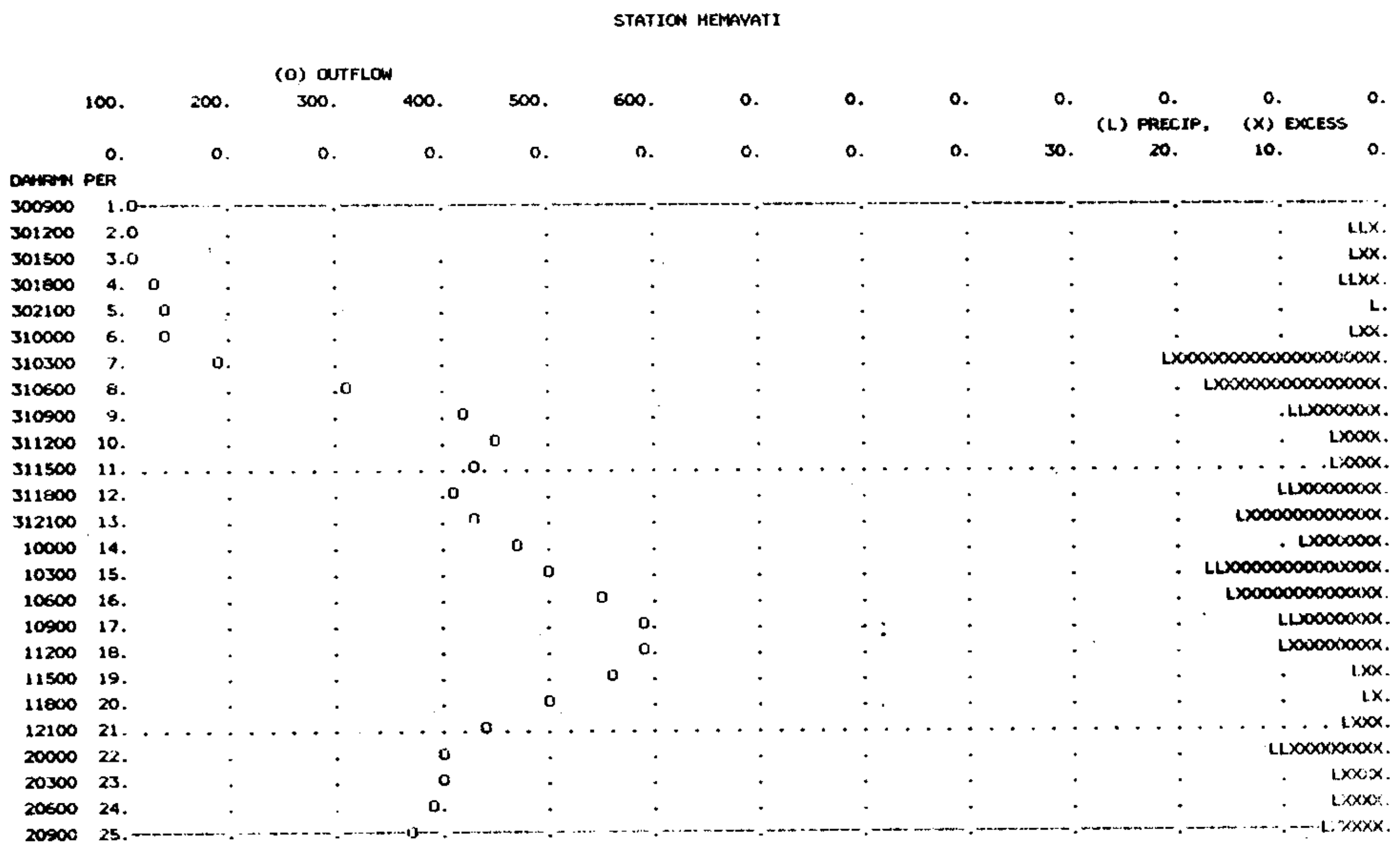


FIG. 10 a SIMULATED HYDROGRAPH FOR EVENT JULY 30 - AUG. 2 , 1979

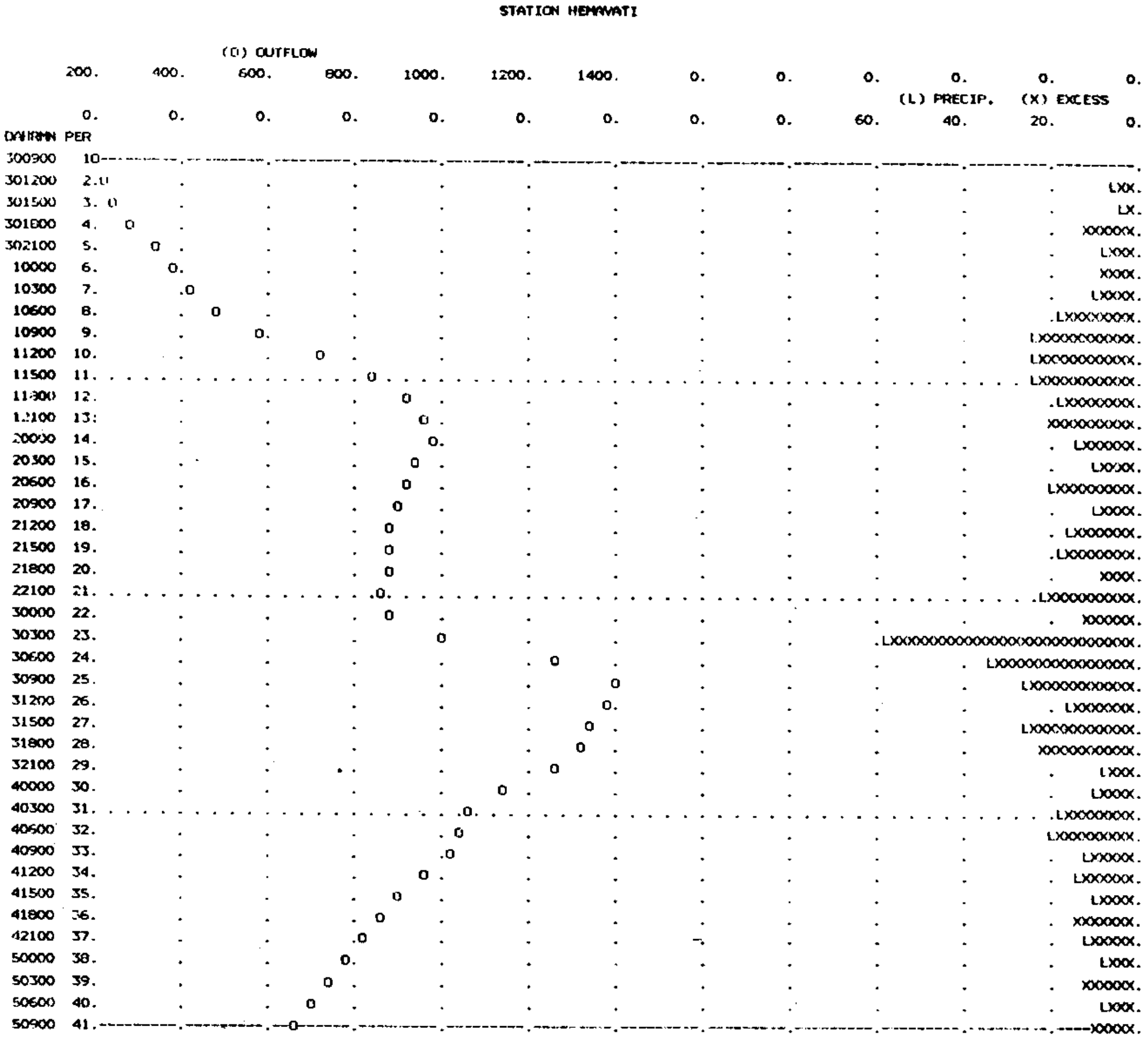


FIG. 10 b SIMULATED HYDROGRAPH FOR EVENT JUNE 20-24, 1980

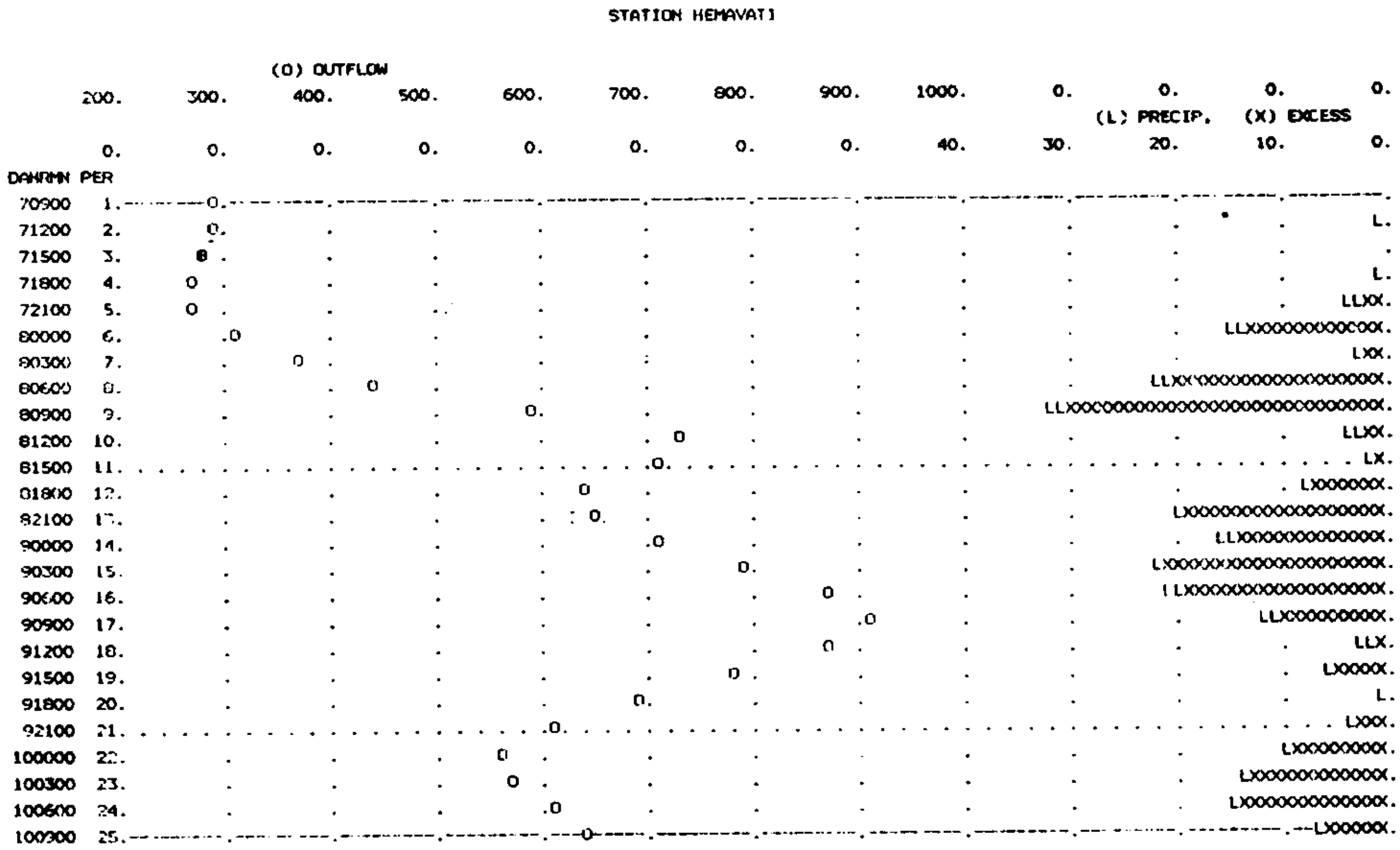


FIG. 10 d SIMULATED HYDROGRAPH FOR EVENT JULY 7-10, 1980

CUMULATIVE AREA = 600.00 SQ KM

STATION HEMAVATI

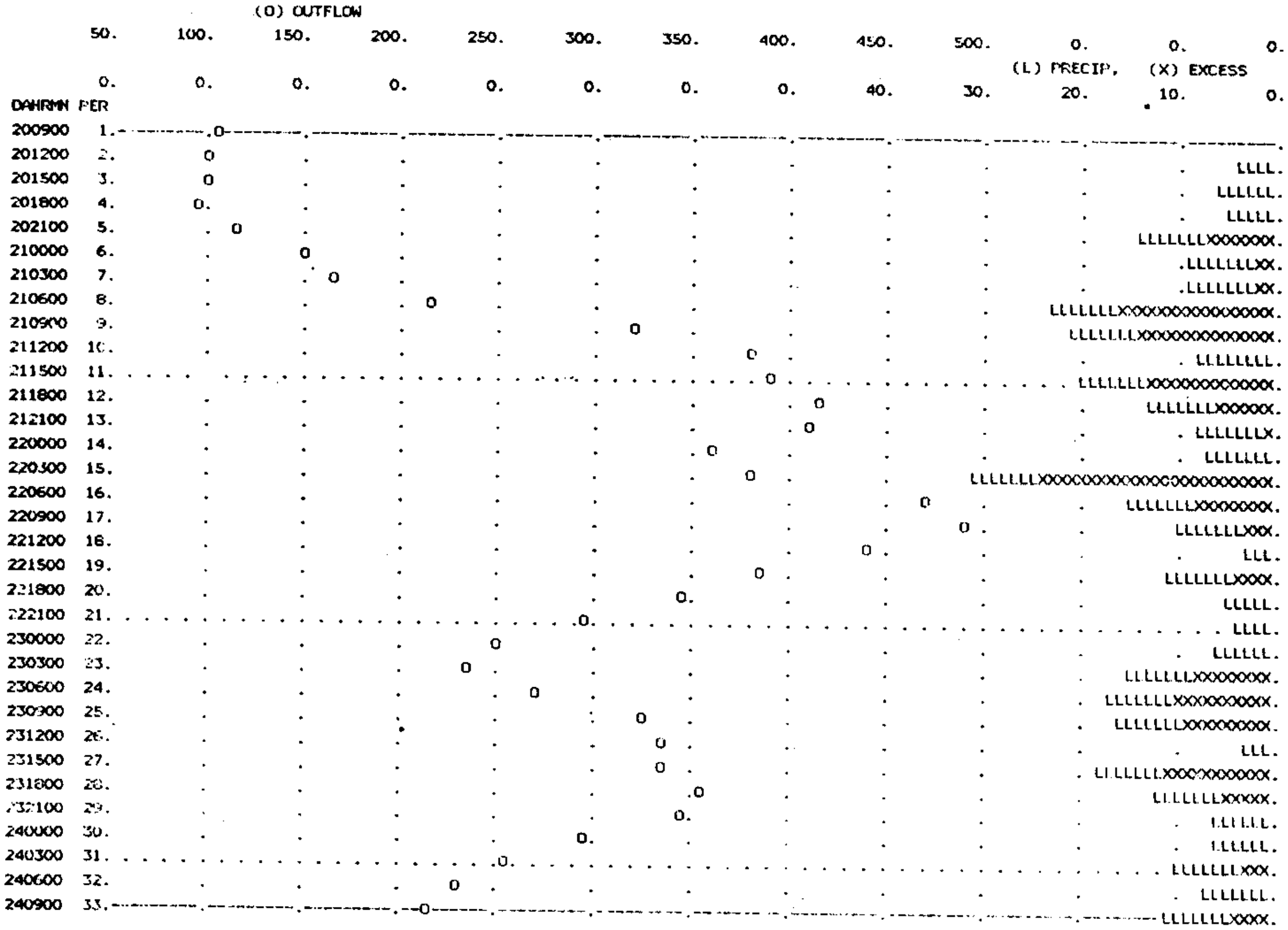


FIG. 10 c SIMULATED HYDROGRAPH FOR EVENT JUNE 30- JULY 5, 1980

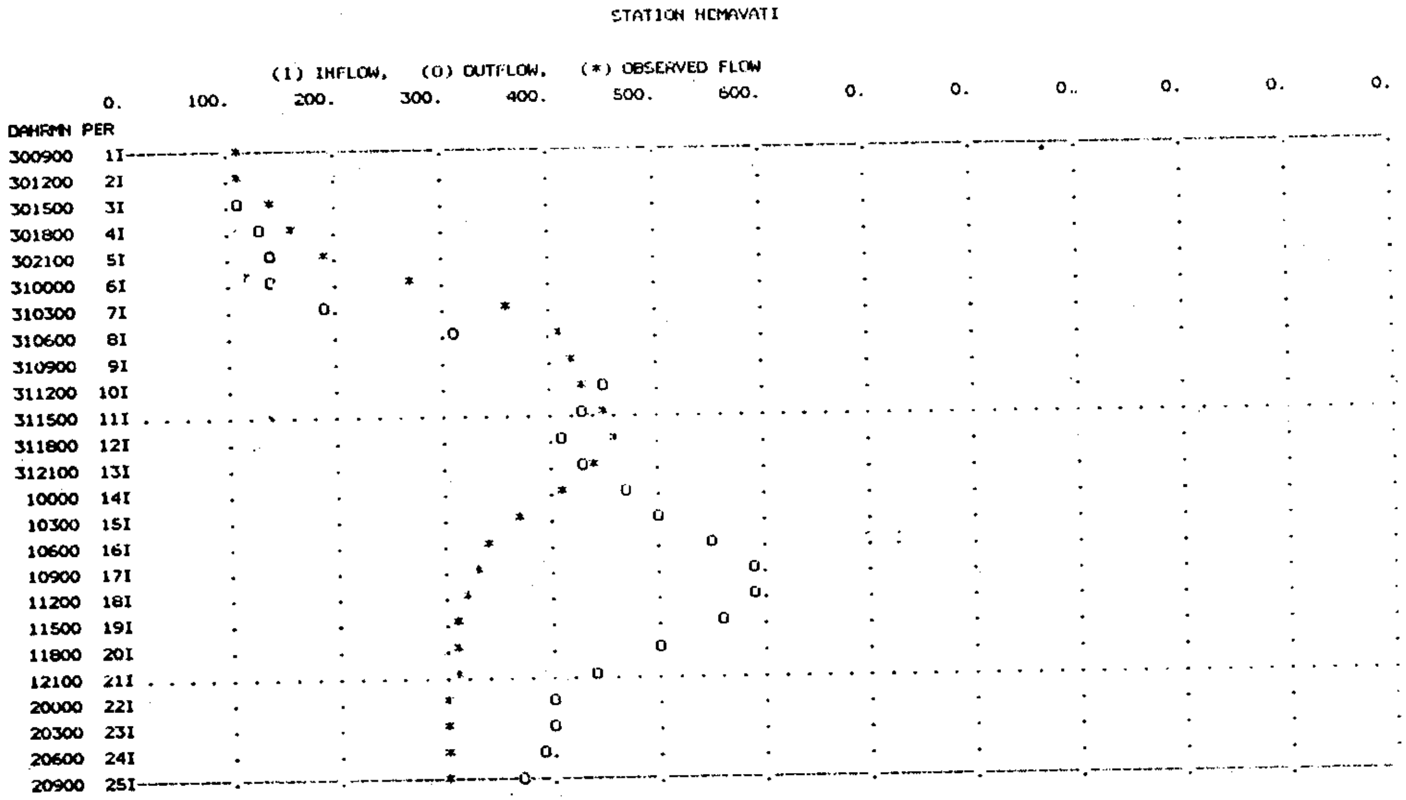


FIG. 11 a COMPARISON OF OBSERVED AND SIMULATED HYDROGRAPH FOR EVENT JULY 30 - AUG. 2, 1979

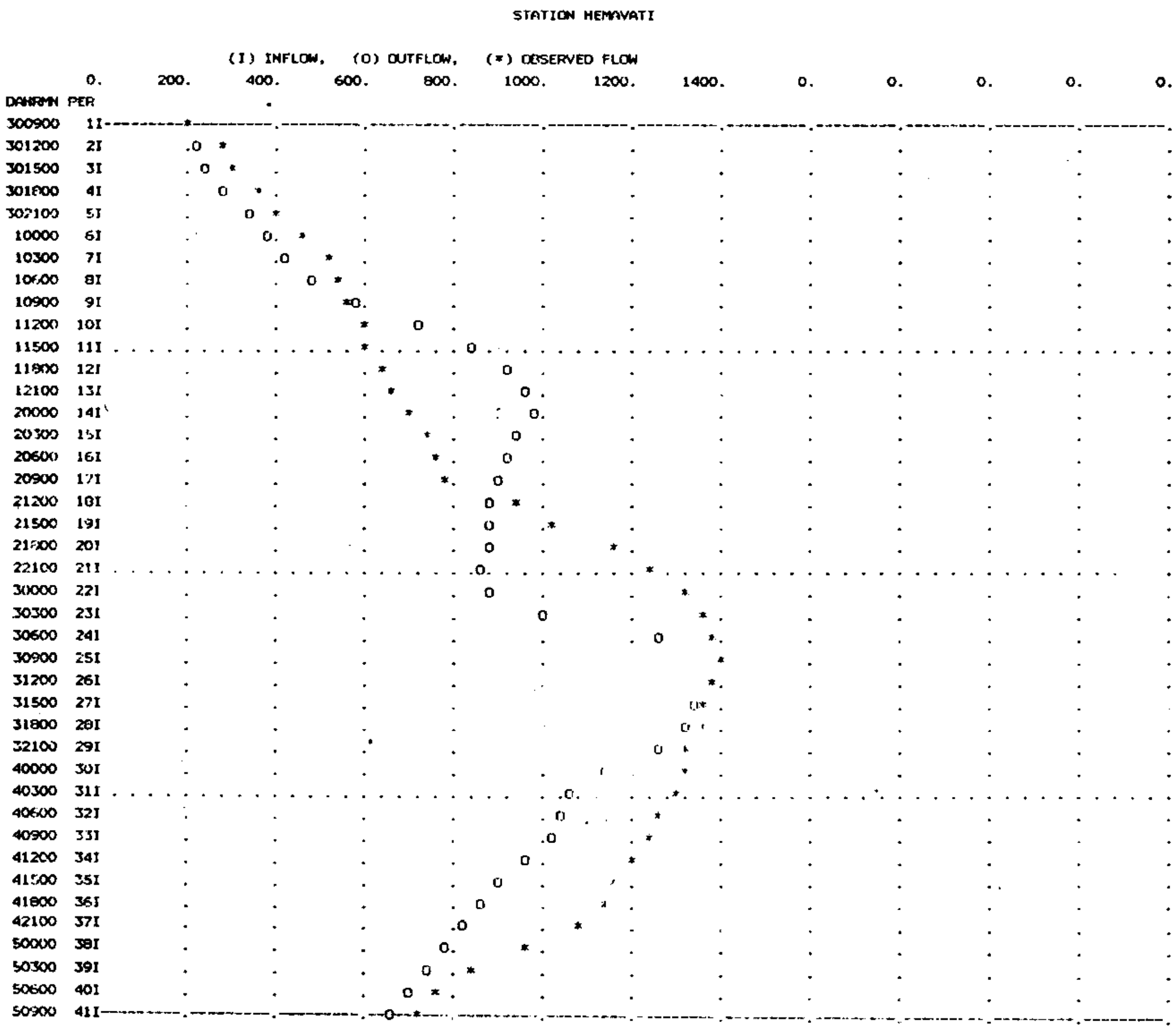


FIG. 11 b COMPARISON OF OBSERVED AND SIMULATED HYDROGRAPH FOR EVENT JUNE 20-24 , 1980

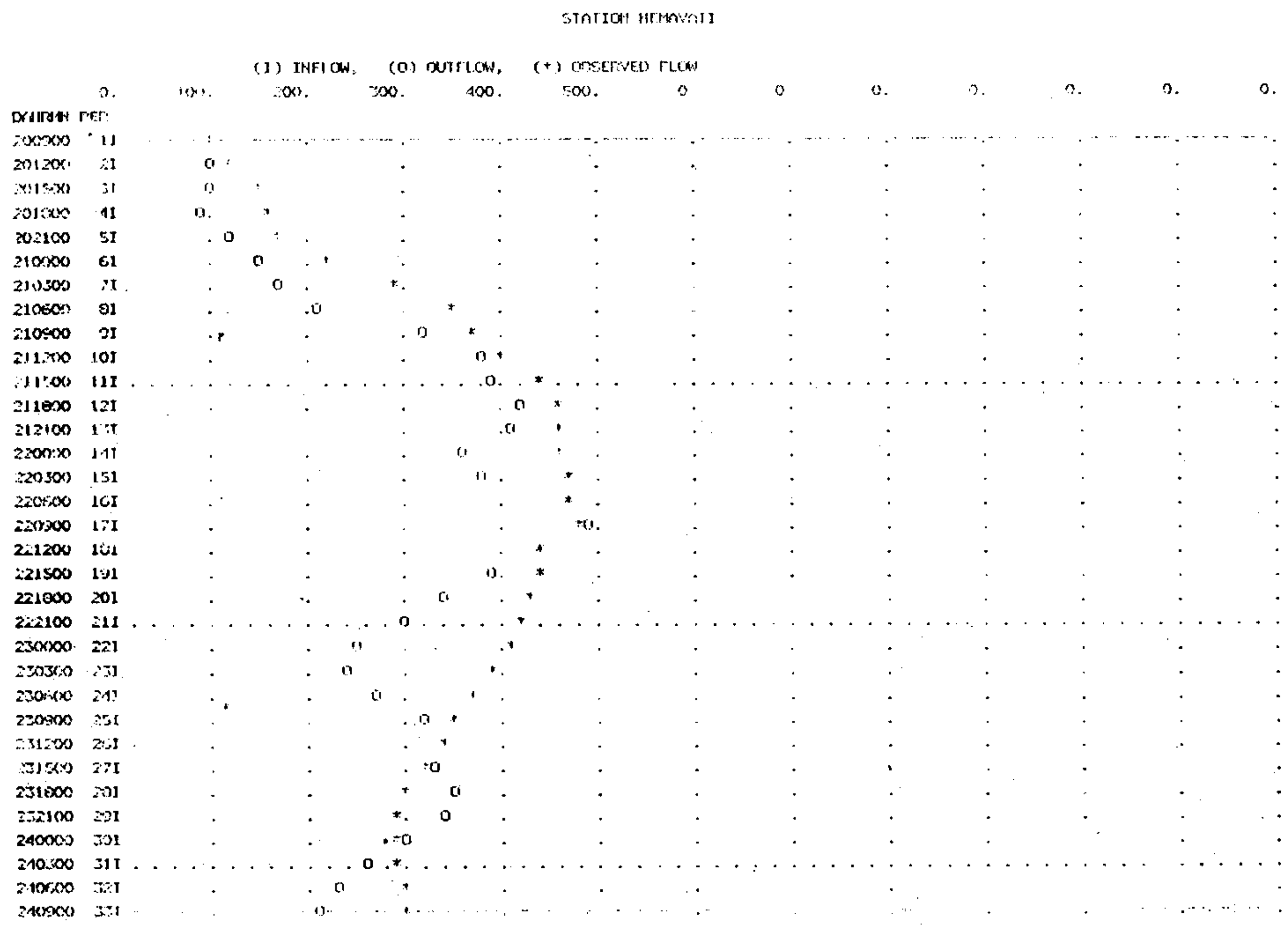


FIG. 11c COMPARISON OF OBSERVED AND SIMULATED HYDROGRAPH FOR EVENT JUNE 30-JULY 5, 1980

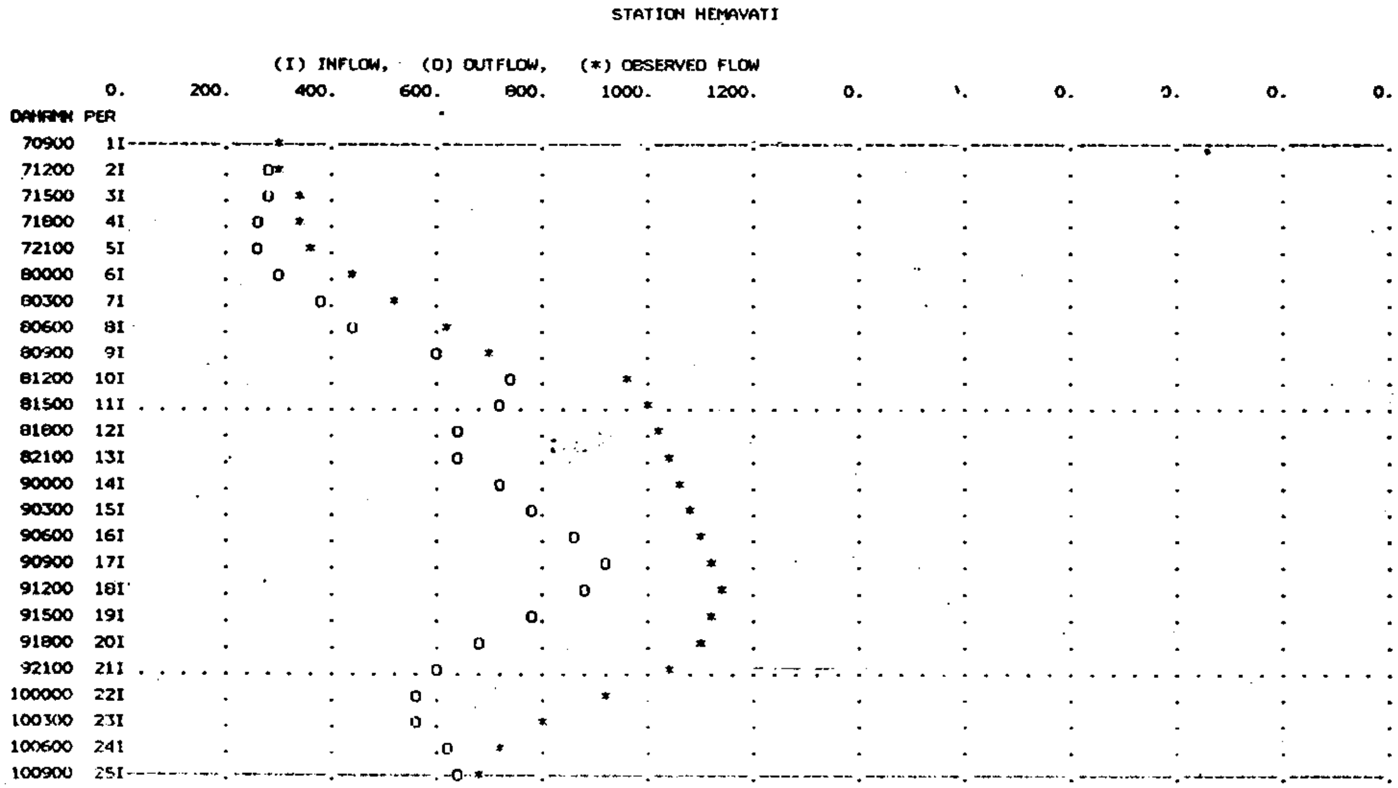


FIG. 11 d COMPARISON OF OBSERVED AND SIMULATED HYDROGRAPH FOR EVENT JULY 7-10, 1980

6.0 CONCLUSIONS

The present study deals with the application of HEC-1 model to a sub-basin of Hemavati river. The river Hemavati (upto 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 modelling rainfall runoff response of Hemavati (upto 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 raingauge 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.
3. In an earlier study a physically-based distributed model was applied for the same basin and it was reported that there remain considerable uncertainties in the input data and model parameters and improvement of calibration will require a more extensive spatial and temporal change of input parameters. The results obtained by this study are comparable to that study.

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