CASE STUDY CS(AR) - 188

HEC-1 APPLICATION TO HAMIDNAGAR SITE

आपो हिष्टा मयोभुवः

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PREFACE

A catchment model describes relevant phases of the hydrclogic cycie with the objective of simulating the conversion of rainfall into runoff. Much efforts have been devoted to the development of methods to relate streamflow and rainfall for use in hydrologic analysis. The HEC-1 is a well known hydrologic model whose component characteristics, features and algorithms are familiar. It has been designed to simulate the response of flood events of a watershed to precipitation events. The model simulates the rainfall-runoff process as it occurs in a river basin.

The river Punpun is one of the important right bank tributary of the river Ganga. It joins the river Ganga near Fatwa about 25 Kms. downstream of Patna, covering a total distance of 232 Kms. In the present study, Punpun basin area upto Hamidnagar(3314 sq.km.) has been considered for rainfall-runoff simulation using HEC-1 model. The HEC-1 model provides a powerful optimization technique for estimation of some of the parameters when gauged precipitation and discharge data are available. The optimization technique of the model has been utilized in the present study and model parameters have been calibrated and validated for the study area. The Clark method for unit hydrograph development, Initial and constant loss rate method for losses, and an empirical method for base flow separation were used in the analysis. The relevant input data have been collected from various sources and computer programs were developed for simple calculations.

The study has been carried out by Sri Ramakar Jha, Scientist'B', Sri M.Arora, S.R.A. under the guidance of Dr.K.K.S.Bhatia, Scientist 'F' and Head, Ganga Plains Regional Centre, Patna. Thanks are due to Sri R.D.Singh Scientist 'E', National Institute of Hydrology, Roorkee for his valuable suggestions. The co-operation of Hydrology Cell, Water Resources Department, Govt. of Bihar for this study is highly appreciated. The assistance by Sri Sivadas, A.K. and Santosh, M.B. are acknowledged.

(S.M.SETH)

DIRECTOR

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ABSTRACT

Surface runoff occurs when rainfall intensity exceeds the abstractive capacity of the catchment. Eventually, large amount of surface runoff concentrate to produce large flow rates referred to as floods. The HEC-1 model has been designed to simulate the response and flood events of a basin to precipitation events. The model simulates the rainfall-runoff process as it occurs in a river basin. Mathematical relationships are intended to represent individual meteorological, hydrological and hydraulic processes encompassing the rainfall-runoff phenomena.

In the present report, HEC-1 model has been used for rainfall-runoff simulation and estimation of flood events in the Punpun basin upto Hamidnagar. The components of the HEC-1 model simulates the rainfall-runoff process as it occurs in the river basin. Calibration of the model parameters has been performed by the mathematical optimization algorithm included in the HEC-1. The initial and constant loss rate technique for losses, Clark technique for unit hydrograph and a empirical equation baseflow separation were utilized for optimization, calibration and validation of the model parameters. Fairly good results have been obtained by using calibrated model parameters.

1.0 INTRODUCTION

The river basin is represented as an interconnected system of hydrologic and hydraulic components. Certain applications of a river basin may require complex analysis involving temporal and/or spatial variations of precipitation, hydrologic abstractions and runoff. Typically, such analyses involve a large number of calculations and are therefore suited for use with digital computers. The use of computers in all aspect of hydrology has led to increased emphasis on catchment modelling. Catchment modelling comprises the integration of key hydrologic process into a modelling entity. i.e a catchment model for purpose of either analysis, design, long-term runoff volume forecasting, or real-time flood forecasting.

A catchment (watershed or river basin) model is a set of mathematical abstractions describing relevant phases of the hydrologic cycle, with the objective of simulating the conversion of precipitation into runoff. In principle, the techniques of catchment modelling are applicable to catchment of any size, whether small (a few hectares), mid-size (tens of square kilometers) or large (many thousands of square kilometers). In practice, however, catchment modelling application are generally confined to the analysis of catchments for which the description of temporal and/or spatial variations of precipitation is warranted. Usually this is the case for midsize and large catchments.

A typical catchment modelling application consists of the following : (1) Selection of model type, (2) model formulation and construction (3) model testing and (4) model application. Comprehensive catchment models include all relevant phases of hydrologic cycle and, as such, are composed of one or more techniques for each phase. Commonly used methods and techniques for hydrologic modelling are (1)HEC-1, (2)TR-20 (3)SWMM (4)SSARR, (5)SWM & (6)Sacramento model. In practice, the hydrologic engineer would either (1) select an available model, with knowledge of its structure, operation, capabilities, and limitations or (2) develop a model or modify an existing one, based on perceived needs, data availability, and budgetary constraints.

Most of the applications are of first type, in which case it is necessary to become thoroughly familiar with the model's characteristics and features. During the past ten years, much effort has been devoted to the development of methods to relate streamflow with rainfall for use in hydrologic analysis(Feldman,1981; HEC,1981; HEC,1982; Sastri and Seth,1984; NIH,1991; Jain and Sastri,1991). The HEC-1 model, developed by Hydrologic Engineering Center (HEC) of US crops of Engineer, is a well known hydrologic model whose component characteristics, features and algorithms are familiar.

The HEC-1 is a Flood Hydrograph Package specifically designed to be used for the simulation of flood events in watershed and river basins. 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 precipitation (rain-fall, snowfall/melt) to run-off process can be simulated for large complex watersheds. In the present study, HEC-1 model has been used for the simulation of flood events of Punpun catchment upto Hamidnagar.

2.0 THE RIVER SYSTEM

The river Punpun, one of the important right bank tributary of the river Ganga, originates from Chottanagpur hills of Palamau district in Bihar at an elevation of 300 m (Fig.1) It joins the river Ganga near Fatwa about 25 Kms downstream of Patna covering a total distance of 232 Kms. The river has a number of tributaries joining it mostly from its right bank. The entire Punpun catchment lies between longitude 84°10'E to 85°20'E and latitude 24°11'N to 25°25'N . It is located on the right bank of the Ganga and is bounded by the Sone river system on the west and Kiul-Harohar-Falgu river system on the east. On its northern side is the river Ganga and on its southern side, it is bounded by Chottanagpur hills.

A Project is proposed for the construction of diversion barrage on river Punpun at Hamidnagar at longitude 84° 38' E and latitude 25° 4' N in the district of Aurangabad near Goh, which is 112 km below its origin (Fig. 2). The barrage will have irrigation systems to irrigate a GCA of 58,870 hectare during kharif season. To estimate the water availability and runoff due to precipitation in the upper catchment, rainfall-runoff simulation techniques need to be utilized and developed.

In the present study, a rainfall-runoff simulation model, HEC-1 has been used with several options in the Punpun catchment upto Hamidnagar. The topographical area upto Hamidnagar(3314 Sq.km.) is having steep slopes with forest at the upper part and

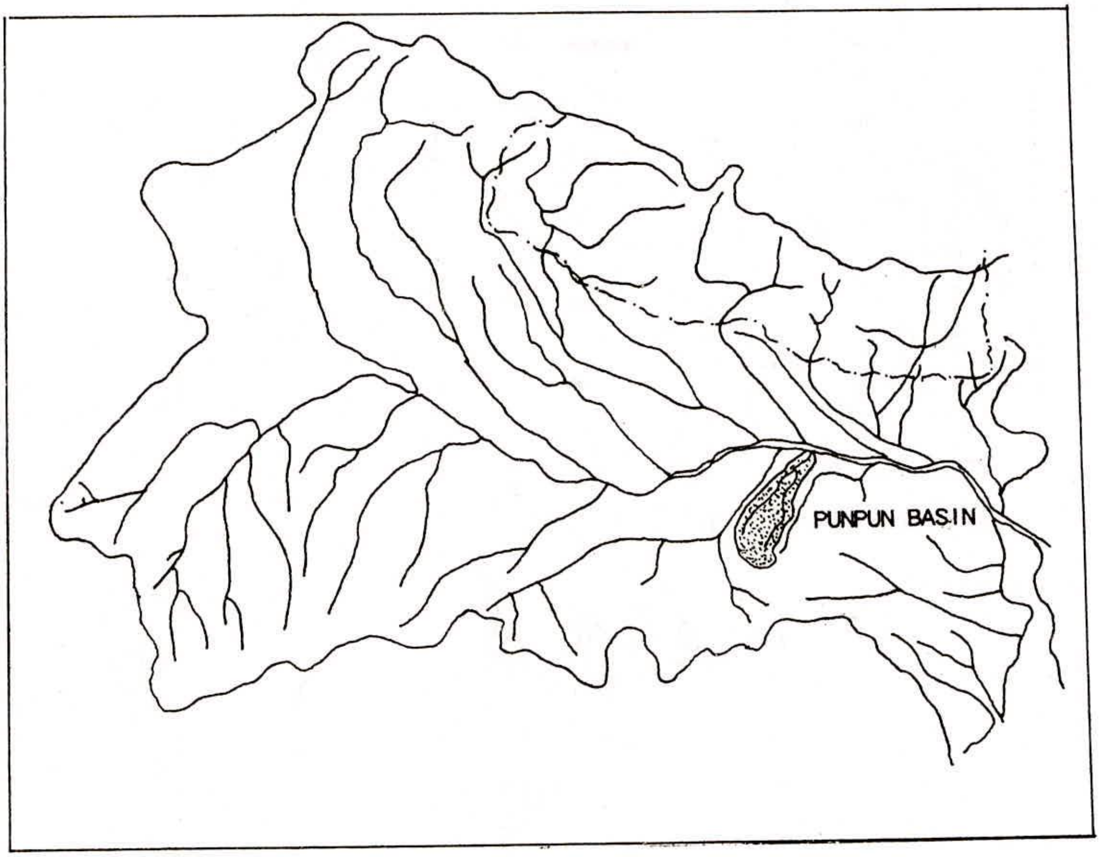

FIG.1: INDEX MAP OF PUNPUN BASIN

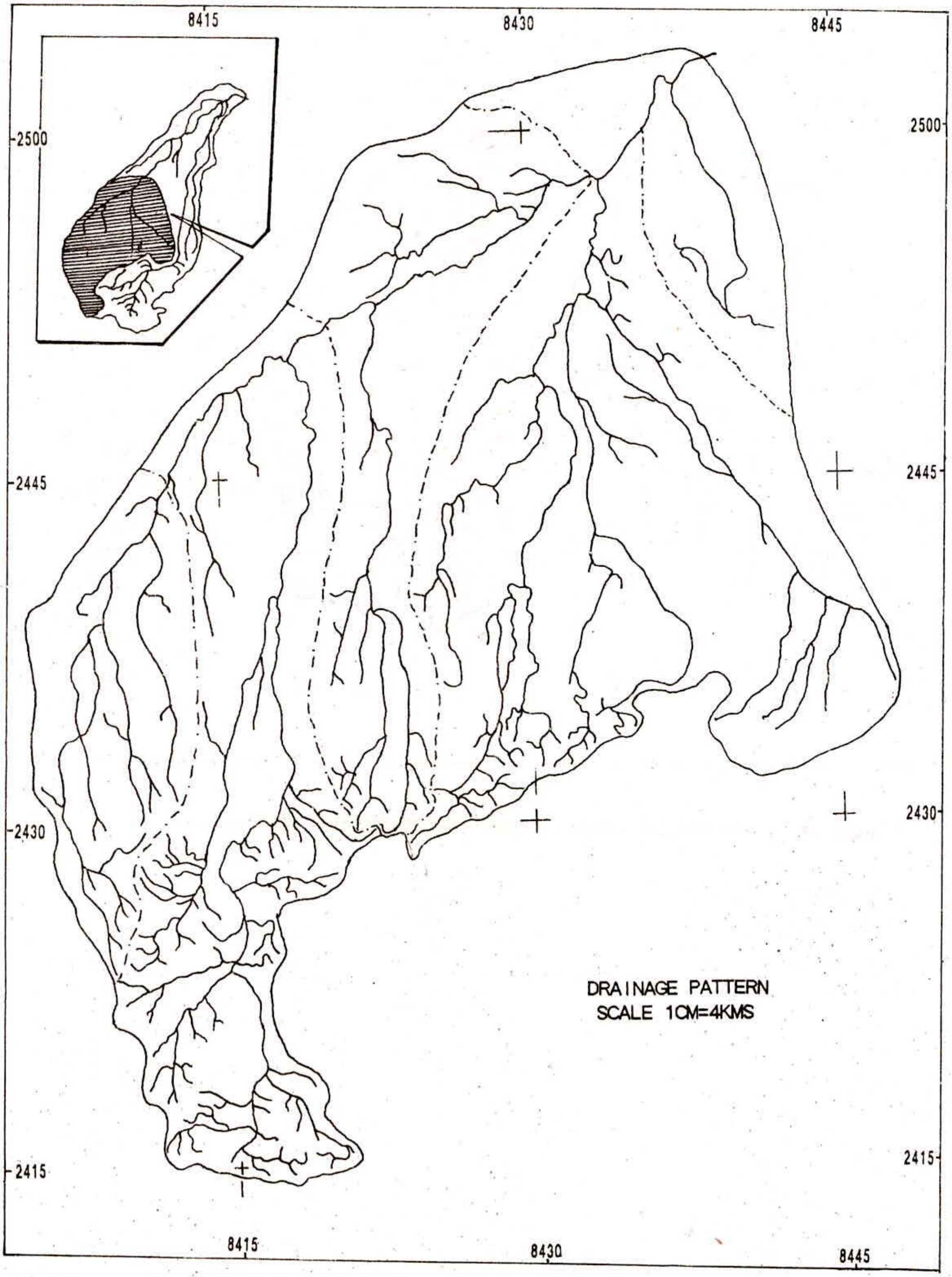

FIG.2: THE STUDY AREA UPTO HAMIDNAGAR

mild slope at the lower part(Fig.3). In the upper part. precipitation occurs more frequently and sometimes with high intensities for longer duration. Interception losses are significant due to forest type of vegetation. Infiltration losses are varying due to change in slope & soil characteristics. In the lower part, precipitation is uniform and not varying frequently. Runoff from the catchment emerges when rainfall undergoes through various component processes such as interception, detention, evapo-transpiration, overland flow, infiltration, inter-flow, percolation, sub-surface flow, base flow, etc.

The geology of the area varies from granite, gneiss, charnokites in the hills to the recent alluvium in the plains(Fig.4). The broad soil groups are calcium and non calcium, recent and old alluvium and brown forest soils, red soil podzowe, lateritic soil with cover being very deep in plains and deep to shallow in hills.

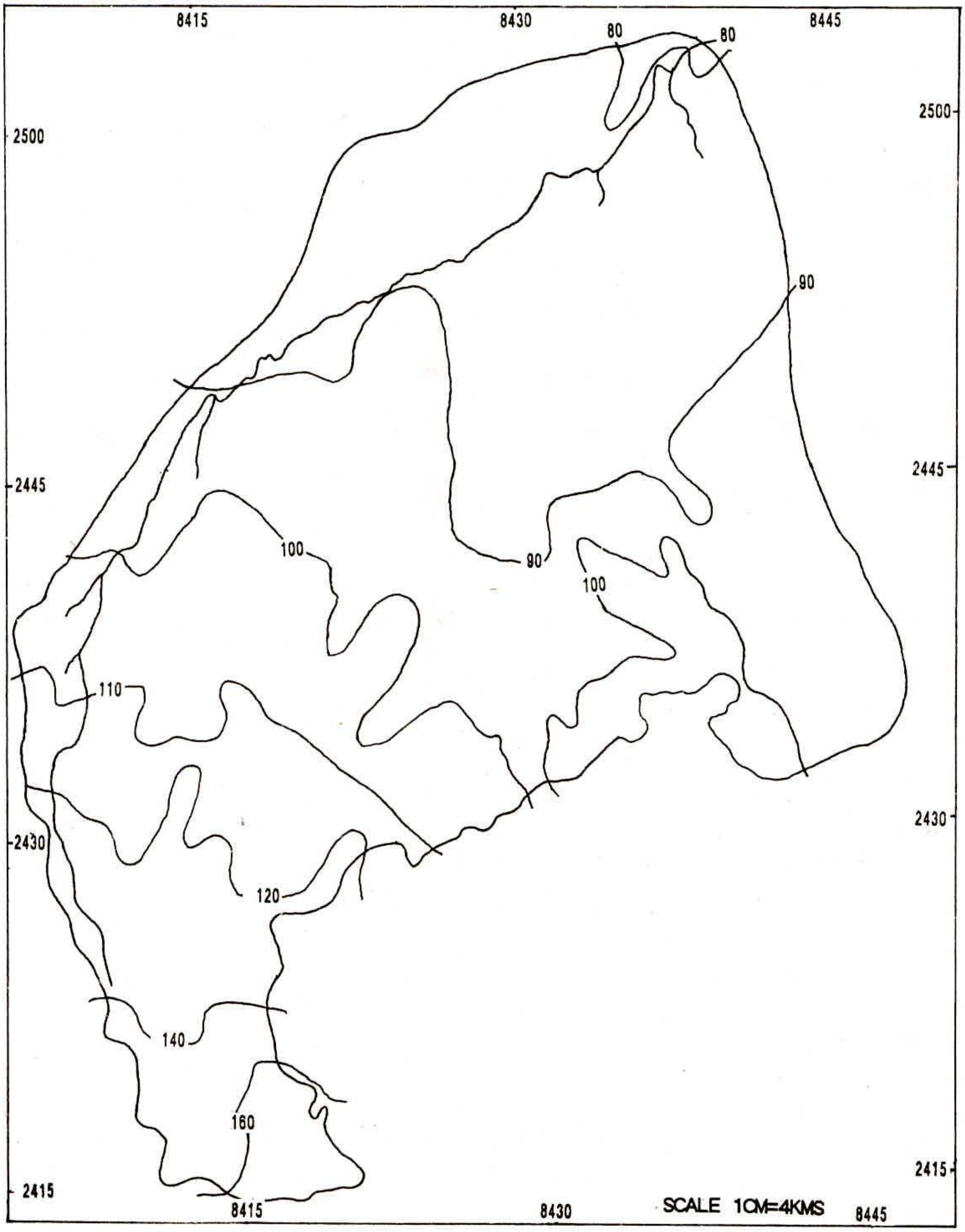

FIG.3: TOPOGRAPHICAL MAP

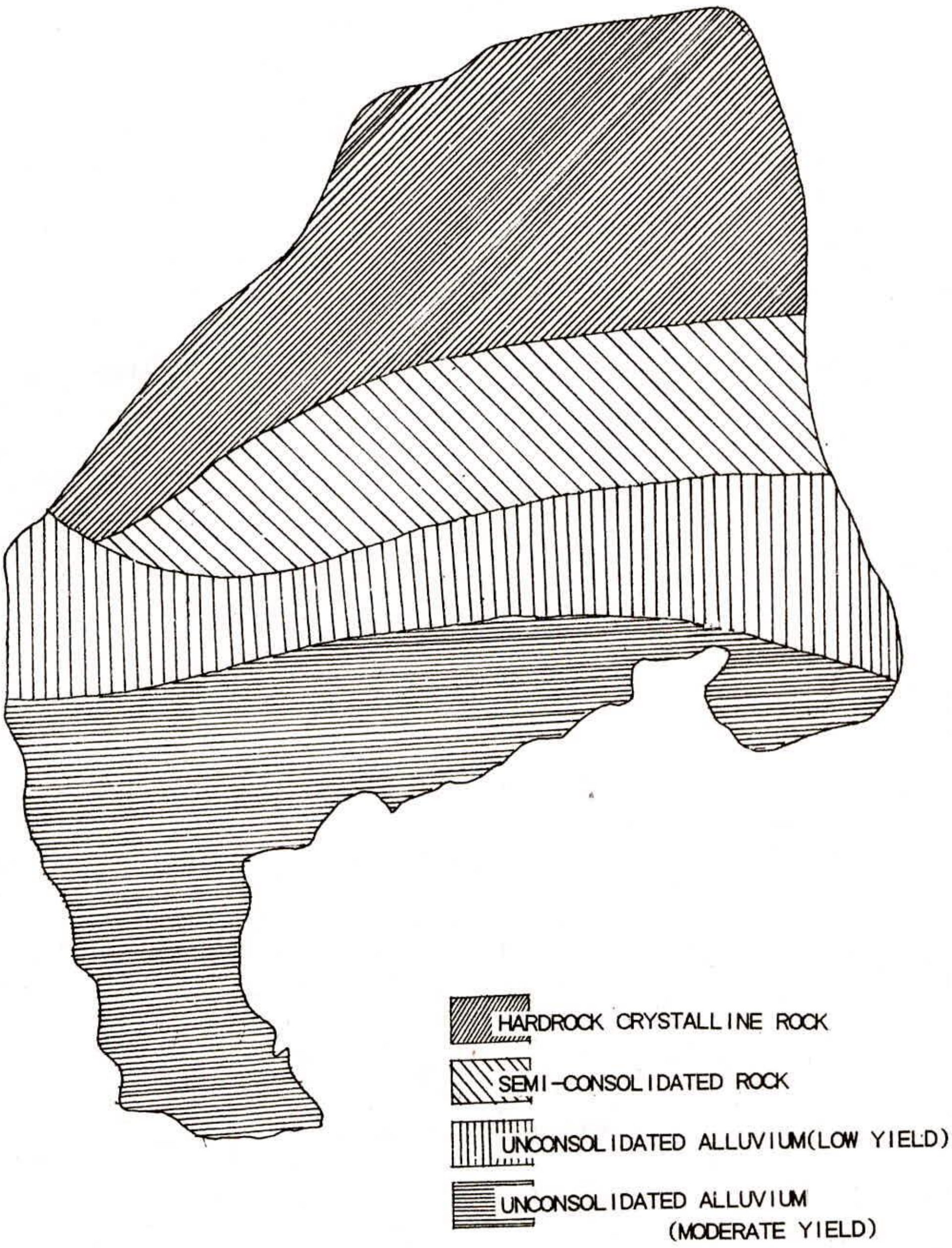

FIG.4: GEOLOGICAL MAP

3.0 DATA COLLECTION AND PROCESSING

For the study area, the input data collected & processed for rainfall-runoff simulation using HEC-1 package are as described below:

3.1 Rainfall data

There are ten raingauge stations evenly located in the catchment area of river Punpun up to Hamidnagar. Most of these raingauge station have rainfall data for 12-13 years **(Table 1)**. All these raingauge stations are available in Block head quarters and are maintained by the BDO's.

All the rain gauge stations have ordinary raingauges except Palmerganj raingauge station. In the present study, rainfall records for eight severe storm events, single peaked were collected from all the raingauge stations(recording and non-recording) as input for HEC-1 program. Daily observed rainfall data were converted into hourly rainfall data using hourly rainfall ratio of the Palmerganj's observed hourly rainfall data(**Appendix I**). Five events were used for Calibration and optimization of the model parameters and three events were used for validation.

Theissen polygon technique was applied to compute equivalent mean rainfall of Punpun catchment upto Hamidnagar(**Fig.5**). Theissen weights for each raingauge stations calculated are given in **Table 2**.

Table 1: Ranfall data availability for raingauge stations

SNo.	Raingauge Station	Area sq.km.	Period	Years	Type of Station
1.	Goh	3314	1974-85	12	ORG
2.	Rafiganj	"	1974-86	13	ORG
3.	Gurua	"	1974-86	13	ORG
4.	Sherghati	"	1974-86	13	ORG
5.	Obra	"	1974-85	12	ORG
6.	Aurangabad	"	1974-86	13	ORG
7.	Palmerganj	"	1974-86	13	SRRG
8.	Hariharganj	"	1974-86	13	ORG
9.	Chatarpur	"	1974-86	13	ORG
10.	Nabinagar	"	1974-86	13	ORG

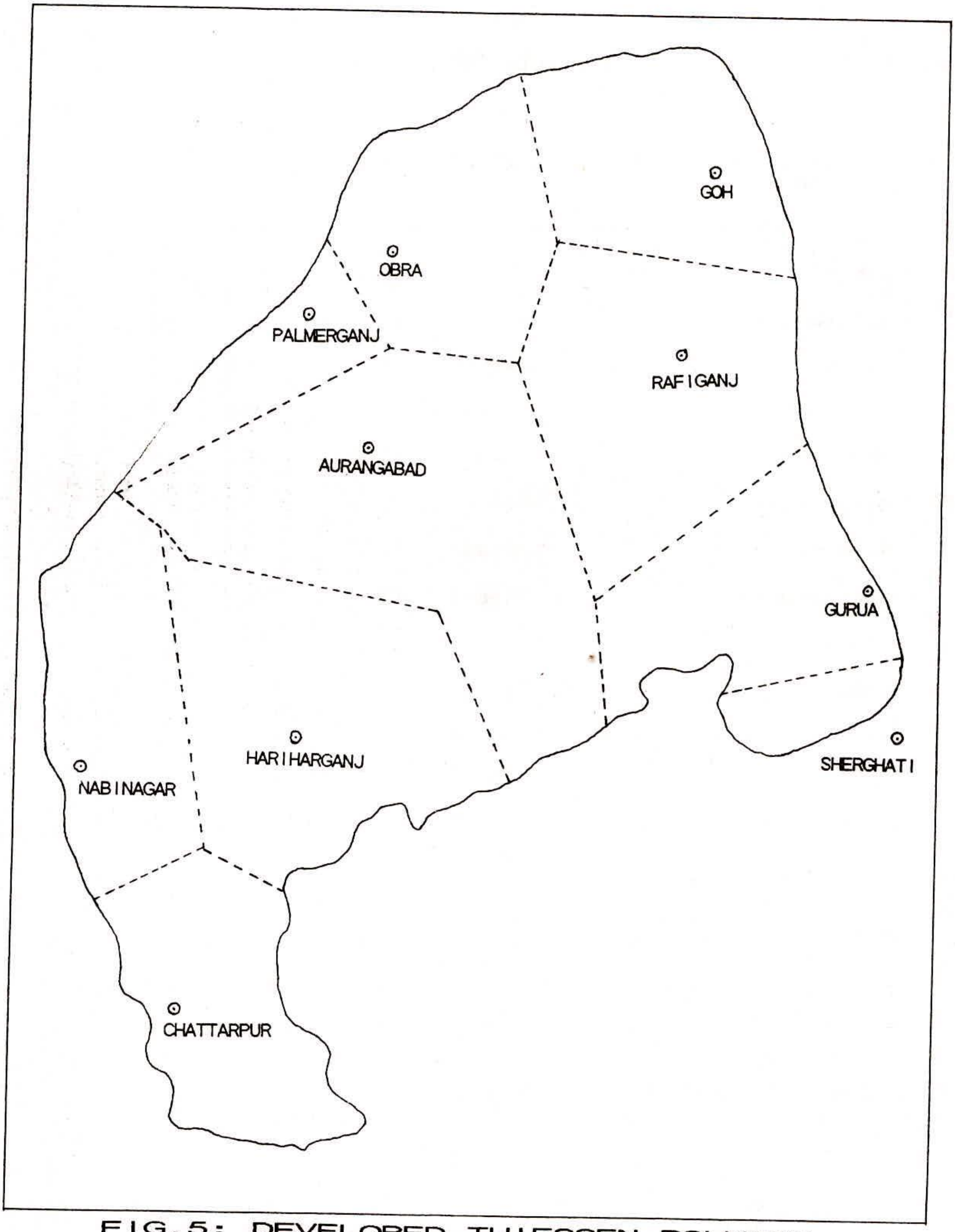

FIG. 5: DEVELOPED THIESSEN POLYGON

Table 2: Theissen weights for raingauge stations

Raingauge Station	Area in Sq.km	Thiessen weight
1. Goh	308	0.093
2. Rafiganj	464	0.141
3. Gurua	302	0.091
4. Sherghati	71	0.022
5. Obra	259	0.078
6. Aurangabad	689	0.208
7. Palmerganj	131	0.039
8. Hariharganj	485	0.146
9. Chattarpur	299	0.090
10. Nabinagar	306	0.092

3.2 Gauge & Discharge data

Gauge and discharge data at Hamidnagar barrage site are available from 1976 to 1986 i.e for 11 years for monsoon season only. The gauge sites are maintained by Water Resources Department, Govt. of Bihar. Velocities of flowing water were measured by float method and the corresponding discharge values were worked out by developing rating curves. However the rating curves were compared with the rating curve of Sripalpur (C.W.C) site and found to be consistent.

In the present study, the discharge data observed at Hamidnagar were examined and eight single peaked observed hydrographs were randomly selected for the analysis(**Appendix I**). The observed runoff data are available at 6 hourly interval i.e. four times a day at 0600, 1200, 1800 and 2400 hours. The data for the rest of the duration are not being observed. In the present study these data were interpolated at one hour interval.

3.3 Topographic data and other ancillary data

The topographic data, salient features of the study area, landuse, contours, soil information and other relevant data were obtained from various Central, State and Non-Govt. organizations/departments. Longitudinal profile of the main channel and its tributaries were developed using topographic maps. The loss rate were estimated by the available relevant information of the study area.

4.0 METHODOLOGY

In the present study, the following techniques/options of HEC-1 model were used for rainfall-runoff transformation /simulation in the study area of the catchment:

4.1 Initial and Constant Loss-rate computation

There is no data available for the loss-rate. Result of study of 134 flood events recorded for 15 big catchments in Sone, Punpun and Falgu basin of area ranging from 27 sq.km. to 1040 sq.km. shows that 80% of loss rate values exceeded 2 mm/hour and 10% of values exceeded 1.5 mm/hour. Mode value of 2.5 mm/hour is recommended for assessment of design flood of 50 years; 100 year return period for design of highway and railway bridges. In these studies, attempts have been made to compare the storm input rainfall over the basin with measured runoff that has come out for the event. Loss-rates are never uniform i.e, there are higher losses in the beginning with tapering to a suitable loss rate. There are limitations in denoting loss rates due to inaccuracies in flood flow measurement and also inaccuracies in assessment of areal distribution of rainfall and base flow separation. Thus, what is an approximate stable loss for a severe storm of 100 years return period of for a standard project storm or probable maximum storm is to be based on proper justification of suitable of loss rates, it may be taken as 2.5 mm/hour. In the present study, initially the value of loss rate is taken to be 2.5. This value was further optimized for different storm events and averaged. The validity of the averaged value of loss rate was then tested.

Rainfall-excess is one of the important component of precipitation and is that portion of precipitation which makes its way towards stream channels, lakes or ocean as surface flow. Rainfall excess is the rate at which water may infiltrate into the soil in addition to other abstraction. The volume of rainfall-excess resulting from a particular storm event was determined using initial and constant loss rate method.

4.2 Time-area curve development

For the development of the Time-area curve, the concentration time, T_c, was calculated for all the streams of the watershed. The concentration time, T_c, of a watershed is the travel time of the waterway in the watershed and was determined by the following Kirpich's(1940) empirical equation in the present study:

$$T_c = 0.0195\ L^{0.77} S_l^{-0.385} \qquad (1)$$

in which,

L = the main stream length (m), and

S_l = the equivalent mean slope of the main stream. S_l for the watershed was determined by an empirical equation proposed by Wu (1964):

$$S_l = \sqrt{\ } [N / \{1/\sqrt{s_1} + 1/\sqrt{s_2} + \ldots\ldots\ldots + 1/\sqrt{s_n}\}] \qquad (2)$$

where,

N = Total number of observations, and

s_1, s_2, s_2, = slopes at various distances

Fig.6 illustrates the procedure & calculation for computation of concentration time of the main stream using equations 1 and 2. Based on the computed concentration time, T_c, isochrones (area of equal travel time) of 1/2 hour interval were plotted for the study area(**Fig.7**) and further a time area curve representing the percent of the travel time and cumulative area contributing to the outlet was developed(**Fig.8**). The Time area curve developed was used for computation of outflow hydrograph by Clark unit hydrograph method. **Table 3** gives the details of Time in percentage of T_c and contributing area.

4.3 Base flow separation

The base flow was separated from the total hydrograph using an empirical method of HEC-1 package(Refer HEC-1 manual).

4.4 Clark method

The Clark method(1945) needs to compute the following three parameters for transformation of rainfall-excess into runoff: T_c, the Concentration time; R, the storage coefficient; and a time-area curve. In the present study, all these parameters were computed, optimized and calibrated using HEC-1 model and its capabilities.

4.5 Calibration and Validation of the Model Parameters

4.5.1 Calibration

Model calibration involves manipulating a specific model to some range of accuracy. **The fitting or** calibration procedure

Distance from upstream in meters	Elevation in meters	Slope
0.00	140.00	
		} 0.0011765
17000.00	120.00	
		} 0.0011111
26000.00	110.00	
		} 0.0005556
44000.00	100.00	
		} 0.0005882
61000.00	90.00	
		} 0.0001961
112000.00	80.00	
		AVERAGE = 0.0007255

$T_c = 0.0195 \times (L)^{0.77} \times (S)^{-0.385}$

$T_c = 0.0195 \times (112)^{0.77} \times (0.0007255)^{-0.385}$

T_c = 13.32 hours = Say 14.00 hrs.

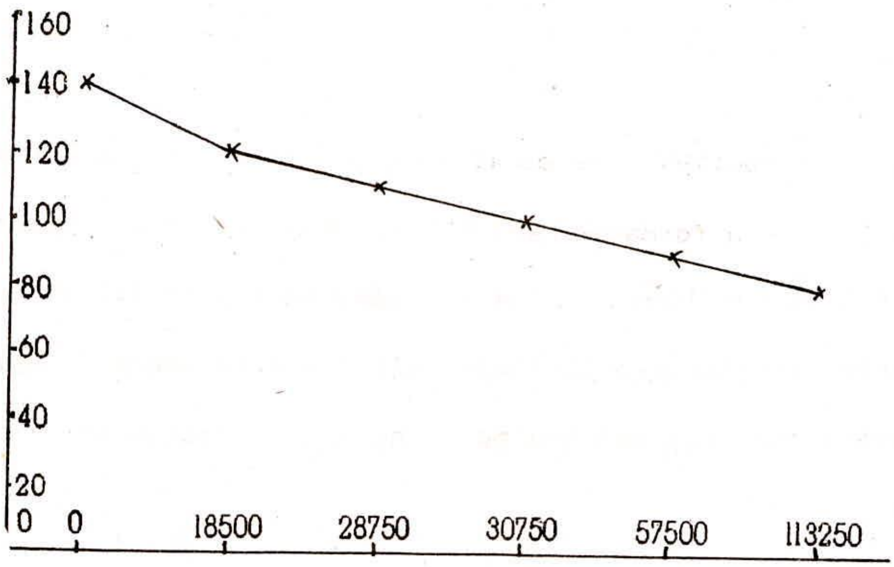

FIG.6: CONCENTRATION TIME ESTIMATION

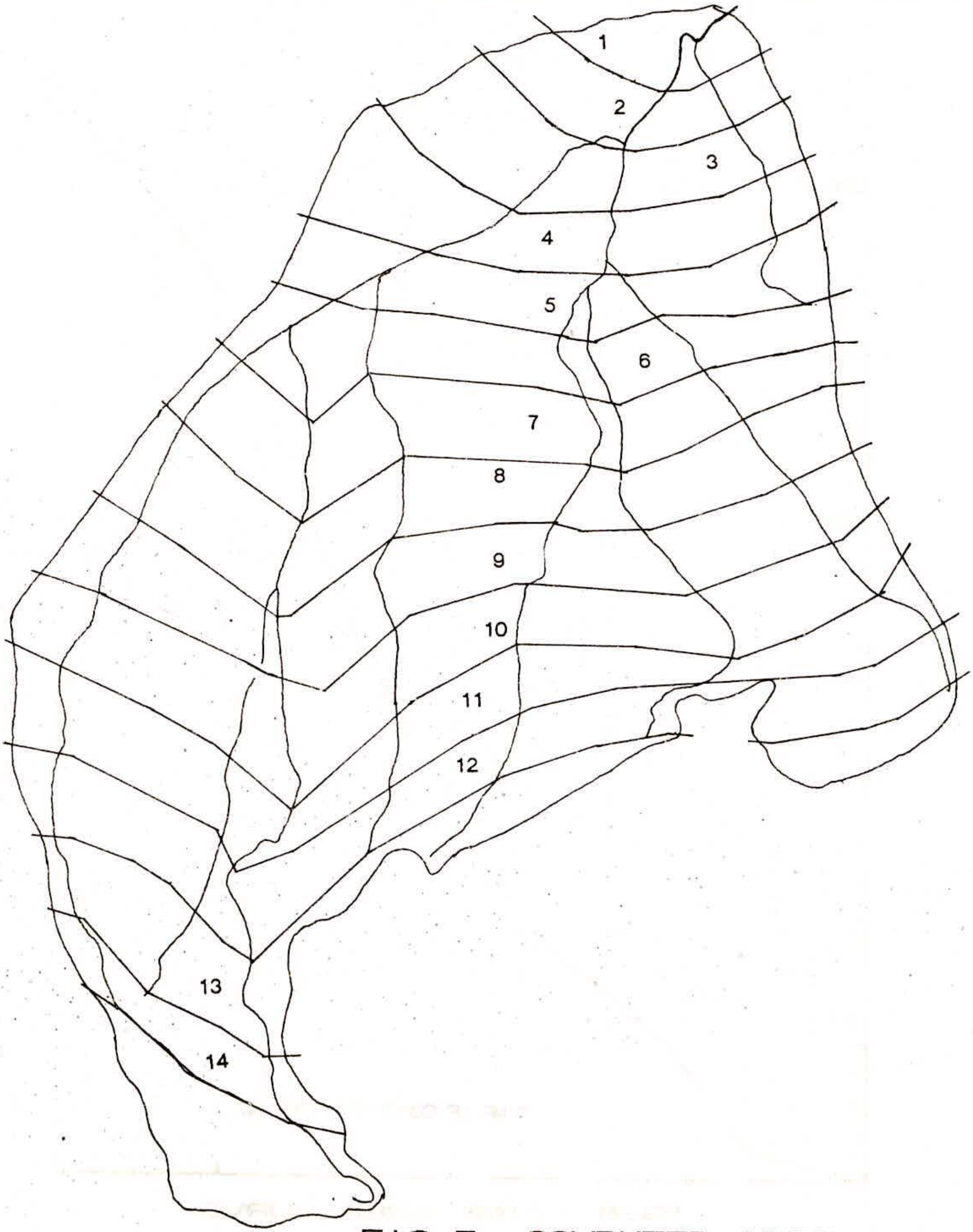

FIG. 7: COMPUTED ISOCHRONES

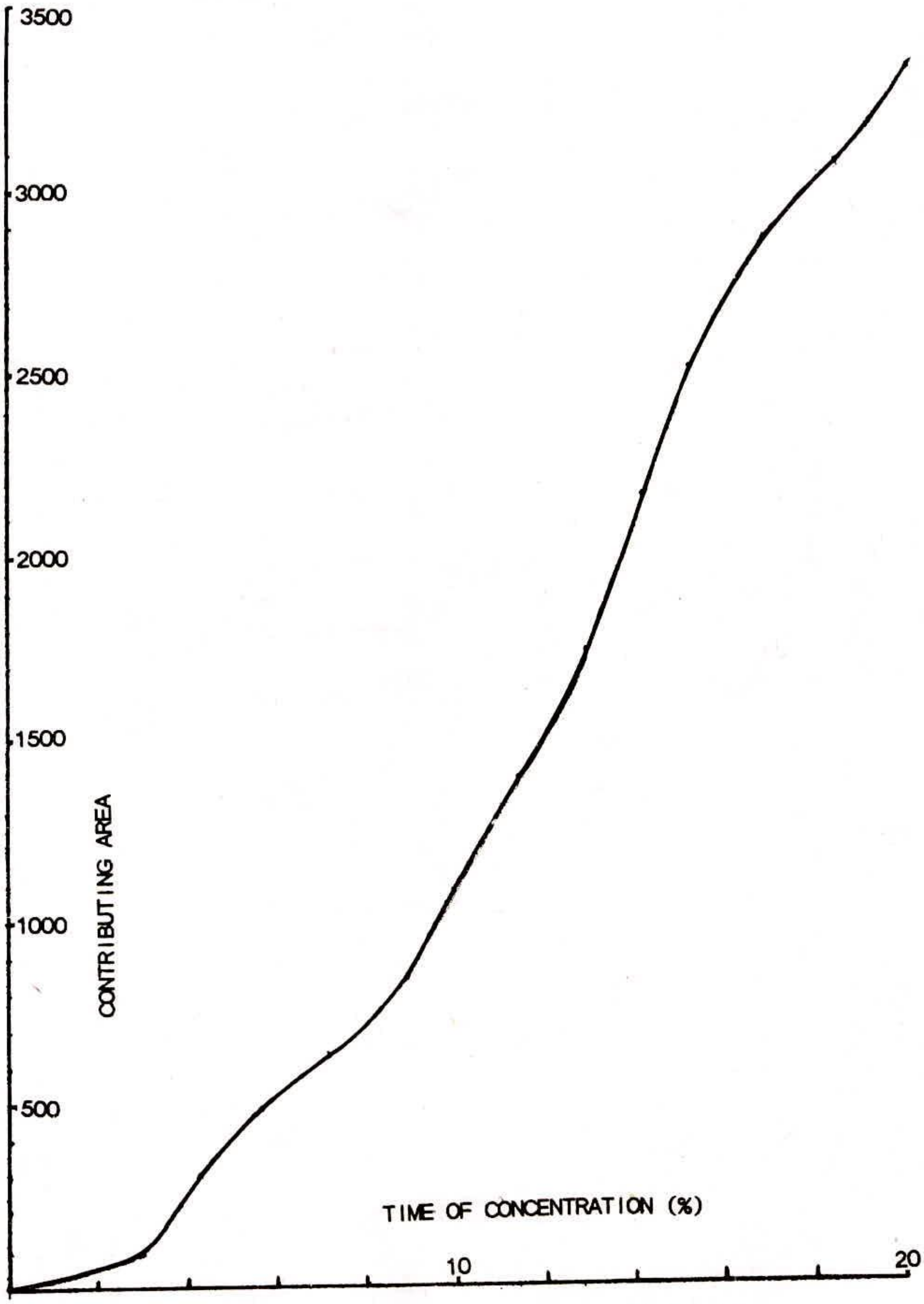

FIG.8: TIME-AREA CURVE

Table 3: **Data for Time-area diagram**

S.No.	Time in % of T_C	Contributing area
1.	0.00	0.00
2.	14.28	147.00
3.	21.42	320.00
4.	28.57	510.00
5.	35.71	684.00
6.	42.85	891.00
7.	50.00	1133.00
8.	57.40	1445.00
9.	62.48	1791.00
10.	71.43	2206.00
11.	78.57	2570.00
12.	85.71	2881.00
13.	92.86	3089.00
14.	100.00	3314.00

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). Data requirement for the optimization is : basin average precipitation, basin area, starting flow base flow parameters and the outflow hydrograph. Unit hydorgraph, T_c, R and loss rate parameters can be determined individually or in combination.

In the present study, five observed storm events were randomly selected from the period 1976 to 1984 and were used for the calibration of model parameters(**Table 4**). To gain initial estimates of different parameters, for initial runs of the models, the parameters T_c, R and initial and constant loss rates were optimized using automatic parameters optimization capability of the model(**Appendix II**). The following procedure was adopted for optimization:

1. Initially T_c, R, initial and constant loss rate values were kept to be -15, -15, -2.5, and -2.0 respectively for optimization.

2. After first run, the computed initial and constant loss rates for all the storm events were averaged and then fixed to be 3.12

Table 4: Storm events used for calibartion and validation of the model

Sl.No.	Storm events used for calibration runs	Storm events used for validation
1.	July 17, 1979	August 7, 1982
2.	July 27, 1982	August 30, 1982
3.	July 28, 1983	July 23, 1984
4.	August 8, 1984	
5.	August 4, 1986	

and 2.43 respectively .

3. After second run, the compute values of the ratio $R/(T_c+R)$ for all the storm events were averaged and then fixed to be 0.51 .

4. After third iteration, the computed values of T_c and R for all the storm events were averaged and then fixed to be 14.63 and 15.23 respectively.

5. After fourth iteration, the computed hydrographs for all hydrographs and the corresponding observed hydrographs were plotted(Figs.9,10,11,12,and 13). Results showing change in volume, depth percentage error for all optimization runs(iterations) are given in Appendix III.

4.5.2 Validation

For validation of different model parameters, three single peaked observed hydrographs were used(Table 4). In the present study, the model parameters, T_c, R, initial loss rate and constant loss rate were optimized and calibrated to be 14.63, 15.23, 3.12 and 2.43 respectively. Using these parameters, the computed hydrographs were developed. The computed hydrographs were then compared with the corresponding observed hydrographs (Figs.14,15,16). Appendix IV shows the results of optimization run using calibrated values of model parameters. It can be seen that the observed and computed hydrographs are matching and the calibrated model parameters may be used for rainfall-runoff simulation.

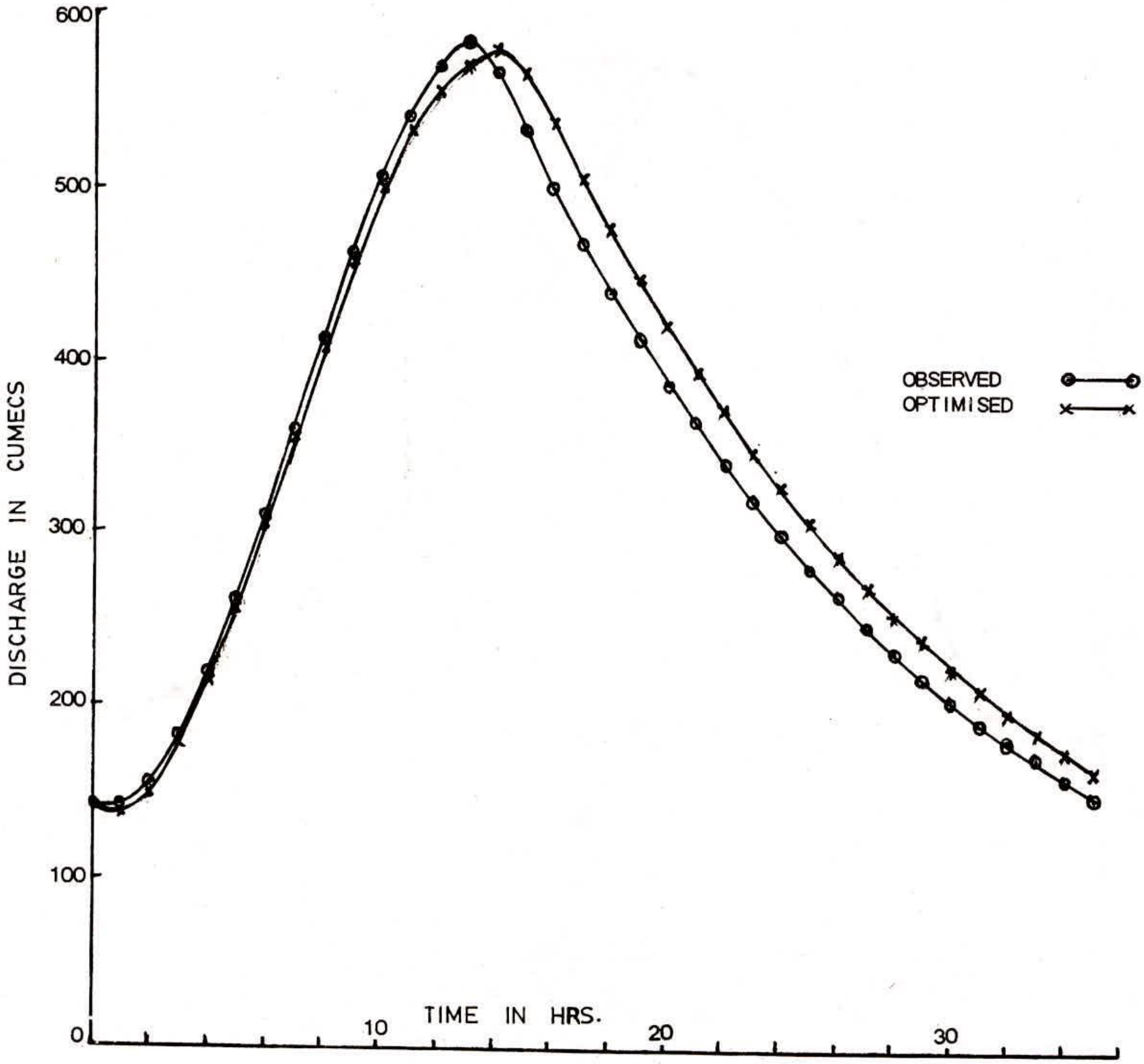

FIG.9: OBSERVED AND OPTIMISED HYDRO GRAPH FOR THE STORM OF JULY 17,1979

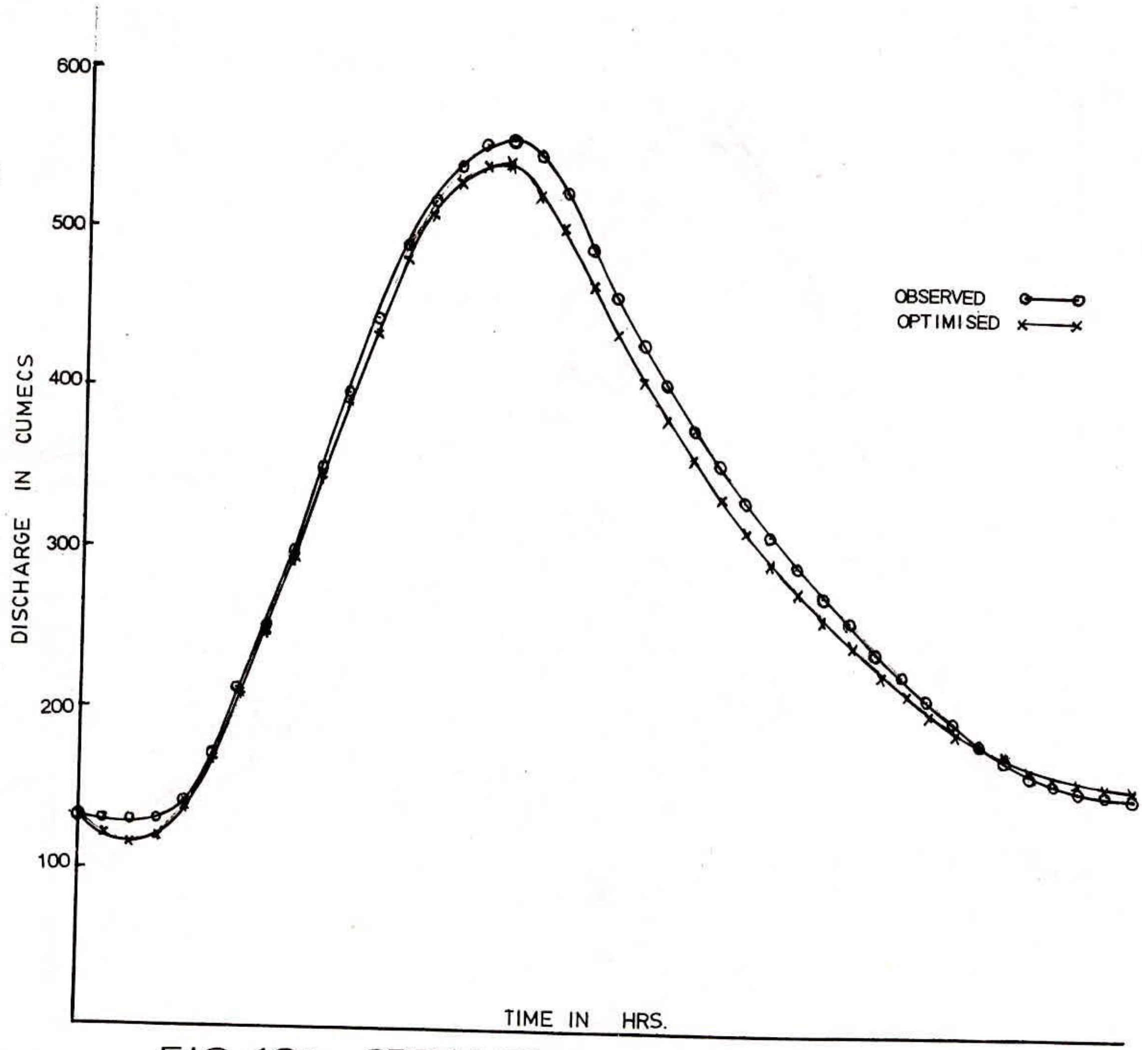

FIG.10: OBSERVED AND OPTIMISED HYDRO GRAPH FOR THE STORM OF JULY 27,1982

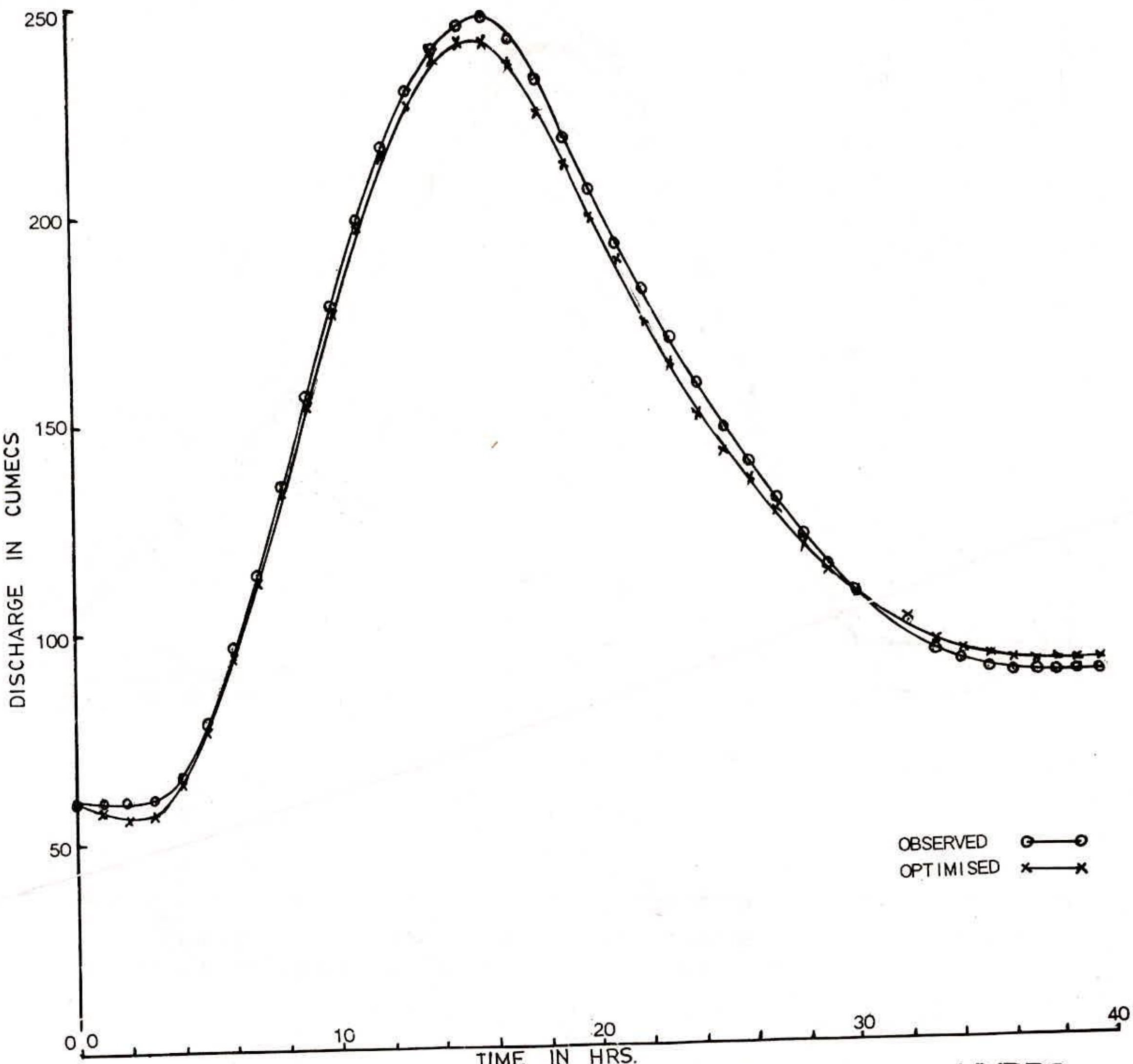

FIG. 11: OBSERVED AND OPTIMISED HYDRO GRAPH FOR THE STORM OF JULY 28, 1983

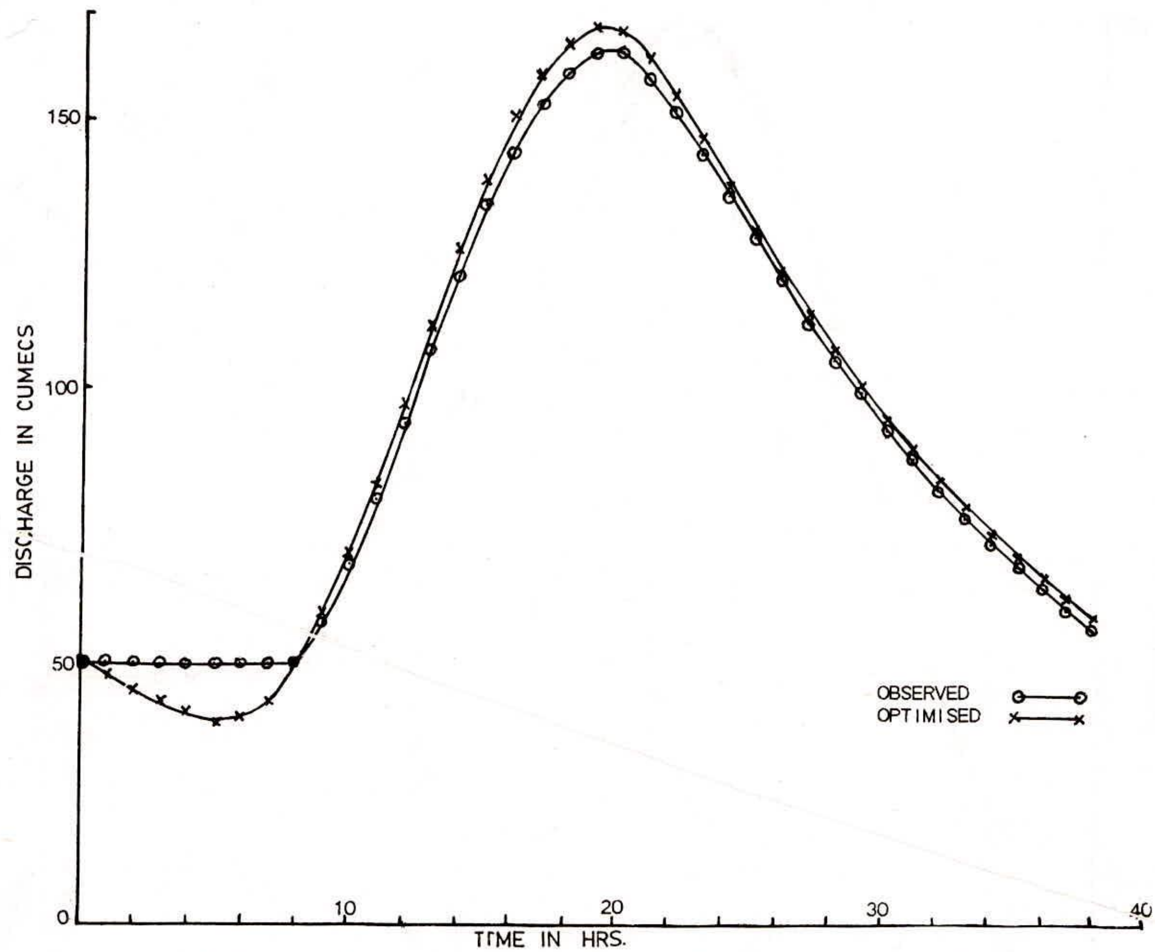

FIG.12: OBSERVED AND OPTIMISED HYDROGRAPH FOR THE STORM OF AUG 8,1984

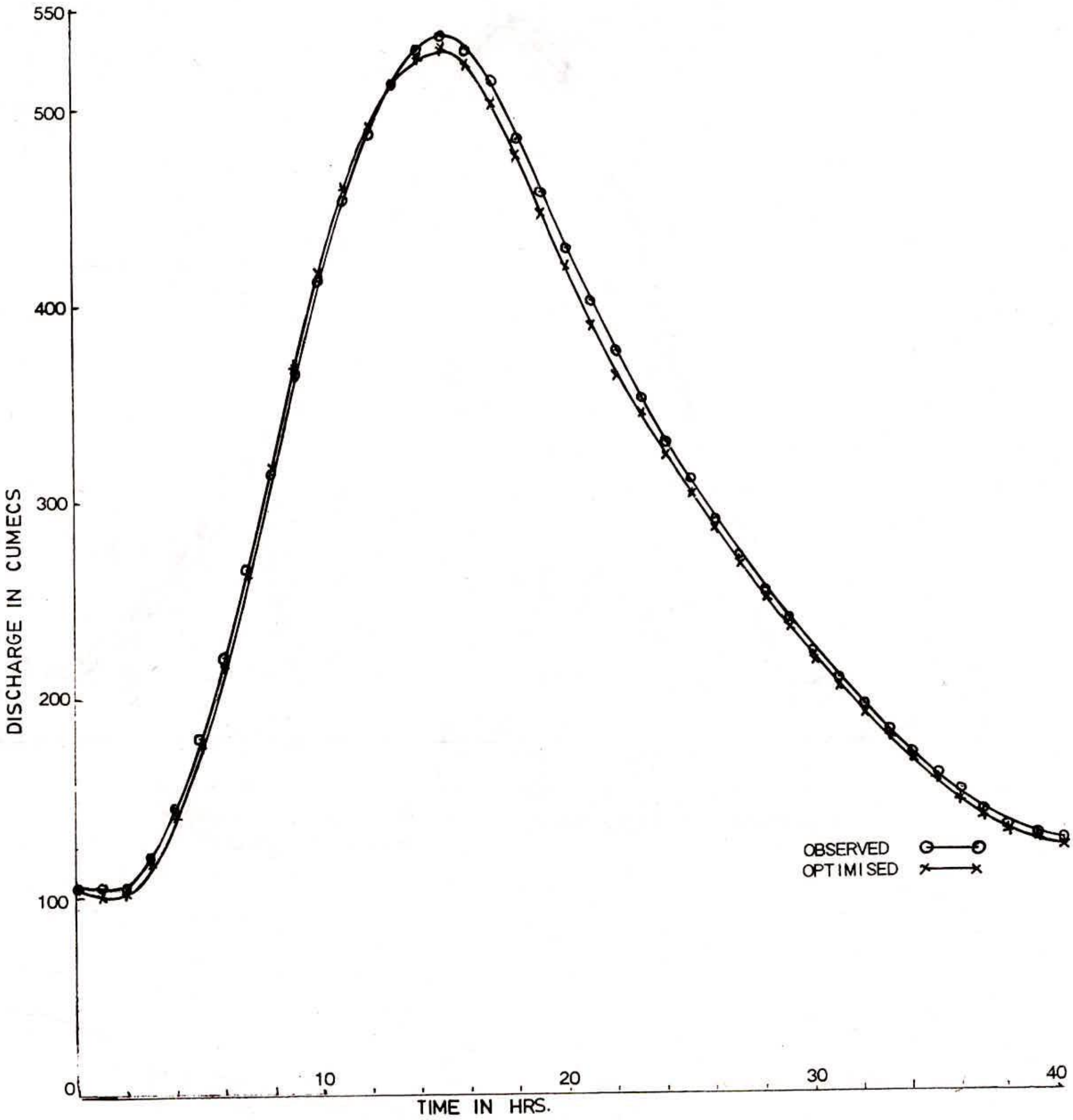

FIG. 13: OBSERVED AND OPTIMISED HYDRO GRAPH FOR THE STORM OF AUG 4, 1986

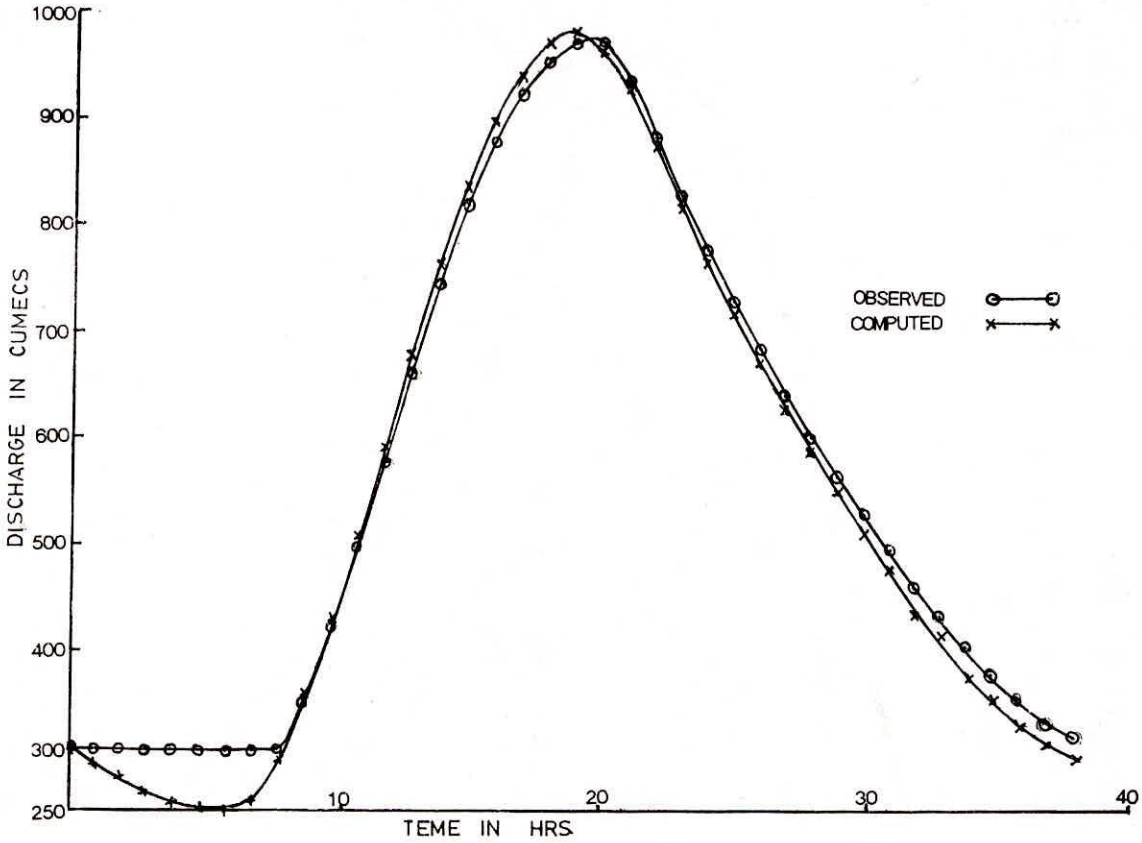

FIG. 14: COMPARISON OF OBSERVED WITH COMPUTED HYDROGRAPH FOR THE STORM OF AUG 7, 1982

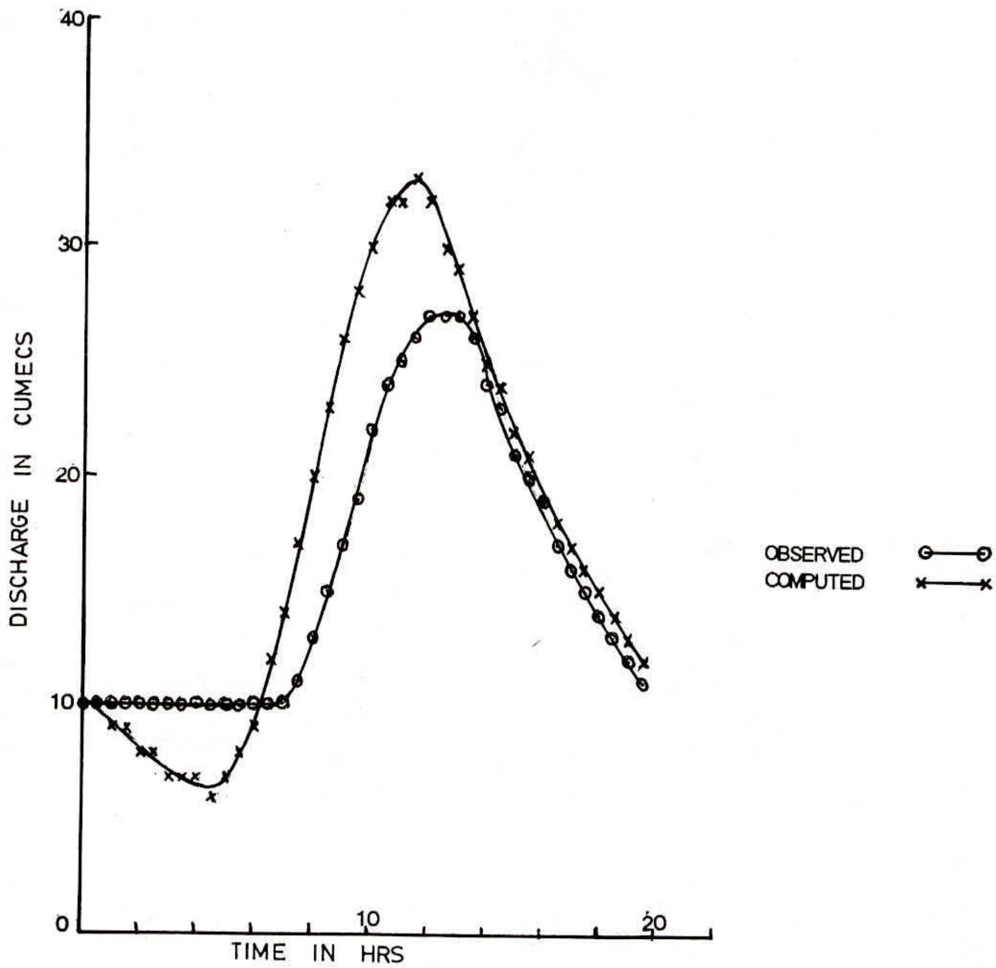

FIG. 15: COMPARISON OF OBSERVED WITH COMPUTED HYDROGRAPH FOR THE STORM OF AUG 30, 1982

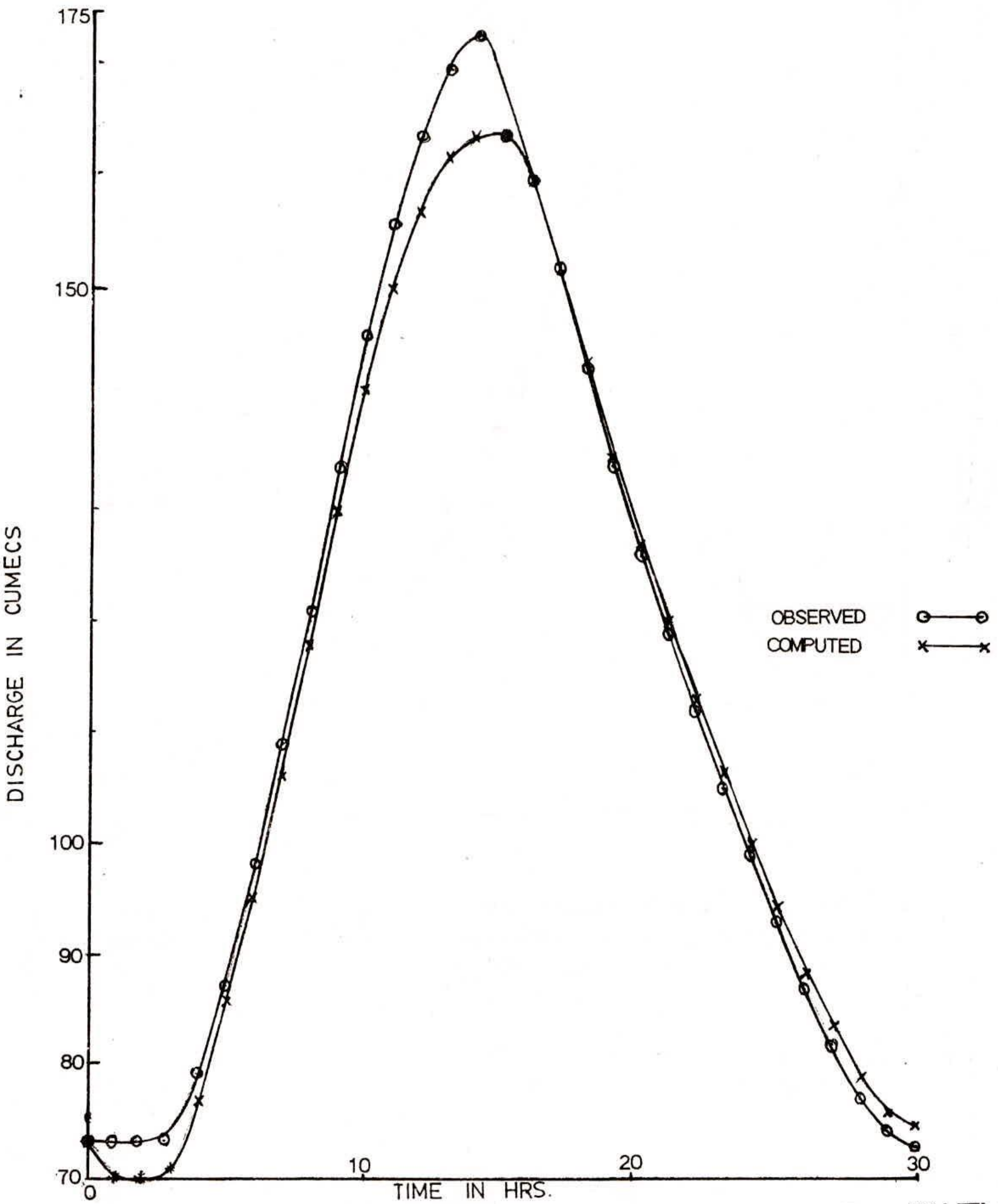

FIG.16: COMPARISON OF OBSERVED WITH COMPUTED HYDROGRAPH FOR THE STORM OF JULY 23, 1984

5.0 CONCLUSIONS

Based on this study, the following conclusions have been drawn:

1. HEC-1 package has been successfully used for modelling rainfall-runoff simulation of Punpun basin upto Hamidnagar within the constraints of data availability. The simulation results shows good reproduction of stream flow volumes, peaks and hydrographs.

2. The model parameters calibrated and then validated may be used for simulation of rainfall-runoff simulation and flood estimation in the Punpun basin upto Hamidnagar.

3. HEC-1 needs extensive input data base which may not be available for all the basins. In the present study, due to non-availability of sufficient data, some of the input data were assumed based of the available information. The results obtained gives an good approximate results.

4. In the present study only one recording raingauge station is available which is not adequate for good results. Also, the recording and non-recording raingauge network, though adequate, are not well distributed within the basin.

5. At present, there is only on gauge-discharge site in the study area of 3314 sq.km.. This may not give very accurate results.

6.0 RECOMMENDATIONS

1. There should be 2 to 3 recording raingauge stations as well as gauge-discharge sites each covering an area of 1000 sq.km. in the basin.

2. The calibrated and validated model parameters should be verified with other methods(options) available in the HEC-1 model.

3. The existing precipitation gauge network should be checked with available methods(Kagan, Halls, WMO guidelines or Optimum technique) and then appropriate modifications should be made.

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APPENDIX I(A)

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ID RAINFALL-RUNOFF SIMULATION
ID PUNPUN SUB-BASIN UPTO HAMIDNAGAR
ID BIHAR
IT     60  17JUL79      0900         36
IO                2
OU
IM
IN     60  17JUL79      0900          4
PG      1
PC      0       9.1      13.7      14.8
PG      2
PC      0         0         0         0
PG      3
PC      0         0         0         0
PG      4
PC      0     101.7    152.75     165.5
PG      5
PC      0      34.4      51.7        56
PG      6
PC      0      25.8      38.8        42
PG      7
PC      0        40        60        65
PG      8
PC      0      89.4     134.2     145.4
PG      9
PC      0      53.1      79.7      86.4
PG     10
PC      0      46.1      69.2        75
* **********
KK      A
KM Basin runoff calculation for       A
IN     60  17JUL79      0900         36
QO    139       139       154       182       219       262       310       360       413       464
QO    508       543       570       587       567       534       501       469       440       413
QO    387       363       340       319       299       280       263       246       231       217
QO    203       191       179       168       157       148
BA   3314
BF    139      -.25      1.05
PR      1         2         3         4         5         6         7         8         9        10
PW   .093      .141      .091      .022       078      .208      .039      .146      .095      .092
LU   -2.5        -2
UC    -15       -15
* **********
ZZ
```

APPENDIX I(B)

```
ID RAINFALL-RUNOFF SIMULATION
ID PUNPUN SUB-BASIN UPTO HAMIDNAGAR
ID BIHAR
IT     60 27JUL82     1900        40
IO              2
OU
IM
IN     60 27JUL82     1900         7
PG      1
PC      0        1     7.2      54.9     62.2      63.6     65.8
PG      2
PC      0        0       0         0        0         0        0
PG      3
PC      0      .11     .86      7.19     7.46      7.63      7.9
PG      4
PC      0      .13       1      8.55     8.88      9.08      9.4
PG      5
PC      0       .3     2.4        20     20.8      21.2       22
PG      6
PC      0        0       0         0        0         0        0
PG      7
PC      0       .5       4     33.25     34.5     35.25     36.5
PG      8
PC      0      .55     4.2      35.5     36.8      37.7       39
PG      9
PC      0        0       0         0        0         0        0
PG     10
PC      0       .2     1.4      11.8     12.3      12.5       13
* *********
KK      A
KM Basin runoff calculation for         A
IN     60 27JUL82    1900         40
QO    125      125     125       125      137       169      207      250      297      347
QO    398      446     486       517      540       554      557      548      523      490
QO    459      431     404       378      355       332      312      292      274      257
QO    241      226     211       198      186       174      163      153      144      136
BA   3314
BF    125     -.25    1.05
PR      1        2       3         4        5         6        7        8        9       10
PW   .093     .141    .091      .022     .078      .208     .039     .146     .095     .092
LU   -2.5     -2.0
UC    -15      -15
* *********
ZZ
```

APPENDIX I(C)

```
ID RAINFALL-RUNOFF SIMULATION
ID PUNPUN SUB-BASIN UPTO HAMIDNAGAR
ID BIHAR
IT     60 28JUL83      0400        38
IO              2
OU
IM
IN     60 28JUL83      0400         9
PG      1
PC      0       0         0         0         0         0         0         0         0
PG      2
PC      0       0         0         0         0         0         0         0         0
PG      3
PC      0       0         0         0         0         0         0         0         0
PG      4
PC      0     .04       1.5       3.4      4.51      4.66      4.83       4.9         5
PG      5
PC      0     .64      25.5     57.46     76.67     79.22     82.11     83.38        85
PG      6
PC      0     .28     11.28     25.42     33.91     35.04     36.32     36.88      37.6
PG      7
PC      0       1        40        90       120       124     128.5     130.5       133
PG      8
PC      0     .34      13.6     30.62     40.86     42.22     43.76     44.44      45.3
PG      9
PC      0     .49      19.5     43.94     58.63     60.58     62.79     63.76        65
PG    1.0
PC      0     .15         6      13.4     18.04     18.64     19.32     19.62        20
* **********
KK      A
KM Basin runoff calculation for        A
IN     60 28JUL83      0400        38
QO     61      61        61        61        66        79        96       114       135       156
QO    178     199       216       230       240       245       247       242       232       218
QO    205     192       180       169       158       148       139       130       122       114
QO    107     101        94        88        83        78        73        68
BA   3314
BF     61    -.25      1.05
PR      1       2         3         4         5         6         7         8         9        10
PW   .093    .141      .091      .022      .078      .208      .039      .146      .095      .092
LU   -2.5    -2.0
UC    -15     -15
* **********
ZZ
```

APPENDIX I(D)

```
ID RAINFALL-RUNOFF  SIMULATION
IT     60 08AUG84     1300       39
IO               2
OU
IM
IN     60 08AUG84     1300       11
PG      1
PC      0       .12       .12       .13       .52       .98      2.04      2.12      2.17       2.9
PC      3
PG      2
PC      0       .84       .84       .94      3.63      6.87     14.28     14.87      15.2     20.33
PC     21
PG      3
PC      0         0         0         0         0         0         0         0         0         0
PC      0
PG      4
PC      0       1.6       1.6       1.8      6.92     13.08      27.2     28.32     28.96     38.72
PC     40
PG      5
PC      0      1.08      1.08      1.21      4.67      8.83     18.36     19.12     19.55     26.14
PC     27
PG      6
PC      0       .27       .27        31      1.18      2.72      4.62      4.81      4.92      6.58
PC    6.8
PG      7
PC      0         3         3       3.5      13.5      25.5        53     55.25      56.5      75.5
PC     78
PG      8
PC      0      1.34      1.34      1.51      5.79     10.95     22.78     23.72     24.25     32.43
PC   33.5
PG      9
PC      0        .6        .6       .67      2.59       4.9      10.2     10.62     10.86     14.52
PC     15
PG     10
PC      0        .1        .1       .11       .43       .82       1.7      1.77      1.81      2.42
PC    2.5
KK      A
KM Basin runoff calculation for         A
IN     60 08AUG84     1300       39
QO     49        49        49        49        49        49        49        49        49        56
QO     67        79        93       107       121       134       144       153       159       163
QO    163       158       152       144       136       128       120       112       105        99
QO     92        87        81        76        71        67        63        59        55
BA   3314
BF     49      -.25      1.05
PR      1         2         3         4         5         6         7         8         9        10
PW   .093      .141      .091      .022      .078      .208      .039      .146      .095      .092
LU   -2.5      -2.0
UC    -15       -15
ZZ
```

APPENDIX I(E)

```
ID RAINFALL-RUNOFF SIMULATION
ID PUNPUN SUB-BASIN UPTO HAMIDNAGAR
ID BIHAR
IT     60 04AUG86      1500         43
IO              2
IM
OU
IN     60 04AUG86      1500          5
PG      1
PC      0     7.92     19.8      27.39       33
PG      2
PC      0        0        0          0        0
PG      3
PC      0    16.32     40.8      56.44       68
PG      4
PC      0     9.84     24.6      34.03       41
PG      5
PC      0        0        0          0        0
PG      6
PC      0     8.26    20.64      28.55     34.4
PG      7
PC      0     2.02     5.04       6.97      8.4
PG      8
PC      0       12       30       41.5       50
PG      9
PC      0        0        0          0        0
PG     10
PC      0    10.61    26.52      36.68     44.2
* **********
KK      A
KM Basin runoff calculation for          A
IN     60 04AUG86      1500         43
QO    105      105      105        120      146      181      222      267      315      365
QO    412      454      488        513      530      537      532      514      484      457
QO    428      401      376        352      330      310      290      272      255      239
QO    224      210      197        184      173      162      152      142      134      127
QO    121      115      110
BA   3314
BF    105     -.25     1.05
PR      1        2        3          4        5        6        7        8        9       10
PW   .093     .141     .091       .022     .078     .208     .039     .146     .095     .092
LU   -2.5     -2.0
UC    -15      -15
* **********
ZZ
```

APPENDIX II(A)

RESULT OF CALIBRATION RUNS

1. Summary

Date	Percent error				Optimization Results							
	Avg.	Vol.	Lag	Peak	T_C	R	$R/(T_C+R)$	Tp	Cp	Qp	Strtl	Cnstl
17JUL'79	1.2	0.5	0.0	-3.5	13.72	14.99	0.52	12.73	0.55	28.0	3.50	2.70
	4.2	2.6	1.4	-3.4	13.28	16.74	0.56	12.50	0.50	26.0	**3.12**	**2.43**
	5.6	5.3	1.7	-.1	14.43	15.02	**0.51**	13.41	0.56	27.0	3.12	2.43
	6.0	4.7	2.3	-1.4	**14.63**	**15.23**	0.51	13.53	0.56	27.0	3.12	2.43

2. Comparison of Computed and Observed Hydrographs

S.No.	Details of Hydrograph	Sum of Flows	Equiv. Flow	Mean Flow	Time to center of mass	Lag C.M. to C.M.	Peak Flow	Time of Peak
1.	Observed	11765	12.78	327	17.38	15.04	587	13.0
2.	Computed (Ist Run)	11829	12.85	329	17.38	15.04	566	13.0
3.	Computed (IInd Run)	12075	13.117	335	17.54	15.24	567	13.0
4.	Computed (IIIrd Run)	12385	13.453	344	17.64	15.30	586	14.0
5.	Computed (IVth Run)	12320	13.383	342	17.33	15.39	579	14.0

APPENDIX II(B)

RESULT OF CALIBRATION RUNS

1. Summary

Date	Percent error				Optimization Results							
	Avg.	Vol.	Lag	Peak	T_C	R	$R/(T_C+R)$	Tp	Cp	Qp	Strtl	Cnstl
27JUL'82	0.7	-.1	0.3	0.0	14.94	15.11	0.50	13.83	0.57	27.0	2.78	2.22
	2.5	-1.6	-0.6	-0.4	15.32	14.03	0.48	14.17	0.61	27.0	**3.12**	**2.43**
	3.4	-3.1	-0.8	-2.5	14.52	15.11	**0.51**	13.46	0.56	27.0	3.12	2.43
	3.3	-3.3	-0.4	-3.2	**14.63**	**15.23**	0.51	13.53	0.56	27.0	3.12	2.43

2. Comparison of Computed and Observed Hydrographs

S.No.	Details of Hydrograph	Sum of Flows	Equiv. Flow	Mean Flow	Time to center of mass	Lag C.M. to C.M.	Peak Flow	Time of Peak
1.	Observed	12292	13.334	307	19.78	15.78	557	16.0
2.	Computed (Ist Run)	12274	13.334	307	19.82	15.82	557	16.0
3.	Computed (IInd Run	12095	13.138	302	19.69	15.69	555	16.0
4.	Computed (IIIrd Run)	11916	12.944	298	19.66	15.66	543	15.0
5.	Computed (IVth Run)	11883	12.909	297	19.72	15.72	539	14.0

APPENDIX II(C)

RESULT OF CALIBRATION RUNS

1. Summary

Date	Percent error				Optimization Results							
	Avg.	Vol.	Lag	Peak	T_C	R	$R/(T_C+R)$	Tp	Cp	Qp	Strtl	Cnstl
28JUL 83	0.9	-0.1	0.4	-0.1	14.88	15.17	0.50	13.75	0.55	27.0	3.01	2.39
	1.6	-1.0	-0.1	-0.1	15.09	14.44	0.49	13.96	0.59	27.0	**3.12**	**2.43**
	2.2	-2.0	-0.3	-1.7	14.56	15.15	**0.51**	13.48	0.56	27.0	3.12	2.43
	2.3	-2.2	-0.1	-2.1	**14.63**	**15.23**	0.51	13.53	0.56	27.0	3.12	2.43

2. Comparison of Computed and Observed Hydrographs

S.No.	Details of Hydrograph	Sum of Flows	Equiv. Flow	Mean Flow	Time to center of mass	Lag C.M. to C.M.	Peak Flow	Time of Peak
1.	Observed	5386	5.851	142	19.22	15.16	247	16.00
2.	Computed (Ist Run)	5379	5.843	142	19.28	15.22	247	16.00
3.	Computed (IInd Run)	5333	5.793	140	19.20	15.13	247	16.00
4.	Computed (IIIrd Run)	5279	5.735	139	19.17	15.10	243	15.00
5.	Computed (IVth Run)	5269	5.724	139	19.20	15.13	242	16.00

APPENDIX II(D)

RESULT OF CALIBRATION RUNS

1. Summary

Date	Percent error				Optimization Results							
	Avg.	Vol.	Lag	Peak	T_c	R	$R/(T_c+R)$	Tp	Cp	Qp	Strtl	Cnstl
08AUG'84	4.0	-0.1	2.1	0.9	14.79	15.58	0.51 •	13.69	0.56	26.0	3.05	2.44
	3.9	-0.6	2.3	-0.1	14.62	16.13	0.52	13.59	0.54	26.0	**3.12**	**2.43**
	4.3	0.2	2.6	0.8	15.00	15.61	**0.51**	14.02	0.57	26.0	3.12	2.43
	4.8	1.2	1.7	3.3	**14.63**	**15.23**	0.51	13.53	0.56	27.0	3.12	2.43

2. Comparison of Computed and Observed Hydrographs

S.No.	Details of Hydrograph	Sum of Flows	Equiv. Flow	Mean Flow	Time to center of mass	Lag C.M. to C.M.	Peak Flow	Time of Peak
1.	Observed	3685	04.003	94	21.19	13.31	163	19.00
2.	Computed (Ist Run)	3682	04.000	94	21.47	13.59	164	19.00
3.	Computed (IInd Run)	3663	03.980	94	21.54	13.65	164	20.00
4.	Computed (IIIrd Run)	3692	04.010	95	21.54	13.65	164	20.00
5.	Computed (IVth Run)	3729	04.051	96	21.42	13.53	168	19.00

APPENDIX II(E)

RESULT OF CALIBRATION RUNS

1. Summary

Date	Percent error				Optimization Results							
	Avg.	Vol.	Lag	Peak	T_C	R	$R/(T_C+R)$	Tp	Cp	Qp	Strtl	Cnstl
04AUG'86	0.5	0.1	0.2	0.2	15.00	15.00	0.50	13.92	0.58	27.3	3.01	2.41
	0.7	-0.5	-0.1	0.0	14.98	14.81	0.50	13.84	0.58	26.0	**3.12**	**2.43**
	1.0	-1.0	-0.1	-0.1	14.65	15.25	**0.51**	13.54	0.56	27.0	3.12	2.43
	1.1	-1.0	-0.2	-0.84	**14.63**	**15.23**	0.51	13.53	0.56	27.0	3.12	2.43

2. Comparison of Computed and Observed Hydrographs

S.No.	Details of Hydrograph	Sum of Flows	Equiv. Flow	Mean Flow	Time to center of mass	Lag C.M. to C.M.	Peak Flow	Time of Peak
1.	Observed	12156	13.205	283	20.17	16.78	537	15.00
2.	Computed (Ist Run)	12171	13.222	283	20.20	16.82	538	15.00
3.	Computed (IInd Run)	12101	13.145	281	20.15	16.76	537	15.00
4.	Computed (IIIrd Run)	12030	13.068	280	20.15	16.76	532	15.00
5.	Computed (IVth Run)	12036	13.074	280	20.14	16.75	533	15.00

APPENDIX III(A)

```
ID RAINFALL-RUNOFF SIMULATION
ID PUNPUN SUB-BASIN UPTO HAMIDNAGAR
ID BIHAR
IT    60 07AUG82     0800      39
IO            2
IM
OU
IN    60 07AUG82     0800      10
PG     1
PC     0     1.2      3.1     5.1     8.2    12.6    28.3    47.1    50.2    54.2
PG     2
PC     0     1.2      3.2     5.3     8.5      13    29.2    48.7    51.9      56
PG     3
PC     0       0        0       0       0       0       0       0       0       0
PG     4
PC     0     .03      .07     .11     .18     .28     .62    1.04    1.11     1.2
PG     5
PC     0    1.17      3.1       5     8.1    12.3    27.7    46.1    49.1      53
PG     6
PC     0    1.11     2.92    4.73     7.7    11.7    26.3    43.8    46.7    50.4
PG     7
PC     0     .75        2    3.25    5.25       8      18      30      32    34.5
PG     8
PC     0    .097      .26     .41     .67    1.02     2.3    3.82    4.08     4.4
PG     9
PC     0       0        0       0       0       0       0       0       0       0
PG    10
PC     0      .2       .6       1     1.5     2.4     5.3     8.9     9.5    10.2
* **********
KK     A
KM Basin runoff calculation for       A
IN    60 07AUG82     0800      39
QO   309     309      309     309     309     309     309     309     309     355
QO   422     498      579     663     747     821     881     927     958     973
QO   968     940      891     836     784     735     689     646     606     568
QO   533     500      468     439     412     386     362     340     319
BA  3314
BF   309    -.25     1.05
PR     1       2        3       4       5       6       7       8       9      10
PW  .093    .141     .091    .022    .078    .208    .039    .146    .095    .092
LU  3.12    2.43
UC 14.63   15.23
* **********
ZZ
```

APPENDIX III(B)

```
ID RAINFALL-RUNOFF SIMULATION
IT     60 30AUG82      1300        41
IO             2
IM
OU
IN     60 30AUG82      1300        13
PG      1
PC      0       .65       2.6      3.25      5.21      6.51      9.14      11.1     12.71     15.34
PC  21.54     26.75      28.4        31
PG      2
PC     22       .53      2.14      2.68      4.28      5.35      7.52      9.13     10.45     12.62
PC  17.72        22     23.36      25.5
PG      3
PC      0      .441      1.76      2.22      3.53      4.41      6.19      7.52      8.61     10.39
PC  14.59     18.12     19.24        21
PG      4
PC      0       .38      1.53      1.91      3.06      3.82      5.37      6.51      7.46         9
PC  12.65      15.7     16.67      18.2
PG      5
PC      0       .21       .84      1.05      1.68       2.1      2.95      3.58       4.1      4.95
PC   6.95      8.63      9.16        10
PG      6
PC      0        .9       3.6       4.5       7.2         9     12.65     15.36     17.59     26.23
PC  29.81     37.02      39.3      42.9
PG      7
PC      0        .5         2       2.5         4         5         7       8.5      9.75     11.75
PC   16.5      20.5     22.75     23.75
PG      8
PC      0         2       7.9       9.9      15.8      19.7      27.7     33.65     38.54     46.53
PC  65.33      81.1      86.1        94
PG      9
PC      0      1.07      4.28      5.35      8.57     10.71     15.04     18.26     20.91     25.24
PC  35.44     44.01     46.72        51
PG     10
PC      0       .44      1.76       2.2      3.53      4.41       6.2      7.52      8.61     10.39
PC   14.6     18.12     19.24        21
KK      A
KM Basin runoff calculation for      A
IN     60 30AUG82      1300        41
QO     10        10        10        10        10        10        10        10        10        10
QO     10        10        10        10        10        11        13        15        17        19
QO     22        24        25        26        27        27        27        26        24        23
QO     21        20        19        17        16        15        14        13        13        12
QO     11
BA   3314
BF     10      -.25      1.05
PR      1         2         3         4         5         6         7         8         9        10
PW   .093      .141      .091      .022      .078      .208      .039      .146      .095      .092
LU   3.12      2.43
UC  14.63     15.23
```

APPENDIX III(C)

```
ID RAINFALL-RUNOFF SIMULATION
ID PUNPUN SUB-BASIN UPTO HAMIDNAGAR
ID BIHAR
IT     60 23JUL84     2000        30
IO             2
IM
OU
IN     60 23JUL84     2000         5
PG      1
PC      0     3.27    14.06     16.34       19
PG      2
PC      0     2.74     8.85      13.8       16
PG      3
PC      0        0        0         0        0
PG      4
PC      0     4.99    21.46     24.94       29
PG      5
PC      0     1.55     4.66      7.74        9
PG      6
PC      0     8.12    34.93     40.59     47.2
PG      7
PC      0       10       43        50       58
PG      8
PC      0     6.41     27.6     32.08     37.3
PG      9
PC      0     1.72      7.4       8.6       10
PG     10
PC      0     8.94    38.48     44.72       52
* **********
KK      A
KM Basin runoff calculation for         A
IN     60 23JUL84     2000        30
QO     73       73       73        73       79       87       98      109      121      134
QO    146      156      164       170      173      173      170      163      153      144
QO    135      127      119       112      105       98       92       87       82       77
BA   3314
BF     73     -.25     1.05
PR      1        2        3         4        5        6        7        8        9       10
PW   .093     .141     .091      .022     .078     .208     .039     .146     .095     .092
LU   3.12     2.43
UC  14.63    15.23
* **********
ZZ
```

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