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DAILY RAINFALL - RUNOFF MODELLING OF SAGILERU RIVER USING HYSIM

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PREFACE

Hydrologic modelling has come to play an important role in the process of making decisions on the most suitable strategies for river basin management. The models are increasingly being used for various purposes e.g., extension of flow records, real time flood forecasting, evaluating the effects of arteficial influences in the basin on river flow regime etc. The choice of a model for an application depends on many factors; the important ones being the type of problem to be tackled and the quality and quantity of available data. However, a model before using it for a real application needs to be assessed for its applicability and potential accuracy under the climatic and hydrologic conditions in which it is intended to be used.

In the present study, a hydrologic simulation model called HYSIM which is developed by R E Manley in United Kingdom is applied for the first time to any Indian river to model the daily river flows. The model is applied to Sagileru river basin of Pennar river system using the available data of four years. The model is calibrated and validated for daily flows using split data approach and the model performance in reproducing the flow hydrographs is assesed. The results of the study along with the various model performance indices are presented in the report.

The present study titled " DAILY RAINFALL-RUNOFF MODELLING OF SAGILERU RIVER USING HYSIM " is carried out as a part of the

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ABSTRACT

HYSIM, a hydrologic simulation model which is developed by R.E. Manley in United Kingdom is applied for the first time in India to model daily flows of river Sagileru which is a tributary of Pennar river. The modelling is carried out for a drainage area of 2486 sq.kms upto Nandipalli gauging site by considering the entire drainage area as a single unit. The model calibration and validation for the daily flows is performed using independent set of data by adopting the split data approach for the available data of 4 years. The data used in the study, the methodology adopted and the results obtained from the study are discussed in the report.

The results of the study are quite encouraging. It is observed from the results that the model reproduced the flow hydrographs to a fair degree of accuracy. However, before making a general conclusion on the model's applicability, it is recommended that the model performance should further be assessed by applying it to few more Indian catchments.

1.0 INTRODUCTION

The planning and management of water resources systems are dependent upon information relating to the spatial and temporal distribution of hydrologic phenomena. Hydrologic data bases are seldom large enough to provide for the extraction of precise information and as a result, planning and management decisions are subject to hydrologic uncertainty in addition to uncertainties of a non-hydrologic nature. A feasible course of action is, therefore, to develop or select from the existing hydrological models and use the same for extrapolating and interpolating information over time and space. When a model has been developed or selected for use in predicting hydrological outputs for a particular practical problem, it is then necessary to assess the applicability and potential accuracy for the problem at hand, and to determine the values of the model parameters or constants for the catchment under consideration. The models themselves do not assure that information generated at specific points in time and space is sufficiently precise. However, the models allow information to be generated instantaneously and objectively, and the models provide a quantitative measure of the quality of generated information, as well as efficiency in the information generating process via the use of computers.

In the present study, a hydrologic simulation model called HYSIM which is developed by R E Manley in United Kingdom is applied for the first time to any Indian river for modelling the river flows. The model is applied to river Sagileru of Pennar river system to model the daily flows at Nandipalli gauging site, the drainage area upto the gauging site being 2486 Sq.Km. The model is calibrated and validated using independent set of data by adopting the split data approach for the available data of 4 years and the model performance in reproducing the flow hydrographs is assessed.The description of study area, model, data and methodology used and the results of the study are presented in the following chapters of the report.

2.0 STUDY AREA

2.1 Location and Extent

The river Sagileru is one of the major tributaries of river Pennar joining the Pennar river on left side. The Sagileru river originates from Nallamalai Hills at an altitude of about 700 m above msl near Cumbum in Ongole District and flows towards south in the districts of Ongole and Cuddapah of Andhra Pradesh. It joins the main Pennar river in Sidhout Taluk of Cuddapah District. Geographically, the Sagileru basin is located between latitude $14^{\circ}28'$ to $15^{\circ}34'$ N and longitude $78^{\circ} 46'$ to $79^{\circ}10'$ E and is covered in Survey of India toposheets No.57/I, 57/J, 57/M and 57/N of 1:2,50,000 scale. The total geographical area of the basin is about 3203 sq.kms. and falls in two districts as below.

(i) Ongole District -- 960 sq.kms.
(ii) Cuddapah District -- 2243 sq.kms.

Total -- 3203 sq.kms.

However, for the purpose of present study the basin is considered upto Nandipalli gauging site having a catchment area of about 2486 sq.kms.

2.2 Drainage

The Sagileru basin is characterized by sub-dendritic type of drainage pattern. The total length of Sagileru river along its course is about 152 kms. and the river runs almost in central part of the basin from North to South. There are only small tributaries to this river, worth mentioning streams being Enamaleru, Tadukuvagu and Maderu. The Enamaleru stream drains into Sagileru river at 49th km of Sagileru. The Tadukuvagu and the Maderu streams join the Sagileru at 68th km and 111th km respectively. The drainage network of Sagileru basin is shown in Figure 2.1. The basin has a maximum length of 122 km from North to South and a maximum width of 40 kms from West to East. In general, the Sagileru river rises in the later half of June. July, August, September, October and November are the months of maximum discharge. After January the river becomes almost dry.

2.3 Topography

The basin comprises of rather undulated country with deep valleys between two big hill ranges on either side through out the length. Most of the area in the basin lies between contours 500 to 2500 feet. There is unbroken line of hill range on the western side (Right side of river flow) and eastern side (left) of the Sagileru River. The western hill ranges consist of Cumbum Range forest between contours 1750-1250, Uyyalawada hill range forest at contours 2000-1000, Kothakota Dasaripalli range forest at contours of 2250-1250, Kancharla Morem forest at 2250-750 and Lankamalai range forest at 2250-500 feet.

The eastern un-broken hill range consists of Ambavaram Range forest at contours 1000, Velikonda R.F. at 2000, Sancherla R.F. at 2250, Kavalkunta R.F. at 1500 and Ganugapenta R.F. at 2000 feet.

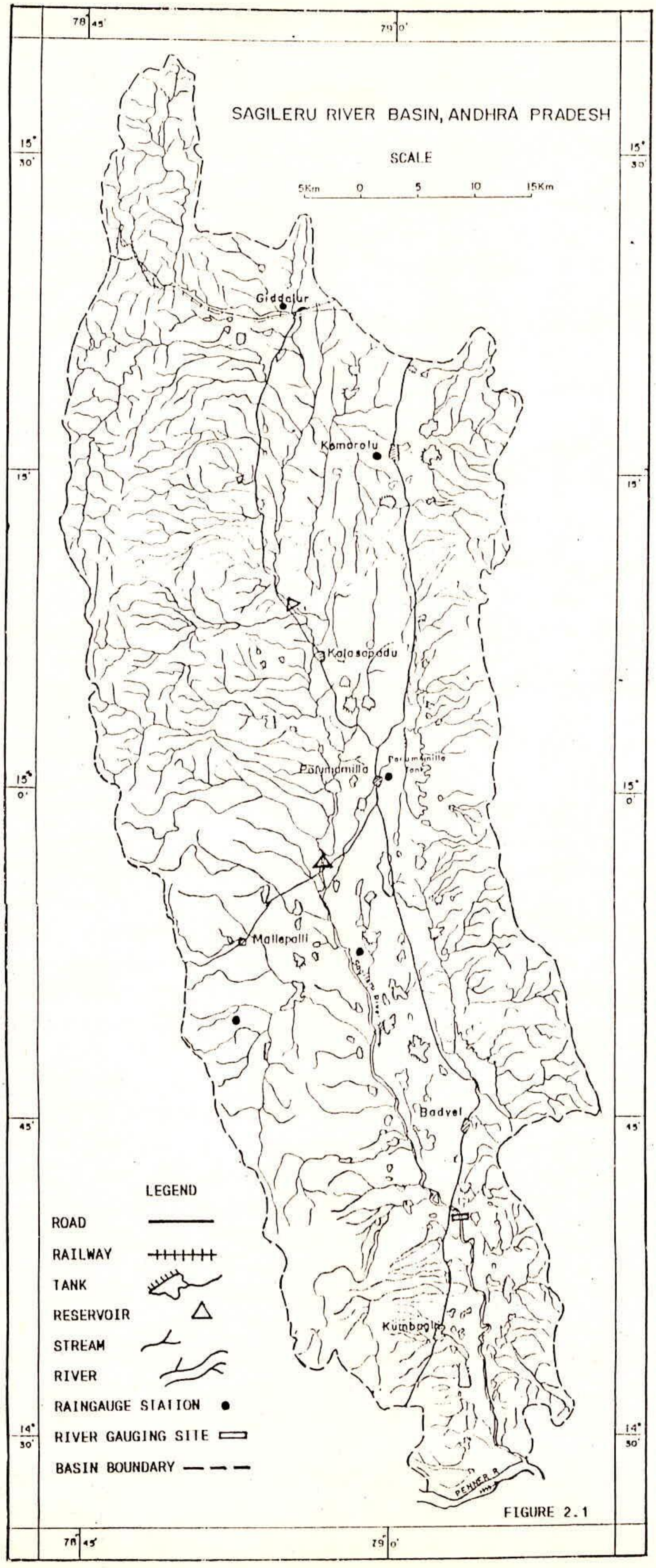


FIGURE 2.1

COURTESY: A.P. STATE REMOTE SENSING APPLICATION CENTRE (APSRAC) HYDERABAD

The hill ranges on the western side of the Sagileru River now called Nallamalais and Lankalais run northward along the boundary line. The Sagileru basin is formed between the parallel ranges of Nallamalais and Velikonda hill range in a beautiful regular development of all longitudinal valleys. Velikonda hills of the eastern ghats run northward going through the eastern borders of Sidhout and Badvel Taluks, forming the boundary line between Cuddapah and Nellore Districts.

2.4 Climate

The climate of Sagileru basin is generally regarded as unpleasantly hot which is probably due to the early setting in of high temperatures. The average maximum temperatures in April and May are $42^{o}c$ and $43^{o}c$ respectively. The temperature during January, May and October which may be taken as representative of winter, summer and monsoon months ranges from $16^{o}c$ to $35^{o}c$, $23^{o}c$ to $43^{o}c$ and $20^{o}c$ to $38^{o}c$ respectively. Though the basin is unpleasantly hot for about 4 months, the climate is quite tolerable for the rest of the year.

The Sagileru basin lies in medium rainfall zone as the annual average rainfall in the basin is 767 mm. The basin is under the influence of both the southwest and northeast monsoons. From the rainfall pattern it is observed that during early of the year, the rainfall is less. The southwest monsoon sets in during middle of the June, which though precarious, brings fair quantity of rains to the basin upto the end of September. There are heavy rains in the upper portion of the basin during this period. The northeast monsoon breaks in October and the rains continue till December. These rains are heavier in lower portion of the basin than the earlier rains. On the whole, the incidence of rainfall during southwest monsoon is greater than northeast monsoon in the basin.

The average annual potential evaporation measured at Brahmanapalli station in the Sagileru basin is 1714 mm.

2.5 Geology and Hydrogeology

The Sagileru basin comprises of shales and phyllites of Pullampet formation, occupying a major portion. Quartzites and limestones of the same stage occur in patches, occupying very little part of the basin. Bairenkonda quartzites occupy the north-western, south-western and eastern parts of the basin to a limited extent. The general trend of the formation is north-south direction with a little variation of 10^o to 15^o, dipping 60^o to 80^o due east. The shales and phyllites are well bedded and jointed in east-west, northwest-southeast, northeast-southwest directions. Fractures extending to depths of 30 to 70 meters below ground level are common in this formation expect near mounds and foot hills. Bairenkonda quartzites are hard and massive and rarely comprises of fractured zones.

Exploitation of groundwater in the basin is being done through dug wells, dug cum bore wells and bore wells. The depth of dug wells ranges from 8 to 14 m, with in-well bores extending to depths of 30 to 70 m in some of the dug wells. Bore wells are constructed to depths of 60 to 90 m. The average density of wells in the basin is about 3.2 wells per sq.km. The depth to water level varies from 12 to 15 m during pre monsoon and 6 to 10 m during post monsoon periods.

2.6 Land use and Cropping Pattern

The land use pattern of Sagileru basin is given in Table 2.1.

Table 2.1 Land use pattern of Sagileru basin

Sl.No	Land Use	Area (Sq Kms)	Percentage
01	Hills and Forests	1572	49
02	Uncultivable Land	825	26
03	Cultivable Land	806	25
	Total	3203	100

The principal crops grown in the basin in descending order of the areas covered by them are Paddy, Groundnut, Bajra, Jowar, Ragi, Vegetables and Sugarcane. Paddy is the wet irrigated crop and is grown mainly in the Kharif season i.e. from July to November. The second crop of Paddy during Rabi season is taken in a very small area in the ayacut of only few tanks. The Sugarcane is perennial and is another wet irrigated crop which covers a very negligible area in the basin. The remaining crops viz. Groundnut, Bajra, Jowar, Ragi and Vegetables come under dry irrigated crops i.e. only supplementary irrigation is provided to these crops. The groundnut and vegetables are grown in both the seasons of Kharif and Rabi while Bajra and Jowar are grown mainly in Kharif season only. Ragi is grown mostly in Rabi season.

2.7 Soils

The principal soil types in the sagileru basin are (1) Red Loam (2) Red Sand (3) Black Loam and (4) Black clay. Red Soils cover a major portion of the basin. Texturally, red soils comprise of course sandy loam, fine sandy loam and loams. These are sufficiently permeable to be well drained. Black soils are alluvial soils and occur in minute extent in the basin.

2.8 Surface Water Structures and Irrigation

Two medium projects are constructed across the Sagileru river (1) Upper Sagileru project (USP) and (2) Lower Sagileru Project (LSP). The Upper Sagileru Project constructed in 1896 near Diguva Thamballapalli Village in Badvel Taluk is an anicut across the river. This project does not have any direct command area. However, through its only canal i.e. left bank canal, it feeds 10 numbers of tanks which inturn irrigate an area of about 2210 ha. The lower Sagileru project constructed in 1960 in Badvel Taluk of Cuddapah district is a storage reservoir. This project also does not have any direct command area but feeds 34 number of tanks through its left bank canal. The right bank canal of this project is not yet operational. The location of these projects are shown in Figure 2.1.

3.0 HYSIM MODEL

3.1 Overview

HYSIM is a conceptual rainfall-runoff modelling system. The acronym HYSIM stands for HYdrologic SImulation Model. The model was originally developed by R E Manley in UK and has been used extensively in the United Kingdom and also in Madagaskar, Indonesia, Thailand, and Taiwan. The major applications of this model include the extension of flow data records, flood studies, data validation, simulation of groundwater, modelling of soil moisture, generation of flow data for ungauged catchment. The model used in the present study is a menu driven PC based version and contains the modes for both optimization and production runs. The rainfall-runoff model is only one component of the HYSIM system and other modules deal with data preparation, parameter estimation and graphics.

The model can use five types of input data as given below:

(i) Precipitation :- This is given as catchment areal average in mm per time increment.

(ii) Potential evaporation rate :- Estimates based on an empirical relationship or Tank data in mm per time increment.

(iii)Potential snow melt rate :- This can be based on degree day method or a more complex one in mm per time increment.

(iv) Discharge to/abstraction from river channels :- The net figure for these is used in cumecs.

(v) Abstraction from groundwater :- It is given in cumecs.

In addition, it can use a flow record given in cumecs, as input to the channels. A gauged flow record expressed in cumecs can also be used for comparison with the simulated flow.

The data can be of monthly, daily or any shorter time increment. The time increment for different types of data, the hydrologic calculations and the hydraulic calculations can all be independent of one another. The only restriction to this is that the time increments for any data less than a day must be in an exact integer ratio to one another. For example, one could use 2-hourly precipitation, 12-hourly PET and 6-hourly snow melt data as the ratios are 1:6(precipitation:PET), 2:1(PET:snow melt) and 1:3 (precipitation:snow melt). The time increment for the flow record used for comparison must be daily.

3.2 The Rainfall-Runoff Model

HYSIM uses mathematical relationships to determine the runoff from precipitation upon a catchment. These relationships use variables which change with time to define the state of the catchment, and time invariant parameters to define the nature of the catchment. The HYSIM has the capability to model the natural inhomogeneity of a catchment by sub-dividing the catchment into as many sub-catchments as necessary to have the reasonably homogenous sub-catchments with respect to soil types and meteorology. Similarly, the river channels can be divided into reaches with reasonably uniform hydraulic characteristics for the purpose of hydraulic routing.

The model can be divided into two parts, (1) Hydrology and (2) Hydraulics. The hydrology part is the heart of the model and deals with various hydrological processes which are responsible for production of runoff as received in minor channels in a catchment. The hydraulics part deals with the routing of runoff through major river channels in the catchment. The model has the conceptual modularity that the hydrologic processes can be simulated without the hydraulic routing component and also the routing component can be used without hydrologic simulation. The structure of the model is shown in Figure 3.1 and the various components of the model are briefly discussed below.

3.2.1 Hydrology

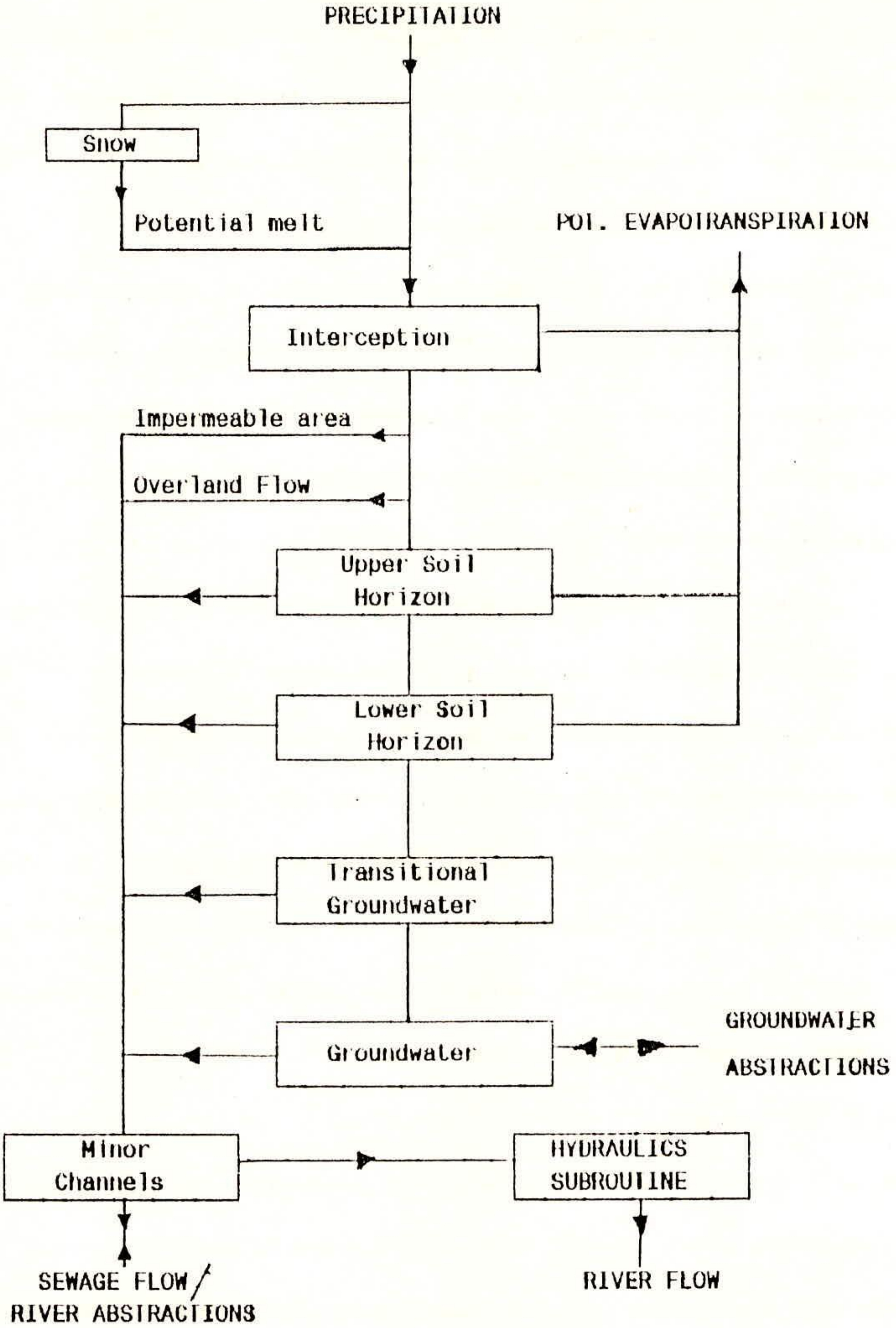
The model represents seven natural storages, these being: (i) Snow (ii) Interception (iii) Upper Soil Horizon (iv) Lower Soil Horizon (v) Transitional Groundwater (vi) Groundwater and (vii) Minor Channels.

(i) Snow Storage

Any precipitation falling as snow is held in snow storage from where it is released into interception storage. The rate of release is equal to the potential melt rate.

(ii) Interception Storage

This represents the storage of moisture on the leaves of trees, grasses etc. Moisture is added to this storage from



STRUCTURE OF HYSIM

Figure.3.1

rainfall or snowmelt. The first call on this storage is for evaporation which, experiments have shown, can take place at more than the potential rate particularly on the leaves of trees. This is allowed for in the model. Any moisture in excess of the storage limit is passed on to the next stage.

After leaving the interception storage, a proportion of the moisture is diverted to minor channel storage to allow for the impermeable proportion of the catchment. The next transfer of the moisture is to the upper soil horizon storage.

(iii) Upper Soil Horizon

This reservoir represents moisture held in the upper soil horizon, i.e. top soil. It has a finite capacity equal to the depth of this horizon multiplied by its porosity. A limit on the rate at which moisture can enter this horizon is applied, based on the potential infiltration rate. This rate is assumed to have a triangular areal distribution, as in the models of Crawford and Linsley and of Porter and Mc Mohan. The potential infiltration rate is based on Philip's equation, i.e.

$$X = \phi\, t^{0.5} + \chi\, t^{1.0} + \omega\, t^{1.5} + \ldots\ldots$$

Where, X is the distance travelled downwards by the wetting front, t is time since X = 0 and ϕ , χ, and ω are functions of soil type and condition. It has been shown by Manley that this relationship can be closely approximated to,

$$X = (2K\,Pt)^{0.5} + Kt$$

Where, P is the capillary suction (mm of water) and K the saturated permeability of the medium (mm/hr). This allows determination of the potential infiltration rate.

Brooks and Corey have shown that P can be expressed as,

$$P = P_b/S_e^{1/\gamma}$$

Where, P_b is the bubbling pressure (mm of water), γ is a parameter (called the pore size distribution index) and S_e is the effective saturation defined as,

$$S_e = (m-S_r)/(1.0-S_r)$$

Where, m is the saturation and S_r is the residual saturation, i.e the minimum saturation that can be attained by dewatering the soil under increasing suction. By simulating the moisture content in the upper horizon the forces causing movement of the water can therefore be simulated. The first loss from the upper horizon is evapotranspiration which, if the capillary suction is less than 15 atmospheres, takes place at the potential rate (after allowing for any loss from interception storage). If capillary suction is greater than 15 atmospheres evaporation takes place at a rate reduced in proportion to the remaining storage.

The next transfer of moisture that is considered is interflow (i.e. lateral flow). The rate at which this occurs is a very complex function of the effective horizontal permeability, gradient of the layer and distance to a channel or land drain. Brooks and Corey have also shown that the effective permeability of porous media is given by,

$$K_e = K(S_e)^{(2+3\gamma)/\gamma}$$

Where, K_e is the effective permeability (mm/hr) and the other terms are as defined previously. Because of its complexity no attempt is made to separate the individual parameters for interflow and it is given as,

$$\text{Interflow} = Rfac_1(S_e)^{(2+3\gamma)/\gamma}$$

Where, $Rfac_1$ is defined as the interflow run-off from the upper soil horizon at saturation. The final transfer from the upper horizon, percolation to the lower horizon, is given by,

$$\text{Percolation} = K_b(s_e)^{(2+3\gamma)/\gamma}$$

where, k_b is the saturated permeability at the horizon boundary and S_e is the effective saturation in the upper horizon. By combining the above equations the rate of increase in storage is given by,

$$\frac{ds}{dt} = i-(Rfac_1+K_b)S_e^{(2+3\gamma)/\gamma}$$

where, i is the rate of inflow and S and t are moisture storage and time respectively. Unfortunately this equation cannot readily be solved explicitly so it has been assumed that the total change in storage in any time increment is small compared to the initial storage. In this case the equation can be simplified and an approximate solution obtained. As a check for extreme situations the change in storage is constrained to lie within an upper and lower limit. The upper limit is defined by the level of storage at which the rate of outflow is equal to the rate of inflow. The lower limit results from setting i equal to zero in the above equation, in which case an explicit solution is possible.

(iv) Lower Soil Horizon

This reservoir represents moisture below the upper horizon but still in the zone of rooting. Any unsatisfied potential evapotranspiration is subtracted from the storage at the potential rate, subject to the same limitation as for the upper horizon (i.e. capillary suction less than 15 atmospheres). Similar equations to those in the upper horizon are employed for interflow runoff and percolation to groundwater.

(v) Transitional Groundwater

This is an infinite linear reservoir and represents the first stage of groundwater storage. Particularly in karstic limestone or chalk catchments many of the fissures holding moisture may communicate with a stream rather than deeper groundwater and the transitional groundwater represents this effect. Its operation is defined by two parameters: the discharge coefficient and the proportion of the moisture leaving storage that enters the channels. Being a linear reservoir the relationship between storage and time can be calculated explicitly.

(vi) Groundwater

This is also an infinite linear reservoir, assumed to have a constant discharge coefficient. It is from this reservoir that groundwater abstractions are made. As in the above case the rate of runoff can be calculated explicitly.

(vii) Minor Channels

This component represents the routing of flows in minor streams, ditches and, if the catchment is saturated, ephemeral channels. It uses an instantaneous unit hydrograph, triangular in shape, with a time base equal to 2.5 times the time to peak.

3.2.2 Hydraulics

The runoff from minor channels is routed through the major river channels. The HYSIM allows for dividing the river channels in a number of reaches with reasonably uniform characteristics and the runoff is routed through each of these reaches of the river channels.

The model uses the simplified form of the Saint Venant equations known as the kinematic wave method(Lightall & Withman) for hydraulic routing in the river channels. The velocity of a kinematic wave, V_W, is given by,

$$V_W = \Delta Q / \Delta A$$

Where, ΔQ is the incremental change in flow and ΔA is the incremental change in area.

The equations for Manning's formula when applied to a triangular and a broad rectangular channel can be given as,

$Q \propto A^{4/3}$ for triangular channel

$Q \propto A^{5/3}$ for rectangular channel

Since most channels fall between these two extremes then it has been assumed that,

$$Q = C A^{1.5}$$

For flow in bank, A as a function of Q, is calculated by re-arranging the above equation. And for flow out of bank, exponential relationships are developed at the start of the programme. They are of the form,

$$A = a Q^b$$

Where, a and b are constants. They are based on the geometry and roughness of the flood plain using Manning's equation. Two such relationships are used in the model, one for when the flood plain is filling up and one for when it is full.

3.3 Optimization

When running HYSIM there are three optimization options available as described below.

3.3.1 No Optimization

In no optimization mode the model is run once only and then the print option is available. This option is useful in validation of the model and production runs.

3.3.2 Single Parameter Optimization

It uses the Newton-Raphson method of successive approximation. In this option, only one chosen parameter is adjusted until the simulated mean flow is corrected to within a given degree of accuracy. This option is used to obtain a water balance at an early stage of fitting.

3.3.3 Multiple Parameter Optimization

It is based on Rosenbrock method in which several parameters are varied incrementally to get the best values of objective functions. The method searches for a minimum contour of error in multi-dimensional space. It starts by incrementing each parameter by 10 %. If this is successful then the step is multiplied by a factor of 3.0 and in case of unsuccess, by a factor of -0.5. If a step would take one of the parameters outside its acceptable limits the step size is progressively reduced until a satisfactory one is obtained. A trial is considered successful if it does not lead to a worsening of the objective function. This process is continued for each parameter until either an improvement followed by a failure has occurred for that parameter or an almost negligible improvement has been followed by another very small improvement. A new set of directions is then searched, one of which is the direction from the starting point to the final value after the first stage and the others are orthogonal (at right angles) to this one. The process is repeated until either the maximum permissible number of iterations is exceeded or the improvement between stages is less than a specified amount.

For the Rosenbrock method three objective functions are available in the model as given below.

(i) The Proportional Error of Estimate (PEE) defined by,

$$PEE = \{\Sigma ((F-F_R)/F_R)^2/(n-1)\}^{0.5}$$

Where, F is the simulated mean daily flow, F_R the recorded daily flow and n the number of days used for the calibration. This function leads to minimisation of proportional errors, e.g, an error of 1 cumec when the recorded flow is 10 cumecs has the same weight as an error of 0.1 cumec when the flow is 1 cumec. The PEE is especially useful when only low flows are of interest.

(ii) The Reduced Error of Estimate (REE) defined by,

$$REE = \{\leq(F-F_R)^2/\leq(F-F_m)^2\}^{0.5}$$

Where, F_m is the mean daily flow. This function gives equal weight to equal errors, e.g. an error of 1 cumec has the same weight whether the recorded flow is 10 cumecs or 1 cumec. The REE should be used for flood modelling purposes.

(iii) The Extremes Error of Estimate (EEE) defined by,

$$EEE = \{(\leq((|F-F_R|*|F-F_m|)/(F_R*F_m)))/(n-1)\}^{0.5}$$

This function gives much greater weight to the extremes be they high or low flows and is therefore a general purpose objective function. It should be tried first and only if adequate results are not obtained should one of the other two be tried.

Because of the data inadequacy the optimum of the objective functions may occur when the simulated mean and standard deviation are different to those recorded. To allow for this the objective function can be constrained. A maximum acceptable error in the mean flow, $EM_{max}\%$, and a maximum acceptable error in the standard deviation $ESD_{max}\%$ are selected. Based on the experience, the errors of 5% for the mean and of 10% for the standard deviation are taken as acceptable errors and incorporated in the programme. The objective function in this case becomes,

$$OF_{const} = OF \times CF_m \times CF_{std}$$

Where, OF is either the REE, the PEE, or the EEE, CF_m a correction factor based on the mean, CF_{std} a correction factor based on the standard deviation and OF_{const} the constrained objective function.

If the error of the mean is within the limits then CF_m is equal to 1.0, otherwise,

$$CF_m = 1.0 + (EM_{max} - EM)^2 / 10.0$$

Where, EM is the error in the mean.

CF_{std} is calculated in a similar way but using the error in the standard deviation.

4.0 DATA AVAILABILITY AND METHODOLOGY

4.1 Data Availability

The following data as available with various departments and organisations were collected and used in the study.

4.1.1 Rainfall

The daily rainfall data of six raingauge stations viz., Badvel, Giddalur, B.Koduru, Kumarolu, B.Mattam and Porumamilla located in the Sagileru basin are available for a period of four years from 1991 to 1994. The location of these raingauge stations are shown in Figure 2.1. Since the model requires mean areal rainfall as input, the daily mean areal rainfall over the basin was calculated using the Thiessen Polygon method. The plot of daily mean areal rainfall for the years 1991-1994 are given in Figure 4.1 to 4.4.

4.1.2 Streamflow

The actual streamflow data are required for comparison with the simulated flows during calibration and validation of the model. There is only one gauging site at Nandipalli on Sagileru river and the location of the same is shown in Figure 2.1. The catchment area upto the gauge-discharge site is about 2486 sq.kms. The daily discharges at this site as available with Central Water Commission from Jan., 1991 to Nov., 1994 were collected and used in the modelling study.

MEAN AREAL RAINFALL

OVER SAGILERU BASIN IN 1991

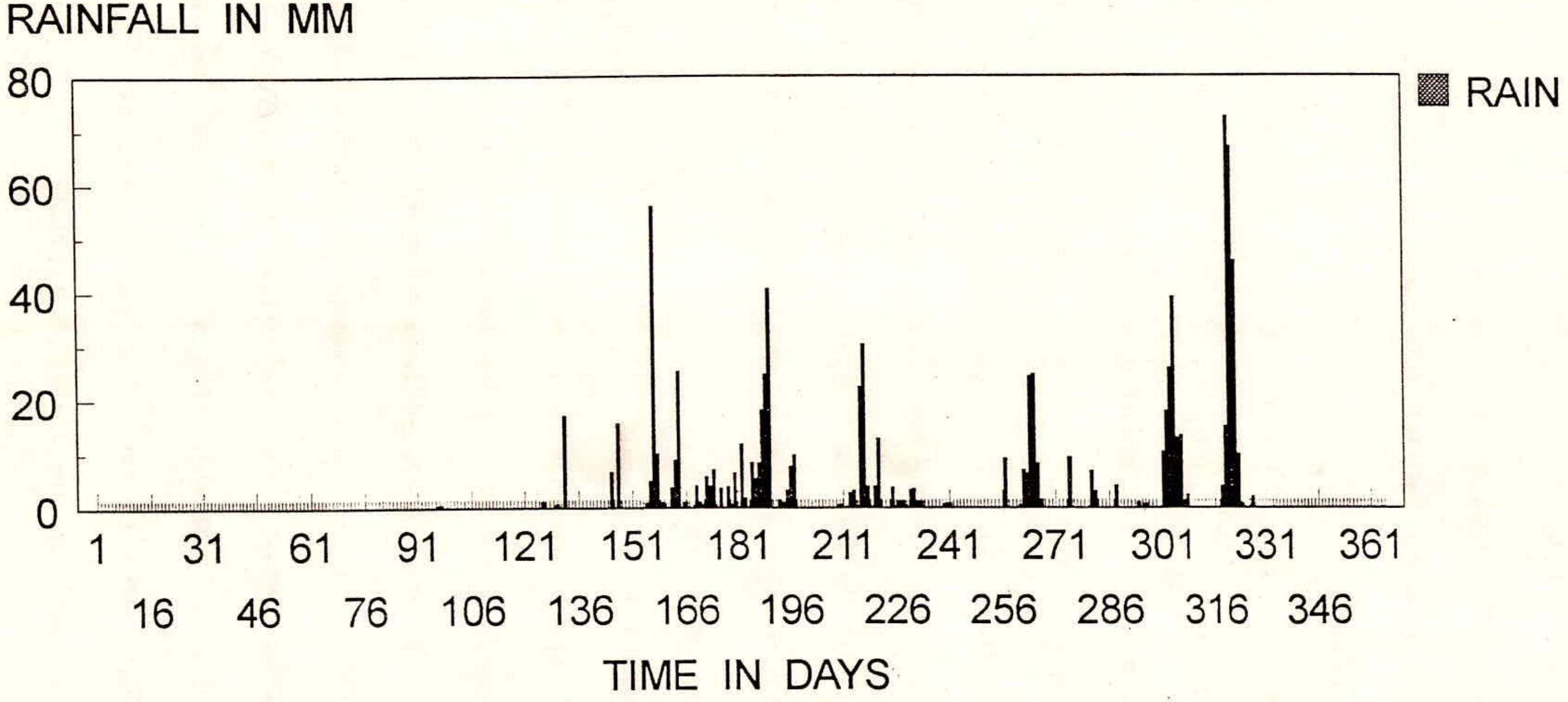


FIGURE 4.1

MEAN AREAL RAINFALL

OVER SAGILERU BASIN IN 1992

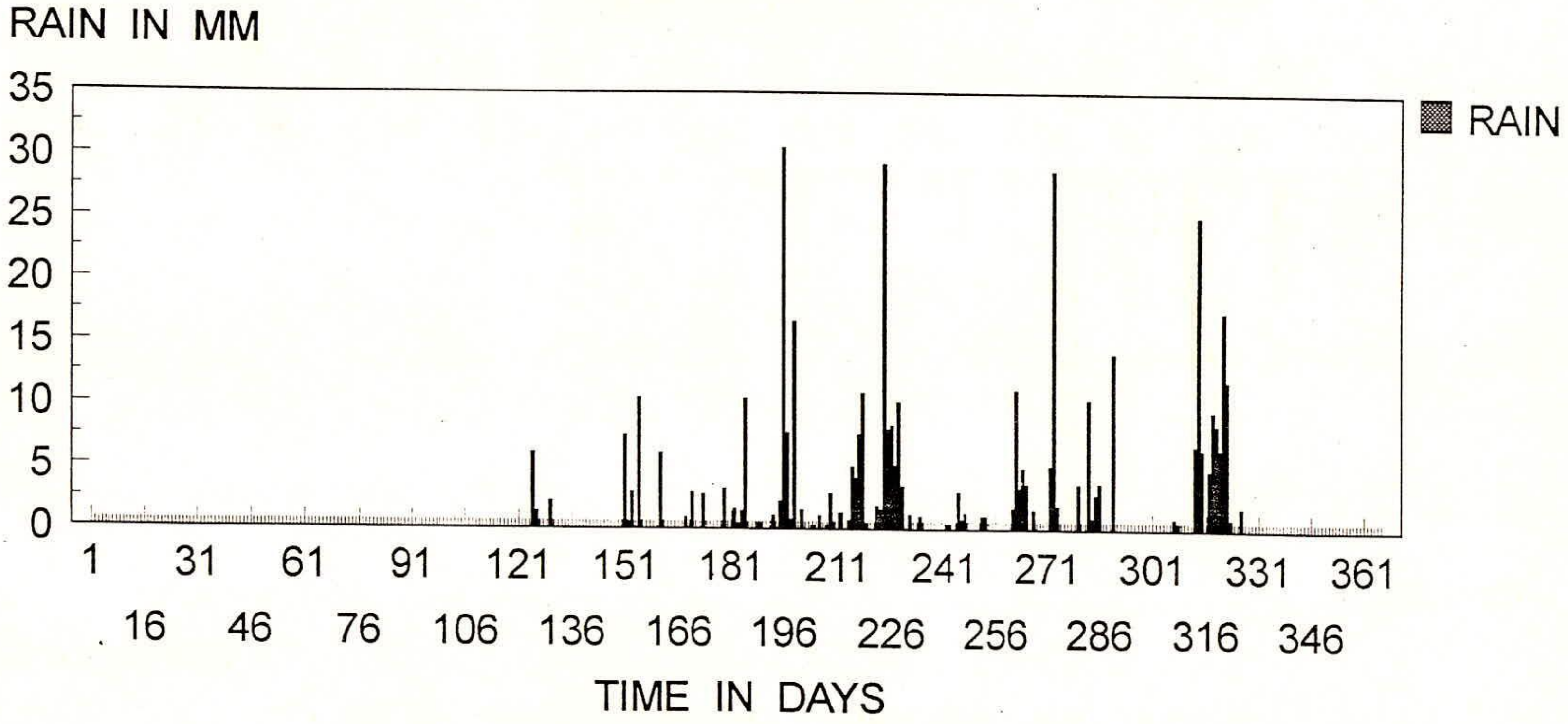


FIGURE 4.2

MEAN AREAL RAINFALL

OVER SAGILERU BASIN IN 1993

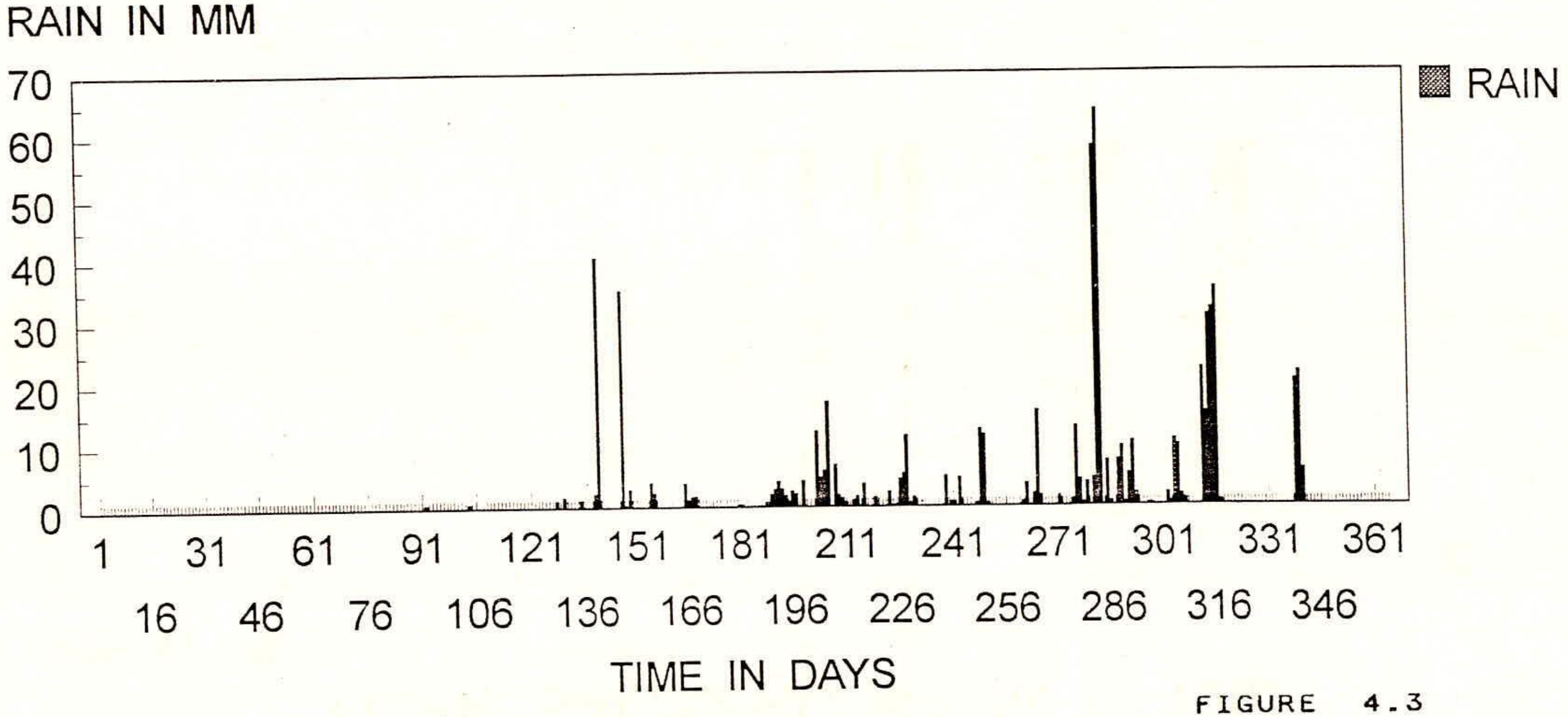


FIGURE 4.3

MEAN AREAL RAINFALL

OVER SAGILERU BASIN IN 1994

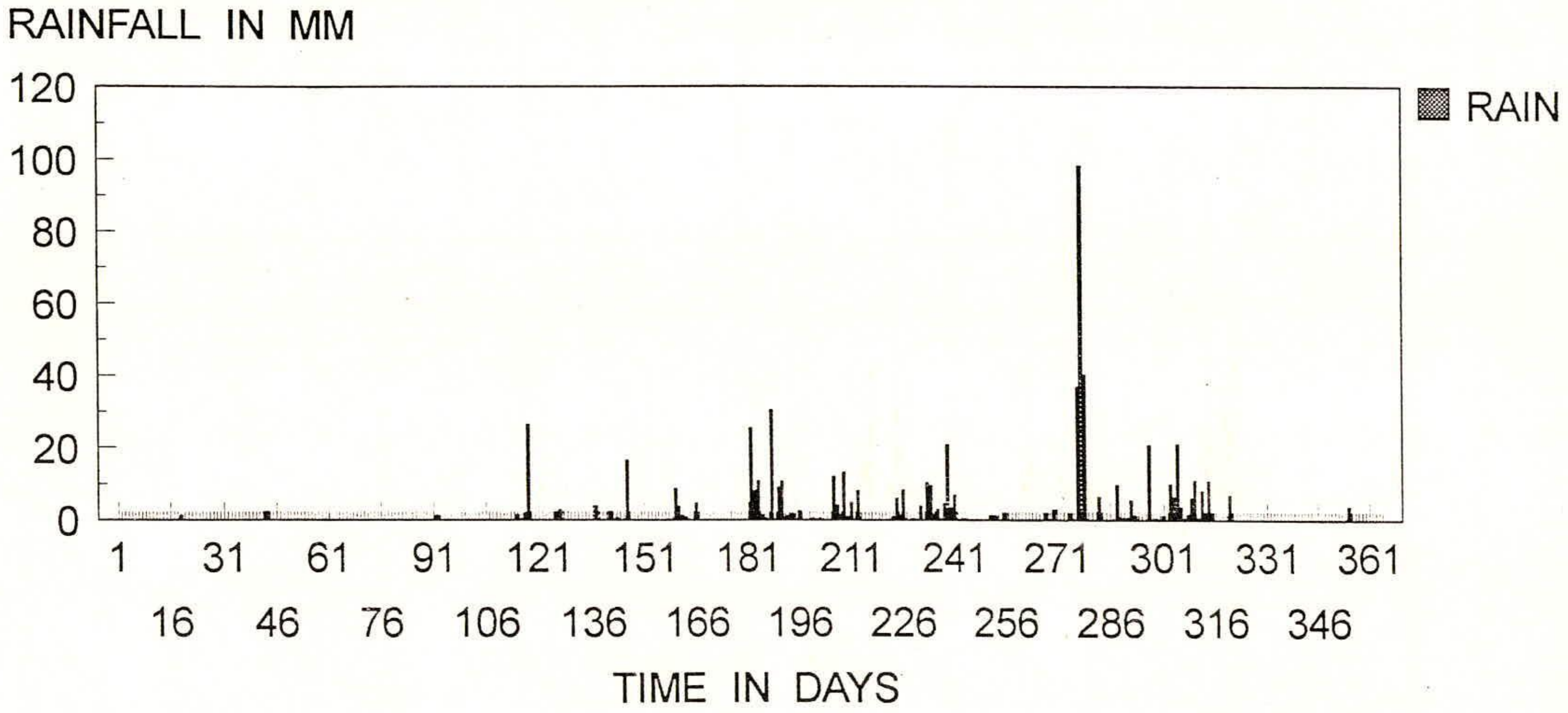


FIGURE 4.4

4.1.3 Potential Evapotranspiration

The mean monthly potential evapotranspiration values of Brahmanapalli meteorological station which is located in Sagileru basin are collected and used in the study.

4.1.4 In addition to above, the data/information pertaining to the morphology, hydrogeology, soils and extent of the basin are also available and used in the study.

4.2 Methodology

The HYSIM is used for modelling of daily flows of Sagileru river at Nandipalli. The methodology adopted in conducting the study is explained below.

4.2.1 Data Preparation

The entire catchment of 2486 sq.kms. upto Nandipalli gauging site is considered as a single unit. The study is carried out using 4 years of meteorological data i.e. from 1991 to 1994 for which the stream flow record is available. The data of first two years are used for the calibration and of remaining two years for the validation of the model. The daily values of point rainfall of 6 ordinary raingauge stations are analysed for daily mean areal rainfall. The data files of mean areal rainfall, the mean monthly potential evapotranspiration and the recorded daily flows are then prepared in the format as required by the Input file.

4.2.2 Model Calibration

The aim of model calibration is to obtain a unique and conceptually realistic parameter set which closely represents the physical system and gives the best possible fit between the simulated and observed hydrographs (Sorooshian, 1988). There are 22 hydrologic parameters in HYSIM which define the nature of the catchment and are used by the model to compute the transfer of moisture. These parameters do not change with time. Assigning suitable values to these parameters is crucial to the accuracy of the simulation. Similarly, ten parameters pertaining to the hydraulic characteristics of river channels are used by the model for routing through the major river channels. These parameters along with their possible values are discussed below.

A. Hydrologic Parameters

i) Interception storage - From 1 mm for grass land and urban areas upto 5 mm for woodland.

ii) Proportion of impermeable area - 0.02 for rural areas and upto 0.20 or even more for urban areas.

iii) Time to peak for minor channels (within catchment and not important enough to be dealt in routing section) - is given by,

$$T_p = 2.8\ (L/\sqrt{S})^{0.47}$$

where, L is stream length in Kms., S is stream slope in m/kms. and T_p is time to peak in hours. The value used for this parameter should be the average value obtained from 4 or 5 small streams.

iv) Total available Soil moisture storage - is given by,

total soil moisture storage

= rooting depth x porosity x (1-residual saturation)

The residual saturation is moisture content below which a soil can not be dewatered by capillary suction and is approximately equal to that of the wilting point.Its value ranges from 0.1 for sand to 0.25 for clay soils.

v) Proportion of total moisture storage in upper horizon - A value of 0.3 may be used.

vi) Saturated permeability at the top of the upper horizon - Generally a value of 1000 mm/hr. can be adopted for a wide range of soils. A lower value can also be used for clayey soils.

vii) Saturated permeability at the base of the lower horizon - This parameter controls the rate at which the moisture leaves the soil layers.In a catchment with no groundwater it should have a value of zero. In catchments where ground water is present its value can vary from 1 mm/hr.for heavy soils to 100 mm/hr. or more for sandy or gravelly soils. This parameter has to be adjusted during calibration process.

viii)Saturated permeability at the horizon boundary - This parameter controls the rate at which moisture moves between the two horizons. Its value can vary from 5mm/hr. in clay upto 500mm/hr. or more in sandy or gravelly soils. This parameter also has to be adjusted during calibration process.

ix) Porosity - Its value ranges from 0.40 for sandy soils to 0.50 for silty clay type of soils.

x) Bubbling pressure - Its value ranges from 80mm for loamy sand upto 630 mm for clay loam.

xi) Discharge coefficient for transitional groundwater - This parameter represents the recession from transitional groundwater storage and its value is equal to the proportion of groundwater storage leaving per hour. It is estimated by hydrograph analysis.

xii) Discharge coefficient for groundwater storage - This parameter represents recession from lower groundwater storage and its value can be assessed by studying periods in a dry summer when little or no rain has fallen.Its value is given by,

$$DCAG2 = \log_e(f_1/f_2) / T$$

Where, DCAG2 is equal to the discharge coefficient, f_2 is the flow at the end of the time period chosen, f_1 is the flow at the start of the time period and T is the time period being studied in hours. Where the natural recession rate is complicated by groundwater abstractions, and/or discharges to the rivers, the following equation should be used.

$$DCAG2 = \log_e((f_1-a+b)/(f_2-a+b)) / T$$

where, a is the net sewage discharge over the period and b is the abstraction rate from groundwater.If there is no groundwater this parameter should have the value of zero.

xiii)Proportion of outflow from transitional groundwater that becomes runoff and enters channels - This parameter can be used to delay the response from groundwater. In this case, the parameter has to be given a value close to zero. This will route all flow through the main groundwater reservoir after passing through the transitional reservoir. This parameter is optimized during calibration.

xiv) Interflow runoff from upper soil horizon at saturation - This parameter given in mm/hr. controls the direct or lateral runoff from the upper soil horizon. It has to be adjusted during calibration process. However, as an initial estimate it can be set equal to the permeability at the horizon boundary.

xv) Interflow runoff from lower soil horizon at saturation - This parameter controls the direct runoff from the lower horizon. Initially this too can be set equal to the permeability at the horizon boundary which has to be adjusted later during calibration.

xvi) Precipitation correction factor - This parameter is adjusted to allow for the fact that the raingauges used may over or underestimate the true catchment rainfall. As a standard raingauge collects less than a ground level gauge this parameter is normally given a value of 1.04. However, a different value may also be used depending upon the evidence whether the rainfall is under or overestimated.

xvii) Potential evapotranspiration correction factor - This parameter is adjusted during the initial fitting period to obtain a water balance.

xviii) Factor for evapotranspiration from interception storage - The evaporation from interception storage generally takes place at a higher than the normal rate. So, a value of above 1.0 for grass lands upto 1.5 for wood lands may be assigned.

xix) Snowfall correction factor - A standard raingauge underestimates the catch of snowfall. So, a factor of around 1.5 depending upon the exposure of the gauge may be used when snowfall is being simulated.

xx) Ratio of contributing groundwater catchment area to surface catchment area.

xxi) Ratio of area not contributing to groundwater to surface catchment area.

xxii) Pore size distribution index - This parameter is one of the most important parameters in the model and controls the way in which the soils respond, appearing as an exponent in both the 'moisture/capillary suction' and 'moisture/effective permeability' relationships. Its value ranges from 0.09 for clay soils upto 0.25 for sandy soils.

B. Hydraulic Parameters

The following hydraulic parameters are required for each river channel section.

(i) base width, (ii) top width, (iii) flood plain width, (iv) channel depth, (v) flood plain depth, (vi) maximum flood depth, (vii) Manning's n for channel, (viii) Manning's n for flood plain, (ix) channel gradient, and (x) length of river channel.

The above hydrological and hydraulic parameters were estimated using the guidelines described above and the available information and maps of the basin, viz drainage map, soil map, hydrogeomorphological map, river cross sections and other available information pertaining to the basin. The initial estimates of these parameters were given as input to the model and then the model was calibrated to optimize the values of parameters which play an important role in computation of moisture transfer. The following procedure was adopted during calibration process.

(i) Run the model with initial estimates of parameters. At this stage the simulated flows may not closely resemble the recorded flows, however, at the same time the differences may not be very much unless there is error in the input data or its format.

(ii) Adjust the PET correction factor using the single parameter optimization option to obtain the same mean of recorded and simulated flow.

(iii) Run the model in multi parameter optimization option which uses Rosenbrock approach. If there is no groundwater then the three parameters which should be optimized are,

i) Permeability at the horizon boundary.
ii) Interflow runoff at saturation - upper horizon
iii) Interflow runoff at saturation - lower horizon

If groundwater is present the following parameter should also be included.

i) Permeability at base of lower horizon.

Update the parameter file for new values.

(iv) Run the model with the new parameters and plot the output. At this stage no further calibrations may be necessary but there may be certain aspects where improvements could be made. If there are consistent errors then the following should also be tried.

a) Are small summer storms consistently over or underestimated ? If so, adjust the impermeable run-off factor.

b) Is the total groundwater volume correct but the distribution in time wrong ? If so adjust the recession rates or the proportion of the transitional groundwater storage contributing to runoff.

c) Do the simulated flows change too soon, or too late, from summer conditions to winter conditions ? In the former case increase the total soil storage and in the latter reduce it.

d) Are major summer storms consistently over or underestimated ? In the former case increase the proportion of soil storage in the upper horizon, in the latter case reduce it.

For most of the above changes a comparison of recorded and simulated flows will also give a good indication of the size of the correction required.

e) The above approach is not suitable for optimizing the hydraulic parameters. The first check of the hydraulic parameters that should be carried out is that the values given by the model for bankfull discharge correspond to those known to occur. If they do not, check that the areas and depths of flow given are correct. If they are, adjust the individual values of manning's n to obtain the correct bankfull discharges.

For two or three minor flood events when the flood did not exceed bankfull, compare short time increment simulated and recorded flows. So that routing errors will not be masked by other errors, select events for which the model has correctly simulated the volume of the floods. If the shape is correct but the timing is wrong check the lengths of the channel sections. If the hydrograph shape is wrong adjust the channel roughness and the minor channel routing coefficient alternatively to obtain the correct shape. next select a few events when the bankfull discharge was exceeded by atleast a factor of two. If these events are not satisfactorily simulated then adjust the flood plain roughness to obtain the correct shape and timing.

4.2.3. Model Validation

The main objective of the validation process is to satisfy the following two conditions (Sorooshian, 1988).

i) The parameter values are conceptually realistic and,

ii) The confidence in the model's ability to forecast using the optimized parameter values is high.

The model validation was carried out by checking the model performance for a period of record not used in fitting the model. The model was run in no optimization mode for two years of data allocated for the purpose and the optimized parameter values as obtained during calibration were used without any change in the validation process.

5.0 RESULTS AND DISCUSSION

HYSIM is calibrated and validated for daily flows of Sagileru river at Nandipalli using four years of data from 1991 to 1994 (upto November). The split data approach is adopted in using the model i.e. the first two years of data from 1991 to 1992 are used for calibration and of the remaining two years for validation of the model.

The model calibration was done using both the single and the multiparameter optimization options by following the methodology as described in Chapter 4. The Extremes Error of Estimate (EEE) which is a general purpose objective function was selected in multiparameter optimization mode. The optimized values of various hydrologic and hydraulic parameters are given in Table 5.1 and the hydrographs of simulated and recorded flows for the calibration period are given in Figures 5.1 and 5.2. It is observed from the hydrographs that during 1991 the flow is overestimated on 6th June while it is underestimated on 8th July and 5th August. For the remaining period of the year the simulated peaks are almost matching with the recorded ones. The time of rise and fall of simulated hydrographs is also more or less matching with those of the recorded hydrographs. In the year 1992, the flows are overestimated during the periods 14th July to 20th July, 3rd August to 12th August and on 30 th September and the timings of hydrographs also differ from the

TABLE 5.1 Optimised values of model parameters

S.No.	Parameters	Values
	A. Hydrologic Parameters	
01.	Interception Storage	2.20 mm
02.	Impermeable proportion	0.05
03.	Time to peak for minor Channels	2.2 hrs.
04.	Soil moisture in upper soil horizon	223.83 mm
05.	Soil moisture in lower soil horizon	522.27 mm
06.	Staturated permeability at the top of the upper horizon	1000.00 mm/hr.
07.	Staturated permeability at the base of the lower horizon	0.291 mm/hr.
08.	Staturated permeability at the horizon boundary	579.75 mm/hr.
09.	Soil porosity	0.44
10.	Bubbling Pressure	190.00 mm
11.	Recession from transitional groundwater storage	0.723 E - 002/hr.
12.	Recession from lower groundwater stroage	0.125 E - 003/hr.
13.	Proportion of upper groundwater runoff that enters channel	0.51
14.	Runoff from upper soil horizon at saturation	64.98 mm/hr.
15.	Runoff from lower soil horizon at saturation	65.00 mm/hr.
16.	Correction factor for Precipitation	1.04
17.	Correction factor for PET	0.75
18.	Adjustment for evapotransipiration from interception storage	1.01
19.	Snowfall correction factor	Not used in the study
20.	Ratio of Groundwater to surface catchment	1.00
21.	Proportion of surface catchment without groundwater	0.00
22.	Pore size distribution index	0.20
23.	Catchment area	2486 sq.kms.
	B. Hydraulic Parameters	
01.	Average base width of river	30.0 m
02.	Average top width of river	60.0 m
03.	Flood plain width	100.0 m
04.	Average depth of river	4.5 m
05.	Flood plain depth	0.5 m
06.	Maximum flood depth	1.0 m
07.	Manning's n for river	0.03
08.	Manning's n for flood plain	0.1
09.	River gradient	0.002
10.	River length	125 kms.

SIMULATED AND RECORDED FLOWS

DURING CALIBRATION PERIOD OF 1991

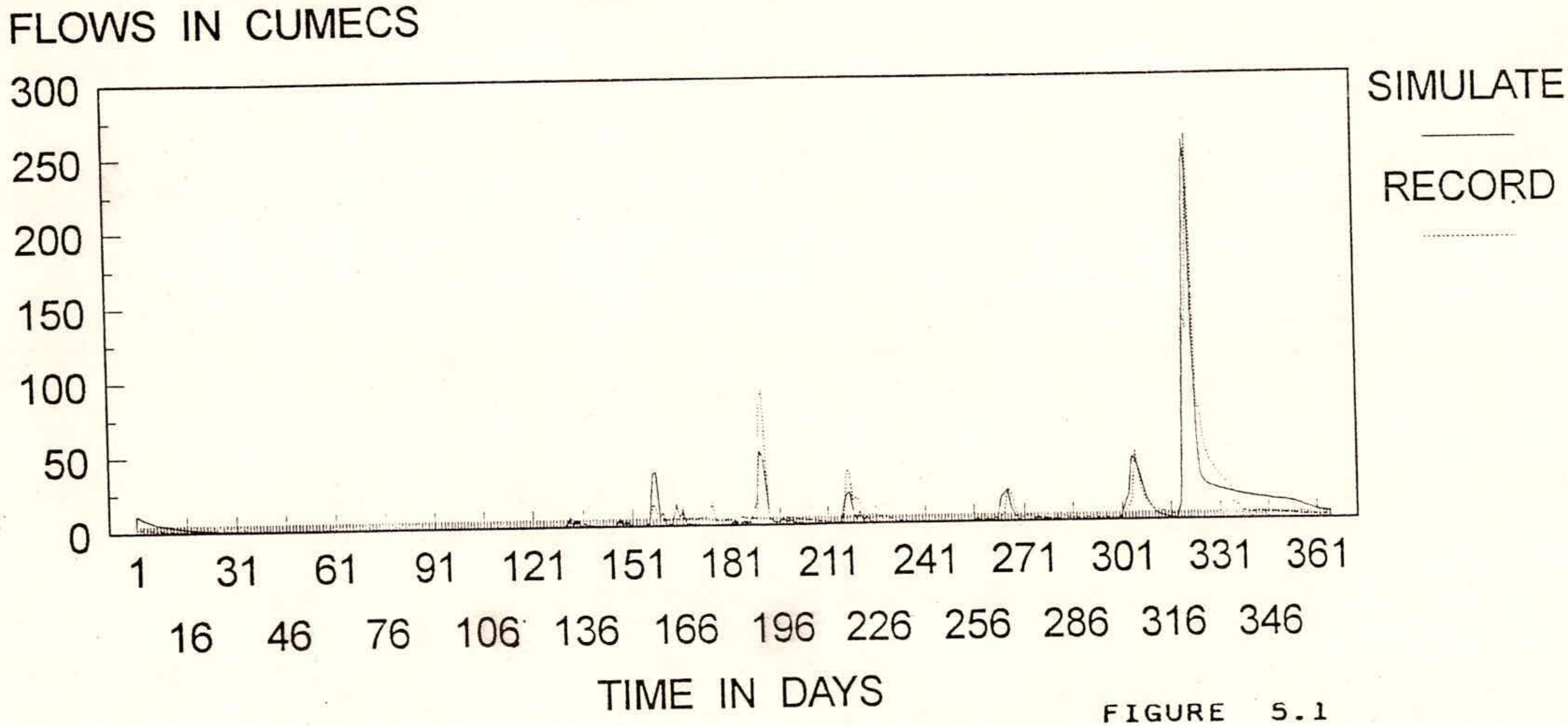


FIGURE 5.1

SIMULATED AND RECORDED FLOWS

DURING CALIBRATION PERIOD OF 1992

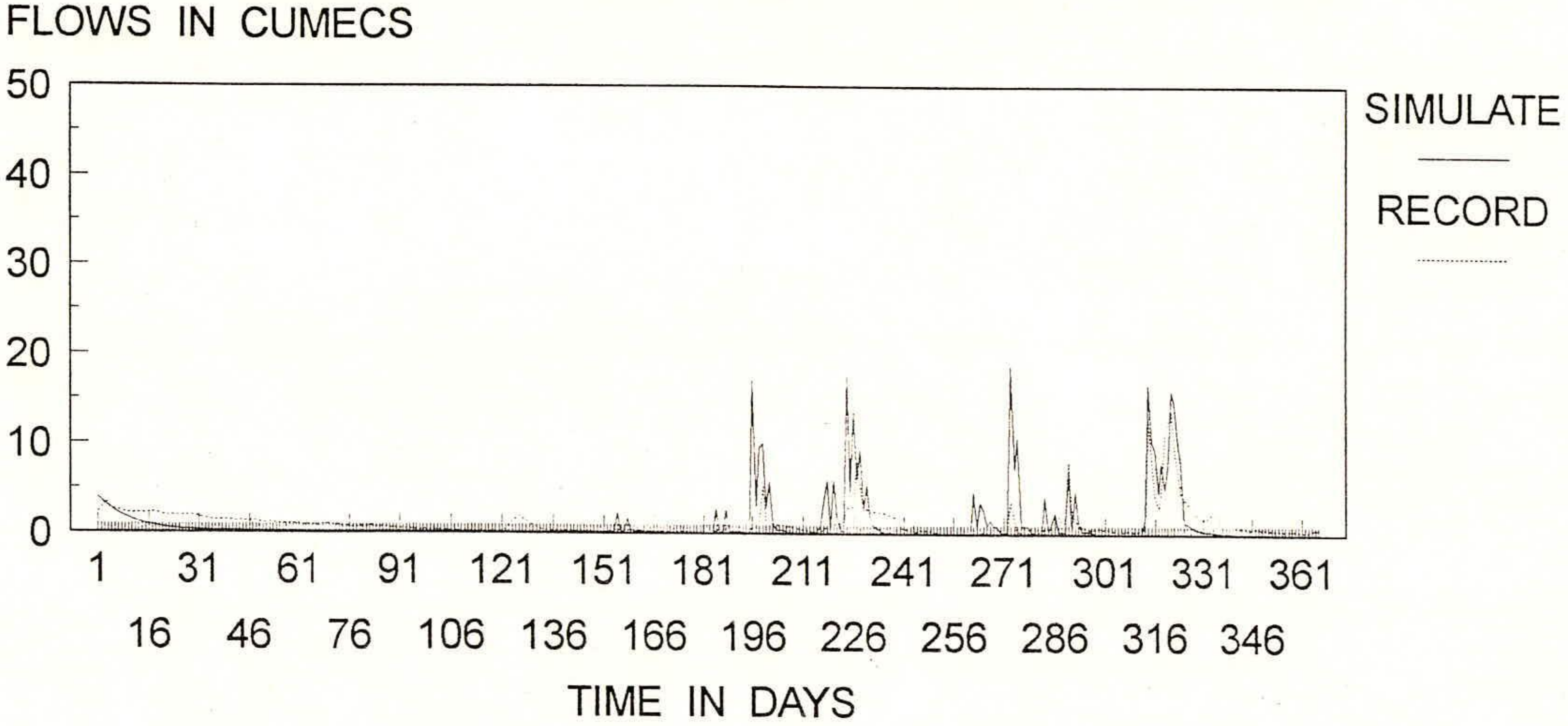


FIGURE 5.2

recorded hydrographs during the above periods. However, for the remaining part of the year the simulated peaks and their timings are comparable with those of recorded hydrographs. One of the reasons for difference in simulated and recorded flows during the initial months of the monsoon season may be that the model requires a warm up period to allow errors in the assumed initial soil moisture condition to become ineffective. Once the conditions are stabilized the model performs better. The second and probably the most important reason for the difference in simulated flows seems to lie in the fact that there are two storage structures on the Sagileru river upstream of the gauging site, and also a number of small irrigation tanks with their independent catchment area exist in the basin. The runoff from the catchment and the river discharges in the initial period of monsoon season are abstracted by these tanks and the reservoirs for their filling and only a controlled flow is released to the down stream of the reservoirs. This fact can further be justified by analysing the rainfall distribution charts as given in Figures 4.1 to 4.4. It is observed that despite good rains in the initial months of monsoon period the recorded flows are very negligible while the model is responding to these rains. The statistical summary of simulation for the calibration period is given in Table 5.2. The values of three objective functions viz., EEE, REE and PEE as achieved for daily flows during the calibration process are 1.06, 0.50 and 3.70 respectively. While the correlation coefficients for daily and monthly flow values are of the order of 0.875 and 0.964 respectively, the efficiency of simulation which is 75.46% and 91.97% for daily and monthly flows respectively is also good enough. The other statistical measures viz. mean and standard deviation of simulated flows for both the daily and the monthly flow values are also comparable with those of recorded flows. It was felt that the model calibration was in an acceptable stage and the calibrated values of parameters were used for validation of the model.

The hydrographs of simulated and recorded flows for validation period of two years i.e. for 1993 to 1994 (upto November 1994) are given in Figure 5.3 and 5.4 respectively. It is observed that the simulated flows during early period of monsoon season are higher than the recorded flows but they match well during later part of the monsoon season. This indicates the same trend as observed for the calibration period which is perhaps due to the reasons as mentioned earlier. The timings of simulated hydrographs tally with the recorded ones for most of the period of simulation. The statistical summary for the validation period is given in Table 5.3. The REE and PEE for the daily flow values are obtained as 0.52 and 7.08 respectively. The correlation coefficients for daily and monthly flow values are 0.91 and 0.98 respectively.

In general, it is observed that the model reproduces the flow hydrographs with a fair degree of accuracy. The model

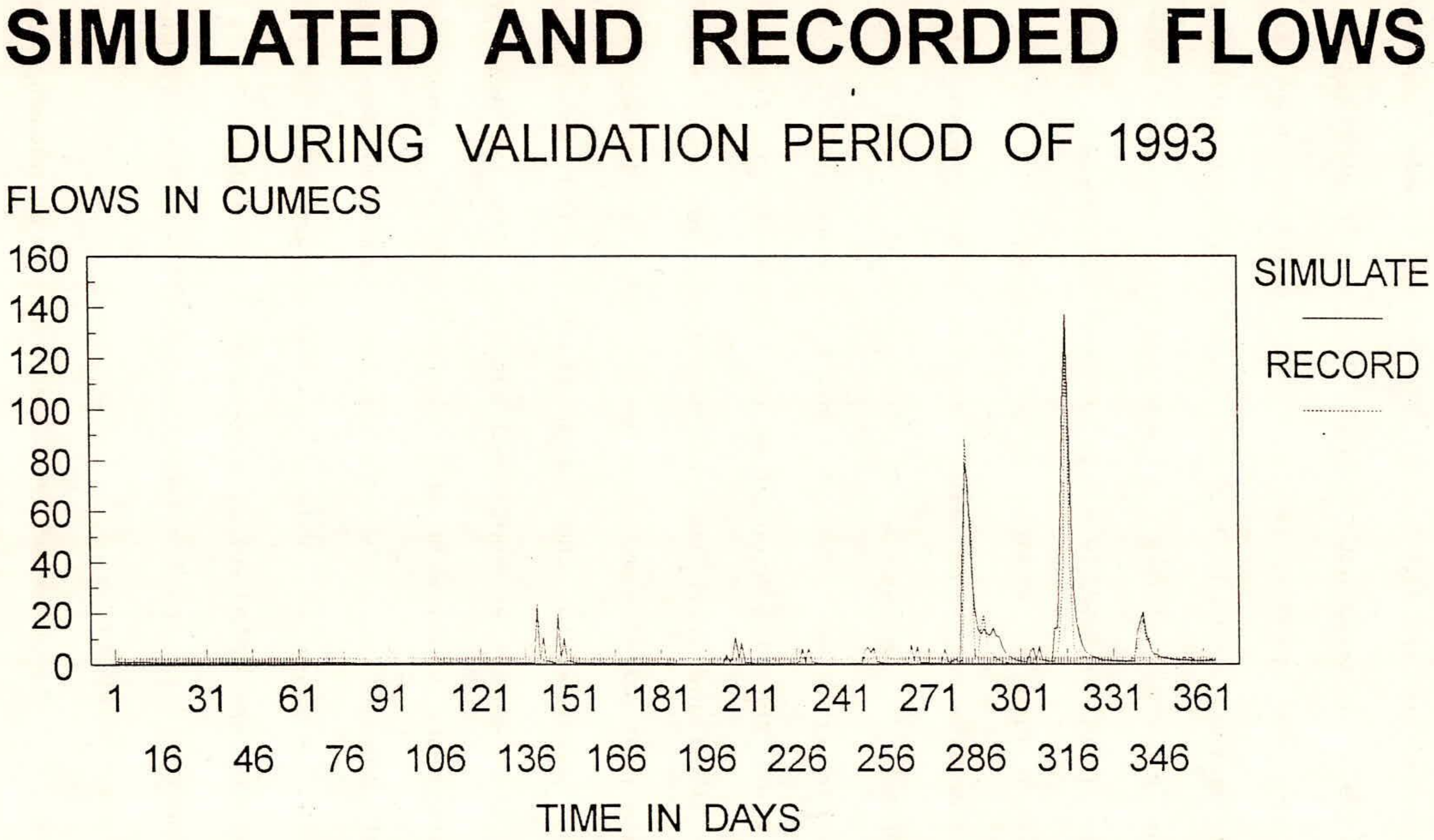

SIMULATED AND RECORDED FLOWS
DURING VALIDATION PERIOD OF 1993
FLOWS IN CUMECS
160
140
120
100
80
60
40
20
0
SIMULATE
RECORD
1
31
61
91
121
151
181
211
241
271
301
331
361
16
46
76
106
136
166
196
226
256
286
316
346
TIME IN DAYS

FIGURE 5.3

SIMULATED AND RECORDED FLOWS

DURING VALIDATION PERIOD OF 1994

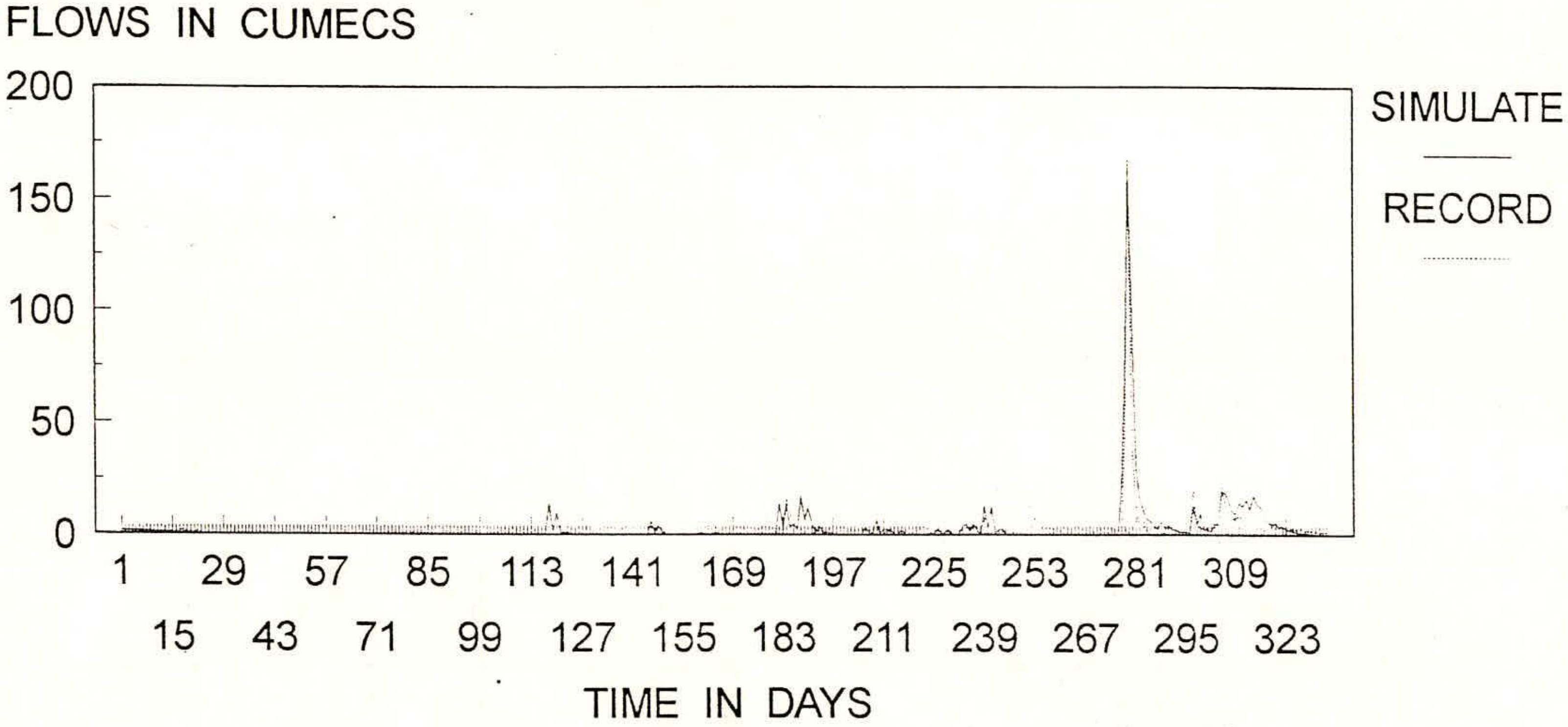


FIGURE 5.4

Table 5.2: Statistical summary of simulation for calibration period

S.No.	Statistical Indices	Daily Flow Values	Monthly Flow Values
01.	Mean		
	- Simulated flows	3.81	3.73
	- Recorded flows	4.03	3.94
02.	Standard deviation		
	- Simulated flows	15.51	7.80
	- Recorded flows	15.89	8.98
03.	Objective functions		
	- Extremes Error Estimate (EEE)	1.06	--
	- Reduced Error of Estimate (REE)	0.60	0.283
	- Proportional Error of Estimate(PEE)	3.70	--
04.	Correlation Coefficient	0.875	0.964
05.	Efficiency	75.46%	91.97%

Table 5.3: Statistical summary of simulation for validation period

S.No.	Statistical Indicies	Daily Flow Values	Monthly Flow Values
01.	Mean		
	- Simulated flows	8.56	6.42
	- Recorded flows	5.80	4.11
02.	Standard deviation		
	- Simulated flows	20.31	6.26
	- Recorded flows	17.27	4.04
03.	Objective functions		
	- Reduced Error of Estimate (REE)	0.516	0.834
	- Proportional Error of Estimate(PEE)	7.087	--
04.	Correclation coefficient	0.911	0.979
05.	Efficiency	73.35%	30.48%

performance could have been even better, had the data on reservoir operating policy been used in the study which is unfortunately not available.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the results obtained from the study the following conclusions are drawn.

1. The performance of HYSIM is found quite satisfactory both in terms of simulating the flow peaks and the time of their occurrence for the study basin.

2. As the model is capable of reproducing the flow hydrographs it can be used for tackling various hydrological problems such as extension of flow data records, checking the consistency of flow record and simulation of flows for ungauged catchments with reasonable degree of accuracy.

However, before making the general conclusions on the model's applicability and using the model for a real application, it is recommended that the model performance should further be assessed by applying it to few more Indian basins and using the data record of sufficiently long period.

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