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DAILY RAINFALL-RUNOFF MODELLING OF BRAHMANI RIVER AT RENGALI RESERVOIR

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ABSTRACT

A hydrologic simulation model, HYSIM has been applied to Brahmani river basin for modelling the daily flows of the river at Rengali reservoir. Keeping in view the large catchment area of 25,250 sq.km. at Rengali reservoir, the basin for the modelling purpose has been divided into two sub-basins viz., upper sub-basin and lower sub-basin. The upper sub-basin having a catchment area of 16,900 sq.km. upto Bolani gauging site is treated as a nominal sub-basin since the daily flows from this sub-basin as recorded at Bolani gauging site are available. The lower sub-basin below Bolani and upto the reservoir with its catchment area of 5,350 sq.km. is simulated for daily flows. The recorded flows from the upper sub-basin are routed through the lower sub-basin along with the flows from local runoff from the lower sub-basin to the reservoir site. The model is calibrated using 3 years of data and is validated for its performance for a set of next 3 years of data.

The results of the simulation study are quite encouraging. The model has reproduced the peaks and the shape of the hydrographs reasonably accurate despite the constraints that the PET values used in the study are normal monthly values and secondly, the flows at Rengali reservoir as used for comparison purpose are the average daily reservoir inflows computed from the reservoir capacity curves. From the analysis of the results, it is concluded that the model can be effectively used for forecasting of flows at Rengali reservoir which will be useful for planned regulation of the reservoir storage during high flow periods.

1.0 INTRODUCTION

Rainfall - runoff models are a tool which can contribute to the wider process of making decisions on the most suitable strategies for river basin management. They are not replacement for direct data sources but they allow the most to be made of existing data where such data are scarce. For example, in evaluating reservoir yield, streamflow records are rarely long enough to allow reliable estimates of yield to be obtained; longer records of rainfall are frequently available and a rainfall-runoff model can be used to simulate the river discharges and thus for extending the streamflow record for providing more information for reservoir yield evaluation. The increasing use of telemetry in the short term management of water resources systems now means that rainfall-runoff models can be employed as real-time flow forecasting tools. As far as the choice of a model is concerned, the selection is never a simple one and is largely based on the type of problem to be tackled, economic constraints and personal preferences as well as other hydrological considerations. Data availability is often a crucial factor in such a decision. However, any general criteria for model choice should be based on matching the requirement of a management problem with the complexities of the model used.

The present study aims at modelling the daily runoff of river Brahmani at Rengali reservoir. The river Brahmani originates in Ranchi district of Bihar and drains through Bihar, Madhya Pradesh and Orissa. The Rengali reservoir constructed across the river Brahmani in Orissa is a multi-purpose reservoir providing flood control in the river delta, power generation and irrigation. Forecasting of river flows at the reservoir site is, therefore, essentially required for operation of the reservoir during high flow periods. The total length of the river upto the dam site, through its longest path, is about 420 km., draining an area of 25,250 sq.km. Keeping in view the large catchment, the basin for the study purpose has been divided into two sub-basins i.e. upper and lower sub-basins. HYSIM ,which is a very versatile hydrologic simulation model having 22 hydrologic parameters for computation of moisture transfer and 10 hydraulic parameters for routing of flows through major river channels is used for simulation of runoff and routing of flows to the reservoir. The description of the model used, study area, methodology and the simulation results are presented in the following chapters of the report.

2.0 HYSIM MODEL

2.1 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 and 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 flows.

The data can be of monthly, daily or of any other 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.

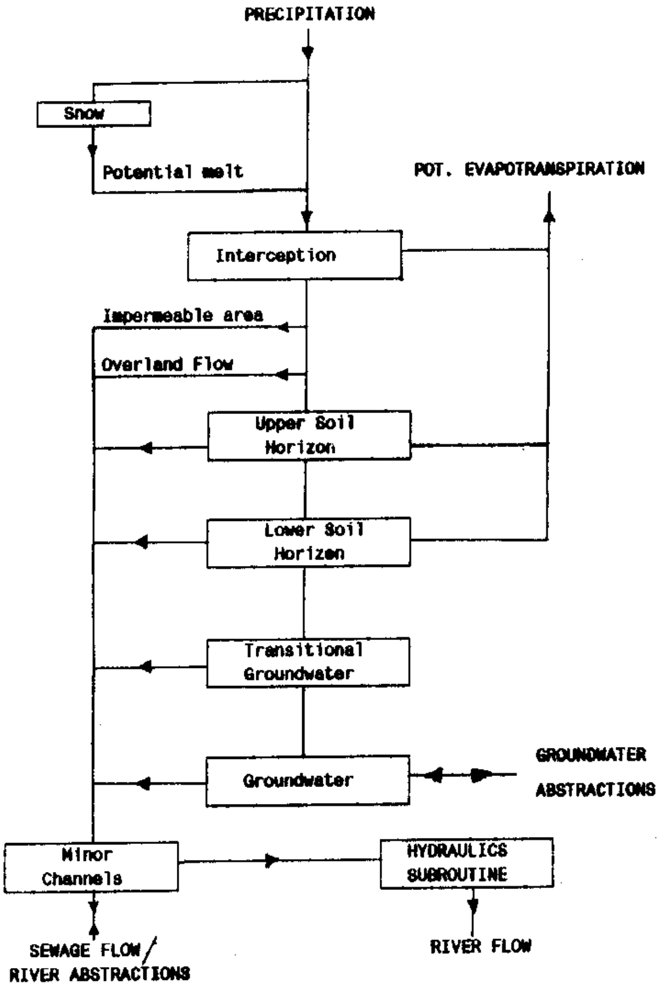
2.2 THE RAINFALL - RUNOFF MODEL

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. In case of more than one sub-catchment, the flows from upstream catchments are routed through the catchment being modelled together with flows from local runoff. For this option, either the recorded flows from upstream catchments may be used or they may be simulated separately for each of the upstream catchments.

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 2.1 and the various components of the model are briefly discussed below.

2.2.1 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.



STRUCTURE OF HYSIM

FIGURE 2.1

(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 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 outflow is equal to the 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.

2.2.2 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 (Lighthill & Witham) 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.

2.3 OPTIMIZATION

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

2.3.1 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.

2.3.2 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.

2.3.3 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 procers 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 minimization 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,

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

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,

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

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,

$$OF_{const} = OF \text{ X } CF_m \text{ X } CF_{std}$$

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.

3.0 GENERAL DESCRIPTION OF STUDY AREA

3.1 BRAHMANI RIVER BASIN

The river Brahmani, known as South Koel in the upper reaches, rises in Ranchi district of Bihar at an elevation of about 600 m above msl. The river initially flowing in a north-westerly direction takes a turn to the left and flows in south and south-easterly direction receiving many small tributaries on both the banks.

The Karo, the Sankh and the Tikra are the major tributaries of Brahmani river. The Karo originates in Chhotanagpur plateau of Bihar in Ranchi district at an elevation of 600 m above msl and flows for a total length of 112 km to join the South Koel in Singhbhum district of Bihar. It drains an area of 2,741 sq.km. Below this confluence the river is known as Koel. The tributary Sankh also rises in Ranchi district of Bihar at an elevation of 900 m above msl and traverses for some distance in the state of Madhya Pradesh before entering Bihar territory again. The tributary draining an area of 6,933 sq.km. flows for a total length of 196 km. and joins the Koel near Rourkela in Orissa. Below the confluence of Sankh and Koel, the river is known as Brahmani. The Tikra originating in Sambhalpur district flows for about 101 km. to join the Brahmani river . It drains an area of 2,528 sq.km. The Brahmani enters into its delta at Jenapur and has a catchment area of 36,260 sq.km. at head of the delta. The river carries very high discharges during floods. A highest flood discharge of 24,246 cumecs is measured at the delta head. A multi-purpose storage reservoir intercepting a catchment area of 25,250 sq.km. is constructed at Rengali to moderate the floods to 12,740 cumecs.

The total length of the Brahmani river from its origin to the outfall into Bay of Bengal at Damra mouth is about 785 km, of which 258 km is in Bihar and the rest is in Orissa. The total drainage area of the river is 39,033 sq.km, of which 15,769 sq.km. lies in Bihar, 22,364 sq.km. in Orissa and the remaining 900 sq.km. lies in Madhya Pradesh.

The river Brahmani passes through three distinct topographic regions. The upper reach of the river runs through hilly catchment of chhotanagpur plateau covered with dense tropical forests, the middle reach through erosional plains mostly situated in the district of Sundargarh, Sambhalpur and Dhenkanal, and the lower reach through deltaic plains near the sea shore .

There are a few number of medium and minor irrigation projects in the Brahmani basin. The projects which have already been completed include Pitamahal, Gohira, Rengali multi-purpose reservoir, Derjang, Aunli diversion weir and Ramiala dam. The total command area of these projects is reported to be 28,570 ha. In addition to above, the ongoing projects namely Kansbahal, Samal Barrage, Dadra Ghati and Sapua Badjore also envisage a command area of 2,47,740 ha. in the basin.

3.2 STUDY AREA UPTO RENGALI RESERVOIR

The modelling of Brahmani river is carried out for a drainage area of 25,250 sq.km. at Rengali reservoir. The study area lies between the latitudes $23^0\ 37'$ to $21^0\ 12'$ N and longitudes $83^0\ 55'$ to $85^0\ 48'$ E . As mentioned in section 3.1, the major tributaries of Brahmani in the study area upto Rengali dam are Sankh and Karo. Besides, a number of other small tributaries also join the river on both the sides. The Karo rises in Ranchi district of Bihar and after flowing for a distance of 112 km joins the South Koel (i.e. Brahmani as it is known in the upper reaches) in Singhbhum district of Bihar. The tributaries Sankh joins Brahmani at Panposh in Orissa. The flows from this upper part of the basin are being monitored at Bolani gauging site which is situated at about 290 kms of the river run having a drainage area of 16,900 sq.km. The Rengali mutipurpose reservoir is constructed across the river Brahmani at 420 kms. of the river. The total catchment area at the dam site is 25,250 sq.km., the free catchment between Bolani and the dam being 5,350 sq.km. The upper sub-basin upto Bolani is treated as a nominal sub-basin as the recorded flows from the sub-basin are available. The lower sub-basin of 5,350 sq.km. is simulated for daily flows which alongwith the recorded flows from upper sub-basin are routed to the Rengali reservoir. The map of the study area is given in Fig. 3.1.

The study basin is a fairly fan-shaped with an average slope of 1 in 650. The upper basin lies mostly in the northern plateau which is hilly and covered with tropical mixed forests. The lower basin is in erosional plains and is mostly converted into agricultural fields. The plain has been created in the process of erosion and has a soil cover of a few feet deep overlying the bed rocks in different stages of decomposition. The basin as it exists can not retain sub-soil water for future use and the runoff joins the river as quickly as possible.

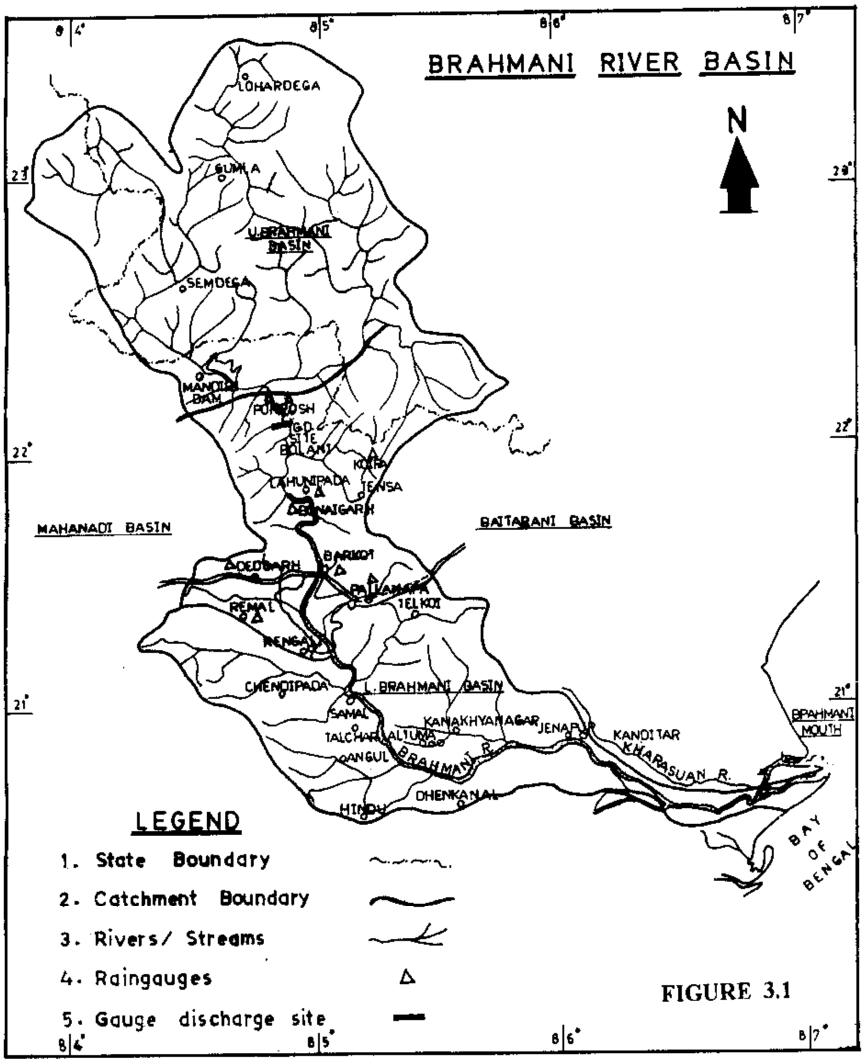

BRAHMANI RIVER BASIN
N
84°
85°
86°
87°
23°
22°
21°
LOHARDEGA
GUMLA
U. BRAHMANI BASIN
SEMDEGA
MANDIRA DAM
PANPOSH
G.D. SITE
BOLANI
KOIRA
LAHUNIPADA
JENSA
DEOGARH
BAITARANI BASIN
MAHANADI BASIN
DEOGARH
BARKOT
PALLAHARA
TELKOI
REMAL
RENGALI
CHENDIPADA
L. BRAHMANI BASIN
SAMAL
KANAKHYANAGAR
JENAPUR
KANDITAR
TALCHAR
ALTUMA
ANGUL
BRAHMANI R.
KHARASUAN R.
HINDOL
DHENKANAL
BRAHMANI MOUTH
BAY OF BENGAL
LEGEND
1. State Boundary
2. Catchment Boundary
3. Rivers/ Streams
4. Raingauges
5. Gauge discharge site

FIGURE 3.1

The climate of the basin is tropical with a hot summer and mild winter. The temperature rises upto 45^0 C during summer and falls down to 10^0 C during winter. The average annual rainfall is about 1500 mm of which nearly 90% is received from south-west monsoons during the period of June to October. The rainfall received in rest of the months has little significance as most of it is lost in evaporation.

The basin has two broad groups of soils, (a) red and yellow soils and (b) mixed red and black soils. Rice, Wheat, Maize, Ragi and pulses are the main crops in the basin. The land use pattern of the lower sub-basin (i.e. for which the simulation is carried out) is given in Table 3.1.

Table 3.1 : Land Use Pattern of Lower Brahmani Sub-basin

Land use	Area (Sq. Km.)	% age to total area
01. Forests	2057	38.40
02. Other Trees	397	7.40
03. Cultivated Area	2243	42.00
04. Pastures and Fallow	465	8.70
05. Land Put To Non-Agricultural Use	188	3.50
Total	5350	100.00

4.0 DATA REQUIREMENT AND METHODOLOGY

4.1 DATA REQUIREMENT

HYSIM requires an extensive data and information on hydrologic, hydraulic, topographic and soil characteristics of the river basin for estimation of model parameters, and rainfall and potential evapotranspiration for simulation of the flows. The following data as available with various field agencies were collected and used in the study.

4.1.1 Rainfall

A total of 8 ordinary raingauge stations viz., Remal, Deogarh, Barakot, Pallahara, Bonaigarh, Lahunipara, Lathikota and Koira, located in lower sub-basin were identified and their daily rainfall values of 7 years from 1988 to 1994 were analysed for mean areal rainfall using the Thiessen polygon method. The location of these raingauge stations is shown in Fig. 3.1, and the plots of daily mean areal rainfall are presented in Figures 4.1 to 4.7.

4.1.2 River Flows

The mean daily river flows from upper sub-basin as recorded at Bolani gauging site, and the mean daily inflows of Rengali reservoir are collected for a period of 7 years from 1988 to 1994 and used in the study. The location of these sites are shown in Fig. 3.1.

4.1.3 Potential Evapotranspiration

Since the actual daily PET data is not available, the normal monthly PET values as applicable for the study area are used.

4.1.4 Other Information pertaining to basin size, topography, soils, river characteristics were also collected and used in the study for estimation of model parameters.

4.2 METHODOLOGY

HYSIM is calibrated for daily flows of river Brahmani at Rengali reservoir by comparing the simulated flows with the available record of reservoir inflows. Keeping in view the large

MEAN AREAL RAINFALL IN LOWER SUB-BASIN OF BRAHMANI RIVER
DURING 1988

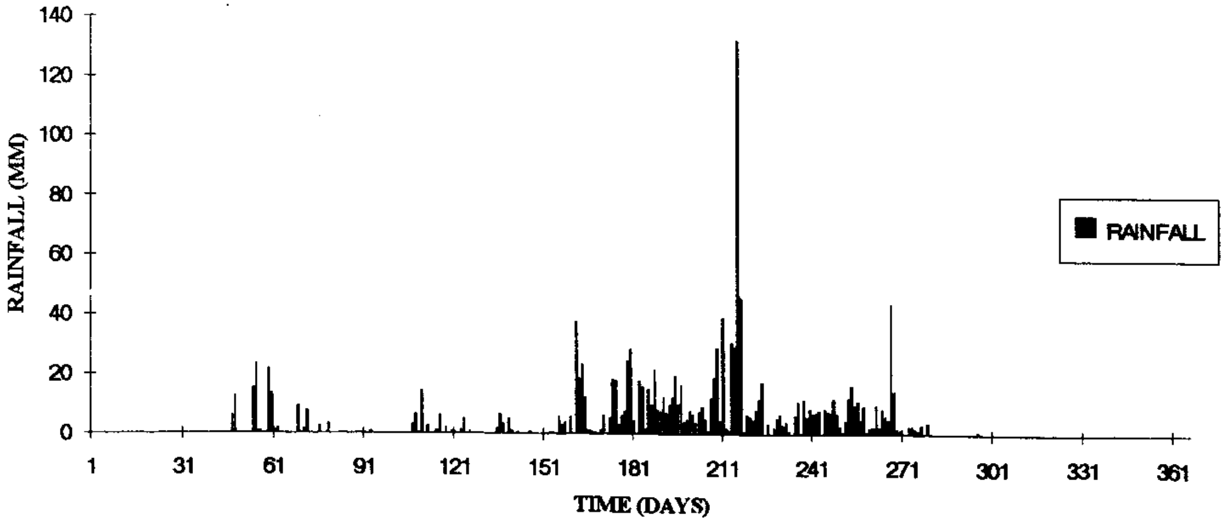


FIGURE 4.1

MEAN AREAL RAINFALL IN LOWER SUB-BASIN OF BRAHMANI RIVER
DURING 1989

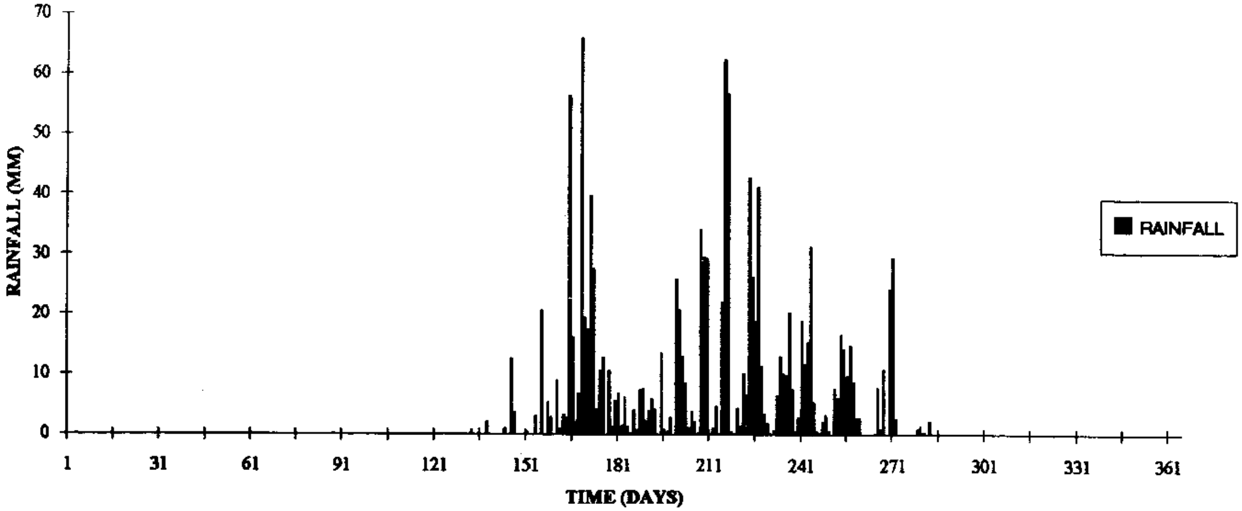


FIGURE 4.2

MEAN AREAL RAINFALL IN LOWER SUB-BASIN OF BRAHMANI RIVER DURING 1990

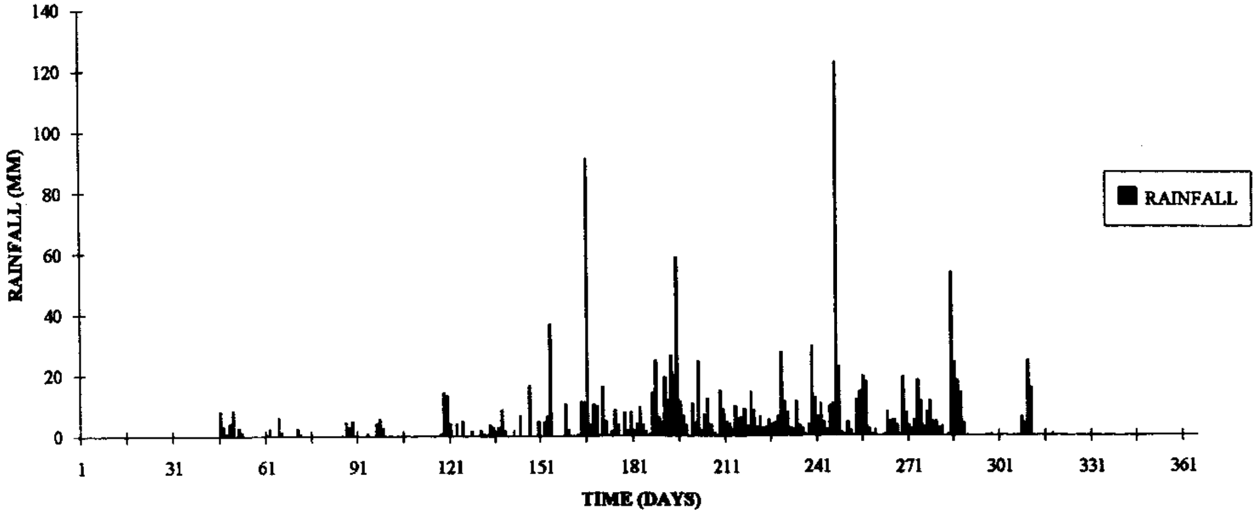


FIGURE 4.3

MEAN AREAL RAINFALL IN LOWER SUB-BASIN OF BRAHMANI RIVER DURING 1991

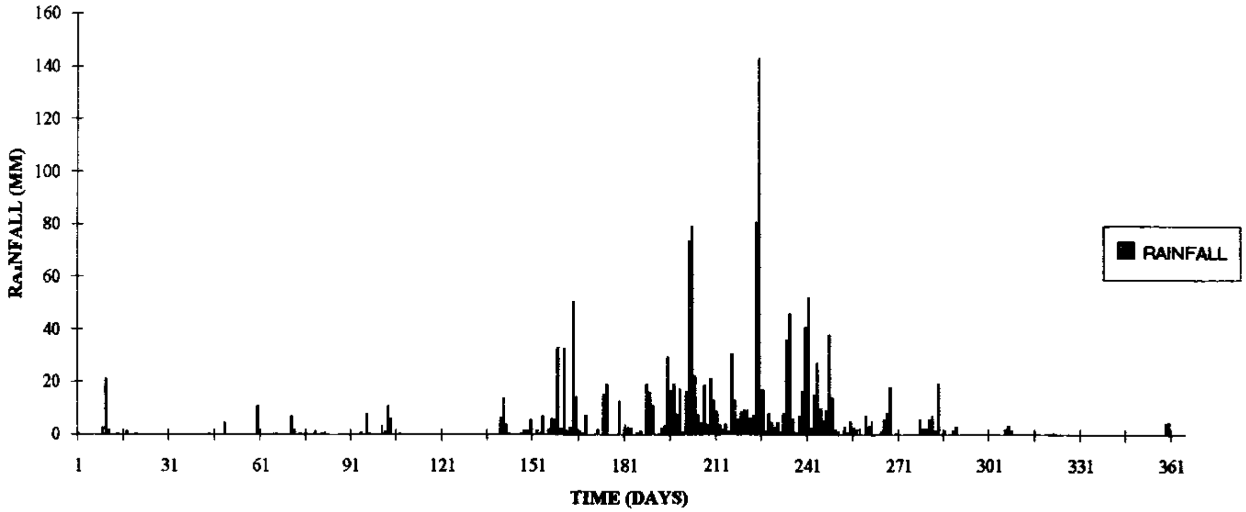


FIGURE 4.4

MEAN AREAL RAINFALL IN LOWER SUB-BASIN OF BRAHMANI RIVER DURING 1992

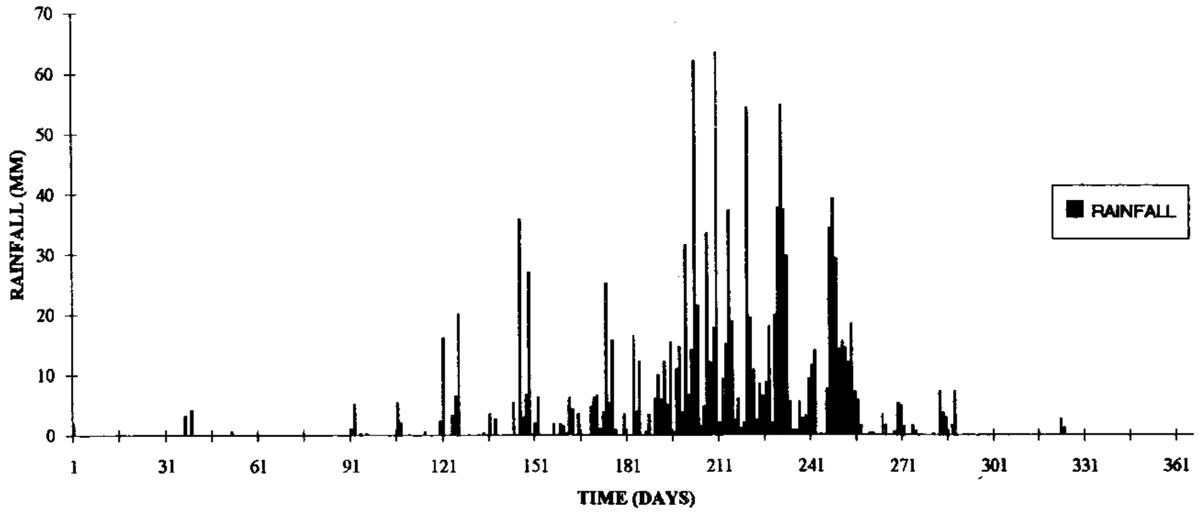


FIGURE 4.5

MEAN AREAL RAINFALL IN LOWER SUB-BASIN OF BRAHMANI RIVER DURING 1993

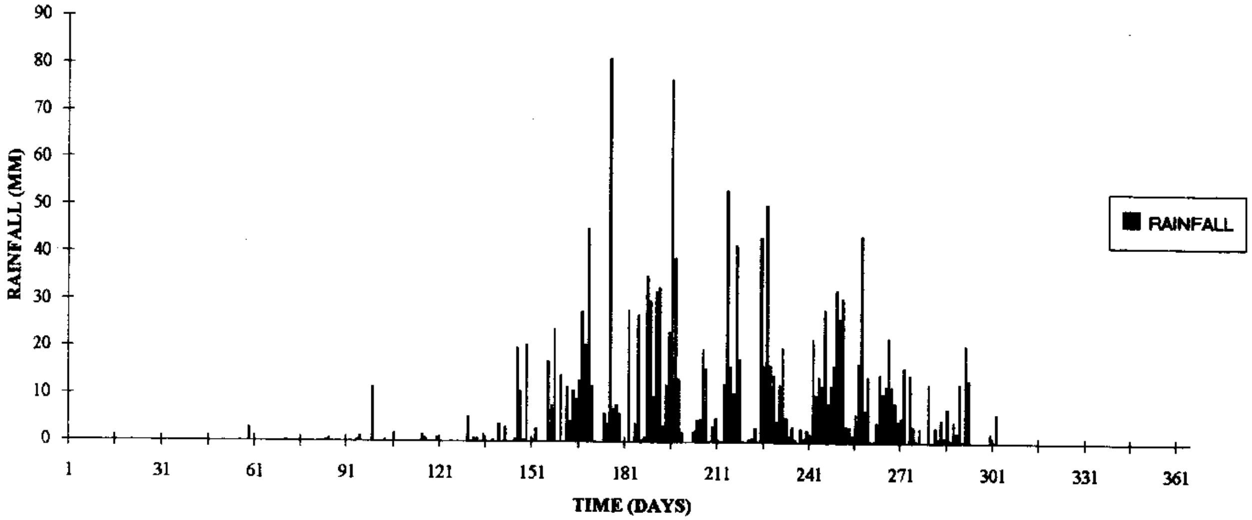


FIGURE 4.6

MEAN AREAL RAINFALL IN LOWER SUB-BASIN OF BRAHMANI RIVER
DURING 1994

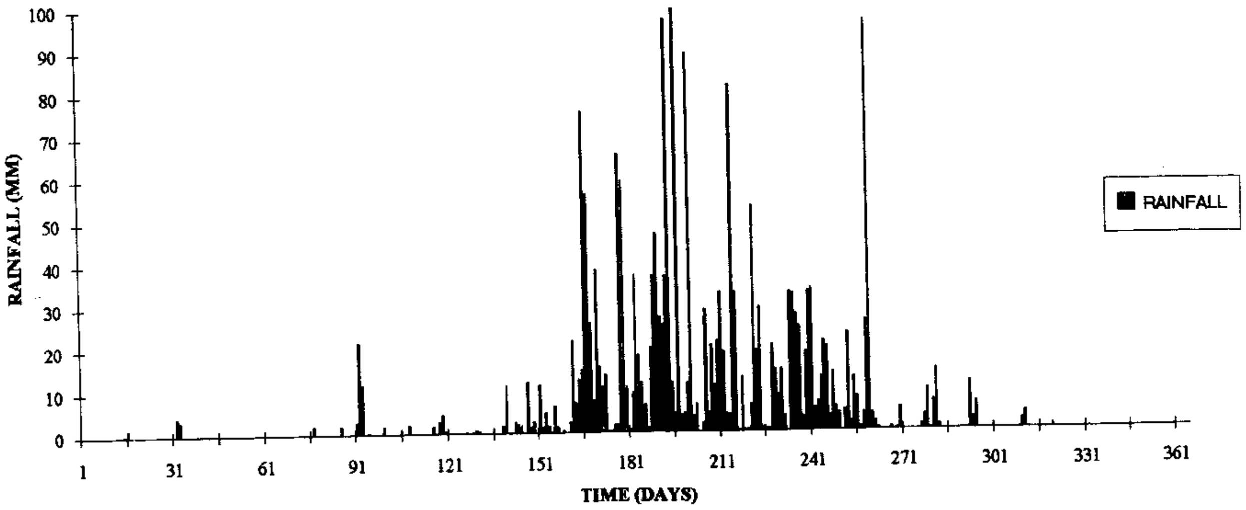


FIGURE 4.7

catchment area of 25,250 sq.km. at the dam site, the basin is sub-divided into two sub-basins viz., upper and lower sub-basins. The upper sub-basin with its catchment area of 16,900 sq.km. upto Bolani Gauging site is considered as a nominal sub-basin as the recorded flows at this site are available. The lower sub-basin having a catchment area of 5,350 sq.km. is taken between the Bolani gauging site and the dam. The flows from the lower sub-basin are simulated by the model using the parameter file and the rainfall and the PET data. The recorded flows from upper sub-basin are then routed by the model through lower sub-basin alongwith the simulated flows from local runoff.

The study is conducted using 7 years of data of which, first year of data is used for warming up of the model, the next 3 years for calibration purpose and the remaining 3 years are used for validation of the model. The catchment data files for mean areal rainfall, PET and recorded flows are prepared in the required format for calibration and validation period separately. The calibration and validation are performed as described below.

4.2.1 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,

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

where, L is stream length in Km, S is stream slope in m/km. 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 the 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 500 mm/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 80 mm 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,

$$DCAG2 = \mathrm{Log}_e(f_1 / f_2) / T$$

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.

$$DCAG2 = \mathrm{Log}_e((f_1 - a + b) / (f_2 - a + b)) / T$$

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 such a 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 on the basin. The initial estimates of the parameters which play an important role in computation of moisture transfer were further optimized through calibration process by adopting the following procedure.

(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) Select Extremes Error of Estimate objective function and run the model in multiparameter 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.

4.2.2 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 three 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

The daily flows of river Brahmani are modelled at Rengali reservoir using HYSIM. The model is calibrated using 4 years of data from 1988 to 1991; the first year of data being used for warming up of the model and the remaining 3 years for actual calibration. The performance of the calibrated model in reproducing the flows (validation) is assessed for a different set of data of 3 years from 1992 to 1994. The detailed procedure as adopted for calibration and validation of the model is discussed in Chapter 4.

The hydrographs of simulated and observed flows for the calibration period are given in Fig. 5.1, 5.2, and 5.3 and the optimized values of hydrologic and hydraulic parameters of the model for the study basin are given in Table 5.1. It is observed from these hydrographs that except for a very short period at the beginning of the monsoon seasons, the rising limbs and the recession limbs of the simulated hydrographs match very well with those of the observed hydrographs. Further, it is also observed that the simulated peak values in most of the cases are very close to the observed peak values. The reason for poor simulation at the beginning of the monsoon seasons seems to lie in the fact 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 statistical summary of simulation for calibration period is presented in Table 5.2. It can be seen from the table that while the correlation coefficient for the daily and monthly flow values is achieved as high as 0.961 and 0.997 respectively, the model efficiency of simulation for the corresponding flows is also of the order of 92.25% and 99.0%. The other statistical measures viz., mean and standard deviation of simulated flows are also comparable with those of observed flows.

The hydrographs of simulated and observed flows for the validation period are given in Fig. 5.4, 5.5 and 5.6. From these validation hydrographs it is observed that the flows in the later part of the year 1993 are slightly over estimated while for the corresponding period in 1994 are under estimated. It will be worthwhile here to mention the data limitation that the PET values used in the study are the normal monthly values as the actual daily PET values for the study area are not

SIMULATED AND RECORDED FLOWS FOR CALIBRATION PERIOD OF 1989

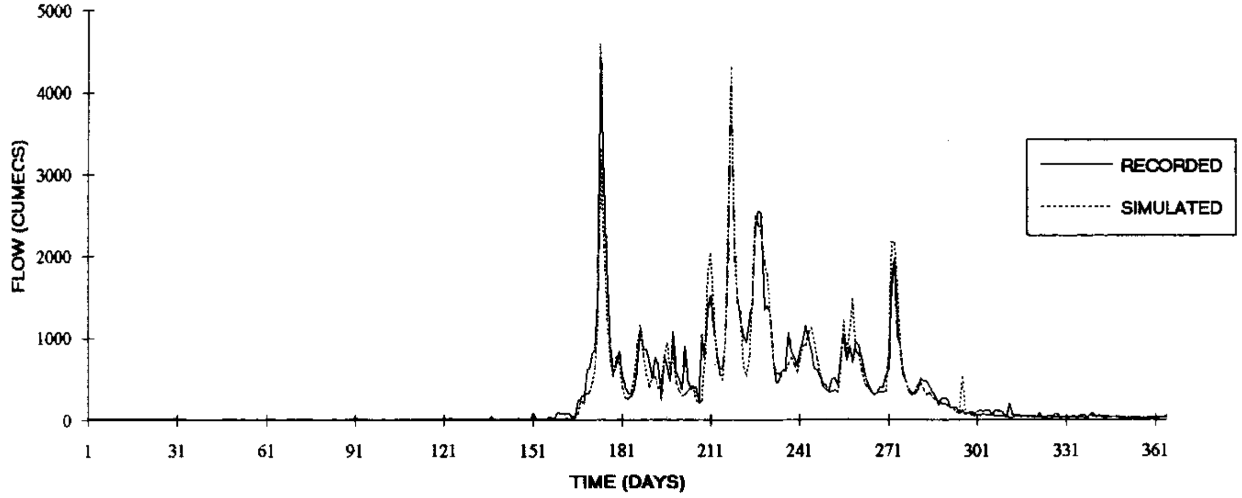


FIGURE 5.1

SIMULATED AND RECORDED FLOWS FOR CALIBRATION PERIOD OF 1990

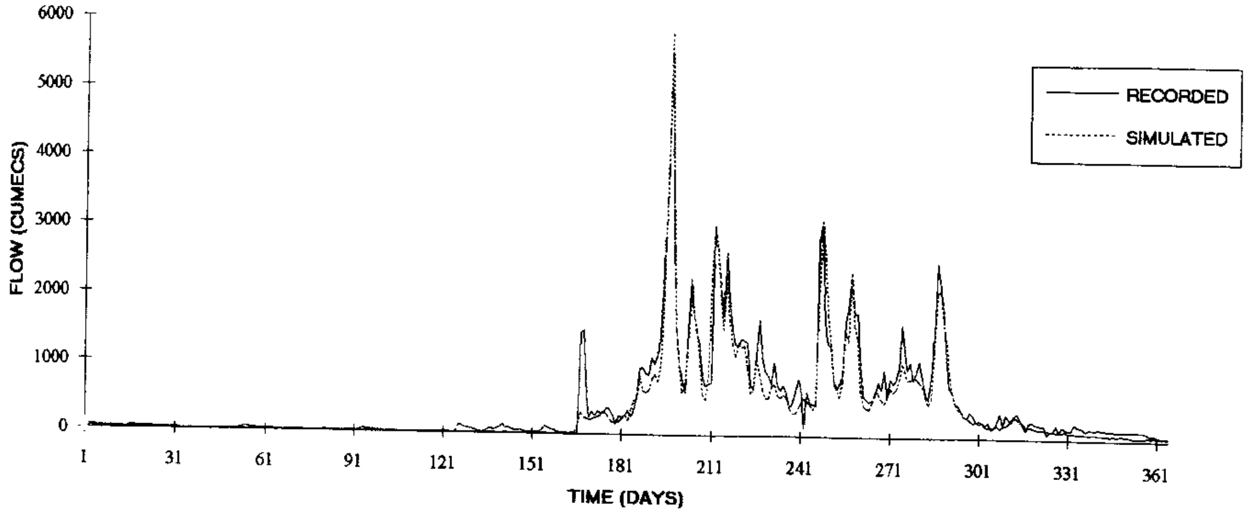


FIGURE 5.2

SIMULATED AND RECORDED FLOWS FOR CALIBRATION PERIOD OF 1991

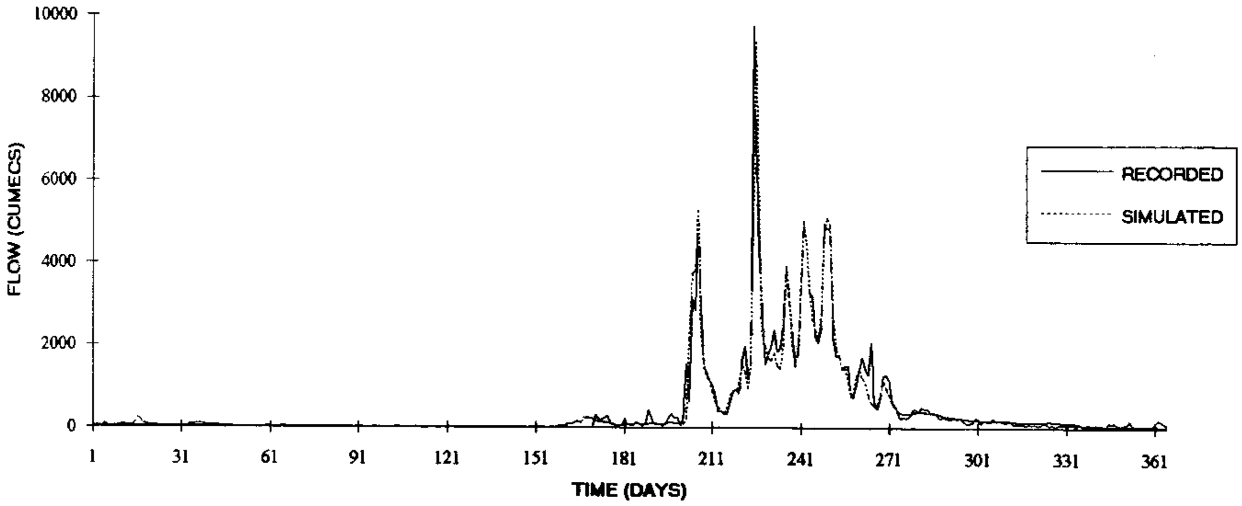


FIGURE 5.3

TABLE 5.1 : Optimised Values of Model Parameters

S.No.	Parameters	Value
	A. Hydrologic Parameters	
01.	Interception Storage	3.00 mm
02.	Impermeable proportion	0.04
03.	Time to peak for minor Channels	4.00 hrs.
04.	Soil moisture in upper soil horizon	287.09 mm
05.	Soil moisture in lower soil horizon	191.39 mm
06.	Saturated permeability at the top of the upper horizon	700.00 mm/hr.
07.	Saturated permeability at the base of the lower horizon	3.09 mm/hr.
08.	Saturated permeability at the horizon boundary	28.57 mm/hr.
09.	Soil porosity	0.48
10.	Bubbling Pressure	400.00 mm
11.	Recession from transitional groundwater storage	0.165 E - 002/hr.
12.	Recession from lower groundwater stroage	0.220 E - 002/hr.
13.	Proportion of upper groundwater runoff that enters channels	0.40
14.	Runoff from upper soil horizon at saturation	44.715 mm/hr.
15.	Runoff from lower soil horizon at saturation	24.406 mm/hr.
16.	Correction factor for Precipitation	1.10
17.	Correction factor for PET	0.80
18.	Adjustment for evapotranspiration from interception storage	1.00
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	5350.0 sq.kms.
	B. Hydraulic Parameters	
01.	Average base width of river	60.0 m
02.	Average top width of river	90.0 m
03.	Flood plain width	250.0 m
04.	Average depth of river	5.0 m
05.	Flood plain depth	1.5 m
06.	Maximum flood depth	2.0 m
07.	Manning's n for river	0.050
08.	Manning's n for flood plain	0.070
09.	River gradient	0.0015
10.	River length	130.0 kms.

SIMULATED AND RECORDED FLOWS FOR VALIDATION PERIOD OF 1992

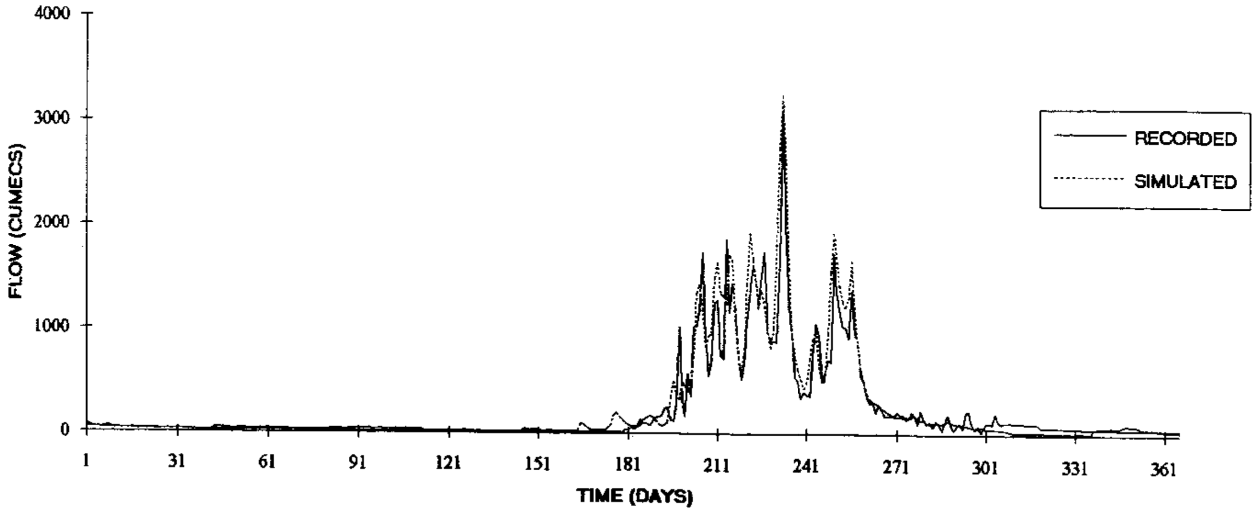


FIGURE 5.4

SIMULATED AND RECORDED FLOWS FOR VALIDATION PERIOD OF 1993

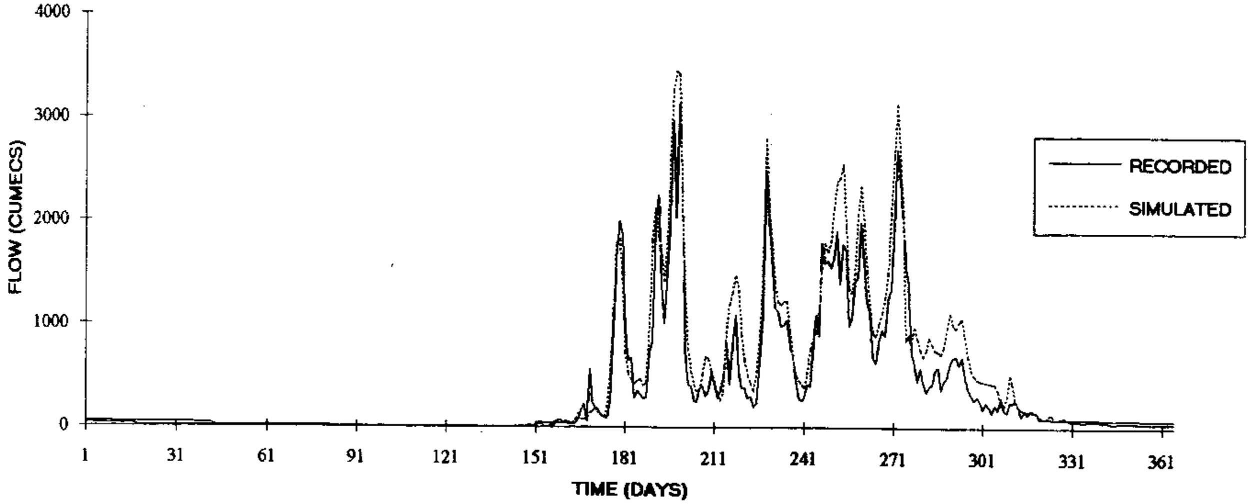


FIGURE 5.5

SIMULATED AND RECORDED FLOWS FOR VALIDATION PERIOD OF 1994

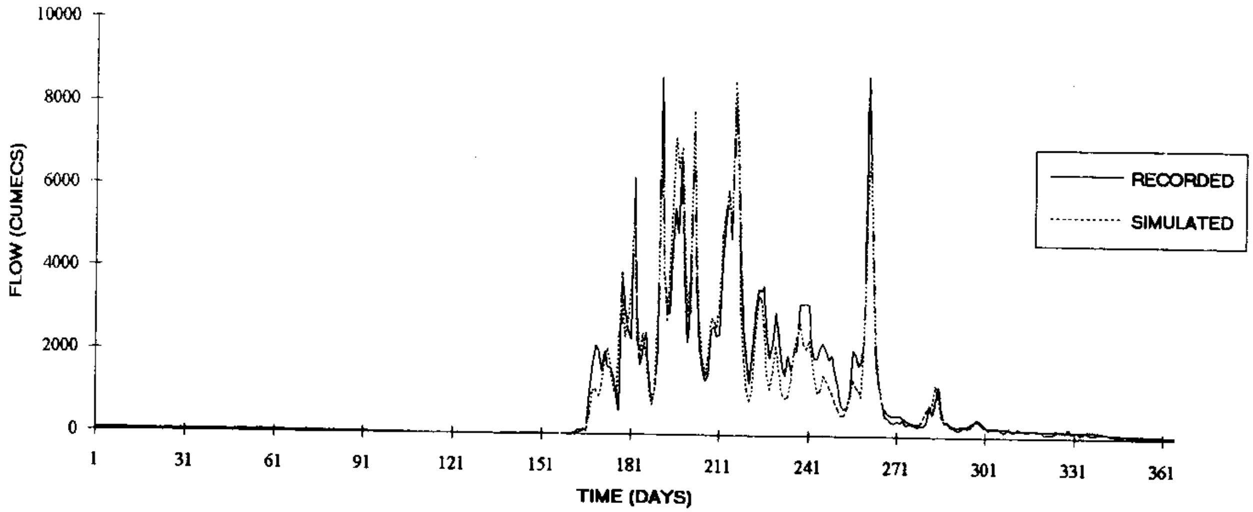


FIGURE 5.6

Table 5.2: Statistical Summary of Simulation for Calibration Period

S.No.	Statistical Indices	Daily Flow Values	Monthly Flow Values
01.	Mean		
	- Simulated flows	408.008	381.597
	- Recorded flows	432.597	403.893
02.	Standard deviation		
	- Simulated flows	818.161	557.696
	- Recorded flows	840.246	588.761
03.	Objective functions		
	- Extremes Error of Estimate (EEE)	1.003	--
	- Reduced Error of Estimate (REE)	0.278	0.100
	- Proportional Error of Estimate (PEE)	2.834	--
04.	Correlation Coefficient	0.961	0.997
05.	Efficiency	92.25%	99.00%

Table 5.3: Statistical Summary of Simulation for Validation Period

S.No.	Statistical Indices	Daily Flow Values	Monthly Flow Values
01.	Mean		
	- Simulated flows	493.270	488.740
	- Recorded flows	474.608	470.489
02.	Standard deviation		
	- Simulated flows	1015.058	798.076
	- Recorded flows	1003.986	794.690
03.	Objective functions		
	- Reduced Error of Estimate (REE)	0.271	0.184
	- Proportional Error of Estimate (PEE)	1.106	--
04.	Correlation coefficient	0.964	0.983
05.	Efficiency	92.65%	96.60%

available. Secondly, the flows at Rengali Reservoir as used for comparison purpose are the average daily reservoir inflows computed from the reservoir capacity curves which are normally subject to errors as involved in computation of seepage and evaporation losses and the releases and leakages from the reservoir. Keeping these constraints in mind, it can be concluded that the model has reproduced the daily flow hydrographs with a fair degree of accuracy. From the statistical summary of simulation for the validation period as given in Table 5.3, it is seen that the correlation coefficient for the daily and monthly flow values is 0.964 and 0.983 respectively and the efficiency of the model is 92.65% and 96.60 % respectively.

In the above calibration and validation processes, the model was run for a continuous input data series allocated for the purpose which included no flow, dry flow as well as high flow periods. Since the no flow and low flows are observed over a significant period of the study, it w s felt that the high values of correlation coefficient are probably dominated by these periods. So to have a higher level of confidence in the model's prediction ability during high flow periods, the model was run for high flow periods only i.e. from June to October for individual years of the study using the optimised parameter values as obtained through the calibration for a continuous data sets. The statistical summary of simulation for monsoon periods for each year of the study is given in Table 5.4. It is observed from the table that the model has performed equally good on this set of data also as the correlation coefficient for the daily flow values for monsoon periods of individual years is found to vary within a range of 0.935 to 0.950 showing a variation of just 1 to 3% from that of the combined data set.

Table 5.4 : STATISTICAL SUMMARY FOR MONSOON PERIODS

SL NO.	STATISTICAL INDICES	1989		1990		1991		1992		1993		1994	
		D	M	D	M	D	M	D	M	D	M	D	M
01.	Mean												
	- Simulated Flows	756.096	736.347	925.138	921.667	1119.105	1116.914	579.517	577.070	1067.291	1067.648	1889.688	1857.666
	- Recorded Flows	728.600	708.817	958.929	955.373	1080.371	1078.696	478.697	476.558	806.212	807.151	1937.315	1905.133
02.	Standard Deviation												
	- Simulated Flows	743.235	338.788	870.037	419.506	1515.827	851.927	675.108	477.340	824.816	440.047	1892.133	1171.227
	- Recorded Flows	691.358	316.607	833.744	398.850	1492.933	902.845	553.736	393.196	689.249	365.392	1865.699	1152.421
03.	Objective Function												
	- Reduced Error of Estimate (REE)	0.349	0.126	0.330	0.208	0.334	0.112	0.482	0.341	0.581	0.757	0.319	0.289
	- Proportional Error of Estimate(PEE)	1.116	--	3.396	--	10.617	--	2.398	--	0.767	--	2.030	--
04.	Correlation Coefficient	0.947	0.998	0.950	0.984	0.946	0.996	0.938	0.998	0.935	0.991	0.950	0.960
05.	Efficiency %	87.83	98.41	89.13	95.66	88.85	98.75	76.79	88.39	66.29	42.76	89.81	91.67

Note : 'D' and 'M' represent daily and monthly flow values

6.0 SUMMARY AND CONCLUSIONS

The HYSIM which is a very versatile hydrologic simulation model having 22 hydrologic parameters for computation of moisture transfer and 10 hydraulic parameters for routing of flows through river channels has been applied to Brahmani river basin for modelling the daily flows of the river at Rengali reservoir. From the analysis of the results it is found that in most of the cases the model has reproduced the flow hydrographs fairly accurate as the simulated peaks and their time of rise and fall match well with the recorded ones. However, the error observed in few hydrographs can be attributed, to some extent, to the data since the PET values as used in the study are normal monthly values and also the flows at Rengali reservoir used for comparison purpose are taken as the average daily reservoir inflows computed from the reservoir capacity curves. Keeping in view these constraints, the results of the simulation can be rated as quite good.

The results of the study indicate that the model can be effectively used for forecasting the flows of the river reasonably accurate. The model can also be used for extension of flow data records, checking the flow data record for its consistency (data validation), and for simulating the flows from ungauged sub-basins of the Brahmani river basin. As the model has the capability to simulate the flows at shorter time intervals including hourly, it can also be used for real time flood forecasting purpose.

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v) Sri Kumud Ranjan Acharya, Asst. Director, O/o Chief Engineer, Project Planning and Formulation

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iii) Sri RK Behra, AEE

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IV. Central Ground Water Board, Bhubaneswar

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ii) Sri B.B. Basak, Scientist 'D'

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