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DAILY RAINFALL-RUNOFF MODELLING OF RUSHIKULYA RIVER, ORISSA

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ABSTRACT

A hydrologic simulation model known as HYSIM is applied to the Rushikulya river basin to model the daily flows of the river at Purushottampur. The model used in the study is a menu driven P.C. based version and contains modes both for optimisation and production runs. The model can use five types of input data namely, precipitation, PET, potential snowmelt rate, discharges to/abstractions from river channels and abstraction from ground water. In addition, it can use a gauged flow record for comparison with the simulated flows. The model can use the input data and simulate the flows either on monthly, daily or on any other shorter time increment including hourly. The model also 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 reasonable homogeneous sub-catchments with respect to soil types and meteorology. In such a case the flows from upstream catchments are routed through the catchment being modelled together with flows from local runoff. For this purpose, either the recorded flows from upstream catchments may be used or they may be simulated separately for each of the upstream sub-catchments.

The river Rushikulya having a drainage area of about 8200 sq.km. is one of the medium sized east flowing rivers in the state of Orissa. The modelling of flows from the basin is carried out for a drainage area of 7112 sq.km. at Purushottampur G-D site. The entire drainage area upto the site has been considered as a single unit in applying the model. The model is calibrated using three years data of rainfall, PET and gauged flow record. The model validation is performed by simulating flows for three different data sets. The results of the study show that the model has simulated the flow hydrographs to a fair degree of accuracy despite some short-comings in the input data. Based on the results, it is concluded that the model can be effectively used for simulation studies of Rushikulya basin and its sub-basins.

1.0 INTRODUCTION

The relationship between rainfall and runoff has been one of the central themes of hydrological research for many years. With the growth of digital computing power, the science of modelling the rainfall-runoff process has developed in response to the research community's perceived opportunities for advancing the state of knowledge in the subject, and the engineering community's need for predictive hydrological tools. Records of flow in rivers are seldom sufficiently long to give reliable estimates of water resources available. Since rainfall is more easily measured than stream-flow, its measurement in a river basin commonly begins some years before that of stream flow. When long records of rainfall are available a model of rainfall-runoff relationship may be used to estimate flows before stream flow records began. Important for the management of water resources are the estimation of water availability and simulation of flows from ungauged catchments, extension of flow data records, flow data validation (checking the data for its consistency), flow forecasting, flood studies, reservoir simulation studies and the prediction of the effects of land use change on the river flows. To handle these problems a wide range of hydrological models have been developed by the researchers. When enough data are available, sophisticated physically-based models such as SHE can take account of basin topography, vegetation, soil and channel characteristics; when data are scarce, more empirical and conceptual models must be used, to make the best use of what data are available by incorporating hydrological experience gained elsewhere.

In India, a large number of catchments have a scarce data base and limit the use of physically based models. As a result, simple hydrological models are commonly used by the field engineers to simulate the runoff response of the catchment from the rainfall input. With this view point, a hydrologic simulation model called HYSIM, which is relatively a simple but very versatile model having 22 hydrologic and 10 hydraulic parameters was earlier applied to Sagileru river basin in A.P. and Brahmini river basin in Orissa for simulation of daily river flows. Encouraged by the simulation results of these two basins, the model in the present study is applied to the Rushikulya river basin in Orissa to simulate the daily flows and to analyse the performance behaviour of the model for the river basin. The description of the model used, study area, data used, and the results and analysis alongwith the conclusions are presented in the following sections 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.

(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.

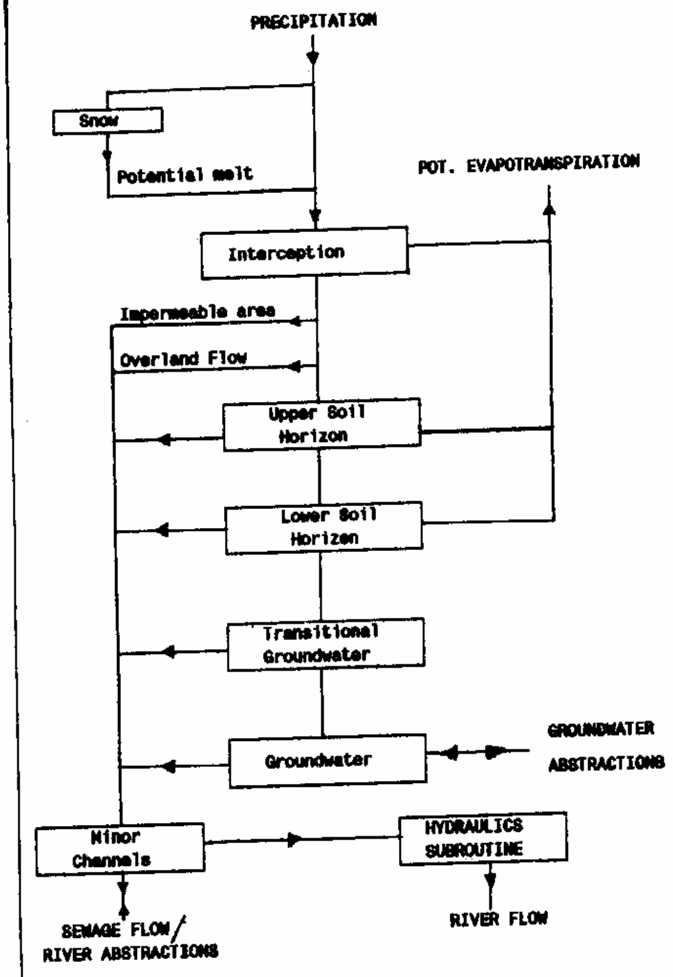
(ii) Interception Storage

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



STRUCTURE OF HYSIM

FIGURE 2.1

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,

$$\text{Interflow} = \text{Rfac}_1\ (S_e)^{(2+3\gamma)/\gamma}$$

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,

$$\frac{ds}{dt} = i - (\text{Rfac}_1 + K_b)\ S_e^{(2+3\gamma)/\gamma}$$

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,

$$V_w = Q / A$$

Where, Q is the incremental change in flow and A 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,

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

$Q \alpha A^{5/3}$ 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 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 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,

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

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,

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

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.

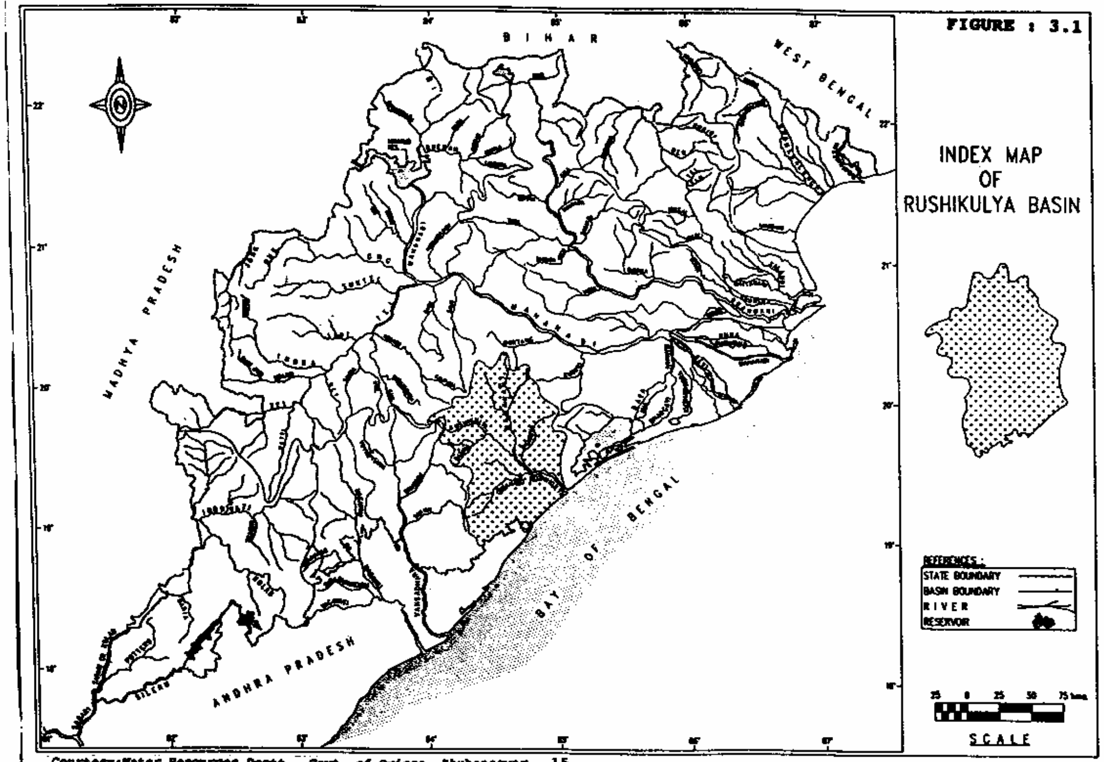
3.0 STUDY AREA

The river Rushikulya is one of the medium sized east flowing rivers in peninsular India. It is an important river of Orissa state having a drainage area of about 8200 sq.km. which is approximately 5.71% of the total area of the state. The drainage basin spread over the parts of the district of Ganjam, Phulbani and Puri lies within the geographical coordinates of 19°07′ to 20°19′ N latitudes and 84°01′ to 85°06′ E longitudes. The Index Map of the Rushikulya basin is given in Figure 3.1 and the detailed basin map is given in Figure 3.2.

The river Rushikulya originates from Ararha bity and Kutrabor hills of eastern ghats at an elevation of 500 m above msl in Ganjam and Phulbani districts. It flows in the south eastern direction through Purushottampur and falls to the Bay of Bengal near Chhatrapur in Ganjam district. The length of the main stream from its origin to the outfall is about 175 km. The principal tributaries of the river are Padma and Ghodahado on the right and Badanadi, Baghua, Dhanei and Kharakhari on the Left side. A number of irrigation structures exist on some of these tributaries. The Rushikulya Irrigation System which is a century old system consists of (a) two reservoirs namely(i) Bhanjanagar reservoir on Boringa nalla, a sub-tributary of Bada nadi, and (ii) Sorada reservoir on a small nala of Padma tributary; and (b) three diversion weirs at (i) Madhoborida, (ii) Janivilli, and (iii)Sorisomuli. The Rushikulya irrigation system provides irrigation to an area of about 610 sq.km. in Kharif season only and has no Rabi ayacut. In addition to this system, the other existing irrigation projects which include Ghodahado Daha, Ramanadi, Baghua Stage-I, Dhanei, Jayamangal and Hirdharbati projects also provide irrigation to an area of about 320 sq.km.

The climate of the study area is moderate having four distinct seasons namely, Winter (Dec. to Feb.), summer (March to May), south-west monsoon (June to Sept.) and Post monsoon period

FIGURE : 3.1

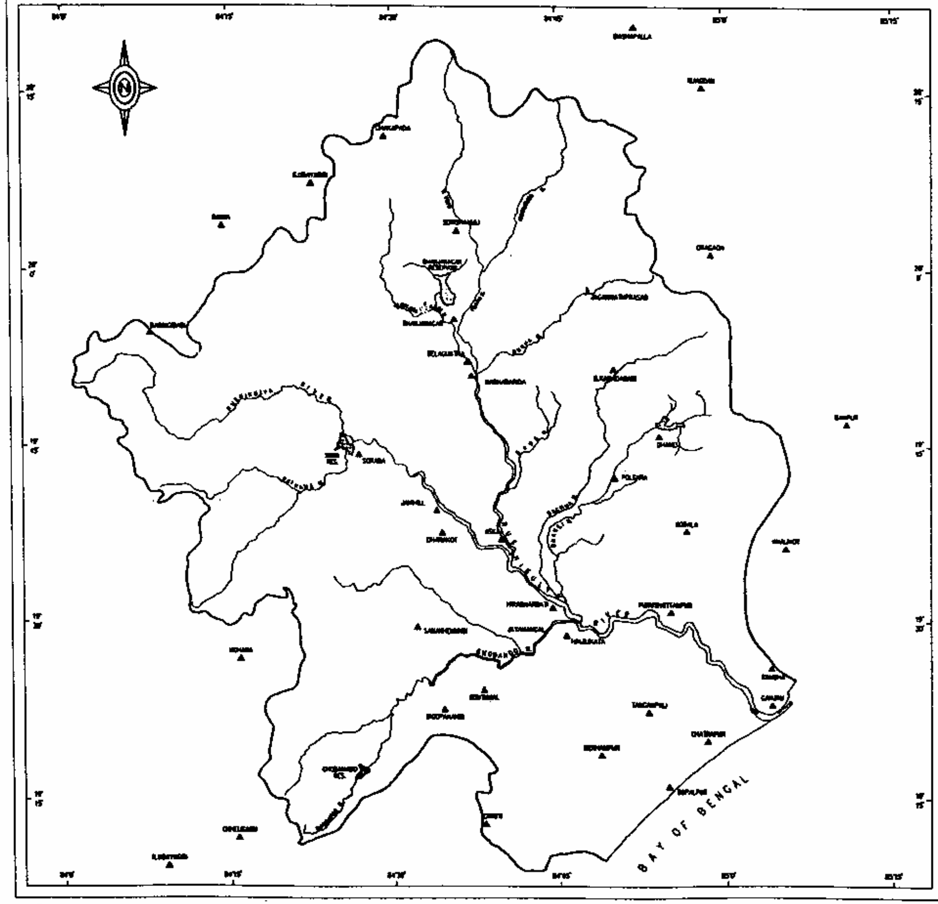


INDEX MAP
OF
RUSHIKULYA BASIN

Courtesy:Water Resources Deptt., Govt. of Orissa, Bhubaneswar.

FIGURE : 3.2

MAP OF
RUSHIKULYA RIVER BASIN



Courtesy:Water Resources Deptt., Govt. of Orissa, Bhubaneswar

(Oct. & Nov.). The maximum and minimum temperatures of the basin are recorded as 45°C and 12°C respectively. Relatively humidity during July to September varies from 88% to 93%. The average annual rainfall in the basin is about 1235 mm, of which about 80% occurs during south-west monsoon season. Besides the monsoon rains, cyclonic rains which caused severe floods have also been observed in recent years. In certain years, serious drought also occurred due to inadequate rainfall.

The entire basin is grouped into flat plains and valleys with isolated hills. The basin is continuously sloping towards the main valley and hence no drainage congestion problem is anticipated. The total geographical area of the basin is 8200 sq.km., of which about 4010 sq.km is forest and about 3370 sq.km. is arable area. While a major portion of the upper basin is covered with forest, the lower portion of the basin which is located near the sea has mostly plain lands with fertile soil and is suitable for agriculture. The location of major forest area with basin is given in Figure 3.3.

The geologic features in and around the basin mostly comprises of Khandolite and Charnolite groups of rock formation. The rocks have given rise to different soils through different processes of weathering and erosion. The soils in the study basin have been classified as red and yellow soils, alluvial soils, black soils, laterite soils, coastal alluvium and saline soils. The red and yellow soils are coarser in texture and slightly to moderately acidic in reaction. These soils are dominated by vaolinite type of clay minerals and are generally poor in organic matter, lime and nitrogen content. The alluvial soils are light grey to pale yellow in colour, deep to very deep, loamy in texture and are generally neutral in reaction. They are poor in nitrogen and have poor drainage characteristics. Black soils in the basin occur in medium to upland conditions and are dark grey brown to black in colour. They are shallow to moderately deep, finer in texture, slightly saline in nature and are normally well

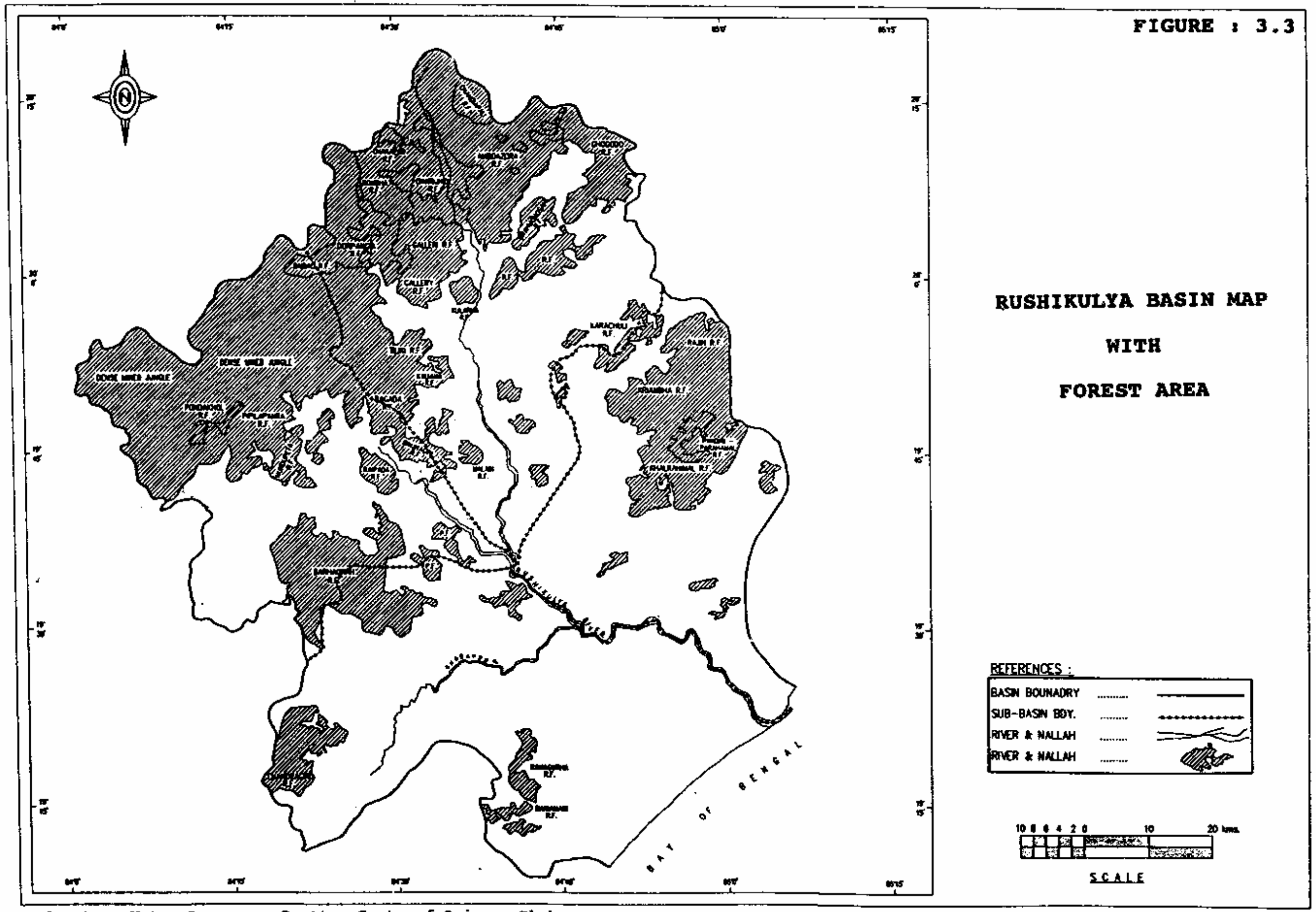


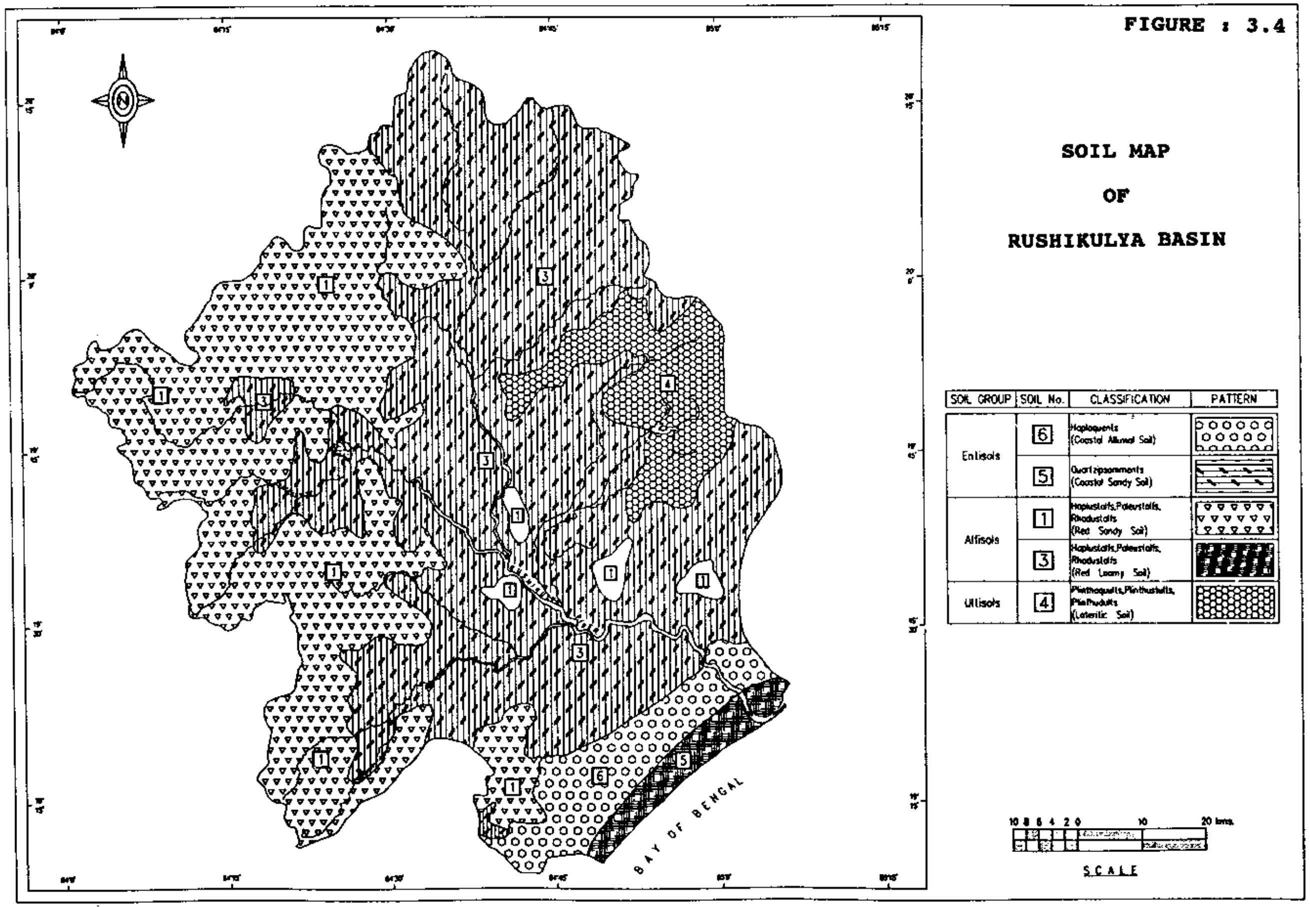
FIGURE : 3.3

RUSHIKULYA BASIN MAP
WITH
FOREST AREA

Courtesy:Water Resources Deptt., Govt. of Orissa, Bhubaneswar drained. Laterite soils contain laterite mass at some depth of the profile. They are poor in organic matter and are generally acidic in reaction. Coastal alluvium soils have variable characteristics and their colour ranges from light grey and pale yellow to deep grey. The texture ranges from coarse sand to clay depending upon the type of alluvium. They are generally fertile and slightly acidic to neutral in reaction. Saline soils have been described as alluvial soils with high insoluble salts. The salinity of the soils near sea is due to tidal water. The soil map of the basin is given in Figure 3.4.

FIGURE : 3.4

SOIL MAP
OF
RUSHIKULYA BASIN



SOIL GROUP	SOIL No.	CLASSIFICATION	PATTERN
Entisols	6	Haploquents (Coastal Alluvial Soil)	○
	5	Quartzipsamments (Coastal Sandy Soil)	▤
Alfisols	1	Haplustalfs, Paleustalfs, Rhodustalfs (Red Sandy Soil)	▽
	3	Haplustalfs, Paleustalfs, Rhodustalfs (Red Loamy Soil)	▩
Ultisols	4	Plinthaquults, Plinthustults, Plinthudults (Lateritic Soil)	⬡

Courtesy: Water Resources Deptt., Govt. of Orissa, Bhubaneswar

4.0 DATA USED AND METHODOLOGY

4.1 DATA USED

HYSIM uses the rainfall and the potential evapotranspiration data for simulation of river flows. A record of observed flows may also be used if comparison of simulated and observed flows is to be carried out as required for calibration and validation processes of the model. In addition to above, the information on hydrologic, topographic and soil characteristics of the river basin and the hydraulic characteristics of the river channels is also required for estimation of model parameters. In the present study, the following data and information as available with various field agencies were collected and used.

4.1.1 Rainfall

The daily rainfall data of 14 ordinary raingauge stations in Rushikulya basin were collected for a period of 7 years from 1990 to 1996. The locations of these raingauge stations is shown in Figure 3.2. The point values of these stations were then analysed using Thiessen Polygons method to get the daily mean areal rainfall over the basin. The plots of daily mean areal rainfall for the study periods are given in Figure 4.1 to 4.4.

4.1.2 River Flows

The mean daily river flows as observed at Purushottampur G-D site on Rushikulya river are used for calibration and validation of the model. The G-D site started functioning from June 1990 and observations were made only in monsoon seasons during 1990 and 1991. However, from June 1992 onwards the observations were made round the year and the river flow data are available upto May 1996. Accordingly, the flow data for the periods (i) June to October, 1990, (ii) June to November, 1991 and (iii) June 1992 to May 1996, were collected from Central Water Commission, Bhubaneswar and used in the study.

MEAN AREAL RAINFALL FOR CALIBRATION PERIOD
FROM JUNE 1, 1993 TO MAY 31, 1996

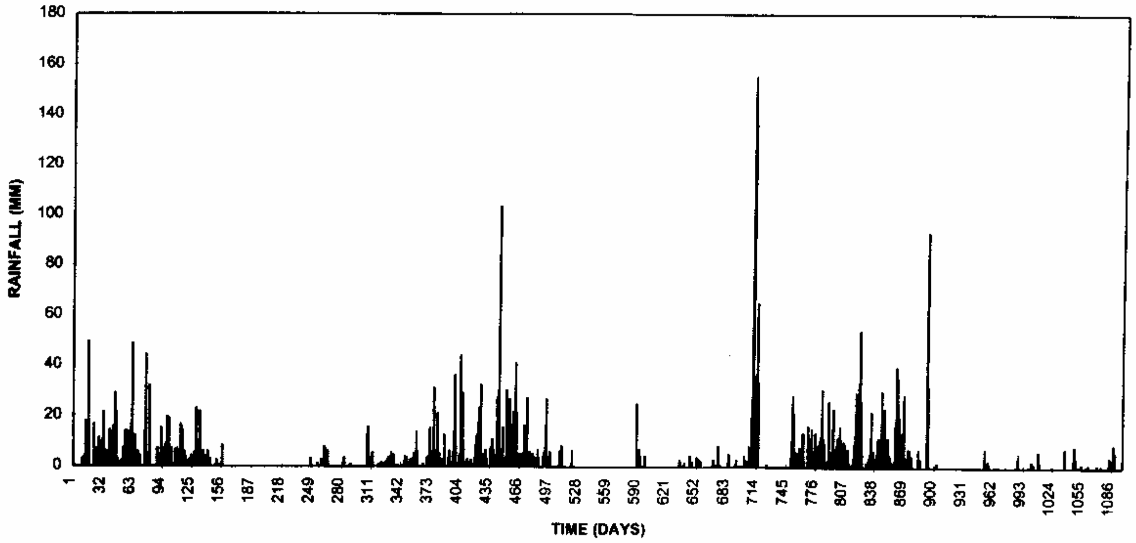


FIGURE : 4.1

MEAN AREAL RAINFALL FOR VALIDATION PERIOD
FROM JUNE 1, 1990 TO OCT. 31, 1990

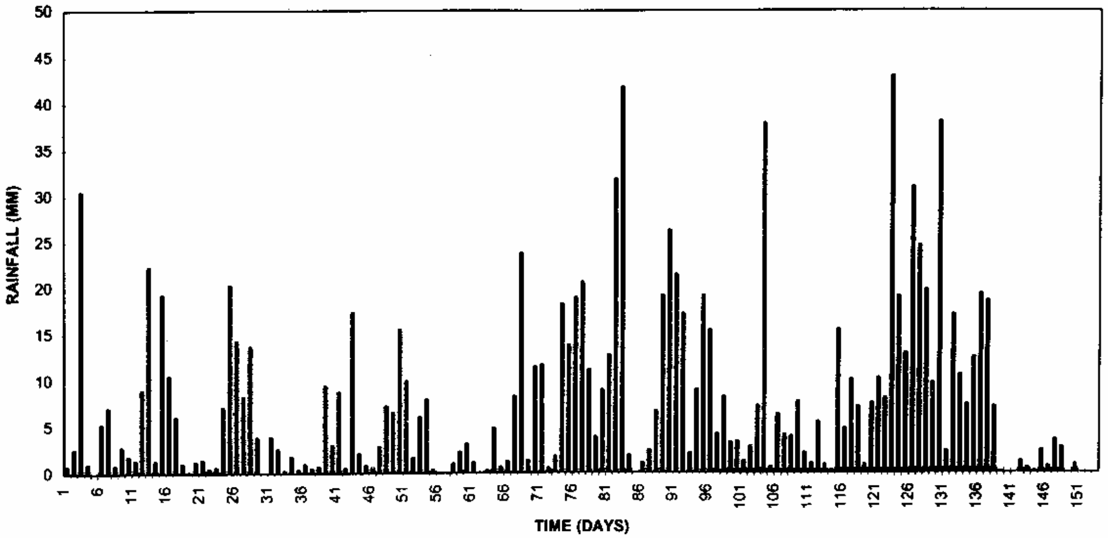


FIGURE : 4.2

MEAN AREAL RAINFALL FOR VALIDATION PERIOD
FROM JUNE 1, 1991 TO NOV. 30, 1991

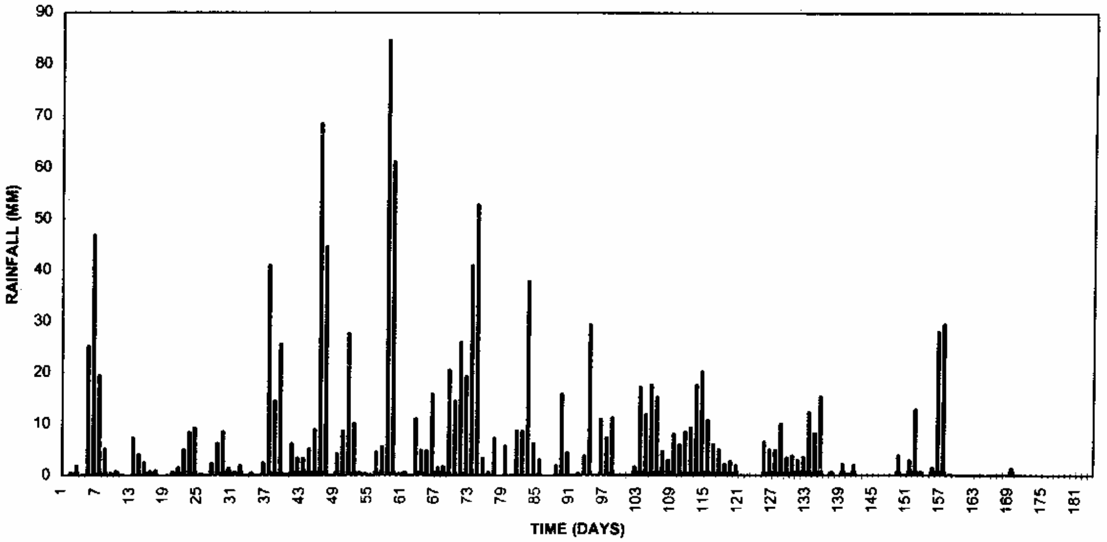


FIGURE : 4.3

MEAN AREAL RAINFALL FOR VALIDATION PERIOD FROM JUNE 1, 1992 TO MAY 31, 1993

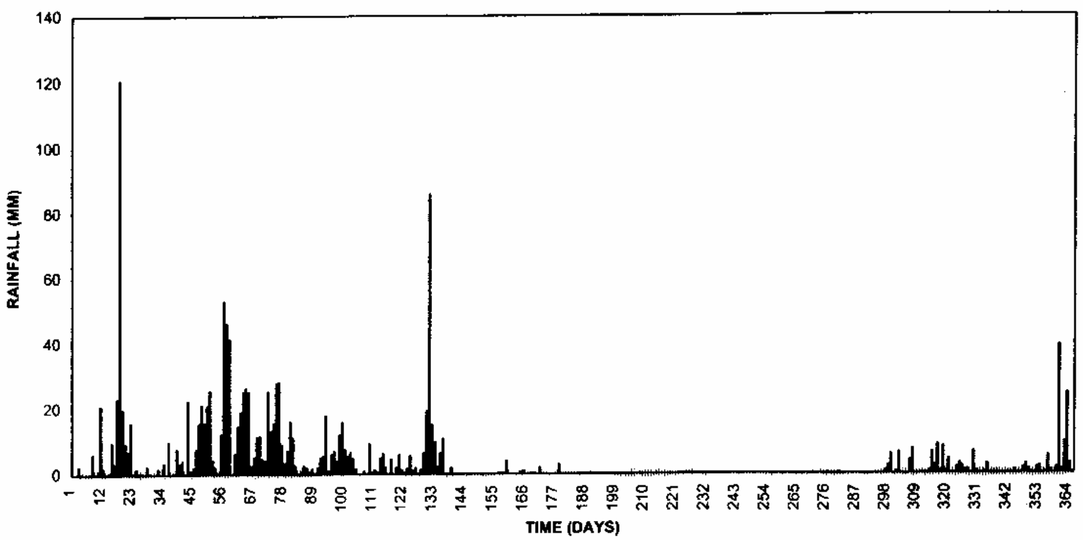


FIGURE : 4.4

4.1.3 Potential Evapotranspiration

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

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

4.2 METHODOLOGY

The modelling of daily flows is carried out for a basin area of about 7112 sq.km. at Purushottampur G-D site. The entire drainage area upto the site has been considered as a single unit in applying the model. Depending upon the available record of observed river flows, the model is calibrated using the continuous data of the period from June 1993 to May 1996. The model validation is carried out for three data sets of the periods (i) June to October 1990, (ii) June to Nov., 1991, and (iii) June 1992 to May 1993. The catchment data files for mean areal rainfall, PET and recorded flows are prepared in the required format for calibration and validation periods 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 coeff. 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,

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

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/efective 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 ANALYSIS

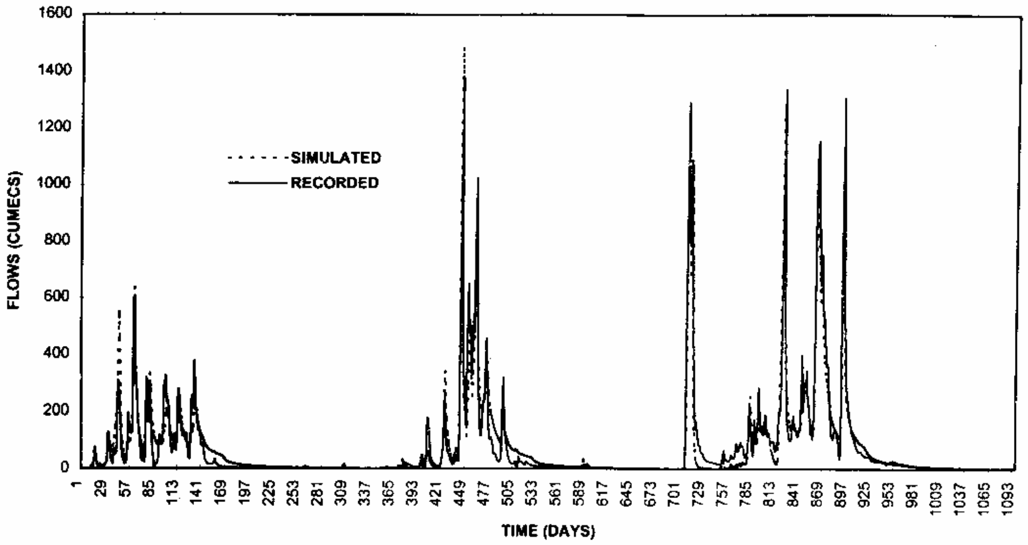
The present study has been carried out to model the daily flows of Rushikulya river at Purushottampur G-D site. The basin area of 7112 sq.km. upto the G-D site is considered as a single unit for modelling purpose. As per the procedure discussed in Chapter 4, the model is calibrated using 3 years of data from June 1993 to May 1996. The performance of the calibrated model in reproducing the flows (validation) is assessed for three data sets of the periods (i) June 1990 to Oct.1990, (ii) June 1991 to Nov.1991, and (iii) June 1992 to May 1993.

The hydrographs of simulated and observed river flows for the calibration period are given in Figure 5.1 and the optimized values of hydrologic and hydraulic parameters of the model are given in Table 5.1. A comparison of these hydrographs indicate that the rising and the recession limbs of the simulated hydrographs match very well with those of the observed flow hydrographs. The simulated peak flow values in most of the cases are also very close to the observed peak values. The statistical summary of simulation for calibration period as given in Table 5.2 shows that the correlation coefficient for the daily and monthly flow values is of the order of 0.942 and 0.984 respectively. The model efficiency of simulating the daily and monthly flows is also achieved as high as 88.68% and 96.78% respectively. The other statistical measures viz., mean and standard deviation of the simulated flows are also comparable with those of the observed flows.

The validation of the model is performed on three different data sets for which the hydrographs of simulated and recorded flows are given in Figures 5.2 to 5.4. The statistical summary of simulation for these periods are also given in Table 5.3 to 5.5. For the validation period from June 1990 to Oct.1990, it is observed that except for a small period at the beginning the simulated flow hydrographs almost fit the observed flow hydrographs. The correlation coefficient for the daily and the monthly flows is observed as 0.962 and 1.0 respectively and the efficiency of simulation for the corresponding flows is observed to be 91.30% and 95.15% respectively. The hydrographs for the validation period from June 1991 to Nov.1991 as given in Figure 5.3 show some mismatch during low flow periods. However, the flows are reproduced fairly better during the high flow periods. In this case, the correlation coefficient for daily and monthly flows is 0.93 and 0.98 respectively and the efficiency of simulation for these flows works out to be 83.84 and 92.96% respectively. For the third case of validation i.e. for the period from June 1992 to May 1993, the time of rise and fall of simulated hydrographs match with the observed flow hydrographs but the peak values of simulated hydrographs are observed to differ from those of the observed hydrographs. The correlation coefficient for daily and monthly flow values is found to be 0.911 and 0.983 respectively. The efficiency of simulation as 78.42% and 87.40% for daily and monthly flows respectively is found to be lower as compared with other cases.

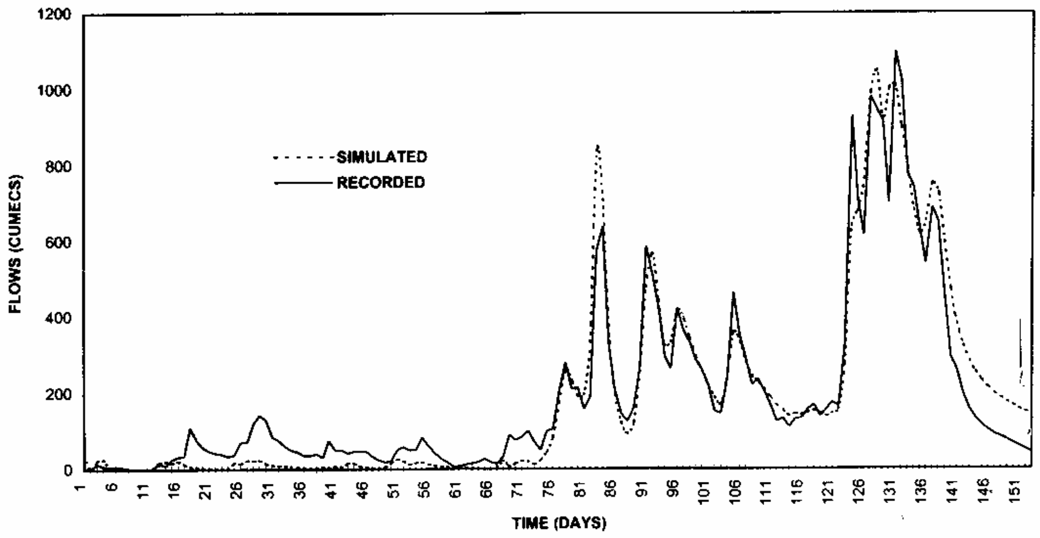
The poor simulation at the beginning of the study periods can possibly be attributed to the reason that the model requires a warm up period to allow errors in the assumed soil moisture conditions to become ineffective. Once the conditions are stabilized the model performs better. While discussing the simulation results, it is also important here to highlight the quality of data used in the study which directly affects the simulation results. Firstly, the PET data used in the study are the normal monthly values as actual PET data is not available. Secondly, the observed flows used for comparison purpose in the study are the average daily river flows which may not give the true values of the peak flows. And thirdly, the study basin consists of a number of structures such as reservoirs, diversion weirs and tanks etc. These structures obstruct the flow in the river and instead of natural runoff response, the modified flows are observed at the G-D site.

The results and discussion presented above indicate that the model has reproduced the flow hydrographs to a fair degree of accuracy despite some shortcomings in the data. As such, the model's performance in simulating the flows of the river Rushikulya can be rated as very good.



SIMULATED AND RECORDED FLOWS FOR CALIBRATION PERIOD FROM JUNE 1, 1993 TO MAY 31, 1996

FIGURE : 5.1



SIMULATED AND RECORDED FLOWS FOR VALIDATION PERIOD
FROM JUNE 1, 1990 TO OCT. 31, 1990

FIGURE : 5.2

SIMULATED AND RECORDED FLOWS FOR VALIDATION PERIOD
FROM JUNE 1, 1991 TO NOV. 30, 1991

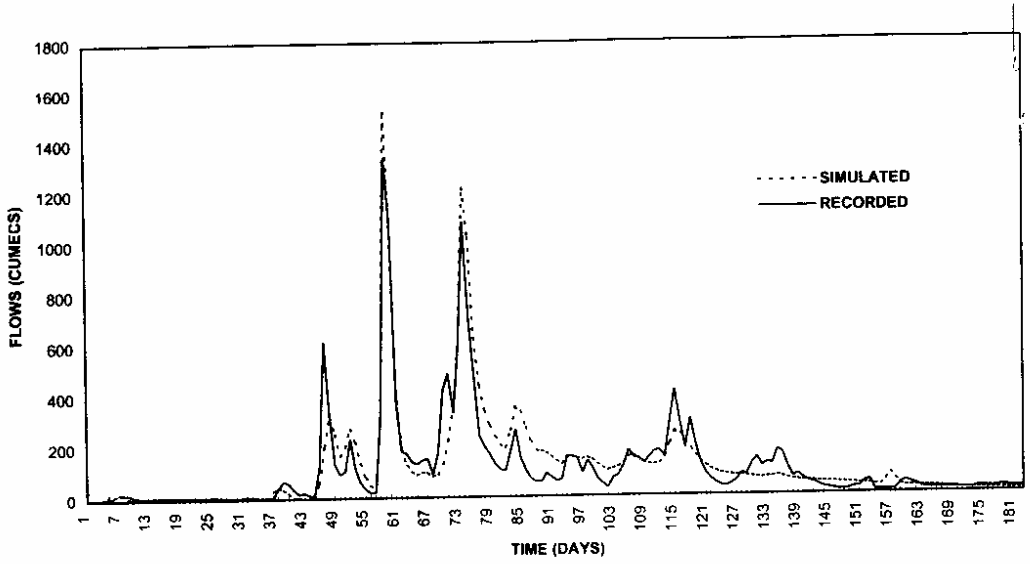


FIGURE : 5.3

SIMULATED AND RECORDED FLOWS FOR VALIDATION PERIOD
FROM JUNE 1, 1992 TO MAY 31, 1993

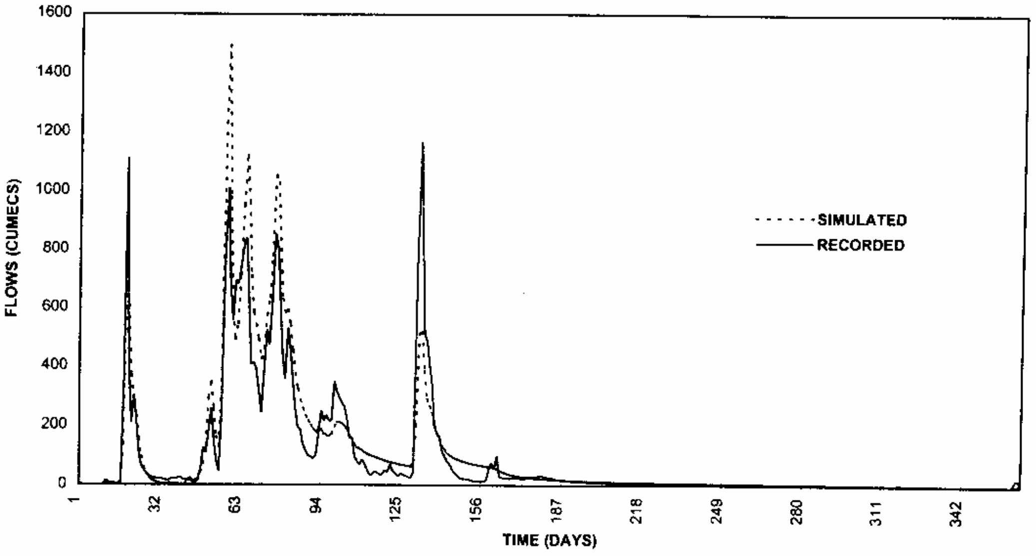


FIGURE : 5.4

TABLE 5.1 : Optimised Values of Model Parameters

S.No. Parameters	Value
A. Hydrologic Parameters	
01.Interception Storage	2.00 mm
02.Impermeable proportion	0.03
03.Time to peak for minor Channels	4.00 hrs.
04.Soil moisture in upper soil horizon	265.83 mm
05.Soil moisture in lower soil horizon	352.37 mm
06.Saturated perm. at top of upper horizon	1000.00 mm/hr.
07.Saturated perm. at base of lower horizon	28.75 mm/hr.
08.Saturated perm. at horizon boundary	26.43 mm/hr.
09.Soil porosity	0.45
10.Bubbling Pressure	200.00 mm
11.Recession from transitional gw storage	0.220 E - 002/hr.
12.Recession from lower gw stroage	0.590 E - 002/hr.
13.Prop. of upper gw runoff that enters channels	0.70
14.Runoff from upper soil horizon at saturation	19.362 mm/hr.
15.Runoff from lower soil horizon at saturation	35.587 mm/hr.
16.Correction factor for Precipitation	1.00
17.Correction factor for PET	0.99
18.Adjustment for et 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 gw	0.00
22.Pore size distribution index	0.20
23.Catchment area	7112.00 sqkms.
B. Hydraulic Parameters	
01.Average base width of river	10.0 m
02.Average top width of river	60.0 m
03.Flood plain width	100.0 m
04.Average depth of river	3.0 m
05.Flood plain depth	1.0 m
06.Maximum flood depth	4.5 m
07.Manning's n for river	0.04
08.Manning's n for flood plain	0.04
09.River gradient	0.015
10.River length	162.0 kms.

Table5.2:Statistical Summary of Simulation for Calibration Period

S.No.	Statistical Indices	Daily Flow Values	Monthly Flow Values
01.	Mean		
	- Simulated flows	89.003	80.762
	- Recorded flows	88.254	79.856
02.	Standard deviation		
	- Simulated flows	172.003	106.095
	- Recorded flows	182.406	111.326
03.	Correlation Coeff.	0.942	0.984
05.	Efficiency	88.68%	96.78%

Table5.3:Statistical Summary of Simulation for Validation Period From June 1990 to october 1990

S.No.	Statistical Indices	Daily Flow Values	Monthly Flow Values
01.	Mean		
	- Simulated flows	193.982	191.830
	- Recorded flows	194.190	192.168
02.	Standard deviation		
	- Simulated flows	258.511	190.703
	- Recorded flows	240.778	156.431
03.	Correlation Coeff.	0.962	1.000
05.	Efficiency	91.29%	95.15%

Table5.4:Statistical Summary of Simulation for Validation Period From June 1991 to November 1991

S.No.	Statistical Indices	Daily Flow Values	Monthly Flow Values
01.	Mean		
	- Simulated flows	119.126	118.170
	- Recorded flows	110.303	109.490
02.	Standard deviation		
	- Simulated flows	196.970	99.440
	- Recorded flows	182.383	83.947
03.	Correlation Coeff.	0.930	0.980
05.	Efficiency	83.84%	92.96%

Table5.5:Statistical Summary of Simulation for Validation Period From June 1992 to May 1993

S.No.	Statistical Indices	Daily Flow Values	Monthly Flow Values
01.	Mean		
	- Simulated flows	127.444	103.494
	- Recorded flows	110.977	89.641
02.	Standard deviation		
	- Simulated flows	231.957	154.889
	- Recorded flows	209.229	122.583
03.	Correlation Coeff.	0.911	0.983
05.	Efficiency	78.42%	87.42%

6.0 CONCLUSIONS

HYSIM is calibrated for daily flows of Rushikulya river at Purushottampur G-D site. The results of the simulation runs during validation process indicate that in most of the cases the model has reproduced the flow hydrographs to a fair degree of accuracy despite some short-comings in the input data. Keeping in view these results, the performance of the model in simulating the daily flows of Rushikulya basin can be rated as very good. The model is recommended for simulation studies of Rushikulya basin and its sub-basins.

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