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SINGLE COLUMN HYDROLOGIC SIMULATIONS USING SHE MODEL

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ABSTRACT

The SHE is a physically based distributed model and it provides a useful setup for understanding importance of evaporation data and soil parameters. In this study, single column hydrologic simulations have been carried out for examining the sensitivity of this model to pan evaporation data of the various stations as well as increase in conductivity of unsaturated zone, reduction in the value of exponent appearing in the Averjanov's formula and reduction in the values of moisture content at wilting point and residual water content has been studied for a single grid of 2 km x 2 km size of river Narmada. It is observed that simulated runoff and actual evapotranspiration are somewhat sensitive to the choice of the various pan evaporation measurement stations. However, depth to ground water table does not show any significant variations when the pan evaporation data of the different stations are used.

Increase in the value of conductivity of unsaturated zone leads to increase in actual evapotranspiration and decrease in runoff. Reduction in value of the exponent appearing in Averjanov's formula which is used in the SHE model decreases the simulated runoff and increases actual evapotranspiration significantly. Reduction in the values of water content at wilting point and residual water content of soil also reduces runoff and significantly increases actual evapotranspiration. Also, it is observed that the ground water table depletes considerably particularly during the dry periods for these cases.

1.0 INTRODUCTION

With increasing population and improved standard of living, rising demand of water for irrigation, drinking as well as other domestic purposes, industrial use and hydropower generation etc. has drawn attention towards optimal utilisation of water resources the world over. The rapid growth in water resources development activity calls for proper assessment and optimal planning of water resources. There are many practical hydrological problems which are becoming increasingly pressing. These problems are arising from the adverse impacts of man's activities on the hydrological cycle and consequently on water resources. Surface and ground water resources are being polluted by fertilizers and pesticides associated with intensive agricultural practices. Transport of contaminants from waste disposal sites and the more recently publicized effects of acid rain represent further threats to water quality. In the developing world, major water resource projects are detrimentally affected by large-scale deforestation under increasing population pressure, which is causing significant changes to the high and low flow regimes of rivers. Deforestation is also leading to massive soil erosion, the products of which are causing the rapid siltation of reservoirs. It is therefore all the more imperative that development options, and particularly their environmental impact, should be evaluated more rigorously to ensure the optimum exploitation of water resources.

Development and application of computer based mathematical models for solving the various hydrological problems have increased significantly during last two decades. A mathematical model provides a quantitative mathematical description of the processes through a collection of mathematical equations, logical statements, boundary conditions and initial conditions expressing relationships between inputs, variables and parameters. In classifying mathematical models following terms are widely used:

A large number of hydrological models exist. However, many of the models function in basically the same way. For instance, atleast twenty different rainfall runoff models of the lumped ,conceptual type exist. A model represents the physical/chemical/biological characteristics of the catchment and simulates the natural hydrological processes. It is not an end in itself but is a tool in a larger process which is usually a decision problem. A model aids in making decisions, particularly where data or information are scarce or there are large numbers of options to choose from. It is not a replacement for field observations. Its value lies in its ability, when correctly chosen and adjusted, to extract the maximum amount of information from the available data, so as to aid in decision making process.

In classifying hydrological models the following terms are widely used :

A deterministic model is one in which no uncertainties in prediction are admitted, so that two equal sets of input always yield the same output if run through the model under identical conditions. The model has no component with stochastic behaviour, i.e. the variables are free from random variation and have no distribution in probability.

A stochastic model has some component of random character, having a distribution in probability through time. Identical inputs may result in different outputs if run through the model under identical conditions.

A lumped model is a model where the catchment is regarded as one unit. The inputs, variables and parameters represent average values for the entire catchment.

A black box model is a model developed without any consideration of the physical processes in the catchment. The model is merely based on analyses of concurrent input and output time series.

A conceptual model is based on some consideration of the physical processes in the catchment. In a conceptual model physically sound structures and equations are used together with semi-empirical ones. However, the physical significance is not so clear that the parameters can be assessed from direct measurements. Instead, it is necessary to estimate the parameters from calibration, applying concurrent input and output time series. A conceptual model, which is usually a lumped-type model, is often called a grey box model.

A fully physically based model describes the system using the basic equations governing the flows of energy and water. For catchment models,a fully physically based model in practice also has to be a fully distributed model. This type of model, also called a white box model, thus consists of a set of linked partial differential equations together with parameters which, in principle, have direct physical significance and can be evaluated by independent measurements.

It is considered that the further development or enhancement of the conventional hydrological models can not provide a sound scientific basis for tackling many of the problems concerned with the effects of land-use change related to agricultural and forestry practices, hazards of pollution and toxic waste disposal and general problems arising from conjunctive uses of water. These lumped parameter, rainfall-runoff models depend essentially on the availability of sufficiently long meteorological and hydrological records for their calibration and such records are not always available. Their calibration also involves a significant element of curve fitting, thus making any physical interpretation of the fitted parameter values extremely difficult. Under these circumstances, prediction of the effects of land-use changes on the hydrological regime of a catchment, particularly where only part of the catchment is affected, can not be undertaken with any confidence. Because of their inherent structure these models also make very little use of contour, soil and vegetation maps, or of the increasing body of information in such areas as soil physics and plant physiology. Similarly, much historical information frequently consulted during project planning, for example crop yields over specific periods, survival patterns of particular types of vegetation and characteristic events occurring during floods and droughts, is not used directly. A considerable improvement in project planning could therefore be derived from the integration of such information into the modelling process. In particular physically-based, distributed models can in principle overcome many of the above deficiencies through their use of parameters which have a physical interpretation and through their representation of spatial variability in the parameter values.

The traditional lumped, conceptual models are well suited for simulation of the following hydrological problems when sufficiently long term data are available:

a) Extension of short stream flow records; and

b) Real time rainfall-runoff simulation e.g. flood forecasting.

Other fields of possible application where these models can be used if no better model or method is available are: prediction of runoff from ungauged basins (In such cases model parameters are typically estimated by calibrating against hydrologically similar, neighbouring catchments), general water balance studies, etc.

Whereas, a physically based-distributed model is based on understanding of the physics of the hydrological processes which control catchment response and use physically based equations to describe these processes. Physically based-distributed models can simulate the spatial variations in hydrological variables within a catchment and in principle can be applied to almost any type of hydrological problem. Some of the typical fields of application of the physical based distributed models for which lumped conceptual models are not applicable are:

a) Catchment changes. viz. both natural and man made changes such as change in land use;

b) Spatial variability in hydrological variables in a catchment;

c) Interaction between surface and ground water such as conjunctive use and water management in irrigation command areas; and

d) Water quality and soil erosion modelling, movement of pollutants and sediments etc.

During the recent period considerable attention has been drawn towards physically based modelling of the hydrological processes. The physically based and spatially distributed nature of the hydrologic models gives these models advantages over simple regression and lumped models in simulating land use change impact, hydrologic response of ungauged basins, spatial variability in catchment inputs and outputs, ground water and soil moisture conditions, interaction between surface and ground water, management in irrigation command areas and water flows controlling the movements of pollutants and sediment etc. The Systeme Hydrologique European-Europeen Hydrological System (SHE) is an advanced, physically based, distributed catchment modelling system. It has been applied for simulating hydrologic response of six sub-basins of river Narmada(Refsgaard et al., 1992 and Jain et al., 1992) as well as two other sub-basins under a collaborative project sponsored by the Commission of European Communities. Earlier the SHE had been applied to small research catchments, abroad(Bathurst, 1986); whereas, these Indian basins are larger and have a rather limited data coverage compared with previous applications.

For any hydrologic model, its calibration is a prerequisite before considering the model for simulation studies. Though, in principle a physically based model like the SHE should not require any calibration for the parameter values. However, in practice, some calibration of the parameter values is required because (a) some degree of lumping is done at the level of grid size as well as parameters in the SHE, though it is considered to be fully distributed and physically based model; and (b) the measured values of the several parameters are not available at different locations in the basin, particularly for the Indian context. Since, a large number of parameters are involved in the physically based model like the SHE model, hence the calibration can be carried out by the trial and error method. Once, the model is calibrated, it has to be validated using the historical records which have not been used in calibration.

In this study, the setup of the SHE model has been used for carrying out the single column simulations for one grid of 2 km x 2 km of the Narmada Basin for studying the effect of sensitivity of the evaporation data of some of the pan evaporation measurement station and soil parameters.

2.0 THE SHE MODEL

2.1 General

The Systeme Hydrologique Europeen - European Hydrological System (SHE) is an advanced, physically based, distributed catchment modelling system. It has been developed jointly by the Danish Hydraulic Institute, the British Institute of Hydrology, U.K. and SOGREAH (France) with the financial support of the Commission of the European Communities. Currently British responsibility for the SHE lies with the Natural Environment Research Council's Water Resource System Research Unit at the University of Newcastle upon Tyne (UON). In France the responsibility has been transferred from SOGREAH to Laboratorie d'Hydroulique de France (LHE).

The SHE was developed from the perception that conventional rainfall/runoff models are inappropriate to many hydrological problems, specially those related to the impact of man's activities of land use change and water quality. These problems can be solved only through the use of models which have a physical basis and allow for spatial variations within a catchment. The SHE is a physically based model in the sense that the hydrological process of water movement are modelled either by finite difference representations of the partial differential equations of mass, momentum and energy conservation or by empirical equations derived from independent experimental reseyrch. Spatial distribution of catchment parameters, rainfall input ang hydrological response is achieved in the horizontal by an orthogonal grid network and in the vertical by a column of horizontal layers at each grid square. River channels are superimposed on the grid element boundaries. Parameters must be evaluated as appropriate for each grid element, river link and subsurface layer. Basic processes of the land phase of the hydrological cycle are modelled in separate components viz. interception by the Rutter accounting procedure; evapotranspiration, by the Penman-Monteith equation or by an approach developed by Kristensen and Jensen (1975); overland and channel flow by simplications of St.Venant equations; unsaturated zone flow, by one dimensional Richard's equation; saturated zone flow by the two dimensional Boussinesq equation and snowmelt, by an energy budget method. The SHE software is structured in such a manner that each hydrological process is allowed its own component and simultaneous operation of each component is controlled by a central frame component. For flexibility, the components can be modified or omitted i.e. replaced by dummy exchange components in any given application, depending on availability of data and hydrological conditions.

The SHE has a modular structure in order to incorporate improvements or additional components such as irrigation return flow, sediment yield and water quality etc. in future. Considerable operating flexibility is available through the ability to vary the level of sophistication of the calculation made to make use of as many or as few data as are available and also to incorporate data related to topography, vegetation and soil properties which are not usually incorporated in catchment models. The SHE does not require long term hydrometeorological data for its calibration and its distributed nature enables spatial variability in catchment inputs and outputs to be simulated. However, the large amount of data required by the model means that new operation methodologies must be evolved. Thus spatial scale effects or simply a lack of data may create significant uncertainties in the values of the catchment parameters used in simulation. These uncertainities give rise to corresponding uncertainties in the predictions. However, the SHE is able to quantify these uncertainties by carrying out sensitivity analysis for realistic ranges of the parameter values, even when there is a lack of data. Therefore, the SHE can act as a valuable 'decision support system'(Abbott et al.1986).

The SHE is designed as a practical system for application in a wide range of hydrological resource conditions. Its physical and spatially distributed basis gives it advantage over simpler regression and lumped models in simulating land use change impact, ungauged basins, spatial variability in catchment inputs and outputs, groundwater and soil moisture conditions, and water flows controlling the movements of pollutants and sediment.

In particular, the physical basis of the SHE suits it to predictions of the hydrological consequences of man-made changes in a catchment and for pollutant and sediment transport studies. However, the flexibility of the SHE also makes it possible for the one modelling system to perform predictions for a wide range of hydrological problems and at various levels of complexity. The logistics and benefits of the SHE, including a detailed review of potential areas of application, are discussed further by Abbott et al (1978) and additional information is supplied by Beven and O'Connel (1982) and Beven (1985). The schematic diagram of a catchment and a quasi three dimensional physically based distributed SHE model is shown in Fig. 1. Table-1 Summarises some of the possible fields of application of the SHE.

2.2 Approaches for Modelling of the Various Processes

In the SHE, major hydrological processes of water movement, are modelled in the following components:

1. FRAME (central control) component
2. Interception and-evapotranspiration component
3. Overland and channel flow component
4. Unsaturated zone component
5. Saturated zone component

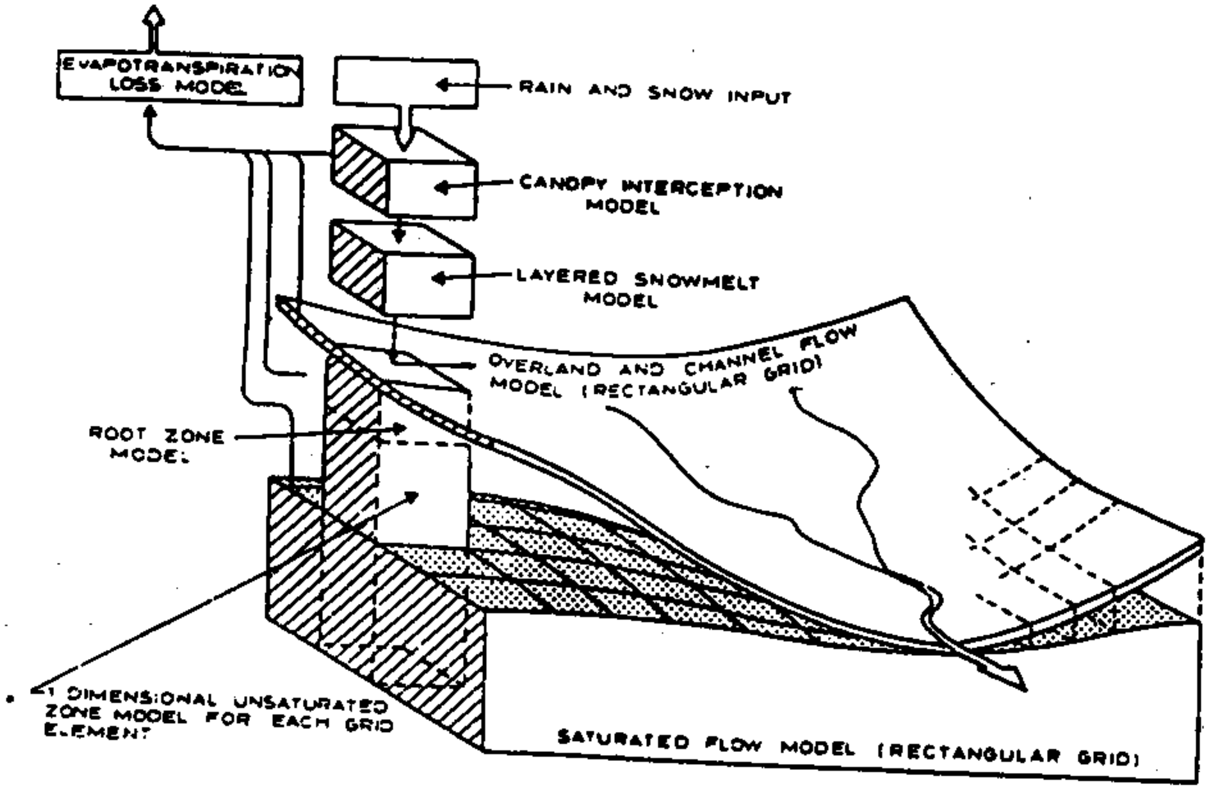

FIGURE 1 - STRUCTURE OF THE EUROPEAN HYDROLOGIC SYSTEM (SHE)

TABLE - 1

Possible fields of application for the SHE at different operation scales for some of the topics a water quality comonent would need to be added to the existing water quantity model:

Topics	Primary hydrological process	Possible scale of operation
Irrigation Scheme		
Irrigation water requirement	ET/UZ	field
Crop production	ET/UZ	Project
waterlogging	ET/UZ	field
Salinity/Irrigation management	UZ	field
Land-use Change		
Forest clearance	ET/UZ/SZ	Catchment
Agricultural practices		field/catchment
Urbanisation		catchment
Water developments Groundwater supply	SZ	catchment
Surface water supply	ET/UZ/SZ	catchment
Irrigation	UZ/SZ	Project/catchment
Streamflow depletion	SZ/OC	catchment
Surface water/groundwater interaction	ET/UZ/SZ	Project/catchment
Groundwater contamination Industrial and municipal waste disposal	UZ/SZ	field/catchment
Agricultural chemicals	UZ/SZ	field/project catchment
Erosion/sediment transfer	OC/UZ	Project/catch.
Flood prediction	OC/UZ	catchment

Note: ET= evapotranspiration. UZ=unsaturated zone. SZ=saturated OC=overland and channel flow

6. Snowmelt component

A detailed description of the above components is given by Abbott et al.(1986). Some of the salient feature of the components of the SHE are briefly be mentioned hereunder.

2.2.1 FRAME (Central Control) Component

The FRAME component coordinates the parallel running of the other components by selecting their different time scales and organizing their data interchanges. Its functions include the following.

(i) Controlling the reading of the parameter sets and the initialization of all computations variables.

(ii) Controlling the sequence in which each component is called to perform its computations.

(iii) Controlling the exchange of data between components.

(iv) Controlling the mass balances between all components and within each component separately.

2.2.2 Interception and Evapotranspiration Component

This component uses meteorological input data and vegetation parameters to simulate the total evapotranspiration and net rainfall amounts resulting from the processes of

(i) interception of rainfall by the vegetation canopy;

(ii) drainage from the canopy;

(iii) evaporation from the canopy surface;

(iv) evaporation from the soil surface;

(v) uptake of water by plant roots and its transpiration.

Net rainfall, transpiration and soil evaporation rates are supplied to the unsaturated zone component, which in return provides information on soil moisture conditions in the root zone. Because interception can significantly affect evapotranspiration, the two processes are modelled within the one overall component.

Interception

The interception component calculates net rainfall reaching the ground through the canopy, the amount of water stored on the canopy and evaporation from the canopy. Interception itself can be modelled by a modified Rutter model or based upon vegetation cover indices. The Rutter model (Rutter et al., 1971-72) is essentially an accounting procedure for canopy storage. From the canopy storage, which can vary during the growing season, e.g. as a function of the leaf area index, the intercepted water may either evaporate directly or drain to the soil surface according to a prescribed function. Consideration of interception loss is particularly important when dealing with forest areas.

Evapotranspiration

The evapotranspiration component calculates actual evapotranspiration and translates it into a loss term, describing uptake of water by plant roots and its transpiration in a response which is continuous as the canopy varies from a dry, through a partially wetted, to a fully wetted state. The loss term is then used in the calculation of soil moisture changes by the unsaturated zone component. The most complex and physically realistic model used in the SHE is the Penman - Monteith equation for actual evapotranspiration (Monteith, 1965) in which three approaches are used, giving flexibility and allowing the model to be adapted to whatever is known of local conditions. In the first two approaches, actual evapotranspiration at subpotential rates is assumed to be limited, at least in part, by vegetation factors, particularly the stomatal resistance to movement of water. In the third approach the limitation is assumed to be due only to the resistance of the unsaturated soil to water movement. The other model (Kristensen and Jensen, 1975) offered as option two, calculates actual evapotranspiration on the basis of potential rates which are required as input data and the actual soil moisture status in the root zone. The derivation of the equations has been based on comparisons with actual measurements.

The total actual evapotranspiration calculated for each grid square depends on how wet the canopy is and on the degree of ground coverage by the canopy. Extraction of moisture for transpiration from the root zone is distributed according to the vertical distribution of root mass in the root zone. Moisture for the soil evaporation is drawn from the top of the soil column.

2.2.3 Overland and Channel Flow Component

This component uses topographic, channel shape and flow resistance parameters to route surface water as overland and channel flow. The depth of surface water available as runoff is determined from the net rainfall and evaporation rates supplied by the interception/evapotranspiration component and from the soil infiltration rate determined by the unsaturated zone component. In addition there is an exchange between channel and aquifer to allow for seepage losses and ground water input.

Both the overland flow and channel flow are modelled by approximations of the St.Venant equations of continuity and momentum (inertia terms neglected). In the modelling of overland flow the slope of the water surface is assumed to be parallel to the ground slope (kinematic wave assumption), but for channel flow, a water surface slope term is included in the mathematical formulation so that backwater effects can be modelled. An equivalent roughness coefficient is used to characterize resistance to overland flow, while depth-dependent flow resistance functions are required for the river flow description.

2.2.4 Unsaturated Zone Component

This component determines the soil moisture content and tension, or pressure, distributions in the unsaturated zone. The zone extends from the ground surface to the phreatic surface. It is mostly nonuniform in its physical properties and the upper part, the root zone, exhibits considerable fluctuations in moisture content as a result of evapotranspiration and rainfall infiltration. Its lower boundary also varies through time, as the phreatic surface elevation changes. The component plays a crucial role in the SHE since all the other components draw upon the boundary data which it supplies.

Two functional relationships are needed to solve the equation. These are the relationship between unsaturated conductivity and the volumetric moisture content and the relationship between soil tension and the volumetric moisture content. The latter, called the retention curve, is known to exhibit hysteresis effects in nature but is approximated for the moment by a single-valued relationship in the SHE. The solution is obtained by an implicit finite difference scheme.

Infiltration into the soil is determined by the upper boundary condition which may shift from flux-controlled conditions to soil-controlled (i.e. saturated) conditions and vice versa. The lower boundary is usually the phreatic surface and a mass balance calculation for the unsaturated zone determines the exchange with the saturated zone. A particularly difficult problem is the calculation of the change in the phreatic surface level. This requires linking the one-dimensional, vertical flow, unsaturated zone model with the two-dimensional, horizontal flow, saturated zone model. In particular the simulated soil moisture profile in the lower part of the unsaturated zone must remain compatible with the phreatic surface level computed by the saturated zone component. In the SHE, the approach used is based on the water balance of the total soil column, including the saturated zone. Upto four soil layers with different characteristics can currently be incorporated in a simulation. Allowance is also made for the disappearance of the unsaturated layer as the phreatic surface rises to the ground surface.

2.2.5 Saturated Zone Component

This component computes the phreatic surface level and the flows, assumed to be horizontal only, in the saturated zone. At present only single-layer, unconfined aquifers can be modelled. However, the component is designed so that it can easily be expanded to account for confined and multilayer aquifers in the future. Otherwise allowance is made for spatial variations in aquifer permeability and the impermeable bed level. The component receives net percolation rates from the unsaturated zone calculations and supplies in return the phreatic surface level as a lower boundary condition for those calculations. Stream/aquifer interactions, ground water seepage at the ground surface and artificial pumping are also simulated.

The variation through time of the phreatic surface level at each square is modelled by the nonlinear Boussinesq equation. This combines Darcy's law and the mass conservation of two-dimensional laminar flow in an anisotropic, heterogeneous aquifer.

The Boussinesq equation is solved by a finite difference approximation using an alternating-direction, non-iterative implicit scheme. Allowance is made for both the complete disappearance of the saturated zone and the rise of the phreatic surface to the ground surface.

2.2.6 Snowmelt Component

This component uses snowpack and vegetation parameters, along with meteorological input data, to predict the transfer of moisture resulting from processes of :

i. snowfall addition to the snowpack;

ii. snowmelt from the snowpack;

iii. spatial variations in snowpack conditions;

iv. interception and evapotranspiration in the presence of a snowpack and at air temperatures below freezing.

Its aim is to model the snowpack thickness as it is affected by precipitation and melting and to model the rate of delivery of meltwater from the snowpack to the soil-surface. The component is structured so that first the total heat flux to the snowpack is calculated, then the amount of melting engendered by this flux is determined and finally the meltwater is routed through the snowpack. Thus both energy and mass fluxes within the snowpack are modelled.

Again, depending on the availability of data or on general requirements, two different calculation modes can be used to determine the total heat flux. The simplest is an adaptation of the degree-day method. Because of its empirical nature, this method is used only when available data are limited to air temperatures. At a more sophisticated level, the heat flux is determined from a budget of the energy inputs and outputs. The snowmelt resulting from the total heat flux is derived from an energy balance equation, in which due account is taken of the latent heat gained by movement of water into the snowpack.

2.3 Data Required for SHE Model Application

Application of a distributed, physically-based model such as the SHE requires the provision of large amounts of parametric and input data, some of which, like crop parameters, may be time dependent. Such data will not always be readily available and therefore options have been built into the system to allow components to degenerate to simpler modes of operation and thereby reducing the data requirements. It is stressed that parameter values are in principle measurable in the field and it is hoped that a general availability of models like SHE, which are able to utilize almost any hydrological information, will instigate more widespread measurements of the data required, if not on a routine basis, then at least as part of the application of the model to specific projects.

Parametric values and data input to the model can vary from grid square to grid square or from point to point in the vertical. However, in most cases the same input data and parametric values will be associated with an assembling of grid squares. Both input data and parametric values are assumed to be valid over the entire area associated with a grid point. An option for variable grid spacing both in the horizontal and vertical direction is included in the system. Thus a refined grid may be introduced around rivers, pumping fields and other such areas, characterized by a significant variation in natural or man-influenced hydrologic processes. The parameters and parametric functions required by the SHE at each grid square for the most comprehensive calculation modes are listed below:

FRAME Component

Model parameters	(i) Ground surface elevation
	(ii) Impermeable bed elevat
	(iii) Distribution codes for rainfall and meteorological source stations
	(iv) Distribution codes for soil and vegetation types

Interception Component

Input data	(i) Rainfall rate
Model parameters (for each crop type)	(i) Drainage parameters
	(ii) Canopy storage capacity (time varying)
	(iii) Ground cover indices (time varying)

Evapotranspiration Component

Input data	(i) Meteorological data
Model parameters	(i) Canopy resistance (for each crop type)
	(ii) Aerodynamic resistance
	(iii) Ground cover indices (time varying)
	(iv) Ratio between actual and potential evapotranspiration as a function of soil moisture tension
	(v) Root distribution with depth

(For Kristensen and Jensen model only (iii) and (v) are required)

Overland and Channel Flow Component

Input data	(i) Specified flows or water levels at boundaries
	(ii) Man-controlled diversions and discharges
	(iii) Topography of overland flow plane and channel cross-sections

Model parameters	(i) Strickler roughness coefficients for overland and river flows
	(ii) Coefficients of discharge for weir formulae

Unsaturated Zone Component

Model Parameters (for each soil type)	(i) Soil moisture tension/ content relationship
	(ii) Unsaturated hydraulic conductivity as a function of moisture content

Saturated Zone Component

Input data	(i) Impermeable bed elevations
	(ii) Specified flows or potentials at boundaries
	(iii) Pumping and recharge data
Model parameters	(i) Porosities or specific yields
	(ii) Saturated hydraulic conductivities

Snowmelt Component

Input data	(i) Meteorological and precipitation data
Model parameters	(i) Degree-day factor
	(ii) Snow zero plane displacement
	(iii) Snow roughness height.

The components interact with each other through a series of internal boundary conditions, either as flow or pressure conditions, which appear as a result of progress in time in the other components. No iteration between the components are performed but they are run in parallel. This means that time steps are taken which are based on 'old' information.

In principle the parameter values should not need to be calibrated, since they are based on physical measurements. However, in practice a certain amount of calibration is likely to be required. One reason for this is that measured values are often obtained at the point scale and may not be representative of the grid scale to which the model parameters are applied.

2.4 Studies Elsewhere using SHE Model

Physically based models of the individual components in SHE have been known for years. The uniqueness of SHE is, however, that it is one of the few models integrating all submodels into one system of the entire land based part of the hydrological cycle. In recent years, application of SHE has moved from purely research oriented studies to projects of practical significance. Examples include:

(i) a study of the effects of land use changes on floods and sediment loads (Thailand),

(ii) a study of the environmental impact of the use of fertilizers (Denmark),

(iii) a water supply planning project for the city of Aarhus (Denmark),

(iv) a comparative study of different models to simulate runoff from medium size catchments (Zimbabwe an Denmark),

(v) a study of the effects of irrigation development (India)

[within the frame work of the project ALA 86/19].

Further developments are currently undertaken to promote its use as an operational tool for water resources and environmental studies.

3.0 STUDY AREA AND DATA AVAILABILITY

In this study, sensitivity analysis has been carried out for a typical grid of 2 kmx2km of the Narmada basin. The index map of Narmada basin is shown in Fig. 2. As network density of pan evaporation measurement stations is relatively less in India, sensitivity of pan evaporation data of various pan evaporation measurement stations located at different places near the considered grid on the hydrological response from a single grid of the sub-basin has been studied with a aim to evaluate how sensitive the simulation results are to the pan evaporation data and whether pan evaporation data of nearby pan evaporation measurement station could be used with the desirable accuracy, in absence of any pan evaporation station in the catchment. The effects of increase in conductivity of unsaturated zone, reduction in value of exponent(n) appearing in Averjanov's formula and reduction in water content at wilting point and residual water content have also been studied.

4.0 Data Processing

A large amount of data need to be processed for application of the physically based and distributed catchment modelling system the SHE. It includes transfer of rainfall, evaporation and discharge data to computer files, checking of the files for errors and digitization of the topography and river system etc. A number of reports were referred for obtaining the relevant information on basin properties.

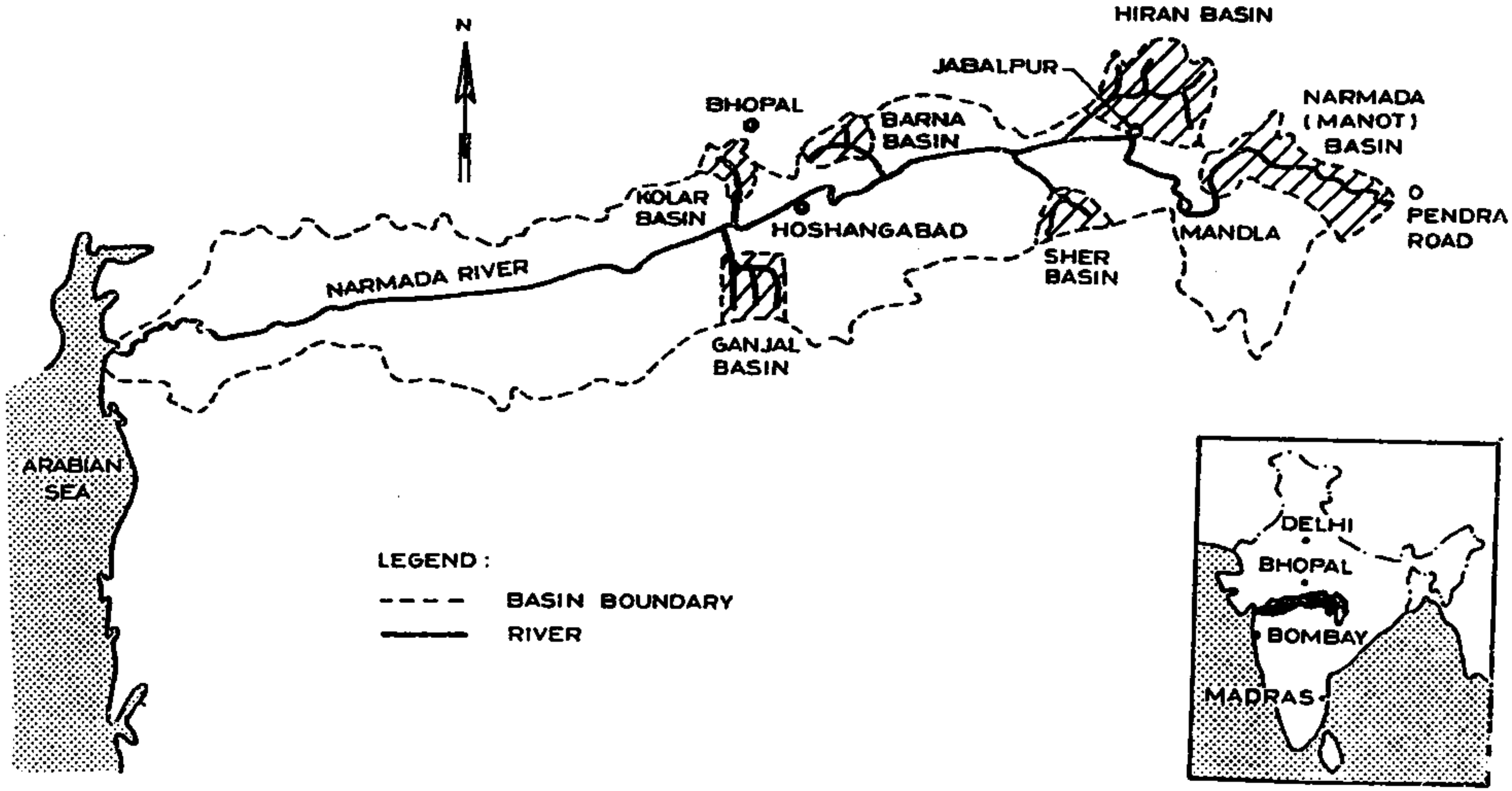

FIG. 2. NARMADA BASIN

5.0 SINGLE COLUMN HYDROLOGIC SIMULATIONS

Single comumn hydrologic simulations have been carried out for studying the sensitivity of the network of pan evaporation data of the various pan evaporation measurement stations as well as increase in conductivity of unsaturated zone, reduction in the value of exponent appearing in the Averjanov's formula and reduction in the values of moisture content at wilting point and residual water content has been studied for a single grid of 2 km x 2 km size of river Narmada. Bathurst(1986) mentions the basic philosophy behind sensitivity analysis of the physically based distributed models like the SHE. It may be summarized that sensitivity analysis is carried out to identify how sensitive are the simulations to the model parameters and how accurately these parameters should be defined. In the simulation studies carried out for the six sub-basins of river Narmada(Refsgaard et al., 1992 and Jain et al., 1992) and elsewhere(Bathurst, 1986) the sensitivity analysis for Strickler coefficient, land use changes, grid size and using mean areal rainfall instead of distributed rainfall etc. were examined.

The sensitivity analysis has been conducted considering one typical grid of the Nrrmada basin. Since, the evapotranspiration is more pronounced for dense forest area as compared to open forest, agricultural land or waste land, the grid under dense forest is considered in this study. Rainfall over this grid is represented by the Makrai rain gauge station. In each of the sensitivity runs, the response of the basin was simulated by changing just one parameter value and keeping other parameters same as adopted in the calibration run. This response was then compared with the results obtained by adopting the parameters used in the calibration run, referred to as the reference run in remaining part of the discussion. The following sensitivity runs were taken and the hydrological response from the grid of 2 km x 2 km size was estimated applying the SHE model, considering the grid as a single column using the record for the period March 1983 to February 1985:

Run (1) Using the parameters adopted in the calibration run, with Jabalpur pan evaporation data(reference run);

Run (2) Using pan evaporation data of Betul pan evaporation measurement station;

Run (3) Using pan evaporation data of Powar Kheda pan evaporation measurement station;

Run (4) Using pan evaporation data of Pendra Road pan evaporation measurement station;

Run (5) Increasing the conductivity of unsaturated zone from 0.1 to 0.5.

Run (6) Reducing exponent(n) appearing in Averjanov's formula (for calculation of unsaturated conductivity as a function of moisture content) from 14 to 10

Run (7) Reducing both water content at wilting point and residual water content from 0.21 to 0.12.

6.0 DISCUSSION OF RESULTS

The various single column hydrologic simulation runs have been taken and the simulated values of monthly actual evapotranspiration and runoff simulated for each of the runs have been compared with the respective values computed for the reference run. Simulated runoff for the various sensitivity runs for the periods March 1983 to February 1984 and March 1984 to February 1985 are given in Tables 2 and 3 respectively. Tables 4 and 5 provide actual evapotranspiration for the above periods. Ratios of simulated runoff to rainfall(RO/RF), actual evapotranspiration to rainfall (ET/RF) and actual evapotranspiration to potential evapotranspiration(ET/PT) for the above periods are given in Table 6. Variation of ground water table for the period June 1983 to November 1984 is shown in Fig. 3. Fig. 4 shows percent change between simulated runoff of the reference run and each of the other sensitivity runs for the period July 1983 to October 1984. Percent change between actual evapotranspiration simulated for the reference run and simulated for each of the other sensitivity runs for the period March 1983 to February 1984 are shown in Fig. 5.

Run (1) In this run, the values of the model parameters adopted in the calibration run i.e. the best fit parameters have been used. Pan evaporation data of Jabalpur pan evaporation measurement station have been considered. It is seen from the Tables 2 to 5 that Makrai rain gauge station has an areal rainfall of 1845.5 mm and 1873.9 mm and Jabalpur pan evaporation station reports potential evaporation of 1300.2 mm and 1377.6 mm for the period 1983-84 and 1984-85 respectively. It is observed from Tables 2 and 3 that actual evapotranspiration is 592.8 mm and 494.6 mm and Tables 4 and 5 show that runoff is 1351.8 and 1224.2 mm for the above periods respectively. The variation of ground water table is shown in Fig. 3. The values of RO/RF, ET/RF and ET/PT ratios are 0.733, 0.321 and 0.456 for the period 1983-84, and 0.731, 0.295 and 0.359 for the period 1984-85 respectively.

Run (2) In this run, potential evaporation data of Betul pan evaporation measurement station have been used. This station reports potential evaporation of 1198.7 mm and 1224.6 mm for the periods 1983-84 and 1984-85. The actual evapotranspiration is 690.3 mm and 527.9 mm and runoff is 1263.2 mm and 1190.8 mm for the above periods respectively. It is observed that actual evapotranspiration for this run is more, even though potential evaporation is relatively less. It is seen from Fig. 3 that there is no significant change in the position of ground water table in comparison to the reference run. It is seen from Figs. 4 and 5 that percentage change in the simulated runoff as well as actual evapotranspiration is relatively low for this run.

Run (3) In this run, potential evaporation data of Powar kheda pan evaporation measurement station have been used. This station reports highest observed potential evaporation i.e. 1708.9 mm and 1736.6 mm among all the stations for the periods 1983-84 and 1984-85. The actual evapotranspiration of 724.5 mm and 557.2 mm

Table 2 : Simulated Runoff for Various Runs for the Period March 1983 to February 1984 (in millimeters)

Month	Rain fall	Run(1)	Run(2)	Run(3)	Run(4)	Run(5)	Run(6)	Run(7)
March	0.0	0.7	0.7	0.7	0.7	0.2	0.3	0.4
April	0.0	0.1	0.2	0.1	0.1	0.0	0.0	0.0
May	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
June	71.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
July	515.8	173.1	153.7	116.4	199.9	119.3	84.8	96.4
Aug.	609.9	579.4	549.8	554.8	592.5	578.1	570.3	573.8
Sept.	606.9	537.9	516.3	513.1	535.5	538.9	538.5	538.3
Oct.	40.9	41.6	35.1	32.5	45.8	39.9	40.2	40.5
Nov.	0.0	8.9	8.6	8.0	9.3	5.6	5.6	6.3
Dec.	0.0	5.5	5.2	4.8	5.8	0.7	0.6	1.5
Jan.	0.0	3.1	2.8	2.5	3.4	0.0	0.0	0.0
Feb.	0.0	1.5	1.1	0.9	1.7	0.0	0.0	0.0
Total	1845.4	1351.8	1263.2	1233.8	1394.7	1282.7	1240.3	1257.2

Table 3 : Simulated Runoff for Various Runs for Period March 1984 to February 1985 (in millimetgrs)

Month	Rain fall	Run(1)	Run(2)	Run(3)	Run(4)	Run(5)	Run(6)	Run(7)
March	0.0	0.3	0.1	0.1	0.4	0.0	0.0	0.0
April	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
May	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
June	34.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
July	179.8	27.4	23.4	19.4	28.3	7.6	16.1	16.6
Aug.	1436.0	1156.4	1138.2	1111.8	1197.9	1080.2	1016.4	1043.4
Sept.	17.8	21.5	13.6	18.6	22.2	19.7	17.5	16.6
Oct.	5.4	9.1	7.9	8.6	9.4	5.4	5.3	6.1
Nov.	0.0	5.2	4.5	4.8	5.5	0.0	0.0	0.0
Dec.	0.0	2.9	2.4	2.6	3.2	0.0	0.0	0.0
Jan.	0.0	1.3	0.7	0.9	1.5	0.0	0.0	0.0
Feb.	0.0	0.2	0.0	0.0	0.3	0.2	0.0	0.0
Total	1673.9	1222.4	1190.8	1166.8	1268.7	1112.9	1055.5	1083.6

Table 4 : Actual Evapotranspiration for Various Runs for the Period March 1983 to February 1984 (in millimeters)

Month	Rain fall	Run(1)	Run(2)	Run(3)	Run(4)	Run(5)	Run(6)	Run(7)
March	0.0	71.3	57.7	72.5	66.0	84.5	100.0	94.5
April	0.0	42.4	42.7	46.9	41.6	58.8	70.0	66.9
May	0.0	29.3	29.4	31.2	25.8	43.9	53.1	50.5
June	71.9	46.2	50.0	64.4	43.7	54.8	60.8	58.0
July	515.8	75.5	110.4	115.6	60.7	76.7	77.0	76.2
Aug.	609.9	72.7	105.5	86.5	60.5	72.7	60.0	72.7
Sept.	606.9	56.9	82.4	87.6	58.3	60.0	60.0	60.0
Oct.	40.9	78.2	88.2	103.8	66.7	78.2	78.2	78.2
Nov.	0.0	41.1	52.1	47.3	49.1	61.9	61.9	61.9
Dec.	0.0	29.7	32.3	27.2	28.9	54.1	54.2	54.2
Jan.	0.0	20.6	22.3	18.4	22.1	40.4	44.4	44.9
Feb.	0.0	22.9	17.3	23.1	21.2	36.6	57.6	42.1
Total	1845.4	592.8	690.3	724.4	544.6	722.6	789.9	760.8

Table 5 : Actual Evapotranspiration for Various Runs for the Period March 1984 to February 1985 (in millimeters)

Month	Rain fall	Run(1)	Run(2)	Run(3)	Run(4)	Run(5)	Run(6)	Run(7)
March	0.0	24.5	17.0	22.9	26.0	36.7	47.6	42.3
April	0.0	30.4	20.0	28.9	27.2	41.4	50.3	48.9
May	0.0	28.1	21.2	25.9	24.8	35.6	41.8	42.8
June	34.9	52.6	50.6	57.8	45.1	56.5	61.3	59.9
July	179.8	87.7	92.2	111.6	58.0	89.4	91.0	88.9
Aug.	1436.0	50.6	96.2	69.9	55.4	50.6	50.6	50.6
Sept.	17.8	72.6	15.2	81.9	66.7	73.9	73.9	73.9
Oct.	5.4	63.0	57.0	65.6	56.9	96.5	86.8	86.6
Nov.	0.0	30.1	33.0	31.3	33.0	52.4	66.8	58.5
Dec.	0.0	20.8	24.8	22.8	24.7	36.4	54.4	38.3
Jan.	0.0	15.8	16.6	20.6	13.0	27.1	37.5	30.6
Feb.	0.0	18.4	12.7	17.4	19.8	30.5	37.9	34.2
Total	1673.9	494.6	527.8	557.2	450.6	617.0	699.9	654.9

Table 6 : Ratio of Runoff to Rainfall (RO/RF), Actual Evapotranspiration to Rainfall (ET/RF) and Actual Evapotranspiration to Potential Evapotranspiration (ET/PT)

Run No.	RO/RF	ET/RF	ET/PT	RO/RF	ET/RF	ET/PT
	Period(Mar 1983 to Feb 1984)			Period(Mar 1984 to Feb 1985)		
Run(1)	0.733	0.321	0.456	0.731	0.295	0.359
Run(2)	0.684	0.374	0.576	0.711	0.315	0.469
Run(3)	0.669	0.393	0.424	0.697	0.333	0.321
Run(4)	0.756	0.295	0.540	0.758	0.269	0.449
Run(5)	0.694	0.392	0.556	0.665	0.369	0.448
Run(6)	0.672	0.428	0.608	0.631	0.418	0.508
Run(7)	0.681	0.412	0.585	0.647	0.391	0.475

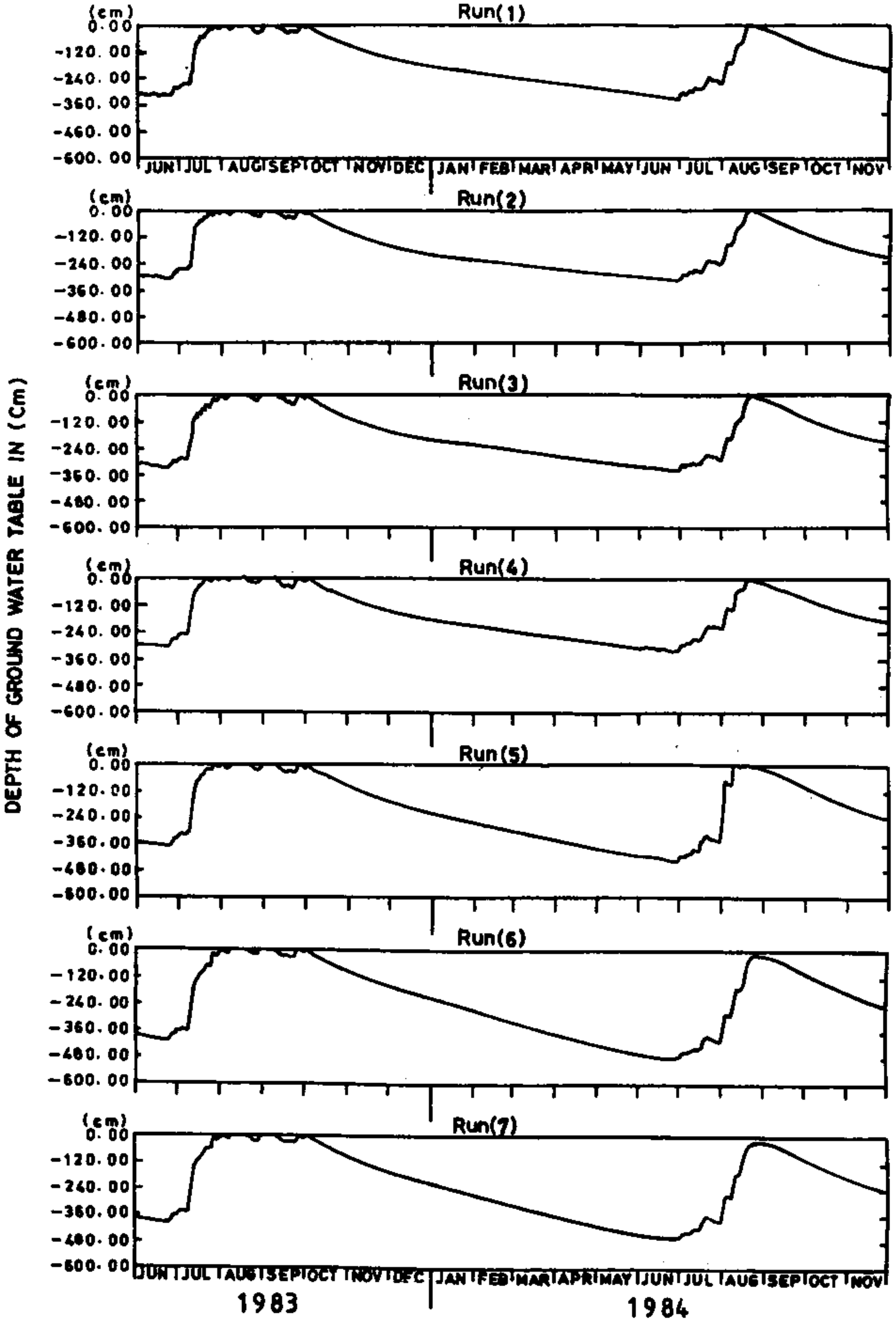

FIG.3–VARIATION OF GROUND WATER TABLE FOR VARIOUS SENSITIVITY RUNS

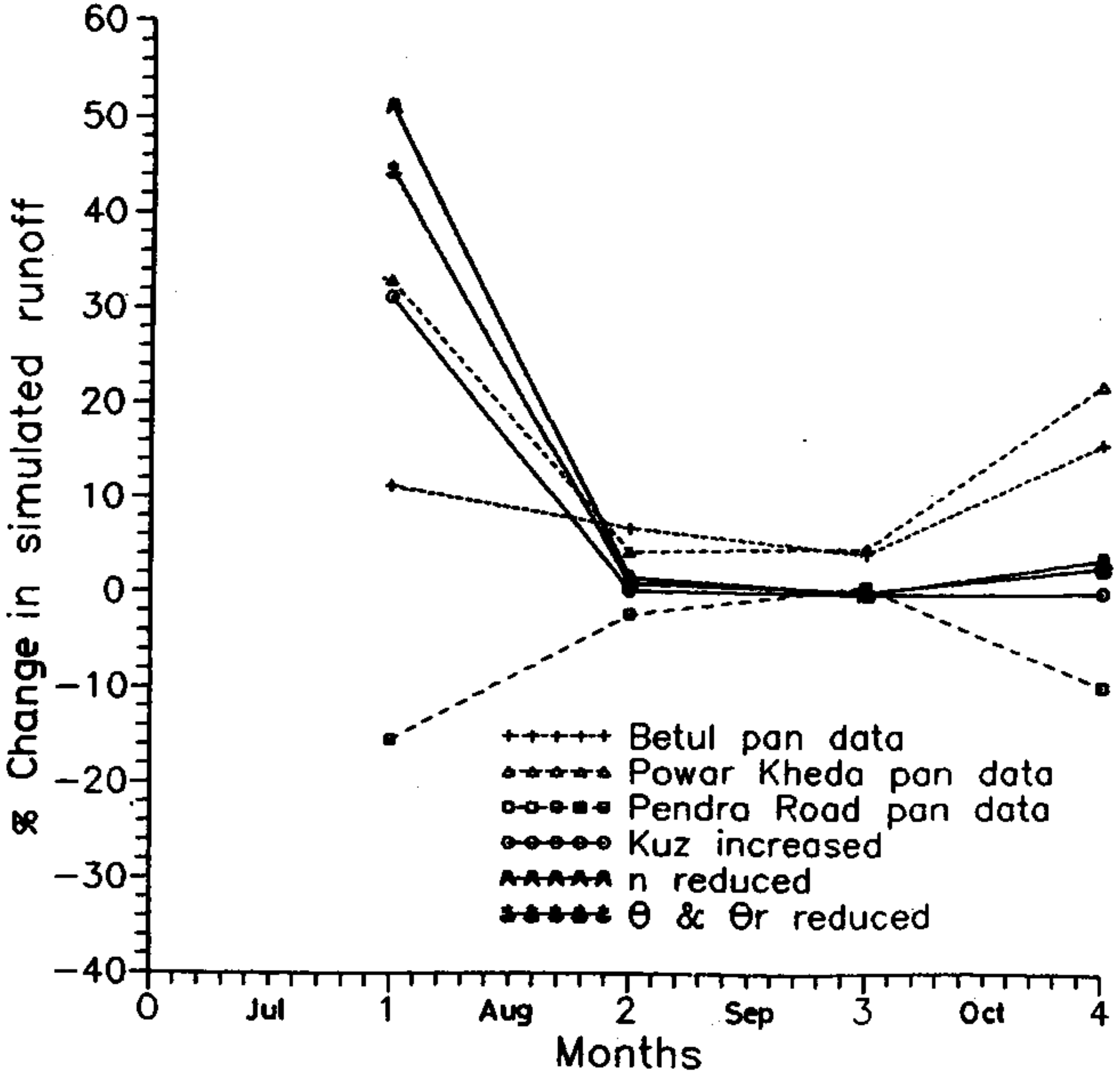

Fig.4 - % Change in simulated runoff for various sensitivity runs for July 83 to Oct. 84

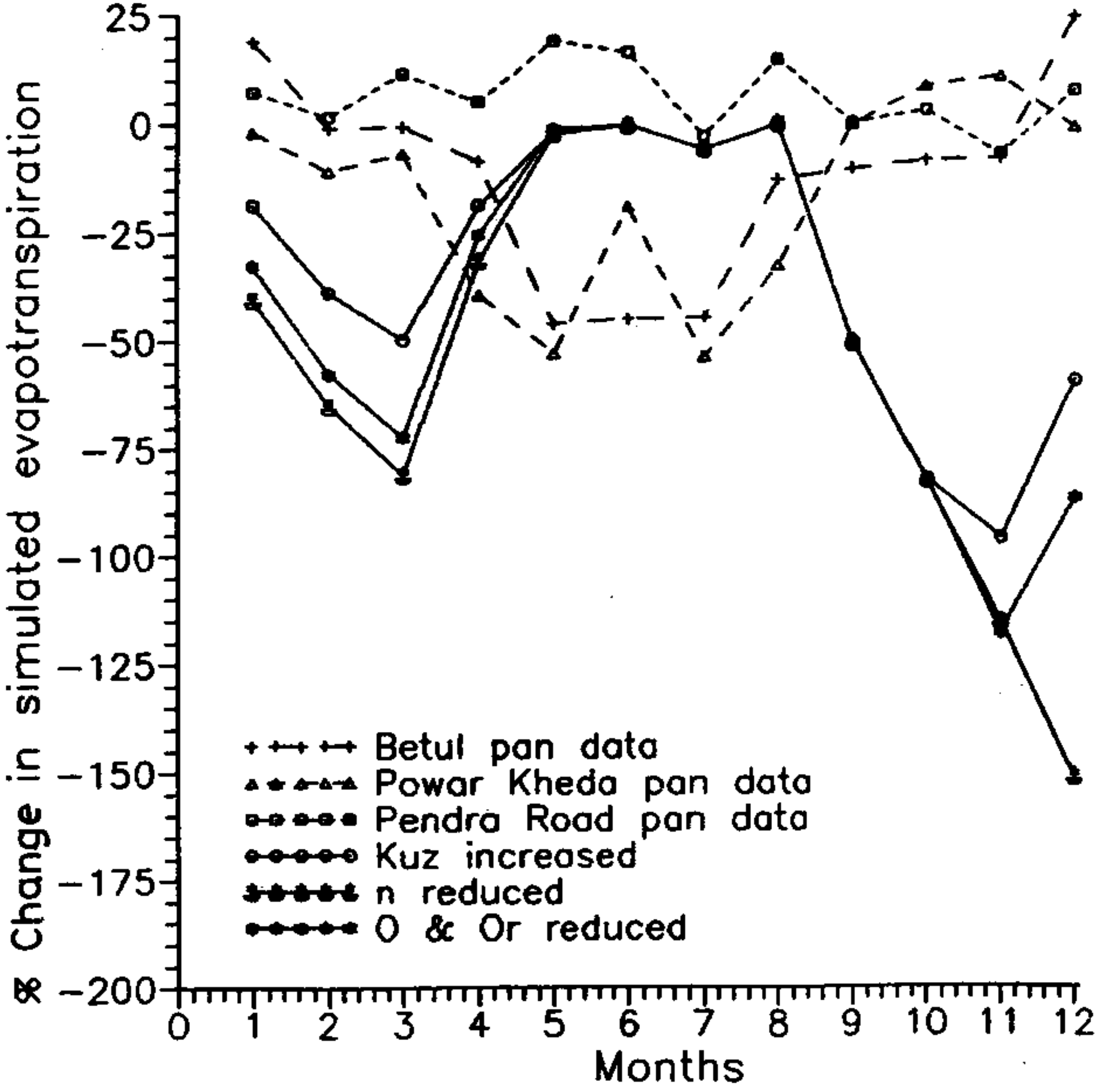

Fig.5–% Change in simulated evapotranspiration for various sensitivity runs for Mar. 83 to Feb. 84

and runoff of 1233.8 mm and 1166.8 mm have been simulated for 1983-84 and 1984-85. Fig.3 shows that there is no significant change in the position of ground water table in comparison to the reference run. Percentage change in the simulated runoff as well as actual evapotranspiration are relatively high for this run as illustrated from Figs. 4 and 5.

Run (4) In this run, Potential evaporation data of Pendra Road pan evaporation measurement station have been used. This station reports the lowest potential evaporation of 1008.0 mm and 1004.5 mm for the periods 1983-84 and 1984-85. The actual evapotranspiration of 544.6 mm and 450.6 mm and runoff of 1394.7 mm and 1268.7 mm have been simulated for the periods 1983-84 and 1984-85 respectively. There is no significant change in the position of ground water table as observed from Fig. 3.

Run (5) In this run, saturated conductivity of unsaturated zone was increased from 0.1 to 0.5. It is observed that actual evapotranspiration increases by 22% and 25% and runoff decreases by 5% and 9% for the periods 1983-84 and 1984-85 respectively. Fig. 3 shows that the ground water table goes much down in dry season. Initial peaks decrease due to higher rate of infiltration. Actual evapotranspiration is higher in dry season. It is due to loss of moisture by capillary rise resulting from higher soil conductivity. Reduction in runoff is on account of higher infiltration as a result of higher soil conductivity.

Run (6) In this sensitivity run, the exponent(n) was reduced from 14 to 10. It is observed from Tables 2 and 3 that simulated runoff decreases by 8% and 14% for the periods 1983-84 and 1984-85 respectively. It is also observed from Tables 4 and 5 that actual evapotranspiration increases by 33% and 41% for the same periods. RO/Rf ratio shows the maximum decrease whereas ET/RF and ET/PT ratios exhibit the maximum increase as compared to the other runs as observed from Table 6. Fig. 3 shows that ground water table goes much down specially during the non monsoon period. This occurs because of larger loss of water from soil through transpiration by capillary rise during the dry season. Figs. 4 and 5 show that reduction in the value of (n) leads to the highest percent change in the values of simulated runoff and actual evapotranspiration. From, this run, it is observed that the exponent(n) appearing in Averjanov's formula used in SHE has an immense effect on actual evapotranspiration.

Run (7) In this sensitivity run, water content at wilting point and residual water content of soil i.e. inaccessible water content in soil due to adsorption, both were reduced from 0.21 to 0.12. It is observed from the Tables 2 and 3 that annual runoff reduces by 7% and 11% and actual evapotranspiration increases by 28% and 32% and for the periods 1983-84 and 1984-85 respectively. It is seen from Table 5 that ET/RF ratio increases significantly. Fig. 3 shows that ground water table goes much down during non-monsoon season. Decrease in water content at wilting point and residual water content of soil leads to larger evapotranspiration from soil and lesser runoff.

7.0 CONCLUSIONS

In this study, single column hydrologic simulations have been carried out using the potential evapotranspiration data of four pan evaporation measurement stations as well as for studying the sensitivity of the important soil parameters such as saturated conductivity of unsaturated zone, exponent(n) used in Averjanov's formula and water content at wilting point and residual water content on some of the hydrologic variables. It is observed from the study that the simulated runoff and actual evapotranspiration are somewhat sensitive to the choice of the various pan evaporation measurement stations. However, depth to ground water table does not show any significant variations when the pan evaporation data of the different stations are used.

Increase in the value of conductivity of unsaturated zone leads to increase in actual evapotranspiration and decrease in runoff. Initial peaks decrease due to higher rate of infiltration. Also, actual evapotranspiration is higher in dry season. It is due to larger loss of moisture by capillary rise resulting from higher soil conductivity. Reduction in runoff is on account of higher infiltration as a result of higher soil conductivity. It is also observed that reduction in value of the exponent(n) appearing in Averjanov's formula which is used in the SHE model decreases the simulated runoff and increases actual evapotranspiration significantly. Reduction in the values of water content at wilting point and residual water content of soil also reduces runoff and increases actual evapotranspiration. The analysis shows the importance of representativeness of evaporation data in hydrological modelling studies. It also indicates likely affects of selection of particular values of soil parameters on model response.

This study has been carried out for a typical grid, where interactions among all the hydrological processes could not be considered. Thus, inferences made in this study are restricted to the response from one grid only. Further studies may be carried out to examine the sensitivity of the evapotranspiration data as well as soil and other parameters by setting up the SHE model on a catchment scale.

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