CS-47

KOLAR BASIN SIMULATION STUDIES USING THE SHE MODEL

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P R E F A C E

The increasing water resources development activity has focussed attention on development and application of physically based hydrological models to deal with constantly changing hydrological environment. When the hydrological system is subject to change or when a realistic physical representation of flow in space and time is required, the conceptual representation or traditional rainfall runoff models with lumped approach are not suitable.

The SHE (Systeme Hydrologique European) Modelling system developed by Institutes of three countries, namely: Denmark, France, and U.K. has been transferred to NIH under a collaborative project. This Model has capability to consider physical processes of the catchment in a distributed manner including soil, vegetation, and land use distribution, topography, etc. Since the commencement of the 3 year project in November 1987, the Model has been applied to six sub-basins of River Narmada, including Kolar basin. Subsequently, field investigations and laboratory analysis have been carried out to improve soil related data base for Kolar basin.

The present report describes an updated study related with simulation of behaviour of Kolar basin using SHE Model. The study has been carried out by Dr. S K Jain, Scientist 'C' in close coordination with the Consultants and the Project Coordinator, SHE Model Project.

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CONTENTS

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LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The Kolar subbasin is one of the six subbasins chosen for simulation using the SHE model. After the first phase of simulation of this basin completed in later half of 1989, it was felt that the simulation results can be improved if a field investigation programme is carried out with a view to improve the parameter base for the model. This report describes the updating of simulation of Kolar basin in the light of results of the field investigation carried out during Jan, 1990.

A brief description of the study area is given followed by data availability and processing. A summary of field investigation and laboratory analysis is also given. The calibration and validation of model for Kolar basin and the have been discussed. The results of the model validation are reasonable. Although the discharge is over predicted in some cases and under predicted in some other cases, the overall results are reasonable subject to availaiblity and reliability of data. The model performance with improved information of parameters has also been compared with simulation results of previous study.

A sensitivity analysis was carried out to determine the sensitivity of model output to input data errors. It was found that the model output is very sensitive to soil depth, input rainfall and potential evaporation.

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1.0 INTRODUCTION

The mathematical modelling of hydrologic system is a powerful tool for both the research hydrologists and the practicing water resources engineers involved in planning, development and management of water resources, Clarke(1973). Due to ever increasing cost of water resources development, there has been increasing demand for better approach to hydrological modeling, of late, also concerned with the effects of land use changes on hydrologic regime, implications of existing and proposed irrigation schemes and several problems arising from conjunctive use of water, Anderson and Burt(1985). Conventional hydrological models are often inappropriate for such problems and a new generation of hydrological models is needed. Attention is, therefore, being focused on physically based distributed catchment models which have the potential to overcome many of the deficiencies associated with the traditional approaches, Beven(1985). It is in the light of these facts that three European Organizations, viz., the Danish Hydraulic Institute, the British Institute of Hydrology and the French consulting company SOGREAH have jointly developed the European Hydrological System - Systeme Hydrologique Europeen (SHE) model.

A financial agreement entitled "*Hydrological computerized modelling system (SHE)*", ALA 86/19, was signed in June/July

1987 between the Commission of European Communities (CEC) and the Government of India, on a project to transfer the SHE model to NIH, India, by the above organizations and to apply this model to selected focus basins in India.

In view of the large scale water resources development activities taking place in the Narmada Basin and the availability of data, 6 sub-basins of this basin namely : Kolar, Barna, Sher, Ganjal, Hiran, and Narmada upto Manot were selected as focus basins for simulation studies after discussions with M.P. Irrigation Department. The available data about these basins, though provided reasonable information regarding rainfall, discharge, topography, evaporation, land use, etc., was lacking in terms of direct information on soil and vegetation properties, root zone depths, vegetation growth and cropping pattern, soil depths, and channel cross sectional dimensions. For the simulation work carried out up to 1989, such information was obtained indirectly from the reports and papers related with neighboring areas to the extent required.

The Kolar subbasin was one of the six subbasins chosen for simulating hydrologic response using the SHE model. The details of this study and results up to 1989 have been described [Jain(1989) and Jain(1990)].

1.1 UPDATING OF KOLAR SIMULATION

The SHE, being a distributed model, requires a huge amount of input data - both about the catchment as well as its inputs and outputs - for model setup, calibration and validation. The data required about catchment includes topography, soil depth and hydraulic properties, land use, river channel geometry and properties. The time varying input data which is required for modelling consists of precipitation input, potential evaporation, vegetation leaf area index and root depth along with their temporal variations. The data pertaining to output from the catchment which are needed for model calibration and validation mainly include discharge at various locations in the basin and position of phreatic surface level at various observation points at different times.

It is a well recognized fact that proper modelling of soil behaviour is the key to catchment modelling. At the time of previous work (carried up to 1989), no direct measurement of a number of soil parameters such as soil depth and hydraulic properties, and other parameters such as channel network geometry, etc. were available.

In the absence of measured values of various parameters the values adopted in modelling were based on measurements of nearby catchmnets as well as values reported in the literature.

However, this introduced a degree of uncertainty in the results. Further, the possibility that at the time of model calibration, either the errors in the input data were getting compensated by the unrepresentative values of the parameters or one or more of the input parameters were compensating for other parameters, can not be totally ignored.

A field investigation programme was therefore carried out to overcome the above deficiencies in previous simulation and update the same with improved data base for physical characteristics.

1.2 SCOPE OF PRESENT REPORT

The present report describes the updating of Kolar simulation in the light of the results of a field investigation carried out in the basin during the month of Jan, 1990 followed by laboratory analysis of the samples.

The report starts with brief introduction of the SHE model. A brief description of the study area is given followed by data availability and processing. A brief description of field investigation and laboratory analysis of samples is also given. The calibration and validation of SHE setup for Kolar basin is described. The results of a sensitivity analysis carried out to determine the sensitivity of a few model parameters and input data have also been discussed. The model performance with improved information of parameters has also been compared with previous simulation results.

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2.0 BRIEF DESCRIPTION OF SHE

The SHE model has been briefly described in the previous report Jain(1990). Meanwhile, an updated version of the model has been brought out recently. This new version used in the present study is briefly described below.

The SHE is a deterministic, distributed and physically based modelling system. It has been jointly developed by the Danish Hydraulic Institute (Denmark), the Institute of Hydrology (UK) and SOGREAH (France). The partial differential equations describing the processes of overland and channel flow, saturated and unsaturated zone are solved by finite difference methods. In addition, different methods are used for description of interception, evapotranspiration and snowmelt. The unsaturated zone computations are made in one-dimensional columns, Abbott et al (1986a, 1986b). The structure of the model is illustrated in Fig. 2.1.

In the SHE model, the basin is divided in a number of equal sized grid squares. The size of the individual squares depends upon the size of the basin, the data availability, the purpose of the study and the computational facilities available.

In the SHE model, a separate sub-model component is solved for each hydrological process with a master component

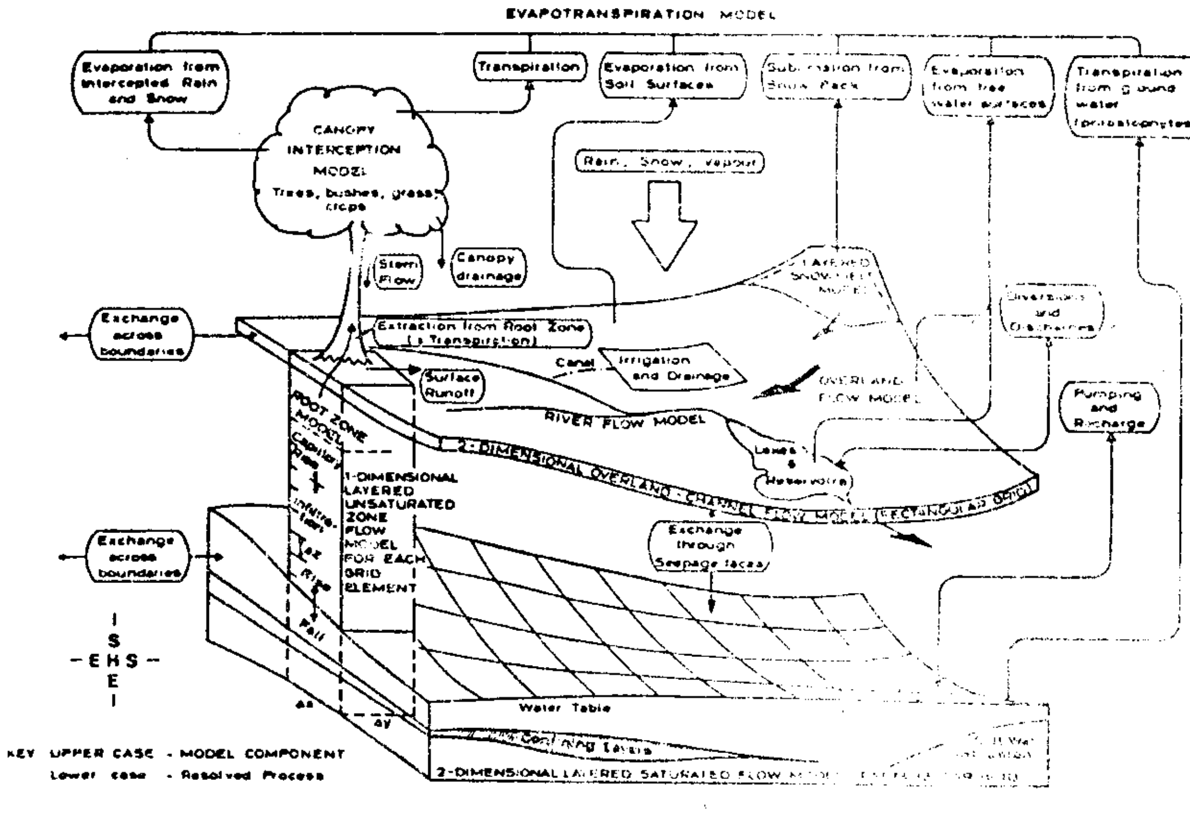

Fig. 2.1 Schematic representation of the structure of the SHE model

controlling the running of each of these as well as data exchange among them. The linkage of one-dimensional unsaturated zone and two-dimensional saturated zone is achieved through a coupling component. Similarly, the exchange of water between river and aquifer is achieved with the help of an exchange component. The SHE, by virtue of being a modular system, allows the user to make a choice among the components which he wants to invoke. In case it is decided to skip execution of a particular component, a corresponding dummy component is called which sets and transfers boundary conditions. This permits greater application-flexibilities since the same code can be used for modeling a single unsaturated zone column as well as a large basins with manifestations of all component processes.

A brief description of various components follows.

2.1 EVAPOTRANSPIRATION (ET) COMPONENT

This is a one -dimensional interception and evapotranspiration component. The interception model calculates net rainfall reaching the ground through canopy, water stored on the canopy and evapotranspiration from the canopy. No distinction is made between throughfall and stemflow nor the interception of snow and fog is accounted for. The approach based on Leaf-Area is used to calculate interception :

$$C = C_{int} * LAI \qquad (2.1)$$

where

C = water stored on canopy,

C_{int} = Interception coefficient,

LAI = Leaf-area index for the vegetation.

The input rainfall in excess of C+Evaporation will only reach to the ground.

The evapotranspiration module of SHE calculates evaporation of intercepted moisture from the canopy surface, from the soil surface, uptake of water by plant roots and its transpiration. Four calculation options are available. The choice of a particular option depends on data availability and the understanding of the evapotranspiration process in a particular application.

2.2 SNOWMELT (SM) COMPONENT

This component models the snow pack thickness as affected by precipitation and melting and also the rate of deliveries of meltwater from the snow pack to the soil surface. The model is structured so that the total heat flux to the snow pack is calculated either by Degree-Day or by Energy Budget method, the amount of melting by this flux is calculated and finally the meltwater is routed through the snow pack.

2.3 OVERLAND AND CHANNEL (OC) FLOW COMPONENT

The generation of overland flow takes place in three conditions : a) when precipitation input is greater than infiltration capacity of soil in which case it is termed as Hortonian Flow, b) when top soil layer is saturated in which case even a low intensity rainfall is able to generate flow termed as saturation excess flow, and c) when subsurface flow is forced up to the ground surface where it flows as overland flow and in which case any rainfall will generate overland flow (Dunne's overland flow mechanism). The surface runoff is routed in the down gradient towards the river system. During the journey, whose route is determined by the topography and surface resistance, the quantity of water undergoes changes because of evaporation infiltration and additional rainfall. The water reaching river system is routed in the downstream direction.

In SHE the overland flow is modelled using a two - dimensional model and the river flow is modelled using a one - dimensional model. In the model, it is assumed that the rivers run parallel to grid boundaries. The routing of surface runoff as well as streamflow is done using the St. Venant Equations. In the simplified form, these continuity and momentum equations can be written as :

$$\partial A/\partial t + \partial Q/\partial x = 0 \quad (2.2)$$

$$\partial Q/\partial t + \partial(U^2A)/\partial x + gA(\partial h/\partial x - S_0) + gAS_f = 0 \quad (2.3)$$

where

$A = A(x,t)$ is wetted cross section area,

$U = U(x,t)$ is flow velocity.

S_o = Bed slope,

S_f = Friction slope,

Q = Discharge.

Provision has been made in the model which enables a user to specify the catchment roughness on a distributed basis. The model also accounts for the surface detention storage

The finite difference form of Eq. (2.2) and (2.3) is solved using an implicit scheme. An efficient numerical scheme which takes advantage of the special matrix structure is used to obtain the solution.A module to simulate the behaviour of a lake inside a catchment has also been developed.

2.4 UNSATURATED ZONE (UZ) COMPONENT

This is a one - dimensional model component which is used for computation of soil moisture changes in the unsaturated zone. The upper part of this zone loses water due to soil evaporation and extraction by plant roots. In the lower part of unsaturated zone, moisture changes take place due to fluctuations in water table. The UZ columns are modeled by one-dimensional Richards equation :

$$C\partial\psi/\partial t = \partial(K\partial\psi/\partial z)/\partial z + \partial K/\partial z - S \quad (2.4)$$

where,

$C = \partial\theta/\partial\psi$ = slope of soil water retention curve,

θ = volumetric soil moisture content,

ψ = pressure head,

K = unsaturated hydraulic conductivity,

S = root extraction sink term.

This equation is non-linear and its solution requires knowledge of physical properties of soil. Two important parameters of soil physical property are $K(\theta)$ and $\psi(\theta)$ The hydraulic conductivity $K(\theta)$ decreases sharply as the moisture content decreases from saturation. This happens because as saturation decreases, more pores get filled with air, less area becomes available for flow and also the flow path becomes more tortuous. In SHE, the relationship between $K_r(\theta)$ and θ is described using Averjanov's (1950) formula according to which

$$K_r(\theta) = \{ (\theta - \theta_r) / (\theta_s - \theta_r) \}^n \quad (2.5)$$

where,

θ = actual moisture content,

θ_s = saturated moisture content,

θ_r = residual moisture content,

n = Averjanov's exponent, varying with soil type.

In the SHE model, a fully implicit formulation has been adopted to solve the Richards equation. The space derivatives are represented by their finite difference analogs at time level n+1. The values of $C(\theta)$ and $K(\theta)$ are referred to at time level n+1/2. These are evaluated in an iterative procedure.

2.5 SATURATED ZONE (SZ) COMPONENT

As the name suggests, this component is used to simulate the response of saturated subsurface zone of ground water. The present version is capable of handling three dimensional multi-layered aquifer systems. Applying the Dupit assumption of horizontal flow, the partial differential equation describing the flow is

$$\partial / \partial x_i \; (K_{ij} \; H \; \partial h / \partial x_j) = S \; \partial h / \partial t + R \qquad (2.6)$$

where H is the saturated thickness of the aquifer, h represents the position of water table, K_{ij} is the hydraulic conductivity tensor, S is the storage coefficient, t is time and R is local volume flux per unit area. The solution of this equation is obtained using a finite difference approximation.

In the SZ component, provision of horizontal drainage has also been made. This drainage acts as a bypass and water can quickly pass to the river. The elevation of the drainage and its time constant are specified by the user.

2.6 IRRIGATION (IR) COMPONENT

A new module, named Irrigation component has been recently added to the SHE to model the process of irrigation. This is a two - dimensional model to simulate the irrigation practice in an area.

2.7 WATER BALANCE PROGRAMME

A SHE water balance programme has been developed to prepare component wise water balance summary of the catchment for a specified span of time or in instantaneous mode. The output from this programme can be inspected to determine the response mechanism of the basin, to find the contribution of each individual component, to find *where water in going*, and *from where water is coming to river*, etc.

2.8 PROGRAMMING ASPECTS

In the SHE programme, separate set of routines are available for modeling of different components of the hydrologic cycle. The main programme named FRAME, is responsible for calling initialization routine, reading the input data and determining the time step size. It also calls different subroutines in proper order and ensures data exchange among them. In case it is decided to omit a particular component, a dummy is called instead. The advantage of this moduled programming is that whenever a new version of any component is developed it can replace its older version without affecting any other component. Each component reads its input data from separate files.

The SHE requires rather large computational requirements - both in terms of size (CPU memory and disk storage) and execution time. Just to give an idea, for a machine having speed of the order of several mips, the time required for simulation of a basin of size 1000 square km will be of the order of one hour of CPU time for data of one year. Of course, this time is dependent on a number of factors, e.g., number of grids, river links, calculation columns, and volume of precipitation input etc. However, with the current trend in developments in the computer industry, it will be possible to run SHE on micro computers within a few years.

2.9 DATA REQUIREMENTS

A large number of parameters describing the physical characteristics of the catchment on a spatially distributed basis is required in addition to the hydrological and meteorological time series for successful running of the SHE model. The purpose of model application will govern the accuracy of input data.

The data required for a typical SHE Model application may be obtained from field measurements and from such measurements supplemented by the available scientific literature. For example, the soil hydraulic properties which are required for a SHE application may not be available in Indian context and field and/or laboratory measurements will have to be carried out in such cases to determine the required parameters.

The data and parameters required for a typical SHE application can be divided in two categories - fixed data and time series data.

The fixed or time unvarying data for each grid square (or channel link) for the SHE model consists of a) Ground surface elevation, b) Impermeable bed elevation, c) distribution codes for rainfall and meteorological stations, d) distribution codes for soil and vegetation types, e) soil hydraulic properties, f) river channel geometry and conveyance properties, g) surface roughness characteristics, h) surface detention storage.

The time series data consists of the following a) precipitation data series, b) potential evaporation data series, c) temperature data series, d) variation of root zone depth and leaf area index with time, and e) initial phreatic surface level.

For further details, reference is made to DHI(1988).

2.10 DATA PREPARATION

Since the model requires a huge amount of spatially distributed data, it is a very time consuming and tedious process to prepare the input files for SHE in the particular format required. Moreover, the data are often available on maps of different scale. It is, therefore, convenient to provide the data on the scales available and then automatically set up the spatially distributed data on the scale which has been selected for the numerical computation. In order to facilitate the data preparation, a preprocessor, SHE Array Formatting Routine (SHE.AF), may be used.

2.11 THE SHE ARRAY FORMATTER (SHE.AF)

The SHE.AF reads a series of data files containing various arrays of spatially distributed data, prepares a setup for SHE model on the desired grid scale, and writes the data to the appropriate files in the required format. It also requires a set of existing SHE input files which are read and updated again with appropriate new data arrays. The entire data preparation can be finalized within short time for grid systems comprising several thousands squares using SHE.AF.

With each component, one data file is attached. The naming of the files is usually given in a way which identifies the specific catchment followed by three letters indicating the component :

KOLAR.FRD - Frame data file,
KOLAR.SZD - Saturated zone data file,
KOLAR.UZD - Unsaturated zone data file,
KOLAR.OCD - Overland and channel flow data file,
KOLAR.ETD - Evapotranspiration data file,
KOLAR.SMD - Snowmelt data file,
KOLAR.PRD - Precipitation data file,

2.12 RUNNING SHE PROGRAMME

After preparation of the required SHE datafiles,the SHE simulation can be started. The user is prompted to give the catchment name. Using this catchment name, appropriate data files are opened. These data files are then read in and the input data is obtained.

Two output files are created in a SHE run. The SHE output printfile contains various results, warnings and error messages. It is recommended that in the initial phase of a SHE application, the initial conditions may be written on the print file for checking up of data.

The results of a SHE run are stored in a result file which is a binary file. The results may be retrieved from this file by applying the output retrieval routine, SHE.OR.

2.13 PRESENTATION OF INPUT AND OUTPUT DATA

The SHE Graphical Display Routine SHE.GD can be applied either for display of SHE results which are retrieved by applying the SHE.OR, or for display of indata to the SHE. A number of options are available.

A host of other peripheral programmes have been developed as a part of the SHE package to do a variety of chores.

A flow chart of the SHE package is given in Fig. 2.2. For detailed description of various programmes and input data preparation, reference is made to the model documentation, DHI (1988).

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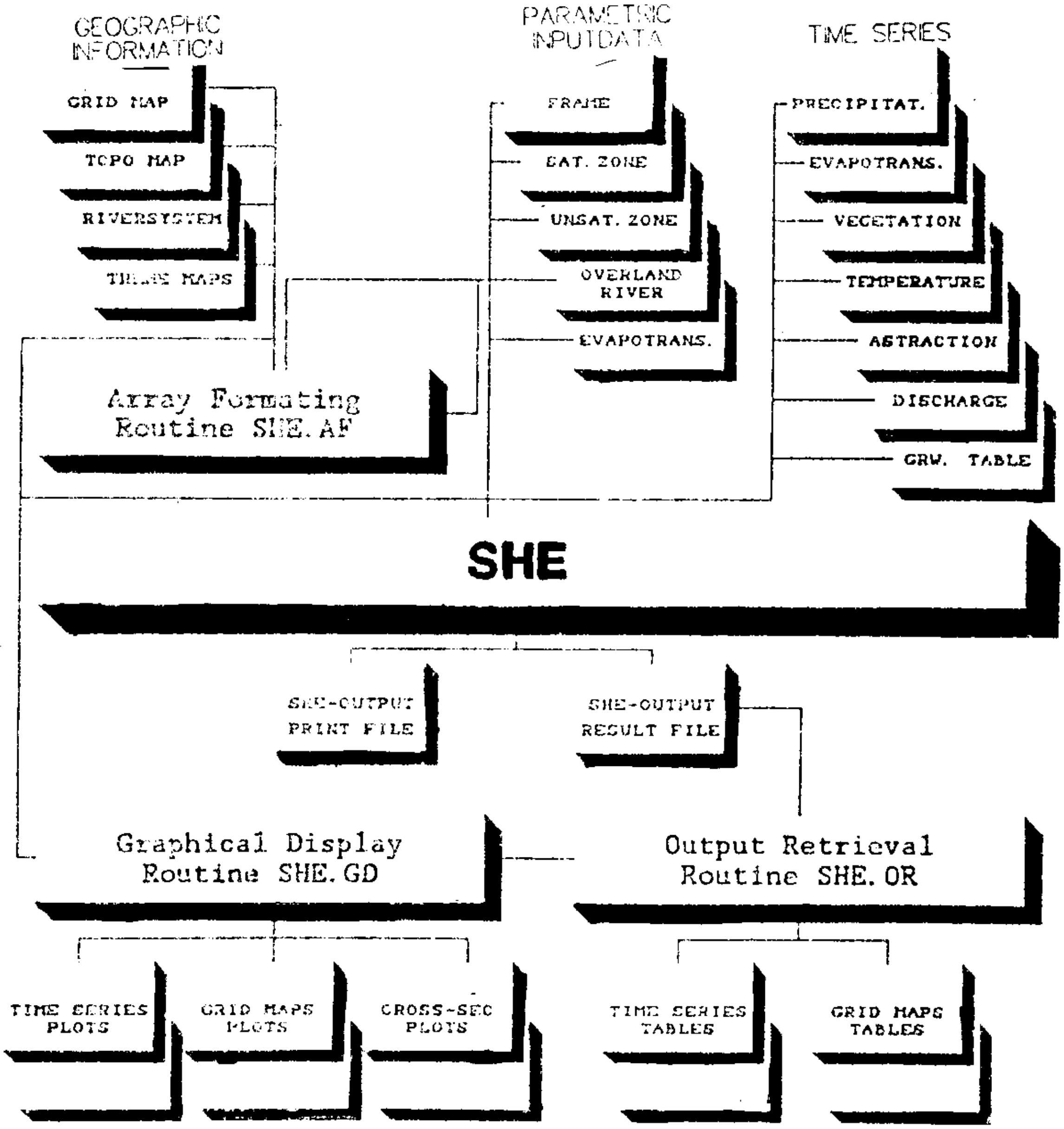

Fig. 2.2 Flow chart of the SHE Programme Package.

3.0 GENERAL DESCRIPTION OF KOLAR BASIN

The Kolar subbasin is located in the latitude range of 22° 40′ to 23° 08′ and longitude 77° 01′ to 77° 29′. The Kolar river originates in the Vindhyachal mountain range at an elevation of 550 m above mean sea level (msl) in the district Sehore of Madhya Pradesh (M.P.) state. The river, during its 100 km course first flows towards east and then towards south before joining the river Narmada near a place named Neelkanth. During its course, the Kolar river drains an area of about 1350 sq. km. In the present study the catchment area of 820 sq. km. up to Satrana gauge & discharge measurement site has been modeled.

The entire basin lies in two districts, Sehore and Raisen. The index map of the basin showing the locations of gauge - discharge stations, rain gauging sites and other hydraulic structures is given in Fig. 3.1.

In the basin, a dam is nearing completion near the village Lawakheri. This Kolar dam will be used to provide drinking water to the city of Bhopal which lies at a distance of 30 km towards north. The water stored in the dam will also be used for irrigation. For this purpose, a barrage has been constructed in the basin near Jholiapur. Two canals will take off from this barrage. Construction of these lined canals is also nearing completion and they will be operational soon.

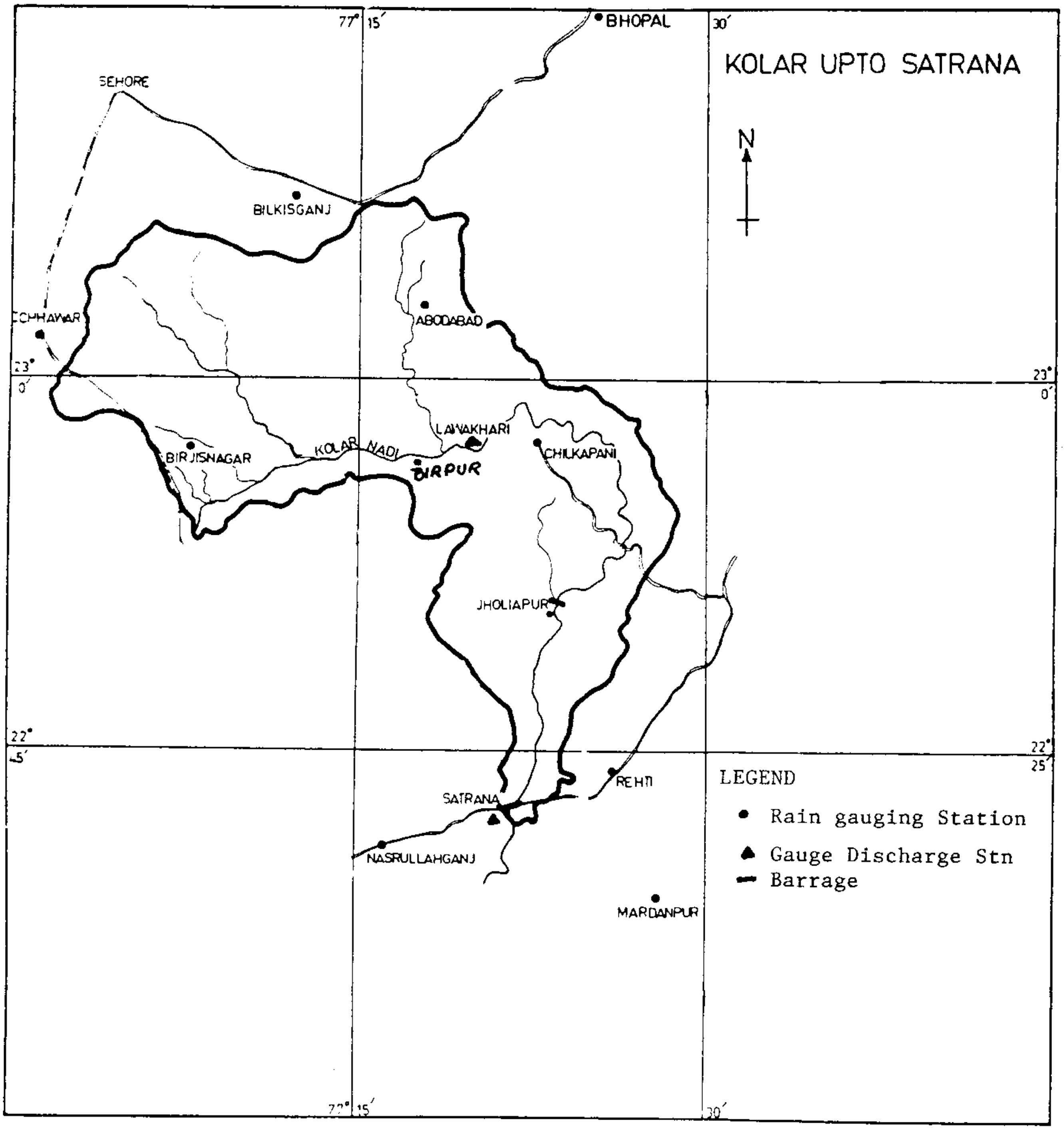

Fig. 3.1 The Kolar basin upstream of the Satrana gauging station.

3.1 HYDROLOGY OF KOLAR BASIN

Topographically, the Kolar basin can be divided into two distinct zones. The upper four-fifth part of the basin and lower one-fifth part. The upper four-fifth part having elevations ranging from 600 m to 350 m is predominantly covered by deciduous forest (dense and open). The boundaries of catchment are mild sloped at the northern end of the basin. The river enters in the plains from this area upstream of Jholiapur through ramp shaped southward sloping topography. The soils are skeleton to shallow in depth except near channels where they are relatively deep. The rock outcrops are easily visible at many places. In this area, the rocks are weathered and deep fissures can be seen. The channel beds are rocky or graveled. The thin soils get saturated even during low intensity rains and movement of water through the fissures is rapid. Agricultural activity is carried out in relatively large areas in the north western part (adjacent to Ichhawar) and in small pockets elsewhere in which the main crops are wheat and grams. The general response of this upper part of basin to rain appears to be quick.

The lower part of the basin consisting of flat bottomed valley narrowing towards the outlet and having elevations ranging from about 350 m to 300 m is predominantly cultivable area. The soils are deep in this area and ground slopes are flat. The places where agricultural activity is carried out have bunded fields in which water is impounded during the monsoon period. The response of this area to input rainfall is likely to be quite slow. Part of this area comes under the command of Kolar dam.

3.2 DATA AVAILABILITY

The topographic map of the Kolar basin was prepared using the Survey of India toposheets of scale 1:50,000. This map formed the base map for setting up of computational grid points, river network and topographic elevations. Later on basin simulations were made on a grid size of 2 km * 2 km. The representation of the basin on this grid scale is shown in Fig. 3.2. The average topographic elevations for the grids are shown in Fig. 3.3.

The soil and land use maps on scale 1:250,000 were obtained from the Narmada Valley Development Authority (NVDA). However, these maps and the data regarding soil hydraulic properties were found to be inadequate in the simulations carried out during 1988-89. A field investigation was carried out to supplement this information. Results of this investigation are described in subsequent sections.

The availability of rainfall data for Kolar basin at the time of carrying the present study is shown in Table 3.1. The

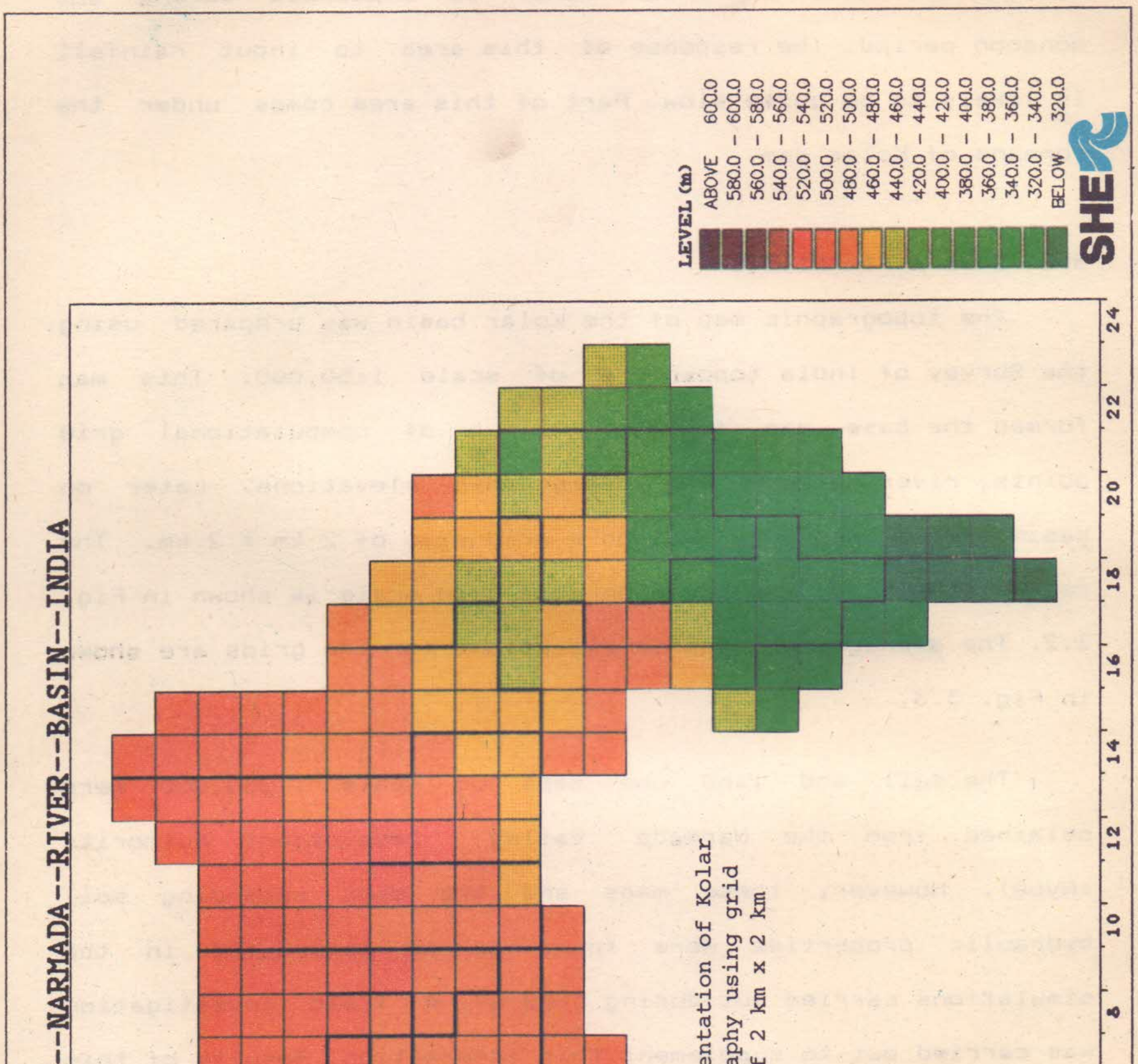

Fig. 3.2 : Representation of Kolar Topography using grid size of 2 km x 2 km

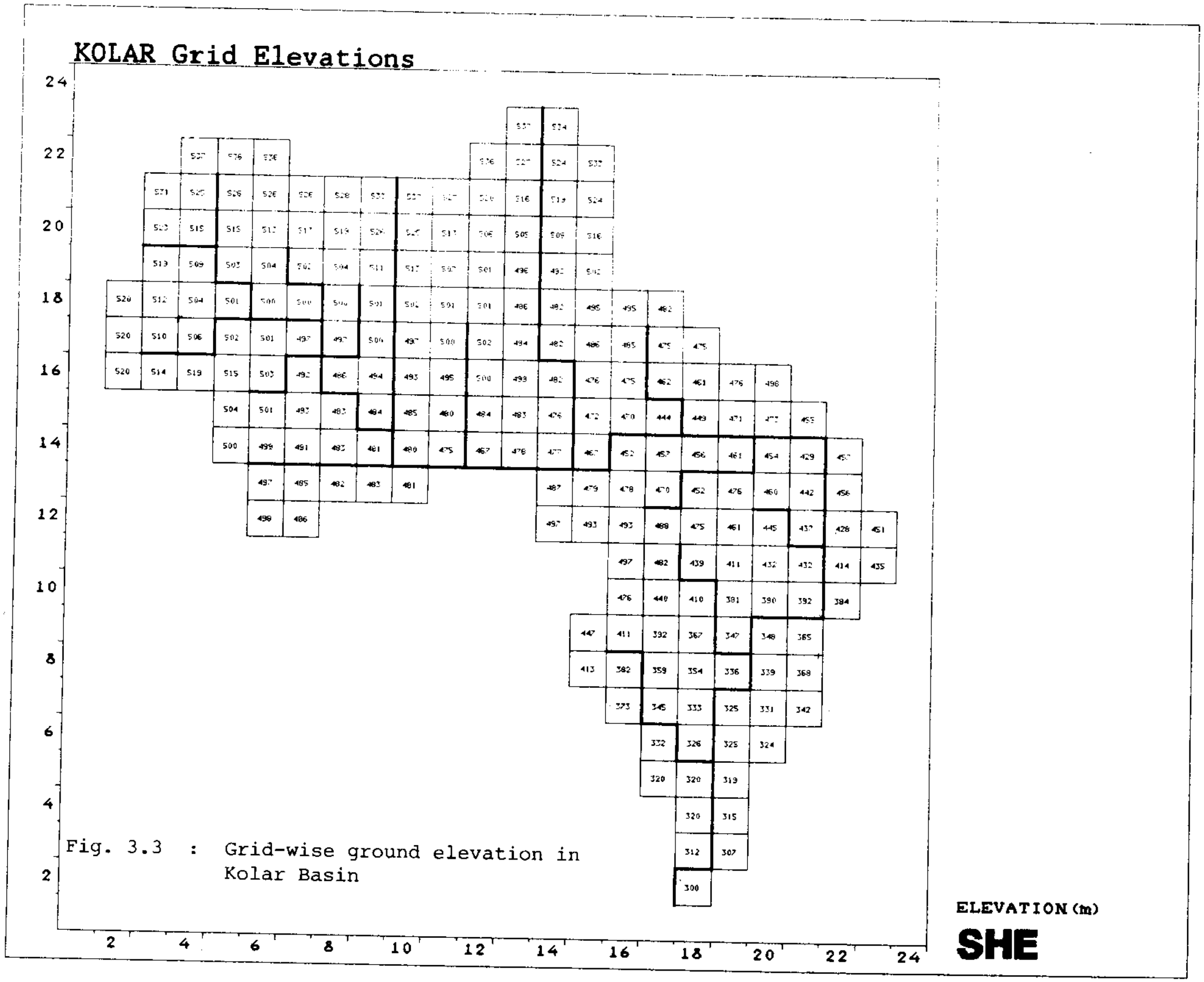

Fig. 3.3 : Grid-wise ground elevation in Kolar Basin

Table 3.1
Availability of Rainfall Data for Kolar Basin

Raingauge Station	1983 (J F M A M J J A S O N D)	1984 (J F M A M J J A S O N D)	1985 (J F M A M J J A S O N D)	1986 (J F M A M J J A S O N D)	1987 (J F M A M J J A S O N D)	1988 (J F M A M J J A S O N D)
Brijeshnagar (SR)	Hourly data	Hourly data	Hourly data	Hourly data	Hourly data	Hourly data
Birpur Colony (SR)	Hourly data	Hourly data	Hourly data	Hourly data	Hourly data	Hourly data
Jholiapur (SR)	Hourly data	Hourly data	Hourly data	Hourly data	Hourly data	Hourly data
Rehti (SR)	Hourly data	Hourly data	Hourly data	Hourly data	Hourly data	Hourly data
Ichhawar (OR)	Daily data	Daily data				

Legend: Hourly data; Daily data

discharge data was available at two gauging sites in this basin. The Satrana gauging site located at the outlet of this basin was established in 1983. The gauge measurements are made at a bridge on Rehti- Nasrullaganj road where an automatic gauge recorder has been installed. The flow velocity is measured using current meter. At this site, hourly gauge observations and daily discharge measurements were available for the monsoon months during 1983-88. The cross section of the river at the gauging station was also available. At the second site, Lawakheri, the hourly river stages and rating curve were available for the period 1981-86. The flow velocity at this site is measured using floats and because of this, the discharge estimates are highly uncertain. The data for this site was, therefore, not used in this study.

In MP state, the ground water levels are observed by the State Ground Water Board at selected permanent observation wells. Normally three observations are taken every year - one each before and after the monsoon season and one during winters. In case of Kolar, only one well is located inside the basin. In the downstream area several wells are located near the periphery of the basin. The information about ground water level was used as general guideline about the position of water table before and after the monsoon season.

The pan evaporation data for a station named Powerkheda which is located near the basin was available from 1983 onwards (weekly during 1983-87 and daily during 1987-88) and used in the simulations.

3.3 PURPOSE OF FIELD INVESTIGATION

One of the conclusions drawn based on the Kolar simulations carried during 1989, Jain(1990) was :

"*In case of Kolar, additional field measurements are necessary to reduce the uncertainty associated with the parameters of soil hydraulic properties to improve the simulation.*"

Further, during the sensitivity analysis it was found that the soil hydraulic properties are very important for catchment simulation. Therefore it was decided to carry out a simple but detailed programme of field measurements and sampling in the Kolar basin. The main objectives of this campaign were :

a) To get the values of soil related and other parameters through in-situ measurements and laboratory analysis of the soil samples brought from the field. The aim was to achieve reduction in the uncertainty in input parameter values. Although a large number of parameters are required for a successful SHE application, the soil related parameters are by far the most important ones. However, directly measured values of these parameters were not available at the commencement of this study.

b) To get experience in planning and execution of a field program, approach for measurement and sampling, use of appropriate equipment and techniques, logistics & coordination, analysis of results, and finally, interpretation of the results vis-a-vis the intended use.

3.4 APPROACH ADOPTED IN FIELD INVESTIGATION

A combination of field and laboratory methods as described below was adopted during the field investigation campaign to determine various parameters :

a) The saturated hydraulic conductivity for the unsaturated zone was measured using in-situ infiltrometry. A double ring infiltrometer was used for this purpose.

b) The unsaturated zone moisture content & hydraulic conductivity relationship was determined from laboratory analysis of soil cores and disturbed samples brought from the sites. The pressure plate apparatus was used for this purpose.

c) The information about soil depth & profile and root zone depth was obtained by digging pits or auguring. The information about vegetation leaf size, geometry of river channels and surface roughness was also gathered.

Because of the size of the basin, and the time available, it was decided to carry the sampling programme along 4 traverses. These traverses provide coverage of the upper area, the middle area, and the lower area of the catchment. Along each traverse, measurements were made at three different sites. The exact location of the site was decided based on accessibility, availability of water for infiltrometer test and suitability of the area regarding driving the infiltrometer in the ground. About one day was spent at each site. However, some sites were studied in greater details.

Further details of this field campaign are described in Jain & Erlich(1990).

3.5 LABORATORY ANALYSIS OF SAMPLES

The undisturbed soil samples were taken from 12 sites by driving core pipes of inner dia 3.8 cm and length 23.5 cms into the soil. The samples were sealed on both sides by molten wax and were brought to Roorkee for laboratory analysis. At each site about 3 kg disturbed soil sample was taken for use in laboratory analysis for determining particle size distribution, soil moisture vs. tension relationship and permeability.

For determining particle size distribution of the samples, sieve analysis was performed. The material passing through 75 micron sieve was subjected to sedimentation analysis using hydrometer method. From the particle size distribution curves, the percentages of clay, silt, sand, and gravel in the respective samples were ascertained.

For determination of the coefficient of permeability for the disturbed samples the falling head permeability test was conducted. The density of the soil was determined by three tests : (i) considering the inner volume of the pipe sampler, (ii) considering the volume of dried sample after shrinkage, and (iii) considering the sample prepared after removal of gravel. The results in three cases were considerably different.

To determine the $\psi - \theta$ curve, pressure plate apparatus was used. The moisture retention was estimated for pressures of 0.5, 1.0, 2.0, 3.0, and 15.0 bars and then the curve was plotted passing through these points.

From the various analysis performed, it was found that there were broadly three groups in the soil samples collected. However, it was difficult to give definite divisions in these three groups. Therefore, the soils were broadly classified in three categories - Black soil, Red soil and Yellow soil. The soil moisture retention versus tension curves for these three soils are plotted in Fig. 3.4. It was considered appropriate that simulation runs based on this grouping would be adequate. However, in order to study the effect of differences among the moisture retention curve, it was planned that a sensitivity

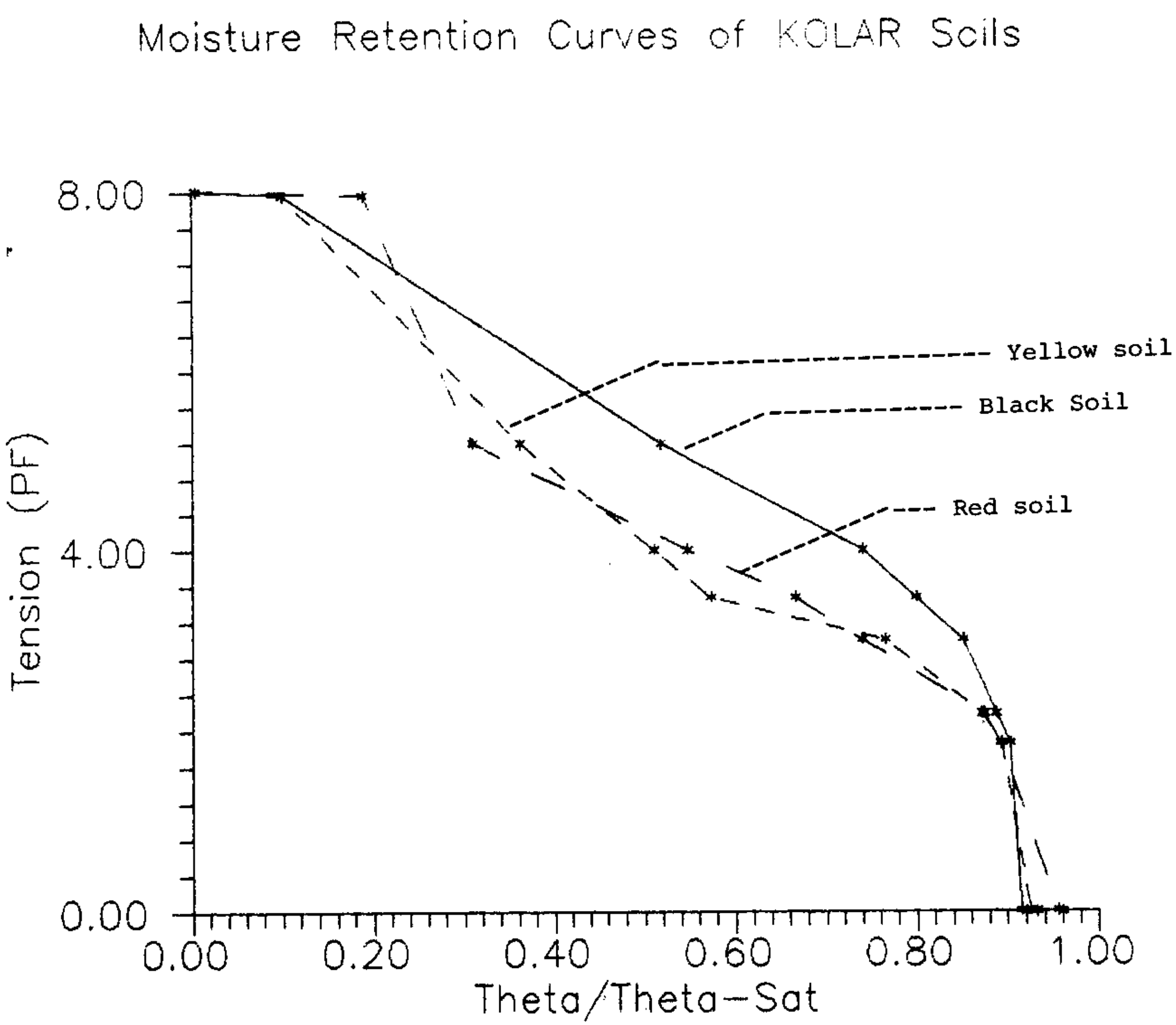

Fig. 3.4 Moisture retention of the three soils found in Kolar basin

study should be carried out on single column basis. This course of action was adopted in carrying out studies regarding effect of land use and soil changes on hydrologic regime, are described in Jain & Seth (1990).

The laboratory analysis of the soil samples along with the results obtained is described in details in Seth(1990).

3.6 INFORMATION DERIVED FOR SIMULATION

Based on the results obtained from field investigation and laboratory analysis, the following information was derived for use in the update of simulations.

3.6.1 SOIL RELATED INFORMATION

Based on the results obtained from the analysis of samples, a soil map of the basin was finalized. This map is given in Fig. 3.5. The entire basin was classified in three soil types - black, red and yellow. The soil depth map for the basin is given in Fig. 3.6.

Based on the results of infiltration tests, permeability analysis, and the particle size analysis (to determine clay content), the following values of saturated soil conductivities in unsaturated zone were arrived at :

Black	Soil	-	2 mm/hour,
Yellow	Soil	-	10 mm/hour,
Red	Soil	-	20 mm/hour.

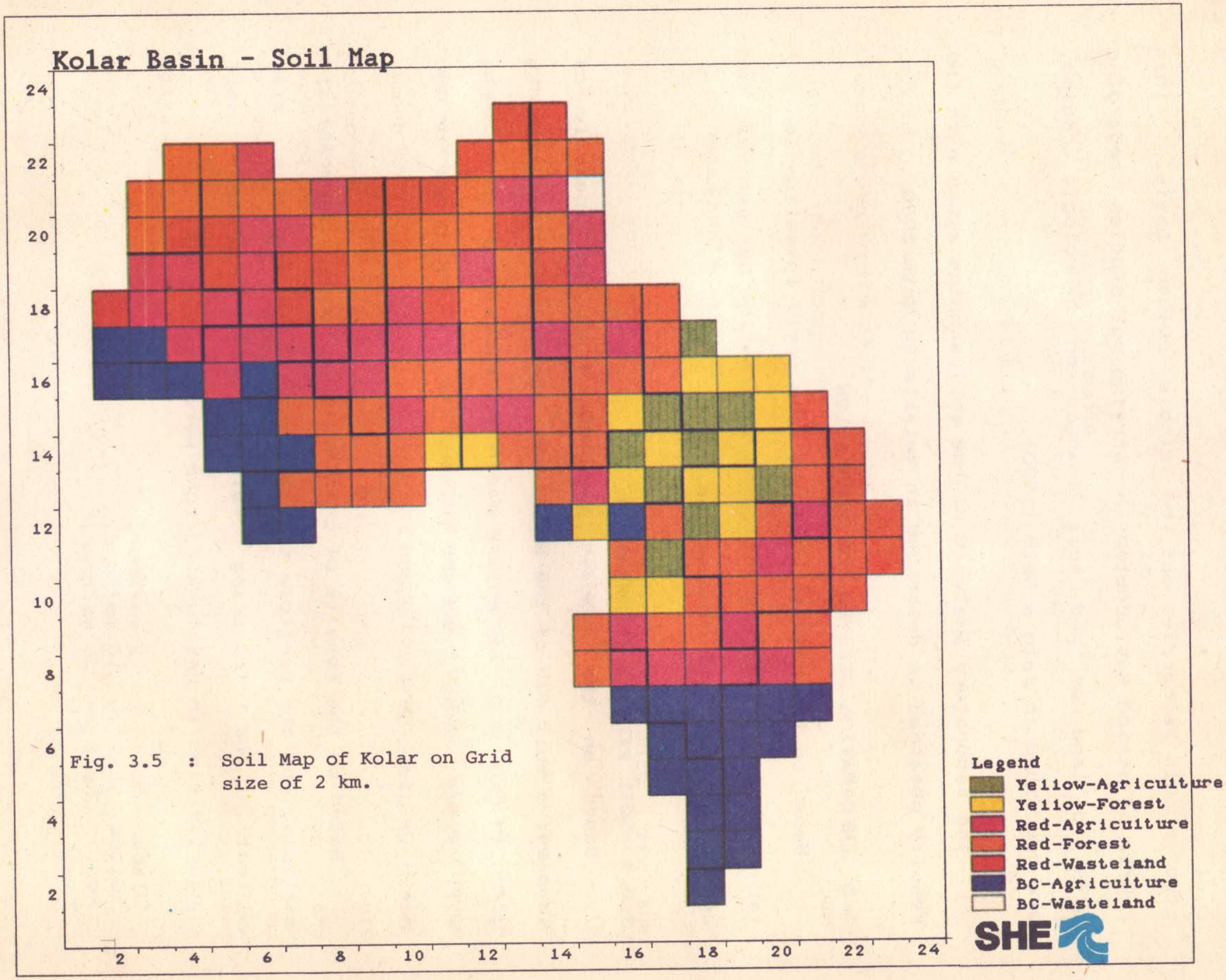

Fig. 3.5 : Soil Map of Kolar on Grid size of 2 km.

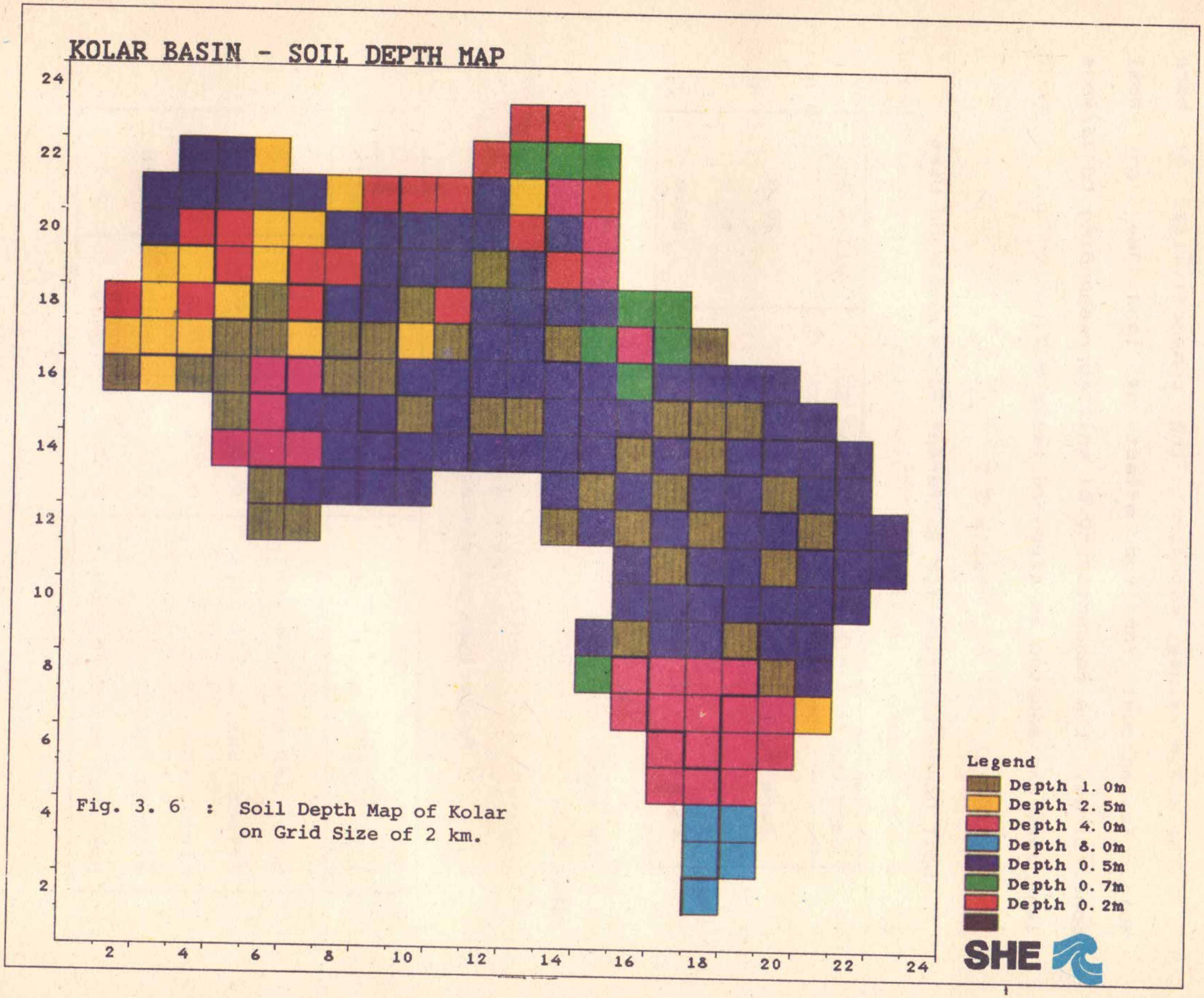

Fig. 3. 6 : Soil Depth Map of Kolar on Grid Size of 2 km.

The above values represent the conductivities of bare soil. To account for the effect of land use on soil conductivity, the conductivity of soil corresponding to various land uses was adopted as given in Table 3.2.

Table 3.2

Soil Conductivities for Different Soils and Land Uses in mm/hour

Land Use	Black Soil	Red Soil	Yellow Soil
Bare soil	2.0	10.0	20.0
Cropland	4.0	20.0	40.0
Forest	20.0	40.0	50.0

The other relevant information about soils is given in Table 3.3.

Table 3.3

Properties of different type of soils

Property	Soil type		
	Black	Red	Yellow
Saturated moisture cont.	0.675	0.42	0.47
Effect. sat. moist cont.	0.62	0.403	0.438
Field capacity	0.575	0.31	0.36
Wilting Point	0.36	0.15	0.18
Residual moisture cont.	0.252	0.10	0.17

The saturated zone conductivity was taken as 50 mm/hour for the entire catchment.

3.6.2 Vegetation Data

The land use map of the catchment which was prepared after the field investigation is given in Fig. 3.7. The variation of leaf area index and root zone depth for different vegetation types are plotted in Fig. 3.8. The root depth in forest and wasteland area was assumed to be unvarying - it was 0.2 m for wasteland and 0.3 m for forests in shallow soil zone and 0.5 m in deep soil zone.

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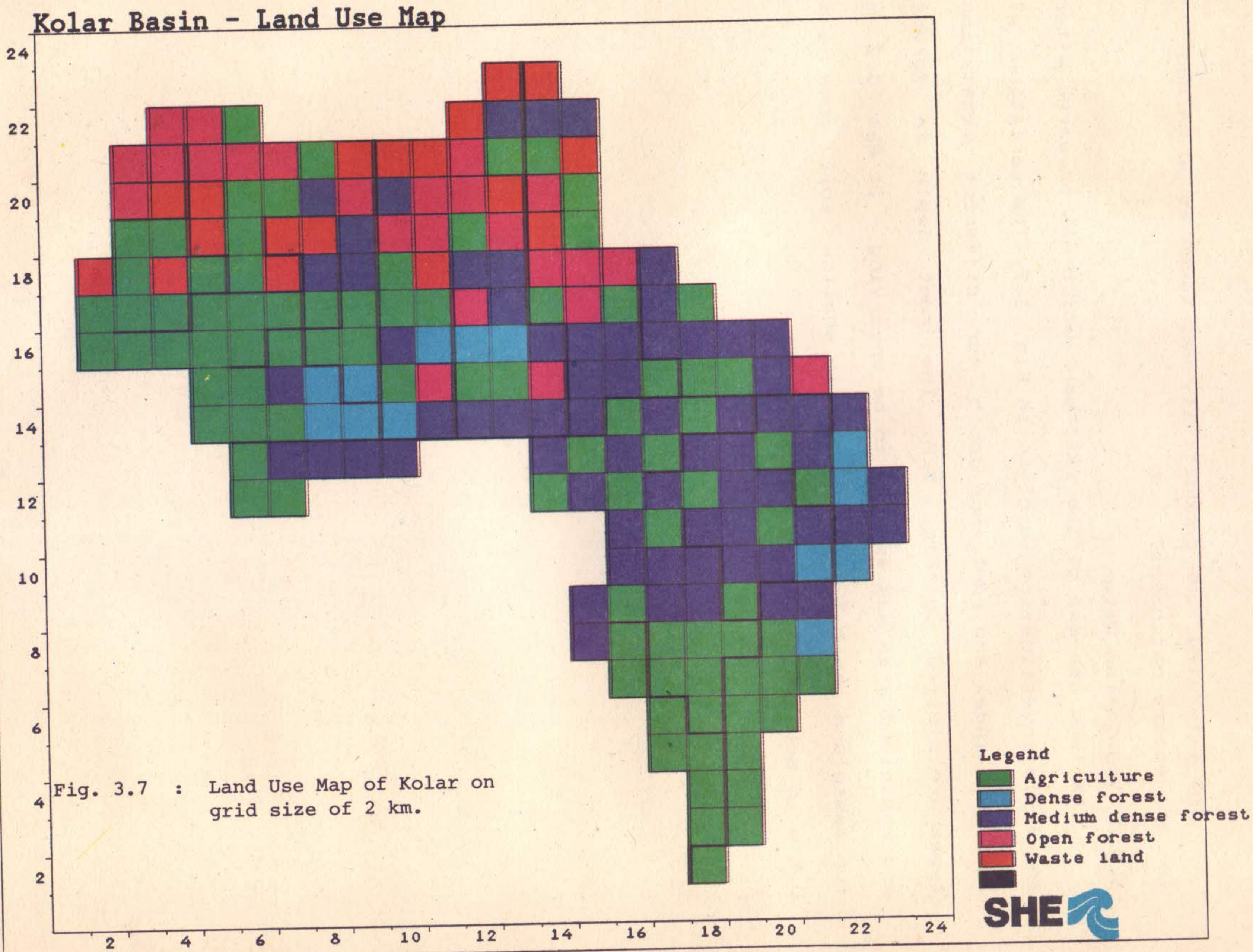

Fig. 3.7 : Land Use Map of Kolar on grid size of 2 km.

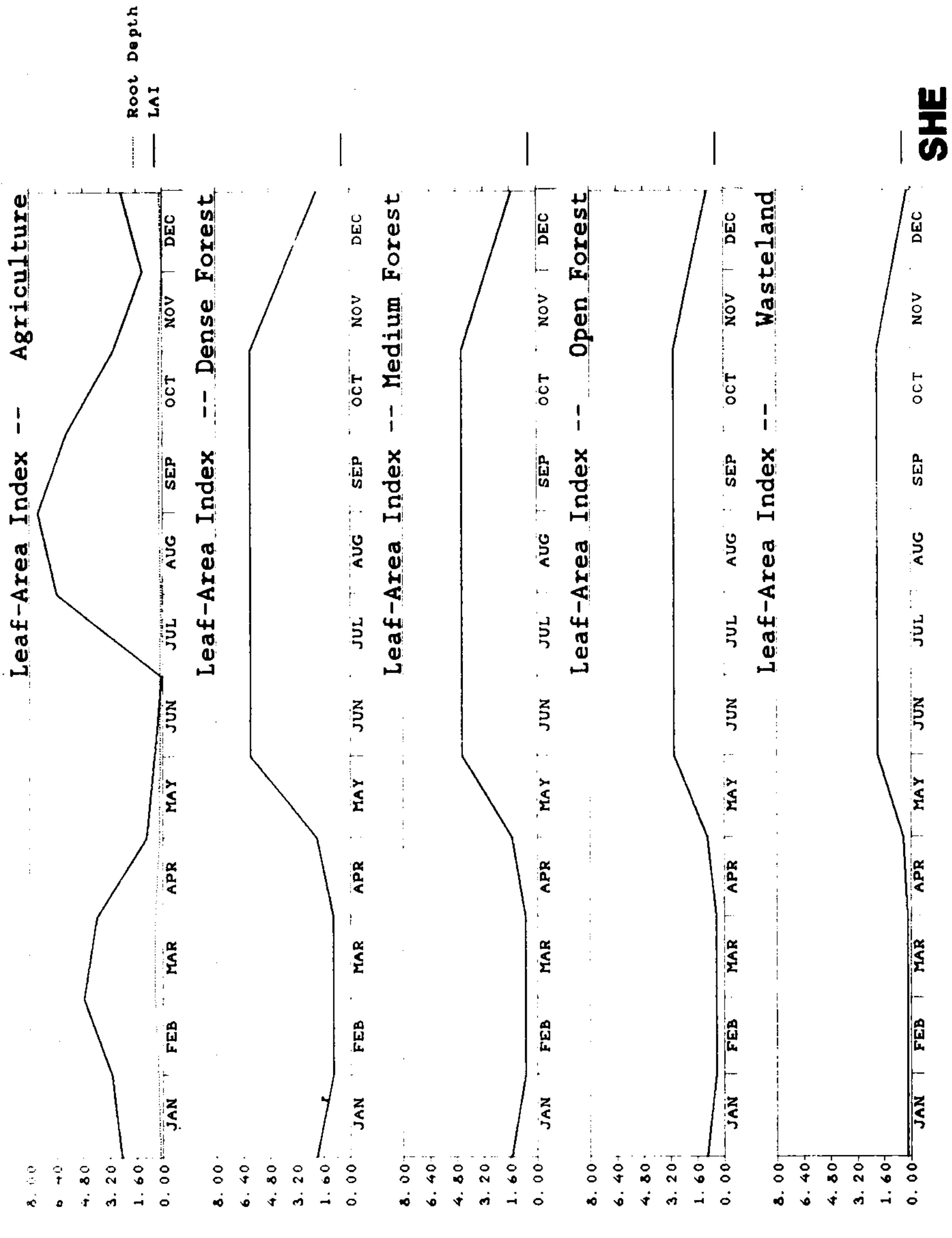

Fig. 3.8 : Variation of Leaf-Area-Index with time for various vegetations

4.0 DATA PROCESSING AND PREPARATION

A grid network was drawn on the topographic map to establish the computational points. The basic network was drawn for square grids of size 500 m * 500 m. The ground elevation at the grid points were read in. These were used to determine the grid elevation. The land use and soil maps used in the previous study were modified based on the field investigations, as described in the previous chapter. The land use was classified in five categories- dense forest, medium forest, open forest, agriculture, and waste land. This data was used to prepare model setup on 2 km * 2 km grids.

The hourly rainfall data at Rehti, Jholiapur, Birpur and Brijeshnagar was used for this study. Using the gauge discharge data at Satrana site for the monsoon months rating curves were developed and used to get hourly discharge values corresponding to hourly stages. Two different rating curves were used -- one for the years 1983 - 1985 and other for 1986 - 1988.

The pan evaporation data at Powerkheda was processed and presented in the format required for the SHE.

4.1 WATER BALANCE

The water balance calculations for the Kolar basin were done on a lumped basis. The rainfall, river flow at the outlet and the evaporation data was used in this analysis. The runoff coefficients were determined for the Kolar basin on monthly basis, cumulative for the monsoon season and for the entire monsoon season.

basis, cumulative for the monsoon season and for the entire monsoon season.

The results of the water balance calculations are given in Table 4.1. No data inconsistency was detected in this analysis and the runoff coefficients were found to be within the acceptable range.

4.2 SHE SETUP FOR KOLAR BASIN

As mentioned above, the computational grids were initially drawn on the grid size of 500 m. Since the computational requirements for a set up on this size of grid are enormous, the set up for grid size of 2 km * 2 km was used in simulations. In the model, the rivers can run only along the grid boundaries, hence their course was approximated by straight lines. The river network representation for grid size of 2 km is shown in Fig 4.1. For Kolar, the number of grids (size of one grid 4 Sq Km) was 208, and the number of river links representing the river system was 107.

For the purpose of setting up land use and soil depth, a grid map was prepared in which codes were assigned to different grids and corresponding parameters were specified. The initial position of water table was specified in similar way.

Since the UZ calculations consume significant CPU time,

TABLE 4.1
Water Balance for Kolar Basin

1983 — All figures are in mm

Month	Monthly rainfall at				Mean rain-fall P	Flow at Satrana Q	Pot. Evap.	Q/P	ΣQ/ΣP
	Rehti 0.04*	Jholiapr 0.18*	Birpur 0.40*	Brjngr 0.38*					
Jan	-1	-1	8	12			47		
Feb	-1	-1	0	0			82		
Mar	-1	-1	0	0			148		
Apr	-1	-1	0	0			232		
May	0	0	22	44	24		380		
Jun	0	29	1	0	7	0	247		
Jul	269	470	213	214	270	29	134	0.12	
Aug	407	612	617	443	548	361	89	0.76	0.54
Sep	331	357	308	487	382	248	92	0.63	0.57
Oct	0	27	11	0	10	37	118	3.9	0.60
Nov	0	0	0	0	0		102		
Dec	0	0	0	0	0		74		

Note : a) -1 indicates that data is not available.
b) * these are Thiessen weights for the station.

1984 — All figures are in mm

Month	Monthly rainfall at				Mean rain-fall P	Flow at Satrana Q	Pot. Evap.	Q/P	ΣQ/ΣP
	Rehti 0.04*	Jholiapr 0.18*	Birpur 0.40*	Brjngr 0.38*					
Jan	0	53	7	0	14		50		
Feb	0	0	11	2	3		87		
Mar	0	0	0	0	0		158		
Apr	0	0	0	0	0		247		
May	0	0	0	0	0		405		
Jun	66	120	163	136	141	10	230	0.07	
Jul	195	181	97	163	141	20	141	0.14	0.16
Aug	828	938	943	698	851	592	98	0.70	0.55
Sep	48	21	22	34	27	53	85	1.96	0.58
Oct	0	10	5	1	4	23	112	5.8	0.60
Nov	0	0	0	0	0		92		
Dec	0	0	0	0	0		67		

Contd...

1985

All figures are in mm

Month	Monthly rainfall at Rehti 0.04*	Jholiapr 0.18*	Birpur 0.40*	Brjngr 0.38*	Mean rain-fall P	Flow at Satrana Q	Pot. Evap.	Q/P	ΣQ/ ΣP
Jan	0	0	0	0	0		85		
Feb	0	0	0	0	0		90		
Mar	0	0	0	0	0		126		
Apr	0	0	2	2	1		216		
May	0	0	6	4	4		322		
Jun	72	151	117	163	139		260		
Jul	294	323	302	263	293	76	121	0.26	
Aug	398	388	389	381	386	218	89	0.56	0.52
Sep	90	176	165	210	181	60	149	0.33	0.53
Oct	123	128	92	143	118	40	85	0.34	0.50
Nov	0	0	0	0	0		69		
Dec	0	0	0	0	0		62		

Note : a) -1 indicates that data is not available.
b) * these are Thiessen weights for the station.

1986

All figures are in mm

Month	Monthly rainfall at Rehti 0.04*	Jholiapr 0.18*	Birpur 0.40*	Brjngr 0.38*	Mean rain-fall P	Flow at Satrana Q	Pot. Evap.	Q/P	ΣQ/ ΣP
Jan	0	0	0	0	0		70		
Feb	0	0	37	15	20		67		
Mar	0	0	1	0	0		124		
Apr	0	0	0	0	0		224		
May	0	0	13	4	7		245		
Jun	176	176	162	265	201	0	113	0.96	0.79
Jul	1069	787	1047	953	958	918	90	0.76	0.78
Aug	360	345	269	310	302	230	79	0.58	0.77
Sep	168	56	58	55	60	35	90		0.79
Oct	5	0	0	0	0	24	110		
Nov	0	0	0	0	0		75		
Dec	0	0	0	0	0		60		

Contd...

1987

All figures are in mm

Month	Monthly rainfall at				Mean rain-fall P	Flow at Satrana Q	Pot. Evap.	Q/P	ΣQ/ ΣP
	Rehti 0.04*	Jholiapr 0.18*	Birpur 0.40*	Brjngr 0.38*					
Jan	0	0	45	0	18		52		
Feb	0	0	30	16	18		65		
Mar	0	0	5	9	5		96		
Apr	0	0	0	0	0		200		
May	0	0	18	0	7		212		
Jun	43	159	96	89	105		179		
Jul	142	152	239	77	160	42	146	0.26	
Aug	506	639	515	425	509	30	79	0.1	0.11
Sep	78	77	55	48	58	201	105	3.5	0.38
Oct	0	51	62	63	58	64	88	1.1	0.43
Nov	0	0	0	0	0	17	78		0.45
Dec	0	0	18	16	13		81		

Note : a) -1 indicates that data is not available.
b) * these are Thiessen weights for the station.

1988

All figures are in mm

Month	Monthly rainfall at				Mean rain-fall P	Flow at Satrana Q	Pot. Evap.	Q/P	ΣQ/ ΣP
	Rehti 0.04*	Jholiapr 0.18*	Birpur 0.40*	Brjngr 0.38*					
Jan	0	0	17	14	12		88		
Feb	0	0	0	0	0		100		
Mar	0	0	0	0	0		172		
Apr	0	0	11	13	9		202		
May	0	0	16	0	6		270		
Jun	112	209	168	221	195	5	173	0.02	
Jul	462	494	551	432	494	154	55	0.31	0.23
Aug	403	434	308	277	327	189	48	0.58	0.34
Sep	88	96	85	97	92	45	89	0.49	0.36
Oct	28	30	39	42	38	40	98	1.05	0.37
Nov	0	0	3	3	1		91		
Dec	0	0	0	0	0		73		

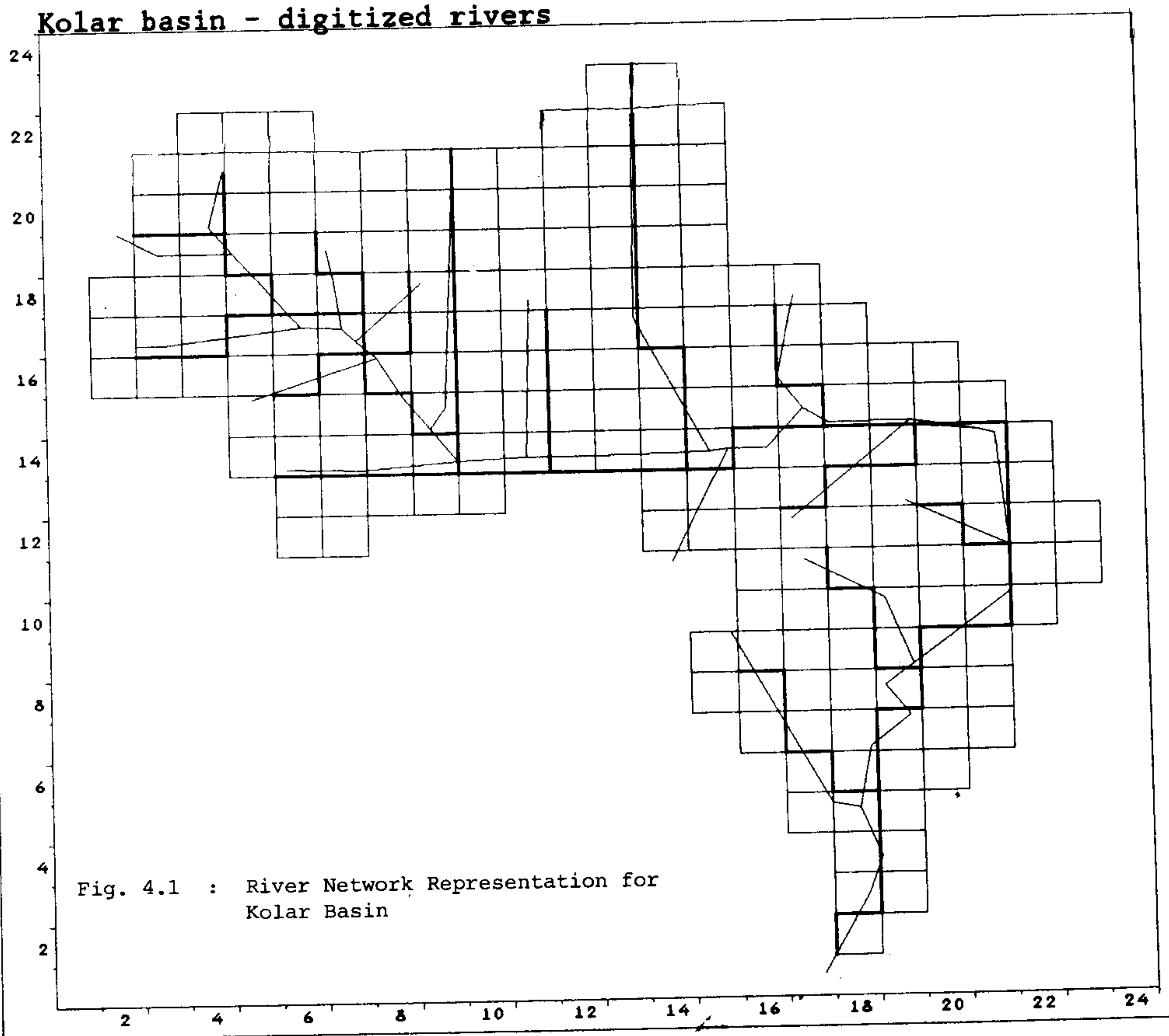

Fig. 4.1 : River Network Representation for Kolar Basin

these calculations are not made for all grids. A classification scheme is followed to group the grids whose response is likely to be same. The computations are made for one grid in each group and the results are transferred to other grids.

The SHE array formatting routine was used to prepare the model setup according to the format required by the different model components. An overlay of topography, land use, soil types, and soil depth is given in Fig. 4.2.

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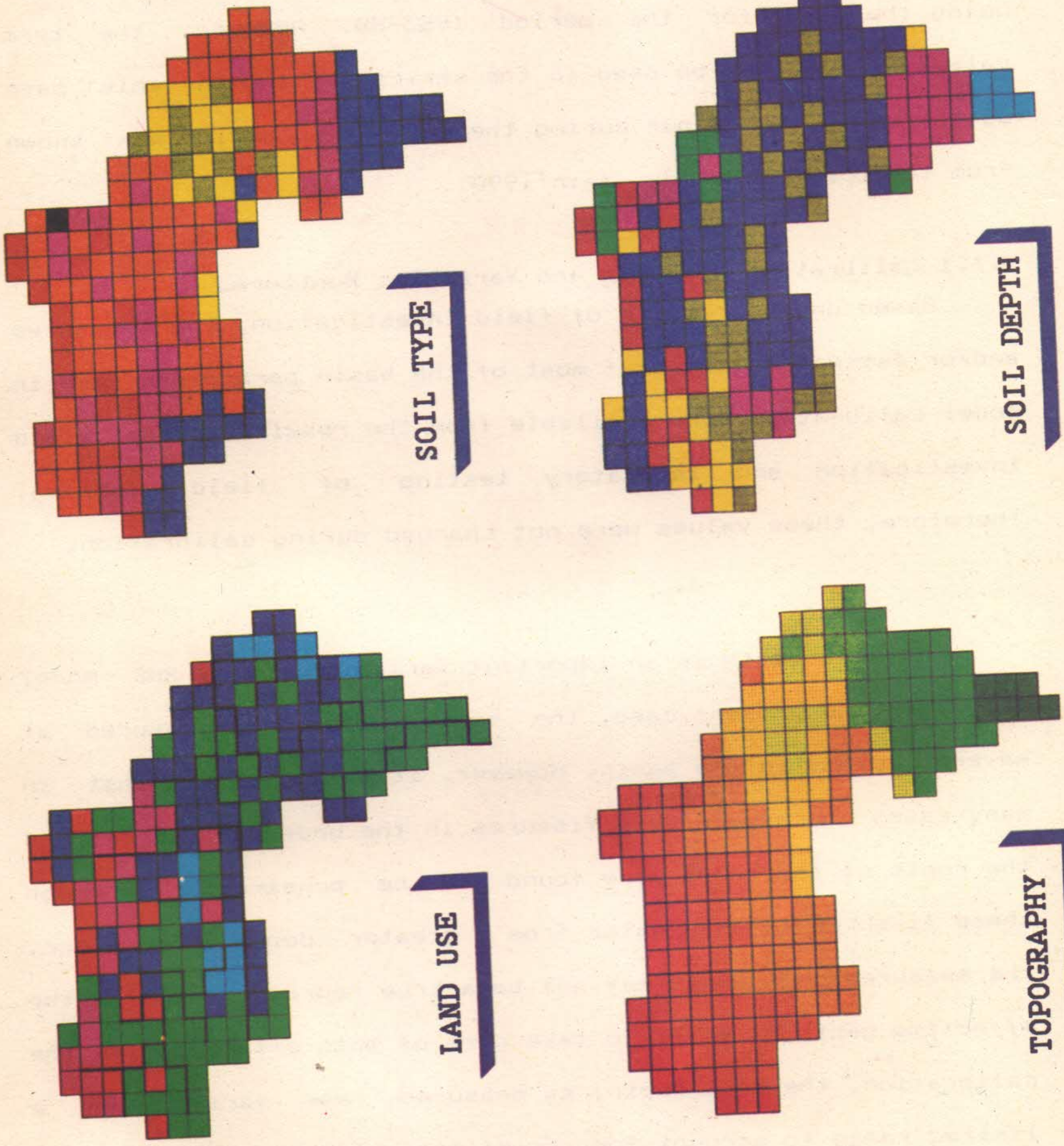

Fig. 4.2 : Overlay of Topography, Soil Depth, Land Use and Soil Type for Kolar Basin

5.0 MODEL CALIBRATION AND VALIDATION

The SHE was calibrated and validated for the Kolar basin using the data for the period 1983-88. However, the term validation can not be used in the strict meaning in this case as the basin behaviour during the validation period was known from the previous study, Jain(1990).

5.1.1 Calibration Approach and Variables Monitored

Based on the results of field investigation, the measured and/or estimated values of most of the basin parameters used in model calibration were available from the results of the field investigation and laboratory testing of field samples. Therefore, these values were not changed during calibration.

The soil depth is an important variable in the SHE model setup. In the present case, the soil depth was measured at several points in the basin. However, it was observed that in many cases there were deep fissures in the underlying rocks and the roots of the trees were found to be penetrating through these fissures to draw water from a greater depth. Therefore, the measured soil depth may not be a true representation of the *effective* depth of soil. To take care of this effect during the calibration, the soil depth, as measured, was varied over a limited range to account for the effective depth and the value which gave best results was finally adopted. Along with the soil depth, the parameters governing the properties of the subsurface drainage were also tuned during the calibration.

The calibration approach consisted of obtaining the best match between the observed and simulated discharge volumes on a monthly basis as the first step. The next step was to obtain the best match between the shape of observed and simulated hydrograph. The factors considered were the general hydrograph shape, hydrograph peaks, the shape during recession, and base flow. To improve the behaviour of the hydrograph during recession period, the subsurface drainage characteristics in the SZ component were tuned. Since the subsurface zone in Kolar consists of more than one layer of aquifer while only one layer was modelled in the present study, the response of the phreatic surface is not realistic, more so in the region of shallow soils. However, it was ensured that the behaviour of the water table in the deep soil zones follows the observed trend.

It is recognized that even after the field investigation and with an extensive data base, the chances of uncertainties in the inputs -- both time series data and catchment properties -- can not be ruled out. Therefore, no attempt was made to undertake a too fine tuning of the parameters.

5.1.2 Calibration results and final parameters

The comparison of volumes of observed and simulated hydrographs for the period 1983-85 for the final calibration run on a monthly basis is given in Table 5.1. The final values of various variables are given in Table 5.2.

The observed and simulated hydrographs for the calibration period are plotted in Fig. 5.1. The plots of variation of moisture content in unsaturated zone, actual and potential evapotranspiration, and rainfall for two typical cases, grid no (6,22) and (17,5) have been given in Fig. 5.2 and 5.3.

5.2 Model Validation

The data for the period 1986-88 was used for validation purposes. The comparison of volumes of observed and simulated hydrographs on monthly basis for the validation period is given in Table 5.3.

The observed and simulated hydrographs for the validation period are plotted in Fig. 5.4. The plots of variation of moisture content in unsaturated zone, actual and potential evapotranspiration, and rainfall for two typical cases, grid no (6,22) and (17,5) have been given in Fig. 5.5 and 5.6.

It can be seen from these figures that the results for the

Table 5.1

Comparison of Volumes of Observed and Simulated Discharges for Calibration Period

Year	Mon	Obs mm	Sim mm
1983	6	0	0
1983	7	29	19
1983	8	361	310
1983	9	248	333
1983	10	37	35
Sum		675	697
1984	6	10	0
1984	7	20	0
1984	8	592	547
1984	9	53	60
1984	10	23	2
Sum		698	609
1985	6	0	0
1985	7	76	13
1985	8	218	290
1985	9	60	65
1985	10	40	80
Sum		394	448

Table 5.2
Final Parameters for Kolar Basin

	Black Soil		YellowSoil		Red Soil	
WASTE LAND						
1. Proposed Soil Depth [m]	.3				.3	
2. Calibrated Depth [m]	.2		%		.2	
3. Ks {UZ} [mm/h]	2				20	
4. Kstr {OC} [m 1/3/s]	7				7	
5. no. of grids [-]	1				17	
OPEN FOREST						
1. Proposed Soil Depth [m]	.3	.5	.3	.5	.3	.5
2. Calibrated Depth [m]					.5	.7
3. Ks {UZ} [mm/h]	%	%	%	%	50	50
4. Kstr {OC} [m 1/3/s]					5	5
5. no. of grids [-]					22	2
MEDIUM D. FOREST						
1. Proposed Soil Depth [m]	.3	.5	.3	.5	0.3	0.5
2. Calibrated Depth [m]			.5		.5	.7
3. Ks {UZ} [mm/h]	%	%	40	%	50	50
4. Kstr {OC} [m 1/3/s]			3		3	3
5. no. of grids [-]			17		43	6
DENSE FOREST						
1. Proposed Soil Depth [m]	.3	.5	.3	.5	.3	.5
2. Calibrated Depth [m]					.5	
3. Ks {UZ} [mm/h]	%	%	%	%	50	%
4. Kstr {OC} [m 1/3/s]					4	
5. no. of grids [-]					13	
AGRICULTURE						
1. Proposed Soil Depth [m]	8.0		8.0		8.0	
2. Calibrated Depth [m]	8.0					
3. Ks {UZ} [mm/h]	4		%		%	
4. Kstr {OC} [m 1/3/s]	7					
5. no. of grids [-]	5					
AGRICULTURE						
1. Proposed Soil Depth [m]	1.7		1.7		1.7	
2. Calibrated Depth [m]	4.0				4.0	
3. Ks {UZ} [mm/h]	4		%		40	
4. Kstr {OC} [m 1/3/s]	7				7	
5. no. of grids [-]	13				13	
AGRICULTURE						
1. Proposed Soil Depth [m]	1.0		1.0		1.0	
2. Calibrated Depth [m]	2.5				2.5	
3. Ks {UZ} [mm/h]	4		%		40	
4. Kstr {OC} [m 1/3/s]	7				7	
5. no. of grids [-]	3				13	
AGRICULTURE						
1. Proposed Soil Depth [m]	.5		.5		.5	
2. Calibrated Depth [m]	1.0		1.0		1.0	
3. Ks {UZ} [mm/h]	4		20		40	
4. Kstr {OC} [m 1/3/s]	7		7		7	
5. no. of grids [-]	8		10		22	

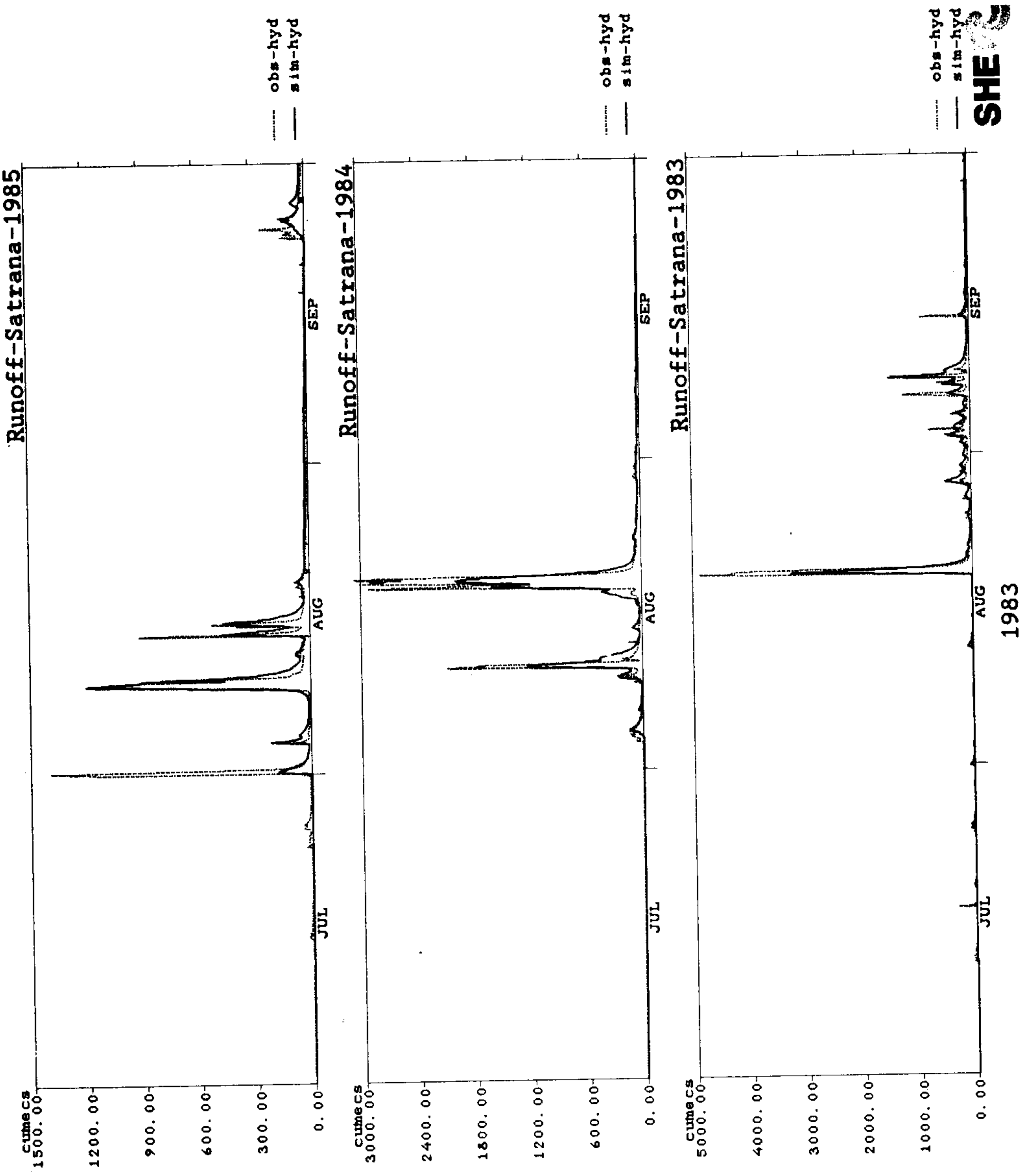

Fig. 5.1 : PLOT OF OBSERVED AND SIMULATED HYDROGRAPHS FOR THE CALIBRATION YEARS

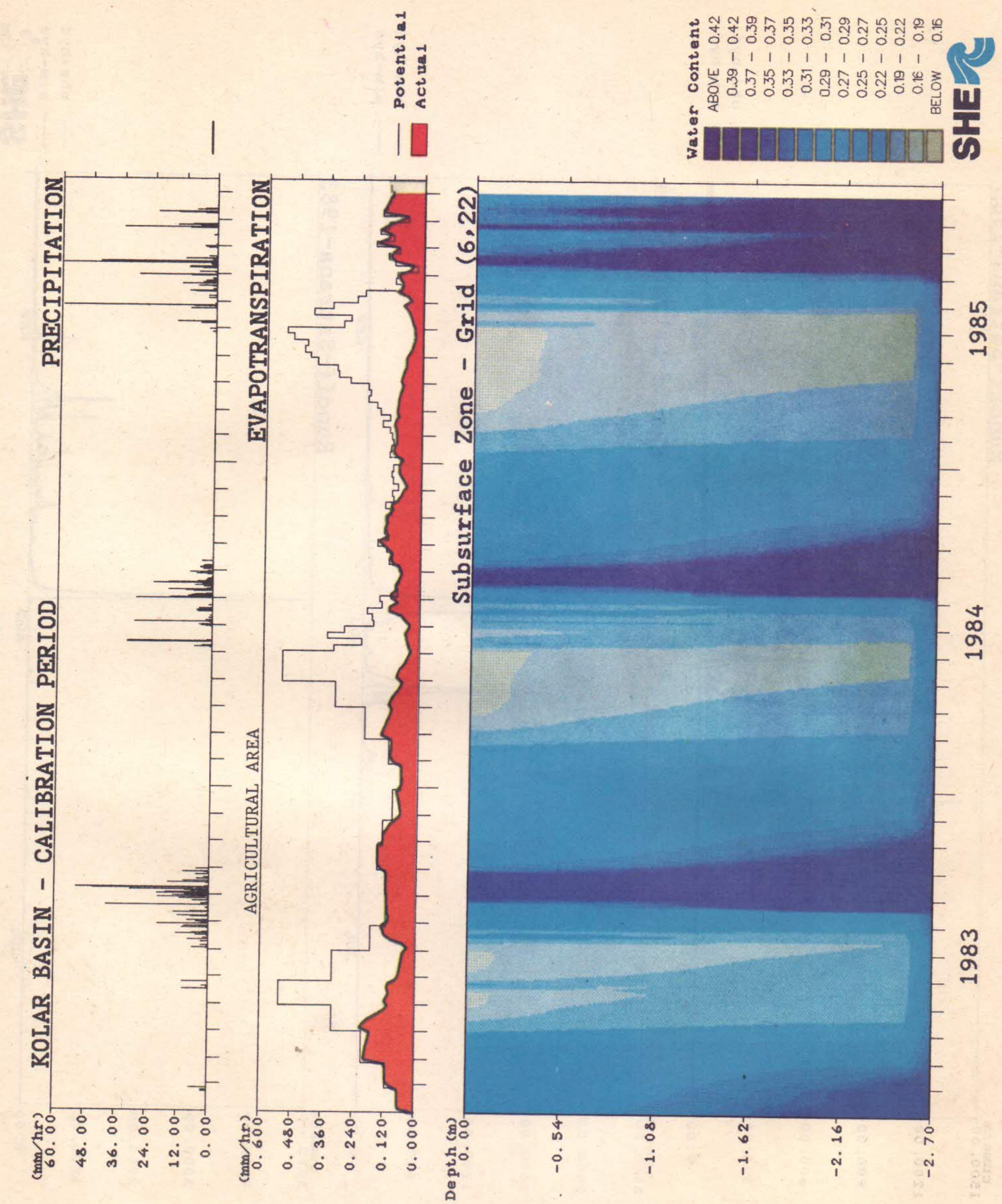

Fig. 5.2 : Variation of Moisture content in Unsaturated Zone, Actual and Potential Evapotranspiration and precipitation for a typical case

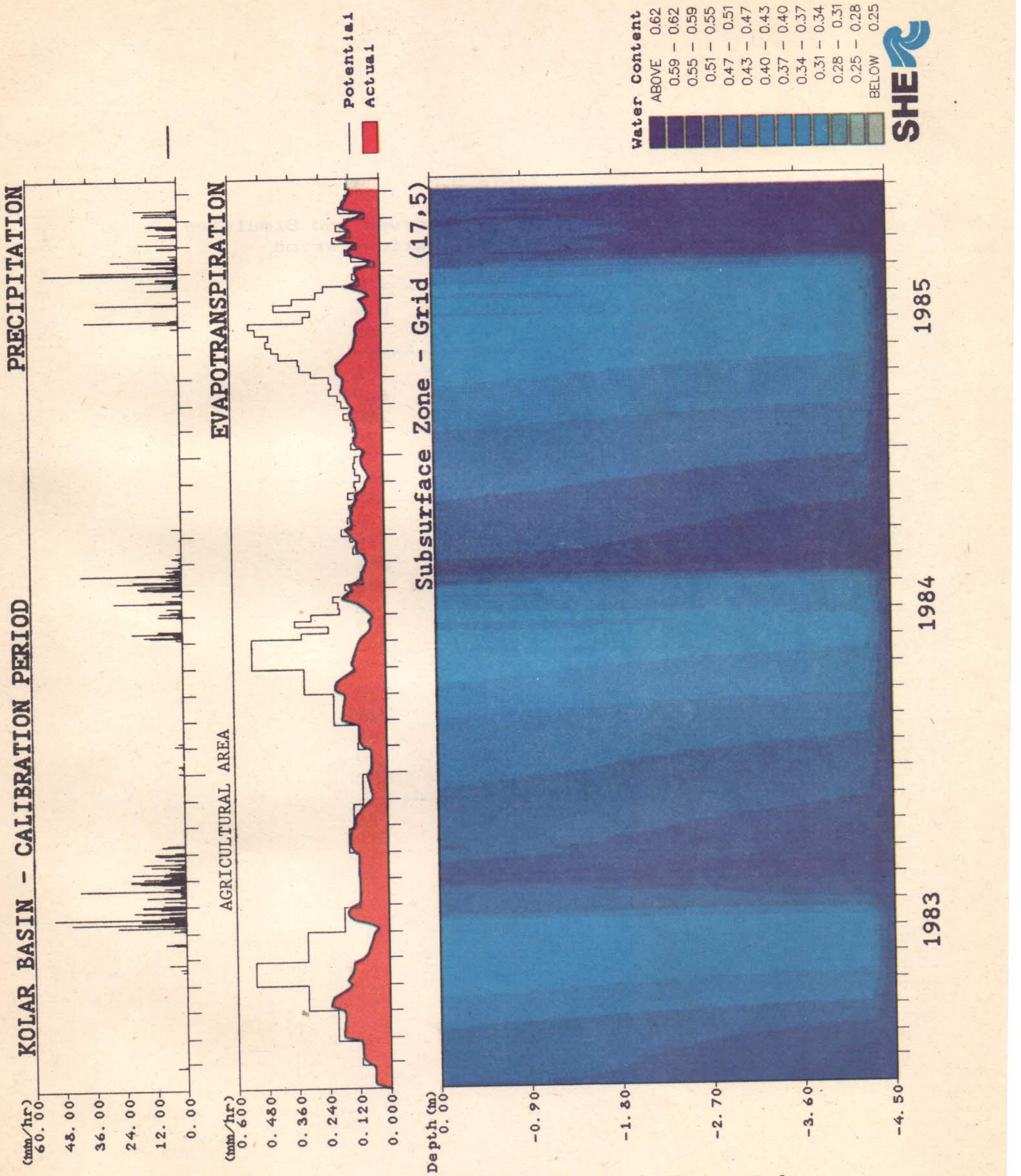

Fig. 5.3 : Varivation of Moisture Content in Unsaturated Zone, Actual and Potential Evapotranspiration and Precipitation for a Typical Case

Table 5.3

Comparison of Volumes of Observed and Simulated Discharges for Validation Period

Year	Mon	Obs mm	Sim mm
1986	6	0	6
1986	7	625	689
1986	8	218	280
1986	9	36	20
1986	10	22	2
Sum		901	997
1987	6	21	0
1987	7	30	12
1987	8	201	204
1987	9	61	88
1987	10	18	3
sum		331	307
1988	6	6	2
1988	7	148	235
1988	8	182	229
1988	9	43	56
1988	10	39	10
Sum		418	532

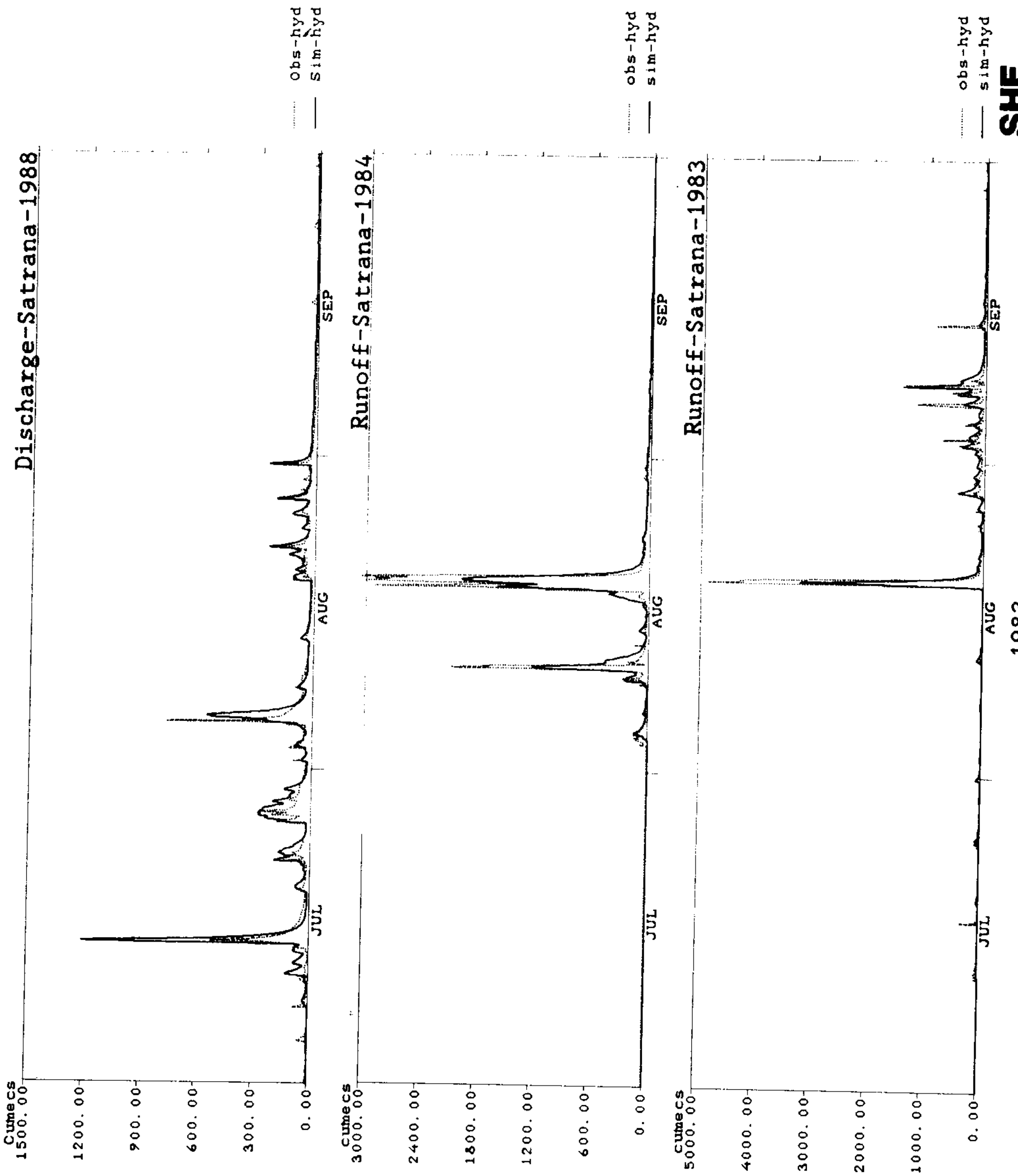

Fig. 5.4 : Plot of Observed and Simulated Hydrographs for Validation Years

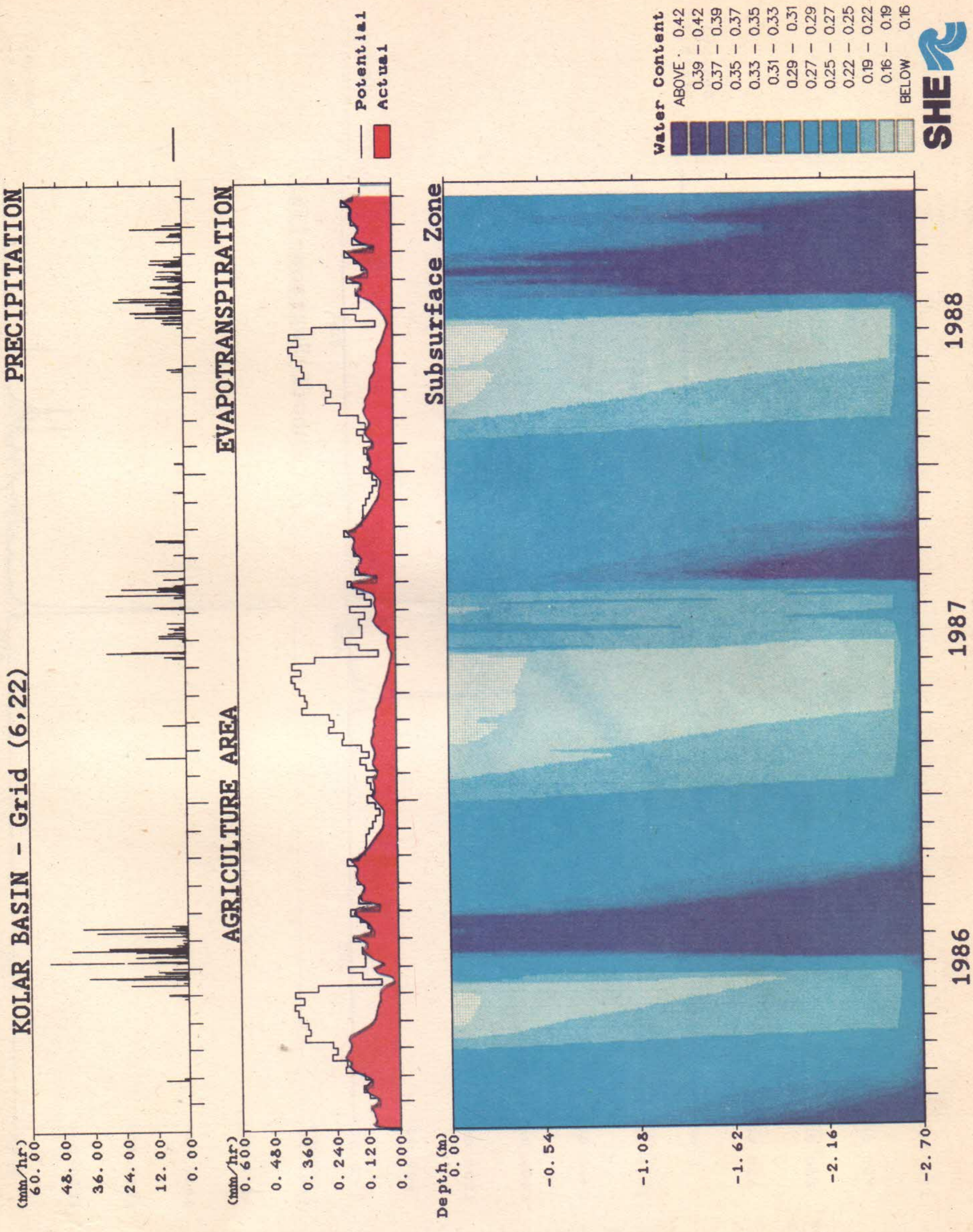

Fig. 5.5 : Variation of moisture content in the unsaturated zone, actual and potential evapotranspiration and precipitation for a typical case

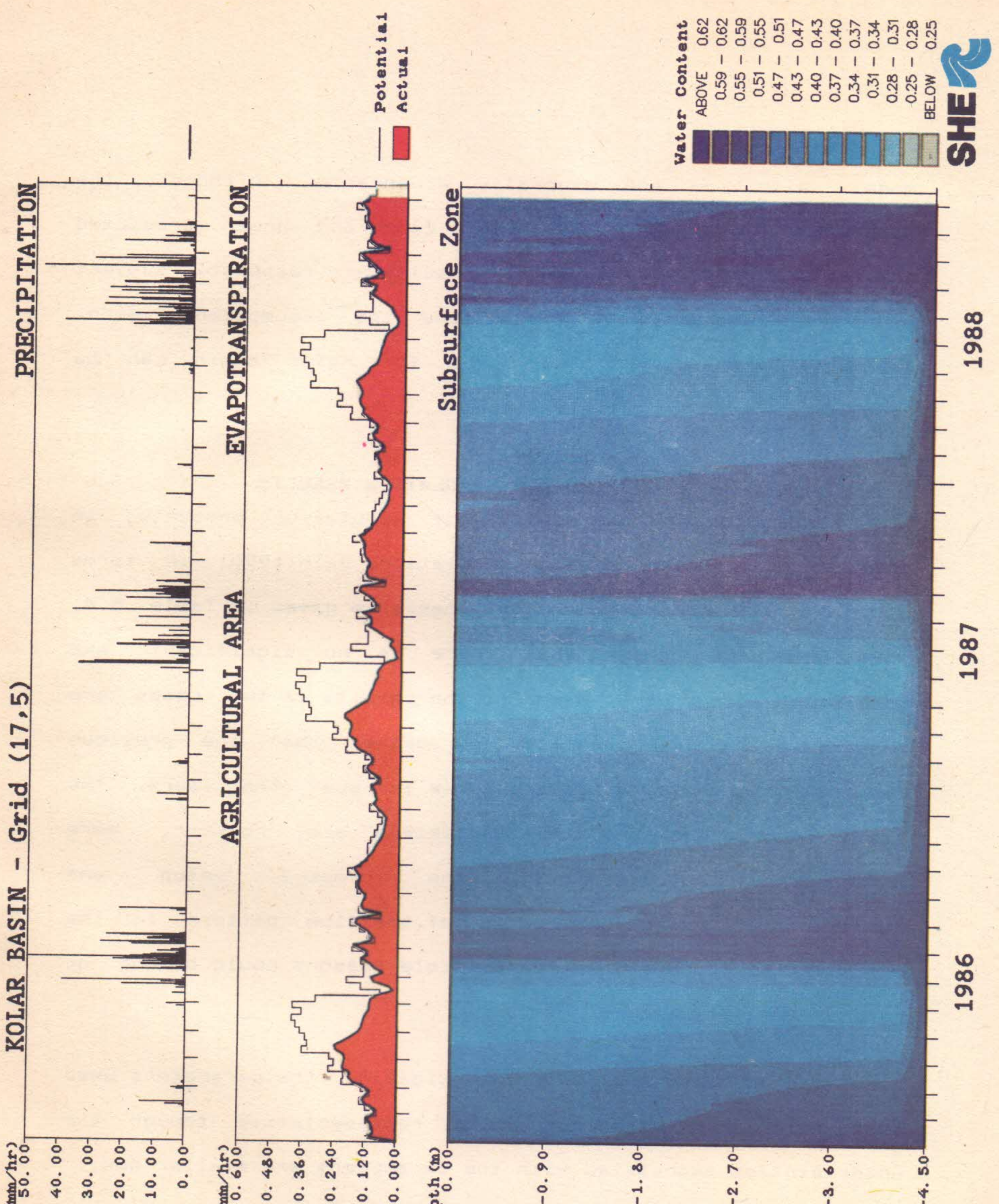

Fig. 5.6 : Variation of moisture content in the unsaturated zone, actual and potential evapotranspiration, and precipitation for a grid in agricultural area.

model validation are generally acceptable. Although the discharge is over predicted in some cases and under predicted in some other cases, the overall results are reasonable subject to the uncertainty in inputs and the assumptions made. Therefore, the present SHE setup for Kolar basin can be considered as an acceptable setup.

5.3 COMPARISON OF OLD AND NEW SIMULATION RESULTS

A comparison of the results of simulation presented in this report with the previous simulation, Jain(1990), in terms of volume of discharge on monthly basis is given in Table 5.4. This comparison shows that there is no significant and consistent improvement. Overall, the results in two cases are comparable. The new results are better than the previous results for some years and are worse for some other years. The basin description and the parameters are, however, more physically realistic in the present setup and consequently a better description of the flow pattern in the catchment is present now. The possible reasons could be one or more of the following :

a) Even after the field investigation, the parameters used in the simulation are not fully representative though the uncertainties associated with the parameters are smaller now.

Table 5.4

Comparison of Volumes of Simulated Discharges for Old and New Simulation

Year	Mon	Obs mm	Sim(1989) mm	Sim(1990) mm
1983	6	0	6	0
1983	7	29	42	19
1983	8	361	330	310
1983	9	248	231	333
1983	10	37	13	35
Sum		675	621	697
1984	6	10	5	0
1984	7	20	6	0
1984	8	592	602	547
1984	9	53	5	60
1984	10	23	6	2
Sum		698	624	609
1985	6	0	10	0
1985	7	76	119	13
1985	8	218	230	290
1985	9	60	80	65
1985	10	40	47	80
Sum		394	485	448
1986	6	0	23	6
1986	7	625	687	689
1986	8	218	182	280
1986	9	36	11	20
1986	10	22	8	2
Sum		901	911	997
1987	6	21	6	0
1987	7	30	22	12
1987	8	201	275	204
1987	9	61	17	88
1987	10	18	6	3
sum		331	326	307
1988	6	6	17	2
1988	7	148	218	235
1988	8	182	127	229
1988	9	43	22	56
1988	10	39	16	10
Sum		418	400	515

b) The input data contains some erroneous observations. In the previous simulation, the possibility - wrong parameters compensating for errors in inputs - might have occurred.

c) Some assumptions made in the model setup, e.g., accounting for only one layer of soil, do not hold good. This may, however, not significantly influence the hydrograph.

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6.0 SENSITIVITY ANALYSIS

In order to determine the sensitivity of model output to errors in the input data, a sensitivity analysis was carried out. In this analysis, one parameter was varied at a time and its impact on the basin behaviour was monitored. This behaviour was compared with the behaviour during the best calibration runs (also referred to as the reference runs in the following discussion) to determine the impact of the individual changes.

The following sensitivity runs were taken :

- By doubling the soil depth in the entire catchment,
- By reducing the input rainfall by 5%,
- By adopting the potential evaporation in the forest areas at 1.4*pan evaporation.

The data for the period 1983-85 and 1986-88 was used in the analysis. The comparison of volumes of observed and simulated discharges for these sensitivity runs for the periods 1983-85 and 1986-88 is given in Tables 6.1 and 6.2 respectively. The discussion on individual cases follows :

6.1 Sensitivity of Potential Evaporation

The potential evaporation in the forest areas was set to 1.4* pan evaporation. The increase in potential evaporation will allow more water to be lost as evapotranspiration losses during the wet season (when supply is more) and consequently

Table 6.1

Comparison of Volumes of Observed and Simulated Discharges for Sensitivity Runs

Year	Mon	Obs mm	Sim mm	EP mm	RF mm	SD mm
1983	6	0	0	0	0	0
1983	7	29	19	8	15	8
1983	8	361	310	271	280	267
1983	9	248	333	318	312	344
1983	10	37	35	25	32	40
Sum		675	697	622	639	659
1984	6	10	0	0	0	0
1984	7	20	0	0	0	0
1984	8	592	547	514	495	505
1984	9	53	60	51	57	71
1984	10	23	2	1	1	1
Sum		698	609	566	553	577
1985	6	0	0	0	0	0
1985	7	76	13	8	8	8
1985	8	218	290	270	257	270
1985	9	60	65	47	56	47
1985	10	40	80	60	81	60
Sum		394	448	385	402	385

Note : EP - Sensitivity run for evaporation,
RF - Sensitivity run for rainfall,
SD - Sensitivity run for soil depth.

Table 6.2

Comparison of Volumes of Observed and Simulated Discharges for Sensitivity Runs

Year	Mon	Obs mm	Sim mm	EP mm	RF mm	SD mm
1986	6	0	6	4	4	0
1986	7	625	689	645	636	642
1986	8	218	280	254	261	287
1986	9	36	20	13	20	21
1986	10	22	2	2	2	2
Sum		901	997	918	923	952
1987	6	21	0	0	0	0
1987	7	30	12	4	8	1
1987	8	201	204	150	178	165
1987	9	61	88	75	81	100
1987	10	18	3	1	3	1
sum		331	307	230	270	267
1988	6	6	2	1	1	0
1988	7	148	235	187	207	182
1988	8	182	229	192	209	229
1988	9	43	56	47	52	71
1988	10	39	10	13	19	23
Sum		418	532	440	488	505

reduction in the streamflow and moisture content in the subsurface zone. Its impact during the dry season, due to obvious reasons, will be insignificant.

The motivation for taking this run came from the observation (made during the calibration phase) that the forested area remains saturated for a long time during the wet season and consequently gives rise to a huge amount of overland flow, significantly higher than the observed flow. It was conjured that in reality, higher volume of water is being lost due to evapotranspiration in the forested areas.

It is seen from the Tables 6.1 and 6.2 that the overall discharge volume during the monsoon season is less by 10-15% as compared with the reference run. The runoff volume in the individual months is also less than the runoff in the corresponding months in the reference runs.

In the present study, the pan evaporation data of one station which was located in cropped area was used. It can be argued that in the forested area, evapotranspiration losses are higher due to higher wind turbulence and lower albedo and hence adoption of a higher potential limit is justified. However, in the final calibration run, a uniform potential evaporation was used in absence of availability of any definite figure.

6.2 Sensitivity of Rainfall Input

The aim behind this run was to examine the sensitivity of basin response to the uncertainties in inputs. To test the sensitivity of basin response to uncertainties in rainfall, the input rainfall for each rain gauge was reduced by 5%. One sensitivity analysis on similar lines was performed during the previous study by increasing the input rainfall, Jain (1990).

It was found in this case that a reduction of 5% in the volume of the input rainfall gives rise to about 10% reduction in the catchment yield. This shows the sensitive nature of the model setup to the errors in rainfall measurements. In case erroneous inputs are used in model calibration, the parameters will not be realistic because during the calibration, one will be unknowingly choosing those parameters which will be compensating for input errors. Further, this also brings out the nonlinear nature of the rainfall runoff process.

6.3 Sensitivity of Soil Depth

This sensitivity analysis was performed in view of the discussions reported in section 5.1.1. In this case, the soil depth in the model setup was doubled at all grids in the catchment. The SHE simulation was carried out with this revised setup keeping everything else unchanged.

The most important consequence of increasing soil depth is higher moisture storage capacity of the subsurface zone. Consequently, more moisture is needed for saturation of subsurface zone in case of shallow soils. Further the base flow which is sustained by movement of water from the subsurface zone to the rivers will be higher in volume and longer in duration if the soil depth is more.

It is seen from the Tables 6.1 and 6.2 that by increasing the soil depth, the discharge volume during the monsoon season is reduced by about 7 - 10%. Further it is seen that in the beginning of the monsoon season, the discharge is less than the reference run while in the later months, it is higher. The reason is that more moisture infiltrates and gets stored in the subsurface zone in the initial monsoon months. This moisture comes out in the form of streamflow in the later periods.

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7.0 CONCLUSIONS

Based on the study described in this report, the following conclusions can be drawn :

a) The SHE model has been successfully used for modelling of Kolar basin within data availability constraints.

b) A field investigation was carried out to improve information about soil properties and catchment charactristics. As a consequence of this, the catchment representation and the parameter values are more physically realistic now. It was found that the simulation results with improved parameters are comparable with the previous simulation.

c) The measurement uncertainties and the problem of representativeness of rainfall stations generates a basic "noise" which defines the upper level of accuracy which can be achieved in simulation. Thus one essential step for improving the simulations will be to have a better coverage of catchment through rainfall stations.

d) A sensitivity analysis was carried out to determine the sensitivity of model output to input data errors. It can be concluded based on this sensitivity analysis that the model output is very sensitive to soil depth, input rainfall and potential evaporation (in wet season).

e) Only one layer of soil was modelled in the present study. However, it is apparent that this is a too simplified representation of the reality.

f) To further improve the results, a detailed modelling of subsurface zone is necessary. This requires strengthening of the data and parameter base and reliable input parameters. This will improve the groundwater description but will have limited effect on quality of discharge simulations. This will, inter alia, require much finer grids

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