# HYDROLOGICAL MODELLING OF SMALL CATCHMENTS USING PHYSICALLY BASED DISTRIBUTED MODEL - SHE

## 1.0 INTRODUCTION

Water is the most essential natural resource for life and is likely to become a critical scarce resource in the coming decades due to continuous increase in population. Water in all its forms, solid, liquid and gaseous, is constantly on the move in and around the globe along the paths of hydrological cycle. The circulation of fresh water over the earth can be represented by a continuous process under the influence of solar energy and other climatic factors, where by water follows a cycle of evaporation from the earth's surface (mainly from the oceans), condensation, precipitation, flow over the land surface and below it and returning back to the oceans. Variations in climatic characteristics both in space and time are responsible for uneven distribution of precipitation. In India precipitation is confined to only about three or four months in the year and varies from 10 cm in the western parts of Rajasthan to over 100 cm at Cherrapunji in Meghalaya. This uneven distribution of the precipitation causes highly uneven distribution of available water both in space and time, which leads to floods and drought affecting vast areas of the country. Man's activities such as land use changes, deforestation or afforestation, agricultural practices, urbanization, constructions of water resources structures for irrigation, hydro-power, water supply and navigation, etc. influence the hydrologic cycle to a certain extent which modify the pattern of natural availability of fresh water supplies, with respect to space and time. An accurate assessment of the available water, both on surface and ground is needed for optimum design, planning and operation of the water resources projects as well as for watershed management in order to meet the basic needs of the people in coming decades. Since the hydrological processes are continuous and quite complex, therefore, an accurate assessment of quantities of water simultaneously passing through all these processes is quite a difficult task. The problem becomes even more complex when the natural hydrological cycle is getting distributed by the man's activities. Mathematical modelling of hydrological processes provides a most powerful technique for an accurate assessment of the available water in space and time considering the physical processes to a certain extent close to the reality and incorporating the various factors affecting the natural hydrologic cycle due to man's influence. Such modelling exercises are very much helpful for both the research hydrologists and the practicing water resources engineers involved in developing the integrated approaches for planning, development and management of water resources projects.

A model is a simplified representation of a complex system. It aids in making decisions, particularly where data or information are scarce or there are large-number of options to choose from. Hydrological models represents the physical/ chemical/biological characteristics of the catchment and simulates the natural hydrological processes. Hydrological models are essentially mathematical models where the physical processes of hydrologic cycle are described by a set of mathematical equations (often partial differential equations), logical statements, boundary conditions and initial conditions, expressing relationships between inputs, variables and parameters. Hydrological models may be broadly classified in two groups:

(i) Deterministic Hydrological Models
(ii) Stochastic Hydrological Models.

A deterministic hydrological model is one in which the processes are modelled based on definite physical laws and no uncertainties in prediction are admitted. It has no component with stochastic behaviour, i.e. the variables are free from random variation and have no distribution in probability. Deterministic models can be further classified according to whether the model gives a spatially lumped or distributed description of the catchment area, and whether the description of the hydrological processes is empirical, conceptual or fully physically based.

Empirical or black box models contain no physically based transfer function to relate input to output. In other words no consideration of the physical processes is involved in such types of models. These models are basically input-output based models. Within the range of calibration such models may be highly successful. However, in extrapolating beyond the range of calibration, the physical link is lost and the prediction then relies on mathematical technique alone.

Lumped conceptual models occupy an intermediate position between the fully distributed physically based approach and empirical black box analysis. Such models are formulated on the basis of a relatively small number of components, each of which is a simplified representation of the process element in the system being modelled. Parameters of such type of models are calibrated using trial and error method or automatic optimisation technique or combination of both.

Fully distributed physically based models are based on our understanding of the physics of the hydrological processes which control catchment response and use physically based equation to describe these processes. From their physical basis such models can simulate the complete runoff regime, providing multiple outputs (e.g. river discharge, phreatic surface level and evaporation loss) while black box models can offer only one output. Unlike lumped conceptual models, physically based distributed models do not consider the transfer of water in a catchment to take place between a few defined storages. Instead the transfers of mass, momentum and energy are calculated directly from the governing partial differential equations.

Now-a-days engineers, scientists and planners involved in water resources development have become more concerned with the effect of land use changes related to agricultural and forestry practices, hazards of pollution and toxic waste disposal and general problem arising from conjunctive uses of water. Conventional rainfall runoff models (empirical as well as lumped conceptual models) are often not able to provide satisfactory solutions to such problems. Attention is, therefore, being focused on the physically based distributed catchment models since these have the potential to overcome many of the deficiencies associated with simpler approaches. On the other hand, such models are complex and considerable resources in human expertise and computing capability are needed for their development and applications. In the light of these concerns, three European Organisations (the Danish Hydraulic Institute, the British Institute of Hydrology and the French Consulting company SOGREAH) jointly developed the European Hydrological System - Systeme Hydrologique European or SHE. This is a general, physically based, distributed modelling system for modelling all or any part of the land phase of the hydrological cycle for any geographical area.

## 2. O THE SHE MODEL

### 2. 1 The SHE Model Structure

The SHE model is a deterministic, distributed and physically based hydrological modelling system developed from the partial differential equations describing the processes of sub-surface, overland and channel flow solved by finite difference methods, and includes the processes of interception, evapotranspiration and snowmelt. The SHE is physically based in the sense that the hydrological processes 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 research. Spatial distribution of catchment parameters, rainfall input and hydrological response is achieved in the horizontal through the representation of the catchment by an orthogonal grid network of specified grid size and in the vertical by a column of horizontal layers at each grid square. The channel system is represented on the boundaries of the grid squares.

The model structure is illustrated in Fig. 1.

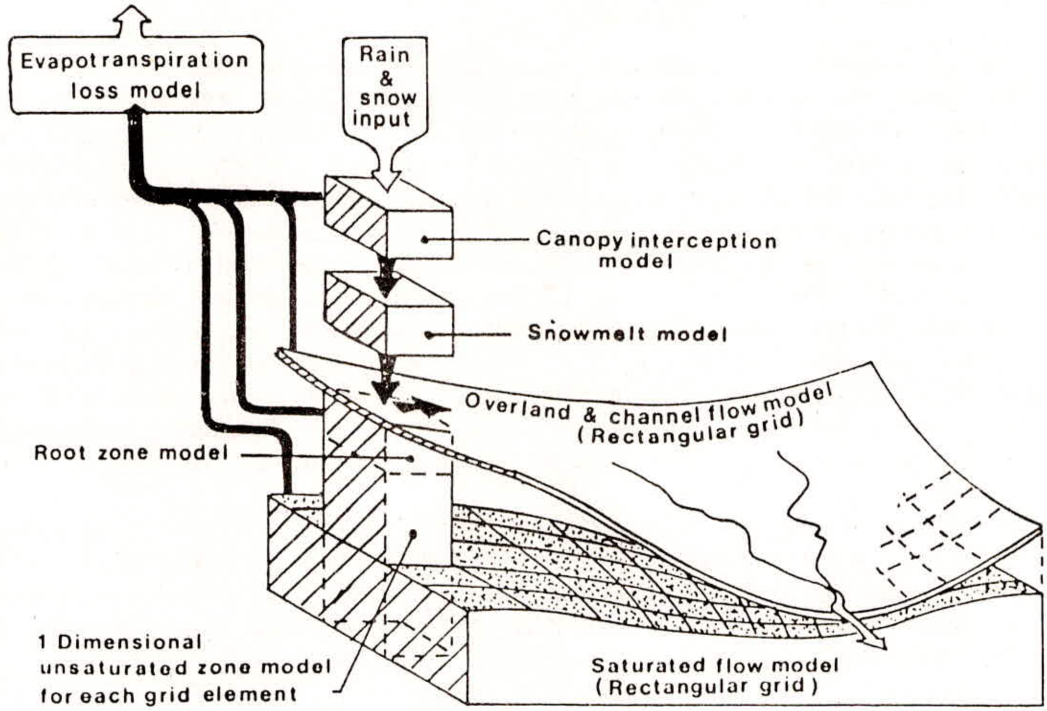

Fig. 1 : Schematic representation of the structure of the European Hydrological System (SHE) [Adapted from Beven et al, 1980]

At present only the primary components of the land phase of the hydrological cycle namely: snowmelt, canopy interception, evapotranspiration overland and channel flow and unsaturated and saturated sub-surface flow are being modelled using SHE. 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 implications of St. Venant equations; unsaturated zone flow, by one dimensional Richards equation; saturated zone flow by the two dimensional Boussinesq equation and snowmelt, by an energy budget method. Secondary details, such as soil macropores and an under growth of the vegetation below the major vegetation, are not currently explicitly modelled because of the extra complexity and economic penalties which would be involved. Similar simplifications have been introduced in the computer software in order to reduce Computing requirements. Thus, it is assumed that, for most slope, flow in the unsaturated subsurface zone is essentially vertical and flow in the saturated sub-surface zone is essentially horizontal. The result is a model Structure in which independent one dimensional, unsaturated flow columns of variable depths link a two dimensional overland flow component with a two dimensional saturated flow component. Furthermore the unsaturated flow equations are solved only for some representative columns selected taking spatial variability into consideration and then the calculations are transferred to different grids. Such an arrangement ensures acceptable computing costs at an acceptable level of approximation of the catchment processes. However, it also poses the numerical problems of linking one dimensional and two dimensional sub-surface models at a time Varying interface (the phreatic surface). It also means that, in a simulation, runoff can reach the river system only as overland flow or as saturated flow.

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 of simply a lack of data may create significant uncertainties in the values of the catchment parameters used in simulation. These uncertainties 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.

The SHE model software was transferred to the National Institute of Hydrology, Roorkee under a project financed by Agreement ALA 86/19 between the Commission of European Communities and the Government of India. The SHE model was applied in close interaction with the Consultants to eight river basins of India, at NIH. The following section deals with one of such applications, viz. the application of SHE model to Ganjal basin of river Narmada.

### 2.2 Data Requirement

A large number of parameters describing the characteristics of the catchment on a spatial distributed basis are required in addition to the hydrological and hydrometeorological time series for successful running of the model.

Data required for SHE model may be obtained either from field measurements or from field measurements supplemented by the information from available scientific literature. The data and parameters required for each grid square (or channel link) in the SHE model for the most comprehensive calculation models are given below:

a) Frame Component
  i) Model Parameters
    Ground surface elevation, impermeable bed elevation, distribution codes for rainfall and meteorological source stations, and distribution codes for soil and vegetation types.

b) Evapotranspiration/Interception Component
  i) Model Parameters (for each vegetation type)

Option One:

Canopy resistance, aerodynamic resistance, ground cover indices (time varying), ratio between actual and potential evapotranspiration as a function of soil moisture tension, root distribution with depth, canopy storage capacity (time varying).

Option Two:

Evapotranspiration parameter; root distribution (time varying); leaf area index (time varying); ground over indices (time varying); canopy storage capacity coefficient.

ii ) Input data

Meteorological data

c) Overland and channel flow component

i) Model Parameters

Strickler roughness coefficient for overland and river flows, coefficient of discharge for weir formulae.

ii) Input data

Specific flows or water levels at boundaries, man controlled diversions and discharges, topography of overland flow plane and channel cross sections.

d) Unsaturated Zone Component

i) Model Parameters (for each soil type)

Soil moisture tension/content relationship, unsaturated hydraulic conductivity as a function of moisture content. Field capacity, wilting point and saturated hydraulic conductivity for unsaturated zone.

e) Saturated Zone Component

i) Model Parameters

Porosities or specific yields, saturated hydraulic conductivities.

ii) Input data

Impermeable bed elevations, specific flows or potentials at boundaries, pumping and recharge data.

f) Snowmelt Component

i) Model Parameters

Degree Day factor, Snow zero plane displacement, Snow roughness height.

ii) Input data

Meteorological and precipitation data

## 2.3 Input Data Files Organisation for SHE Model

Application of SHE requires the provision of a large amount of parametric and input data organisation in an array of data files. To each component a 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. The data input necessary to run SHE successfully are divided into four categories:

i) Program Organizational data

ii) Catchment Organizational data
iii) Physical characteristics data
iv) Meteorological data

The first three types of data are read in during the initialization phase, while the meteorological data are read during the simulation phase. The major part of the programme organization data are read from the FRAME COMPONENT. This includes information about organisational and operation of the simulation, i.e. length of simulation, grid square set up and times at which data should be stored or printed. Codes describing the soil and vegetation type distribution, and rainfall and meteorological station network are also read from FRAME. The distributions are presented as an array of codes, allocated to each grid square. A code number signifies a particular characteristics. The physical data associated with these characteristics are read from the different process components where the data are used.

### 2.4 Running SHE Model

After preparation of the required SHE data files, SHE can be run by typing SHE. The user is then requested to type the catchment name, which would correspond to the name given to the data files.

If specified in the frame data file XXX.FRD results will be both printed and stored on a file respectively. The SHE output print file XXX.PRI contains various results and warning error messages. It is recommended in the initial phase of SHE application to print the initial conditions for checking of the Data. Stored results in the file XXX.RES may be retrieved and presented by applying the routines SHE.OR or SHE.GD.

### 2.5 Field of Application of SHE

SHE model has significant advantages over existing hydrological models for a wide range of applications due to its distributed Model structure. Almost for any kind of hydrological problems, SHE model will be able to provide the answer, although further development and refinement is still needed to achieve the optimum goal of its general applications. Moreover, cheaper conventional rainfall-runoff models may be successfully applied to provide the solutions for many simple hydrological problems. But for the more complicated problems, the conventional models fail to provide the satisfactory results and hence there may be a little alternative but to use a system such as the SHE. Some of the possible applications are given in the following examples:

(a) Catchment changes:

Catchment conditions are non-stationery due to nature and man made changes in land use, such as the effects of fires, urbanisation and forest clearance for agricultural purposes, etc. The parameters of SHE model have direct physical interpretation and can be evaluated for the new state of the catchment conditions before the change actually occurs. The new set of parameter values can be used to examine the possible effect of such changes in advance taking different alternatives of simulation runs.

(b) Ungauged catchments:

The parameters of SHE model can be easily derived from the short term field investigations. The model may be calibrated using much shorter and therefore more cheaply obtained, hydrometeorological record than is necessary for more conventional models. It means for an ungauged catchment in which a project has been proposed, one or two years of hydrometeorological records are sufficient to calibrate SHE model whereas for the conventional rainfall-runoff models this record length is too short.

(c) Spatial variability in catchment input and output:

Distributed models can be used to study the effects on flood flows of different directions of storm propagation across a catchment and also the effects of localized river and ground water abstractions and recharge.

(d) Movement of pollutants and sediments:

Water flows provide the basic dispersion mechanism in the movement of pollutants and sediments. Thus, modelling the flows is prerequisite to model the movement of pollutants and sediments. Most water quality and sediment problems are distributed in nature, so distributed models are the most suitable for supplying the basin information on water flow.

In brief, some possible fields of application of SHE model are listed below:

i) Irrigation Schemes
    Irrigation water requirement
    Crop production
    Water logging
    Salinity/Irrigation management

ii) Land use change
    Forest clearance
    Agricultural practices
    Urbanisation

iii) Water developments
    Ground Water Supply
    Surface water supply
    Irrigation
    Streamflow depletion
    Surface water/ground water interaction

iv) Ground water contamination
    Industrial and municipal waste disposal
    Agricultural chemicals
    Erosion/sediment transfer

v) Flood Prediction

## 3.0 APPLICATION STUDY FOR KOLAR BASIN

An application study of the SHE Model to Kolar Sub-basin of River Narmada was carried out and based on this study a technical report CS-47 has been prepared. This report discusses the results in comprehensive manner. However, the abstract of the study is discussed here.

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 modelled.

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. 2.

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.

### 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 gravelled. 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 (adjaceent 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 the 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 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 hourly rainfall data for Kolar basin for the years 1983-88 was available at four stations : Birpur, Birjishnagar, Jholiapur and Rehti. The 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

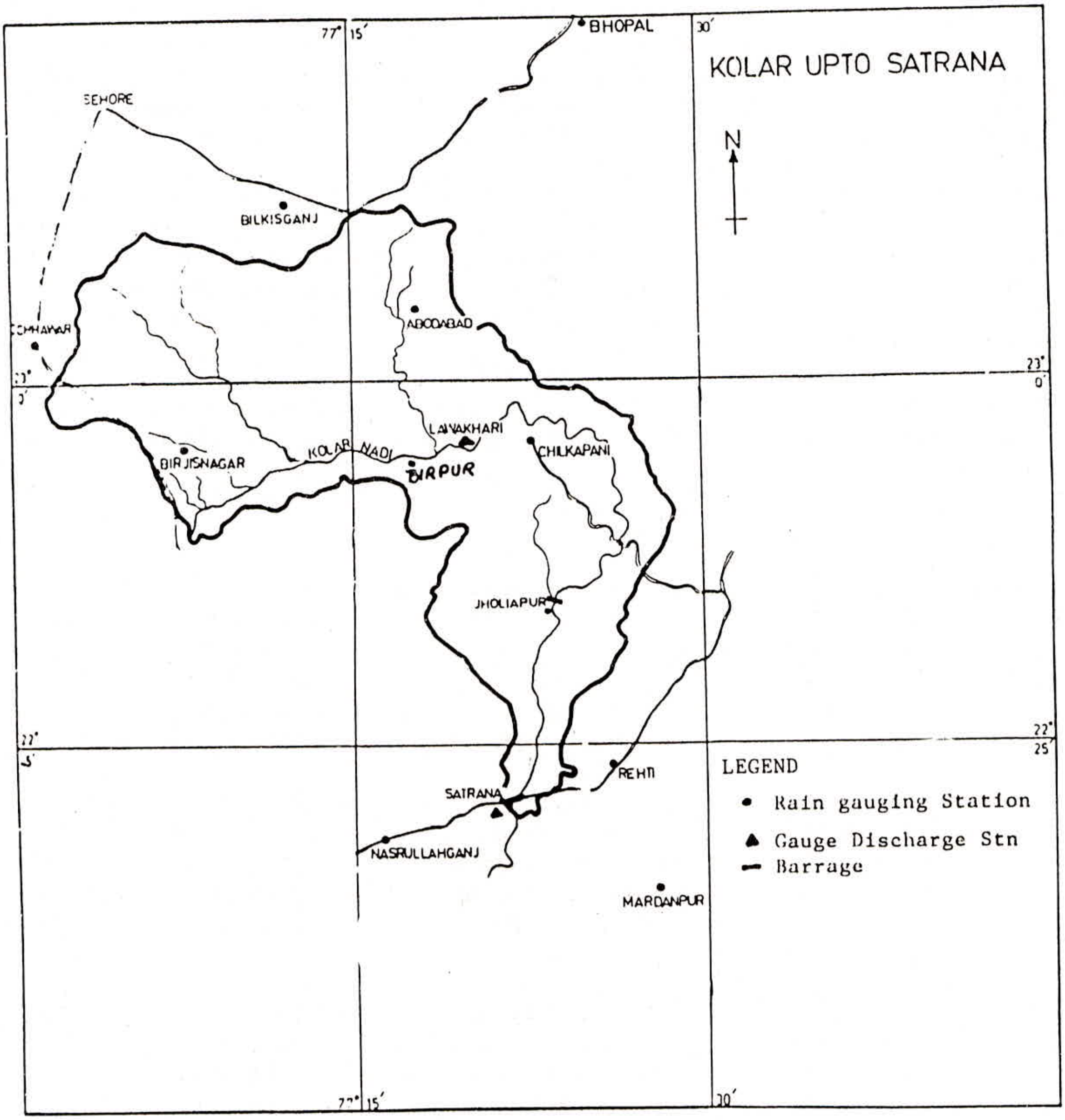

Fig. 2 : The Kolar basin upstream of the Satrana gauging station

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 Field Investigation in Kolar Basin

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 are, 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 cm 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 : (1) considering the inner volume of the pipe sampler, (ii) considering the volume of dried sample and 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 were derived. 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 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. The entire basin was classified in three soil types - black, red and yellow. The soil depth map for the basin was also prepared. 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. |

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 1.

Table 1: 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 2.

Table 2 : Properties of different type of soils

| Property | Black | Soil type | |
|---|---|---|---|
| | | Red | Yellow |
| Saturated moisture Effect. | 0.675 | 0.42 | 0.47 |
| Residual moisture cont. | 0.62 | 0.403 | 0.438 |
| Wilting Point | 0.575 | 0.31 | 0.36 |
| Field capacity | 0.36 | 0.15 | 0.18 |
| sat. moist cont.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 was prepared after the field investigation. The variation of leaf area index and root zone depth for different vegetation types were quantified. 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.

## 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. 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. 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, 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.

## 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 and Validation Results

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 3. The observed and simulated hydrographs for the calibration period are plotted in Fig. 3. 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 4. The observed and simulated hydrographs for the validation period are plotted in Fig. 4.

It can be seen that the results for the 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.

Table 3
Comparison of Volumes of Observed and Simulated Discharges for Calibration Period - Kolar Basin

| Year | Mon | RF<br>mm | Obs_Q<br>mm | Sim_Q<br>mm |
|---|---|---|---|---|
| 1983 | 6 | 7 | 0 | 0 |
| 1983 | 7 | 270 | 29 | 19 |
| 1983 | 8 | 548 | 361 | 310 |
| 1983 | 9 | 382 | 248 | 333 |
| 1983 | 10 | 10 | 37 | 35 |
| Sum | | 1217 | 675 | 697 |
| 1984 | 6 | 141 | 10 | 0 |
| 1984 | 7 | 141 | 20 | 0 |
| 1984 | 8 | 851 | 592 | 547 |
| 1984 | 9 | 27 | 53 | 60 |
| 1984 | 10 | 4 | 23 | 2 |
| Sum | | 1164 | 698 | 609 |
| 1985 | 6 | 139 | 0 | 0 |
| 1985 | 7 | 293 | 76 | 13 |
| 1985 | 8 | 386 | 218 | 290 |
| 1985 | 9 | 181 | 60 | 65 |
| 1985 | 10 | 118 | 40 | 80 |
| Sum | | 1117 | 394 | 448 |

Table 4
Comparison of Volumes of Observed and Simulated Discharges for Validation Period - Kolar Basin

| Year | Mon | RF<br>mm | Obs_Q<br>mm | Sim_Q<br>mm |
|---|---|---|---|---|
| 1986 | 6 | 201 | 0 | 6 |
| 1986 | 7 | 958 | 625 | 689 |
| 1986 | 8 | 302 | 218 | 280 |
| 1986 | 9 | 60 | 36 | 20 |
| 1986 | 10 | 0 | 22 | 2 |
| Sum | | 1521 | 901 | 997 |
| 1987 | 6 | 105 | 21 | 0 |
| 1987 | 7 | 160 | 30 | 12 |
| 1987 | 8 | 509 | 201 | 204 |
| 1987 | 9 | 58 | 61 | 88 |
| 1987 | 10 | 58 | 18 | 3 |
| Sum | | 890 | 331 | 307 |

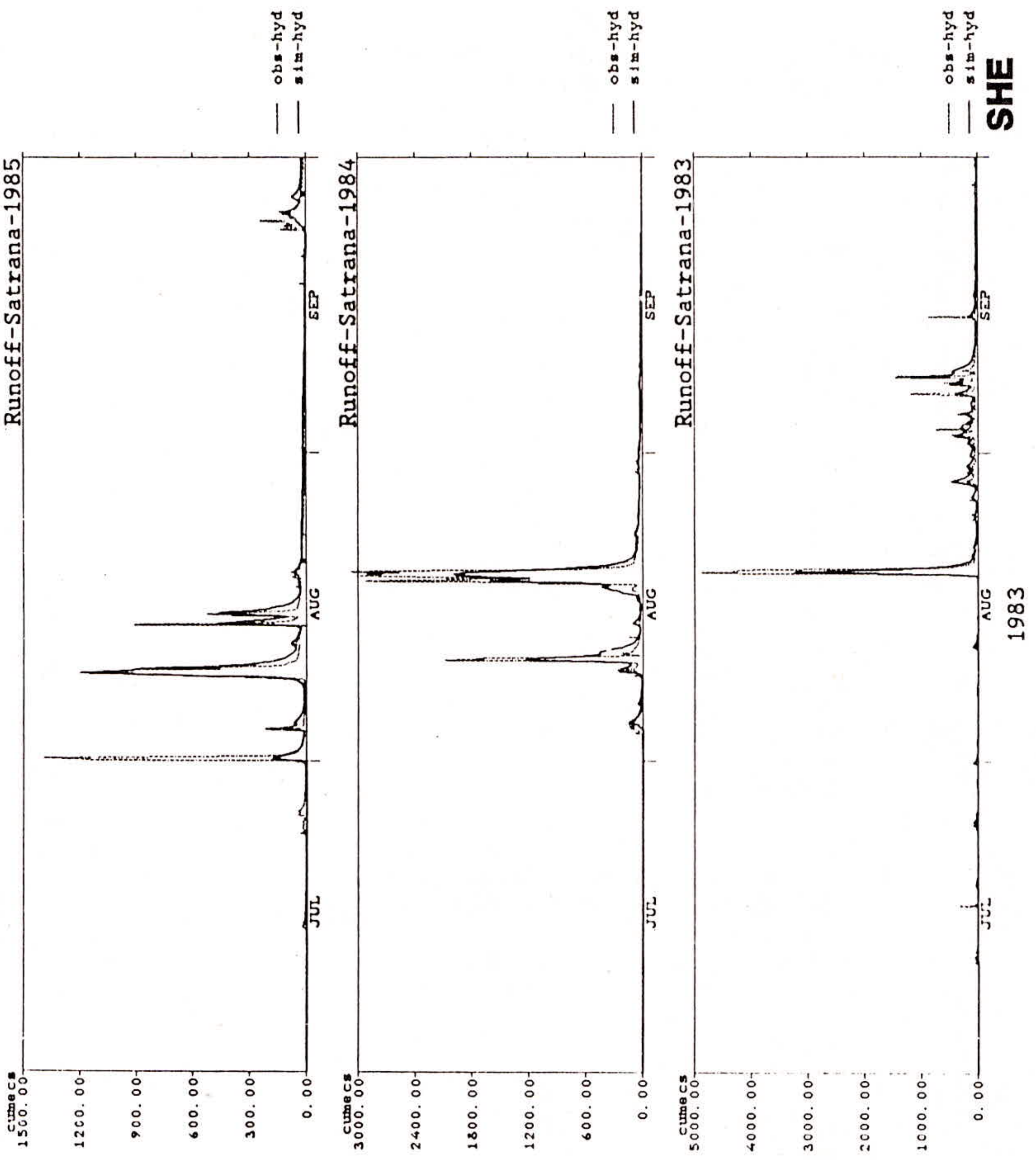

Fig. 3 : PLOT OF OBSERVED AND SIMULATED HYDROGRAPHS FOR THE CALIBRATION YEARS

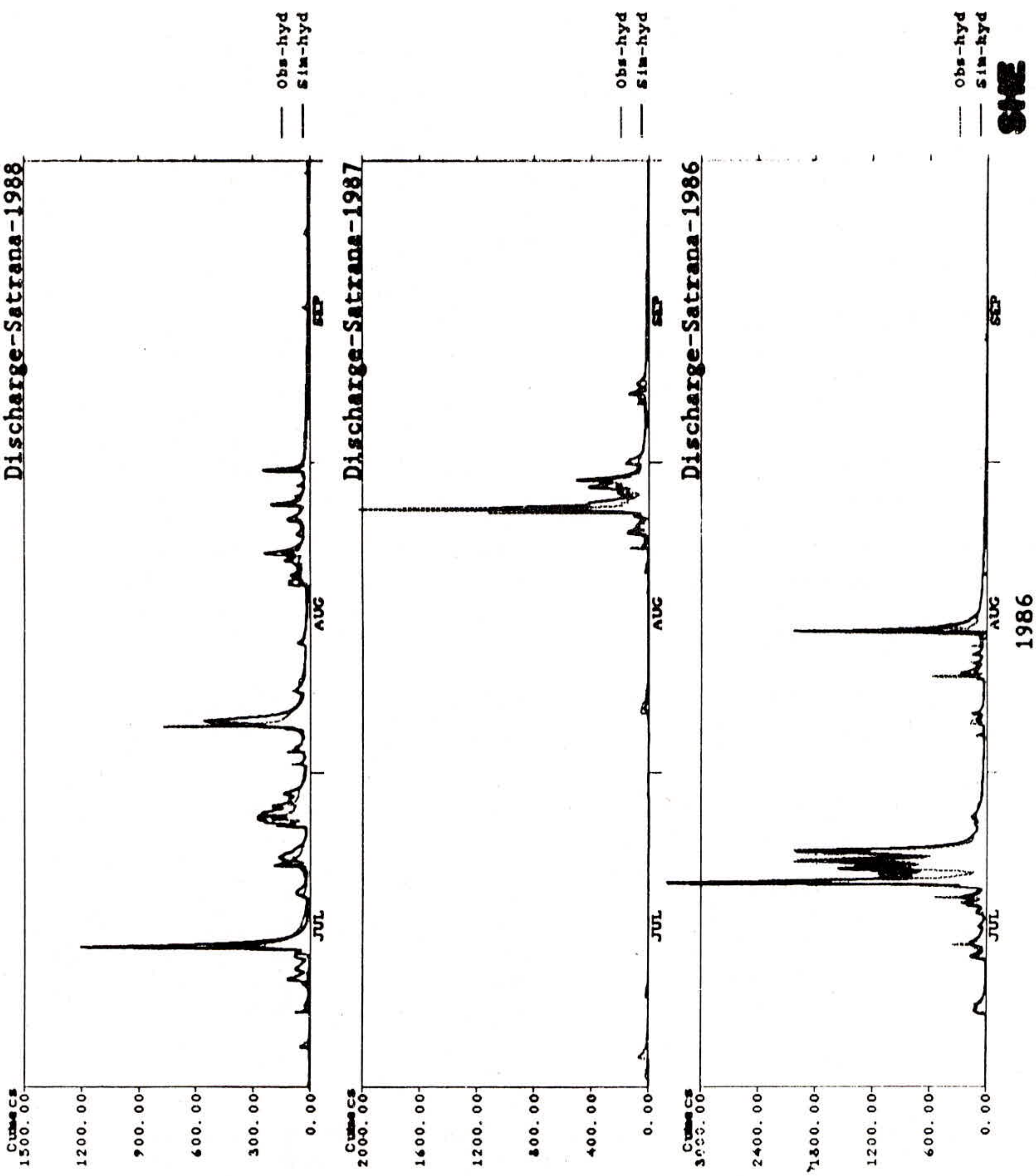

Fig. 4 : Simulated and observed hydrograph for the validation period 1986-88

## 6.0 CONCLUSIONS

Based on the above study, the following conclusions can be made:

a) The SHE model has been successfully used for modelling entire land phase of hydrologic cycle for Kolar basin with a reasonable accuracy, within the constraints of data availability. The simulation study of the basin well represents the hydrological regime the basin, except the groundwater response which has adequate scope for improvement.

b) The values of soil parameters, which play a dominant part in the simulation in their absence have been derived from indirect sources for adjacent basins and available literature. Further, the detailed spatial distribution of soil depth was unknown and the required information was collected during field investigation.

c) The vegetation parameters have also been based on review of literature and general experience. The simulation results can be improved by input of accurate values of these parameters.

d) The rainfall data does not provide the desired level of representation in the study. Out of the considered four raingauge stations, one lies outside the basin. Further, there was no raingauge station in the upper part of the basin. Thus the spatial representation of rainfall was not up to the desired level.

e) The computation requirement are dependent on the grid size used for simulation. In this study the model was set up on 2km x 2km grid size. Though the physical processes are accurately represented by smaller grid size.

f) The processes of soil evaporation, transpiration and canopy evaporation can be well simulated by the SHE model.

g) The well calibrated SHE model can be used to model the land phase of hydrologic cycle including the effect of land use changes on the hydrologic regime of the basin. However, extensive data and computational requirements of the model are its major limitations. Hence, the use of SHE is not warranted for dealing with routine hydrological problems.

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