CS - 31

APPLICATION OF SHE MODEL TO SHER SUB BASIN

NATIONAL INSTITUTE OF HYDROLOGY

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PREFACE

India has primarily an agriculture based economy and nearly 85% of the present use of water is for agricultural activities. Due to typical monsoonal climate of the country about 80% of the annual preciitation takes place during four monsoon months of June to September in most part of the country. The water resources activities have been increasing since Independence. As a result, the irrigation potential has gone upto 74.57m.ha.m. (till 87-88) from the level of 22.6 m.ha. (pre-plan periods). In the process of water resources development, the Narmada basin is currently undergoing major developmental acativities and there is need to evaluate effects of various aspects of these activities for example change in land use on hydrologic regime of the basin which can be done by application of a sophisticated hydrologic model. Under an agreement between Govt. of India and European Economic Community (EEC), the SHE (European Hydrologic System) model technology was transferred to the National Institute of Hydrology by a group of consultants from Denmark, U.K. and France. The SHE which is a physically based distributed hydrologic model, can model entire land phase of hydrologic cycle and is developed jointly by three European organisations namely; DHI, Denmark; Institute of Hydrology, U.K. and SOGREAH, France. As a part of its application, it was decided to apply SHE to six sub-basins of Narmada river basin.

One of the sub-basins for which SHE was applied is SHER sub-basin. The study was conducted by Mr. V K Lohani, Scientist 'C'. Dr. S.M. Seth, Sciectist 'F' and Project Coordinator and a team of consultants coming from three European Organisations as mentioned above have rendered valuable guidance during course of study. The results have indicated that assessment of physical parameter values especially of soil and vegetation is an important requirement for application of the model. Extensive data requirements and need for sophisticated computing systems are the major limitations of the model.

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ABSTRACT

The Govt. of India signed a financial agreement entitled 'Hydrological Computerised Modelling System (SHE)' with the European Economic Community (EEC) in June/July 1987. The project has the aim to improve India's capacity in formulating water and land resources development strategies and includes transfer of SHE model technology to the National Institute of Hydrology for its application on hydrological problems all over the country.

The SHE is a physically based distributed modelling system and as a part of its application six sub-basins of Narmada basin have been chosen. One of the sub-basins is of Sher river which is a left bank tributory of Narmada river. The Sher river is being gauged at a place called Belkheri about 40 km upstream of the confluence of river Sher with Narmada. The gauging station, which is being maintained by the C.W.C. is located at a distance of 16 km from Narsinghpur district headquarter on the state highway No. 26. The flow records at the site are existing since year 1978. There are a number of raingauge stations located in and around the sub-basin. Data of three stations namely, Lakhandon, Harai and Mungwani were used for simulation excercise. Due to non-availability of long term hourly data, the hourly records at Jabalpur were used to convert daily rainfall into hourly rainfall. The simulation period was taken as from 1978-86. The evaporation data as needed for simulation excer

cise was used as recorded at the Jabalpur station. The land use map of the sub basin was prepared using the information as obtained from NVDA. The soil parameter values and retention curve were extracted from the information published regarding the black cotton soil of the sub basin. Topographic maps of the basin were perpared in the scales of 1:250,000 and 1:50,000 using the toposheets. The vegetation parameters in respect of each type of land use as recorded in land use map were extracted from the published information.

The data were processed and were arranged in the required formats as used for SHE simulation. The grid maps as needed for model application were prepared for topography, landuse etc. A grid size of 2km x 2km was selected for preparation of grid maps. The information regarding the river cross sections, bank levels and strickler coefficients for channel and overland flow were introduced using the published works and data collection from field visits. The observations as recorded in the wells located within the basin were used for specifying initial conditions for ground water table. The simulation excercise was performed from 1978 to 86 for monsoon months only. The calibration period was taken as 1978-82 during which the set of parameter values for best simulation match were decided. The validation period was taken from 1983-86. The simulation results were not obtained upto desired level of satisfaction.

In order to see sensitivity of parameter values some sensitivity runs were also taken during which the sensitivity of parameters like strickler coefficient, hydraulic conductivity in unsaturated and saturated zones were seen. The soil parameter values were found to be most sensitive to simulation results. The strickler coefficient for overland flow was found to affect peak and volume of simulated response.

Few reasons for not getting satisfactory results could include non-representation of the actual rainfall scenario over the basin as the hourly rainfall data recorded within the data were not available. Besides, the soil parameter values which have been chosen from the publised literature may need thorough investigation as these are quite sensitive to simulation results. Also the parameters used for vegetation have also been derived from the available literature and general experience. The spatial variation in the parameter values which were not accounted for would also influence the simulation results. The grid size chosen for simulation excercise may influence the results as the physical processes may not be actually represented. It has, however, been observed that the entire land phase of hydrological cycle can be modelled accurately with the help of SHE model provided all required data are available. The well calibrated model can be effectively used to predict effects of land use changes on hydrologic regime of a basin. The extensive data requirements are the main limitations of the model.

1.0 INTRODUCTION

India has been primarily an agricultural country from the dawn of civilisation. Nearly 85% of the present use of water has been for agriculture. The snow melt from Himalayas in the north and the rainfall are the sources of water in the country. Rainfall in different regions varies considerably in intensity and distribution. Years of scarcity are followed by periods of excessive floods. The demand of water for various uses is increasing day after another. Estimates indicate that annual requirement of fresh water for various uses including irrigation, domestic purposes, industries etc. will be around 750 cubmic km by 2000 A D, which will increase to 1050 cubic km by 2050 A D. In order to face the natural calamities like floods and droughts and to meet the growing needs it is necessary to develop the water resources for assured irrigation and drinking water supply. It is with this aim the country has taken up extensive water resources development activities taking the irrigation potential from 22.6 m.ha (pre-plan periods) to 74.57 m.ha. (till 87-88).

Mathematical modelling has became an important tool for hydrologists to deal with various problems of hydrology and water resources. A model aids in making decisions, particularly where data or information are scarce or there are large number of options to choose from. There are a number of ways for classifying hydrologic models. Clark (1973 b) has suggested that many models available in the literature can be classified as deterministic and stochastic. The deterministic models can be further classified according to whether the model gives a spatially lumped or distributed description of the hydrological processes as empirical, conceptual or fully physically based. The black box or empirical models contain no physical based transfer function to relate input to output, in other words no consideration of the physical process is involved. The unit hydrograph model is the best known empirical model. The lumped conceptual or grey box models are formulated on the basis of a relatively small number of components, each of which is a simplified representation of one process element in the system being modelled. Some examples include Standford watershed model, NAM model etc. However, these types of hydrologic models were unable to tackle the problems arising from the adverse impacts of man's activities on hydrologic cycle and hence on water resources development and management.

Besides, the problems arising out of pollution of surface and ground water resources by fertilisers and pesticides, transport of contaminants from waste disposal sites, large scale of deforestation leading to change in high and low flow regimes of rivers, massive soil erosion and consequent reservoir siltation problems etc. led to focussing attention on developing rather sophisticated physically based distributed hydrologic models which can model the hydrologic systems in more precise manner. This process of advancing modelling technique was further aided by rapid advancement in computer technology. Moreover, the cost of water resources development has increased manifold and therefore there is a definite need to adopt new approaches to hydrologic modelling to help optimise planning. Therefore, the need for developing a physically based distributed modelling system developed around the middle of the 1970s.

In view of these developments, three European Organisations (The British Institute of Hydrology, The Danish Hydraulic Institute and The France Consulting Company SOGREAH) pooled their efforts and developed the European Hydrological System (SHE) model which is physically based distributed hydrologic model. The SHE can be applied in various fields problems including irrigation schemes , land use change, water developments, water quality, erosion and sedimentation etc.

In view of increasing activities of water resources development in the country and with the aim to improve India's capacity in formulating water and land resources development strategies, the Govt. of India signed a financial agreement entitled 'Hydrological Computerised Modelling System (SHE)' in June/July 1987 with the European Economic Community (EEC). The project includes transfer of SHE model technology to the National Institute of Hydrology (NIH), Roorkee for its application on hydrological problems all over the country.

As a component of the project, the model was applied to some sub-basins of Narmada river basin which is currently undergoing major developmental activities. These activities are associated with complex hydrological problems and studied would, therefore, be required on following main aspects:

- estimation of runoff from ungauged catchments
- surface water/groundwater interaction
- conjunctive use
- prediction of effects of land use change on water yields
- floods, low flows, soil erosion etc.

In order to start applications of SHE model to intiate studied on above aspects, six sub-basins of Narmada basin ranging from 800-4000 sq.km. were selected. One of the sub-basins selected was SHER sub-basin in respect of which the author has carried out the studies. The following sections give description of the study including a brief description of the model.

2.0 SHE MODEL

2.1 Introduction

SHE model, which is a physically based distributed model can be applied to represent all or any part of the land phase of the hydrological cycle for any geographical area. Separate software modeles have been developed for modelling the individual components of hydrologic cycle namely snowmelt, interception, evapotranspiration, over lands and channel flow, unsaturated and saturated zones. Certain information generated by one module acts as input or boundary condition for other module. The main input and output flow is controlled by the main programme FRAME designed as a central control element. The FRAME is also responsible for the parallel running of the other components, which may have different time steps, and for the exchange of information betweeen them. For efficient setting up of the model for a catchment, service programmes have also been developed at Danish Hydraulic Institute. Such programmes are much helpful in providing the required data for each module as well as for main programme.

2.2 SHE Model Structure

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 different methods. Further, the model 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 respresentations of the partial differential equations of mass, momentatum and energy conservation, or by emirical equations derived from independent experimental research. Spatial distribution of catchment parameters, rainfall input and hydrological response is achieved in the horizontal plane through the representation of the catachment 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.

At present only the primary components of the land phase of the hydrological cycle namely snomelt, canopy interception evapotranspiration, overland and channel flow and unsaturated and saturated sub-surface flow are being modelled using SHE. Secondary details, such as soil macropores and under growth of the vegetation below the major vegetation, are not currently explicitely modelled because of the extra complexity and economic burdon 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 slopes, flow in the unsaturated 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 saturated flow component. Furthermore, the unsaturated flow equations

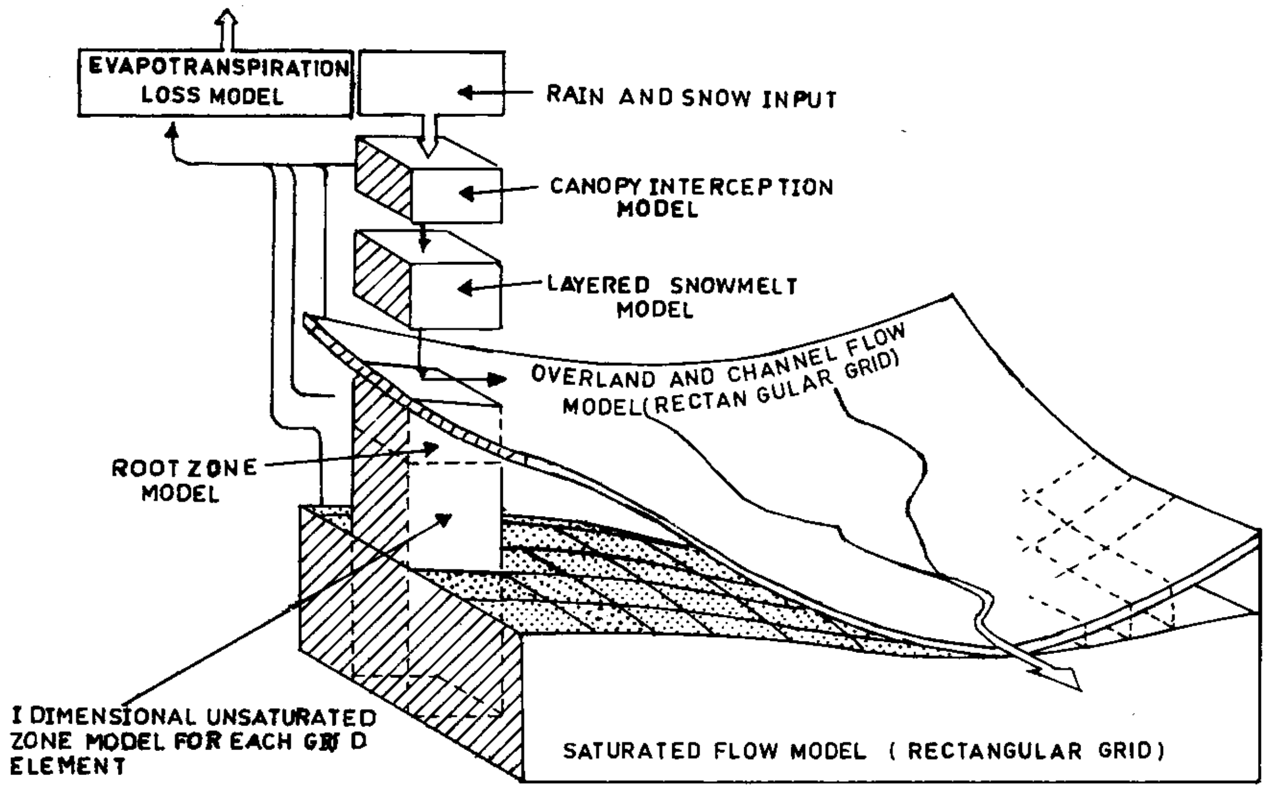


FIG. 1.0-SCHEMATIC REPRESENTATION OF THE STRUCTURE OF SHE MODEL

are solved only for some selected representative columns 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.

2.3 Data Requirements

A large number of parameters describing the physical characteristics of the catchment on a spatially 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 mseasurements supplemented by the 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

1) 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 evapo-transpiration as a function of soil moisture tension, Root distribution with depth, Canopy storage capacity (time varying)
Option Two	Evapotranspiration parameters Root distribution (time varying) Leaf area index (time varying) Ground cover indices (time varying), Canopy storage capacity co-efficient
ii) Input data	Meteorological data

c) Overland and Channel Flow Component

i) Model parameters	Strickler roughness co-efficients for overland and river flows, co-efficient 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/, 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

In order to provide ease in the data collection programme the data requirement for SHE model may be classified in the following categories:

a) Topography:

- Contour maps showing the elevation over the catchment

b) River cross- sections, L-Sections and Roughness parameters

- River and channel cross secations and L-sections for importent reaches
- Information about the width, depth and slope for in different river reaches upstream to the gauging site.
- Roughness parameters for different river reaches as well as for overland flw plane

c) Soil Data

- Soil maps showing the spatial distribution of different types of soil over the catchment
- For each soil type a soil moisture retention curve and the hydraulic conductivities, soil texture analysis, volumetric water content at saturation, field capacity and wilting point

d) Vegetation data

- Vegetation (land use) maps showing the vegetation distribution over the catchment
- Canopy resistance, Aerodynamic resistance, and canopy storage capacity ,or
- For each vegetation type the typical varia- of root depth and leaf area index over the year.

e) Meteorological Data:

- Rainfall data (time series) for all daily and hourly recording stations in the area
- Snow related data, if the basin is snowfed
- Potential evapotranspiration data or daily climatological data (wind speed, humidity, temperature ,radiation or sunshine hours etc.)

f) Hydrological Data:

- Stage and discharge data (time series) for all daily and hourly recording stations.
- Rating curve to convert the stage values into discharge values

g) Hydrological Data:

- A hydrogeological description of the aquifer system
- Aquifer geometry (thickness, boundary conditions etc.
- Aqluifer parameters (leakage, transmissivity, storage co-efficient)
- Ground water level fluctuations
- Ground water management (pumping etc)

h) Man made influence (historical) as well as proposed

- Irrigation
- Reservoir regulation
- Water development
- Details of weirs, if any
- Aforestation or deforestation
- Urbanisation

2.4 Data Preparations

Application of SHE requires the provision of a large amount of parametric and input data organised in an array of data files as has been described in previous section. Flow chart of the SHE programme package is illustrated in fig. 2.0. To each component a data file is attached. The naming of the files is usually given in a way, which identifies the speeific catchment followed by three letters indicating the component.

XXX. FRD	Frame
XXX. SZD	Saturated zone
XXX. UZD	Unsaturated zone
XXX. OCD	Overland and channel flow
XXX. ETD	Evapotranspiration

The input data which are required as time series are arranged in separate set of files. These files are stored in similar way so that these can be read by SHE or read and displayed by the graphical display Routine SHE.GD). In addition a series of data utilised for calibration and validation is

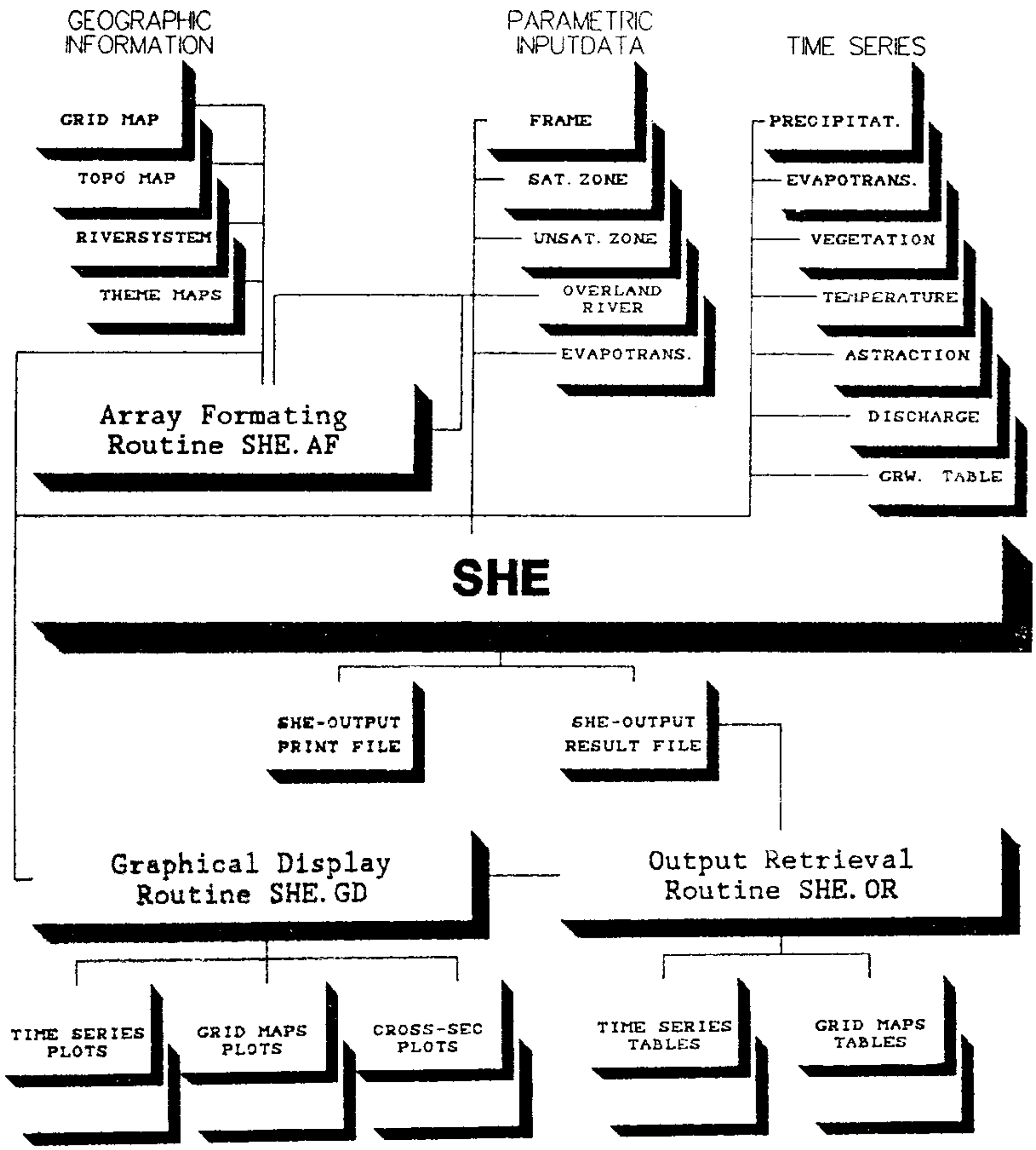


FIG.2.0 : FLOW CHART OF THE SHE PROGRAMME PACKAGE

stored on data files for example, observed discharge values, ground water table elevations etc. The naming of the time series files follows, the component files e.g.:

XXX. PRD	Precipitation Data
XXX. EPD	Potential Evaporation Data
XXX. VED	Vegetation data (leaf area index, root depth).

The model requires a huge amount of spatially distributed data concerning catchment geometry, hydrogeology, land use pattern and meteorological network etc. It is, therefore, a very time consuming and tedious process to prepare the input files for SHE in the particular format required. Especially, the river system set up requires a vast number of data/information concerning levels and cross sections at each link in the computational grid square network to which the river system is approximated.

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 spatially the data on the scale, which has been selected for the numerical computation. In order to facilitate the data preparation, a SHE Array Frmatting Routine (SHE. AF) has been developed. The entire data preparation can be finalised within short time for grid systems comprising several thousands squares. SHE. AF is a very powerful tool in connection with digitalization of the spatial data.

The SHE.AF reads a series of data files containing various arrays of spatially distributed data and transforms these to new SHE data files with the appropriate maps. While running SHE.AF the user will be requested the name of SHE data files and files containing various maps. In order to identify the form of the data, data types are assigned. Some examples are as below:

Identification	Data Type
Grid codes identification	100
Grid codes with corresponding data	101
Grid codes with corresponding data below surface	102
Point values	103
Average grid values	104
Average grid values below surface	105

2.5 Running SHE

Having prepared the required SHE data files, SHE can be run by typing SHE form the home data directory. The user is then requested to type the catchment name which should correspond to the name assigned to the data files. Having successfully completed the SHE run, the results will be both printed and stored on filesin case it has been specified in the frame file. The SHE output printfile (XXX.PRT) contains various results and warning and error messages. It has been recommended to print the initial conditions for checking the data during initial phase of SHE application. Results are stored in a binary file (XXX.RES) which can be retrieved and presented by applying routines SHE.OR and SHE.GD.

2.6 Retrieval of SHE Results

The purpose of the SHE Output Retrieval Routine, SHE.OR is to retrieve data stored on the SHE result file XXX.RES The file is binary and the output data are stored as single values or arrays with one record for each data type.

It is only possible to retrieve a particular data from SHE Result file, if specified in the SHE Frame File that the same data type should be stored in the Result File. There are about 34 types of various output/input data which can be retrieved from XXX.RES File. These data are assigned numbers which can seen from following example:

Number	Input/Output data
1	Net rainfall
2	Actual evapotranspiration
14	Phreatic surface level below surface
22	River flow in specified link

2.6.1 Applying SHE.OR

After a SHE-run, the relevant data are retrieved by running the SHE.OR. The user types: SHE.OR on the home data directory and a suite of questions appears on the screen. Data can be retrieved as a time series for a specified period or as a map at a fixed time.

2.7 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 directly be applied for display of in data to the SHE. In case SHE results are plotted, the concerned data should be stored temporarily after retrieval on a datafile which then is read by SHE.GD. The routine can be used to present ttime series, grid map data and cross section data. The SHE.GD can run interactively by typing SHE.GD and uses the SHE-standard data format. While running SHE.GD, first the plot type for time series, grid plot or cross section plot is required, the detailed data requirements to produce the different types of plots can be seen in the USER's Guide and Documentation of SHE. There is also provision to prepare coloured plots, provided necessary software and hardware facilities are available.

2.8 Need for Field Investigations

As has been described SHE is a physically based distributed hydrologic model nd it needs evaluation of realistic parameter values representing the hydrologic system. The model includes representation of overland flow, evapotranspiration, unsaturated flow, saturated flow and requires realistic values of vegetation and soil parameters. Besides for overland flow and channel flow, values of Strickler co-efficient are required to be evaluated as existing under the real conditions. The vegetation parameters mainly include variation of leaf area index and root zone depth values with crop growing stages. Based on the experience of working with SHE, it has been found that the soil parameters are most sensitive to the simulation results. It is therefore, field investigations are required to be carried out in the basin being modelled to evaluate the soil parameters. A brief description of various field investigations to be done is as below:

2.8.1 Particle Size Analysis

The distribution of particle size often referred to as texture of soil is an important information about the soil which needs to be evaluated. Once the texture of soil is known then other physical properties like moisture retention characteristics, soil moisture constants, bulk density etc. can be estimated based on published information. Two techniques are generally used in this analysis to separate the soil particles into particle-size ranges. Coarse particles (sands and gravels) can be separated with mechanical sieves. The distribution of fine particle sizes (silts and clays) are determined by uniformly dispersing the soil in water and measuring how quickly the particles fall in the mixture. In this exercise, a hydrometer is used to measure the fall rate which can be related to particle size by Stokes' equation. Based on the proportions of sand, silt and clay, the texture of soil can be determined using the texture traingle (U.S.D.A., 1951 Handbook No. 18, Soil survey manual, p.503).

2.8.2 Soil Water Holding Capacity and Soil Moisture constants

Soil, due to the geometry of its pore spaces between the soil particles, has the capacity to hold water. This property allows the soil to retain precipitation or irrigation water in the root zone to be used by plants over time. The soil's porosity, pore size distribution and capillary pressure of water in the soil determines the amount of water that can be held by a particular soil type. The relationship between soil moisture tension and amount of soil moisture is referred to as soil moisture retention curve. The model requires evaluation of saturated moisture content, field capacity, wilting point and soil moisture retention curve. The saturated moisture content is equal to the porosity of soil. The field capacity represents the water content at which the moisture level in the soil begins to remain relatively constant as the capillary pressure continues to increase. In the field, field capacity is defined as the water which remains in the soil after the soil has drained to deep water table and is considered equivalent to moisture content at 1/3 bar of capillary pressure. The permanent wilting point is the moisture content at which plant will permanently wilt. It varies with both plant and atmospheric conditions but being primarily dependent on the energy status of the soil water it is usually defined as the soil water content at the capillary pressure equivalent to 15 bars. The available water for plant use is from field capacity to permanent wilting point.

The moisture retention curve for a soil can be developed in laboratory by creating differencial pressure between the soil water and the surrounding air while allowing water to move out of the soil sample. After flow has stopped, the moisture content of the sample can be determined by gravimetric method. By repeating this exercise at several pressures, a moisture retention curve can be developed. A pressure plate apparatus can be used to develope the retention curve in the laboratory. Field capacity of a soil can be determined in the field by saturating a soil and allowing it to drain while restricting evaporation and transpiration from the surface. The soil water content after 2-3 days when gravity draining is complete will give field capacity. The permanent wilting point is corresponding to 15 bar of capilary pressure which can be determined by pressure plate apparatus.

2.8.3 Infiltration Tests

Infiltration is the entry of water into soil through the soil surface. Knowledge of the infiltration characteristics of a soil is basic information required for designing efficient irrigation systems or predicting runoff. The time rate at which water is absorbed by the soil is the infiltration rate. This rate usually decreases over time until or relatively steady basic infiltration rate is asymptotically approached. The decrease is caused by the decreasing capillary pressure of the soil as it becomes wet. The constant rate is due to the constant gravity force, the other component of the driving force. Several methods can be used to determine the infiltration characteristics of a soil under field conditions. Use of cylinder infiltrometer is most common in field to measure infiltration rate. However, two types of problems are encountered in infiltrometer tests, one is that the soil may be disturbed when the rings are driven into the ground and second is that the ponded water may not duplicate real field conditions.

2.8.4 Auger Hole Test

The Auger hole method is a quick and simple field technique with minimal equipment requirements for determining hydraulic conductivity of porous media below a water table. The method basically entails pumping or bailing out a hole which extends below the water table and measuring how quickly the hole refills. There exists a particular relationship between hydraulic conductivity and rate of water rise in the auger hole. The rate of rise of water in the auger hole can be observed and with the help of the relationship the hydraulic conductivity can be calculated.

2.8.5 Permeability Tests

The measurement of hydraulic conductivity of soil in the laboratory can be done with the help of permeameters. Two types of permeameters are generally used ,a constant head, and a falling head permeameter. Both measure the one dimensional flow of water through a column of soil. The standard Darcy's equation is used to calculate hydraulic conductivity with known values of flow and hydraulic gradient. In the constant head permeameter, the water flows through the soil sample under constant head while in falling head permeameter, the water flows through the sample with the water head falling with time. The volumes of water flowing through the sample is recorded per unit time and using Darcy's law the hydraulic conductivity is calculated.

2.8.6 Soil Moisture Profile

The SHE model has capability to model the soil moisture profile in the unsaturated zone. In order to validate the results it is required to have idea of soil moisture variation in the soil profile. For this purpose some typical measurements of soil moisture profile can be done in the area being modelled. The soil samples at different depths can be collected and the moisture content can be found using gravimetric technique or using instruments like infrared moisture meter, neutron probe etc. The measured profile can be used to validate the results of simulation by the model.

2.9 Other Applications of SHE Model

Since its development the SHE model has been used for carrying out different studies in a number of countries. Some of these applications include studies in Denmark, U.K., Thailand, Zimbabwe etc.

In Thailand, the SHE model was used to quantify the hydrological behaviour and effects of land use changes on the hydrological regime of small and medium sized catchments. The catchments were located north-east of capital city Bangkok. The land use change study was done with two catchments namely Khlong Yang and Khlong Samo Pun which were calibrated earlier using streamflow data of wet season and observed well observations. The simulated response corresponded well with the existing hydrologic regime of the catchments. In Denmark, a comprehensive R&D programme was initiated with an objective to reduce pollution from nutrients and organic matter in agriculture. In this programme SHE model will be used to provide hydrological framework for finding water and nutrient losses from farming areas through the unsaturated and saturated zones. In another application the model is being applied in the county of Aarhus in Denmark for estimating water availability and groundwater development potential. It will also evaluate effects of ground water abstraction on river flows and efforts will also be made to model transport of pollutants from waste disposal. In an application of SHE in upland catchment in mid-Wales in U.K., sensitivity of parameter values was carried out by Bathurst (1986). It was observed that simulation results were sensitive of model grid spacing and time step. Likewise applications of SHE have also been done for various problems of hydrology and water resources in the countries of Zimbabwe, New Zealand.

3.0 GENERAL DESCRIPTION OF STUDY AREA AND DATA AVAILABILITY

3.1 Narmada Basin

As has been mentioned earlier, the SHE model application was done for some sub-basins of Narmada Basin (Fig.3) The Narmada river is the major west flowing river in Central India running through the States of Madhya Pradesh, Gujarat and Maharashtra. The river rises in the Amarkantak plateau in Shahdol district of M.P. at an elevation of 1057 metres above mean sea level. From the source to its outflow in the Arabian sea, the water travels a distance of 1312 km. The basin has a catchment area of 85859 km^2. The river basin is bounded to the north by the Vindhyas, to the east by the Maikala range, to the south by the Satpuras, and to the west by Arabian Sea. The Narmada basin consists of sub-basins of 41 tributories penetrating the catchment in north-south directions. The climate of the basin is humid tropical ranging from sub-humid in the east to semi-arid in the west. The normal annual rainfall of the basin is reported as 1.178 mm. The south west monsoon accounts for nearly 90% of the annual rainfall. The soil survey made in the basin in connection with the various water resources projects indicate that the soils in the basin are mainly black soil. Estimates indicate that about 35% area of the basin is under forest and about 60% under arable land and remaining under grass land, waste land etc . The Central Water Commission, State Irrigation Departments, India Meteorological Department and other organisations have set up gauging/meteorologic stations

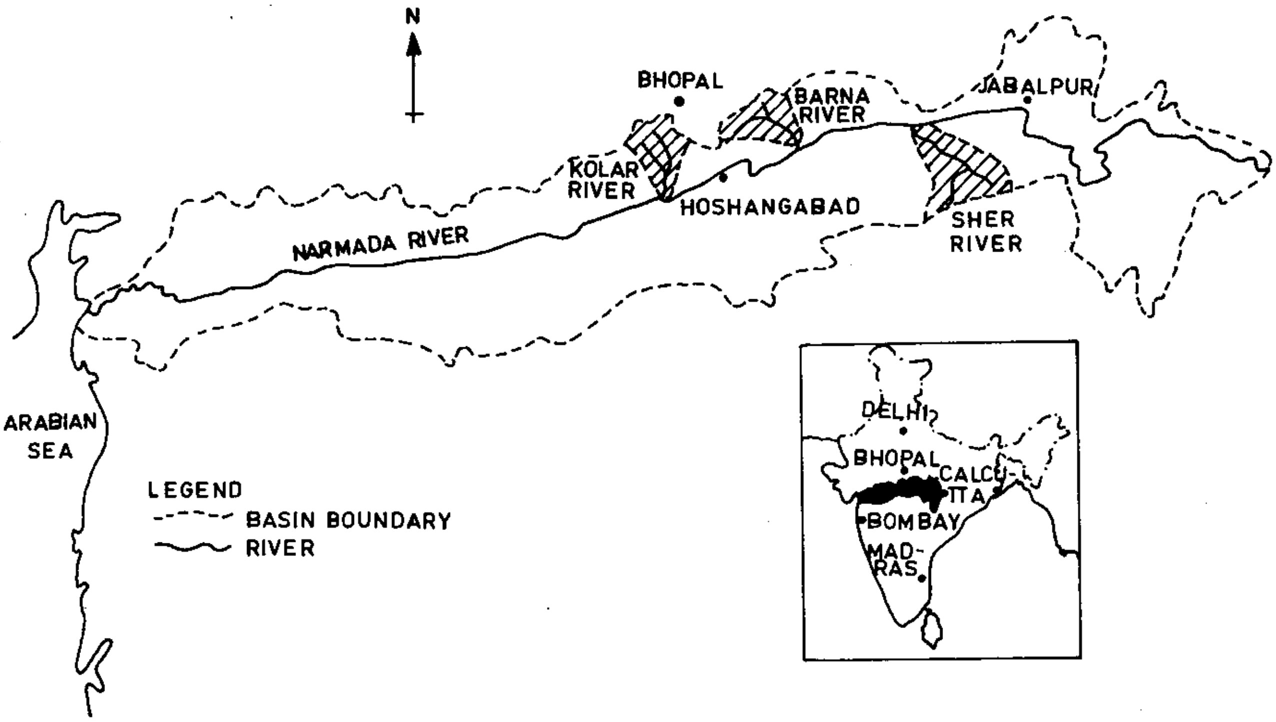


FIG. 3.0 - INDEX MAP OF THE NARMADA RIVER BASIN WITH SUB BASINS FOR SHE MODEL APPLICATION.

to record various hydrometeorological variables in the basin. The river has a huge potential for water resources development and about 29 major, 135 medium and approximately 3000 minor irrigation projects have been identified in the basin.

3.2 Sher Sub-basin

One of the sub-basins identified for SHE application is Sher sub basin.

The Sher river rises in the southern Satpura range in the Durg district of M.P. at an elevation of 600 m above sea level. The catchment area upto the confluence point of Sher with Narmada is about 2900 km^2 . However, the Central Water Commission has established a gauging site upstream of the confluence covering about 1500 sq.km. of Sher catchment. The catchment is identified with hilly terrain and is heavily intersected by streams and rivers. The third and higher order streams in the catchment are ephemoral. The vegetation of the basin consists of forest of medium density, scrub land, spread pockets of cultivation on undulating land and some denuded land. At present there is no major water resources development activity in the Sher basin. The existence of minor tanks in the basin is currently being assessed. A map of basin in the scale of 1:250,000 is given in Fig. 4.0.

As can be seen, the sub-basin lies in the districts of Narsimhpur, Chindwara and Seoni in Madhya Pradesh. The average annual rainfall as recorded in two rainfall stations of the sub-basin, namely Narsimhpur, and Lakhandan is reported

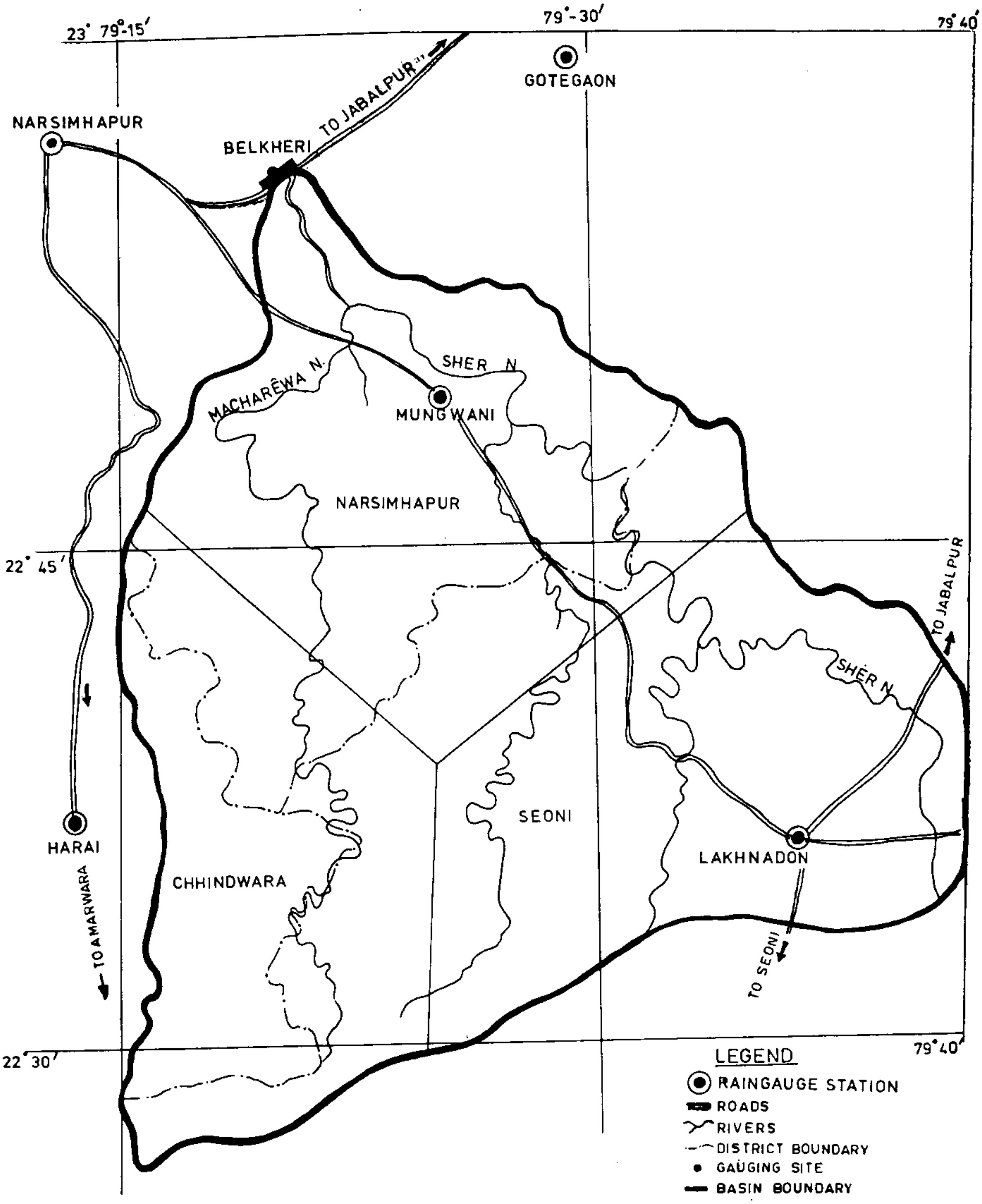


FIG. 4.0-SHER SUB-BASIN (1:250,000)

as 1241 and 1269 mm., respectively.

The river Sher is fairly big tributory of river Narmada. About 40 kms. upstream of the confluence of river SHER with river Narmada, the Narsinghpur-Jabalpur road crosses the river Sher. At this point the Belkheri gauging site being maintained by the Central Water Commission, is located in Belkheri village which is situated at a distance of 16km. from Narsinghpur on state highway No. 26. The geographic features of the site are as below:

Latitude $22^{0}54'$ 54" N

Longitude $79^{0}20'$ 24" E

In about 20 km. reach of Sher river i.e., between the site Belkheri and the point upto which back water effect of river Narmada affects river Sher, no big nala or river joins this river. The river reach about 600 m upstream of the road bridge has river flow in a fairly straight reach. The river flows within the banks. The flow is confined within the low banks and there is only a single channel even in the lean season at the site. The height of the left bank is about 14m. on the left and about 12 m. on the right bank. The left bank is somewhat steep but the right bank is gently sloping above the height of the normal flood, below which it is steep. The width of the river between left and right bank is about 103 m between foot to foot and 131 m between normal high banks. The bed configuration is fairly flat.

3.3 Data Availability:

The SHE model carries out simulation of all aspects of land phase of the hydrologic cycle. Therefore, a variety of data are required for simulation which calls for evaluation of a large number of parameters and their spatial distribution The various types of major data as needed for the model are listed below:

i) Rainfall ii) Discharge iii) Evaporation iv) Seasonal well observation v) Topographic maps vi) Landuse maps vii) Soil and vegetation properties.

The extent of availability of these data is discussed in following sections:

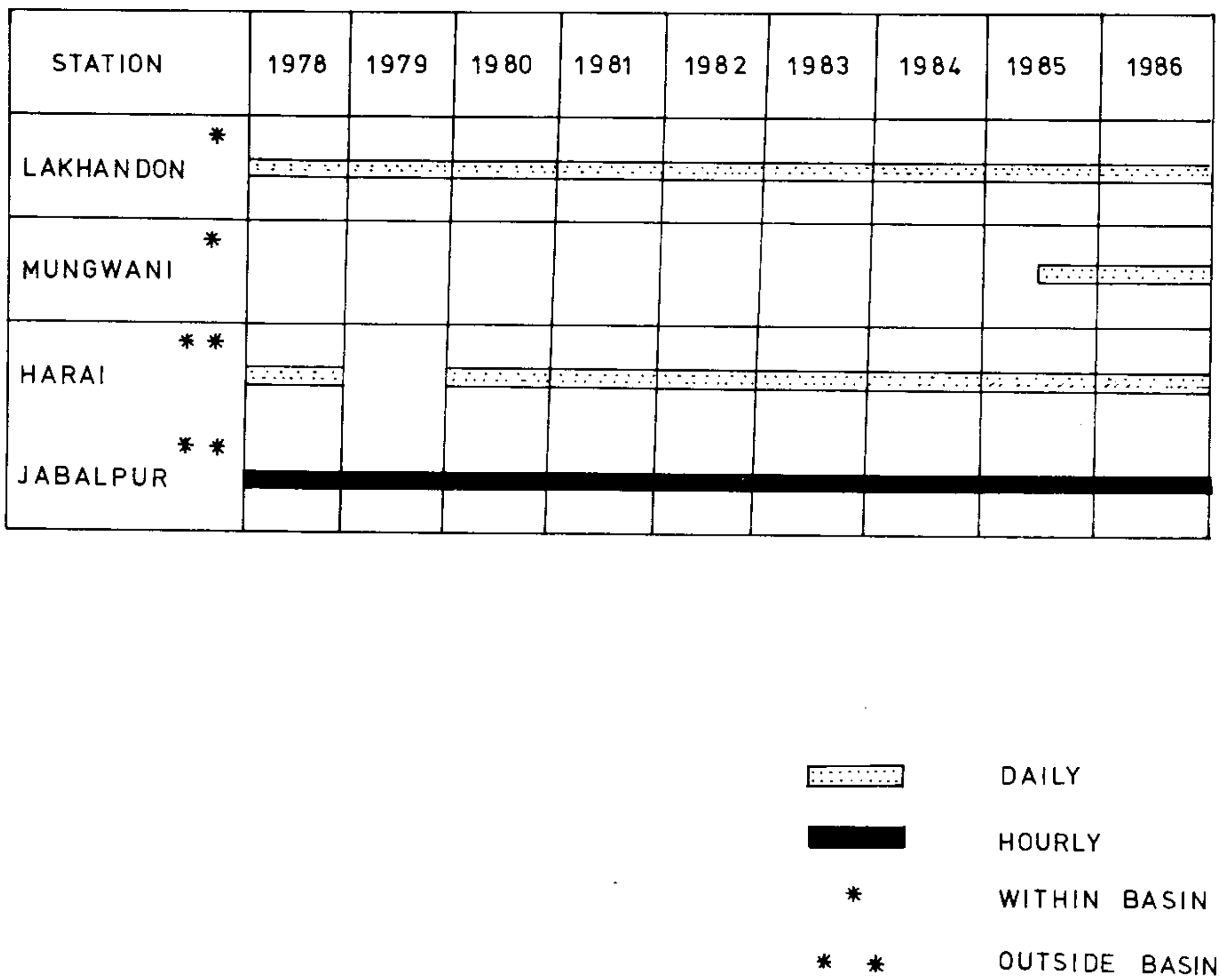
3.3.1 Rainfall:

There are three ordinary raingauges within or near the sub-basin. There is one SRRG reported to the operational at Lakhandon in the sub-basin. The names of these stations alongwith length of period for which data is available is given in Table 1. Despite lot of efforts, the hourly data for Lakhandon could't be collected. Therefore, the hourly data as recorded at Jabalpur station were used for simulation.

3.3.2 Discharge data:

The gauging site at Belkheri is being maintained by the Central Water Commission (CWC) on Sher river. The daily gauge and discharge data at this site are recorded round the year while during monsoon period hourly stage data are recorded. The site is located on the road bridge linking

TABLE 1.0 - AVAILABILITY OF RAINFALL DATA FOR THE SHER SUB-BASIN AND NEIGHBOURING AREA, 1978-1986



Narsinghpur to Jabalpur. The discharge data availability status has been indicated in Table 2. The data has been collected from the office of CWC in Bhopal.

3.3.3. Evaporation:

The daily evaporation data available from the meteorological station in Jabalpur has been used for Sher sub-basin. The daily data of evaporation from 1978-88 are available.

3.3.4. Seasonal Well Observations:

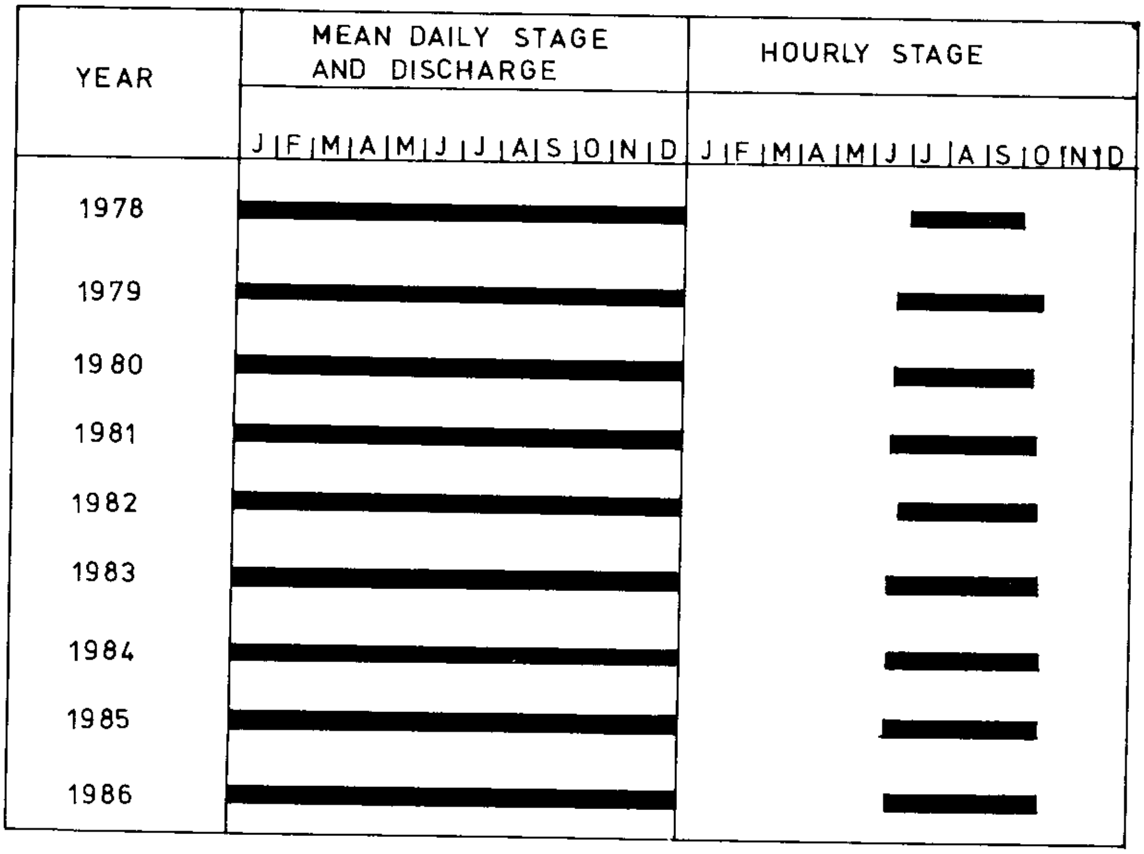
The ground water survey organisations of M.P. Irrigation Department maintains observation wells in all districts for carrying out regular monitoring of ground water status of the state. The location maps of observation wells were collected from all three relevant districts of Seoni, Chindwara and Narsinghpur from the ground water survey office in Bhopal and district office in Narsinghpur. The data of well fluctuations for last 8-9 years were obtained for selected observation wells in the districts which fall in the basin.

3.3.5 Topographic Maps:

The topographic maps of the basin were got prepared using toposheets as issued by the Survey of India. The toposheets required are as listed below:

Scale	Toposheet No.
1:250,000	55 N
1:50,000	55 N1, N2, N5, N6, N7, N10

TABLE 2 AVAILABILITY OF STAGE AND DISCHARGE DATA FOR SHER SUB-BASIN AT THE BELKHERI GAUGING STATION 1978 – 1986



* OBTAINED FROM UP TO THREE DIRECT GAUGING EACH DAY

* * OBTAINED FROM CONTINUOUS CHART RECORD

3.3.6 Land Use Map:

The Narmada Valley Development Authority (NVDA) has prepared landuse map of Upper Narmada basin which includes the Sher sub-basin. This map was collected from NVDA and a land use map for the sub-basin was prepared. The following types of land use were considered for the map: Dense forest, Medium Forest, Agriculture and Wasteland. Fig. 5 shows the land use map of the sub-basin on scale 1:250,000. The percentage areas of dense forest, medium forests, agriculture and wasteland are 26.2, 39.9, 30.9 and 3.0%, respectively.

3.3.7 Soil Map:

Based on the information as supplied by NVDA, the soil map of the sub-basin was got prepared in the scale of 1:250,000. It was assumed that the soil has varied with the type of land use.

3.3.8 Gauge Site Sections & Rating Curve:

The X-section at the gauging site was obtained from the office of CWC at Bhopal. Based on the daily gauge and discharge values, rating curves were developed for changing hourly gauge values to hourly discharges. Two sets of rating curves were fitted for upper and lower values of gauges.

3.3.9 Soil & Vegetation Properties:

The properties in respect of the soil and vegetation of the sub-basin were derived from the published reports and available literature. The soil moisture retention curve was developed based on data of ICAR (1984). The time variant

LAND-USE-MAP--SHER-BASIN-GRID-SIZE-2Km

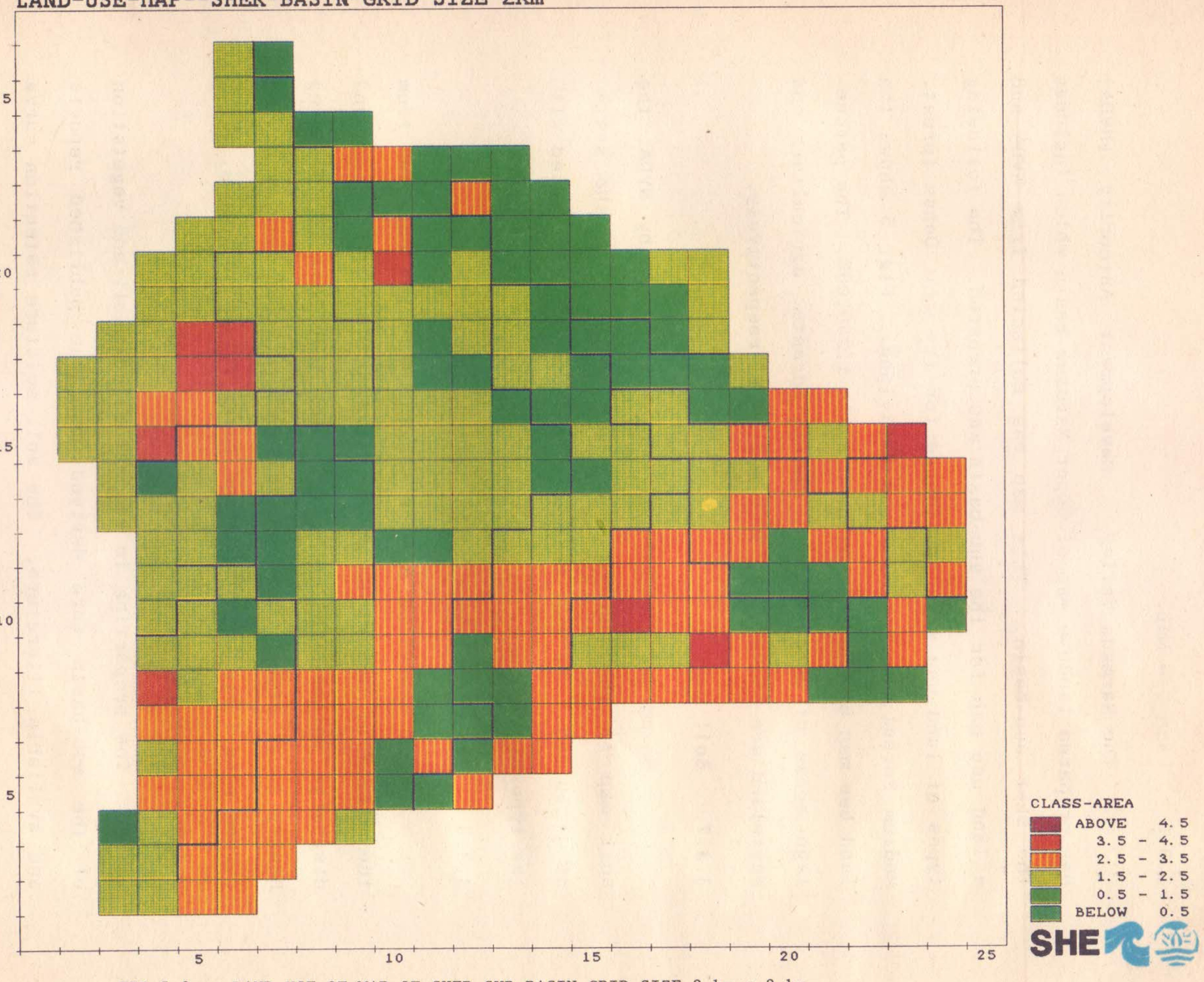


FIG.5.0 : LAND USE OF MAP OF SHER SUB-BASIN GRID SIZE 2 km x 2 km.

leaf area index values for various kinds of landuse were derived based on general experience and published information. The soil moisture retention curve and temporal variation in leaf area index are shown in Fig. 6 (A & B).

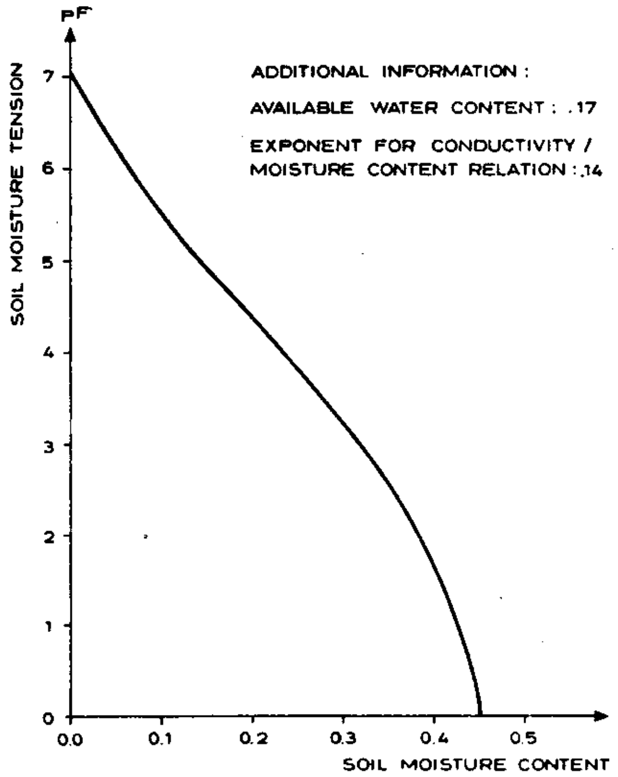


Fig. 6(A) : Soil moisture retention curve used for all soil types in the simulations. Based on data from ICAR (1984).

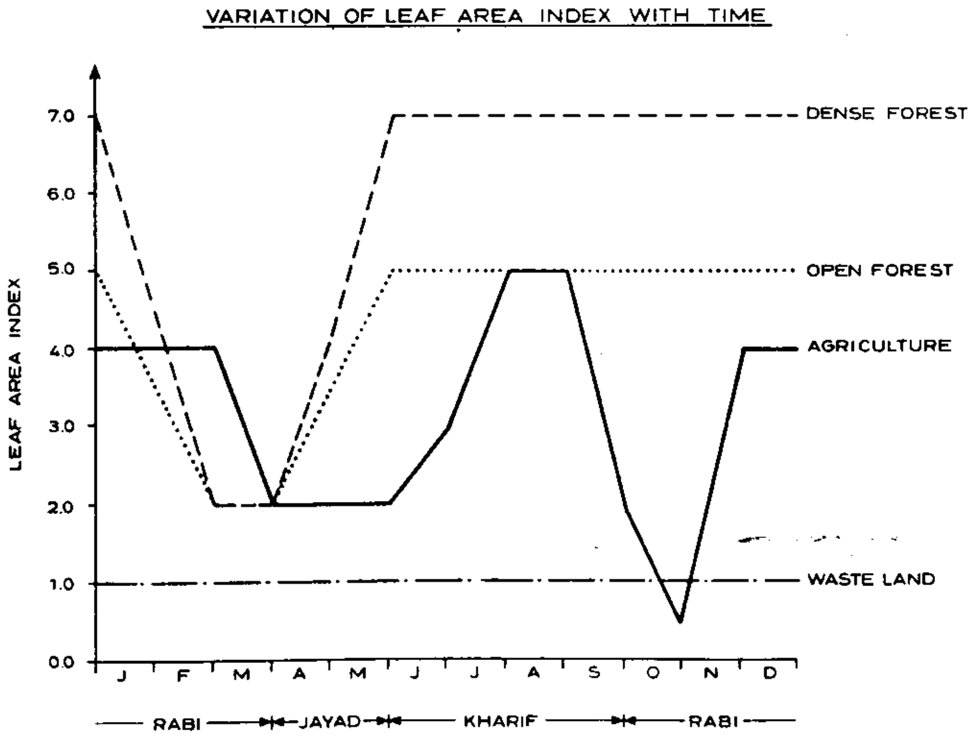


Fig. 6(B) : Time variation of leaf area index for the four land-use types used in the simulations.

4.0 DATA PROCESSING & PREPARATIONS:

The detail of processing and preparations of various kinds of data is given in following sections:

4.1 Rainfall:

As can be seen from Table 1, there are three ordinary and one recording raingauge station in the basin. Due to non-availability of hourly data of the recording station, an attempt was made to see the correlationship between the daily rainfall recorded at yet another hourly station at Jabalpur, about 70 km away from site, and the daily rainfall at Lakhandon station at which daily records were available from 1978 till date. The correlation was studied by plotting double mass curve and was found to be satisfactory. In view of this the daily rainfall records of three raingauge stations, namely, Lakhandon, Mungwani and Harai were converted into hourly value using hourly data of Jabalpur station. The daily data at Mungwani station were available from 1985 onwards since the station was established that year. The data for rest period were generated using distance power method. The thessien weights of each station were established and a file 'LMH.PREC' was prepared giving relative weightage of rainfall over the basin.

4.2 Discharge data:

The flow records were processed to develop rating curve for converting hourly gauge values to hourly discharge values. It was decided to use two sets of rating curves for lower and upper values of gauge records. Using the rating curves, the hourly discharge values were computed for the entire length of simulation period. The discharge values were converted into mm of depth monthwise for comparison with computed values. The peak and time to peak was also computed out of the observed series of discharge values.

4.3 Evaporation:

The daily evaporation data of Jabalpur station was converted into hourly values as needed for SHE format.

4.4 Topographic Maps:

Using the toposheets, the basin maps were prepared in the scales of 1:250,000 and 1: 50,000. With the use of toposheets, elevations at each node point of 500 x 500 m square grids were read throughout the basin and a file TOP.500 was prepared. Using the information at 500 x 500 m sq. grids, the elevations for 1000 x 1000 m and 2000 x 2000 m square grids were established.

4.5 Land Use Map:

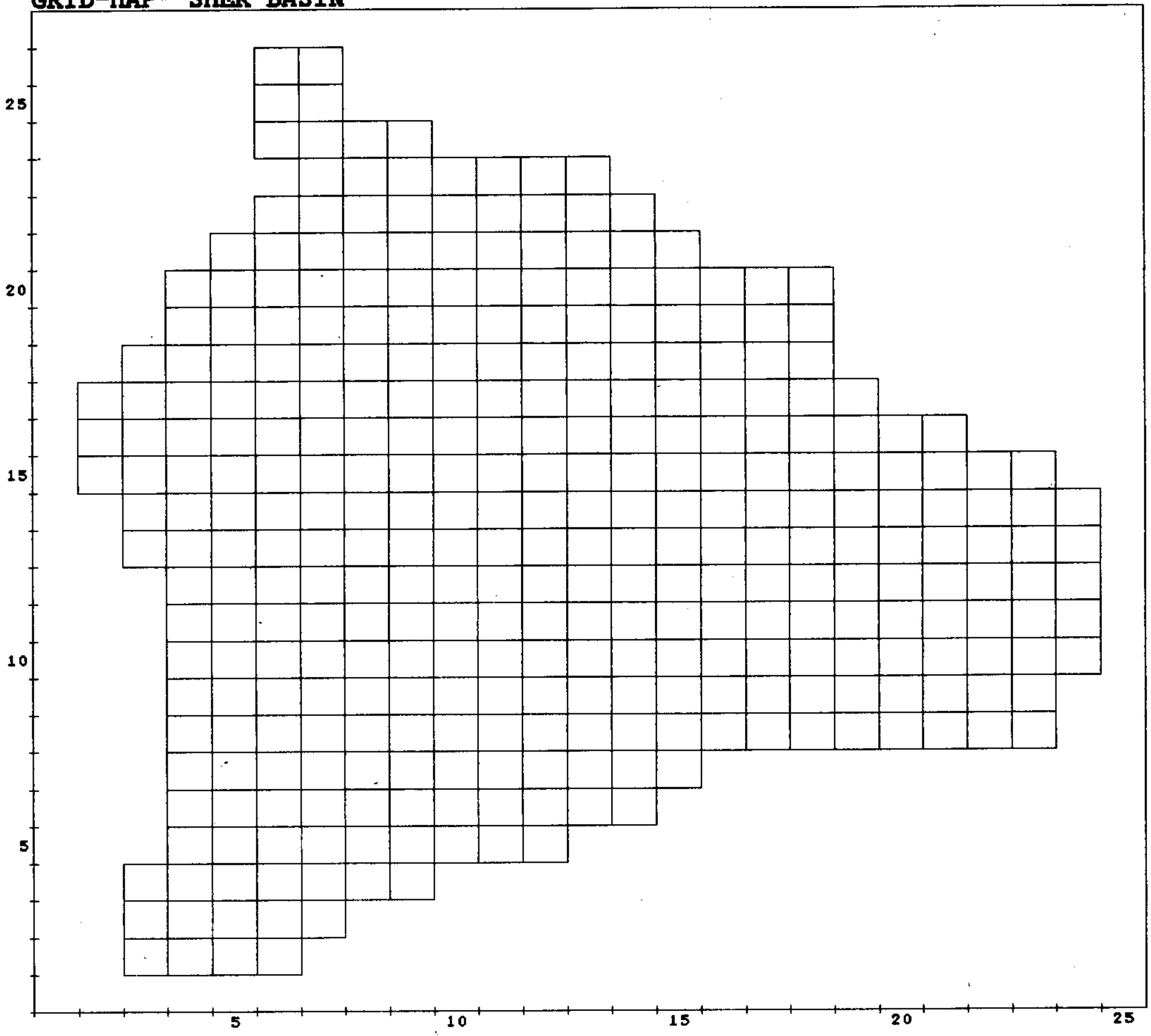
A file LAND 2000 was prepared to show type of land use within the basin. The numerical codes used are 1,2,3 and 4 for Agriculture, Dense forest, open forest and waste land respectively (Fig. 5.0).

4.6 Model Set Up:

As has been mentioned, computational grids in the size of 500 x 500 m were prepared initially all over the sub-b;asin. Having prepared all such maps, the model was attempted to run on 500 x 500 m square grids. This resulted in enormous computational requirements. Therefore, the set up was then prepared for 1 x 1 km and 2 x 2 km grid sizes. Ultimately, the grid size of 2 km x 2 km was chosen for calibration, validation and sensitivity runs. The representation of the sub - basin on 2 x 2 kms grid size is shown in Fig. 7. In the model, the rivers are set up along the boundaries of the grids. A service programme SHE. AF was used for setting up rivers which needed information about the coordinates of the points set up along straightened river channels, bank levels, strickler roughness coefficient for channels and river cross sections. The river set up on the sub-basin in 2 x 2 kms grid size is shown in Fig. 8.0.

In order to set up the land use and soil depths within the basin, a grid map was prepared with the help of the basin grid map and different codes were assigned of different grids corresponding to land use and soil type of the representative grids. Based on the data of ground water table as observed from the various observations wells located in the basin, the initial position of water table was specified. In the model computations, unsaturated zone component takes considerable CPU time. In order to avoid this, the calculation of unsaturated zone are done only in some representative columns. These columns are decided based on a simple run of SHE. The computations after selecting some representative column get significantly reduced and the results of computatins of these calculation columns are transferred

GRID-MAP--SHER-BASIN



GRID-SIZE--2Km

FIG.7.0 : GRID MAP OF SHER SUB-BASIN, GRID SIZE 2 km x 2 km.

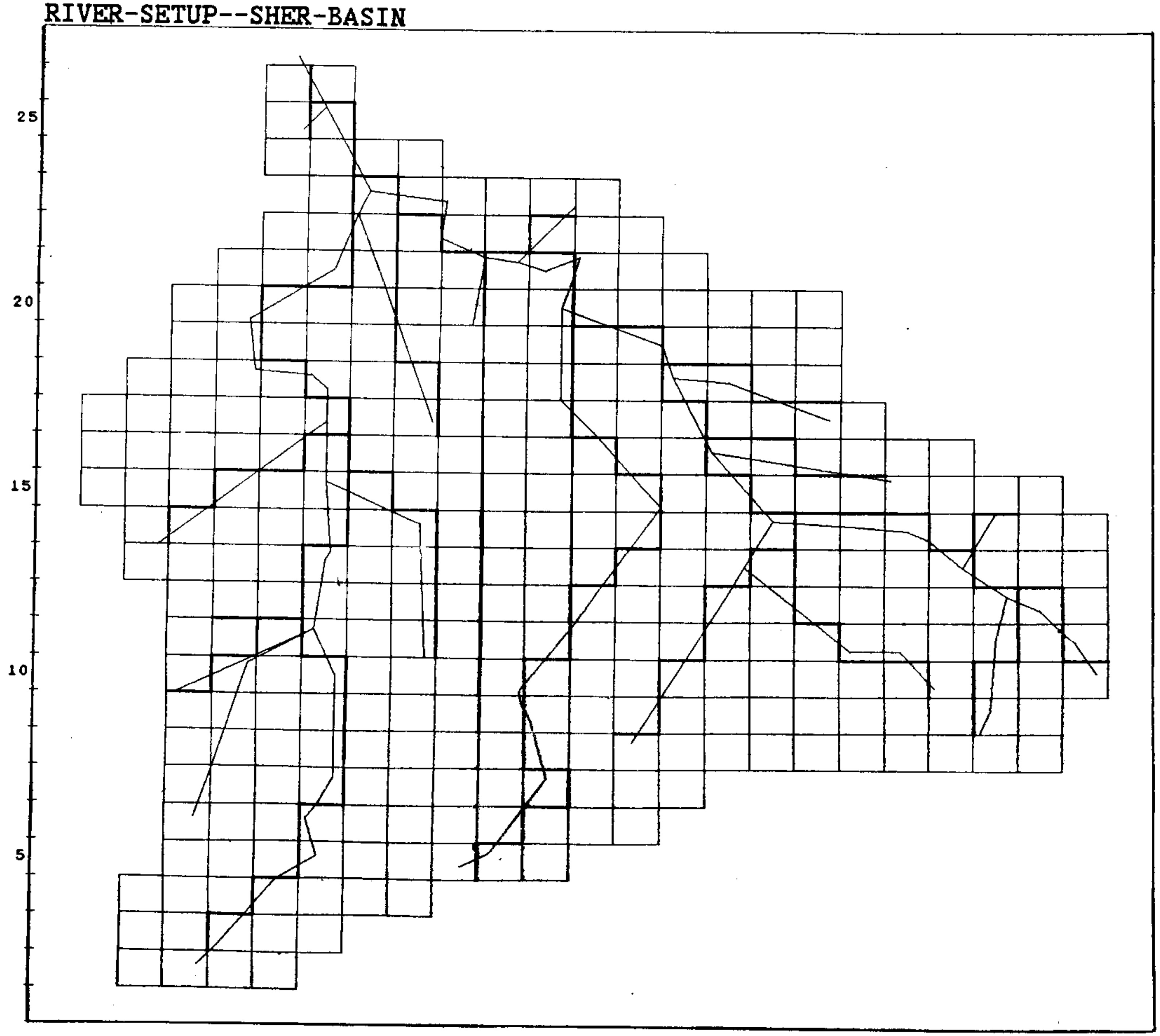


Fig. 8.0 : River setup for Sher sub basin, grid size 2 km (scale 1:250,000)

to other corresponding columns. In order to classify the columns, variability in land use, soil type, meteorological inputs and ground water fluctuation are taken into account. Having carried out the classification, the number of columns where ultimately the UZ calculation will take place are decided. In the case of SHER sub basin 16 nos. of calculation columns were taken up. Lastly, the SHE array formatting routine which requires information of land use, soil type, depth of soil, initial ground water conditions, raingauge network, river set up was used to set up the model according to the format as required for different components of SHE model.

4.7 Water Balance Studies

In order to see the correctness of observed input it is worthwhile to carry out water balance exercise for the basin. This exercise was performed for monsoon months from 1978-86. The runoff coefficient was determined by dividing observed runoff values by average rainfall over the basin. Also, the percentage values of recharge to groundwater based on rainfall minus runoff minus actual evaporation were computed for monsoon season of each year. The values of runoff co-efficients in general have ranged between 0.2 to 0.65 with some exceptions of unrealistic values. On seasonal basis the recharge percentage was computed to range between 14-21% with most values being close to 18% for all years except years 1978 and 1984. The computations are shown in Table 2.0 (A).

Table 2(A) : Water Balance Calculations for SHER Sub-basin

Year	Month	Rainfall (P)	Obs. Runoff (Q)	Runoff Coeff. (Q/P)	Potential	S=P-Q-.7E	$\frac{S}{P}$ x 100 (on seasonal basis)
1978	June	155.57	0.0	-	236.9	-	
	July	326.36	149.07	0.45	109.5	100.59	1.5
	August	309.20	283.68	0.91	72.4	-25.1	
	September	55.99	42.44	0.75	111.3	-64.4	
1979	June	134	13.0	0.097	302.0	-90.0	
	July	328	24.9	0.076	144.9	201.7	18.5
	August	302	144.09	0.48	123.8	71.2	
	September	93.0	8.19	0.09	153.9	-22.9	
1980	June	209.02	29.15	0.14	222.0	24.5	
	July	202.04	57.45	0.28	91.1	53.5	18.23
	August	389.64	257.23	0.66	92.3	67.8	
	September	97.68	97.73	-	140.7	-	
1981	June	272.7	67.08	0.24	336.7	-30.08	
	July	328.8	90.74	0.28	116.1	156.0	18.01
	August	254.3	162.33	0.63	121.5	6.86	
	September	182.3	50.03	0.27	111.6	54.2	
1982	June	150.05	3.34	0.02	280.3	-49.4	
	July	194.3	17.63	0.09	198.6	38.0	14.0
	August	277.99	124.74	0.45	69.0	104.9	
	September	313.73	198.09	0.63	110.7	38.3	

TABLE 2(A) CONT.

Year	Month	Rainfall (P)	Obs.Runoff (Q)	Runoff Coeff. (Q/P)	Potential	S=P-Q-.75	$\frac{S}{P} \times 100$ (on seasonal basis)
1983	June	131.39	8.67	0.07	302.2	-88.8	
	July	328.54	73.17	0.22	42.6	176.6	16.84
	August	306.00	158.59	0.52	110.8	69.6	
	September	396.54	302.15	0.76	80.0	38.4	
1984	June	91.96	6.59	0.07	283.5	-112.9	
	July	216.44	32.2	0.15	125.4	96.4	-
	August	671.66	638.84	0.95	74.6	-19.3	
	September	49.84	31.27	0.63	102.7	-53.3	
1985	June	95.84	19.95	0.20	237.3	-90.2	
	July	317.02	72.23	0.22	95.6	177.9	21.2
	August	352.61	216.58	0.61	72.7	84.5	
	September	110.81	23.36	0.21	105.0	13.94	
1986	June	186.49	8.79	0.05	246.9	4.9	
	July	402.14	131.58	0.33	101.4	199.7	18.8
	August	226.12	134.84	0.34	101.9	19.9	
	September	26.65	3.85	0.15	127.0	-66.1	

5.0 CALIBRATION AND VALIDATION

As has already been mentioned in earlier section that hourly rainfall data in case of SHER sub–basin was not available within the basin, only data of three daily raingauge stations was available. Therefore, it was decided to distribute the daily rainfall into hourly rainfall based on the hourly data recorded at another hourly station at Jabalpur. The length of data availability was from 1978 to 1986. Therefore, it was decided that for calibration runs, the data from 1978-82 be used and for validation runs the data of remaining years for 1983-86 be used.

From the detailed review of literature and the experienced gained from running the SHE model and during the field visits, various trails were attempted to decide the parameters which include strickler roughness coefficient for overland and channel flows, soil conductivities for saturated and unsaturated zones, representàtive of cracks in soils, soil depths and initial water table position. Though the SHE model is a physically based distributed model ideally it should not require any calibration for selection of parameters values, however, due to non availability of actual parameters values under field conditions and the element of lumping being introduced due to larger grid size (2 x 2 km) it became necessary to select the parameters values for simulation runs.

Based on published information a range of parameter values was established. For example, strickler coefficient for overland flow was changed from 1-10. A strategy was adopted to change parameter values one by one during the calibration phase. A number of calibration runs were tried with variations in strickler coefficient, hydraulic conductivities, etc. The parameters were tuned up for the closest results in respect of observed peak and volumes (from June-Oct. each year). Somehow, the trials did not show encouraging results. The absence of realistic field data about spatial variability of soil depths and initial phreatic tables within the sub basins, attempts were also made to run the model by changing these values also. These attempts also did not yield significant improvements in the results.

During the calibration runs it was observed that by increasing the strickler roughness coefficient for over-land flow the runoff volumes get increased and peaks are also affected. By reducing the soil depths the runoff volumes also tend to increase due to less storage in the soil column. The saturated zone hydraulic conductivity affects the baseflow as also thickness of the saturated zone. The soil cracks and retention storage have effects on initial peaks as has been observed.

Despite several attempts better results could not be obtained. Then based on various calibration runs a set of parameter values was selected. The result of calibration and parameter values are given in Table 4 and 3 respectively.

Table 3.0 : Details of Soil and Vegetation Parameters and Distributions used in the Simulations of Sher sub-basin

Land Use	% of Basin covered	Soil Type	Soil conductivity (m/day)		Saturated soil moisture content (m**3/m**3)	Soil Depth (m)	Initial depth to phreatic surface (m)	Vegetation root zone depth (m)
			Unsaturated zone	Saturated zone				
1	26.2	1	0.01	10.0	0.45	8.0	6.0	0.6
2	39.9	2	0.01	10.0	0.45	3.0	2.5	2.0
3	30.9	3	0.1	10.0	0.45	2.5	2.0	1.5
4	3.0	4	0.04	10.0	0.45	1.5	1.3	0.5

Land use 1 = Agriculture
2 = Dense forest
3 = Open forest
4 = Waste land

TABLE 4 - MONTHLY WATERBALANCE FOR SHER BASIN UP TO BELKHERI - CALIBRATION RUNS

YEAR :- 1978

ALL VALUES IN MM.

MONTH	RAINFALL	OBSERVED RUNOFF	COMPUTED RUNOFF	POTENTIAL EVAPORATION
JUN	155.57	0.0	4.09	236.9
JUL	326.36	149.07	65.66	109.5
AUG	309.20	283.68	145.64	72.4
SEP	55.99	42.44	18.03	111.3
OCT	0.00	0.00	7.63	126.3

OBSERVED MAXIMUM PEAK FLOW (M**3/SEC) = 1392.0 CORRESPONDING TIME TO PEAK (HRS) = 2571.0

COMPUTED MAXIMUM PEAK FLOW (M**3/SEC) = 2277 CORRESPONDING TIME TO PEAK (HRS) = 2577

YEAR :- 1979

MONTH	RAINFALL	OBSERVED RUNOFF	COMPUTED RUNOFF	POTENTIAL EVAPORATION
JUN	134.0	13.0	8.19	302.0
JUL	328.0	24.9	57.38	144.9
AUG	302.0	144.09	170.93	123.8
SEP	93.0	8.19	6.33	153.9
OCT	2.0	2.67	4.7	170.4

OBSERVED MAXIMUM PEAK FLOW (M**3/SEC) = 2321.0 CORRESPONDING TIME TO PEAK (HRS) = 11167.0

COMPUTED MAXIMUM PEAK FLOW (M**3/SEC) = 3328 CORRESPONDING TIME TO PEAK (HRS) = 11157

TABLE 4 CONT.

YEAR :- 1980

MONTH	RAINFALL	OBSERVED RUNOFF	COMPUTED RUNOFF	POTENTIAL EVAPORATION
JUN	209.02	29.15	3.67	222.0
JUL	202.04	57.45	2.87	91.1
AUG	389.64	257.23	171.80	92.3
SEP	97.68	97.73	6.44	140.7
OCT	0.00	5.03	2.69	122.6

OBSERVED MAXIMUM PEAK FLOW (M**3/SEC) = 3412.0 CORRESPONDING TIME TO PEAK (HRS) = 20426

COMPUTED MAXIMUM PEAK FLOW (M**3/SEC) = 1917 CORRESPONDING TIME TO PEAK (HRS) = 20408

YEAR :- 1981

MONTH	RAINFALL	OBSERVED RUNOFF	COMPUTED RUNOFF	POTENTIAL EVAPORATION
JUN	272.7	67.08	44.59	336.7
JUL	328.87	90.74	77.59	116.1
AUG	254.29	162.33	75.03	121.5
SEP	182.34	50.03	37.31	111.6
OCT	0.65	10.26	10.32	112.5

OBSERVED MAXIMUM PEAK FLOW (M**3/SEC) = 1367 CORRESPONDING TIME TO PEAK (HRS) = 27905

COMPUTED MAXIMUM PEAK FLOW (M**3/SEC) = 1098 CORRESPONDING TIME TO PEAK (HRS) = 28839

TABLE 4 CONT.

YEAR :- 1982

MONTH	RAINFALL	OBSERVED RUNOFF	COMPUTED RUNOFF	POTENTIAL EVAPORATION
JUN	150.05	3.34	5.81	280.3
JUL	194.30	17.63	2.95	198.6
AUG	277.99	124.74	33.18	69.0
SEP	313.73	198.09	139.22	110.7
OCT	17.44	9.14	0.00	120.5

OBSERVED MAXIMUM PEAK FLOW (M**3/SEC) = 2753 CORRESPONDING TIME TO PEAK (HRS) = 38270

COMPUTED MAXIMUM PEAK FLOW (M**3/SEC) = 1181 CORRESPONDING TIME TO PEAK (HRS) = 38133

As has already been mentioned, the period from year 1983-86 was used for validation of the model. The results of calibration phase however, were not very satisfactory. Even then based on the chosen set of parameters the model was run for a period from 1983-86. The results of validation in the form of computed runoff volumes and computed hydrograph peaks are given in Table 5.

6.0 SENSITIVITY ANALYSIS

Sensitivity analysis is generally carried out to evaluate the relative sensitivity of calibration parameters to the simulation results. This analysis is particularly important to examine the relative importance of parameters which significantly affect the simulation results and therefore requires a detailed investigation. During these sensitivity runs, the value of one of the parameters is changed and the response is computed by reference run which is chosen either from the calibration or validation runs. Since SHE model is distributed model, it has capability to model influence of change of parameter values over some specific grids. This capability may be used to evaluate effects of land use changes on simulated response which help in assessing impacts of a partiacular land use on hydrological regime.

In order to carry out the sensitivity analysis, the following runs were taken for the period from 1983-86:

Case I : Using Calibration parameter values (reference runs)

Case II : Doubling strickler coefficient

Case III: Doubling the UZ conductivity

Table: 5 - Monthly Water Balance for SHER Basin upto Belkheri Validation Runs

YEAR 1983

ALL VALUES IN MM.

Month	Rainfall	Observed Runoff	Computed Runoff	Potential Evaporation
June	131.39	8.67	9.97	302.2
July	328.54	73.17	72.75	112.6
August	306.00	158.59	90.07	110.8
Sept.	396.54	302.15	226.70	80.0
Oct.	58.45	51.15	23.24	112.7

Observed Maximum Peak Flow (M^3/Sec) = 2227 Corresponding Time to Peak (Hrs) = 3136

Computed Maximum Peak Flow (M^3/Sec) = 2486 Corresponding time to Peak (Hrs) = 3085

Table - Monthly Water Balance for SHER Basin upto Belkheri

YEAR 1984

Month	Rainfall	Observed Runoff	Computed Runoff	Potential Evaporation
June	91.96	6.59	3.923	283.5
July	216.44	32.2	11.217	125.4
August	671.66	638.84	374.77	74.6
Sept.	49.84	31.27	9.004	102.7
Oct.	2.28	13.09	7.19	125.6

Observed Maximum Peak Flow (M^3/sec) = 6616 Corresponding Time to Peak (Hrs) 11415

Computed Maximum Peak Flow (M^3/sec) = 1971 Corresponding Time to Peak (Hrs) 11023

Table5 (cont) Monthly Water Balance for SHER Basin Upto Belkheri

YEAR- 1985

Month	Rainfall	Observed Runoff	Computed Runoff	Potential Evaporation
June	95.84	19.95	7.53	237.3
July	317.02	72.23	39.39	95.6
August	352.61	216.58	175.37	72.7
Sept.	110.81	23.36	12.71	105.0
Oct.	100.47	33.75	17.40	88.8

Observed Maximum Peak Flow (M^3/Sec) = 2516 Corresponding Time to Peak (Hrs) = 20150

Computed Maximum Peak Flow (M^3/sec) = 1049 Corresponding Time to Peak(Hrs) = 19927

Table: : MonthlyWater Balance for SHER Basin upto Belhheri

YEAR 1986

Month	Rainfall	Observed Runoff	Computed Runoff	Potential Evaporation
June	186.49	8.79	21.75	246.9
July	402.14	131.58	142.71	101.4
August	226.12	134.84	91.59	101.9
Sept.	26.65	3.85	12.52	127.0
Oct.	15.05	2.27		148.5

Observed Maximum Peak Flow (M^3/sec) = 2684 Corresponding Time to peak (Hrs) = 28300

Computed Maximum Peak Flow (M^3/sec) = 1735 Corresponding Time to Peak (Hrs) = 28303

Case IV : By reducing the saturated zone conductivity to 1/2 of its reference run value.

Case V : Without soil crack modelling

The results of these runs are as discussed below and are given in Table 6.

Case II

It can be observed from Table 6, the results reported for Case II, by doubling the Strickler coefficient for overland flow, the peak of the computed hydrograph has increased. The increment has been in the range of 8-33% during various years of simulation. The increase in the volume of simulated response has been observed in some years which is not very significant. This run was taken to see the effects of making the catchment surface more smooth (increasing strickler coefficient) on runoff volume and peak.

Case III

In this case a run was taken by doubling the conductivity in the unsaturated zone. In general, it was observed that this change has resulted in reducing computed peak and volumes. It has been found that reduction in peak was in the range of 6-17% while the volume reduced by about 18% in three out of four years. This was perhaps because of more entry of water into the soil zone, as a result of increased conductivity in the unsaturated zone. The logic of taking this run was to see effects of conductivity in unsaturated zone on overland flow response. An accurate assessment of this parameter is must for reasonable results of simulation of unsaturated zone.

Case IV

In this case the conductivity in the saturated zone was reduced to half. This resulted in lowering marginally the peak and total volume values in some years and otherwise in remaining years. This will actually affect the baseflow. The run was taken to see the impacts of changes in saturated zone conductivity on the flow response of the basin. There has not been much change in the computed volumes of runoff indicating less sensitivity of this parameter.

Case V

A run was taken without introducing crack modelling aspect assuming that before beginning of simulation no cracks were developed in the soil. The comparison of results indicate that the computed runoff volumes were slightly higher than the reference run values, barring exceptions during few months in some years. The seasonal flows were higher by just 1% in year 1984. The idea of taking this run was to see as to how the simulation results are affected if no crack modelling is done.

Table 6 : Sensitivity Runs for Sher sub-basin, monthly volumes and Peak values

Year &	Month	Obs. flows (mm)	Case I	Case II	Case III	Case IV	Case V
			Simulated Flows(mm)				
1983	6	8.67	9.97	12.10	6.89	8.39	11.33
	7	73.17	72.75	82.06	44.24	71.67	69.89
	8	158.59	90.07	88.84	84.69	88.67	90.31
	9	302.15	226.70	218.09	228.75	228.63	225.45
	10	51.15	23.24	21.83	37.95	19.81	22.92
	ΣQ	593.73	422.73	422.92	402.52	417.16	419.2
	QP	2227	2486	3119.58	2527	2459	2497
	TP	3136	3085	2030.99	3085	3085	3085
1984	6	6.59	3.92	3.92	3.726	3.13	3.79
	7	32.2	11.22	11.64	3.57	10.31	17.02
	8	638.84	374.77	383.29	294.55	374.03	377.47
	9	31.27	9.04	8.08	23.67	6.72	6.02
	10	13.09	7.19	6.79	9.93	5.05	6.10
	ΣQ	721,99	406.14	413.72	335.44	399.24	410.4
	QP	6616	1917	2129	1626	1971	1985
	TP	11415	11023	11023	11023	11023	11023
1985	6	19.95	7.53	7.63	5.38	7.25	10.24
	7	72.23	39.39	42.02	10.75	39.75	42.38
	8	216.58	175.37	179.54	145.04	174.26	175.31
	9	23.36	12.71	12.26	14,95	10.37	9.73
	10	33.75	17.40	15.78	30.67	16.01	12.26
	ΣQ	365.87	252.40	257.25	206.79	247.64	249.92
	QP	2516	1049	1149.11	861	1049	1043
	TP	20150	19927	19927	19927	19927	19927

Year	Month	Obs. flows (mm)	Case I	Case II	Case III	Case IV	Case V
					Simulated Flows(mm)		
1986							
	6	8.79	21.75	23.67	6.608	25.3	30.57
	7	131.58	142.7	149.82	106.29	140.7	143.78
	8	134.84	91.59	81.22	96.78	85.95	79.65
	9	3.85	12.52	0.0	10.43	6.09	10.42
	10	2.27	0.239	0.0	0.271	0.165	0.209
	ΣQ	281.33	268.8	254.71	220.45	258.2	264.6
	QP	2684	1735	2315	1619	1742	1732
	TP	28300	28303	24836	24837	24837	28303

NOTE: QP - (Cumecs)

TP - (Hours)

7.0 CONCLUSIONS

Based on the experience of the simulation exercise, following concluding remarks can be made:

i) The SHE model can be used for modelling entire land phase of hydrologic cycle with a reasonable accuracy which very much depends on data availability and quality of data.

ii) The results of simulation excercise with the Sher sub-basin have not been upto the desired level of expectation. Few reasons could be as below:

a) The rainfall data may not be actually representative of actual situation. The absence of having hourly data of the station in the basin may cause significant difference in simulation results.

b) The values of soil parameters, which play a significant role in overall simulation exercise, have been derived out of available literature. The values chosen do not seem to produce acceptable results in case of Sher sub-basin and call for thorough scrutiny. These can be well verified by carrying out systematic field investigations.

c) The vegetation parameters have also been based on literature and general experience and have scope for improvement.

d) The evaporation data used for simulation exercise was recorded away from the sub-basin and may not represent realistic situation.

e) The rainfall data used for simulation exercise may not represent the actual variation of rainfall with sub-basin topography.

f) The antecedent soil moisture condition as used for simulation exercise may not represent the actual field conditions. However, for long runs (more than 1 year) this may not be a significant reason.

g) There can be spatial variation of parameter values within the sub-basin which may affect results.

h) The cracking and swelling effects of soils may not be actually represented in the model.

iii) The grid size has an important bearing on computa-tational requirements. The selection of grid size be based on representation of physical processes being modelled.

iv) The processes of transpiration, soil evaporation and canopy evaporation can be well modelled throughout the simulation period.

v) The well calibrated model can be effectively used to predict effects of land use changes on hydrologic regime of a sub-basin. The extensive data and computation requirements are the major limitations of the model, and as such the use of SHE model is not warranted for dealing with routine hydrological problem.

vi) Efforts are required to be made to incorporate effects of open water bodies present in the basin to be modelled using SHE.

vii) Investigations of important soil and vegetation parameters should from part of application study of SHE in a particular basin.

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9.0 REFERENCES

Abbott, M.B. et.al. (1986). An Introduction to the European Hydrologic System - System Hydrologique European, 'SHE', 2: Structure of a physically based distributed modelling system, J. Hydrol; 87:61-77.

2. Abbott, M.B. et.al (1987), An Introduction to the European Hydrological System Hydrologique European, 'SHE', 1:History & Philosophy of a Physically-Based Distributed Modelling System, Journal of Hydrology 87(1986) 45-59.

3. Hodnett, M.G., & Bell, J.P. 1981: Soil physical processes of groundwater recharge through Indian black cotton soils. Rep. 77, Institute of Hydrology, Wallingford.

4. Hodnett, M.G., & Bell, J.P. 1986: Soil moisture investigations of groundwater recharge through black cotton soils. Madhya Pradesh, India. Hydrol. Sci. J. 31(3), 361-381.

5. Lecture Notes and Exercises, Hydrological Computerised Modelling System (SHE), Commission of Eurapean Communities, Govt. of India,Training Course 1988 at DHI, Denmark.

6. Note on the reconnaisance of hydrological observation of site No. 48 on river Sher tributory of Narmada, C.W.C., Bhopal.

7. Sutcliffe, J.V., Agarwal, R.P., & Tucker, J.M. 1981 The Water; balance of the Betwa basin, India. Hydrol. Sci. Bull. 26(2), 149-158.

8. Sutcliffe, J.V. & Green, C.S. 1986: Water balance investigation of recharge in Madhya Pradesh, India Hydrol. Sci. J., 31(3), 383-394.

9. Unl, V.W., & Joshi, V.G. 1986: Results of pumping tests in theDeccan Trap basalts of Central India. J. Hydrol, 86. 147-168.

10. User's Guide and Documentation 1988, Hydrological Computerised Modelling System (SHE), Commission of European Communities, Govt. of India, Training Course 1988 at DHI, Denmark.

11. Versey, H.R & Singh, B.K. 1982: Groundwater in Deccan basalts of the Betwa Basin, India. J. Hydrol. 58, 279-306.

12. Clark, R.T. (1973b), 'Mathematical Models in Hydrology', F.A.O. Irrigation 7 Drainage Paper No. 19.

13. United States Department of Agriculture, Soil Conservation Service, 1979, Engineering Field Manual, S.C.S.

14. Trout, T.J., G.G. Ignacia & W.E. Hart (1987)'Soil Water Engineering Field and Laboratory Manual, Academic Publishers, Jaipur.

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