CS-30

APPLICATION OF SHE MODEL TO HIRAN SUB-BASIN OF RIVER NARMADA

NATIONAL INSTITUTE OF HYDROLOGY
JALVIGYAN BHAWAN
ROORKEE - 247 667 (U.P.)
INDIA

1989-90

CONTENTS

PREFACE

The water resources development activities of the Narmada Basin have significant impact on its hydrological regime.SHE model has been applied to the Hiran sub-basin of Narmada basin with the objective to study the hydrological problems using distributed approach. These problems can not be solved through the use of conventional rainfall runoff models, while the models like the SHE, which have physical basis and allow for spatial variations within a catchment are suitable for this purpose. Though, the existing data base of Narmada basin is not exhaustive, it is reasonably adequate for modelling exercise. It was therefore, considered appropriate to carry out typical application studies of the SHE model using data of some of the sub basins of river Narmada.

The present study is a part of the project concerned with transfer of the Systems Hydrologic European (SHE) 'Hydrological Modelling System' to the National Institute of Hydrology, Roorkee and is intended to increase India's capabilities for formulating water and land resources development strategies through numerical modelling. The project is financed by Agreement ALA 86/19 Hydrological Computerised Modelling System, signed between the Commission of the European Communities (C.E.C.) and the Govt. of India. Under the project, six NIH scientists have been trained in theoretical and practical aspects of the SHE, at Danish

Hydraulic Institute, Denmark.

Hiran sub-basin is one of the six sub-basins selected for the model application in the Narmada basin. The present study deals with data processing and preparation, evaluation of model parameters, assessment of uncertainty in input quantities, carrying out simulation runs including calibration validation and sensitivity analysis and interpreting the results. The study has been carried out by Mr Sushil Kumar Singh, Scientist B under the guidance of Dr S M Seth, Scientist F and Project Co-ordinator, SHE Model Studies and in close interaction with the consultants.

Satish Chandra
(SATISH CHANDRA)
DIRECTOR

ABSTRACT

The Narmada basin is presently undergoing water resources development activities. The hydrological regime of the basin is changing owing to these developmental activities. The study of these effects on hydrological regime is not feasible by the use of conventional rainfall runoff model, especially those arising from landuse changes, conjunctive use of groundwater and surface water, soil moisture condition etc. These problems can be best solved using physically based distributed models which allow for the spatial variations within the catchment.

In the present study 'SHE' model has been used which is a flexible deterministic, physically based distributed hydrological modelling system with modular design having separate modules for the modelling of the each basic process of land phase of hydrologic cycle. The development of 'SHE' has been a large scale attempt to translate scientific hydrology at its current level into a practical instrument for water resources development. 'SHE' is the out come of the joint efforts of British Institute of Hydrology, Danish Hydraulic Institute, Denmark, and SOGREAH (France).

The present study is the out come of the training received by the author at Danish Hydraulic Institute Denmark, Aug. 9 to Dec. 1989 under a collaborative project (ALA/86/19) signed between Commission of European Communities and Republic of India. In this study, the 'SHE' model has been applied to the Hiran Sub-Basin of river Narmada.

The Hiran is the biggest right bank tributory of Narmada which rises in the Bhaner range in Jabalpur district of Madhya Pradesh near Kundam village at an elevation of 600 m at north latitude 23°27' and east longitude 80°27' and flows in a generally south westerly direction for a total length of 188 km to join the Narmada from the right near Sankal village. It drains a total area of 4,792 sq.km. The sub-basin covers part of areas of Jabalpur and Damoh districts of Madhya Pradesh.

The hydrological data used for the model study includes the daily rainfall for a number of stations lying within the basin a close. to the basin boundary, hourly stages and daily stage discharge data, Pan evaporation data and soil and land use parameters, assessed from the various reports pertaining to the area. Topographic details, and river network were obtaioned from Toposheets on 1:50,000 scale provided by Survey of India, Soil and Vegetation data were also used. The simulation and validation were done using a split sample approach on 2 Km x 2 Km grid. Sensitivity analysis was carried out to check the sensitivity of the rainfall and adequacy of raingauges.

In this application study, the entire land phase of the hydrologic cycle has been modelled for Hiran Sub-Basin with reasonable degree of accuracy inspite of the limitation of the data and assumptions made at various steps. It gave reasonable reproduction of hydrograph of stream flow in terms of volume and peaks.

1.0 INTRODUCTION

Water is a prime necessity of life and has been the fundamental for the development of civilization from the ancient period. When we look back to the history of ancient period, we find that the beginnings of our civilization was confined to the river basins like Indus valley, Mesopotamia, Huang-Ho valley etc. The main factor behind it was obviously the availability of water. With the development of civilization, for meeting the various demands of the people and society, developments were started within the basin. These developments in the river basins (which are the results of man's activities in the basin) disturb the virgin hydrologic cycle and re-establishment of hydrologic cycle takes place under the effects of the developments. As the result of these developments occured within the river basin from time to time since the beginning of the civilization and increased population, now we have to face the problems of water, i.e., too much, too little and too dirty. Our present useful water resources consist of freshwater available on the surface of the earth and sub-surface water. This water is in constant movement through the hydrologic cycle which comprise of the interaction of the processes like rainfall, snowmelt, interception, evapotranspiration, overland and channel flow and unsaturated and saturated sub surface flow. Thus, the hydrologic processes combined together form the complex problem even for undisturbed river basin.

The constantly increasing demands for a sufficient quantity and quality of water properly distributed within space and time, has forced the engineers togather with economists, political scientists, lawyers, planners, and conservationists for the development of available water resources in a planned manner. These in turn result in further increasing the influence of Man's activities on the hydrological processes within the basin making the processes more complex, thus leading to complications/difficulties in the planning and development of water resources. Some of the man's activities within the basin include, for example, constructions of dams, diversions, canlas, tanks for various specific and multiple purposes, development of agriculture, changes in lanuse pattern,urbanization etc. Thus, we observe that the system is huge, hydrological processes involved are complex owing to the Man's influence and there exists multiplicity of man's activities affecting one or many processes of water movements and their interrelations and hence, we have multi-scenario objective of water resources development. While decision making in planning these developments we have to have a solution to the various problems with the understanding of the processes under the current state of knowledge, with varying conditions and changes which are expected to occur in future. With the above mentioned complications and with the advent of high speed computers, the mathematical modelling has been proved to be the only tool for the analysis of such type of complex hydrological problems.

The model for a catchment is the simplified representation of the hydrological processes in the catchment and is used in the simulation and prediction of hydrological events and their consequences. It aids in making decisions related with the planning of water resources development projects, especially where data are scarce and a large number of alternatives are there to choose from. The model may be physical or mathematical.

Physical Model:

Physical model is a scale model built of concrete or other materials and is useful for the study of complex flow problems, the theories of which are not completely understood, e.g., complicated scour and turbulance effects and many such river problems. For representing the changes in a catchment or river, it requires physical rebuilding, which is expensive and in this sense it is less flexible and is not very useful for the full hydrologic cycle because of the wide range of physical and temporal scales of the processes involved therein.

Mathematical model: is the simplified representations of the process by a set of mathematical equations (generally partial differential equations), logical statements, boundary and initial conditions, expressing relationships between inputs, variables and parameters. It offers varying degree of flexibility depending upon the way in which the processes are being represented. The accuracy of the simulation depends upon following factors.

1. The mathematical representation of the processes of the system is how much close to the natural processes in terms of their actual responses reflecting the real behaviour of the system.
2. Mathematical constraints and computational constraints.
3. Data availability and user's requirements.

The detailed classification of hydrological models can be had from Fleming (1975), Woolhiser (1973) and Clarke (1973). However, the brief description of some of the model type is being given below:

Black box or empirical model has no physical basis of processes which relate input to output. In such models the relationship between input and output is established through calibration using hydrometeorological records. This type of model may be successful within the range of calibration data thus back box models can not be used to predict the effect of future changes in the catchment.

Lumped conceptional models occupy intermediate position between fully physically based approach and empirical black box analysis. A detailed treatment of lumped models is given by Blackie and Eeles (1985).

Physical based distributed models is based on the understanding of the physics of the hydrological process that control the catchment response and use physically based equations to describe these processes. The governing equations of the processes are the representation of the conservation of mass, momentum and energy. A detailed treatment of physically based distributed models is presented by Beven(1985).

1.1 Advantages and Disadvantages of Physically Based Distributed Models:

1. The physically based models can be applied to any range of data and are limited only by the range of **applicability of the physical laws within the model while the black box models cannot be applied beyond the range of conditions for which they are calibrated.**
2. The parameters of physically based model have physical meaning and in principle can be evaluated from direct measurements, while the parameters of black box model vary in a way that has no physical meaning and cannot be derived from the measurements of catchment characteristics.
3. The physically based models, in principle do not require a lengthy record for its calibration while the black box model does require.

In view of computational and data requirement, the physically based distributed models do have few disadvantages that are listed below:

1. Computer requrements are heavy because of the iterative numerical solution techniques for solving non linear equations at large number of calculation modes at very short time intervals. This disadvantages may be expected to be overcome as computers

increase in power.

2. It requires the evaluation of large number of spatially distributed parameters describing the physical characteristics of the catchment (e.g. topography, soil, vegetation).

3. The parameters are likely to be sampled and evaluated at spatial scale significantly different from those of model grid scale, thus, the parameter values may not be representative of the condition as they are simulated in the model.

4. Due to lack of the data, the spatial and temporal variation of some of the parameters cannot be considered.

1.2 Application of Physically Based Distributed Models:

In view of the advantages mentioned above over conventional Hydrologic models, the physically based distributed models are capable of handling more complicated problems in hydrology. Some examples are as follows:

1. Catchment changes: Since the parameters of a physically based, distributed model have a direct physical interpretation, they can be evaluated for a new state of catchment before the changes actually occur in the catchment. This enables the determination of the response of the catchment to the changes in advance of such changes. Besides this, localized nature of catchment changes can easily be accounted for within

the spatially distributed model structure.

2. Ungauged Catchments: The physical significance of its model parameters enables the physically based distributed model to be applied to ungauged catchments. On the basis of a much shorter hydrometeorological record there is a necessity for more conventional models.

3. Spatial Variability in Catchment Inputs and Outputs:

Distributed models can be used to examine the effects on flood flows of different directions of storm propogation across a catchment and also the effect of localised river and ground water abstractions and recharge. This facility is beyond the capability of lumped catchment models which can deal only with quantities averaged across the catchment.

4. Movement of pollutants and sediments:

In order to model the movements of pollutants and sediments, it is first necessary to model water flows which provide the basic dispersion mechanism. Most water quality and sediment problems are distributed in nature, so distributed models are the most suitable for supplying the basic information on water flows.

1.3 Present Study

The present study is the application study of a physically distributed 'SHE' model developed jointly by Danish Hydraulic Institute, Denmark, SOGREAH (France), and the British Institute of Hydrology. The 'SHE' was applied to the

Hiran sub-basin of Narmada basin, at DHI Denmark as a part of training under a collaborative project between EEC and Republic of India.

2.0 SHE MODEL

The 'SHE' is a physically based distributed modelling system which covers modelling of the hydrologic system with respect to all the components of hydrologic cycle. The'SHE' is the out-come of joint efforts of Danish Hydraulic Institute, Denmark, SOGREAH (France) and the British Institute of Hydrology with the financial support of Commission of European Communities. The particular difficulties encountered in the development of 'SHE', which represents the scientific advances represented by the system are

a) representation of spacial variations in hydrological quantities, both across the catchment and through the soil column.

b) representation of the major land phases of the hydrological cycle in a physically and computationally acceptable manner.

c) allowing for interaction between the different hydrological processes, each having its own characteristic space and time scale.

The 'SHE' was developed in order to overcome the incapabilities of conventional rainfall runoff models to many existing hydrological problems, especially those related to the impact of man's activities on land use change and water quality.

The development of 'SHE' has been large scale attempt to translate scientific hydrology at its current level into a practical instrument for water resources development. In the development of 'SHE', snowmelt , evaporation and evapotranspiration components were the responsibility of Institute of Hydrology, overland and channel flow components were developed by SOGREAH, and unsaturated and saturated zone components were developed by Danish Hydraulic Institute, Denmark.

2.1 Salient Features:

The salient features of 'SHE' have been briefly described in the following paragraphs.

It is a physically based model in the sense that the major component of hydrologic cycle (snowmelt, overland flow and channel flow, interception, evapotranspiration, unsaturated and saturated sub-surface flow) have been modelled either by finite difference approximation of governing partial differential equations describing the respective processes of water movement on by relevant empirical equations developed based on experimental research. In the modelling of the process of physical basis, the model parameters bear physical meaning and can be directly measured in the field. When the process is modelled using relevant empirical equations, the parameters do not have a fully physical basis, i.e., they cannot be directly measured in the field. Since the catchment parameters are based on direct field measurements, the simulation can be improved on the basis of physical reasoning indicating the capability to this type of modelling system. Also, in principle, the physically based models do not require an extensive hydrological record for their calibration (Beven and O'Connell, 1982).

It is a distributed model in terms of its capability to take into account the spatial distribution of catchment parameters, rainfall input and produces the hydrological response in horizontal through the representation of the catchment by an orthogonal grid network and in vertical by a column of horizontal layers at each grid square. In the model, independent one dimensional unsaturated flow columns of variable depth link a two dimensional overland flow component with a two dimensional saturated flow component.

It has modular design in the sense that each component (within the 'SHE' each hydrological process is allocated its own component) was constructed as a separate software module with tentative but well defined information exchange characteristics, i.e., certain information generated by one module was to act as input data or boundary conditions for other modules and their simultaneous operation is controlled by a central frame component. In this type of model structure further components can be added without much difficulty and new information can be incorporated as needed, hence, the 'SHE' can easily be updated as fresh scientific advances are made.

It is flexible With the facility to modify or omit the components for a particular application depending on hydrological conditions and availability of data and each component may be used with different time steps in order to accomodate variations in time scale which characterize hydrological processes. Consequently, it allows dummy components to be used when one or more of the hydrological processes are irrelevant to a particular application. Examples include the following:

1. A flood study of a catchment where the surface is bed rock and infilteration is so small that the unsaturated and saturated flow components can be neglected.

2. An irrigation area where all or nearly all of the precipitation infilterates or is evaporated from the canopy and soil surface so that the overland and channel flow is not required.

3. An arid or semi-arid catchment where there is little or no vegetation present and the calculations in the evapotranspiration component needs consideration of potential rather than actual evapotranspiration.

Additional flexibility is assured through the ability of 'SHE' to use as few or as many data as are available, either from field measurements or from the scientific literature.

Having the above mentioned features the 'SHE' is capable of handling almost any kind of hydrological problem particularly the more complicated problems. The possible fields for the application of 'SHE' at different operation scales have been given in Table 2.1.

2.2 Structure and Components of 'SHE'

In the 'SHE' only the primary components of the land phase of hydrologic cycle are modelled, i.e., snowmelt, canopy interception, evapotranspiration, overland and channel flow and unsaturated and saturated sub-surface flow. The catchment is represented in the horizontal plane by grid squares in which the river system is represented by its superimposition on the boundaries of the grid squares. The spatial distribution in the vertical plane is represented by a column of horizontal-layer at each grid square. The unsaturated flow equations are solved for vertical columns of variable depth at each grid square in vertical direction only for simplicity. The columns link a two dimentional surface flow component to a two dimensional groundwater flow component. The model structure has been illustrated in fig. 2.1.

In the 'SHE' each major hydrological process is soved in a separate model component. The programs for all the model components have been written in FORTRAN-77. The program structure of 'SHE' has been illustrated in fig. 2.2.

The brief description of the various model components of the 'SHE' alongwith method of solution technique adopted within 'SHE' are as follows:

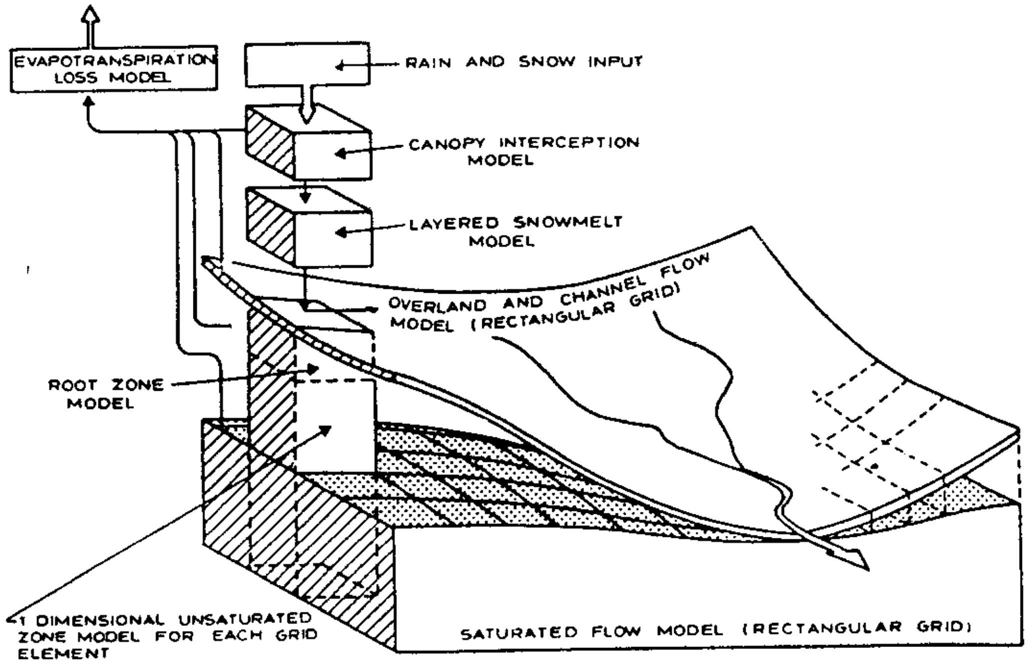


Fig. :2.1 Structure of the European Hydrologic System.

TABLE : 2.1

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

Topic	Primary hydrological process	Possible scale of operation
Irrigation schemes		
Irrigation water requirement	ET/UZ	field
Crop production	ET/UZ	project
Waterlogging	ET/UZ	field
Salinity/irrigation management	UZ	field
Land-use change		
Forest clearance	ET/UZ/SZ	catchment
Agricultural practices		field/catchment
Urbanization		catchment
Water developments		
Groundwater supply	SZ	catchment
Surface water supply	ET/UZ/SZ	catchment
Irrigation	UZ/SZ	project/catchment
Streamflow depletion	SZ/OC	catchment
Surface water/groundwater interaction	ET/UZ/SZ	project/catchment
Groundwater contamination		
Industrial and municipal waste disposal	UZ/SZ	field/catchment
Agricultural chemicals	UZ/SZ	field/project/ catchment
Erosion/sediment transfer	OC/UZ	project/catchment
Flood prediction	OC/UZ	catchment

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

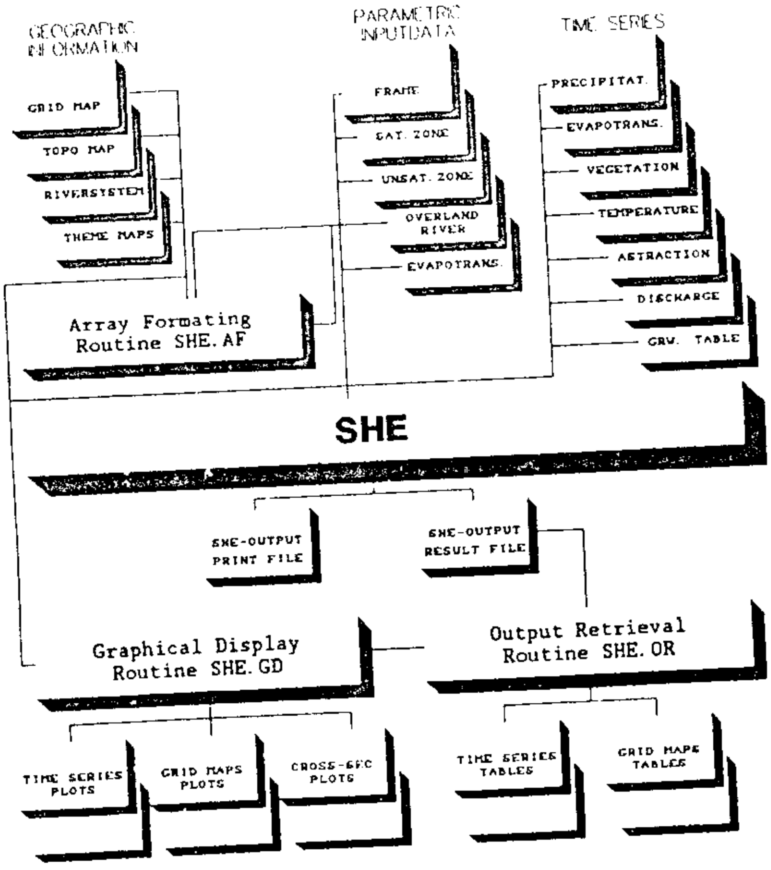


Fig. 2.2: Flow Chart of the SHE Programme Package.

2.2.1 Frame component:

The frame component controls and corrdinates the parallel and consistent execution of other components and transfer of data between them. Its functions are summarized below.

1. Overall control of the reading of data for each component and parameter sets. It organises the data required for each square of the grid network, such data relate to topography, soil, vegetation, rainfall and meteorological station codes. The vales of soil conductivity, overland and channel flow resistance and of other such parameters are called later by relevant process components.

2. Controls the sequence of the components in which they are called to perform their computations. It selects and controls the time steps of the computations for different processes during simulation and time steps for output control (Depending upon the rate of response of the process, each component may have different time step. Apart from this the changed in the time step of a component may occur because of the changing rate of response of the process due to varying external stress on it).

3. Controls the exchange/transfer of data between components in such a way as to minimize inaccuracies in the overall mass balance for the simulation. (This

transfer becomes necessary in view of the fact that the output from one component need to be processed into a different form for input to another component).

4. Controls the mass balance of water between all components and within each component separately except for the river (errors in the mass balance occur due to the changes in the water storage from one time step to the next).

5. Records the calculation results on permanent storage and prints a summary of the results at specified intervals .

2.2.2 Interception and evaporation component

This component uses meteorological input data and vegetation parameters to simulate the total evapotranspiration and net rainfall amount resulting from the following processes.

1. Interception of rainfall by the vegetation canopy
2. drainage from the canopy
3. evaporation from the canopy surface
4. evaporation from the soil surface
5. up take of water by plant roots and its transpiration.

The rates of evaporation and transpiration alongwith net rainfall thus obtained are supplied to the unsaturated zone component, which in terms provides information on soil moisture conditions in the root zone. Since interception can significantly affect the evapotranspiration, these two processes are modelled in 'SHE' within one overall component.

2.2.2(a)Interpretation

The interception model calculates

1. net rainfall reaching the ground through canopy
2. amount of water stored on canopy
3. evaporation from the canopy

The calculations are based on the model developed by Rutter et al. (1971/72) which is essentially an accounting procedure for canopy storage. The relation between rate of change of interception storage and net input (precipitation-evaporation) with drainage from the canopy is given by

$$\frac{\partial C}{\partial t} = Q - ke^{b(C-S)} \qquad \ldots(2.1)$$

Where

Q is the net input

C is the storage or depth of water on the canopy

S is the canopy storage capacity

(i.e., the minimum depth of water required to wet all canopy surface)

k & b are the drainage parameters

t is the time

If E_p is the potential rate of evaporation, evaporation from the canopy will be E_p (when $C \geqslant S$) and E_p C/S (when $C < S$). Hence, the net input will be

$Q = p_1 p_2 \; (P - E_p C/S)$ when $C < S$

$Q = p_1 p_2 \; (P - E_p)$ when $C \geqslant S$

Where,

p_1 is the portion of ground in plan view hiden by vegetation.

p_2 is the ratio of total leaf area to the area of ground covered by vegetation.

Equation (2.1) is solved by analytical integration. The model parameters S,k,b,p_1 and p_2 and the canopy storage C must be estimated indirectly from measurement of rainfall, net rainfall below the canopy and evapotranspiration because they cannot be measured directly in the field. The temporal changes in vegetation cover (land use changes with time) can be taken into account by varying S, p_1 and p_2 with time. The interception is modelled for only one vegetation in each grid square, hence, secondary vegetation, e.g., grass below a tree cover is ignored. On the other hand, the use of space averaged vegetation type to represent mixed vegetation is possible.

Since the model was initially developed for trees and it has not been evaluated for other vegetation, the characteristics values of k and b (whose physical significance is not entirely clear) remains undefined for grasses and crops. The princip-les being same, it is being applied in 'SHE' for all type of vegetation.

2.2.2(b)Evapotranspiration:

The evapotranspiration component calculates the actual evapotranspiration including evaporation of intercepted moisture, evaporation from the soil surface and the uptake of water by plant roots and its transpiration. The loss terms, thus calculated is then used in calculating soil moisture changes by unsaturated zone component. Both the actual and the potential evapotranspiration is calculated. The potential evapotranspiration is that which occurs when the supply of water to the plants/soil system with a dry canopy is unlimited The potential evapotranspiration forms the upper limit of actual evapotranspiration and other wise is less because of the restrictions in the supply of water from the soil due to physiological controls (such as stomatal resistance within the plants). However, even the supply of water being unlimited, the factors affecting evapotranspiration are not well understood and hence, an operational model of the process inevitably contains simplifications. Depending upon the data availability, the potential rate may be provided from direct measurements minimize the calculations) or may be determined from the basic principles. Keeping this in view, and in order to have flexibility that the model can be adopted to whatever is known of local conditions, four approaches/ options are available within the 'SHE'. The first two options makes use of the Penman - Monteith equation which is a modification of penmans's potential evapotranspiration equation taking into account the average stomatal resistance to vapour flux via a canopy resistance factor (monteith, 1965). The equation used in the program is

$$E_a = \frac{R_n \cdot \Delta + \rho_a \cdot c_p \cdot \delta e / r_a}{\lambda [\Delta + \gamma (1 + r_c / r_a)]} \qquad \ldots(2.2)$$

Where

E_a is the actual evapotranspiration rate (m/s)

R_n is the net radiation (W/m²)

Δ is the rate of increase (with air temperature) or the saturation vapour pressure of water at air temperature mb/°C)

ρ_a is the density of air

C_p is the specific heat of air at constant pressure (J/Kg/°C)

δe is the vapour pressure deficit of air (mb)

λ is the latent heat of vaporization of water (J/Kg)

γ is the psychrometric constant (mb/ °C)

r_a is the aerodynamic resistance to transport of water vapour from the canopy to a plane 2 m above it (s/m)

r_c is the conopy resistance to water transport from some region within or below the transpiring surface to the surface itself, being zero for a wet canopy and equal to the average stomatal resistance (varying vegetation type) in the dry conditions (s/m).

The greater is the surface roughness, the less is the resistance to water vapour transfer and the lower is r_a, e.g., trees have lower value of r_a than does grass.

In the first option r_c is assumed to be constant for each vegetation type and for a perticular vegetation it does not vary with soil moisture. In the second option, r_c varies with soil moisture tension as well as vegetation type. In the third option r_c is assumed to be zero, so that the equation

(2.2) gives potential evapotranspiration, E_p. The actual evapotranspiration rate, E_a is then calculated by defining the ratio E_a/E_p as a linear function of soil moisture tension (Feddes et al, 1976).

In the first three option described above the interception is calculated using the procedure presented in 2.2.2.(a).

Leaf Area Index Method:

The forth option makes the use of leaf area midex (LAI). This model was developed at the Royal Veterinary and Agricultural University in Denmark (Kristensen and Jensen (1975).

This method makes use of potential rate of evapotranspiration and actual soil moisture status in the root zone as the input to calculate the actual evapotranspiration. The derivation of the governing equation forms the experimental basis (actual measurements).

The interception process is modelled incorporating an interception storage which has to be filled before through fall to the ground surface takes place and the intercepted water evaporates directly. The interception storage capacity I_{max} depends upon

- vegetation type and
- stage of development of vegetation through the leaf area index (LAI).

$$I_{max} = Cint. (LAI) \qquad \ldots(2.3)$$

where,

Cint is the interception parameter (mm)

LAI is the leaf area index (ratio of the total area of leave to the total projected area covered by trees or vegetation).

Cint depends on the time of resolution and is independent of vegetation type. The typical value of Cint is 0.05 mm, however, the exact value may be assessed from calibration. LAI varies between 0 and 7.

The transpiration from vegetation is considered to depend upon.

a) density of crop(green material which is described by LAI).

b) Actual soil moisture content in the nodes of the root zone.

c) root density

The model makes use nof the following equation

$$E_{at} = f_1 (LAI). f_2(Q). (RDF). E_p \qquad ...(2.4)$$

where

E_{at} is the transpiration

RDF is the root distribution function

f_1 (LAI) is the function of LAI and the empirical parameters C_1 and C_2

$f_2(Q)$ is the function of volumetric moisture contents at field capacity and wilting point, volumetric moisture content and an emperical parameter C_3.

Cint is the interception parameter (mm)

LAI is the leaf area index (ratio of the total area of leave to the total projected area covered by trees or vegetation).

Cint depends on the time of resolution and is independent of vegetation type. The typical value of Cint is 0.05 mm, however, the exact value may be assessed from calibration. LAI varies between 0 and 7.

The transpiration from vegetation is considered to depend upon.

a) density of crop(green material which is described by LAI).

b) Actual soil moisture content in the nodes of the root zone.

c) root density

The model makes use nof the following equation

$$E_{at} = f_1 \text{ (LAI)}. f_2(Q). \text{ (RDF)}. E_p \qquad \ldots(2.4)$$

where

E_{at} is the transpiration

RDF is the root distribution function

f_1 (LAI) is the function of LAI and the empirical parameters C_1 and C_2

$f_2(Q)$ is the function of volumetric moisture contents at field capacity and wilting point, volumetric moisture content and an emperical parameter C_3.

Equation (2.4) is applied to all the nodes in the root zone. This approach has been discussed in details by Kristensen and Jensen, 1975.

2.2.3 Over Land and Channel Flow Component:

When the net rainfall exceeds the infilteration capacity of soil, water is ponded on the ground surface. This water is available as surface runoff, and is routed downgradient towards the river system. In this component the depths, velocities and discharges of overland and channel flow is simulated using the theoretical partial differential equation of conservation of mass and momentum. Thus, this component uses topography, channel shape and flow resistance parameters (overland flow resistance and channel flow resistance) and losses due to evaporation and infilteration along the flow path, to calculate the quantities. The evaporation rates are supplied by the interception/evapotranspiration component while the infilteration rates are supplied by the unsaturated zone component (discussed at 2.2.4). Apart from it, there is an exchange of water between channel and aquifer which determines the input to groundwater and seepage losses. This exchange component has been described in more details later.

For modelling of overland and channel flow, finite difference approximations of St. Venant equations of continuity and momentum in two dimension have been used.

Over Land Flow

A two dimensional solution, neglecting inertial term is obtained using the equation

$$\frac{\partial h}{\partial t} + \frac{\partial (uh)}{\partial x} + \frac{\partial (vh)}{\partial y} = q \qquad \ldots(2.5)$$

$$\frac{\partial h}{\partial x} = S_{ox} - S_{fx} \quad (x - \text{direction}) \qquad \ldots(2.6)$$

$$\frac{\partial h}{\partial y} = S_{oy} - S_{fy} \quad (y - \text{direction}) \qquad \ldots(2.7)$$

where,

$h\ (x,y)$ is the local water depth

t is the time

x,y are the Cartsian Coordinates

$u(x,y)$ is the flow velocity in x - direction

$v(x,y)$ is the flow velocity in y -direction

$q\ (x,y,t)$ is the net precipitation minus infilteration

$S_{ox}\ (x,y)$ & $S_{oy}(x,y)$ are the ground slope in x and y directions respectively.

S_{fx}, $S_{fy}\ (x,y)$ are the friction slopes in the x and y directions respectively.

The friction slops are given by the expression (using Strickler/Manning's resistance law)

$$S_{fx} = \frac{u^2}{k_x^2 . h^{4/3}} \qquad \ldots(2.8)$$

$$S_{fy} = S \frac{v^2}{k_y^2 h^{4/3}} \qquad \ldots(2.9)$$

where,

k_x and k_y are the strickler roughness coefficients for the flow in x and y direction.

The equations (2.5) through (2.9) are combined and solved using an explicit procedure described by Preissmann and Zaoui (1979).

Channel Flow

For determining the flow along channel, the above solution is repeated but in one dimensional from (i.e., along the channel) which is obtained by using the equations.

$$\frac{\partial A}{\partial t} + \frac{\partial (Au)}{\partial x} = qL \qquad \ldots(2.10)$$

$$\frac{\partial h}{\partial x} = S_{ox} - S_{fx} \qquad \ldots(2.11)$$

$$S_{fx} = \frac{u^2}{k_x^2 . h^{4/3}} \qquad \ldots(2.12)$$

where

A (x) is the cross-sectional area of flow

S_{ox} is the slope of channel bed

$q_L(x)$ is the source/sink term for evaporation, rainfall, lateral inflow and outflow, stream aquifer exchange.

Again the strickler/Mannings equation is used and the final solution is carried out by an implicit finite difference scheme(Preissmann and Zaoui 1979).

2.2.4 Unsaturated Zone Component:

The part of rainfall which infilterates and flows through soil or rock strata becomes subsurface flow. The subsurface flow may usually be divided into two zones having entirely different characteristics. The first zone extends from the soil-atmosphere interface to the water table while the second zone is the ground water zone below the water table in which the porous media is saturated. In the first zone, i.e., soil water zone the flow is usually unsaturated flow, however, saturation may occur temporarily during high rainfall rates. This soil water zone is also termed as unsaturated zone.

The unsaturated zone plays an important role in 'SHE' model as it links the two dimensional overland flow component to a two dimensional subsurface flow (i.e., saturated ground water flow) together. It is also important in the sense that various results from UZ component are used as input to the other components of the SHE. An accurate description of the subsurface fow phenomena requires a detailed information about

- the spatial distribution of soil properties.
- the catchment geometry.

This component calculates the soil moisture content and the tensions and their distribution in saturated zone. The upper part of the zone, i.e., root zone exhibits considerable variations in physical properties (soil moisture and tension) as a result of evapotranspiration and rainfall infilteration. Thus, the lower boundary also varies with time with the changing phreatic surface elevation. The flow in this zone is assumed to be essentially vertical (neglecting the lateral flow) and is described by the one dimensional Richards Equation which constitute the governing equation of flow process.

$$C\frac{\partial \psi}{\partial t} = \frac{\partial}{\partial z} \left(K\frac{\partial \psi}{z}\right) + \frac{\partial k}{\partial z} - S \qquad \ldots(2.13)$$

where,

ψ is the soil moisture tension or the pressure head,

t is the time,

z is the vertical space coordinate (positive upwards)

$C = \frac{\partial \theta}{\partial \psi}$ and is the soil water capacity

θ is the volumetric water content

$K(\theta, z)$ is the hydraulic conductivity

$S(z)$ is the source/sink term for root extraction and soil evaporation.

In order to solve the above equation the following relationship is needed as input

- the relationship between unsaturated conductivity k and the volumetric moisture content θ.
- the relationship between soil moisture tension ψ and the volumetric moisture content. This relationship is called moisture retention curve and is known to exhibit hysteresis effect in nature but is approximated by a single valued relationship in the 'SHE'.

The equation (2.13) is solved by an implicit finite difference scheme. The scheme is also interative in order to allow for the pronounced nonlinearity resulting from the strong dependence of K and C on θ and ψ. More detailed descriptions of the technique are provided by Abbott et al. (1982) and Jensen (1981, 1983).

The upper boundary condition may shift from flux controlled conditions to soil controlled conditions and viceversa and determines the infilteration into the soil. The lower boundary is usually the phreatic surface and a mass balance calculation for the unsaturated zone determines the exchange with the saturated zone. A particularly difficult problem is the calculation of the change in phreatic surface level. This requires linking the one dimensional vertical flow unsaturated model with the two dimensional horizontal flow saturated zone model. The soil moisture profile in the lower part of unsaturated zone must remain compatible with the phreatic surface level computed by the saturated zone component. In the 'SHE' an approach similar to that of Belmans et al. (1983) is used, based on the water balance of the total soil column including the saturated zone.

2.2.5 Saturated zone component:

The saturated zone (SZ) component computes the phreatic surface level and the flows, assumed to be horizontal only in the saturated zone. But options are available in an extended SZ component to cope with

- multilayered confined/unconfined aquifers
- three dimensional unconfined flow
- artificial drainage

This component receives net percolation rates from the unsaturated zone calculations and supplies in return the phreatic surface level as a lower boundary condition for those calculations. Stream/aquifer interactions, groundwater seepage at the ground surface and artificial pumping are also simulated.

The spatial and temporal variations in the phreatic surface level at each grid square is modelled by the nonlinear Boussinesq equation. This combines Darcy's law and the mass conservation of two dimensional laminar flow in an anisotropic, heterogeneous aquifer, to give

$$S \frac{\partial h}{\partial t} = \frac{\partial}{\partial x} \left(K_x H \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_y H \frac{\partial h}{\partial y} \right) + R \qquad ..(2.14)$$

where,

$S(x,y)$ is the specific yield, h (k,y,t) is the phreatic surface level

K_x (k,y), K_y (x,y) are the hydraulic conductivities in x and y direction respectivity.

$H(x,y,t)$ is the saturated thickness

t is the time

x,y are the horizontal Cartesian Coordinates

$R(x,y,t)$ is the instantaneous vertical recharge into the saturated zone.

The equations (2.14) is solved by a finite difference approximation using an alternating direction, non iterative implicit scheme. Stream/aquifer interactions are simulated for the following cases

1. phreatic surface in direct contact with a flowing stream.
2. phreatic surface in direct contact with a dry stream.
3. phreatic surface lying below a flowing stream
4. phreatic surface lying below a dry stream

In addition, the channel boundary can be assigned a hydraulic conductivity different from that of surrounding aquifer. This is to account for the higher or lower conductivities which may characterize the sediments in the immediate vicinity of the channel.

2.2.6 Snow melt component:

This component uses snowpack and vegetation parameters, along with meteorological input data, to predict the transfer of moisture resulting from processes of snow melt and snow packs. Its aim is to model the snowpack thickness as it is affected by precipitation and melting and to model the rate of delivery of meltwater from the snowpack to the soil surface. This component has not been used for the present study. A detailed description of the component is given by Morris and Godfrey (1979) and Morris (1982, 1983).

2.3 Parameters and Data Requirements:

'SHE' being a distributed and physically based model it requires in each application study a large amount fo data and parameters describing the physical characteristics of the catchment. For a successful 'SHE' application study major emphasis should be on data collection and data processing phase. The data requirement can be broadly classified into two groups, viz., input data and parametric data. There is a vide variety of different parameters and functions to be quantified and each parameter must be quantified for each grid square. In principle because of the physical significance of the parameters, it is possible to measure the parameters in the field. The principal catchment parameters and input data required for each grid square (or channel link) in the 'SHE' model is given below component-wise.

Frame Component

Model Parameters:

- Ground Surface Elevation
- Impermeable bed elevation
- Distribution Code for rainfall and meteorological source stations
- Distribution codes for soil and vegetation type.

Interception Component

Model Parameters (for each crop type):

- Drainage parameters

- Canopy storage capacity (time varying)
- ground cover indices (time varying)
- Leaf area index (for other option)

Input Data:

- Rainfall rate

Evapotranspiration Component:

Model parameters (for each crop type)

- 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
- Leaf area Index (for other option)

Input data:

- Meteorological data

Overland and Channel Flow Component:

Model parameters:

- Strickler roghness coefficients for overland and river flows.
- Coefficient of discharge for weir formulae.

Input data:

- Specified flows or water levels at boundaries
- Man controlled diversion and discharges
- Topography of overland flow plane and channel cross-sections.

Unsaturated Zone Component:

Model Parameters (for each soil type)

- Soil moisture tension/content relationship
- Unsaturated hydraulic conductivity as a function of moisture content.

Saturated Zone Component:

Model parameters:

- Porosities or specific yield
- Saturated hydraulic conductivities
- Impermeable bed elevations

Input data:

- Specified flows or potentials at boundaries
- Pumping and recharge data

Snowmelt Component:

Model Parameters:

- Degree day factor
- Snow zero plane displacement
- Snow roughness height

Input Data:

- Meteorological and precipitation data.

Some of the data are required which may be time dependent. Such data will not always be available and it may then be necessary to choose the simpler calculation modes in the model which require fewer data. 'SHE' being a physically based model, in principle, the parameter values should not need to be calibrated since they are based on physical measurements. Therefore, application of 'SHE' is likely to involve the transfer of parameter values measured at representative sites and the general use of parameter values available in the literature. (In long term there is a considerable potential for the use of remote sensing techniques in providing parameter values on a spatially distributed basis). All the data needed for the application of 'SHE' are to be organized in a set of SHE data files, one for each component including the Frame Component. A data file need to be prepared, if the concerned component is required in the simulation. Apart from this, a set of data file containing time series data is also needed. These data files are used both as input to the 'SHE' and for calibration and validation purposes. A series of maps and other input like grid network, catchment geometry, soil and land use maps, river network etc., describing the spatial distribution of data are required in the SHE data files.

Data required for calibration purposes include

* Time series of discharge data at salient points of the river network

* Time series of groundwater table data with spatial variations.

The data as per requirement mentioned above are not available as such in its above stated form and therefore, should be collected in the form in which available and subsequently may be processes accordingly for 'SHE' application. In view of the data collection programme, the data requirement for 'SHE' application may be classified into the following categories.

1. Topography:

   Toposheets on the scale of 1:50,000 showing the general topographic details and the elevations over the catchment at 20 m contour interval.

2. Land Use:

   Land use/vegetation maps showing the vegetation distribution over the catchment. This map should preferably be on the same scale as that of the topographic map, i.e., 1:50,000. This map can be prepared from satellite imagery or from the details shown on the toposheets.

3. Soil Distribution:

   Soil maps (1:50,000 scale) showing the spatial distribution of different type of soil over the catchment.

4. Soil and Vegetation Properties:

   - For each vegetation type the variation of root zone depth, leaf area index, vegetation growth with time is required.
   - For each soil type, soil depth, soil moisture retention curve, variation in unsaturated hydraulic conductivity with moisture content, saturated hydraulic conductivity **aquifer** parameters and volumetric water content at

saturation, field capacity and wilting point are required.

- The information related with the soil and vegetation properties may have to be collected from the reports and papers on the area or neighbouring areas as information based on direct measurements may not be available with the Govt. Agencies.

5. River Cross-section and roughness parameters:

   - River cross-section and longitudinal sections for important reaches.
   - Roughness parameters for different river reaches and for overland flow.

6. Meteorological Data:

   - Time series of rainfall data (daily and hourly for all the raingauge stations.
   - Potential evapotranspiration data (time series) and the daily climatological data wind speed, humidity, temperature, radiations, sunshine hours etc.
   - Snow related data and parameters if the catchment is snowfed.

7. Discharge Data:

   - Daily stage discharge data from all the gauging stations for a number of years.

- Hourly stage values recorded at each gauging site.
- Rating curve to convert the hourly stage value into corresponding discharge values.

8. Groundwater Observation Data:

   - Time series of groundwater table observation data for all the wells within the basin.

9. Hydrogeological Data:

   - Aquifer geometry (extent and location of aquifers and boundary conditions).
   - Aquifer parameters (transmissivity, leakage and storage coefficient)
   - Hydrogeological description of the entire basin. Bore-Log charts for various locations and the test pumping data.

2.4 Brief Review of 'SHE' Application Studies:

Apart from the application of 'SHE' to the six catchments of India under present project, the 'SHE' has been also successfully applied for the catchments of the other countries for various specific problems with satisfactory results. Some of these application studies are listed below:

1. Study of soil erosion aspect in the three medium size basins in Thailand, viz., Khlong Yang, Khlong Samo Pun and Lamtakong, located north-east of Benkok

with a special emphasis to high flows. The results of the model simulation were encouraging as the hypothetical test runs carried out for the analysis of land-use changes alongwith their comparative study for different catchments yielded results compatible with the existing situations in respective catchments in terms of hydrological regime and soil erosion.

Study of environmental impacts of fertilizer application in Denmark with a view to reduce the pollution from nutrients and organic matters in agriculture. The 'SHE' is applied to the two basins, viz., Karup (438 sq.km.) and Langvad (178 sq. km.). Both the catchments were modelled in 500 m grid size.

'SHE' was applied in Aarhus, Denmark with a view to study the following aspect.

a) estimation of water availability and groundwater development potential at various sites.

b) the impact of groundwater abstraction on the river flow and meadow areas

c) establishment of optimal control and monitoring programme.

d) modelling of transport and geochemical processes of pollutants from waste disposals.

The catchment area is approximately 700 sq.km. The 'SHE' was set up for a multilayer aquifer system, consisting of one unconfined and two confined aquifers spared by aquitards.

4. 'SHE' was applied to an upland catchment in mid-wales. The calibration validation and sensitivity analysis for the same have been presented with satisfactory and reasonable results (Bathurst, 1986).

3.0 GENERAL DESCRIPTION OF STUDY AREA AND DATA AVAILABILITY

In the present study, the SHE model has been applied for simulation studies for Hiran sub-basin, which is a sub-basin of Narmada river. The general description of the Narmada basin and the Hiran sub-basin is given in the subsequent paragraphs.

3.1 General Description of Narmada Basin:

Narmada is the largest west flowing river of central India which rises near Amarkantak in Maikala range in Shahdol district of Madhya Pradesh at an elevation of 1057 m above mean sea level and joins the gulf of Cqmbay in Arabian Sea near Bharuch in Gujarat. Out of its total length of 1312 km., it flows 1079 km. in Madhya Pradesh, 35 km as boundary between Madhya Pradesh and Maharashtra; 39 km. as boundary between Maharashtra and Gujarat and the last length of 159 km. in Gujarat. The river has a number of falls in its head reaches . It has 41 tributories; out of which 22 are left bank tributories and 9 are right bank tributories.

Narmada basin lies between east longitude 72°32' to 81°45' and north latitude 21°20' to 23°45' and is bounded by Vindhiyas on the North, Maikala range on the east, Satpuras on the south and Arabian sea on the west. It has an elongated shape with a maximum length of 953 km from east to west and a maximum width of 234 km from north to south. Out of the basins total area of 98,796 sq.km.; 85,859 sq.km. is in Madhya Pradesh; 1,538 sq.km. in Maharashtra and 11,399 sq.km. in Gujarat. Major portion of the basin lies just below the Tropic of Cancer. The basin has humid and tropical climate, in general; but at some places extremes of heat and cold are often encountered. Four distinct seasons occur in the year, viz. cold, hot, southwest monsoon and post monsoon. The mean temperature varies between 17.5°C to 20.0°C; 30°C to 32°C, 27.5°C to 30°C and 25°C to 27.5°C in cold, hot, monsoon and post-monsoon seasons respectively. Southwest monsoon is the principal rainy season and accounts for about 90% of the annual rainfall concentrated during only four months of the year, i.e, from June to Sept. About 60% of the annual rainfall is received during July and August. During this season, a number of storm originating in Bay of Bengal and moving in West Northwest direction towards the basin and sometimes moving parallel to the length of the basin are responsible for most of the rain in the basin. The normal annual rainfall for the basin is 1,178 mm. There is significant spatial variation of rainfall in the basin; heavy rainfall in the upper hilly and upper plains area, gradually decreasing towards lower plains and lower hilly areas, which again increases towards the coast and southwestern portion of the basin. Maps showing the Narmada basin is given in fig. 3.1.

Reconnaissance soil survey made by the Central Water and Power Commission in connection with the investigations of the Bargi, Punsa, Barna and tawa Projects indicate that the Narmada basin consists mainly of black soils. The coastal plains in Gujarat are composed in alluvial clays with a layer of black soils on the surface. District-wise principal

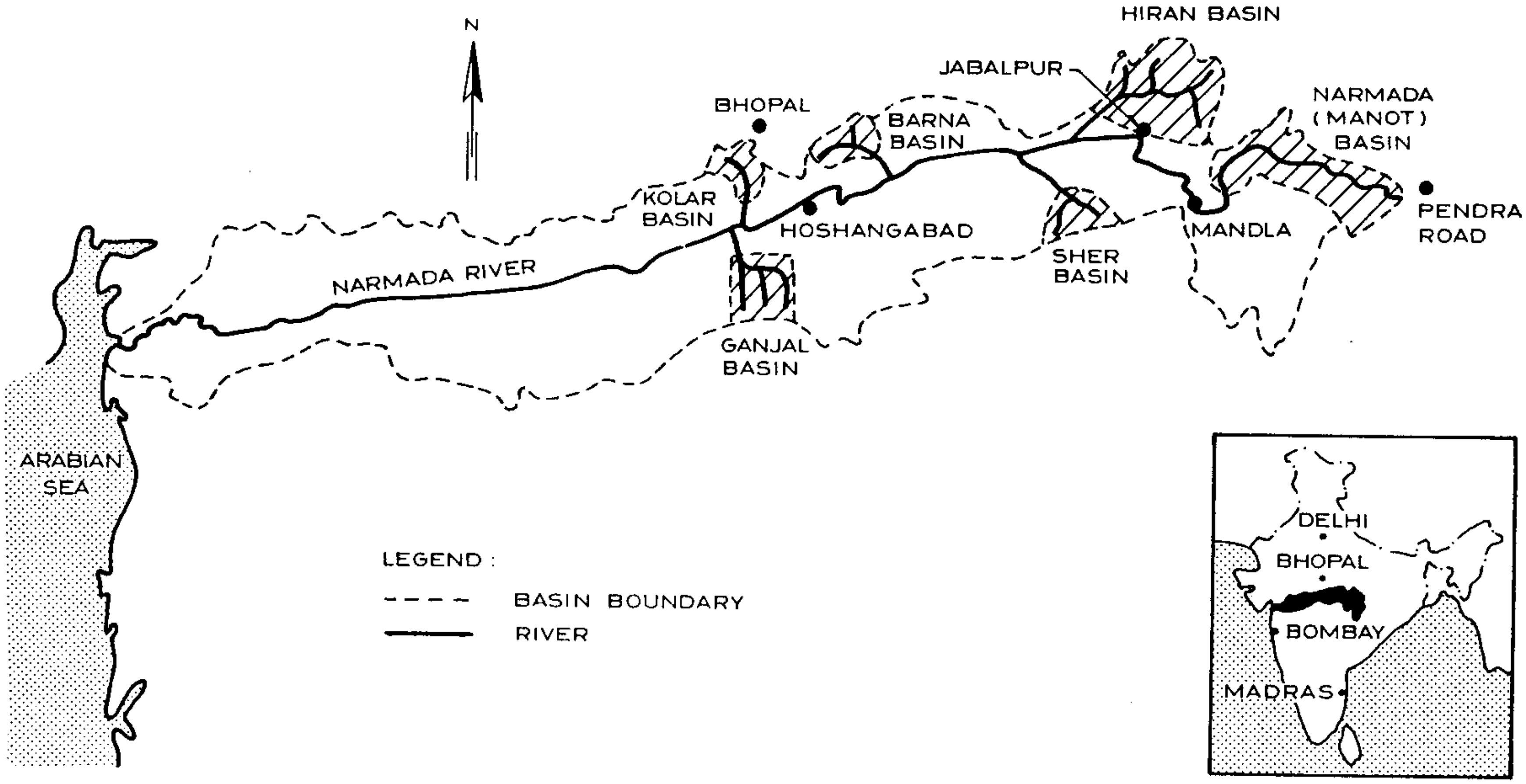


Fig. 3.1. Map Showing Location of Narmada Basin and selected Sub-Basin

soil types of Narmad~~a Bas~~in is presented in table 3.1.

TABLE 3.1

Soil in the Narmada Basin (Districtwise)*

S.No.	Name of the State/District	Type of soils
1.	Shahdol	Red, Yellow, mixed red and black and medium black.
2.	Mandla	Red, Yellow, Shallow black & Skeletal.
3.	Durg	Red loamy, red and yellow
4.	Balaghata	Red loamy, red, yellow and shallow black.
5.	Seoni	Shallow black and skeletal
6.	Jabalpur	Medium and deep black and skeletal
7.	Narasimhapur	Deep black and skeletal
8.	Sagar	Medium black
9.	Damoh	Medium and deep black and mixed red and black
10.	Chhindwara	Shallow black and skeletal
11.	Hoshangabad	Medium and deep black and skeletal
12.	Betul	Shallow and medium black and skeletal
13.	Raiosen	Medium and deep black
14.	Sehore	Medium black
15.	East Nimar (Khandwa)	Medium Black
16.	West Nimar (Khargone)	Medium black
17.	Dewas	Medium black
18.	Indore	Medium black
19.	Dhar	Medium black
20.	Jhabua	Medium black

* Soils of India by S.P. Raychaudhari, R.R. Agrawal, N.R. Datta Biswas, S.P. Gupta and P.K. Thomas

3.2 General Description of Hiran Sub-Basin:

The Hiran is the biggest right bank tributory of Narmada which rises in the Bhaner range in Jabalpur district of Madhya Pradesh near kundam village at an elevation of 600 m at north latitude 23°12' and east longitude 80°27' and flows in a generally south westerly direction for a total length of 188 km to join the Narmada from the right near Sankal village.

It drains a total area of 4,792 sq. km. The sub basin covers part of areas of Jabalpur and Damoh districts of Madhya Pradesh. The location of Hiran sub-basin is shown in Fig. 3.1 and the detailed map of the sub basin is given in Fig. 3.2

In general the climate of the basin is the same as that for Narmada basin which has been discussed in section 3.1. As compared to other five sub-basins for which SHE has been applied under present project, Hiran sub-basin has a flat topography and higher drainage density. The topographic elevations vary from about 600m above sea level to about 320 m above mean sea level. About 57% of the area is under agriculture and the dense forest occupy nearly 36 percent of the total area of the basin. About 80% of the agriculture is practiced on low land area the elevation of which is less than 400 m above mean sea level, however on the hill slope some agriculture is also practiced. Nearly 5% the total basin area is waste land and eroded forests

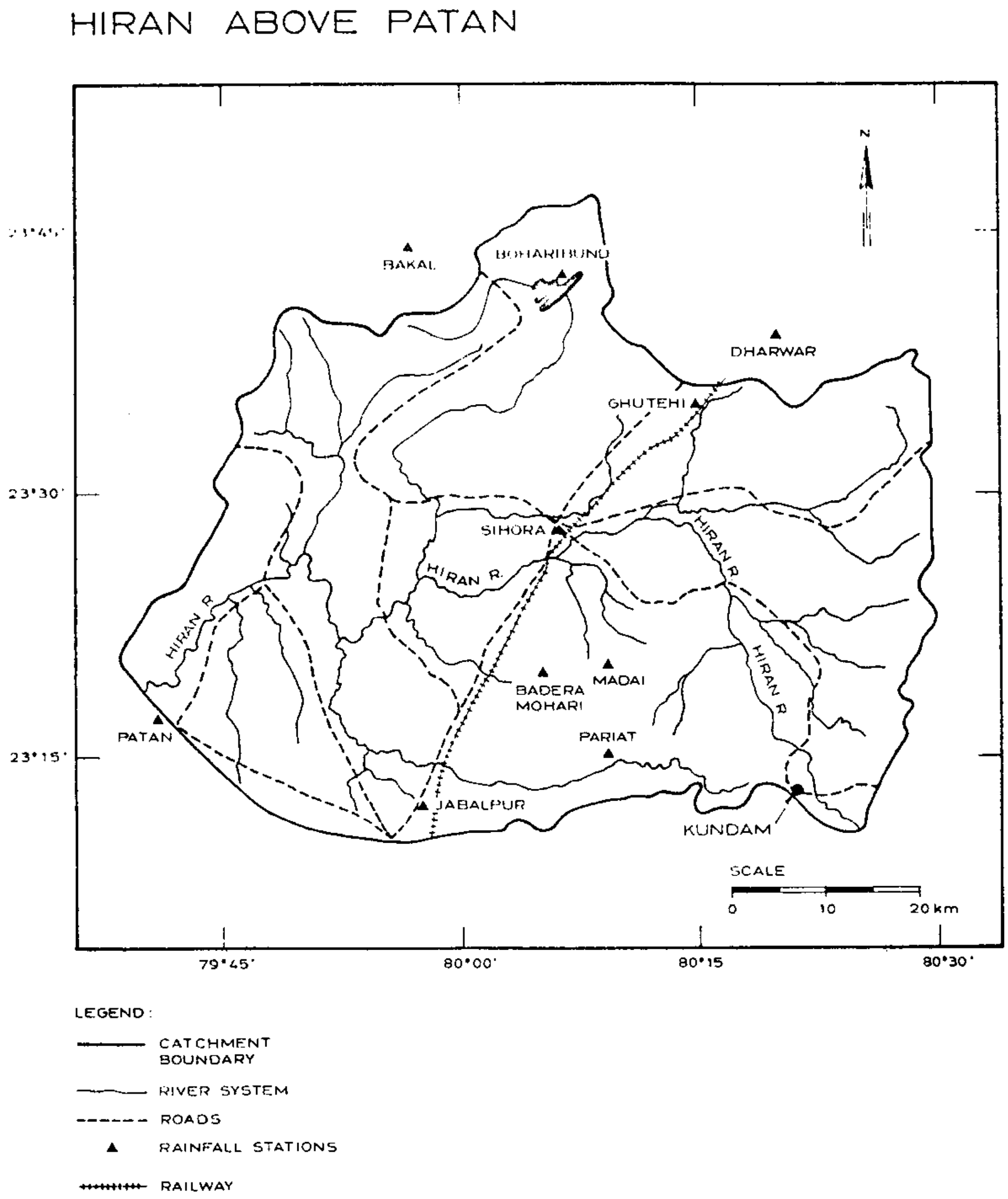


Fig. 3.2 The Hiran basin upstream of the Patan gauging stations. Aslo shown are the locations of relevant rainfall stations.

which exist at higher elevations. Among the major crops sown are wheat and paddy. Paddy is grown during monsoon season and wheat during winter.

The source area, near kundam, is charactertised by low hills with medium forest cover and by flatter areas on hill slope and in the valley with a mixed cover of fields and open forests. The land is flat towards the central region near Sihora with a mainly agriculture cover. The lower part of the basin is generally flat, fertile farm land.

The soils of the basin are mainly black cotton soils which occur in different depths in different region. The low land area (elevation 400m) is mainly deep black cotton soil on which agriculture is practiced. Most of the forests lie on red sandy soil which exists at higher elevations. However, a part of the forests exist on shallow black cotton soils and red loamy soils. The depth of the soil varies from 0.5 m to as much as 12.0 m. The black cotton soil in low land is very deep, but on hill slope the depth of black cotton soil is much less. The root zone depths are of the order of 0.75 m (as viewed from the survey of the small portion of the area). Typically, the water table varies between 4 m to 10 m. The water table level vary on average from 5.5 m depth in May/June to 3.5 m in Nov./Dec. but are by no means restricted to this range. Drawdown of 0.26m to 8.2 m have also been observed seasonally.

The outlet gauging station is at Patan road bridge. The bridge top is at bank top height and is designed hills is likely to be relatively rapid while in the flat agricultural area the field bunds impound the surface runoff, impeding its flow to the main river channels. The construction of fields and field bunds greatly hinders the surface runoff.

During the monsoon, the field bunds ensure that the fields are submerged to a depth of about 1 foot (0.3 m) in support of rice cultivation. In the Bahoribund tank command area, these conditions are further maintained by interstorm irrigation releases. The soil there bcomes saturated below about 5 ft. (1.5 m) from the ground surface. These conditions are maintained until about mid October when the rice is harvested. Cracks to a depth of about 1 m were observed in the black cotton soil. However, premonsoon ploughing of the fields generally obscures at least the surface appearance of cracks in these fields.

3.4 Data Availability:

A data assembly programme was carried out for collecting the required data and parameters needed for the computation of various components of 'SHE'. Since the application of the "SHE" requires variety of data which are available with various Central and State Govt. Agencies. Therefore, the concerned Central Govt. departments and Madhya Pradesh State Govt. organisations were approached for collecting the various types of data. Some of the parametric data have also been collected through the published technical papers, thesis and reports pertaining to the area under study and neighbouring areas. A detailed list of the various organisations/offices from which data were received for this study is given at Annexure 1.

The topographical maps covering the entire basin were obtained from Survey of India. According to standard numbering procedure, the following toposheets combined together provide the topographic information about the Hiran sub-basin.

(i) 55 M/10
(ii) 55 M/11
(iii) 55 M/12
(vi) 55M/14
(v) 55 M/15
(vi) 55M/16
(vii) 64A/1
(vii) 64A/2
(ix) 64A/3
(x) 64A/4
(xi) 61A/6
(xii) 64A/7
(xiii) 64A/8

The principal difficulty with the rainfall data was to locate sufficient stations to provide representative coverage of spatial variability throughout each basin. However, for the present study of the Hiran sub-basin, 10 raingauge stations have been located for which the almost continuous past record was available. But most of these raingauges lie in the left half portion of the basin and the right half portion is not well represented to have spatial variability. Out of these 10 stations only one station, i.e., at Jabalpur is self recording for which the hourly rainfall is available. The location of these stations have been shown on map in fig. 3.2 and the corresponding coordinates are given in table 3.2.

There is only one river gauging site at Patan (at outlet) at which the hourly gauges and daily discharges are recorded.

The time series of hourly gauges and the daily gauge-discharge data were collected for the Patan site from Central Water Commission. The rating curves for different years were also collected. The cross-sectional dimension of the river only at the gauging site is available.

Daily pan evaporation data were collected for the site at Jabalpur. No other pan evaporimeter is located in the basin.

Land use maps were provided by Narmada Valley Development Authority on a scale of 1:250,000 but are currently available only to the west of 80°E longitude. Information regarding landuse were also obtained from 1:50,000 topographic maps.

Soil distribution map is available for the basin only to the west of 80°E longitude, which were obtained from Narmada Development Authority. Soil distribution information were also obtained from 1:2 million scale map in the Agricultural Atlas of India.

Soil and vegetation properties were collected from the various soil survey reports pertaining to the area, published research papers and from published work of Agricultural Research Stations.

Ground Water table observations for 38 wells evenly distributed within or close to the basin, two times in a year - before and after monsoon for a number of years were obtained.

The data availability for the basin is summarised in Table 3.2 .

Table 3.2 Data availability for the Hiran basin (December 1989)

DATA TYPE	DATA AVAILABILITY	
Rainfall	<u>DAILY</u>	
	Patan :	1978-October 1988
	Sihora :	1978-February 1989
	Pariat :	1981-June 1987
	Badera Mohari:	1981-87
	Madai :	1978-88 (except March, April, December 1987)
	Ghuteli :	1978-89 (except April-June 1984 & October 1985)
	Dharwar :	1981-88 (except March-May 1987 & January 1988)
	Boharibund :	1981-February 1989
	Bakal* :	1981-March 1989
	Jabalpur (Adhartal) :	1978-Feb. 1989
	<u>HOURLY</u>	
	Jabalpur :	1978-86, 1987 (August-September, out of order January-July)
	* Station lies outside the basin.	
Discharge	Patan (outlet) - daily gauged discharge 1979-May 1988; hourly stage record for monsoons 1980-87	
Evapotranspiration	Jabalpur - daily pan evaporation data: 1978-88	
Well observations	Observations for 38 wells evenly distributed within or close to the basin, two times per year - before and after monsoons, May & October 1978-88	
Channel cross-section	Surveyed at Patan; 5 rough sections between Hiran source and Sihora	
Rating curve	Patan: monsoons 1981-86	
Boharibund tank	Elevation/capacity relationship and daily elevation during monsoons 1981-88	

4.0 DATA PROCESSING AND PREPARATION

4.1 General:

The raw data collected cannot be used direcatly for the SHE application study as it may contain discrepancies and there may be gaps in time series for which the data do not exist for various reasons. Therefore, it becomes necessary to process the data to have a continuous record and possibly to rectify the errors of the raw data. The processing of various type of data for 'SHE' application also include bringing of the data into the format as required for 'SHE' model. In this chapter, the processing of various type of data have been discussed alongwith the data organisation for simulations study using the SHE Model.

4.2 Processing of Topographical and River Network Data:

The sub-basin boundary was marked on the toposheets (1:50,000 scale) and was digitized using a electronic digitizer by taking a suitable origins, thus the points so digitized are recorded in the computer by its x and y coordinates during the process of digitization. Similarly, the river network containing all the rivers and channels were digitized alongwith the digitization of all the contours. During the digitization of the contours, the point digitized is recorded in the computer by its x,y and z coordinates, z showing the elevation of the contour (or the value of the contour). The digitized river system data with the appropriate numbering of the channels based on order of streams were processed to yield the data into a format suitable for plotting the river system using plotting programe of SHE.

Once the boundary of the sub-basin is digitized, basin can be discretized in plan into square grids of required dimension by running SHE-AF software. The digitised data of contours over the entire basin were used to find out the elevations at each node of the grid and the average elevation of each grid by using a suitable interpolation software for a 500m grid size as the basic grid size. 500m grid was selected because in this way when the values will be extended for coarser grid, it would involve less errors. The elevations for 1km , 2km , 4km , grids and likewise can be obtained from the elevations obtained for 500 m grid size by running SHE.AF. The discretization of area into computational grid network and representation of channel paths by the sides of the grids, converts the basic network into network with squares. Digitized and model river system dimensions for 1km x 1km , 2km x 2km and 4km x 4km are given in Fig. 4.1, 4.2 & 4.3 respectively. The dizitized topography is shown in fig. 4.4 for 2km x 2km grid. The coloured plot of topography on the grid network with contours (based on interpolated elevations at grid points) is given in fig. 4.5 . The grid and channel network dimensions for different grid sizes are shown in table 4.1 and in fig. 4.6.

The model simulation was limited to 130km length of the Hiran tributary and the 4064 km^2 catchment defined by the Central Water Commission gauging station at Patan. For calibration 2km x 2km grid was taken because for the finer grid than this the simulation would result in impractically long computer run times.

4.3 Processing of Soil and Vegetation Data:

Soil maps of the basin was taken from the Agricultural Atlas of india (1:2 million scale) and was enlarged and digitized. Then the map was suprimposed on the grid map of the basin of the appropriate grid size. For the soil distribution five type of soils were considered, viz., deep black, shallow black, red sandy, red loamy and medium black. Fig. 4.7 shows the distribution of soils on grid network.

The land use pattern were taken from the land use map provided by Narmada Valley Development Authority for the portion of the basin west of longitude 80^0 E and for the portion east of 80^0E was taken from the 1:50,000 topographic maps (toposheets). The land use map thus prepared was digitised, and was suprimposed on the grid network. Fig. 4.8 shows coloured landuse pattern for Hiran Sub-basin. Based on data availability only three types of vegetation were considered, viz. cultivation, thick forest and eroded land. The above mentioned basic divisions of landuse were further split into components for hilly or upland areas, semi hilly or hill slope areas and low land areas, giving a possible total of nine categories. This type of distribution for Hiran sub-basin is given in fig. 4.9 and table 4.2. The range of elevations for low land semi hilly and hilly regions are given as follows:

(i) low land elevation $\leq$ 440m

(ii) semi hilly elevation between 440m and 480m

(iii) hilly elevation $>$ 480m

Table 4.1

Grid and Channel Network Dimensions for Different Grid Scales

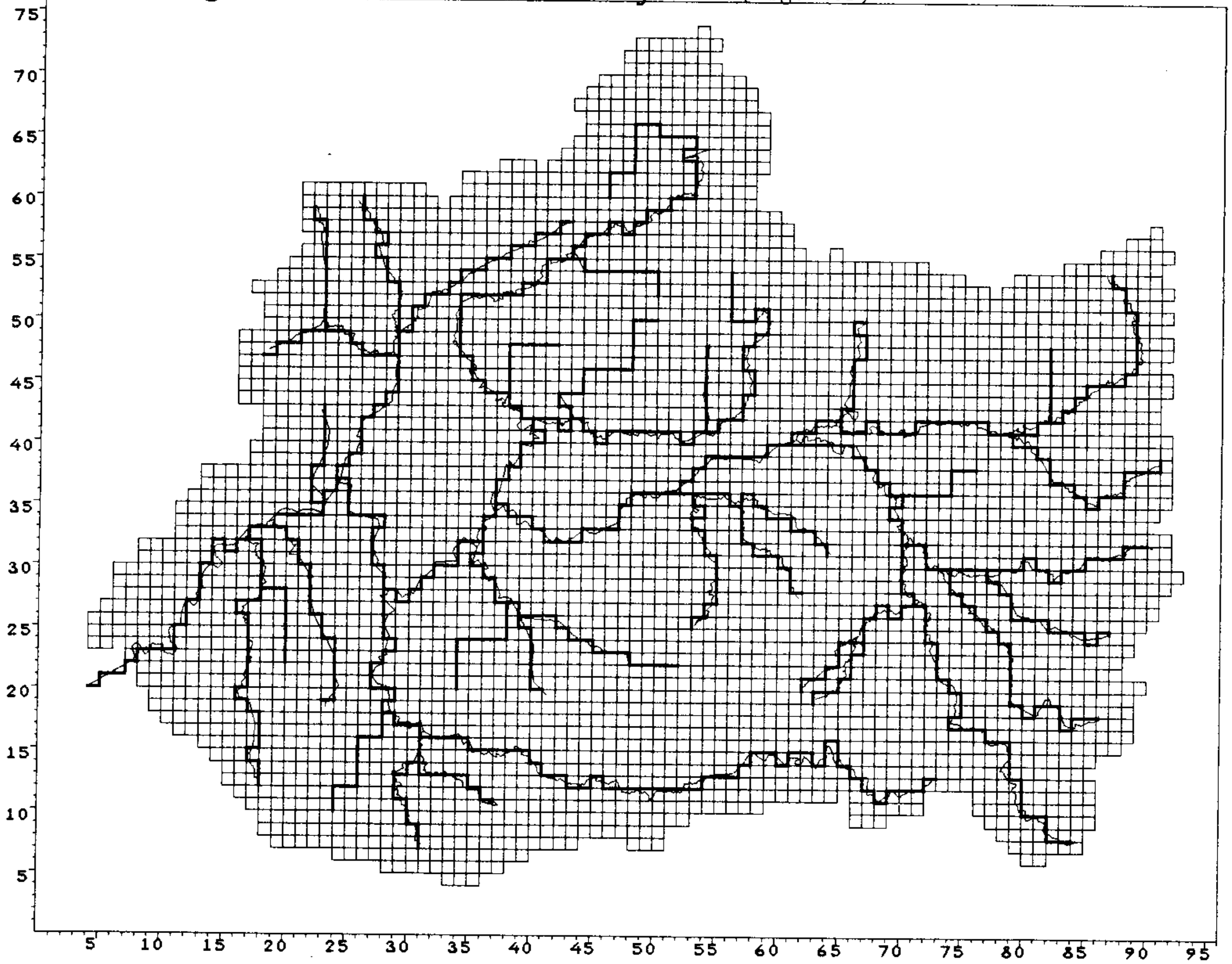
Grid Square size km. x km.	Represented km^2	No. of grid squares representing the basin	No. of River links representing the river system	Ratio of no. of links to no. of squares
0.5 x 0.5	4032	16128	1746	0.11
1 x 1	4026	4026	871	0.22
2 x 2	4060	1015	413	0.41
4 x 4	4064	254	175	0.69

TABLE 4.2

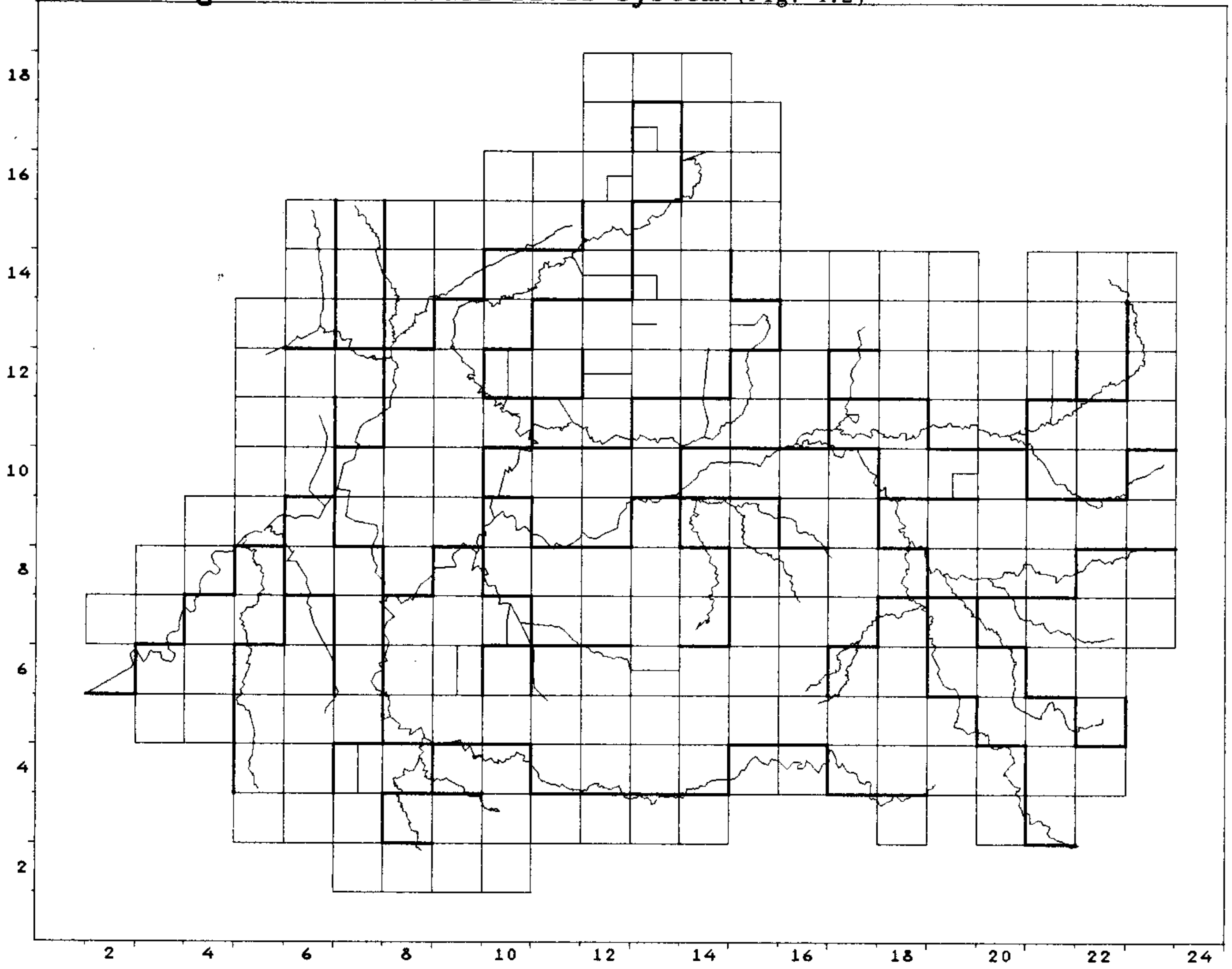
Distribution of each Land-use Type

S.No.	Land Use		Percentage of Basin area covered by each sub category
	Basic Category	Sub Category	
1.	Agriculture	Low land	50.8
		Semi hilly	2.8
		Hilly	5.0
		Total	58.6
2.	Dense forest	Low land	14.9
		Semi hilly	9.4
		Hilly	11.9
		Total	36.2
3.	Waste land	Low land	4.5
		Semi hilly	0.3
		Hilly	0.4
		Total	5.2

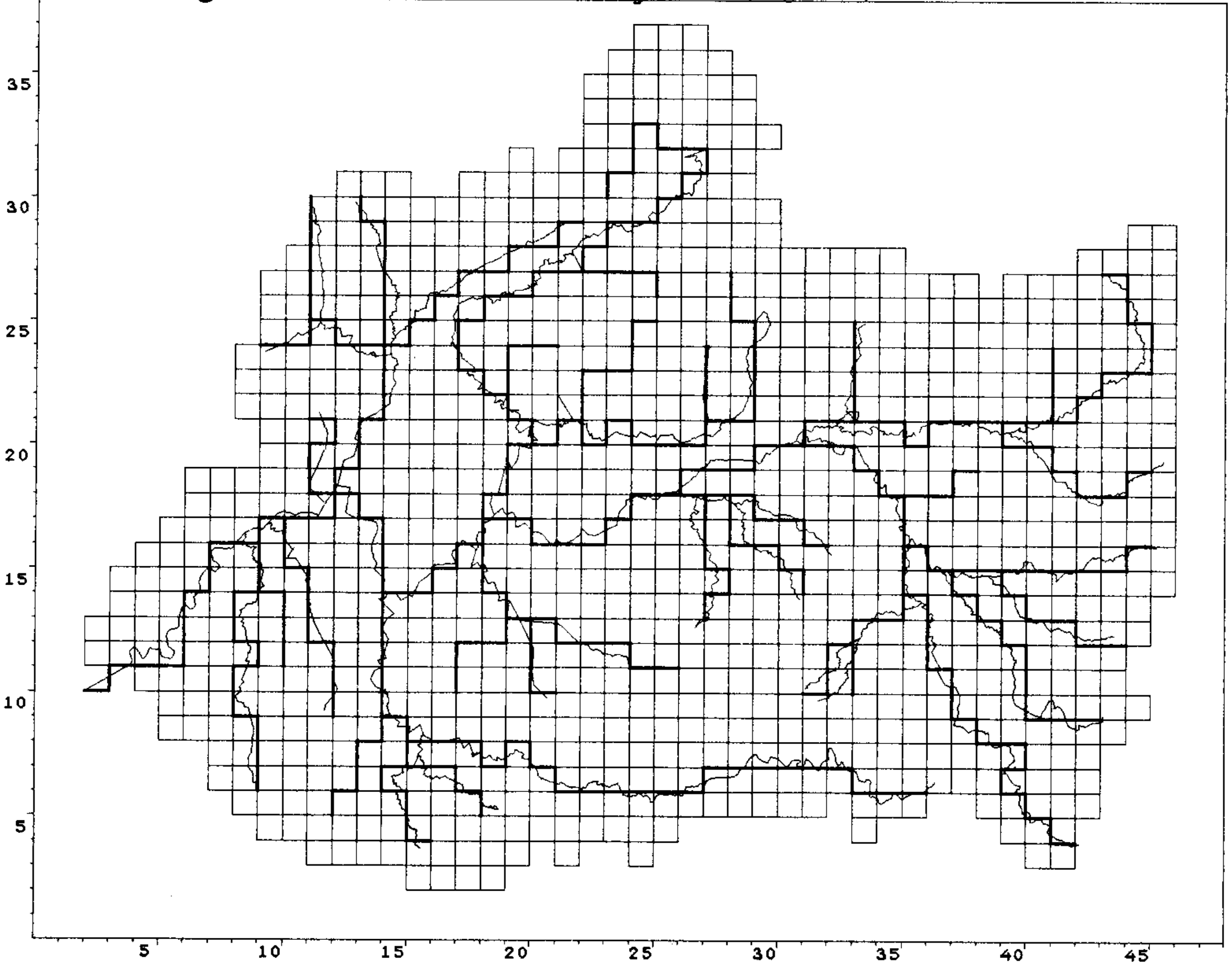
Hiran, digitized and model river system. (Fig. 4.1)



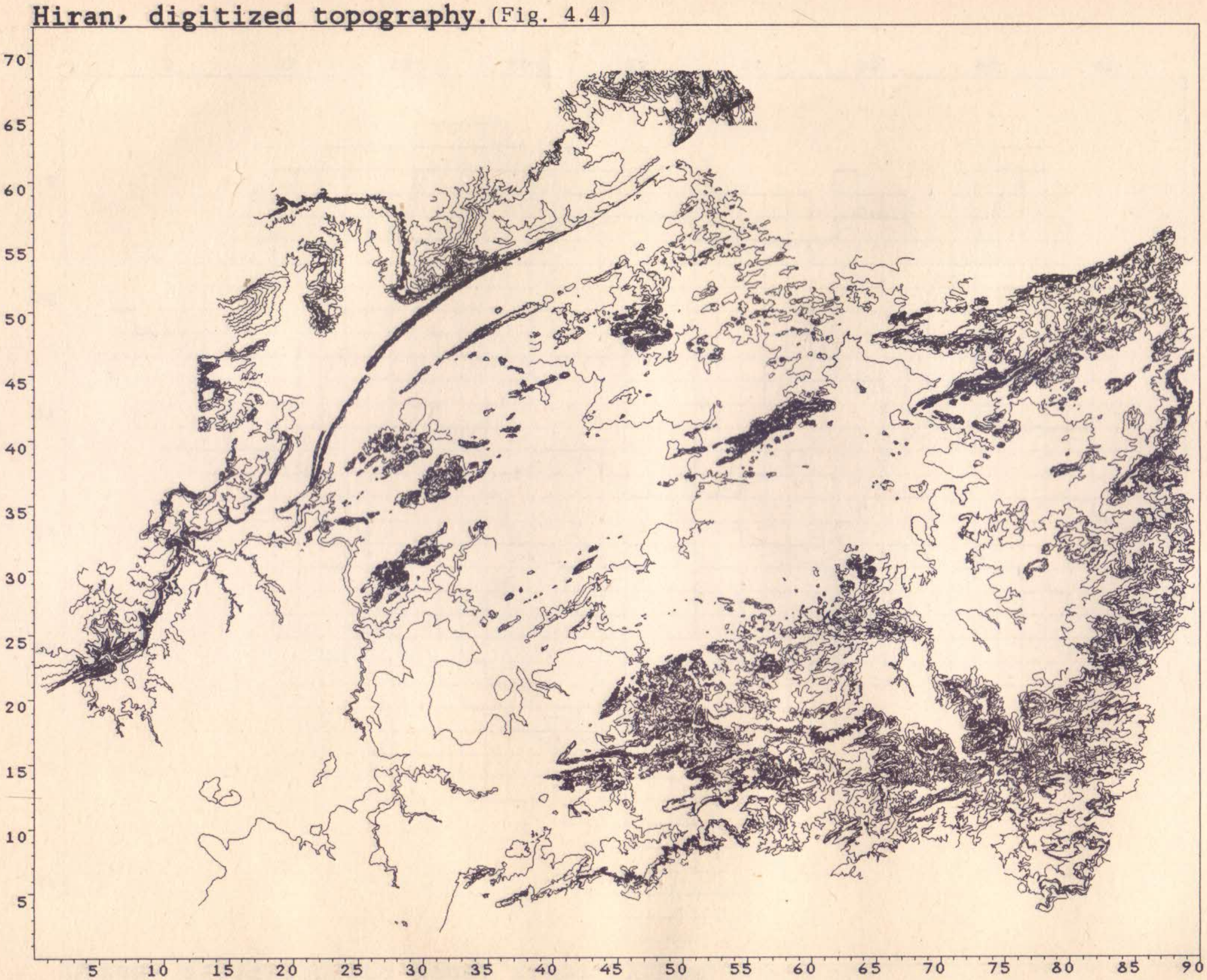
Hiran, digitized and model river system. (Fig. 4.2)



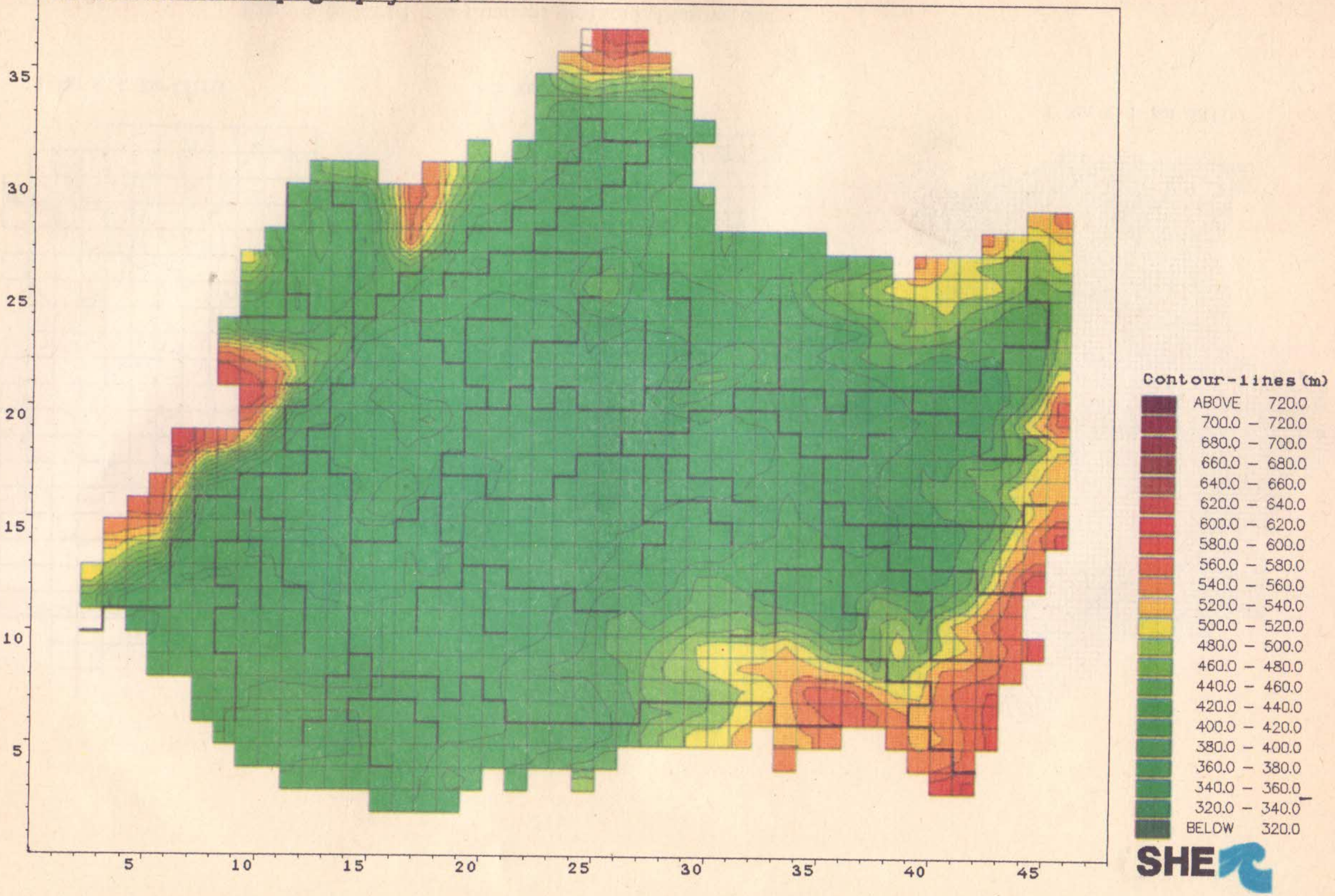
Hiran, digitized and model river system. (Fig. 4.3)

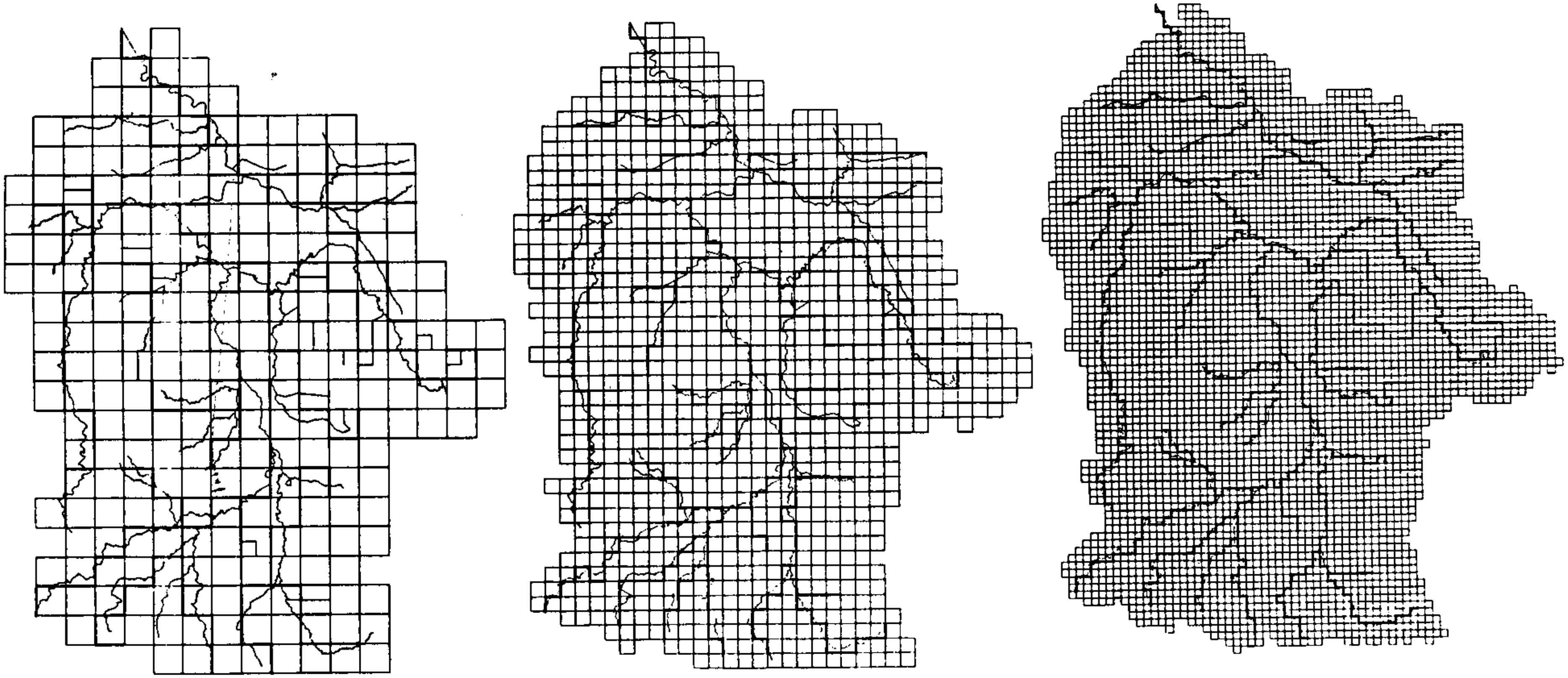


Hiran, digitized topography.(Fig. 4.4)



Hiran, model-topography.(Fig. 4.5)





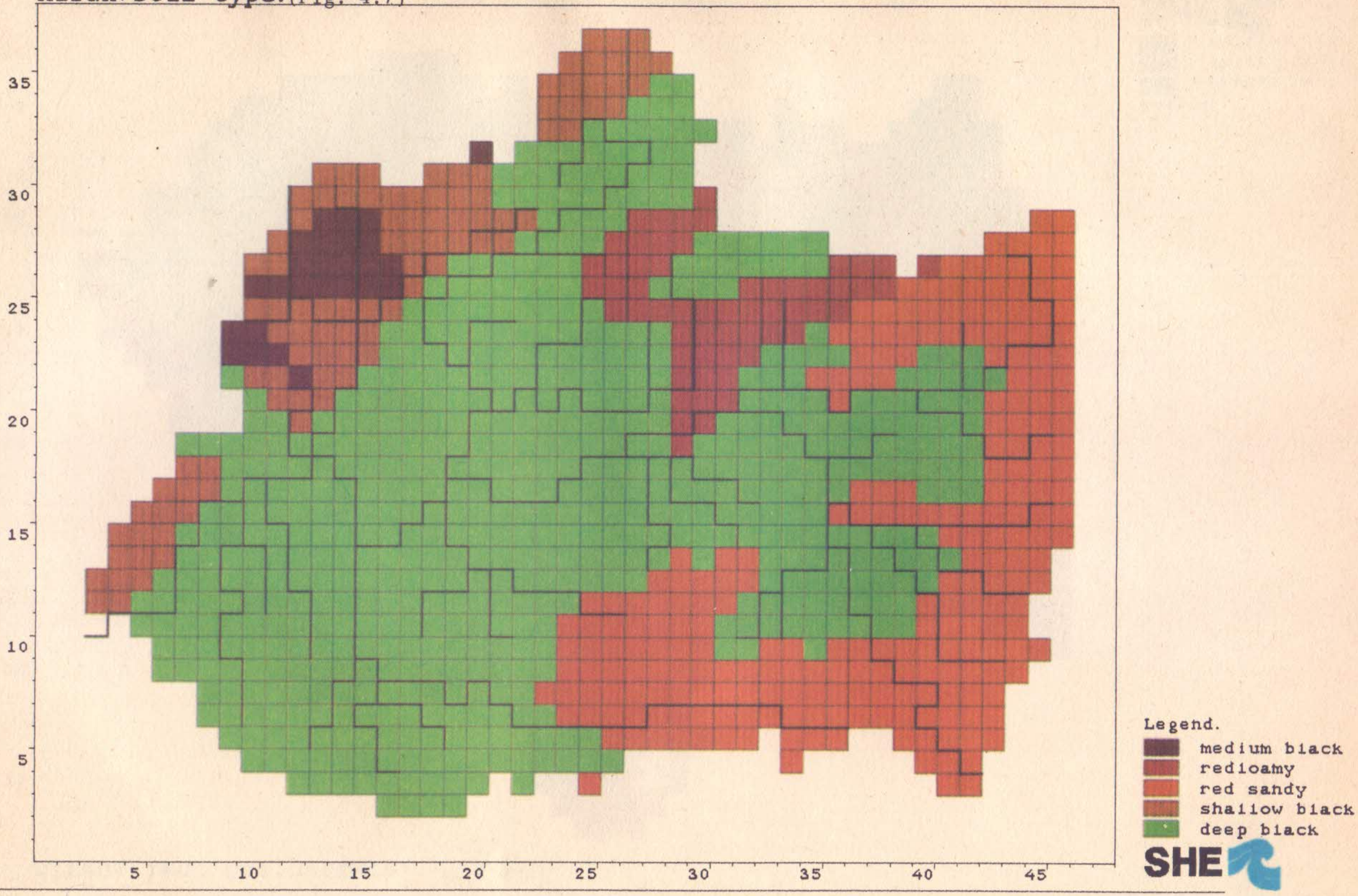
4 Km x 4 Km GRID

2 Km x 2 Km GRID

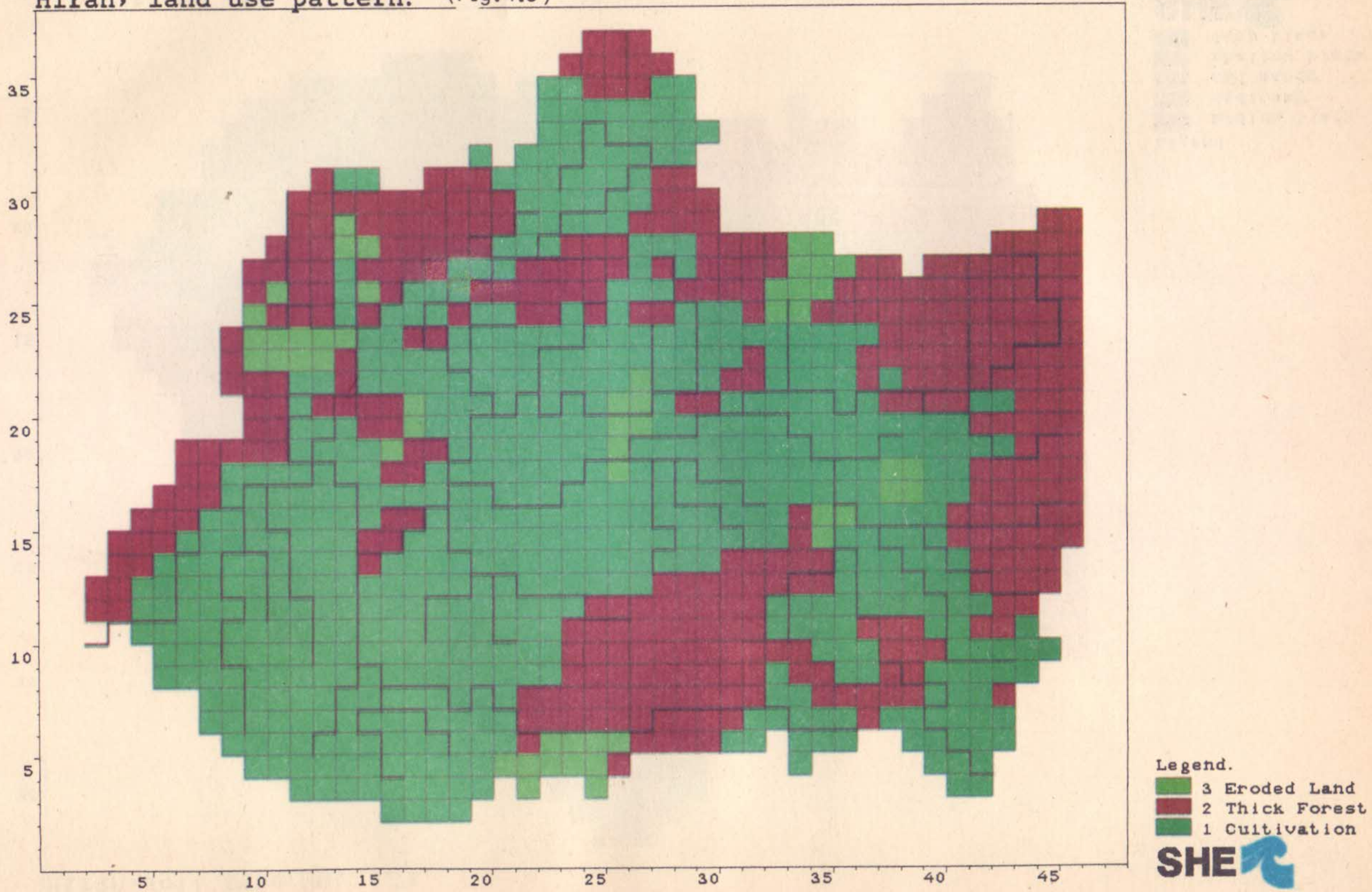
1 Km x 1 Km GRID

Fig. 4.6: Grid and Channel Network Dimensions

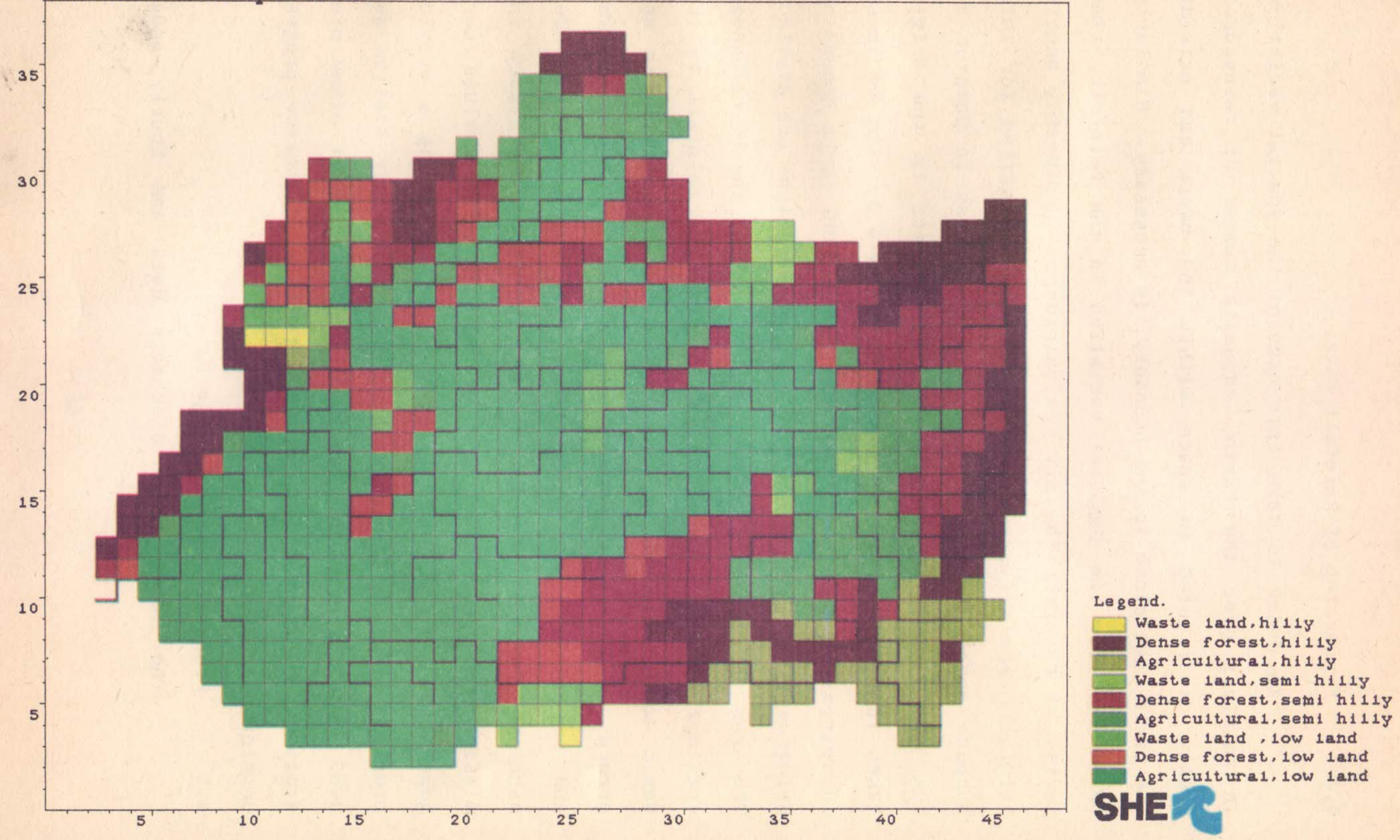
Hiran, soil type. (Fig. 4.7)



Hiran, land use pattern. (Fig.4.8)



Hiran, landuse pattern. (Eig. 4.9)



4.4 Processing of Rainfall Data:

In order to take into account the spatial variation in rainfall over the basin, adequate number of raingauges evenly distributed in space within the basin and outside the basin but close to the boundary, is necessary. Similarly, to account for the temporal variation in the rainfall, time series of rainfall for all the rainguages (preferably hourly rainfall) are required. The raingauges identified for this purpose based on data availability are given in Chapter 3. The coordinates of raingauges with respect to the origin taken for grid-network is listed in table 4.3. Out of these 10 raingauges only one at Jabalpur is a SRRG (self Recording Raingauge) for which hourly rainfall observations are available. The area of the basin represented by each of the 10 raingauge stations is shown in fig. 4.10 . Since the rainfall is the basic input data its processing for consistency checks and errors is necessary otherwise, it will affect the entire simulation and can mislead the interpreter. The rainfall records for each of the stations was checked for its consistancy and missing records. The missing daily rainfall values were generated using the distance power method using a service program. The hourly rainfall data at Jabalpur station was used to distribute the daily rainfall values at other nine stations, into hourly rainfall values by a service program developed for the purpose.

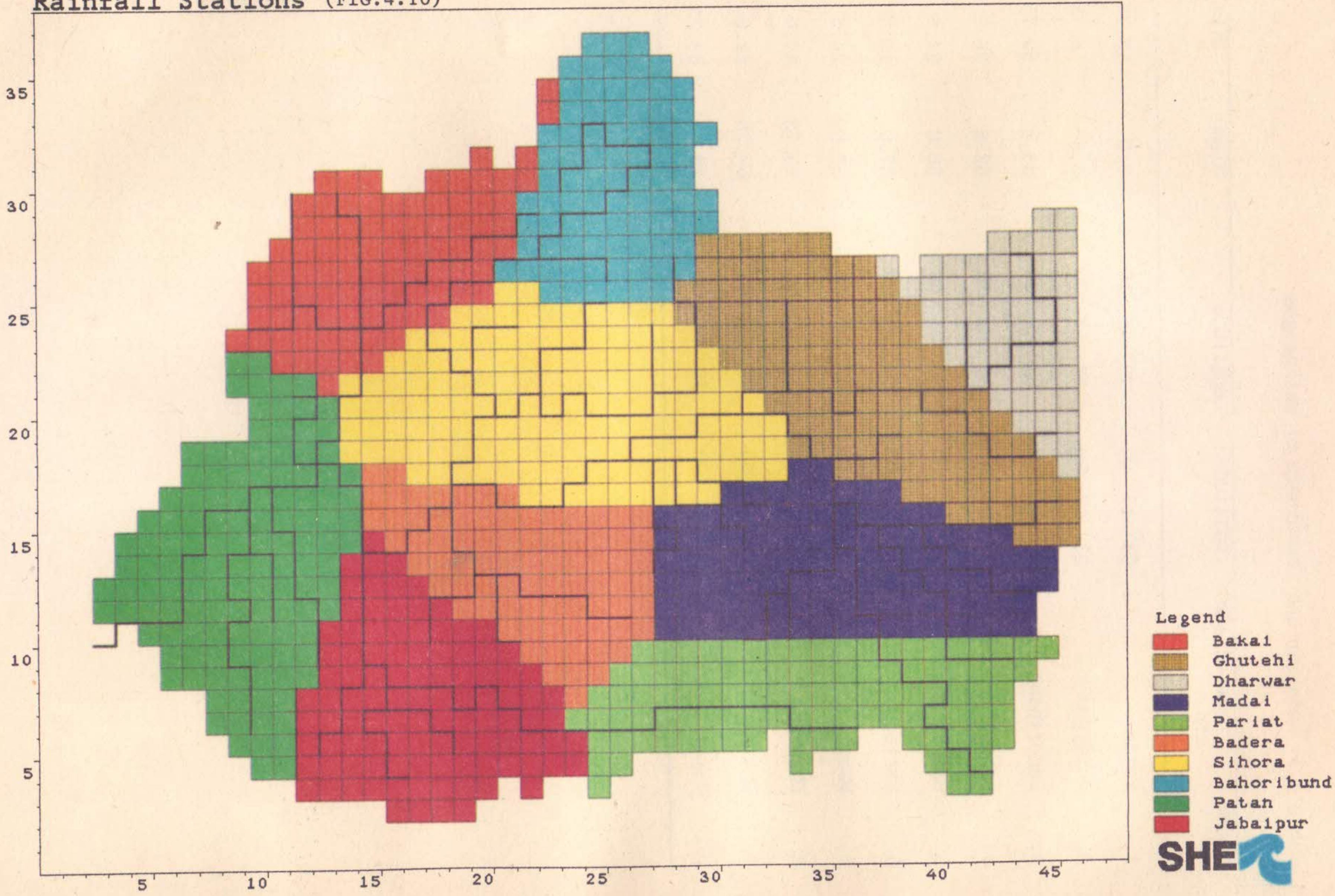
4.5 Processing of Discharge Data:

The daily stage discharge data and hourly gauge

Table 4.3: Location and Coordinate of Raingauges

Sl.No.	Name of the stn.	Latitude			Longitude			X(km)	Y(km)
1.	Patan	23°	17'	00''	79°	41'	15''	9.0	18.75
2.	Jabalpur	23	12	00	79	57	00	36.5	9.75
3.	Bahoriband	23	42	00	80	07	00	53.5	62.75
4.	Sihora	23	29	00	80	06	30	52.5	38.5
5.	Badera Mohari	23	20	00	80	05	00	50.0	24.5
6.	Pariat	23	15	00	80	09	00	57.0	15.0
7.	Madai	23	20	00	80	09	00	57.0	24.5
8.	Dharwara	23	40	00	80	20	00	75.75	59.0
9.	Ghutehi	23	36	00	80	15	00	67.25	51.5
10.	Bakal	23	45	00	79	58	00	36.0	68.25

Rainfall Stations (FIG.4.10)



data at Patan site provided by Central Water Commission were used for the present study. The daily gauge discharge data supplied contains average daily gauge and corresponding average daily measured discharge at Patan gauging site. In each year, only for certain days the values of measured discharge have been specified on other days its calculated value have been given, while the value of average stage is available for each day. Nothing have been specified about the procedure by which the discharge for certain days (days for which claculated values of discharge is reported in the data provided by CWC) were interpolated/extrapolated. The rating curves which were available, appeared to be unreliable. Therefore, it was decided to develop the rating curve (stage-discharge) for each year considering only those discharge value which have been reported as daily average of measured discharge values.

Since, the discharge data are the basic calibration data its processing need careful attention. The analysis of daily state-discharge data has been carried out for each year, in order to fit the equation of the following type.

$$Q = a(G-e)^b \qquad \ldots\ldots (4.1)$$

Where,

Q is the average discharge for the day (m^3/s)

G is the average stage for the day above the fixed datum (m) a,b, & e are the constants.

From the above equation it is obvious that e is the value of stage above datum at which the discharge is zero. In order to calculate the value of e, the data points having discharge less than 10 cumecs were taken and the discharge was plotted against stage and a smooth line was drawn to get the value of stage at zero discharge. Fig. 4.11 shows such graph for the year 1980 and the values of e thus obtained by plotting similar graphs are given in table 4.4.

TABLE 4.4

Calculated Value of e for Different Years

S.No.	Year	Value of e in m
1.	1980	0.80
2.	1981	0.70
3.	1982	0.75
4.	1983	0.70
5.	1984	0.80
6.	1985	0.70
7.	1986	0.70
8.	1987	0.70

Using the above values of e as initial estimate, the regression analysis was carried out to fit the equation 4.1 for each year and the values of e was varied in a narrow range and thus those estimates of a, b, and e was obtained which gave the maximum correlation coefficient and reasonable value of a, b using a service program developed for this purpose.

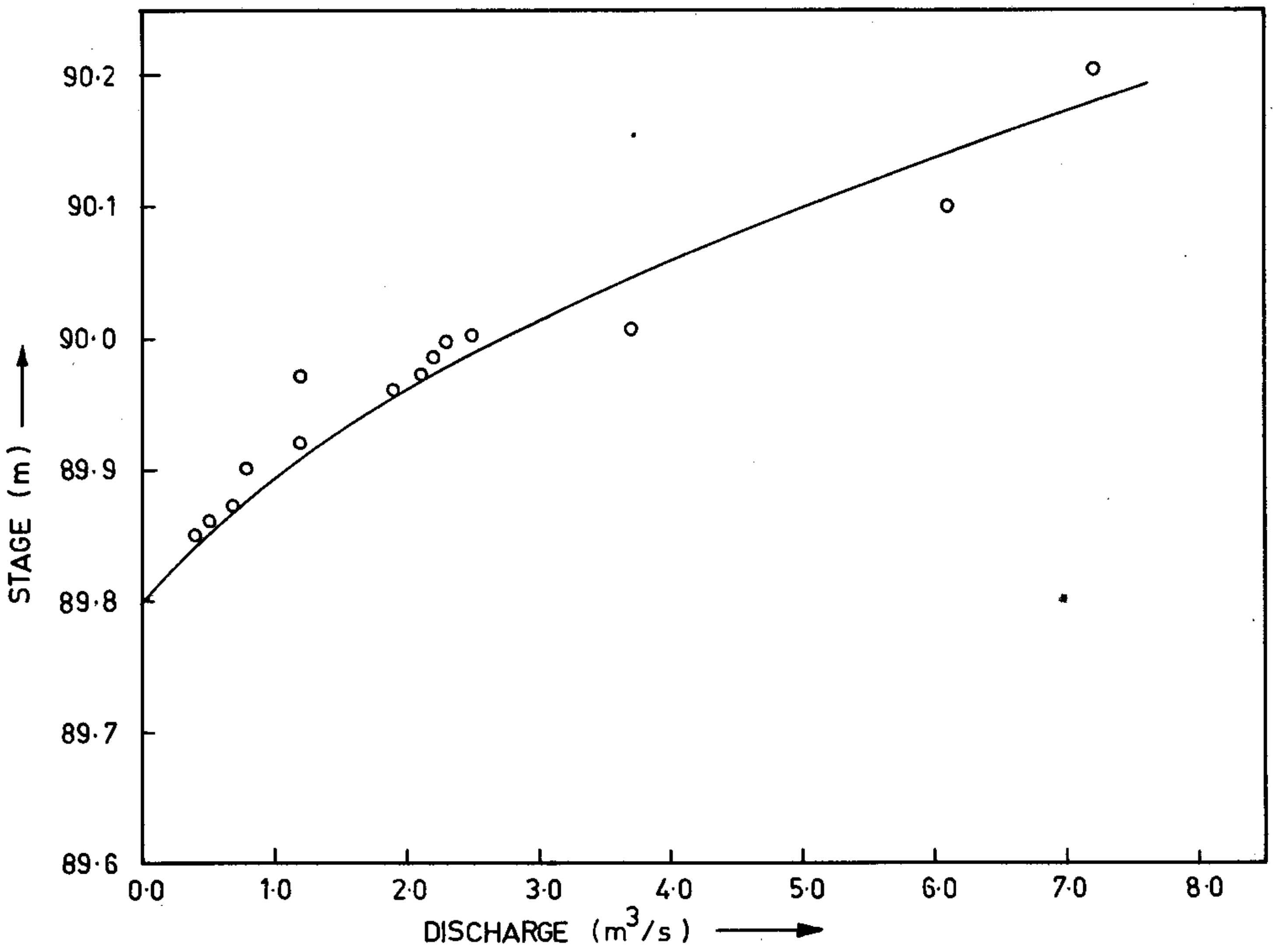


Fig. 4.11 : Stage Discharge Plot for Finding Value of e (for low discharge)

Keeping the above factors into account, the final values of a, b and e thus obtained are tabulated in table 4.5 .

TABLE 4.5

Values of the contants of Rating Curve (Yearwise)

S.No.	Year	a	b	e*	Correlation Coeff.
1.	1980	28.30	1.67	89.70	0.990
2.	1981	32.05	1.62	89.70	0.992
3.	1982	23.40	1.70	89.75	0.998
4.	1983	39.07	1.42	89.70	0.962
5.	1984	28.07	1.59	89.70	0.991
6.	1985	28.22	1.65	89.70	0.965
7.	1986	31.02	1.56	89.70	0.950
8.	1987	30.08	1.62	89.70	0.975

* datum is at 89.0m.

The above rating curves were developed in view to convert the hourly measured stage into corresponding discharge values. Due to to changes in the side slopes of the river cross-section at higher stages, the value of constants of rating curve are liable to change at higher stage. Also during the flood when water reaches on the flood plains the stage-discharge relationship, i.e., rating curve suddenly changes over a particular stage. The data collecated shows that in each year the maximum measured discharge is limited to a certain value and that corresponds to a fixed measured stage value. Actually the rating curve developed for any year is valid only upto this stage value. The yearly maximum measured discharge value for different year are given in table 4.6.

TABLE 4.6

Yearly Maximum Measured Discharge

Datum for stage measurement = 89.0m.

S.No.	Year	Maximum measured discharge m^3/s	Corresponding stage (m) (above datum)
1.	1980	768.0	8.140
2.	1981	112.5	3.100
3.	1982	888.9	8.965
4.	1983	998.9	9.790
5.	1984	882.1	9.000
6.	1985	659.7	7.210
7.	1986	150.6	3.347
8.	1987	1016.0	9.500

The rating curves, the constants for which are given in table 4.5, are applicable only upto corresponding stage value mentioned in table 4.6 for respective years. But in each year the maximum observed stage mentioned above, e.g., for 1980, the equation of rating curve (a=28.30, b=1.67, e=89.70) is valid only upto a stage value of 8.140m but the observed maximum stage in this year is 14.56m, thus the problem is as how the rating curves should be extrapolated to get the discharge values for the corresponding stage lying between 8.140m to 14.560m. (Maximum observed stages for each year as obtained from hourly stage record have been given in table 4.7). In order to solve this problem of extrapolation of rating curve, a log-log plot was prepared for the data of all years taken together, by adjusting the constant e to get an approximately straight line fit. Such a plot is shown in fig. 4.12 . The rating curve equation obtained by this straight line is $Q=24.0\ (G-89.4)^{1.7}$

TABLE 4.7

Maximum Observed Stage from Hourly Stage Records

S.No.	Year	Maximum observed stage above datum (m)
1.	1980	14.560
2.	1981	5.010
3.	1982	9.565
4.	1983	14.170
5.	1984	11.350
6.	1985	9.850
7.	1986	5.94

To check the reasonability of the extrapolation of the rating curve developed for each year, the following procedure was adopted.

1. The cross-section of river at outlet was approximated by a traperidal section (side slopes 45°) with top

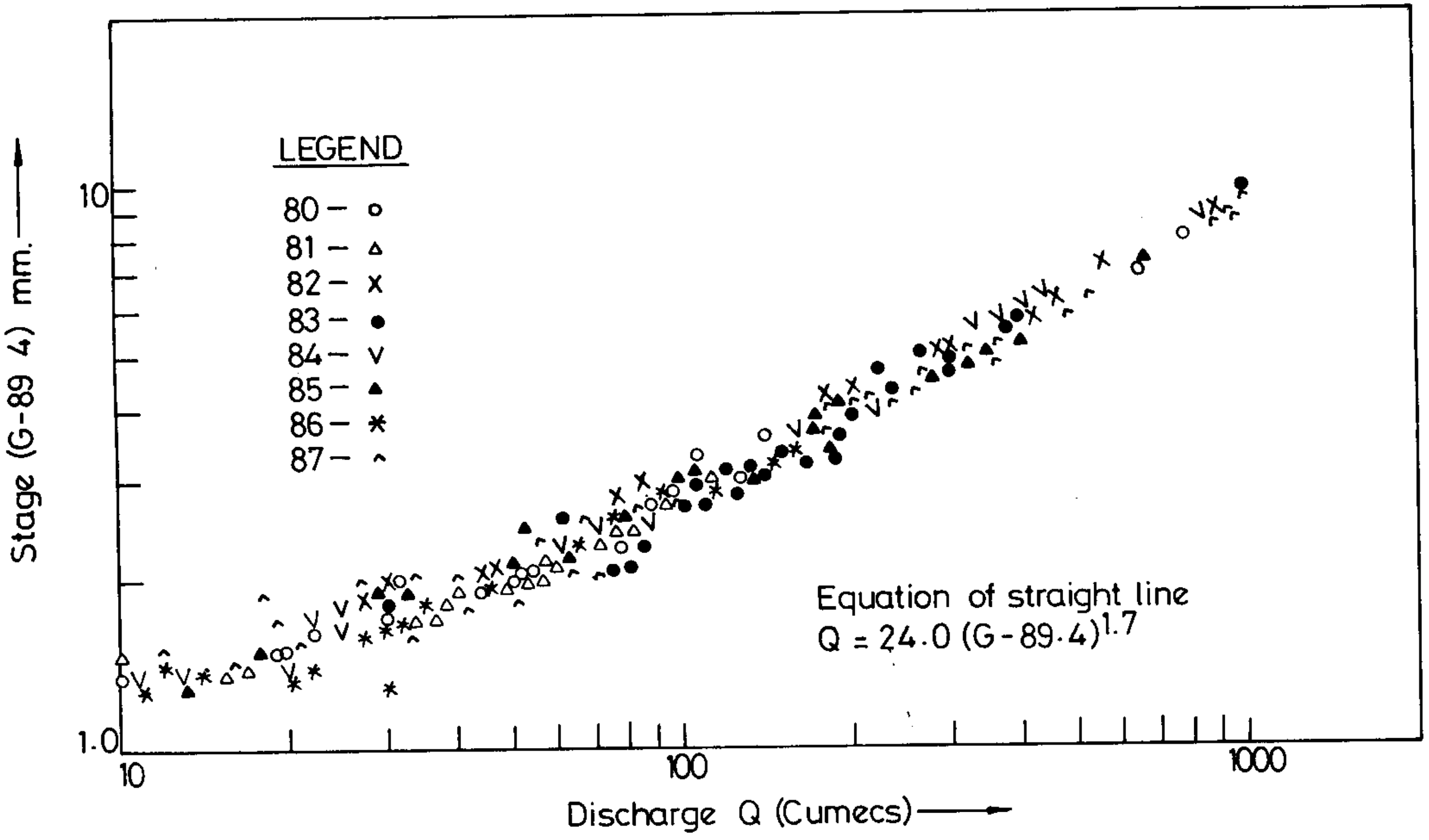


Fig. 4.12 : Stage Discharge Relationship (Date of all years)

and bottom width as 200m and 80m respectively and with a depth of 15m*. The longitudinal slope of the river was calculated at Patan site using digitized data and thus $S^{1/2} = 0.011$ was obtained.

2. If w is the width at height h from bottom of the channel, then

$w = 80+8h$

A = area of cross-section = $(80+4h)h$

d = hydraulic radius = $\frac{A}{W} = \frac{(80+4h)h}{80+8h}$

3. Maximum measured discharge of each year was taken and the value of manning's n was found out using Manning's equation.

$$n = \frac{Ad^{2/3} S^{1/2}}{Qmax}$$

4. Individual year rating curve was used to give the discharge for maximum measured stage of that year, i.e., Q by extrapolation.

5. Calculate cross-sectional area & hydraulic radius for that maximum stage (for that year) using expressions given at step 2.

6. Calculate Q by the following equation.

$$Q = \frac{Ad^{2/3}S^{1/2}}{n}$$

where, value of n was taken from as obtained at step 3. This value of Q is by calculation.

---

* The data for cross-section was obtained during field visit.

7. The two values of Q were compared to check the reasonability of the extrapolation of the rating curve developed for that year.

Tables 4.8 & 4.9 shows the calculations using above procedure. The average value of mannings n was found to be 0.08, i.e., strickler coefficient for channel flow $K=\frac{1}{n}=20.8$. From table 4.9 we see that the discharge obtained from extrapolation of rating curves vary much with respect to the calculated discharge. The stage vs discharge plot on double log **Paper for the data of each year shows two different straight lines, one representing the discharges less than 250 cumec and other representing discharges greater than 250** cumes. One such plot for the year 1983 is given in fig. 4.13. Fig. 4.13 also shows that there exists two different slopes of straight line. One corresponding to lower discharges and other corresponding to higher discharges. The slope of the straight line for discharge greater than 250 curves remains almost same for different years. Therefore, for converting the stage values into corresponding discharge values it was decided to use the rating curve equation of the individual year if the discharge is less than 250 cumecs and if the discharge is greater than 250 cumecs as obtained using individual year rating curve equation, the discharge was calculated using a single equation for all the years, i.e.,

$$Q = 24.70\,(G - 89.40)^{1.65} \quad .... (4.2)$$

The equation 4.2 was obtained by fitting a curve using regression analysis of type given in equation (4.1)

Table : 4.8

Comparison Between Extrapolated and Calculated Discharge

Year	Max^{m} observed stage (m)	$A=(80+4h)h$ (m^2)	$d=\frac{A}{80+8h}$ (m)	$Q=\frac{Ad^{2/3}S^{1/2}}{n}$ (Cumecs)	Q from rating curve (Cumecs)
1980	14.56	2012.8	10.24	2324.8	2104.5
1981	5.01	503.0	4.19	263.8	341.7
1982	9.565	1131.2	7.23	1013.7	946.4
1983	14.17	1936.8	10.02	2030.9	1568.7
1984	11.35	1423.3	8.33	1374.0	1060.4
1985	9.85	1176.1	7.41	1169.1	1088.7
1986	5.94	616.3	4.83	557.0	411.0

Table 4.9

Calculation of n from Daily Observed Data (Stage-Discharge)

Year	Max measured discharge (cumecs) Qmax	Corresponding state (m)	$A=(80+4h)h$ (m^2)	$d=\frac{A}{80+8h}$	$n = \frac{Ad^{2/3}\ S^{Y2}}{Qmax}$	K
1980	768.0	8.14	916.2	6.31	0.047	21.3
1981	112.5	3.10	286.4	2.73	0.057	17.5
1982	888.9	8.965	1038.7	6.85	0.048	20.8
1983	998.9	9.790	1166.6	7.37	0.051	19.6
1984	882.1	9.000	1044.0	6.87	0.049	20.4
1985	659.7	7.210	784.7	5.70	0.044	22.7
1986	150.6	3.347	312.6	2.93	0.049	20.4
1987	1016.0	9.500	1121.0	7.19	0.047	21.3
				Av	0.048	20.8

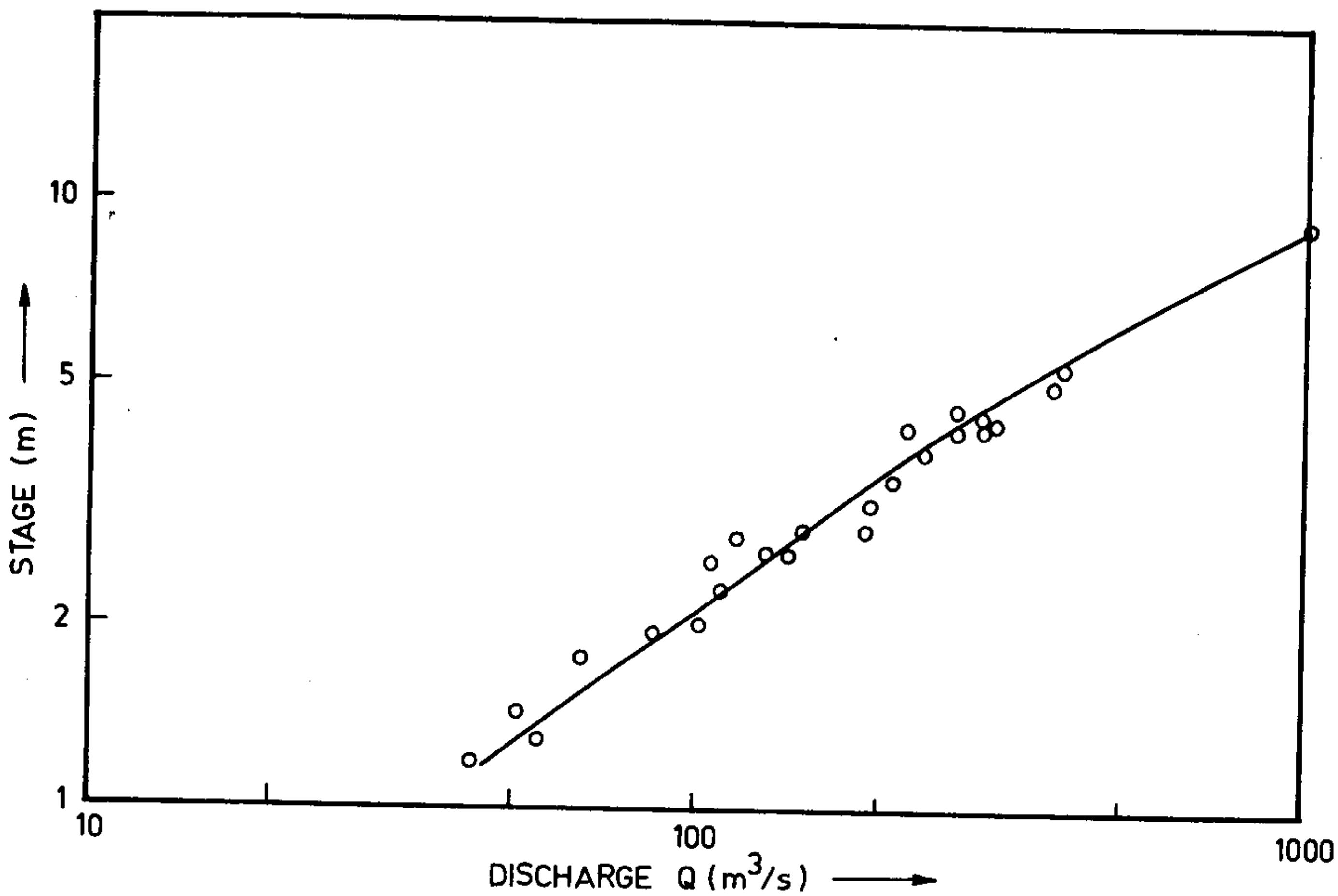


Fig 4.13 : Stage Discharge Plot Showing two slope of Straight Lines

for all the data of all years for which discharges are greater than 250 cumecs.

4.6 Processing of Evaporation Data:

The evaporation data for Jabalpur station was used for the simulation. No other station was available within the basin with evaporation station. The evaporation data of Jabalpur station was multiplied by a coefficient of 0.70 to convert it into potential evaporation. A service program was used to convert the data into 'SHE' format. The monthly average evaporation over the basin is given in table 4.10.

4.7 Evaluation of Parameters:

The evaluation of parameters were done based on the available literature and field survey of the area. For presentation, the evaluation of parameters has been divided broadly into two catagories, i.e., soil parameters, and overland and channel flow parameters.

4.7.1 Soil Parameters:

Direct measurement of some of the soil properties at few sites located in Jabalpur, Patan and Sihora tehsils of the Hiran Basin were obtained from Kausal (1981). These values are listed in table 4.11. Out of the above sites, the sites lying within the basin have been given in table 4.12 along with their coordinates with respect to the selected crigin for plotting the basin map. Fig. 4.14 shows the location of soil properties measurement sites on a soil type distribution map. After identifying the

TABLE : 4.10

MONTHLY AVERAGE EVAPORATION OVER THE BASIN

Year	Month	Pan evaporation (mm)	Potential evaporation (PET) (mm)
1980	1	95.52	66.00
1980	2	125.04	87.84
1980	3	223.92	156.00
1980	4	339.12	236.88
1980	5	471.36	330.24
1980	6	234.24	163.68
1980	7	107.76	75.12
1980	8	103.20	72.48
1980	9	142.56	99.60
1980	10	121.92	86.16
1980	11	92.16	64.56
1980	12	72.00	51.12
1981	1	79.44	54.96
1981	2	119.28	83.52
1981	3	170.40	118.80
1981	4	319.92	224.40
1981	5	350.88	244.80
1981	6	336.72	235.20
1981	7	116.40	81.36
1981	8	121.68	84.96
1981	9	111.60	77.76
1981	10	112.08	78.24
1981	11	82.32	57.84
1981	12	76.56	53.76
1982	1	64.56	45.84
1982	2	89.76	63.12
1982	3	174.24	121.68
1982	4	291.84	203.76
1982	5	270.24	188.40
1982	6	280.08	196.32
1982	7	198.72	138.96
1982	8	68.88	48.00
1982	9	110.64	77.04
1982	10	120.48	84.48
1982	11	77.76	54.24
1982	12	80.16	55.68
1983	1	84.72	59.76
1983	2	108.24	75.36
1983	3	211.44	147.60
1983	4	249.36	173.52
1983	5	354.24	247.68
1983	6	307.20	214.80
1983	7	112.32	78.48
1983	8	110.64	77.52
1983	9	79.92	55.44
1983	10	112.08	78.96
1983	11	90.00	62.88
1983	12	78.72	55.68
1984	1	64.80	44.88
1984	2	89.52	62.88
1984	3	173.52	121.44
1984	4	270.48	189.60
1984	5	464.64	325.44
1984	6	283.92	198.48
1984	7	125.52	88.08
1984	8	74.40	51.84
1984	9	102.96	71.52
1984	10	124.80	87.12
1984	11	98.64	69.12
1984	12	79.92	56.40
1985	1	72.96	50.88
1985	2	95.28	66.96
1985	3	188.16	131.52
1985	4	258.72	181.20
1985	5	361.44	253.44
1985	6	243.84	169.44
1985	7	114.00	79.44
1985	8	78.00	55.20
1985	9	107.28	75.12
1985	10	90.48	63.12
1985	11	89.28	63.60
1985	12	87.84	62.16
1986	1	81.36	56.64
1986	2	77.04	54.24
1986	3	165.36	116.16
1986	4	259.92	182.40
1986	5	350.88	245.52
1986	6	246.48	172.80
1986	7	101.52	70.80
1986	8	102.48	71.28
1986	9	127.68	88.56
1986	10	138.72	96.72
1986	11	102.96	72.48
1986	12	70.56	49.44
1987	1	63.84	44.88
1987	2	89.04	62.16
1987	3	174.00	121.44
1987	4	288.24	201.84
1987	5	331.20	231.36
1987	6	32[illegible].16	224.64
1987	7	154.80	108.48
1987	8	113.52	79.68
1987	9	104.16	72.72
1987	10	103.68	72.96
1987	11	85.68	59.76
1987	12	66.24	46.32

TABLE 4.11

Important physical properties of soils of the Jabalpur district (Kansal, 1981).

LOCATION Tehsil & Village	SOIL TEXTURE	SOIL MOISTURE CONTENT (%) AT SUCTIONS			SOIL BULK DENSITY g/cc	INFILTRATRATION RATE mm/hr	AVAILABLE WATER %
		0 bar	1/3 bar	15 bar			
<u>JABALPUR</u>							
Panagar	clay	40.44	29.56	14.67	1.35	3.5	14.9
Kheri Farm (JNKVV)	clay	53.0	33.27	16.35	1.40	2.0	16.92
Adhartal Farm (JNKVV)	clay	47.2	33.2	20.3	1.35	3.0	12.9
Bargi	clay	51.3	39.8	21.2	1.30	3.0	18.6
Kundam	clay	57.9	31.8	17.9	1.32	3.0	13.9
Mean value		50	33.5	18.1	1.34	2.9	15.4
<u>PATAN</u>							
Belkheda	clay	52.0	35.9	19.6	1.30	2.8	16.3
Suriya	clay	60.2	42.8	24.8	1.25	2.5	18.0
Poondi	clay	70.4	39.6	25.9	1.32	4.0	13.7
Mean value		60.9	39.4	23.4	1.29	3.1	16
<u>SIHORA</u>							
Majholi	silty clay loam	54.6	27.8	14.4	1.35	5.0	13.4
Manjhganwa	clay	53.4	38.4	22.7	1.35	-	15.7
Dimarkheda	clay	53.2	34.4	20.0	1.31	8.0	14.4
Mean value		53.7	33.5	19.0	1.34	6.5	14.5

TABLE - 4.12

Soil Properties Measurement Sites in Hiran Sub Basin and their Coordinates

Sl. no.	Measurement sites	Coordinates x (km)	Coordinates Y (km)
1.	Panagar	21.5	9.5
2.	Adhartal	19.5	5.5
3.	Kundam	39.5	6.5
4.	Belkheda	12.5	8.5
5.	Poondi	6.5	8.5
6.	Majholi	16.5	21.5
7.	Majhganwa	30.5	15.5
8.	Dhimarkheda	52.5	19.5

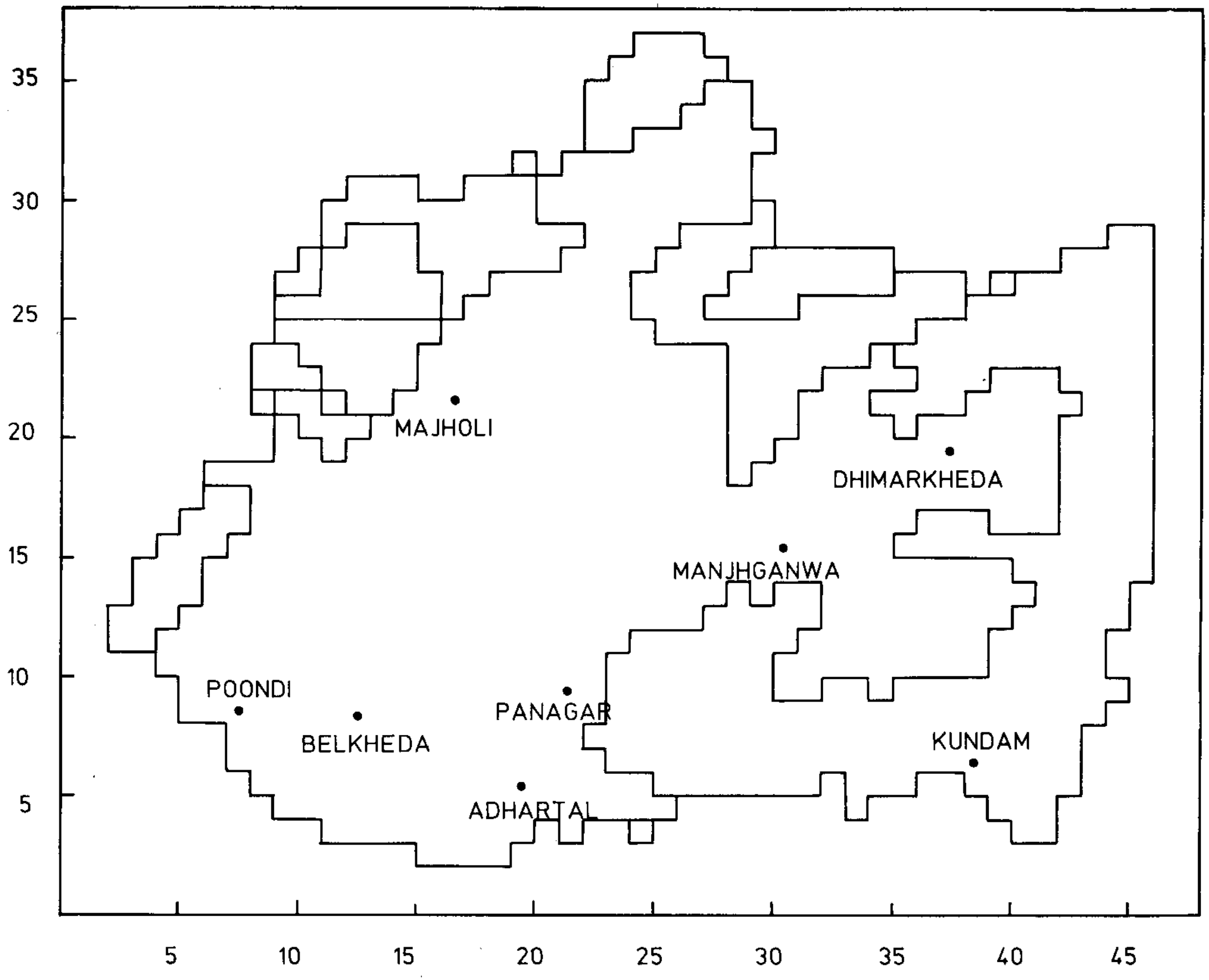


FIG. 4.14 - LOCATION OF SOIL PROPERTIES MEASUREMENT SITES

soil properties measurement sites in each type of soil the average values of soil properties were calculated taking the average of such values obtained for the sites comming under each soil type. Thus, the values obtained were taken as the first approximate values for initial calibration. These values are given below:

i) For shallow black, medium black and deep black soils (Since the variation was not much, single value was taken to be appropriate for trial calibration): water content at saturation θ_s = 0.53 and infiltration rate (Ks) = 0.1 m/d

ii) For Red loamy soils: θ_s = 0.58 and Ks = 0.072 m/d (This type of soil occurs near Kundam.)

iii) For Red loamy soils: θ_s = 0.40 and Ks = 0.14 m/d

The soil moisture retention curve used in earlier simulation study for Kolar basin was adopted for the present study. This retention curve is based upon the data received from Indian Council for Agricultural Research (ICAR, 1989). This curve is shown in fig. 4.15.

Summary of insitu measurements of the variation of moisture content with tension for a Jabalpur vertisol (Kauraw, 1982) is given in table 4.13. As obtained from available literature, the information on well levels for fourteen wells in the Jabalpur, Patan, Narsinghpur and Gadarwara tehsils is given in table 4.14.

From available geohydrological reports supplied

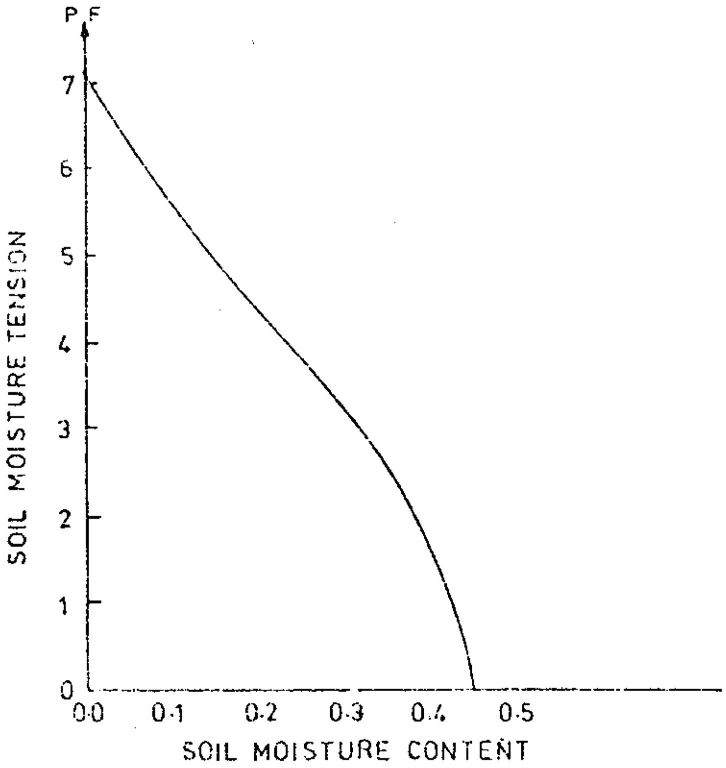


Fig.4.15 Soil moisture retention curve used for all soil types in the simulations. Based on data from ICAR.

TABLE : 4.13

Summary of in situ measurements of the variation of moisture content with tension for a Jabalpur Vertisol (From Kauraw,1982).

SOIL TENSION bar	MOISTURE CONTENT (%)		
	Mean value over depth	At 0-0.2 m depth	At 1.6-1.8 m depth
0.3	35.8	35.5	36.0
15	29.1	26.5	30.0
20	28.1	26.0	29.5
30	26.9	24.4	28.8

TABLE : 4.14

Summary of information on well levels for fourteen wells in the Jabalpur, Patan, Narsinghpur and Gadarwara Tehsils. (Kauraw, 1982)

	DEPTH (m) TO WATER TABLE IN		
	June	August	October
Mean	8.9	3.7	5.6
Maximum	23.1	18.1	19.9
Minimum	4.3	0.5	1.5
Standard deviation	5.7	5.8	4.9

Table 4.15: Soil Type and Depth Obtained from Bore-log chart (Kundam Block)

SlNo.	Village	x (km)	y (km)	soil type	Depth (m)	Sl.No. of well log
1.	Kalayanpur	74	17	Moorum	0.50	43
				Boulder with soil	7.50	
2.	Mahagwan	67	15	Soil	1.00	61
				Boulder	3.50	
3.	Karanpura	76	15	Black soil	3.90	2
				Rock (Hard Moorum)	-	
4.	Kubarhat	86	17	Black soil	1.50	5
				Hard rock	-	
5.	Padariya	85	12	Black soil	3.00	1
				Rock	-	
6.	Tithakala	85	23	Red soil	3.00	3
				Rock (Moorum soft)	-	
7.	Turmadar	86	23	Red soil	4.50	9
				Rock (Moorum soft)	-	
8.	Ghugra	78	18	Soil	7.00	13
				Boulder	15.00	
9.	Bhjia	68	13	Soil	1.25	58
				Hard rock	-	

Table 4.16: Soil Type and Depth Obtain from Bore-log Chart (Dhimarkheda Block)

Sl.No.	Village	Coordinate		Soil type	Depth (m)
		X(km)	Y(km)		
1.	Pipriya	71	48	Moorum	1.5
				Soft Stone	4.5
2.	Jinna Pipariya	85	41	Yellow clay	6.0
				Moorum	21.0
3.	Devri	65	43	Moorum	4.5
				Soft Stone	11.9
4.	Dadar Singhori	89	33	Yellow clay	6.2
				Clay with boulder	15.5
5.	Dashrman	76	30	Red soil	16.0
				Hard rock	-
6.	Paherua	98	48	Moorum	3.0
				Yelloow clay	6.0
7.	Kachargaon	77	26	Moorum	10.0
				Clay with boulder	15.0
8.	Kodro	100	52	Boulder	4.5
				Soft stone	18.5
9.	Mehgaon	94	33	Granite	4.3
				Clay with boudlers	9.3

by groundwater Survey, Bhopal, tubewells were identified which fall within the basin and their coordinates were calculated with respect to the origin of basin map. Most of the tubewells for which borelog charts were available pertain to Kundam and Dhimarkheda Block. Table 4.15 and table 4.16 shows soil type and depth of top soil and total depth of soil at different sites in Kundam Block and Dhimardheda Block respecatively. Fig. 4.16 shows the location of such sites along with top soil depth, and total depth of soils on a soil type boundary map. Based on above plots, it was observed that the soil depth is much related with the elevation of the ground. Therefore, from critical examination of Fig. 4.16, the following table values of soil depth in different elevation range were taken for use in simulation study.

TABLE - 4.17

Soil depth in Different Elevation Range considered for Simulation

Sl.No.	Elevation range	Depth of soil (depth of impermeable bed)
1.	greater then 480 m (up land)	3.0m
2.	between 440 m and 480 m (hill slopes)	6.5m
3.	less then 440m (deep bed)	12.0m

4.7.2 Overland and channel flow parameters:

Cross sectional details of Hiran main river from its source area to the gauging station at Patan were approximately measured by a field survey team under the guidance of Dr. J.C. Bathurst, a SHE expert. Such measured cross-sectional details are given in table 4.18, which shows the width of bank-top, bed width and bank high at five intermediate points. The cross-section at Patan gauging site as provided by CWC is also given in the above table. The above table shows that the channel dimension, vary with the upstream drainage area. Therefore, the drainage area up stream of the site where the rough measurement of cross-sections were made, were calculated and following relation slips were established.

a) Drainage area (km^2) vs map river length (km)
b) Cross-sectional area (km^2) vs map river length (km)
c) Bank full depth (m) vs map river length (km)
d) Top width (m) vs map river length (km)
e) Bed width (m) vs map river length (km)
f) map river length (m) vs SHE river length (km)

The above graphs are given in fig. 4.17. The relationships, thus obtained are given below,

$$\begin{aligned} L &= 0.64\, D^{0.625} \\ A &= 20\, L \\ d &= 1.7\, L^{0.5} \\ W_t &= 15\, L^{0.5} \\ W_b &= 8.5\, L^{0.5} \\ L &= 0.5\, L_{SHE}^{1.1} \qquad \ldots\ldots \quad (4.3) \end{aligned}$$

Where, D is the drainage area up stream of the

TABLE : 4.18

Cross Sectional characteristics of the Hiran river from its source area to the gauging station at Patan. Dimensions are approximate.

Section Location	Banktop Width m	Bed Width m	Bank Height m	Bed Type	Remarks
(1)48km from Jabalpur on Jabalpur-Dindori road	15	11.3	3.5	Boulders. bedrock	
(2)6km from Kundam on Kundam-Silondi road	30	50	1	Cobbles. boulders	Soil type: hard Moorum with boulders. Medium forest on hills. open forest - fields in valley bottom
(3)Khirhni Kala. 25km from Sihora on Sihora-Silondi road	80	50	10	Sand	Sand replaces coarser material as the dominant bed material about 5 km upstream
(4)3km from Sihora on Sihora-Silondi road	80	60	12	Sand to depth of 10m	Soil type: sandy loam surface with Domatta (black cotton/yellow clay). Bed partly cultivated at time of visit
(5)Sihora (Simariya Ghat) on Sihora - Jabalpur road	320	100	12	Sand	Soil type: top 3m. sandy yellow soil; next 5m. hard black cotton mixed with yellow soil; 2m above bed. sand.
(6)Patan	200	80	15	Sand	

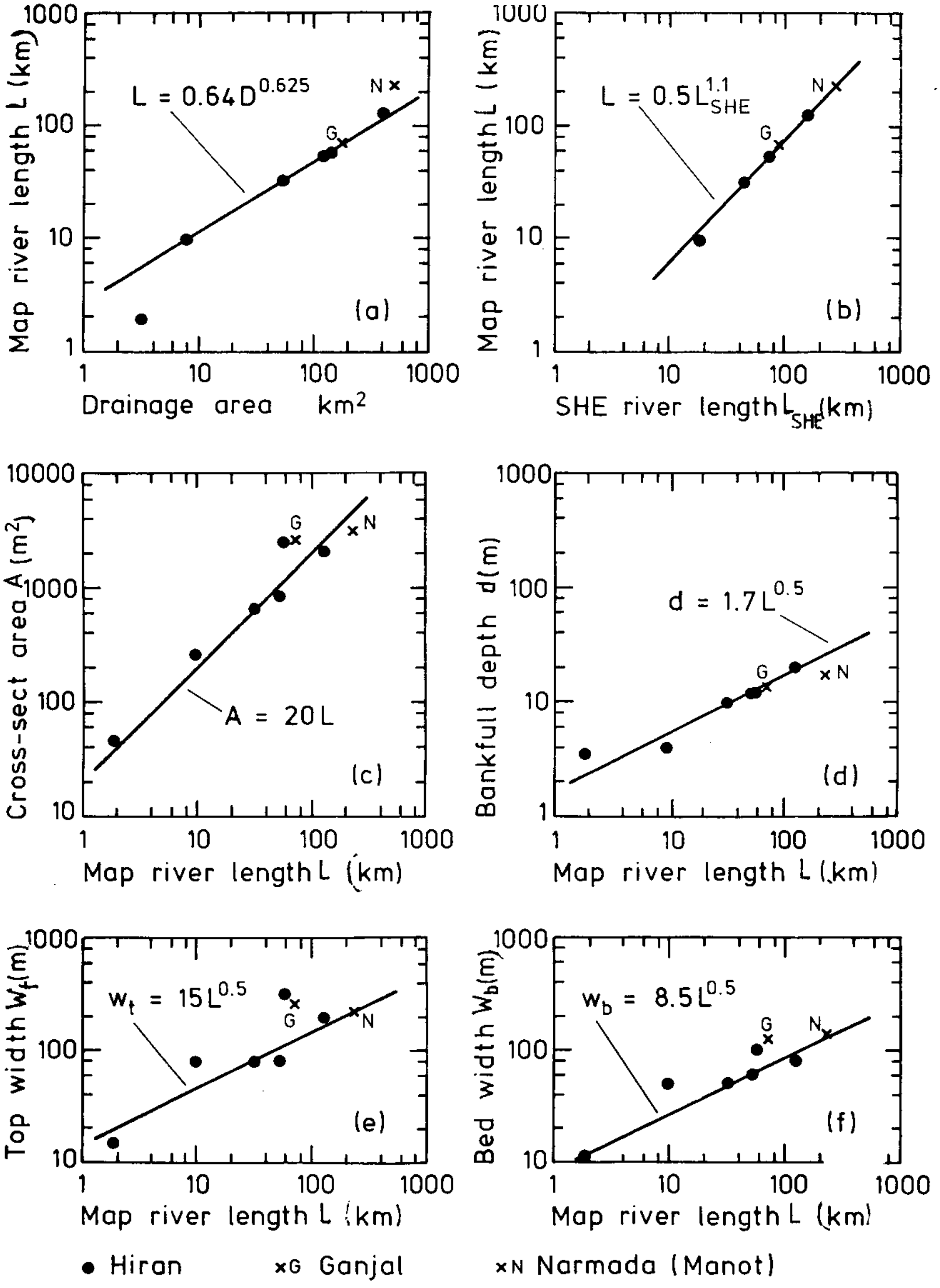


Fig.4.17:Cross Sectional Relationships

section (km^2)

A is the area of cross-section of the channel (km^2)

d is the bankful depth of channel (m)

W_b & W_t are the width of channel at bottom and top respectively (m)

L is the map length of channel up stream of the section (km)

L_{SHE} is the SHE length of the channel up stream of the section (km)

Using the above set of equations, the channel dimension at each node of the river system was calculated, knowlng the values of L_{SHE} using a service program developed for this purpose.

Roughness Parameters:

Since no information was available on the variation of surface roughness characteristics over the catchment, the Strickler roughness coefficient for channel flow and for overland flow were assumed to be uniform having no spatial variation over the basin.

On the basis of field visits and comparison of the topography and surface roughness of the basin with that of other basins for which the SHE was applied elsewhere earlier, a rough estimate of Strickler roughness coefficient for overland flow was made and a value of $2m^{1/3}/s$ was used as initial estimate. However, during calibration this parameter was varied in a narrow range.

In order to access the Strickler coefficient for channel flow, sample calculation were done using the measured flow, cross-sectional data and the slope (slope was measured using the longitudinal profile and digitized river data) and the value of Strickler roughness coefficient was found to vary in the range of 19 to $23 m^{1/3}/s$. This range was also obtained in the calculations shown in table 4.9 .

4.7.3 Initial Groundwater Table:

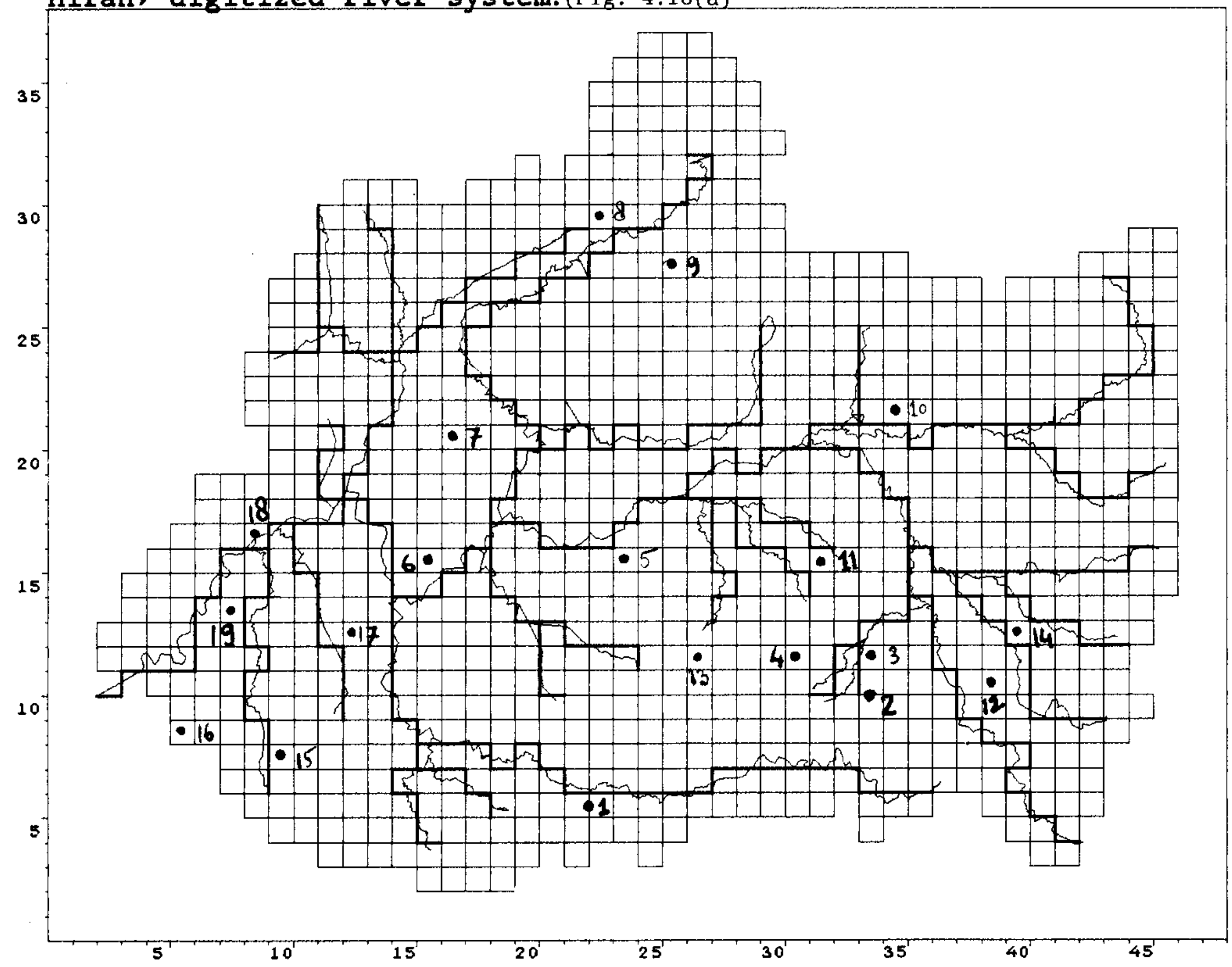
In order to assess the initial groundwater table elevation which is an input to the model, the premonsoon and postmonsoon absorvation of the groundwater table at 19 wells from 1980 to 1986 were scrutinized . The coordinates of the wells in respect to basin origin alongwith their identification code is given in table 4.19 and their location as plotted on Basin-grid map is given in fig. 4.18. The premonsoon and post monsoon water table depth from 1980-86 for each well is given in table 4.20. No pattern of variation over the basin could be identified. However, it was decided to use initial groundwater table depth as 6.0m, 4.5m and 2.0m in low land (elevation $\leq$ 440m), semi-hilly (elevation between 440 m and 480 m), and hilly (elevation greater than 480 m) regions as an initial calibration estimate. With the above estimate of groundwater water table depth, the model was run and the stabilized water table condition after one year was taken as the initial groundwater table condition for subsequent run.

TABLE 4.19

Coordinates of g.w. observation wells

Sl. No.	Code no. of well	Coordinates	
		X(km)	Y(km)
1.	009	44.5	11.0
2.	010	67.0	20.0
3.	011	67.0	22.0
4.	012	61.5	12.5
5.	015	48.0	31.0
6.	016	32.5	31.0
7.	017	34.5	42.0
8.	019	46.0	59.5
9.	020	52.0	55.5
10.	021	70.0	44.0
11.	023	63.0	31.0
12.	025	78.5	22.0
13.	026	53.0	23.5
14.	027	80.0	25.5
15.	033	20.5	14.0
16.	034	10.5	18.0
17.	035	25.5	25.5
18.	036	18.5	34.5
19.	037	15.0	27.5

Hiran, digitized river system.(Fig. 4.18(a)



Groundwater observation wells (Fig. 4.18b)

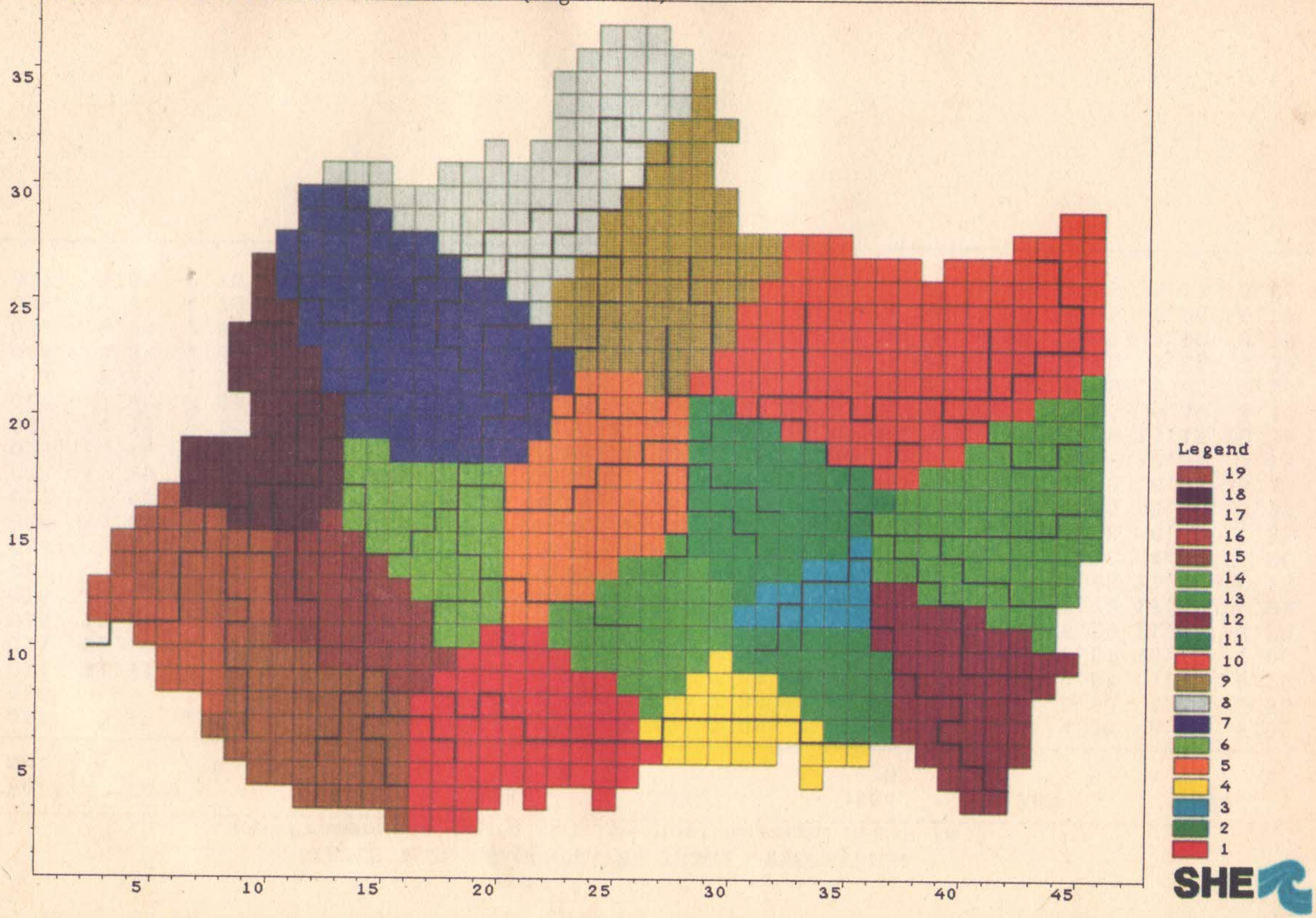


TABLE 4.20: GROUNDWATER TABLE OBSERVATION
(A- Premonsoon depth (m), B- Post monsoon depth (m))

Sl. No.	Well no.	1980		1981		1982		1983		1984		1985		1986	
		A	B	A	B	A	B	A	B	A	B	A	B	A	B
1.	008	7.37	4.52	6.27	5.60	6.60	5.10	6.45	7.05	7.05	4.68	6.85	4.90	8.47	5.05
2.	010	-	2.65	3.85	2.75	4.10	2.90	4.10	2.85	3.50	2.30	4.10	2.70	4.25	2.55
3.	011	10.93	8.02	10.30	9.10	10.50	9.35	10.90	7.95	10.95	9.40	10.55	9.08	10.70	9.15
4.	012	11.10	6.90	9.30	6.60	9.85	6.95	9.80	6.90	10.85	7.40	9.65	6.95	10.15	7.00
5.	015	15.35	5.85	11.30	8.0	11.40	6.50	11.56	5.40	9.71	7.44	10.55	6.29	11.65	6.70
6.	016	-	11.65	-	14.10	14.55	13.50	11.60	7.13	11.90	8.35	11.65	8.70	13.75	9.95
7.	017	-	6.35	-	10.91	11.10	10.55	12.10	6.05	3.74	7.70	13.90	8.65	12.65	6.35
8.	019	-	5.95	11.65	6.70	11.25	5.10	3.65	1.23	4.78	1.93	4.05	1.10	4.10	3.00
9.	020	10.60	6.65	9.70	5.50	9.05	5.40	9.75	5.80	10.35	7.20	9.35	6.08	8.70	7.55
10.	021	11.92	3.60	10.25	3.86	6.50	4.90	7.20	3.40	7.10	4.74	9.75	3.55	9.70	3.90
11.	023	15.40	4.10	-	5.05	17.05	4.90	12.60	4.45	10.90	5.10	11.05	4.30	8.05	5.30
12.	025	10.70	7.45	9.55	8.08	10.05	8.00	9.80	7.15	9.90	8.10	9.75	7.45	10.05	7.15
13.	026	14.75	9.10	13.35	10.60	12.20	10.10	13.25	8.50	14.15	10.70	12.95	9.20	13.15	10.33
14.	027	7.80	3.48	6.40	4.10	7.40	4.00	6.05	3.81	6.35	3.80	6.7	3.55	6.40	4.10
15.	033	7.35	1.80	6.10	4.10	7.00	2.60	6.20	1.90	5.75	3.26	6.55	2.40	6.00	2.60
16.	034	9.59	4.60	8.85	4.10	9.10	4.80	8.50	4.40	8.50	5.80	8.80	4.65	8.25	7.37
17.	035	9.60	2.85	7.06	4.40	8.85	3.15	7.75	2.77	6.60	3.15	6.66	2.35	8.00	3.20
18.	036	11.65	4.70	9.02	8.00	11.00	6.00	10.60	4.62	8.60	6.24	10.15	5.25	5.00	5.72
19.	037	5.25	2.10	4.45	3.00	5.38	2.45	4.10	2.40	4.30	2.40	5.70	2.25	5.25	5.65

4.8 Data Consistency Check Using Water Balance Approach:

The reliability of the output of any distributed model like SHE depends to a great extent on the correctness of input data, and its calibration is very much dependent on the measured output with which the model output is compared. For SHE the basic input is the rainfall data and the basic output is the runoff data at discharge site. Therefore, the consistency checks should be applied to check the reasonability of data and possibly to correct them, before going in for modelling study.

A water balance study on seasonal basis was carried out to check the consistency of the rainfall, runoff and evaporation data from the year 1980-81 to 1986-87. The monsoon season was considered from June to Oct and non-monsoon season from November to May. Before proceeding for water balance study, the rainfall of all the stations were serutinized and found that the rainfall values for some of the stations for few months were unexpectedly low as compared to that of other neighbouring rain gauge stations. Therefore, discarding such stations, only following six stations were considered.

		Wt
1.	Jabalpur (SRRG)	---- 0.102
2.	Patan (ORG)	---- 0.124
3.	Sihora (ORG)	---- 0.354
4.	Badera Mohari (ORG)	---- 0.096
5.	Pariat (ORG)	---- 0.181
6.	Ghutehi (ORG)	---- 0.43

The water balance study for checking the consistency of the data was done as given below:

a) The monsoon rainfall and the monsoon runoff for all the year were plotted and runoff coefficient for monsoon season was computed. Fig. 4.19 shows the rainfall runoff relationship for monsoon season.

b) Relationship between non-monsoon runoff (after substracting base flow) and non-monsoon rainfall was examined. Non-monsoon b;ase flow was estimated from the observed discharge data. Fig. 4.20 shows variation of non-monsoon runoff with non-monsoon rainfall.

c) Monsoon groundwater recharge, i.e., R_1 was estimated assuming actual evapotranspiration as 70% of the potential evapotranspiration. The equation for the calculation of R_1, is given below:

$$R_1 = P_m - Q_m - 0.7\ PE_m \qquad .....(4.4)$$

where: R_1 is the groundwater recharge during monsoon season
Pm is the average rainfall during the monsoon season
Qm is the average runoff during monsoon season
PEm is the potential evapotranspiration during monsoon season

Monsoon groundwater recharge was also calculated assuming it to be 12% of monsoon rainfall. Designating it as R_2, we have R_2=-.12 Pm. Seeing the rainfall runoff relationship and the water balance calculation, we observe that for 1980-81 recharge is excessively low and for 1981-82 recharge is coming out to be negative which creates doubts about the reasonability of the data. Hence, the data from 1980 to 1982 have been excluded from the study.

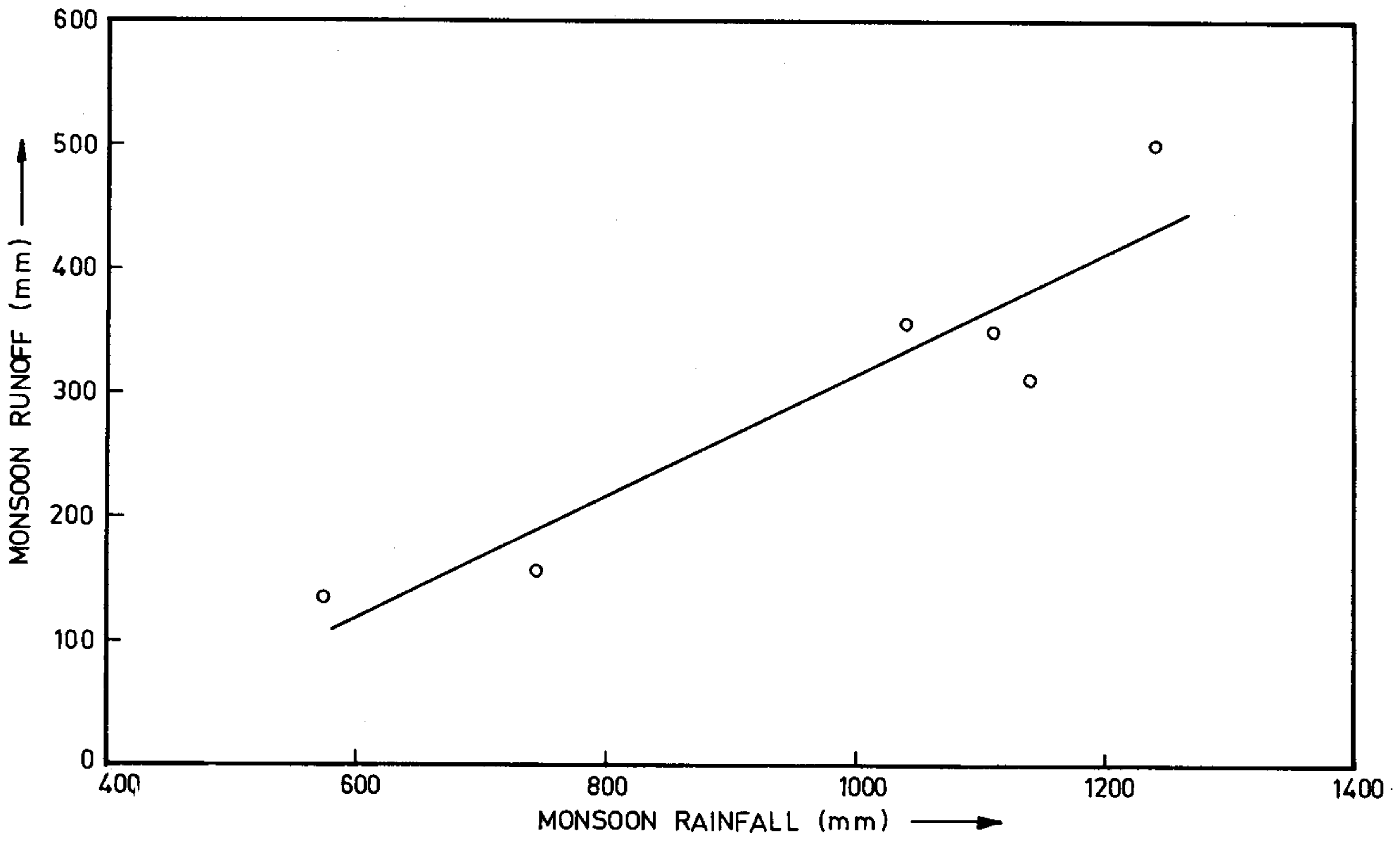


Fig. 4.19 : Rainfall Runoff Relationship for Monsoon Season.

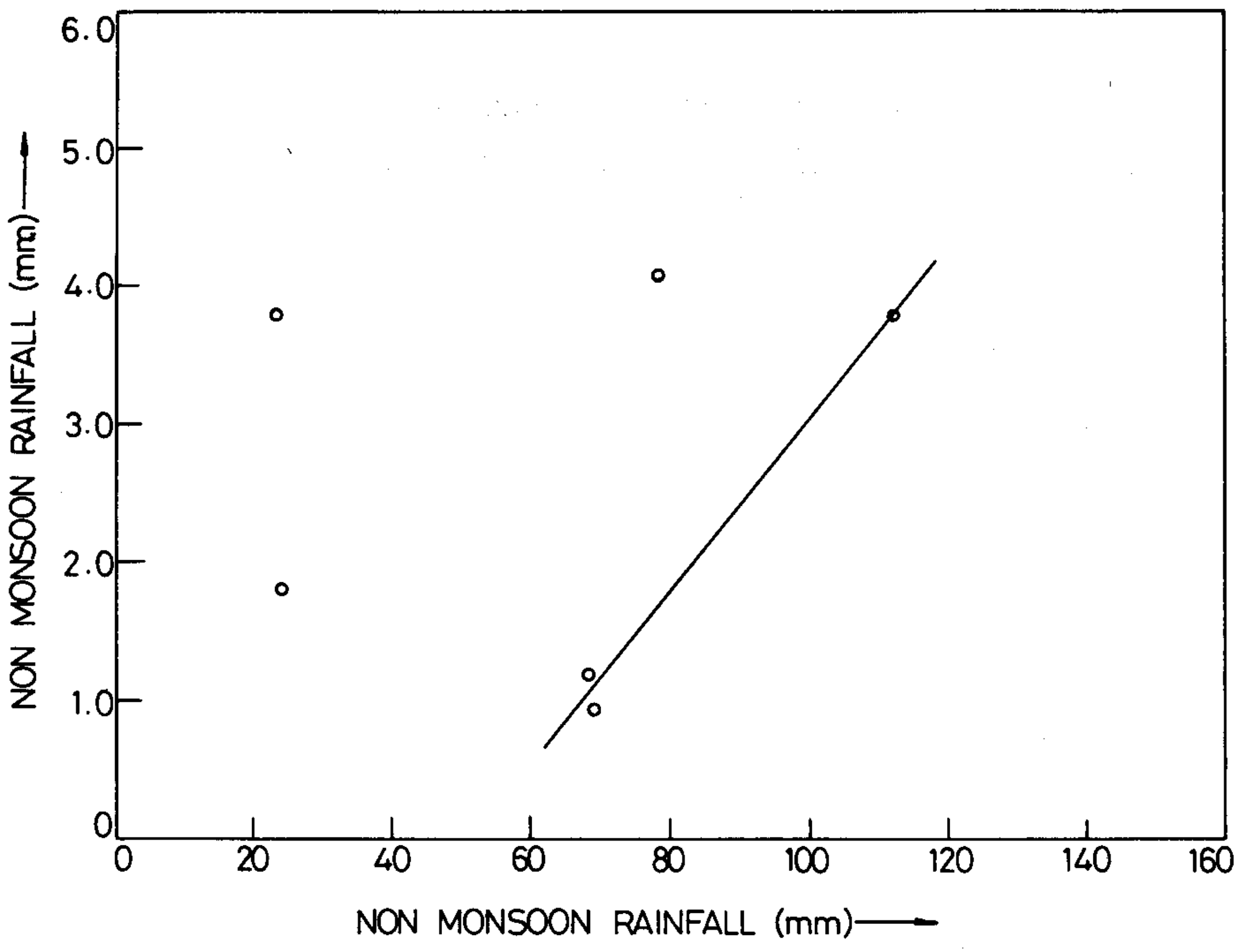


Fig. 4.20 : Rainfall Runoff Relationship for Non-monsoon Period

Figure 4.21 shows variation of non-monsoon base flow with groundwater recharge during monsoon season (R_1) and fig.4.22 shows the variation of non-monsoon base flow with R_2. The above figures and rainfall runoff relationship for monsoon season show that the data for the year 1982-83 to 1986-87 are reasonably consistent. The calculations for water balance study have been given in table 4.21.

4.9 Model Set Up for Hiran Sub-Basin:

The digitized topographic, river network and boundary data were transformed into a grid network of required dimension using SHE. AF Software developed for this purpose. The present study has been carried out using a 2 km x 2 km grid size. Details of application has been given in section 4.2 and subsequent sections of this chapter.

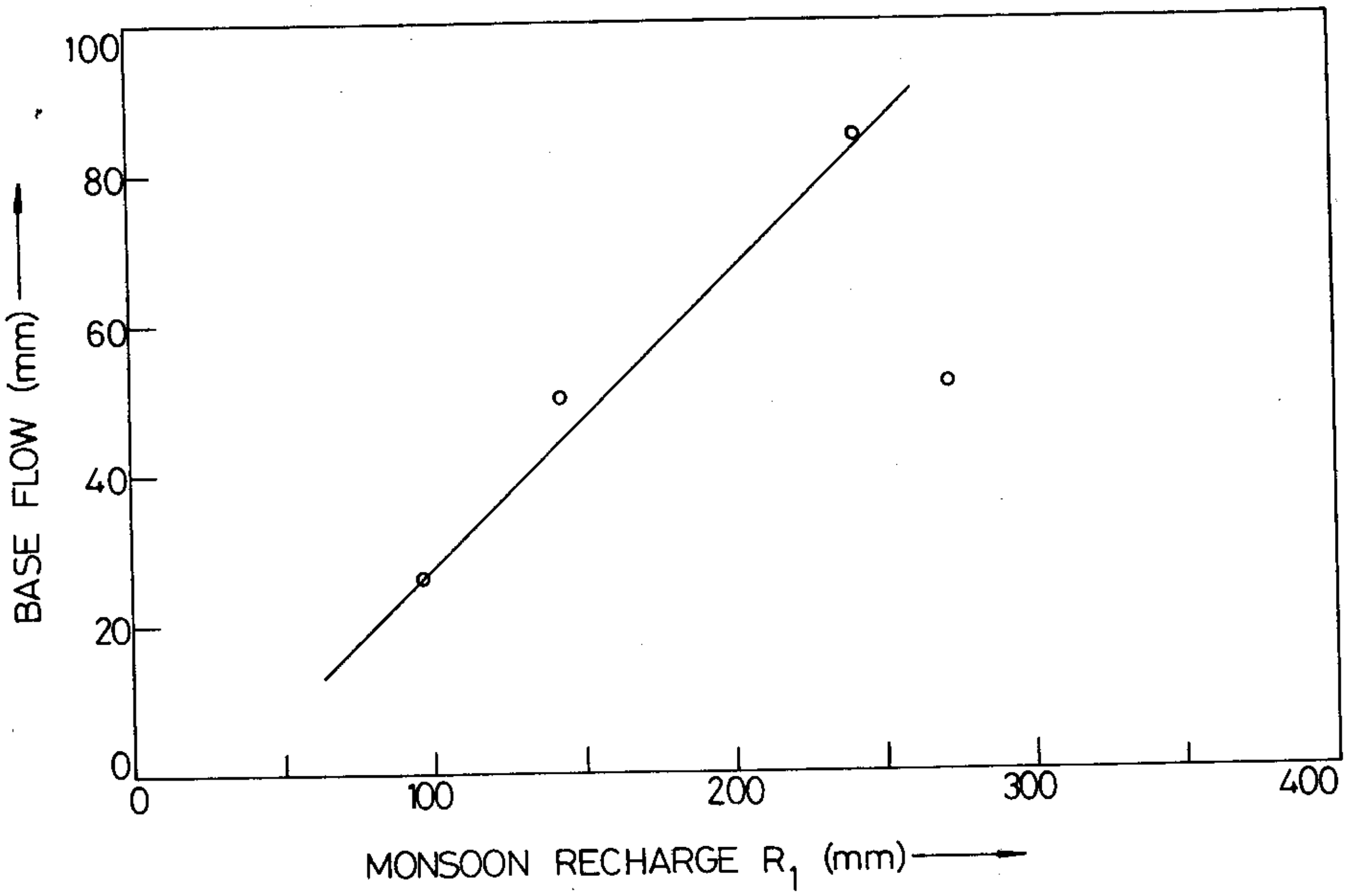


Fig. 4.21 : Relationship Between Base Flow and Monsoon Recharge R_1

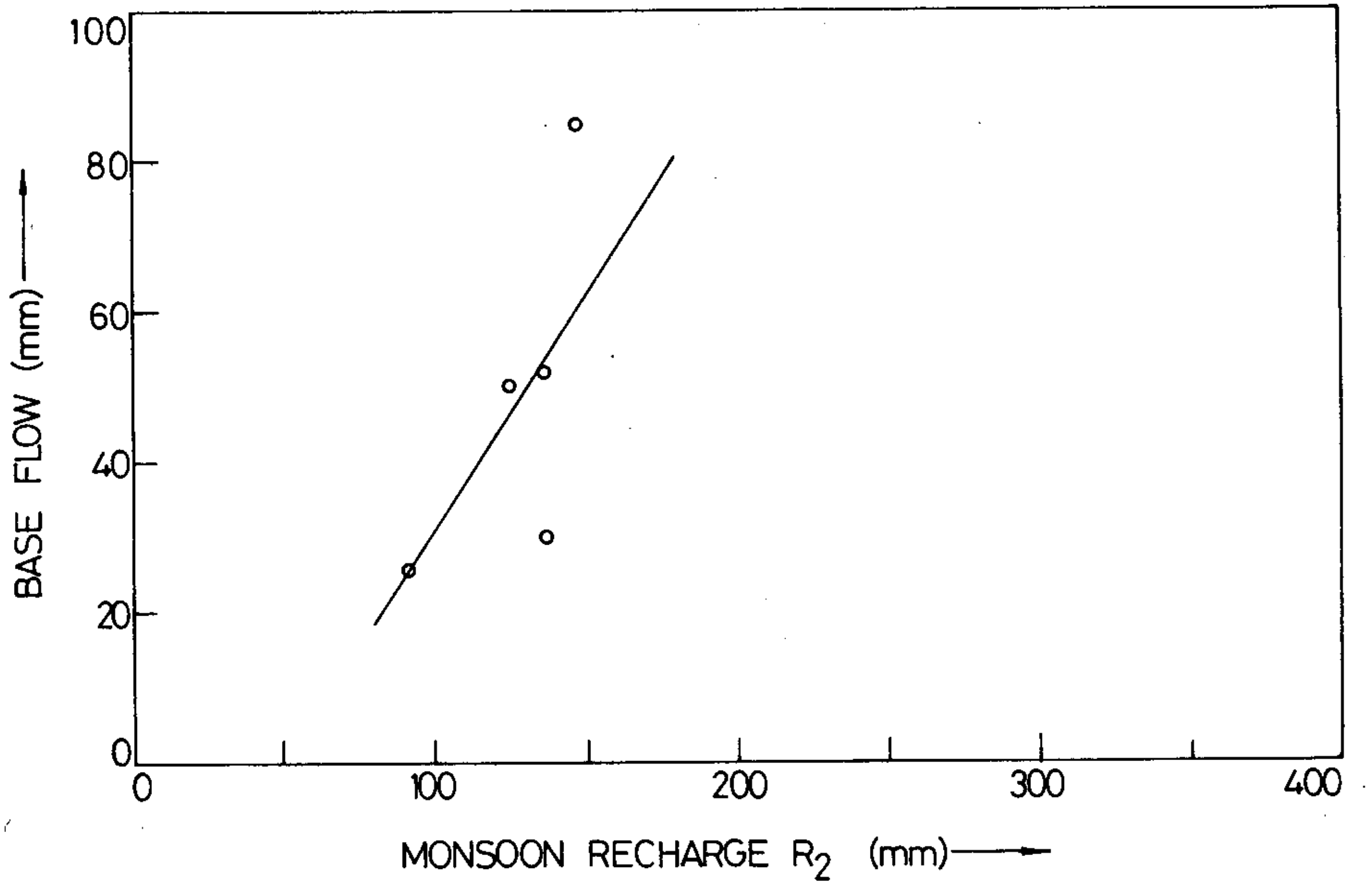


Fig. 4.22 : Relationship Between Base Flow and Monsoon Recharge R_2

Table 4.21: Water Balance Calculations for Hiran Sub-Basin

Sl.No.	Year	Monsoon season						Non-monsoon meason			
		Rainfall (mm)Pm	Runoff (mm)Qm	Runoff Coeff. Qm/Pm	Potential evaporat- (mm)PEm	Recharge (mm) R_1=Pm −0.7PEm −Qm	Recharge R_2(mm) R_2=0.12Pm	Rainfall (mm)Pnm	Runoff (mm)Qnm	Base flow (mm) Q_{Bnm}	Runoff (non-monsoon) (mm) $Q_{nm}-Q_{Bnm}$
1.	1980-81	1084.7	585.5	0.54	704.7	5.9	130.2	24.4	26.8	25.0	1.8
2.	1981-82	574.6	135.3	0.24	788.7	-52.8	69.0	112.3	49.4	45.6	3.8
3.	1982-83	1040.5	357.2	0.34	773.4	141.9	124.9	23.0	50.7	46.9	3.8
4.	1983-84	1242.2	500.0	0.40	714.9	241.8	149.1	67.7	85.8	84.6	1.2
5.	1984-85	1112.2	350.7	0.32	698.3	272.7	133.5	73.9	54.8	50.7	4.1
6.	1985-86	1138.2	310.1	0.27	631.0	386.4	136.6	125.9	30.0	29.8	0.2
7.	1986-87	744.1	154.2	0.21	709.6	93.2	89.3	69.0	26.5	25.6	0.9

5.0 CALIBRATION AND VALIDATIOIN OF SHE FOR HIRAN SUB-BASIN

The strategy for calibration and validation was adopted based on splitsample approach. Initially data were made ready for 1982-87 and it was intended to do the calibration of SHE using three years data from 1982 to 1984 and to do the validatioin with another three year data, i.e., from 1985 to 1987. Few calibration runs were taken with the above strategy, but afterwards it was realised that with the over-loading on the DHI computer (all the three basin running simultaneously) it would not be feasible to cope up with the above strategy. Therefore, in a meeting with SHE experts, it was decided that for Hiran sub-basin calibration should be done on only one year data of 1982 and validation should be carried out with two year data, i.e. data for 1983-84.

5.1 Calibration of the Model:

The model was calibrated by analysing and comparing the following:

a. Simulated discharge hydrolograph with observed hydrograph of discharge at gauing site.

b. Simulated monthly runoff volumes with observed runoff volumes.

c. Simulated peaks during monsoon with observed peaks

d. Simulated secondary peaks in runoff hydrographs.

The ranges for the different parameter values within which they were varied for calibration study, were selected and have been discussed in detail in previous chapter. However, the importance of few parameters which was not discussed in chapter 4, includes drainage parameter and cracking parameter. In order to represent the drainage at shallow depth level, drainage parameter was introduced specifying the coefficient of drainage and the location of drain, i.e., depth of drain below ground level. The black cotton soils cover the most of the parts of the Hiran-sub-basin , which shows deep cracks in the soil during non-monsson period. When rain starts, a part of it is directly transferred to the bottom of the root zone and does not contribute to overland flow. Thus for initial period of the monsoon period the small peaks were not observed in the result of a simulation. In order to simulate the initial peaks during the start of monsoon period a certain percentage of rainfall was considered to join the bottom of the root zone directly and the accumulated flow (since the specified month each year upto which this bypass of rain was considered effective) was also specified as a parameter. The above two parameters which were used for modelling the cracks, i.e., percentage of rainfall which is bypassing and the maximum amount of accumulated rainfall upto which the bypass is effective, were also varied during calibration. The percentage of rainfall was varied from 15% to 25% and accumulated depth of rainfall was varied from 100mm to 300 mm. Coefficient of detention storage in the model represents minimum depth of water over the land surface before overland flow occurs. The strategy followed for calibration by varying values of parameters was first to take runs with extreme values of a parameter to identify the range of varitioin in model output then the parameter was systematically varied to have the best fit. The range of values for different parameters within which it was varied during calibration are discussed in details in previous chapter. The land use pattern and the initial ground water condition and depth to impermeable bed used in the simulation study have also been dealt in chapter 4. The root zone depth were taken as 2.0 m, 0.6m, and 0.5m. in dense forest, agricultural area and waste land respectively. The Averjanov Exporent was varied between 10 and 20 during simulation.

In the model, the uz calculations were performed only for few selected columns and their calculated water balance were transferred to the similar columns having same rainfall area and some type of soil. Hence, no two uz columns have the same rainfall and the same soil type. The uz columns for the present study are given in Table 5.1 and in fig. 5.1, all the uz columns have been shown along with the basin boundaries and rainfall station polygon.

In final calibratioin run, the simulated and observed discharge peaks and discharge volumes were compared on monthly basis. The final parameters thus selected, are given in table 5.2. The observed and the simulated hydrographs along with areal rainfall for final calibration run are shown in fig.5.2.The monthly accumulated values of observed and simulated discharge alongwith monthly rainfall, monthly PET and observed and simulated peaks have been given in Table 5.3. Fig. 5.2 and table 5.3 show that the runoff volumes and the peaks for 1982 during calibration were reasonably simulated. During the month of August, the simulated peaks are lower than the observed one. On the contrary, in the recession period, i.e., in the month of September, the simulated peaks are higher than the observed peaks. Also, there are seen a lateral shift in the simulated peaks as compared to observed peaks. This may be due to the fact that the right half portion of the basin is not properly represented by sufficient number of raingauges.

5.2 Validation of the Model

The data for the period of two years,i.e. 1983 and 1984 were used for the validation of the model. In validation run, the model set up and the parameters were kept the same as during the final calibration run. The initial conditions were also kept the same as in the calibrtion run. The observed and the simulated discharge hydrographs are shown in fig. 5.3, and the monthly accumulated values of discharge, rainfall PET alongwith values of peaks have been given in table 5.3. For comparison

Table 5.1:Basin Grid Map Showing UZ Columns (2km Grid)

SL. No.	X Grid No.	Y Grid No.	Column No.	Rainfall* Statioin No.	Soil** Type	Terrain
1.	13	31	18	6	2	Semi Hilly
2.	32	28	13	3	2	Semi Hilly
3.	17	26	15	6	1	Hilly
4.	10	24	17	6	3	Low Land
5.	10	23	16	2	3	Hilly
6.	32	18	12	3	1	Low Land
7.	36	16	14	3	3	Low Land
8.	35	15	4	5	3	Semi Hilly
9.	41	11	5	5	1	Hilly
10.	24	10	9	4	2	Low land
11.	27	9	7	5	2	Semi Hilly
12.	7	12	6	2	1	Low Land
13.	22	7	8	1	2	Low land
14.	21	5	3	1	3	Low land
15.	21	7	2	1	1	Low land
16.	21	14	10	4	1	Low land
17.	6	16	11	2	2	Hilly

* 1 - Jabalpur
2 - Patan
3 - Sihora
4 - Badera Mohari
5 - Pariat
6 - Ghutehi

** 1 - Agricultural Land
2 - Dense Forest
3 - Waste Land

Hiran, landuse pattern. map showing UZ Columns (Fig. 5.1)

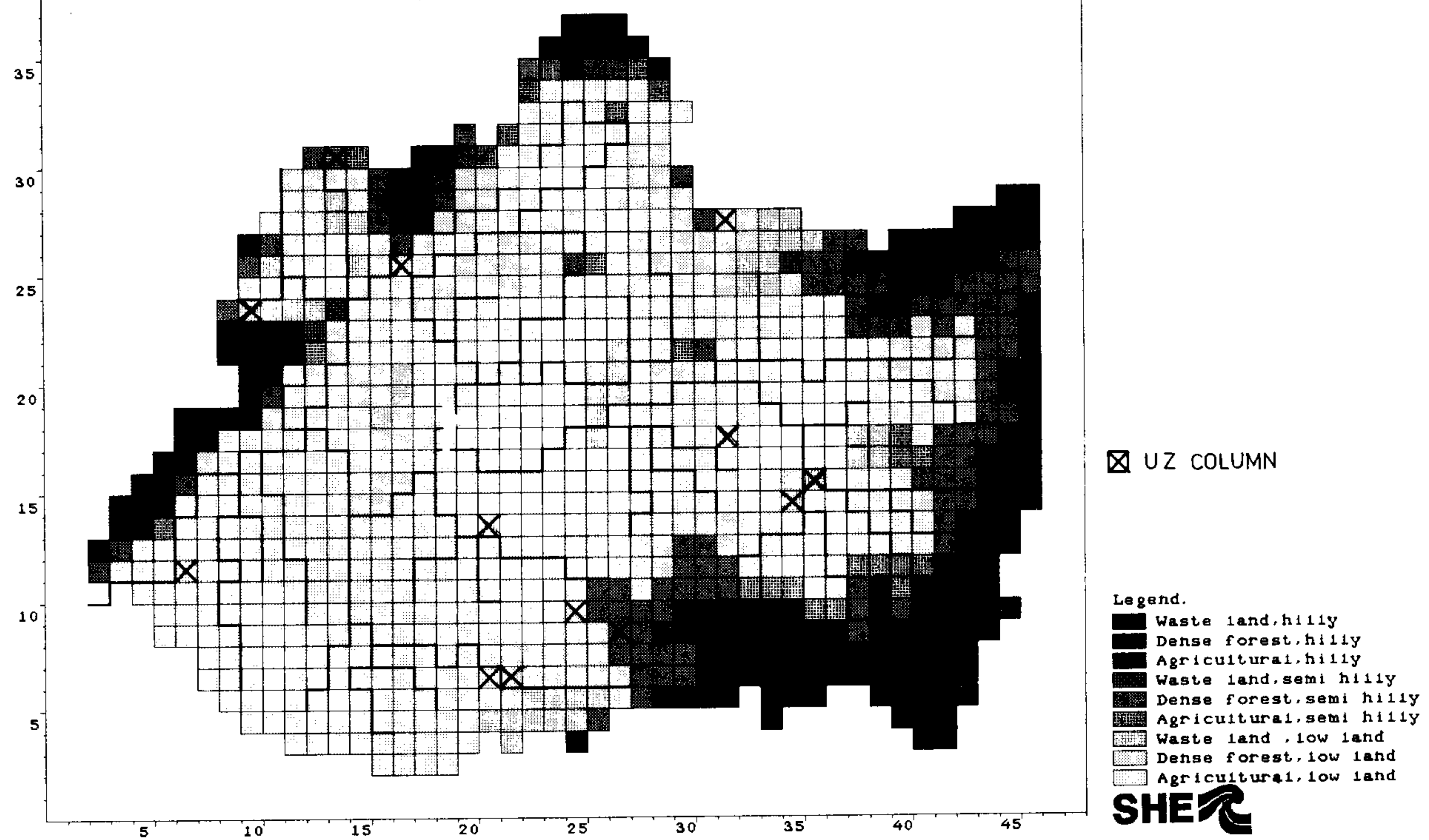


Table 5.2: Values of Parameters Used

Sl.No.	Parameters	Value
1.	Strickler Coeff. for overland flow	1.0
2.	Strickler coeff. for river flow	20.0
3.	Detention storage	0.02
4.	Drainage	
	a. Drainage system elevation	-0.6 m
	b. Drainage coeff.	0.005
5.	Cracking	
	a. Percentage of rainfall which bypass rootzone through cracks	15
	b. Maximum accumulated rainfall since March, upto which cracks are still prsent.	200 mm
6.	Soil Parameters	
	a. Saturated vertical hydraulic conductivity	0.1 m/d
	b. Horizontal conductivity	7.5 m/d
	c. Water content at Saturation	0.478
	d. Effective Saturation	0.450
	e. Water content at F.C.	-0.373
	f. Tension at F.C.	-3.08
	g. Water content at Wilting point	0.19
	h. Residual water content	0.19
	i. Averjanov Exponent	12.00

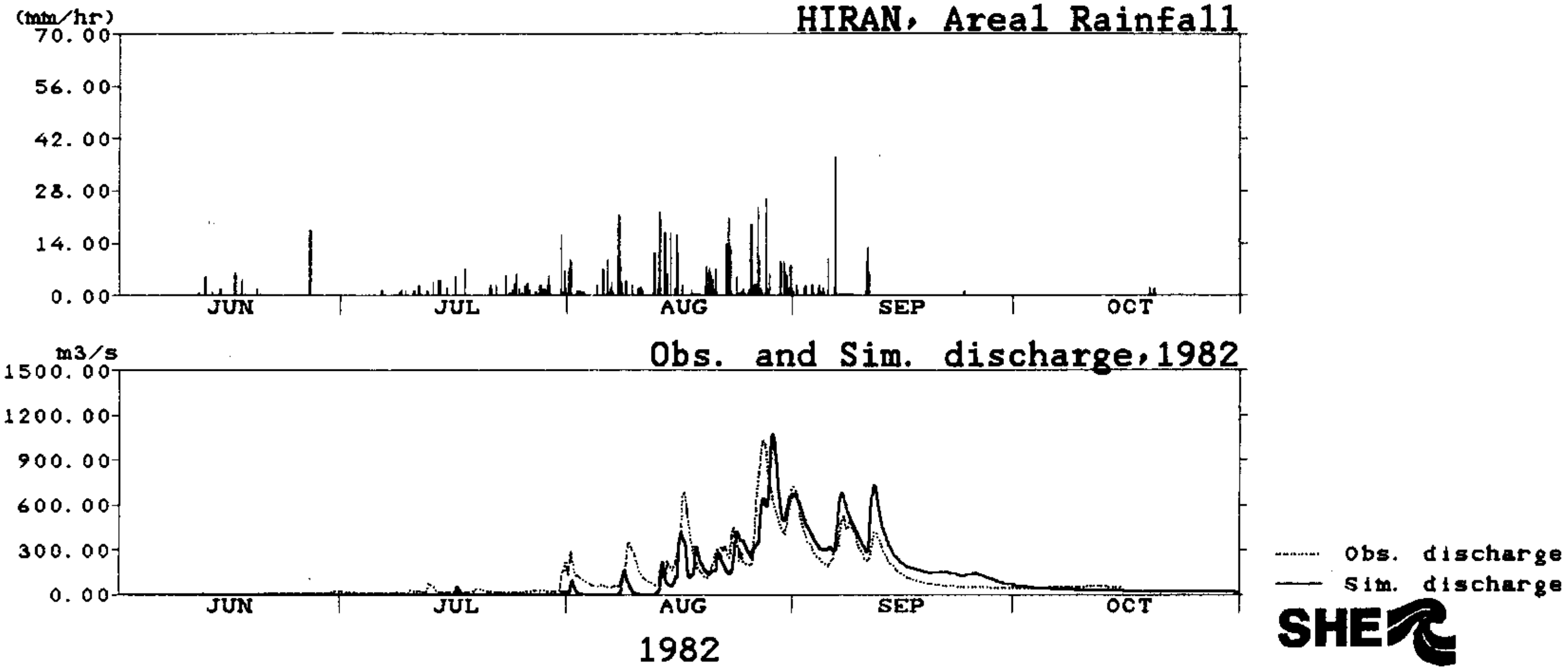


Fig. 5.2(a) : Simulated and Observed Discharge Hydrograph (Calibration)

Fig.5.2b:Results of simulation

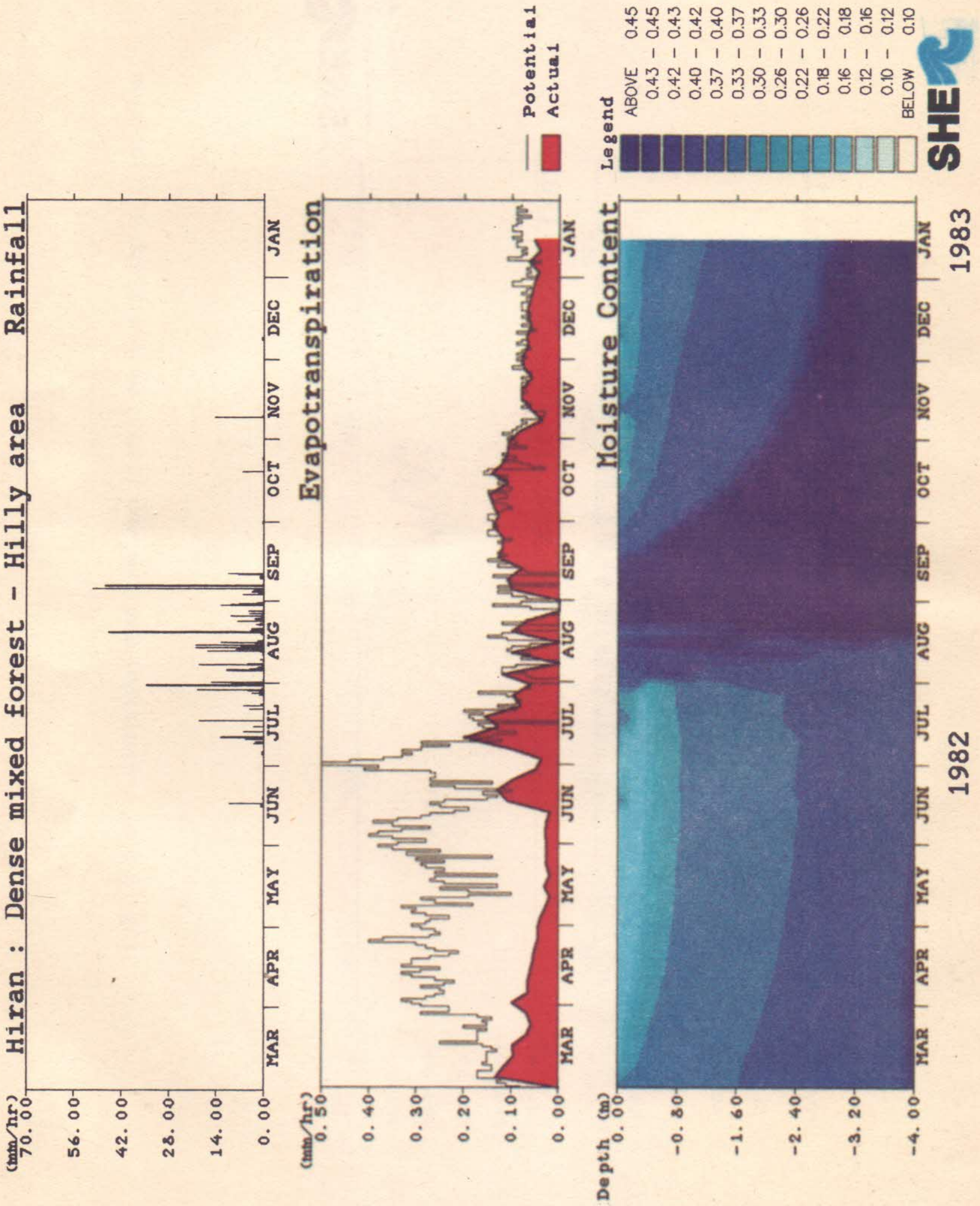


TABLE : 5.3

RESULTS OF CALIBRATION AND VALIDATION

Year	Month	Rainfall (mm)	PET (mm)	Qobs (mm)	Qsim	Values in cumecs
1982 Calibration	June	64.2	198.7	7.3	4.0	Obs peak = 1037
	July	170.7	131.5	16.5	4.6	
	Aug.	649.7	48.0	183.1	138.0	Sim. Peak= 1071
	Sept.	150.1	79.1	129.7	185.8	
	Oct.	5.8	84.0	20.6	21.9	
1983 Validation	June	125.3	208.8	8.9	5.0	Obs. Peak=2072
	July	327.2	79.1	47.9	12.9	
	Aug.	217.6	76.9	81.90	57.6	Sim.Peak=3968
	Sept.	501.4	56.9	284.4	335.8	
	Oct.	70.7	78.7	76.9	113.5	
1984 Validation	June	88.7	190.4	9.5	7.3	Obs-Peak=1404
	July	168.6	87.8	15.4	10.1	
	Aug.	719.3	51.1	177.4	266.0	Sim.Peak=1859
	Sept.	135.3	72.6	122.3	239.0	
	Oct.	0.25	87.0	26.1	24.0	

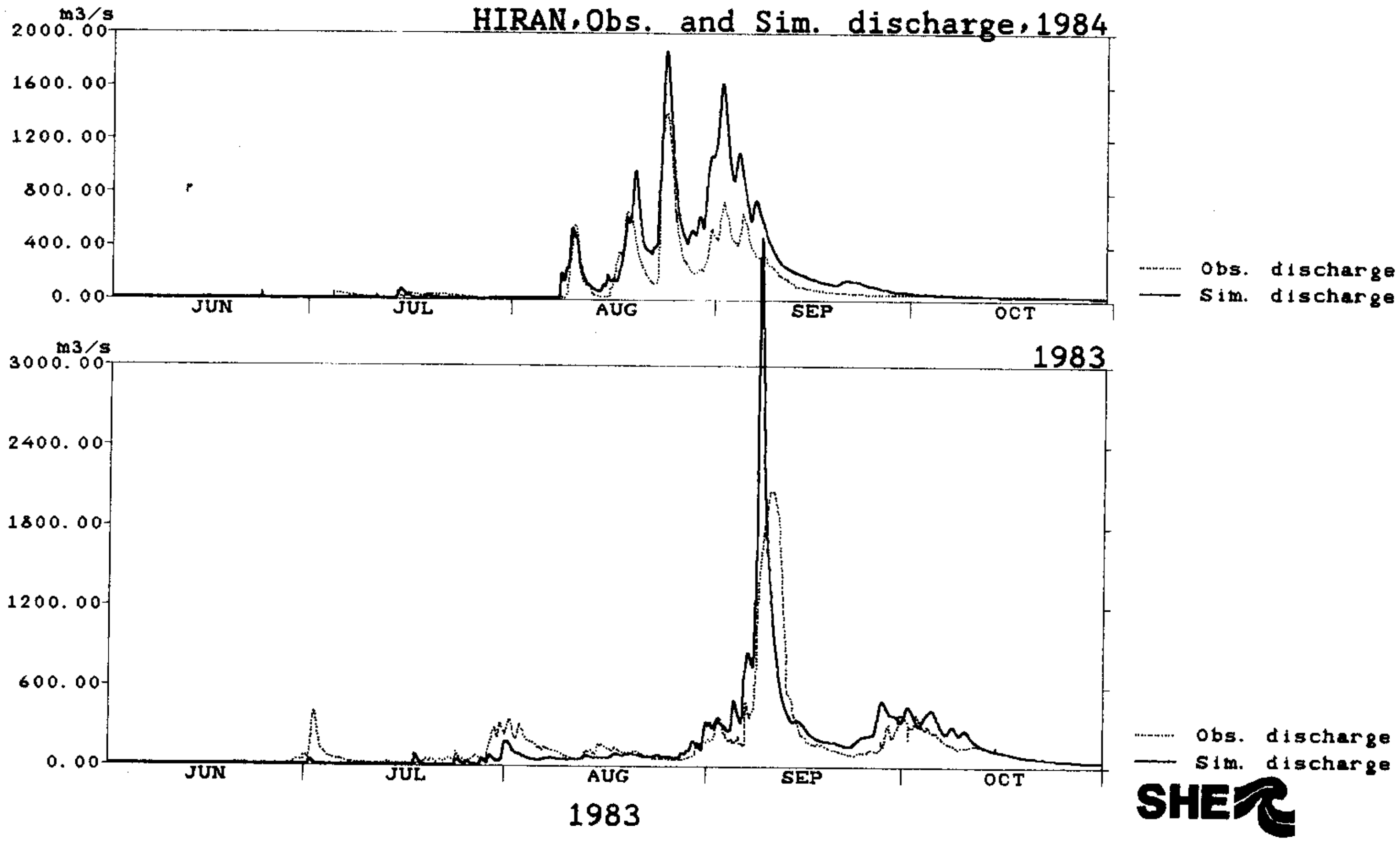


Fig. 5.3: Observed and Simulated Discharge Hydrograph (Validation)

areal daily rainfall is given in fig.5.4. The groundwater response for selected columns situated in different rainfall zones different soil type and in different slopes are given in fig.5.5 and fig.5.6. The above validation results show the the simulated peak are higher than the observed peaks. This may be explained on the basis that the areal rainfall is not the true representation of the actual because the right half portion of the basin does not have adequate number of raingauges. And this clearly shows that the rainfall in the right half portion might be higher as compared to that in the left half portioin. Thus, with the existing number of raingauges, we are simulating the areal rainfall towards higher side. Therefore, it is very necessary that the basin for which application study of the model is intended, must have adequate number of rainguages so as to get true picture of areal rainfall over the basin otherwise the simulation results will be misleading.

Fig.5.5 and 5.6 show that during the months of September and October and some times in the month of August groundwater able comes to the ground surface, this is because of the fact that the initial groundwater table was not taken as per actual (As we were having groundwater observation only at few selected points and the model requires values at each grid point). The results of the validation are also seem to be affected by the initial groundwater table condition taken, because the same initial condition of groundwater table was taken as considered for validation, i.e., for 1982 and not the initial condition of the water table at the start of the validation period, i.e., the beginning of 1983.

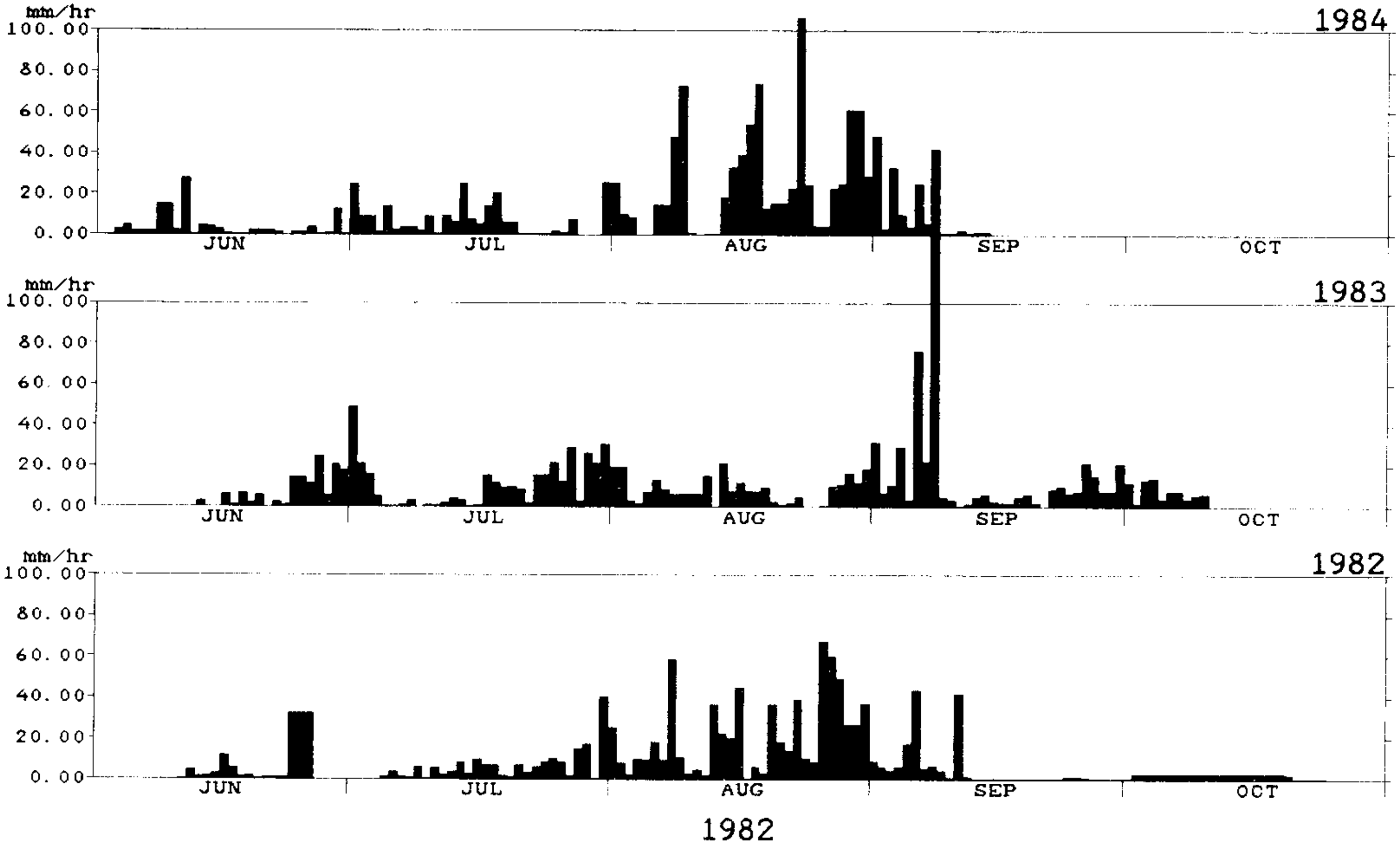


Fig. 5.4: Areal Daily Rainfall (Hiran Basin)

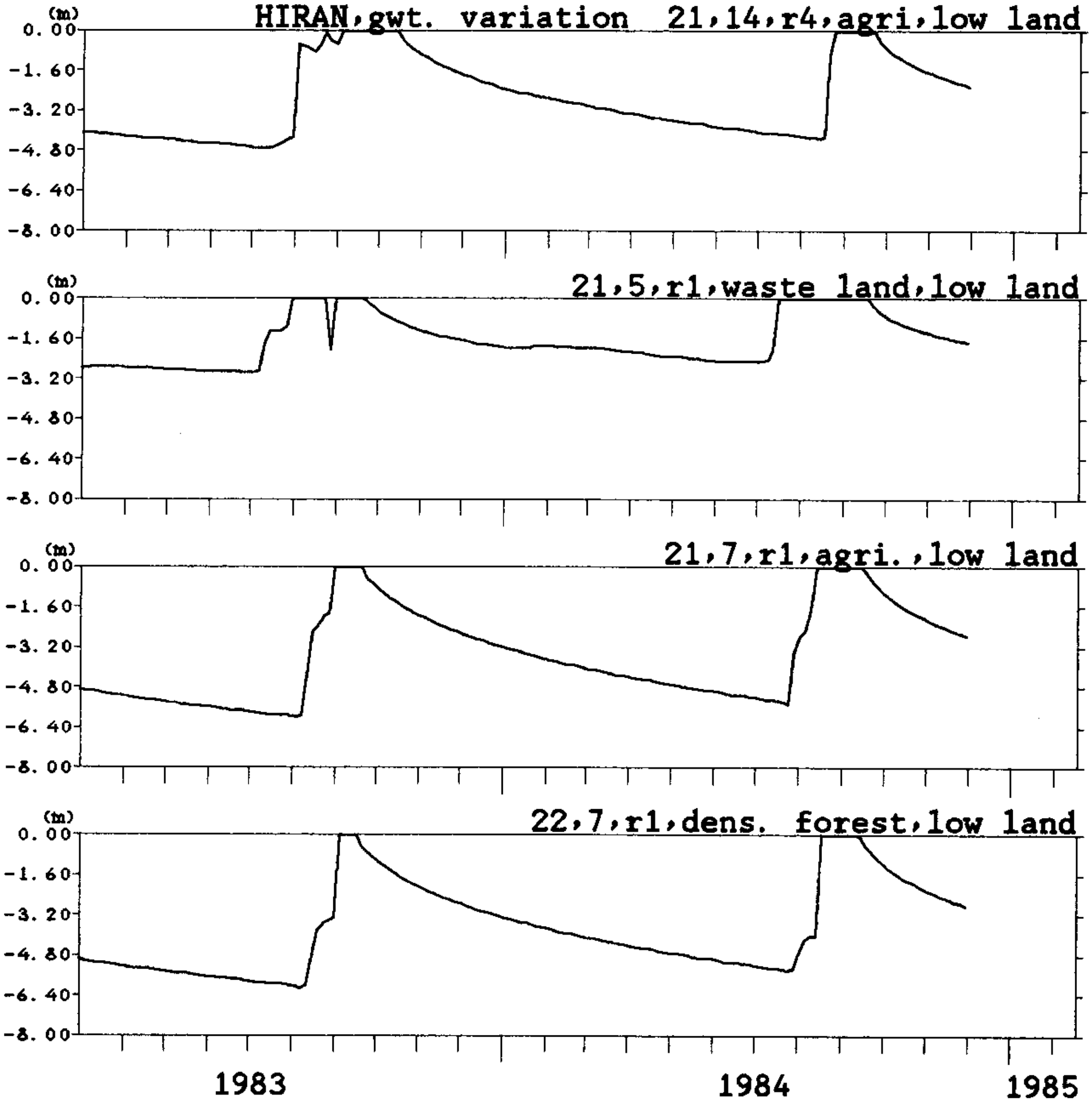


Fig. 5.5: Groundwater Response for Selected of Columns

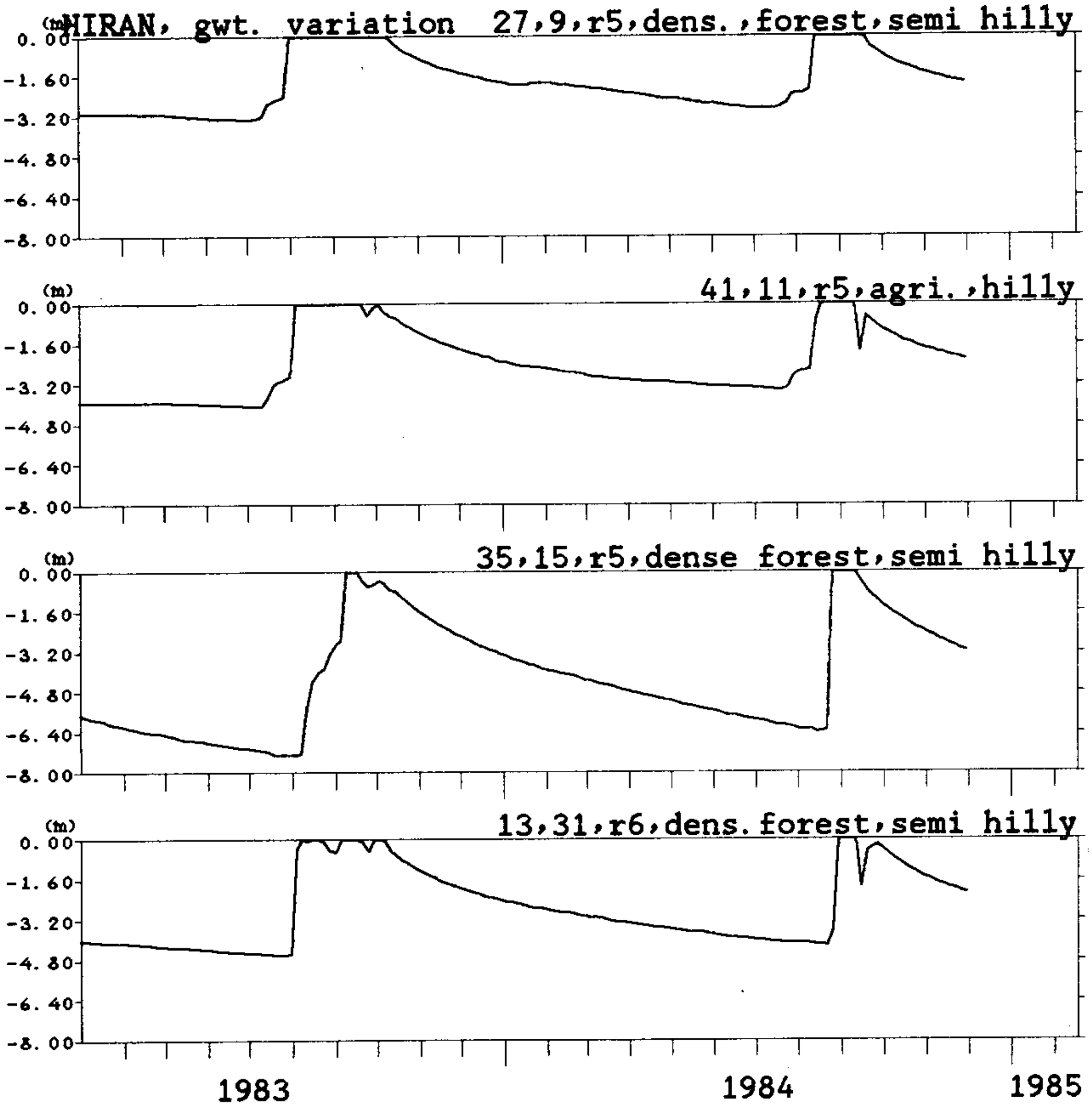


Fig. 5.6: Groundwater Response for Selected Columns.

6.0 SENSITIVITY ANALYSIS

The aim of sensitivity analysis is to examine the sensitiveness of the important calibration parameters and other input parameters on the simulation results. Due to overburder on DHI computer and with the limited time available it was decided in the meeting with SHE experts that sensitivity of rainfall should be examined for HIRAN sub-basin. Therefore, as a sensitivity run the results of simulation for 1982 was compared with the simulation results for that year considering only one rainfall station, i.e., Jabalpur. The observed and simulated discharge hydrographs of calibration run and that of sensitivity run (taking only one rainfall station at Jabalpur with its hourly data) alongwith hourly rainfall of Jabalpur have been shown in fig. 5.7. Second sensitivity run was taken in which the results of the simulation for 1982 was compared with the results of the sensitivity simulation for that year considering only one rainfall station having the hourly rainfall as the areal hourly rainfall over the basin (considering the average of all the six raingauge station considered for simulation for 1982). The results of second sensitivity is shown in fig. 5.8. Fig. 5.7 shows, if we take only one raingauge station instead of six stations, we see that the results are very much different. Fig. 5.8 shows, if we take the area rainfall, even then the simulation results are different but difference is less pronounced. Therefore,it may be concluded that the basin intended to be modelled should

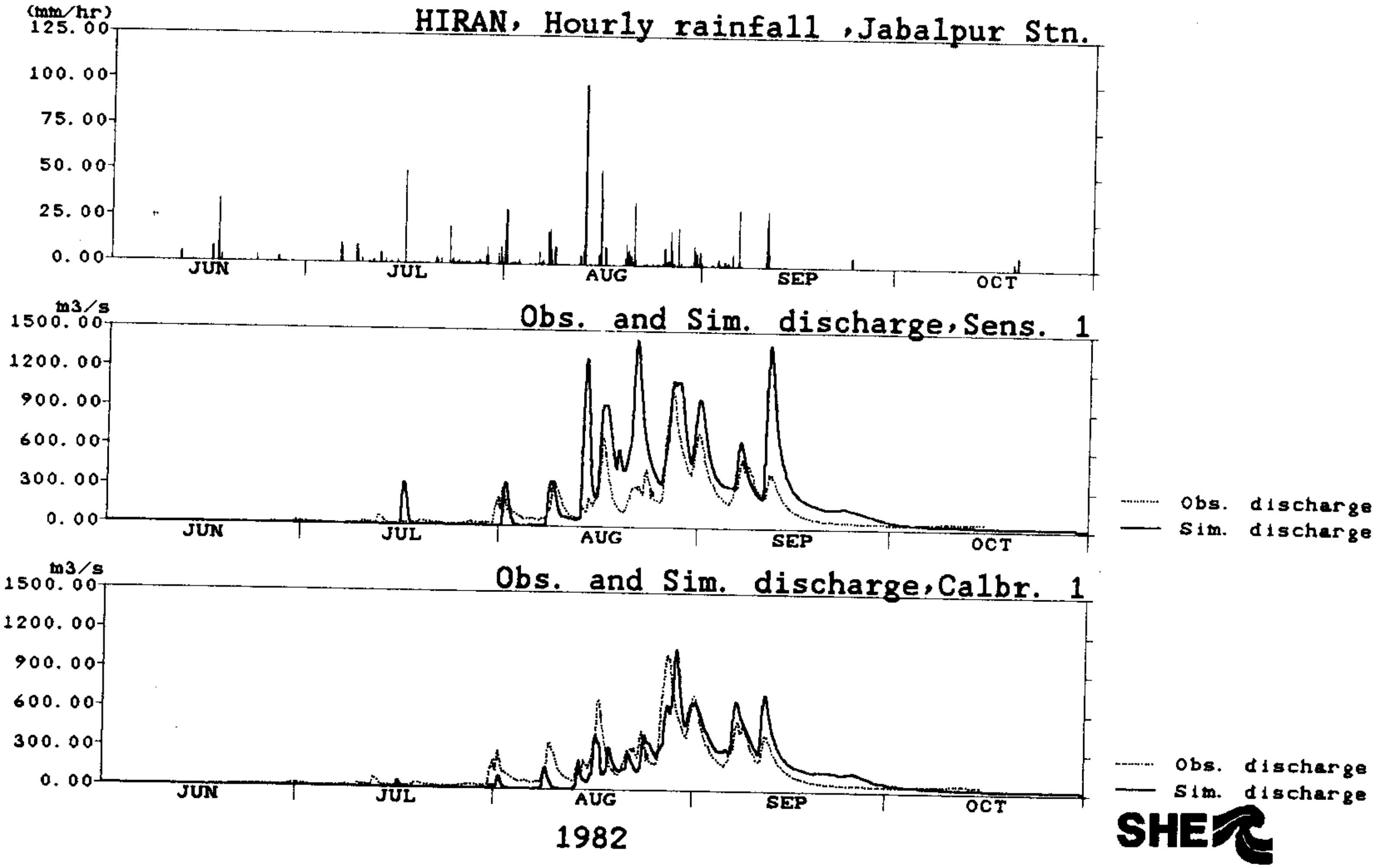


Fig.5.7:Observed and Simulated Discharge Hydrographs(Sensitivity-1)

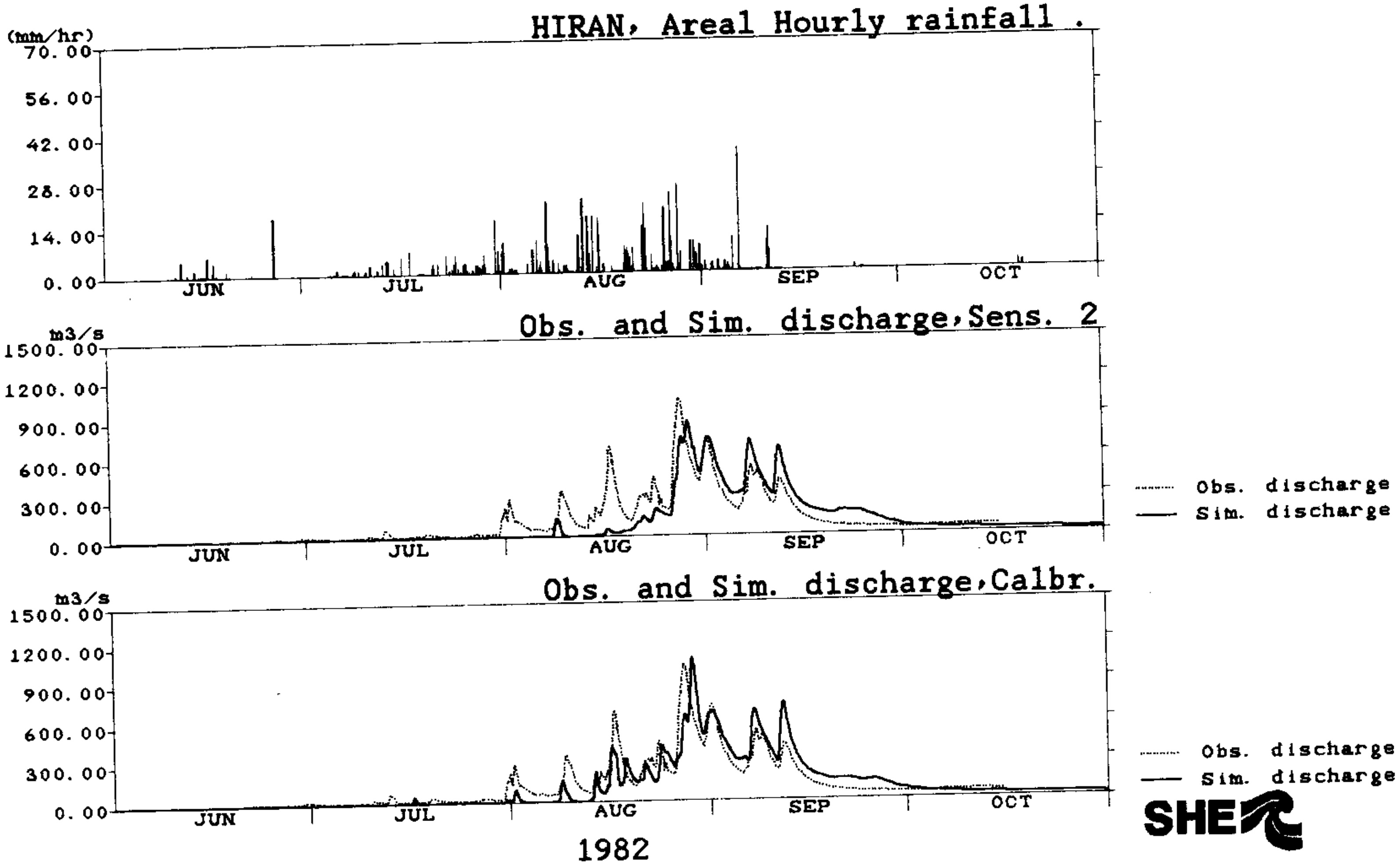


Fig.5.8: Observed and simulated discharge hydrographs (Sensitivity-2)

have adquate number of raingauges stations, otherwise the simulation results will be misleading and the entire efforts on calibration will be of no use.

During calibration runs, sensitiveness of some of the important parameters were identified. The qualitative response of the change in the values of the parameters as observed during calibration runs are summarised below.

1. The increase in Strickler roughness coefficient for channel flow resulted in higher peaks. This was because of the fact that for model representation increase in Strickler coefficient implies that the basin was more smooth and gives a quick response to overland flow. In this case smoother surface allows water to move rapidly giving less apportunities for evaporation and infilteration.

   The Strickler coefficient for overland flow has also the same sensitiveness as that shown by Strickler coefficient for channel flow.

2. The increase in saturated soil conductivity in unsaturated zone resulted in reduction of simulated discharge volume because higher conductivity allows more infilteration and hence, less water for overland flow. This parameter is not very sensitive to discharge peaks.

3. The increase in saturated zone conductivity resulted in less volume of discharge and lower peaks because higher the conductivity higher is the infilteration

and overland flow volume is less. The volume of water thus infiltered into the ground comes up after long period and in the next year it showed higher volume of discharge and higher peaks.

4. The increase in Averjanov's exponent resulted in increase in simulated discharge. This is because higher is the Averjanov's Exponent lesser is the evapotranspiration and thus more will be the surface runoff.

5. The increase in the water content at wilting point resulted in lesser volume of discharge. This is because the greater is the water content at wilting point the greater is the evapotranspiration and hence the overland surface flow will be less.

7.0 CONCLUSIONS:

The SHE model was successfully applied to model the entire land phase of hydrologic cycle for HIRAN Sub basin of riaver Narmada within the limit of time, computer load, data availability and assumption made. The available data includes the daily rainfall data for a number of stations situated within the sub basin, hourly rainfall record at only station i.e. Jabalpur close to the sub-basin outlet, hourly stage (gauge) data at Patan gauging site daily pan evaporation data at Jabalpur and values of some of the soil parameters at few sites within the sub-basin. The simulation study was carried out for a 2km x 2km grid size and split sample approach was adopted for calibration and validation of the model. The calibration was done using the data for the year 1982 and validation of the model was carried out using the data of two year, i.e., 1983 and 1984. Sensitivity analysis was performed to examine sthe effect of rainfall. This was done taking one rain gauge stations and comparing the results with the results obtained using all the rain gauge stations. Sensitivity of areal rainfall evenly distributed over the basin was also examined by comparing the results with the simulation run taking all the six station with their rainfall. Concluding remarks of the study are given below:

1. The calibration results show a reasonable reproduction of discharge hydrograph in terms of stream flow volumes and peaks with all the assumptions

and data limitations. In sthe absence of groundwater table data, actual evapotranspiration and moisture conditions, the results of simulation could not be compared with the actual values of these parameters.

2. The results of simulation in respect to the groundwater response was not very good as the initial ground water condition could not be taken as per acatual in the absence of data. Thus, from groundwater point of view neither the actual input could be taken nor the response of water table could be compared with the actual response. But ist can be anticipated that if groundwater response were to be reproduced, the groundwater draft will have to be taken into account and this will certainly modify simulation results resulting in slight change in the selected values of different parameters. Also, only one layer of aquifer was assumed with constant value of hydraulic conductivity.

3. The validation results using indepent data set show qualitative agreement with the measured value of discharge, peaks. The reproduction is not as good as obtained for calibration, the reason for this may be the non existence of the adequate number of raingauges; especially in the right half portion of the basin. The groundwater response has also been obtained for validation period.

4. The sensitivity runs show that the basin should have adequate number of raingauges which can truely represent the spatial and temporal distribution of rainfall, otherwise the results of the calibration will be very much misleading.

5. The values of the soil and vegetation parameters and overland flow roughness, have been taken from mindirect sources and available literature and their spatial over the basin were assumed constant. Therefore, the simulation results are subjected to uncertainties. Hence, for better simulation results reliable values of various parameters and its distribution should be given due importance.

6. The values of the parameters should be acertained for each grid square and the selection of the grid scale should be compatible with the intermediate distances between sites at which measurement of parameters are made, otherwise the results of the simulation will have scale effects.

7. The present form of 'SHE' does not allow the consideration of water bodies like, reservoirs, lakes, irrigation canals etc. existing in the basin. Thus, their effect on the hydrological response of the basin can not be modelled.

8. The river network and the basin boundary has to be along the grid sides and hence, on coarser grid scale, the river network and the boundary get distor-

ted. The huge data requirement in respect of soil and vegetation parameters are the major limitations of the model, particularly for developing country like India.

However, with all limitations of data and assumptions made, the results of simulation are encouraging and with reasonable degree of accuracy 'SHE' can be effectively applied to study the effect of future landuse changes and the problems associated with conjunctive use of water, irrigation etc.

REFERENCES

1. Abott, M.B.; Clarke, R. and Preissmann, A. (1978 'Logistics and benefits of the European Hydrologic System' Proc. International Symposium on Logistics and Benefits of Using Mathematical Models of Hydrologic and Water Resource Systemes, Pisa, October.

2. Abott, M.B; Anderson, J.K.; Havn, K. Jensen, K.H. Kroszynski, U.I. and Warren, I.R. (1982), 'Research and development for the unsaturated zone component of the Europena Hydrologic systeme' -Systeme Hydrologique European (SHE)', In; M.B. Abott and J.A. Cunge, (Editors) Engineering Applications of Computational Hydraulics, Pitman, London, Vol. I, pp. 42-70.

3. Abott, M.B.; Bathurst, J.C.; Cunge, J.A.; O'Connell, P.E; & Rammussen, J.(1986a), 'An Inroduction to the European Hydrological System-Systeme Hydrologique European, 'SHE', 1: History and Philosophy of a physically based distributed modelling system, Journal of Hydrology, 87, 45-59.

4. Abott, M.B.; Bathurst, J.C.; Cunge, J.A.; O'Connell, P.E; and Rammussen, J. (1986b), 'An Introduction to the European Hydrological System-Systeme Hydrologique European (SHE', 2: Structure of a physically based distributed modelling system, Journal of Hydrology, 87, 61-77.

5. Bathurst, J.C. (1986a), Physically based distributed modelling of an upland catchment using the Systeme Hydrologique European'. J. Hydrology, 87; 79-102.

6. Bathurst, J.C. (1986b), 'Sensitivity analysis of the Systeme Hydrologique European for an upland catchments, J. Hydrol., 87: 103-123.

7. Belmans, C.; Wesseling, J.G. and Feddes, R.A. (1983), 'Simulation model of the water balance of a cropped soil' SWATRE. J. Hydrology, 63, pp. 271-286.

8. Beven, K. (1985), 'Distributed models'. In: M.G.Anderson and T.B. Burt (Editors), Hydrological Forecasting, Wiley, Chichester pp. 405-435.

9. Beven, K. and O'Connell, P.E. (1982), 'On the role of physically based distributed modelling in Hydrology'. Institute of Hydrology. Wallingfore, Oxon Rep. No. 81.

10. Beven, K., Gilaman, K. and Newson, M., (1979), 'Flow and flow routing in upland channel networks', Hydrol. Sci. Bull., 24:303-325.

11. Blackie, J.R. and Eeles, C.W.O. (1985), 'Lumped catchment Models., In: Hydrological Forecasting (M.G. Anderson and T.P. Burt, eds), Wiley, Chichester, UK, pp. 311-345.

12. Clarke, R.T. (1973a), 'A review of some mathematical models used in Hydrology, with observations on their calibrations and use', Journal of Hydrology, 19, pp. 1-20.

13. Clarke, RT (1973b) 'Mathematical models in Hydrology, FAO Irrigation and Drainage paper No. 19.

14. Danish Hydraulic Institute (1988), 'Lecture notes Exercises' Training Course 1989 at DHI.

15. Engman, F.T. (1986), 'Roughness coefficients for routing surface runoff', Proc. Am. Soc. Giv. Engnrs., J. Irrig. Drainage Engg., 112 (1), pp. 39-53.

16. Feddes, R.A. Kowalik, P., Neuman, S.P. and Bresler, E. (1976), 'Finite difference and finite element simulation of field Water uptake by plants', Hydrol. Sci. Bull., 21:81-98.

17. Fleming, G. (1975), Computer simulation techniques in Hydrology 'Elsevier, New York.

18. ICAR (1987), ' Soil Management to Increase Crop Production', Report, Indian Council of Agricultural Research, New Delhi.

19. Jensen, K.H. (1981)' Application of soil water flow theory in field simulation', Nord. Hydrol., 12: 167-184.

20. Jensen, K.H. (1983)., Simulation of Water flow in unsaturated zone including the root zone, 'Ser. Pap. No. 33, Institute of Hydrodynamics and Hydraulic Engineering, Technical University of Denmark.

21. Kauraw, D.L., Verma, G.P. and Tiwari, Y.D. (1983), 'Evaluation of Soil Structure of Medium and Fine Textured Soils in Situ', J. Indian Soc. and Soil Seri. Vol. 31, pp. 13-19.

22. Kauraw, D.L. (1982), 'Insite hydraulic properties of vertisols and water uptake by plant roots, 'A Ph.D. Thesis, Deptt. Soil Science, JNKVV, Jabalpur, M.P., India.

23. Kaushal, G.S. (1981), 'Characterization and classification of solid of Bargi Project (Distt. - Jabalpur and Narsminghpur), A Ph.D. Thesis, Deptt. Soil Science and Agricultural Chemistry, JNKVV, Jabalpur, Madhya Pradesh, India.

24. Kristensen, K.J. and Jensen, S.E. (1975), ' A model for estimating Actual evapotranspiration from potential evapotranspiration, Nordic Hydrology, Vol. 6, pp. 70-88.

25. Monteith, J.L. (1965), 'Evaporation and environment'. In: The State and Movement of Water in Living Ooganisms, Proc. 15th Symposium Society for Experimental Biology, Swansea, Cambridge University Press, London, pp. 205-234.

26. Morris, E.M., (1982), 'Sensitivity of the European Hydrological System snow models', In: Hydrological Aspects of Alpurie and High Mountain Areas, Proc. IAHS Exeter Symposium, IAHS Publ. No. 138, 221-231.

27. Morris, E.M. (1983). 'Modelling of flow of mass and energy within a snow pack for hydrological forecasting', Ann. Glaciol., 4.1 188-203.

28. Morris E.M. and Godfrey, J.G. (1979), 'The European Hydrological System Snow routine, In: modelling of Snow Cover Runoff, S.C. Colbeck and M. Ray (eds), conference Proc., Cold Regions Research Laboratory, Hanover, N.H., pp. 269.

29. Rutter, A.J., Kershaw, K.A., Robins, P.C. and Morton, A.J. (1971/72), 'A predictive model of Rainfall interception in forests, In; Derivation of the model from observation in a plantation of corsican pine, Agric. Meteoral., 9, 367-384.

30. Versey, H.R. and Singh, B.K. (1982), 'Ground water Decdcan Basalts of the Betwa Basin, 'India, Jr. Hydrology 58, pp. 279-306.

31. Woolhiser, D.A. (1973), 'Hydrologic and Watershed modelling-State of art' Transactions of the ASAE 16, pp. 533-559.

ACKNOWLEDGEMENTS

The author wishes to express his deep sense of gratitude to Ministry of Water Resources, Government of India for providing him the opportunity to undertake four months training (9th August, 1989- 8th December, 1989) at Danish Hydraulic Institute (DHI), Denmark under the project agreement entitled, "Hydrological Computrised Modelling System (SHE)" signed between European Economic Committee (EEC) and the Republic of India.

The author is extremely grateful to Dr Satish Chandra, Director, National Institute of Hydrology (NIH), Roorkee and Project Director and to Mr J.C. Refsgaard, Project Manager, Danish Hydraulic Institute, Denmark for their keen interest in providing necessary guidance and constant encouragement before, after and during the training. The author expresses his gratitude to the European Economic Community for providing necessary financial help and to Dr S M Seth, Scientist F and Project Coordinator, NIH Roorkee for his valuable guidance and suggestions at every stage of the study. The author is also grateful to Dr P V Seethapathi, Scientist F, NIH, Roorkee for his kind encouragement and moral support.

The author is extremely thankful to Mr B Storm, Chief SHE Modelling (DHI), Dr J C Bathurst, SHE MOdelling Expert, University of Newcastle Upon Tyne (UK), Mr M Erlich, SHE Modelling Expert (France), Mr G H JOrgenson and Mr Thomas Clausen, SHE MOdelling Experts from DHI and other staff members of DHI for providing necessary guidance, help and support in making the training programme successful. The help rendered by the supporting staff of DHI is also acknowledged.

The author thankfully acknowledges the help and guidance received as and when required from Mr R D Singh, Mr S K Jain and Mr V K Lohani, Scientists of NIH who received SHE model training during the year 1988. The help and cooperatiion during the course of training rendered by Mr Rakesh Kumar, Scientist B and Mr C P Kumar, Scientist B and the help provided during the data preparation by Mr Avadhesh Kumar, Scientist B, Mr Mukesh Mohan, Scientist B, Mr Sudhir Kumar Goyal, Mr P K Agarwal and Mr S K Verma, Senior Research Assistants of NIH; is also thankfuily f acknowledged.

The author is also thankful to Mrs Meenakshi Mishra, NIH and Shri Dayal Singh for neatly typing the manuscript and Shri YPS Varma and Mrs Nisha Kichlu for final typing. Thanks are also due to all seniors, colleagues and well-wishers who have directly or indirectly contributed towards the prepartion of this report.

Last but not the least, the author records his sincere appreciation and thanks to the officers of various Central Government Organisations and of Madhya Pradesh Government for their cooperatioin and help in providing the required data and information for the study.

(S K SINGH)

ANNEXURE 1

Organisations from which the data were collected includes

1. M.P. Irrigation Department
    a) Director Hydrometeorology
    b) Upper Narmada Circle
    c) Superintending Geologist
    d) Various concerned circles, Divisions and sub-divisions.
2. Narmada Valley Develoment Authority
    a) Superintending Engineer, Circle 2
    b) Joint Director (Agriculture)
3. Central Water Commission
4. J.N.K.V.V. Agricultural University
5. India Meteorological Department, Delhi and its offices at Pune, Nagpur and Bhopal
6. Central Groundwater Board - North Central Region
7. Survey of India, Dehradun
8. Narmada Control Authority, Delhi and Bhopal
9. All India Soil and Landuse Survey Organisation, New Delhi and Nagpur
10. Director, Department of Agriculture, Bhopal and zonal Agriculture Research Stations at Powerkheda, Khandwa and Adhartal
11. M.P. Groundwater Survey Board, Bhopal and its other offices
12. State Forest Research Institute, Jabalpur
13. College of Agriculture, Indore
14. Institute of Devidiuens Forest, Jabalpur
15. Offices of Statistics and Land Record in the concerned districts.

ANNEXURE - 2

DIRECTOR	SATISH CHANDRA
PROJECT COORDINATOR	S M SETH
SCIENTIST	S K SINGH
SCIENTIFIC STAFF	S K VARMA
	P K AGRAWAL
OFFICE STAFF	MEENAKSHI MISHRA
	DAYAL SINGH
DOCUMENTATION STAFF	Y P S VERMA
	NISHA KICHLU