CHAPTER 7

STUDY OF IMPACT OF SOIL AND LAND USE CHANGES ON HYDROLOGIC REGIME USING SHE MODEL

7.0 INTRODUCTION

In hydrology, mathematical models are used for a number of applications like rainfall runoff modelling, flood forecasting, reservoir operation and ground water exploitation. Distributed models, which form an important class of models of land phase of hydrological processes in a catchment, are based on detailed description of component processes. The SHE is one such model.

Beven(1985) mentions four major potential areas of application of the distributed models. One of these areas is forecasting the effects of land-use changes on hydrological regime of a catchment. In the present study, the SHE model was used in the context of study of effect of land use changes on hydrologic regime of a hypothetical catchment.

7.1 STRATEGY ADOPTED

In this study the behaviour of a microscale catchment was simulated under different conditions in terms of soil hydraulic properties, soil depth, land use, and surface roughness for overland flow. The results of this study provide insight into behaviour of a real catchment since such catchment can be visualized to be composed of a number of small elemental areas.

The changes in the physical characteristics of a catchment lead to changes in the associated parameters. In practice, seldom only one parameter changes; alteration in one parameter triggers changes in a number of associated parameters. For example, change in land use leads to change in the amount of interception of input precipitation, the evapotranspiration from the area, surface roughness, and soil hydraulic conductivity etc. In the present study, several simulation runs were taken in which the parameters of catchment response were different. The results of those runs in which only one parameter differed were intercompared to determine the effect of the individual changes.

The relevant information of Kolar basin was used in the study. The results of simulation of Kolar basin are described in Jain (1990).

7.2 DETAILS OF STUDY AREA

In this investigation, the study area was single square shaped grid with a river flowing along one of the sides. This square, which represents a single soil column in SHE setup, was assumed to be surrounded by impervious boundaries. Schematic representation of this catchment area is shown in Fig. 7.1 and 7.2. The dimensions of the square were 2 km * 2 km.

7.3 SCENARIOS STUDIED

The various combinations of soil type, soil depth and land use, as used in the simulation of Kolar basin are shown in Table 7.1. A percentage sign (%) in a particular box indicates that no grid square fell in that combination. In this table, there are sixteen combinations of soil depth, soil hydraulic properties, vegetation type and Strickler's roughness coefficient. Each of these scenario was separately simulated.

In Table 7.1, the numbers given in square brackets refer to that simulation run using the corresponding parameters. In the subsequent discussion, R followed by this number is used to

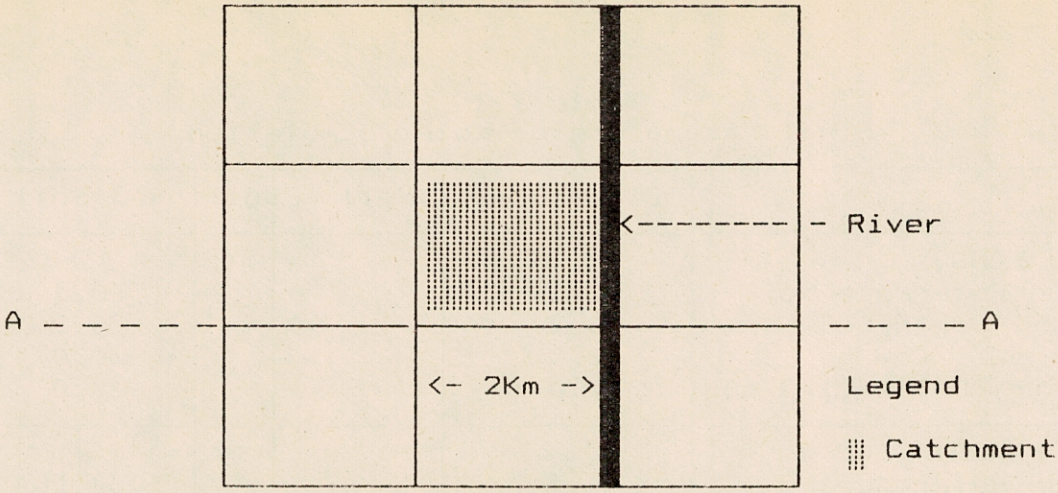

Fig. 7.1 Schematic representation of single column catchment

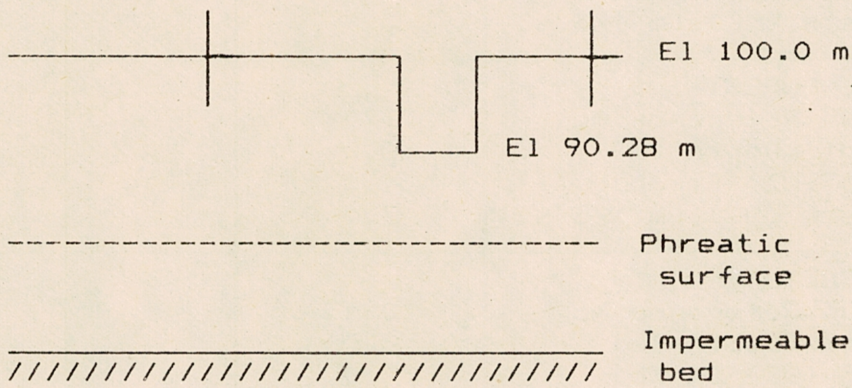

Fig. 7.2 Section along A-A

Table 7.1
Final Parameters of Kolar Simulation

	Black Soil	Yellow Soil	Red Soil	
WASTE LAND				
1. Run Reference No	[01]		[02]	
2. Soil Depth [m]	0.2	%	0.2	
3. Ks {UZ} [mm/h]	2.0		20.0	
4. Kstr {OC} [m 1/3/s]	7.0		7.0	
OPEN FOREST				
1. Run Reference No			[03]	[04]
2. Soil Depth [m]	%	%	0.5	0.7
3. Ks {UZ} [mm/h]			50.	50.
4. Kstr {OC} [m 1/3/s]			5.	5.
MEDIUM DENSE FOREST				
1. Run Reference No		[05]	[06]	[07]
2. Soil Depth [m]	%	0.5	0.5	0.7
3. Ks {UZ} [mm/h]		40.0	50.	50.
4. Kstr {OC} [m 1/3/s]		3.	3.	3.
DENSE FOREST				
1. Run Reference No	[17]*		[08]	
2. Soil Depth [m]	8.0	%	0.5	
3. Ks {UZ} [mm/h]	4.0		50.	%
4. Kstr {OC} [m 1/3/s]	7.0		4.	
AGRICULTURE				
1. Run Reference No	[09]			
2. Soil Depth [m]	8.0	%	%	
3. Ks {UZ} [mm/h]	4.0			
4. Kstr {OC} [m 1/3/s]	7.0			
AGRICULTURE				
1. Run Reference No	[10]		[11]	
2. Soil Depth [m]	4.0		4.0	
3. Ks {UZ} [mm/h]	4.0	%	40.0	
4. Kstr {OC} [m 1/3/s]	7.0		7.0	
AGRICULTURE				
1. Run Reference No	[12]		[13]	
2. Soil Depth [m]	2.5	%	2.5	
3. Ks {UZ} [mm/h]	4.0		40.0	
4. Kstr {OC} [m 1/3/s]	7.0		7.0	
AGRICULTURE				
1. Run Reference No	[14]	[15]	[16]	
2. Soil Depth [m]	1.0	1.0	1.0	
3. Ks {UZ} [mm/h]	4.0	20.0	40.0	
4. Kstr {OC} [m 1/3/s]	7.0	7.0	7.0	

* This is a hypothetical scenario.

refer to the particular run, e.g., R1, R4.

7.4 INPUT DATA USED

The input time series data pertaining to Kolar basin was used. The detailed information about these data is given in Chapter 5 on Kolar simulation update. THe hourly rainfall data for the station Jholiapur was used because the order of rainfall volume at this station is in the same range as is the mean of all four SRRG stations used in Kolar simulation.

The data for the three year period 1986-88 was used in the present analysis. During these years, the volume of rainfall during the monsoon season was 1491 mm, 983 mm, and 1168 mm respectively. During 1986, rainfall was a mixture of few big isolated events and a number of events of low intensity rainfall. In 1987, the rainfall occurred mostly in the form of isolated events of short duration intense storms. The year 1988 consisted of low intensity long duration events with few intense rainfall events.

The starting date of simulation runs was 01 January 1986. The initial soil moisture profile was set at field capacity. The results of first year of simulation, ie, year 1986 are, therefore, affected by the initial conditions.

7.5 ANALYSIS OF RESULTS

The analysis of results of simulation runs is presented in this section. The results have been analyzed to determine the impact of soil depth, soil hydraulic properties, land use, and surface roughness characteristics on the hydrologic regime.

7.5.1 Output variables monitored

The variables which were monitored in the present study were runoff, moisture content in the unsaturated zone, and evapotranspiration from the catchment.

A summary of results of all runs is given in Table 7.2. The plot of variation of soil moisture in the unsaturated zone, actual and potential evapotranspiration, outlet discharge and input rainfall for a typical case is given in Fig. 7.3.

7.5.2 Impact of Soil Depth on Hydrologic Regime

The soil depth along with soil properties governs the moisture storage capacity of the sub-surface zone in a catchment. This along with the soil conductivity affects the water available for runoff as well as that available to meet evapotranspiration requirements.

In the runs R9, R10, R12, and R14, all parameters except the soil depth were same. A comparison of results of these runs is given in Table 7.3.

Table 7.3

Summary Results of Simulations - Impact of soil depth

Run No.	Run parameters *SD/Kuz/Kstr	Outflow Volume during monsoon (mm)		
		1986	1987	1988
R9	8.0/ 4./ 7.	813	79	171
R10	4.0/ 4./ 7.	847	70	242
R12	2.5/ 4./ 7.	874	151	323
R14	1.0/ 4./ 7.	1098	450	611
Monsoon Rainfall		1491	983	1168

Note : * = Soil depth.

Table 7.2
Summary Results of Simulations - River Flow

Run No.	Outflow Volume during monsoon (mm)		
	1986	1987	1988
R1	1253	605	785
R2	1250	591	816
R3	1174	510	684
R4	1122	458	631
R5	1167	506	680
R6	1172	508	684
R7	1120	457	631
R8	1175	508	684
R9	813	79	171
R10	847	70	242
R11	803	109	299
R12	874	151	323
R13	859	174	367
R14	1098	450	611
R15	1100	455	615
R16	1099	455	615
R17	766	73	128
Monsoon RF	1491	983	1168

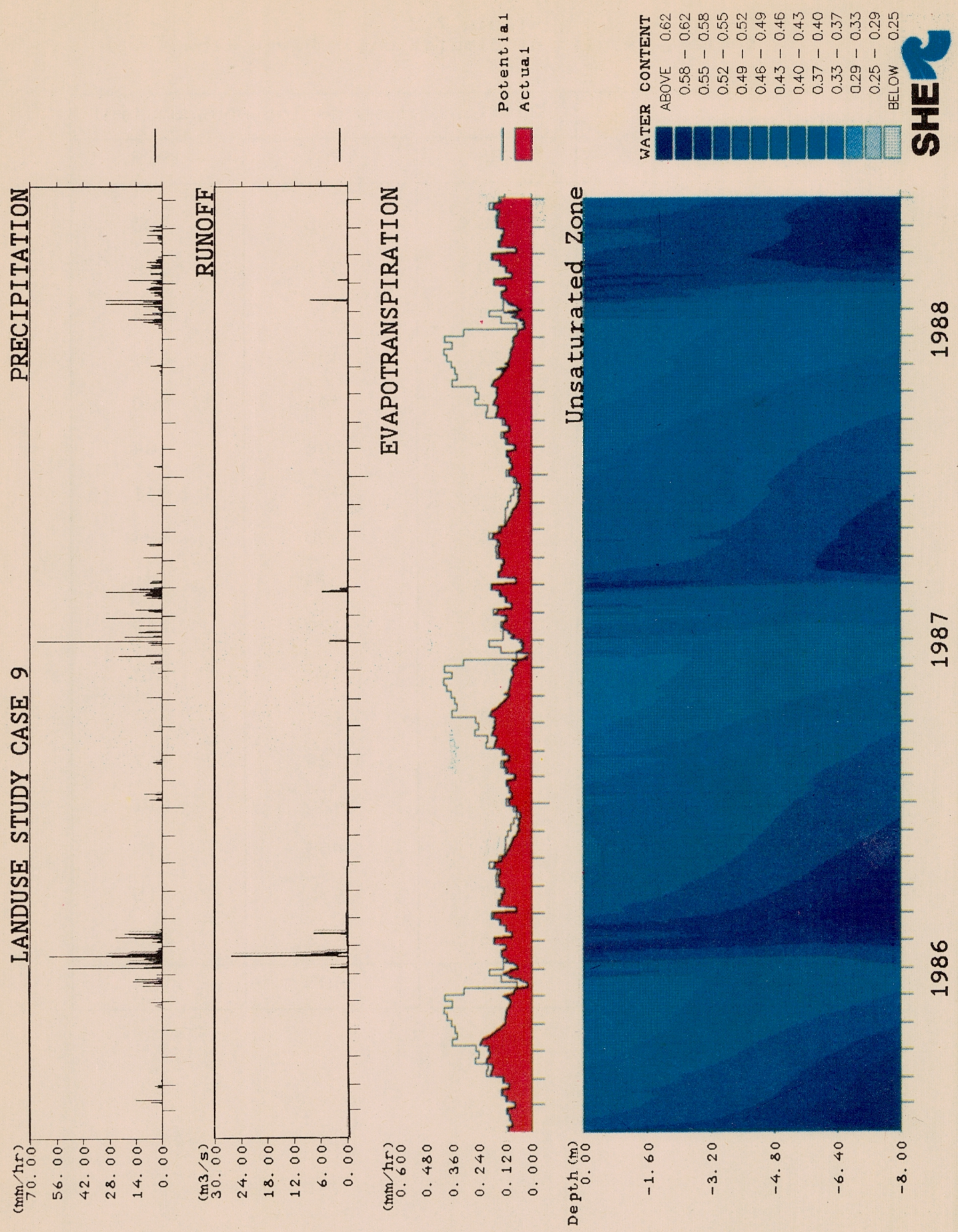

Fig. 7.1 : Variation of Precipitation, Runoff, Actual & Potential Evapotranspiration and Moisture Content in Sub-surface Zone for a Typical Case

A study of this table shows that lesser soil depth produces more runoff because lesser moisture can be stored in the soil. In the run R14, the soil depth was 1.0 m and the soil got completely saturated several times during the simulation in this case. In case of R9, the runoff volume for the three monsoon seasons was 813 mm, 79 mm, and 171 mm while in case of run R14, this volume was 1098 mm, 450 mm, and 611 mm. Thus there is a significant difference in the runoff, of the order of 500%, in the two cases where the soil depth was 8.0 m and 1.0 m respectively. The increased soil depth gave lesser runoff coefficient.

The results of the runs R10 and R12, soil depth 4.0 m and 2.5 m respectively, also support these observations (Table 7.4). Here because of less variation in soil depth, the variation in the discharge was also less.

Table 7.4
Summary Results of Simulations - Impact of soil depth

Run No.	Run parameters SD/Kuz/Kstr	Outflow Volume during monsoon (mm)		
		1986	1987	1988
R10	4.0/ 4./ 7.	847	70	242
R12	2.5/ 4./ 7.	874	151	323
Monsoon Rainfall		1491	983	1168

Similar effect of soil depth is seen while comparing the results of the runs R11, R13, and R16, as given in Table 7.5. A comparison of results of R11 (soil depth 4.0 m) and R16 (soil depth 1.0 m) shows that a four fold reduction in soil depth gave about 37% increase in discharge during monsoon of 1986, more than 4 times increase in 1987 and about twice big in 1988. The reduction in soil depth also gives increased flashiness in the basin response. This is because the soil storage also acts as a reservoir.

Table 7.5
Summary Results of Simulations - Impact of soil depth

Run No.	Run parameters SD/Kuz/Kstr	Outflow Volume during monsoon (mm)		
		1986	1987	1988
R11	4.0/40./ 7.	803	109	299
R13	2.5/40./ 7.	859	174	367
R16	1.0/40./ 7.	1099	455	615
Monsoon Rainfall		1491	983	1168

This analysis clearly brings out the likely consequences of soil erosion on the catchment yield. It is true that the changes of such a large order as studied here will normally, if at all, take place over a very big time span. Nevertheless the bottom line is that the changes in yield volume from a big area can not be overlooked.

7.5.3 Impact of Soil Properties on Hydrologic Regime

In the runs R1 and R2, everything except the soil properties was same. An intercomparison of the results (Table 7.6) shows that the difference between the results is not

Table 7.6
Summary Results of Simulations - Impact of soil properties

Run No.	Run parameters SD/Kuz/Kstr	Outflow Volume during monsoon (mm)		
		1986	1987	1988
R1	0.2/ 2.0/ 7.	1253	605	785
R2	0.2/20. /7.	1250	591	816
Monsoon Rainfall		1491	983	1168

significant. Similarly, in the runs R10 and R11, only soil properties were different but the response of the basin is significantly different in the two cases. It is seen that, in general, the runoff in case of R10 (in which soil conductivity was smaller) is higher than R11 (in which soil conductivity was larger) in the initial months of the wet period while it is vice versa in the later months of the wet period.

Table 7.7
Summary Results of Simulations - Impact of soil properties

Run No.	Run parameters SD/Kuz/Kstr	Outflow Volume during monsoon (mm)		
		1986	1987	1988
R10	4.0/ 4./ 7.	847	70	242
R11	4.0/40./ 7.	803	109	299
Monsoon Rainfall		1491	983	1168

Overall, the discharge volume in run R10 was higher than R11 in 1986 and was lower in 1987 and 1988. From the detailed results it was observed that the soil moisture deficit in case of R11 was higher by about 10% in 1987 and 1988 and about 20% higher in 1986. The moisture storage capacity of R10 soil is higher as compared with R11 and hence less runoff is produced. The results of 1986 seem to be affected by initial conditions. The shape of hydrograph was spiky in R10 and smooth in R11. This can be attributed due to UZ conductivity.

While comparing the results of the runs R12 and R13 and the runs R14, R15, R16 (Table 7.8), not much difference is observed. It appears that in case the soil depth is small, the soil properties do not play a significant role.

Table 7.8
Summary Results of Simulations - Impact of soil properties

Run No.	Run parameters SD/Kuz/Kstr	Outflow Volume during monsoon (mm)		
		1986	1987	1988
R12	2.5/ 4./ 7.	874	151	323
R13	2.5/40./ 7.	859	174	367
R14	1.0/ 4./ 7.	1098	450	611
R15	1.0/20./ 7.	1100	455	615
R16	1.0/40./ 7.	1099	455	615
Monsoon Rainfall		1491	983	1168

7.5.4 Impact of Surface Roughness on Hydrologic Regime

The results of runs R3, R6, and R8 can be compared to determine the effect of the surface roughness characteristics on the basin response. The summary results are given in Table 7.9. In these runs only the Strickler roughness coefficient was different. An examination of the results shows that this coefficient does not have a significant influence on the long term water balance of the basin. This factor, however, is very important in determining the shape of the hydrograph during the flood season or the flashiness of the basin response.

Table 7.9
Summary Results - Impact of surface roughness

Run No.	Run parameters SD/Kuz/Kstr	Outflow Volume during monsoon (mm)		
		1986	1987	1988
R3	0.5/50. /5.	1174	510	684
R6	0.5/50. /3.	1172	508	684
R8	0.5/50. /4.	1175	508	684
Monsoon Rainfall		1491	983	1168

7.5.5 Impact of Vegetation on Hydrologic Regime

The results on run R9 and R17 (Table 7.10) provide a comparison to determine the impact of vegetation changes on the hydrologic regime.

Table 7.10
Summary Results - Impact of vegetation

Run No.	Run parameters SD/Kuz/Kstr	Outflow Volume during monsoon (mm)		
		1986	1987	1988
R9	8.0/ 4./ 7.	813	79	171
R17	8.0/ 4./ 7.	766	73	128
Monsoon Rainfall		1491	983	1168

It is seen from that less runoff was produced in R17 as compared with R9. The reason was that in case of R17, soil was more dry when the monsoon rains arrived. There was high loss of moisture due to evapotranspiration. Here, it may be mentioned that the consequences of vegetation change will heavily depend on the properties of vegetation regarding interception and water requirements for transpiration.

7.5.6 Impact of Land Use on Hydrologic Regime

As mentioned earlier, the change in land use will lead to change in a host of associated parameters. The sum total effect of the changes will be the cumulative effect of the individual influences.

7.6 CONCLUSIONS

Based on the findings arrived at above, the following conclusions can be made regarding the effects of soil properties and land use change on the hydrologic regime of a micro catchment.

a) **Soil Depth** - Reduction of soil depth will lead to higher yield from the catchment. In case of shallow soils, the soil properties do not have significant effect on catchment response.

b) **Soil Properties** - Higher soil conductivity will lead to less runoff and less spiky hydrograph. Shape of soil moisture retention curve mainly affects the response during early part of wet season. The degree of effect depends on the shape of the curve.

c) Change in vegetation - The amount of ET losses will change - - they will increase or decrease depending on the related crop characteristics, viz., leaf area index (higher losses with higher index and vice versa), depth and size of roots, and the growth characteristics.

d) Change in surface roughness characteristics -- This will lead to change in degree of flashiness of catchment response.

The composite effect of various changes for a real catchment will be combination of individual effects along with their interactions for various elemental units. It would therefore be desirable to carry out studies on similar lines for real catchments.

7.7 REFERENCES

1) Beven,K., "Distributed models in Hydrological Forecasting", In Hydrological Forecasting, M.G. Anderson and T.P. Burt (ed.), Wiley Chichester, UK, 405-435, 1985.

2) Jain,S.K., Application of SHE model to Kolar subbasin of River Narmada, Report CS - 33, National Institute of Hydrology, Roorkee, 1990.

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