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IMPACT OF FOREST ON GROUND WATER

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PREFACE

Forests, major component of the ecological cycle, have great influence on hydrological variables. Studies have been done in our country and elsewhere to assess the forest influences on various component processes as well as hydrological variables. The results of such studies have been compiled in the form of status reports and needs for further studies have been identified.

Forest influence on groundwater have not been studied at large scale. A number of opinions in this regard have been experienced by various research workers. An attempt have been made in the present report to study the influence of forest as ground water using a methodology, which is based on the equation developed by Hantush (1967) to predict rise & fall of ground water mounts using horizontal flow theory. The values of recharge and evapotranspiration have been used from studies reported under cultivated land and shola vegetation in Nilgiris. Using the methodology, the position of groundwater has been computed over the year.

The present study entitled 'Impact of Forest on Groundwater' is a part of work programme of 'Man's Influence' Division of the Institute. The study has been carried out by Sh. V.K. Lohani, Scientist 'C' and Sri N.S. Raghuwanshi, Scientist 'B' under the guidance of Dr. G.C. Mishra, Scientist 'F'.

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ABSTRACT

Forest influences on groundwater storage can be estimated from evapotranspiration and discharge relationships. Studies have been done in various countries to establish relationship between forests and groundwater, however, these have not been on extensive scale. The findings of these studies have not been very coherent as studies conducted in the USA claim that water tables collapse as a result of deforestation or forest fires; while studies done in Switzerland do not seem to indicate any effects on ground water as a result of forest cover changing to grass. In an International Symposium held in 1980 in Helsinki, Guillerne (1980)reported while describing the influence of deforestation on groundwater in temperate zones that there did not seem to be any historical evidence of any direct influence of deforestation on the lowering of water tables. On the other hand, there have been opinions that logging of tropical forest watersheds had caused wells, springs, streams, and even major rivers to cease flowing. There have also been opinions that roots of forest exhibit 'sponge' effect that soaks up water in the wet periods and let it release slowly and evenly in dry season to keep water supplies adequately restored. In its forestry sector policy paper, the world bank has advocated reforestation of upland watersheds partially on the grounds that it will indicate dry season flows and raise groundwater well levels. On the contrary, most of well conducted experiments have shown that reforestation reduced streamflow experiments have universally given increased total water yield over the year. There are instances where trees have been planted to arrest rising groundwater level in water logged areas.

In view of the prevailing state of knowledge, it is necessary to conduct systematic study to spell out effects of forests on groundwater. For this purpose, a comprehensive review of literature has been carried out. Also a methodology has been presented to determine the forest influence under different land uses.

1.0 INTRODUCTION

The influence of forest on their environment forms part of a vast and complex relationship between environment and forest vegetations. Many workers have been trying for past several decades to assess the influence of forest on various hydrological parameters and processes viz. rainfall, interception, infiltration, soil moisture, evapotranspiration, groundwater, water yield, flood and soil loss etc. However, as yet the results reported to this effect have been mainly confined to small experimental watersheds or runoff plots. Also as the water shed experiments are long term and expensive, not much such studies have been done in developing countries.

Ground water is one of the main components of hydrological cycle. One of the predominant factors which affects the movement of water over and into the ground surface is the vegetation cover of the watershed. There could be several types of covers or the land uses on the soil surface for example, forests, grass, agriculture, barren land etc. Different land uses have different kinds of effects on movement of water over and under the ground surface. In the presence of forest, water movement and water action are different because of the canopy, forest floor, and distinctive soils. Forest on one hand due to their deep rooting system and added contribution to organic matter content of the soil have been generally found to improve the soil structure resulting in better surface recharge conditions. On the other the evapotranspiration requirements of the forests have been found relatively higher than other land uses. Therefore, the net effect of forests on groundwater regime becomes an important issue for investigation by hydrologists which in turn is useful for water resources planners and environmentalists.

Besides carrying out experimental studies, qualitative assessment of effects of forests on ground water regime can also be done by use of mathematical models which predict position of ground water table as a result of recharge abstraction from ground surface. The present report discusses such an approach alongwith giving a detailed overview of such studies carried out in the country and abroad.

2.0 HYDROLOGIC ROLE OF FORESTS

The important components of a forest from hydrological point of view are canopy, leaf litter and humus with dense roots. Interception, surface ponding and detention, obstruction of the surface runoff by leaf litter, mulch, debris, storage of water by humus and organic matter, dead root and burrows of organisms are the effects of forest cover on hydrology of the basin. Leaf litter and humus act as a cushion against the impact of rain drop and provide temporary pondage as the rich organic content of the dense leaf litter helps in high infiltration and soil moisture storage. Water holding capacity of humus is several times its weight and the presence of organic matter improves the soil structure. The leaf litter and humus is high in temperate sub tropical zone and low in tropical zone. Hence, good cover, high organic matter, ramified root system and protective-cum-productive vegetation as found in a forest catchment regulates the streamflow. Thus the important components of a forest which influence hydrology of a catchment are canopy (including top storey, under wood, and undergrowth), density, leaf litter and humus with dense roots. Researchers have been trying for past several decades to ascertain the hydrological importance of forests. Kittredge (1948) suggested that the important phases of forest influences concerned with water, such as precipitation soil-water, streamflow, floods may be grouped under 'Forest Hydrology'. Some major processes/parameters related with ground water regime which are affected by presence of forests may include infiltration, soil structure conditions and moisture retention capacity, ground water status and evapotranspiration. A detailed discussion in these parameters/processes is as below:

2.1 Infiltration

Infiltration is the downward movement of water through the surface of mineral soils; its rate is usually expressed in the same units as precipitation intensity (mm/hr). The moisture seeps in, toward the plant roots and into the groundwater from the soils surface due to gravity as well as to suction by capillary menisci, to pressure from higher lying layers of water, and to some other courses. Thus the infiltration rate can not exceed the intensity of precipita=-tion over bare soil, and in the forest it can not exceed the intensity of effective precipitation. Besides, the rate of infiltration depends on the soil moisture content, soil texture, organic matter content, amount of precipitation and temperature (which affects soil solution) etc. The depth to which moisture percolates depends on the rate at which it penetrates into the soil, and this in turn, depends on the amount of precipitation, on the water table, and on the correlated moisture content of the soil. When the water table is shallow, the soil's moistness is at a maximum, because the capillary rise of moisture reaches almost to the day surface. When the ground water lies deeper the capillary stratum of the soil and latter's moisture content decrease, so that seepage of precipitation moisture slow down, Molchanov (1960). Infiltration capacity on the other hand, is the highest rate at which water can be absorbed by a given soil.

Soils with course texture or with fine particles clumped into stable large aggregates, have high infiltration rates. The advantages of soil texture and structure are minimized on bare areas because the beating action of raindrops and the sorting action of flowing water break down aggregates and plug pore spaces with fine particles.

In respect of the permeability of frozen soils, a number of studies have been carried out by Zhilinskii (1892), Bogdan (1900), Shalabanov (1903) Karamzin (1912), Kachinskii (1927), Zaikov (1935), Kabanov (1938), Komarov (1939, 1955), Serebrayanskaya (1946) etc. The studies have found varying rates of infiltration in frozen soil owing to following reasons:

(1) freezing of water in open capillaries, i.e., junctional moisture and that in beaded, retained by forces of surface tension; this makes the soil less permeable, in comparison with a thawed-out soil;

(2) freezing of capillary moisture (i.e., in cosed capillaries), as well as gravity moisture, which is highly mobile.

(3) freezing of bound water, which is present in the soil in amounts not exceeding the wilting coefficient.

Studies have been attempted to find out effects of land use on infiltration rates. Molchanov (1960), based on the observations in various areas in U.S.S.R., has deduced that the forest soils have a higher moisture absorptive capacity than soils on treeless terrain. The moisture filtration in the soils changes according to type of forest, to age of stand, and to degree of improvement cutting, as well as to composition of species, Molchanov (1960).

The abosorptive capacity of soils changes during the summer, depending on the duration and intensity of rainfall. At the start of rain, infiltration proceeds at a higher rate than at the end, and the decrease is greater in the longer lasting rains.

Closeness of stand is also very important. For instance, expenditure of moisture on replenishment of reserves within the soil, and on percolation into the ground, must differ in forests which have been more or less cleared by improvement cutting (Table 1) . The expenditure on replenishment of moisture reserves is greatest in stands where no improvement cutting has been practiced. In such stands, there is less moisture available for percolation into the ground. Strongest percolation is observable after moderate cutting, when least amounts of moisture are expended on replenishing of soils moisture reserves.

Moisture does not penetrate very well into the soil under spruce, the uppermost layer becomes saturated, and much of the moisture runoff the horizens of illuviation. Pine has a deep and ramified root system, which increases the permeability of soils and results in a better moisture regime. Oak, with its very deep roots exerts on exceptionally favourable influence on the soil's moisture regime. Ash stands are also

TABLE 1

Moisture filtration in arboreal stands cleared by improvement cutting

Degree of clearing	Closeness	Expenditure of moisture, in mm	
		on replenishment of reserves within soil	on percolation, below the 5-meter stratum
Check plot	1.0	239.8	80.3
Slight clearing	0.9	157.6	177.1
Moderate clearing	0.7	157	193.0
Strong clearing	0.6	171.2	183.0

very good for the permeability of soils.

Regarding rates of infiltration under forests Burger (1954) observed at sperbel and Rappen Graben (Switzerland), a layer of 100 m water will take 1-2 minutes to seep into a forest soil which has a good structure and an undistributed litter, but it will take 120 minutes in the case of a forest soil which has been used for grazing and 1-3 hours, wherever the soil have been much trampled. The infiltration through a 25 cm layer sandy soil covered with grass amounts to 22% of total precipitation, it is 44% on bare soil, and 60% in forest, on the same soil, but covered with mossy vegetation. In a study in Japan, Tsukamoto (1975) observed that infiltration rates decreased markedly for all soil horizons following litter removal (Table 2). These results lead to believe that forest litters hold water temporarily and release it gradually to the soil along with dissolved and particulate organic mineral, which improve the soil structure and infiltration capacity. In the absence of the litter layer, rain drops compact the soil, and infiltration capacity is reduced. When the volume of infiltrating water exceeds the detention capacity of the soil profile on a permeable geologic structure, an increase in groundwater level can be expected.

Murai (1973) found that compactation of the soil surface by animals does reduce infiltration rates and thus could affect groundwater accessions negatively as indicated in (Table 3). Mott et al. (1979) found that heavy grazing and drought caused soil seals in open eucalypt wood land in

Table 2 Effects of Litter Removal on Infiltration Capacity

Soil Horizon	Untreated Infiltration Rate (mm/min)	Treated Infiltration Rate (mm/min)
H	120	2
A_1	60	0
A_2	14	4
B	5	3

Source: Tsukamoto (1975).

Table 3: Surface Erosion and Infiltration Rates under Pine Forest

			Infiltration Rates	
Slope	Grazing Treatment (cow/days)	Three-Year Erosion Depth (mm)	Before Grazing (mm/hr)	After Grazing (mm/hr)
0°–10°	31–40 (light)	15.7	205.1	48.9
	55–70 (heavy)	18.5	200.6	44.5
20°–40°	31–40 (light)	26.1	285.3	137.0
	55–70 (heavy)	40.5	357.4	158.0
Rolling	Not grazed	14.9	365.1	353.9

Source: Adapted from Murai (1973).

northern America.

In Fig. 1 , infiltration rates for grassland were substantially less than under forest and runoff was almost 100 percent. Runoff coefficients were 0.90 for grass catchments, 0.45 in forest and scrub, and 0.15 in undisturbed forest (Cochrane, 1969).

The high rates of infiltration typical of undistributed forest in comparison with other forms of land use have been shown by a large number of tests and demonstrations. From these tests Kittredge (1948) concludes that

(a) undistributed natural forest canopy and floor maintain infiltration at a maximum for a given situation;

(b) infiltration is greater in old than in young plantations, greater in ungrazed than grazed forest, and greater in unthinned or lightly thinned than heavily thinned plantations;

(c) the difference in infiltration between forested and cropped soils may be in the ratio of 100 to 2 in one inch depth of soil surface;

(d) the influence of forest on infiltration is least on sands or other highly permeable soils.

In India, studies have been carried out to determine the infiltration rates under varying forest cover by some organisations. Patnaik and Virdi (1962) reported higher infiltration rates (8.95, 5.9 and 5.85 cm/hr for first three hour) for Bidhouli Sal forest with good leaf litter than (3.65, 2.00 and 2.20 cm/hr) for Horwala Sal forest with very little

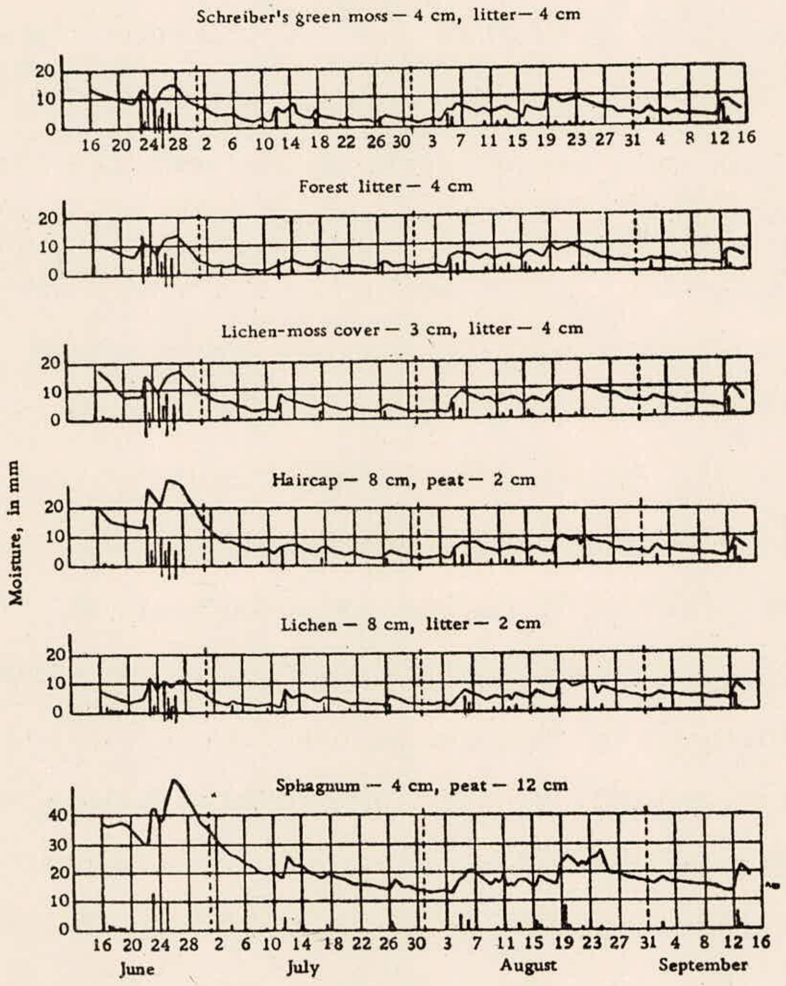


FIGURE 1 Changes of moisture reserves in [moss] cover and live litter, during the summer.

leaf litter. Also, infiltration rates for crop lands were reported lower than forested area. The infiltration rates for maize crop in Dhilkot were 3.70, 1.94 and 1.91 cm/hr for first three hours while for forested area these values were reported as 5.87, 3.78 and 3.63 cm/hr. The results of studies on infiltration rates for one hour runoff under various land use patterns at Bellary shows that the infiltration rates under woodland, grassland and agricultural land were 17.0, 2.6 and 1.0 cm/hr, respectively. Ghosh (1974) reported the infiltration rates under forests, natural grassland and terraced cultivation as 5.16, 3.00 and 1.40 cm/hr, respectively for black cotton soil in Bellary. In a study done as Oactamund on infiltration rates on various soils under various land uses it has found that the soil having a miscellaneous type of vegetation (Shola) had a high infiltration 12.5 cm for a period of 3 hours while infiltration under Broom (Cystisus Scoparius) was 11.25 cm for the same period. Tejvani et al. (1975) reported that infiltration rate was highest for Shola forest followed by Bluegum plantation, grassland and cultivated land in a study done in Ootacamund, Shrinivas et al. (1967) studied the infiltration rates of Shola forest, bulegum plantation, grassland and cultivated land at Ooctamund. It was observed that the shola forest have higher steady rate of infiltration followed by bluegum plantation, cultivated land and grassland (Table 4) . In Bihar , Mistry and Chatterji (1965) recorded infiltration rates under forest land, permanent grass and rable croplands as 26.0 , 12.0 and 9.0 cm/hr, respectively. The initial infiltration rates under eucalyptus,

Table 4, : Steady rate of infiltration(cm/hr) for different months (3 years mean)

Months	Shola forest		Bluegum plantation		Grassland		Cultivated land	
	Dry run run	Wet run	Dry run	Wet run	Dry run	Wet run	Dry run	Wet run
January	4.55	2.46	8.40	6.49	6.63	5.01	25.68	4.00
February	9.42	4.70	18.08	13.22	6.75	5.72	13.24	12.70
March	18.73	11.27	3.91	2.08	5.62	4.13	12.00	8.45
April	33.71	23.25	14.36	14.16	6.49	5.93	8.09	3.07
May	12.13	8.49	15.20	8.37	10.60	9.73	11.47	5.95
June	15.20	7.33	4.80	2.13	8.87	5.13	8.67	2.97
July	20.30	5.30	19.26	19.26	1.87	1.33	3.37	1.91
August	11.73	9.20	13.91	13.22	4.19	2.15	12.07	6.33
September	12.43	2.99	11.04	7.63	1.79	0.89	5.72	1.55
October	5.63	1.51	5.35	2.80	0.92	0.33	7.73	4.09
November	8.36	1.55	10.04	5.37	1.74	0.84	5.73	1.44
December	5.35	3.78	5.62	3.96	2.05	1.18	2.43	1.27
Total	157.54	81.83	129.97	93.69	57.52	42.37	116.20	53.73
Mean	13.13	6.82	10.83	8.22	4.79	3.53	9.68	4.48

sal, chir, teak, bamboo and grassland were determined to be 54.0, 21.4, 12.0, 9.6 and 7.6 cm/hr respectively at FRI, Dehradun. The Environmental Research Station, Simla has also conducted studies to study the infiltration rates under various land uses and has reported that the forestland has higher initial infiltration rate than the agricultural lands (cited in Lohani, 1985).

The results of various infiltration studies conducted in India and other countries under different vegetation covers, confirm that infiltration rates are higher under forest. The percentage increase, however, depends, on soil type, forest, species and biotic interference. This is due to fact that the vegetated land is generally more absorbent because surface litter reduces raindrop impact effects, and organic material, micro organism, and plant roots tend to increase soil porosity and stabilize soil structure. Vegetation also depletes soil moisture to greater depths, incrasing the water storage opportunity and favouring higher infiltration rates, these effects are more pronounced under forest cover where roots penetrate deeper and evapotranspiration rates and higher.

2.2 Soil properties and Soil Moisture

The moisture properties of a soil are governed mainly by texture. content of decomposed organic matter, structure and constitution (i.e, compactness or looseness). By changing any of these the conditions of water seepage may get altered. However, it is impossible in practice, to improve a soil's texture. A more practical way of improving the soil's structure and physical properties consists in regular cultivation, sowing of grasses. By such means there may to a considerable extent transformations of surface runoff into sub-surface runoff; however, in this respect forestation is particularly effective

Forest litter plays an important part in soil forming processes and is one of the principle factor in the conservation and productivity increase of forest soils. It also impedes any very deep freezing of soil, and improves the thermic regime of deeper soil horizons. Lastly, forest litter has a very great hydrologic significance, namely its role of a litter and sponge in regard to the atmospheric moisture penetrating the soil.

The study of the moisture capacity of forest litter is of considerable practical interest; it discloses the amounts of precipitation absorbed by the litter, which then seeps into the soil. As early as 1869, F. Baur (according to Ya. Veinberg, 1884) was studying the question, but lack of sufficient data did not permit to draw general conclusions pertaining to moisture regime of litter in relation with its thickness and its several varieties. More detailed research work was carried out during 1869-1879 by Ebermayer (1878), but still manifold aspects of the hydrologic role of forest litter remained to be covered. Malyanov (1938) and Sozykin (1939) also studied the hydrologic role of forest litter. Sozykin (1939)also studied the hydrologic role of forest litter. Sozykin (1939) used to determine the moisture content of the litter at the moment of sampling, and then establish amount of water in it after 10 minutes of sprinkling, and after seaking for

20-40 hours. These samples were cleared of soil admixture before weighting and treatment with water. The follwing are some of the conclusions from Sozykin's study;

1. Forest sod (chiefly in leafy forests) and leafy litter have the least content of organic matter. Fallen leaves have usually had time to decay by early summer, and therefore they do not absorb much moisture, either in the short period of sprinkling or during the prolonged soaking.
2. Litter containing a high amount of needles does not absorb very much moisture in sprinkling, but it swells by prolonged soaking.
3. A cover of great mosses absorbs much moisture in a short period of soaking.

The moisture capacity of both moss and litter, of various thickness, in various types of forest is shown in Table 5. It is evident from the table 5 that the thicker a moss and litter layer, the greater its absorption of atmospheric precipitation. it is understandable that thin litter and moss absorb a minimum of precipitation, so that most of the moisture reaches the soil at once, and saturates it, whereas the excees moisture seeps into deeper strata of soil and ground.

Rutkouskii (1936) concluded that the moisture holding capacity of mossy-grassy cover was more than that of the mossy cover. According to Kostyukevich (1948), the forest litter intercepts a much higher amount of precipitation than moss

Table 5 : Moisture capacity of moss and of forest litter (after Sozykin)

Type of litter and of live plant cover	Number of observations	Oven-dry weight of moss or of litter, in kg/m^2	Moisture absorption, mm	
			after 10 min. sprinkling	after 20 hrs soaking
Thin cover of green moss (3 cm) in spruce stand with green moss	42	1.37	1.56	2.56
Id., but somewhat inhibited in spots . . .	16	1.01	1.46	2.75
Thick cover of green moss (5-7 cm), in spruce-leafy plantation	21	2.31	3.78	10.28
Thick cover of green moss (5-7 cm) with European blueberry, in mixed, bogged-up forest	2	3.99	4.15	13.83
Thin litter of spruce litter fall, in spruce stand with green moss	19	2.20	2.54	3.34
Thicker litter (3-5 cm), with European blueberry	2	4.27	4.60	9.09
Thick litter (5-7 cm) of spruce litter fall	25	4.81	5.48	16.71
Live plant cover, with some sphagnum . .	14	4.07	6.13	19.09
Sphagnum spots	15	5.42	7.97	24.61

or grasses.

Molchanov (1960) reported the variation of moisture holding capacity of litter under various seasons as shown in Fig. 1. Within natural conditions, the moistness of the moss cover and of the forest litter varies greatly during the growing season. In spring, after completion of thews and rainfall, all species of moss and all kinds of letter are saturated to full moisture capacity. From the start of the growing season, the moisture content of the litter decrease due to evapotranspiration by mid-summer, it is usually at a minimum in the litter as well as in the moss cover, especially so when there are no rains. However, even very light rains will increase in that season the moistness of the litter, which is highly hygroscopic although part of the rain moisture seeps into the soil, and part evaporates back into the atmosphere. Moisture seeps through litter and moss as fast as through a sieve, and thus reaches the soil very soon. Litter of needles has a lower hygroscopicity and absorbs less moisture than the green mosses do. Litter with lichen cover, despite its high hygroscopicity, lets through much of the moisture, because of its low moisture capacity. Highest reserves of moisture are retained in peat, which has both a high hygroscopicity and a high moisture capacity.

FAO (1962) reported that the role of forests in increasing permeability and pore space within the soil is extremely important in the reduction of peak flows. The large pore space also provides detentions for storm water, thus reducing the surface runoff and prolonging the time for percolation of water to deeper layers. The quantity of detention storage may be as low as 0.1 inch in soils compacted by improper use. Detention storage often exceeds 3 inches in the surface foot of forest soils. This form of storage, functions after the field capacity has been reached; it is an addition to that retained against grovitational forces by the soil mantle.

In forest soils, the underlying soil horizons are dense, root channels may be the principle pathway for water movement. Gaiser (1952) found more than 4,000 vertical channels per acre in a hardwood forest growing on silt loam soils. These channels were formed by the decay of roots. They may be nearly hallow, they may contain organic material. Many lateral channels radiate outward from the central core and they also contain very permeable materials. It was concluded that in the course of one forest generation, several thousands of vertical channels must be formed. The fact that the decayed root systems are interlocking in a horizontal and vertical network increases their efficiency in distributing water throughout the deeper soils. Generally, the forest soils are rich in humus and organic matter content. Leaf litter and humus acts as a cushion against the impact of raindrops and provide temporary storage as the rich organic content of dense leaf litter helps in high infiltration and soil moisture storage water holding capacity of humus is several times, it weight and the presence of organic matter improves the soil structure. it may be concluded that the forests play an important role in improving soil structure, permeability, texture and ultimately the ground water regime.

2.3 Soil Moisture

Water that infiltrates the soil surface may be discharged quickly as interflow, percolate to underlying rock strata and the groundwater reservoir, or be transiently stored as soil moisture. Soil moisture performs vital functions in dissolving nutrients and supporting plant life, but hydrologically it represents a rapidly fluctuating storage reservoir from which water is extract by plant roots for transpiration and by direct evaporation from the surface. As reported by Lee (1980), the forest cover generally reduces the levels of soil moisture and groundwater-compared with corresponding levels under other vegetation types-especially during the negative water balance. The amount of water held by soil at field capacity, wilting point and available moisture limits depends to a large extend on soil texture. For a range of textural classes of soil the soil moisture at these limits are listed in Table 6.

In India, studies on soil moisture monitoring under forest cover has been done by CSWCRTI, Dehradun and its centres; FRI, & Colleges, Dehradun, and CWPRS, Kandala. Soil moisture study from depth of 0.3 to 1.2m were made at FRI, Dehradun by Debral et. al. (1965) in chir pine, teak and sal plantations and by Yadav et al. (1963) under bamboo plantation. Gupta (1980) reported that soil moisture remains at a higher level under forest than grass. The soil moisture acceration for teak and sal were generally the same, whereas the depletion values were slightly lower under teak and sal.

Table 6

Soil Moisture in Millimeters per Meter of Soil Depth

Textural class	Field capacity	Wilting point	Available moisture
Sand	100	25	75
Fine sand	116	33	83
Sandy loam	158	50	108
Fine sandy loam	217	67	150
Loam	267	100	167
Silty loam	283	116	167
Light clay loam	300	133	167
Clay loam	317	150	167
Heavy clay loam	325	175	150
Clay	325	208	117

Chir recorded lower acceleration and depletion rates as compared to teak and the results of studies conducted by Dhruvanarayana and Shastri (Anon, 1983) showed that in forest watershed (Shorea robusta) relatively higher soil moisture values were observed in top 45 cm. soil depth as compared to agricultural watershed.

It may be concluded that much efforts have not been made to quantify soil moisture storage of forested land in the country. The Desk studies indicate that the forest area of India has a soil moisture storage capacity of about 447.6m ha. m on a temporary basis and 223.8m ha. m on a prolonged basis (Mathur, 1982).

2.4 Evapotranspiration:

Evapotranspiration denotes the quantity of water transpired by plants during their growth, or retained in the plant tissue, plus the moisture evaporated from the surface of the soil and vegetation. Evaporation of moisture from the soils surface and transpiration by plants are of great importance for the changes of the soil's moisture regime.

Evaporation:

Evaporation is the process during which a liquid changes into a gas. The process of evaporation of water in nature is one of the fundamental components of the hydrological cycle by which water changes to vapour through the absorption of heat energy. This is the only form of moisture transfer from land and oceans into the atmosphere. Evaporation is affected directly or indirectly by atmospheric pressure, wind velocity, atmospheric humidity, temperature and solar radiation. In addition, evaporation is strongly affected by the wetness of the evaporating surface (Kittredge, 1948).

Evaporation of moisture from the soil is a three stage process (Kossovich, 1904; Keen, 1914 and Fisher 1923, 24). Therefore, even within identical conditions of meteorology, evaporation from a bare soil proceeds with different intensity, depending on the soil's condition. In a saturated soils, the evaporation rates are not greatly different from those of a water surface at same temperature. When the soil surface is not saturated, the rate of evaporation may be limited by the rate at which moisture is transferred from below, even though meteorological conditions might favour faster rates (Linsley et al. 1949).

Molchanov (1960) reported that in case of shallow water table, the loss of moisture at soil's surface is compensated by capillary rise, so that the first stage of moistening may persist for a fairly long time. But there are some cases when considerable evaporation is obsevable even on terrain with deep water table; this occurs because of capillary shifting of moisture in such sections of the capillaries where the capillaries are narrower at one end and broader at the other. If the capillaries become narrower at their upper end, pointing toward the surface, then according to the Law of Laplace - the moisture rise to the upper layer of soil and is expanded on evaporation. Because of such peculiarities of moisture ~~shifting~~, one may expect differences in the sinking of the water table in different locations.

According to observations by Kovda (1946), evaporation from a soil with shallow water table is equal to evaporation from the surface of water, on the other hand, a soil which is moistened by pellicular (film-Like) capillary moisture will evaporate a much smaller amount of water because the rate of rise of the ground water is then very slow. Least evaporation is observable at the surface of soils without ground moistening. According to the researches of Kon'kov (1928), Krylov (1936), Besednov (1935), and Kovda (1946), evaporation of ground water ceases, depending on the nature of grounds at the following depth of water table:

Loam	3.0 m
Heavy loam	2.0 m
Stratified loam	2.0 m
Very heavy loam	1.3 m

Evaporation from fine-textured soils affects water tables to greater depths than evaporation from coarse-textured soils. On upland soils, unaffected by the water table, the depth to which evaporation proceeds depends on soil structure and porosity. Coarse sandy soils and soils with large crakes and cleavages dry more rapidly and to lower depths than fine textured compact soils, (Lassen et al, 1952). In a study done in California, evaporation from the surface of sandy soils ceased when the water table ment deeper than 1.2 m (Molchanov, 1960). In loamy soils, the rate of expenditure, and amounts of ground water expended on evaporation, increase because of the more rapid capillary shifting of soil solutions, which is a feature of loam.

Krylov (1936, 1939) and Kenesarin (1940) conducted experiments for determination of evaporation from the soil surface and reported the results as evaporation rates with respect to water table depth; 6.8 mm per 24 hour when water table lies at 1.5 m; 9.0 mm when it lies at 1.0 m; and 12.87 mm when it lies at 0.5 m, which indicates that as water table decreases the evaporation rate increases.

The presence of plant cover greatly reduces evaporation from the soil surface because plants withdraw water themselves. Continuous tree cover is particularly effective in reducing soil evaporation. Both the crown canopy and the forest floor are effective in reducing evaporation. The evaporation in soil covered with forest floor is 10 to 80 percent of that from bare soil. The reduction varies with the kind of litter, and it increase as the floor becomes thicker atleast up to a thickness of 2 inches (Kittredge, 1948). The composition of surface cover also affects to a great extent evaporation from surface (Table 7). Dead litter evaporates the least amount of moisture; green moss evaporates some what more, hair cap and sphagnum - still more. Among the grassy vegetation, least evaporation is with melte grass; it is somewhat greater with wood sorrel, and still greater with reed grass.

Transpiration:

It is the most complex evaporative process, which is regulated by evaporological situation, the conditions

Table 7 : **Moisture expended by surface cover under forest canopy (mm) (Prokudin bor)**

Cover	Year	Months						Total, 6 months
		V	VI	VII	VIII	IX	X	
Dead litter	1946	5.0	10.3	12.7	16.0	9.3	7.3	60.6
	1947	6.5	11.5	12.9	18.1	10.6	6.0	65.6
	1948	6.5	13.5	12.9	13.4	17.6	6.1	70.0
	1949	12.7	11.2	11.3	9.0	5.2	4.1	53.5
	Average	7.9	11.6	12.5	14.1	10.7	5.9	62.7
Lichen cover	1946	7.5	17.3	15.3	17.3	8.0	1.2	66.6
	1947	12.6	18.6	15.1	19.4	12.4	2.6	87.7
	1948	16.1	24.6	22.3	18.6	9.7	5.3	96.6
	1949	11.2	15.3	16.7	15.0	5.9	2.3	66.4
	Average	11.9	18.9	17.4	17.3	9.0	4.6	79.1
Pleurozium [i. e. Pleurosium] schrebery Wild [sic]	1946	8.5	14.2	19.1	19.6	10.2	2.1	73.7
	1947	15.6	12.0	20.9	12.1	12.4	9.4	82.4
	1948	14.1	22.7	15.1	17.1	19.9	5.3	94.2
	1949	13.6	14.7	18.8	16.0	4.7	5.1	72.9
	Average	12.9	15.9	18.5	16.2	11.8	5.5	83.8
Polytrichum commune L.	1947	27.9	39.1	36.2	26.1	20.5	28.4	178.2
	1948	28.0	50.2	45.7	56.2	28.0	6.0	215.0
	1949	26.3	41.1	39.6	40.1	25.0	5.6	177.7
	Average	27.4	42.8	40.5	40.8	24.5	13.6	189.6
Sphagnum	1948	64.1	55.4	42.0	43.7	35.2	10.1	249.5
	1949	43.4	47.4	42.5	33.2	34.0	5.0	205.5
	Average	53.7	51.4	41.7	38.4	34.6	7.5	227.5
Melic grass	1946	18.1	26.5	28.5	30.3	20.8	2.6	126.8
	1949	24.6	29.7	42.4	32.3	18.0	2.1	159.1
	Average	21.3	33.1	35.4	31.3	19.4	2.4	142.9
Sorrel [presumably wood sorrel, Oxalis acetosella]	1947	20.4	49.9	55.5	30.6	18.2	7.4	182.0
	1948	21.1	49.0	22.0	25.5	20.3	6.1	144.0
	1949	16.8	27.9	30.0	28.1	20.0	5.1	127.9
	Average	19.4	42.3	35.9	28.1	19.5	6.2	150.8
Reed grass	1947	29.7	50.1	50.8	43.8	26.0	5.3	205.7
	1948	29.0	50.6	56.6	38.3	24.1	6.3	205.1
	1949	24.0	50.0	60.1	40.3	28.1	4.1	206.6
	Average	27.6	50.2	55.6	40.8	26.1	5.1	205.4
Foxberry	1948	24.1	31.1	31.9	27.7	18.6	3.0	136.4
	1949	16.2	27.1	38.4	13.9	20.0	5.0	120.6
	Average	20.2	29.1	35.2	20.8	19.3	4.0	128.6
European blueberry	1946	10.0	22.0	20.8	23.5	17.6	0.6	94.5
	1947	14.1	26.8	32.3	20.5	18.8	0.6	113.1
	1948	22.9	38.5	22.1	22.4	24.4	3.3	133.6
	1949	13.3	26.3	36.7	21.2	20.0	5.0	122.5
	Average	15.1	28.4	28.0	21.9	20.2	2.4	116.0

within the plant and the water relations of the soil. Among the plant factors the albedo of the plant surface, root development characteristics, stand structure, interception characteristics and physiological structure of plants are important ones.

Experimental results of Kusane (1901) indicate that there is little difference in the foliar transpiration of conifers and the stemp transpiration of decidous species when each is expressed on the basis of an equal area. Kusane (1901) and Koslowski (1943) found that the winter transpiration rates were higher for broad leaved evergreens than they were for coniferous species, although the confiers surpassed the broad leaves evergreens during the warmer seasons. The rooting characteristics of plants influence the amount of transpiration to a significant extent. The rooting depths can vary enormously depending on the types of vegetation (Lohani, 1985). Soil moisture available to the plant is contained in the mass of soil encomposed by its root system and it is limited to the soil volume occupied by roots. Lassen et al. (1952) and Hoover et al. (1953) reported that the roots have a tendancy to obtain soil moisture from the soil layer, where it is held with least force. Thus, they help to create a situation where moisture is held with equal force throughout the rootzone. This is a contrast to evaporation, which proceeds progressively downward from the surface. However, some trees can also withdraw water from depths of 10 meters or more white evaporation from soil surface rarely withdraw water from a greater depth than 30 cm. Plants whose root tap the water table

(Phreatophytes) can cause transpiration of the order of 2 m per year in some areas in terms of equivalent depth of precipitation on the surface, where they are growing (Robinson, 1958). According to Teller (1968), the phreatophytes in arid and semi-arid regions of U.S. waste more than 30 x 10^9 m^3 of water annually.

Rates of transpiration also depends on the soil moisture content. According to Yanovchik (cited in Loske, 1913) with the increase in moisture content the transpiration rate also goes up. Conversely (Kiselev, 1934; Krasulin, 1940) transpiration slow down with decreasing moisture content of soil. Greenwood and Bresford (1979) while studying the transpiration behaviour by different species of eucalyptus in different rainfall regions observed higher transpiration in high rainfall areas and lower transpiration in low rainfall areas. They also showed that when the roots of eucalyptus reach the zone of higher water content in the soil the average transpiration rate per unit area increased three fold. The eucalyptus species are capable of transpiring heavy amount of water under conditions of abundent availability. At the same time, they are capable of controlling the transpiration rate under conditions of restricted soil moisture availability as has been demonstrated by Rawat et al. (1984) by studying the transpiration and growth rate of eucalyptus tereticornis seedlings at different moisture regimes. Rawat et al (1985) also studied the stomatal behaviour and transpiration of eucalyptus hybrid plants maintained at four different soil moisture viz 28 percent (flooded), 22.5 percent (field capacity), 15 percent and 7.5 percent as shown in Table (8) Gurumurti et al. (undated) reported that evapotranspiration of eucalyptus is dependent on soil moisture recharge, higher during wet spells and negligible during dry spells and in the absence of water table, evapotranspiration, on annual basis, never exceeded the incident rainfall. The results of another study show the transpiration in eucalyptus in dependent on soil moisture availability. Thus, when the plants are maintained at field capacity or under flooded condition they transpire copiously, restricting the soil moisture results in reduction in transpiration rate accomplish through partial closure of stomata. Higher as well as lower consumption of water by eucalyptus hybrid during rains and summers respectively, was found to be related with the availability of water (Dabral et al., undated). Dabral et al. (1965) gave the following rough estimates of evapotranspiration losses as observed at Dehradun (upto soil depth of 1.22 m) on the basis of one year's observations:

Chir (Pinus roxburgii) (25 years) = 840 mm
Teak (Tectona grandis) (35 years) = 840 mm
Sal (Shorea robusta) (37 years) = 560 mm

The evapotranspiration of eucalyptus citridora, populus casale, dalbergia latifolia and pinus roxburgii in Juvenile stage was reported to the 5526, 2704, 1143 and 536 mm respectively from September to June at FRI by Dabral (1970). In West Bengal, Benerji (1972) reported evapotranspiration loss to be 1136 mm for eucalyptus plantation during the period from October, 1970 to October, 1971. Rajagopalan et al. (1985) evaluated the monthly and yearly ET for the forested area

TABLE 8

WATER USE EFFICIENCY OF *EUCALYPTUS* HYBRID SEEDLINGS UNDER DIFFERENT SOIL MOISTURE LEVELS (RAWAT ET AL, 1985)

Soil moisture (per cent)	Total water transpired* (Litre)	Total dry matter produced (g)	Water transpired in Litre/g of dry matter	Dry matter produced in g/liter water
28.0 (Flooded)	40.80	106.06	0.38	2.60
22.5 (Field capacity)	43.39	124.08	0.35	2.86
15.0	30.09	111.04	0.27	3.69
7.5	13.283	44.26	0.30	3.33

* May to December - 245 days.

in Khandala, western ghats. The annual crop coefficient as evaluated by the authors is 0.542 for evergreen forested area of Khandala in western ghats. The ET rate of dry decidous forests in Damodar catchment was reported to be 560 mm per year by Mishra (1948). Champion and Seth (1968) determine potential ET for moist decidous forest by Thernthwaite, Rohwar and Leeper methods as 1172, 753 and 825 mm respectively. Das et al. (1970) reported the structure of evaporation, water balance under four management practices at Ooctacamund by Thornthwaite method as given in Table 9.

Based on studies conducted in India and elsewhere it can be said that the evapotranspiration is more in forest than other land use. The evapotranspiration rate is much depends on soil moisture, higher as well as lower ET was reported in rains and summers respectively. The evaporation from bare soil is also reported equal to the evaporation from the free water surface.

2.5 Ground Water

The effect of forest cover on ground water storage can be inferred from evapotranspiration, soil moisture and discharge relationships. It depends partly on the depth and proliferation of rooting system and on growing season length. Not many studies have been reported to find effects of forests on groundwater. Ototskii(1925) found that wherever the groundwater is not deep, the water table is always shallow on open, treeless terrain than in forest. The water table is reported sinking rapidly with the age of the plantation due to the

Table 9 : Structure of evaporation, water balance under four management practices at Ootacamund. After Thornthwaite, 1955 (All values in cm)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year	Remarks
P. E.	4.65	4.64	6.18	7.00	7.30	6.30	5.83	6.99	5.71	5.66	5 15	4.80	70.21	
P	0 29	0.25	0.80	6.56	11.56	7.14	26.45	10.07	10.02	18.22	9.85	6.13	107.34	
St.	22.26	18.79	15.51	15.27	19.53	20.37	26.62	26.62	26 62	26.62	26.62	26.62		Cultivated land (Bench terrace) field capacity 26.62 cm.
A. E.	4.65	3.72	4.08	6.80	7.30	6.30	5.83	6.99	5.71	5.66	5 15	4.80	66.99	
W. D.	—	0.92	2.10	0.20	—	—	—	—	—	—	—	—	3.22	
W. S.	—	—	—	—	—	—	14.37	3.08	4.31	12.56	4.70	1.33	40.35	
St.	25.54	22.00	18.55	18.30	22.56	23.40	29.90	29.90	29.90	29.90	29.90	29.90		Shola field capacity 29.90 cm.
A. E.	4.65	3.79	4.25	6.81	7.30	6.30	5.83	6.99	5.71	5.66	5.15	4.80	67.24	
W. D.	—	0 85	1.93	0.19	—	—	—	—	—	—	—	—	2 97	
W. S.	—	—	—	—	—	—	14.12	3.08	4.31	12.56	4.70	1.33	40.10	
St.	26.12	22.57	19.10	18.85	23.11	23.95	30.48	30.48	30.48	30.48	30.48	30.48		Grassland (Deteriorated) Field capacity 30.38 cm.
A. E.	4.65	3.80	4.27	6.81	7.30	6.30	5.83	6.99	5.71	5.66	5.15	4.80	67.27	
W. D.	—	0 84	1.91	0.19	—	—	—	—	—	—	—	—	2.94	
W. S.	—	—	—	—	—	—	14.09	3.08	4.31	4.61	4.70	1.33	40.07	
St.	22.92	19.45	16.13	15.89	20.15	20 99	27.28	27.28	27.28	27.28	27.28	27.28		Bare land field capacity 27.28. cm.
A. E.	4.65	3.72	4.12	6.80	7.30	6.30	5.83	6.99	5.71	5.66	5.15	4.80	61.03	
W. D.	—	0.92	2.06	0.20	—	—	—	—	—	—	—	—	3.18	
W. S.	—	—	—	—	—	—	14.33	3.08	4.31	12.56	4.70	1.33	40.31	

Note : P. E. = Adjusted potential evapotranspiration ; S_t = Storage, WD = Water deficiency ; P = Precipitation.
A. E. = Actual evapotranspiration & W. S. = Water surplus.

fact that tree roots remove large amount of groundwater and soil moisture by suction (Vysotskii, 1930). There have been opinions that the roots of forest trees exhibit a 'sponge' effect that soak up water in the wet periods and let it release slowly and evenly in the dry season to keep water supplies adequately restored. But such opinions are difficult to believe due to the fact that cutting experiments in small watersheds have universally given increased total water yield over the years (Hamilton and King, 1980); Boasch and Hawlett, 1982; and Boughton, 1970). Ram Prasad et al. (1984) (cited by David-son) in a study found that in the case of eucalyptus camaldulensis of 5 and 15 years age, root depth was less than 3m and lateral spread was upto 9 m and 20 m, respectively. This indicates that most of the water demand by this species was met from the surface layers rather than from the permanent groundwater table (Anon., 1984). Based on the studied conducted in Shipov forest, Russia, Morozov (1900) concluded that water table lies at a greater depth under forest than under field. Higher position of the water table under forest was confirmed by the researches of Ribbentrop in India and of Hermann in the mountainuous districts of Bavaria. (Tkachenko, 1932). Bergy (1938), within the regions of plans in Russia, the influence of forest upon groundwater is more or less similar to that of meadow and field. The groundwater under the forest in Hungery, lies below the water table under meadow, (Iijacz, 1939) Hungarian lowland, the groundwater under acacia plantations is at a higher level in spring, but same as in open terrain during the summer and autumn (Ijjacz, 1939). Basov (1948) showed that there is no progressive sinking of the groundwater under forest strips, as foreseen by Ototskii's theory, in fact, the water table has risen by 1.7m during the last 54 years.

Eitingen (1945) has observed a periodic fluctuation of the water table in connection with changes of precipitation within the zone of mixed forests. Yakovlev (1925) reported the seasonal fluctuations of water table are not simultaneous in forest and on fields as in the forests. The water table rises slowly whereas on fields the water table is sinking. In August, it sinks under forest while there is a rise under field. The reverse occurs in October. In December, the level of ground water is again the same under forest and field.

In the opinion of Tkachenko (1943), the summer lowering of the water table due to transpiration is not the same in different forests, because various arboreal species do not expend the same amounts on transpiration. Hence, it may be concluded that the fluctuation of water table depends on the composition of the forest. Raj et al. (1986) reported that the water table under bluegum and under grass cover rose to maximum level in the July/August due to monsoon rains and gone to lowest in the month of May/June. They observed that there was a fall of 29 cm in the water table in grassland and 70 cm in bluegum.

Aside from cloud forest, increasing heights of water table have usually followed cutting of forests in areas where permanent water table are found (Wicht, 1949). Gilmour (1977) observed an approximate 10% increase in groundwater storage after logging in a tropical rain forest situation. O'Lough Lin (1981 cited in Hamilton and king, 1983) suggested that experience with forest cutting on flat valley bottom lands in the wet parts of New Zealand is for an increase in groundwater level. In France, clearing of forest did not have any significant effects on ground water source or fountains. Guillerme, (1980), direct influence of deforestation on the lowering the water table does not seem any historical evidence. Eckholm (1976) and Sharp and Sharp (1982) have opined that logging of tropical forest watersheds had caused well, springs, streams and even major rivers to cease flowing, at least during the dry season. Boughton's (1970) review of experience in Australia and elsewhere showed almost total consensus on increase in ground water following clearing.

Grazing of the forest lands reduce the infiltration capacity to a great extent and thus could groundwater accessions negatively as shown in Table (3), Murai, (1973). Burning of forets cause reduction in canopy cover permitting greater through fall and reducing evapotranspiration losses, which could account for increased accessions to ground water. Following fire in a Pinus penderosa an increase in the base flow component of the hydrograph was observed (Meghan, 1981 and Boughton, 1981). Surface sealing of soil has occured after fire in the Philippines and thus reduced infiltration and percolation into groundwater aquifers. (Costales, 1979) cited in Hamilton and King, 1983). Boughton (1970) reviewed Australian experience in converting forest to grassland by cutting, burning and ringbarking. He found increase in ground water level when trees were replaced with shallower rooted native grasses. Melzer (1962) has reported water table rise of 33 feet following conversion to grassland. On the other hands in Japan, Murai et al. (1975) have found infiltration under artificially established grassland to be 20-25 percent less than under the forest. In Fiji, infiltration rates for grassland were substantially less than under forest, and runoff was almost 100 percent (Cochrane, 1969). Reforestation of open land usually leads to decreased water table, with effects most pronounced in the dry season. The additional evapotranspiration demand from a developing plantation as its rooting depth increases will reduce the amount of soil moisture available to groundwater recharge (Holmes and Wronski, 1982). Whereas the reforestation of upland watersheds will induce dry season stream flows, rise groundwater well levels, and also restore the reliability of spring (World Bank, 1978). In northern Thailand, Chunkao (quoted by Himilton & King, 1983) reported a decrease in well levels in dry seasons following reforestation. The Leader of Chipko movement in the country also claims that tree plantation, particularly the broad leaved varieties creates water in soil (World Water, 1981). In southern Australia, Cassells (as cited in Hamilton & King, 1983) reported that some areas under grass, about 10 percent of the annual 632 mm rainfall reached the underground aquifer, but under nearby pine plantations, no recharge at all occurred. In China, in order to improve areas where watertable is too close to the surface planting of populus is being done to arrest the ground water table (cited Lohani, 1985). Increase in the water table due to afforestation and other soil conservation measures in a watershed of 314 has been evidenced in C.R. Halli, Chittardurga (Anon, 1983). In the semi-arid areas of Gujarat, the water levels of the wells of eucalyptus hybrid plantation did not go deeper than that of well in surrounding farms during period of seven years Samraj (1984) observed that plantation of eucalyptus trees in Nilgiris has resulted in significant lowering of base flow. Siimilarly a survey conducted by Gujarat Forest Department in April 1984 showed that out of 143 tubewells in eucalyptus plantations of six districts, there was no drop of water table in four districts whereas in two districts the drop in level was less than that of control wells located outside the plantation area (Chandrasekhran, 1984).

Singhal (undated) reviewed Indian experiences of effects of eucalyptus plantation on groundwater table. He concluded that the tap root of eucalyptus is not a major absorber of water from the water table in the low lying area, however, where the superficial root system is in contact with the capillary fringe of water tables direct absorption could be significant.

Forest influences on groundwater regime has been a controversial issue and due to lack of wide spread and systematic studies it may not possible to arrive at definite conclusions. However, at attempt has been made in the following sections to illustrate effects of forests on groundwater using mathematical model.

3.0 METHODOLOGY

The influences of forests on ground water regime of a forested watershed can be mainly attributed to the deep rooting characteristics of forests, higher organic water content of soils leading to improvement of soil structure, and higher rate of evapotranspiration. Studies have been done at various places in the country as also abroad to find out infiltration rates under various land use conditions. Few such results have been summarised in previous section, There have, however, been few studies giving details of evapotranspiration requirement of forest species. Some such studies have been reported in previous section.

While carrying out water budgeting of forested and nonforested regions, the main components that will vary will be the recharge rate and the rate at which evapotranspiration is taking place. Researchers have attempted to find out ground water mound positions as a result of recharge from ground surface. Bianchi and Muckel (1970) have given a dimensionless graph defining the rise and horizontal spread with time of a water table mound beneath a square recharge area. The various parameter required in using the graph are storage coefficient, recharge rate, time since recharge began, length of one side of basin, aquifer transmissivity, and saturated aquifer thickness.

Hantush (1967) developed equations to predict rise and fall of groundwater mounds using horizontal flow theory. The equation for rise or fall of mound in unconfined aquifers below rectangular recharge basins can be written as:

$$h_{x,y,t} - H = \{\frac{V_a t}{4f}[\, F\ (W/2 + x)n,\ (L/2+y)n$$

$$+ F\ (W/2 + x)n,\ \ (L/2-y)n$$

$$+ F\ (W/2-x)n,\ (L/2+y)n$$

$$+ F\ (W/2-x)n,\ (L/2-y)n\,\} \qquad \ldots(i)$$

where,

$h_{x,y,t}$ = height of water table above impermeable layer at x,y and time t

H = original height of water table above impermeable layer

V_a = arrival rate at water table of water from infiltration basin

t = time since start of recharge

f = fillable porosity ($1>f>0$)

L = length of recharge basin (in y direction)

W = width of recharge basin (in x direction)

n $=(4t\ T/f)^{-\frac{1}{2}}$

$F(\alpha,\beta) = \int_0^1 \mathrm{erf}\ (\alpha T^{-\frac{1}{2}})\ \mathrm{erf}\ (\beta T^{-\frac{1}{2}})\ d$

The geometry and symbols for rectangular infiltration area and underlying groundwater mound in unconfined aquifer for which the equation (i) has been developed are shown in fig. 2. As can seen from figure 2 that before start of recharge of water transmissivity (T) can be taken as K.H. but once recharge or abstraction starts the position of water table will start fluctuation and accordingly the transmissivity (T) be taken as $K(H \pm h_{x,y,t})$ to allow for increase/ decrease in water table position. The equation (i) is valid only if $(h_{x,y,t} - H) < 0.5$ H. The values of F have been tabulated

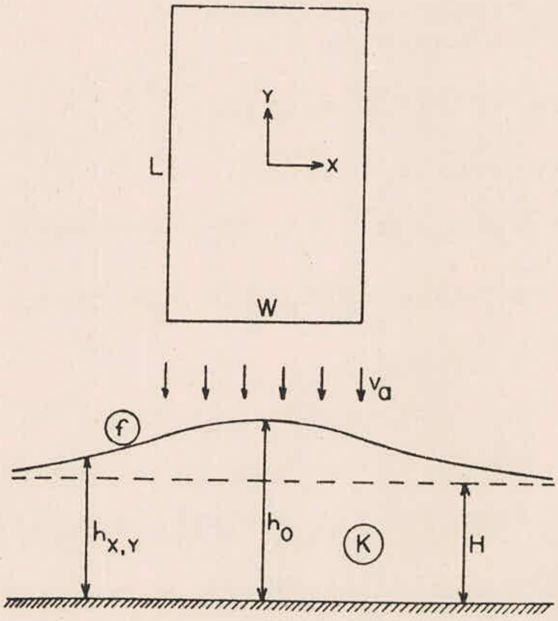


Fig.2: Geometry and symbols for rectangular infiltration area (top) and underlying groundwater mound in unconfined aquifer (bottom).

by Hantush for different values of α and β .

As has been already described, for working out effects of forests on ground water regime the exact rate of forest ET and the increment in recharge rate due to forests will be required. Very limited studies have been reported on such aspects of forest hydrology in the country. However, such vlues can be derived from water balance studies conducted in small watersheds with varying land uses. Das et al (1970) have reported some results of studies on disposition of incident rainfall by water balance method as given in Table 9. The water balance has been carried out for fields under four management practices viz. cultivated land, shola forest, grass land and bare land. As can be seen in table 9 the soil moisture storage in all months were few above the permanent wilting point values. During July to December months excess rainfall was recorded resulting in water surplus after bringing soil moisture in root zone upto field capacity level. Experiments have also been reported in Nilgiris regarding rainfall-runoff relationships. Using some of these relationship the fraction of surplus water converted into runoff can be worked out and rest surplus water can be assumed as recharge to ground water.

Using the solution given by Hantush, the rise or fall in ground water level under various land uses can be worked out. For such analysis let's assume time steps be discreetised into time steps of uniform size. The recharge rate under various land uses may be assumed as R_e (T), T = 1,n : where η is total time steps. The response of the aquifer at coordinate (x,y) at time m due to unit recharge rate per unit area occurring during the first unit time period only is given by:

$$\begin{aligned}\delta(x,y,m) = \frac{1\ m}{4\ f}\ \{&F\ [(w/2+x)f(m),\ (L/2+y)f(m)]\\ &+ F[(w/2+x)f(m),\ (L/2-y)f(m)]\\ &+ F[(w/2-x)f(m),\ (L/2+y)f(m)]\\ &+ F[(w/2-x)f(m),\ (L/2-y)f(m)]\\ &- \frac{1\ (m-1)}{4f}\ \{F[(w/2+x)f(m-1),(L/2+y)f(m-1)\\ &- F[(w/2+x)f(m-1),\ (L/2-y)f(m-1)]\\ &- F[(w/2-x)f(m-1),\ (L/2+y)f(m-1)]\\ &- F[(w/2-x)f(m-1),\ (L/2-y)f(m-1)]\}\end{aligned}$$

and

$$\begin{aligned}\delta(x,y,1) = 1/4f\ F\ [&(w/2+x)f_1,\ (L/2+y)f_1]\\ &+ F[(w/2+x)f_1,\ (L/2-y)f_1]\\ &+ F[(w/2-x)f_1,\ (L/2+y)f_1]\\ &+ F[(w/2-x)f_1,\ (L/2-y)f_1)\end{aligned}$$

The water table rise/fall at coordinate (x,y) at the end of time step 'n' due to time variant recharge is given by:

$$S_1(x,y,n) = \sum_{T=1}^{n} \delta(x,y,n- +1)\ Re(T)$$

Considering the net evapotranspiration due to different land uses in various time steps as ET (T) ,T = 1,n.

Therefore, fall in water table due to evapotranspiration will be:

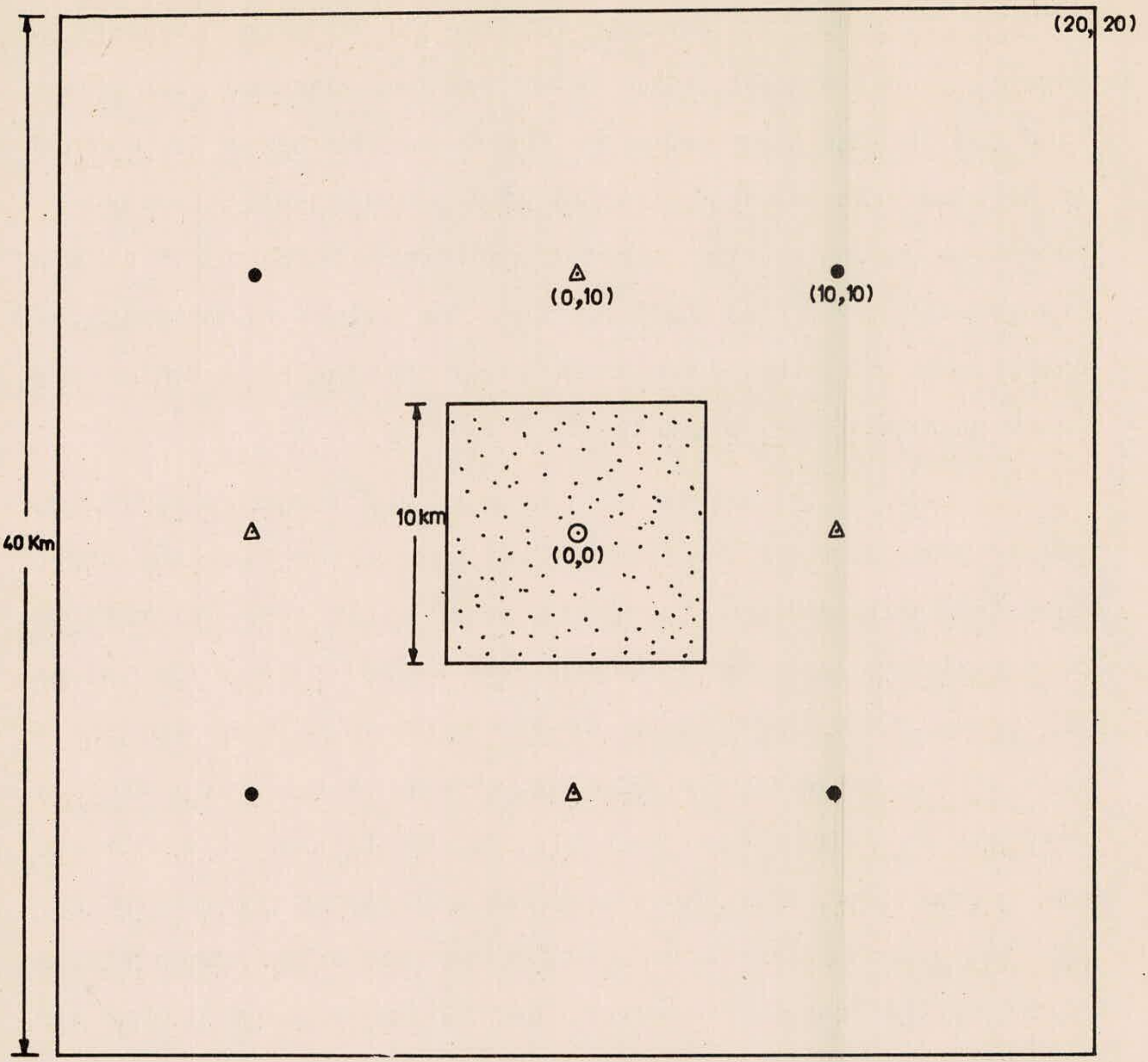
$$S_2\ (x,y,n) = -\sum_{T=1}^{n} \delta(x,y,n- \ +1)\ ET\ (T)$$

The resultant water table is therefore given by:

$$S(x,y,n) = S_1(x,y,n) - S_2(x,y,n)$$

In order to demonstrate use of this methodology a square sub-basin (100 Sq.Km. area) has been assumed with forest land use as has been shown in figure 3. The basin is assumed to have an unconfined aquifer of 1000 m thickness, 1 m/day hydraulic conductivity, storage coefficient (S) of 0.01 and transmissivity (T) of 1000 m^2/day. The values of monthly recharge and ET rates have been given in Table 10 which are based on experiments reported in Nilgiri's.

With the values of recharge and evapotranspiration rates, the response of aquifer was calculated with the above described methodology. The position of water table at various observation points for 12 months was found out and the values are given in Tables 11 and 12 for cultivated land and shola vegetation, respectively. The position of water table at some observation points has been plotted in figures 4 and 5 for cultivated land and shola vegetation, respectively. As can be seen from figures 4 & 5, the water table has shown rising trend during monsoon, however, during non-monsoon period the water tables declined sharply. The water table variation is steep at the centre of the basin and towards corners the variation starts decreasing.



▨ FORESTED AREA

☐ BASIN WITH UNCONFINED AQUIFER

AQUIFER PARAMETERS = 0.01
T = 1000 m / day
THICKNESS = 1000 m

FIG.3 - FOREST SUB BASIN IN A BASIN

TABLE : 10

Monthly ET and Recharge Values under Cultivated land and Shola Vegetation in Nilgiris

Month	Cultivated Land		Shola Vegetation	
	Actual ET	Recharge	Actual ET	Recharge
June	6.30	0.00	6.30	0.00
July	5.83	139.08	5.83	141.13
August	6.99	29.04	6.99	30.77
Sept.	5.71	41.34	5.71	43.07
October	5.66	122.42	5.66	125.55
November	5.15	45.28	5.15	46.98
December	4.80	12.23	4.80	13.29
January	4.65	0.00	4.65	0.00
February	3.72	0.00	3.79	0.00
March	4.08	0.00	4.25	0.00
April	6.80	0.00	6.81	0.00
May	7.30	0.00	7.30	0.00

All values in mm.

TABLE 11: POSITION OF GROUND WATER TABLE IN CULTIVATED LAND AT VARIOUS OBSERVATION POINTS

Month	Observation Point				
	(0,0)	(0,5000)	(5000,5000)	(5000,10000)	(5000,0)
June	-0.6	0.6	-0.6	-0.3	0.0
July	12.7	12.7	12.7	6.4	0.1
August	14.9	14.9	14.9	7.5	0.1
September	18.5	18.5	18.5	9.3	0.1
October	30.1	30.1	30.1	15.1	0.2
November	-3965.9	-3965.9	-3965.9	-1992.8	-19.8
December	-3965.1	-3965.1	-3965.1	-1992.5	-19.8
January	-3965.6	-3965.6	-3965.6	-1992.7	-19.8
February	-3965.9	-3965.9	-3965.9	-1992.9	-19.8
March	-3966.4	-3966.4	-3966.4	-1993.1	-19.8
April	-3967.0	-3967.0	-3967.0	-1993.4	-19.8
May	-3967.7	-3967.7	-3967.7	-1993.8	-19.9

TABLE 12 : POSITION OF GROUND WATER TABLE IN "SHOLA" VEGETATION AT VARIOUS OBSERVATION POINTS

Month	Observation Point				
	(0,0)	(0,5000)	(5000,5000)	(5,000,10,000)	(5000,0)
June	-0.6	-0.6	-0.6	-0.3	-0.0
July	12.9	12.9	12.9	6.5	0.1
August	15.3	15.3	15.3	7.7	0.1
September	19.0	19.0	19.0	9.6	0.1
October	31.0	31.0	31.0	15.6	0.2
November	-5964.9	-5964.9	-5964.9	-2997.3	-29.8
December	-5964.0	-5964.0	-5964.0	-2996.9	-29.8
January	-5964.5	-5964.5	-5964.5	-2997.2	-29.8
February	-5964.9	-5964.9	-5964.9	-2997.3	-29.8
March	-5965.3	-5965.3	-5965.3	-2997.6	-29.8
April	-5966.0	-5966.0	-5966.0	-2977.9	-29.8
May	-5966.6	-5966.6	-5966.6	3500.7	-34.9

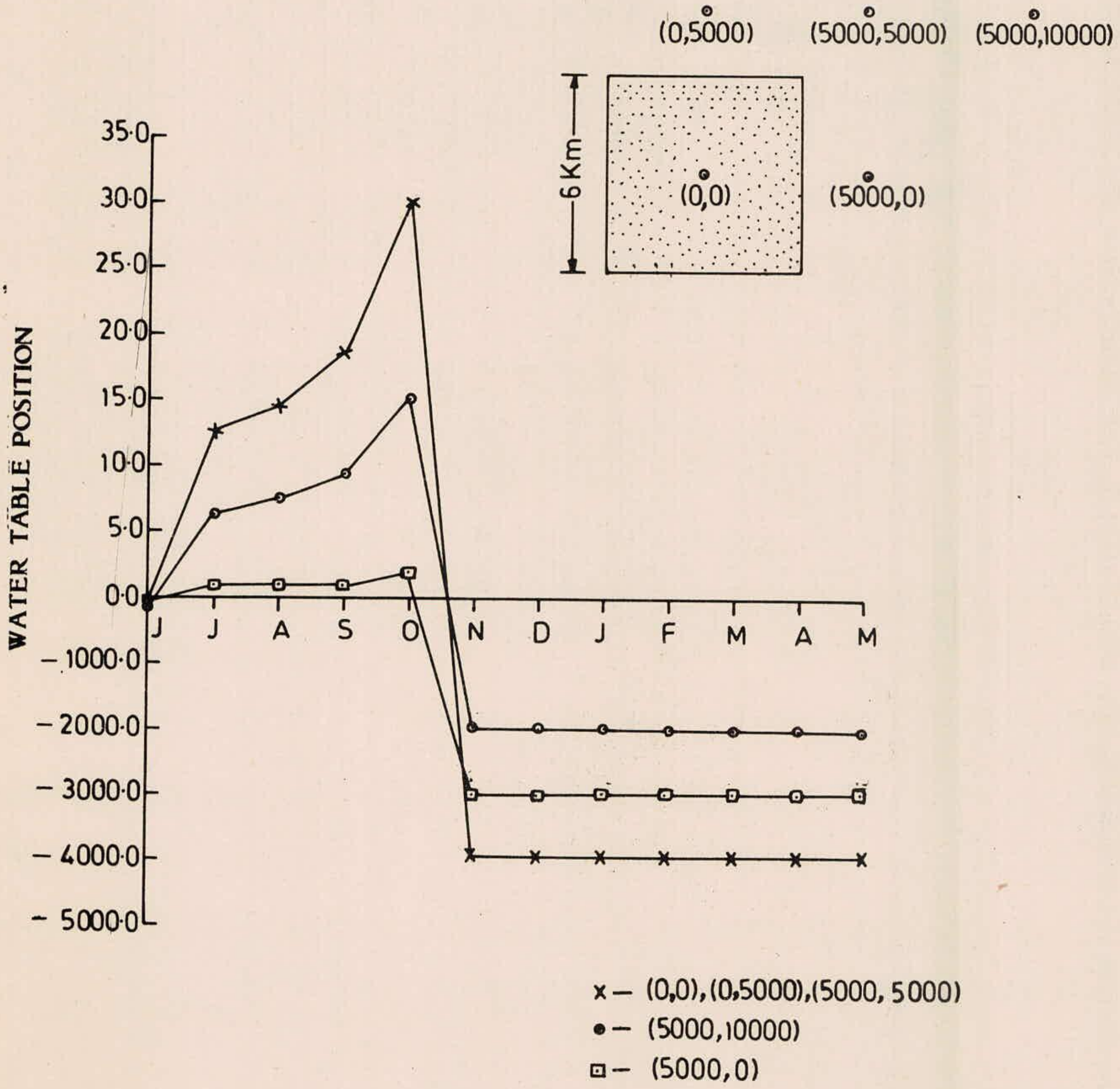


FIG.4 - VARIATION OF GROUND WATER TABLE UNDER CULTIVATED LAND

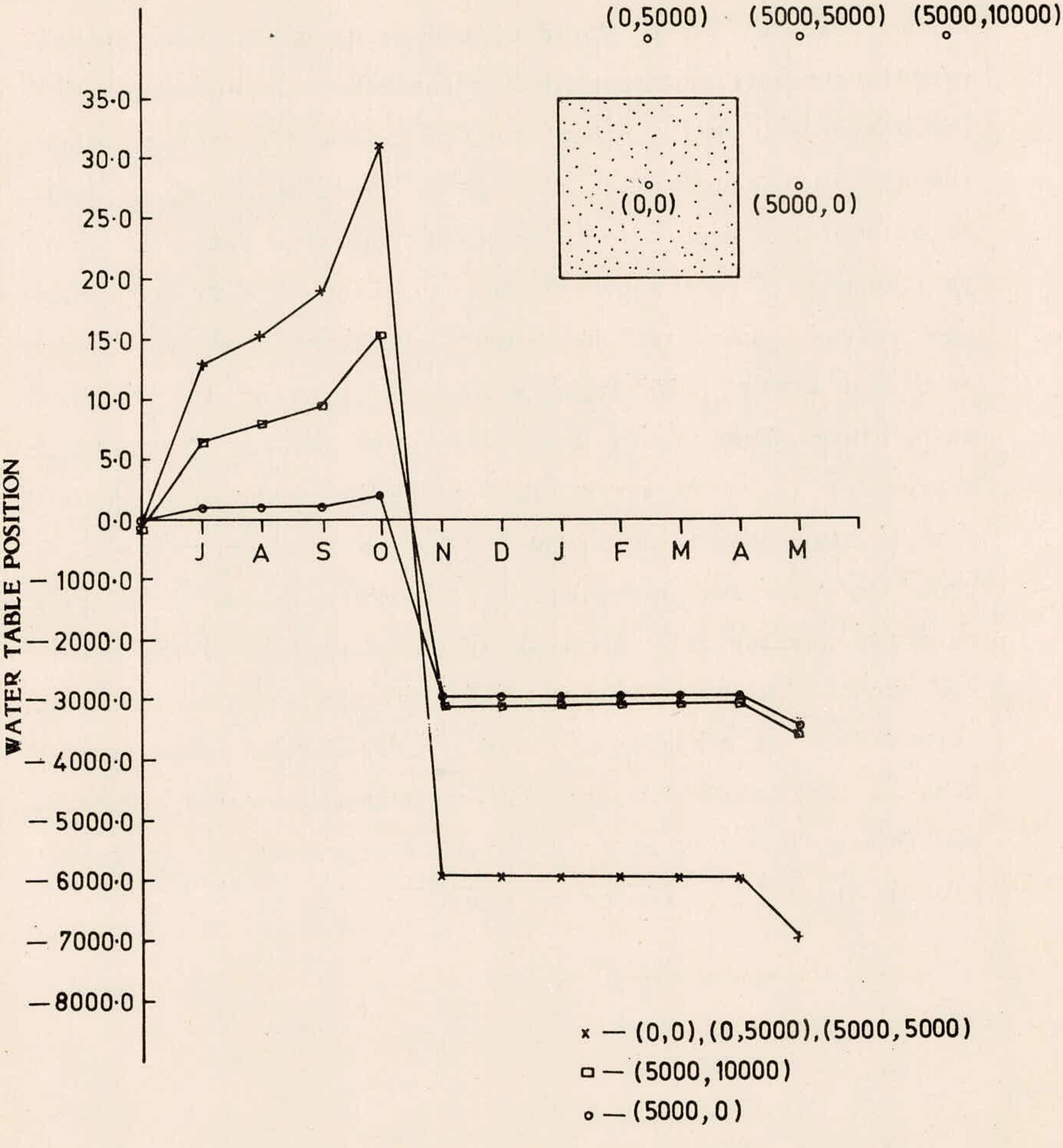


FIG. 5 — VARIATION IN GROUND WATER TABLE UNDER 'SHOLA' VEGETATIION

4.0 CONCLUSION

Forest influences on ground water regime has been a controversial issue. While on one hand due to improved soil structure conditions, the forests contribute in building ground water storage, on the other hand due to their higher ET requirements the ground water storage is expected to be affected An attempt has been made in the report to find out water table positions as affected by various land uses. The ET and recharge values under two management practices viz. cultivated land and shola vegetation were used to find the vanation in monthly water table positions. The results indicate an increasing trend in water table in rainy season when the recharge component is predominent. The results can further improve by carrying out similar analysis with more realistic data for smaller time interval as the values of ET and recharge have been derived from water balance studies. However, actual data in respect of actual recharge rate under various land use and ET data do not exist much and generally are derived from such allied studies. It would be worthwhile to attempt studies in field to verify the results.

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