SR-5

FOREST INFLUENCES ON HYDROLOGICAL PARAMETERS

SATISH CHANDRA
DIRECTOR

STUDY GROUP

V K LOHANI

NATIONAL INSTITUTE OF HYDROLOGY
JALVIGYAN BHAVAN
ROORKEE-247667(UP)
INDIA

1985-86

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The influence of forests on their environment forms part of a vast and complex relationship between environment and forest vegetation. Researchers have been trying for past several decades to ascertain the hydrological importance of forests. In this context, forests influences on various hydrological parameters, viz., rainfall, interception, infiltration, evapotranspiration, ground water, water yield, floods, water quality etc. have been described in this report which are based on studies conducted in India and abroad.

As regards to forest infouences on rainfall, the majority of researchers have concluded that forests did not affect rainfall on a regional scale. Rainfall has been found to be affected by forests on local scale in some cases. In coastal fog belts, the forests have been found affecting rainfall by intercepting moist air masses. The interception losses in forested catchments are function of types of forests, precipitation characteristics and climate. The interception losses by foresets do not have much importance during large rainstorms but these are certainly important from soil conservation point of view. The evapotranspiration losses in forested catchments are higher than other types of land uses. More studies are required to compute ET losses of different types of forests. The infiltration characteristics of forested

soils are better than other soils due to increased amount of organic matter and protection of soil by vegetal cover. Forest influences on ground water regime need to be studied carefully. There are opinions that due to deep rooting system and higher ET requirements the forests decline ground water table. The annual water yield from a watershed gets increased following forest removal due to reduction in ET losses. The effects of forests are limited to moderate and flash floods. The cutting of forests results in more soil loss which after getting deposited on stream and river beds and in reservoirs reduces their capacities and cause situations of floods. The quality of water gets deteriorated by coming into contact with trees in a forested ecosystem. More studies to this effect are required.

The studies which have been reported in this report have been done mostly on small watersheds and so the results obtained can not be directly extrapolated to large watersheds. More systematic studies are therefore required on large representative basins to ascertain hydrological behaviour of forests.

1.0 INTRODUCTION

The habitable surface area of our globe remains more or less fixed. The number of people that inhabits it, on the other hand, is on a fast increasing trend. Those charged with the management of the earth's natural resources must,therefore, be aware of the likely consequences of their actions, so that each unit area of precious land will produce the optimum yield of its resources. Water is only one of these resources and is the prime mover. Food, fiber, and space for habitation, recreation and industry are others. The use of land for one purpose may make it unusable for others. However, forested land, which covers 30% of the earth's surface, is generally capable of yielding a variety of products. A wide range of claims have been made about the miraculous benefits of trees, whether in rows, groves or forests. It is alleged that they can stop floods, make rain, provide fuelwood, yield fodder, produce resins, provide food, renew springs and wells,prevent erosion, shelter and feed wildlife, keep sediment out of rivers, lakes and reservoirs, release water during the dry season, enhance landscape beauty, supply commercial wood products such as timber and biomass for energy, and protect gene pools of biotic diversity (Hamilton,1985). A watershed is the virtually accepted unit of management for efficient, collective and simultaneous management of its resources including water, soil and vegetation. In this context, watershed management has been defined as the management of watershed including forests, range, agricultural and wild lands so as to maintain or attain a desirable hydrological regime in terms of a) water yield b) timing of the runoff and c) quality of the water, within the framework of natural resources conservation. In the broader environmental sense, watershed management is also defined as the objective to meet the total needs of land and water use for a basin on the basis that all resource and uses are interdependent and must, therefore, be considered together (Lassen et al.,1952). The National Commission of Agriculture (1976) has projected that India would be needing about 200 million tonnes food grains, 350 million m^3 of fuel wood and sufficient fodder for over 350 million cattle heads and 110 million goats and sheep. In view of this projected increase in the demand of food, fibre, fuel, forage, fruit and water, it will be the logical aims of watershed managements to manage its resources efficiently and effectively.

The vegetation cover in the context of watershed management generally refers to forests, grasses and crops. The influence of vegetation on the climate and the hydrological regime of a watershed has always been of great interest to foresters and hydrologists. The present report presents a critical review of studies done in India and abroad to find out forest influences on various hydrological parameters including precipitation, interception, evapotranspiration, infiltration, water yield, floods etc.

2.0 HISTORY OF DEVELOPMENT

In Europe, researchers had started establishing close relationship between vegetation and water many centuries ago. Kittredge (1948) traces the history of forest influences on hydrological parameters from the thirteenth century which led to the evolution of the specific field of forest hydrology. Published reports dealing specifically with vegetative influences on climate and hydrologic phenomena began to appear with greater frequency during the eighteenth and ninteenth centuries. According to Kittredge (1948), Noah Webster was convinced by 1799 that forest cleaning by the American colonists had cuased winds and winter weather to be more varilable, autumn to encroach upon winter, spring upon summer, and snow to be less permanent ; apparently these modifications were thought to extend even to areas not originally forested.

Interest on forest influences on hydrological parameters increased rapidly during nineteenth century. The Earth as Modified by Human Action (Marsh,1907) was published in 1863 which contained a good summary of European experience and opinion on forest influences. In 1877, Brown published a book on Forests and Moisture in English which was probably first amongst this kind of works. By the end of the ninteenth century the infulences of forest cover on stream flow had many proponents and opponents both. However, none had any hard evidence to establish the facts. This issue was taken up by researchers for establishing the facts in the beginning of current century in Switzerland and the USA. Studies were carried out on small catchment areas which raised new important questions with regard to experimental design, instrumental accuracy, the independent effects of other factors, and interactions among factors.

Zon (1927) summarised literature concerning to forest influences in ' Forests and Water in the Light of Scientific Investigation'. He observed in his book ' Of all the direct influences of the forest the influence upon the supply of water in streams and upon the regularity of their flow is the most important in human economy'. In 1948, Kittredge discussed the forest influences in his text ' Forest Influences' which became a standard text and reference book later.

By the middle of the current century, population growth, industrialisation, urbanisation, land disturbance, and the increased use of forested areas for recreation and other purposes had caused widespread concern for environmental quality. Such concern coupled with increasing awareness of forest influences in general, and the intimate association of forests and water in particular, led to renewed efforts in the search for knowledge and to the development of forest hydrology and management of forested watersheds.

3.0 HYDROLOGIC PROCESSES AND FORESTS

The term hydrological cycle describes the world's circulation of fresh water as it evaporates from the sea into the atmosphere, is transported by the wind until it condenses as water droplets into clouds and is precipitated as rain, snow or hail. It has been recognised for sometime that the vegetation cover influences a number of components in the hydrologic cycle (Chow,1964). The important aspects of the hydrological influences of the vegetation cover in a watershed system include interception, infiltration,evapotranspiration, flow peaks, ground water regime, sediment yield, soil erosion, and water quality. The removal of vegetative cover or denudation of forested lands have various kinds of influences on these hydrological parameters. Cassells et al.(1982) have described some likely hydrologic changes following deforestation as shown in Figure 1.Storey et al.(1964) has summed up the hydrologic functions of the vegetative cover as ' breaking the impact of rainfall, direct interception of the precipitation by the aerial portions of the plants, dissipation of soil moisture by ' blotter' effect of the litter'. The beneficial effects of vegetal cover as described by Chow (1964) are the result of the following ;-

1. Building up and maintaining the organic content of the soil, thus developing a more open soil structure and thereby greatly increasing both the infiltration capacity and the storage capacity of the soil layer within the root zone.

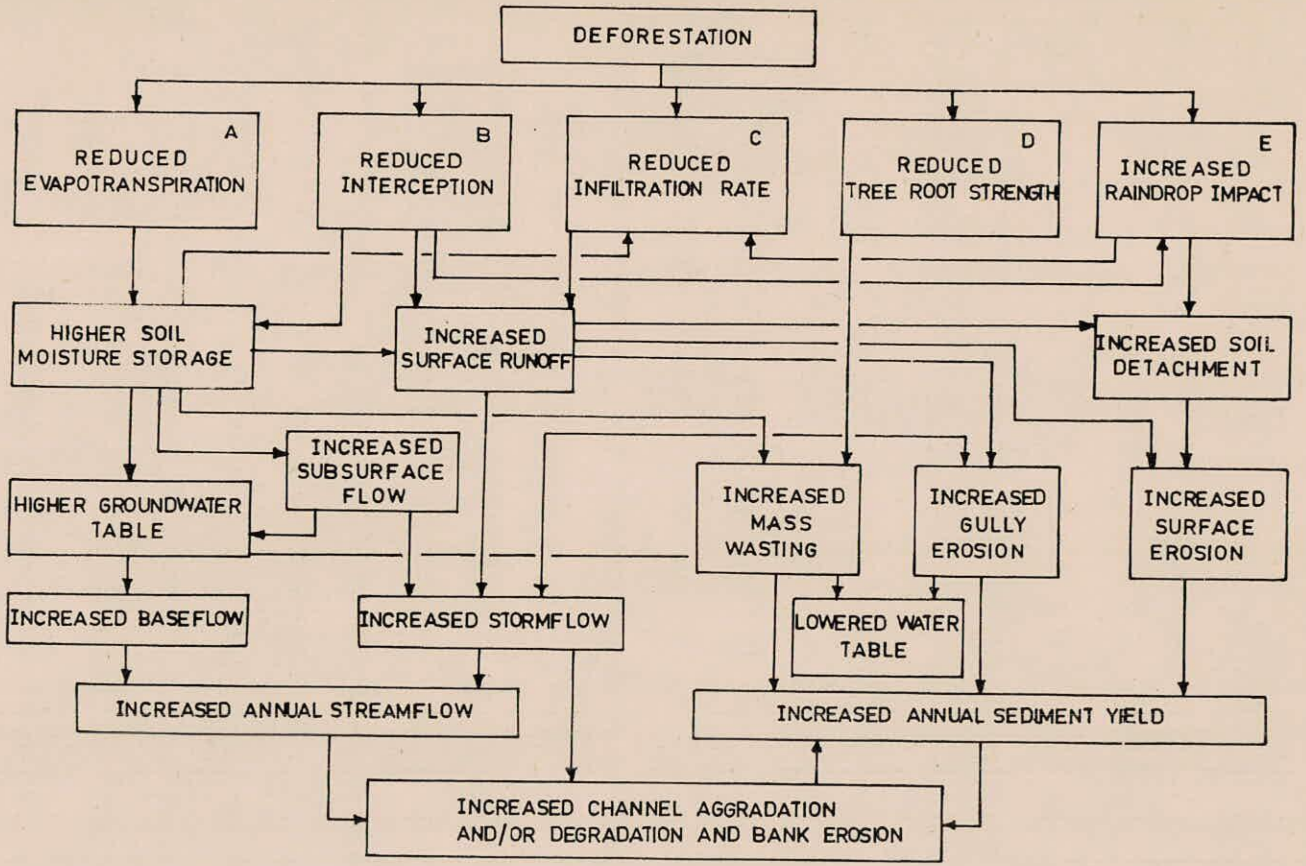

FIGURE 1. Some Likely Hydrologic Changes Following Deforestation (Adapted from Cassells, Hamilton, and Saplaco, 1982)

2. Establishing and maintaining a partial or complete cover of undecomposed or partly decomposed organic matter at or near the surface of the soil, which tends to prevent surface water from picking up fine soil particles and thereby protects the pores and interstices of the soil from being closed to the passage of water.

3. Keeping the water spread out the surface of the land and mechanically retarding or hindering runoff, so that water moves more slowly and thereby affords much more time for absorption.

4. Increasing infiltration and reducing overland flow, resulting in less erosion of the soil and less formation of gullies.

5. Shading the ground and minimizing wind movement, reducing snow-melting rates. This lessens rapid runoff and promotes infiltration.

The field of forest hydrology is concerned with the vegetative cover and soil mantle of drainage basins and the role which this soil-vegetative layer plays in the hydrological cycle. In this regard forest hydrologists seek to understand the extent to which man's forest activities alter the hydrological cycle. The effects of forests on various components of hydrologic cycle is discussed separately in the following sections:

3.1 Rainfall

There have been a number of opinions regarding influence of forests on rainfall which are being described as below:

3.1.1 Forests influence rainfall

Zon (1927) has stated that forests increase both the abundance and frequency of local precipitation over the areas they occupy. He has indicated that the excess of precipitation as compared with that over adjacent unforested areas amounting in some cases to more than 25 percent. In order to see the effects of vegetation/forests on annual precipitation, Hursh (1948) conducted a study in the Copper Basin in eastern Tennessee, USA where 2800 ha. of forest land had been denuded by smelter fumes; between the denuded area and the surrounding forest there was a 4800 ha.zone, 1 to 3 km. wide, that supported grass cover. The annual averages of precipitation and wind speed measured over a 4-Yr. period at two stations in each zone are given in Table 1.

Table 1. Copper Basin Data and Adjusted Precipitation

Zone	Mean wind speed (cm/sec)	Annual precipitation (mm)	
		Observed	Adjusted*
Denuded	226	1277	1458
Grass	167	1339	1462
Forest	33	1459	1466

* Values are adjusted to wind speed.

Source : Lee (1980)

The results given in Table 1 show that precipitation in forested zone exceeded that in the denuded zone by 14.3% and in the grassed zone by 9%. Molchanov (1960) also disagreed with the fact that the forests had hardly any effect on the amount of precipitation. In his own words ' To sum up, forests do increase the amount of precipitation even though slightly so, but if the condensation of water vapours is taken into account, such increases may reach even by 10%. Anderson, et al.(1976)estimated that in the conterminous United States, the forested areas receive twice as much precipitation as other land (1140 mm/yr. versus 570 mm/yr.), which is the same total volume as other land on half as much area(forests occupy one-third of the total land area); the forested land generates three-fourths of the annual streamflow volume.

Some Russian work, cited and summarized by Shpak(1968) showed approximately 10 percent more rain in forest areas. He,however, pointed out precipitation measuring problems that invariably allow forest gagues to catch more rain. In this context, it is worthwhile to note that the error range for typical point measurements of rainfall is around ± 3-5 percent and for whole-catchment average, rainfall precision is never likely to be better than ± 5 percent. Agarwala (1985) while highlighting importance of forests, has stated that forests tend to increase local precipitation, at least to the extent of increasing the number of rainy days . He has further stated that during ancient period in India Rishis had warned against deforestation and had advocated against cutting of trees because they thought that , that would result in poor rainfall. Referring to studies conducted abroad, Agrawala (1985) has stated that forests may increase local rainfall by not more than 3 percent, and the rainfall in cleanings in the forests may be about one percent or more than under similar conditions in the open.

Hewlett (1965) has drawn attention to the increase in precipitation by forests by condensation or fog drip from leaves and stems. The phenomenon as explained by Lee (1980) is when fog moves horizontally into a forest canopy, fog droplets are deposited by contact on the foliage. Hamilton and King (1983) have opined that in certain physiological situations e.g. in coastal fog belts or at high elevations characterised by frequent on persistent cloud, forests could capture and condense atmospheric moisture which in some cases might form a significant portion of total precipitation. For example, in Hawaii it represented extra 760 mm above a non-forested 2600 mm of rainfall (Ekern,1964). Lee (1980) further adds that in coastal fog belts or mountainous areas the total accummulation of droplets at the leading edge of a forest may add a depth of water approaching the total for other forms of precipitation. The forest influence is undeniable with regard to this 'occult' precipitation, but the phenomenon is severely limited to geographic extent. Kunkle (1975) has cited example of coastal forests of western north America where forests and other vegetation are apparently related to the ability of trees to capture water on the needles (leaves) by the process of ' fog drip' - dependent on the fog banks moving in from the Pacific Ocean during the summer. In reference to condensation of fog, Teller(1968) has given example of the east coast of Japan, where 6-10 times as much fog water was measured in a forest as compared to an open field. In coastal south eastern Australia also precipitation in the forest was measured 12% higher than in the open due to condenstation of fog. Therefore, based on above described concepts and examples it can be deduced that cutting down the coastal forests where foggy situations prevail may result in loss of captured and condensed moisture or in other words loss of ' Occult precipitation' and hence, saving of cloud forests and fog forests makes good hydrologic sense.

3.1.2 Forests do not influence rainfall

According to Lee (1980), it is a most persistent misconception that forests increase local precipitation or in other words forest cutting would supposedly decrease gross precipitation and cause the drying up of springs and streams. He refuted Zon's (1927) statement that forests increase rainfall and stated that forests enjoyed greater total precipitation because they mostly occur on higher elevations where rainfall frequency was generally higher. Lee (1980) did not agree with the interpretation of studies conducted by Hursh (1948) as reported in table 1. He opined that wind did influence the catch of rainfall in raingauges and if precipitation values were adjusted to wind speed, almost same values of annual precipitation were found in denuded, grass and forest zones (Table 1.). Pereira (1973) has agreed with Lee and stated: " There is no corresponding evidence as to any effects of forests on the occurrence of rainfall". Bernard (1945, 1953) also did not find any support for any influence of forest on rainfall in his study in the Central Congo Basin but suggested that local forest cleaning, by increasing heat reflection, might introduce local instability and convergence, thus serving to promote rainfall in a very stable area. It is alleged that evaporation from forests increase rainfall, but McDonald (1962) illustrated quantitatively that evaporation from reservoirs and irrigated areas could not modify the dry climate of Arizona in the USA. The evidences and arguments concerning forest influences on rainfall were reviewed by Penman (1963) who concluded that although vegetation did affect the disposal of precipitation, there was no evidence that it could affect the amount of precipitation to be received. Teller (1968) also does not seem to agree with the argument that large areas of forest increase regional precipitation. He quotes Gilman's (1964) remark ' As for the effect of increased evapotranspiration on precipitation in the same locality, it should be remembered that the air into which the water is evaporated is usually some distance away even a few hours later (no exact figures are available) but they are probably of the order of several hundreds of miles in summer and a thousand miles or so in winter'.

The experiences in India as regards to forest influences on precipitation also tend to suggest that forests do not have appreciable effect on rainfall over a large area but they may have limited effect on local rainfall. An enquiry set up by

Govt. of India in 1906 to find out relation between forests, atmosphere and soil moisture in all Indian provinces concluded that the influence of forests on rainfall was probably small (Lal and Subba Rao,1981). The effects of trees on precipitation has been described by Dr.Voelekar in his report on Improvement of Indian Agriculture, pertaining to Ootacamund and the neighbouring areas of Nilgiri hills which was devoid of trees before 1870. He considered that the rainfall that occurred other than June,July and August months is not of local origin. During 4 years period (1870-74) such rainy days were recorded to be 374 when there were no trees. Later after plantation the rainy days increased to 416 during 4 years of wooded period (1886-90). Updated figures of the same with two more such observations were reported by Ranganathan (1949). These are given in Table 2.

Table 2. Number of Rainy Days With or Without Trees in Nilgiri Hills Area

Period	No. of rainy/days (excluding,June,July August months)	Rainfall
1870-74(no trees)	374	-
1886-90(with trees)	416	-
1902-06(with trees)	467	4120
1918-22(with trees)	481	4420

Source : Ranganathan (1949)

Nicholson has commented on the effects of forest destruction in Chota Nagpur district. He stated ' About 50 years ago when the district was well-wooded, afternoon showers,known as instability rain, were fairly frequent during the hot weather and at that time several tea gardens were opened up. During the last half century, the forests (which were private) have been destroyed. There is no evidence to show that the monsoon rainfall has been affected thereby; but so serious has been the decrease in the instability rain that tea gardens can no longer infill and they are drying out'. There are no tea-gardens in the Chota Nagpur at present (Ranganathan,1949). Martin (1944) has stated that forests increase evaporation and rainfall as a whole over large area owing to increased humidity caused by evaporation of entrapped raindrops on the leaf surface. Bhattacharya (1956) has studied the effects of deforestation on the intensity and frequency of rainfall in Pathri,Ranipur and Ratmau catchments in Uttar Pradesh. It was found that planned deforestation in either of the catchments was not having any significant effect on rainfall which did not exhibit any marked change in either its intensity or distribution. Based on various studies, Lal and Subba Rao (1981) have concluded that presence of forests might locally affect the incidence and distribution of rainfall and even increase it, through these effects might not be significant on a regional scale.

A number of opinions given by various researchers have been described above on forest influences on rainfall. Most of the studies quoted in this report have been conducted on small catchments, and conclude that either there is little on no influence of forests on rainfall except for its redistribution. In coastal forests, however the precipitation is more due to condensation of fog. More comprehensive studies are required to be done in larger watersheds in order to establish a clear understanding regarding forest influences on rainfall.

3.2 Interception

Rainfall that falls on a forest canopy is redistributed and reduced in quantity as it moves toward the forest floor. This reduction of precipitation due to forest canopies is referred to as interception. Hewlett and Nutter (1969) have described following categories of interception :

i) Interception storage: It is the amount of water and snow held by living and dead plant material at any given time.

ii) Crown interception loss: It is the amount of water evaporated or sublimated directly from water or snow intercepted by the crowns of vegetation.

iii) Throughfall: It is that portion of gross precipitation that falls or drips through the tree crowns.

iv) Stemflow: It is that portion of the intercepted water which collects and runs down stems of the trees.

v) Forest floor interception loss: It is the amount of water caught and lost from the forest floor before it can infiltrate mineral soil.

vi) Total interception loss: It is the amount of water evaporated or sublimated from rain or snow caught by living and dead plant material.

The various important factors that influence interception are wind, rainfall intensity and type and density of vegetation. Very light rainfall of small size may be totally intercepted while heavy rainfalls of large drop size rapidly saturate the canopy; which thereafter transmits most of the water received. Pereira (1973) has described that interception of raindrops by a forest company was a physical process governed more by amount of rainstorm than by the species of trees present. The values of rainfall interception over a range of storm sizes have been compared for tropical bamboo forests, a cypress plantation near the equator in East Africa and a temperate zone hardwood forest in Appalachian Mountains. This has been shown in Figure 2.

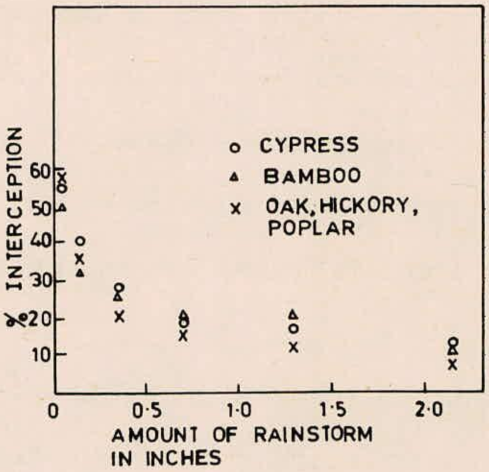

Figure 2. Interception of Rainfall by Tropical and temperate forests

Source: Pereira (1973)

As can be seen in Figure 2 that the data are well fitted by hyperbolae, i.e. the curves are of known shape. Rotacher(1963) also found the same relationship to size of rainstorm for dense stands of Douglas firs in Oregan, USA. Based on these observations Pereira (1973) concluded that hydrological importance of interception by a continuous forest canopy depended directly on the pattern of rainstorms and was similar for many species of trees.

Kittredge (1962) has illustrated the trend of interception loss with rainfall per storm by data from a 30-year old stand of Cryptomeria in Japan which is given in Table 3.

Table 3. Interception Vs. Rainfall per Storm

Rainfall per storm (mm)	0-1	1-3	3-6	6-10	10-20	40-70	70+
Interception (%)	83	61	51	35	18	12	11

Source : Kittredge(1962)

Lull (1964) has reported interception for various forest types which is given in Table 4.

Table 4. Interception for various forest types. (Hardwoods with leaves for rain)

Forest type	Stemflow (%)	Net rain interception (%)
Northern U.S.Hardwoods	5	15
Aspen-birth (Populus-Betula)	5	10
Spruce-fir(Picea-Abies)	3	32
White pine(Pinus Strobus)	4	26
Hemlock(Tsuga)	2	28
Red pine (Pinus resinosa)	3	29

Source : Lull (1964)

The results given in Table 4 indicate that the conifers, such as spruce and fir, generally intercept more rainfall water than the hardwoods. Dunne and Leopold (1978) also described that conifers could hold more interception storage than broad leaves as the conifers have greater masses of foliage and branches throughout the year. Based on various research works, the authors presented a figure (Figure 3) showing throughfall or stemflow as related to gross strom precipitation for both hardwoods and conifers. The authors have also given median values of conopy interception as a percentage of annual or seasonal gross precipitation which are reported in Table 5.

Table 5. Median Values of Canopy Interception as a Percentage of Annual or Seasonal Gross Precipitation

Type of Forest	Number of Observations	Median canopy Interception (% of Gross precipitation)
Deciduous Forest All data	10	13
Coniferous Forest Rainfall only	11	22
Observations that include rain and snow	26	28
European Data only	9	35
North American data only	27	27
Taixyrn	1	8

Source : Dunne and Leopold (1978)

Molchanov (1960) has reported summary of various studies done in Russia with the conclusion that spruce stand intercept four to five times more water that oak and pine trees and light storms of only 1-2 mm are mostly intercepted in spruce stands. As can be seen from figure 3 that for both conifers and hardwoods the throughfall is more than stemflow. Similar results were also reported by Leonard (1961) for decidous forests near the Quebec and U.S.border. This is shown in Figure 4. Zinke (1967) surveyed a large volume of American literature on effects of vegetation on interception and concluded that i) interception loss is mainly a function of size of storm,ii) interception loss is greater from needle-leaved trees(conifers) than from broad leaved trees, iii) interception losses may be large in regions of high evaporation and are usually low in regions where they are compensated by fog or cloud dript,iv) percent interception loss is greater for storms with small amounts of precipitation. Kunkle (1975) based on Zinke's (1967) observations summarised the major considerations of interception as : i) interception represents a probable loss of precipitation in many cases, ii) interception storage is greater for trees within a forest than for isolated trees, iii) interception varies with forest conditions, stocking density,age, species etc. and iv) most hardwood trees have a very similar interception loss during the growing season. Goodell (1963) had raised an important point regarding whether to term interception a real loss from land phase of hydrologic cycle or not. The supporting argument given by him was that because of the process of interception, the transpiration losses

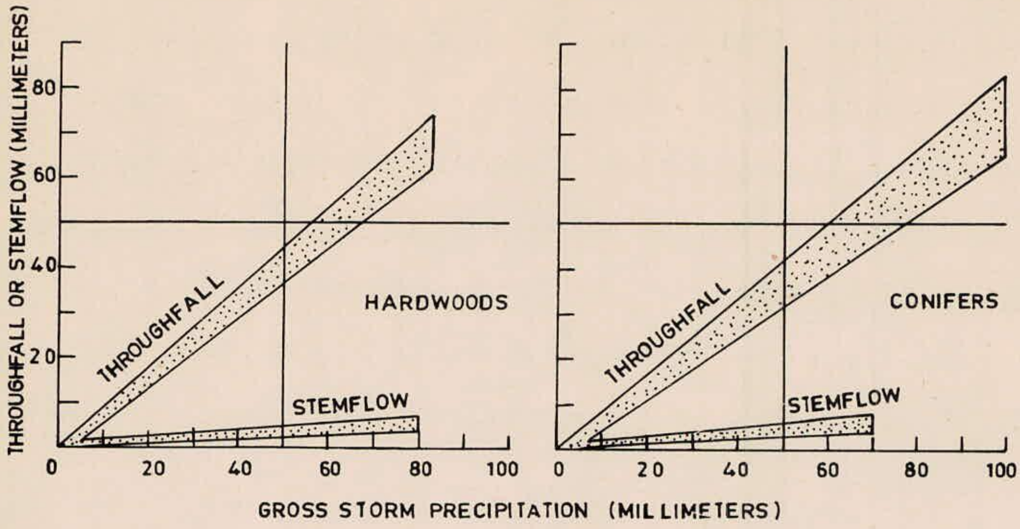

FIGURE 3. Relation of Throughfall and Stemflow to Gross Precipitation

Source : Dunne & Leopold(1978)

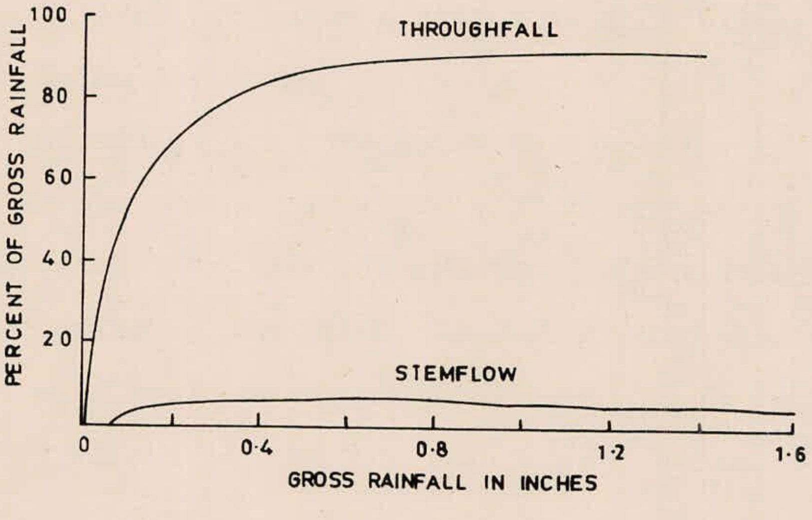

FIGURE 4. Throughfall and Stemflow As Related to Gross Precipitation for Deciduous Forests

Source : Leonard (1961)

from leaves get reduced as wet leaves transpire less water than dry leaves. Costin and Dooge (1973) have also given similar opinion and stated that evaporative losses of intercepted moisture were partly offset by reduced transpiration. Dunne and Leopold (1978) have also pointed out controversy about the importance of interception in the water budget. The authors stated that in energy budget calculations the total energy available for evaporation of water from the leaf surfaces was the same, whether evaporation was supplied from intercepted rainfall or from within the leaves of plants. It is ,therefore, the authors suggested that the evaporation of intercepted water was not a loss, but was balanced by a reduction of transpiration that would otherwise have occurred. The authors quoted studies done by Burgy and Pomeroy (1958) and McMillan and Burgy (1960) in favour of their suggestions. The data reported in Table 6 also give similar interpretation as the total amount of water evaporated from each plot was approximately the same whether the water came from interception or from the soil, because the evaporative demand imposed by the incoming energy was the same.

Table 6. Water Loss under Grass at Yangambi,Zaire

Water Loss (mm)	Plot Treatment		
	Rain only	Irrigation and Rain	Irrigation,Rain and Fertilizer
Evaporation of Intercepted water	115	238	654
Water drawn from soil	1003	817	521
Total Water Loss	1118	1055	1175

Source:(From Bernard, quoted in Penman,1963)

In India, interception studies have been reported by various researchers. Interception studies conducted in plantation of Chir ,Teak,Sal and Khair as reported by Qureshi and Subba Rao,1967, Dabral and Subba Rao 1968,1969, and Dabral et al.1963,1965 indicate that the canopy interception by Sal,Khair,Chir and Teak were 38.2,28.5,22.1 and 22.1

percent of rainfall respectively. Gupta (1980) has given a table describing results of interception studies carried out at different places in India which is given in Table 7. Based on studies conducted at CSWCRCT and FRI Dehradun, Lal and Subba Rao (1981) have suggested to assume interception losses as 20%,10% and 5% for dense canopies, ground vegetation and leaf litter respectively thus making a total of the order of 35% of rainfall for a dense forest cover. Not many studies have been reported concerning interception of rainfall by ground vegetation, however a conservative estimated of 10% has been suggested by Ghosh and Subba Rao (1979). The effects of rainfall intensity on interception has been reported by Dalal et al.(1967) in a study at Dehradun (quoted from Tejwani et al., 1975). It was observed that interception in a forest of Shorea robusta was higher in the case of light showers (37.3 percent) when the rainfall was 4.2 mm and low in the case of heavy showers (4.1 percent for 140.3 mm rainfall and 4.7 percent for 65.4 mm rainfall) accompanied by winds. Gupta (undated) has stated that interception losses are large in regions with high evaporation and are usually low in regions where they are compensated by fog or

Table 7. Interception by Forest Cover

Species	Stand density [trees/ha/age]	% of rainfall				Remarks
		Throughfall (1)	Streamflow (2)	(1 + 2)	Interception	
Acacia nilotica (Chandigarh)	7 years	–	–	–	26.00	(Tejwani *et al.*, 1975)
A.catechu (Chandigarh)	7 years	–	–	–	15.5	(Tejwani *et al.*, 1975)
A.modesta (Chandigarh)	7 years	–	–	–	21.2	(1975)†
Dalbergia sissoo (Chandigarh)	7 years	–	–	–	13.2	(J. P. Singh and M. C. Prajapati, 1974)†
Dalbergia sissoo (Chandigarh)	10–14 years	–	–	–	6.5	(1971)†
Acacia mearsnii (Ootacamund)	31.5*	–	–	–	28.5	(P. Samraj *et al.*, 1977)†
Eucalyptus globulus (Ootacamund)	12.1*	–	–	–	27.20	(P. Samraj *et al.*, 1977)†
Shola forest	30.6*	–	–	–	40.10	(P. Samraj *et al.*, 1977)†
Eucalyptus hybrid	1658	80.75	7.69	88.4	11.56	(Tejwani *et al.*, 1975)
Shorea robusta	1678	66.4	8.30	74.7	25.3	(Dabral *et al.*, 1963)
Shorea robusta	668	54.6	7.2	61.8	38.2	(Dabral *et al.*, 1963)
Alstonia scholaris	1675	57.0	17.0	74.0	26.0	(Dabral and Subbarao, 1968)
Pinus roxburghii	1156	74.3	3.6	77.9	22.1	(Dabral and Subbarao, 1969)
Tectona grandis	1742	73.2	6.0	79.2	20.8	(Dabral and Subbarao, 1969)
Acacia catechu	574	67.3	4.2	71.5	28.5	(Dabral *et al.*, 1963)

* Average canopy (m^2/tree)

† Citations from the annual reports of the Central Soil and Water Conservation Research and Training Institute, Dehradun, for the corresponding years.

Source : Gupta (1980)

cloud drip.

A great deal of work has been done on effects of forests on interception losses. Based on these studies it can be said that interception loss is a function of vegetation,precipitation and climative characteristics. The needle leaved trees intercept more water than broader leaved trees. Smaller storms result in higher interception losses by trees. The total interception from forest cover including the leaf litter is around 35% of the rainfall. In regions of high evaporation the interception losses are also higher. Some researchers have opined not to consider interception as the loss from the hydrologic cycle. Arguments to this effect have also been given. As the substraction of intercepted water from gross precipitation becomes insignificant during very large rainstorms, the interception has,therefore, little effect upon the development of major floods. However, interception has great significance from the point of view of soil conservation.

3.3 Evapotranspiration

The combined loss of water by evaporation from soil and plant surfaces and transpiration through plant leaves is termed as evapotranspiration. It is a key component of any water balance.

The methods those are generally used to compute evapotranspiration are either based on experimental studies or by using empirical relations which have been developed by correlating climatic variables with ET. Not many studies have been reported concerning forest evapotranspiration. In order to observe the effects of forests on evapotranspiration it is necessary to examine forests effects on main components of evapotranspiration, i.e., evaporation and transpiration which is dealt in following sections:

3.3.1 Evaporation: Water is lost to the atmosphere by vaporization from various catchment surfaces. As noted by Goodell (1966) there are mainly following four categories of surfaces from which vaporisation of water takes in wildlands in addition to actual water bodies:

i) external surfaces of leaves and plant stems;

ii) internal plant surfaces, mainly those of stomatal cavities;

iii) soil surfaces

iv) snowpack surfaces or ice (where and when they exist)

In the process of evaporation the essential force of driving is solar energy, and it is the fluxes of radiation and heat on which evaporation losses in hydrologic cycle depends. The presence of forest may provide shade to the ground thereby reducing both air and soil temperatures and also wind velocity which finally reduces evaporation. Kunkle (1975) has observed that at higher elevations where generally forests are found evaporation losses are comparatively less mainly because of reduced air temperature. However, with increase in altitude the wind velocity and short wave radiation get increased with decrease in vapour pressure which lead to increase in evaporation rates.

The land use on a watershed, e.g. forests, pasture, arable crops or bare soil, creates differences in albedo which have important effects on the energy balance and hence on the water balance. Pereira (1973) has observed that reflection ranged from 12% for a pine forest to 40% for desert. Clearly, lower the albedo or reflection, more is the energy absorbed to become available for evaporation. Angstorm (1925) reported albedo values for grass, oakwood and pine forest as 26%, 17.5% and 14% respectively and Blackie and Rawlings (1972) have reported albedos of tea bushes, bamboo forest and tall rain forest in Kenya as 20%, 16% and 9% respectively. Thus, depending upon the type of vegetation the energy available for surface evaporation is determined which ultimately controls the rate of evaporation.

Gupta (undated) has noted that on forested areas the solar radiation, maximum temperature, vapour pressure difference and wind velocities are reduced as compared to unvegetated areas and these reductions keep increasing as the density of vegetation increases. Evaporation decreases with decrease in each of these factors. Evaporation from soil covered by forest is 10-80% of that from bare soil. Kittredge (1962) has noted similar values, hence the removal of forest vegetation by either partial or complete harvesting results in increased evaporation from the forest floor which is, however, generally more than compensated by decreased transpiration loss, resulting in a net gain to soil moisture and possibly to runoff.

3.3.2 Transpiration

From the point of view of forest influences,transpiration is one of the sources of loss of water of precipitation alongwith interception and evaporation before the remainder appears in streamflow. In the process of transpiration the water vapour moves out to atmosphere by diffusion through the opened stomata when the vapour pressure of the atmosphere is less than that of the intercellular spaces. The opening and closing of stomata is affected by light, humidity of the air and the moisture supply of the leaf. In the majority of plants, stomata are open during the day and closed at night. Lal and Subba Rao (1981) have reported night time transpiration as 5.18% of the day time transpiration.

Transpiration is mainly controlled by environmental and plant factors. The environmental factors include radiation, water availability in the root zone, infiltration and water retention characteristics of soil, saturation deficit in the air and wind movement characteristics. Among the plant factors the reflectivity (albedo) of the plant surface, root development characteristics, stand structure, interception characteristics and physiological structure of plants are important ones. Teller (1968) notes that compared to other catchment surfaces, the forest absorbs a great deal of solar radiation, reflecting only about 15-20%, as compared to 80-95% for snow, 25 to 45% for light sandy soils and 6% for water. With more absorption of radiation energy, the forest plants make more energy available for transpiration. The rooting characteristics of plants influence the amount of transpiration to a significant extent. The rooting depths can vary enormously depending on the type of vegetation. For example, roots of grass rarely go more than 3 m deep, whereas alfalfa roots may in some cases go as deep as 20 m. Shallow rooting trees such as spruce and poplar may extend their roots only to 1.5 to 2 m, whereas for deep rooting trees, eq. oak and pine the rooting depth may reach 4-6 m (Reader & Masur, 1968). Due to greater depths of rooting the trees can withdraw water from depths of 10 meters or more while evaporation from the soil surface rarely withdraws water from a greater depth than 30 cm Plants whose roots 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). Teller (1968) has described serious problem caused by phreatophytes in arid and semi-arid regions of the U.S. where they waste more than 30 x $10^9 m^3$ of water annually. To describe the huge transpiration losses caused by streambank vegetation,Pereira (1973) has cited example of south-western USA. According to him in this region the water use of highly adapted streambank vegetation tamarisk known as the ' salt cedar', is of major importance. Clearing of large areas of salt cedar in Arizona,U.S.A. has resulted in substantial savings of water. As per forests, a well stocked forest of mature trees uses more water then does any other form of vegetation. Gupta (undated) has cited Engler's observation as the transpiration of forest compared with crop land and weadows could be indicated as 100:43:22.

Transpiration losses for conifers and broad leaved evergreens are usually less than deciduous species. Winter losses for deciduous species are only from 0.4 to 4% and for coniferous species 10 to 18% of those during rest of the year.

Studies have been done to compare ET requirements of forests with other landuses. Kunkle (1975) has compared 10 year average ET data from two catchments in Switzerland, one fully forested and the other largely range cover. The forested watershed lost 50% of precipitation by ET while the second one lost only 38% of precipitation by ET. Lee (1980) has given precipitation (P) and stremflow (Q) values for a small (40 ha) undisturbed forest catchment for fifteen year period (1955-1969) during which precipitation was observed to be in decreasing at an average rate of 27 mm/yr. The corresponding decreasing rate of evapotranspiration was noted as 12 mm/yr. Cassells et al.(1982) have stated that deforestation resulted in reduced evapotranspiration as has been shown in Figure 1.

In India, studies leading to computation of evaporation and transpiration for forested areas have not been done on large scale. In Dehradun, the annual ET for chir,teak and sal species was found to be 840,840 and 560 mm respectively (Dabral et.al,1965). In a study at Dehradun, the ET losses for Eucalyptus citridera, Populas casale,Dalbergia latifolia and Pinus roxburgii were reported by Dabral (1970) as 5526,2704, 1143 and 536 mm respectively. Rajgopalan et.al.(1985) used daily meteorological records available from 1980 to 1983 at the Experimental Watershed Observatory at Khandala to determine estimates of monthly and yearly potential ET for the forested area in Khandala,Western ghats. The annual crop coefficient as reported by the auhtors is 0.542 for evergreen forested area of Khandala in Western ghats. Champion and Seth (1968) computed potential ET for moist deciduous forest by Thornthwaite, Rohwar and Leeper methods as 1172,753 and 825 mm respectively. Mishra (1948) gave evapotranspiration estimation for Damodar catchment (area 18650 sq.km dry decidous forests) as 560 mm/ yr which is about 49% of the annual precipitation. In a study on Eucalyptus plantation in West Bengal,Banerji(1972) reported evapotranspiration loss to be 1136 mm during the period from October 1970 to October 1971.

Forest evapotranspiration is essentially a physical process of mass and energy exchange with atmospheric, edaphic, and biological control mechanism. Based on studies discussed above it can be said that forests generally have higher ET requirements than other land uses. Systematic studies leading to computation of ET for different forest types are essential for determining actual water requirement of forests which will be helpful for water balance of forested catchments. This will also be required to find out effects of forest cutting on stream flow and water yield of a forested catchment.

3.4 Infiltration

Infiltration is the process by which liquid water enters the surface soil or zone of aeration. Infiltration is important hydrologically because it marks the transition from fast moving surface water to slow-moving soil and ground water.

The rate of infiltration into and through the soil is mainly a function of the size, number and arrangement of the pores in the soil. Water infiltrates a forest soil under the influences of gravity and capillary attaraction. The infiltration capacity has positive correlation with the soil porosity and organic matter content. The presence of leaf litter and vegetation in forested lands increases the organic matter content of the soil and improve structure of the soil which increases its infiltration capacity. Lee (1980) has reported infiltration capacity values for bare and vegetated soil as given in Table 8 .

Table 8. Typical Values of Infiltration Capacity as Related to Soil Texture and Cover

Texture	Infiltration Capacity (mm/hr)	
	Bare soil	Vegetated
Clay	0-5	5-10
Clay Loam	5-10	10-20
Loam	10-15	20-30
Sandy Loam	15-20	30-40
Sand	20-25	40-50

Source: Lee (1980)

Vegetated land is generally more absorbent because surface litter reduces raindrop sealing effects. Tsukamoto (1975) has reported effects of litter removal on infiltration capacity of soil in a study in Japan which is decscribed in Table 9.

Table 9. Effects of Litter Removal on Infiltration Capacity

Soil horizon	Untreated infiltration rate (mm/min)	Treated infiltration rate (mm/min)
H_1	120	2
A_1	60	0
A_2	14	4
B	5	3

Source: Tsukamoto (1975)

The results given in Table 9 clearly show the reduction in infiltration rate as a result of litter removal.

Infiltration rates vary through different forest floors. In the forest land, the organic matter in the soil (leaves, twigs etc.) separates soil particles and thereby creates more space for improving infiltration rates. Lassen et al. (1952) have reported that the forest soils had five times more storage capacity for the temporary detention of precipitation than the agricultural soils. The difference in the infiltration rates of forest and field soils in Russia has been reported in the International Symposium on forest influences and watershed management held in Moscow in 1970. This is shown in Figure 5

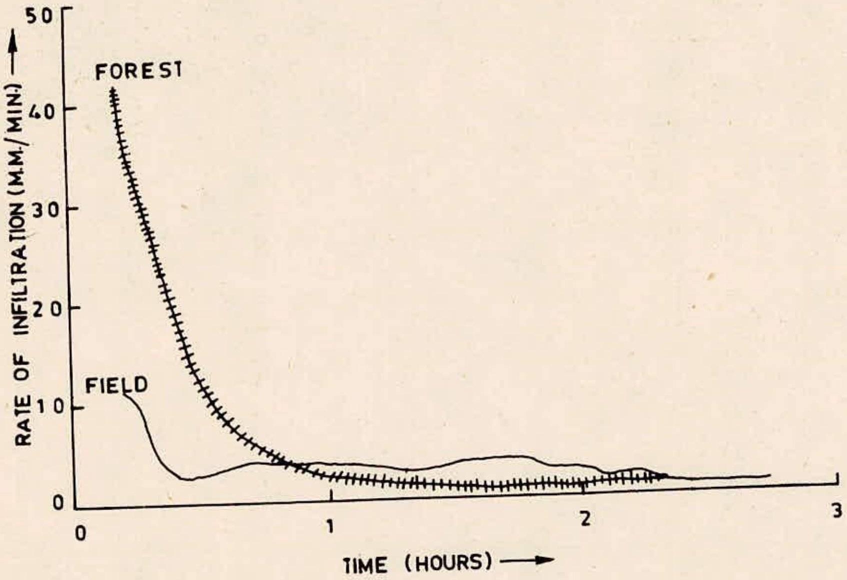

FIGURE 5. Difference in Infiltration Rates of Forest and Field Soils

Infiltration rates of forest and agricultural lands with soil texture being same has been reported by Odinokava as cited by Molchanov (1963) which are given in Table 10 .

Table 10 Infiltration rates for forest and agricultural land(soils are similar, at 48-59% porosity)

Land use	Age (Yrs.)	Infiltration rate (mm/min)
Oak forest	26	11.4
	60	12.5
	180	7.0
Ash Forest	18	20.7
	36	22.9
	65	16.8
Meadow		6.0
Plowland		1.2
Pasture		0.3
Forest felling area		7.6

Source : Molchanov,1963

The increased detention storage of forest soils helps in retarding the floods. However, if the rain continues for longer durations there may not be significant difference in the infiltration rates of forest and field soils. Constin and Doose (1973) have noted that most forests under good condition exhibit higher infiltration rates, with a corresponding reduction in surface runoff and soil erosion. These properties are attributed to relatively stable and porous structure of the forest soils, and to the protection of soils by the leaf mound and ground cover. Gupta (undated) has noted that as the forest vegetation keep transpiring water leading to continuous reduction in soil moisture which provides high infiltration capacity during initial period of rain.

In India, studies have been carried out to study infiltration rates under varying forest cover by CSWCRTI and FRI, Dehradun. In the field infiltration studies in Doon Valley Patnaik and Virdi (1962) reported higher infiltration rates for Bidhouli Sal forest with good leaf litter than for Horawala Sal forest with very little leaf litter. The infiltration rates reported for the former type of forest cover were 8.95,5.9 and 5.85 cm/hr for first three hours while for the latter these were 3.65,2.00 and 2.20 cm/hr. The infiltration rates for crop lands were reported lower than forested area. In Dhulkot, the cultivated valley with Maize crop had infiltration rates 3.70 ,1.94 and 1.91 cm/hr for first three hours while for forested area these values were 5.87,3.78 and 3.83 cm/hr. Studies done at Bellary reported infiltration rates for one hour run for woodland, grassland and agricultural land as 17.0,2.6 and 1.0 cm/hr respectively. Another study done in Ootacamund on infiltration rates on various soils under various land uses has found that the soils having a miscellaneous type of vegetation (Shola) had a high infiltration of 12.5 cm for a period of 3 hours while infiltration under Broom (Cystisus Scoparius) was 11.25 cm for the same period. The infiltration studies conducted at Ootacamund with four management practices showed that mean total absorption was highest for Shola forest followed by Bluegum plantation, grass land and cultivated land (Tejvani et al.,1975). In a study in the black cotton soil in Bellary,Ghosh (1974) reported infiltration rates under forests, natural grassland and terraced cultivation as 5.16, 3.00 and 1.40 cm/hr respectively. Studies done at FRI,Dehradun report the initial infiltration rates under Eucalyptus,Sal, Chri,Teak,Bamboo plantations and grasslands as 54.0,21.4,12.0 9.6,9.6 and 7.6 cm/hr respectively. The Environmental Research Station,Simla has also conducted studies to study the infiltration rates under various land uses and has reported that forest land has higher initial infiltration rate than the agricultural lands. In Bihar, Mistry and Chatterji (1965) recorded infiltration rates under forest land,permament grass and arable croplands as 260,120 and 90 mm/hr respectively.

The various studies reported above in India and elsewhere indicate that the infiltration rates under forest cover are higher than under cultivated lands. This is due to increased amount of organic matter in the soil which promotes the activity of microorganisms . Also in vegetated lands, the raindrop impact effects are reduced and the plants roots tend to increase soil porosity and stabilise the soil structure. Vegetation also depletes soil moisture to greater depths, increasing water storage opportunity and favouring high infiltration rates; these effects are more pronounced under forest cover where roots penetrate deeper and ET rates are greater. Though it is established that forested lands have higher infiltration rates, however, the magnitude of the forest is influence on infiltration will depend to some extent on the nature of the soil and the intensity of precipitation. Thus sandy soils which normally have high infiltration capacities are not likely to be influenced greatly by forest establishment. Similarly, the infiltration on a site with predominantly high rainfall intensity is not likely to change significantly when forest vegetation is replaced by grass or crops. These aspects are needed to be studied in detail. Also more efforts are needed to find effects of various types of alterations done on soil cover, e.g. change of land use,burning,grazing etc. on infiltration capacity of soil.

3.5 Ground Water

Forest influences on ground water storage can be estimated from evapotranspiration and discharge relationships. Many research projects carried out in the USA,Switzerland and Japan have attempted to show the influence of forests on underground water tables. The findings have not been very coherent as the Americal studies claim that water tables collapse as a result of deforestation or forest fire; while Swiss studies seem to indicate no effects on water table which forest cover changing to grass (Rakhamanov,1960; Penman,1963). In France, during the late eighteenth century and early nineteenth century, the writers, members of the French Royal Academy of Agriculture made it clear that because of deforestation carried out following the sale of properties belonging to the church and aristocracy at the time of French Revolution, numerous fountains dried up and rivers decreased in volume. However, there have also been instances when clearing of forest did not have any significant effects on ground water sources or fountains in

France. Hence, there does not seem any historical evidence of any direct influence of deforestation on the lowering of water tables (Guillerme,1980). Eckholm (1976) and Sharp and Sharp (1982) have opined that logging of tropical forest watersheds had caused wells, springs, streams, and even major rivers to cease flowing, at least during the dry season. There have been opinions that roots of forest trees Vexhibitaif ' Sponge' effect that soaks up water in the wet periods and let it release slowly and evenly in the dry season to keep water supplies adequately restored. Such opinions are difficult to believe especially in light of the fact that small watershed cutting experiments have universally given increased total water yield over the year and some cutting experiments have shown increases in ground water levels (Hamilton and King,1980,Bosch & Hawlett 1982 and Boughton,1970). Reforestation of upland watersheds has been advocated partially on the grounds that it will induce dry season stream flows and raise groundwater well levels and restore the reliability of springs (World Bank,1978). The Leader of Chipko movement claims that tree planting particularly the broad leaved varieties creates water (World water,1981). However, most well conducted experiments have shown that reforestation reduced streamflow year-round (Van Lill et al.,1980) Lowering of ground water levels has usually followed reforestation (Holmes and Wronski,1982). In China, in order to improve areas where water table is too close to the surface planting of Populus is being done to arrest the ground water table.

In India, significant efforts have not been made to study effects of forests on ground water. Systematic studies are therefore required in this direction. The planting of fast growing trees like Eucalyptus in water logged areas needs careful study. Based on studies done abroad, it may be concluded that lowering of water tables during nineteenth century has its origin in consumption and urbanisation, not in deforestation.

3.6 Water Yield

The Water yield and streamflow regimen are distinctly and importantly influenced by the presence of forest cover; this principle has been verified by practical experience and scientific experimentation in every major forest zone of the earth. But as forest cover has hardly any effect on gross precipitation, its influence on the water budget must be related entirely to energy-budget effects, specifically latent heat exchanges, and short term or seasonal modifications of discharge phenomena.

Hibbert (1965) has reported a study conducted in 1900 to study effects of forest treatment on water yield in Emmenthal mountains of Switzerland. Measurement of climate, precipitation and streamflow were made on two small catchments,one forested and the other pasture land and difference in streamflow was recorded. A second attempt to analyze the influence of forests on water yield was made in the Wagon Wheel Gap investigation of 1911 in the U.S.A. (Bates and Henry 1928).

It was found that clearing forest cover increases streamflow. In 1934, the Coweeta Hydrologic Laboratory was established by U.S.Forest Service to analyse the effects of various forests cutting and vegetative conversion treatments on water yield in the humid mountains of the eastern USA (Hibbert, 1965). With the exception of limited thinning (25 percent of basal area removed), the treatments evaluated increased water yield by varying amounts. In Kamabuti,Japan, a significant increase in water yield was observed by clearing conifers and deciduous forest overstories on a small mountainous catchment in 1948. A large increase in water yield was observed following clearing the high montane and bamboo forests on a experimental catchment at Kimakia in Kenya, East Africa (Hibbert,1965). Analysis of streamflow from an experimental catchment on the Jankershock Forest Reserve, South Africa, has shown a 50% increase in water yield after one third of the radiata pine forest cover was removed 16 years following planting (Van Der Zel,1970).

Annual water yield increases following forest removal have been obtained from numerous catchment experiments under a wide variety of conditions. A list of results is given in Table 11. It can be seen from Table 11 that complete deforestation generally increases the annual yield by between 20-40% of normal. Hewlett and Hibbert (1967) have reported results of studies in 15 forested catchments of the U.S. that direct runoff in those catchments varied from 4-18% of annual precipitation which amounted to 7-33% of total streamflow. Molchanov (1963) gave surface and subsurface runoff values for some forested and non-forested sites in the U.S. as given Table 12.

Table 11. Annual Water Yield Increases Following Forest Removal (Anderson *et al.*, 1976)

Location	Forest type[a]	Removal		Normal yield (Q, mm/yr)	Yield increase by years (mm/yr)			$\Delta Q_1/Qf$ (%)
		Fraction (f)	Method		ΔQ_1	ΔQ_2	ΔQ_3	
North Carolina	MH[b]	1.00	Clearcut	792	370	283	279	47
	MH[c]	1.00	Clearcut	607	127	95	59	21
	MH	0.50	Strips	1275	198	155	130	31
	MH	0.22	Selection	1222	99	56	71	37
West Virginia	MH	0.85	Clearcut	584	130	86	89	26
	MH	0.36	Selection	660	64	36	–	27
	MH	0.22	Selection	762	36	–	–	21
	MH	0.14	Selection	635	8	–	–	9
Colorado	AC	1.00	Clearcut	157	34	47	25	22
	PSF	0.40	Clearcut	283	86	53	79	76
Oregon	DF	1.00	Clearcut	1448	462	457	–	32
	DF	0.30	Clearcut	1448	150	163	150	35
Arizona	PP	1.00	Clearcut	153[d]	96	23	46	–
	PP	0.32	Strips	170[d]	50	15	9	–
	PP	0.75	Thinning	194[d]	22	37	-38	–

[a] MH, mixed hardwoods; AC, aspen-conifer; PSF, pine-spruce-fir; DF, Douglas fir; PP, Ponderosa pine.

[b] Northeast aspect.

[c] Southeast aspect.

[d] Winter discharge.

Table 12 Surface and subsurface flows for Forested and Non-forested sites

		Surface runoff	Subsurface runoff
North Carolina,USA	Forest	5-10%	90-95%
	Bare Soil	60-80%	15-95%
	Grass	80%	20%
Wisconsin,USA	Oak Forest	Max 3%	-
	Fields	Max 26%	-
Mississippi,USA	Oak Forest	Max 1%	-
	Abandoned Cotton fields	Max 47%	-
	Pseudocacia Plantation	Max 2%	-
	Old plowland	Max 40%	-

Source : Molchanov(1963)

The Tennessee Valley Authority(TVA) of the USA has tested the hydrologic effects of afforestation on denuded and farm lands. Studies were carried out from 1941-1960 on a watershed (35.6 ha) by bringing it under 100% forest cover from the original coverage of 23%. The percent reduction in the surface runoff following afforestation since 1941 are given in Table

Table 13 Percent Reduction in Surface runoff(%)

Season		(1941-45)-(1946-50)	-(1951-55)	-(1956-60)	Total (1941-60)
Summer	25 mm storm	59	9	15	83
	50 mm storm	30	13	13	56
Winter	25 mm storm	69	11	2	82
	50 mm storm	40	21	2	63

Source : Tennessee Valley Authority,1962

Studies have also been carried out to study the effects of deforestation on runoff peak and volume. Dils (1953) has reported clearing of trees from small (9 ha) forested watershed for its cover conversion to grazing and farm land. The peak discharge after cleaning and grazing was reported to be increased by ten-fold with the infiltration rate going down from 77 mm/hr before grazing to 16 mm/hr after 30 animal use days/ acre. In an African Study reported by Dagg and Blackie(1965) 334 ha. of a 700 ha. forested catchment was cleared and planted to tea. The storm runoff from the treated catchment was compared with a central forested catchment (565 ha) and increase in runoff from treated catchment was observed. In a study in the New York State, a small watershed (808 ha) was 58% reforested between 1934 and 1957. The reduction in peak discharge as observed due to this afforestation was by 66% in the month of November and by 16% in the month of April. The volume of total runoff was however, not found changed which suggested that the degree of forestation was only enough to influence the peak flows (Schneider and Ayer,1961).

In India, some studies have been done to find effects of forests and their management practices on water yield. Studies on two small basins at Dehradun showed that reforestation of a small watershed (1.45 ha) by Eucalyptus species reduced volume and peak rate of runoff by 28 and 73 percent respectively from 1969-73 (Mathur et al.,1976).

Subba Rao et al.(1973) observed runoff as 42% of rainfall in decidous moist forest in Rajpur,Dehradun. An increase of 86% was observed in the peak rate of flow after having a treatment involving 20% thinning (Subba Rao et al.1984). In a study in Kumaon hills, Pathak et al.,(1984) found overland flow as 1.24%, of rainfall for Pine-mixed broad leaved forests and for mixed oak, it was found to be 0.68% of incident rainfall. Studies have also been done to compare water yields from different land use covers. Under different forest cover conditions in West Bengal (Ghosh,1967, Ray,1971) maximum runoff was recorded on wastelands and least under forest cover. Bahadur et al.,(1980) have reported values of runoff coefficient,fraction of rainfall being converted to runoff, for different land uses which are reported in Table 14.

Table 14 Runoff Coefficient for different land uses and soils

Soil type	Values of C for different land uses		
	Cultivated	Pasture	Forest
With above average infiltration rates usually sand or gravel	0.29	0.15	0.10
With average infiltration rates-no clay pans,loam or similar soils	0.40	0.35	0.30
With below average infiltration rates heavy clay soils with clay pan near the surface shallow soils above impervious rock	0.50	0.45	0.40

Source : Bahadur et al.,1980

Ghosh and Subba Rao (1979) have reported that in a study done for selected storms on two basins, one under agricultural use and another forested, the forested basin gave 10% less peak discharge than agricultural basin. Similar studies at Ootacamund indicated that plantation of Eucalyptus and wattle reduced the peak discharge by nearly 62% as compared to agricultural land (Lal & Subba Rao,1981). Chinnamani et al.(1965) reported studies on amount of runoff under different vegetation covers including shola,bluegum,wattle,broom and grasses. (1965). Not much difference was recorded on effects of various vegetative covers namely,shola,bluegum,wattle,broom and grasses on runoff. Results obtained from micro watersheds studies at Chandigarh indicate that burning,cutting of trees and overgrazing increase peak discharge by 73% (Anon.,1975). Studies on experimental runoff plots at Nurpur (H.P.) showed increased runoff from regularly grazed areas as compared to the areas under shrub and grass cover (Sinha, 1975; cited from Lal and Subba Rao,1981).

Based on studies described above it can be said that the annual water yield increases following forest removal, the increase in water yield is proportional to area of deforestation. The effects of cutting of forestation are maximum in the first year and then decrease logarithmically with time. The increased water yield is attributed to decreased ET demand following deforestation as the ET demand accounts for a significant proportion of the annual precipitation input on most watersheds.

3.7 Floods

The forest influence on floods is a matter of considerable controversy for many years. The effects of forests on floods are better evaluated by methods which attempt to evaluate infiltration, surface runoff, subsurface storage, interception, and other factors in the water cycle. As said in earlier sections the forests directly influence the surface runoff by having its effects on infiltration, subsurface-storage and interception. So influence of forest in reducing floods will be significant in cases where the floods are result of excess surface runoff which exceed the infiltration capacity of the soils. There is a widespread belief that forest covered upland watersheds will prevent floods on the mainstream,downstream, on major rivers. In 1978 World Forestry Congress, the cause of floods in Indian sub-continent was pointed out to be removal of tree cover from catchment areas (Avery,1978). The Europian Environmental Bureau (1982) is also of the opinion that forests guard against flooding even on large rivers. In the Phillippines the cause of great Agusan flood of 1981 was partially (30%) placed on logging of headwater forests (Corvera,1981). overlogging has been officially recognised as the cause of the July,1981 severe flooding of the Yangtze. Lee (1980) has opined that earlier the foresters had opinions that deforestation caused floods but now their opinion seemed to be changing. In this reference the data of peak flows from larger forested watersheds as reported by Anderson et al.,(1976) are of interest which are given in Table 15.

Table 15. Some Record Peak Flows from Larger Forested Watersheds

Watershed	Area (km^2)	Peak flow (m^3 / sec. km^2)	Forest Cover (%)
North Atlantic			
Ellis River, N.H	73	5.78	100
Rondout Creek, N.Y.	259	2.92	80
Rapidan River, Va.	1204	1.37	53
South Atlantic			
Morgan Creek, N.C.	70	12.14	61
Henry Fork, N.C.	207	4.27	88
Yrdkin River, N.C.	1277	3.54	90
Ohio Basin			
Elk Creek, N.C.	109	7.16	67
Watauga River, N.C.	236	6.12	62
Watauga River, Tenn.	1106	1.84	64
Paciffic Slope (South)			
San Antonio Creek, Ca.	44	13.85	63
San Gabriel River, Ca.	264	3.65	100
Los Angeles River, Ca.	1326	1.43	28
Pacific Sloe (North)			
Skokomish River, Wa.	155	4.24	75
Wynoche River, Wa.	272	2.60	90
Skykomish River, Wa.	1386	1.62	78

Source : Anderson et al., (1976)

Lee (1980) has agreed that higher peak flows generally occur in forested basins but the reasons for the same were the upland location of forests where precipitation was greater

,soils were shallower and topography was steeper. Hewelett (1982) has reported that there was no cause effect relationship between forest cutting in the head waters and floods in the lower basin. Hamilton (1985) felt that even if a whole basin were under a forest harvesting regime, normally it would not be logged off all in one year. Those portions that are logged rather quickly return to a prelogging hydrologic regime as the forest regenerates and full canopy is restored, even though it is young growth. Thus, proper conservation logging can reduce any small effects on upstream flooding. The most important influence of forest cover on floods, and flood damages, has more to do with sedimentation and debris discharge than with absolute volume or rate of flow. The organic and inorganic sediments when deposited in a stream channel will reduce its carrying capacity and thus increase chances of overbank flooding. Similarly the sedimentation in reservoirs reduces its usefulness for flood control and other purposes. As cutting of forest will result in more erosion of soil, therefore, more reduction in stream channel capacities and flood storage of reservoirs can be expected following deforestation. However, these effects will be confined to streams close to the deforested regions.

In India, the extent of estimated flood damages increased a lot in last two decades. The Rastriya Barh Ayog set up by the Government of India in 1976 noted that the unscientific and over-utilisation of land and water resources due to increasing population has disturbed the ecological balance which is resulting in excessive loss of soil from land. In consequence, the rivers and streams which originate in such ecologically upset regions experience flash floods and carry heavy sediment laods which gets deposited on their beds and leads to reduction in capacities. The presence of forests certainly reduces the peak and volume of runoff but generally flood situations occur during intense storms with saturated watershed conditions. Under such conditions there may not be significant effects of forests of flood but for having check on soil erosion. The high rate of evapotranspiration by forest trees keeps providing storage space for moisture in the root zone of the soil so a saturated soil profile under good forest cover continues to absorb rainwater though the afforestation measures help in reducing speed and amount of runoff, minimise soil loss and sediment delivery to stream but these effects are not enough to prevent major flood situations. However, these effects of forests can have some effects on moderate and flash floods. Recognising the need of forest preservation,Government of India enunciated the National Forest Policy in 1952 in which it was envisaged that at least 33% of the land area should be covered by forests. As per the statistics quoted by the report of Rashtriya Barh Ayog , there is about 75 million ha. area under forest presently which accounts for 22.8 percent of total geographical area. These figures have however, been disputed by some politicians and researchers. In order to have more knowhow concerning forest influences on floods, it may be worthwhile to attempt studies envisaging systematic inventory of forest cover complex and the hydrologic grouping of forested lands. It is also necessary to prepare uptodate maps of land uses and cover complexes of the upland watersheds of chronically flood prone rivers. The critical areas can be identified on such maps and proper watershed management measures can be taken to undo harmful effects of critical zones. Studies are also required to evaluate extent of damages caused by floods as a result of deforestation. Such studies can be taken up in representative basins based on which definite conclusions regarding forest influences can be drawn.

3.8 Water Quality

Pure water never occurs in a forested ecosysystem. When rain strikes a tree canopy, a series of dynamic processes being which may greatly alter the water's constituents and properties; accordingly, at any point in its movement through the ecosystem, water quality is defined in terms of its physical, chemical and bilogical characteristics. The main quality parameters that are closely related to the condition of vegetative cover of the soil are silt content in stream flows, dissolved substances, common particulates and gases. Fleming (1969) developed design curves for estimating suspended loads from the mean discharge for various forest covers. He concluded that various types of forest cover yielded different amount of suspended load to affect water quality. Likens et al.(1977) reported both throughfall and stemflow get considerably enriched in all the major cations and anions except hydrogen by contact with trees. Tarrant et al.(1968) observed increase in nitrogen in throughfaull and stemflow in some forest species. The alteration of chemical composition of stemflow and throughfall was reported to be mainly because of the solution deposited on trees from the atmosphere during non-storm periods, leaching for plant tissues and actions of nitrifying and ammonifying bacteria and other micro-organisms. Slack and Feltz (1968) have discussed the changes in water quality due to litterfall. Litterfall, especially from deciduous species, added to water bodies with low flushing rates may increase true color, iron bicarbonate and manganese concentrations, and decrease dissolved oxygen levels and pH of water. The forest reduces the soil temperature fluctuations and closed forest stands limit the temperature of forest stream to a relatively stable temperature regime which directly influences the bilogical productivity of the stream.

In India, extensive studies for finding effects of forest cover on water quality are yet to be done. The Environmental Research Station of FRI, and the CSWCR&TI, Dehradun have taken some steps in this direction.

4.0 CONCLUSION AND RECOMMENDATIONS

Various studies concerning forests influences on hydrological parameters have been critically examined in foregoing sections. Most of the studies as reported have been done on small watersheds and runoff plots and their results may not serve the purpose as far as their applicability on larger watersheds is concerned. There have been two school of thoughts regarding influences of forests on rainfall , however, majority of opinions are in favour of no influences of forests on rainfall on regional scale. There have been some studies which have indicated that cutting of forests led to reduction in rainfall. Studies done in coastal forests have confirmed that cutting of coastal forests where conditions of fog prevail would lead to reduction in condensation of moisture from moist air masses or in other words the ' Occult precipitation'. While the amount of interception losses in forested watershed is a function of type of vegetation intensity of rainfall and climatic characteristics, it still remains to be confirmed whether to consider interception as a loss of water from land phase of hydrologic cycle. This hypothesis has significance in light of the aruguments given by some researchers that the loss of water by interception is more or less compensated by reduction in transpiration from trees. Studies on evapotranspiration needs of different forest types have not been done on large scale. However, it can be concluded based on available studies that forests' ET requirements are higher than other land uses. As regards to components of evapotranspiration i.e. evaporation and transpiration, a forested watershed has comparatively less loss of water by evaporation from land surface due to the shade provided by trees but relatively more loss of water by transpiration is recorded. More studies are essential for funding out actual ET requirements of different types of forests as it will be of great help for estimating increase or decrease in water yield of a watershed as a result of deforestation or afforestation. Soils in forested watershed have been found to exhibit good infiltration capacities due to increased amount of organic matter and accelerated activities of microorganisms. However, the magnitude of forests ' influences on infiltration capacity will very much depend upon type of soil and intensity of precipitation. The claims made by some people that deforestation has led to drying up of springs wells etc. have not been found scientifically sound. The soaking effects of the roots of forest trees in wet season and slow release of water in dry season still need to be verified.

The effects of forests on water yield have been more or less established on small watersheds. The total water yield have been found increasing with cutting of forests. The results obtained from studies conducted in small watersheds or runoff plots, which are sometimes unrepresntative of large catchments, may be misleading if these are applied to large watersheds. In case of large watershed the effects of forests on the sub-surface component of total water yield may be different than on small watersheds. As regards to floods in major river basin, the responsibility can not be placed altogether on deforestation in upland watersheds. However, due to increased sedimentation in rivers, stream and reservoirs as a result of deforestation, the moderate and flash floods are certainly affected but only close to the zone of deforestation. Studies are required for effects of forests on water quality in forested catchments.

Based on the review of research work done on forest influences it is recommended that further research work may be taken up in following aspects:

i) Representative basin studies should be initiated to verify the results of runoff plots or experimental waters regarding forests influences.

ii) Studies are required to find effects of type and density of forests and their management practices on hydrological regime of a forested watersheds.

iii) The aspect whether interception to be considered as a loss from land phase of hydrologic cycle needs careful study.

iv) Methods may be evolved to compute the ET requirements of various kinds of forests. This will help in doing water budget of a forested watershed.

v) Vegetation manipulation practices for change in water yield is a field of thorough investigation. This may even be done on municipal watersheds for drinking water supply.

vi) Studies may be taken up to develop Resource Management Model for optimal utilisation of watershed resources.

vii) Effects of different cultural and management practices including thinning, logging and social problems like forest fires, grazing, shifting cultivation etc. on hydrological regime of a forested catchment need to be studied in a scientific manner.

viii) Effects of forests on ground water regime of a catchment need to be studied in depth.

ix) The role of forests in water resources planning and management of a forested catchment needs to be clearly defined.

REFERENCES

Anderson,H.W., M.D.Hoover and K.G.Reinhart(1976),'Forests Management of Floods, Sedimentation and Water Supply, General Technical Report PSW-16,Washington,D.C.,U.S.D.A., Forest Service.

Angstorm,A.(1925),' The Albedo of Various Surfaces of grama', Geografiska Annaler,H4,323-342.

Anonymous (1975),' Annual Report of Central Soil and Water Conservation Res. & Trg. Institute',Dehradun.

Avery,D.(1978), ' Firewood in the Less Developed Countries', Eighth World Forestry Congress,IUKRO Voluntary Paper,Agenda Items.

Bahadur,B.,S.Chandra and D.K.Gupta(1980),' Hydrological Studies on Experimental Basins in Himalayan Region', Proc.Symp.IAHS on the Influence of Man on the Hydrological Regime with Special Reference to Representative and Experimental Basins.

Bates,C.G., and A.J.Henry(1928),' Forest and Streamflow Experiments at Wagon Wheel Gap,Colorado', U.S.Weather Bureau Monthly Weather Review, Supplement No.30,pp.1-79.

Bernard,A.E.(1953),'L' Evapotranspiration annuelle de'la forest equatoriale congolaise et son influence sur la pluvidsite', Comptes Rendus,IUFRO Congress,Rome,201-204.

Bernard,A.E.(1945),' Le Climat Ecologique de la Cavette Centrals Congolaise', INEAC,Brussels.

Bhattacharya ,A.P.(1956),' Study of the Effects of Deforestation on the Intensity and Frequency of Rainfall and floods in Pathri,Ranipur and Ratmau Torrents', Indian Forester, 82(8): 411.

Blackie,J.R. and M.H.Rawlings(1972),' Ann.Rept', Inst. of Hyd.,UK.

Boughton,W.C.(1970),' Effects of Land Management on Quantity and Quality of Available Water: A Review', Australian Water Reso.Con.Res.Proc. 68/2,Report 120, Monly Vale: Univ. of New South Wales.

Brown,J.C.(1877),' Forests and Moisture; or Effects of Forests on Humidity of Climate', London; Simpkin, Morshall.

Burgy,R.H. and C.R.Pomeroy(1958),' Interception Losses in Grassy Vegetation;'EOS', American Geophysical Union Transactions,Vol.39', pp.1095-1100.

Cassells,D., L.S. Hamilton and S.R. Saplaco(1982),'Understanding the Role of Forests in Watershed Protection', Honolulu,East West Centre Environment and Policy Institute Working Paper.

Champion,H.G. and S.K.Seth (1968),' General Silviculture for India', Manager of Publications,Delhi.

Chinnamani,S. et al.(1965),' Runoff and Soil Loss Studies under Different Vegetative Covers', Indian Fors, 91,672-682.

Chow,V.T.(1964),' Hand book of Applied Hydrology', McGraw Hill Book Company,New York.

Corvera,A.K.(1981),' What Caused the Great Agusan Flood'? Weekend,March 1,1981,pp 12-13.

Costin,A.B. and J.C.I. Dooge(1973),' Balancing the Effects of Man's Actions on the Hydrological Cycle', Man's influence on the hydrological cycle,special issue 17,FAO,Rome.

Dabral,B.G.,P. Nath and R.Swarup(1963),' Some Preliminary Investigations on the Rainfall Interruption by Leaf Litter', Indian For.89,112-116.

Dabral,B.G., J.S.P.Yadav and D.R.Sharma(1965),' Soil Moisture Studies in Chir,pine,teak and sal plantations at New Forest',Dehradun,Indian For.,91(10).

Dabral,B.G. and B.K.Subba Rao(1968),' Interception Studies in Chir and Teak Plantations', New Forest, Dehradun, Indian For.,94,341-351.

Dabral,B.G. and B.K.Subba Rao(1969),' Interception Studies in Sal (Shorea robusta) and khair (Acacia catechu) Plantations', New Forest,Dehradun,Indian Forester,95,313-323.

Dabral,B G.(1970),' Preliminary Observations on Potential Water Requirement in Pines roxburghii, Eucalyptus citriedera,Populas Casale (480) and Dalbergia litifolia', Ind. For., 86(10).

Douglass, J.E. (1981),' Watershed Experiments by the Coweeta Hydrologic Laboratory', Unpublished paper given to watershed Forest influence Workshop,East-West Centre, Honolulu.

Dunne,T. and L.B.Leopold (1978),' Water in Environmental Planning', W.H.Freeman & Company,San Francisco,USA.

EcKholm,E.(1976),' Losing Ground', New York: W.W.Norton.

Ekern,P.C.(1984),' Direct Interception of Cloud Water on Lanaihale,Hawaii', Proc.Soil Sci Soc. of America, 28; 417-21.

European Environmental Bureau (1982),' The Environmental Importance of Tropical Moist Forest', Deforestation and Development Newsletter,June 1982,pp.1-7.

F.A.O.(1962),' Forest Influences: An Introduction to Ecological Forestry', Second Printing 1978,F.A.O.,Rome.

F.A.O.(1972),' Proceedings of the Joint FAO/USSR International Symposium on Forest Influences and Watershed Management', Moscow,1970,FAO,Rome,452 pp.

Fleming,G.(1980),' Design Curves for Suspended Load Estimation', Inst. of Civil Engineers,43 : 1-9.

Flolliott, P.F.,' Vegetation Management and Water Yields- Possibilities and Limitations', Univ. of Arizona, Tucson, USA (undated).

Ghosh,R.C.(1974),' The Protective Role of Forestry to the Land', Tenth Commonwealth For.Conf.,London.

Ghosh,R.C. and B.K.Subbarao (1979),' Forests and Floods', Ind.For.,105,pp.249-257.

Goodell,B.C.(1963),' A Reappraisal of Precipitation Interception by Plants and Attendant Water loss.Jr. Soil and Water Conservation', 18(6),pp.231-234.

Gilman,C.S.(1964),' Rainfall', Section 9 in Handbook of Applied Hydrology (Ed.V.T.Chow),McGraw-Hill,New York, p.9-1 to 9-68.

Goodell,B.C.(1966),' Watershed Treatment Effects on Evapotranspiration', Reprint,Int.Symp. of Forest Hyd., Pennsylvania St.Univ.,1965,Pergamon Press, New York, pp.477-482.

Gupta,P.N.(undated),' Hydrology and Forest Influences', Working Plan Circle(I), U.P.,Nainital.

Gupta,R.K.(1980),' Consequences of deforestation and overgrazing on the hydrological regime of some experimental basins in India', Proc. IAMS Symposium on the influence of man on the Hydrological Regime with special Reference to Representative and Experimental Basins, June,1980, Helsinki.

Guillerme,A.(1980),' The Influence of Deforestation on Groundwater in Temperate Zones: an Historical Perspective', In Proc.Symp. IAHS on the Infouence of Man on the Hydrological Regime with Special Reference to Representative and Experimental Basins', June 23-26,1980,Helsinki.

Hamilton,L.S. and P.N.King (1983),' Tropical Forested Watersheds' West view Press, Bouldor,Colorado,USA.

Hamilton,L.S.(1985),' Towards Clarifying the Appropriate Mandate in Forestry for Watershed Rehabilitation and Management Experts Meeting on Strategies Approaches and Systems for Integrated Watershed Management, Feb 25- March,1985, Kathmandu,Nepal.

Hewlett,J.D.(1965),' Summary of forests and Precipitation', Session Proc.Int.Sym. on Forest Hydrology,Pennsylvania, Pegrmon Press.

Hewlett,J.D. and W.L.Nutter(1968),' An outline of Forest Hydrology' Pthens,Georgia,Univ. of Georgia Press.

Hewlett,J.D.(1982),' Forest and floods in light of recent investigation,In Proc.Canadian Hy.Symp.June 14-15 Federiction, pp.543-66.

Hewlett,J.D. and A.R.Hibbert(1967),' Factors affecting the response of small watersheds to precipitation in humid areas', In Int. Symp. on Forest Hyd.,ed.W.E.Sopper and H.W.Lull,pp.275-90,Oxford,Pergomon.

Hibbert,A.R.(1965),' Forest Treatment effects on water yield, Proceedings, International Symposium on Forest Hydrology, Pennsylvania State University,(91965),pp. 527-543.

Holmes,J.W. and E.B.Wronski(1982),' On the Water Harvest from Afforested Catchments', Proc. First National Symp. on Forest Hydrology,pp.1-6,Melbourne.

Hursh,C.R.(1948),' Local Climate in the Copper Basin of Tennessee as Modified by the removal of vegetation Circular 774', Washington D.C.,U.S.Department of Agriculture.

Kunkle,S.H.,' An introduction to Forest Hydrology', Teaching Notes, F.A.O. Rome,June,1975.

Lal,V.B. and B.K.Subba Rao(1981),' Hydrologic Influence of Vegetation Cover in Watershed Management', National Workshop on Watershed Management,Dehradun,April 22-24.

Lassen et.al.,(1952),' Some plant-soil-mater relations in watershed management', Deptt. of Agril,Circular No.910,U.G.Govt. Printing Office,Washington,D.C.pp.64.

Leonard,R.E.(1961),' Interception of Precipitation by northern hardwoods', Station Paper 159, Northeastern Forest Experiment Station,Upper Derby,PO.,USA,16 pp.

Lee,R.(1980),' Forest Hydrology', Columbia University Press,New York.

Likens et al.(1969),' Nitrification: Importance to nutrient losses from a cutover forest ecosystems', science 163: 1205-6.

Lull,H.W.,(1964),' Ecological and Silvicultural aspects', In Handbook of Applied Hydrology(Ed. Van Te Chow),McGraw-Hill Book Co.

Marsh,G.P.(1907),' The Earth as modified by Human action', New York: Scriber's.

Martin,O.M.(1944),' Influence of Forests on Rainfall', Indian Forester, 70(10), October, P.233.

McMillan,W.D. and R.H.Burgy(1960),' Interception Loss from Grass", Journal of Geophysical Research,Vol.65, pp.2389-2394.

Mathur,et.al(1976),' Effect of clearfelling and reforestation on runoff and peak rates in small watersheds', Indian For.,102,219-226.

Mathur,H.N. and S.Naithani(1982),Proc. Int.Symposium of Hydrological Aspects of Mountainous Watershed,UOR, Roorkee,Nov.4-6,1982.

McDonald,J.E.(1962),' The Evaporation precipitation faccacy', Weather 17,168.

Molchanov,A.A.(1960),' The Hydrological role of forests, Acad of Science of USSR, Inst. of Forestry, Moscow (Translated by a Gouresitch,Israel,1963).

Mishra,R.K.(1948),' Damodar Catchment-Preliminary Survey to study water losses by transpiration and evaporation', C.B.I.P.,Jour,5(3).

Mistry,P.C. and B.N.Chatterji (1965),' Infiltration Capacities of Soils in Ranchi', J.Sal and Water Cons. India,13,43-47.

Patnaik,N. and S.S.Virdhi(1962),' Field Infiltration Studies in Doon Valley', Irrig. and Power,19,1003-12.

Patterssen,S.(1969),'Introduction to Meteorology', New York,Mc-Graw Hill Co.

Penman,H.L.(1963),' Vegetation and Hydrology', Technical Communication No.53, Fartham Royal,England: Commonwealth Organisational Bureau.

Pereira,H.C.(1973),' Land Use and Water Resources', Cambridge University Press,London.

Pereira,H.C.(1952),' Interception of rainfall by Cypress Plantations', E.Afg.Azric J.,18,1-4.

Qureshi,I.M. and B.K.Subbarao (1967),' Hydrological and Micro-climate Studies at Rajpur Forest Experimental Station', Proc. of Xith All India Silva Conference.

Rajagopalan,K.S., K.K.Patil and C.Ramesh(1985),' Estimation of Potential Evapotranspiration from a Forested Catchment', Proc. 52nd R & D Session,CBIP,Tech.SessionI, Aurangabad

Ranganathan,C.R.(1949),' Protective functions of forests', Proc. U.N.Cont. on Conservation and Utilisation of Resources.

Raeder,Roitzch, J.E. and A.Masur(1968),' Some hydrologic relationships of natural vegetation in the chir pine belt of Pakistan', Proc. First Pakistan Watershed Management Conference, Pakistan Forest Inst. ,Peshawar,pp.345-60.

Report Rashtriyr Barh Ayog,Vol.1,Govt. of India.

Rothacher,J (1963),' Net precipitation under a Douglasfir forest'; Forest Sci.,9,423-429.

Robinson,T.W.(1958),' Phreatophytes, U.S.Geological Survey Water-Supply paper 1423,U.S.Govt. Printing Office, Washington,D.C.,84 pp.

Sharp,D. and T.Sharp(1982),' The desertification of Asia', Asia 2000 1(A), 40-42.

Shpak,I.S.(1968),' Effect of Forest on Water Balance Components of Drainage Basins', Kiev,pp.137-43, Academy of Sciences of the UKraine SSR (Translated from Russian 1971), Israel Programme for Scientific Translations, Jerusalem).

Slack,K.V. and H.R.Feltz(1968),' Tree leaf control on low flow ater quality in a small Virginia system', Environmental Science and Technology 2: 126-31.

Storey, H.C., R.L.Hobba and J.M.Rosa (1964),' Hydrology of forest lands and rangelands', In Handbook of Applied Hydrology (Ed.Van Te Chow).

Tarrant et al.(1968),' Nutrient Cycling by Throughfall and Stemflow Precipitation in Three Coastal Oregan Forest Types', Forest Service Research Paper PNW-54, Portland,Oregan,USDA.

Tejwani,K.G., S.K.Gupta and H.N.Mathur(1975),' Soil and Water Conservation Research',1956-71, New Delhi,pp. 1-358,ICAR.

Tennesse Valley Authority(TVA)(1962),' Reforestation and erosion control influences upon the hydrology of the Pine Tree Branch Watershed, 1941-1960,TVA,Knoxville.

Teller,H.L.(1968),' Forest Hydrology and Watershed Management',Lecture notes,FAO,Rome.

Tsukamoto,Y.(1975),' Effect of Forest litter on runoff cycle in a small experimental watershed Publication 117 de l', Association Internationale des Sciences Hydrologigues, Symposium de Tokyo,pp 487-95.

Van Lill, W.S., F.J.Kruger and D.B.VanWyk,(1980),' The Effect of Afforestation with Eucalyptus Grandis and Pinus Patula on Streamflow from Experimental Catchments at Mokobulaean,Transvalli,Hydrology 48:107-18.

World Water(1981),' How Tress can Combat Drought and Floods', World Water 4(10):18, October.

World Bank(1978),' Forestry Sector Policy Paper', Washington: World Bank.

Zinke,P.J.(1967),' Forest Interception Studies in the United States', Proc. Int.Symp.Forest Hyd.,137-162, Penn.State Univ.,(Pergamon Press).

Zon,R.(1927),' Forests and Water in the light of scientific investigation', Washington,D.C.,U.S.Govt.Printing Office.