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STATUS OF HYDROLOGICAL STUDIES IN FORESTED CATCHMENTS

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ABSTRACT

The forests are largely confined to upper catchments of various water resources projects and catchments of flood prone areas. The manipulation of forest vegetation in upland watersheds may be one way to alter the water budget of a catchment. The report brings out status of important research works done so far in India on the hydrological behaviour of forested catchments. There are nearly 16 Hydrological Research Stations working in India on some aspects of forest hydrology. Mainly two research organisations viz., Central Soil and Water Conservation Research and Training Institute, Dehradun and its centres and Forest Research Institute and Colleges, Dehradun have done some appreciable studies on the hydrology of small forested watersheds. The organisations like DVC,CWPRS,Pune, CWC,New Delhi, Central unit of Soil and Water Conservation, Ministry of Agriculture, New Delhi etc. have been also doing works on some aspects of forest hydrology. The research studies conducted so far are mostly limited to small experimental watersheds ($<$ 100 ha) where mostly the effect of land use changes, different vegetative covers and other watershed treatment measures on hydrological behaviour of watersheds have been studied by operating groups of two or more watersheds. The work done so far in India is rather meagre. The studies are required to be carried out on large representative basins. Attempts have been made to review the effect of forests and

forest management practices on hydrological parameters. The report attempts at emphasising the future research needs and ends with an exhaustive bibliography.

1.0 INTRODUCTION

Watershed is a natural physiographic or hydrologic unit where land, water and vegetation interact in a perceptible manner. Watershed has a number of distinct characteristics which affect its hydrological behaviour. Type of land use, its extent and management are important characteristics in determining the functioning of a watershed. Watersheds may have pure (single) or mixed land use e.g.agriculture,forests, grasslands, waste lands or mixture of these. The hydrological functioning of a vegetated (forested) watersheds in turn is influenced by the type of vegetation, its extent and management. Forests may occupy smaller or greater fraction of watersheds. The upland watersheds have relatively more area under forests which have influence on the hydrological behaviour of watersheds.

The forests are largely confined to upper catchments of various water resources projects and catchments of flood prone areas. Forests occupy 22.7% land area of the country as against 33% envisaged by the National Forest Policy (1952). The forests are classified into 16 major forest types spread over 74 m ha of country's land area mostly restricted to mountainous, undulating and rugged terrain. The distribution of area under different land uses in the catchments of 31 River Valley Projects(RVP's) spread over an area of 78.6 m ha indicates that on an average agricultural lands account for 62%, forest for 20% and other lands (grass land,waste land etc.) for 18% of the total area (Das et al., 1981).It indicates that nearly 22% of the country's forests area is under the upper catchments of these RVP's which are the prestigious multipurpose water resources projects of the country. There are number of subcatchments predominantly covered with forests. The poorly managed and degraded forests with tremendous biotic interference in the upper catchments are counter productive for proper hydrological functioning.

Integrated management of forests vegetation on upper watersheds may be one way to alter the water budget of a catchment which has substantial area under forest. The scientific management of vegetation on upper catchments is often of special interest to hydrologists and water resources planners to, a) increase the yield of usable water for down stream consumers i.e. municipal water supply catchments in the hill districts, b) reduce runoff volumes and peak discharges, c) improve soil moisture storage for sustained baseflow, and d) check soil erosion and sedimentation and maintain water quality of the streams. The type of tree species, forest management practices/systems and biotic interference have influence on the watershed hydrology. But their quantitative effect on large scale is perhaps not fully known. The questions are being invariably raised at the scientific and administrative forums about the effect of forests and forest management practices on runoff, soil erosion, floods, rainfall, water quality etc. Most of studies carried out in the world have tried to extrapolate the results obtained from small experimental watersheds. It is also known that transformation of results from small to large basins has many problems and limitations. Only few studies in USSR,USA etc. have been done on relatively large watersheds. In India limited studies have been carried out on small watersheds at couple of places. Though the studies made on small forest watersheds are appreciable but their results perhaps cannot be generalised on large scale to provide appropriate answers for various questions.

In view of this, the efforts have been made in this report to review the various research findings and present the state of knowledge on the subject in India so as to study the extent of forest influences on hydrology of a watershed and to identify the research gaps and to spell out future research needs to narrow down the existing gap.

2.0 HYDROLOGY AND FORESTS - AN OVERVIEW

2.1 Definition and Concept

Hydrology is concerned with the processes governing depletion and replenishment of the water resources of land areas of the earth. Forest influences are defined as all effects resulting from the presence of forest upon the climate, soil-water, runoff, streamflow, floods, erosion and soil productivity. Kittredge (1948, cited from Lee, 1980) suggested that the important phases of forest influences concerned with water, such as precipitation, soil-water, streamflow, floods etc. may be grouped under ' Forest Hydrology'. Forest Hydrology can thus be defined as the Science of water related phenomena that are influenced by forest cover. Forest watershed management (as applied forest hydrology) is also used extensively to denote operational activities based on a knowledge of forest hydrology.

2.2 Components of Forest Related to Hydrology

2.2.1 Forest characteristics

The important components of a forest from hydrological point of view are canopy, leaf litter and humus with dense roots. The canopy of a forest can be divided into top storey, underwood and undergrowth. Top storey or canopy consists of dominant trees which form the upper most canopy and includes predominant trees. Underwood refers to trees growing under top storey consisting of second and third tier of trees. Undergrowth is the fourth tier/storey of forest canopy and consists of tall bushes and trees and ground cover. Evergreen forests, semi-evergreen and moist deciduous forests have four tiers while dry deciduous forests have three tiers, thorn forest and natural grass land have one or two tiers whereas agricultural crops have one tier only. Therefore, forests with more tiers of canopy have greater influence on soil erosion and hydrology of a catchment.

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 subtropical 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, underwood, and undergrowth), density, leaf litter and humus with dense roots.

Water that is intercepted by tree crowns is important hydrologically because it causes non-uniform wetting of the forest soil, inhibits transpiration and reduces the draft on soil moisture, evaporates more rapidly than transpiration can occur in the same microclimate and adds significantly to vaporisation loss. Hydrologists need estimates of these losses because interception loss may effect total water yield from forested catchments.

<u>Canopy interception</u> is that part of precipitation which does not reach the forest floor and quantitatively it is the difference between precipitation and the sum of throughfall and stemflow.

<u>Throughfall</u> is that portion of precipitation which reaches the forest floor directly or by dripping from leaves, twigs and branches. It is the difference between precipitation and the sum of canopy interception and stemflow. The duration of throughfall is greater than that of rain or snowfall and its intensity smaller.

<u>Stemflow</u> is a minor element in the water budget of a forest and is usually less than 10% of rainfall and is often omitted in interception studies. But in any complete interception study, stemflow must be measured.

<u>Litter interception</u> is a function of the amount of litter on the forest floor, its moisture holding capacity and climate. A fraction of rainfall during the storms is retained by the litter layer (leaf litter) , where it is not available to plants

but is subject to evaporation. Its quantitative role in forest water budget is small.

2.2.2 Forest operations/manangement

In addition to forest types and their characteristics, forest operations/management practices play an important role in modifying the hydrology of a forested catchment. These include the silvicultural system (i.e. the systems of forest regeneration), other forest operations varying from simple cultural operations to thinning of different grades to clear-felling, burning, grazing and other biotic interferences which influence hydrological attributes of a catchment to a certain extent depending upon the severity of these operations.

Silvicultural systems - The system of forest regeneration,known as silvicultural systems by which forest crops are tended, harvested and replaced by new crops of distinctive form, has been briefly discussed with reference to its role in modifying the land phase of hydrologic cycle.

The clearfelling and coppice systems affect the hydrologic cycle more adversely than the other systems. The clear-felling system involving wholesale elimination of the existing cover and replacement by new cover (naturally or planted) is a drastic one associated with many of environmental ill effects. It affects the water quality and yield of a catchment as there is considerable time lag between the disappearance of the old cover and appearance of an effective new cover. The coppice system involving coppicing (cutting) of existing crops such that the coppiced shoots produce new shoots which grow into the next crop is less drastic than clearfelling system from hydrologic point of view, because restoration of cover is relatively quick in this system and it does not involve soil disturbance. The shelterwood system, where crop is replaced gradually in three successive stages called seeding, secondary and final fellings and the regeneration takes place naturally, is slow and less drastic than the clearfelling and coppice systems in terms of hydrologic effects. It helps in conservation of the environment quality. The selection system causes least disturbance , is close to nature and brings about very little hydrological changes in the catchment as only some mature trees above a particular diameter limit not creating permanent gaps are felled. This sytem is generally suitable for areas where conservation of water supply, minimisation of silt load, moderation of peak discharge etc. are of prime importance. The improvement system in which dead, dying and diseased trees are disposed off does not bring any drastic change to hydrological attributes of a catchment. The systems of protection and non-exploitation and protection and planting are for full protection to an area . These are close to nature and no hydrological attributes are disturbed.

2.3 Interaction between Forest Cover and Hydrology

The influence of forest characteristics, forest operations and management practices on hydrological cycle can be visualised in the following stages:

The first stage includes interception by foliage and subsequent evaporation from the canopy and litter on the forest floor.

The second stage includes infiltration into the soil and subsequent percolation, soil moisture storage, ground water recharge and sub-surface or base flow.

The third stage includes surface runoff (i.e. the portion which can not infiltrate flows over the surface). The interactions between various components of the hydrologic cycle and forest characteristics and management practices have been diagrammatically represented and discussed by Qureshi et al. (1964), Anderson and Hoover (1976), Gupta (1978) and Mathur and Naithani (1982).

3.0 STATUS OF RESEARCH IN INDIA

The studies concerning forest hydrology have not been done on large scale in India. The limited number of studies which have been done by the Central Soil and Water Conservation Research and Training Institute and some other organisations have been mostly on small watersheds varying in size from 0.21 ha to 84 ha with exception of very few studies which have been recently initiated on large watersheds (370 to 1754 ha). The hydrological studies have been also carried out on small runoff plots varying in size from 0.02 to 0.09 ha. The type of studies being done at various places are (i) to evaluate the effect of various land uses and vegetative covers on various elements of hydrologic cycle e.g. interception, infiltration,soil moisture,runoff and soil loss, (ii) to study hydrological behaviour of natural and man made forests, (iii) to study hydrological behaviour of forest watersheds under permanent vegetation and grass cover, (iv) to study influence of various forest management practices and biotic interference on hydrologic cycle,(v) to establish rainfall-runoff and sediment yield relationships and develop runoff prediction models for small watersheds,(vi) to assess the impact of soil conservation measures on runoff and soil loss, (vii) to identify suitable tree species and management practices from conservation point of view, and (viii) to study hydrological behaviour of ravinous watersheds.

The effect of forests on important hydrological parameters viz., rainfall, interception, infiltration, soil moisture, evapotranspiration, ground water, water yield, sediment yield, water quality and floods have been discussed.

3.1 Rainfall

In India, the systematic and scientific studies have not been done in a planned way to study the effect of afforestation or deforestation on rainfall. The experience in India on the basis of few observations tends to suggest that forests do not have appreciable effect on rainfall over a wide area whereas they may have limited effect on local rainfall due to high rate of evapotranspiration taking place from vegetation cover. The results of an enquiry initiated by Government of India in 1906 (Lal and Subbarao ,1981) also concluded that the influence of forests on rainfall was probably small. However, Dr.Voelekar published interesting data pertaining to the areas of Nilgiri hills which was later updated suggesting that the number of rainy days increased with the increase of forest, excluding the months of June,July and August as the rains during these months are not of local origin (Ranganathan,1949 cited from Lal and Subbarao,1981). Martin (1944) in a study on the influence of forests on rainfall observed that forest increases rainfall as a whole over large area owing to increased humidity and forests make rain more frequent and gentle. While studying the effects of deforestation on the intensity and frequency of rainfall and floods in Pathri,Ranipur and Ratmau torrents, Bhattacharya(1956) found that the planned deforestation in either of the catchments was not having any significant effect on rainfall which did not exhibit marked change in either its intensity or distribution. It may thus be concluded that the results of limited studies indicate that large scale afforestation may locally affect the incidence and distribution of rainfall and even increase it, but these effects on a regional scale may not be significant. In case of coastal forests, the precipitation is more because of interception and then condensation of fog by forest vegetation. Studies on large upland watersheds are required to be taken upto get a better understanding on the effects of forests on rainfall.

3.2 Interception

Studies carried out by FRI,Dehradun on the interception losses of Chri,Teak,Sal and Khair indicate the canopy interception as 22.1, 20.8, 38.2 and 28.5 percent of rainfall respectively (Quereshi and Subbarao ,1967,Dabral and Subbarao 1968,1969, Ghosh et al. 1980).

The CSWCRTI has carried out interception studies at Chandigarh, Dehradun and Ootacamund and the results are presented in table 1. The regression equations have been also developed between precipitation and interception at Chandigarh and Ootacamund (Tejwani et al,1975 and Annon.,1982) on couple of important tree species.

The results obtained in the various interception studies carried out in India indicate that the canopy interception varies from nearly 12% for Eucalyptus hybrid to 35% under Shola forest in Nilgiris. There are evidences that interception varies not

TABLE 1 - Interception by Forest Cover

Species	Stand density (trees/ha/ or age)	% of rainfall			Remarks
		Throughfall	stemflow	Interception	
Babul (Acacia nilotica)	7 years	-	-	26.00	(Tejwani et al.,1975)
Khair (Acacia catechu)	574	67.30	4.20	28.50	(Dabral et al.,1963)
Teak (Tectona grandis)	1742	73.20	6.00	20.80	(Dabral & Subbarao,1969)
Chir (Pinus roxburghii)	1156	74.30	3.60	22.10	(-do-)
Sal (Shorea robusta)	1678	66.40	8.30	25.30	(Dabral et al.,1963)
Black Wattle (Acacia mearsnii)	31.5*(15 yrs.)	70.50	4.30	25.10	(Samraj et al, Anon.1982)++
Bluegum (Eucalyptus) globulus)	12.1*(15 yrs)	76.70	1.50	21.90	(-do-)
Natural Shola Forest (Age indeterminable)	30.6*	65.00	1.30	33.80	(Singh & Prajapati,1974)+
Sisham (Dalbergia sissoo)	10-14 years	-	-	6.50	(1971)+

* 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.

++ 25 years of research on Soil and Water Conservation in Southern Hilly High Rainfall Regions

CSWCRTI, Research Centre, Udhagamandalam (ICAR), 1982.

only with the type of species, canopy density etc. but also with intensity of rainfall as given in table 2. Based on the figures available from experimental studies the interception losses could be assumed to be around 20% for dense canopies for all the preliminary purposes. There are no details available for interception by ground vegetation which could be conservatively assumed around 10%. There have been very few studies on interception by leaf litter. Dabral et al.(1963) found the litter interception in the order of 5 to 8% of rainfall. In summary it could be safely said that the average total interception by forest cover(including top/middle storey, undergrowth and litter interceptions) appears to be around 35% of rainfall.

It seems that quite a few important tree species including spruce and fir are yet to be studied for interception losses and studies under different densities and age groups could also be undertaken. Studies abroad have shown that the conifers(spruce and fir) generally intercept more rainfall than the hardwoods. The studies in other countries have demonstrated that grasses and herbs cause substantial interception. No such study appears to have been conducted in India, so efforts could be made in this direction also.

3.3 Infiltration

Infiltration, an important element of hydrologic cycle is amenable to vegetation manipulation by virtue of its effect on soil structure. The forest cover provides a layer of decaying organic matter associated with deep roots which helps

Table - 2 Rainfall Disposition at Dehradun Under Shorea Robusta (Sal).

Rainfall expressed as percentage of rainfall in open

Rainfall in open (mm)	Through-fall	Stem flow	Total rain fall under forest	Intercep- tion loss percentage
4.2	61.6	1.1	62.7	37.3
18.9	71.6	3.9	75.5	24.5
21.7	79.4	3.7	83.1	16.9
39.6	85.9	5.5	91.4	8.6
57.1	90.0	4.1	94.1	5.9
63.4	92.9	3.4	96.3	4.1
140.3	92.1	3.8	95.9	4.1

Source : Tejwani et al. (1975)

in making the soil structure more conducive to infiltration. Tejwani et al.(1975) reported average infiltration rates under different types of site conditions which are given in table 3.

The results of infiltration studies conducted at Bellary and Ootacamund under different vegetative covers as given in table 4 (Tejwani et al.,1975) indicate maximum infiltration rates for woodlands in Bellary (17 cn/hr) and Shola forest i.e. miscellaneous vegetation in Ootacamund (12.5 - 16.8 cm/hr). The analysis of data from small forest and agricultural watersheds of Doon Valley done by Dhruvanarayana and Sastry (Anon.,1983) indicate that the rate of infiltration is twice in forest watershed (Shorea robusta) as compared to agricultural watershed as shown in Figure 1.

A comparative study of infiltration rates conducted by FRI at Dehradun in Eucalyptus,Sal,Chir,Teak,Bamboo and grassland gave 54.0,21.4,12.0,9.6,9.6 and 7.6 cm/hr. initial infiltration rates respectively. Chir plantation after fire gave significantly reduced infiltration rate i.e. 3.6cm/hr. The preliminary studies conducted by ERS at Simla under forest and agricultural lands both under snow and without snow also confirm that forest land has higher initial infiltration rate. Maximum infiltration rate was obtained under Shola forest (30.0 cm/hr) followed by Bluegum (23.6 cm/hr) and grass land (8.7 cm/hr) at Ootacamund by ERS in their preliminary studies (Personal Communication). In Bihar, Mistry and Chatterji (1965,cited from Gupta,1980) recorded infiltration rates under forest land, permanent grass and arable crop lands as 26,12 and 9 cm/hr respectively.

Table 3 - Hourly and Average Infiltration Rates for Different Sites under Forest Area in Himalayan Upland (Foot Hills Slopes)

Site No.	Site description	Elevation above MSL (metre)	Infiltration Rates (cm/hr) I hr.	2nd hr.	3rd hr.
13	BIDHAULI-Sal forest with good leaf litter	838	8.95	5.90	5.85
14	HORAWALA- Sal forest with very little leaf litter and compact surface	671	3.65	2.0	2.20
15	MADARI R.F.Sal forest with little leaf litter and compact surface	567	4.55	2.45	2.50
16	CHANDUR R.F.Sal forest with little leaf litter	533	4.85	2.53	2.88
17	DHULKOT R.F.Sal forest with good leaflitter Average	...	5.87	3.78	3.83

Source : Tejwani et al.(1975)

Table 4 - Infiltration Rate under Different Vegetative Covers

Vegetative cover or land use	Infiltration rate (cm/hr)	Remarks
Bellary		
Woodland	17.00	For one hour run
Grass land	2.60	"
Agricultural land	1.00	"
Ootacamund Study No.1		
Shola forest	16.84	For three hours run
Bluegum plantation	20.69	"
Grazed grassland	5.13	"
Ootacamund Study No.2		
Shola forest	12.50	"
Broom (*Cytisus scoparius*)	11.25	"
Grazed grassland	6.25	"

Source : Tejwani et al.(1975)

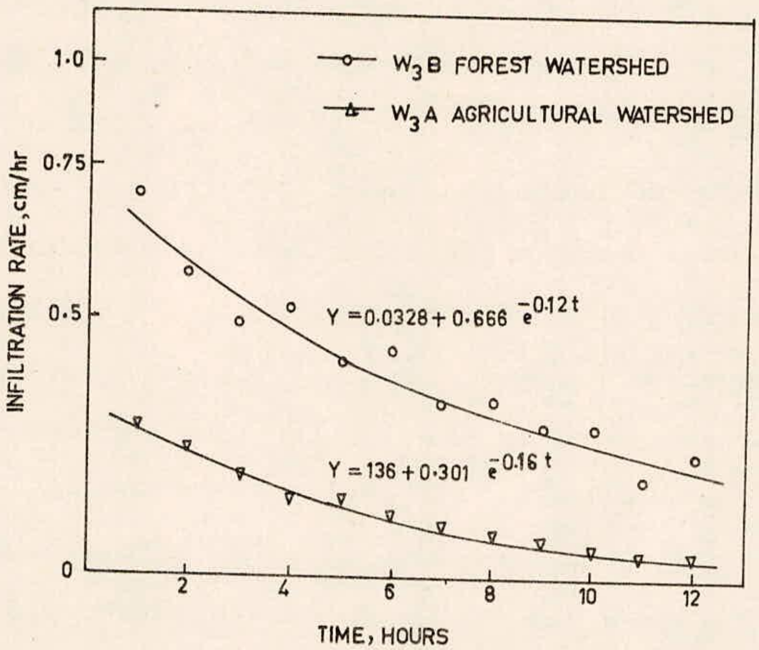

FIGURE 1-INFILTRATION CHARACTERISTICS OF FOREST AND AGRICULTURAL WATERSHEDS.

Source: Dhruvanarayana and Sastry(Anon.,1983)

The infiltration studies conducted in India at various places under different vegetation covers confirm that infiltration rates are higher under forests. The percentage increase would vary depending on soil type, species to species and biotic interferences. The leaf litter produced under the forest cover is mainly responsible for increased infiltration rates, as evidenced in table 3 where the same type of tree cover with very little leaf litter recorded much less infiltration rates. It appears very little work has been done in this field and there is a need to carry out field infiltration studies under different forest types, sub-types, and associations. The efforts must be channeled to evaluate the effect of species changes, burning, logging, extensive soil working, grazing etc. on the infiltration so that the possibilities of manipulating infiltration rates can be explored for improving hydrological regimes of watersheds. Appropriate values of infiltration for different forest covers could, therefore, be used for estimating water yield from forest watersheds.

3.4 Soil Moisture

The ability of soil to store moisture works as a reservoir during heavy rainfall and influences the peak discharges and floods. The slow releasing mechanism from the soil moisture storage increases the lean season flow in streams which could be of great help during drought situations. The sporadic soil moisture monitoring (measurements) under forest cover has been done by CSWCRTI and its centres, FRI Dehradun and CWPRS at Khandala.

It has been recorded (Ghosh and Subbarao,1979 cited from Gupta,1980) that soil moisture remains at a higher level under forest than grass e.g. bamboo (14-102), teak(30-73) Chir pine (20-77), Sal (20-108) and grass (9-95). In a study at Dehradun, the forest watershed gave relatively higher soil moisture values in top 45 cm soil depth as compared to agricultural watershed as analysed by Dhruvanarayana and Sastry, (Anon.,1983). The burning of leaf litter and its removal for manure as is being practised in hills results in low soil moisture conditions. Whereas a better moisture regime has been found when leaf litter is burnt but not removed from forest floor.

In India much efforts have not been made to quantify soil moisture storage of forested lands, water holding capacity of forest soils etc. Under a forest cover soil moisture content is not uniform due to uneven wetting resulting from stemflow and interception. Desk studies (calculations) indicate that the forest area of India has a soil moisture storage capacity (water holding capacity) of about 447.6 m ha-m on a temporary basis and 223.8 m ha-m on a prolonged basis (Mathur,1982). Thus, there is an urgent need to determine soil moisture storage of forested catchments and to evolve ways and means to improve over the present status. The regular soil moisture monitoring of forested catchments is becoming increasingly essential in forest hydrology.

3.5 Evapotranspiration

Very little has been done to work out evaporation and transpiration losses from forested watersheds in India. It has been observed that the albedo of forest areas are difrerent as compared to other areas which has its effect on evaporation losses from forested watersheds. Dabral et al. (1965) gave the following rough estimates of annual evapotranspiration losses as observed at Dehradun (upto soil depth of 1.22 m) on the basis of one year's observation.

Chir (Pinus roxburgii) (25 years) = 840 mm

Teak (Tectona grandis) (35 years) = 840 mm

Sal (Shorea robusta) (37 years) = 560 mm

The evapotranspiration losses of Eucalyptus citridora, Populus casale, Dalbergia latifolia and pinus roxburgii in juvenile stage were reported to be 5526,2704, 1143 and 536 mm respectively from September to June at FRI using lysimeters by Dabral (1970). Banerji (1972) reported evapotranspiration loss to be 1136 cm for Eucalyptus plantation in West Bengal during the period from October,1970 to October,1971.

Transpiration is more important during the growing season than the evaporation. It depends on the type and species of the plant, characteristics of soil, water table and treatments of vegetation e.g. frequent cuttings etc. In an experiment at Ootacamund carried out to work out transpiration of Bluegum (E.globulus) in Nilgiris by calcium carbide method, the annual transpiration rate was estimated to be about 34.7 cm at an average annual rainfall of 130 cm. Some work has also been carried out at Calcutta University on leaf area, number of Stomata and Stomatal area as reported by Mathur (1980). Rajagopalan et al. (1985) reported annual consumptive use crop coefficient for forested catchments in Khandala to be 0.542 which is on the lower side of crop coefficient of deciduous orchard. Since the study has been conducted for a short time on micro catchment, it would be desirable that such studies may be carried out in different vegetation types to arrive at appropriate crop coefficient values under different forest mixtures.

It would be desirable to carry out evapotranspiration studies of different tree crops and forest types all over the country so that correct estimates of water use by forests can be assessed. Studies are required to be done to observe the effects of changing forest structure and composition (including clearing or thinning overstories) on evapotranspiration losses. The efforts are required to initiate research on the use of anti-transpirants so as to reduce evapotranspiration loss and increase streamflow. This could be of great use for improving municipal water supplies by properly manipulating the vegetation in municipal watersheds. The application of Bowen ratio energy balance method may be explored for estimating forest ET as being done in other countries as reported by Black and McNaughton (1971), Mc Naughton et al. (1973), Gay and Fritschen (1979), Spittlehouse and Black (1979) and many others.

3.6 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 the rooting system and on growing season length. It is generally believed and has also been experienced in some countries that in areas where the groundwater table is near the surface, forest cutting will cause it to rise. conversely reforestation can eliminate water logged or semiswamp conditions. But in India, no efforts have been made to study the influence of forests on groundwater. Recently,the ERS has taken up a project to evaluate the role of land use and different forest covers on groundwater table through regular groundwater monitoring at Siliguri under cryptomeria and under Bluegum,Shola and grassland at Ootacamund centres. The increase in water table due to afforestation and other soil conservation measures in a watershed of 314 ha has been evidenced in G.R. Halli,Chittardurga (Anon.,1983) and elsewhere. In most of the watershed hydrology research studies, the groundwater component is normally not being mentioned which is considered to be an important component for studying the complete hydrology of a watershed. There has been a recent trend to plant fast growing tree species but as on today there has been no systematic study on the impact of the fast growing trees like Eucalyptus etc. on ground water recharge. The impact of vegetation in lowering water table and thus reclaiming water logged areas is also to be studied.

3.7 Water Yield and Soil Loss

Experimental studies have been conducted at various places in India to assess the effects of forests and forest management practices on water yield, peak flows and soil loss. Studies under different vegetative covers like Kudzu (*Pueraria hirusta*), *Dichanthium annulatum*, *chrysopagon fulvus*, and *Eulaliopsis binata* (Bhabhar grass), on 11% slope gave minimum runoff and soil loss under kudzu whereas bhabhar grass produced maximum runoff during the observation period from 1961 to 1966 (Tejwani et al., 1975). Mathur et al. (1976) reported that reforestation of a small watershed (1.45 ha) by *Eucalyptus grandis* and *Eucalyptus camaldulensis* (replacing the brushwood) reduced volume and peak rate of runoff by 28 and 73 percent respectively from 1969-73. The soil loss before and after treatment is given in table 5 which indicates increased soil loss in the first year after clear felling but decrease in the subsequent years due to growth of low dense vegetative cover.

Table 5 - Soil Loss (kg /ha)

Year	Before W_1F	Treatment* W_2F	Year	After W_1F (Treated)	Treatment** W_2F (Control)
1964-65	270	279	1969-70	536	290
1965-66	472	752	1970-71	151	707
			1971-72	339	1902

*Before treatment : Forest with brush wood

**After treatment : Clearfelling and reforestation with Eucalyptus species

Source : Tejwani et al. (1975), cited from Prakash Bahadur et al. (1980).

The runoff and soil loss data collected from 3 Doon Valley Watersheds (4.4 to 83.4 ha under agril, forest and combination of both) from 1960-1983 indicate minimum runoff (0.8% of monsoon rainfall during 1983) from agricultural watershed (54.6 ha) where bunding has been done. Relatively high seasonal runoff (15.1% of rainfall) was recorded in forest watershed (5.3 ha) perhaps due to the fact that no mechanical soil conservation measures were implemented (Anon. 1983). However, peak rate of runoff was also maximum from forest watershed which could be due to relatively high drainage density, relief ratio and low time of concentration. A relatively large watershed (1754 ha) with 87% of forest area in the lower Himalayas at Bemunda (Tehri-Garhwal) is also being gauged with the R.C.C.trapezoidal flume since 1980 to study the hydrological behaviour of forest watershed and develop rainfall- runoff relationship (Puri et al.,1982). The first two years of data indicated that the total runoff (including base flow) was observed to be 69% and 79% of the total precipitation during the main rainy months of July and August in the years 1980 and 1981 respectively. The data for water year 1981-82 indicates 54% of the total precipitation going as total runoff from the catchment. The hydrological monitoring is also going on since 1975-76 at two sites in the Bhaitan watershed (370 ha) to study the hydrological behaviour of watersheds before and after the watershed treatments at Fakot (Tehri-Garhwal).

Data on the peak discharge computed for selected storms of some agricultural and forested watersheds(Sal forest) at Dehradun has shown 10% less peak discharges and 38.5% less soil loss in forest watersheds than agricultural watersheds (Ghosh and Subbarao,1979). The results of a study carried out by FRI in two experimental watersheds(6.5 ha each under Coppiced sal deciduous moist forest) at Rajpur gave runoff as 42% of rainfall and soil loss of about 91 t/km^2 as observed by Subbarao et al. (1973). A treatment of 20% thinning was imposed subsequently in one of the watersheds which showed that the peak rate of flow increased by 8.6% in the first year which later on subsided in subsequent years (Subbarao et al., 1984). At Chandigarh results of microwatersheds(0.7-4.15 ha) studies indicated that (i) burning,(ii) cutting of trees, and (iii) overgrazing increased peak discharge by 73% (Anon. 1975). The contour trenching and afforestation reduced the peak by 73% (Anon.1975). The afforestation with Acacia catechu(Khair) on slopes and Sisham in low lying areas in a highly denuded siwalik watershed (20 ha with 9% slope)supported by check dams, staggered contour trenches and debris basin reduced the sediment yield from 80 t/ha/ year to 7 t/ha/year within the first four years of treatment (Misra et al.,1976).

The studies have been also conducted at few places to evaluate the effect of management of grass lands on runoff and soil loss. The experimental studies have been carried out at Deochanda (DVC) to study the effect of grazing on runoff and soil loss. The 5 years of data (1955-60) indicated runoff as 27,19 and 11% of rainfall and soil loss as 2.37,0.79 and 0.40 t/ha from overgrazed, properly grazed and ungrazed areas respectively (cited from Singh,1985). This clearly indicates the gross effects of overgrazing on hydrologic behaviour of a watershed.

Studies at Ootacamund on peak discharges from different land uses indicate that the plantation of Eucalyptus and Wattle reduced the peak discharge by nearly 62% as compared to agricultural land (Lal and Subbarao,1981). Studies on the amount of runoff and soil loss under different vegetative covers e.g. Shola (i.e. natural forest), bluegum, wattle, broom and grasses carried out on 0.02 ha plots on 16% slope indicate highest water loss (runoff) amounting to 1.27% of total precipitation from wattle and shola covers whereas in bluegum runoff is recorded to be 1.08% of total precipitation. It reveals that there was not much difference in runoff between different vegetative covers. The soil loss was also negligible (Annon.,1982). The runoff and soil loss data obtained from 0.09 ha plots with different treatments in natural Shola forest at Ootacamund (i.e. Sholas in treatment A,B and C were clearfelled in 1965 and planted with bluegum, black wattle and mixture of these two in 1968) are given in table 6 (Anon.,1982). The results do not show any appreciable change in runoff and soil loss pattern even after the application of treatments.

The hydrological studies conducted on two identical watersheds (32 ha each) at Glenmorgan (Ootacamund) to study the behaviour of watersheds with natural as well as introduced plantation

Table 6 - Effect of Plantation on Runoff and Soil Loss

Year	Mean Annual rain-fall (mm)	Runoff as % of total rainfall				Soil loss kg/ha	Remarks
		A mixed plantation	B *Acacia mearnsii*	C *Eucalyptus globulus*	D Shola		
Calibration of 9 years before felling (1957 to 1965)	1361	0.01	0.01	0.03	0.05	Nil	Mean for 9 years
Calibration period of 3 years after felling (1965 to 1967)	1191	1.02	1.05	1.05	1.02	Nil	Mean for 3 years
Man-made forests in the first rotation (1968 to 1977)	1138	1.05	1.03	1.03	1.04	Nil	Mean for 10 years

Source: 25 years of Research in Soil and Water Conservation, CSWCRTI, Res. Centre, Ootacamund (1982) of bluegum indicate that the observed discharge from natural vegetation (grassland,Sholas and Swamps) and grassland with bluegum were 31.4 and 29.9 percent of total precipitation respectively (from 1972-76) and the soil loss was zero,Anon. (1982). It may be worth noting here that the similar plantation produced nearly 1% rainfall as runoff in runoff plots whereas in watershed studies the same has produced nearly 30% of rainfall as runoff. This is indicative of the limitations of small plot studies. The preliminary analysis of the runoff data of Glenmorgon watersheds indicates that at the end of 10 years rotation the watershed planted with bluegum (Eucalyptus globulus) produced 16% less annual water yield as compared to natural watershed (Research Highlights CSWCRTI,1983).

The studies on 17 large natural watersheds(7.5 - 335 sq.km. area) in the Nilgiris carried by Raghunath et al(1970) for studying variation with water yield have shown that due to extensive introduction of bluegum and black wattle and large scale cultivation of benches, watershed retention was enhanced by about 28 cm per annum. The annual water yield varied from 14 to 68% of the corresponding rainfall and in natural grassland watersheds there was almost no sediment loss.

In the ravinous areas of Yamuna, Chambal and Mahi rivers also the decreasing trend of runoff and soil loss has been noticed under forest and grasslands. Sharda et al. (1982) conducted hydrological studies on two ravinous watersheds (0.20 and 0.29 ha) at Agra and observed reduction in runoff as percentage of rainfall from 32.02 (1966) to 23.45 (1970) and 17.65 to 6.88 under grass cover alone (Cenchrus cilliaris) and Shisham (Dalbergia sissoo) with grass cover respectively. The comparison of the two indicate that grass cover alone is not as effective in checking runoff as sissoo plantation with natural grasses. The two ravinous watersheds(10 and 4.8 ha) under mixed land use (forest + agril) being gauged at Vasad from 1961 also indicate that runoff volume and peak rate both decrease progressively as the vegetation in the watershed increases due to the closure against biotic interference. The average value of runoff coefficient is estimated as 0.20 (using data from 1961-1981) which seems to be in close agreement with the value of USDA (0.18) given for such land use (Anon,1981). The experimental studies conducted at Kota (1979-82) on small watersheds (0.4 - 1.45 ha) showed that runoff and soil loss were maximum from agricultural watersheds (15.1% and 3.83 t/ha) followed by trees(A.nilotica) + grasses (D.annulatum), (6.8% and 1.15 t/ha) and grasses alone (1.9% and 0.43 t/ha) as reported in Annual Report(1982) of CSWCRTI,Dehradun.

The hydrological studies have been carried out by Pathak et al. (1984) on six forested sites in microwatersheds of 25 m^2 in Kumaun Himalaya. Overland flow was found to be negatively related with tree canopy and ground vegetation cover. The overland flow was maximum (1.24% of rainfall) for Pine-mixed-broad leaved forest and minimum (0.38% of rainfall) for mixed oak, Tilonj-dominated forest with average value of 0.68% of incident rainfall. The sediment yield was maximum (57.2 kg/ha) for sal forest and minimum (15.3 kg/ha) for mixed-oak-pine forest with average value of 32.5 kg/ha for all the six different forest sites. These results are obtained from very small plots, however, their application on watershed basis may be doubtful.

The data of an experimental(80 ha, predominantly covered with forest) at Khandala for years 1979-81 has been analysed by Saxena et al.(undated) to establish the relationship between discharge and sediment yield. A sediment rating curve relating suspended sediment discharge and water discharge has also been established for the purpose of estimating suspended sediment load for periods during which data are not collected. But the established relationship is based on few observations therefore it has a limited application.

Studies on experimental runoff plots at Nurpur(H.P.) also showed increased runoff and soil loss from regularly grazed areas as compared to the areas under shrub and grass cover (Sinha,1975; cited from Lal and Subbarao ,1981). The phenomenal extension of torrents (chos) in the Punjab from 194 km^2(1852) to 2000 km^2(1939) was attributed to large scale deforestation on the hill slope (Kaith et al ,1948 cited from Das and Singh,1979).

In the River Valley Projects at number of sites hydrological monitoring is being done to evaluate the effect of soil conservation and watershed management in checking the sediment inflow to the reservoirs. The analysis of data by the Central Unit of Soil Conservation (Govt. of India) has revealed a decreasing trend of sediment production in respect of Bhakra, Maithon, Panchet,Machkund and Hirakud. The decrease in sediment production rate ranged from 13.11% to 31.95% (Das et al.,1984). Similar trends have been observed in respect of other watersheds also. In watershed management programmes, the afforestation and bunding measures have been considered as effective measures in areas where major contribution of sediment is in the form of sheet erosion. Hydrological monitoring of Sukhna lake catchment at Kansal, Ghareri and Nepli (from 1979 onwards) have also shown considerable reduction in sediment yield due to afforestation and other watershed measures. The hydrological data collected by the Kalagarh Project Authority before and after the commencement of soil conservation works in the catchment (307,644 ha) was recorded as 0.1795 ha-m/ sq. km. (1958-62) and 0.1444 ha m/sq.km. (1967-71) which means a reduction in silt load of 0.0351 ha m/sq.km. of the catchment (Pathak,1974). The reduction in silt load mostly appears to be due to afforestation as the cultivated area treated was comparatively very less till then. Recently,CWC,New Delhi also sponsored a project in collaboration with G.B.Pant University,Pant Nagar and I.I.T., Delhi to evaluate the effects of soil conservation measures on hydrology and sedimentation of the Ramganga river. The data adequacy reports were yet to be completed and reviewed before making any conclusions (Shah,1985 Personal Communication).

3.8 Water Quality

Water quality is as important and vital parameter of forest hydrology as the water quantity because nearly 80% of the human diseases are attributable to drinking of polluted water and most of the population living in rural areas gets water from natural streams. The silt content in streamflow is one of the important factors which is obviously intimately related to the vegetative cover conditions. Besides this, there are other quality parameters like common particulates, dissolved substances and gases which are significantly responsive to forest cover. Temperature directly affects the biological productivity of the stream and the temperature is very much influenced by forest due to changes in micro-climate. Dissolved solids are usually small from forested areas and primarily reflect the geology of the area. Nitrogen concentration may be an element to be watched in the flow from forested watersheds.

There are hardly few studies done in India to see the effects of forest cover on water quality. In Doon Valley, water quality studies have been taken up by ERS of FRI in relation to forest cover and the management. The parameters like colour, odour, temperature,electrical conductivity, sediment concentration, p^H, calcium,sodium,potassium,phosphate, iron,chloride, dissolved oxygen (Do) and biological oxygen demand (BOD) are being determined on monthly basis at eight sites located on 3 streams. Water quality of stream affected by mining is also being carried out. Study on some aspects of water quality has also been initiated by CSWCRTI,Dehradun at Saha stradhara mine area in a watershed of 64 ha. The preliminary data analysis indicate that Ca,Mg,Sulphate and suspended sediments are very high. Mine rehabiliation through afforestation and mechanical measures is underway. There is an urgent need to study the influence of different forest covers and forest management practices on water quality of streams like clearfelling, forest fire, logging etc. Experimental watershed studies are required to be carried out in this direction.

3.9 Floods

It can not be denied that forests considerably modify the water yield , peak runoff, sediment yield and regulate the stream flow. Admittedly flood occurs when there is excessive or intense rainfall over a short span of time associated with saturated watershed conditions (that the bulk of rainwater is not retained by the watershed). Under such conditions the presence of forest cover may not prevent large floods but retards erosion and debris flows to down stream reaches. The same view is expressed by the National Flood Commission (1980). It is found that the effect of forest in intercepting rainfall gets reduced during high intensity storms. It is also believed that with very heavy storms the soil gets saturated and forest cover may not have any significant control on floods.

Examination of soil moisture data under forest and other vegetative cover did not corrobate the soft quoted belief that soil gets often saturated even under vegetation and thus become ineffective in holding the runoff and flood waters (Das and Singh,1979). Similarly observations also indicate that intense storm seldom covers the entire catchment and thus saturate the same simultaneously. It has been observed that the increased load of silt carried by the rivers of the Indian sub-continent raises their beds inducing annual flood water to spread outward more rapidly. Chairman, High Level Committee on Flood (cited from Das and Singh, 1979) also indicated that the flood problem rise is not so much due to excessive discharge in rivers as due to excessive sediment load in them. Afforestation measures basically retard the speed of runoff,minimise soil loss and consequently the sediment load in the rivers. Such measures cannot entirely prevent floods but however medium and flash floods can be moderated and thus their frequency lowered. The effect of afforestation on large floods may be insignificant.

There seems to have been no study done to evaluate the extent of damage caused by deforestation on floods in a large scale in some representative basin on basis of which any significant conclusion could be made. In most of the studies carried on experimental watersheds, the results are extrapolated for large basins which may not be true. While studying the effects of deforestation on the intensity and frequency of floods in Pathri,Ranipur and Ratmau torrents, Bhattacharya(1956) found that the planned and limited deforestation did not have any untoward consequence for Pathri and Ranipur catchments. Some effect was found on the frequency (and not intensity) of floods in Ratmau,indicating that floods were recurring at somewhat more frequent intervals consequent upon deforestation.

In light of the above discussions, it could perhaps be mentioned that the forests may not have significant effect on large floods. The extent of damage caused by deforestation in causing flood depends upon the proportion of basin convered by forest which could be relatively small in large river basins. Therefore, the percentage of the basin area disturbed is a critical factor in estimating effects on flooding potential. Morever, hydrological studies carried out on small experimental watersheds are extrapolated to show the effects of forests on water and sediment yield for large basins which may not be always true. However, forests may moderate the medium floods and flash floods due to checking peak flows, soil loss and rising of stream beds which induce floods. In view of the role played by forests, a systematic inventory of the forest cover complex and the hydrologic grouping of the forest land should be attempted to help in planning any extensive and effective afforestation programme in upper catchments of floods prone areas.

3.10 Effect of watershed size on forest Hydrology

The systematic studies carried out in India to study the effect of forests on the hydrological behaviour of a catchment are largely confined to small (micro) watersheds. It has been observed and reported by the investigators abroad that the size of the catchment is one of the most important aspects for consideration while evaluating the effect of forest cover and the management practices on the hydrologic response of a catchment. In small watersheds the contribution to water yield (runoff) is mainly from overland flow which inturn is largely influenced by the land use cover, vegetation etc. In case of medium and large watersheds total runoff (i.e. stream flow) is, however, dependent upon sub-surface flow (base flow) also in' addition to overland flow and it is influenced by the channel system. In forested catchments effect of watershed size may be more important a factor to be considered because increased forest cover is associated with more and deeper roots which help in longer and deeper percolation as evidenced by the result of lower surface runoff (i.e. overland flow) and less water available for flow in smaller stream. The portion of water which is induced to go into deeper profile on the small watersheds (within the medium and large watersheds), comes out later into the channel system of medium and large watersheds), as sub-surface flow. This delayed release assures longer and larger dry weather flow. To sum up, it could be mentioned that in the small catchments forests decrease to a great extent the overland flow and the runoff while in medium and large catchments the total runoff (i.e annual water yield) may however be increased due to forests because of dry weather flow.

Numerous observations and studies have been made by the investigators in USSR & USA to confirm this conclusion. The effect of watershed size and limitations of small plot studies can also be explained considering the results of runoff plot and watershed studies conducted at Nilgiris. The runoff studies in small runoff plots (0.02 & 0.09 ha) under different forest covers indicated nearly 1% of rainfall as runoff whereas both Eucalyptus and grassland watersheds (32 ha each) at Glenmorgan yielded about 30% of annual rainfall as runoff.

Therefore, the results obtained from small watersheds may not be easily applicable for large watersheds. It can be extrapolated only with certain reservations. In India, the studies are yet to be carried out systematically on medium and large watersheds.

In may not be out of place to mention that the proportion of total catchment area under forest is also an important factor to be considered while studying the effect of forests on hydrology of a catchment. Increased water yields from clear cutting have been found to be proportional to the percent of the catchment area cleared. The least increases in the yield result from partial cutting of trees. Rothacher (1971) suggests that removing 20% or less of the forest cover would not produce a significant change in streamflow. Similar observations have been recorded by Subbarao et al (1985) where no significanct increase in water yield and peak flow was recorded after imposing 20% of forest thinning in coppice sal forest at Rajpur(Dehradun).

4.0 SUMMARY AND CONCLUSIONS

4.1 Summary

The studies in India on the hydrologic influence of forests have been on a modest scale and largely limited to small watersheds only. There are nearly 16 Hydrological Research Stations working in India at present on some aspects of forest hydrology as mentioned in Section 3.1 and Appendix 1.

The studies as regarded to effect of forest on rainfall are very limited. However, based on these limited studies it can be said that forests may have very limited influence on local rainfall (particularly on distribution) but these effects are not significant on a regional scale. In case of coastal belts the rainfall may increase in forested areas due to interception of fog. As per interception losses by forest cover, on an average the total interception (including top and middle storey, undergrowth and litter interception) as found in various studies may range between 30-40% of rainfall depending upon type of species, canopy and rainfall pattern. Rainfall interception by vegetation is reduced under heavy storms. The infiltration studies under different vegetative covers confirm the higher infiltration rates under forest soils due to improved structure of soils. Studies have also revealed that infiltration rate gets significantly reduced due to grazing and forest fire. The studies as regard to the effect of forest covers on soil moisture have not been on large scale and they show relatively higher soil moisture content under the forest soils than that of agricultural lands. Also, the forest soils have been found to have better moisture holding capacity due to its high humus content. Due to variability of vegetation, soil and climate and limited evapotranspiration studies in the forest areas, any range of ET losses of forests may not be given. The annual ET values of 560 mm for sal and 840 for chir and teak have been reported at Dehradun. The influence of forests on ground-water has also not been studied to the extent that any quantitative conclusion can be made.

Afforestation is found to reduce runoff volume and peak and soil loss from a watershed. The hydrological consequences of different forest management practices/systems and biotic interference have been studied in a limited extent. The peak rate of runoff is found to have been reduced by 60 to 73% by introduction of proper forest cover and other soil conservation measures in various small watershed studies. The burning, cutting of trees and overgrazing have been found to have increased peak rate of runoff considerably. There has been a study which indicated that sediment yield from forested catchment was 20% of the y eld that was found from the fields under cultivated terraced and unterraced lands (Das and Singh,1979).

The studies carried out in the couple of selected sub-catchments of certain River Valley Projects e.g. Chambal,DVC, Hirakud, Lower Bhawani, Matatila etc. have revealed perceptible decrease in the peak flow and sediment production after implementation of watershed treatment measures including afforestation. It may be also worth mentioning here that forests decrease the overland flow and the direct runoff to a great extent in small catchments while in medium and large catchments the total runoff (i.e. annual water yield) may however increase due to forests because of dry weather flow. However, the forest hydrology studies are hardly taken up in large catchments in India.

The occurrence and frequency of floods can not be linked with presence or absence of forest cover in absence of factual figures. Since the forest area is small as compared to total area of a basin or flood prone areas, so forests in such cases may not have significant effect on large floods at downstream reaches. However, the medium and flash floods may be moderated by the forests by reducing peak discharge, soil loss and sediments inflow to the streams and checking rising of stream beds.

4.2 Conclusion

4.2.1 Present state-of-knowledge

On the basis of foregoing review, the present state-of-art on the subject is summarised below:

1. The studies have been directed to study the effect of land use changes, different vegetation types etc. on hydrological regime and conservation measures that can effectively control water and sediment yield from watersheds.

2. Very little efforts if none have been made to study the effect of different forest management practices, silvicultural systems and biotic interferences like thinning, logging, forest fires, grazing etc. on the hydrology of a forested catchment.

3. The number of Forest Hydrological Research Stations are not enough keeping in view the variability and diversity of climatological, terrain, soils and vegetation characteristics in the country.

4. The research studies conducted so far are mostly limited to small experimental watersheds (< 100 ha) where normally a study of comparisons is made by operating groups of two or more watersheds.

5. The studies indicate that forests reduce the surface runoff both volumes and peak rates, sediment yield and regulate the stream flow by maintaining the flows during dry weather (i.e. lean flow period) due to slow release mechanism of soil moisture storage from forest soils.

6. It is difficult to generalise the effect of forests on rainfall and floods as hardly any scientific study has been done in this direction on large catchments. Few studies have pointed out that forests may locally affect (increase) the rainfall (intensity or distribution) whereas on regional scale the effects are doubtful. Similarly, the presence of forests may not have significant effect on large floods whereas medium and flash floods may be moderated due to reduced peak flows and sediment

yield which checks the rising river or stream beds due to siltation that induces floods however, this hypothesis is not yet fully verified.

7. Most of the studies have generally used the regression based approach which have been found to give a good indication of impact of land use changes on the hydrological regime. However, these models do not provide a good understanding of the processes involved in the system. The extrapolation of such results may have severe limitations.

4.2.2 Recommendations/future research needs

In the following sections recommendations for future research are given based on the present state of knowledge on the subject and the existing problems. It is proposed that NIH should identify some forested catchments to study the forest influences on hydrological and hydrometeorological parameters.

1. The systematic and scientific studies to assess the changes in water yield (including regenerated flow) and sediment yield of large watersheds and variations in water quality due to different land uses and vegetative covers viz., different tree species and forest types, grasses, shrubs etc. need to be given much more emphasis.
2. The hydrological investigations on the effects of different tree species and forest types on interception, infiltration, soil moisture, evapotranspiration and ground

water need more attention as very limited work has been done in this regard. Appropriate values of interception, infiltration and soil moisture for different forest covers, thus developed could be used for estimating water yield from forest watersheds.

3. Efforts may be made to study the effect of changes in the structure and composition of vegetation (including clearfelling or thinning of forest over stories) in the upland watersheds on evapotranspiration and runoff and to initiate research on the use of anti-transpirants. Such studies are particularly needed in municipal water supply catchments of the hill districts.
4. Effect of different cultural and management practices like thinning,logging, timber harvesting etc. and silvicultural systems on water yield, flood peaks, regulation of streamflows, sediment yield, water quality etc. need to be investigated in a scientific way on a large scale.
5. There is a need to study the hydrological consequences of biotic interferences and social problems like forest fires, grazing, illicit fellings, shifting cultivation, deforestation etc.
6. There is a need to gain a better understanding of the various parameters representing the hydrological processes within a catchment and to develop process based model using hydrological parameters, vegetation cover and basin characteristics to make the model generally applicable to different situations/ ungauged watersheds.

7. There is a strong need to initiate research efforts on representative basins to intensively study hydrological aspects of forested catchments as the studies have been limited to small experimental watersheds only. In this reference, it may be useful to mention on the remarks made by Toebes and Ouryvaq(1970) in a contribution of IHD that the nations with a currently spares network of hydrological stations should establish representative basins before experimental watersheds are attempted. Small runoff plots and experimental watersheds from large representative basins may be selected after a long term observation period to get both micro and macro level effects of forests and forest management practices and other land management practices on the hydrology of a catchment.

8. There is a need to enhance the number of experimental and representative basin studies to cover different vegetation type of the country and to establish a 'model forest hydrological research watershed' fully instrumented which can develop standard methodologies and serve as a model for understanding the system in a better way and also may be used for training purposes.

9. The pattern of rainfall and other meteorological parameters in the forested areas over India may be studied to examine the frequencies of relatively high intensity storms as the effect of forests may not be significant on interception,infiltration, runoff, peak discharges etc. during intense storms.

10. A systematic and scientific study may be taken up in a large upper catchment of flood prone areas to examine the effects of forests on rainfall and floods. A systematic inventory of the forest cover complex and the hydrologic grouping of the forest land may also be attempted in the upland watersheds of flood prone areas.

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APPENDIX - I

DETAILS OF EXPERIMENTAL FOREST WATERSHEDS IN INDIA

S.No.	Organisation	Region(s)	No. of catch-ments under study	Location	Area and land use (ha)	Type of Studies	Period of study	Remarks
1.	CSWCRTI, Dehradun	Northern Himalayan Forest and part of upper Gangetic alluvial plain region	7	Selakui (Dehradun)	0.87-83.37 ha. Agri., Forest, Forest + Agril., Brush Wood etc.	To evaluate effect of various land uses, vegetative covers & land treatment measures on the hydrological behaviour of small watersheds and to develop rainfall-runoff sediment relationship	Since 1960-61	Various treatments were imposed after pre-calibration of watersheds, Paired watershed techniques have been used.
	ORC Fakot (Tehri Garhwal)	Northern Himalayan region	2	Fakot (Bhaitan watershed)	240-270 ha mixed landuse (36% forest)	To study the effect of watershed management measures on watershed hydrology on relatively large watershed	Since 1975	
			1	Benunda (Tehri Garhwal)	1754 ha mainly under forest (i.e. 87%)	To study watershed hydrology of hilly forested watersheds	Since 1980	
2.	FRI, Dehradun	-do-	2	Rajpur (Dehradun)	6 ha each with Sal coppice forest	To study various aspects of forest hydrology	1965	Interception and runoff have been found under natural and thinned conditions

S.No.	Organisation	Region(s)	No. of catch-ments under study	Location	Area and land use (ha)	Type of Studies	Period of Study	Remarks
3.	CSWCRTI Chandigarh	Punjab, Haryana Alluvial Plains and Siwalik Hills	20	Mani Majra farm (low lying Shivaliks)	0.7-20 ha Natural hilly watersheds	To study forest influences and effectiveness of soil conservation measures on hydrological aspects and to develop rainfall runoff and sediment relationships for Siwalik hills	Since 1963	Some studies are concluded and some are going on
		-do-	1	Sukhomajari	85 ha Mixed landuse	Watershed management for sediment control	Since 1975	Part of watershed is being gauged for experimental studies
4.	Chandigarh Forest Department	-do-	3	Kansal, Ghareri & Nepli (Sukhna lake catchment)	1214 acres) 574 acres) 1485 acres) Mixed land use mostly forest (84.5%)	To monitor effect of watershed treatment measures on sediment yield	Since 1979	
5.	HRS(FRI),* Simla	Northern Himalayan Snow Clad region	9	Simla	small forest catchment	Forest watershed management for municipal water supply	Since 1980	* Mathur(1980)
6.	CSWCRTI, Agra	Upper Gangetic Alluvial Plain Region with problem of Yamuna ravines	2	Challesar Agra	0.206 ha(grass) 0.29 ha(sishan)	To study hydrological behaviour of ravinous watersheds with trees and grass covers	Since 1965	Some results have been already reported
			2	-do-	3.7-8.4 ha (Mixed land use)			

S.No.	Organisation	Region(c)	No. of catchments under study	Location	Area and Landuse (ha)	Type of Studies	Period of Study	Remarks
7.	CSWCRTI, Kota	N.E.Rajasthan region with Chambal ravines mixed yellow, red and black soil region	3	Kota	0.4-1.45 ha Agril, forest + grass and grass only	To study hydrology of small watersheds under different land uses	Since 1979	
8.	CSWCRTI, Vasad	Gujrat Alluvial Plain region, mixed soil region	2	Vasad	10 ha(60% forest + 40% Agril) 4.6 ha (56% Forest + 44% Agril)	To study effect of land uses on hydrological behaviour and determine runoff coefficients	Since 1961	
9.	CSWCRTI Ootacamund	Nilgiris hills (part of southern red soil region)	17 sub-watersheds	In Nilgiris at various locations in Moyar and Bhawani basins	7.51-334.64 Km. (mixed land use)	To study variations in water yield and develop regression models for ungauged watershed using physiographic characteristics	Since 1971	Study completed and relationships developed. These are not the experimental watersheds.
			Runoff Plots	Ootacamund	0.02 ha on 16% slope (shola Shrub and grass and trees)	To monitor effect of different vegetative covers on runoff & soil loss	Since 1958-63	
			-do-(4)	-do-	0.09 ha (Forest)	Small catchment studies on the effect of forest covers both in natural degraded shola forest and man made forests	Since 1958	
			2	Glenmergen (Ootacamund)	32 ha each natural forest and introduced plantation	To study hydrological behaviour of watershed with natural vegetation as well as introduced plantation	Since 1964	

S.No.	Organisation	Region(s)	No.of catch-ments under study	Location	Area and land use (ha)	Type of Studies	Period of study	Remarks
10.	ERS(FRI)* Ootacamund	Nilgiris Hills (part of southern red,soil region)	4	Ootacamund	small forest watersheds	To study aspects of forest hydrology including ground water	Since, 1981	* Mathur(1980)
11.	ERS(FRI)* Kurseong	Assam Valley region	2	i) Sonada ii) Relling	i) experimental watershed ii) Bench mark watershed both under forest	To carry out investigations on various aspects of forest hydrology and develop rainfall-runoff models	Since, 1981	* Mathur(1980)
12.	CWPRS, Pune	Western Ghats	1	Khandala Khopali forest range	80 ha(mainly forest & grassland)	To evaluate impact of soil conservation on runoff and soil loss and develop suitable rainfall runoff and sediment yield models	Since 1978-79	Only 20 ha is well instrumented and divided into microwatersheds
13.	DVC+ Hazaribagh	Eastern red soil region	47	Upper catchment of Damodar-Barkar	35-450 km^2 (mixed landuse)	Hydrological monitoring to study the effectiveness of watershed measures on runoff and sediment yield	1964-78	The No.47 indicates the number of gauging sites
14.	Ramganga Project Authorities	U.P.Himalaya region	7	Upper catchments of Ramganga	Mixed land use	-do-	Since 1966-69	Number 7 indicates number of gauging sites

+ part of River Valley Project Schemes.

Source : i) Annual Reports of CSWCRTI, Dehradun

ii) Anon. (1982)

iii) Das et al. (1984)