HYDROLOGICAL INFLUENCES OF FORESTS

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ROORKEE

GENERAL

Forest hydrology is clearly an interdisciplinary science the union of forestry and hydrology. It is rooted in the ancient concern for forests and water and has evolved through various stages to become a major area of scientific specialisation. As in any hydrologic science, the focus is on water but the operational sphere is forest land. Forests cover about 4 billion hectares (or one fourth) of the land area of earth and are restricted to various regions of relatively high precipitation where they yield an unproportionate share of high quality streamflow. Forest hydrology can be defined as the science of water related phenomena that are influenced by forest cover.

History of Development

The various Vedas written about 1500 B.C. include description of forests in various forms. A good deal of information about forests is available in Ramayan and Mahabharat. According to Vishnu Puran and other scriptures, nine important forest regions were recognised in India even though their exact boundaries were not worked out. Information about the forests during Maurya period is available from various sources including Kautilya's Arthashastra (321BC), Indika of Megasthenes (305 BC), Mudrarakshas of Visakhadatta, inscription of Ashoka (273 BC-236 BC) etc.

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 hydrolcgy. Published reports dealing with vegetative influences on climate and hydrologic phenomenon began to appear with greater frequency during the eighteenth and nineteenth centuries. According to

Kitteredge (1948), Noah Webster was convinced by 1799 that forest cleaning by the American Colonists had caused winds and winter weather to be more variable, 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 and opinion on forest influences. In 1877 Brown published a book on forests and moisture.

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'.

Russian researchers have also done a commendable work on the hydrological influence of forests. Vysotskii (1930) has come out with a book of the, Doctrine of the relevance of forest'. Some Russian work cited and summarised in 1968 by Shepak dealt mainly with forest influences on rainfall. A number of studies were done on several parameters of hydrology and on influence of forest on these parameters by Russian researchers.

By middle of the current century, population growth, industrialisation, land disturbances 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 association of forests and water in particular, led to the development of forest hydrology and management of forested watershed.

World Forest Resources

Much of the forested area in the world is yet to be surveyed but reliable estimates indicate that about 3×10^{10} ha area has about 20% or more tree crown cover, roughly one third of the world's land surface and about the same average percentage as that for United States alone. The total forest land in United States as reported in MG Graw-Hill Encyclopedia of environmental science is about 296 Mha.

Latin America and tropical regions of Africa and South-West Asia have most of the hardwood forests, while the softwood areas are concentrated in North America and the Soviet union. Latin America has about 43% of the world's hardwood growing stock and this is nearly half again as much as the hardwood area of Africa, Latin America and Africa account for 72% of the world's hardwood, with south-east asia adding another 15%. North America has only 5% of the total hardwood.

In the important softwood category, however the Soviet Union and North America rank first and second respectively and both together account for 83% of world's softwood. Soviet Union has about $2\frac{1}{2}$ times as much softwood as North America. The forest coverage of some countries as percentage to land area is as given in the following table :

S.No.	Country	% to land area
1.	World Average	30
2.	Australia	4
3.	U.K.	6
4.	Mexico	24
5.	India	23
6.	USA	31
7.	USSR	39
8.	Canada	45
9.	Burma	62
10.	Japan	70

India's Forest Wealth

According to the survey made by Forest Survey of India during the period 1985-87, the estimate of the forest cover in the country is as follows :

Category	Area in Km^2	% of the total Geographical area of the country
A. Forest		
1. Dense forest (crown density 40% and over)	3,78,470	11.51
2. Open forest (crown density 10% to less than 40%)	2,57,409	7.83
3. Mangrove forest	4,255	0.13
Total forest	6,40,134	19.47
B. Shrub area		
(Tree lands with less than 10% crown density)	66,121	2.01
C. Uninterpreted area		
(Under clouds, shadows etc.)	3,893	0.12
D. Non Forest		
(includes tea gardens)	25,77,649	78.40
Grand Total	32,87,797	100.00

Source : F.R.I., Dehradun

According to the assessment in 1985-87 the actual forest cover was 64.01 million ha against the previous assessment of

64.20 million ha. (1981-83). Thus on the basis of gross figures there has been a reduction of 0.19 million ha. of forest cover during the last 4 years. The annual rate of loss of forest cover works out at 47,500 ha. The comparison however, indicates that during the 4 years, the extent of dense forest cover increased by 16,456 sq. km. But there is a decrease in open forest by an extent of 19,174 sq. km. The comparative situation is indicated in the following table :

Sl. No.	Category	Period 1981-83 sq.km.	Period 1985-87 sq.km
1.	Dense forest (crown density 40% and over)	3,61,412	3,78,470
2.	Open forest (Crown density 10% to less than 40%)	2,76,583	2,57,409
3.	Man-grove forest	4,046	4,255
	Total	6,42,041	6,40,134

Source : F.R.I., Dehradun

World Deforestation Estimates

According to the recent estimates made by U.N. the total deforestation of the world forest is approximately equal to the geographical area of West Germany. i.e. 247851.7 sq. km. The estimates of UNDP indicate that there is a loss of 10.40 million acres of forest every year mainly due to forest fire. All these estimates were made through satellite survey. This information was aired by BBC on 8th June 1990 at 7.40 AM and subsequently by All India Radio (Delhi) at 8.15 AM on the same day.

Components of Forest Related to Hydrology

Forest Characteristic

The important components of 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, Underwood refers to trees consisting of second and third tier of bushes, trees and ground cover. Forests with more tiers of canopy have greater influence on soil erosion and hydrology of catchment. The classification of forest according to tiers of canopy is as follows :

Type of Forest	Tiers
* Evergreen forest, semi-evergreen and moist, deciduous- forest	— Four
* Dry deciduous forests	— Three
* Thorn forest and natural grass	— One or Two
* Agricultural crops	— One

Leaf litter and humus act as a cushion against the impact of raindrop and provide temporary pondage as the rich organic content of dense leaf litter helps in high infiltration and soil moisture storage. The leaf litter and humus is high in temperate subtropical zone and low in tropical zone. Thus, the important component of forest which influence hydrology of a catchment are canopy (including top storey, underwood and undergrowth), density, leaf litter and humus with dense roots.

Forest operations/management

Forest operations/management practices play an important role in modifying the hydrology of a forested catchment. These include silvicultural system (i.e. the systems of forest regeneration), other forest 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.

The system of forest regeneration is known as Silviculture

system. In this system forest regeneration is known as Silviculture systems. In this system forest crops are tended, harvested and replaced by new crops of distinctive form. The clear felling system involves elimination of the existing cover and replacement by new cover. It effects 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 involves cutting of existing crops such that coppicted shoots produce new shoots which grow into the new crops This system is relatively quick and produce less drastic effect than clear felling system on hydrologic system. In the shelterbelt system, crop is replaced gradually in three successive stages called seeding, secondary and final fellings and the regeneration takes place naturally. This system is less drastic than clear felling and coppice system.

Interaction between forest cover and hydrology

The influence of forest characteristics, forest operations and management practices on hydrological cycle can be visualised in three distinctive 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, groundwater recharge and subsurface or base flow. The third stage includes surface runoff.

Areas of Hydrological Studies on Forest Influences

Rainfall

Water gets evaporated when solar radiations fall on the water bearing surfaces and escapes to atmosphere. In the atmosphere these water vapours get condensed and rainfall occur. Rainfall is the most important factor in the influence of forest on climate. Precipitation is a general term of atmos-

pheric condensation products that reach the surface e.g rainfall, snow, hail and sleet. Researchers have expressed diverse opinions about forest influences on rainfall. 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. Other studies on this aspect indicate that :

* With the increase in the area of forest in Nilgiri hills the number of rainy days also increased.

* The study at Chota Nagpur district reported that there is no evidence to show that the monsoon ra nfall have been affected by cutting of natural forests of the district.

* Large scale afforestation may locally affect the incidense and distribution of rainfall and even increase it, but these effects on a regional scale may not be significant, was reported in the study carried out at Pathri, Ranipur.

Some studies abroad have reported that ...

* In coastal fog belts or mountaineous areas characterised by frequent cloud, forest could capture and condense atmospheric moisture which in some areas might increase rainfall was reported in a study at Hawaii.

* It is a most persistant misconception that forests increase local precipitation or in other words forest cutting would supposedly decrease gross precipitation, was reported in forest hydrology, Columbia University press, New York.

* The study conducted by some Russian researchers have showed approximately 10% more rain in forested area.

* The study on the east coast of Japan showed 6-10 times as much fog water in forest as compared to an open field.

* Study in the central Congo basin in Brussels also showed that forests do not influence rainfall.

* The precipitation at coastal south eastern Australia was measured 12% higher than that in the open, due to the condensation of fog.

* Based on the studies, some researchers claim that there is no corresponding evidence as to any effects of forests on the occurrence of rainfall.

Interception

Precipitation over a forest is depleted before it contacts the mineral soil, the total depletion which is subsequently evaporated is called interception. Precipitation is intercepted within the canopy and also within the forest floor of organic litter. 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.

* The interception losses of Chir, Teak, Sal and Khair in northeastern Himalayan region indicate the canopy interception as 22.1, 20.8, 38.2 and 28.5 percent of rainfall respectively.

* The interception losses can safely be assumed around 20% for dense canopies, as reported in a study at north eastern hill region.

* The safe limit of average total interception by forest cover (including top/middle storey, undergrowth and litter interceptions) appears to be around 35% of rainfall, was reported in a study at CSWCR & CT, & FRI, Dehradun.

Some studies abroad have concluded that ..

* Forest floors under conifers stands in Sierra Nevada Mountains can retain from 0.3 to 0.4 inch of water between air dry weight and field capacity.

* The forest floor under 80 year old hardwoods has an initial storage capacity 40% greater than that of a 30 year old hardwood stand, and 300 percent larger than a grazed white pine stand.

* It is now generally accepted, that the intercepted water on vegetation can evaporate at a higher rate than an equivalent area of open water surface and can evaporate as much as 4 to 5 times faster than transpiration rate for the forest under some climatic condition.

* In a study at Janlappa nature reserve of secondary lowland tropical rainforest region, the measurement of rain and net rainfall indicated that interception losses were 21% of the gross rainfall.

* The evidences and arguments were reviewed by Penman (1963) who concluded that there is no evidence that vegetation could affect the amount of precipitation to be received.

* That the results of a study on hydrological regime of three regions of USA namely northen USA, west Dregon and Southeast California revealed that with an increase of 50% in percentage of forest cover, the increase obtained are 150 mm per year for precipitation and from 100 to 400 mm per year for runoff.

Infiltration

Infiltration can be defined as the flow or movement of water downward into the soil surface from atmosphere. It is equal to the difference between precipitation and surface runoff.

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

making the soil structure more conducive to infiltration. The infiltration studies conducted in the country indicate that :

* Good leaf litter cover results in higher infiltration rate, was reported in several studies done at Dehradun and other parts of the country.

* The maximum infiltration rates for woodland in Bellary is of the order of 17 cm/hr and for Shola forest i.e. misc. vegetation in Ootacamund is of the order of 12 5 to 16.8 cm/hr.

* The initial infiltration rates for Eucalyptus, Sal, Chir, Teak, Bamboo and grassland is reported as 54.0, 21.4, 12.0, 9.6 and 7.6 cm/hr, respectively in a study at Dehradun.

* Maximum infiltration rate was obtained under shola forest (30.0 cm/hr) followed by Blugum (23.6 cm/hr) and grassland (8.7 cm/hr) in a study at Ootacamund.

* In Bihar, infiltration rates under forest land, permanent grass and areable crop lands vary as 26.12 and 9 cm/hr respectively.

* Higher infiltration rates of the order of 8.95, 5.9 and 5.85 cm/hr for first three hour for Bidhouli Sal forest with good leaf litter than for Horwal Sal forest 3 65, 2.0 and 2.2 cm/hr with very little leaf litter were reported in the field infiltration studies in Doon valley.

* Infiltration rates under forests, natural grassland and terraced cultivation were reported as 5.16, 3.0 and 1.4 cm/hr respectively for black cotton soil of Bellary.

* Studies done at Shimla reported that forest land has higher initial infiltration rates than agrilculture lands.

Studies abroad showed that ..

* With the varying species of California chaparrel, 8 to 30% of the annual precipitation reaches the ground at the base of Shrub.

* Under young lablolly pine, 16 to 18 percent of the annual precipitation is delivered directly to the base of the tree.

* Some general studies have concluded that the difference in infiltration between forested and cropped soils may be in the ratio of 100:2 and infiltration capacity of soil devoid of leaf litter gets reduced, was reported in a study in Japan.

* A study at Sperbel and Rappen Graben of Switzerland reported that a layer of 100m of water will take 1-2 minutes to seep into a forest soil having good structure and an undisturbed litter but it will take 120 mins. in case of a forest soil which is over grazed.

* The infiltration through a 25 cm of sandy soil layer covered with grass amount to 22% of total precipitation, it is 44% on bare soil and 60% in forest on the same soil has been reported in an study at Switzerland.

* In a study in Russia higher infiltration rates were reported from forests than from field soils.

* The study on infiltration capacity as related to soil texture and cover have shown that infiltration rates is approximately double in vegetated cover as compared to bare soil for clay, loam and sandy soil. This was reported in forest hydrology, Columbia University press.

Soil Moisture

The ability of soil to store moisture works as a reservoir during heavy rainfall and influences the peak discharges and floods. The snow releasing mechanism from the soil moisture storage increases the lean seasonal flow in streams which could be of great help during drought situations. The studies by various agencies on soil moisture as affected by forest have shown 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) was reported in a study at Dehradun.

* Forest area of the country has a soil moisture storage capacity of about 447.6 m. ha m, on a temporary basis and 223.8 m. ha.m. on a prolonged basis as reported by desk calculation.

* The soil samples collected at perurannamuzhi catchment Kerala were analysed and max. surface moisture during June was reported to be 30% for dense forest catchment, and 37% and 26% for partially exploited and fully exploited catchments.

* Studies at Dehradun have revealed that soil moisture is relatively higher in forest watersheds than agricultural watersheds in top 45 cm of soil depth.

Some studies done in abroad have indicated that...

* Forest cover generally reduces the levels of soil moisture and groundwater compared with corresponding levels under other vegetation types-specially during the negative water balance, was reported by scientists of New York, USA.

* FAO has reported that forests increase permeability and pore space within the soil which in turn results in higher moisture content of soil and lower surface runoff or peak flow.

Ground Water

A part of the precipitation gets infiltrated into the soil and joins the water table below the soil surface. Ground water occurs in the zone of saturation below the earth surface. The effects of forest cover on groundwater storage can be inferred from evapotranspiration, soil moisture and discharge relationships. The experiments have shown that :

* Where the ground water table is near the surface, forest cutting will cause it to rise, conversely, deforestation can eliminate waterlogged or semi-swamp conditions.

* The increase in water table due to afforestation alongwith other soil conservation measures in a watershed of 314 ha has been reported by ERS at Siliguri.

* Higher positions of water table under forest has been confirmed by researchers of ribben trop in the country.

* A typical study in the Nilgiris area had reported that plantation of Eucalyptus trees has resulted in significant lowering of base flow.

Studies abroad have indicated that...

* Water table collapsed as a result of deforestation, was reported in a study in USA.

* No effect on water table was found in a study in Switzerland when forest cover was changed to grass cover.

* In northern Thailand a decrease in well level in dry season following deforestation has been reported.

* Based on the studies conducted in Shipov forest, Russia, it was concluded that water table lies at a higher depth under forest than under field.

* A study in Australia has reported that converting forest to shallow rooted native by cutting, burning and ring barking resulted in increase in ground water level.

* A study in France have showed that cleaning of forest did not have any significant effects on ground water source.

* Studies in Fiji have showed that infiltration rates for grassland are substantially less than under forest.

Evapotranspiration

Evapotranspiration includes two processes namely; evaporation from land surfaces and transpiration from plant bodies.

Studies in the country and abroad have indicated that evaporation from soil covered by forest is 10—80% of that from bare soil. Since, forests absorb a great deal of solar radiations compared to other land surfaces and with more absorption of solar energy, the forest plants make more energy available for transpiration. Studies have been done in determination of evapotranspiration requirement of forests. Results of some studies done in this respect are as below :

* Evapotranspiration losses at Dehradun (upto soil depth of 1.22 m) for Chir, Teak and Sal was reported as 840 mm, 840 mm and 560 mm respectively on the basis of one year's observation.

  The evapotranspiration losses of Eucalyptus, Citridora, Populas Casale, Dal-bergia datifolia and pinus roxburgil in juvenile stage were reported to be 5526, 2704, 1143 and 536 mm respectively from September to June using lysimeters in the albedo forest areas of the country.

* 1136 cm of water was lost through evapotranspiration for Eucalyptus plantation of West Bengal between October 1970 to October 1971.

* Annual transpiration rate of about 34.7 cm was estimated at Ootacamund at an average annual rainfall of 130 cm.

* The average consumptive use crop coefficient for forested catchments in Khandala was reported as 0.642.

* In a study at Nainital, evaporation from soil covered by forest was reported to be 10—80% of that from bare soil.

Some studies abroad have reported that ..

* At higher elevations where generally forests are found evaporation losses are comparatively less mainly because of reduced air temperature.

* That the ten year average data of Switzerland was analysed

which revealed that forested watershed lost 50% of precipitation by evapotranspiration while it was only 38% of precipitation from other land uses.

* Measurement of transpiration was made from a region of secondary low land tropical rain forest located in the Janlappa nature reserve. The mean daily evaporation rate was 2.6 mm/day and the calculated evaporation from site for year from August 1980 to July 1981 was reported to be 1481 mm of which 886 mm was transpiration.

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 flow and soil loss. The results state that :

* Vegetative covers like Kudzu, Dichonthium, annulatum, chrysopagon, fluves and Bhabhav grass on 11% slope gave minimum runoff and soil loss under Kadzu whereas Bhabhav grass produced the maximum runoff.

* Reforestation of a small watershed (1.45 ha.) by Eucalyptus reduced the volume and peak rate of runoff by 28 and 73 percent, was reported in a study at Dehradun.

* In the lower Himalayan region at Bamuda, the total runoff was observed to be (59% and 79%) of the total precipitation during the month of July and August in 1980 and 1981 respectively.

* At some Agricultural and forested watersheds at Dehradun the forested watersheds have reported 10% less peak discharge and 38.5% less soil loss than agricultural watersheds.

* Rajpur area of Dehradun of Sal forest gave runoff as 42% of rainfall and soil loss of about 91 t/km^2.

* Afforestation within Acacia catechu on slopes and Sisham in low lying areas in a highly denuded siwalik watershed (20 ha with 9% slope) supported by check dams, contour trenches and debris basin reduced the sediment yield from 80 t/ha/yr to 7 t/ha/yr within the first four years of treatment.

Some studies abroad have reported that...

* 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.

* The study at North California, West Virgina, Colorado and Oregon in USA has revealed that complete deforestation increased the water yield by 20—40% of the normal.

* In a study in New York State, on a small watershed (808 ha.) which was 58% reforested, the reduction in discharge obtained was 65% in the month of November and 16% in the month of April.

Water Quality

Water quality is an important and vital parameter of forest hydrology because nearly 80% of the human diseases are attributed to drinking of polluted water and most of the population living in rural areas get water from natural streams. Such as silt content in stream flow dissolved substances and gases are significantly responsive to forest cover. The studies on the effect of forest on water quality have suggested that...

* A general study on forest influence on water quality from a cut over forest eco-systems (et. al 1969) reported that both through fall and streamflow get considerably enriched in all the major cations and anions except hydrogen by contact with trees.

* A study in three coastal Oregan forest types in Portland,

Oregan by USDA observed increase in nitrogen in through fall and streamflow in some forest species.

* Litterfall from deciduous species, added to water bodies with low flushing rates may increase true colour, iron bicarbonate and manganese concentrations and decrease dissolved oxygen levels and pH of water was reported by Slack and Felt (1968) in their paper "Tree leaf control on low flow litter quality in a small Virginia system".

Floods

Floods occur when there is excessive or intense rainfall over a short span of time associated with saturated watershed conditions. Under this condition presence of forest cover do not prevent large floods but retards erosion and debris flow to downstream reaches. Diverse opinions are reported in literature regarding role of forests in causing floods. Some are summarised below :

* Afforestation measures retard the speed of runoff, minimise soil loss and consequently the sediment load in the rivers.

* Rise in stege during floods is not as much due to excessive discharge in rivers as due to excessive sediment load in them.

* The World Forestry Congress in 1978 reported that the cause of floods in Indian sub continent is the removal of tree cover over catchment areas.

* The European Environmental Bureau is of the opinion that forests guard against flooding even on large rivers.

* Overlogging of headwater forest has been officially recognised as the cause of floods in the great Agusan flood at Phillippines and at Yangtze in China.

The role of forests on floods as cited by Rastriya Barh Ayog can be as below :

* That planned and limited deforestation do not have any untoward consequences with regard to floods.

* That whenever intense flood occurs, the casual factors are sought in the vanishing forests.

Note : The information/statistics presented in the brochure have been extracted from published literature and all authors are hereby acknowledged.


cool coniferous forest
temperate mixed forest
warm temperate moist forest
equatorial rainforest
tropical moist deciduous forest
dry forest