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FOREST INFLUENCE ON HYDROLOGICAL PARAMETERS

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PREFACE

Disturbance or elimination of vegetation mantle by man has introduced a new agent capable of upsetting an ecosystem, in general and hydrological cycle in particular. It has posed a latent if not chronic environmental problem ever since agriculture became the dominant mode of subsistance in parts of the old world, almost 10 millenia ago. Cultivation and the pressures of livestock grazing marked the first serious impact of man on hydrological cycle, and thus opened a Pandora's Box of complications in regard to the balance of vegetation cover, soil mantle and runoff.

Until the 19th century A.D. the hydrological crisis provoked by man were limited and essentially confined to parts of Europe and America. After the establishment of International Union of Forest Organisation, forest influences on hydrological parameters have been main topics of discussion globlly. Consequently, a new branch of hydrology has emerged, viz., "forest hydrology" which deals with the effects of forests and associated wildland vegetation on water cycle, including the effect on erosion and water quality.

The forest hydrology is still in its infancy stage which is developing rapidly. Student persuing a career in forest and wildland resources soon learns that no natural science is more fundamental to the art of water and land management than hydrology.

How the forest influences various hydrological parameters ? An attempt is made through this Water Science Education Series brought out by National Institute of Hydrology. The Institute shall feel rewarded if the contents help create awareness among the masses and educate the people about the various hydrological aspects influenced the forest in general and management of land and water in particular for rational utilization of these resources.

(S.M. SETH)
Director

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1.0 INTRODUCTION

1.1 Forest – a Valuable Resource

Forest are our one of the most important consumable and renewable natural resources. These are the source of food, medicianals, fuels, clothing, shelter and a host of other life essentials. In general it is the protective cover of our earth.

Approximately thirty percent of our lithosphere is covered by different succession of plant formation. Table 1 lists a number of the most important plant formation classes with brief notes on the character of the vegetation and the associated latitude zones and climates. Figure 1 consists of three schematic profiles showing how one formation class grades into another along a north-south profile from equatorial zone to the arctic zone, and along 40° N east-west profile.

1.2 Vegetation Structure

Based on the physical structure, i.e., size and shape, the plants are divisible into different groups, i.e., tree, shrubs, lianas, and herbs and grasses. "Trees" are large, woody perennial plants (Plate 1A) having a single upright main trunk, often with few branches in the lower part, but branching in the upper part to form a crown.

"Shrubs" are woody perennial plants (Plate 1B) having several stems branching from a base near the soil surface, so as to place the mass of foliage close to ground level. "Lianas" are also woody plants, but they take the form of vines supported on tree and shrubs. "Herbs" are tender plants, looking woody stems and are usually small. Some are annual and others are perennial. Some are broadleaval, others are grasses (Plate 1C).

"Forest" is a vegetation structure in which trees grow close together with crowns in contact to their foliage largely shades the ground. In most forests the life form are arranged in distinct layers and the vegetation is said to be stratified as the tree crown forms the upper most layer, shrubs an intermediate layer and herbs a lower layer. The lower most layer consists of mosses and related plants (Fig.2).

1.3 Forest Hydrology

Type of plant formation and nature of plant structure play very significant role in effecting water cycle, nutrient cycle and biogeochemical cycle in particular, and the entire ecological system in general. The study of the influence of forests on the hydrologic

Table - 1: The Plant Formation Classes.

FOREST BIOME	
Equatorial rainforest (Tropical rainforest)	Tall, smooth-barked, evergreen, broadleaf trees with high crowns. Warm, wet equatorial and tropical climates with large water surplus.
Monsoon forest	Open forest of tropical lands with dry, cool season and wet monsoon season. Many trees are deciduous; shed leaves in low-sub season.
Midlatitude deciduous forest	Broadleaf, deciduous trees shed leaves in winter. Substantial soil-water surplus.
Needleleaf forest	Needleleaf, evergreen trees forming dense forest in high latitudes. Long, very cold winters.
Sclerophyll forest	Open forest of hard-leaved, evergren trees. Midlatitude regions with very dry summer and moist winter.
SAVANNA BIOME	
Tropical savanna woodland.	Scattered trees with grassland. Tropical climate with long, dry season and short, wet monsoon season.
GRASSLAND BIOME	
Tall-grass prairie	Dense growth of tall grasses and herbs. Midlatitude regions of subhumid climate.
Short-grass prairie (Steppe)	Short, sparse grasses. Semiarid plains in midlatitudes. Moderate soil-water deficit.
DESERT BIOME	
Semidesert	Woody shrubs and grasses. Semiarid climate in midlatitudes. Much bare soil. Large soil-water deficit.
Dry desert	Widely scattered desert shrubs with bare ground intervening. Dry desert climate in tropical and midlatitude zones. Large annual soil-water deficit.
TUNDRA BIOME	
Arctic grassy tundra	Treeless landscape with sedges, grasses, mosses, flowering herbs. Severely cold climate of subarctic zone. Permanently frozen ground below soil (permafrost).
Alpine tundra	Similar to arctic tundra. Occurs at high altitudes, above tree-line, in wide range of latitudes.

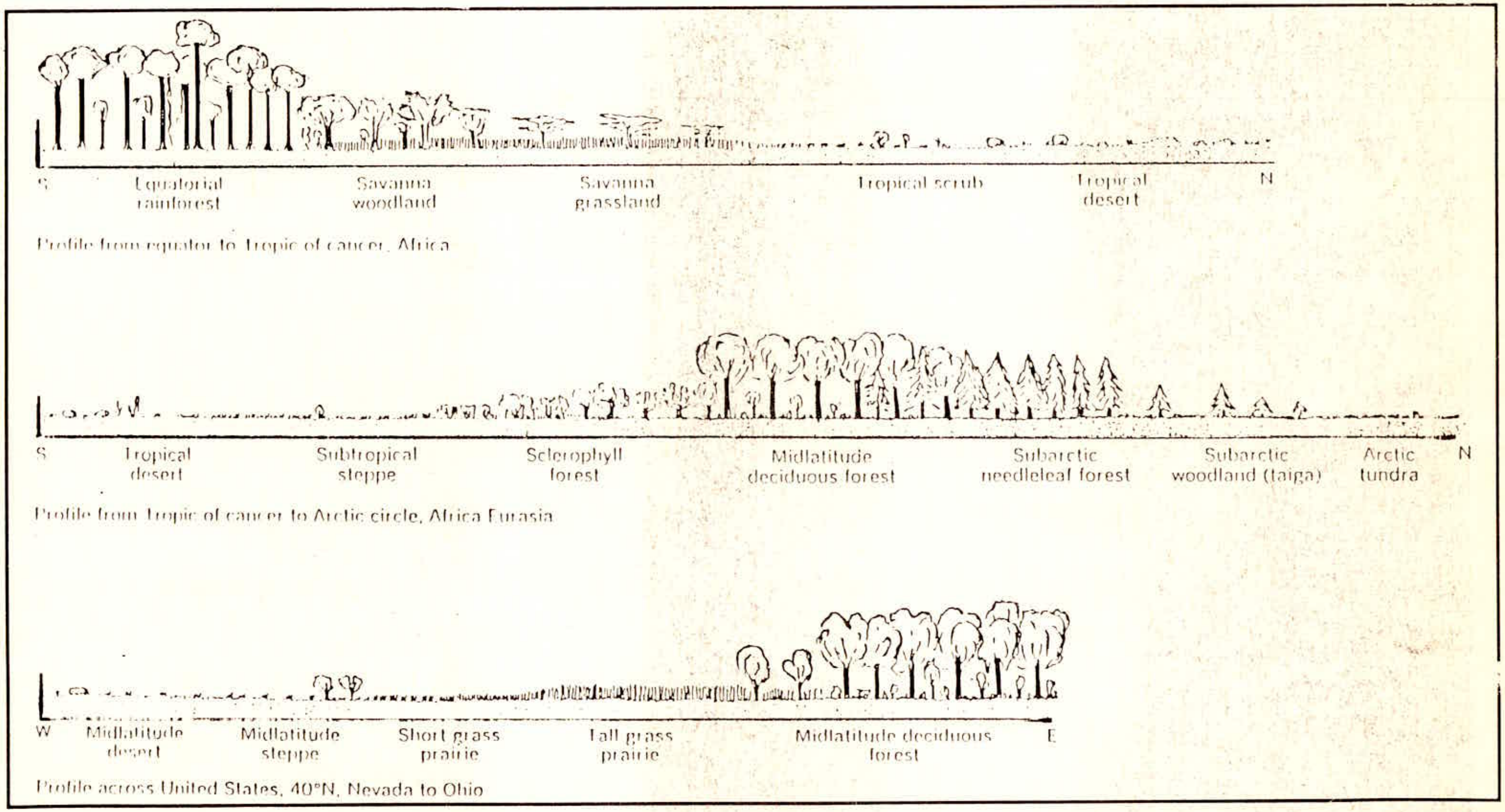
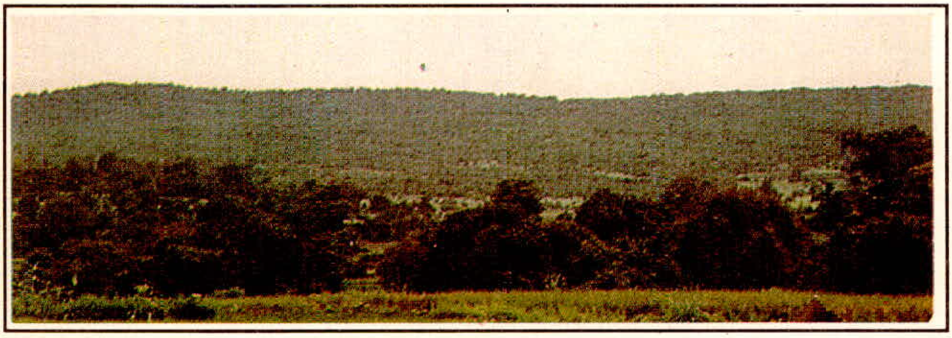


Fig. 1 ***Three schematic profiles showing the succession of plant formation classes across climatic gradients (after Strahler and Strahler, 1977)***

A - A view of large and dense coniferous trees casper creek experimental forest watershed, USA



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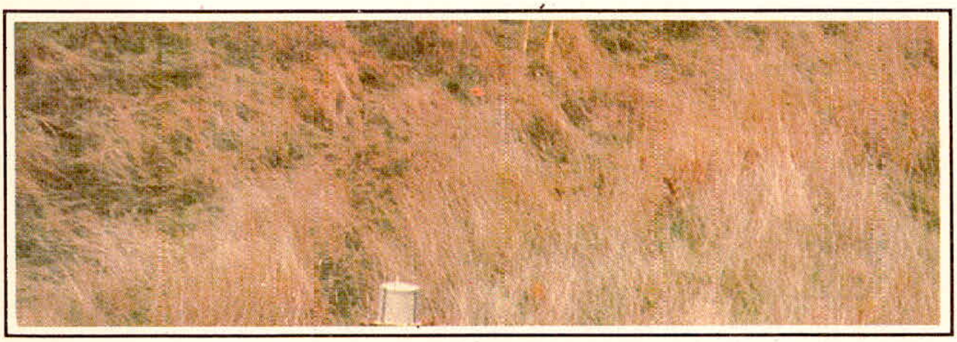


C - A view of dense grass land in the lone-tree creek catchment USA. The grass land is being used as Natural laboratory for Hydrological studies.

PLATE 1: Different Types of Natural Vegetations

cycle in general and on different hydrological parameters in particular is known as "forest hydrology". It is a newly emerging branch of the interdisciplinary science. viz., hydrology. According to Hewlett (1982), **"Forest Hydrology is a branch of hydrology that deals with the effects of forests and asociated wildland vegetation on the water cycle, including the effect on erosion, water quality, and micro-climate"**. The knowledge of forest influence on hydrological systems soon realises that no natural science is more fundamental to the art of land management than hydrology.

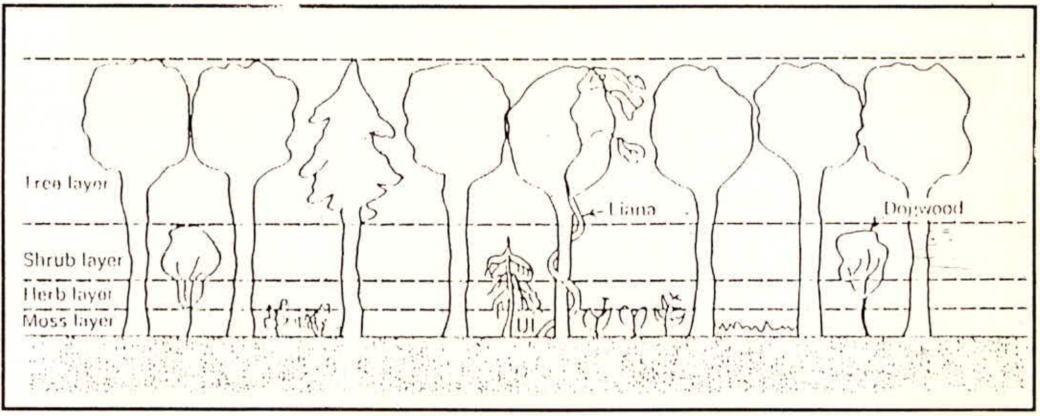


Fig. 2 A schematic diagram showing the different layers of tree canopy (after Strahler and Strahler, 1977)

2.0 HYDROLOGICALLY IMPORTANT COMPONENTS OF FORESTS

There are numerous components of forest which are related to nutrient cycling, biogeochemical cycling and water cycling. The important components of forest from hydrological point of view are :

i) type of tree canopy.
ii) tiers of tree canopy.
iii) percentage of tree canopy.
iv) quantity and type of litter, and
v) root density and soil.

The type of tree canopy influences the amount of throughfall, channel runoff and channel erosion etc. For example the amount of throughfall is generally higher from coniferous forests than that of the broadleaved forests (Sinun, et.al., 1992). The water generating capacity of land to channels is recorded about four times higher in the broadleaved Oak forests than that of the pine forests in the Central Himalaya (Table -2)

Table- 2 : Water generating capacity of land to channels in Central Himalaya.

Forest Type	Average Runoff	Source
Oak forest	3315 $m^3/Km^2/day$	Shastri, et.al (1990)
Pine	838 $m^3/Km^2/day$	Rawat and Rawat (1990)

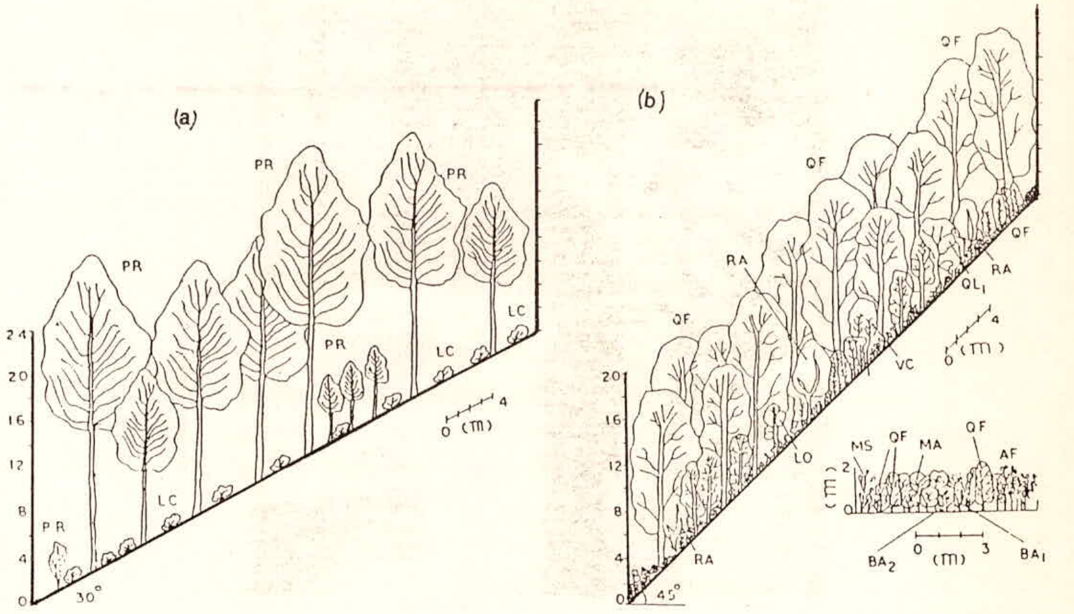
Number of plant canopy stories (Fig.2) effects entire the chain of hydrological system. Forests with more tier of canopy (Fig.3b) control the overland flow, soil erosion and flooding and encourage infiltration, subsurface flow, deep percolation, while the forests with less tiers (Fig. 3a) increase overlandflow, erosion and decrease infiltration, subsurface flow and percolation. Classification of tier of canopy under different forest types is given in table 3.

Table- 3: Number of tiers of canopy under different types of forests

Forest type	Number of tiers.
Evergreen forest Semi-evergreen forest and moist deciduous forests.	Four tier
Dry deciduous forests	Three tier
Thorn forest and grass land	One or two tiers.

Percentage of tree canopy cover influences the hydrological parameters such as rainsplash erosion, sheetwash erosion, rill and gully erosion, overland flood and infiltration etc. Under very dense canopy these hydrological parameters are controlled except infiltration. As the density of tree canopy cover decreases, the amount and magnitude of these parameters accelerated except infiltration which is discouraged (Plate 2).

Dense fresh litter act as a cohesion against the impact of raindrop, partially decomposed litter and biologically rich humus soil provide temporary storage and helps in high soil moisture storage and infiltration. Tree roots and decay plant roots provide natural passage ways for the infiltration of water.



Profile diagram for *Pinus roxburghii* forest. LC=*Lantana camara;* PR=*Pinus roxburghii.* (b) Profile diagram for *Quercus floribunda* forest. The inset diagram respresents the shrub layer magnified from the main diagram for an area equivalent to $15.7m^2$. AF=*Arundinaria falcata;* BA_1=*Boenninghausenia albifiora;* BA_2=*Berberis asiatica;* LO=*Lyonia ovalifolia;* MA=*Myrsine africana;* MS=*Myrsine semiserrata;* QF=*Quercus floribunda;* LQ_1=*Quercus leucotrichophora;* RA=*Rhododendron arboreum;* VC=*Viburnum continifolium.* Each profile diagram represents an area of $200m^2$. The inset scale is for crown diameter.

Fig. 3 A view of less tree canopy in Pinus roxburghii (a), and more tree canopy in Quercus floribunda forest in the Kumaun Lesser Himalaya (after Singh and Singh, 1985).

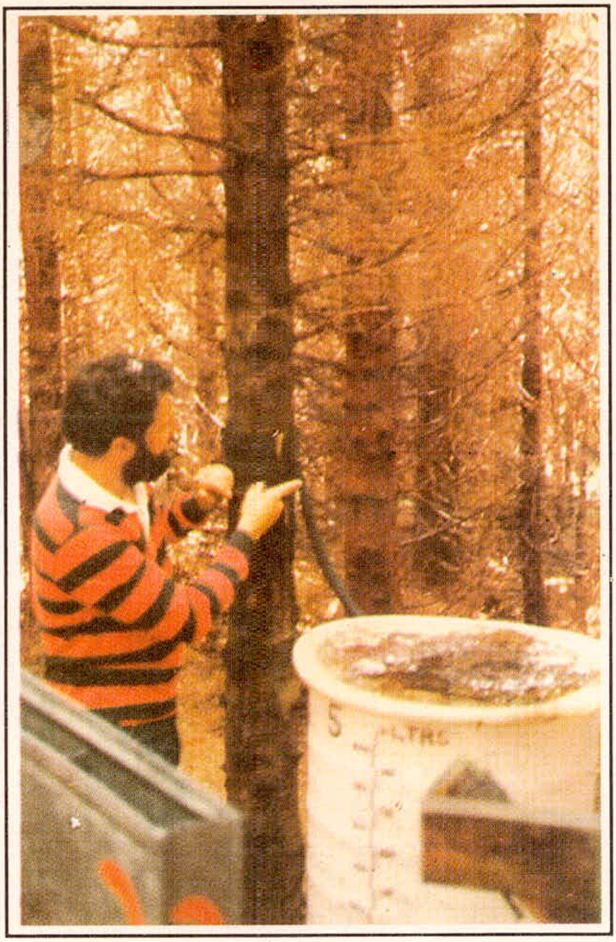


PLATE - 2: Stemflow study in pine wood, Institute of Hydrology, wales, U.K. (Photo by the courtsey of Martin Hagh)

3.0 REVIEW OF PAST WORKS

3.1 History

The history of the knowledge of various forms of forests and classification of Indian forest dates back to Vedic period i.e, about 1500 B.C. when the felling of trees was believed as a crime;

असिपत्र वनं याति वनच्छेदी वृथैव यः ।
(Sri Sri Vishnu Puran,Vol.2.27)

A person who cuts the trees without a creative case, goes to hell, viz., Ashipatra Hell.

The history of forest influence on hydrological parameteres dates back to the thirteenth century which led to the evolution of the specific field of forest hydrology. The study was rapidly increased during the later half of nineteenth century when Marsh (1863) devoted a long chapter in his famous book "Man and Nature" to the forest influences, a term he apparently coined, and thus called attention to hydrological role of forests.

Following Marsh's alarming description of evils of deforestation, there occurred a "propoganda period" of forest influences. The public perception of these influences played a large role in forestry and conservation movements.

In late nineteenth century, since the formation of International Union of Forest Research Organisation (IUFRO) problems regarding forest hydrology have been main topics of discussions. During the first congress, at Vienna in 1893, of IUFRO, terms like "forest and climate","forest and springs" and "the influence of forest on water level" were used. At the fourth congress in 1903 again at Vienna, the term "forest and water" was established. Afterwads research activities such as "forest influence", "forest hydrology"took place quickly specially in western countries. In 1948 Kiltredge has presented a detailed account of the development of forest hydrology including a summary of early notions about forests effect on rain, water flows and droughts

3.2 Recent Studies.

Recently, the studies on the forest influence on different hydrological parameters are in progress in different parts of the earth. Some of the important works of Chapman (1948), Kittredge (1948), Molchanov (1960), Nye and Greenland (1960), Anderson and Hoover (1976), Jackson (1975), Bormann and Likens (1979), Rechar (1980), Manokaran (1980), Swanson, et.al. (1982), Hewlett (1982), Hatch (1983), Hamilton and King (1983), Hickin (1984), Brandt (1988), Herwitz (1988), Lloyd and Marques (1988), Bruijnzed (1989, 1990), Veen and Dolman (1982), Spencer, et.al. (1990), Wong (1991), Sinun, et.al(1992) and numerous others.

However, the efforts in this direction in India are limited and the forest hydrology in the country is in its infancy stage. Ranganathan (1949), Bhattacharya (1956), Dabral et.al.(1963) and Dabral (1965) are the pioneer workers who initiated the work on the protective functions of forests and on the effects of forests on hydrological parameters such as effect of deforest on the intensity and frequency of rainfall and floods, rainfall interception by leaf litter, soil moisture in chir, pine, teak and Sal forests etc.

Later on slow progress was made in this direction. Some of the important works are effect of clearfelling and reforestation on runoff and peak flow (Mathur et.

(el. 1976), vegetation characteristics and their effects on) their runoff and peak rates (Mathur and Sajwan, 1978), water consumption of Chir Pine, Banj-Oak, Sal and Ipil-Ipil (Raturi and Dabral, 1976), effect of forest cover on rainfall distribution (Biswas, 1980), consequences of deforestation and overgrazing on the Hydrological regime (Gupta, 1980), Hydrological influences of vegetation cover in watershed management (Lal and Subba Rao, 1981), infiltration rates in various landuses (Mohan and Gupta, 1983), overland flow, sediment output and nutrient loss from forest sites (Pathak, et. al. 1984), apportionment of rainwater in forest (Pathak et.al., 1985), hydrologic response of forested mountain watershed to thinning (Subba Rao, et.al. 1985), hydrological studies in forested catchments (Sikka, 1985), forest influences on hydrological parametres (Lohani, 1985), sediment yield from different landuses (Bhatia 1986), forest grass land and agroforestry and its impact on water (Chinnamani, 1985), forest ecology and related weather influences (Dutt and Manikiam 1987), anthropogenic transformations of channel networks (Rawat, 1988a, 1988b) hydrological impact of deforestation (Haigh, et. al. 1988), hydrological responses of Landuses (Chandra, 1989), Channel runoff from oak (Shastri, et.al. 1990) and Pine (Rawat and Rawat, 1990) etc.

In view of the existing gap in defining exact role of forests in relation to their effects on hydrological parameters, the National Institute of Hydrology took up work of compiling results of related studies done in the country and abroad. The litrature available has been critically scanned and based on these efforts, following three reports have been published.

(i) Forest influences on hydrological parametres
(ii) Status of hydrological studies in forested catchments
(iii) Sediment yield from different landuses.

4.0 HYDROLOGICAL PARAMETERS

4.1 Hydrologic Cycle

Hydrologic cycle is a process by which water is evaporated from ocean, sea, lakes, soil surface and vegetation etc. and goes to atmosphere in vapour form. The vapour gets condensed and returns to the surface as precipitation. After reaching the surface, water moves towards ocean as surface and subsurface flood and the complete process restarts. According to Strahler and Strahler (1977) **"The Hydrologic cycle traces the various paths of water from oceans, through atmosphere, to lands, and return to ocean".** (Fig.4)

4.2 Hydrological System and Parameters

To complete a hydrological cycle the water has to travel through a complex system under forest environment. This complex hydrological system may be divided

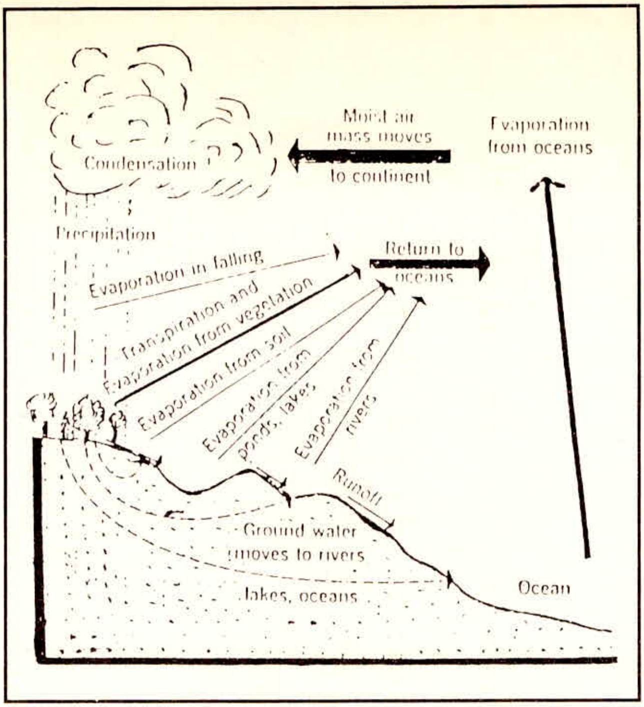


Fig. 4 The hydrologic cycle traces various paths of water from ocean, through atmospher, vegetation, land and return to ocean.

into three main components consisting of different hydrological parameters. These are (Fig. 5).

i) Different pathways.
ii) Storage
iii) Losses.

4.2.1 Different Pathways - Under the forest environment the raindrops hit the leaves of tree canopy and travel through tree canopy. This process is known as "**through fall**". Some of the water runs down through tree stems which is known as **"Stemflow"**. After reaching at surface some of the water passes through soil surface known as **"infiltration"** process. After travelling through the soil profile a small part of water penetrates into the rocks which is known as “”**percolation"** when the rain continues to fall beyond the limit of infiltration and when the deep percolated water reappears on the surface. The water flows in the sheet and channel form respectively. The former is known as **"overland flow"** and the later as **"stream flow".**

4.2.2 Storage - During the rain much of the water is held in droplets on the leaves, stems, and in dead plant material and leaf litter. This is known as

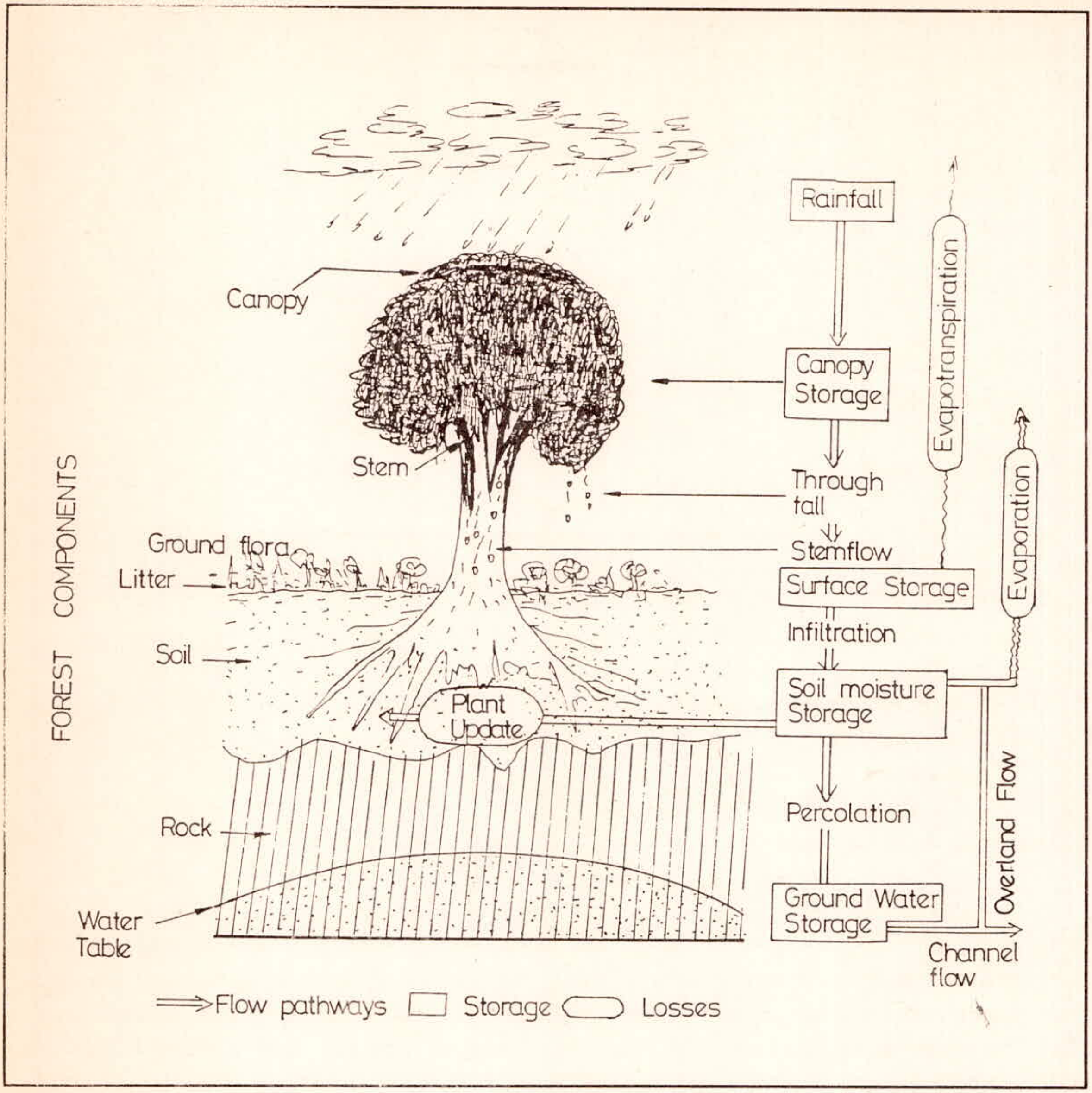


Fig. 5. A model of hydrological parameters and hydrological system under forest land.

"interception storage". The infiltrated water is absorbed by soil which is retained within soil for a long period. This is known as **"Soil moisture Storage".** The deep percolated water is stored into the rock pones and fissures which is known as **"groundwater storage".**

4.2.3. Losses - The intercepted water by tree canopy, ground flora and leaf litter is returned back to the atmosphere through evapotranspiration which is known as **"crown interception loss"** respectively. A significant part of the water goes back to atmosphere by sun heat from soil storage, overland flow and channel flow. This is known as **"evaporation loss".**

Few studies of different hydrological parameters are available. But, study of all the hydrological parameters for a certain forest environment is yet not available which could define the entire hydrological system and water budget of a particular forest. However, attempts are made by Pathak (1983) and Hewlett (1982) to study the apportionment of gross rainfall through different pathways, storage and losses for the Kumaun Himalayan forests (Fig. 6 and 7). Figure 6 reveals that in the Central Himalayan forest 83.3% of the total rainfall reaches to the forest floor by throughfall (82.8%) and stemflow (0.5%). Remaining 16.7% is returned to atmosphere through canopy interception losses. From the forest floor again 12.3% is returned to the atmosphere by the groundflora interception (3-7%) and litter interception (8.6%). Thus, out of the total rainfall 71% water reaches to the soil which infiltrates (70.3%), and flows in the form of overland flow (0.7%) and subsurface flow (56.3%). Measurements of evapotranspiration, soil moisture storage, groundwater storage and channel flow are not included in this study.

5.0 INTERCEPTION

Interception denotes a process in which precipitation of any type strikes, vegetal material above the mineral surface. Through the vegetation cover rainwater or snow is intercepted through two pathways through vegetation crown, viz., throughfall, and through plant stems, viz., stemfall.

5.1 Throughfall

Throughfall is that portion of gross precipitation which falls or drips through the crown. Measurement of throughfall are very limited. Recent study conducted by Sinun, et.al. (1992) have deduced that throughfall amounts approximately 80.7% of the incident rainfall in the tropical rain forest. This is comparable to results obtained elsewhere in the tropical rainforest (Bruijrizeel, 1989). Based on forty four single rainfall events,Sinun, et.al (1982) have expressed the relationship between rainfall (P) and throughfall (T) as follows:

$$T = 0.84P - 0.51 \quad (r^2 = 0.97,\ P = 0.001)$$

In the Central Himalaya Pathak (1983) has observed throughfall rate between 75 to 92% of the total rainfall having a mean value of 82.8% (Table 4 and Fig. 6).

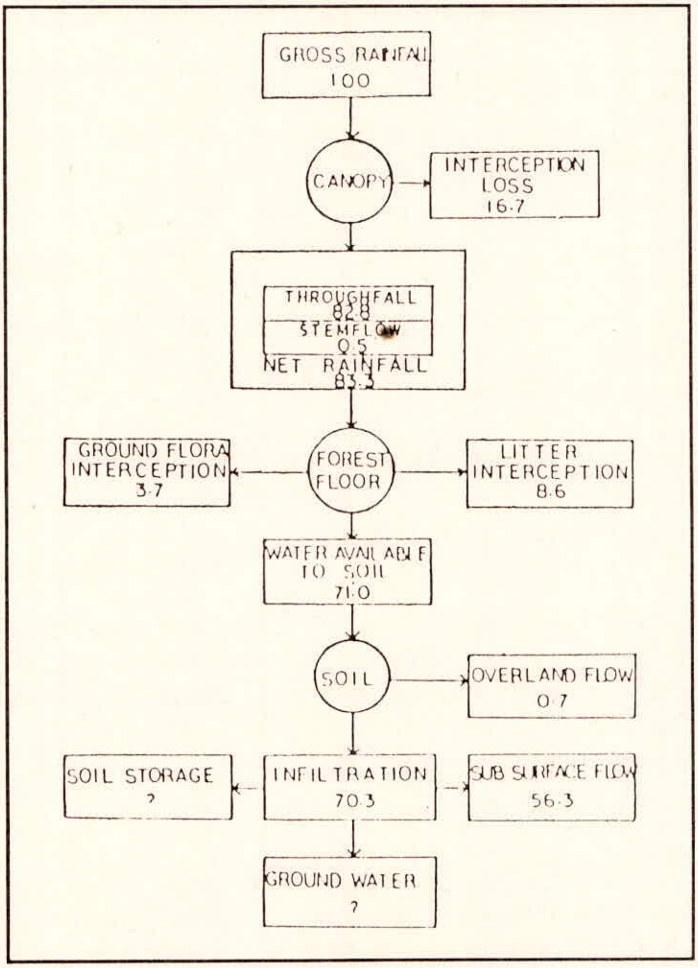


Fig. 6 A canonical model showing the apportionment of gross rainfall into different pathways for the Kumaun Himalayan forests. Values are percentage of gross rainfall (after Pathak, 1983).

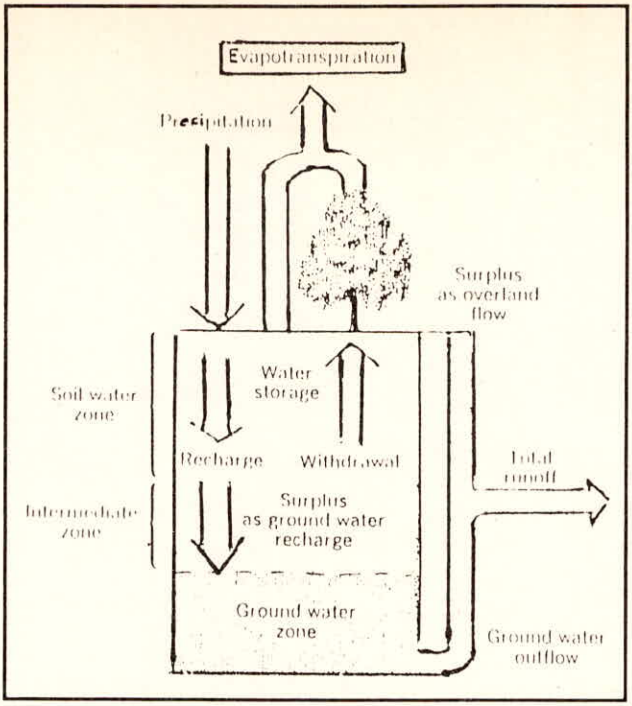


Fig. 7 A schematic diagram of hydrological parameters under forested environment (after Strahler and Strahler, 1977)

Table - 4: Rates of throughfall.

Forest	Rate	Source
Tropical Rainforest	80.7%	Sinun,et.al. (1992)
Temperate Coniferous	82.8%	Pathak, (1983)

5.2 Stemflow

Stemflow (Plate 2) is that portion of intercepted water which collects and runs down stems. The results obtained in stemflow studies carried out in India and abroad (Table 5) indicate that the stemflow varies from 0.3 to 9.0% of the total rainfall under different forest environment.

Table - 5 : Rates of Stemflow under different forest environment.

Forest	Stemflow	Source
Temperate coniferous forest	0.3-0.9%	Pathak, et.al. (1985)
Pine forest Himalaya	4%	Dabral, et.al. (1968)
Broadleaved forest	6-9%	Ghosh and Subha Rao (1979)
Tropical rainforest	1.85%	Sinun, et.al. (1992)

Pathak, et.al. (1985) found that stemflow in the temperate coniferous forest accounted for less than 1% (range 0.3 - 0.9%, mean 0.5%). Dabral, et.al (1968) however, considered that stemflow in Himalayan pine forest could reach 4% of the total rainfall, and Ghosh and Subha Rao (1979) have reported that it could reach 6 to 9% of the total rainfall in broadleaved forest.

Recent study of Sinun, et.al. (1992) has indicated that the rate of stemflow in the tropical rainforest stands at 1.85% of the incidental rainfall. They have indicated that the stemflow requires a certain measure of antecedent rainfall. This amount of required antecedent rainfall is not yet clearly defined. However, in case of the tropical rainforest it stands around 4.24 mm (Sinun, et.al. 1992).

The amount of stemflow varies in an irregular manner between trees. When one tree lost its leaves, it tended to produce more stemflow than when its folige was complete. The amount of stemflow collected is not related to tree size also. Only after large events such as 32 mm rainfall (in case of tropical rainforest) did the large trees stems (Plate 3) systematically produce more stemflow than smaller trees. In other smaller rain events stemflow is not related to size of the tree.

6.0 INTERCEPTION LOSS

During the rain much of the rainwater and snow (Plate 4) is held in droplets on leaves, plant stems, ground flora and leaf litter. The intercepted water may later be returned directly to the atmosphere by evaporation, and, if the rainfall is less a small part of rainwater will reach the ground.

The interception loss is largely controlled by the size, structures, above-ground arrangement of plants and the total surface area of plant materials. The total interception loss is the vaporization of water intercepted during rain from plant

PLATE - 3 : The large tree stems systematically produce more stemflow during heavy rain.

PLATE - 4 : A view of Intercepted snow in the crown of tall coniferous trees surfaces, i.e., leaves, stems, twigs, down trees, ground litter and hamus layer.

The results obtained in various interception studies (Table 6) indicate that the interception varies between 8-35% of total rainfall for different species of forest.

Table - 6: Rainwater interception loss from different trees and forest types

Tree/Forest Types	Interception Loss (%)	Source
Spruce - Spruce - fur	35.0	Gregory and Walling (1973)
Red Pine	32.0	Gregory and Walling (1973)
White Pine	30.0	Gregory and Walling (1973)
Hemlock	30.0	Gregory and Walling (1973)
Khair	28.5	Dabral, et.al. (1963)
Babul	26.0	Mathur, et.al. (1975)
Sal	25.3	Dabral, et.al. (1963)
Pine	22.1	Dabral and Rao (1969)
Eucalyptus	21.9	Samraj, et.al. (1982)
Teak	20.8	Dabral and Rao (1969)
Pine	20.0	Gregory and Walling (1973)
Dense forest	8-35	Dunn and Leopold (1978)

Efforts to measure interception loss have resulted in identification of four sub-components. These are interception loss:

i) from crown
ii) from ground flora
iii) from litter, and
iv) at different rainfall amount

6.1 Crown Interception Loss

Crown interception loss is the amount of water evaporated or sublimated directly from water intercepted by the crowns of vegetation. The crown interception rate varies from 8 to 34% of the total rainfall under different species and different forest environment (Table 7).

6.2 Ground Flora Interception.

The ground surface interception loss is the amount of water caught and loss from the ground flora. The ground flora interception generally accounts for less than 5% of the total rainfall. Ground flora interception studies conducted at 6 different sites in the Kumaun Himalaya have suggested that ground flora interception accounts for 2.6 to 5.2% of the total rainfall (Pathak, et.al., 1985).

6.3 Litter Interception.

The litter interception loss is the amount of water from the litter deposition before it can infiltrate mineral soil. The results obtained in various litter interception studies carried out in different parts (Table 7) indicate that the litter interception varies from 5 - 10% of the total rainfall for different species of forest.

Table - 7: Interaction loss through tree canopy, ground flora and litter layer.

Components	Interception loss (%)	Tree/Region	Source
CANOPY INTERCEPTION	8 - 25	Kumaun Himalaya	Pathak, et.al. (1985)
	22	Garhwal Himalaya	Dabral, et.al. (1968)
	34	Sal Forest	Ghosh & Rao (1979)
GROUND-FLORA INTERCEPTION	3.7	Kumaun Himalaya	Pathak, et. al. (1985)
	7.10	Kumaun Himalaya	Pathak, et.al. (1985)
	7.6	Pine	Dabral, et.al. (1968)
LITTER INTERCEPTION		9.0	Sal Dabral, et.al. (1968)
	8.9	Teak	Dabral, et.al.(1968)
	5.0	Sal	Dabral, et.al. (1968)

6.4 Rainfall Amount/Intensity

The amount and intensity of rainfall largely effect the interception loss. Most of a 5 mm rainstorm is lost by evaporation from crown and litter but, not much more is lost from a 100 mm rainstorm. Studies of Mathur, et. al. (1975) and Kittredge (1962) have shown the rates of interception loss at different rainstorms (Table 8) which reveals that the interception in forested areas does not have significant effect during heavy storm, i.e. ____100 mm.

Table - 8: Interception loss in percent of the total rainfall at different rainfall amount.

Rainfall (mm)	Sal forest, India (Mathur, et.al.1975)	Cryptomeria, Japan (Kittredge, 1962)
0.1	--	83.0
1.3	--	61.0
3.6	37.3	51.0
6.10	--	35.0
10.20	24.5	18.0
20.40	13.0	--
40.60	5.9	12.0
60.10	4.1	11.00
100 & above	4.1	

7.0 EVAPOTRANSPIRATION

The term evapotranspiration covers the combined moisture loss from direct evaporation and the transpiration of the plants as shown in Fig.7. The total evapotranspiration loss depends upon the air temperature and vegetation structure.

During summer, the rising air temperatures, increasing evaporation and full growth of plant foilage bring on heavy evapotranspiration. The soil water falls below the storage capacity. By midsummer, generally a large water deficit exists in the soil profile even the occasional heavy evapotranspiration. The rate of evapotranspiration goes down as soil water supply becomes depleted during a dry summer period because plants employ various devices to reduce transpiration. In general the less water remaining, the slower is the loss through evapotranspiration.

The total evaporation loss also depends largely on the above ground mass of plant cover and the number and length of drying period between storms. It is controlled by the total surface area of the living and dead plant materials, i.e., percent crown coverage, flora of forest floor, leaf area and seasonal differences in leaf surface area, i.e., deciduous and non-deciduous. A drying period 12 hours is usually required to separate successive rainstorms for interception consumption.

Studies conducted to observe forest evapotranspiration as listed in table 9 have indicated that forest may return 38 to 50% of the incidental rainfall back to the atmosphere through evapotranspiration. It varies under different forest types. For example, the coniferous pine forest has a lower rate than the broadleaved but that it consumes more water than either sal or oak which chir pine is tending to replace on many hillsides in Uttarakhand (Raturi and Dabral,1986).

The most broadleaved forests may return as much as 50% of the incident rainfall back to the atmosphere through evapotranspiration (Seth and Khan, 1961) while from eucalyptus Globules forest about 38% of the incident rainfall return back to the atmosphere through evapotranspiration (Thomas,1972).

Table - 9: Rate and amount of evapotranspiration from different types of forest.

Forest	Evapotranspiration	Source
Broadleaved Forest	50% of rainfall	Seth and Khan (1961)
Eucalyptus Glubules	38% of rainfall	Thomas (1972)
Grasslands	38% of rainfall	Gupta (Undated)
Dry Deciduous	560 mm	Mishra (1968)
Teak	840 mm	Dabral, et.al. (1965)
Chir	840 mm	Dabral, et. al. (1965)
Sal	560 mm	Dabral, et. al (1965)
Pinus	536 mm	Dabral, et.al. (1965)

8.0 INFILTRATION

When the rainwater continues to fall beyond the limits of interception and reaches the soil surface, it enters the soil. This process is known as infiltration. Thus, infiltration is a process by which water passes through the soil surface.

Most of the soil surface under dense forest environment (Plate 5) are capable of absorbing completely by infiltration the water from light to moderate intensities

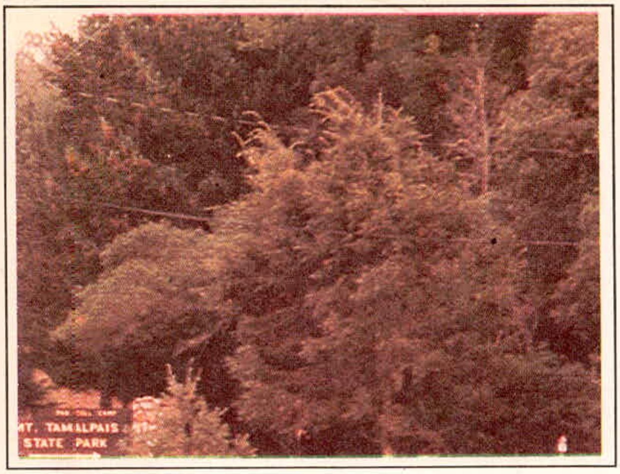


PLATE - 5 : A typical example of dense forest Environment, Mt. Thamaplis State Part, U.S.A.

rains. Various biological activities, organic material, and depth and types of mulches and forest floor or vertical cover increases infitration capacity of forest soils. Such soils have natural passage ways between poorly fitting soil particles as well as larger openings such as cavities left from decay of plant roots, boring of worms and animals and opening made by heaving and collapse of soil as frost crystals alternately grow and melt. A mat of decaying leaves and stems breaks the force of falling drops and helps to keep these openings clear. In addition, forest soils have advantage of the main effect of root network (Plate 6) which enable water to penetrate and increase infiltration capacity.

Results of the infiltration studies conducted in different parts of the earth are presented in table 10. On the basis of these results, in general it can be stated that the forest lans has maximum infiltration capacity which varies between 20 cm/hr in thin forest and 124.2 cm/hr in Ash forest. In the hardwood forest and Oak forest it has been observed 77.6 cm/hr and 66 cm/hr, respectively.

PLATE - 6: A typical example of dense Root Network.

The pasture and grassland are second important lands where the infiltration rate are generally higher than crop and bare land, and lower than forest land. Table 10 reveals that the rate of infiltration in the pasture land varies between 1.8 cm/hr and 57 cm/hr, and in grass land it varies between 1.33 cm/hr and 21.5 cm/hr.

The crop lands have relatively higher infiltration rates than that of the bare land but lower rates than pasture and grass lands. Table 10 reveals the infiltration rate in the crop land generally varies between less than 1 cm/hr to 9 cm/hr.

The bare lands have minimum capacity of infiltration which varies between 0 to 1.14 cm/hr (Table 10).

The analysis of infiltration data from small forests and agriculture watershed in Doon Valley indicated that the rate of infiltration was twice in forest watershed as compared to agricultural watershed (Dhruvanarayan and Shastri, 1983). Dunford (1954) has reported reduced infiltration capacity of soul devoid of leaf litter in Ponderosa Pine Forests of Calorado, U.S.A.

Table - 10: Infiltration rates under different land use

Land use	Infiltration Rate (cm/hr)	Source
A - FOREST		
Ash forest	124.20	Molchanov (1963)
Oak forest	66.00	Molchanov (1963)
Shola forest	16.84	Tejwani, et. al. (1975)
Hardwood forest	77.60	Whipkey, (1969)
Forest land	26.00	Gupta (1980)
thin forest	3.5 - 20.00	Mohan and Gupta (1983)
Forest	26.00	Mistry and Chatterjee (1965)
B. PASTURE		
Open permanent Pasture	57.00	Musgrave and Holtan (1964)
Permanent pasture, moderately grazed	19.00	Musgrave and Holtan (1964)
Permanent pasture moderately grazed	2.00	Musgrave and Holtan (1964)

Contd.

Permanent pasture heavily grazed	13.00	Musgrave and Holtan (1964)
Old permanent pasture Grazed grass land	5.13	Tejwani et.al. (1975)
Pasture	1.80	Molchanov, 1964
4 to 8 years old pasture	4.60	Musgrave and Holtan (1964)
3 to 4 years old pasture	3.05	Musgrave and Holtan (1964)

C- RANGE LAND

Ungrazed range	Dry 6.4-8.4 Wet 4.2-5.5	Lusby, et. al. (1963)
Grazed range land	Dry 4.7-5.2 Wet 3.1-3.3.	Lusby et.al. (1963).

D- GRASS LAND

Grass land	21.5	Mohan and Gupta, 1983
Grass land	12.0	Gupta, 1980
Blue grass	0.4-1.53	Musgrave and Holtan, (1964)
Hay	1.50	Musgrave and Holtan, (1964)
Brush and grass	1.30-4.30	Kinchaid, et.al. 1966
Grass land	12.00	Mistry and Chatterjee (1965)

E - CROP LAND

Cultivated land	7.2	Molchanov (1963)
Crop land	8.0-41.5	Mohan and Gupta (1983)
Crop land	9.0	Gupta, 1980
Corn	0.2-0.46	Musgrave and Holtan ((1964)
Weeds and grain	1.00	Musgrave and Holtan (1964)
Weeds and grain	9.0	Musgrave and Holton (1964)
Strip cropped	10.0	Musgrave and Holton (1964)
Crop land	9.0	Mistry and Chatterjee (1965)

F - BARE LAND

Bare	0.20	Pearce, 1973
Bare	0.76-1.14	Musgrave and Holton (1964)
Bare	0.38-0.76	Musgrave and Holton (1964)
Bare	0.12-0.38	Musgrave and Holton (1964)
Bare	0.0-0.12	Musgrave and Holton (1964)

9.0 OVERLAND FLOW

Rainwater enters the soil through natural openings between soil grains and soil clumps. At times when the soil is saturated, movement of water into soil is blocked from the downward passage. Then the excess water flows over the land surface to lower level as overland flood. This is also known as sheet runoff.

The forest land produces overland flow only after heavy rains which varies from place to place depending upon the nature and types of forests (Fig.7). Experimental study conducted in three plots having different landuse patterns, namely forest, barren land and agriculture in an area having fairly uniform geology, climate and topography in Kumaun Himalaya (Rawat,1988) reveals that the least disturbed forest land produces the minimum overland flow while the maximum disturbed agricultural land produces maximum overland flow (Fig.8). Thus, removal of forest have increased the quantity of overland flow in the hillslopes by a factor approximately seven times greater in the Kumaun Himalaya (Fig.8).

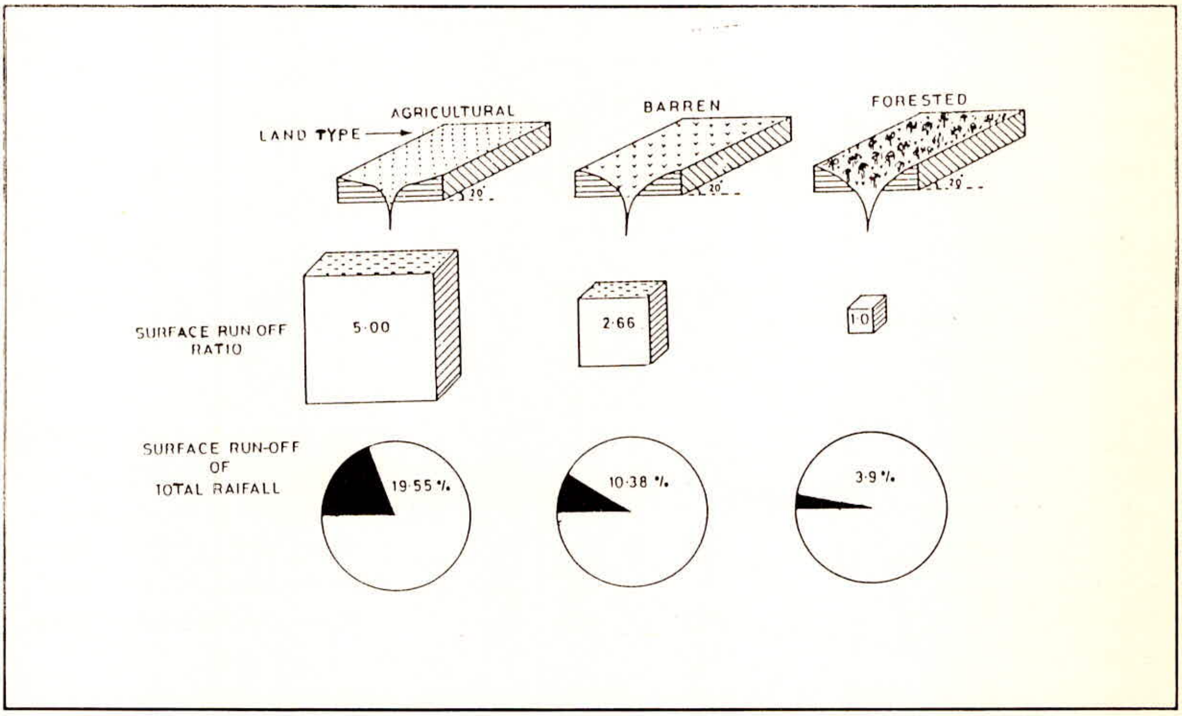


Fig. 8 Surface runoff or overland flow from forest, agricultural land and barren land, which have uniform geology, climate and topography in Kosi Valley (after Rawat, 1988).

Noble (1965) (cited in Gregory and Willing,1973) has indicated the effects of reduction in ground cover on overland flow. He has reported that from good ground cover (60-75% cover) about 2% of the total rainfall flows as overland flow while in poor ground cover (10% cover) about 73% of the total rainfall flows immediately as overland flow. Similar results have been reported by S.J. Ursil (cited in Strahler and Strahler 1977). Figure 9 gives data of annual average overland flow from several types of upland and reveals that overland flow decrease greatly with increasing effectiveness of the protective vegetal cover.

Results obtained from some studies done in the country and abroad regarding overland flow are presented in table 11. Based on these results it can be inffered that the rate of overland flow is minimum under forest land where it varies between 0.2 and 1.3% of the total rainfall under disturbed forests. Under grass land the rate of overland flow is more than forest but less than barren and cultivated land. In barren land the rate of overland flow varies from 2.7 to 14.0% of the total rainfall. In the barren and cultivated lands the rate of overland flow varies between 10 and 73% and 19.55 and 58.2% of the total rainfall.

Table - 11 : Overland flow in percent of the total rainfall under different landuse.

Landuse	Overland flow in % of the total rainfall	Source
Forest	0.49	Pandey, et. al. (1983)
Forest	0.2-1.3	Pathak (1983)
Quercus Forest	0.44	Pandey, et. al. (1983)
Oak forest	0.80	Meginnis (1935)
Scallered and lopped Oak forest	3.9	Rawat (1988)
Scrub and Oak	7.9	Meginnis (1935)
Dense grass	2.7	Hudson and Jackson (1959)
Good ground cover	2.0	Gregory and Walling (1973)
Fair ground cover	14.0	Gregory and Walling (1973)
Poor ground cover	73.0	Gregory and walling (1973)
Bare soil	47.0	Choudhri and Nizahi (1985)
Bare ground	38.0	Hudson and Jackson (1959)
Barren land	10.38	Rawat (1988)
Barren abandoned land	48.7	Meginnis (1935)
Cultivated land	47.00	Meginnis (1935)
Cultivated land	58.2	Meginnis (1935)
Cultivated land	19.55	Rawat (1988)

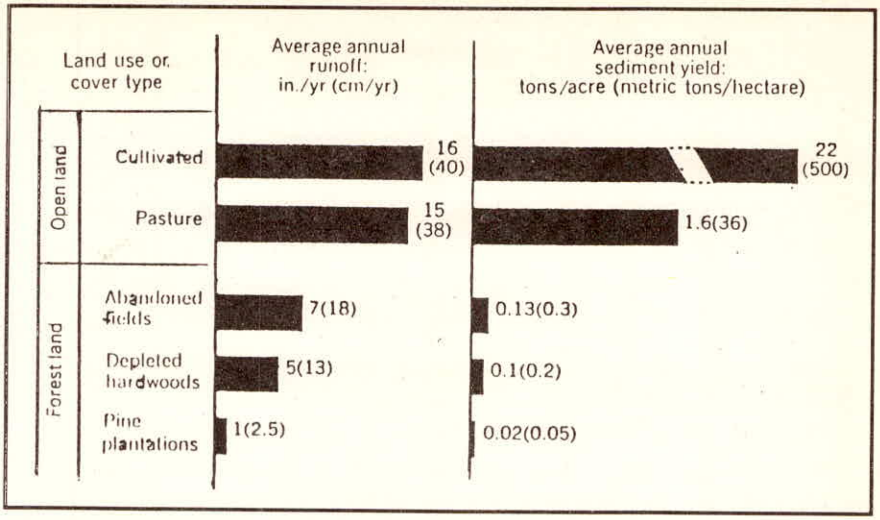


Fig. 9 : The bar graphs show that both surface runoff and sediment yield are much greater for disturbed (open) land than undisturbed forest land (after S.J. Ursic, 1965 cited in Strahler and Strahler, 1977).

10.0 SOIL MOISTURE

The emerging concensus in the forest influences in soil moisture shows that 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 flood in streams which could be a great help during drought situation; and soil moisture remains at a higher level under forest than grass.

10.1 Soil Moisture Suction

Technical literature (Gray,1977) shows that soil moisture suction, at low antecedent rainfall levels, is considerably higher in the forested areas than that of the deforested areas. At high levels of antecedent rainfall there appears to be little difference (Fig.10). In other words after intese and prolonged rainfall the hydrologic response of both forested and deforested slopes becomes same (Fig.10) Thus, a forest cover affects the dry side (during low rainfall) of the soil moisture suction but not the wet side (during heavy rains).

10.2 Storage Potential

Forest cover provides additional soil water storage potential. Because evapotranspiration from forest is greater than from other types of cover, the soil moisture under forest is more often dry during dry seson. If a flood producing rain occurs, sub-surface flow is diverted to retention storage under the forest and the flood peaks downstream may be reduced. When the soil mantle is recharged during rainy season, forest evapotranspiration plays a minor role in reducing the volume of direct runoff. Therefore, from an engineering design viewpoint, the additonal storage provided under forest cover cannot be depeded on, because the largest flood flows usually occur when antecedent soil moisture is high, with or without forest cover (Hewlett,1982).

11.00 CHANNEL RUNOFF

The excess quantity of water over and under the ground ultimately flows in a channel known as channel runoff (Plate 8.) It is generally believed that by removing the forest cover, the amout of channel runoff increases and vice-versa. A brief account of some of the recent experimental studies in this regard is discussed below.

In Japan it was dscovered that in losing a 69% pine cover, the water yield of an 69 hectare catchment increased by 110 mm. Base flows were 50-100% greater at different seasons of the year and the reason was the reduction in evapor-transpiration following the death of trees (Abe and Tani,1985).

A - Very dense Oak Forest (Syahi devi, Almora): Overland Flow, Sheetwash Erosion - Controlled : Infiltration V.High Groundwater Storage-V. High

PLATE - 7 : Overlandflow, Sheetwash Erosions etc. Depending upon the nature and type of Forest

B - Pine Forest (Basoli, Almora) : Overland Flow, Sheetwash Erosion - Litttle, Infiltration - Moderate.

C - Disturbed Pine-Oak mixed Forest (Kathpuria, Almora): Overland Flow and Sheetwash Erosion Accelerated; Infiltration - Decreasing Trend.

D - Scattered Pine Forest (Syali Dhar, Almora): Overland Flow and Sheetwash Erosion highly Accelerated, Infiltration capacity low, Groundwater Storage V.low.

Pierce, et.al. (1970) has also reported that on the effect of total elemination of the forest vegetaion of a New Hampshire watershed on stream quantity. They found stream flow increase of 340 mm to 346 mm per water year with a large part of this augmentation during the previous flow season.

PLATE - 8 : Channel Runoff : and hydrological station in St. Andrew's National Park Forested Catchment, U.S.A.

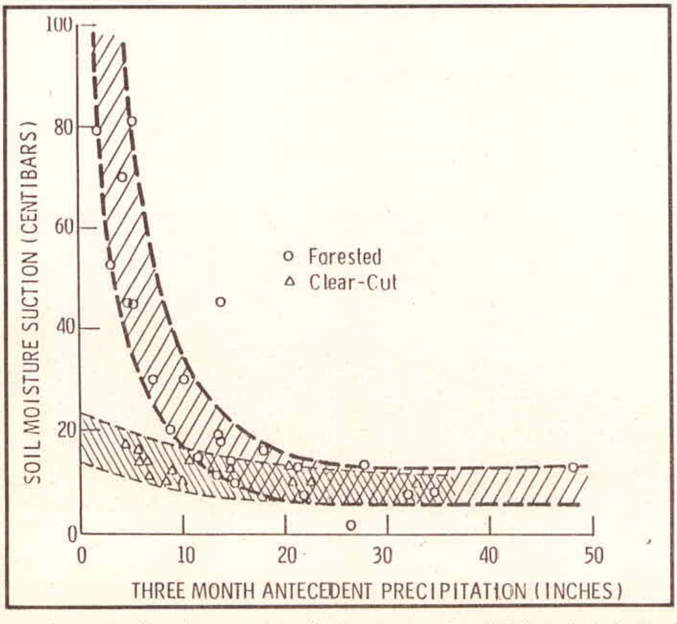


Fig. 10 : Comparison of soil moisture suction in the forested and deforesteds in the H.J. Andrews Experimental Forest, U.S.A. (after Gray, 1977).

Results from the Fazequt hydrological station in Swat, Pakistan show that, of a 57 to 61 mm rainfall event, 49-58% was converted to runoff and of a 19.5 to 21.4 mm event 5 to 23% was converted to runoff (P.F.1. 1987 unpublished data)

A sal forest watershed near Dehra Dun in the foothills of Garhwal, Western U.P. Himalaya, was cleared for agriculture as part of a paired catchment study. The volume of channel runoff increased by 15% and the peak rate of runoff by 72% compared to an undisturbed catchment (Shastry et.al. 1986). In sum less vegetation means more channel runoff.

It has also been observed that with increasing effectiveness of the protective vegetation cover or afforestation the channel runoff decreases considerably. For example, the average annual runoff in the northern Mississippi, USA has decreased greatly with increasing effectiveness of the protective vegetativer cover (Strahler and Strahler, 1977). Similarly, planting eucalyptus in a degraded catchment near Dehra Dun, reduced discharge by 28% and the peak flow by 73% (Mathur,et.al.1976). Increasing grass yield from 659 q/ha. to 85 q/ha in a sloping (24.2 degree) grass land in the Siwalik foothill, decreased channel runoff from 38% to 31% of the incident rainfall (Agnihotri, et.al.1985). In sum more vegetation means less channel runoff.

Nevertheless, it is on off repeated, if less easily substantiated complaint of the hill people of the fragile Himalaya that streams are drying up; as a result of forest degradation (Haigh et.al. 1988). However, there is more than anecdotal evidence for this phenomenon, which appears to be caused by dramatic changes in the infiltration and water storage capacity of the soils in areas which have suffered forest degradation (Haigh, et.al.1988). Almora Town, the traditional capital of Kumaun, eastern Uttrakhand straddles a ridge with steep slopping sides. Since 1560 A.D. its demand for timber and fuel has stripped away local forest cover. The area once possessed some 360 springs but to-day, less than 10% still function (Joshi et.al.1983). A detailed survey of springs in the Gaula River catchment Nainital District found that 45% have gone dry in recent memory mainly due to deforestation (Bartarya, 1988; Valdiya,1985; Moddi,1985). In U.P. Himalaya as a whole 55% of springs are said to have dried up during the last 20 years while the number of villages suffering water scarcity may have increased by 40% in the last 13 years (U.S.N.,1986).

A study of a typically Lesser Himalayan Gaula River in the outer belt (Bartarya, 1988) showed that the yearly runoff at Jamrani dropped from an average of 8809 m^3/day in the period 1958-1964 to any 5007 m^3/day during 1965-1981, that is, a drop of 35% in only one and a half decade (Fig.11B) due to mainly rackless deforestation and other anthropozenic activities. Similar trend of decreasing channel runoff is shown by a stream of the higher altitudes. (Fig.11A).

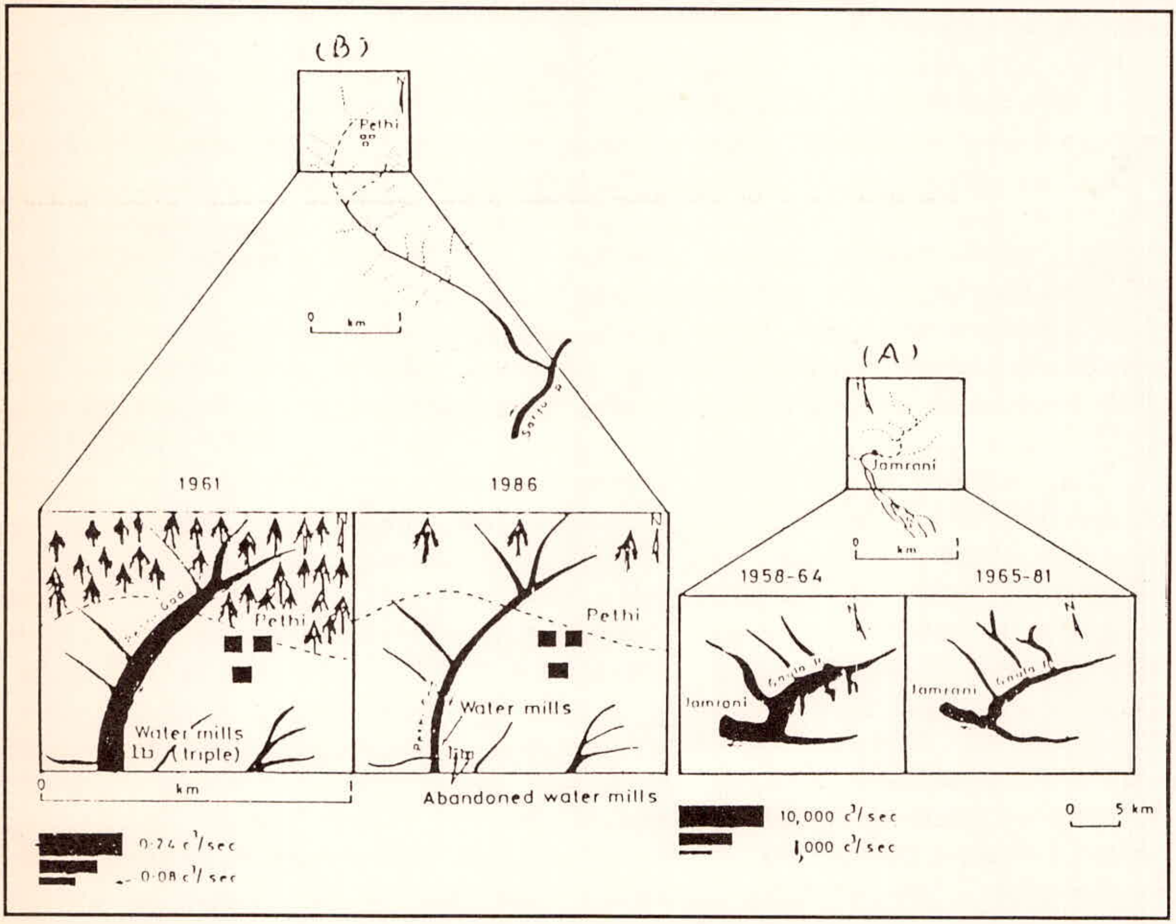


Fig. 11 : Diminishing discharges of Kumaun rivers : (A) between 1958 and 1964, the average discharge of the Gaula River at Jamrani was 8809 m³/day, and between 1965-1981 it came down to 5007 m³/day; (B) Water discharge of a small tributary stream of the Sarju Rine was 292 m³/day in 1985, an amount sufficient to serve one water mill. About 25 years earlier when its catchment was covered by dense Oak forest, the capacity of this stream was sufficient to serve 3 water mills at a time. Two water mills have been abondoned (after Rawat, 1988).

Experimental study conducted in the micro catchments of the Nana Kosi basin, district Almora (Rawat 1987) revels that in the month of the heaviest rainfall, streams of the greatly disturbed land i.e. agricultural land have maximum channel capacity carrying water at the rate of 8734.3 $m^3/Km^2/day$ (Fig.12), while the streams of the forest land, under identical rainfall, rocks and terrain conditions have the minimum channel capacity i.e., 4478.2 $m^3/Km^2/day$ (Fig.11) which is about 50% lower than the agricultural land. During the driest month, the situation of channel runoff is opposite. The agricultural land has minimum channel capacity of 180 $m^3/Km^2/day$ (Fig.12). It is evident from this experimental study that vegetation means less channel runoff during monsoon rains and more channel runoff during dry months in comparison to the areas of devoid of vegetation cover. Due to this fact the rackless deforestation in the fragile Himalaya has alarmingly increased the channel runoff during monsoon rains and generates floods. A small fraction of rainwater infiltrates and percolates which results the lowering of groundwater level and consequently the springs on either sides of the hillslopes are becoming perinomel or drying up.

Most researchers agree that a reduction in forest cover tends to lead an increase in flood peaks and in runoff, due to substantial reductions in infiltrations. The land area considered by India to be flood prone has doubled in the last 10 years to 1989 from 20 to 40 million hectares (Govt. of India, 1989).

12. GROUNDWATER

Very few studies have been conducted to define the effect of vegetation on the groundwater and there still appears to be controversy in the state of art of present knowledge.

Boughton (1970) has reported that groundwater table increases due to deforestation. In northern Thailand, Chunkao (as cited in Hamilton and King,1983) has reported a decrease in well levels in dry seasons following reforestation. In Southern Australia, Cassells (cited in Hamilton and King,1983) has reported that some areas under grass, about 10 percent of the annual rainfall (632 mm) reached the underground aquifer, but under nearly pine plantation no recharge at all occured. Similar results have been observed by Samraj (1984). He has deducted that plantation of Eucalyptus trees in Nilgiris in India has resulted in significant lowering of base flows.

On the other hand American studies claim that groundwater table collapsed as a result of deforestation or forest fire and Swiss studies indicate no effect on water table by forest cover changing to grass (Hamilton and King,1983).

The effect of vegetation of groundwater is not universal. It depends upon

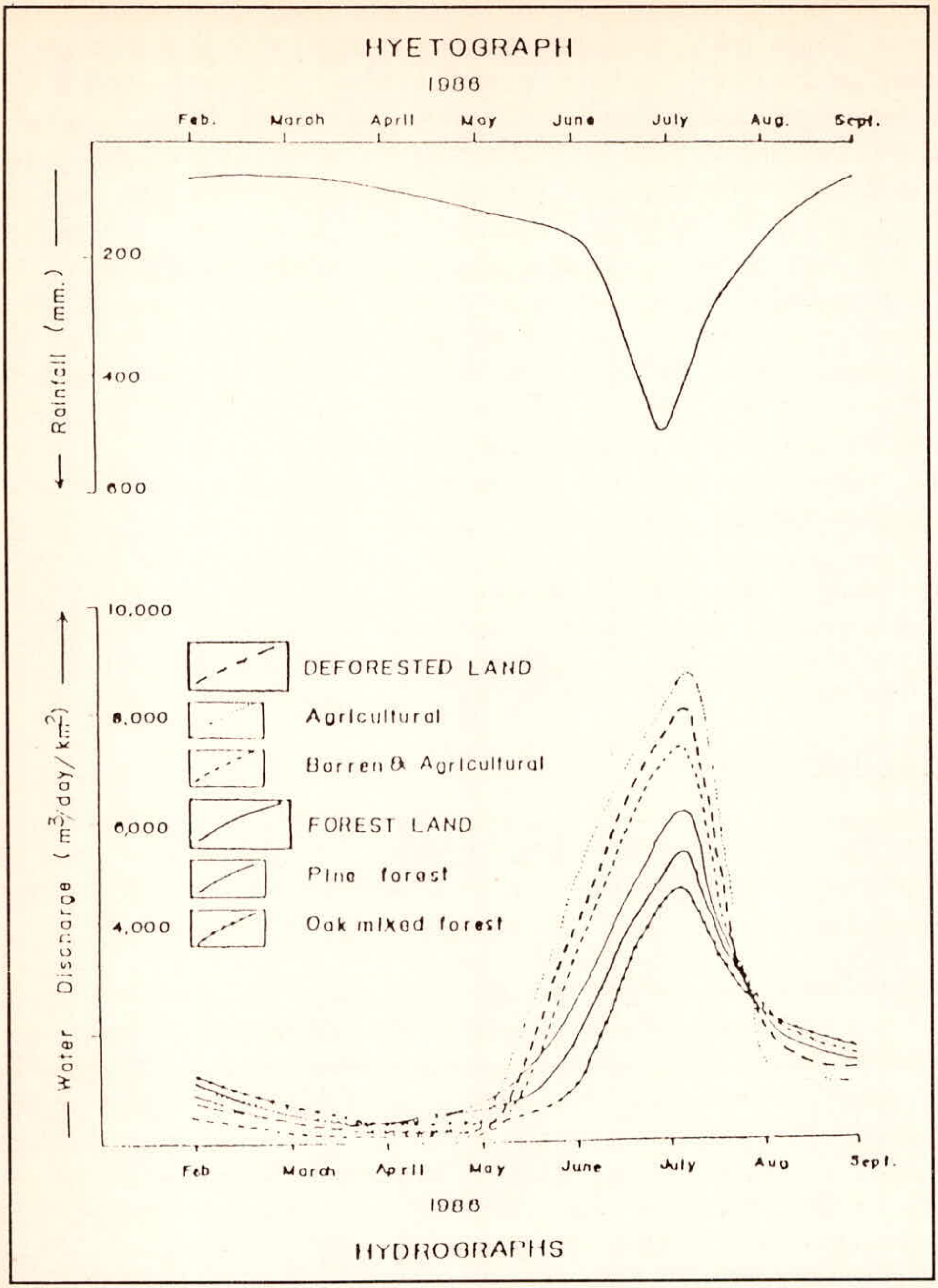


Fig. 12 : The hydrographs and hyetograph under identical geological geomorphological and climate conditions but different landuses in the Nana kosi basin (after Rawat, 1986).

the topographic condition and underlying rock material. In the plains and coastal plain, there is little impact in the infiltration rate but very high impact in the evapotranspiration due to deforestation. Hence it is common in these regions that water table rises following forest cutting, due to reduced evaportranspiration of cutover land. But in the steep mountains terrain, like the young, lofty and fragile Himalaya, there is very high effect in the infiltration rate and relatively low effect in evapotranspiration due to deforestation. Hence it is common in the steep mountainous terrain that water table generally depleted following forest cutting. It is due to drastic reduction in infiltration from the deforested land. Due to depletion in groundwater level the springs are drying-up and stream discharge is dwindling in the steep terrain of the Himalaya (see section 11).

13.0 WATER QUALITY

Vegetation play a significant role in changing the concentration and solute load of rainwater on different pathways, i.e. tree canopy, forest floor, sub-surface flow and channel flow.

13.1 Tree Canopy Water

Through fall and stemflow are the major pathways by which the concentration of rainwater is changed. Recent experimental study (Sinun, et.al.,1992) conducted in the tropical rainforest of Malaysia has shown that rainfall was found to be extremely dilute, with no element exceeding a concentration of 1 mg. per litre. After travelling through tree canopy, the concentration of sodium decreases, but all other measured elements increase, especially silica and potassium which are leached and washed off the foilage (Table 12)

Table - 12: Mean chemical composition in milligrams per litre of water in various pathways of the forest hydraulic system at east Ridge Danun Valley (after Sinun, et.al.1992)

Parameters	Ca	Mg	Na	S	P	K
Rainfall	0.22	0.07	0.02	na	0.08	0.18
Throughfall	0.81	0.34	0.01	0.59	0.30	6.04
Overland Flow	3.34	1.14	1.03	2.26	0.09	5.22
50 cm deep	1.40	0.81	0.99	1.81	0.16	2.52
100 cm deep	0.55	0.53	0.66	4.76	nd.	0.89

Due to increase in the concentration of chemical elements, the annual quantities of water moving through vegetation also increase considerably. In the tropical rainforest the pattern of chemical transfer from vegetation cover was recorded 3.3 times higher (5.87 tonnes/Km^2) in case of Ca than that of the rainwater (1.76tonnes/Km^2), 8 times higher (4.50 tonnes/Km^2) in Si, 3.3 times higher (2.11 tonnes/Km^2) in P (0.69 tonnes/Km^2) and 28.6 times higher (41.16 tonnes/Km^2) in K (1.44 tonnes/Km^2).

13.2 Forest Floor Water

Forest floor are generally covered by fresh litter, partially decomposed litter and completely decomposed layer. The overland flow water exhibits the influence of contact with biota and mineral matter, with considerable increase in concentration of mineral derived Ca, Mg, Si, Na and P. Study in the tropical rainforest (Table 12) has recorded 4.1 times increase in the concentration of Ca in overland flow water (3.34 mg/1) than that of the throughfall water (0.81mg/1). Similarly, the increase in other chemical elements such as Mg, Na, and Si is recorded 3.3, 1.03 and 3.8 times high in overland flow water than that of the throughfall water (Table 12).

13.3 Sub-Surface Water

Mineral uptake is one of the important process of forest hydrology. Due to mineral cycling through plant root uptake the concentration of chemical elements gradually decreases into the sub-surface soil, Sinun, et.al.(1992) have recorded 2.4 times decrease at 0.5 m depth and 6.1 times decrease at 1 m depth in the concentration of Ca in sub-surface water in comparison to forest floor water, i.e., overland flow (Table 12). Table 12 contains such changes in other chemical elements, i.e., Mg, Na, Si and K due to plant uptake.

13.4 Stream Water

It has been perceived by conducting experimental studies that quality of stream water is also effected by different types of vegetation species and by the entire forest cover.

Experimental studies of Pierce et.al., (1970) announced radical changes in the stream chemistry in response to the vegetation removal, including a 50% rise in nitrate concentration a 3 to 20 fold elevation in cation levels, and particulate matter increases to 9 times the previous concentration.

Rawat (1988) has reported dramatic changes in physiochemical properties of streams water from the micro watersheds, of Kumaun Himalaya, identical in geology, geomorphology and climate inputs but different in landuse pattern. Table 13 contains the mean values of physiochemical properties of stream water under different landuse pattern.

Table - 13: Mean Values of Physiochemical properties of Stream's Water under different landuse pattern in the Nanakosi basin, Kumaun Lesser Himalaya (Rawat,1988)

Physiochemical Parameters	Landuse			
	Oak-Pine Mixed	Pine	Barren/ Agriculture	Agriculture
Ph	7.7	8.1	8.	8.4
Hd (mg/1)	43.0	45.0	60.0	78.0
Alk (mg/1)	48.0	51.0	54.0	58.0
HCO3 (mg/1)	57.3	60.8	67.0	63.0
Co3 (mg/1)	0	0.32	0.74	0.65
Na (mg/1)	3.80	4.50	4.60	5.28
Ca + Mg (mg/1)	0.42	0.41	0.60	0.71
K (mg/1)	0.45	0.52	0.70	0.80
TDS (mg/1)	34.45	92.75	106.0	212.0

14.0 SOIL EROSION

The major role of forest is to interception of the rain drops so that their Kinetic energy is dissipated by the plants rather than imparted to the soil. Generally forests are the most effective in reducing erosion because of their canopy. For adequate erosion protection at least 70% of the ground surface must be covered (Fouriner, 1972; Elwell and Stocking, 1976). The effectiveness of a forest cover in reducing erosion depends upon the height and continuity of the canopy, the density of the ground cover and the root density (Plate 6). The height of the canopy is important because water drops falling from 7 m, may attain over 90% of their terminal velocity. Further raindrop intercepted by the canopy may coalesce on the leaves to form larger drops which are more erosive. A ground cover not only intercepts the rain but also dissipates the energey of running water, imparts roughness to the flow and thereby reduces its velocity. Since erosion rates vary with either the cube or fifth power of velocity, the effect on soil loss is considerable (Morgan,1979).

Consolidation of the soil mass by root system (Plate 6) is one of the primary function of vegetation by which soil erosion is controlled. The top soil consists of two components, mainly the so called depositional soil due to deposition of eroded soil and on the weathering surface material. The vegetation has a large influence on these both the parts of top soil.

The depletion of forest has imposed a serious problem of accelerated erosion globally. Removal of vegetation cover upsets the natural rate of erosion and the ecosystem within a short temporal span. On a land covered by grass, even a deep layer of overland flow causes little erosion because the energy of moving water is dissipated in friction with grass stems, which are tough and elastic. On a heavily forested land, countless check dams made by leaves, twigs, roots and fallen tree trunks take up the force of overland flow. Without such vegetation cover the eroding force is applied directly to the bare soil surface, easily dislodging the grains and sweeping them downslope.

On a world scale investigation of the relationship between soil loss and landuse pattern (Table14) show that erosion reaches maximum upto 75 Kg/m^2/yr in the bare land while it approaches maximum upto 0.30 kg/m^2/yr only under the natural conditions.

Table - 14: Rates of soil erosion under different landuse pattern (kg/m^2/yr)

	Natural	Cultivated	Bare
China	0.20	15.00 - 20.00	28.00 - 36.00
U.S.A.	0.003 - 0.30	0.50 - 17.00	0.40 - 9.00
Ivory Coast	0.003 - 0.02	0.01 - 9.00	1.00 - 75.00
Nigeria	0.05 - 0.10	0.01 - 3.50	0.30 - 15.00
India	0.05 - 0.10	0.03 - 2.00	1.00 - 2.00
Belgium	0.01 - 0.05	0.30 - 3.00	0.70 - 8.20
UK	0.01 - 0.05	0.01 - 0.30	1.00 - 4.50

Source : Bollinne, 1979 Browing, Norton, McCall and Bell, 1948; Fournier, 1972; Jianag Qi and Tan 1981; Lal, 1976; Morgon, 1981,Rao,1981; Roose,1971, Douglas,1969

Results of the studies conducted by Meginnis (1935), and Hudson and Jackson (1959) in different experimental plots of different landuses are presented in table 15 which reveals that the rate of soil loss approaches maximum upto 24.4 mm/yr in the barren abondoned land and 29.8 mm/yr in the agricultural land while on forest pasture and scrub lands iut approaches between 0.008 0.10 mm/yr only.

Table - 15 : Rate of soil loss (in mm/yr) from differnt landuse

Landuse	Soil loss	Source
Oak	0.008	Meginnis (1935)
Dense grass	0.018	Hudson and Jackson (1959)
Pasture	0.030	Meginnis (1959)
Scrub-Oak	0.10	Meginnis (1959)
Bare land	2.30	Meginnis (1959)
Barren abondoned	24.40	Meginnis (1959)
Cultivated	29.8	Meginnis (1959)

Noble (1965) has indicated the effects of reduction in ground cover from good (60-75% cover) through fair (37% cover) to poor (10% cover) on sediment production. Ursic (1965) (cited in Strahler and Strahler, 1977) has suggested that sediment yield decrease greatly with increasing effectiveness of the protective vegetative cover and has reported that sediment yield are much greater for open land than for land covered by forest and Shrubs (Fig.9).

Results of the catchment responses, as cited in table 16 also present the same trend. In Tjiloetoeny Java the sediment yield from cultivated catchment is recorded more than 200 times higher than forested catchment (Table 16).

Table - 16: Comparison of sediment yields from forested and cultivated tropical catchment

Location	Sediment Yield $m^3/km^2/Yr$	
	Forested	Cultivated
Mbeya, Range, Tamania	6.9	29.5
Cameron Hills Malaysia	21.1	103.1
Tjiloetoeng, Java	900.0	1900.0
Biarron, Queensland	5.7	13.6
Millstream,. Queensland	6.2	12.3
Northern Ra, Trinidad	1.8	16.0
Apiodoume, Ivory Coast	97.0	1700.0

Source: Douglas (1969)

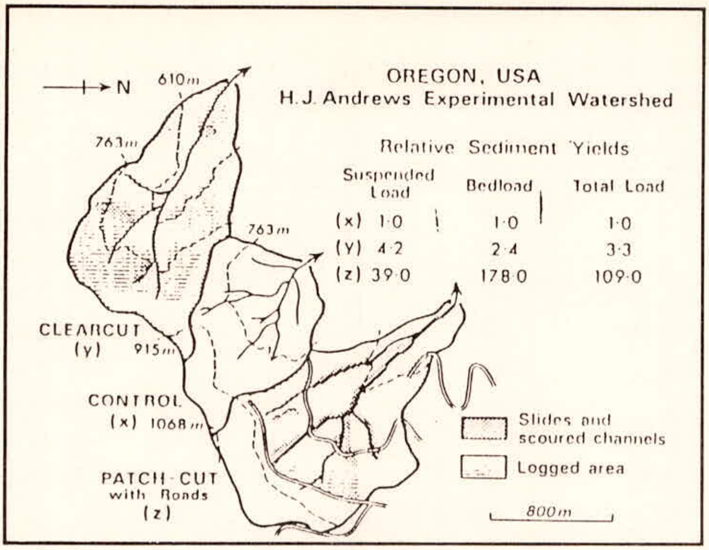


Fig. 13 : Relative sediment yield from the control, clearcut and patchcut watersheds in H.J. Andrews experimental watershed, USA (after Fredriksen, 1970).

Fredriksen (1970) also compared the response of three small watersheds, i.e. clearcut, control and patch cut. Contrast in sediment yields between the three catchments were found very significant (Fig.13). Recently, Rawat (1988) has also reported dramatic changes in the suspended (Fig.14) and dissolved load (Fig.15) load yields from micro watersheds of the Kumaun Himalaya. This study has noticed that under identical geological, geomorphological character and climatic inputs the poorly managed agricultural land produces 24 times higher suspend load and 5 times higher dissolved load in the stream water than that of the Oak mixed forest.

Based on various studies, some classified rates of soil loss are listed in table 17.

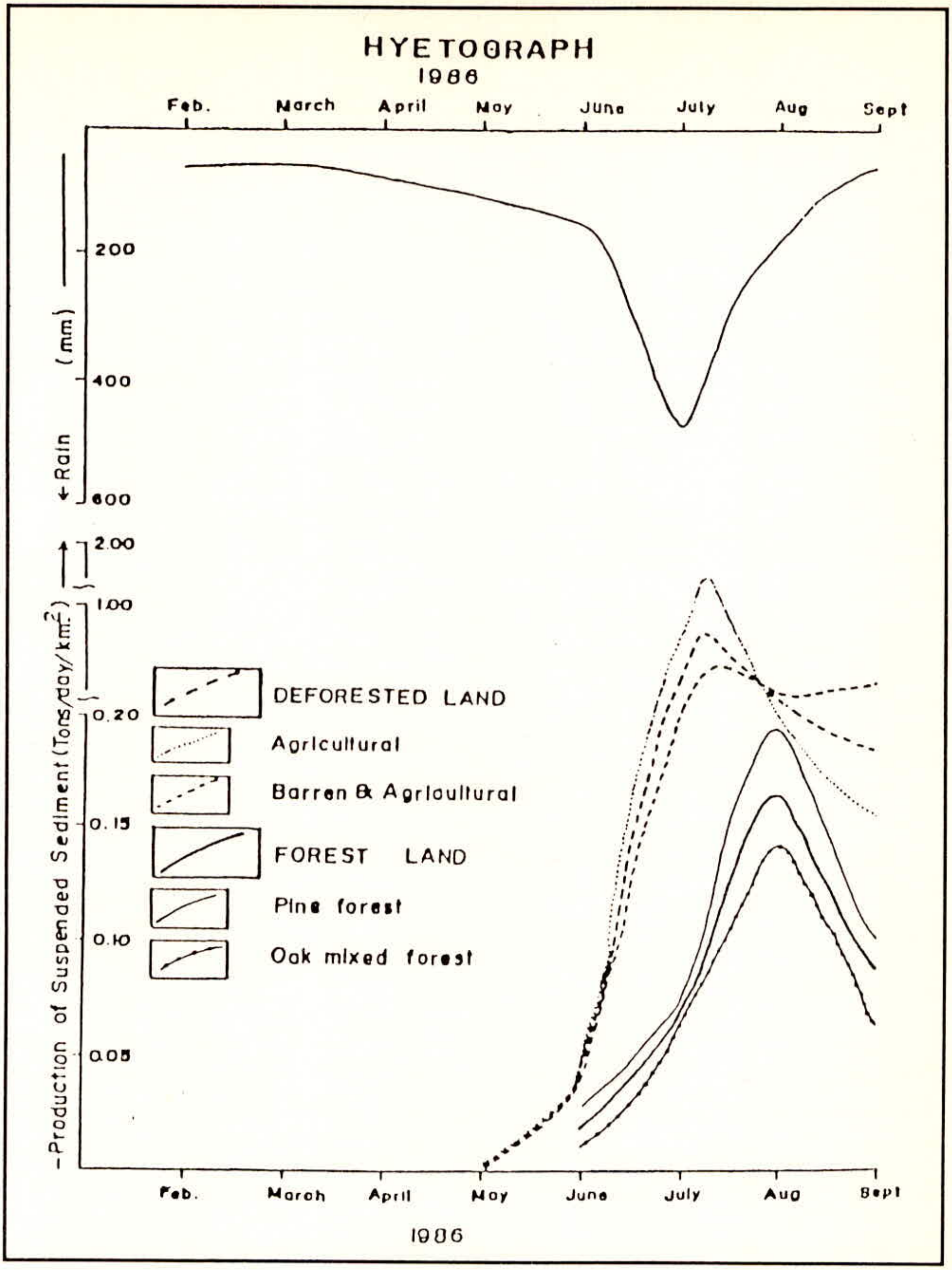


Fig. 14 : The hyetograph and its function, i.e., suspendedflow graph on different landuse pattern under identical, geological and geomorphological character in the Nana Kosi basin (after Rawat, 1988).

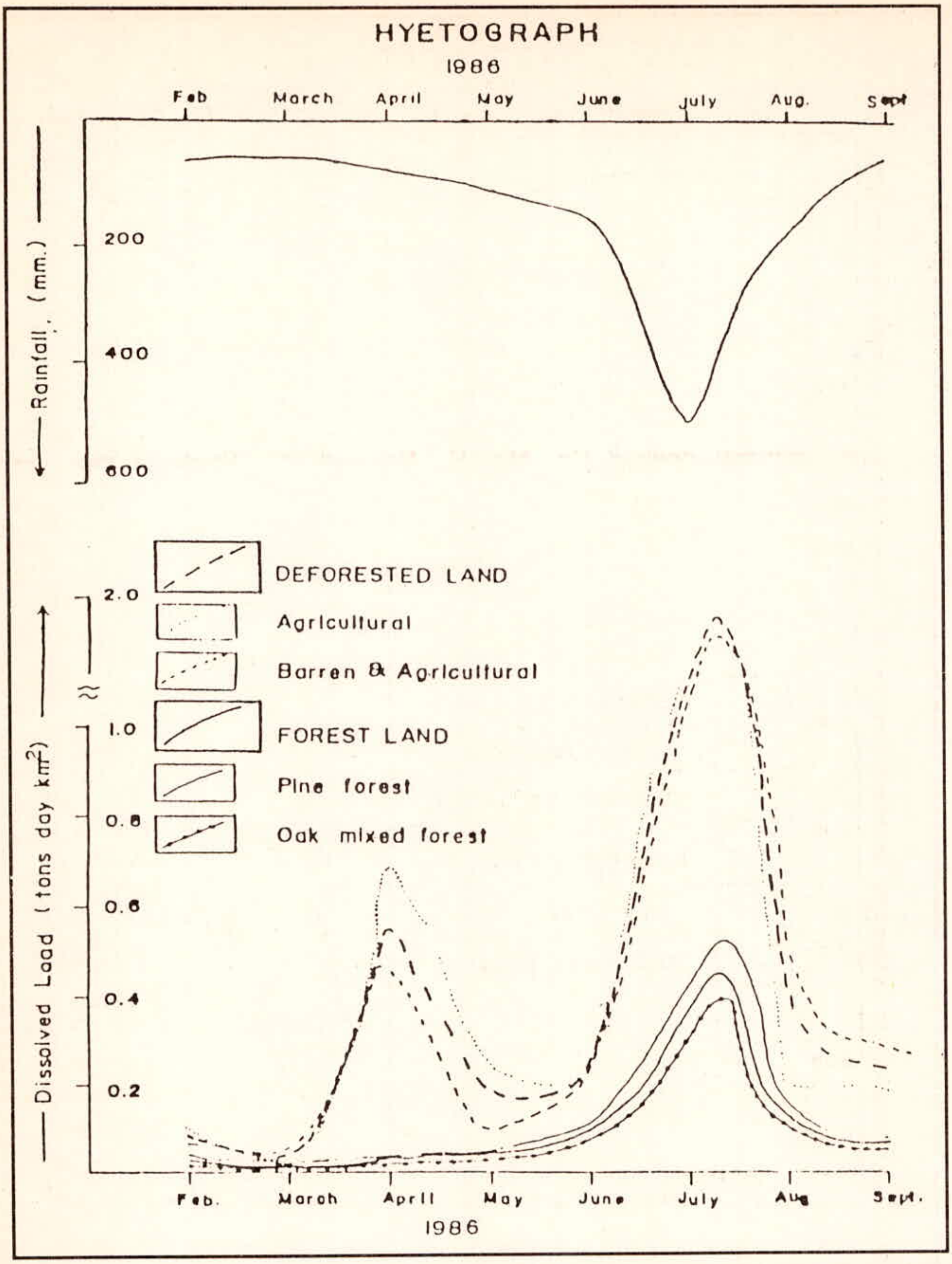


Fig. 15: The hyetograph and its function, i.e., dissolved load flow graph in different landuse pattern under identical geological and geomorphological character in the Nana Kosi basin (after Rawat, 1988).

Table - 17 : Rates of soil loss from different Landuses

	Landuse type (tonne/ha/yr)	Soil loss	Source
100% Sal forest (protected)		0.06	
Forest	Bamboo forest (well managed)	0.29	Compiled by Bhatia (1986)
	100% Sal (dense well managed)	0.94	
	Well managed forest	0.6	
	Ill managed forest	20.60	
	Oak forest	3.2	Pandey et.al.(1983)
	Forest	15.5	Sinun et.al.(1992)
	Forest	29.3	Sinun et.al.(1992)
Grass land	Gaint grass	0.57	Compiled by Bhatia (1986)
	Thin grass	0.68	
	Grass NW Himalaya	1-2.1	
	Good ground cover	12	Noble (1965)
	Fair ground cover	122	
	Grass ground cover	135	
Grazing land	Not grazed	0.40	Compiled by Bhatia (1986)
	Properly grazed	0.79	
	overgrazed	2.37	
Fellow land	Bare fellow	42.7	
	Cultivated fellow	70.7	
	Cultivated fellow NE Rajasthan	4.0	
	Cultivated fellow Gujarat, Assam	5.16	
	Cultivated fellow upper Gangetic plain	15.67	

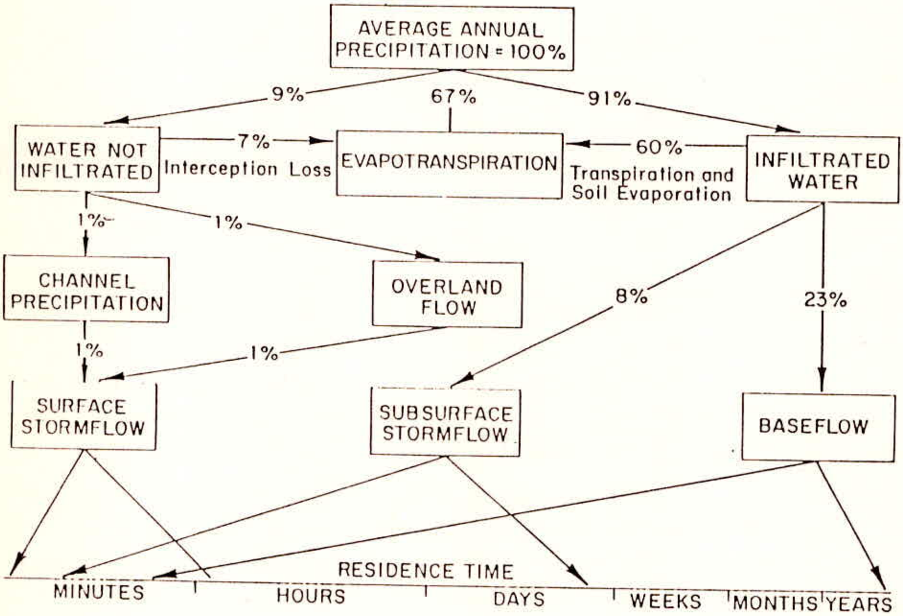


Fig. 16 : A model of apportionment of rainwater from different pathways through a complex hydrological system and the eastern U.S. Forest (after Hewlett, 1982).

15.0 LAND STABILITY

Forest enhance the stability of steep slopes by mechanical reinforcement from root system and by soil moisture depletion and transpiration. Forest may also improve stability by a buttressing or soil arching action particularly in sandy slopes.

Soil moisture depletion by transpiration leads to drier soils and longer recharge tomes which in turn improves shear strength and stability. Interception and transpiration by a forest canopy partially mitigate or delay onset of waterlogged conditions in a slope. A forest slope might not reach a critical moisture stress level as quickly. Also drier condition set least part of the year may retard the rate of weathering in the soil profile and hence slow down the decrease in shear resistance and instability over time. Gray (1970) argued that forested slopes which tend to be drier may be able to tolerate a storm of greater intensity or duration before a critical saturated condition develops. Thus, forest can be expected to affect land creeps rates through their influence on soil moisture characteristics. Deforestation results in a decline of root strength which in turn effects soil shear strength. Reduced evapotranspiration following deforestation may result in wetter conditions (Gray, 1970; Rothacher, 1971) and a greater duration of a annual period of land creep activity, thereby, increasing the annual creep rate. Thus, as forest does tend to maintain high suctions in the dry season and thus limit the duration and extent of creep by maintaining a higher mobilized shear resistance relative to the yield shear stress over a longer period of time.

Surface creep rates measured in a deforested slope and adjacent forested slope in the experimental watershed in H.J. Andrews Oregon, U.S.A., can be ascertained from table 18. Average creep rate in the deforested slope (0.59 mm/yr) is more than twice the creep rate in forested slope 0.24 mm/yr).

Table - 18 : Average down slope movement rates of land surface under forested and deforested watersheds (after Gray, 1977)

Location	Status	Land Movement Rate mm/yr
Watershed No. 1 H.J. Andrews, Oregon, USA	Deforested	0.59
Watershed No. 2-1 H.J. Andrews, Oregon, USA	Forested	0.24
U.S. Naval Radio Station, Washington	Deforested	0.71

CONCLUSIONS

Based on the available results on forest influence in hydrological parameters, the following can be concluded.

1. Under forest cover the rainwater has to travel through a complex hydrological system which increases the residence time of water or age of water (Fig. 16).

2. About 85% of the total rainfall reaches to the forest floor by interception processes, i.e., throughfall and stemflow. Out of which about 82% (range 81% in tropical broadleaved forest to 83% in temperate coniferous forest) reaches the forest floor by throughfall, and about 3% (range 0.3% in temperate coniferous to 9.0% in broadleaved forest) by stemflow.

3. The intercepted water storage is returned back to atmosphere. The average interception loss accounts for 35% of the total rainfall out of which 22% (range - 8% in Pine forest to 34% in Sal forest) accounts for canopy interception, 8% for litter interception and 5% for ground flora interception.

4. Depending upon type & structure of forest about 38% to 50% of the total rainfall is returned back to the atmosphere by evapotranspirations.

5. Infiltration rates are relatively more higher under forest cover (average-rate 50 cm/hr, range-20 to 124 cm/hr) compared to other land, i.e., pasture (average-2 cm/hr, range-2 to 57 cm.hr), grassland (average -9 cm/hr, range-0.4 to 21.5 cm/hr), agricultural land (average-8 cm/hr, range-0.2, - 41 cm/hr and bare land (average-0.5 cm/hr, range-0to 1.4 cm/hr).

6. Overland flow is relatively very low under forest cover (average 2% of the total rainfall, range 0.2 to 7.9%) compared to other land uses, i.e., grass land (average 6%, range 2 to 14%) agricultural land (average 41%, range 19 to 47%) and barren land (average 43%, range 12 to 73%).

7. Forest cover provides additional soil moisture storage potential because evapotranspiration, the soil moisture under forest is more dry during dry season. If a flood producing rain occurs, sub-surface flow is diverted to retention storage under the forest land and the flood peaks downstreams are generally controlled.

8. Less vegetation means more groundwater and channel base runoff under level terrain such as plains/coastal plains due to less evapotranspiration following deforestation, but less vegetation means less groundwater and less channel base flows on the steep terrain due to drastic reduction in infiltration following deforestation.

9. Vegetation also play a significant role in changing the Chemistry of rainwater. Due to wass off the foliage at tree canopy and due to biota-mineral contact at forest floor, the concentration and solute load of water increases considerbly. A subsurface water due to mineral uptake by plant roots the concentration of chemical elements gradually decreases in comparison to the forest floor water. Vegetation removal may increase the concentration in cation levels upto 13 to 20 times higher in streams water.

10. The average land creeping rate on deforested land may increase more than twice the creep rate in forest land. Forest enhance the stability of steep slopes by mechanical reinforcement from root system and by soil moisture depletion and transpiration.

11. The major role of forest is to interception of the rain drops so that their kinetic energy is dissipated by the plants which imparts roughness to the flow and thereby reduces its velocity and control erosion. The depletion of forest has imposed a serious problem of a accelerated erosion globally. Removal of vegetation cover upsets the natural rate of erosion and the entire ecosystem within a short temporal span. Available studies have shown that the soil erosion may accelerate upto more than 200 times following deforestation. For adequate erosion protection at least 70% of the ground surface must be covered.

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