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Review on the Role of Forest Landscapes in Watershed Hydrologic Processes

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Abstract
Forest hydrology examines the flow paths and storage of water in forests and how forest disturbance and management modify the hydrologic response. Despite, the huge amount of data and knowledge acquired over the world, the result of deforestation seems to reappear every time a new catastrophic flood or drought occurrences somewhere in the world. This paper reviews literatures on the relationship between forest cover and watershed hydrologic processes. There is strong evidence that in well-watered regions, at least, stream flow response is proportional to reduction in forest cover. Response in stream flow may be almost immediate or considerably delayed, depending on climate, soils, topography, and other factors. Most of the existing literature suggests that forest has potential to reduce annual water yield and base flow, but have limited effects on peak flow rates and flooding events. The variability of the hydrologic effects is large due to differences in watershed hydrologic processes which are controlled by climate, soils, and the stage of vegetation development. Re-forestation campaigns are not likely to cause large scale changes in water yield, base flow, and flood peaks before the hydrologic properties of degraded soils are fully improved. By degrading forests, which is essential for erosion control by stabilizing the soil with roots, erosion occurs and as a result the stream carries more sediment and water becomes worse. The presence of vegetation cover in general and forest cover in particular modifies the climatic parameters and creates a microclimate whose characteristics depend on the general climate itself and the physical characteristics defining the nature and structure of the cover.
Keywords: Forest, Hydrology, deforestation, Hydrologic impacts

1. Introduction

1.1 Concepts about Forest Landscape & Watershed Hydrology

Interception, evaporation, transpiration and changes in soil water storage are hydrologic processes that affect the amount of precipitation that would be available for runoff. Forest cover directly affects these processes and modifies watershed hydrologic processes that again directly influence the water balance of the watershed in space and time (Hetherington, 1987). Hydrologists and geomorphologists are often consulted to predict or detect the potential effects of forest management activities on watershed processes.

1.1.1 Forest Landscape

According to the statement given by (Change, 2003) forest landscape refers to the area where the biotic community is predominated by trees and woody vegetations that cover a large area with an array of complex flora and fauna. Moreover, this term is explained by (Abdul Rahim, 1988) as it is not a mere collection of trees rather it is an ecosystem with different components and functions. Forests occupy approximately one-third of the earth's land area accounting for two-thirds of the leaf area of land plants and thus play a very important role in terrestrial hydrology (Bond et al., 2007). Forests are found where there are large quantities of water, normally where precipitation is abundant or in around riparian areas where soil moisture is high (Calder, 2002). For instance, one can consider the tropical rainforest of the world which exists with heavy rainfall throughout the year. The southwest and western forest landscapes of Ethiopia alive in areas where there is an intense and long lasting rainfall is common. No matter what type of the forest is, the plant sizes, canopy density, litter floor and root systems are significantly taller, greater, thicker and deeper than other vegetation types (Andreassian, 2004). These characteristics make forests able not only to provide a number of natural resources, but also to perform a variety of environmental functions (Change, 2003).

Many established forests have managed to achieve one or more of these environmental functions, while others are preserved to prevent reduction in biodiversity and degradation of the ecosystem (Susswein *et al.*, 2001). We have all probably heard or read that, the removal of forests and/or deforestation, will have a negative impact on the flow of waterways, the volume of water in waterways, cause floods, cause desertification, reduce rainfall, cause erosion, damage to wildlife habitats and degradation to watershed areas, among others (Calder,2002).

The above issues gave emphasis as the loss of forest cover and conversion to other land uses can adversely affect freshwater supplies and compound human disasters resulting from hydro meteorological extremes. To come with a comprehensive solution for these interlinked watershed problems, researches worldwide are beginning to question the simplistic view of looking at the relationships between forest functions and their effects on watersheds. Our understanding of the hydrological cycles, forests and their role in the hydrological cycle will be important in enabling rational decision making at different levels (Andreassian, 2004). Watershed conditions can be improved and over all water resource management will be facilitated if forests are managed with achieving hydrologic objectives kept in mind. While not a panacea for resolving water issues, simultaneously forests can provide tangible economic and environmental benefits. A watershed framework helps to identify these benefits in both upstream and downstream areas.

1.1.2 Watershed hydrology

Using the concept that water runs down hill, a watershed is described as all points enclosed within an area from which rain falling at these points will contribute water to the outlet (Raghunath, 2006; Suresh, 2005). Naturally the earth's land surface is divided into watersheds based on the drainage of water at which all land within a specified area drains to the same outlet point. This implies that large watersheds are originated from many smaller watersheds. Therefore, it is necessary to define watershed in terms of a point. This point is usually the location at which the hydrologic design is made and referred as the watershed outlet (McCuen, 1989) whereas; hydrology is concerned with the problems of water on the earth. Such problems may involve water quantity and quality, interrelations between water and environment and the impact of man's activity on occurrence, circulation and distribution of water (Change, 2003; Raghunath, 2006; McCuen, 1989; Suresh, 2005). It looks for the causes and effects of these problems, predicts water related events and problems, studies the adjustment, management and operation of water resources to the benefit of the society and the environment. Therefore, the phrase watershed hydrology deals with the integration of hydrologic processes at the watershed scale to determine the watershed response (McCuen, 1989).

Having the above concepts, this review paper is designed to make an in depth literature search and a through reading related to forest hydrology in order to gain a theoretical knowledge about the role of forest landscapes on watershed hydrologic conditions. Specifically, this review is aimed to survey the issues about forest landscapes and the role these areas could play in water yield by giving more focus on watershed hydrologic impact studies which are discussed in terms of changes in water quantity and quality.

2. Forest covers and their role on hydrologic processes

We now know, in general, forests provide the best water quality since soil erosion in undisturbed forests is extremely low besides to their usage of more water than other agricultural crops that have fewer root mass and shallower rooting depth (Grant *et al*., 2008). On the other way, literatures show that large spatial and temporal variability of hydrologic response to reforestation follows the large gradients in climate, topography, soils and disturbances (Andreassian, 2004; Calder, 2002; Grant *et al*., 2008). In general, afforestation or converting from rain fed croplands to tree plantations will likely reduce total annual stream flow (Andreassian, 2004). A number of literatures also clearly shows this conclusion because the fact that trees generally use more water than crops that have short growing season and shallow rooting depth.

2.1 Forest cover and hydrologic Process interaction

Forest hydrology examines the flow paths and storage of water in forests and how forest disturbance and management modify the hydrologic response (Susswein *et al.,* 2001). The long history of scientific research examining the effects of forests and forest practices on hydrology reveals a much more complex story. Forest hydrology researches during the early decades of their age were focused only on how forest can be managed without adversely affecting flooding, erosion and water quality but the concept in past century has led to a clear understanding of the processes regulating water movement through forests and has produced general principles of hydrologic responses to forest landscapes (Bosch and Hewlett, 1982; Chang, 2003; Ice and Stednick, 2000). Although these principles can help for managing forest landscapes in response to the enhancement of water yield, it is difficult to predict the specific effect of forest management on water quantity and unless other large watersheds or basins are established for monitoring the effect over long period of time. Most forests were subsequently found to use great amount of water, contrary to the early thinking, therefore, the long tradition of catchment studies in hydrology results from the need to understand the water balance process operating in the basins, the processes controlling water movements and the impacts of forest cover change on water quantity and quality (Andreassian, 2004; Grant *et al*., 2008).

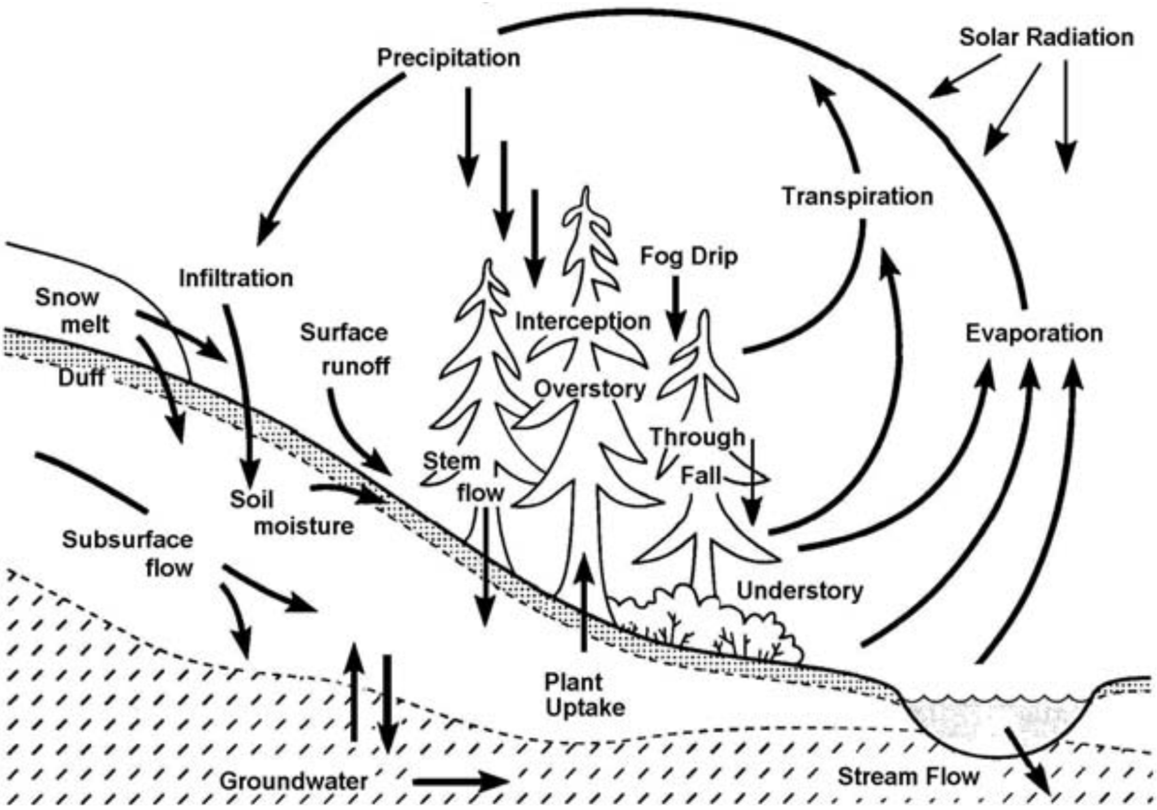

Figure 1: Hydrologic processes in forest landscape
(Adopted from Scherer and Pike, 2003)

Briefly, precipitation supplies the water that moves through the hydrologic process while the solar radiation provides the energy requirement of the cycle as it is observed from (Figure 1) above. The percentage of rainfall partitioning for each components of the process is given in (Figure 2) below.

2.2 Forest cover influence on water quantity

In contrary to the widely accepted myths that deforestation causes a reduction in watershed run-off, and thus a reduction in the quantity of water in reservoirs and that available for irrigation purposes downstream, some forest hydrology researches state as forests have been found to reduce runoff (Hodnett *et al*.,1994). The authors who are supporting this issue set two argumentative reasons. Firstly, they argued that, forest have long and well developed root systems which penetrates deep into the soil to search water so as they are large consumers of water, especially in the dry season. The effect of this is a reduction in the availability of ground water thus, a declination in runoff. Secondly, forest areas are likely to have more Evapotranspiration than areas with shorter crops, because the trees have long roots enabling them to have more access to soil water thus there is more water lost through Evapotranspiration which leads forest to diminish runoff from the catchment where they exists (Susswein *et al*., 2001). A report by Abdul Rahim (1988) from Malaysia depicts that catchment water yield shows an increment following forest removal while reduction is observed following forest recovery.

The hydrological functions of forests appear to have been erroneously attributed to the trees rather than to other aspects of a forested landscape especially their role in recharge of groundwater leading to base flow which supplies water in the off season (Jakeman and Green, 1998). But, the soil's state of porosity and permeability is one of the chief factors in the forest's effect on water systems. Any action which tends to decrease this natural porosity is a big factor in the increase of runoff (Bosch and Hewlet, 1982). What are implicated, however, are the management activities associated with logging, such as drainage, road construction and soil compaction and also the cultivation activities which may follow logging; these will most likely influence flood response rather than the absence or presence of forest vegetation (Scherer and Pike, 2003). Seasonal distribution of stream flow response to forest treatment is variable i.e. the response may be almost immediate or considerably delayed depending on climate, soil type, topographic nature and other factors (Susswein *et a*l. 2001; Scherer and Pike, 2003).

2.2.1 Water loss comparison

It is now well established that forested catchments have higher evapotranspiration than grassed catchments. Thus, land use management and rehabilitation strategies will have an impact on catchment water balance and hence water yield and ground water recharge. The key controls on Evapotranspiration are rainfall interception, net

radiation, advection, turbulent transport, leaf area and plant available water capacity (Grant *et al*., 2008).
As (Figure 2) below depicts, tree transpiration (ET) was the largest flux since it comprises about 94% of the incoming precipitation ,but soil evaporation(ES) is also a significant component in this system having 36% part of the precipitation. Soil water adsorption (A) occurred on summer nights but re-evaporated during the following sunny hours which balanced out on diurnal and longer time scales. On the other way, soil water storage (S) shows negative value indicating an addition from precipitation inputs. Losses out of the system (L= runoff (Q) + Subsurface flow (F) + Deep drainage (D) accounted as 7% the input (Yaseef *et al*., 2010). Results from catchment studies worldwide shows that for a given forest cover, there is a good relationship between long term average Evapotranspiration and rainfall (Zhang et al., 2001). For example, (Moreira *et al*., 1997) found that in the Amazon forest, transpiration was responsible for nearly all of the loss in water vapor. Wang and Yakir (2000) found that soil evaporation was only 1.5-3.5 % of the Evapotranspiration flux from crops in a desert environment. Williams *et al.* (2004) also found that soil evaporation changed from 0% in an olive orchard prior to irrigation, to 14-31% for the 5 days following irrigation. Thus, even with wet soils in a system with relatively low canopy cover, transpiration far exceeds soil evaporation.

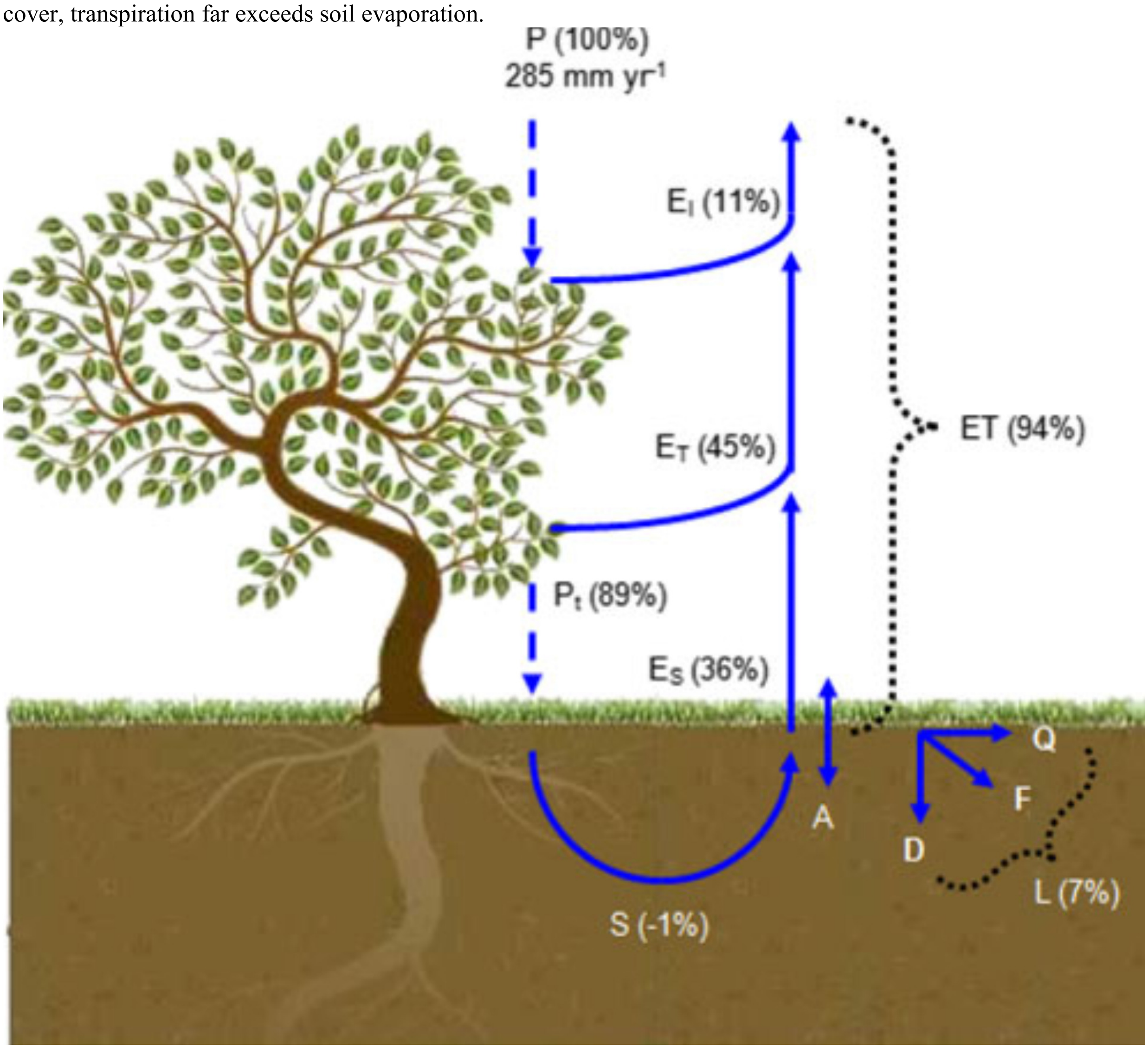

Figure 2: Rainfall partitioning in forest landscape (Adopted from Yaseef *et al*., 2010)

Moreover, changes in the structure and function of forests through developmental stages impact hydrologic processes. Different investigations also tried to depict the role of forest stands at different stages. One of the most dramatic impacts of forest land is the alteration of forest age class structures. The structural and functional modifications of forests through the entire lifecycle is reported by (Franklin *et al*., 2002) and the impact that these changes relay on the hydrologic process by changing the Evapotranspiration loss from the forests were reported (Moore *et al.,* 2004) and stream flow (Jones and Grant, 1996; Thomas and Megahan, 1998). The dramatic impacts of forest harvest and early regeneration on hydrology have been well documented by (Swank *et al*., 2001; Jones and Post, 2002).

Less well recognized are slow but profound changes that may occur as the composition, structure and function of the new forest continue to develop. Interception water losses were the chief cause of reduced water yield following afforestation of pasture or farmed land with eucalypts (Sahin and Michael, 1996) and increase interception also affects site water balance in regenerating forests after harvest. As with developmental changes in transpiration, leaf area is an important determinant of change in interception in the early stages of stand development, but it is less important in subsequent stages (Moore *et al.,* 2004). The different types of forests behave differently even in the matter of evaporation for they combine their own action with the reciprocal action of the climate. A similar plant cover will bring about a steeper reduction in Evapotranspiration as compared with bare land, where the climate is warm and windy.

2.2.2 Forest cover impact on peak flow

Changes in stream flow i.e. increased stream flow after deforestation have often been noted but this may be due to opening up of the landscape and improved drainage by reducing the surface roughness rather than to the removal of the forest or trees (Andreassian, 2004; Grant et al., 2008). If reforestation returns trees to a landscape but don't block off all roads, create swamps and return surface roughness may come with a negative effect on downstream water availability as additional transpiration and interception losses from tree canopies (on average about 300mm/year) are assumed (Rose and Yu, 1998). Re-vegetation can improve soil properties such as increasing hydraulic conductivity and macro porosity. However, it may even take a long time for vegetation to affect soil infiltration capacity and eventually stomflow peaks and volumes (Andreassian, 2004; Sahin and Michael, 1996). These parameters are mostly controlled by soil water storage capacity (Grant *et al*., 2008). Large floods occur normally when the soil water storage has been filled, thus vegetation has very limited influence on flooding during large storm events. Antecedent soil moisture conditions are important when evaluating roles of forests in reducing peak flow (sun *et al*, nd; Grant *et al*., 2008).

2.2.3 Forest cover impact on base flow

In contradiction to the general perception that forests enhance low flow or have more springs, forestation may actually reduce base flow in the short term. As base flow are stream flow components during non-rainfall periods originated from groundwater and soil water storage reservoirs, reforestation on degraded land is not likely increase ground water storage capacity and soil water storage in the short term (Grant *et al*, 2008). The increased infiltration due to vegetation establishment may be exceeded by the increased water loss by Evapotranspiration of the newly established forest (Smakhtin, 2001; Sahin and Michael, 1996). But, other research reports revealed that forest cover enhances the base flow through increasing the infiltration capacity of the soil since water through infiltration will improve the ground water recharge potential(Scherer and Pike, 2003). One thing which is obvious from this is that the decline or enhancement in base flow could be also affected by the species water intake potential and the soil water storage capacity.

2.3 Forests and water quality relationship

Water pollution impairs water use by downstream users and seriously affects human health. The exceptionally high quality of water discharged from forested watersheds is the main reason that protected forests are preferred for municipal watersheds (Susswein *et al*., 2001). In terms of erosion, forests play a positive role by reducing the incidence of surface runoff which in turn reduces erosion transport (Susswein *et al*., 2001). Forest canopies can also slow down the speed of raindrops before they hit the soil thus reducing the soil water pressure (Susswein *et al*., 2001). Forests are effective cyclers of nutrients and chemicals, and decrease the sediment exported, thus reducing pollutants such as phosphorous and some heavy metals (Kiris *et al*. nd; Pomeroy, 2003).

In many developing countries the food and resource needs of the rural poor coupled with land scarcity and institutional limitations, constrain efforts to protect frosted watersheds for municipal water supplies (Kiris *et al*. nd). However, the problems of polluted drinking water and associated diseases significantly jeopardize the welfares of rural populations and urban communities alike (Wilder and Kiviat, 2009). Water storage and transport facilities are sorely needed in many areas, along with improved sanitation minimal requirements for water treatment. Long neglected and often exploited, riparian forests help to stabilize stream bank, reduce wastewater and chemical discharge into water bodies from upland areas and maintain cooler water temperatures, thus improving dissolved oxygen levels in water (Pomeroy, 2003; Wilder and Kiviat, 2009). One can obviously, observe the difference in the hydrologic effects of various land uses as it is given in the (Table 1). Here, forest landscapes show a higher percentage of infiltration (84%), smaller percent of surface flow (18%) and negligible erosion. Under fallow land use type the portion of the incoming precipitation which is infiltrated is smaller which is below half while the large proportion is contributed to surface run-off and creates a relatively sever erosion to take place on it.

Table 6: Hydrologic effect of different land use types (Adopted from Kiris *et al*. nd)

Land use types	**Hydrologic parameters**						**Time to be eroded for 15cm soil layer**
	Precipitation	**Infiltration**		**Surface flow**		**Erosion**	
	mm	**mm**	**%**	**mm**	**%**	**Ton/ha**	**Years**
Fallow	1336.2	591.7	44	744.5	56	16.014	122
Pasture	1336.2	855.6	64	480.6	36	1.360	1434
Forest	1336.2	1094.8	82	241.4	18	------	------

2.4 Forest cover and change in Micro Climate

All variables defining climate such as radiation, air and soil temperature, rainfall, humidity and wind are greatly modified by forest cover which creates a microclimate (Pomeroy, 2003). The presence of vegetation cover in general and forest cover in particular modifies these climatic parameters and creates a microclimate whose characteristics depend on the general climate itself and the physical characteristics defining the nature and structure of the cover (Aussenac ,1999; Grimmond *et al*.,2000). Rainfall is strongly influenced by the nature and structure of the cover as much with regard to interception as to its distribution on the ground. Rainfall is considerable in stands with closed cover and may reach 30-45% of annual precipitation; the grass layer alone can intercept up to 4 to 5% (Aussenac, 1999)**.**

Land use change is related to climate changes as both a causal factor and a major way in which the effects of climate change are expressed. As a causal factor, land use influences the flux of mass and energy and as land cover patterns change; these fluxes are altered (Aussenac, 1999; Grimmond *et al*., 2000). Wherever vegetation first establishes on terrain of new formation, we have the primary regressive succession and this consists of successive phases which correspond to the influence of ecological factors (Segal *et al*., 1988). When these factors are favorable, forest vegetation is also subject to succession, until it culminates in the balance formation. Whatever value the experiments may have in themselves, they ought to be interpreted and, above all, coordinated with the aim of broadly determining the influences of the forest on environment and relating those influences to each type which, in turn, corresponds to the equivalent range of climate types (Aussenac, 1999; Pomeroy, 2003; Segal *et al*., 1988).

In fact, cover, i.e. the trees and vegetation in which it consists, adapts to these new microclimatic conditions by modifying its specific architectural and functional components. Thus, it is really an interactive and even a retroactive system at which any change in one of the components results in an adjustment of the others, and so on. In reality, for a forest tree, it is the overall ecophysiological behavior which is affected by these interaction phenomena as much in terms of photosynthetic processes, transpiration, translocation, transport and storage of assimilates as growth, flowering or fruiting phenomena (Segal *et al*., 1988).

3. Summery

There are now quite long series of hydro meteorological observations, which make it possible to address the question of long term, possible non stationary impacts of forest cover on the hydrology of the watersheds. A key issue in the study of the long term effects of reforestation or deforestation is the soil forest relationship. The soil may keep the memory of its previous cover for centuries and several researchers have pointed out that the alleged effect of deforestation might be more precisely characterized as the effects of an alteration of the forest soil. There are still controversial issues concerning the increase or decrease in the influence of forest cover change on river flow patterns. But almost all studies agreed by that forest cover reduces the water yield capacity of a certain landscape while removal of forest cover shows an enhancement in water yield given that there is no significant change in rainfall pattern. Various literatures also reveal micro climatic change following reforestation and deforestation process. Literatures depict that There is sever degradation problem following this happening of unusual hydrologic phenomenon becomes frequent. Even if, contradictory investigations in different times and places are launched, all agrees by that forest landscapes and forest management activities can induce crucial influence on the hydrologic processes. Therefore, it is advisable to endow attention for forest landscapes and strengthen the researches on forest-soil-water relationship to come with appropriate and sustainable forest management strategies which would able to sustain the hydrologic processes.

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