REPORT
OF THE COMMITTEE

ON

IDENTIFICATION OF THE AREAS OF RESEARCH IN FOREST HYDROLOGY AND SUGGESTED MEASURES TO ACHIEVE THE RESEARCH MANDATE

November, 2011

EXECUTIVE SUMMARY

Forests are dynamic ecosystems subject to both incremental and episodic disturbances that vary in frequency, severity, and extent. The forests are managed for a number of purposes—timber harvesting, wilderness, habitat, and recreation—but arguably their most important output is water. Precipitation is cycled through forests and soil, and ultimately some is delivered as stream-flow to receiving bodies of water. The current knowledge in forest hydrology science provides the general magnitudes and directions of direct hydrologic responses to changes in forests over short time scales and in small areas. However, today's forest and water managers need forest hydrology science to predict or indicate the hydrologic responses in forest landscapes that are changing over large areas or long time scales. Predictions are needed to understand the indirect and interacting hydrologic responses to changes in forested landscapes associated with climate change, forest disturbances, forest species composition and structure, and land development and ownership, and how these changes will affect water quantity and quality downstream and over long time scales. A sound knowledge base supported by the findings of research studies in the area of forest hydrology science would help support forest and water management decisions in many ways.

Considerable progress has been made in forest hydrological research all over the world. However, studies in India on forest hydrology have been done on a modest scale, and largely limited to small watershed scales only. The initial studies focused on the hydrologic effects of forest degradation. Recently, the research has shifted to studying reforestation hydrology, large-scale watershed hydrology, climate change impacts, and application of hydrological models. But, the forest hydrology in India is still in an infant stage because most of the studies conducted are in the scattered form. The information to define the entire hydrological system and water budget of a particular forest type is not yet available. Further, most of the studies have been conducted at plot or small watershed scale with study period ranging from a single storm event to a few years.

The present report is an outcome of the committee constituted by the Director General, Indian Council of Forestry Research and Education (ICFRE)) to identify the areas of research and suggest measures to achieve the mandate on Forest Hydrology as a component under All India Coordinated Research work on Climate Change. The report is divided into seven chapters. The first Chapter gives a brief background for preparing the report, the details of the committee and the meetings held by the committee to deliberate on research areas in forest hydrology. The second Chapter on 'Forest and Water' reviews the general understanding of how forests and their dynamic nature affect various hydrological processes within the catchments and the catchment output in terms of water quantity and quality. Since forests serve as an important means to capture and store atmospheric carbon dioxide in vegetation, soils and biomass products, the aspects related to carbon sequestration in forested soils are discussed in Chapter 3. A brief review of forest hydrology science in India and the emerging research issues are presented in Chapter 4. Considering the current status of forest hydrology in India, a number of actions are suggested and potential research areas are identified in Chapter 5. The suggested actions that could help address key questions about the long-term hydrologic effects of forest change and conversions include (i) compilation of status of research on forest hydrology (ii) preparation of a catalogue of historical & modern hydrologic records, and (iii) continuing current small watershed experiments and re-establishing small watershed experiments where research has been discontinued. The research studies identified in the report need to be carried out through a chain of interlinked long-term projects using paired watershed approach in different geo-ecological conditions. The nested approach on sub-watershed basis within selected watersheds is suggested for long term hydrological measurement using an integrated approach of hydrologic instrumentation, field investigation, remote sensing and GIS techniques. The reminiscent measures to implement the proposed research studies are presented in Chapter 6. It is suggested that a separate Division of Forest Hydrology may be established at ICFRE, Dehradun to provide an impetus to the much needed research work in the area of forest hydrology. Concerted and joint efforts are also needed by the scientists from premier research institutes working in the area of hydrology and forestry to take up the sponsored research projects in the area of forest hydrology. An All India Coordinated Research Project is suggested for carrying out various research studies suggested in the report. The project is suggested to be implemented jointly by NIH, ICFRE and CSWCRTI in a collaborative project mode as these organizations have their research centres / institutes across the country. Finally, the need for capacity building in the area of forest hydrology is emphasized in Chapter 7.

CONTENTS

1. BACKGROUND

A committee was constituted by the Director General, Indian Council of Forestry Research and Education (ICFRE) vide Office order no. 31-19/2001-ICFRE dated 8th July, 2011 (Appendix 1) to identify the areas of research and suggest measures to achieve the mandate on Forest Hydrology as a component under All India Coordinated Research work on Climate Change. The committee held its first meeting on 11th August, 2011 in New Delhi and deliberated on various research issues in the area of forest hydrology and also on the action plan for preparation of the report. Dr. Jaivir Tyagi, Scientist 'F' was nominated as Member-Secretary of the committee and was entrusted with the work of preparation of the draft report based on the inputs received from other members of the committee. Based on the recommendations of the committee members in the meeting, two more members were also included in the above committee. The modified constitution of the committee and the minutes of the first meeting are given in Appendix 2 and 3 respectively.

In partial modification of the above said office order, the Director General, ICFRE further expanded the committee vide office order no. 31-19/2001-ICFRE dated 26th Sept. 2011 (Appendix 4). The second and final meetings of the committee were held on 13th and 14th October, 2011 respectively at FRI, Dehradun. The list of members who attended these meetings is given in Appendix 5.

The present report is being presented based on the deliberations by the committee members during these meetings. The information and suggestions received from various committee members have been duly incorporated in the report.

2. FORESTS AND WATER

Forested areas often constitute head water catchments for many large rivers. However, forests vary due to differences in geography; ecology; and social, economic, and land use histories. These are also managed for a range of objectives and goals, using a wide variety of forest management practices that tend to change the forest composition and structure. There is now a broad scientific agreement that type of forests and their management practices have the potential to alter the quantity, quality and timing of water moving through catchments by altering the interception, evapotranspiration, soil infiltration, nutrient and sediment load of runoff etc. (Anderson et al., 1976; Ice and Stednick, 2004). Further, there is a prevalent assumption that there exists a positive correlation between forested lands and water flows which is reflected both in the national forest and water policies and in the implementation of watershed development programs in India. However, scientific studies from various parts of the globe have also shown that this is not a universal truth and that there are situations where the general perceptions regarding the forest-water interface are not supported by empirical findings. In fact, the findings forewarn against adverse impacts in the long run and emphasize the necessity for a scientifically-informed approach to forests and water management programs. In recent years, concern has also grown of the potentially large but uncertain effects of climate change on forests and their water output. Climate change may cause shift in snow line, increased favourable conditions for forest fires, outbreaks of insects and disease, and changes in forest structure and species composition, producing direct hydrologic effects.

2.1 Natural Forest Modifiers and Forest Management Practices

Forests are dynamic systems which can be modified by (1) natural disturbances, and (2) forest management practices. The natural disturbances generally include (a) wildfire (b) species changes, and (c) insects and disease. The management practices may include (a) forest harvest and silvicultural activities (b) construction of roads and trails, and (c) grazing (Fig. 1). Historically, many forest management practices have centred on timber management. Timber management encompasses silvicultural treatments to establish and sustain wood production; protection against or control of wildfire occurrences, insect infestations, and diseases; and of course, harvesting of merchantable trees in a forest (NRC, 2008). Silvicultural practices include selection of species and genotypes, site preparation, planting, drainage, fertilization, watering, herbicide application, and thinning to maximize the growth of the most desirable species. Forest protection practices include fuel reduction treatments such as over-story thinning, understory removal, or prescribed fire; construction of fire breaks and fire lines; applications of soil, water, or fire-retardant chemicals; application of insecticides and fungicides; and introduction of biological control agents. Timber harvest practices include selection of rotation age, which determines the ranges of forest ages; road and path construction, including road drainage systems such as culverts; felling and skidding of logs to landings; and movement of logs, usually by trucks, to timber mills for processing.

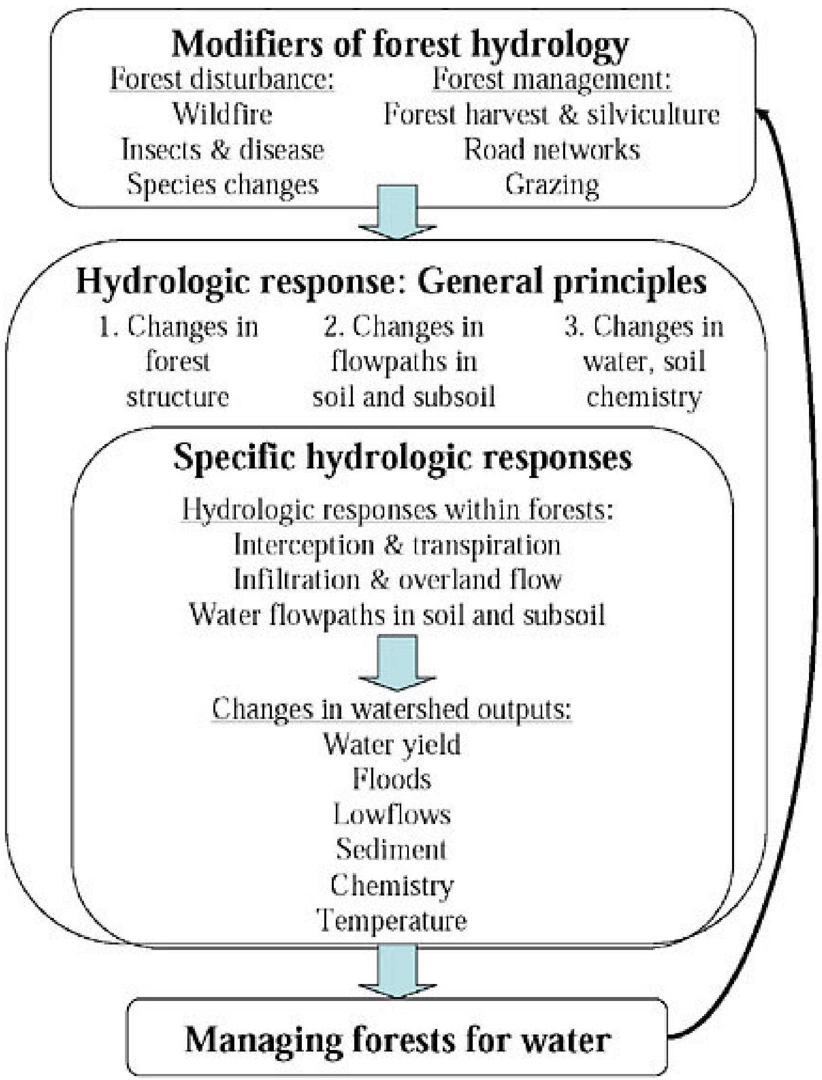

Fig. 1: Schematic diagram of the hydrologic response to forest modifiers and forest management practices (Source: NRC, 2008)

2.2 Hydrologic Effects of Forests Disturbances and Management Practices

Forest disturbances and management activities involve a number of actions which cause changes in the forest structure, flow paths of water in soil and sub-soil, and the water and soil chemistry within the forest system that individually and cumulatively can modify the watershed output in terms of water quantity, quality, and timing. The science of forest hydrology has built a foundation of general principles that elucidate direct effects of forest management and disturbance on hydrology. The principles are derived from plot studies, process studies and watershed experiments. These principles are briefly discussed below.

2.2.1 Changes in Interception and Evapotranspiration

During a precipitation event, much of the rainwater or snow is temporally held on leaves, plant stems, ground flora and leaf litter. The temporary storage slows down the rate at which precipitation arrives at the forest floor. If this captured moisture evaporates, it effectively decreases the amount of precipitation. Reduction in leaf area and other intercepting surfaces due to fire, trees harvest, insects, disease, forest types and forest age results in reduced interception loss and therefore increased amount of water reaches the mineral soil (Verry, 1976), which is available for soil moisture storage, transpiration, or runoff (Helvey, 1971). Where forest canopies capture additional moisture from clouds, a reduction in leaf area can decrease net precipitation (Harr, 1982; Hutley et al., 1997).

The process of evapotranspiration in forests accounts for considerable loss of gross precipitation. A reduction in leaf area reduces evapotranspiration and increases water available for runoff. The magnitude and persistence of the reduction in transpiration depends on the amount and type of the vegetative canopy removed and the rate at which the vegetative cover is re-established. A reduction in leaf area also increases the amount of light reaching the forest floor, increasing energy exchange between soil or snow and the atmosphere and altering the energy budget. Increased exposure of snowpack to solar radiation and to turbulent heat transfer by wind leads to increased snowmelt rates and earlier onset of snowmelt relative to undisturbed forest canopies (Hornbeck et al., 1997; Jones and Post, 2004).

2.2.2 Changes in Infiltration and Overland Flow

Layer of organic material, surface obstacles, root system and activities of micro-organisms facilitates higher infiltration rates in forest soils than other land uses (Mohan and Gupta, 1983). Most of the soil surfaces under dense forest environment facilitate complete infiltration of rainwater from light to moderate intensity rains. In most cases this water moves by subsurface pathways to the stream. Because of high infiltration rates in forest soils, little water flows over the ground surface as infiltration excess.

Forest management activities and forest disturbances may remove or alter the surface layers of forest soils, and thereby reduce infiltration and increase overland flow. When organic surface layers are removed or burned, underlying mineral soil is exposed to raindrop splash and fine soil particles can accumulate on surface, reducing infiltration and increasing overland flow. Forest management activities and disturbances also create impervious surfaces (e.g., roads and trails) and modify hill-slope in ways that alter water flow paths in soils and sub-soils, shift subsurface flow to surface flow, and increase runoff and erosion rates. If soils are compacted to the extent that infiltration rates are lower than rainfall or snowmelt rates, the resulting overland flow can greatly increase runoff rates and surface erosion.

2.2.3 Changes in Soil Properties and Soil Moisture Storage

Forests alter the bulk density, porosity, structure and water holding capacity of the soil and these properties are responsible for retention and mobility of water and nutrients; habitat for micro and macro fauna. The additional soil water storage potential in forested soils is possibly due to (i) high organic matter content (ii) dense tree roots system and (iii) high soil organic carbon content. The organic matter and the root system improve the soil structure, increase the infiltration of water and water holding capacity of the soil (Marshall and Holmes, 1988; Kang et al., 1996; Jiang, 1997; Teresaecheverria and Martinez, 2001). The higher percentage of soil organic carbon improves the overall soil environment and the water holding capacity (Bhattacharyya et al., 2007). Jones (2006) reported an additional water holding capacity of 144,000 litres per ha per percentage of soil organic carbon. Tyagi et al. (2011) reported higher soil moisture storage under dense sal forest that that under open sal forest. It is also reported in the literature that root system of an oak tree is very extensive and soil-root complex system of each mature oak tree has a capacity to store several hundred litres of water, which is released as base flow during the lean season.

2.2.4 Changes in Watershed Outputs

2.2.4.1 Changes in water yield, peak flows and low flows

Removal of forests due to forest fires or cutting of trees increases water yield because of reduced interception and transpiration losses (Bosch and Hewlett, 1982; Jones and Post, 2004; Brown et al., 2005). The increase in water yield varies with factors such as climate, seasonal timing of precipitation, amount of forest removed, storage of water in soil and snow, type and age of forest removed, and time since harvest. In regions of low rainfall and high evapotranspiration, the increase in water yield is largely offset by increased soil evaporation and evapotranspiration by any remaining vegetation. As forests regenerate after harvest, water yield increases disappear. The water yield increases have been found to persist ranging from a decade in some areas to multiple decades in other areas depending on the type of the forest, soils, climate, reforestation methods, and harvest treatments (Bosch and Hewlett, 1982; Troendle and King, 1985; Hornbeck et al., 1997; Jones and Post, 2004; Brown et al., 2005). Forest roads and trails also increase overland flow because of their compacted soil surfaces with very low infiltration rates. Roads constructed on steep slopes intercept water flowing in the subsurface and further increases overland flow (Megahan, 1972; Wemple and Jones, 2003).

Recent compilations of studies show wide variability in the magnitude of peak flow response to forest harvest (Grant et al., 2008). Much of this variation is attributed to the factors like event size, type of precipitation, proportion of area harvested, topographic relief and elevations, and time since harvest. In many cases, the absolute increase in peak flows was larger with larger storms. In rain events, forest harvest affects peak flows directly through changes in soil water. In events involving snow, the effect of forest harvest on peak flows depends on how forest harvest changes snowpack size and snowmelt, as well as soil moisture. Peak flow increases have been detected after only 25 percent harvest of a small watershed (Harr et al., 1979; Jones and Grant, 1996). As forests regenerate, peak flows return to pre-harvest levels (Troendle and King, 1985; Jones, 2000). Roads redistribute water locally and alter flow routing. They contribute to an increase in the size of peak flows by increasing the amount of surface runoff from impervious surfaces, intercepting subsurface storm flow, and speeding the delivery of this runoff to the stream network through ditches or gullies (Megahan, 1972; Wemple and Jones, 2003).

Relative to peak flows or annual water yields, few studies have examined the effects of forest harvest on low flows. Most studies show an initial increase in low flows immediately after forest harvest but these are often short-lived due to the relatively rapid recovery of leaf area, interception capacity, and transpiration rates. The increase in low flows often is followed by a decrease in low flows to below pre-harvest levels (Hicks et al., 1991; Hornbeck et al., 1997; Swank et al., 2001). These decreases occur when a forest with relatively high transpiration and/or interception replaces a forest with relatively low transpiration or interception, such as during species conversion (e.g., deciduous to evergreen) (Swank and Crossley, 1988); or regeneration of a young stand with higher water use than the mature stand it replaces (Hicks et al., 1991; Perry, 2007). Because relatively few studies have examined long-term trends in low flows, there is much uncertainty about this subject.

2.2.4.2 Changes in water quality

Many studies have shown that timber harvest practices greatly increase surface erosion (Dunne and Leopold, 1978). Overland flow and surface erosion are very low in undisturbed forests, but logging operations expose surface soils and lead to surface erosion. After forest harvest on steep slopes, decreased root strength, increased soil moisture and pore water pressures result in reduced soil cohesion and contribute to decreased slope stability and increased likelihood of landslides during precipitation events. Forest clear cutting may increase the landslide erosion rate by two to nine times relative to undisturbed areas (Sidle and Ochiai, 2006; Miller and Burnett, 2007). High rates of overland flow along unpaved road surfaces entrain sediment, erode road surfaces, and contribute fine sediment to forest streams (Reid and Dunne, 1984).

After forest fires, ash deposition can increase pH of surface water and soil. Transient pH values of 9.5 were measured in streams after a fire in eastern Washington (Tiedemann et al., 1979). Fire can cause a short-term increase in stream nitrate concentrations, and the delivery of ash and fine sediment can increase phosphorus concentrations in streams. During forest fires, chemical fire retardants are applied aerially to forests. Recent studies have shown that the effects of these chemicals on water quality may persist for years after application (Morgenstern, 2006). Fire retardants can contain nitrate and possibly sulphate, phosphate, and some trace elements. When these materials enter rivers, streams, and lakes, they react with sunlight to form compounds that are toxic to aquatic organisms.

3. CARBON SEQUESTRATION IN FORESTED SOILS

There is a growing international concern over the accumulation of greenhouse gases in the earth's atmosphere. Carbon dioxide (CO_2) is one of the major greenhouse gases and it has increased significantly in recent decades. Concentration of atmospheric CO_2 can be lowered either by reducing emissions or by taking CO_2 out from the atmosphere and stored in the terrestrial, oceanic or aquatic ecosystems.

Soil has a vicious relationship with vegetation. The accumulation of soil organic matter under trees is the most commonly reported effect of trees on soils. Tree growth serves as an important means to capture and store atmospheric carbon dioxide in vegetation, soils and biomass products (Makundi and Sathaye, 2004). After the litter fall, the detritus is decomposed and forms soil organic carbon by microbial process. This sequestered carbon finally act as sinks in the forest land. Soil Carbon has much longer residence mean times than the Carbon in the vegetation that the soils support. Soils provide a significant reservoir for organic carbon, storing twice as much as the atmosphere and three times as much as plants. On comparing the carbon storage in top 1 foot of soil under six land uses, it was found that forests had the best mitigation potential followed by agro-forestry, plantations, agriculture etc. (Jha *et. al*., 2001). Soil Organic Carbon (SOC) has been ignored because it was treated as a dead biomass. After the awareness of climate change its importance has been recognized worldwide. Changes in forest type, productivity, decay rates and disturbances can effectively modify the carbon contents of forest soils. Land use and soil management practices can significantly influence soil organic carbon dynamics and carbon flux of the soil (Batjes, 1996; Tian *et al.,* 2002). Input of organic matter is largely from above ground litter, therefore, forest soil organic matter tend to concentrate in upper soil horizons. This layer is readily depleted by anthropogenic disturbances such as land use changes and cultivation. Forest fire, overgrazing, etc. lead to the soil degradation and loss of soil organic matter store. Deforestation is one of the most important sources of CO_2 emission in to the atmosphere. From hydrologic point of view, the SOC also plays a key role in improving the physical properties of soil, which are responsible for infiltration, percolation, permeability, and hydraulic conductivity of land.

The variety of soils occurring in India offers different potential for carbon sequestration. They also need different sets of strategic management for improving their mitigation potential because of their different mineralogical, biophysical and chemical behaviour and response to a given input (Negi and Gupta, 2010). There is a need to formulate a strategy for more precise SOC estimation and monitoring thereafter under different forest covers, land uses and also under the Trees Outside Forest (TOF). Major considerations for soil management are to develop knowledge bank on geological/ mineralogical, physical, chemical, biological and microbiological properties and the inter-linkages. The regional specificity of soil behavior could then be understood and managed for finally stabilizing GHGs nationwide on a sustained basis.

4. FOREST HYDROLOGY SCIENCE IN INDIA AND EMERGING ISSUES

4.1 Forest Hydrology Science in India

Forest hydrology draws from the sciences of hydrology and forestry to address primary questions about forests and water: What are the flow paths and storage reservoirs of water in forests and forest watersheds; how do modifications of forests influence water flow paths and storage; and how do changes in forests affect water quantity and quality? The science of forest hydrology helps to understand the changes that occur in catchment water balance and stream flows resulting from many interacting factors within forest systems including climate change, forest disturbances, forest species composition and structure, and forests defragmentation.

Researchers seeking to answer these kinds of questions have obtained most of their data from what are known as "paired watershed" studies. Using this approach, two watersheds that are similar in size, initial land use or land cover, and other attributes are selected for study. Both are monitored, and while one is left as a "control," the other is "treated" (subjected to manipulations such as forest cutting, road building, fires, and so on). The measured changes in the stream flow and water quality between the two watersheds quantify the effects of forest treatment and growth. Paired watershed studies, along with process measurements, plot-scale studies, and hydrologic modelling are important elements of forest hydrology. However, plot studies and paired watershed studies have generally been conducted in small, homogenous, areas and over short time spans, ranging in size from less than a square meter to few km^2 and typically spanning only a few growing seasons.

Considerable progress has been made in forest hydrological research all over the world. However, studies in India on forest hydrology have been done on a modest scale, and largely limited to small watershed scales only. The initial studies focused on the hydrologic effects of forest degradation. Recently, the research has shifted to studying reforestation hydrology, large-scale watershed hydrology, climate change impacts, and application of hydrological models. But, the forest hydrology in India is still in an infant stage because most of the studies conducted are in the scattered form. The information to define the entire hydrological system and water budget of a particular forest type is not yet available. Further, most of the studies have been conducted at plot or small watershed scale with study period ranging from a single storm event to a few years.

4.2 Emerging Issues in Forest Hydrology

Undoubtly, the micro-watershed based research has proved very useful in studying the influence of forests on various hydrological processes and in understanding the hydrological behaviour at micro level. However, forests are now being affected by many interacting factors, including climate change, forest disturbances, forest species composition and structure, and land development and ownership, which can break up forests into smaller, non-contiguous parts. Today's forest and water managers need forest hydrology science that helps them understand and predict how such factors will affect water quantity and quality across large areas and over long time scales. The key unresolved issue in forest hydrology is how to scale up findings that were developed in small, homogeneous watersheds to predict long term hydrologic responses across large, heterogeneous watersheds and landscapes. A landscape perspective allows analysis of forest and water connections over larger areas so as to be able to use the general principles of forest hydrology to make predictions about forests and water that can address current and anticipated future issues, including cumulative watershed effects, climate change, and forest management practices in the 21st century.

4.3 Research Needs

The future research should focus on following aspects for quantitative characterization of hydrologic variables at different temporal and spatial scales.

4.3.1 Cumulative Watershed Effects

Cumulative watershed effects are the hydrologic effects resulting from multiple land use activities over time within a watershed. Extreme precipitation events often reveal cumulative watershed effects and spur public interest in better understanding how land uses in forested headwaters are related to downstream flooding and other effects. Assessing cumulative watershed effects requires an understanding of the physical, chemical, and biological process that route water, sediment, nutrients, pollutants, and other materials from slopes and headwater streams to downstream areas. Future research in this area should strive to elucidate the relationships among forests, water flow paths and quality, and watershed land use over large spatial and long temporal scales. This can be achieved through hydrological modelling.

4.3.2 Climate Change

The effect of climate change on forests and water is increasingly evident, and future aspects of climate change are likely to have major effects on forest hydrology. Direct effects of climate warming on forests and hydrology are being observed, such as changes in the timing of snowmelt runoff and increases in wildfires, but more research is needed to better predict indirect effects of climate change, including evaluations of how changes in forests and forest management influence hydrologic response.

4.3.3 Forest Management

Forest management practices evolve over time. The forces that modify forests today are triggering forest managers to institute novel and contemporary forest management practices. These new practices such as thinning for fuel reduction and best management practices have not yet been assessed for their hydrologic effects. Hydrologic effects of these contemporary management practices need to be understood over long temporal and large spatial scales.

5. SUGGESTED FUTURE ACTIONS AND AREAS OF RESEARCH

In view of the discussion in the preceding chapters, a chain of actions and interlinked long-term projects need to be carried out in the area of forest hydrology. These are summarised below.

5.1 Suggested Future Actions

The following actions are suggested that could help address key questions about the long-term hydrologic effects of forest change and conversions.

1. Compilation of status of research on forest hydrology incorporating the thorough and critical review of the works done in the area of Forest Hydrology in India and abroad including references (published and unpublished literature both).
2. Preparation of a catalogue of historical & modern hydrologic records.
3. Continuing current small watershed experiments and re-establishing small watershed experiments where research has been discontinued.

5.2 Suggested Future Areas of Research

1. Selection of paired representative watersheds (two watersheds similar in size, initial land cover & other attributes) in different geo-ecological conditions for long term hydrological measurement using an integrated approach of hydrologic instrumentation, field investigation, remote sensing and GIS techniques. One watershed may be kept as control while other may be treated subject to manipulations such as change in forest cover and forest management practices.

   The rainfall, runoff and soil loss from forests of various composition representing different agro ecological regions of the country on watersheds basis (500 to 10,000 ha consisting of homogenous land use) is rarely available. It is therefore recommended that a nested approach may be adopted within the paired watersheds for extensive gauging on sub-watershed basis consisting of homogeneous forest land use and ranging in size from micro (about 500 ha) to macro-watersheds (about 10,000 ha).

2. Hydrological investigations on the effects of different tree species and forest types on interception, infiltration, soil moisture, ET, water yield and groundwater in representative watersheds.

3. Investigations on changes in soil physical properties, moisture holding capacity of soils and carbon sequestration under different forest species.

4. Effect of different forest management practices and forest defragmentation resulting from social changes on water yield, flood peaks, regulation of stream flows, sediment yield, water quality, etc.

5. Monitoring of spring discharge which represents the groundwater in the forested mountainous watersheds.

6. Monitoring water quality parameters of streams and springs in the selected representative watersheds

7. Effect of global warming and climate change on migration of forest types with respect to altitude, changes in structure and composition of forests; and the effects thereof on hydrological parameters including ET & runoff

8. Use of long term observed data for development and application of physically based distributed hydrological models to predict the impacts of changes in forests on large and un-gauged basins.

Water is the most important resource among different ecosystem services from a forest watershed and plays an important role in the survival and livelihood of local people. Social milieu of local communities is intertwined with water related traditions, ITKs, myths and so on. Hence, water related social aspects must also find their due place in any research project on forest hydrology.

6. SUGGESTED ROAD MAP

The advancement of the forest hydrology science encompasses a chain of interlinked projects to study the relationship amongst various vegetative & hydrological parameters and to assess the cumulative effect of these interactions in terms of water output using hydrological modelling approach. As such, these studies require long-term field measurements of vegetation and hydrologic variables using an integrated approach of hydrologic instrumentation, field investigation, remote sensing and GIS techniques. Therefore, concerted and joint efforts are required by teams of scientists and professionals from various disciplines including hydrology and forestry.

6.1 Recommendations

(i) Indian Council of Forestry Research and Education (ICFRE), an apex body in the national forestry research system, needs to strengthen its capabilities for conducting hydrological research studies in forested areas. It is recommended that a separate Division of Forest Hydrology may be established at ICFRE to provide an impetus to the much needed research work in the area of forest hydrology. For this purpose, the scientific expertise may be pooled from the existing resources at the ICFRE. Alternatively, the scientists may be deployed through direct recruitment at junior level and on deputation basis at senior level.

(ii) The studies identified in the report need to be initiated in different geo-ecological regions in long-term projects mode. The following premier research institutes in the area of hydrology and forestry which have their research centers across various regions of the country (Fig. 2) may take up the research projects either in sponsored project mode or consultancy mode.

National Institute of Hydrology (NIH), an autonomous body under Ministry of Water Resources, Govt. of India, is a premier research institute in the area of hydrology. The Institute with its headquarters at Roorkee (Uttarakhand) was established with the main objective of undertaking, aiding, promoting and coordinating systematic and scientific work in all aspects of hydrology. The Institute also has six Regional Centres located at Jammu (J&K), Sagar (M.P.), Patna (Bihar), Guwahati (Assam), Belgaum (Karnataka) and Kakinada (A.P.). The Institute is well equipped to carry out computer, laboratory & field oriented studies. The Institute has a team of highly qualified and dedicated scientists engaged in carrying out field and computer based research studies in various disciplines of hydrology and water resources. The NIH has carried out a number of studies in the area of forest hydrology in recent past either independently and in collaboration with State Governments / other organisations. Currently, a project on forest hydrology is being carried out in collaboration with FRI, Dehradun.

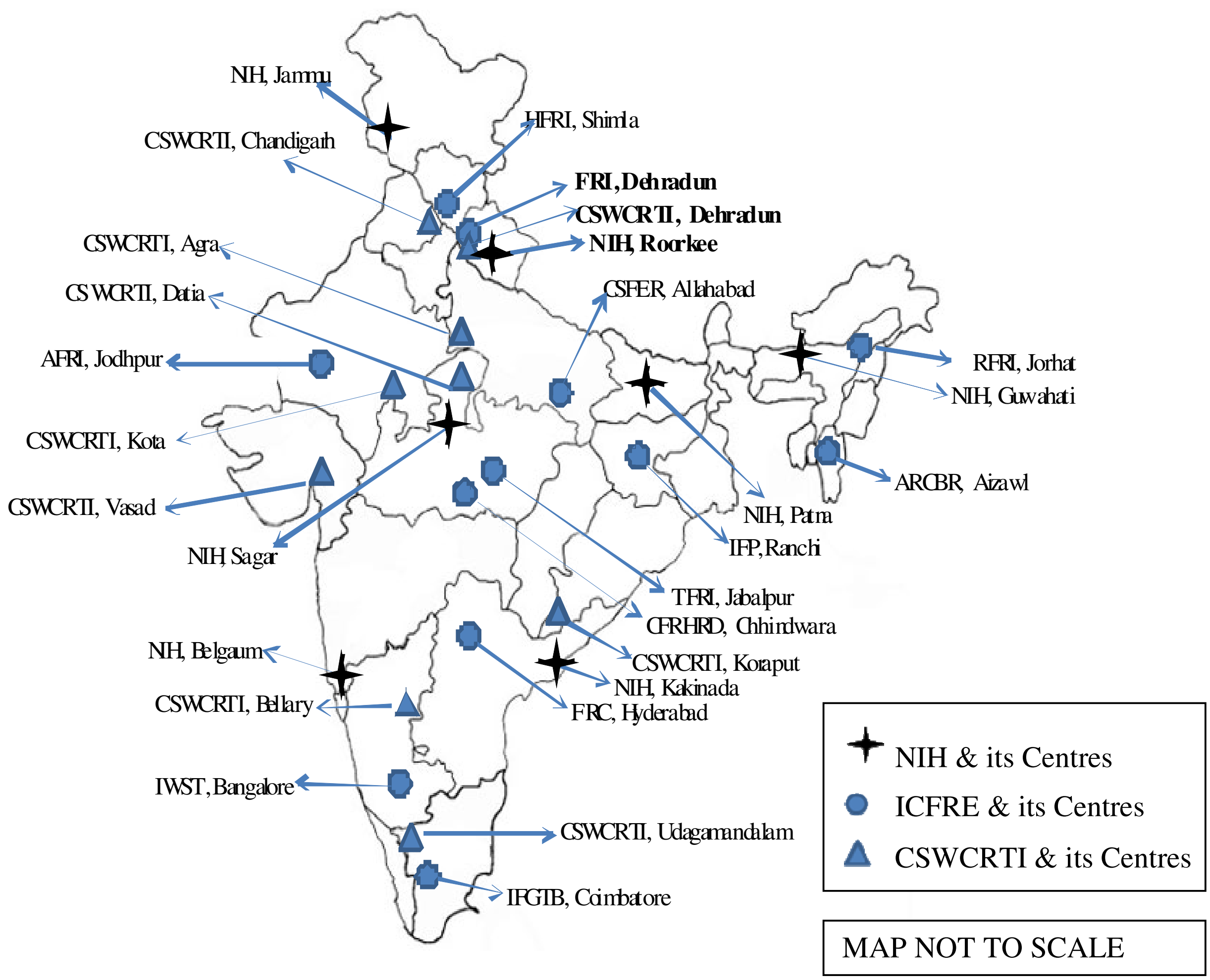

Fig. 2: Locations of NIH, ICFRE and CSWCRTI and their regional Centres / Institutes

Central Soil & Water Conservation Research & Training Institute (CSWCRTI), with headquarters at Dehradun and its eight research centres located at Agra (U.P.), Bellari (Karnataka), Chandigarh, Datia (M.P.), Kota (Rajasthan), Koraput (Orissa), Udhagamandalam (T.N.), and Vasad (Gujarat) are engaged in undertaking research studies in soil and water management and hydrology aspects under all primary production systems; developing strategies for controlling land degradation; and rehabilitation of degraded lands in different agro-ecological zones of the country.

Indian Council of Forestry Research and Education (ICFRE), an autonomous body under MOEF, GOI, is the apex body in the national forestry research system. The ICFRE, with its headquarters at Dehradun, has eight Regional Institutes located at Dehradun, Shimla, Ranchi, Jorhat, Jabalpur, Jodhpur, Bangalore and Coimbatore and four Research Centres at Allahabad, Chhindwara and Hyderabad, etc. ICFRE is striving for the holistic development of forestry research at national level through planning, promoting, conducting and coordinating research, education and extension on all aspects of forestry for ensuring scientific management of forests, improvement in forest productivity through genetic and biotechnological researches, bioremediation of degraded land, efficient utilization of forest products, conservation of biodiversity and integrated management of pests & diseases of forests.

The detailed cost of the individual projects may vary depending on the site conditions, objectives, instrumentation required, duration of the project, involvement of experts and infrastructure required.

(iii) The committee also endorses for initiating an All India coordinated research project in forest hydrology. A project proposal for initiating such a project in different forest types in various geo-ecological regions may be jointly prepared by NIH, CSWCRTI and ICFRE for funding from MOeF. The research centers of these organizations would also be involved in implementing the projects. The proposal should include relevant review of literature, well defined objectives, expected output, linkages, budget requirement and year wise activity chart. Since it will be a huge task, it is recommended that based on the strength of individual organization, the role and responsibilities of each partnering organization may be clearly defined in the project proposal along with their budgetary requirement. The sanctioned budget of each organization may be transferred to respective organization for smooth conduct of the research components proposed by individual organizations.

7. CAPACITY BUILDING IN THE AREA OF FOREST HYDROLOGY

The research needs for advancing forest hydrology science include understanding long-term and landscape-scale hydrologic effects of forests and the cumulative watershed effects. Hydrologists use hydrological modelling techniques to predict water quantity and quality in catchments where there are no measured records. Most hydrological models are developed and tested for gauged basins and subsequently are validated and applied to un-gauged areas. However, models that have been fitted to data in small, gauged watersheds often provide inaccurate or imprecise predictions when they are (1) extrapolated to other small forested headwater basins, (2) extrapolated to future time periods, or (3) applied to large catchments. This problem of prediction in un-gauged basins has preoccupied hydrology researchers for several decades, and is compounded by a lack of information about how direct hydrologic effects interact under the multiple sets of specific conditions that occur in changing forest landscapes. Spatially explicit assessments and physically based models designed to simulate, predict, or represent these phenomena form the basic needs of forest hydrology related models for today and the foreseeable future.

In forest hydrology, several hydrologic models have been developed for many different objectives including prediction of the hydrologic impacts of wild fires and land use change over different spatial scales and time periods. These models vary in how they represent hydrologic processes linked with vegetation characteristics, soils, groundwater, and runoff; they also vary in the spatial and temporal scales at which they simulate hydrologic processes. However, uncertainties in landscape properties and climate inputs, choice of model structure, and methods of information transfer from gauged to un-gauged watersheds make the modelling task a very complicated phenomenon. In India, the science of forest hydrology is still in infant stage and the use of forest-specific hydrological models is very uncommon. The studies conducted so far in forest hydrology rely on the analysis of observed data from plot scale or small watershed scale to quantify hydrological processes and the stream flows. Sporadically, the general hydrological models have been only fitted to observed data but these models do not consider forests-specific processes to account for any change in forest characteristics. Therefore, for the advancement of the forest hydrology research in India, the capacity building is required for the scientists to understand and use the advanced models, developed by academicians and researchers abroad, to simulate the effect of various kinds of changes in forests on hydrologic processes across large watersheds and on water output. These capacity building and man power development activities can be achieved by arranging trainings for the scientists at the organizations engaged in the development of the advanced models of forest hydrology in countries like USA, Australia and other European countries.

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ACKNOWLEDGEMENTS

The committee members thankfully acknowledge the guidance and support provided by the Director General, ICFRE, Dehradun in bringing out the report. The committee also express sincere thanks to the Director, FRI, Dehradun and the Secretary, ICFRE Dehradun for extending the help, logistic support and facilities during the course of committee meetings and preparation of the report. The committee members are also grateful to the Director, NIH Roorkee and the Director, CSWCRTI Dehradun for sparing their scientists to work in the committee and extending all cooperation during completion of the report. Thanks are also due to all those who directly or indirectly helped the committee in completing the task.

APPENDIX 1

No.31-19/2001-ICFRE
Indian Council of Forestry Research and Education
(An Autonomous body of the Ministry of Environment & Forests, Govt. of India)
P.O. New Forest, Dehradun – 248 006 (Uttarakhand)

Dated the 8th July 2011

OFFICE ORDER

All India Coordinated research work on climate change has been approved and Director, FRI and Vice Chancellor of the Deemed University Dr. S. S. Negi will be the National Project Coordinator for this project.

2. One of the important research items to be undertaken in this Project is the work on **Forest Hydrology**. The Director General, ICFRE is pleased to constitute a committee headed by Dr. K.D. Sharma, Technical Expert, National Rainfed Area Authority, Planning Commission, New Delhi who was previously the Director of National Institute of Hydrology, Roorkee.

3. The committee shall consist of the following:

1.	Dr. K.D. Sharma, Technical Expert, National Rainfed Area Authority, Planning Commission, New Delhi	Chairman
2.	Director, National Institute of Hydrology, Roorkee or his Representative (Dr. J. V. Tyagi, Sc'F' is nominated)	Member
3.	Dr. Laxmi Rawat, Head, Ecology & Environment Division, FRI, Dehradun	Member
4.	Dr. A. K. Raina, Head, Forest Soil & land Reclamation Division, FRI, Dehradun	Member
5.	Dr. S.P.S. Rawat, ADG (M&E), ICFRE, Dehradun	Member
6.	Dr. Renu Singh, Head, Bidiversity & Climate Change Division, ICFRE, Dehradun	Member

4. The committee shall identify the areas of research and suggest measure to achieve the mandate. The committee may co-opt other members as and when found necessary. The committee may submit the report by 30th of September, 2011.

8/7/2011
(Sudhanshu Gupta)
Secretary, ICFRE

Distribution:-

1. Dr. S. S. Negi, IFS, Director, FRI and National Project Coordinator
2. Dr. K. D. Sharma, Technical Expert, National Rainfed Area Authority, Planning Commission, New Delhi
3. Director, National Institute of Hydrology, Roorkee
4. Dr. Laxmi Rawat, Head, Ecology & Environment Division, FRI, Dehradun
5. Dr. A.K. Raina, Head, Forest Soil & Land Reclamation Division, FRI, Dehradun
6. Dr. S.P.S. Rawat, ADG (M&E), ICFRE, Dehradun
7. Dr. Renu Singh, IFS, Head, BCC Division, ICFRE, Dehradun

APPENDIX 2

Modified Constitution of the Committee Based on the Suggestions of the Committee Members in the First Meeting Held on August 11, 2011

As per Office order no. 31-19/2001-ICFRE dated 8th July, 2011		
1.	Dr. K.D. Sharma Technical Expert, National Rainfed Area Authority (NRAA), Planning Commission, New Delhi	Chairman
2.	Dr. Jaivir Tyagi (Nominee of Director, NIH) Scientist 'F', National Institute of Hydrology, Roorkee	Member-Secretary
3.	Dr. Laxmi Rawat Head, Ecology & Environment Division, FRI, Dehradun	Member
4.	Dr. A.K. Raina Head, Forest Soil & Land Reclamation Division, FRI, Dehradun	Member
5.	Dr. S.P.S. Rawat ADG (M&E), ICFRE, Dehradun	Member
6.	Dr. Renu Singh Head, Biodiversity & Climate Change Division, ICFRE, Dehradun	Member
Following two members were included in the above committee based on the recommendation made by the committee members during first meeting held on August 11, 2011.		
7.	Dr. K.P.Tripathi (Nominee of Director, CSWCRTI) Principal Scientist Central Soil and Water Conservation Research and Training Institute, Dehradun	Member
8.	Dr. M.K. Gupta Scientist E, Forest Soil & Land Reclamation Division, FRI, Dehradun.	Member

APPENDIX 3

MINUTES OF THE FIRST MEETING OF THE COMMITTEE HELD ON 11 AUGUST 2011 AT NRAA, NEW DELHI TO IDENTIFY THE AREAS OF RESEARCH AND SUGGEST MEASURES TO ACHIEVE THE MANDATE ON FOREST HYDROLOGY

The first meeting of the committee was held in the office of Dr. K.D. Sharma, chairman of the committee at 2.30 P.M. on 11.08.2011 in New Delhi. The Director, NIH vide his letter no. 15/18/2011-NIH/Dir/Nomi, dated 25 July 2011 nominated Dr. Jaivir Tyagi, Scientist 'F' as representative of NIH in the above committee. The following members were present in the meeting.

1.	Dr. K.D. Sharma Technical Expert, NRAA, New Delhi	Chairman
2.	Dr. A.K. Raina Head, Forest Soil & Land Reclamation Division, FRI, Dehradun	Member
3.	Dr. S.P.S. Rawat ADG (M&E), ICFRE, Dehradun	Member
4.	Dr. Jaivir Tyagi Scientist 'F', NIH Roorkee	Member

Dr. Laxmi Rawat and Dr. Renu Singh could not attend the meeting due to preoccupation.

At the outset, the chairman welcomed the members of the committee and briefed about the background and mandate of the committee. He then invited the members to suggest the research issues in the area of forest hydrology and the roadmap to achieve the goal. A detailed discussion was held on various research issues related to forest hydrology in the context of Climate Change. After thorough deliberations by the members, the following actionable points were agreed upon:

1. Dr. Jaivir Tyagi, Scientist 'F' was nominated as Member-Secretary of the committee.
2. The Member-Secretary was entrusted with the work of preparation of the draft report based on the inputs received from other members of the committee.

3. Dr. A.K. Raina would provide the write up on various soil properties including physical, hydrological, chemical, geological and mineralogical, in different forested regions of India which have significant impact on water quantity and quality generated from the forested lands.

4. Dr. S.P.S. Rawat would provide the write up on suggested measures/roadmap to achieve the research mandate proposed by the committee.

5. In view of the additional specific inputs needed for preparation of draft report, the present committee needs to be expanded to include the following experts:

    (i) Director, Central Soil & Water Conservation Research & Training Institute (CSWCRTI) Dehradun or his representative.

    (ii) Dr. M.K. Gupta, Scientist E, Forest Soil & Land Reclamation Division, FRI, Dehradun.

6. The CSWCRTI would provide the write up on present status of research on forest hydrology and the research gaps.

7. Dr. M.K. Gupta would provide the details on the role of forests on carbon sequestration and its impact, if any, on hydrological regime of forested watersheds.

8. The members would provide the inputs as decided in the meeting to the Member-Secretary through email by the end of August 2011.

9. The following broad areas of research on forest hydrology in the context of climate change were tentatively identified by the committee:

    (i) Compilation of status of research on forest hydrology in India and abroad.
    (ii) Preparation of a catalogue of historical and modern hydrologic records
    (iii) Continuing current small watershed experiments and re-establishing small watershed experiments where research has been discontinued
    (iv) Selection of paired representative watersheds (two watersheds similar in size, initial land cover and other attributes) in different geo-ecological conditions for long term hydrological measurement using an integrated approach of hydrologic instrumentation, field investigation, remote sensing and GIS techniques. One watershed may be kept as control while other may be treated subject to manipulations such as change in forest cover and forest management practices.

(v) Monitoring water quality parameters of streams and springs in the selected representative watersheds

(vi) Effect of global warming and climate change on migration of forest types with respect to altitude, changes in structure and composition of forests and the effects thereof on the hydrological parameters including ET and runoff.

(vii) Hydrological investigations on the effects of different tree species and forest types on interception, infiltration, soil moisture, ET, water yield and groundwater

(viii) Effect of different forest management practices on water yield, flood peaks, regulation of stream flows, sediment yield, water quality, etc.

(ix) Monitoring of spring discharge which represents the groundwater in the forested mountainous watersheds.

(x) Investigations on changes in soil physical properties, moisture holding capacity of soils and carbon sequestration under different forest species.

(xi) Besides above, any other pertinent research topics may also be suggested by the members for inclusion in the draft report and may be communicated to Member-Secretary along with brief write up.

10. The next meeting of the committee will be held in the third week of September at FRI, Dehradun to finalize the draft report.

At the end, the chairman thanked the members of the committee. The committee members also expressed thanks to the chair.

APPENDIX 4

Sudhanshu Gupta, IFS
Secretary, ICFRE

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INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION
(An Autonomous Body of the Ministry of Environment and Forests, Govt. of India)
P.O. New Forest, Dehradun – 248 006 (Uttarakhand)

No. 31-19/2001-ICFRE Dated the 14 September 2011

OFFICE ORDER

In partial modification of this office order of even number dated 08th July 2011, the Director General, ICFRE is pleased to nominate the following experts as additional members in the Committee constituted to identify the areas of research and suggest measures to achieve the mandate on Forest Hydrology as a component under All India Coordinated Research work on Climate Change.

1.	Director, Central Soil and Water Conservation Research & Training Institute, Dehradun
2.	Dr. M.K. Gupta, Scientist 'E' Forest Soil & Land Reclamation Division, Forest Research Institute, Dehradun
3.	Dr. S.P. Rai, Scientist, NIH, Roorkee
4.	Dr. G.P. Juyal, Head, Hydrology and Engineering, CSWCRTI
5.	Head, Climate Change and Forest Influence, Forest Research Institute, Dehradun

26/9/2011
(Sudhanshu Gupta)
Secretary, ICFRE

Distribution:
1. Dr. S.S. Negi, IFS, Director, FRI and National Project Coordinator
2. Dr. K.D. Sharma, Technical Expert, National Rainfed Area Authority, Planning Commission, New Delhi
3. Director, National Institute of Hydrology, Roorkee
4. Dr. Laxmi Rawat, Head, Ecology & Environment Division, FRI, Dehradun
5. Dr. A.K. Raina, Head, Forest Soil & Land Reclamation Division, FRI, Dehradun
6. Dr. S.P.S. Rawat, ADG (M&E), ICFRE, Dehradun
7. Dr. Renu Singh, IFS, Head, BCC Division, ICFRE, Dehradun
8. Director, CSWCRTI, Dehradun
9. Dr. S.P. Rai, Scientist, NIH, Roorkee
10. Dr. G.P. Juyal, Head, Hydrology and Engineering, CSWCRTI, Dehradun
11. Head, Climate Change & Forest Influence, FRI
12. Dr. M.K. Gupta, Scientist 'E', FSLRD, FRI, Dehradun
13. Guard file.

APPENDIX 5

Meeting on "forest hydrology" at the board room of FRI, Dehradun on 13th Oct, 2011
Meeting attended by the members

Sr. no.	Name & Address	Phone no.	Email	Signature
1.	Dr K. D. Sharma	9810584400	drkdsharma@gmail.com	[illegible]
2.	Dr G. P. Juyal	9410359886 (M) 0135-2757236	juyalgp@yahoo.co.in juyalgp@rediffmail.com	[illegible]
3.	Dr J. Tyagi	9897736025	tyagi@nih.ernet.in jv_tyagi@yahoo.com	[illegible]
4.	Dr K. P. Tripathi	09412910418	tripathikp1@gmail.com	[illegible]
5.	Dr Laxmi Rawat	9411511424 0135-2752674	rawatl@icfre.org	[illegible]
6.	Dr A. K. Raina	9410320517	rainaak@icfre.org	[illegible]
7.	Dr M. K. Gupta	9412047973	guptamk@icfre.org	[illegible]
8.	M. P. Singh	9410393936	singhmp@icfre.org Head_ccfi@icfre.org	[illegible]
9.	Dr. D. R. Sena	7895178159	drsena_icar@yahoo.co.in	[illegible]
10.				
11.				

Annexure 1

Reviews on Status of Research in Forest Hydrology in India

K.P.Tripathi[1], D.R.Sena[2] and G.P.Juyal[3]

[1]Principal Scientist [2]Senior scientist (Soil and Water Conservation Engineering)
[3]Head (Division of Hydrology and Engineering)
Central Soil & Water Conservation Research & Training Institute, Dehradun

Forest hydrology deals with the role of forest over precipitation (loosely rainfall) and Water yield (loosely runoff) generating potential of the forest in conjunction with other parameters namely soil, topography, vegetation management and land management practices. The runoff resulting from rainfall is paramount importance to all living on this earth. The runoff can be manipulated by modifying the parameters influencing it. The runoff is a function of rainfall, soil, topography, vegetation and its management, and land management practices

Forestry is the science that seeks to understand the nature of forests and the interactions between the parts comprising a forest.

Hydrology is the science that studies the waters of earth. Hydrology seeks to understand where water occurs; how water circulates; how and why water distribution changes over time; the chemical and physical properties of water; and the relation of water to living organisms. The water goes through various forms of transformation from one kind to another. The main source of water for all of us in the sea and which roughly occupies about 70 percent of the total area of the earth. The relationship of rainfall and run off is explained by hydrological cycle.

The hydrologic cycle, also known as the water cycle, describes the continuous movement of water on, above and below the surface of the earth. Since the water cycle is truly a "cycle," there is no beginning or end. Water can change states among liquid (rain), vapour (evaporation and transpiration), and solid (ice) at various places in the water cycle. Although the balance of water on earth remains fairly constant over time, individual water molecules can come and go. Over geological time, water-rich planets such as the earth lose gases such as hydrogen over time, which can lead to run away greenhouse effects which in turn accelerate hydrogen loss, and by association water loss, from a planet's atmosphere**.**

Principles of hydrologic response to changes in forest structure:

1. Partial or complete removal of the forest canopy decreases interception (precipitation captured by leaves and branches) and increases net precipitation arriving at the soil surface.
2. Partial or complete removal of the forest canopy reduces transpiration (water lost from plants to the atmosphere).
3. Reductions in interception and transpiration increase soil moisture, water availability to plants, and water yield.

4. Increased soil moisture and loss of root strength reduces slope stability.
5. Increases in water yield after forest harvesting are transitory and decrease over time as forests re-grow.
6. When forests of high interception (or higher annual transpiration losses) replace forests with lower interception (lower transpiration losses), this change reduces water yield as the new forest grows to maturity.

Principles for changes in water flow paths in soils and sub soils:

1. Impervious surfaces (roads and trails) and altered hill slope contours (cut slopes and fill slopes) modify water flow paths, increase overland flow, and deliver overland flow directly to stream channels.
2. Impervious surfaces increase surface erosion.
3. Altered hill slope contours and modified water flow paths along roads increase landslides.

Principles of hydrologic response to applications of chemicals:

1. Forest chemicals can adversely affect aquatic ecosystems especially if they are applied directly to water bodies or wet soils.
2. Forest chemicals (fertilizers, herbicides, insecticides, fire retardants) affect water quality based on the type of chemical, its toxicity, rates of movement, and persistence in soil and water.
3. Chronic applications of chemicals through atmospheric deposition of nitrogen and sulfur acidify forest soils, deplete soil nutrients, adversely affect forest health, and degrade water quality with potentially toxic effects on aquatic organisms.

The influence of forests on their environment forms part of a complex relationship between environment and forest. Investigators have investigated for past several decades to ascertain the influences of forests on hydrological parameters and water availability. In this direction, forest influences on various hydrological parameters viz. rainfall, interception, infiltration, soil moisture, evapotranspiration, groundwater, water yield, soil loss and floods etc. forms an important area of hydrological studies. A summary of results of studies done in this regard in the country and elsewhere is given in following sections.

Rainfall

In India, limited studies have been directed towards the effects of forests on rainfall. In 1906, a committee was set-up by Govt. of India to find the relationship among forests, atmosphere and soil; which concluded that the effects of forest on rainfall were probably small (Hill, 1.916). Voeleker (Lohani, 1985) had conducted studies on small plots for about 52 years on rainfall and forest data in Nilgiris and had concluded that the planting of trees increased the number of rainy days on local scale. Another study indicated that there was no increase in rainy days during monsoon period (Ranganathan, 1948). Bhattacharya (1956) after conducting intensive studies in Pathri, Ranipur and Ratmau (in U.P. hills) concluded that planned deforestation did not have any effect on rainfall. Pisharoty opined that local changes due to deforestation are less likely to affect the meteorological aspects and quoted experiments done in Germany and England in support of his opinion (quoted from Mistry, 1987). Biswas (1980) has related percentage of forest cover with total rainfall in A&N Group of Islands and concluded that rainfall seems to increase with forest cover. However, India Meteorological Department (IMD) denies any correlation between deforestation and rainfall (Agarwal *et. aI*. 1987). In a detailed study conducted in Western Karnataka and part of Kerala. Mehar Homji (1986) concluded that forest clearance did not seem to reduce the total number of rainys days. Dutt and Manikiam (1987) have concluded based on results of several studies that deforestation has effects on rainfall on local scale but on regional or global scales these effects are not significant. Gupta et al. (2005) based on simulation model using T42 version of CCM3 with a horizontal resolution of 2.8o X 2.8o that for 100% deforestation there will be change in spatial distribution of rain rate in India i.e. Northern part of India, rain rate is expected to decrease upto 2 mm/day where as over southern part of India, including Arabian Sea and Bay of Bengal the rain rate will increase up to 5 mm/day. In north eastern part of India there will be decrease in rainfall about 4 mm/day. However this study is the case due to large scale deforestation.

Based on the limited studies done in India it may be concluded that the results are generally inconclusive in nature, indicating that forests and *rainfall relationship are not monotonic on a regional scale. However, in coastal forests the precipitation may be more because of interception and then condensation of fog by forests.*

Interception

The results obtained in various interception studies carried out in India and abroad by Dabral *et. al.* (1963), Dabral and Subbarao (1969), Mathur *et. al*. (1975), Lull (1964) and others (as given in Appendix-I) indicate that the canopy interception varies from 15% to 35% of rainfall for different species of forests. There is evidence that interception varies not only with type of species, canopy density etc. but also with intensity of rainfall, as is evident *from* Table 1 & 2 (Mathur *et.al*., 1975). It indicates that interception reduces with increase in rainfall amount and beyond 60 mm rainfall/storm; the interception loss reduces to significantly low values.

It can be concluded that the interception is a function of forest type. density, composition, structure and rainfall amount/intensity. Partial or complete removal of the forest canopy decreases interception (precipitation captured by leaves and branches) and increases net precipitation arriving at the soil surface It may be inferred that the average total interception by a dense forest cover (including canopy interception 20%, undergrowth 10% and litter interception 5%) appears to be around 35%. It has also been observed that the interception is higher from needle leaved trees as compared to broad leaved trees. The interception in forested catchments does not have significant effect during heavy storm (100 mm or so). However, this is important from soil conservation view point.

Infiltration

Results obtained from some studies done in the country and abroad regarding infiltration *rates* under various land uses are presented in Table 3. I n a study conducted at Bellary (semi-arid region) and Ootacamund (Nilgiri hills) under different vegetative covers, the results indicated maximum infiltration *rates* for woodlands as 17 cm/hr and for Shola forest (miscellaneous vegetation) as 12.5 - 16.8 cm/hr. In Bihar, Mistry and Chatterjee (1965) recorded average infiltration rates as 26, 12 and 9 cm/hr under forests grasslands and crop lands, respectively. A comparative study of infiltration rates conducted in Dehradun (North-

Western Himalayan region) under Eucalyptus, Sal, Chir, Teak, Bamboo and grassland gave initial infiltration rate*s* as 54.0, 21.4, 12.0, 9.6, 9.6 and 7.6 cm/hr, respectively. In the same study,. effects of fire on infiltration in Chirr plantation was studied and infiltration was found to reduce to a value of 3.6 cm/hr. 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 (Shorea Robusta) as compared to agriculture watershed (Dhruvanayayana and Shastri (1983). A study in Sainji, a forest watershed of Himalaya suggests that old oak forest (with humus content more than 3% with top 10 to 12 cm of humus content) infiltration rate is as high as 159.48 cm/h comparison to young oak forest which has 36.55 cm/h. A scrub forest with biotic activities has infiltration rate as low as 6.25 cm/h (Sena et al., 2011). This is due to a complex combination of infiltration, infiltration and macro flow phenomenon

In general, it can be inferred d that the infiltration rates are relatively more in forested soils as compared to agricultural areas & grasslands. Based on the results of some of the infiltration studies carried out, it could be inferred that infiltration rates from arable crop land and grasslands are nearly 30 to 35% and 40-50%, respectively of that from forest lands. However, it is drastically affected due to biotic interferences like forest fires tampling by cattles, removal of leaf litter etc.

Soil Moisture

A limited number of studies have been conducted to observe the effects of forest on soil moisture regime. In a study conducted at Dehradun, it has been observed that soil moisture (in mm of soil depth) remains at higher level under forest than grass, e.g. bamboo (14-102%), teak (30-73%). Results of soil moisture studies conducted in Nilgiris in latritic soil under various land uses are given in Table 4. It can be observed that soil moisture always remains' higher in forested lands as compared to agricultural lands.

In general, it can be concluded that much efforts have not been made to quantify soil-moisture storages under forests. However, forested soils have a better soil moisture retention capacity due to improved soil structure because of more humus and organic content.

Evapotranspiration

As for the effects of forests on evaporation, the presence of forests may provide shade to ground, thereby reducing both air and soil temperatures and also wind velocity which finally reduces evaporation. One of the measures to reduce reservoir evaporation is by growing thick forest along the periphery of the reservoir. As a result the wind velocity at the reservoir surface gets reduced which reduces evaporation from reservoirs. The presence of forests also affects temperature in terms of having effects on surface albedo. As stated by Pereria (1973) the reflection ranges from 12% for pine forest to 40% for deserts. Obviously lower the albedo and more will be the energy available for evaporation losses in case of forested area.

Studies leading to computation of forest transpiration have indicated that forests generally absorb more radiant energy which is available for transpiration. A limited number of studies done, have indicated that forests have generally high evapotranspiration (ET) requirement as compared to other land uses. Results of few such studies have been summarized in Table 5. Gupta (undated) has cited Engler's observation as the. transpiration of forest compared with crop land and meadows could be indicated as 100: 43 : 22.

The studies conducted in India and abroad indicate that forests have higher ET requirements as compared to other land uses. However, more studies are required to be done for systematic computation of ET by forests.

Groundwater

There exists limited information in Indian context that corroborates the relationship of forest in augmenting groundwater recharge. In the studies conducted for Nilgiris in India, Samraj (1984) observed that plantation of Eucalyptus tree has resulted in significant lowering of base flows.

The effects of forests on groundwater have not been studied on large scale. A *limited number of studies have indicated non-coherent results.*

Water Yield

The availability and quality of water in many regions of the world are more and more threatened by overuse, misuse and pollution, and it is increasingly recognized that climate change is altering forest's role in regulating water flows and influencing the availability of water resources. Therefore, the relationship between forests and water is critical issue that must be accorded highest priority.

Trees through their root system allow a definite volume of percolation and subsequent movement of percolated water. The roots also extract soil moisture regularly to provide necessary nutrients to super-structure above the ground. Thus, when forest is cut, this system gets snapped all of a sudden and thereby water gets stored into the soil profile and its subsequent utilisation or deposition by plant body gets disturbed. This results in sudden increase in water yield in the form of surface runoff. The results of experimental studies conducted in USA and elsewhere have shown increased stream flow following *forest* cutting in a watershed. In Japan and Kenya also a large increase in water yield was observed following clearing of forests (Hibbert, 1965). It has also been observed at places that removing 30% or less of the forest cover would not produce *a* significant change in stream-flow. In India, Subbarao *et. al* (1985) did not record any significant increase in fortnightly water yield after imposing 20% of forest thinning in coppice sal forest at Dehradun. It has also been observed that reforestation of a small brushwood watershed (1.45 ha) by Eucalyptus species (replacing brushwood) reduced water yield by 28%. Results of some such studies under Indian condition are summarized in Table 6.

Based on studies reported above, it can be inferred that substantial reduction of densities of forest overstories and thinning (more than 30%) increase water yield and establishment of forest over-storey on sparsely vegetated land and/or changing to fast growing species like Eucalyptus decrease water yield. This decrease is more significant in first few years of growth. Besides, the type of land cover, the size of watershed have also important bearing on water yield. Based on various studies, it appears that in small watersheds forests tend to decrease the water yield (i.e. due to decreased surface runoff) while in large watersheds, the subsurface component of total water yield (delayed yield) gets increased.

Eucalyptus (Bluegum) plantation and Water Yield

The hydrological behaviour of small identical watersheds; one with natural grassland and "shola" forest and the other with *Eucalyptus globulus* (bluegum) plantation was studied from 1968 to 1992 following the paired watershed technique in the Niligris in Western Ghats of South India. Following the calibration period from 1968-1971, bluegum plantation was raised in 59 per cent area of a watershed above the frost lien during 1972 and it was felled after first rotation of 10 years and subsequently after another 10 years rotation of the coppiced bluegum. Regression and double mass curve techniques were employed to analyze stream flow data to determine changes in water yields. Flow duration curves and Low Flow Index (LFI) were used to quantify the effect of bluegum on low flow regime. Effect of bluegum on high flows was investigated using simple ratios, regression analysis, cumulative frequency plots and probability analysis. Growth parameters of grassland and bluegum plantation were also studied.

The study area is located at Glenmorgan (latitude 11°28'10" N and longitude 76°37'14"E), 24 km away from Udhagamandalam on Udhagamandalam Mysore road in Wenlock Downs Forest Reserves in the Nilgiris district of Tamil Nadu. The study area consists of two small adjoining watersheds (each about 32 ha; Table 7) having nearly identical topography, slope, vegetation and soil characteristics. It falls in the catchment of Glenmorgan storage reservoir feeding the Pykara hydro-electric project in Moyar basin.

The bluegum plantation was spread over an area of 18.76 ha out of 26.8 ha of grassland and possessed 20463 marketable bluegum trees in addition to a few Acacia trees which invaded into the bluegum coppiced plantation. The wood biomass production for the second rotation was 14.1 t/ha/yr as against 10 t/ha/yr (1972-1981) during the first rotation, registering an increase of 41 per cent in wood biomass.

Conversion of natural grassland into bluegum plantation reduced seasonal and annual water yields, decreased low flow as well as decreased peak flows and increased soil moisture losses. These effects were more pronounced during the second rotation *(i.e.* First coppiced growth) as compared to the first rotation. Average annual reduction in water yield of the order of 16% and 25.4% was determined from the bluegum watershed over the natural grassland during the first and second rotation, respectively (Table 8). Maximum reductions in runoff were observed during the winter, summer and pre-monsoon seasons. Significant reduction in low flows as a result of decline in base flow could be predicted with Low Flow Index (LFI) decreasing by 2.0 and 3.75 times, in the first and second rotation respectively. Moderation in peak discharge rates was also observed as a result of bluegum plantation. A sudden increase in runoff immediately after the coppicing of bluegum lasted for about one year. The wood biomass for the second rotation was also 41 per cent higher than the first rotation. These results clearly suggest that hydrological caution may have to be exercised while planning large scale conversion of natural grasslands into bluegum plantations in the catchments of hydel projects in the Nilgiris.

There was an increase in annual flow (14 to 17%) immediately after felling of bluegum trees at the end of first and second rotation. Hydrologic recovery was very fast and this increase lasted for a short duration of about one year. Significant difference (reduction) in soil profile moisture at 0.5 m to 1.0 m depths was observed during the second rotation of 10 years of bluegum watershed over the grassland and this reduction was more than that of first rotation of 10 years. During second rotation bluegum appears to have extracted moisture from 1.0 m soil depth as the roots penetrated upto 3.2 m.

Increases in water yield after forest harvesting are transitory and decrease over time as forests regrow.

Water yield from various watersheds at Almas (Tehri, Uttarakhand)

The annual runoff (%) as that of annual rainfall from three nested watersheds of (i) 535 ha mixed with Forest, Grassland and Agriculture, (ii) 105 ha with mixed Forest, and (iii) 267.5 ha with oak forest located at Almas watershed (Tahsil: Dhanulti; District : Tehri; State: Uttarakhand) was measured with the help of rectangular/ trapezoidal weir with the help of mechanical water level recorder from 2001 to 2009.Water yield from the 535 ha watershed varied from 0.70 percent to 22.6 percent as that of annual rainfall. The water yield from nested bouldry watershed of 105 varied from nil to 11.3 percent. The thick oak forest of 267.5 ha recorded water yield of 7.5 % to 41.3 % m recoded during 2008 **(Table 9).** The variation was mainly due to the rainfall characteristics of each year, diversion of water by 65 mm underground pipe line for irrigation during long spell between two successive storms (Anonymous, Annual Report, CSWCRTI Dehradun, 2000-2010; Tripathi *et.al.*).

Water yield from various watersheds at Sainji (Tehri, Uttarakhand)

The impact of various conservation measures on flow behaviour of three micro watersheds was analysed by dividing the entire data set of 09 year (2001-2010) into two blocks covering treatment period (2001-02 to 2003-04) and post treatment period (2004-05 to 2009-10). Trends of flow during 2001-02 to 2003-04 in the main watershed (WS_1), scrub forest watershed (WS_2) and oak forest watershed (WS_3) reveal that the average surface runoff in WS_1, WS_2 and WS_3 was 3, 4.8 and 2.4% of total rainfall, while the corresponding values of sub-surface runoff were 43.5, 38.8, and 47.3% respectively. After implementation of soil conservation interventions i.e. during the post-treatment period (2004-05 to 2009-10) the average surface runoff recorded was 2.0, 2.6 and 1.6% and sub-surface runoff as 51.5, 46.8 and 55.9% in WS_1, WS_2 and WS_3, respectively **(Table 10).** This indicates that after imposition of soil conservation measures, sub-surface flow increased by 0.8% in WS_1, WS_2 and 8.6% WS_3 micro-watersheds, respectively. In the oak forest watershed, the sub-surface runoff was 55.9% after implementation of treatments as compared to 38.8% in the scrub forest watershed before treatment i.e. approximately 17.1% higher over scrub forest watershed (Anonymous, Annual Report, CSWCRTI Dehradun, 2000-2010; Sharda *et.al.*).

Water yield from "Shola" forest, treated and untreated watersheds in Nilgiri (Tamilnadu)

Hydrological studies were conducted in three small watershed viz; W_1, W_2A and W_2B having an area of 5.1, 5.7 and 19.8 ha under different management practices viz; with poor conservation measures (untreated), conservation measures (treated) and forest management, respectively to quantify the runoff, soil and nutrient losses. The results indicated that the land cover under perennial vegetation of shoal forests reduced the runoff by 55% and land cover under annual crops with proper soil and water conservation measures reduced by 52.4% as compared to untreated watershed without any conservation measures. The base flow component of total runoff was highest in the watershed under shola forest (73.6%) followed by watershed treated with soil and water conservation (68.5%) and lowest under untreated watershed (3.19%). The surface flow component reduced by 71% and 77% in the watershed W_2A and W_2B respectively as compared to watershed W_1. The soil loss was negligible in watershed W_2A and nil for W_2B. The loss of nutrient was higher under untreated watershed as compared to treated and forest watershed (Sahoo *et. al., 2006).*

Impact of Climate Change on Soil and Water Conservation

A study on "Impact of Climate Change on Soil and Water Conservation" was under taken under ICAR sponsored project on "Impacts, Adaptation and Vulnerability of Indian Agriculture to Climate Change" from 2004 - 05 to 2006-07.Under this study the projected daily rainfall of seven watersheds located in different agro-ecological regions of the country (1.Almas, Tehri Garhwal, Uttaranchal; 2. Umiam, Meghalaya; 3. Udhagamanadalam, TheNilgiris, Tamil Nadu; 4. Pogalur, Coimbatore, Tmailnadu; 5. Jonainala, Keonjhar, Orissa; 6.Belura, Akola, Maharastra and 7. Antisar, Kehda, Gujarat) having an area of 491 ha to 816 hawas obtained from Indian institute of Tropical Meteorology (IITM), Pune on a pixel size of $0.44^0 * 0.44^0$ run under Regional Circulation Model (RCM; PRECIS; generated from GCM ofHADCM3 for A2a Scenario) for the period of 1961-1990 and 2071-2100. These data were analyzed and run off and soil loss was assessed using soil conservation service (curve number method) method and AVSWAT respectively. It is assessed that the annual and monsoon rainfall in the 7 watersheds is projected to change by 3.4 to 46.9 per cent and -8.9 to 42.2 percent respectively. The annual and monsoon rainy days are also projected to change by -2.8 to 86.7 per cent and -16.0 to 91.4 per cent respectively. It is very likely that high intense rainstorm may be very common leading to frequent drought and flood. The annual run off is projected to change between 55.9 per cent to 1211.1 percent assessed under 3 options (i) Present system of management practices adopted for crop production (ii) Management system deteriorating and (iii) Management system getting improved. The frequency of flood and drought is also projected to change. The annual runoff of the magnitude of over 300 mm is projected to increase between 26 to 200 percent thus increasing the frequency of flood. The annual runoff of less than 50 mm is expected to reduce by 10 to 100 per cent thus increasing the frequency of drought. The soil loss is expected to increase by 3.7 to 757 per cent. The most feasible and relevant mitigation measure will be to adopt the watershed management programme more earnestly in combination of planting the permanent vegetation i.e. tree and maintaining at least 15-20 per cent of undisturbed forest in every watershed of about 500 ha (Tripathi *et. al.* , 2007).

Effect of Soil and Water conservation measures on water Yield in Shiwaliks

In a long term investigation (1956-88) conducted in 21 ha watershed in Shiwalik region of Haryana State revealed that with adoption of *in situ* soil water conservation techniques (trenching, brushwood/stone check dams, debris detention structures and water spreaders etc.) runoff reduced from 30 to 4 percent, peak discharge from 10 cumec per sq. km to zero in 32 years and sediment yield from 150 to 0.2 t per ha due to development of dense vegetation (Table 11).

Mass Erosion Control in Fragile Eco-systems of Outer Himalayas and its effect on water Yield

Areas of hilly region are generally susceptible to mass soil erosion and degradation problems caused by landslides, minespoils and torrents Rehabilitation of such highly degraded lands through bio-engineering measures has been successfully demonstrated by CSWCRTI, Dehradun. Nalota nala landslide project, Sahastradhara minespoil rehabilitation project and Bainkhala torrent control project, Dehradun is the successful examples of recommended technology. The highly degraded mine spoil and landslide slopes were treated with small engineering structures such as loose stone/gabion check dams, contour trenches, wattling, geojute etc. and planted with suitable vegetative species. The bioengineering technology not only rehabilitated the area but also improved the water and vegetation cover in the area on a sustained basis for use by the local people.

The rehabilitation measures in the landslide affected and mined watersheds (64 ha) rejuvenated water springs with sustained water yield even during dry season as depicted in Tables 12 & 13 (Sastry and Juyal, 1994; Juyal et al., 1998). The project was found economically viable too in the long run, since the rehabilitation efforts saved an amount of about 1.5 lakh being spent annually by the State P.W.D. in removing the debris before the project was undertaken.

Vegetation recovery in a disturbed moist temperate oak forest

It is well established theory that broad leave trees help in increased silt free base flow which is very important from forest hydrology point of view. In this study though flow measurement has not been made, but the recovery in a disturbed moist temperate oak forest has been documented in Kumaon Himalayas. Chronosequence of vegetation recovery in a disturbed moist temperate oak forest in Kumaon Himalayas revealed that while the herb layer did not change significantly in 21 years, seedlings of certain pioneer tree species appeared in 1-13 years and climax oak species appeared only when the herb layer was fully developed. This was attributed to increased contribution by the herb layer to soil organic carbon and total N levels which created an ambient medium for the oak acorns to establish themselves (Pandey and Singh, 1984; Table 14).

Soil Loss

The soil loss in a catchment would largely depend upon the land use pattern. Bhatia (1986) presented the results of various experimental studies conducted by researchers in India for soil loss from different land uses. The results were presented for various land uses e.g. forests, grass lands, agricultural lands, fallow lands, ravine lands, bare rocks etc. From the results of various studies, a summary **(Table 15)** has been derived to give specific ranges of soil loss for each land use under Indian condition.

From the limited studies, it can be concluded that soil loss is less from dense, well managed forests in comparison to ill managed (denuded) forests. However, soil loss is very less from well managed grass lands. Soil conservation is an effective answer to soil loss problems.

Future Research Needs

1. The most important unresolved issue in forest hydrology is how to “scale up” findings from the general principles of forest hydrology that were developed in small, homogeneous watersheds to improve predictions of hydrologic responses across large, heterogeneous watersheds and landscapes. A landscape perspective allows analysis of forest and water connections over larger areas so as to be able to use the general principles of forest hydrology to make predictions about forests and water that can address current and anticipated future issues, including cumulative watershed effects.

2. The effect of climate change on forests and water is increasingly evident, and future aspects of climate change are likely to have major effects on forest hydrology. Direct effects of climate warming on forests and hydrology are being observed, such as changes in the timing of snowmelt runoff and increases in wildfires, but more research is needed to better predict indirect effects of climate change, including evaluations of how changes in forests and forest management influence hydrologic response.

3. Cumulative watershed effects are the hydrologic effects resulting from multiple land use activities over time within a watershed. Extreme precipitation events often reveal cumulative watershed effects and spur public interest in better understanding how land uses in forested headwaters are related to downstream water availability and other effects. Assessing cumulative watershed effects requires an understanding of the physical, chemical, and biological process that route water, sediment, nutrients, pollutants, and other materials from slopes and headwater streams to downstream areas. Future research in this area should strive to elucidate the relationships among forests, water flow paths and quality, and watershed land use over large spatial and long temporal scales. This can be achieved through hydrological modeling. The model needs to be calibrated and validated with past data. However the rainfall, runoff and soil loss from forests of various composition representing different agro ecological regions of the country on watersheds basis (500 to 10,000 ha consisting of homogenous land use) is rarely available. It is therefore strongly recommended that extensive gauging of watersheds of homogeneous forest land use of the size of 500 to 10,000 ha may be initiated immediately for different ecological regions of the country in a nested configuration.

4. Use the whole body of paired watershed data as a “meta experiment” to better understand hydrologic responses to forest disturbance over large spatial and temporal scales and across a range of forest types.

5. Extensive use of high science tools such as GIS and GPS to expand capability for visualization and prediction of hydrologic response in large watersheds through advanced models.

6. Forest management practices evolve over time. The forces that modify forests today are triggering forest managers to institute novel and contemporary forest management practices. These new practices such as thinning for fuel reduction and best management practices that manage wider riparian buffers for headwater

protection have not yet been assessed for their attendant hydrologic effects. Hydrologic effects of these contemporary management practices need to be understood over long temporal and large spatial scales.

7. Proper instrumentation for gauging is very much needed for continuous uninterrupted data collection. It is observed that in absence of suitable instruments data is not collected. The testing of instrument of the instruments from an institute of repute is therefore recommended before the instruments are installed for data collection.

8. It is necessary to develop, expand the capacity of the present database warehouse such CWC and IMD with a centralised setup to pool decentralised hydrological database and disseminate the users/ planners with customised information for planning.

Table 1. Effect of forest species on interception

Forest type	Interception as % of rainfall	References
Babul	26.0	Mathur et al., 1975
Khair	28.5	Dabral et al., 1963
Teak	20.8	Dabral and Subba Rao, 1969
Chir	22.1	-do-
Sal	25.3	Dabral et al., 1963
Eucalyptus (Bluegum)	21.9	Samraj et al., 1982
Natural Shola forest	33.3	Singh and Prajapati, 1974
Northern US Harwooda	15.0	Lull, 1964
Spruce Fir	32.0	-do-
While pine	26.0	-do-
Hemlock	28.0	-do-
Acacia	25.1	-do-
E.Hybrid	11.56	-do-
Shisham	6.5	-do-
Cybress	36.0	-do-
Shorea Robusta	25.3	-do-
Bamboo	20.0	-do-
N.Carolina Hardwoods	23.0	-do-
Conifers (Rain)	220	-do-
Confiers (Rain snow)	28.0	-do-
Deciduous forest	13.0	-do-

Table 2. Effect of rainfall amount/intensity of interception

Rainfall (mm)	Interception as percentage of rainfall (%); Sal Forest (India, Mathur *et al*. 1975)
0-1	-
1-3	-
3-6	37.3
6-10	-
10-20	24.5
20-40	13.0
40-60	5.9
60-100	4.1
100 & above	4.1

Table 3. Effect of forest species on infiltration

Landuse	Infiltration rare (cm/hr)	References
Shola forest	16.84	Tejwani et al., 1975
Bluegum	20.69	-do-
Grazed grassland	5.13	-do-
Forest land	26.00	Gupta, 1980
Grass land	12.0	-do-
Crop land	9.00	-do-
Ash forest	124.2	-do-
Meadow	36.00	-do-
Cultivated land	7.2	-do-
Pasture	1.8	-do-
Sal	2.2-8.95	-do-
Ash	16.8	-do-
Old oak forest	159.64 (42.73[#])	Sena et al. (paper communicated)
Young Oak Forest	36.55 (37.05[#])	-do-
Scrub Forest	6.25 (4.26[#])	-do-

Table 4. Effect of forests on soil moisture (soil type – lateritic, Nilgiris, India)
Source : Derived from Anon. (1982)

Forest type/ landuse (India)	Soil moisture (cm/mt depth)											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Cultivated bench/ terrace	223.5	19.0	20.5	20.0	19.5	2.0	17.5	17.5	17.5	17.5	20.0	16.0
Shola	30.5	27.0	23.0	28.5	26.0	31.0	22.5	22.5	22.0	24.0	25.0	20.0
Bare (Earlier Grassland)	30.0	25.0	22.0	28.0	17.5	27.0	18.0	21.0	20.0	23.0	25.0	24.0
Grassland	38.0	30.0	27.0	30.0	18.5	32.6	17.0	24.0	20.0	22.0	22.5	23.0

Table 5. Effect of forests on evapotranspiration

Forest type/landuse	Evapotranspiration (mm)	Transpiration	Referene
Chir	840	-	Dabral et al., (1965)
Teak	840	-	-do-
Sal	560	-	-do-
Eucalyptus	268-5526	-	-do-
Grassland	38% of precipitation	22	Gupta (undated)
Cropland	-	43	Gupta (undated)
Eucalyptus Globulees	38% of precipitation	-	Thomas (1972)
Dry deciduous forest	560	-	Mishra (1968)
Pinus	536	-	Dabral et al. (1965)
Radiata	760-885	-	-do-
Pinaster	149	-	-do-
Macarthuri	368	-	-do-
Stuartiana	1200	-	-do-
Diversi colour	1248	-	-do-

Table 6. Water yield as affected by land use

Region/Place	Cover conditions	Runoff as % of rainfall	References
N-W Himalayas	Coppice sal forest	35-45	Lal and Subba Rao, 1981
	High sal forest	14-23	Mathur, 1980
	Agril. Watershed		
	Untreated	9	Dhruvanarayana et al., 1985
	Treated	6	
	Grass cover	21-27 (monsoon)	Tejwani et al., 1975
Southern Hills	Forest watershed	4-11 (winter)	
	Well managed	25-43	
	III managed	10-30	Chinnamanni, 1985
	Agril water		
	Well managed	6-30	
	III managed	10-30	
	Grassland watershed	10-30	
Catchment area of Narmada (within Gujarat)	Forest watersheds with >50% forest cover (area between 1.7 to 77 ha)	10-37	(Sena et al., 2010)

Table 7. Comparison of geomorphological and land use characteristics of the watersheds

Characteristics	Watershed A (control)	Watershed B (Treated)
Area (ha)	33.18	31.89
Initial landuse (ha)		
Area under "shola"	5.20	2.66
Area under natural grassland	25.48	26.83
Area under swamps	2.50	2.40
Shape index	2.22	1.03
Max. length of stream (m)	450	380
Stream density (Km/Km^2)	1.36	1.19
Average slope (%)	21	17
Mean elevation (m)	2166	2166
Watershed Relief (m)	55	61
Time of concentration (minutes)	10.30	9.10
Perimeter (m)	2315	2214
Form factor	0.41	0.49
Compactness coefficient	1.13	1.11

Table 8. Observed and computed values of total runoff and base flow for Catchment 'B' with Eucalyptus globulus for two rotations i.e., 1972-1981 and 1982-1991 (CSWCRTI, Research Centre, Udhagamandalam)

Year	Rotation I (1972--1881)				Year	Rotation II (1982-1991)			
	Total runoff (mm)		Base flow (mm)			Total runoff (mm)		Base flow (mm)	
	Comp.	Obs.	Comp.	Obs.		Comp.	Obs.	Comp.	Obs.
1972	609	600	437	431	1982	216.2	209.3	164.9	130.3
1973	541	523	362	346	1983	221.1	189.2	124.3	92.5
1974	431	432	360	349	1984	427.6	293.4	153.6	91.1
1975	787	585	683	438	1985	272.2	219.0	165.9	121.0
1976	259	203	213	167	1986	340.5	278.2	203.8	157.2
1977	556	479	397	302	1987	282.5	182.8	141.2	88.8
1978	713	619	491	392	1988	348.6	226.0	164.9	108.0
1979	697	516	322	311	1989	559.8	404.5	149.6	119.9
1980	436	301	272	212	1990	282.4	222.7	99.5	94.9
1981	483	368	247	258	1991	743.1	538.3	312.98	219.3
Total	5492	4626	3784	3206	Total	3694.5	2763.9	1681.2	1223.6
Diff. between computed & observed value		866 mm or 86.6 mm/y^{-1}	578 mm or 57.8 mm/yr		930.62 mm or 93.06 mm/yr			457.62 mm or 45.76 mm/yr^{-1}	
% reduction		15.76	15.27		25.1			27.22	

Table 9. Monthly rainfall data and wateryield of various watersheds at Almas watershed (Tehri Garhwal, Uttarakhand), CSWCRTI, Dehradun for the year 2000 to 2009 (Anonymous, Annual Report, CSWCRTI Dehradun, 2000-2010; Tripathi *et.al.*)

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Station No. 1 (Gharat, 535 ha mixed with Forest, Grassland and Agriculture)									
Rain fall (mm)	857.2	1381.7	1555.2	1089.1	1399.6	871.2	1257.1	1225.7	1000.5
Water yield (% of rainfall)	3.7	22.6	09.3	10.08	14.2	1.12	9.4	17.9	0.70
Station No. 2 (Arikhal, 105 ha with mixed Forest)									
Rain fall (mm)	857.2	1423.8	1407.1	1100.2	1399.6	871.2	1257.1	1225.7	1000.5
Water yield (% of rainfall)	00.8	4.4	1.2	1.95	10.1	0.00	0.00	11.3	0.17
Station No. 3 (Bharandanda, 267.5 ha with oak forest)									
Rain fall (mm)	857.2	1414.5	1713.5	1199.2	1352.4	1022.9	1419.2	1377.6	894.4
Water yield (% of rainfall)	41.3	16.0	18.8	31.51	34.9	11.73	14.89	19.8	7.5

Table 10. Average total flow, surface flow and sub-surface flow from three micro-watersheds at Sainji watershed (Tehri, Uttarakhand; outer Himalayas) during and after imposition of conservation measures (Anonymous, Annual Report, CSWCRTI Dehradun, 2001-2010; Sharda *et.al*)

Period	Rainfall (mm)	Main watershed WS_1 (240 ha)			Scrub watershed WS_2 (52 ha)			Pure oak cum mixed watershed WS_3 (163 ha)		
		Total flow	Surface flow	Sub-surface flow	Total flow	Surface flow	Sub-surface flow	Total flow	Surface flow	Sub-surface flow
Before project (2001-02 to 2003-04)	1162.4	540.3	35.0	505.3	506.2	55.6	450.6	577.7	28.4	549.3
Flow as % of rainfall		46.5	3.0	43.5	43.5	4.8	38.8	49.7	2.4	47.3
Surface and sub-surface flow as % of total flow		-	6.5	93.5	-	11.0	89.0	-	4.9	95.1
After interventions (2004-05 to 2009-10)	900.5	481.5	18.1	463.4	445.8	23.8	491.9	518.5	14.8	503.7
Flow as % of rainfall		53.5	2.0	51.5	49.5	2.6	46.8	57.6	1.6	55.9
Surface and sub-surface flow as % of total flow		-	3.8	96.2	-	5.3	94.7	-	2.8	97.2

Table 11. Reduction in runoff, outflow peak and sediment yield due to watershed management in Haryana Shiwalik

Period/year		Rainfall (mm)	Runoff		Outflow peak discharge cumec Sq km^{-1}	Sediment yield tha^{-1}
			mm	%		
Before 1956(estimated)		1150.0	350.0	30.00	10.000	150.0
Actual	1964-65	1254.2	276.7	22.06	2.535	37.7
Average	1965-70	1026.7	116.0	11.30	2.408	12.2
Average	1975-79	1274.4	114.8	9.01	2.764	2.4
Average	1979-84	1156.1	83.7	7.24	0.140	1.1
Average	1984-88	828.2	35.1	4.23	0.000	0.2

Table 12. Effect of bioengineering measures on landslide stabilization in Nalota Nala watershed

Description	Before treatment	After treatment (1994)
Runoff (mm)	55	38
Dry weather flow, days	100	250
Sediment load (Tonnes/ha/yr)	320	5.5
Vegetation cover (%)	<5	>95
Nala bed slope (%) -Lower reach	12	7
- Middle reach	23	14
- Upper reach	54	44
Toe cutting	severe	Nil

Table 13. Impact of rehabilitation of mine-spoiled watershed at Sahastradhara, Dehradun

Particulars	Before treatment (1983)	After treatment (1996)
Debris outflow (t/ha/yr)	550	8
Monsoon runoff (%)	57	37
Lean period flow (days)	60	240
Vegetation cover (%)	10	80

Table 14. Recovery over time of disturbed oak forest ecosystem through an age sequence of land stabilized after landslides in Kumaon.

Parameter	Age (years)							
	1	3	6	13	21	40	90	Undisturbed site
No. of annual species	11	6	11	17	16	16	23	15
No. of perennial species	6	2	4	11	10	10	13	13
Herb density (shoot m^{-2})	7	9	19	42	66	66	278	76
Ground surface cover (%)	8	3	12	18	33	33	49	42
Herb+Shrub biomass (gm^{-2})	35	45	50	800	850	850	1375	1050
Organic C (%)	1.5	1.6	1.8	2.0	2.5	2.5	3.9	3.9
Soil loss (kg ha^{-1})	-	-	81	62	42	42	-	26

Source: Modified from Pandey and Singh, 1984.

Table 15. Landuse and Soil Loss Ranges*

S. No.	Landuse	Soil loss (t/ha/yr)	Source
1.	*Forrest*		Bhatia (1986)
a)	Dense, well managed	0.5 to 0.90	
b)	III managed (denuded lands)	20.0 to 60.0	
2.	*Agricultural lands*		Bhatia (1986)
a)	*Without SWC Activities*		
i)	Hilly areas	20.0 to 40.0	
ii)	Plain areas	5.0 to 20.0	
b)	*With SWC activities*		
i)	Hilly areas	1.0 to 19.0	
ii)	Plain areas	0.0 to 3.0	
3.	*Cultivated fallow lands*		Bhatia (1986)
	(1% to 9% slope)	4.0 to 70.7	Bhatia (1986)
4.	*Ravine lands*		
i)	Denuded lands	10.0 to 20.0	
ii)	Treatedlands	0.5 to 5.0	
5.	*Grass lands*		Bhatia (1986)
i)	Well managed	0.0 to 1.0	
ii)	III managed	20.0 to 40.0	
6	Small forest cathment of SSP in Gujarat (more than 50% area under forest) (size 1.7 ha to 77 ha)	5.3 to 39.7	Sena et al. (2010)

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Annexure 2

Carbon Sequestration Through Soil Organic Carbon

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There is a growing international concern over the accumulation of greenhouse gases in the earth's atmosphere. Carbon dioxide (CO_2) is one of the major greenhouse gases and it has increased significantly in recent decades. Concentration of atmospheric CO_2 can be lowered either by reducing emissions or by taking CO_2 out from the atmosphere and stored in the terrestrial, oceanic or aquatic ecosystems.

Soil has a vicious relationship with vegetation. The soil changes slowly through time and its formation takes millions of years. However, soil improvement or enrichment is a rapid process and very closely related with the vegetation composition. The trees initiate and establish the nutrient cycling, provide shade to conserve moisture, promote microbial activities and improve soil physicochemical behaviour. The accumulation of soil organic matter under trees is the most commonly reported effect of trees on soils (Odum, 1960). Tree growth serves as an important means to capture and store atmospheric carbon dioxide in vegetation, soils and biomass products (Makundi and Sathaye, 2004). After the litter fall, the detritus is decomposed and forms soil organic carbon by microbial process. This sequestered carbon finally act as sinks in the forest land. Soil Carbon has much longer residence mean times than the Carbon in the vegetation that the soils support. Soil especially the forest soil is one of the sinks of carbon on earth because these soils normally contain higher soil organic matter. It is a well accepted fact that adoption of better management practices can enhance soil carbon, and improve soil quality and productivity in the forest areas. Moreover, soils provide a significant reservoir for organic carbon, storing twice as much as the atmosphere and three times as much as plants. On comparing the carbon storage in top 1 foot of soil under six land uses, it was found that forests had the best mitigation potential followed by agro-forestry, plantations, agriculture etc. (Jha *et. al*., 2001). Soils and vegetation, therefore, represent potential sinks for this additional carbon and several authors have suggested afforestation as a possible means of mitigating global climate change (Shivanna *et al.*, 2006 and Ramachandran *et al*., 2007). Soil Organic Carbon (SOC) has been ignored because it was treated as a dead biomass. After the awareness of climate change its importance has been recognized worldwide. Soil contains an important pool of active carbon that plays a major role in the global carbon cycle (Melillo *et al.* 1995, Prentice *et al.,* 2001). Changes in forest type, productivity, decay rates and disturbances can effectively modify the carbon contents of forest soils. Land use and soil management practices can significantly influence soil organic carbon dynamics and carbon flux of the soil (Batjes, 1996; Tian *et al.,* 2002). Input of organic matter is largely from above ground litter, therefore, forest soil organic matter tend to concentrate in upper soil horizons. This layer is readily depleted by anthropogenic disturbances such as land use changes and cultivation.

Forest fire, overgrazing, etc. also lead to the soil degradation and loss of soil organic matter store. Deforestation is one of the most important sources of CO_2 emission in to the atmosphere. However, an estimated 1 million ha of abandoned land previously under non-forest use (mostly agriculture) have been reforested by "natural expansion of forests through natural succession (FAO, 2001) and hence an expansion of carbon sink. It has been estimated that the conversion of old growth forest to younger plantation in western Oregon-Washington states (USA) in the last 100 years has added 1.5 x 10^9 to 1.8 x10^9 tones of carbon to the atmosphere (Marland,1988). Soil organic carbon is sensitive to impact of anthropogenic activities. The conversion of natural vegetation to various land uses results in rapid decline in soil organic matter (Post and Kwon, 2000). SOC values decreased over a span of 5–15 years as a consequence of replacement of natural Sal (*Shorea robusta*) forest with Eucalyptus plantation, in West D Dun Forest Division (Jha *et al.,* 1992). A report of IGBP (1997) estimated that 1.6 billion tons of carbon / year are released through land use change in the tropics, while about 2.1 billion tons of carbon / year are absorbed by terrestrial ecosystem through the combined effects of forest regrowth, CO_2 fertilization and nitrogen deposition.

SOC can be made a central consideration in land management strategy more so for forest areas. Silvicultural practices in forests can be revised / improved with the consideration of increasing and maintaining optimum quantities of SOC. This point becomes all the more important when degraded ecosystems are rehabilitated by rising and managing plantations which have a remarkable effect on climate change mitigation. SOC plays a key role in improving the physical properties of soil, which are responsible for infiltration, percolation, permeability, and hydraulic conductivity of land.

The Intergovernmental Panel on Climate Change identified creation and strengthening of carbon sinks in the soil as a clear option for increasing removal of CO_2 from the atmosphere and has recognized soil organic carbon pool as one of the five major carbon pools for the Land Use, Land Use Change in Forestry sector. It is mandatory for all nations to provide soil organic carbon pool and changes from LULUCF sector of the forests under Nation Communications to the UNFCCC.

The concern about increasing atmospheric CO_2 and its role in future global climate change has lead Soil scientists to quantify soil organic carbon content (also referred as stocks or storage) (Lacelle *et al.,* 2001). Accurate quantification of soil organic carbon is necessary for detection and prediction of changes in response to changing global climate.

There is a major potential for increasing soil organic carbon through restoration of degraded soils and widespread adoption of soil conservation practices. The variety of soils occurring in India offers different potential for carbon sequestration. They also need different sets of strategic management for improving their mitigation potential because of their different mineralogical, biophysical and chemical behaviour and response to a given input (Negi and Gupta, 2010). There is a need to formulate a strategy for more precise SOC estimation and monitoring thereafter under different forest covers, land uses and also under the Trees Outside Forest (TOF). Major considerations for soil management are to develop knowledge bank on geological/ mineralogical, physical, chemical, biological and microbiological properties and the inter-linkages. The regional specificity of soil behaviour could then be understood and managed for finally stabilizing GHGs nationwide on a sustained basis.

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Annexure 3

Soil Studies

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The characteristics of soils differ widely depending on the nature of the rock, climate and topography where they were formed. Soils develop over thousands of years through weathering processes and this may include an involvement of plants and soil organisms. While soil formation can be influenced by activities of microorganisms, microfauna, macrofauna and plants, the extent of their influence depends on the climate. Life in soil changes over short periods, in response to changes in the soil environment associated with natural influences (*e.g.* wetting and drying cycles), differences in life stages of organisms (plants and soil biota), and disturbance resulting from management practices such as tillage, fertiliser application and pesticide use and also disturbances such as erosion, logging and digging by animals alter some physical and chemical properties of soil, at least temporarily. Overall, the dynamic processes that occur in soil create an environment where living organisms are continually affected by changing conditions, including seasonal events and climate.

In order to assess the present status of soil fertility in different forested lands of India for suggesting the management practices, its impact on water quantity and quality and site matched species, it is prerequisite to determine the soil attributes such as physical, chemical, biological and geological properties. The suitability of soil for sustaining plant growth and biological activity is a function of its physical properties (Bulk density, porosity, texture, structure and water holding capacity) and these properties are responsible for retention and mobility of water and nutrients; habitat for micro and macro fauna. Information is required about what sort of range in measurements of these factors are appropriate for a particular soil type. Soil morphology can be expressed by soil development indices (Wadia, 1976) which quantify differences in morphological properties between parent material and soil. The chemical components of soil fertility that are most relevant to land management include acidity, alkalinity, salinity and nutrient status. However, the quantity of nutrients in soil is not always related to its fertility as other factors may limit plant growth. An understanding of the methods used in soil and plant analysis is necessary to evaluate the relationship between nutrient levels in soil and soil chemical fertility. Among soil chemical properties pH, organic carbon and available plant nutrients (N, P and K) are important to know the inherent capacity of the soil to supply nutrients to plant growth. Estimation of soil chemical property of a particular site may provide vital information about soil's nutrient bearing capacity and also useful in selection of suitable species on the particular location. Most characteristics that contribute to the fertility of soil, such as soil pH and the susceptibility of the soil to compaction are dependent on the constituents of the original parent rock. Subsequent events, including the growth of plants and addition of fertiliser, modify the soil characteristics and alter its fertility. Issak *et al* (1997) suggested that soil properties of inland valleys were affected by both geology and climate. Soil quality is strongly influenced by microbiological mediated processes. Microbial biomass carbon (MBC) and earthworm population are important parameters to identify the changes in soil quality. Microelements serve important physiological and biological functions in the life of plants (Yelsakov and Vikhman,1994). The biological components of a soil which influence its fertility include many different types of organisms: microorganisms (bacteria and fungi), animals (microfauna, mesofauna and macrofauna) and plants. These organisms range in size from less than a micrometre to more than a metre. Most are only visible with a microscope. Biological components of soil fertility are generally more difficult to measure than both soil chemical and physical components. Information about the abundance and types of organisms present is not very useful unless the relationship between the number of organisms and aspects of soil biological fertility is also known.

Mineralogical studies has special importance in forestry where tree growth lasts over a long period and depends to a large extent on the minerals as a source of nutrients in the soil. Dhar *et al* (1988) ,Osher and Buol (1997), and Gangopadhyay *et al* (1989) stressed the importance of mineralogical research mainly because of the intimate relationship between mineral content and soil fertility. The knowledge of mineralogical behavior of soils at good natural sites and at degraded sites opens the possibilities of optimal management inputs to augment production of the biomass from good site as well as from degraded site after suitable amelioration. In the present intensified programme of raising large scale plantation especially of fast growing species, the fertility potential depends largely on the mineralogical composition of the soil. The underlying parent material plays a vital role in determining the success or otherwise of the plantations especially over a number of rotations in a given year on different climatic conditions The plant nutrients are chiefly derived from the weathering of minerals. The reserve and availability of nutrients depends largely on the mineralogical composition of soils and their parent material.

The importance of geology in forestry research is of great significance in evaluating the soil fertility status and in managing the soils for greater production. A general relationship between geology, soil and vegetation observed that relief and age acting on geology govern the existing soil whereas effect of altitude and climate on geology gives rise to natural vegetation (Raina *et al* 1999). Minhas *et al* (1993) studied the soil formation in relation to forest vegetation in temperate zones of Himachal Pradesh and Uttar Pradesh respectively. The geological study shall be helpful in understanding the ecological status of forest growth and in investigating the various problems like deterioration in growth, quality, loss of vigor, mortality etc. in forest crops often caused by nutrient deficiency and other soil forming factors, most of which are related to mineralogical composition. Troup (1921) gave a number of examples to show that forest vegetation in India is related with geological and soil conditions. The study thus will be helpful for the managers and land users to have a thorough knowledge about the content and nature of minerals present in the soil in diagnosing the fertility status and other soil-plant-parent material relationship developed on different climatic conditions. It will also be useful to work out proper requirement of nutrients for a particular species for a sustainable management of such sites. Geological studies are essential as a prerequisite for a successful afforestation programme on different sites. According to Puri (1949), nature of underlying deposits and structure of the geological formations determine the availability of moisture and plant nutrients. This is borne out by the fact that, in low biologically active sites, weathering of minerals becomes an important source of essential nutrients enriching the soil. The relative efficiency of this mode of soil enrichment cannot be ascertained unless geological and soil studies are carried out.

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Annexure 4

Some Forest Vegetation Studies Related To Forest Hydrology

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1. Biodiversity / Phytodiversity status of different watersheds /catchments having different landscapes (site specific forests, savannahs, lakes, wetlands and river stretch) with special emphasis on endemic species and valuable (ornamental, medicinal, fuel wood, fodder, timber species) species
2. Study of landscape or riverscape alongwith their social values (ecosystem services), which includes climate /microclimate, socio-economic status, food/fodder/fuel and energy production (societal support of watershed)
3. Ecological services of both terrestrial and aquatic ecosystems (including wetland ecosystems; societal support of watershed)
4. Status of invasive species in different landscapes / watersheds/catchments and their impact on different hydrological parameters (by comparing different watersheds /landscapes)
5. Water determinants of particular habitat (for aquatic ecosystems; lake/river/wetland - water quality, silt load etc.) for terrestrial ecosystems - precipitation, evapotranspiration, groundwater table and quality, soil moisture)
6. Litter production/decomposition in terrestrial ecosystems, which play great role in conserving soil moisture, maintaining soil texture, enhancing water holding capacity, infiltration /percolation, altering interception etc.
7. Canopy structure of different forested watersheds, which is important in interception, stem flow, through fall estimation, (important components of hydrological cycle).
8. Phenological (leaf emergence, flowering, fruiting etc.) studies of existing tree species of different watersheds /catchments, which are influenced by changes in hydrological parameters of any area
9. Long term productivity and key ecological services like soil moisture, ground water recharge, flood storage etc.
10. To identify core ecosystems of particular ecological value providing hydrological services and protection from fires, extreme droughts, pollution etc.