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VEGETATION MANAGEMENT FOR INCREASED WATER YIELD

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Studies done in India and elsewhere have indicated that the vegetation management practices have a great potential in increasing water yield from a watershed. The vegetation management practices include various types of forest cutting or removal, or changes of forest cover from one tree type to another, or more drastic changes in which a forest cover is replaced by another type of vegetation. The increase in water yield is attributed to variation in ET losses associated with manipulation of vegetation or change in land use. Evaporation processes generally account for a singnificant portion of the annual precipitation input on most watersheds. Consequently, the potential to increase water yield by decreasing evapotranspiration is attractive. It has been observed that a little change in evapotranspiration causes a significant increase in stream flow runoff.

The report presents a summary of water yield improvement experiments done in India and elsewhere. The studies have indicated that a reduction in the densities of forest overstories and other vegetative cover types can increase water yield,however, it is difficult to predict response of vegetation management on water yield as the results obtained in various studies have beenof diverse nature and suggest the complexity of the hydrologic factors that are involved.Moreover the studies have been mainly done on small experimental watersheds or runoff plots. The results of studies have been

critically examined in this note. Based on results of various studies efforts have been made to quantify water yield from various land uses in terms of rainfall-runoff ratio. In general, the results indicate that vegetation management has a potential for increasing water yields from upstream catchments. The practices of partial cutting/thinning and forest conversions seem to be promising for improving water yield without causing appreciable soil erosion and at the same time maintaining substantial yields of forest products. Experiments need to be done on large catchments as the results obtained from runoff plots or small experimental watersheds may not give good results when extrapolated to larger catchments.

1.0 INTRODUCTION

The increasing demand of water in various sectors is causing great concern to hydrologists, water resources planners and engineers to explore ways and means to augment water resources. A number of approaches for water augmentation and methods of better water management have been explored. The vegetative management on the upland watersheds is one of the ways to increase water supply. The hydrological behaviour of a watershed is affected by land uses besides other watershed characteristics. The hydrological functioning of a vegetated (forested) watershed is influenced by the type of vegetation, its composition, density, extent and management practices. The forested watersheds are largely confined to the upper catchments of various water resources projects.

Management of vegetation on upland watersheds is of special interest to planners and engineers of water resources development projects that are designed to augment the supplies of water for down stream consumers. The vegetation manipulation (i.e. clearing, cutting or removal, thinning, overstory removal or thinning, conversion of forest to grass, change of tree species etc.) in the upstream catchments is one of the ways to alter the water budget of the catchment. The vegetation management may vary from simple thinning to clear-felling or its conversion to some other land uses(i.e. forest cover to be replaced by grass etc).

The amount of water for down stream users can often be increased by upstream vegetative management practice(i.e. changing the structure and compsoition of vegetation) that reduce interception and evapotranspiration losses. The drastic vegetation manipulation may also lead to other hydrological problems like soil erosion, sediment yield, water quality etc. which is kept in view while planning vegetation treatments.

The concepts of vegetation management for water yield improvement alongwith summary of several worldwide studies conducted on experimental watersheds have been reviewed and presented in this report.

2.0 WATERSHED RESEARCH METHODOLOGIES

The land use of a watershed is an important factor which influences the hydrologic behaviour of a watershed. There has not been much developments regarding evaluation of hydrologic effects that result from changes in land use. It was sometime in early forties when attention of researcher was drawn to quantify effects of varying amount of forest and other vegetation over story removal on water yield. Even now the main aspects of watershed management research are devoted to quantification of hydrologic effects as a result of changes in land use. Leopold (1970) scrutinised 101 research papers dealing with watershed management research and found that a majority of them were devoted to find effects of land management practices on water yield. It was concluded by the author that in the USA a bulk of research work being conducted by the USDA Forest Service was aimed at regulating the quantity and timing of water yield as a result of vegetation manipulation.

In the evaluation of hydrological effects of land use changes various methods and techniques are used both for data collection and analysis. Data are collected from small plots, unit source areas, small watersheds, large representative basin and bench mark catchments. Analysis of data is done by number of techniques ranging from simple graphical representation to sophisticated statistical analysis and computer modelling and simulation. The methodologies which are in vouge for watershed management research are described in following sections.

2.1 Studies in Small Plots

Studies in small plots are often done as a first step in testing a hypothesis relating to watershed management research. Ward (1971) described that in order to understand the fundamental mechanics of a basic process at work, studies in small, homogeneous plots which can be isolated under relatively controlled conditions are of great use. Furthermore, as studies can be conducted in small plots under desired set of conditions results obtained can be extrapolated to other areas having similar conditions. However, due to difficulty in relating plot and watershed behaviour and the boundary distortion problems posed by plot retaining wall the results of plot studies can not be reliably used in watershed management research. But the results obtained from plot studies may indicate following up similar studies in larger watershed or experimental basins. For example, in Arizona,USA,Justification for testing many of the specific water-yield improvement involving vegetation management on experimental watersheds have been generated, in past , from results derived from plot studies.

Plot studies in itself are not sufficient to indicate hydrologic influences of land use changes and need to be closely linked with experimental watershed studies. Wasi Ullah et al. (1972) have suggested to consider following points for ensuring accuracy and economy in runoff plot studies:

i) The plot site should be selected having uniform soil conditions in respect of physical properties and fertility status.

ii) The land slope should be natural and land grading to obtain desirable slope should be avoided.

iii) The site selected should provide adequate provisions for installing various instruments for measuring various parameters.

iv) The chosen site should be free from obstructions to avoid any effects on rainfall catch.

Ackerman(1966) suggested plots with no artificial boundaries for reducing boundary distortion problems faced in plot studies. Based on research results obtained in various studies it can be said that plot studies can be used as a complementary technique to experimental watersheds, however, the contributions from plot studies have been significant to watershed management research.

2.2 Experimental Watersheds

A watershed that has been instrumented for studying various hydrologic phenomenon is referred to as experimental watershed. Linsley(1976) defines an experimental watershed as the one which is intensely instrumented, usually small, and used for the indepth study of some portion of the hydrologic cycle. The size of experimental basins is restricted to a maximum of about 4 km^2 as more detailed studies are required on them. The selection of experimental watersheds is done in such a manner that the results of studies obtained from them might be transferred, at least qualitatively to other uninstrumented watersheds with similar characteristics. The experimental watersheds have been utilised for evaluating the hydrologic effects of land use changes on the quantity and timing of water yield from natural catchments,ecological studies, for field laboratories for investigating hydrologic processes and as a source of data for calibrating or validating computer models.

Generally two methods are used for calibrating experimental watersheds for hydrologic study, namely,(i) to use a single watershed and calibrate it upon itself, and ii) paired or multiple watershed method. In case of single watershed approach, a watershed is calibrated for number of years until its behaviour can be predicted from past performance. A treatment is then imposed and its effects are evaluated in terms of deviations from the expected behaviour. Accuracy of results depends upon the ability to predict watershed behaviour from climatic variables. The paired or multiple watershed method involves the use of a control watershed with which the hydrologic behaviour as a result of changes in treated watershed (s) is compared. The watersheds are selected for their similarity in size,shape, topography,vegetation cover, past land use, climate and general location. The watersheds are initially calibrated for a period which is long enough to allow the prediction of the behaviour of a watershed from that of the other. Studies have been done to find out length of calibration periods of watersheds Bethlahmy (1963) & Wilm(1949). Once the watersheds are calibrated, a treatment is applied to one or more watersheds, leaving the control watershed undisturbed. The effects of the treatment are measured as departures from the predicted behaviour of the watershed which is solely based on control watershed. If the characteristics of control watershed have remained unchanged, the changes in the predicted behaviour of treated watesheds are attributed to the imposed treatment.

There have been many criticisms of experimental watershed research expressed by various researchers Hewlett et al.(1969), Ackerman (1966) & others'. The main criticisms include the following.

i) the experimental watersheds are unrepresentative and so transfer of results to other area is difficult

ii) the experimental watersheds are costly to establish because of the need for much more instrumentation and observation

iii) the results obtained from paired watershed studies do not provide a good understanding of the hydrologic processes involved.

iv) In case of yield improvement studies the changes in water yield response following treatments are often too small for detection.

Inspite of above limitations, some satisfactory results have been reported by assuming that the smaller experimental watershed is representative of the larger river basin. The conclusions established by paired and experimental watershed studies that evapotranspiration and streamflow are influenced by the type, size and quantity of vegetal cover have got a good recognition. Various experiments done on experimental watersheds have indicated that such studies are indispensable to the complete understanding of watershed management. It has been agreed that water resources planners still need, and in fact have no alternative to, conducting small experimental watershed studies in well planned manner(Ackerman,1966).

2.3 Computer Modelling

This approach is gaining momentum with the fast development of digital computers and their useful application in understanding the component processes of hydrologic system. A simulation model of the watershed is developed using various characteristics and parameters which requires a complete understanding of the physics of the hydrologic system. Even with complete understanding, the determination and quantification of the parameters required by a model to predict exact results would be extremely difficult because each watershed is unique. Simulation techniques do not necessarily generate optimal solutions, rather they show alternative results that allow an investigator to make a decision on the level of inputs that are best for a given purpose. Generally the computer modelling approaches break down large watershed into a number of small independent units linked together to form the larger unit. Then hydrologic simulation is carried out on each unit through computer synthesis. Hydrologic simulatior involves numerical techniques for conducting experiments on a digital computer, with certain types of mathematical and logical models that describe the behaviour of the hydrologic system, or some component thereof, over extended period of real time. Based on the technqiues used for simulation, models are classified as deterministic and stochastic.

Deterministic models are those in which operating characteristics are in the form of known physical laws or empirical relationship and thus provide a unique output from a given input. Stochastic models describe the response of a system through statistical parameters and have operating characteristics that are described by probability functions. Computer modelling is mainly constrained due to lack of mathematical modelling procedures, inadequate mathematical expressions for describing various hydrologic processes, lack of long term data for evaluating various watershed parameters, spatial and temporal hetrogeneity of the parameters that characterise a watershed etc. Generally a model developed for a particular watershed is good for that only and has limited applicability to ther watersheds because of uniqueness in watershed features. Much work remains to be done to develop a general use watershed simulation model which will predict hydrologic effects of various changes made in the watershed including effects of water yield improvement experiments.

2.4 Estimation of Water Yield Improvement

The basic methods of watershed calibration to develop an adequate reference or basis for comparison have been discussed in the preceeding sections. The calibration equation for predicting effects of land use changes is generally expressed as the relation ship between water yield and precipitation. Let calibration equation is expressed by the following form of regression equation:

$$Q = a P \pm b \qquad \ldots(1)$$

where:

Q = water yield

P = precipitation

a & b = coefficients, which could be obtained using past few years of observed data

Once the calibration equation for a watershed is developed, then water yield can be predicted for a given amount of rainfall.

When forest or vegetation is cut after the calibration period, the change in water yield (ΔQ) is

$$\Delta Q = Q_i - Q = Q_i - aP_i + b \qquad \ldots(2)$$

where,

Q_i & P_i are the total water yield and precipitation respectively during any post calibration year(i). This method can be extended using the double mass analysis or by developing more complex expressions for assumed climatological effects.

Douglas & Swank(1975) developed relationships for predicting year wise change in water yield for the hardwood forest region of eastern USA. The authors predicted the change in yield during first year by following relationship:

$$Q_i = 44\ (f/S_p)1.45 \qquad \ldots(3)$$

where:

Q_i first year change in water yield,mm

f fraction of catchment area affected or treated

S_p potential solar radiation , 10^6x ly/yr

The effect of vegetation manipulation on water yield has been found to diminish logarithmically with time due to forest regeneration.

The assessment of potential water yield increase from a watershed requires two levels of evaluation-extrapolation of research information from experimental watersheds to predict water yield increases resulting from a given vegetation management practice, and identification and evaluation of land areas that appear to have potentials for increasing water yield as discounted by various constaints e.g. ownership, climate,physiographic conditions,type of vegetation,institutional, social , economic constraints etc. Having completed these evaluations, approximations of water yield increases as a result of implementing water yield improvement practices can be made for the areas of interest.

3.0 WATER YIELD AND LAND USES

It has been generally observed that the effect of land use practices both cover management and treatment in a watershed play an important role in determining water yield. The results of water yield studies conducted in runoff plots and small experimental watersheds under various land uses e.g.agriculture, forests, grass land, bare lands etc. in India and elsewhere have been discussed in following sections.

3.1 Agricultural Lands

Studies have been done in runoff plots and experimental watersheds to find out the effects of various agricultural lands on water yield with or without soil conservation measures. The results for various regions in India and abroad are summarised in table 1. Some of the studies conducted in the USA have indicated 25-40% less water yield from an agricultural watershed with conservation practices as compared to no conservation situations. Similar trend has also been observed in various studies conducted in India as evident from table 1.

3.2 Forest Lands

The fact that removal of forest vegetation increases streamflow has been known since 1900's. Studies have been done in India and abroad in forested lands under various conditions to determine effects of forest manipulation on water yield. The results of various studies have been summarised in table 2.

3.3 Grasslands and others

Forest watershed research has shown that conversion of

Table 1 : WATER YIELD FROM AGRICULTRURAL LANDS

Region/Place	Cover Conditions Treatments	Runoff Efficiency(%) (runoff as percent of rainfall)
N-W Himalayas	Agril.Crops	
Dehradun	Up & down cultivation	35-54 (monsoon runoff)
	Contour cultivation	30-40
	With mulches	18-20
	Agril.W.S.(54.6 ha)	
	Untreated	9
	Treated	6
N-E Hills		
Shillong	Agril.W.S.	
	Shifting cultivation	6.5
	Bench terraced	5.9
Southern Hills		
The Nilgiris	Agril.crops	
	Up & down	4-10
	Bench terraced	1-2
	Tead Plantation(new)	
	W/o Soil Cons.measures	9-16
	With -do-	0.1-2
Bhawani Watersheds	Agril.W.S.	
	Well managed	6-30
	Ill managed	10-30
Shivalik Hills	Agril.W.S.	
	Untreated	22-25
	Bunded	14
Ravinous Lands	Agril.W.S.	
	Untreated	8-18
	treated	3-4
Red soils	Agril.lands	11-28
	Agril.lands (With soil cons.measures)	20
Sumatra (Indonesia)	Coffee plantation	
	New	18-30 (May-Oct.)
	Old	33-68 (Jan.-April)

W.S. = Watershed

Source : Ref. Nos. 54,4,13,11,20

TABLE 2 : WATER YIELD FROM FOREST LANDS

Region/Place	Cover conditions/ Treatments	Runoff efficiency(%)
N-W Himalayas Dehradun	Coppice Sal Forest W.S. (6.5 ha)	35-45
	High Sal Forest W.S.	14-23
Southern Hills The Nilgiris	Protected tree covers (runoff plots)	1-1.3
	Forest W.S.(32 ha)	1-6 (SRO) 20-35(SSRO)
Bhawani watersheds	Forest W.S.	
	Well managed	25-43
	Ill managed	10-30
Siwalik Hills	Denuded W.S. (20 ha)	50
Ravinuous Lands	Denuded	10-20
	Vegetated	3-5
USA (in various regions)	Forested W.S.	4-18(SRO)
The Phillippines	Primary forest	0.25
	Logged over forest (plots of $8m^2$)	1.75
Malayasia	Natural Forest W.S.(15ha)	16
	-do- (100 ha)	43
	Secondary Forest W.S.(15 ha)	56
	-d0- (100 ha)	58
	-do- (2 ha)	3
	Eucalyptus (15 ha)	20

W.S. = Watershed
S.R.O = Surface runoff
SSRO = Sub-surface runoff

Source : Ref.Nos. 31,42,11,13,20

forest to grassland as the dominant cover usually resulted in greater water yield with only small increase or no increase in storm flow volume, peak flows, or storm duration flow,depending upon grass density and productivity. The results of various studies done in India and abroad have been given in table 3 wherein water yields from various land uses e.g. grass lands, bare lands have been described.

TABLE 3 : WATER YIELD FROM GRASS LANDS AND OTHERS

Region/Place	Cover conditions/ Treatments	Runoff efficiency(%)
N-W Himalayas Dehradun	Grass cover Grass Cover	21-27 (monsoon) 4-11(winter)
Southern Hills		0.01-0.4
The Nilgiris	Natural Grass (small plots)	
	Cultivated Grass	2.0
Bhawani W.S.	Grassland W.S.	10-30
Siwalik Hills	Natural Grassland W.S.	6.4
Ravinous Lands		
Agra	Grasslands	15-32
Mahi & Chambal	-do-	2.5 - 7
The Phillippines	Imperata grassland	3.0
	Bare lands	
	Hills	30-60
	Plains	20-40

W.S. = Watershed

Source : Ref. Nos. 54,11,13,4,20

4.0 VEGETATION MANAGEMENT FOR INCREASED WATER YIELD

4.1 General Concept

Vegetation management on upland catchments is of special interest to planners and engineers of water resources development projects that are designed to augment the supplies of water for down stream consumers. Vegetation management can alter the water budget of the watershed by modifying the hydrologic processes involved therein. The studies conducted throughout the world have demonstrated the water yield increases after implementation of upstream vegetative management practices. The forest conversion or other type of vegetative manipulation essentially modify the hydrologic cycle which results in water yield increases. The increased water yield may be caused in part, by changes in one or more of the following hydrologic factors as a result of vegetation management:

a) reduced interception losses,

b) reduced evapotranspiration losses

c) changes in the hydrologic properties of the soil's surface and forest floor, and

d) more efficient conversion of a snowpack to stream flow.

The conceptual framework for understanding the principles involved in water yield improvement practices considering the above four hydrologic factors is discussed below.

4.1.1 Reduced Interception Losses

The interception of precipitation by forest canopies is that part of precipitation which does not reach the forest floor and quantitatively it is given as

$$Ic = P - T - S \quad \ldots(4)$$

where,

Ic = canopy interception

P = precipitation

T = through fall(i.e. portion of precipitation which reaches the forest floor directly or by dripping from leaves, twigs & branches)

S = stemflow(i.e. small portion of precipitation which reaches the forest floor through stems of trees)

Canopy interception is important hydrologically as it modifies the water balance by increasing total vapourization from external plant surfaces (i.e. of Canopy interception) and reducing streamflow. Interception is influenced by vegetation conditions e.g. type of tree species, canopy characteristics & canopy density and meteorological conditions e.g. rainfall intensity & duration, wind movements etc. It varies from 15 to 30% of precipitation depending upon the vegetation characteristic By appropriate vegetation manipulation canopy densities are modified which reduce interception losses and thereby increase water yield. The effect of overstory thinnings on the interception losses has been studied in a number of experiments.

4.1.2 Reduced Evapotranspiration Losses

The withdrawal of soil moisture by vegetation and the vapourization of this moisture to the atmosphere by transpiration is another important hydrologic process that affects water yield. The rate of transpiration in a forested watershed is affected by forest density, height of vegetation, leaf structure, seasonal growth patterns and rooting depths, besides climatic and physiographic conditions. In a given watershed, the transpiration losses can be reduced by changing the density of vegetation, structure and composition of vegetation. Clearing a forest overstory from a watershed may effectively eliminate transpiration losses by forest vegetation as long as the watershed remains in a cleared state. However, portions of precipitation input may evaporate from the exposed forest floor and soil surfaces on the cleared areas. The withdrawal of soil moisture for process of transpiration depends on the rooting depth of the vegetation to extract moisture from greater soil depths. The coversion of forest vegetation to perennial grass represents a possible water yield improvement practice. It is because the grass being shallow rooted species than most of the trees would transpire less moisture than the deep-rooted forest trees.

Evaporation & transpiration account for a significant porportion of the annual precipitation in most of the catchments. The increased water yield is attributed, in part, to decreased evapotranspiration on the upstream catchments. That is,following the vegetative treatment or management, less precipitation input is converted to water vapour as a result of rainfall and snowfall interception and vegetative transpiration, and more is made available for stream flow runoff. The potential to increase water yields by decreasing evapotranspiration can be attractive to the planners of water resources development projects. For example, between 85 and 95 percent of the annual precipitation is evaporated or used by plants on many upstream catchments in arid environments, leaving only 5 to 15 percent available for streamflow runoff. On high elevation mountain catchments in snow zones, the annual water yields can be as high as 50 percent of the precipitation input, but the evapotranspration component is still significant and potentially subject to reduction through vegetative management.

The above concepts can best be illustrated with a hypothetical water budget for a forested catchment as given in table 4. As can be seen prior to vegetative treatment, precipitation and evapotranspiration for the hydrologic event of interest were 645 and 560 mm, respectively, leaving 85 mm for streamflow runoff. After implementation of vegetation management operation, the streamflow runoff was increased by 30 mm due to the reduction in evapotranspiration by 30 mm. However, precipitation patterns are usually not affected, at least on large scales, by modifications in the structure and composition of vegetative cover.

Table 4 : PRECIPITATION, EVAPOTRANSPIRATION, AND STREAMFLOW RUNOFF FOR FORESTED CATCHMENT IN THE SOUTHWESTERN UNITED STATES, FOR UNTREATED AND TREATED CONDITIONS

Water Budget component	Untreated mm	Treated mm
Precipitation	645	645
Evapotranspiration	560	530
Streamflow Runoff	85	115

As indicated in the above example a small reduction in evapotranspiration can cause significant increase in streamflow runoff. Studies have indicated that for appropriate conditions and situations water yields can be augmented by upstream vegetative management practices without completely denuding watersheds and keeping the rates of erosion and sedimentation within limits.

4.1.3 Changes in the hydrological properties of the Soil's Surface

The clearing and removal of forest vegetation can modify soil surface conditions to change the hydrologic properties of the soil due to the compaction of surface by logging equipment. Such compaction could reduce the infiltration and thereby increase the amount of overland flow. The changes in forest floor layer may also take place due to vegetative manipulation. The forest floor layer at the soil surface may serve a variety of hydrologically useful functions. It may reduce rainfall impact and subsequent erosion, provide a resistance to overland flow, allow more time for infiltration etc. It may also affect surface runoff.

The amount of water yield increase due to vegetation manipulation depends on following factors:

i) Type of soil and rooting depth- greatest increases in water yield are obtained by removing deep rooted vegetation from deep soils.

ii) Amount of vegetation removal- the increase in water yield is proportional to the percentage of watershed that has been given treatment.

iii) Rainfall input compared to energy supply- greatest increases in water yield are obtained from areas having great amounts of precipitation compared to evapotranspiration. Increase in water yield from north aspects are greater than those from south aspects.

iv) Species differences- different species may result in different amount of increases in water yield due to varying rooting characteristics, plant size, radiation reflectance, interception etc. It has been found that conifers use more water than hardwoods.

v) Type of vegetation removal- clear cutting produces maximum increases in yield, selective cutting produces the least increases. Size and geometry of clearcuts also affect amounts and timing of increases in water yield.

4.2 Vegetation Management Techniques for Water Yield Improvement

Vegetation management practices can modify the structure and composition of vegetation at the interface of the earth and atmosphere to reduce evapotranspiration thereby increasing water yield from upstream catchments. There are different kinds of vegetation management practices imposed in various experimental watershed studies in USA and elesewhere. Broadly the vegetation manipulation practices or treatments carried out in water yield improvement experiments can be classified as

i) Forest cutting or removal

ii) Changes in forest types and vegetative cover

4.2.1 Forest cutting or removal

There are different types of treatments to improve water yield in this method.

i) Clearcut complete removal of the vegetative cover.

ii) Partial cutting: This may include partial cutting, strip cutting/thinning,block cutting etc.

iii) Chemical treatment and forest fires: Chemical spray to control vegetative growth and effects of forest fires.

The results of water yield improvement experiments conducted worldwide are summarised in the following sections to demonstrate that the water yield can be affected by upstream vegetative management practices. Annual water yield increases following forest removal have been obtained from numerous catchment experiments under a wide variety of conditions and a few selected results are presented in the following sections :

i) Water yield increase due to clearcutting

The results of selected experimental watershed studies to analyse the influence of clear cutting forest vegetation on water yields are summarised and presented in table 5. In Wagon wheel gap experiment of 1911 in Colorado,USA,20% increase in water yield was reported following clear cutting. The H.J. Andrews experiment in Oregon state observed a 34% increase in water yield due to clear cutting of Douglas fir and western

TABLE 5: Water Yield Increases due to Clearcutting

Sl. No.	Watershed	Location	Forest type	Area (ha.)	Annual Preci-pitation (mm)	Normal Water Yield (mm)	Annual increase in water yield (first year) (mm)	(%)	Remarks
1.	Wagon Wheel Gap	Colorado, USA	Douglas fir and Englmann Spruce	80	536	165	28	20	Average of 5 years
2.	H.J.Andrews(HJAI)	Oregon, USA	Douglas fir Western Hemlock	96	2388	1376	380	34	
3.	Beaver Creek 12	Arizona, USA	Ponderossa-Pine	182	635	153	-	30	
4.	Coweeta Watershed	North Caro-lina, USA	Mixed deciduous hardwood	16	1778	792	370	18.7	
5.	Fernow Experimental Forest Watershed	West Virginia, USA	Mix deciduous hardwood	23.6	1473	584	130	26	
6.	Hubbard Brook Experimental Forest Watershed-2	-	-do-	15.6	1524	685.8	342.9	50	
7.	-	Colorado, USA	Aspen conifer	-	-	157.0	34	20%	
8.	Kimakiya	Kenya	High Montane & bamboo forest	-	-	-	-	50%	

Source : Ref.Nos. 5,10,14,15,16,17,18,19,20,36,47,48A

Hemlock vegetation. In semi-arid region of Arizona,USA experiments were conducted on watersheds to study the effect of clear cutting on water yield. The results from Beaver Creek 12 watershed indicated 30% increase in water yield due to clearcutting of Ponderosa pine trees. The studies at Coweeta Hydrology Laboratory in North Carolina,USA indicated 18.7% increase in water yield due to clear cutting of mixed deciduous hardwoods. In west Virginia,USA studies at Fernow Experimental Forest Watershed indicated 26% increase in water yield due to clearcutting of mix deciduous hardwood. In Hubbard Brook watersheds in USA the results of clearcutting experiments indicated 50% increase in water yield. The clear cutting of Aspen conifer in Colorado,USA is reported to have increased water yield by 20%. Studies at Kimakiya,Kenya reported 50% increase in water yield by clearcutting of high montane and bamboo forests. Based on various studies as reported in table 5, it can be deduced that clearcutting of forests certainly increases water yield in varying amounts depending on type of forests clearcut along with the total clearcut area. Rao and Raj(1986) have reported that the increase in water yield due to forest removal gets reduced. by 2/3rd after five years of regrowth and gets vanished after about 10 years.

The clearcutting practice involves removing all vegetation and thus increasing chances of erosion and sedimentation besides water yield. Therefore, the practice of clear-cutting can not be recommended for management of forested watersheds for obtaining optimal yields of water within safe limits of erosion and sedimentation hazards.

ii) Water yield increase due to partial cutting:

Experiments on partial cutting of vegetation or forests have been conducted by using various practices like selective thinning , thinning, strip cut, block cut with or without selective thinning on various watersheds at different places. The results of some selected studies have been reported in table 6. It may be seen in the table that partial forest cutting of varying amount has resulted in varying degree of increase in water yield. Higher the portion of area treated, more is the effect on water yield . In H.J.Andrews experiment in Oregon,USA a treatment involving 30% cut in Douglas fir and western Hemlock type of forests resulted in 10% increase in water yield. In Arizona,USA, experiments with Ponderosa Pine forests involving 33% strip cutting(overstorey thinning) and 33% clearcut in irregular strips resulted in 16 and and 22% increase in water yield respectively in Beaver Creek watersheds. When the treatment was changed to 50% clearcut in irregular strips including thinning between strips(65% basal area overall), the water yield was reported to increase by 103%. In Coweeta watershed in North Carolina,USA, a treatment involving 22% selection cutting of mixed deciduous hardwood resulted in 8.1% increase in water yield. In Kamabuti, Japan the oversoty clearing of coniferous and deciduous forests resulted in 5% increase in water yield. Water yield was reported to increase by 56% when one-third of pine forests (man made) were removed at Jonkershock in South Africa. In India, experiments done at Dehradun indicated that 20% thinning

Table 6: Effects of Partial Cutting on Water Yield

Sl. No.	Watershed/ Location	Forest type	Treatment	Area (ha.)	Annual Precipitation (mm)	Normal Water Yield (mm)	Annual increase in water yield (mm)	(%)	Remarks
1	2	3	4	5	6	7	8		9
1.	Alsea (Needle branch) AL 1	Douglas fir Red Alder	82% cut	71	2540	1932	490	27	
2.	Alsea (Decr Creek) AL 3	-do-	25% cut	303	2540	1932	70	5	
3.	HJ Andrews HJA 3	Douglas fir Western Hemlock	30% cut	100	2388	1447	153	10	
4.	Fox CreekFC 1	-do-	25% cut	59	2840	2130	No significant change		
5.	Fox Creek FC 3	-do-	-do-	71	-do-	-do-	-do-		
6.	Beaver Creek(9), Arizona	Ponderosa pine	33% Strip cut (Overstorey) thinning	530	635	170	27	16	% increase in mean of first five years
7.	Beaver Creek(14), Arizona	-do-	33% clear cut in irregular strips, thin between strips, 50% basal area removed overall	540	635	120	26	22	Avg. of three years

Table 6 - Cont......

1	2	3	4	5	6	7	8	9
8.	Beaver Creek(16) Arizona	-do-	50% clearcut in irregular strips, thinning between strips, 65% basal area overall	101	737	14	14.4 103	
9.	Fool Creek, Colorado	Lodgepole pine & spruce	40% strip cut	286	762	307	77 25	
10.	Southwest Arizona, USA	Ponderosa pine	75% thinning	-	-	-	34 19	
11.	South West Arizona, USA	Ponderosa pine	1/3 strip cut	-	-	-	25 16	
12.	-do-	-do-	50% strip cut and thinned	-	-	-	20.6 19	
13.	-do-	-do-	1/6 clean cut 5/6 thinned	-	-	-	15.3 29	
14.	Coweeta watershed 19	Mixed deciduous hardwood	50% (half strip)	-	2032	1275	198 15.5 (161) (12.6)	values in ( ) are average of three years
15.	-do-	-do-	22% selection	-	-do-	1222	99 8.1 (75.1) (6.1)	-do-
16.	Fernow Exp. Watersheds, W.Virginia, USA	-do-	36% selection	15.4	1473	660	64 10	

Table 6 - Cont....

1	2	3	4	5	6	7	8	9
17.	-do-	-do-	22% selection	36.4	1473	762	36 4.7	
18.	-do-	-do-	14% selection	34.4	1473	635	8 1.2	
19.	-do-	-do-	51% selection system	21.9	1473	482.6	165.1 34	
20.	Rajpur, Dehradun	Coppice sal	20% thinning	6	2000	-	Insignificant increase in water yield	
21.	Kamabuti, Japan	Conifers & deciduous	Overstorey clearing	-	-	2200	110 5	
22.	Jonker-Shock, South Africa	Pine forests (Man made)	33% removed	-	-	-	- 50%	
23.	Pennsylvania State, USA.	-	lower 20% clearcut	-	-	-	Significant increase in yield	

Source : Ref Nos. 5,10,14,15,16,17,18,19,20,36,47,48A of coppice sal forest did not increase water yield significantly (Rao et al.) undated

In Ponderose pine forests of Beaver creek waterhseds in Arizona clearing one-third of the forest over storey increased water yield by approximately 3 ha-cm/ ha annualy and an additional clearing of another one-third of the forest overstorey increased water yield by approximately 6 ha-cm/ha annually (Fig.1). These results are location specific and indicate only a tentative trend. Based on various studies as reported in table 6 it can be observed that on an average to get about 10% increase in water yield a minimum of about 30% of area needs to be treated.

The partial cutting practice seems to have a great potential for overall management of forested watersheds. The proportion of cutting/thinning can be decided in such a way that it has significant effects in increasing water yield along with maintaining the yields of forest products and without increasing problems of soil erosion and sedimentation.

iii) Chemical treatment and forest fires

A limited number of experimental studies have been carried out to find effects of chemical treatment, foliar sprays and forest fires on water yield at different places. Prescribed burning is done during the periods of suitable and acceptable fire hazard which will assume the desired control. Chemical sprays can be used to descicate the brush and increase its flammability. Brush can be descicated with fast- acting contact herbicides such as diguat and toxic weed oils containing pentachlorophenol or with slow acting low volatile esters of 2,4-D or 2,4-D plus 2,4,5-T. The

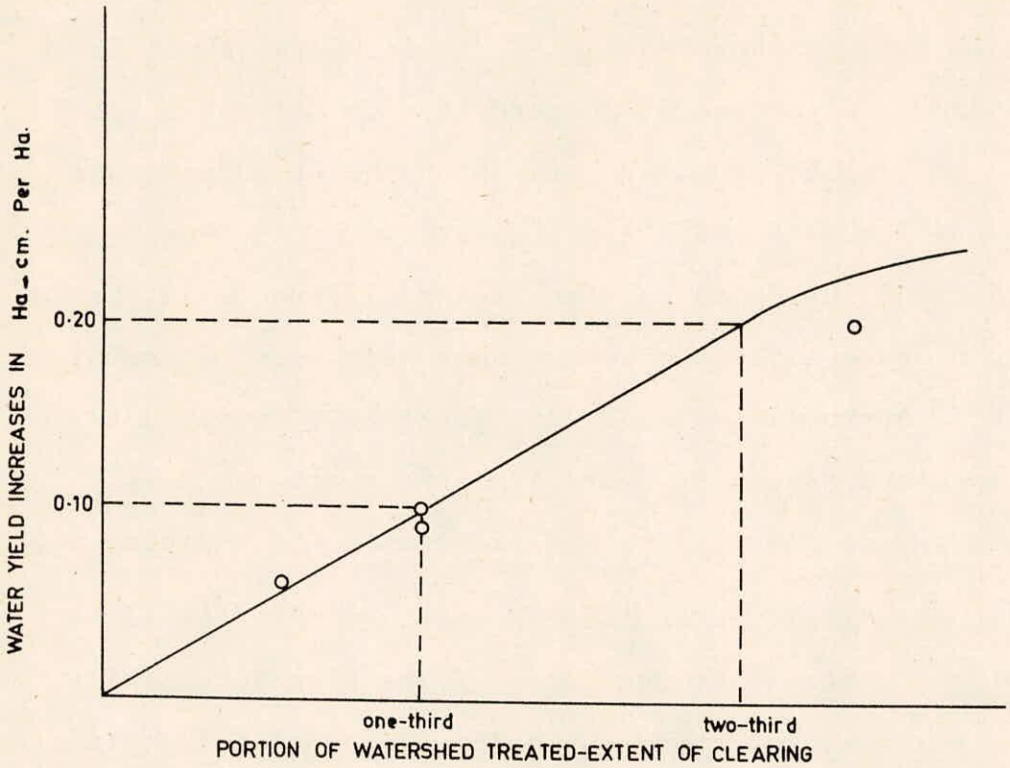

FIG. 1- RELATIONSHIP BETWEEN AVERAGE ANNUAL WATER YIELD INCRESE A AVERAGE CONDITIONS AND EXTENT OF CLEARING OF PONDEROSA PINE FOREST OVERSTORIES.

Figure 1: RELATIONSHIP BETWEEN AVERAGE ANNUAL WATER YIELD INCREASE AT AVERAGE CONDITIONS AND EXTENT OF CLEARING OF PONDEROSA PINE FOREST OVERSTORIES.

Source : FFOLLIOTT ET AL. (1975)

results of some selected studies are summarised in table 7.

Studies on the effects of wildfire in watersheds in Australia have shown to increase streamflow yield by 43-235% (McArther,1964; McArther and Cheney,1965). Following an accidental burn in Japan,Nakano (1971) found an annual water yield increase of around 23-26 percent. In Malayasia, a 10% increase in average annual runoff after forest burning was reported by Toebes & Gob (1975). However,studies done by Langford(1974) indicated no significant difference in streamflow for 5 years after one of the most serious wildfires of Victoria in Australia. Rao & Raj (1986) have reported that foliar sprays annually or every other year are the most efficient way of maintaining high increased water yields.

The results given in table 7 indicate that the areal application of chemicals and forest fires have potential to increase water yield, however, the studies are too limited to make general statement about chemical treatment, foliar application and forest fires for increasing water yield.

4.2.2 Changes in forest types and vegetative cover

Studies have been conducted to find effects of changes in forest types,i.e.,natural forest to tree plantation or from one land use to another,i.e.,forest to grassland, on water yield. Some good data have been generated on how converting natural forest to tree plantation affects water yield, though not very many of the possible combinations have been studied. Most of the experiments have involved a conversion from broad leaved and usually deciduous natural forest to

Table 7: Effects of Chemical Treatment on Water Yield

Sl. No.	Watershed/Location	Forest Type	Treatment	Area (ha)	Annual Precipitation (mm)	Normal runoff (mm)	Increase in water yield (mm)	(%)	Remarks
1.	Beaver Creek(3), Arizona	Pinyon-Juniper	Areal application of Herbicide mixture of 2.5 lbs of picloram and 5 lbs of 2,4-D per acre	145	457.2	17.5	11.4	65	Treatment was given for overstory removal
2.	San Dimas, California	Shrub Oak species	Herbicide application to 40% area	-	-	62.5	5.0	8	
3.	Natural Drainage(C), Arizona	Chaparral with grasses and shrubs interspersed	Spray of 2,4-D herbicide and 2,4,5-T in diesel oil on basal 6" of each scrub.	4.8	452.1	-	13.2	-	
4.	Three bar watershed(C), Arizona	Chaparral with grasses and shrubs interspersed	Burning followed by maintainance spraying with phenoxy herbicides	38	607	30	75	250	

Source : Ref Nos. 5,10,14,15,16,17,18,19,20,36,47,48A coniferous, needle leaved, evergreen forest, conditions under which the effects would be most pronounced. As the replacement plantation moves closer to the original forest in crown characteristics, the effects expected would be less. Most studies have shown at least a slight decrease in streamflow resulting from conversion. Studies conducted in Australia indicated little or no change in yield, mainly from conversion of native Eucalyptus forest to Pinus radiata. Boughton(1970) reported gist of Australian studies stating' All evidence supports the proposition that there is negligible difference in water yield between species of mature forest. When native Eucalyptus forest is cleared to establish an exotic pine plantation, there is likely to be an increase in the amount of water yield while the pine forest is immature and has not established its full root depth, and this difference should disappear as the trees mature'. Pearce and Rowe (1979) reported studies done in New Zealand indicated that conversion of indigeneous evergreen forest to radiata pine decreased streamflow yields to a value not more than 200 mm. At Coweeta in the southeastern USA, replacement of mixed deciduous broad leaved forest with Pinus strobus produced marked differences. Largest reductions occurred in the dormant season and were attributed primarily to greater interception losses by pine (Helvey,1967). Studies done in Kimakia, Kenya indicated that replacement of high montane and bamboo forests by pine trees increased water yield by 50% (Bosch and Hewlett,1982). Mathur et al.(1976) have reported that in Dehradun reforestation of a small experimental brushwood watershed (1.45 ha) by Eucalyptus species reduced water yield by 28 percent.

Forests may be grazed and the trees cut so that over a period of time the once forested area is converted to rough grassland for grazing. Studies from various parts have been reported on effects on water yield as a result of forest conversion to grassland. The processes of converting forest land to pasture have been reported from Indonesia, the Phillippines and most commonly in Latin America. All available research works indicate that there is an increase in water yield when forests are converted to grassland. This occurs not only in the conversion process when trees are cut, but continues after the grass has become the vegetative cover of the area. Cochrane (1969) reported results of studies done in Fiji and observed that under normal forest bankful discharge was not achieved while the forests got changed to grass, a 300 fold increase in discharge occurred within two hours from commencement of heavy rain. In Queensland, Australia the conversion of tropical forest catchment to pasture resulted in 10.2% increase in water yield during first two years(Queensland Department of Forestry,1977). Hibbert (1969) concluded from conversion studies done at Coweeta in the United States that streamflow yield increases varied directly with bio-mass production of grass. Results reported under Arizona watershed program by Ffolliott et al.(1986) indicate that by converting forest overstories to grass cover, an annual water yield increase from 67 to nearly 95 mm, values representing 84-111 percent of the annual streamflows before the conversions, was observed. Studies in chaparral vegetation zone of Arizona suggest that water yield from the chaparral vegetation zone can be increased by the removal of the shrub overstories and the establishment of a replacement cover of grasses.

Studies have been done in Arizona,USA on effects of vegetation conversion and extent of treatment on water yields. Results of some such studies have been presented in figure 2. The results at average conditions of converting mixed conifer forest overstories to perennial grass and sprouting brush on approximately one-third of the watershed, specifically the moist-site vegetation immediately adjacent to the stream channel increased water yield by approximately 3.0 ha-cm per ha annually. An additional conversion of another one-third of the watershed, specifically the dry-site vegetation,immediately adjacent to the moist-site vegetation increased water yield by approximately 13.5 ha-cm/ha annually, as has been shown in figure 2.

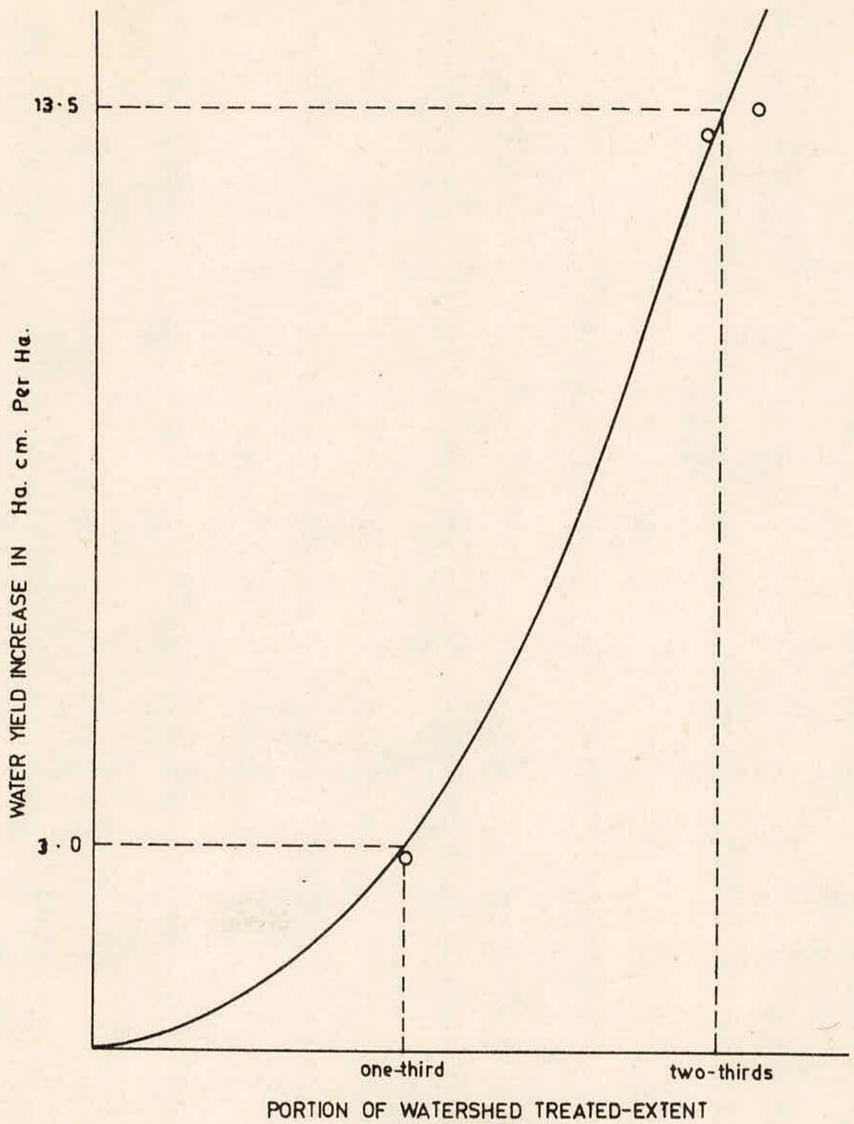

Figure 2 : RELATIONSHIP BETWEEN AVERAGE ANNUAL WATER YIELD INCREASE AT AVERAGE CONDITIONS AND EXTENT OF CONVERSION OF MIXED CONFIFER FOREST OVERSTORIES TO PERENNIAL GRASS

Source : FFOLLIOTT ET AL.(1975)

5.0 DISCUSSION

5.1 Water Yield and Land Use

The results of various studies conducted on small plots and small watersheds establish that the type of land use and vegetative cover have specific effects on water yield. In general, the water yield in hilly region from natural,ill managed or untreated agricultural lands.appears to vary from 10 to 45 percent of annual rainfall whereas in well managed or treated agricultural lands,i.e.,with soil conservation measures it could vary from 4 to 34 percent of annual rainfall depending upon type of conservation measures. The water yield from agricultural lands in plains/ravines may be taken as 10-30% and 3-28% of annual rainfall for untreated and treated watersheds,respectively. In case of forested watersheds, water yield as percentage of rainfall to runoff appears to vary from 1--43% in hilly regions whereas in plains it is in the range of 3-20%. The results given in table 2 indicate the effects of forest management practices on water yield.The well managed forested watershed have relatively lower peak discharge with runoff distributed over a long time period due to increased sub-surface flow. The water yield from ill-managed (grazed) and well managed grasslands varies from 7-30% and 3-20% rainfall respectively. The limited data available for bare lands indicate water yield in the range of 20-60% of annual rainfall.

The water yield values expressed as percentage ratio of rainfall to runoff(i.e. runoff efficiency) are generally for annual water yield, in some cases for seasonal water yield, i.e.,monsoon water yield, and should not be used as it is for other time periods. In general, relatively more water yield may be obtained during peak rainy months (July-August) because watershed reaches near saturation during this period if there are continuous heavy storms. It has also been observed that the runoff efficiency of a vegetal cover could be relatively more during winter rains(i.e. dry period) specially in well managed forested watersheds because of increased sub-surface flow(i.e. delayed yield or regenerated flow). Therefore,these ratios are to be used cautiously.

5.2 Water Yield Improvement Due to Vegetation Manipulation

A number of worldwide studies, although not exhaustive, on the effects of vegetation manipulation on water yield have been reviewed. The studies have,however, been mainly in the USA and based on them following general observations are made:

i) A reduction in densities of forest overstories and other vegetation cover types by cutting or by use of chemicals/foliar sprays can increase water yield and yield increases are proportional to fraction of the watershed treated.

ii) Maximum increases in water yield have been observed during first year after treatment/cutting and the effect of treatment/cutting decreases logarithmically with time.

iii) In case of partial cutting a removal/cutting of 30% or less of the forest cover has not been found to increase water yield significantly i.e. by 10% or more.

iv) Conversion of forests/shrubs to well managed grass lands has been found to increase water yield which may be attributed to reduced soil moisture losses because of shallow root system of grasses.

v) The potential for water yield increase is greater in areas where normal yield is higher, the increase in water yield tends to be greater from north versus south facing watershed in a given climate and the potential increase in water yield is relatively less in coniferous forests as compared to hardwood forests.

vi) The experiments have mainly been done in smaller watersheds and mostly in the USA. Studies at wider scale on larger watersheds should be undertaken in various parts of India and elsewhere for more specific conclusions.

Studies of water yield improvement through upstream vegetative management,conducted worldwide,have shown definite responses in water yields to vegetative alterations with only a few exceptions. However, the magnitude of response has varied considerably. The diverse nature of the results suggest the complexity of the hydrologic factors that is involved in such studies.

In general, the results of the experimental catchment studies suggest that vegetative management through partial cutting/thinning has potential for increasing water yields without causing problems of land degradation from upstream catchments on many river basins throughout the world. Furthermore, many of these vegetative management practices can be implemented to maintain or enhance the production and use of associated agricultural and natural resources including agricultural crop production, timber,domestic,livestock,wildlife,aesthetics, and soils. The vegetation management practices for water yield improvement are also used to benefit other resources. It seems possible, therefore, that vegetative management, when properly planned, can satisfy increasing demands for other agricultural and natural resources, while increasing water yields.

Before intensive vegetative management practices are imposed on a large scale, it may be necessary to deliniate the potential treatable area to account for all possible constraints to the implementation of an operational water yield improvement programme. The major constraints to be considered are land ownership,climate,vegetation,physiography,politics institutions etc. On many river basins in the world, the treatable areas may represent only a fraction of the total area of the river basin. The magnitude of increase in water yield that is realized on upstream catchments is usually not the same as that observed downstream. Inflow from other catchments, channel transmission losses, and evaporation from water surfaces(where water is impounded in reservoirs before reaching downstream consumers) must be analyzed in portraying upstream increases in stream flow runoff to downstream increases in water supplies.

It should be emphasized that, in addition to affecting water yields, vegetative management on upstream catchments can impact other hydrologic factors on a watershed or river basin. Among these impacts are the rates at which erosion and sedimentation processes occur, peak streamflows and time to peak stream flows, and the physical and chemical quality of the water that flows from upstream catchments. All of these , as well as other hydrologic factors must be considered in water yield improvement projects.

5.3 Reccomendations

i) Studies need to be carried out on an urgent basis to evaluate the effects of vegetation mangement specifically partial cutting/thinning and forest conversion on water yield as the same has a great potential to increase water supplies for downstream users.

ii) A comprehensive resource management model to optimally develop resources of a watershed may be attempted and the water yield increases due to vegetation manipulation may form a sub-model of the comprehensive model.

iii) The increased water yield due to vegetation manipulation keeping soil erosion within the permissible limits should be considered as one of the objectives of forest watershed management workplan.

iv) Efforts are required to be made to establish the acceptable compromised solutions for deciding the amount of forest vegetation to be treated including type of treatment without substantially reducing the yields of forest produce.

v) The studies are required to be done on larger catchments for more general conclusions.

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