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WATERSHED RESOURCES DEVELOPMENT MODEL

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ABSTRACT

The present report describes a concept involving management of natural resources of the watershed including land, water, flora and fauna for their sustained yields. The extent of watershed resources and the problems indicating exploitation of the resources have been described. The various problems include soil erosion and land degradation, floods, water quality problems, sedimentation, deforestation, elimination of rare forest and animal species etc. as a result of various developmental activities or unscientific use of various watershed lands. The concept of watershed management for proper utilisation of its resources has been discussed. Often, watershed management involves the development, evaluation and application of land management systems designed to alter water production. The attempts to alter water production may have impacts on production of other resources from upstream lands which are in demand for downstream users. In this reference the concept of integrated resources management has been discussed with an idea of developing a resource development model. The development of the model is based on the concept that all resources uses are interdependent and must therefore be considered together. The relationship among the natural resources has been described. The model is envisaged to evaluate effects of various land management practices on different natural resources including water, land, flora and fauna or natural ecosystem in general The impacts of land management practices on eco - system can be understood by a group of models representing stream flow yields, sedimentation, growth and yield of vegetation and wild life, habitat quality etc.

The limitations for developing such an overall development model have also been discussed along with the data requirement. A brief summary of existing watershed models is also presented.

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1.0 INTRODUCTION

Watershed resources play a significant role in the development of any country. The main water related natural resources of a watershed are water, land, flora and fauna. Depending upon the location of a watershed , they yield water for domestic, agricultural and industrial uses, produce a variety of wood products, contribute forage for livestock and wildlife, and provide many forms of aesthetic and recreational uses.

The basic resource of a watershed is precipitation which falls in the form of rain, hail, sleet, snow and appears at the outlet after passing through different surface and sub-surface paths. The developmental activities of human beings on the watershed alter natural hydrologic flow along these paths. The activities may include change in land use, urbanisation, forest clearing, construction activities and mining works. Unfortunately, these activities can sometime lead to destructive consequences like excessive erosion of productive soil , siltation of water courses and reservoirs, eliminatioin of rare animal species etc. To consider the benefits derived from these developmental activities it will be important to evaluate them in light of negative effects creatred by them. It is, therefore, alongwith the various natural resources products and uses derived from a watershed, the associated disadvantages of developmental activities should also be fully evaluated. It is in this context the concept of integrated resource management is important and needs to be implemented for overall development of watershed resources which will minimise the harmful effects of lopsided developmental policy.

The two important factors currently responsible for misuse of watershed resources could be unscientific manipulation of land use for short -term economic gains and lack of effective resources management approach. This demands for development of a sound resources management approach which will incorporatre both negative and positive aspects of developmental activities and thus choose the best course of action. Such approach will require proper understanding of the watershed eco-system and will incorporate need for long-term environmental monotoring. This may require regular monotoring of biological, geo-physical, chemical and anthropological aspects of environment. These include aspects of flora and fauna conservation, descriptions of biotic poulations and communities, quantification of eco-system processes and dynamics, quantification of stream flow volume, detection of pollutants and monitoring of natural substances through examination of critical components in the atmosphere , precipitation, surface water, soil and litter vegetation, assessment of demographic characteristics and legal structures.

The present report is an attempt towards defining a concept of integrated resources development of a watershed for sustained yields of its natural resources. The interrelationship of the resources has been discussed and a methodeology for development of a comprehensive resources development model has been described.

2.o WATERSHED RESOURCES

A major portion of earth's habitable and surface excluding the well defined agricultural lands and urban areas is referred to as watershed lands which are also termed as wild lands, forest lands or simply undeveloped lands. A rough estimate indicate that about 80% of the land surface of the earth are watershed lands. In view of increasing pressure of rising population, attention has to be diverted to these watershed lands for additional supply food, fibre, energy and living space. It is for this purpose proper evaluation and management of watershed resources aquires significant importance. A brief description of the main resources of a watershed viz., water, land, flora and fauna is given in following sections:

2.1 Land

Land, an integral part of the ecosystam, is the most important endowment of nature for the survival of mankind. The total geographical area of the country is 328 m.ha. out of which only 305.5 m.ha. are accounted for land use statistics (1967-68). The difference of 22.5 m.ha. largely consists of mountains, deserts and forests in inaccessible areas. The National Commission of Agriculture (1976) has given land resources statistics and their projections for 2000 and 2025 A.D. as given in table 1.

Out of the total geographical area of the country, 188 m.ha. are cultivable. The gross cropped area, however, is about 172.31 m.ha. (Anonymous, Vol.IV 1986). The soil is the crucial life supporting natural resource. In order to properly evaluate the soil resources, surveys are conducted dealing with site and soil characterisation, morphological studies of soil profiles, physico-chemical analysis of soil, classification and interpretation for different purposes etc. Basically, there are single purpose soil surveys and the standard soil surveys. The single purpose soil surveys are designed for a specific objective and limited application such as soil fertility, crop suitability, soil conservation, soil erosion, irrigation, trafficability, revenue and taxation etc. Standard soil surveys with appropriate correlation on the other hand, involve comprehensive data collection about soil and land in such a manner that the data could be used for a variety of purposes and uses encompassing most of the single purpose soil surveys. There are various state and central government organisations in the country entrusted with soil survey responsibility. The main ones include All India Soil and Land Use Survey (AIS & LUS), New Delhi; National Bureau of Soil Survey and Land Use Planning; NRSA, Hyderabad; National Atlas and Thematic Mapping Organisation (NATCOM), Calcutta etc. During 1958-83, the AIS & LUS has covered 6.93 m.ha. by detailed surveys and 9.0 m.ha. by reconnaissance survey (Report of the Task Force Soils and Land Use, 1984).

2.2 Water

Water is an important resource for its crucial importance for sustaining life and the agrarian economy under the characteristic climate and hydrologic conditions of India. From time to time water resources of India have been evaluated by several groups. Some important ones are listed in table 2.

According to estimates made by the National Commission on Agriculture (1976), about 400 m.ha.m. of rainfall is received over the geographical area of the country in a year out of which 300 m.ha.m. is received during four monsoon months and rest 100 m.ha.m. during rest eight months. Out of the total rainfall 70 m.ha.m. gets evaporated, 115 m.ha.m. turns as runoff into surface water

Table 1

Land Reso-urce Statistics and Projections (million hectrares)

Classification	1970-71	2000	2025
Geographical area	328	328	318
Reporting area	305	318	318
Forests	66	70	70
Area under non-agricultural use	16	26	36
Barren and uncultural land (mountains, deserts, and areas which can be brought under cultural use at high cost)	29	30	24
Miscellaneous trees, crops and groves not included in net sown area (thatching grass, casurina trees, bamboo bushes and other groves and trees for fuel etc.)	5	5	6
Culturable waste (not cultivated at present for the last 5 years or more)	16	9	4
Fallow lands other than current fallows (out of cultivation for 1 to 5 years)	9	5	3
Current fallows (not cultivated within one year for some reason)	11	8	5
Net area sown	140	150	155
Tot al cropped area	165	200	210

Source: National Commission on Agriculture, Part V, 1976

Table 2 - Surface Water Potential

Source	Water in Potential in km^3
Khosla's estimate (1945-46)	1672.3
Irrigation Commission (1972)	1882.1
National Commission on Agriculture (1976)	2250.0

bodies and 215 m.ha.m percolates into the ground as soil moisture and ground water recharge. Rainfall in the country varies from place to place but the annual average for its total area of 328 m ha is about 120 cm. The variability of water resource with time and space is high in the country. About 75% of the total precipitation falls during the south-west monsoon months (June-September). The spatial variability can be illustrated by the fact that in south the Pennar basin has only about 800 cu m. of surface water available/capita/year while the Brahmaputra basin in North has as much as 10,600 cu m/capita/year.

According to present estimates the country with a geographical area of 328 m.ha. has a water potential of about 178 m.ha.m from surface water and 60 m.ha.m from ground water. About 67 m.ha.m. from surface water and 60 m.ha.m from ground water can be put to beneficial use in ultimate stage because of topographic and other constraints. Besides the renewable water resources, there are water resources which are accumulated above and below ground over long period. Above the ground there are glaciers and permanent snow caps on high mountains, which make some steady flow to the Himalayan rivers. Below the ground there exists trapped ground water in certain geological formations. This trapped ground water or fossil water is likely to be of immense value in arid regions as the ground water explorations proceed. On desalination, the sea water can also be a source of fresh water though it is expensive and can be used for domestic and industrial purposes. The total water resource of the country thus comprise of the annually replenisable surface water and ground water resources, the fossil water under ground, glaciers and permanent snows which make some steady contribution to river flows and the expensive desalinated water which can be produced near the sea coasts.

As indicated earlier, total water potential from surface water is of the order of 178 m.ha.m in our country out of which about 70 m.ha m is utilisable flow. The basin wise break up of this surface water potential and its utilisable flow is given in table 3.

The constraints for utilising surface water resources include limited availability of sites suitable for building reservoirs and therefore the river flows that can not be utilised during rainy period and also can't be stored, flow to sea.

The utilisable portion of ground water depends on its quantity as well as quality. Excluding exploitation of fossil water, the upper limit for exploiting ground water would be the annual recharge including induced recharge reduced by whatever is lost by evapotranspiration and sub-surface runoff or is otherwise unutilisable.

2.3 Flora

India with its wide range of climatic conditions - from the torrid to the arctic - has a rich and varied vegetation, which few other countries of comparable size possess. The main floristic division of the country are Western Himalayas, Eastern Himalayas, Assam, Indus plain, Gangetic plain, Deccan, Malabar and Andamans. The Western Himalayan region extends from Kashmir to Kumaon. The part of the region falling in temperature zone is rich in forests of chir pine, other conifers, and broad leaved temperature trees. Higher up, forests of deodar, blue pine spruce and silver fir occur. The alpine zone extends from the upper limit of the temperate zone to about 4750 meter or even higher. The characteristic trees of this zone are the high level silver fir, silver birch and Junipers. The area extending from Sikkim eastwards embracing Darjeeling, Kurseong and the adjacent tract comprises the estern Himalayan region. The temperate zone of the region has

Table 3

Utilisable Surface Water of India

(in m ha m)

River system	Average annual	Utilisable flow	Approximate present utilisation (1974)
Indus basin	7.7	4.6	3.7
Ganga basin	51.0	25.0	8.5
Brahmaputra basin (including Barak)	54.0	2.4	0.5
Mahanadi & other east flowing rivers up to Godawari	12.3	9.1	2.8
Godavari, Krishna and other east flowing southern rivers	22.5	19.0	7.3
West flowing rivers south of Tapti	21.8	3.0	1.0
Narmada and Tapti	6.2	4.9	0.0
West flowing rivers north of Narmada	2.5	2.0	0.5
	178.0	70.0	25.0

Source: National Commission on Agriculture (1976), Vol.V forests of oaks, laurels, maples, alder and birch; many conifers, junifers and dwarf millows also occur. The Brahmaputra and Surma valleys and the intervening hill ranges come under the Assam region. The vegetation of the region is ever green forests, occasional thick chumps of bamboos and tall grasses. The Indus plain region comprising of plains of Punjab, Western Rajasthan and Northern Gujarat has a dry and hot climate and thus supports scanty natural vegetation. The Gangetic plain region covers the area from Aravalli ranges to Bengal and Orissa. A major portion of the region is cultivated for wheat, sugarcane and rice and a smaller area supports forests of widely differing types. The entire tableland of the Indian Peninsula comes under the Deccan region and supports vegetation of various kinds from scrub jungles to mixed deciduous forests. The humid belt running parallel to the west coast of the Peninsula comes under Malabar region which produces important commercial crops such as coconut, betelnut, pepper, coffee and tea besides being rich in forest vegetation. In some parts of this region rubber, cashewnut and eucalyptus trees have also been successfully introduced. The Andaman and Nicobar Islands of the Andaman region have evergreen, semi-evergreen, mangrove, beach and diluvial forests. The Himalayan region from Kashmir to Arunachal Pradesh through Nepal, Sikkim and Bhutan and Meghalaya, Nagaland and the Deccan Peninsula are rich in endemic flora, i.e., a large number of plants found in these regions are still restricted to these endemic centres and are not found elsewhere. There are about 15000 flowering and 35,000 non-flowering plants in the country (India, 1984 - A Reference Annual).

Forests are an essential part of a country's geography. There are a number of demands that are met by forests. A schematic representation is shown in figure 1. There have been growing concern in past due to reduction in forest resources of the country as a result of various developmental activities. According to the Natural Forest Policy (1952), about 33% of the geographical area (1.10 m.ha.) of the country should be under forests. Against this only 23% of the geographical area or about 75 m.ha. area under forest cover has been reported as per the statistics of State Forest Departments. A little different picture of forest coverage in the country is reported by National Remote Sensing Aggency which has found that forest cover had reduced from 55 m.ha. to 46 m.ha. during the period 1972-1982. If these findings are assumed to be correct, the rate at which the forest coverage is being lost works out to be about 1.5 m.ha. per year and this indicates the gravity of problem of the loss of forest cover in the country. It was in this background a Forest Conservation Act, 1980 was enacted with the objectives of checking the diversion of forest land for non-forestry purposes. It is estimated that the rate of forest diversion has been brought down to about 4600 ha. per year since the above enactment compared to about 1.5 lakh ha. per year during the period 1951-52 to 1979-80 (Anon, 1976). As per the records of creating man-made forests, the total area planted between 1950-80 was 3.7 m.ha. and during 6th plan period a target of 0.4 m.ha. per annum was envisaged and even with full achievement of this target, there would be a net loss of about 1 m.ha. per year. It is, therefore, the 7th plan document accords highest priority to restoratioin of forest cover to achieve the target as was set in the National Forest Policy (1952).

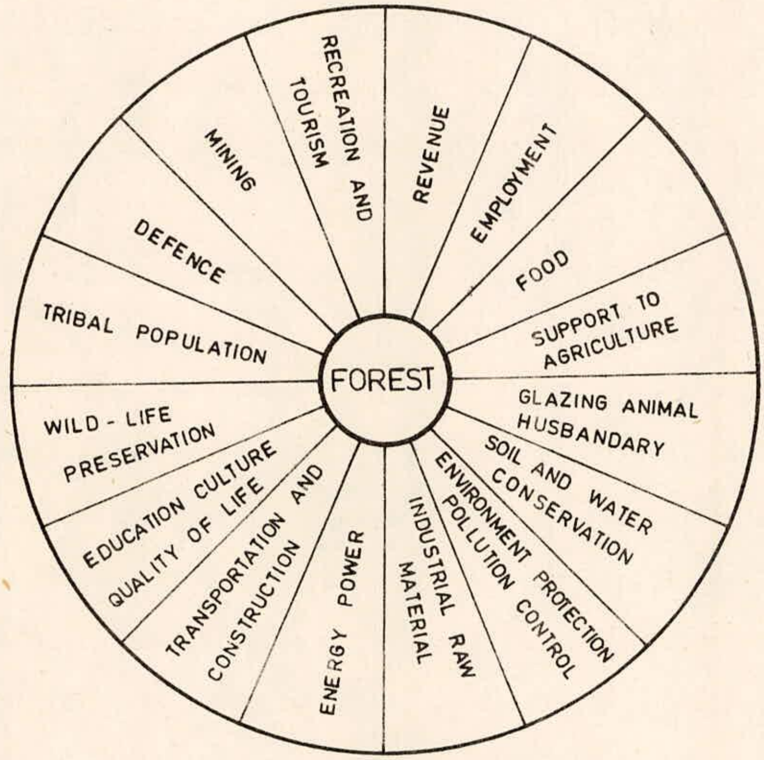

Figure 1 : DEMANDS MET BY FORESTS
SOURCE : MASLEKAR, 1983

The depletion of the country's forest wealth can be attributed to a number of reasons. The increasing pressure of human and cattle populations on the land naturally lead to excessive falling and grazing in adjacent forest areas as well as to encroachments on forest lands and their conversion to agricultural use. In order to resettle refugees oustees and landless farmers, officially forest lands were placed under the plough. Big industrial and irrigation projects along with their township were often located on government owned forest lands. However, there is no doubt that by far the greatest damage to forest resources has been caused by the inexorable pressures to satisfy the increasing demands which a developing economy creates for timber, pulpwood, firewood and other forestry products.

The hydrological importance of forest has been a major issue to research and investigation for past several decades. Studies done at different period of time and at various places including in India and abroad, have tried to establish relationship of forests with various hydrological processes and parameters, namely, rainfall, interception, evapotranspiration, infiltration, ground water, water yield, floods, water quality etc. A majority of researchers feel that forests do not influence rainfall on a regional scale, though there may be local scale effects. The interception losses in forested catchments are function of forest types, characteristics of precipitation and climate. Forested watersheds certainly have higher ET losses than other land uses. Infiltration characteristics of forested soils are better than other type of soils due to soil protection provided by vegetal cover and higher organic matter content. Forest influences on ground water regime is still a matter of investigation. The influences of forests on floods are limited to flash and moderate floods. The quality of water gets deteriorated by coming into contact with trees in a forested eco-system (Lohani, 1985).

A recent report by the World Resources Institute has compared the position of forest cover in developed and developing countries. In former case it has more or less established as it increased from 2.0 billion ha. to 2.1 billion ha. from 1900 to 1985. The reason for this establiation in developed countries could be economic development and employment opportunities in non-agricultural activities. The migration of rural population to urban areas is associated with greater employment opportunities in cities of developed countries. On contrary, a reduction by 50% in forest area during 1900-85 has been reported in the case of developing countries. A large number of marginal farmers and landless labours migrate to cities in developing countries because of a breakdown in the balance between the human population and natural resources of the village.

2.4 Fauna

India which has diverse physical and climatic conditions possess a tremendous varieties of fauna. As per the estimates of Ministry of Information and Broadcasting, Govt. of India, there are about 350 species of mammals and 1200 species of birds in the country. More than 30,000 different species of insects, apart from a great variety of fishes and reptiles are also found. The mammals include elephant, the gaur or Indian bison, Indian buffalo, nilgai, chousingha or four-horned antelope, black buck or Indian antelope, ghor-khur or Indian wild ass and great one-horned rhinoceros. There are also several species of deer, viz., the rare Kashmir stag, swamp deer, spotted deer, musk deer, thamin or brow-antlered deer and mouse deer. Among the animals of prey, the Indian lion is remarkable being the only lion to be found in the world outside Africa. There are about 3500 tigers, the national animal, and of late, their number was found reducing and Government has launched a project tiger to safeguard, its prey and habitat in fifteen selected areas. There are found various species of smaller cats including leapard, clouded leopard, the snow-leopard and species of monkeys and langurs. In rain forest region of east the only ape, the hoolock, is found. Bird life in India include peacock, pheasants, geese, ducks, mynaho, parakeets, pigeons, cranes, hornbills and sunbird. In the rivers and lakes, crocodials and gharials are found. A very interesting fauna including wild sheep and goats, the markhor, the ibex the serow and the taking is found in the great Himalayan range. The lesser panda and the snow-leopard are also found in the upper reaches of the mountains. In order to protect the wild life, the wild life (Protection) Act, 1972 has been adopted by all states except J & K (which has its own Act). The act governs the wild life conservation and protection of endangered species both inside and outside forest areas.

The wild fauna is an integral part of the renewable natural resources of each country. For long ages man has lived in general balance with his environment, both as a hunter harvesting game for food and as a cultivator using alluvial lands for food crops or shifting his farms from plot to plot of burned over forest. Today, with the human population explosion and massive technological innovation, this balance has been destroyed and the natural resources are at hazard. A large number of original flora and fauna have become extinct or come in the endangered list. Particularly in the areas subject to shifting cultivation, some parasites have become scarce in the North Eastern States of Meghalaya and Arunachal Pradesh. A list of animals considered to be threatened with extinction is given in table 4.

The impact of population pressure has together with the need for maximum food production has overshadowed most other considerations of land use planning. Agricultural development has, thus, taken place in areas that would have had greater long term value if they had been given over to other forms of land use. The ecological principles have not been given due considerations in the project planning. Wild life is one of the most valuable and yet least considered resource in overall resources planning of a watershed. People do not observe precautions to preserve the natural balance, with the result that the once-plentiful wild animals are rapidly disappearing. Boonsong (1968) for Thailand and Talbot & Talbot (1964) for the Philippines have reported serious depletion in wild life resources as a result of second world war which made available surplus transport and fire-arms to the people. The practice of food gathering has also resulted in reduction in wild life resources as in Taiwan the number of snakes killed annually for food and skin runs into hundreds of thousands (Wavre, 1969). Fear of animals such as tigers or crocodiles may also contribute to an indifference or antipathy to conservation. The presence of crocodiles is helpful for fish culture, the fact which the fisherman do not recognize. Wildlife, representing the faunal component of the ecosystem, is very closely associated with the vegetation in a tropical area. Any disturbance or destruction of the vegetation will be reflected in the disturbance or

Table 4

List of Animals Considered to be Threatened with Extinction

Name	Present distribution	Reasons for decline
Barasingha	Found only in and around the Kanha National Park, M.P.	- Heavy & continuous illegal hunting - human settlement and grazing of domestic livestock
Hispid Hare	Foot hills of Himalayas in U.P., Bihar, West Bengal, Assam	- Loss of habitat due to cultivation and grazing
Malavar Civet	The coastal district and western ghats of south India	
Asiatic Buffalo	-	-
Asiatic Lion	-	-
Bengal Tiger	-	-
Great Indian Rhinoceros	-	-
Indian Wild Ass	-	-
Tibetan Wild Ass	-	-
Western Tragopan	Rare and local in all its localities	- Human predation and disturbance in habitat
While winged wood duck	-	-
White-eared pheasant	-	-
Great Indian Bustard	-	-
Estuarine Crocodile	-	-

Source: Natural Resources of huymid Tropical Asia, UNESCO Publication 1974 destruction of the wild life. In Taiwan, for example, the extermination of the blue pheasant coincided with the felling of the original primary forests and the planting of softwoods. In Philippines, the extensive reduction in forest resources since 2nd world war has resulted in great depletion in wild life with many species threatened with extinction (Talbot & Talbot, 1964).

In Indonesia, due to lack of sufficient man-power training and inadequate planning the decisions to exploit extensive timber resources have resulted in a poor status of faunal resources. The problem of habitat destruction is everywhere in varying degree and the principles of rational land use and conservation of natural resources are still far from being generally implemented.

2.5 Inventory of watershed resources

An accurate assessment of various natural resources both in quantity and quality is very much essential for watershed resources management. Following sections describe ways to measure or inventory precipitation streamflow, water quality, soil resources, timber production and wild life (Ffolliott, 1981).

2.5.1 Precipitation

It is an integral part of most hydrologic sgudies. Generally information regarding amount, intensity, frequency of precipitation are required for hydrologic studies. There measurements are generally taken with the help of either storage or automatic raingauges. The number of gauges required to measure precipitation will depend upon the size of the watershed and topography. The average value of precipitation over the watershed can be obtained by using methods like arithmatic mean, Thiessen method and isohyetal method. In arithmatic mean method straight average of precipitation records is obtained to arrive at an average value. This method generally yields good results in level topography region. In Thiessen method, polygons are formed from the perpendicular bisectors of lines joining nearby stations. The area enclosed in the polygon represents the precipitation station enclosed in it. The amount of precipitation of each station multiplied by the corresponding polygon area divied by total area gives the average precipitation of the watershed. In case of Isohyetal method the area between the consecutive Isohyetes (lines of equal precipitation) and the average rainfall of the Isohyte is multiplied and is divided by the total area of the watershed.

The measurement of water in a stream can be done with the help of a stream level recorder or a staff gauge. The record of stream flow stages needs to be converted to discharge which is done by determining discharge at the gauging sites by various methods and then relating discharge to corresponding stage of stream to develop rating curves. For small streams use of precalibrated structures such as weir or flumes can be done to measure the discharge.

In order to evaluate various kinds and amounts of substances present is water, samples for water quality measurement are taken and analysed for various parameters. The various chemical constituents of water are derived from many sources, including gases from the atmosphere, weathering products of rocks and soils, and decomposition of plants and other organic materials. The various land management practices result in varying amounts of various chemical constituents in water. The water quality samples are analysed for determining various chemical parameters directly with the help of equipment or by carrying out laboratory analysis. Besides chemical constituents, the quality of water may also get deteriorated by presence of sediments and bacteriological population. Sediment samples from streams are collected by various equipment including Punjab bottle sampler and depth integrating samplers. The samples so collected are analysed in the lab for total sediments. The bio-degradable material in water is indexed by a parameter as biochemical oxygen demand (BOD). The temperature of water determines the type of organisms present in water. Ordinary thermometers or thermocouples are frequently used for measuring water temperature.

2.5.2 Flora

In forests, the measurement of yields may be concerned with forest density, growth rate, volume of timber etc. It is basically measurements of a tree like basal area, height etc. which are used for working out volume and density of trees. The measurement of tree stem diameter at about 1.3m above ground surface is the most common measurement used for calculating basal area. The height measurement of a tree could be of two types; viz., total height (the height between ground and tip of the tree) and merchantable height being a measure of usable portion of a tree. With known height and diameter, the volume of trees can be worked out with the help of tables.

The growth rate of a tree is defined as its volume divided by its age. Generally the age of a tree is determined by either general appearance aided by judgment or by counting annual rings or branch whorls.

Generally, density of forest stand is used to indicate inventory of forests. Density could be expressed by various ways including number of trees, basal area and volume. These indicators of forest density are worked out based on sample surveys. Another indicator of density of forest could be growth rates of individual trees and forest trees. In order to project forest growth rates for future, the analysis of past growth rates is done. The evaluation of the site or the environmental conditions affecting the growth and survival of a forest or other plant community is required to categorise the quality of various forest growing sites. The measurement of site quality could be done by integrating all factors influencing the productivity of forest stands. Of all measures of site quality, tree height in relation to age has been found the most practical, consistent and useful. Height growth is sensitive to differences in site quality, little affected by density of forest stand and is strongly correlated with volume. Therefore, a site index could be defined in terms of total height of dominant or co-dominant trees in well-stocked, even aged stand at specified ages.

The forage production of a watershed can also be indexed in terms of number of animal it can feed per unit of time. The forage produced in sample plots can be weighed and yield of forage in kg/ha., can be found out. The forage production of a watershed can be characterised as its capacity to feed a unit animal per month per unit of land and can be referred to as carrying capacity. In other words, the carrying capacity can be defined as the ratio of usable forage actual produced in the watershed and requirement of forage per unit animal per unit land. With the known value of carrying capacity one can estimate animal supporting capacity of a unit of watershed land per unit of time.

2.5.3 Fauna

The inventory techniques of wild life may include estimation of number of animals, determination of animal productivity and evaluation of wild life habitat .

The number of animals in a watershed can be found out by three main methods including direct census, indexing method and ratio method to assess population change. If the vegetative over-stories are minimal, direct census of animals can be done by aerial counting. Indirect methods of indexing population numbers are based on counts of something other than animal themselves. The ratio method are based on two techniques, one based on banding or marking of animals and second based on kill data from legal hunting.

The productivity of animals is based on census and composition. Generally, the smaller the animal, the fast their production, normal population loss and regeration each year.

Measurement of habitat quality is a third classic wild life inventory and can be broken down into elements of habitat required by most wild life species. The most important elements to describe habitat quality could be water, food, cover and distributioin of these with respect to space. Most of the wild life animals will need these elements in their daily range of movement and if all these are amply available, the habitat quality can be described as highly productive for wild life populations.

2.5.4 Land

Soils of the watershed land is the basic resource and its knowledge is important for watershed resources development. The basic information for inventory of soil resources could include colour texture, structure, depth of soft and hard rocks, presence of salts etc. Such informations could be gathered by soil sampling and laboratory analysis.

Soil samples are collected from the desired location in a watershed from a depth generally about 1 meter or more depending upon soil profile depth.

A vertical section through a soil profile indicates various horizons each varying in composition of organic matter. The various physical properties that may be required for inventory of soils may include its texture, specific gravity, bulk density, consistency, structure, void ratio,porosity, soil depth, color, temperature penetrability, and permeability of soil. The chemical properties may include proportion of various nutrients, soil acidity, oridatioin and reduction potential etc. These are also established by sampling techniques.

2.6 Problems of Watershed Lands

Watershed lands include a major portion of earth's habitable land surface excluding the well defined agricultural lands and urban areas. The watershed lands are often referred to as wild lands, forest lands or simply undeveloped lands. A rough estimate indicatres 80% of the land surface on the earth as watershed lands. In view of increasing pressure of rising population it is these watershed lands which can produce additional food, fibre, energy and living space. The share of cultivated land per capita has gone down to 0.25 ha or even less in many developing countries and the option of increasing cultivated land by clearing grazing areas has limitations in many regions. It is about 50-80 percent of population that live in watershed lands in developing countries and for sustenance of life all possible means are used to exploit resources of these lands which sometime lead to environmental degradation. Clearing of slopy lands for fuel, fodder and primitive cultivation, grazing of forests to the extent that prevents reproduction, uncontrolled forest fires, all these lead to land deterioration, heavy soil loss and reduction of environmental quality. The main causes of watershed deterioration include uncontrolled, unplanned, unscientific land use and activities of men. In agriculture sector, cultivation of sloping land without enough precautions or cultivation along stream banks or growing of erosion permitting crops or over cropping of areas without fertility replacement may lead to deterioration. In forested catchment, unscientific cutting of trees or drastic turning of plantation and in grass lands excessive grazing causes deterioration in catchment behaviour. Forest fires, accidental or intentional also lead to changes in watershed behaviour. Practices of shifting cultivation destroy protective and productive vegetation in preference to a very brief period of immediatre crop production. Also unscientific mining approaches, construction activities especially in hilly watersheds and at time non-co-operation from people also lead to adverse changes in watershed behaviour. The ultimate results of watershed deterioration could be low productivity of land with respect to food, fuel and fibre and forage, heavy erosion losses, sedimentation of streams and reservoirs, poor quality of water yield and reduction in economic standard of watershed inhabitants.

India has a geographical area of about 328 millian ha. The land area is not only inelastic but also heterogenous in different parts and regions with a definite set of capabilities and suitabilities for different uses. While the population of the country is continuously increasing and is expected to touch mark of 1000 million by 2000 A.D., the arable land resources are reported to be shrinking as the net sown area has gone down from 0.33 ha./capita in 1950 to 0.20 ha./capita in 1980. Knowledge from space exploration has clearly indicated that we will have to depend upon the soils for providing the food and other agricultural commodities needed by human beings and animals. Recent advances in agriculture research and development have shown that there is considerable scope for increasing the contribution of both inland and marine water resources to food supply. However, not more than 15% of the world's food requirement is likely to come from aquatic resources. Therefore, the soil has to be the mainstay of national and global nutrition security (Swaminathan, 1985). A brief account of watershed deterioration problems in India is given in following sections:

2.6.1 Soil erosion and land degradation

The land degradation problems are prevalent in many forms in our country. It has been estimated that about 53% of the geographical area, i.e., 175 million ha. Out of this about 132 m.ha. was said to be subject to erosion by water and wind. Land use wise distribution of problem areas indicates that about 105 m.ha. of cultivable land, 19 m.ha. of forest land and 8 million ha. of non-forest and non-agricultural land are subject to wide spread problem of soil erosion through water and wind. About 43 m.ha. of land has been estimated to be degraded through water- logging, alkalanity, salanity, ravines, shifting agriculture etc. Ravines are the most spectacular type of erosion. These are found along the rivers of chambal, Jamuna, Mahi, Sabarmati etc. and within the distance of about a kilometer or so from the water line. The states of Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat mainly have problem of ravinous lands. Gullies are another type of problem found in the plateau region of eastern India, along the foothills of the Himalayas is extensive areas of the Deccan plateau. It has been estimated that about 4 m.ha. land is affected by such problems in various 12 states in India (Mukerjee et al., 1985). The problems of water logging and secondary salinity are becoming cause of concern in commands of surface irrigation projects. Various commissions and organisations, namely, Irrigation Commission (1972), National Commission on Agriculture (NCA) (1976), Rastriya Barh Ayog (1980), Central Soil Salanity Research Institute (1981) and Central Ground Water Board (1982) have from time to time assessed the total water logged area in the country (Anon. Vol. II, 1986). The estimates of NCA (1976) indicate that about 6 m.ha. area over 17 states is subject to problems of water logging divided into two categories, namely, (i) areas water logged due to surface flooding (3.4 m.ha) and (ii) areas water logged due to rise of water - table (2.6 m.ha.). Estimates made by Rastriya Barh Ayog (1980) have put about 2.50 m.ha. area as affected by water logging problems caused by surface flooding in the states of Uttar Pradesh, Bihar, West Bengal and Assam. Due to rise in water table an area is considered water logged when the water table rises to about 2 meter from the land surface and results in saturation of crop root zone which prevents proper aeration resulting in reduced crop yields. Estimates made by Irrigation Commission (1972), Central Soil Salinity Research Institute (1981) and Central Ground Water Board (1982) indicate total water logged area in the country as 3.35, 4.44 and 3.42 m.ha. respectively. The data collected by OFD wing of the Ministry of Water Resources indicate that in 41 major and medium central commands, an area of 7.43 lakh ha. has been affected by water logging (quoted from Sinha, 1986).

The National Commission of Agriculture (1976) has reported an area of 7.16 m.ha. subject to alkalinity and salinity problems of which 2.5 m.ha. comprise of alkali soils. The practices of shifting agriculture has treatened land productivity mainly in North eastern region of India and states of Orissa and Andhra Pradesh. Estimates made by a trask force indicate that about one million ha. land is under shifting agriculture practice annually involving 6.22 lakh families. Over all about 4.36 m.ha. land in 233 blocks of 62 districts in 13 states and 2 Union Territories as under the problem of shifting agriculture (Mukerjee et al., 1985).

The most pronounced effect of soil erosion is loss of productive top cover of soil. Estimates indicate that about 6000 million ton soil gets lost annually from Indian sub continent involving loss of major plant nutrients (NPK) to the tune of 5-8 million tonnes. This loss of major plant nutrients appear to be greater than the amount of chemical fertilisers applied to the sown area in the country. If it is presumed that one ton of fertiliser would produce a crop yield of 6 ton, 30-50 million ton of crop yield is being lost due to such soil erosion problems. About 8000 ha.per year land is being incurred by not developing the ravinous area (NCA, 1976). Water logging problems are an increasing trend in commands of irrigation projects either due to rising water tables or due to submergence over longer periods, particularly in the growing season. For example, in Sharda Sahayak Command Area, while a gross 4 lakh ha. was added to irrigation area, an area of 5 lakh ha., equivalent to 6.5 lakh ha. of gross cropped area, had become water logged due to the irrigation project (Anon. 1984 d).

2.6.2 Floods

In India an area of 40 m.ha. has been identified as flood prone. On an annual basis about 9 m.ha. land gets flooded which includes 3.8 m.ha. of cropped land. The Indo-Gangetic basin accounts for about 60% of the total flood prone area in the country, which is a source of vital industry and mineral resources of the country, have its share of supporting 40% population of the country. In the north-eastern region, Bramhaputra basin is severely affected by frequent floods. Incidences of flash floods have also been noticed in arid and semi-arid regions of India. It has been reported that due to flash floods, about 1.37 m.ha. land in Rajasthan turned useless as a result of sand deposition (Seth et al., 1981). From the statistics of flood damages reported by the various states/union territories during the period 1953 to 1985 an average area of over 8 m.ha. of land in the country was affected by floods involving a population of about 31.5 million. The average loss of life per year amounted to over one lakh head of cattle and 1452 human beings. While these are average figures, in years of heavy damages the maximum area affected has been as high as 18.6 m.ha. involving over 70 million people (Anonymous 1986 IV).

2.6.3 Sedimentation

It has been a persistent problem through out the human history. The direct visible effects of excessive sediment transport in the streams and rivers are increase in flood peak levels, deposition of silt and coarse sediments over good lands, checking of canal head works and excessive drawal of sediment into the canals and accelerated siltation of storage reservoirs. Ganga, Brahamaputra and Kosi river basins of India are among the 200 rivers in the world experiencing severe silt erosion problems. Based on available information it has been estimated that Ganga basin ranks the highest in the sediment load of 586 m.tonnes per year, followed by Brahmaputra with a load of 470 million tonnes per year (Dhruvanarayana and Ram Babu, 1983). Due to increased flow of sediments in the rivers, the rate of siltation in the reservoirs also gets affected which ultimately leads to reduction of useful capacities of the reservoirs built at considerable costs. The excessive sediments brought into the reservoirs and diversion barrages also get drawn into the canals and irrigated tracts thereby choking the canal capacities along with damaging the soil cover in the agricultural area by deposition of coarse material. The reservoir capacity surveys carried out periodically have indicated that annual rate of silting has exceeded the presumed rate which was used at the time of designing. For example, for Bhakra reservoir which was filled in 1958, a sedimentation rate of 4.29 ha.m./100 sq.km/year was assumed for designing while during the reservoir capacity survey carried out in 1973, sedimentation rate of 5.93 ha.m/100 sq.m/year has been observed. Similarly, the reservoir survey results for Hirakund reservoir indicate that annual rate of silting has increased from an assumed rate of 2.52 ha.m/100 sq.km. in 1957 to 6.82 ha.m/100 sq.km. in 1982 (Anon. 1986 A).

2.6.4 Droughts

About ⅓rd of the country (108 m.ha) is suffering from drought. While the average rainfall of the country is 1200 mm per year but about 12% of the total geographical area receives less than 400 mm rainfall and region receiving less than 750 mm rainfall accounts for about 30% of the country's geographical area. Thus out of the total cultivable area of the country (i.e. 188 m.ha.) about 56 m.ha. are subjected to inadequate and highly variable rainfall. A study conducted by the Central Water Commission has identified 99 districts of the country as drought prone.

3.0 INTERRELATIONSHIP AMONG RESOURCE PRODUCTS AND NEED FOR INTEGRATED DEVELOPMENT

On a management unit, i.e.,a watershed, the relationship among resources products could be of three types, viz., complementary, supplementary and competitive. This has been shown in figure 2 which indicates relationship between two watershed resources, i.e., timber and water. As can be seen from this figure with the complementary type of relationship the development of one resource product leads to development of another. For example, once timber has been removed, production of one increase of another. A supplementary relation in one such that changes in one resource product have no influence on another, as may take place with livestock and wild life with limited ranges or changes in forage production. The resource products exhibit competitive relationship when one must be developed at the cost of another as may be the case between timber and water or between timber and forage. The land management policy must ascertain the various kinds relationship existing among the resources before the practices are implemented. Depending on watershed area chosen for overall resources management the relationship among resource products is determined and this relationship determines the area of management confronted by a watershed resources manager. For example, the area chosen is within supplementary relationship between timber and water, it may not be possible to influence production of water due to timber cutting. Therefore, the operating range of relationship must satisfy the demands and needs designed for the most beneficial combination of present and future uses.

As in evident from above description that use of watershed resources is interrelated and inter-dependent and in order to have an

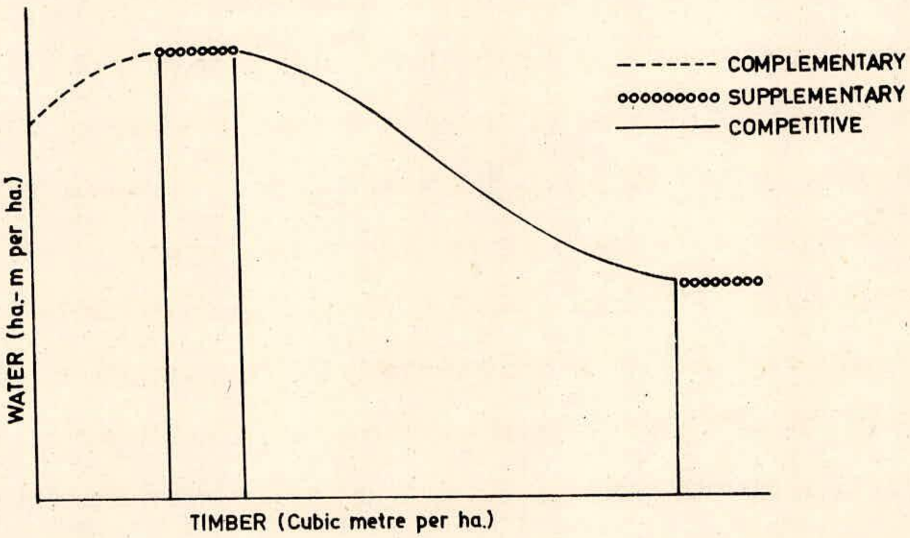

Figure 2 : RELATIONSHIP AMONG RESOURCE PRODUCTS

overall development of these resources the concept of integrated development will need to be developed. While stressing the need for conservation of natural resources, the tenth General Assembly of the International Union for Conservation of Nature and Natural Resources (IUCN) held at New Delhi in year 1969, defined the term conservation as 'the management of the resources of the environment, air, water, soil and living species including man so as to achieve the highest sustainable quality of human life. The underlying principle in this concept, in which conservation is seen as a tool for economic development, is that wise use and exploitation of renewable natural resources are needed in order to achieve the greatest sustainable balanced yield of their valaues. The perpetuation of wild nature and natural resources is now seen as important not only because of its intrinsic cultural and scientific value, but also for the long term economic and social welfare of the country. The conservation of resources can be well taken care of once the overall development strategy of a watershed resources is designed based on interrelationship of resources products and integrated development concepts. This will lead to overall balanced dvelopment of watershed resources and avoid any kind of environmental degradation.

4.0 INTEGRATED RESOURCES DEVELOPMENT APPROACH

The strength and economic stability of a nation are closely interlinked with the judicious and optimal development and utilisation of its natural resources. Land, water, flora and fauna constitute an important part of the natural resources of a watershed. The development of one resource may have impacts on another depending upon the existing interrelationships as has been discussed in earlier section. In many instances and situations, use of only one or two watershed resource products may prevail due to local demands. For example, when one tree or a stand of timber is cut in an attempt to increase water production, production of herbage and esthetic and recreational values will certainly be affected. It is, therefore, an efficient and integrated development of these natural resources is essential to ensure their sustained yields to avoid conditions of imbalance.

For managing these resources a suitable unit of management is needed so that these could be handled and managed effectively, collectively and simultaneously. A watershed has been considered to be an ideal unit for management of these resources, and accordingly a term 'watershed management' has been defined as the comprehensive development of a watershed so as to make productive use of all its natural resources along with their protection. Generally, watershed management involves the development, evaluation and application of land dmanagement systems designed to alter water production. However, as development of all natural resources is inter-dependent so changes in one due to some land management practices will certainly have impacts on another. More specifically, the attempts to alter water production in a watershed may have impacts on production of other resources, e.g., forage, wild life, timber production etc. from upstream lands which are in demand for downstream users. In order to evaluate effects of various land management practices on various resources, it is necessary to measure the yields of these natural resources under various conditions. The yields could be in the form of production of water, timber, forage, range for livestock, wild life conditons, recreational values etc. The methods to have inventory of resources have been discussed in earlier sections. To evaluate the effects of a particular land management system on yield of water and its quality, timber growth, forage production, wild life habitat potential, increase or decrease in hunting practices and other recreational values, their yields could be compared with the situation when such management practice did not exist. The production of various resources from a management unit can be listed in a tabular form indicating change in production of various resources after a land management system is imposed. Table 5 gives an example for such comparison.

TABLE - 5

Yield of Various Watershed Resources

Item	X	Y	Z
Water	0.5	0.75	0.54
Timber Growth	60.0	36.00	79.00
Livestock	1.5	10.5	0.3
Wild life	0.02	0.03	0.03
Timber cut	0.0	1100.00	600.00

Table 5 shows the yields of various watershed resources under various management practices x,y and z. The numbers indicated in the table are in the suitable units in which the yields of the corresponding resource could be expressed. Assuming that x represents the original land management practice and y is the condition when timber was cut and area was coverted to grass. As can be seen from the above table, by bringing about change in one resource product, the others have been directly or adversely affected and a new set of yield values is obtained. Now based on the comparison of the resources yields, the best land management alternative can be decided.

The problems those are expected to be faced in pursuing overall development of watershed resources can be the development of an efficient institutional framework through which land areas subjected the overall development concept can be managed. A realistic overall development plan, such as that outlining a land management system designed to alter water production, must either work within the existing institutional structure or modify it in order to be effective.

5.0 WATERSHED RESOURCES SIMULATION MODELS

With the advent of high speed digital computers, simulation of the hydrologic processes has become a powerful tool for developing better understanding of the complex hydrologic processes for both the research hydrologist and the practising water resources engineer. Hydrologic simulation can be defined as a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that represent the behaviour of the hydrologic system, or some component thereof, over extended periods of real time. A hydrological system is defined as a set of physical, chemical and/or biological processes acting upon an input variable or variables to convert it (them) into an output variable (or variables). Snyder and Stall (1965) defined hydrologic models as symbolic or mathematical representations of known or assumed functions expressing the relationships of segments of the hydrologic cycle, or expressing the effects of a watershed on the runoff portion of the hydrologic cycle. Models are often essential for the solution of the complex hydrologic problems, but models do not have to be complex to be useful.

Hydrologic models can be broadly classified as being deterministic and stochastic. The operating characteristics of deterministic models are in the form of known physical laws or empirical relationships and they provide a unique output from a given input, while a stochastic model has operating characteristics represented in the form of probability functions. Both type of models are useful in watershed resources development, however, the deterministic model is more readily adoptable to the examination of land use changes and provides more insight into the physical processes of the hydrologic cycle. Deterministic models can be either component type models or integrated system type models. The component models deal with the specific phases of the hydrologic cycle, for example, infiltration (Philip, 1954) or the soil moisture regime (Zahner, 1967). The integrated system models simulate the entire hydrologic system to simulate various hydrologic processes, for example, Standford Watershed Model developed by Crawford and Linsley (1966). Based on certain model characteristics the deterministic models are also classified as linear and non-linear, lumped parameter and distributed parameter, and stationary and time-varying types of deterministic models. A unit hydrograph is a good example of linear deterministic model. The relationship between precipitation and runoff is assumed non-linear in case of non-linear models. A lumped parameter model assumes that the parameters used to model various hydrologic processes are representative of the net effect of these processes over the entire watershed, while a distributed parameter model accounts for the spatial variation of processes over a watershed. The parameters of a stationary model are constant over time, while a time varying model has time varient parameters. Another form of deterministic model is the regression model in which runoff is related to precipitatioin by a linear or multiple regression analysis of historical precipitation, runoff, climatic and watershed physical data.

Modelers have used various approaches to develop watershed model of different kinds. Some of the commonly used approaches are as given below;

5.1 Use of Antecedent Precipitation Index (API)

Use of Antecedent Precipitation Index (API) as a measure of soil moisture storage available has been done by various researchers for predicting watershed runoff. Hartman et al.,(1960) developed a model which calculated runoff as a function of the total rainfall amount received and that amount retained by the top three feet soil before runoff begins. Kniesel et al.,(1969) modified this model by adding an additional storage level to account for the three to five foot-soil depth. In Hamon (1964) model, the amount of rainfall retained before runoff began was related linearly to an antecedent soil moisture index which was determined for two levels of soil moisture storage using an unsaturated flow-modulated moisture accounting procedure where moisture loss was a function of day length, daily mean temperature, season and available soil moisture. In a model developed by Betson et al.,(1969) the API - runoff relations were expressed by two equations and five coefficients. Sittner et al., (1969) developed a complete hydrologic model utilising an API type rainfall - runoff relation to compute surface runoff.

5.2 Use of Reservoir Type Storages in Series or Parallel

Another approach to model soil-water components is to consider this portion of the hydrologic cycle as a system of storages and reservoirs connected in series or parallel. Moisture is routed into and between reservoirs based on the concepts that infiltration, percolation, surface runoff, and ground water discharge are functions of the water stored in the soil mantle. Water which leaves soil reservoirs and enters a stream channel is usually routed to the point of hydrograph construction by reservoir or open channel routing techniques. Dawdy and O' Donnell (1965) developed a model in which the channel and ground water storages were considered linear reservoirs and the sum of their outputs produced the basin runoff. Murray (1970) proposed a model in which ground water was assumed as linear reservoir and other storages taken were interception, upper soil and lower soil zone from which the water was depleted by evaporation. Onstd and Jamieson (1970) represented the hydrologic system in two main phases, i.e., land phase and channel phase. The land phase was simulated by non-linear reservoirs and the channel phase was represented by a single linear reservoir. Sugawara (1967) proposed a series type storage model with the elements stacked vertically.

Efforts to develop a comprehensive watershed model which could predict runoff from given storm events alongwith having capability to synthesize a continuous stream flow recorded were taken by Linsley and Crawford (1960) By 1966 a comprehensive model known as Standford Watershed Model IV version was developed (Crawford and Linsley, 1966) which had more detailed description of the hydrologic processes, can be applied to larger basins and more diverse climates, could handle snow input, accumulation and melt. The model has been modified and used by various agencies like engineering consulting firm Hydrocomp, Virginia Water Resources Research Centre, University of Texas, University of Kentucky etc.

5.3 Use of Partitioning

Another approach in developing wateshed models has been to divide watershed into subunits on the basis of one or a set of physical or hydrologic characteristics. The partitioning account for the temporal and spatial variations in watershed characteristics. The methods used in developing such models are just as applicable for lumped models. The only difference is that these techniques are performed individually on each subunit and the subunit outputs are summed or routed to obtrain the total system response. Rowe (1943) made attempts to use partitioning to determine physical effects of watershed management on floods and streamflow. Amerman (1965) introduced the concept of 'unit source area' which referred to a subdivision of a complex watershed and which had a single cover and soil type and was otherwise physically homogeneous. Spangenbery (1969) discussed various diverse techniques of partitioning used in physical process models. The Stanford Wateshed Model IV allows for partitioning on the basis of topographic features or a Thiessen network to accommodate more than one rain gauge on a basin. Hiemstra (1968) developed a rainfall-runoff model for a small catchment by dividing it into five equal areas on the basis of slope clases where each area was considered a single storage system composed of a surface depression and detention storage zone and a soil storage zone. The model was developed to be sensitive to changes in land use.

Another approach to partitioning has been temperal division on the use of isochrones to subdivide a watershed. Laurenson (1964) developed a model using temperal partitioning to account for the temporal and areal variations in surface runoff.

Another basis as has been used by Sugawara (1967) is based on elevation or contour interval for sub-division. He divided basins receiving snow into elevation zones on contour lines to permit appropriate adjustments to temperature and precipitation measurements usually observed in only one zone. Elevation zones were used for snow accounting in the Streamflow Synthesis and Reservoir Regulation (SSARR) model developed jointly by the U.S. Corps of Engineers and the ESSA Weather Bureau (Schermerborn and Kuehl, 1968). Pipes et al.,(1970) also used elevation bonds in a model to simulate snowmelt hydrographs. Snowmelt was computed on a temperature index basis and resultant melt entered stream channels as either surface runoff on ground water where it was then routed as channel flow.

England and Onstad (1968) discussed the partitioning of a watershed into relatively homogeneous units with respect to soil type, land form, and land use which were compatible with the hydraulics of overland and subsurface flow. The USDAHL-70 model (Holtan and Lopez, 1971) uses soils grouped by land capability classes as a basis of partitioning.

Some researchers have also tried to sub-divide a watershed based on a system of cells or a grid rather than subdividing according to the boundaries imposed by physical characteristics. In a model given by Huggins and Monke (1967) they delineated a watershed as a grid of small independent elements whose size were sufficiently small that slope sleepness and direction, vegetation, rainfall, and infiltration rates were uniform within each element boundary.

Having described the various common techniques of modelling it may be worthwhile to discuss some frequently used watershed models.

One of the first comprehensive watershed models developed was the Stanford watershed model developed by Crawford and Linsley (1966). This model has been widely used in water resources studies and has under gone numerous modifications, additions and revisions, the best known version of the model is perhaps the Kentucky version. The various hydrologic processes in the model are represented mathematically as flows and storages. One key feature of the Stanford model is that the infiltration, interflow, and ET are varied over the watershed area but arbitrarily. Primary data inputs to the Stanford model include hourly and daily precipitation and daily maximum and minimum teperatures (for snowmelt only). Observed daily streamflows, if available, are input for comparison to calculated values. In most cases, four or five years of observed runoff data are sufficient for fitting the Stanford model. The most common applications of the Stanford watershed model have been to obtain hydrographs for unusual rainfall events and to extend a short flow record sufficiently for hydrologic analyses.

Another model developed for small, agricultural watersheds is United States Department of Agriculture Hydrograph Laboratory (USDAHL) watershed model (Holtan et al.,1975). The model simulates the hydrologic processes that occur between storms as well as during storms. In applying this model, the soils of the watershed are grouped by land capability classes to form hydrologic response zones which serve as basic units for all calculations. Also depending upon the feature that is important to the problem, the watershed is zoned by land use,by slope or other relevant feature. The model has been applied to all types of land use in almost all geographic parts of the U.S.A.

The U.S. Corps of Engineers (Rockwood, 1958, 1964) developed a model for the planning, design, and operation of water control projects in the Columbia River Basin which is known as Streamflow Synthesis and Reservoir Regulation (SSARR) model. This model consists of a watershed model, a river system model and a reservoir regulation model (U.S.Army Corps of Engineers, 1975). The model can be classified as specific purpose model, applicable for large watersheds and uses lumped parameters. The model uses input of adjusted time-dependent point rainfall and snowmelt and the single or combined input enters a function of moisture input which distributes the input uniformly over a specified area for a given time period. The supply of moisture is divided between runoff and soil moisture increase by use of an approrpriate rainfall/runoff relationship. Moisture entering the soil storage is depleted due to evapotranspiration based on an index. Baseflow is derived using an infiltration index from total runoff. All components of runoff are routed separately and the sum of routed valaues for any given time period is taken as the streamflow for the catchment.

In order to simulate water yields from catchments in climatic range of subhumid to semi-arid in Australia, Boughton (1966) developed a model which is a general purpose model, can be used for 25-70000 ha catchment size, and uses lumped parameters. The model is written in Fortron-IV and consists of three moisture stores, namely, interception store, upper and low soil stores. The model has been extensively applied in Australia and New Zealand and has also been modified for use on British catchments. The model, using daily rainfall and evaporation data, provides continuous simulation of daily runoff.

The various watershed models some of which were described earlier are lumped parameter models. In order to take care of spatial variation of model parameters, need for developing distributed parameter model was felt. The initial development of this concept was reported by Huggins and Monke (1968). Huggins et al.,(1977) cited several advantages of using a distributed parameter model though the distributed parameter models simulate hydrologic processes in a better way, however, the models become more complex and requirements of data and time get increased in operating such models. Beasley (1977) developed a comprehensive distributed parameter model 'ANSWERS (Areal non-point source watershed environment response simulation). The model simulates the hydrologic processes of interception, infiltration, surface and sub-surface flow, and detachment and transport of sediment on a spatial basis. Gupta and Soloman (1977) developed a distributed parameter model for predicting both runoff and sediment discharge using square elements as in the ANSWERS model. Ross et al.,(1978) developed and tested a distributed parameter model for predicting watershed runoff, erosion and sedimentation. The model incorporates dividing the watershed into hydrologic response units (HRU's) each having a certain combination of soil type and land use. Runoff volumes are calculated from each HRU.

The various hydrologic models have been put to various applications. All model applications can be divided into two categories; decision making and research and training. In a decision making application an analyst uses hydrologic information to select an optimal course of action or in other words the hydrologic variates become inputs to the decision making model like other kinds of information (i.e., economic, biological, and social). The model applications by subject can be divided into five major categories, namely, agriculture, forest and rangeland, surface mining, urban and minor structures. In case of research and training, the ultimate goal is to better understand the hydrologic cycle by using the hydrologic models. An essential difference between this category and decision making is that research and training deal with knowledge whereas decision making involves information.

Most of the research efforts have been centred on development of hydrologic models to predict streamflow from precipitation with varying conditions of the watersheds. Of late, there has been increasing awareness to develop/manage all resources of watershed including floral and faunal resources besides water. This has led to concepts of multi-objective planning and development as far as management of forest and range lands is considered. Fogel (1971) lists some of the objectives of forested watersheds as timber production, forage and grazing, water production (quantity and quality), wild life habitat and recreation. Proper management of these all requires integration of all these factors, which leads to the adoption of an ecosystem or general approach (Huff, 1971; Carder, 1976). The hydrologic model maybe operated with alternative management plan of these watershed resources. The Rocky Mountain Forest and Range Experiment Station has sponsored several studies in conjunction with an investigation of Beaver Creek of Arizona which involves multiple use management of forested watersheds in U.S.A. (Carder, 1976). Hydrologic models play an important role in these studies. Forest Management practices (silvicultural practices) designed for increased water yield are being evaluated in terms of their impacts on sediment transport, flooding, timber harvesting yields and wild life. Simons et al.,(1975) gave a model for predicting water and sediment yields as affected by clear cutting and burning. These vegetation manipulation actions were simulated by changing parameters relfecting the canopy cover and ground cover density. Though efforts to introduce effects of land management practices on yields of all resources of watershed have been initiated, however, much is yet to be achieved in this direction and in order to arrive at a perfect model envisaging optimal yields of various watershed resources including water, flora and fauna alongwith preserving land capability, the complex interrelationship among these resources will need to be carefully understood and modelled.

6.0 WATERSHED RESOURCES DEVELOPMENT MODEL

In order to evaluate effects of any land management policy on various resources of a watershed, a comprehensive model incorporating sub-models of various resources can be developed. The sub-models may include simulation models for watershed resources including water, land, flora and fauna. These sub-models would form the resources development model when combined together. Broadly, there can be three main sub-models which can be represented by a resources development model. There are:

i) a sub-model which will include computation of water yield, suspended sediment and chemical quality of streamflow under given and changed land management conditions.

ii) a sub-model that will evaluate growth and yields of forests along with other related aspects such as amount of organic matter on forest floor.

iii) a sub-model to assess the animal habitat, carrying capacities and population dynamics under existing or changed land management conditions.

A sub-model may consist of a number of components depending upon the type of watershed resource it has been developed for. For example, the sub-model describing water will have separate components to assess effects of land management practices on water yield, sedimentation and water quality. These model components can be so designed such that these are simple to operate and the predicted effects of land management practices is evaluated based on measured responses from field data. The input data requirement can be kept to be minimum. Based on comparison of predicted and field observations, the components of all sub-models can be developed. These sub models then can be written in FORTRAN language and can be operated simultaneously on readily available data sets. The data sets may include data which are readily available to any watershed resources manager. Minimum data requirement could form one basis for component design of sub-models.

The sub-models could be developed for land areas ranging from a fraction of hactare to thousand hactare which mainly depends on the data availability and their spatial variability. The various parameters to be used for simulation may represent the average conditions of the area under consideration. For larger areas, the models may be operated several times on sub-areas of the larger area, where each operation of the model uses data values characteristic of the sub-area. Addition of sub-area responses yields those for the entire area.

The users may require default data for using various sub-models in case a particular data element is not available. These default data could be "average" or "typical" values for the specific parameter in the particular ecosystem being simulated. The default data could be generated by review of literature, research and field data. In many cases, the default data are ecosystem specific, i.e., the default values change with the ecosystem being simulated.

The sub-models including the various components may have three phases of operation, viz., initialisation, time cycling and summary. In the initialisation phase all needed input data could be fed to the model. These could be in the form of data coming directly from the user, default data, or data generated from the operation of another simulator. In the second phase the frequency of operation of model is set in depending on the nature of the model. For example, in the simulation of water yield, there are daily reiterations, while for forest growth and yield, they are yearly. For some modular components, the cycling time could be only twice, i.e., before and after the implementation of land management practice. The third phase of model operation could be summary phase when all totalling and processing of the data at the end of simulation can be done. These summaries will show the state of a particular component of the watershed resources at the start of the simulation, and the change in it due to various land management activities or passage of time. The effects of changed management activities become apparent in output summaries based on which the best preactice for overall management of watershed resources for their sustained and optimal yields could be decided.

6.1 Constraints

There could be two type of limits which regulate the degree of success in watershed resources development model. The natural limits include biological, physical and hydrological relationships, which determine the responses of watershed resources to a given management practice. The other type of constraint includes legal, social and economic concerns which are set by human beings to meet specific conditions and can be modified in response to changes in legal, socio-economic and political situations. Legal aspects include considerations of laws regulating ownership and use of water or land. For example, the National Forest Policy (1952) has envisaged that 33% of the geographical area should be under forest coverage and Forest (Conservation Act, 1980 is an example of regulation of land use. The social considerations are also important while planning resources developmental strategy. This aspect gets more significance in view of the fact that there are a number of religious beliefs in the country and all are to be given due considerations. It is, therefore, any land management policy must consider the cutural features and characteristics of a society. The social limitations can be modified to some extent to achieve the desired results but as these limitations are difficult to assess precisely and can not be solved by easy solutions, it may be difficult to include such considerations in overall management policy. Out of various possible alternatives of land management practices, one may select the one which may be economically viable. The economic assessment can be done based on criteria like maximisation of benefits, maximisation of return on an investment or achievement of the goal in least cost.

6.2 Land Management Practices

In order to understand various effects of land management practices, it may be necessary to describe the various such practices which could be adopted in forested watershed. In this reference silvicuture needs to be defined. Silviculture has been defined as the cultivation and care of trees in a forest ecosystem or in simple words it is an art and science of cultivating forest crops. A silviculture system involves the removal of a forest crop, replacing it with new crop of desired form and tending it till next final harvest. It is a technique based on the experience and knowledge of silviculture, including ecology, and applied to a given forest after considering the requirements of the forest management and objectives to be fulfilled. Based on origin of the forest, the silvicultural systems are divided into two broad groups, namely, high forest systems and coppice systems. Higher forest is a forest which originated from seed, either naturally or artificially. Coppice forests have origin from the coppice shoots from the stump of a cut tree and from root suckers. Depending upon the mode of regeneration, production of even-aged or unevenaged crop and removal of mature crop etc. various classification of silvicultural systems both under high forest systems and coppice systems have been done. Under high forest systems the various practices include clear felling system shelter-wood system and selection system. In the clear felling the oldest trees are cut each year, and next oldest trees are to be removed in the next year. The coppice systems are the oldest systems of forest management in the world. In this system regeneration depends on vegetative form of reproduction, e.g., stool coppice, root collor shoots, pollard shoots and seedling coppice. For production of better and strong coppice it is necessary to cut the tree as close to the ground as possible and the stumps are dressed to have sloping surface all around with highest point being the centre of the stumps. A number of coppice shoots may emerge from the stump out of which only the healthy ones are retained after one or two years. The coppice system is not a permanent system, as the coppicing can not be achieved for a number of rotations. The important reason is death of large number of stumps due to various climatic and biotic factors. Example, in case of Eucalyptus globulus it becomes necessary to replant the area with nursery raised seedings after the fourth rotation of coppice crop. Depending upon the local demands, silvi-cultural and economic factors, the silvicultural systems are chosen. The silvicultural factors include conditions of regeneration, rate of growth, soil charcteristics and topography. The economic factors are development of infrastructure, availability of labour, nature of produce required, subject of rights and concession to the local popoulation and other economic considerations (Dwivedi, 1980).

6.3 Data Requirement

The watershed resources development model encompasses mainly three sub-models requiring various kinds of data for having assessment of yields of water, flora and fauna under various kinds of land management practices.

As described earlier the first component will be devoted to compute water yield, sediment yield and changes in chemical quality of water. These may require data pertaining to characteristics of storms including amount, duration and intensity, physical and chemical properties of soil, temperature and precipitation records, evapotranspiration records, deep percolation losses, intercepting characteristics of vegetation etc. For computing sediment discharge in the streams, streamflow runoff is the primary variable besides vegetation density, accumulation of organic material, season of the year, and type of vegetation. Streamflow runoff is also the primary variable for computation of chemical quality of streamflow. Parameters other than streamflow discharge may be variable in a longer temporal senses, but are considered constant for a single runoff event, such as stream pH. The dissolved chemical constituents of water that may be required to assess quality of water include calcium, magnesium, sodium, chloride, sulfate, carbonate, bicarbonate, fluoride, nitrate, phosphate, total soluble salts, and conductivity. The acceptable levels of these constituents for various water uses including irrigation, water supply and aquatic life should be well known for comparison.

The sub-model needed to assess yields of forest products will require data of forest type, density of vegetation, land use, tree species, basal area of trees and its relationship with volume of timber, maximum and minimum basal area of various tree species, data regarding forest growth expressed as volume of timber/ha., production of forage expressed as kg./ha., existing land management practices, age of tree species and ways to determine it, estimation of litter cover and organic matter on the soils or forest floor and soil parent material. The production of herbage may be related to soil charcteristics, precipitation and forest overstory growth.

The effects of land management practices on faunal species can be determined by evaluating carrying capacity of an area depending upon the number of animals that can be fed by this area under consideration. The production of herbage needs to be divided into two components,, i.e., usable and unusable. Proper use factor in respect of the animals of the simulated area needs to be defined. Data concerning forage requirement of animals and durations for forage utilisation need to be collected. For the area under consideration, the carrying capacity of an animal can be evaluated using proper use factor, forage production, area of region and number and type of animal species in the area. Information regarding habitat quality of forest ecosystem as affected by forest trees or in other words the animal population as affected with availability of forage and shade protection is also required. The habitat quality may be expressed in ranking for various land management practices.

The overall model also involves considerations of social, economic and institutional constraints. These constraints, however, are difficult to be incorporated in the model, especially the social ones. All these data arequire an extensive survey and detailed in depth study of the modelling area for ensuring accurate simulation. A schematic representation of watershed resources development model is shown in figure 3.

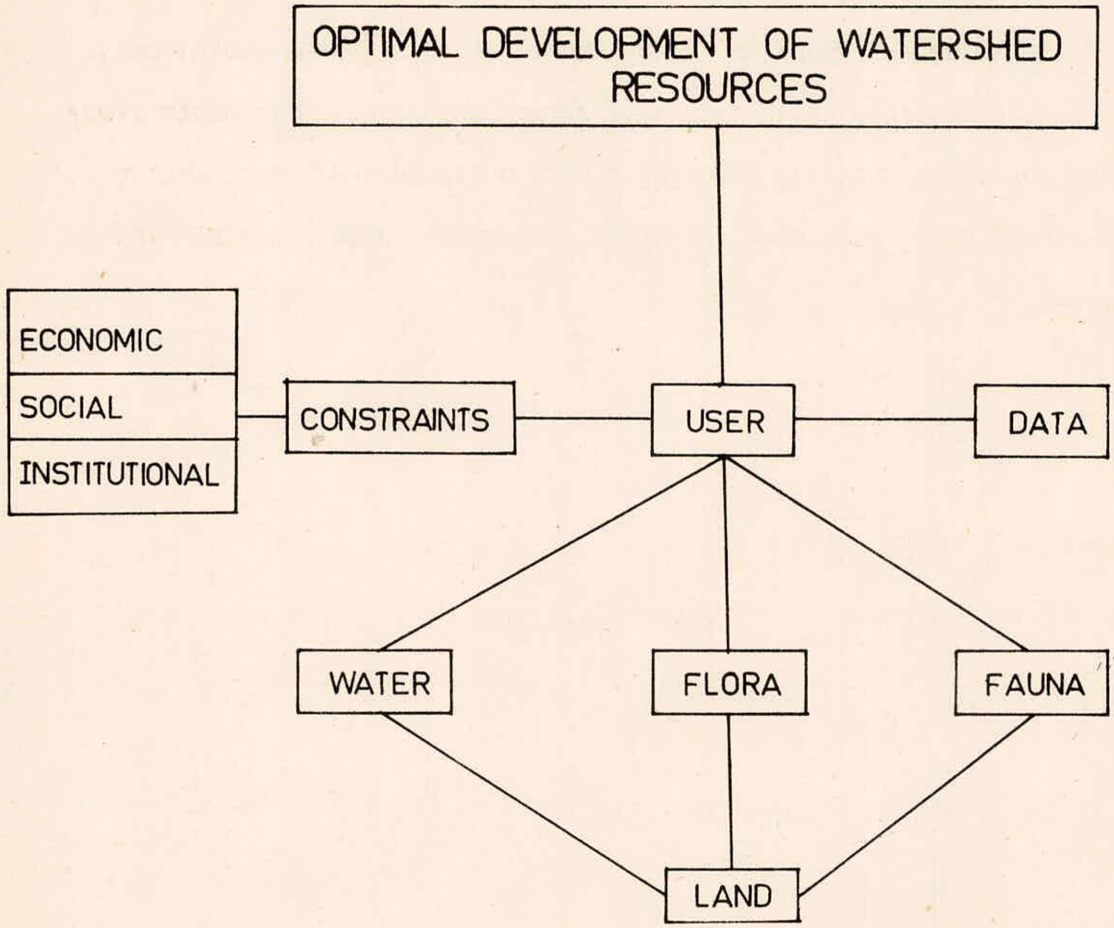

FIG. 3 - WATERSHED RESOURCES DEVELOPMENT MODEL

7.0 CONCLUSION

The watershed resources development model as described in previous sections certainly envisages for the overall development of watershed resources. However, it has main limitation of availability of required data sets. The kind of data required for operation of the sub-models is not easy to collect. Moreover, a lot of time will be required before a complete set of data is made available to run such a model.. The data needed to evaluate responses of flora and fauna to changed land management practices will be difficult to generate. Initially, the models will have to be operated on average values used to represent conditions of given areas.

The social, institutional and economic constraints make it more difficult to operate the model for overall development schemes. The desired policy of development is based on its impact on social, institutional and economic boundaries. Such attempts may, no doubt, take a longer time to yield fruitful results but once this model is developed for a watershed, it will always be helpful to refer to this model. Whenever any attempts to further develop the area are considered its impact on all resources can be found out and so the problem of eneven utilisation of watershed resources will be eliminated thereby avoiding environmental imbalance.

In brief, the overall development plans of a watershed should aim at the following:

i) increase in water yield

ii) provide dependable water supply of water down stream

iii) improve forests, pastures and range lands

iv) improve agricultural land and small farm production

v) maintain a specified standard of water quality

vi) reduce erosion and flood hazards

vii) enhance recreation and wild life.

These objectives can only be met by development of watershed resources development model envisaging optimal yields of various resources.

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