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GUIDELINES FOR HYDROLOGICAL INVESTIGATIONS IN A SMALL WATERSHED

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1.0 INTRODUCTION

India is a vast country with varying topography, climate, and people of different cultures. Because of exploding population, it faces tough tasks in the rational use of its limited natural resources, i.e., vegetation, soil, land and water. Particularly so, highly dynamic water resource's problems are complex and hydra-headed in nature. As such, there are plethora of dimensions to their development, management and utilisation, economic, financial, institutional, legal, physical, political, social and technical aspects and constraints. For the optimal development of the life, all these resources should be managed efficiently by selecting a suitable geographic unit so that these natural resources can be handled practically, collectively, and simultaneously.

Watershed is a unit on which all the measurements regarding natural resources can be made accurately. Therefore, a watershed is considered an ideal unit for management of natural resources.

1.1 Definition

Watershed, also referred as a drainage basin or a catchment, may be defined as a geo-hydrological unit or an area from which all the water, which falls or collects by gravity, drains to a common point.

The watershed may vary in size from fraction of a hectare to thousands of square kilometres. Water from a small plot of several square metres may drain into a small stream, then this plot is called the watershed of that stream. When number of such small streams drain into a main stream, these form a bigger watershed, then the watersheds of small streams are called as subwatershed.

Watershed represents a convenient unit for determination of various processes that are responsible for the formation of specific landscape in a particular region of earth. The most fundamental science that aids to understand watershed evolution is known as geomorphology. Aggradation and degradation are the two main processes that shape a watershed. Aggradation is the process through which the sediments carried by the stream are deposited due to decrease in velocity. Conversely, degradation is the process through which the rocks erode due to the action of water and wind. Therefore, aggradation and degradation processes occur simultaneously in a watershed.

At the first glance, the watershed appears to be a rather static unit of our landscape, yet from a hydrologic standpoint it is a dynamic and changeable area.

1.2 Watershed as a hydrologic unit

To be effective, particularly in rainfed farming, soil and water conservation should be planned and practised in an ecosystem context, e.g., watershed or hydrologic unit area. The hydrologic data is also, therefore, required at the watershed scale. Watersheds have been recognised as useful vehicles for research on complex ecological systems. A watershed is the natural base for studying and modelling terrestrial systems, because inputs and outputs can be defined and quantified, and integrated system responses determined (Swift and Cunningham, 1986). Watershed, which is the locus of those points from which runoff reaches the outlet of the stream, is a natural geographical unit with a certain extent of homogeneity and uniformity. This natural unit is easily visualised in a mountain setting whose boundaries for precipitation, evaporation, and subsurface flow are clearly defined by topography. In addition, it is an open physical system in terms of inputs of precipitation and solar radiation and outputs of discharge, evaporation, and re-radiation. The inter-dependent nature of land and water resources thus necessitates the consideration of watershed as the basic unit in development planning.

The hydrologic behaviour of a watershed is a very complicated phenomenon, which is controlled by large number of climatic and physiographic factors that vary both in time and in space. The amount of precipitation that falls over a given watershed area undergoes number of transformations and abstractions through various components processes of hydrological cycle, i.e., interception, detention, evaporation and evapotranspiration, overland flow, infiltration, interflow, percolation and base flow etc. These components are functions of various characteristics such as topography, landuse, drainage pattern drainage density, geology etc. and are not uniform in the watershed.

1.3 Watershed and the people

1.3.1 Natural resources

A watershed affects the people in every walk of life. It can provide sustained supply of food, fuel, forage, fibre, fruit and water for the humans and animals by the efficient management of its vital resources, i.e., water, soil and vegetation. Proper planning management of the watershed can reduce the negative impacts of floods, droughts, and soil erosion etc.

Water : Watershed characteristics affect and influence water quantity, quality and regime, which is vital for biotic consumption; irrigation; industry; power generation; recreation; transport and many other ways. By manipulating different watershed characteristics, the quantity, quality, and regime can be regulated according to the requirement.

Soil : Soil is the natural medium for the growth of plants life and it occupy the vast portion of earth surface, except the rocky exposed surface. Soil have distinct properties due to integrated effect of climate and living matter, acting upon parent material, as conditioned by relief, over periods of time.

Vegetation : The production of food, fuel, fibre and fruits depends upon the availability of water at right time, of right quantity and quality, and the soil conditions (fertility and erosion) in the watershed.

1.3.2 Natural problems

The watershed also affects the people through the natural problems associated with it such as, floods, droughts, soil erosion, and landslides.

Floods : Floods occur due to he over bank flow of river water and are a function of the watershed characteristics. Floods generally affect the people in the lower reaches. The impact of floods can be minimised with proper management of watershed resources.

Drought : Droughts can occur anywhere in the watershed and are most common in the watershed of semiarid to subhumid climate. As for floods, conserving soil moisture and evolving sound landuse practices can reduce the impact of droughts.

Soil Erosion and Sedimentation : The rate and quantity of sediment produced and transported is of great importance. High erosion affects adversely the productivity of the land and results in loss of land as a natural resource. Transportation of these sediments damages the machinery (turbines, generators etc) and the property. Sedimentation of the transported material in reservoirs downstream, reduces the life and benefits of the reservoirs, and raises the bed of the channel, causing floods.

Landslides and debris flow : These problems are most frequent in mountainous watersheds and are caused by both natural and human action. These problems can be reduces by proper landuse planning in the watershed.

1.4 Objectives of watershed studies

There are many problems associated with the hydrological behaviour of the watershed. This has created an urgent need to study the various aspects of the hydrological cycle so that a satisfactory solution of these problems is evolved. In most of the advanced countries of the world, hydrologic investigations on watersheds are in progress for more than 50 years. Because of this, valuable contributions have been made to explain the hydrological processes active in the watersheds of these countries. The objective of these studies is generally to increase water yield, reduction of peak flood, determination of rainfall-runoff relationship, evaluation of the effectiveness of the land treatment measures, etc.

In India, the problems of water supply for domestic and agricultural purposes, soil erosion and sedimentation, floods and droughts etc are still prevalent even after 50 years of independence. Still, the hydrological investigations on watershed basis are confined to only few research stations of State and Central Government. Large scale investigations are badly needed to be carried out immediately. The objective of these studies should be following :

- To study the hydrological behaviour of the watersheds under different landuses in relation to water yield, peak discharges, and sediment production rates.

- To evaluate the effects of land treatment measures in reducing soil and water losses and to study the processes involved.

- To develop design criteria for engineering structures for soil conservation and upstream flood control.

2.0 TYPE OF WATERSHEDS

A watershed is a geo-hydrological unit or an area that drains at a common point. The watershed should be of such a size that data may not only be collected comparatively easily but also be analysed with reasonable accuracy. Although it is desirable that the watersheds be as large as possible, the maximum size of a watershed will be governed by the ability to attain sufficiently detailed instrumentation (Ward, 1971). A natural physiographic unit whose area is between 500 to 5000 ha is considered as a small watershed. Of course, size of a small watershed will vary in different regions, depending on the local topographical conditions.

Watersheds are generally classified based on hydrological characteristics, size, and landuse.

2.1 Basis on hydrological characteristics

The watersheds (catchments) are classified into three classes i.e., small, midsize or large (Ponce, 1989). Small watersheds are those, which possess some or all of the following properties (i) rainfall is uniformly distributed in space and time, (ii) storm concentration usually exceeds time of concentration, (iii) runoff is primarily by overland flow, and (iv) channel storage processes are negligible.

Midsize watersheds are those, which possess some or all of the following properties (i) rainfall intensity varies within storm duration, (ii) rainfall can be assumed to be uniformly distributed in space, (iii) runoff is by overland flow and stream channel flow, and (iv) channel storage processes are negligible. All other catchments that do not fall in these categories are called the large watersheds.

2.2 Based on size

The watersheds are classified as small, medium or large (Singh, 1996). Small watershed are those which have an area of less than 100 mi^2 or 256 km^2, medium watersheds have an area between small and 1000 mi^2 or 2560 km^2, and greater than 2560 km^2 are called as large.

2.3 Based on landuse

The watersheds are classified as agricultural, urban, forest, rural, desert, mountainous, coastal, marsh, or mixed. Classification of watersheds based on landuse is important, as the hydrology of different type of watersheds is quite different from one another.

2.4 Based on physiography and climate

Knapp (1979) has described the watersheds according to the physiographic setup, such as, upland watersheds or hillslope watersheds, lowland watersheds or alluvial plane watersheds, watersheds of snow and ice, watersheds of arid and semi-arid regions and humid watersheds.

3.0 HYDROLOGY OF SMALL WATERSHED

The hydrology of small watersheds varies from one type to another. Hydrological characteristics of some of the small watersheds is discussed below (Knapp, 1979) :

3.1 Upland watershed or hillslope watershed

Upland watershed are characterised by steep slope, well defined boundaries, thin soils, high rainfall, low evapotranspiration, steep hydraulic gradient, quick response of stream to storms, low soil moisture deficit. Large portions of the rainfall reaches the stream net work. Streams have well defined channels with an efficient cross section, which helps to transmit water effectively. In many cases there is no flood plain to store water as the hill side slope continues right down to the stream bank.

Low temperature and low evapotranspiration tend to inhibit the growth of some forms of vegetation, elsewhere, coarse grass or tree plantations (conifer) are common. However, despite the high rainfall, overland flow is still rare except near the stream or in concavities. Thorough flow dominates over much of the catchment. Most upland watersheds are underlain by impermeable materials giving a negligible ground water flow contribution.

The vegetation cover has significant influence on the runoff response of the watershed. It has been reported that when trees were felled and removed, and natural regrowth of vegetation was allowed in a watershed of 30 ha, time of appearance of peak flow was reduced by five hours. The yield of the catchment was also found six times greater than that of the control catchment during storm runoff period. Removal of vegetation makes a catchment to respond rapidly and markedly flashy.

Removal of trees from upland watersheds reduces groundwater recharge, which may lead to reduction of springflow. Springs are the only dependable source of water in hilly regions.

3.2 Lowland watersheds or alluvial plane watersheds

Lowland watershed are generally more densely cultivated and populated as compared to upland catchment. In lowland areas tress are less common, rivers have low gradient, and erosional energy is reduced, as valley slopes are less steep than in uplands. Soils are deep because of which it is more likely that infiltration capacity is not exceeded. Saturated zone adjacent to river is broader and contributing area to runoff expands more quickly. Lowland watersheds are more prone to floods than the upland watersheds.

3.3 Watershed of snow and ice

Hydrological regimes of catchments dominated by ice and snow are distinctive due to large amount of water equivalent stored during the winter and made rapidly available in early summer. Because of temperature dependence of the regime, high flows can take place without precipitation, runoff can exceed rainfall due to glacier melting.

The glacial watersheds are characterised by (a) steep slopes, (b) thin, intermittent coarse debris cover on solid rock (moraine or outwash deposits) in areas without ice; and (c) very sparse vegetation. These factors cause runoff to occur very rapidly after snowmelt or rainfall, and the streams that flow from such watersheds are very flashy.

3.4 Watershed of semi-arid regions

One third of the world's land surface has been classified as arid or semi-arid. The term arid and semi-arid watershed is applied to those parts where rainfall will not support regular rain fed farming. This definition encompasses all the seasonally hot arid and semi-arid zones classified by means of rainfall, temperature, and evaporation indices. The distinct hydro climatic features of arid zones are high levels of incident radiation, generally high diurnal and seasonal temperature variations, low humidity, strong winds with frequent dust and sand storms, sporadic rainfall of high temporal and spatial variability, generally high infiltration rates in channel alluvium, high sediment transport rates and relatively large ground water and soil moisture storage change (FAO Irrigation and Drainage Paper 37). The natural resources of arid and semi-arid regions are limited. In some areas, land developed for agriculture is being abandoned due to over pumping of the very limited ground water resource or due to increasing salinity. The most obvious negative features of arid zones are lack of water and high evaporation.

Arid and semi-arid watersheds are characterised by intermittent runoff generated by infrequent storm events. Semi-arid regions are distinguished from arid regions primarily by the frequency of the rainfall and amount of vegetation that can survive. For an individual storm event hydrographs have very steep rising limbs and steep decay limbs. Because of the limited runoff, material in transport from the upper slopes is deposited when the gradient reduces resulting in thicker alluvium and high storage. In semi-arid regions, such storage is filled more often so that, if rainfall continues, flooding occurs in lower valley reaches.

3.5 Humid tropical watersheds

The distinctive feature of humid tropical areas is the seasonality of rainfall. One or two wet seasons are separated by dry periods during which virtually no rainfall occurs. River flows show large seasonal fluctuation. In addition, the high temperature increases the rate of chemical weathering such that it may be one hundred times faster than in humid temperate regions. Because rainfall exceeds evapotranspiration in the wet seasons, the combination of high rainfall and temperature promotes the disintegration of rock into clay minerals, which may reach depths of tens of meters. The deep clay soils result in slow percolation rates and, although much water does percolate into the soil, there is a high probability of the infiltration capacity being exceeded so that overland flow occurs during storms. When the seasonal rains are over, the upper soil quickly dries out and potential evapotranspiration may be of the order of ten times the total runoff, leaving only deep throughflow and groundwater flow to maintain water in the rivers.

4 .0 HYDROLOGICAL PROCESSES IN A WATERSHED

A watershed is usually a complex and heterogeneous system. Hydrological processes (components of hydrological cycle), which are function of watershed characteristics and climatic factors vary both in space and time. The spatial variability of theses factors is accounted by dividing the watershed into nearly homogeneous sub-watersheds on the basis of rainfall, soil characteristics, landuse, topography geology etc.

4.1 Hydrological processes

Various hydrological processes, which are generally active in a watershed, are briefly described below.

4.1.1 Interception

The part of precipitation, which wets and adheres to above ground objects and then returns to atmosphere through evaporation, is called interception loss. The amount of water intercepted is a function of the storm characteristics, the species, age and density of flora and the season of the year.

Interception loss is more at the beginning of rainfall and it gradually reduces to a constant value equal to the evaporation rate during the storm period. Percentage of interception loss is more for smaller amount of rainfall. For light shower ($P<0.01$ inch) interception may be 100%, whereas, for showers ($P>0.04$ inches) the loss occurs in the range of 10-40%.

Interception losses in a watershed can be estimated using various models and equations as suggested by Linsley et al. (1949) and Singh (1989).

4.1.2 Infiltration

Infiltration is defined as the process of entry of water from the surface into the soil profile. Infiltration is the important processes at the land surface, which must be carefully considered in models for describing the hydrology of a watershed. Infiltration is required for the determination of effective rainfall and consequently the direct runoff. Hydrological importance of the infiltration process is to be seen from the fact that it marks the transition from fast moving surface water to slow moving soil moisture and groundwater.

Generally, infiltration has a high initial rate that diminishes during continued rainfall to a nearly constant lower rate. The rate at which water enters the soil at a given moment is known as the '**Infiltration rate**'. Infiltration rate is of great interest to the hydrologists and water resources engineers, as it influences many of the hydrological parameters, such as, surface runoff, soil moisture, evaporation and evapotranspiration, groundwater recharge and spring flow rates.

A number of factors affect the infiltration rate, these include soil properties, initial soil moisture conditions, rainfall characteristics, surface sealing and crusting, vegetation cover and movement and entrapment of soil air.

Under special circumstances wherein the rainfall exceeds the ability of the soil to absorb water, infiltration proceeds at a maximal rate called as soil's '**Infiltration capacity**' (Horton, 1940).

Several infiltration models have been developed to estimate the infiltration rates in a watershed. A few important infiltration models used in watershed models are Horton model, Philip model, HEC model, SCS model, and Green-Ampt model.

4.1.3 Depression storage

When rainfall intensity exceeds infiltration capacity of the soil, the effective rainfall begins to accumulate in surface depressions or the water runs off the surface. This accumulated water is called depression storage, which may later get infiltrates, evaporates, or utilised. Depression storage plays an important role in modifying the watershed response. Depression storage in a watershed depends upon size, depth, and number of depressions in a watershed.

4.1.4 Evaporation and evapotranspiration

Evaporation is the process by which water changes to vapour through the absorption of heat energy. The essential requirements for evaporation process are the source of heat to vaporise the water and the presence of a concentration gradient of water vapour between the evaporating surface and the surrounding air. The evaporation takes place from surface water bodies, like reservoirs, lakes, rivers etc., soil surface and other surfaces, which are exposed, to precipitation.

Transpiration is the process by which water vapours leaves the living plant body and enters the atmosphere. It involves continuous movement of water from the soil into the roots, through the stem and out through the leaves to the atmosphere.

Evapotranspiration is a combined process by which water is transferred from vegetated soil surface to the atmosphere. It includes evaporation from soil and intercepted precipitation on vegetation, plus transpiration through vegetation. The term consumptive use is used to designate the losses due to evapotranspiration and that is used by the plants for its metabolic activities.

Evaporation from bare soils differs from evaporation a free surface in availability of water and the resistance that water molecules have to overcome to escape from soil. If the soil water is not limited, then evaporation from saturated soil is approximately equal to the evaporation from a free water surface and is called potential evaporation (PE). When soil water is limited, evaporation is known to occur in several stages and is controlled first by climatic factors and then by soil characteristics; it is called actual evaporation. Likewise, if water is not a limitation and the area is completely covered by vegetation, then ET is called potential evapotranspiration (PET). The actual evapotranspiration is the evapotranspiration form a vegetal cover under the natural conditions of supply of water.

4.1.5 Soil moisture

Soil mmoisture is a transfer function and is the heart of the watershed model. The temporal sequence of surface runoff is determined using an infiltration function based on soil moisture levels to determine the infiltration capacity and then assume that surface runoff is the excess above the infiltration capacity. The antecedent soil moisture conditions also play important role in the estimation of interflow and percolation to the groundwater. Generally, the soil profile upto the root zone depth is considered as soil moisture storage zone and maximum soil moisture storage is estimated from knowledge of soil and vegetation characteristics. The moisture in this zone is depleted by evapotranspiration and is replenished by rainfall infiltration or snowmelt.

4.1.6 Surface runoff and overland flow

The portion of rainfall not lost to infiltration and other losses is transferred to overland flow or surface runoff. Overland flow is the surface runoff that occurs in the form of sheet flow on the land surface without being concentrating in well-defined channels. This kind of flow is the first manifestation of surface runoff, since the latter occurs as overland flow before it has a chance to flow into channels and become streamflow.

The interaction between overland flow and infiltration need to be considered since both processes are occurring simultaneously. The rate of infiltration is very high at the beginning of the precipitation and rate decay exponentially with the time and depends on soil characteristics and landuse.

Overland flow can be calculated by different methods. Most of the methods that are used for the estimation are the governing partial differential equations of continuity and momentum.

4.1.7 Base flow

Base flow is the flow to the channel of a watershed that comes from groundwater or spring discharge. It is called by various names such as groundwater runoff, sustained flow, low flow etc.

4.1.8 Erosion and Sediment Yield

Estimates of watershed sediment yield are required for solution of a number of problems. Design of dams and reservoir; transport of pollutants; design of soil conservation practices; design of stable channels; design of debris basins; depletion of reservoirs, lakes, and wetlands; determination of the effects of basin management; off-site damage evaluation; and cost evaluation of a water-resources project are some of the example problems. Sediment is a pollutant or a carrier of pollutants such as radioactive material, pesticides, and nutrients.

4.2 Modelling of hydrological processes

For better understanding of the hydrological processes involved in the small watersheds, computer simulation models are utilized. These models incorporate various equations to describe hydrologic transport processes and account for water balances through time. Computer models allow for parameter variation in space and time by well-known numerical methods. Complex rainfall patterns and heterogeneous watersheds can be simulated with relative ease and various design and control schemes can be tested if hydrologic data are sufficient.

Numerous hydrological and watershed management simulation models have been developed throughout the world. However, in order to apply simulation models to describe and evaluate hydrological regimes in such watersheds, source data is generally lacking in the country. Some of the widely used simulation models used in watershed studies are given in Table 1 and are briefly described next.

Table 1: Simulation Models for Watershed Studies

NAME OF MODEL	MODEL TYPE	INPUT	OUTPUT
TOPMODEL	Topography based physical hydrological model	DEM, ET, Rainfall, Transmissivity and other catchment information	Runoff, extent of saturated area, ground water table simulation and runoff from each sub-areas, effect of watershed manipulations on runoff etc.
WEPP	Physical based soil loss and sediment deposition model	Rainfall, climate parameters, landuse, soil type, management practice parameters, basin topography etc.	Spatial and temporal predictions of Soil loss, sediment deposition and provides explicit estimates of when and where in a watershed or on a hill slope that erosion is occurring.
ANSWERS	Distributed parameter model	Discritized grid elevations, rainfall, soil parameters, landuse parameters etc.	It simulates the hydrologic processes of interception, infiltration, surface and subsurface flow, and detachment and transport of sediment on a spatial basis
SHE	Physically based distributed catchment modelling system	Rainfall, soil parameters, landuse parameters, topographic parameters, ET and other climatological parameters.	Runoff, effects of landuse changes on runoff, irrigation scheduling etc.
RUSLE	Lumped model	Factors for Rainfall, soil erosivity, crop management, practice and slope length.	Inventorying erosion rates over large areas and estimating sediment production that might become sediment yield in watersheds

TOPMODEL: It is a simple physical hydrological model that aims to represent the effects of catchment heterogeneity and, particularly, topography on the dynamics of hydrological response. This model can be used to study spatial scale effects on hydrological processes, topographic effects on stream flow and stream flow, climate change effects on hydrological processes, the geomorphologic evolution of basins, the identification of hydrological flow paths etc. Today there are a number of projects using TOPMODEL concepts across European in North America with similar work being carried out in Australia.

WEPP: The WEPP erosion model is a continuous simulation computer program which predicts soil loss and sediment deposition from overland flow on hill slopes, soil loss and sediment deposition from concentrated flows in small channels, and sediment deposition in impoundments. The WEPP model computes spatial and temporal distribution of soil loss and deposition. It also provides explicit estimates of when and where, in a watershed or on a hill slope, the erosion is occurring so that conservation measures can be selected to effectively control soil loss and sediment yield.

ANSWERS: The model is a distributed parameter event-oriented watershed model applicable to forest, agriculture, and urban areas of the Midwest. it simulates the hydrologic processes of interception, infiltration, surface and subsurface flow, and detachment and transport of sediment on a spatial basis. Varieties of input and output options exist to tailor the model to the particular user's needs.

SHE: The System Hydrologique European (SHE) is an advanced physically based distributed catchment modelling system. The SHE is designed as a practical system for application in wide range of hydrological resources conditions. It may be used for modelling the entire landphase of hydrological cycle. Its advantage over simple regression and lumped models is in simulating impacts of landuse changes, ungauged basins, spatial variability in catchment inputs and outputs, ground water and soil moisture conditions and water flows controlling the movement of pollutants and sediments.

WATSHED: The model uses kinematic solution of overland and channels flow. Distributed lateral inflow from triangular planes to channel flow and uniform lateral inflow to channel flow can be represented. An interactive infiltration model operates on both plane and channel flow. The model has been applied to range conditions in the Southwest.

KINROS: The model uses kinematic approximation and mass balance for runoff from infiltrating planes. Watershed topography is approximated by sequences of cascading planes and branching channels. Water quality and quantity simulated on storm runoff using transfer function assumptions. Erosion quantities totalled and erosion sedimentation depths calculated (optional). The model has been used in the Midwest and Southwest on range and urban conditions.

HYDPAR: This model computes SCS and Snyder unit hydrograph and precipitation loss rate parameters from a grid cell data bank of spatial geographic characteristics. The model has been used for all types of landuse in the Southeast and Southwest.

HEC-1: Simulates single event rainfall / snowmelt runoff processes in complex watersheds. Automatic optimisation may be made for loss rate and unit graph or routing parameters. Sophisticated hydrologic analysis of basin wide flow-frequencies and analysis of expected annual flood damages may also be accomplished. The model has been used for all types of landuse and in all geographic areas of the U.S.

RUSLE: It is a powerful tool in conservation planning, inventorying erosion rates over large areas, and estimating sediment production that might become sediment yield in watersheds. It can be used on croplands, pasture lands, rangelands, disturbed forests, construction sites, and other areas where surface overland flow occurs because rainfall is greater than infiltration.

5.0 DATA REQUIRED FOR WATERSHED STUDIES

The watershed approach is most rational for programmes pertaining to optimum utilisation of soil and moisture resources. Some of the important watershed characteristics that are required for planning and implementation of programmes which is ultimately depends upon the purpose or type of studies / analysis for which information is required. In absence of ready made availability of required information, the watershed studies data should be generated through surveys, and investigation.

An attempt should be made to compile the large amount of information from the available maps, records, reports, and statistical compilation in order to increase production from land and water resources through their optimum utilisation.

The watershed is a dynamic unit that invariably responds to any change brought about within its boundaries. Therefore, it is necessary to collect all the information regarding the behaviour of watershed.

The data required for the watershed studies include watershed name, location, shape, size, boundaries, presence of stream, tributaries, soils vegetation, geology, climate and hydrological characteristics etc. The watershed need to divide into many sub-watershed and each should be assigned a different name / number for easy identification and further data should be collected on sub watershed basis. General information such as present landuse, existing stage of development, the nature and extent of problems and their location, socio-economic condition, land tenure system, existing tradition, population of area, willingness and acceptance of programmes by local peoples, operational conveniences and difficulties, administrative district, accessibility and roads etc are also useful in watershed studied.

5.1 General watershed information

Name of watershed : Watershed are usually named after the principal stream draining in the area. Sometimes, when the name of the stream is not well defined, the name to the watershed is given after the most prominent village falling with in the watershed boundary.

Location of watershed : Location of the watershed is described by the name of river basin (i.e. catchment), to which the watershed stream is a tributary, physiographic region, block/

tahsil, district, state, longitude, latitude, and principal connection line of communication i.e., National highway or State highway.

5.2 Watershed characteristics

5.2.1. Climatic data

Climatic data such as precipitation, wind evaporation, temperature, humidity etc, which can affect the water balance and erosion of the watershed or influence vegetation and crop growth of the area, is generally required for the watershed studies. Most of this data can be collected from climatic station in a watershed or from station nearby. If such data is not available, then data can be collected with the help of basic instruments such as a standard raingauge plus an automatic raingauge or recorder, a thermometer, a hygrothermograph or psychrometer (for continuous humidity and temperature), an evaporation pan and anemometer. However, some compilation and analysis work is necessary for the climatic data.

Precipitation : Precipitation is the atmospheric discharge of water in the form of solid (hail, snow) or liquid (rain) state on the earth's surface. It is usually measured and expressed in mm, cm or inches. Parameters to be recorded in respect of precipitation are

- type of precipitation i.e., rain, hail or snow,
- amount, distribution, intensity of the precipitation,
- hourly and daily precipitation,
- location of measurement site.

Evaporation and Evapotranspiration : Evaporation is the process by which water precipitate on the earth's surface is returned to the atmosphere by vaporisation. Water is available for evaporation from three types of surfaces i.e., surface water body, ground surface, and vegetation. A part of the precipitated water which makes the soil moisture (and sometimes directly from ground water) is absorbed by the plants and evaporated through the leaves by transpiration. The cumulative loss by evaporation and transpiration is termed as evapotranspiration. Both evaporation and evapotranspiration are measured in mm/day or cm/day or inches/day. The data to be collected about evaporation and evapotranspiration are:

- hourly and daily evaporation / evapotranspiration rate
- location of measurement site

Wind : Extremes wind velocities, prevailing wind direction, and wind damage/hazard record, if available, should be collected.

Other climatological data of the watershed

Other climatological data includes temperature, relative humidity, wind speed, wind direction, radiation etc. These data are required to calculate the evaporation and evapotranspiration losses, if that data is not available. The data to be collected in respect of these parameters include location of measurement, and monthly minimum and maximum values of the parameters.

- Air temperature : mean extreme, by elevation, monthly distribution.
- Soil temperature: Under various landuses, extent and depth of freezing at higher altitude, frost- time of occurrence (early or late frost), duration, frequency, damage to vegetation.
- Relative humidity by seasons: Relationship with fire danger extremes.
- Solar radiation data: are also collected, if available.
- Soil moisture balance: Periods of droughts and their frequency in relation to plant growth. Availability of moisture in the spring season.
- Climate type: such as tropical, semi-tropical, arid type, semi-arid etc.

5.2.2 Physiography

Hydrological characteristics of the watershed are highly influenced by the physiography. Therefore, it is important to collect physiographic data of the watershed, which includes, size, shape, elevation, slope, aspect and orientation and drainage network.

Size of watershed : Size is important to estimate the water resources parameters, such as, total yield and flood potential, and to evaluate how, when and where to apply land and water management measures to control water quantity, quality or regimen. Most importantly, size is an essential consideration in the initial evaluation of the hydrologic behaviour of the watersheds.

Size is represented in terms of area and is reported in standard units of acres, hectares, square miles, and square kilometres. It must be mentioned here, that the area, which is generally reported, is the horizontal projection of the watershed boundary. In case of highly sloping watersheds, the area reported from map may be considerably less than the actual area on the ground.

Shape of watershed : General shape of watershed has profound effect on the runoff hydrograph and stream behaviour, particularly in the case of small watershed, particularly in relation to the movement of storm. The Shape of watershed may be described as rectangular, round, pear, banana, egg, fan shaped, elongated etc.

There are many ways of representing the shape of the watershed numerically. Two of these are given below:

Compactness coefficient (Wisler and Brater, 1949):

$$K_c = \frac{0.28\ P}{A^{0.5}}$$

where, K_c is the compactness coefficient, P is the perimeter of the drainage basin, and A is the area. This dimensionless parameter compares the perimeter of the watershed with a circle of the same area, which is assumed to produce the highest flood peak. Harbaugh (1966) has shown that circular watershed does not produce the highest flood peak flood. Thus, this formula is good only for the descriptive purpose.

Watershed Eccentricity (Black, 1972) :

$$\tau = \frac{(|L_C^2 - W_L^2|)^{0.5}}{W_L}$$

Where, τ is the watershed eccentricity, L_C is the length from the outlet to the centre of mass of the watershed, and W_L is the width of the watershed at the centre of mass and perpendicular to L_C. Watershed eccentricity compares the shape of the watershed to an ellipse with minor axis being half that of major axis. This shape has been found to produce maximum flood peak under laboratory and field testing (with the assumption of instantaneous, uniform, and complete coverage of watershed by a rainstorm).

Elevation : Elevation (in feet/ meter) of specific point on the watershed may be read directly from the topographic map, and interpolated/ extrapolated for other points. Elevation is important because precipitation generally increases with increasing elevation due to orographic effect. Simple inspection of the map reveals maximum and minimum elevations. The mean elevation may be accurately determined by recording and averaging a large number (about 100) of systematically spaced point of the watershed.

A more convenient technique involves evaluating the area between each pair of successive contour line. Based on data obtained, an area- elevation or hypsometric curve prepared. The median, maximum and minimum elevations may also be read directly from this curve, which also provides a visual representation of the watershed profile. In addition, the relation of vegetation distribution with elevation is collected for watershed studies.

Slope : Slope is simply the gradient, or vertical difference between two points whose elevations are known divided by the horizontal distance between them. Slope is important because it is a prime factor in infiltration capacity. It is also important in insolation considerations that play a role in evapotranspiration and snowmelt. Proportions of watershed in different slope groups, length of the slope, mean slope are useful for planning and management of watershed. Slope may be calculated by measuring the length of regularly spaced contour lines over the entire watershed. The formula is:

$$S = \frac{D\,L}{A} \times 100$$

Where S is the average slope, in percent, D is the contour interval use in determination, in meters, L is the length of the contour, in meters, and A is the watershed area, in square meter.

Combined with elevation, slope could be important factor in orographic effects and in insolation considerations that play a role in evapotranspiration and snow melt studies.

Aspect and Orientation : Aspect is the direction of exposure of a particular portion of a slope, expressed in azimuth (0- 360), compass bearings (e.g., N 47^0 E) or the principal compass point (N, NE, E, SE, etc). Orientation is the general direction of the main stem of the stream on the watershed. A watershed with an east- west orientation is likely to have slopes that are predominantly north and south in aspect.

Aspect is an especially important feature of the watershed in view of insolation. Aspect is very important for mountainous area. Information of general orientation, Percentage area under southern, northern, eastern, western aspects and relation of aspects with distribution and growth of vegetation is required to described. In case the area receives snowfall, the melting of snow is also mentioned.

Drainage Network : The drainage network of a watershed is the system that collects the water from the entire area and delivers it to the outlet. This drainage network describes the nature of principal stream and important tributaries. It includes the subsurface and surface drainage, the stream ordering, nature of flow, drainage pattern and drainage density etc.

Stream ordering : The initial evaluation of drainage networks is done on the basis of stream order designated by 1, 2, 3, etc. According to Horton's system of the stream order, designation commence at the tributary level (order I) and number increases as more and more tributaries joins. The higher the number assigned to the main stem, the larger the watershed and the greater the number and extent of tributaries. There are other methods of stream ordering also, such as Strahler's method.

Nature of flow : On the basis of nature of flow, the stream are classified as influent, effluent, or intermittent. The *influent stream* provides water to the ground water storage. The *effluent stream* conveys water from ground water storage round the year. Effluent streams are called as permanent, or perennial stream. The *ephemeral stream* flow immediately following runoff-causing events, especially in arid climate; the bed may dry up rapidly, even following torrential runoff, owing to rapid infiltration into the unsaturated zone beneath the streambed or by evaporation. The intermittent stream, which may flow, immediately following a runoff- causing event, provides water to perched water table or to deep seepage. In hilly areas, these streams flow due to spring discharge following the runoff-causing event.

Drainage pattern : Geomorphologically, the terms drainage pattern are derived from describing leaf venation, fruit- or tree- forms, or other well recognised formations. Thus, the names: dendritic, palmate, pinnate, trellis, radial, annular etc., are among those most often used. In laboratory studies on watershed models, drainage pattern appears more important than drainage density in influencing peak flows and leg times (Black, 1972).

Drainage density : Drainage density is the number of length of permanent stream per unit area of the watershed.

$$D_d = \frac{L}{A}$$

where D_d is the drainage density in km^{-1}, L is the length of stream in km and A is the area in sq km. In general, the greater the valve of D_d, the more efficiently the watershed is drained. D_d appears to be associated with flashier runoff behaviour, greater total surface runoff (lower infiltration), and less water storage. It may be mentioned here that D_d also varies with annual precipitation, map scale, watershed shape, and geology of the area.

Stream Morphology : Stream morphology data is important to understand the channel flow characteristics in the watershed. Stream morphological data includes the nature of the stream, i.e, meandering, straight or braided, longitudinal section and cross-sections, bed material and bank material.

Other data : Other data includes, location and description of lakes, bogs and swamps, if present.

5.2.3 Geology

Geologic factors such as stratigraphy, structure, and lithology constitute the skeleton or framework, which controls the occurrence and movement of groundwater. Therefore, the information about the geological conditions in the area should be collected. Some of the important data is :

- Parent rock type (igneous, metamorphic, and sedimentary) and percentage of each type.
- Structure of the aquifer system i.e., whether folded or faulted; if faulted the magnitude and direction of displacement; if folded type of fold, i.e., syncline, anticline, isocline etc.
- Presence of absence of a dyke (because dyke may act as a barrier)
- Thickness and depth of fractures, joints, density of fractures, filling in the fractures i.e., quartz veins etc.
- Thickness and of weathered zone and degree of weathering
- Presence of channels or solution cavities in limestones / dolomites, if present then their dimensions
- Stratigraphic position of the aquifer
- lithological characters of the aquifer
- Depositional environment of the aquifer system
- Bed rock topography

5.2.4 Soils

Soil cover is an important component of watershed characteristic. Type and thickness of soil controls the infiltration rate and hence the runoff characteristics if the watershed. In hilly watersheds, the depth of soil cover is variable and therefore controls the vegetation type. Important soil data to be collected for watershed study includes :

Soil texture : Soil texture refers to the relative proportions of the various size groups of individual soil grains in a mass of soil. Specifically, it refers to the proportions of clay, silt, and sand below 2 mm in diameter.

Soil structure : Soil structure refers to the aggregation of primary soil particles into compound particles, or clusters of primary particles, which are separated from adjoining aggregates by surfaces of weakness. Field data about soil structure consists of (i) the shape and arrangement, (ii) the size, and (iii) the distinctness and durability of the visible aggregates.

Infiltration characteristics : Infiltration rate is defined as the volume of water entering into the soil per unit area per unit time. Infiltration characteristics of a soil are required for the determination of recharge rate.

Soil moisture characteristics : Soil moisture is the water available in the unsaturated zone and is defined as the ratio of the volume of water to the total unit volume. The soil moisture in the unsaturated zone is a function of suction head. The relationship between the moisture content and the suction head should be established for the soils of the unsaturated zone.

Other data

- Proportion of watershed covered by residual soils, glacial material (specific type), alluvium, and volcanic materials.
- Distribution and hydrologic characteristics of major soil groups in watershed.

5.2.5 Landuse and cover conditions

Landuse and land capability : In this category data usually includes present landuse, landuse history and future trends, land capability or suitability and a number of vegetation surveys. The needed data and survey criteria for each major landuse depend on the objectives and individual condition.

Forest lands (Including fire history and past use) : The forest types and area under each; classification (like stock forest, degraded forest, scrub); hydrological condition (Good, medium, poor alongwith percentage under each); legal status (reserved, demarcated protected, undemarcated protected, unclassed private, community under each); present management, Silviculture system; area cut annually, area under regeneration, felling and logging practices, closures rights biotic factors, forest fire incidence are required to be mentioned for forest land.

Range land : Major classification (hayland, grazing land closed for a season, closed for a month, or a year, grazing incidence); ecological status, important species and their distribution according to elevation, aspect, use incidence and site condition; hydrological condition (good, medium alongwith percentage under each); cattle population (number, types); grazing practices (migrated, settled, grazing fees, grazing rights) are described for range lands.

Agricultural land : Major agricultural use- grain production, cash crop, dairying, fodder crops, orchards mixed farming; land capability classification- area under each class and sub class; area under irrigation, major crops; rainfed area crop grown, orchards- area, and crops are described for all the agriculture land.

Miscellaneous : Habitation (urban, rural, future development) area under each, road (total length- important condition - types or roads, metal road, fair weather road, logging road, bridal path),quarries and mines -type and area; location with respect of main stream, extent of damage are required for planning. If special problem area present like landslides, torrents, stream bank erosion, ravine or gullied land, these area are to be described giving severity of problem, types and causes.

Forest land condition : Forest land condition include type, fire history, and past use etc, if any, should be noted as (i) Good - good stocking, light or no grazing, good litter cover, no evidence or erosion etc., (ii) Medium- moderate stocking, no over grazing or excessive compaction, thin but continuous litter cover, no marked evidence of erosion, and (iii) Poor- inadequate stocking, soil compacted heavy to overgrazing, thin or partial litter cover, sheet erosion or gullies present.

Range land condition - This should be noted based upon evidence of over grazing, type and condition of cover, soil compaction, pedestaling, erosion pavement, gullies etc.

5.2.6 Erosional data

Erosion is major concern in most watersheds, the collection of erosion data becomes a very important, and causes of erosion should be identified. They may includes many activities of human being such as cultivation, grazing, logging, mining, road building, housing, fire, recreational activities.

Sometimes nature also causes erosion in the watershed in form of landslide, stream cutting, wild fire etc. Some of erosion is caused by the combination of both. air photo interpretation plus field checking should be sufficient for most of erosion surveys. They are:

- Geological survey and geomorphological analysis.
- Sheet and gully erosion analysis.
- Road erosion survey.
- Landslide investigation.
- Survey of stream erosion and torrent.

5.3 Hydrological data

5.3.1 Floods

Floods occur due to he over bank flow of river water and are a function of the watershed characteristics. Generally, the floods affect the people in the lower reaches. The impact of floods can be minimised with proper management of watershed resources.

Information about frequency, magnitude, season, and causes of floods should collected from the watershed. In addition, the data about the damage caused by the floods is collected.

5.3.2 Stream flow

Stream flow in a watershed may occur from many sources, e.g., rainfall, lakes, bogs, spring, ground water flow, snowmelt, etc. The stream flow is measured in litres per sec, cubic feet per sec or cubic metre per sec depending upon the discharge. Hourly, daily, monthly, seasonal and annual flow should be measured. The contribution of various sources, in percentage, should also be ascertained. The type of the stream, i.e., perennial, intermittent or seasonal, and the nature of stream reaches in terms of effluent or influent, should also be identified.

From the collected streamflow data, annual yield, seasonal yield; and maximum and minimum yields should be calculated.

5.3.3 Stream water quality

The quality of water flowing in the streams may vary from point to point. The stream water may generally flow clear, turbid always or turbid only in floods. The quality of water may be good or bad depending upon the physical, inorganic, organic or biological constituents present in water. The source of pollution, i.e., natural (minerals, water containing litter from forests, drainage from swamp and bog areas etc.), industrial, municipal and agricultural, should be identified.

5.3.4 Erosion conditions along stream

As the stream water flows, it may erode its banks at some places and may deposit the eroded material at other places. The locations of erosion and deposition should be mapped.

5.4 Water use

In a small watershed, water is required for various type of uses, i.e.,

Domestic water supply : Domestic water use includes water for normal household purposes, such as drinking, food preparation, bathing, washing clothes and dishes, toilets, and watering lawns and gardens.

Commercial water supply : Commercial water use includes water for motels, hotels, restaurants, office buildings, other commercial facilities, and civilian and military institutions.

Industrial water supply : Industrial water use includes water required for processing, washing, and cooling in manufacturing facilities. Major water using industries are steel, chemical, leather, paper and allied products, food processing and dairy, and petroleum refining.

Irrigation : Irrigation water use includes all water that is artificially applied to farm or horticultural crops as well as water used to irrigate public and private lawns, gardens, and golf courses. The quantity of irrigation water required to produce a crop depends on natural rainfall and other climatic conditions, type of crop, length of growing season, method and scheduling of irrigation, soil properties etc.

Power Generation : Power generation constitutes the major demand on water resources. Electric power generation can be grouped into two types, i.e., hydropower, and thermoelectric power. Thermoelectric power generation includes power generation from fossil fuel (coal, petroleum and natural gas), nuclear or geothermal energy. In hydropower generating projects water is required to turn the turbines, whereas in thermoelectric generation projects, water is required to cool condensers and reactors.

Pollution abatement : Water quality in many rivers is less than desirable, due to high concentration of pollutants. The situation is usually aggravated during dry periods when the ratio of effluent discharges to streamflow increases. Therefore, pollution abatement may require low flow augmentation to prevent the pollutants from exceeding a prescribed level of concentration. Occasional flushing of pollutants by surges of high flows from reservoirs may be an acceptable means of reducing the concentration of pollutants.

Recreation, aesthetics and tradition : In many streams, a specific flow regime is desirable because of scenic and recreational purposes, historical interest, religious activity or other intangible uses. Changes in flow regime in these rivers may provoke strong objections and must be planned and executed carefully.

Recreational demand for water usually requires that it has a reasonable quality, a fairly constant level, a fairly constant velocity, and minor wave activity. Sudden changes in water level may be highly objectionable.

Livestock, fish and wildlife conservation : Livestock water use is defined as water used in association with the production of milk, meat, poultry, eggs, wool. It also includes animal specialities, e.g., raising of horses, rabbits, fur-bearing animals in captivity, and fish farms. Fish farms are primarily engaged in the production of food fish under controlled feeding, sanitation and harvesting procedure.

Fish and wildlife, in natural environment, also require water for their survival. A change in water regime may cause changes in the population of various species of fauna and flora.

Source of water and future requirement

The water required for above listed needs has to come from within the watershed. Therefore, the source of water, i.e., surface water (stream, lake, bog etc.) and groundwater (springs, wells etc.) should be identified. After identifying the source, the contribution of various sources (in percentage) should be determined. An assessment should be made about the reliability and adequacy of the water available in the watershed. Also, future needs and supply situation should be analysed.

6.0 SELECTION OF SMALL WATERSHEDS

Before taking up a small watershed for management / investigations. It is important to select a watershed that has some problems. The following criteria may be used in the selection of watersheds :

i. Ones, which have acute shortage of water, especially drinking, water.

ii. Where estimated water yield is significantly higher.

iii. It should be accessible and must have sites for water resources development.

iv. Critical watersheds, which have under gone heavy, soil erosion and have a preponderance of wastelands and highly degraded land. There should be some agricultural activities also.

v. Those which have a preponderance of common property resource.

vi. Those contiguous to another watershed, which has already been developed/may, be selected for conservation.

vii. Watersheds which had been previously taken up for comprehensive development / treatment works. However, if the specific area of the watershed now identified had not previously benefited from any development works, even though it was a part of a larger watershed taken up under any of the earlier programmes, it may be selected for a project now.

viii. Watershed should represent the predominant landuse system of the agro-ecological region.

7.0 DATA COLLECTION

7.1 Type of Data

To investigate properties of hydrologic variables relating to watershed, four types of data are available.

1. The first type is historic or chronological data or observation of processes in time. If not observed initially, this information is lost. A majority of present-day hydrologic data belongs to this type. For example, river discharges, rainfall depths, etc.

2. The second type is field-data observations along lines or surveys of hydrologic phenomena across areas or in space like the determination of depths of groundwater, determination of sediment characteristics along a riverbed and similar surveys. This data can be resurveyed when necessary; the economic factor is usually the limiting condition. A substantial part of hydrologic and data can be of this type.

3. The third type is laboratory and field experimental data related to hydrology acquired by methods similar to data obtained in hydraulic experiments. This type of data is mainly used in basic and applied research.

4. The fourth type is the simultaneous measurement of two or more hydrologic variables in order to establish a relationship among these variables mainly for transferring information among variables.

7.2 Survey and technical investigation

Watershed approach invites integrated inputs of various disciplines for development of minor watershed or sub order stream and streamlets in accordance with their characteristics. The protection, improvement, and rehabilitation of watershed are of critical importance in the achievement of overall development goals.

For preparation of watershed plan, the work can be divided into two groups, i.e., preparatory investigations and detailed investigations (Fig.1). Preparatory investigations are carried out for identification of watershed problem, objective, and priorities. Detailed investigations are done for problem solving.

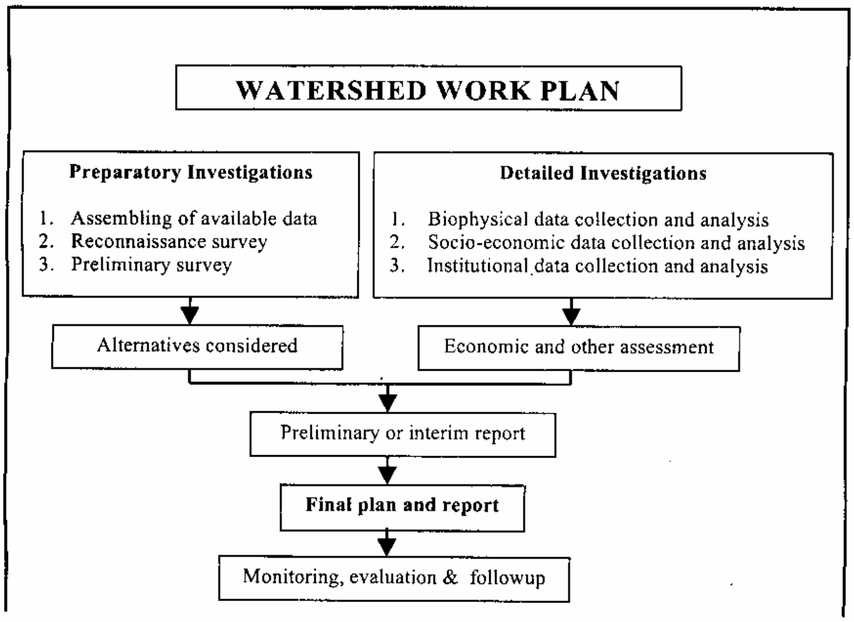

Fig. 1: Watershed work plan

7.2.1 Preparatory investigation

7.2.1.1 Assembling of available information

Demarcation of a Watershed

Often, the watersheds are not readily discernible from the map or on the ground. The first step in watershed analysis is to identify the watershed outlet (lowest point) on the map. This is done on topographic maps on the scale of 1:25,000, 1:50,000 or 1:250,000 depending on the size of the watershed.

The technique for determining the watershed boundary on a topographic map is to start at the outlet and, working uphill, mark the water divide (the ridge) on one side or the other. Care should be taken as to which part of the land should be included in or excluded out of the watershed. This can be done through the judgement whether the water from this piece of land will flow to the stream before the outlet. If yes, then it is included or no then it is excluded. Three simple tips may help in demarcation of watershed boundary: (i) Contour 'V' pointing downhill indicate a ridge, (ii) Contour 'V' pointing upstream indicate a drainage, and water flows perpendicular to the contour lines.

In areas of relatively flat topography, field investigation may be needed to ascertain the location of watershed boundary.

Basic data collection

Collecting the existing data is the first step toward compressive survey and planning of the watershed. In many areas, soil survey, geological survey, forest inventories studies may have already been made. In certain areas, hydro-meteorological studies have also been carried out. Therefore, before conducting the field surveys, the following information/data, if available, should be collected.

- Toposheet of the area of the scale of 1: 50,000 and 1: 25,000 can be collected from Survey of India, Dehradun and nearest regional centres of Survey of India.
- Village maps can be collected from the block/tehsil and/or District level offices of the State Government.
- Aerial photographs and satellite data of the area can also be collected from Survey of India and National Remote Sensing Agency.
- Historical data, such as, rainfall, runoff, temperature etc. should be collected for the watershed and adjoining areas. This data can be collected from IMD, State Meteorological Departments, Forest Department or other State or Central Organisations working in the area.
- Information about landuse changes and various development plans should be collected from the block/tehsil and/or District level offices of the State Government.
- Soil survey report of the area can be collected from All India Soil and Landuse Survey, and State Agriculture Departments.
- Geological report of the area should also be collected from Geological Survey of India / State Geology and Mining Departments / Other Central or State organisations / Universities etc.
- Details about forest activities in the area can be gathered from Conservator of Forest office in the District.

- Previous reports on any technical or socio-economic development in and around the area should also be collected, if available.

After the existing data have been collected and analysed, then a reconnaissance survey plan should be drawn up to check, add and update the existing information.

7.2.1.2 Reconnaissance survey

Reconnaissance survey is done to get first hand knowledge of the problem of the area and to take tentative decision for further investigation. It is done by interviewing the local agencies, institutions, communities and farmers to obtained their views, interests and concern about the watershed. The following should be determined during reconnaissance survey.

Physical problem : Physical problems, such as, steep slope, bad land , slide prone soils, weak geologic formation etc. can easily detected or identified by observation in the field or with the help of existing map. Other problem such as heavy and intense rainfall, excessive runoff, torrential flows, and strong winds should be identified from weather and hydrological data or by gathering information and evidence locally.

Resource use problem : Problem such as shifting cultivation, forest destruction, fire, over-grazing, poor road construction and uncontrolled mining should be identified and if possible, the causes should be determined. Many of these problems can be identified through satellite data / aerial photographs.

End problem (Natural and Man made problems) : The effects of watershed degradation, such as, soil erosion, land slide, heavy sedimentation, water pollution, floods and droughts etc must be identified and extent of these problem can also be determined. This can be done partly by observation and spot-checking and partly from data obtained from local agencies / inhabitants.

Socio-economic and other problems : Serious socio-economic problems should be identified at the beginning of the planning stage, as these problems can be the major obstacles in carrying out watershed work. These may include land tenure, poverty, education, low acceptance of innovation, seasonal shortages of the labour, etc.

Establishing Objectives

After identifying major watershed problems and considering management possibilities, the main objectives of the proposed project should be defined.

- To rehabilitate the watershed through proper landuse and protection/ conservation measurers in order to minimise erosion and simultaneously increase the productivity of the land and the income of the farmers
- To protect, improve or manage the watershed for the benefit of the water resources development (domestic water supply, irrigation, hydropower, etc.)
- To manage the watershed in order to minimise natural disasters such as flood, drought and land slides, etc.
- To develop rural areas in the watershed for the benefit of the economy and people of the region.

This different objective needs different techniques, work force, inputs, and approaches in planning. The monitoring and evaluation criteria will also be different. Therefore, main objectives should be identified and defined before the detailed survey.

Establishing priorities

Priority watershed or sub watershed should be identified during the preparatory stage, as work cannot be carried out at the same time in the entire sub watershed due to work force and resource constraints. A priority list must be set.

Priorities are usually given to those sub-watersheds which are in critical condition, and which are close to the mainstream or to a public installation where a protection is needed, such as, a storage reservoir, water intake or diversion dams. Many times priority areas also selected because of people: their enthusiasm, strategic location, poverty, or others.

Even in a priority sub watershed, some effort needs to be started earlier than others. Therefore, a priority list of work should also be identified for future progressive planning and implementation

7.2.1.3Preliminary survey

After the information and decision taken during the reconnaissance survey, the field surveys are planned. The type of survey and data required will vary from problem to problem and on the proposed measures to be adopted for control.

Preliminary survey are done to collect the data required for initial planning and estimates and if the work is found to be feasible, the detailed construction survey has to be done at the time of execution.

7.2.2 Detail surveys

7.2.2.1Biophysical data collection and analysis

After identifying the major problems of the watershed, detailed biophysical surveys should be design on a problem-solving basis. Although the design of the survey will vary depending on objectives and actual needs, but some general rules should be observed.

- The data collected should be accurate and useful for final analysis.
- Survey forms, tables and guidelines to be used in the field should be easily understand; they should be field tested before extensive use.
- The survey should be designed to identify problems and their location, extent and areas, which will be useful for deciding on treatment and control measures.
- All the field surveys should be so arranged that they can be carried our orderly within the allowable time period. Some times a network analysis or a flow chart is needed to indicate systematic approach.
- To facilitate future surveys all measurement unit, mapping, and photoscale, survey forms and analysis producers and records should be kept in a standard format.

Samples size and sampling techniques:- Many sampling techniques can be used in the biophysical survey of a watershed. The common ones are described briefly;

Random sampling : This sampling method can be used to check large quantities of data like gullies, land slide, stream bank cutting, forest type etc. that can be identified with help of aerial photographs but there specification of each cannot be measured except by field sampling. This method is also used to investigate hydrologic soil condition of entire watershed.

Stratified Sampling: In this method, large area is divided into known size of sub area and then random samples are taken from each stratum/ area.

Cluster sampling: In this method random clustered are selected and then the entire sample in the cluster is surveyed. This method is used to check the survival rates of the plantations, or to estimate landuse pattern.

Mapping scale and mapping : Base map should be prepared at one convenient scale. The watershed maps should have the same scale in order to facilitate the transfer of information or the production of subsequent maps by superimposing one on another.

Data requirement :-The kind of biophysical data needed for survey and planning depends on watershed problems and management objectives. Details of data requirement have already been discussed in Section 5.

Based on data available and rapid appreciation of the updated information, pragmatic implementation of project for exploration, evaluation and exploitation should commence from high potential areas as well as virgin areas. A plan approach to develop the river waters to fill the gap between demand and supply.

- Conserves the soil through reduction of river erosion.
- Increase the soil moisture condition
- Generate the much-needed power.
- Create the economical waterways
- Recharge the ground water.
- Controls the floods & concomitant recurring losses
- Provides finally the water for greening.

Analysis of major biophysical problem

Landuse vs land capability : Determination of proper landuse based on land capability or suitability is always the first step toward the protection and development of watershed. A landuse adjustment map can be produced by superimposition of landuse and land capability maps. Land showing under-used and serious over-use should receive urgent attention. The sites, extent, and seriousness of the problem area, and the area of watershed needing soil conservation treatments should be shown on the map.

Water resources and use problem : From the data collection, an analysis should be made of steam flows including annual, seasonal, maximum, minimum and quantities such as turbidity, type and source of pollution etc. The timing and frequency of flood and drought, and water use problem including rate of use, problem of quality and quantity should also be studied.

Erosion and sedimentation : The various sources and damages of erosion and sedimentation and potential hazards should be identified and analysed, since most watershed rehabilitation or protection programs are centred on the minimisation of potential hazards. A generalised methodology for identification of potential hazard areas includes the following:

- Compiling data from the field surveys, observation or by interviewing people.

- Analysing soil loss and runoff plot data in the area.
- Using erosion models or soil loss prediction equation to estimate quantities.
- Analysing storm frequencies, sediment delivery ratios and yields etc., from the existing hydro-meteorological data.
- Compiling reservoir or water storage and sedimentation data.
- Using geology and geomorphology data for estimating landslide hazards.
- Estimating results from all above data.

The cost of erosion and sedimentation, treatment needs and benefit of minimising or controlling them should eventually be estimated.

Result and products

Map preparation, statistics, and interpretations

Maps and statistics are the major products of this type of biophysical survey. The kind of maps and statistics produced depend on watersheds and management objectives. These include:

1. Location map / Political map:- It shows the details of the location along with means of communication, longitude, latitude, with relation to district, state, or country.
2. Base map:- Its shows the boundary, sub watershed, village, roads etc.
3. Landuse map:- It shows the present landuse with details of type of landuse and problem encountered.
4. Topographic maps:-Its shows the contour, elevations (lowest and highest point of the area), land forms, stream etc.
5. Land capability map / Land suitability maps:- Its shows many data on one map such as soil depth, soil texture, permeability of top and sub soil, type of parent material, drainage condition , erosion hazards, slope, flooding frequency, salinity or any other hazards presents. The land capability map gives at a glance the various information of land present in the area.
6. Drainage map :-Its shows the principle stream and its tributaries present in the area with relation to nature of flow.
7. Aspect map:- Its shows the general orientation of the area, i.e., percentage of area under the Northern, southern, eastern and western aspect. It is very important for mountainous area.

8. Slope maps (land gradient map):- Its shows the proportion of watershed in different slope group, length of slope .It is very useful for planning.
9. Soil maps:- Its shows the distribution of soil types in the area and its boundary. Soil types includes sand, clay, sandy clay sandy silt, silty clay etc.
10. Geological map:- Its shows the lithology , structure, stratigraphy of the area. Its very useful in ground water investigation and are essential where complex stratigraphy and structure are involved.
11. Erosion or Sediment source maps:- Its shows the sites of various types of erosion and sediment potential area. Since erosion is major concern inmost watershed. This includes the gully erosion, road erosion, landslides, stream erosion, torrents.
12. Hydrological maps:-Its shows the water regimes of surface and near surface of the area. In other words, it is presentation of terrestrial hydrological information in geographical relationship.
13. Drainage density map:- Its shows the runoff conditions depending on geomorphological condition and on differences of soil and under lying rocks.
14. Morphometric maps:- Its shows the shape of river bed, its cross section and stream profiles, and changes of profiles. it is very useful in study of flooded river stream.
15. Run off maps:- Its shows the height of the water level and average runoff. It is based on the representation of discharge. It is very useful for showing the amount of water that will flow into a projected reservoir.
16. Ground water potential maps:- Its shows the potential area of ground water with relation to depth.
17. Climatic maps:-Its shows the mainly rainfall, but statistics may includes temperature, humidity, evapotranspiration etc.
18. Water use maps:- Its shows the current and projected use of water are an aid to the explanation of the water development proposals and changes in the local phenomena.
19. Environmental Maps:- Its shows the local natural factor of land water air in relationships to the existing and proposed agricultural, industrial, municipal, recreational and cultural development.

Many other maps and statistics of a detailed nature can also be added according to the needs and requirements such as, forest, vegetation, landslide potential, slope stability, stream profile, land ownership, demographic and population distribution. Many maps can also combined together.

Brief and essential interpretation and analyses of the data collected should be made, which is relevant to watershed problems and management objectives.

7.2.2.2Socio-economic and infrastructural data collection and analysis

Existing reports on general socio-economic conditions of the rural area should be collected and reviewed before beginning of detailed studies. It is give the valuable basic information for the preparation of survey proposals.

Data collection : Survey methodology and techniques: Sampling techniques for socio-economic and infrastructural surveys are similar to biophysical surveys i.e. random, stratified and cluster.

Data of social condition

- What will be the population trend in the watershed, its rate of growth, age structure, migration and other demographic factor that will affect the rate of resource use ?
- What are the possible barriers toward innovative technology; poverty, lack of education, poor extension services, tradition, non- aggressiveness, lack of encouragement and incentives
- What social factors constrain the development and management of the farms in the watershed- land tenure, government rules, traditional farming system, fear of risk or others?
- What do the social structure, system or hierarchy influence the individual or community development in the watershed?
- What are immediate needs of the farmer such as more road, domestic/ irrigation water, housing, marketing arrangements, recreational facilities.
- Do farmers like to work together or tend to be individualities.
- What is status of women in the society and their responsibilities, condition of youth including rate of unemployment, and their willingness to undertake field work and migration trend?
- To what extent are the farmers aware of the causes and problems facing watershed?
- What are the views on the protection and development of the watershed as a whole.

Data of economic status

- The present economic activities in the watershed, including farm production, farm income, farm models, farming system, landuse pattern, employment, labour demand and supply, rural enterprises, marketing etc.

- The potential for economic improvement or development, including farmer capabilities (labour resources and technology), non-farm employment opportunities, infrastructural need, availability of credit or financial aid and agro-industrial development possibilities.
- The constraints and problems of development from an economic point of view, including land tenure, land rental, farm size and fragmentation, capital, knowledge, labour, prices, markets and transportation.
- Farmers' reaction to proposed economic improvement measures including credit and/ or subsidies, extension services, taxation and rental reduction, farming equipment and materials, better marketing arrangement.
- Various cost of cropping and farming activities and their return, the cost and benefit of watershed conservation work and related economic figures.

Data of infrastructural condition in the watershed

The existing infrastructure in a watershed needs to be surveyed. The problem of infrastructure including roads, water supply, market facilities, housing and energy supplies etc.

Periodic socio-economic surveys will be required for monitoring purpose and detecting changes over time and impact of the project.

7.2.2.3Institutional data collection and analysis

Any serious problem regarding institution and culture should be well studied and analysed. Cultural problems can only be solved over a long time period, while the institutional problems can only be solved in relatively short time span; if the Government has the political will and firm commitment. The main institutional problem are :-

- Insufficient support from the higher authorities in term of policy funding and administration.
- Insufficient number of trained personal to carry out planning, design, implementation, field supervision, monitoring and evaluation.
- Weak planning and appraisal activities resulting in waste and ineffectiveness in many area.
- Lack of incentives for technicians working in the field
- Poor co- ordination among the related organization.
- Weak field operation due to lack of efficiency in supervision, reporting and monitoring.
- Poor mobility due to a lack of vehicles and public transportation.
- Lack of research data for continuous improvement.

If there is well defined Government policy on the watershed management, it is worth careful study of policy statement from related field such as forestry, agriculture, conservation, and water resources.

- Agriculture and related law and acts.
- Forestland and range land laws or acts.
- Legislation concerning water resource development and use.
- Legislation on mining activities and control.
- Environmental protection laws and acts.
- Recreation and wildlife legislation.
- Other related legislation, e.g., on rural development, roads and marketing.

Education and training needs

> *"Give a man a fish, you are helping him a little bit for a very short while;*
> *teach him the art of fishing, and he can help himself all his life"*

Since much watershed work relies on the local people for implementation, the importance of farmer's education, training and active participation can't be over emphasized.

Plan and management recommendations

Based on survey data and the results of analysis, a draft plan (including treatment, cost, etc.) are prepared for management recommendations for the further discussion.

8.0 INSTRUMENTATION AND DATA COLLECTION

In a watershed, there exist many kinds of natural resources: water, soil, forest, wildlife, etc. Depending on the management objectives, many basic surveys or investigations of these resources are needed to prepare good management plans (Sheng, 1990).

In order to carry out integrated field and modelling studies in the watershed, instrumentation is required at both the plot and the watershed scales. Measurements are needed for the following hydrometeorological parameters (Table 2):

Table 2: Hydrometeorological parameters for watershed studies

HYDROLOGICAL PARAMETERS	METEOROLOGICAL PARAMETERS
Streamflow/runoff Sediment load - both suspended and bedload Soil moisture Infiltration rate Groundwater level Water and soil quality Water use - domestic, irrigation & industrial	Precipitation Air and soil temperature Relative humidity/dew point Evaporation & Transpiration Interception Wind speed and direction Solar radiation

Types of instrumentation to be specified depend largely upon the objectives of the study, characteristics of the hydrological systems or watershed in question, and availability of manpower. Two of the more important variables measured in most studies are precipitation and streamflow. Other important variables include infiltration, sediment yield, water quality parameters, and meteorological variables including temperature (air and soil), relative humidity (or dew point), and evaporation. Type of instruments required for various measurements are given in Table 3.

Table 3: Type of instruments required for watershed studies

PARAMETER	INSTRUMENT
METEOROLOGY GROUP	
Rainfall	Non-recording Rain Gauge
	Recording Rain Gauge
	Float type
	Weighing type
	Tipping-bucket type
Snowfall	Snow Gauge
Combined Precipitation Gauge	Capacitive Precipitation Gauge
Air Temperature	Pt Resistance Thermometer
Relative Humidity	Capacitive Transducer
Wind Speed & Direction	Optical shaft-encoder & potentiometer
	Ultrasonic Wind Sensor
Solar Radiation	Pyranometer
Sunshine Duration	Thermocouple
Evaporation	Float recorder
	Ultrasonic Level Recorder
Atmospheric Pressure	Digital Barometer Sensor
Multi-parameter Recording	Automated Weather Station (AWS)
SURFACE WATER GROUP	
Flow	Ultrasonic Flowmeter
	Electromagnetic
	Bubbler Sensor
	Current Meter
Water Level (Stage)	Shaft-encoder & Float Sensor
	Pressure Sensor
	Ultrasonic Sensor
Sediment Discharge	Suspended Sediment Sampler
	In-situ Turbidity Meter
	Coshocton Wheel Sampler
	Bed-load Sediment Sampler

PARAMETER	INSTRUMENT
GROUND WATER GROUP	
Ground Water Level	Shaft-encoder & Float Sensor
	Pressure Sensor
	Ultrasonic Sensor
Soil Moisture	Gypsum Block Sensor
	Time Domain Reflectometry Probe
	Conductivity Sensor
	Tensiometer
Infiltration Rate	Ring Infiltrometer
	Tension Infiltrometer
	Suction Crust Infiltrometer
Permeability	Guleph Permeameter
	Velocity Permeameter
Ground Water Flow	Thermal Perturbation Sensor
	Electrical Resistivity Setup
WATER QUALITY GROUP	
Conductivity	Multi-electrode Cell
Temperature	Thermistor Probe
pH	Glass pH Electrode
DO	Polarographic Teflon Electrode
ORP	Pt Electrode
Water Depth	Strain Gauge Transducer
Chemical & Bio-chemical Reactions (for ground water)	In-situ Bio/Geochemical Monitor (ISM)
Water & Wastewater Sampling	Waste Water Sampler
Combined Parameter Analysis	Automated Water Quality Analyzer (includes phosphate, nitrate, ammonia, chloride & has provision for use of met sensors)

9.0 REMOTE SENSING AND GIS IN WATERSHED STUDIES

Applications of distributed hydrological model over large areas require great amount of point data, which are seldom available. Therefore, the use of remote sensing technology to acquire data for these models becomes a practical alternative. The remote sensing makes new types of measurements as well as aerial coverage over entire basin possible. The combination of data acquired from aerial platform and GIS sources obviously is of advantage. The development of remote sensing and GIS based hydrological models is still in its infancy and little work in this field has been done. Hydrologic modelling can be improved through the development of a new generation of models or subroutines for existing models which recognize the characteristics of the new remote sensing capabilities.

Similarly, remote sensing (RS) data play a rapidly increasing role in the field of hydrology. Although very few remotely sensed data can be directly applied in hydrology, such information is of greater value. Many hydrologically relevant data can be derived from remote sensing information. This information is usually digital, in the form of picture elements (pixel), the scale of which depends on the sensor used. The large quantities of data are collected permanently with the aid of various platforms and sensors all over the world. The main fields of remote sensing application in hydrology are rainfall, evapotranspiration, soil moisture, groundwater, surface water, snow and ice, sediments and water quality, as well as hydrological modelling. The use of RS data in hydrology requires efficient storage and retrieval of RS raster data in a data bank coupled to a GIS. Here the original RS data have to be stored for all spectral bands as well as the products which will be derived from the original RS data, e.g., landuse classification maps, snow cover maps, vegetation index etc. The GIS will aid to the hydrologist to produce these derived maps from the original RS data and it will be again of assistance to him when he uses these derived data in hydrological modelling.

Basically, there are four major functions of GIS in hydrologic modelling. First, it performs the complex map overlays and spatial analysis to develop input data for the hydrologic models. Second, it provides the linkage mechanisms between models with different spatial representation. Third, the GIS provide the conversion of digital landforms of different projection and scales to a standardized format (Geo referencing). Finally, the GIS provide post simulation graphics output display and spatial analysis for evaluating hydrologic simulation results. The most obvious use of GIS in watershed studies lies in its capability of linking spatial data in form of maps (e.g. soil characteristics, soil series, crop coverage area, geomorphology, present landuse, drainage, slope, erosion, irrigated area) and non-spatial data in form of tables (e.g. rainfall and other climatic data, demographic data).

With the help of GIS, it is possible to make a combined use of data sets derived from remote sensing and other non-spatial data sets, including ground based data. Remote sensing is primarily intended to provide weather and climate data, and to monitor its repeated changes on a global scale, and earth resources data on regional and local scales. However, with the availability of high-resolution data available from earth resources satellites, studies on watershed scale are possible. In order to assess variables or to estimate variables of interest, comparable with ground based measurements, proper atmospheric and terrain corrections must be applied to the remotely sensed data. In combination with a suitable hydrologic model, GIS can be used for the following functions :

- preparation of digital elevation model (DEM)
- preparation of slope map and slope orientation map
- spatial analysis and data integration, using both remote sensing data and ground data
- stream networking analysis for runoff behaviour of the watershed
- selection of sites for applying soil and water conservation measures

9.1 Watershed attributes and geographical information system

Spatially distributed models of watershed hydrological processes have been developed that incorporate the spatial patterns of terrain, soils and vegetation as estimated with the use of remote sensing and geographical information systems (GIS) (Band et al., 1991; 1993; Famiglietti and Wood, 1991; 1994; Moore and Grayson, 1991; Moore et al., 1993b; Wigmosta et al., 1994). This approach makes use of various algorithms to extract and represent watershed structure from digital elevation data (e.g. Marks et al., 1984; O'Callaghan and Mark, 1984; Band, 1986a; 1986b; 1989a,b; O'Loughlin, 1986; Jenson and Domingue, 1988; Moore et al., 1988). Land surface attributes are mapped into the watershed structure as estimated directly from remote sensing imagery (e.g. canopy leaf area index), digital terrain data (slope, aspect, contributing drainage area) or from digitized soil maps, such as soil texture or hydraulic conductivity assigned by soil series.

Two approaches to the spatial distribution of key surface variables have emerged. The first is to explicitly map surface attributes into a grid or flow element structure, such that water (and sediment) can be directly routed through the flow path network to compute the distribution of soil water and runoff production. A second approach has been to use functional relations between topographic and soil variables and the distribution of soil water following principles of hillslope hydrology to approximate the effects of soil water routing as embodied in TOPMODEL (Beven and Kirkby, 1979) and the steady-slate version TOPOG (O'Loughlin, 1981; 1986) and TAPES (Moore and Grayson, 1991). The latter approach obviate the need for explicit patterns of surface attributes for flow routing, reducing the parameterization requirement to the specification of the attribute density functions.

Two problems present themselves in the extension of these models to regional scale. The first is that much of the process understanding on which these models are built is based on physical interactions and mechanisms that often occur on length scales of metres or less. Current canopy evapotranspiration models assume knowledge of soil profile properties at high vertical resolution, along with a detailed knowledge of canopy and lower atmospheric Conditions. Recent work has shown that simulated surface/atmosphere exchange and runoff production can be very sensitive to the parameter distribution functions specified, and replacement of parameter distributions by mean values often leads to significant bias (e.g. Avissar, 1992; Dolman, 1992; L'Homme, 1992; Band, 1993) under certain conditions. The key topographic and soil variables used in many distributed catchment models typically have length scales smaller than a hillslope or small catchment. At regional scales, however, the best available digital topographic data may not contain sufficient information to resolve flow patterns, and regional soil maps are highly generalized.

The second, related problem has to do with the sampling method that is used to estimate the joint distribution of surface attributes that is inherent in a standard GIS approach. Most GISs have been developed with a cartographic paradigm in which maps (mostly area-category maps) are input, information is combined by overlay analysis, and maps are output. Unfortunately, with the exception of high resolution digital topographic and remote sensing information, the input maps are often heavily generalized and produced at a variety of scales, such that the spatial information for the different surface attributes (soils, vegetation, terrain) are filtered to different levels. Typically, soil information is known with the least certainly and at the greatest level of generalization due to the difficulty of sampling, high-field variability and the general inability to remotely image the required soil properties. Simple GIS overlay of digital terrain data or remotely sensed vegetation data with digital soil maps often results in poor estimates of the co-occurrence of these variables. In terms of parameterization of soil-vegetation-atmosphere-transfer (SVAT) models, this problem is often manifested in the GIS combination of biophysically infeasible soil and vegetation associations. Working in water limited areas, we often find that overlay analysis results in associations of high leaf area index (LAI) as determined by Thematic Mapper imagery with soils of very low available water capacity. In this instance, the generalized soil maps cannot show the locations of pockets of deeper soils or narrow riparian zones due to sampling and scale limitations. Although the overlay method does not need to be used, the more general availability of digital area-category maps for soils and vegetation, and the ease of cartographic overlay analysis in GIS, has resulted in its indiscriminate use, with little regard for how the entire process performs as a sampling strategy to estimate the joint occurrence of model parameters.

In comparison with GIS analysis of surface attribute information, field sampling is expensive, time consuming and can often only measure land surface variables at points or small plot levels (e.g. soil pits or forest plots). However, direct field sampling can have the important property of measuring the important variables at the same or similar resolution, a property that may be lost when combining generalised map information produced at different scales or levels of support. If the models being run are sensitive to the co-variation of model parameters below the resolution of the original mapping units, then it may be necessary to attempt to estimate what the variance and covariance of the significant model variables are within the initial mapping splits and the simulation units, a process which cannot generally be performed with standard GIS techniques.

9.2 Modelling approaches to watershed heterogeneity

Over the past two to three decades, the evolution of hydrological models has proceeded along two key trajectories: increased physical complexity and realism of the process description, and spatially distributing the representation of key hydrological processes. A combination of the two approaches has largely occurred just in the last decade with the advent of available spatial data sets. Before the advent of extensive data sets that could be used to describe the heterogeneity of the land surface, most hydrological models conceptually lumped landscape conditions into average or typical parameter estimates, which were often calibrated to available rainfall-runoff data. In this instance, it was recognized that the calibrated parameters behaved as 'effective' parameters that may be unique to the calibration conditions. The desire to develop more physically realistic, distributed models has been motivated partially by the desire to produce more general models that could confidently be used in situations for which no data is available and for forecasting change in hydrological behaviour due to variety of landuse or climate changes. An important part of this goal is to replace the dependence of models on calibrated 'effective' parameters ' with physically realistic process descriptions that use parameters that can be determined by the direct observation of land surface conditions.

The evolution of more physically realistic models or hydrological processes has been largely based on experiments carried out on small and uniform field plots or under laboratory conditions. Application of the principles and theories learned under these conditions to larger, more complex watersheds necessitates a simplification of the model process description and some method of dealing with land surface heterogeneity. Often, although not always, the greater the degree of heterogeneity acknowledged or represented by the modeller, the greater the degree of process simplification in recognition of the inability to estimate the necessary model variables or parameters. In this respect we may view a number of existing models as existing along a spectrum ranging from those that emphasize a physically complex description of processes while averaging or lumping landscape heterogeneity, to those models that emphasize a representation of the landscape heterogeneity while simplifying process representation. This is by no means a good categorization of all models, and the ability to determine more complex sets of spatially distributed surface variables and parameters is increasing with advances in remote sensing and spatial data processing.

As models become more distributed spatially experimental evidence indicates an unavoidable need for some effective or calibrated, rather than directly observed, parameters, no matter how physically realistic or simplified the model is (e.g. Loague and Freeze, 1985). These parameters may be estimated by experience and (numerical) experimentation or by calibration with rainfall runoff data. The need appears to arise from both the simplification of the process representation and some degree of inability to actually measure or specify an adequate set of physically based parameters. Beven (1989) and others have discussed the need to retain some effective parameters because of limitations in both our understanding and representation of physical processes and in the spatial data available for parameter determination. Note that this need is not necessarily avoided by retaining more physically complex process representations in the models, as this places additional demands on data for adequate parameterization. The unfortunate consequence of relying on the calibrated 'effective' parameters in addition to the GIS derived variables is in the potential confusion of why a model may or may not appear to work relative to the variables used for calibration (e.g. rainfall-runoff.) As a check of the internal consistency, temporal or spatial patterns of model state or flux variables other than those used for calibration could be used as part of a validation exercise, such as the distribution of surface soil moisture, or an observed time series of evapotranspiration, although such data are much more difficult to collect than runoff data and are rarely available except in large field experiments. However, advances in remote sensing technology and the expansion of biophysical models to incorporate a greater number of variables (e.g. vegetation canopy states) will ease this process.

The ability to locate or store the spatial location of individual attribute values is generally either not feasible (e.g. saturated hydraulic conductivity) or is not required for effective simulation over large - areas. In these instances, the limit to the locational accuracy of many important land surface variables may be a definable area (e.g. subwatersheds catchment or hillslope), which can be assigned a description of the variable distribution. Therefore, one important function a GIS can be used for is to spatially organize or partition the land surface into physically meaningful units (e.g. catchments, hillslopes, flow elements) for which the distributions of key model variables and parameters can be estimated and stored for simulation. The concept of the representative elementary area (REA) (Wood et al., 1988; 1990) is attractive as it suggests a scale at which the land surface heterogeneity, and the effects of the heterogeneity on hydrological processes, stabilizes. If such a concept is applicable to real landscapes, it presumably exists at different scales in different types of terrain. It may be possible to identify these scales using appropriate high-resolution data sets and GIS processing in conjunction with specific process models as demonstrated by Wood et at. (988).

Band and Moore (1995) have concluded that GIS can be used for a number of functions in linking to structure and extend watershed models to larger scales. These include:

- Determining the spatial patterns of surface attributes at scales or resolution appropriate to route water through the terrain or represent spatial dependence of certain processes (such as net erosion, run-on infiltration or advection).
- Extracting and representing the water shed structure by the nested system of the stream network and associated hillslope and subcatchment drainage area.
- Sampling and constructing statistical descriptions of key surface variables including variance and covariance structures or joint distribution function.
- Determining the effects of scale on the distribution functions of key land surface variables and correlation structures between these variables, and investigating the scaling behaviour of these distributions as they are sampled across different resolutions.
- Optimal portioning of the surface into sufficiently homogenous land units minimising within unit variance, or into functional watershed units at a scale corresponding to REA.
- Facilitating the storage and retrieval of observed biophysical data for comparison with a set of state and flux variables predicted by the model, such that modelled spatial and temporal patterns of variables not used for calibration can be assessed.

10.0 WATERSHED MANAGEMENT

All watersheds contain many kinds of natural resources, e.g. soil, water, vegetation, wildlife, minerals. The hydrologic response of a watershed is the integrated effect of several complex processes involving land with soil, climate, vegetational characteristics and management changes, etc. Watershed management involves decision-making about use of available natural resources for various purposes without jeopardising the health of the watershed. Therefore, a multidisciplinary approach is essential for watershed management.

10.1 Watershed management objectives

A number of problems can be encountered in a watershed. The most common situations encountered and alternative solutions (preventive or restorative) for overcoming them as they relate to watershed management objectives are given in Table 4.

Table 4: Problems, possible solutions and management objectives in watersheds

PROBLEM	**POSSIBLE ALTERNATIVE SOLUTIONS**	**ASSOCIATED WATERSHED MANAGEMENT OBJECTIVES**
Deficient water supplies	Reservoir storage and water transport	Minimize sediment delivery to reservoir site; maintain watershed vegetative cover
	Water harvesting	Develop localized collection and storage facilities
	Vegetative manipulation; evapotranspiration reduction	Convert from deep-rooted to shallow-rooted species or from conifers to deciduous trees; Maintain vegetative cover to minimized erosion
	Pumping of deep groundwater and irrigation	Management of recharge areas
Flooding	Reservoir storage	Minimize sediment delivery to reservoir site; maintain watershed vegetative cover
	Construct levees, channelization, etc.	Minimize sediment delivery to downstream channels
	Floodplain management	Zoning of lands to minimize human activities in flood-prone areas; minimize sedimentation of channels
	Revegetate disturbed and denuded areas	Plant and manage appropriate vegetative cover

PROBLEM	POSSIBLE ALTERNATIVE SOLUTIONS	ASSOCIATED WATERSHED MANAGEMENT OBJECTIVES
Energy shortages	Utilize wood for fuel	Plant perpetual fast-growing tree species; maintain productivity of sites; minimize erosion
	Develop hydroelectric power project	Minimize sediment delivery to reservoirs and river channels; sustain water yield
Food shortages	Develop agro-forestry	Maintain site productivity; minimize erosion; promote species compatible with soils and climate of area
	Increase cultivation	Restructure hill slopes and other areas susceptible to erosion; utilize contour ploughing, terraces, etc.
	Increase livestock production	Develop herding-grazing systems for sustained yield and productivity
	Import food from outside watershed	Develop forest resources for pulp, wood, and wildlife products, etc. to provide economic base
Erosion/sedimentation from denuded landscapes	Erosion control structures	Maintain life of structures by revegetation and management
	Contour terracing	Revegetate, mulch, stabilize slopes, and institute landuse guidelines
	Revegetate	Establish, protect, and manage vegetative cover until site recovers
Poor-quality drinking water	Develop alternative supplies from wells and springs	Protect groundwater from contamination
	Treat water supplies	Filter through wetlands or upland forests
Polluted stream/reduced fishery production	Control pollutants entering streams	Develop buffer strips along stream channels; maintain vegetative cover on watersheds; develop guidelines for riparian zones
	Treat wastewater	Use forests and wetlands as secondary-treatment systems for wastewater

10.2 Survey and planning for watershed management

Since watershed management is an ongoing process, survey and planning of its resources need be done on a regular basis. Collecting existing data is the first step towards comprehensive survey and planning of a watershed. A master scheme for survey and planning in a watershed could include the activities given in Table 5.

Table 5: Scheme for survey and planning in small watersheds

SUBJECT	ACTIVITY
Landuse & Soil Conservation	*Soils & Geology *Present Landuse *Land Capability *Landuse Adjustment *Erosion Surveys *Soil Conservation Needs
Forest & Natural Resources Conservation	*Forest Protection *Revegetation Needs *Agro-forestry *Minerals *Recreation *Wildlife
Hydrology & Engineering	*Climate *Hydrology *Sediment *Water Resources *Irrigation *Other Water Use
Socio-economic & Institution	*Socio-economic Baseline Survey *Land Ownership *Farming System & Farm Management *Institution and Culture *Community Development
Infrastructure & Services	*Transportation *Housing *Water & Energy Supplies *Public Services *Agro Industry

Although proper methodology for monitoring depends on the watershed management objectives, the general methodology for hydrology related activities may include the major indicators of a project as :

Soil and Water Conservation

- Conducting hydrogeological, geophysical and nuclear surveys for groundwater (including springs) exploration and for identification of suitable sites and structures for aquifer recharge.
- Identification and installation of suitable rainwater harvesting structures.
- Construction of minor irrigation structures for agriculture, industry, etc., and soil & water conservation structures, e.g. check dams, contour bunds, terraces, ditches, drop structures for controlling the runoff flow (Sarkar, 1994), augmenting the groundwater recharge, facilitating the growth of vegetation, etc.

Erosion and Sediment Control

- Setting up a hydrometeorlogical network to collect and monitor rainfall, streamflow, sediment, and pollution data for long-term analysis and comparison.
- Making reservoir, pond or check dam profile surveys to obtain data on sedimentation rates and volumes.
- Establishing small plots on major soils and cropping systems with and without conservation measures to monitor and evaluate differences in soil erosion and runoff.

Flood Prevention

- Establishing rainfall and stream gauging stations as mentioned above.
- After major storms and floods, surveying damages to compare with predictions and past events.

Changes in Landuse and Vegetative Cover

- Analysing satellite data (for every 4-5 years) to monitor periodic changes in landuse and vegetation cover.

11.0 STATUS OF WATERSHED STUDIES IN INDIA

11.1 Major watershed programmes in India

After achievement of the national goal of self-sufficiency in food grains through the development of irrigated agriculture, in the early 1970's, an All India Co-ordinated Research Project was launched at 23 participating research centres in the country. Near these centres, pilot projects of integrated watershed development were launched to test, adopt, and refine the research findings. The results brought out good potential crop varieties, moisture conservation measures and input oriented cropping system. Because of the inherent uncertainties in the amount and intensity and distribution of rainfall and the consequent risk in the dry areas, coupled with resource poor conditions of dryland farmers, the technology could not be adopted in a big way. By the end of 1970's, it became clear that water was the most critical factor and unless rainwater is managed scientifically, the future of rainfed crops would continue to fluctuate.

Therefore, in the early 1980's, during the period of the Sixth Five Year Plan, the Department of Agriculture and Cooperation launched a pilot project for propagation of water conservation/harvesting technology in rainfed areas, in 199 watersheds located in 15 states, representing major agro-climatic regions of the country. The Department of Rural Development also adopted this scheme and 23 watersheds were selected in the Drought Prone Areas Program (DPAP) areas for development as models. Thus, a total number of 42 model watersheds were developed. The central theme was water conservation and water harvesting. Good results were obtained and the need for bringing vegetative conservation measures and promoting a simple and low cost water management technology was highlighted.

Based on accumulated experience, the National Watershed Development Program for Rainfed Agriculture was launched during the Seventh Five Year Plan in 99 selected watersheds of the country. These watersheds demonstrated models of successful crop production.

A National Watershed Development Project for Rainfed Areas (NWDPRA) was launched during the period of the eighth five year plan (1992-97) in the light of the experience gained and lessons learnt. The program operated in 2,500 small (500-1000 ha) pilot watersheds for over 3.9 mha of the nation's 148 mha of rainfed lands.

The following are the major on-going Watershed Management Programs in the country:

National Watershed Development Project for Rainfed Areas (NWDPRA)
World Bank Aided Projects
Danish International Development Assistance (DANIDA) Assisted Projects
European Commission (EC) Assisted Projects
KFW German Assisted Projects
Swedish Development Corporation (SDC) Assisted Projects
FAO/UNDP/UNIDOs FARM Program
Other Watershed Development Programs (through various funding schemes)

Scientists have developed appropriate technologies to find the solution of most problems relating to watershed treatment. They range from simple check-dams to large percolation/irrigation tanks, from vegetative barriers to contour bunds. However, experience has shown that in a large percentage of cases, the farmers/villagers do not show much enthusiasm for adopting these on account of several factors such as high initial investments high operation/maintenance costs, or high technical input requirement. On the other hand, the farmers and the village community have evolved their own technologies based on local knowledge and materials, which are cost-effective, simple, and easy to operate and maintain. While these may be practical innovations, they may not be the best technological options for the whole of the watershed taken as an integrated system.

11.2 Gaps and problems in watershed development programmes in India

The following gaps have been identified after making a review of the status of watershed development studies in Indian context :

i. Data on runoff, erosion, soil moisture content and its variation, soil physio-chemical properties, and nutrient losses are not available at the watershed scales.
ii. Even the routinely monitored hydro-meteorological data is not available on spatial and temporal scales as is required in the study of small watersheds.
iii. Rainfall intensity Vs runoff and soil erosion data is lacking.
iv. Lack of topographic data on desired scales.
v. Delineation of small watersheds on agro-ecological basis has not been done so far.

vi. Effects of different landuses on watershed characteristics are not known.

vii. Undue emphasis is laid on soil and water conservation measures without considering land capability of the area.

viii. Instrumentation at small watershed- and plot-scales is grossly inadequate.

ix. Instruments installed remain out of order during critical periods.

x. Inadequate budget availability for maintenance of instruments.

xi. Lack of technical knowledge among the operators of the instrument.

xii. Trained personnel often transferred from time to time.

xiii. People's participation at different levels of watershed development is generally lacking.

xiv. Lack of coordination amongst different agencies working in the field of watershed development.

11.3 Classification of water resources units in India

In India, the following classification of water resources has been suggested on the bases of size (AIS&LUS, 1990). According to this classification, India has been divided into 6 water resources units, 35 basins, 112 catchments, 500 subcatchments and 3237 watersheds (Table 6). Few more catchments, subcatchments and watersheds are likely to be added.

Table 6: Classification of water resources units in India

(After AIS&LUS, 1990)

S.No.	Water Resources Unit	Mean Size (±50%) sq. km.
1.	Water Resources Region	5,000,000
2.	River Basin	50,000
3.	River Sub-basin	5,000
4.	Watershed	500
5.	Subwatershed	50
6.	Mini-watershed	5
7.	Micro-watershed	<2.5

According to the CAPART's Guidelines (CAPART, 1992), the watersheds with area of 500 to 5,000 hectares could be taken up for development purposes. The selection of a watershed is also guided by other criteria, e.g. ones which have acute shortage of water, especially drinking water; with potential heavy soil erosion and having a preponderance of wastelands and highly degraded land.

11.4 Agro-ecological classification of watersheds in India

In recent years the idea of agro-ecological approaches for the planning and management of watersheds has been emphasized (Paroda, 1994). An ecological region is characterised by distinct ecological responses to macroclimate as expressed in vegetation and reflected in soils, fauna, and aquatic systems. Within a broad agro-climatic region, local conditions may result in several agro-ecosystems, each with its own environmental conditions. However, similar agro-ecosystems may develop on comparable soil and landscape positions. Thus a small variation in climate may not result in a different ecosystem, but a pronounced difference, when expressed in vegetation and reflected in soils, may result in a variety of agro-ecosystems. Based on this approach, the National Bureau of Soil Survey and Landuse Planning (NBSS&LUP) has divided the country into 20 agro-ecological regions (Sehgal, et al., 1992). These regions have been grouped into six broad ecosystems as shown in the Table 7.

Table 7: Agro-ecological regions and ecosystems

ECOSYSTEM	CODE	AGRO-ECOLOGICAL REGIONS	DESCRIPTION	AREA (m ha)	NO. OF SWSs @5000 ha
ARID	1	Western Himalayas	Cold arid	15.2	3040
	2	Western Plain, Kachchh & part of Kathiawar Peninsula	Hot arid	31.9	6380
	3	Deccan Plateau	Hot arid	4.9	980
SEMIARID	4	Northern Plain & Central Highlands including Aravalis Central (Malwa)	Hot Semi-arid	32.2	6440
	5	Highlands, Gujarat Plains & Kathiawar Peninsula	Hot Semi-arid	17.6	3520
	6	Deccan Plateau	Hot Semi-arid	31.0	6200

ECOSYSTEM	CODE	AGRO-ECOLOGICAL REGIONS	DESCRIPTION	AREA (m ha)	NO. OF SWSs @5000 ha
	7	Deccan (Telangana) Plateau & Eastern Ghats	Hot Semi-arid	16.5	3300
	8	Eastern Ghats, TN Uplands & Deccan (Karnataka) Plateu	Hot Semi-arid	19.1	3820
SUBHUMID	9	Northern Plain	Hot Subhumid (dry)	12.1	2420
	10	Central Highlands (Malwa, Bundelkhand & Satpura)	Hot Subhumid	22.3	4460
	11	Eastern Plateau (Chhatisgarh)	Hot Subhumid	11.1	2220
	12	Eastern(Chhotanagpur) Plateau & Eastern Ghats	Hot Subhumid	26.8	5360
	13	Eastern Plain	Hot Subhumid (moist)	11.1	2220
	14	Western Himalayas	Warm Subhumid (to humid with inclusion of perhumid)	18.2	3640
HUMID-PERHUMID	15	Bengal & Assam Plain	Hot Subhumid (moist) to Humid (inclusion of perhumid)	12.1	2420
	16	Eastern Himalayas	Warm Perhumid	9.6	1920
	17	North-eastern Hills (Purvachal)	Warm Perhumid	10.6	2120
COASTAL	18	Eastern Coastal Plain	Hot Subhumid to Semi-arid	8.5	1700
	19	Western Ghats & Coastal Plain	Hot Humid Perhumid	11.1	2220
ISLAND	20	Islands of Andaman-Nicobar & Lakshadweep	Hot Humid to Perhumid	0.8	160

What is really required is the evolution of a system of monitoring and assessment of soil and land degradation in these regions based on the modern technology of intelligent instrumentation and remote sensing. A network of benchmark sites should be established for this purpose (Kanwar, 1994). To start with, it would be adequate for hydrological purposes if 2-3 measurement stations in each of the agro-ecological regions are established.

11.5 Status of hydrological instrumentation and observation in India

Instrumentation plays an important role in the hydrological data collection. The instrumentation technology has attained great heights of technological advancements. However, their application in the field of hydrology has been very limited in India.

Presently Central Water Commission, Central Ground Water Board, Central Pollution Control Board, India Meteorological Department, Soil & Water Conservation Division of Ministry of Agriculture (Govt. of India), and various state government organisations are involved in data collection activity in the country. Study specific and site specific data collection is additionally done by many other organisations, e.g. Brahmputra Board, WAPCOS, National Water development Agency (NWDA), Narmada Control Authority (NCA), Snow & Avalanche Study Establishment (SASE), and various academic institutions.

11.5.1 Surface water observations

Surface water measurements were initiated originally for project planning and design purposes, e.g. irrigation schemes and reservoir facilities, and measurements were often discontinued after achieving these short-term objectives. Some early network was established on major rivers mainly for flood warning purposes and often observed only the river stages. As levels of surface water development increased, a need for evaluation of surface water resources at basin/sub-basin level was felt.

The Central Water Commission (CWC) was established as an organisation for surface water resource evaluation and management, and to provide flood-warning services. CWC now operates networks of hydrometric stations on all major rivers of India. Though the observation sites are generally located with a view to basin resource evaluation, their density is sparse and inadequate for modern needs without complementary data from state networks. Although early interest in surface water hydrometry was concerned almost entirely on water quantity, the last two decades have witnessed a gradual increase in water quality and sediment monitoring in the CWC networks and in some of the state networks.

All stations are provided with a staff gauge for stage monitoring and some stations also have float type autographic water level recorders with stilling wells. Cup type and propeller type current meters are predominantly used for flow measurements, and timed float measurements are more rarely used except in times of high floods. Water depth is measured by sounding rods or echo sounder. The maintenance of these equipment has always been a neglected priority and needs to be improved a lot. Also, a number of deficiencies are observed in actual field practices due to departure from specified standard procedures.

Soil and Water Conservation Division (SWCD) of the Ministry of Agriculture, Govt. of India, is also operating its own network of hydrologic and sediment monitoring stations for various River Valley Projects (RVP) and Flood Prone River (FPR) catchments. The data collected from these observations is used in planning and implementation of watershed management programmes in the country. Their 'silt monitoring stations' have a non-recording rain gauge or a self-recording rain gauge, a weir to measure stream discharge, and mostly a 'Punjab type bottle' for suspended sediment sampling. For modernization of data collection activities in small watersheds, SWCD has been implementing an Indo-German Bilateral Project on Watershed Management in the States of Rajasthan, Himachal Pradesh, Uttar Pradesh, Bihar, Gujarat, Madhya Pradesh, Orissa and Tamilnadu.

11.5.2 Hydrometeorological observations

Systematic observations of the spatial and temporal variations of meteorological parameters (e.g. precipitation, air temperature, and wind) are essential requirements of any hydrological study. The India Meteorological Department (IMD) is organised exclusively to provide the full range of meteorological inputs in hydrological studies. The CWC has also established a network of rainfall and climatic stations, normally located at manned stream gauging sites. Some state organisations are also maintaining hydrometeorological observatories. Most commonly, rainfall stations are equipped with standard daily rain gauges (non-recording type) and many have additionally a Syphon Recording Rain Gauge. The climatic stations are most commonly manned stations equipped for Penman evaporation calculations. Very few sites, both of Central and State organisations, have Automated Weather Stations (AWS).

11.5.3 Groundwater observations

The Central Ground Water Board (CGWB) has established a nation-wide network of about 16,000 observation wells for monitoring groundwater level and groundwater quality variations through time. The groundwater organisations in various states have their own groundwater monitoring networks. The observation points are predominantly open, dug wells in plain, hard rock areas and tubewells in other areas.

Water levels in wells are measured manually using a steel tape (or biaxial electric tape) except at few tubewell locations where autographic water level recorders have been installed. All CGWB water level observations are taken during fixed ten-day periods in January, May, August and November, whereas State organisations follow their own practices (e.g. monthly, bi-monthly, pre- and post-monsoon, quarterly measurements). Water quality observations in these networks are taken at the time of water level measurement immediately prior to the monsoon.

11.5.4 Water quality observations

Water quality monitoring has received increasing attention during the last two decades. It is now recognized that industrialization and urbanization processes and the use of fertilizers and pesticides in agriculture contribute to the deterioration of water resources, and that water quality monitoring must be undertaken seriously to provide a firm basis for development planning and the mitigation of potential hazards.

The government organisations who are involved in and/or who have interest in water quality observations are CWC, CGWB, and State irrigation, water resources, soil and water conservation and groundwater departments. The CGWB maintains laboratories at each of its 12 regional offices, and CWC maintains chemical laboratories at both divisional and regional levels. Most State surface water agencies have only limited laboratory facilities, but State groundwater organisations generally operate such laboratories. State Pollution Control Boards, Public Health Departments and similar other agencies carry out water quality monitoring programmes specific to their mandates, e.g. drinking water supply, control of industrial effluent. The Central Pollution Control Board (CPCB) has a mandate for improvement of water quality in streams and wells throughout the country. CPCB has initiated, to a limited extent, comprehensive monitoring programmes on river basin basis.

Present emphasis on water quality monitoring has been predominantly on chemical contents and dissolved oxygen in surface water. Biological and micro-biological contents and organic micro-pollutants are not being adequately monitored. Another major issue is contamination of suspended and bottom sediments, and on accumulation of pollutants in bio-accumulation. Groundwater pollution from agricultural chemical and industrial waste inputs is yet another major concern. Various in-situ probes required for regular monitoring at field sites, as also the facilities for analyses of heavy metals and organic micro-pollutants, are generally lacking with the concerned organisations.

12.0 RECOMMENDATIONS

A watershed is an individual entity, and is a naturally occurring unit of the landscape, which contains complex array of interlinked and interdependent resources and activities irrespective or political boundaries. In addition, it is a logical unit having readily identifiable boundaries and characteristics of water movement, which helps in co-ordinated planning and management.

The watershed approach is most rational for programmes pertaining to optimum utilization of soil and water resources. Some of the important watershed characteristics, that are required for planning and implementation of programmes, depends upon the purpose or type of studies / analysis for which information is required. In absence of ready made availability of required information, the watershed studies data should be generated through surveys, and investigation.

Based on the discussion in the report, it is recommended that

i. Data on rainfall, runoff, soil erosion, soil moisture content and its variation, soil physio-chemical properties, and nutrient losses should be collected at watershed scales.
ii. Small watersheds on agro-ecological basis should be delineated.
iii. The hydrological behaviour of the watersheds under different landuses in relation to water yield, peak discharges and sediment production rates should be studied for different agro-ecological regions.
iv. The effects of land treatment measures in reducing soil and water losses should be evaluated.
v. Design criteria for engineering structures for soil conservation and upstream flood control should be developed.
vi. Instrumentation at small watershed scales is grossly inadequate, therefore, instrumentation network should be strangthened.
vii. Coordination amongst different agencies working in the field of watershed development should be increased.

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