WORKSHOP

ON

MODELLING OF HYDROLOGIC SYSTEMS

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Hydrological Studies for Watershed Management

by

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HYDROLOGICAL STUDIES FOR WATERSHED MANAGEMENT

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1.0 Introduction

Recently, in many countries, special attention has been paid to comprehensive land development, which enables soil and water conservation, better and productive land use, and optimum and effective use of available water resources. Governments, national and international organisations, and financing agencies have recognised that development of individual or specific components may result in only partial solutions to the overall problems. It is possible to achieve its goals by considering all lands; their potential capabilities for development and reclamation; their possible contribution to food, fuel and timber production; their hydrology, irrigation and water supply; and susceptibility to floods, drought and other natural hazards such as erosion or deposition.

Most of these factors are related to the nature of the drainage basin and the extent to which the improvement facilities are co-ordinated within its boundaries. Area development can be implemented within any boundary selected by its planners. But planning of physical improvements, infrastructure or the mobilisation of the human resources will suffer serious restrictions unless carried out within "*natural*" boundaries - a large watershed or its independent tributaries (sub watersheds).

A watershed is an area having common drainage. It includes all the area which collect rain or stream water and discharges it through a common outlet at its minimum elevation (the watershed mouth). The area of the watershed is generally determined from the topography or watershed divide. The divide represents the highest elevation points along the watershed perimeter.

Watershed management is the management of all the natural resources of drainage basin to protect, maintain or improve its water yields. It has been defined by Frank (1964) as the analysis, protection, repair and utilisation of drainage basins for optimum control and conservation of water with due regard to other resources. Embedded in the concept of watershed management is the recognition of the interrelationships among land use, soil and water and the linkages between uplands and downstream areas. Integration of various aspects of Hydrology, Ecology, Soils, Physical Climatology and other Sciences provide the scientific base for watershed management.

Planning for watershed management involves an integration of three major sets of elements;

objectives; established on the basis of a problem analysis in the watershed area and directives from higher level authorities,
constraints; budget, physical, biological, social, cultural, and political; associated with the specific studies,
techniques; for carrying out technical watershed management activities.

Watershed management actions and activities are employed as either preventive strategies, aimed at preserving existing sustainable land use practices or restorative strategies, designed to overcome identified problems or restore conditions to a desirable level. But in most watershed management situations, some measures will be preventive and some will be direct response to existing problems.

Any watershed management programme includes the following measures;

Afforestation
Construction of check dams and gully control
Stream bank erosion control
Scientific cultivation practices like terracing, contour ploughing and strip cropping
Controlled grazing

The specific objectives of watershed management programme are;

Promotion of in-situ soil and water conservation
Optimal use of land to minimise risks in rain fed farming, increased productivity of lands and better returns to the farmers on a sustainable basis through adoption of better technology of cropping pattern and diversification of sources of income
Proper management of non-arable lands to conserve soil moisture and store runoff for recharging ground water
Production of fodder, fuel, fibre, timber and fruits in the watershed and at the same time help to maintain ecological balance

There are many watersheds upon which no particular water problem exists and where management is not likely to create new ones. In such cases, the need to develop a watershed development strategy does not apply. However, it is usually necessary to conduct at least a brief survey to establish the presence or absence of the need.

The immediate benefits of a watershed management programme are:

Improvement of agricultural production and changing of crop patterns in the watershed areas
Proper utilisation of land and developing awareness among people regarding soil and water conservation
Employment of land less farmers, small agriculturists and women

2.0 Methods of Watershed Management

A watershed management programme can be undertaken in following ways:

a) Upstream of reservoirs
- # terracing
- # drainage of terrace lands
- # contour bunding
- # gully control structures
- # pitching of steep slopes
- # construction of check dams

b) In the command area
- # providing suitable slopes depending on the soil capability
- # terracing and contour bunding
- # provision of adequate drains to drain surplus water
- # re-sectioning of nallas and drains to ensure non-silting, non-scouring velocity with provision of protection when required

c) In the field
- # selection of suitable crop pattern to suit the agroclimatic condition
- # having plantation along canal bunds and afforestation

Effective watershed development programme involves participation of all existing institutions including farmers for sustained development of the watershed. Peoples' participation in watershed development and management programme is crucial for their successful and cost effective implementation. This is so because the watershed approach requires that every field of land located in watershed to be treated with appropriate soil and water conservation methods and used according to its physical capability. For this to happen, it is necessary that every farmer having land in the watershed accepts and implements the recommended watershed development plan.

The watershed development approach to agricultural development in India is generally built on the premise that a systematic exploitation and use of the available water and land resources in the region can greatly enhance agricultural productivity and output. In India, development of rainfed farming has remained a major thrust since long. Rainfed farming calls for both soil and water conservation. The development of rainfed farming on watershed basis aims at development of the area in an integrated manner for increasing overall productivity.

India has a relatively short history of watershed development and management programme. The watershed approach was first adopted on a significantly large scale in 1974 in the catchments of a few river valley projects. Recognising the need for an integrated development of dry land, the Government of India, in 1982, took up for implementation 99 watershed projects in different agroclimatic regions of the country. The

programme was given further impetus in 1983, when the World Bank came forward with financial assistance for the establishment of 4 watersheds, one each in Karnataka (Kabbalanalla), Andhra Pradesh (Maheswaram), Maharashtra (Manoli), and Madhya Pradesh (Perunala). The Government of Karnataka, however, took lead in 1984-85 when it decided to establish a watershed project in 18 districts, identical to the World Bank aided project. There are, however, certain differences between the National and State sponsored programs in respect of size of the watershed, cost of development, administration, peoples' participation, and emphasis on treatment of non-arable lands.

A quick review of the dry farming technology in India culminates into five main issues, viz., lack of holistic planning, absence of precision plans and exaggerated yield gaps, weak technological options, heterogeneity of environment, and languid societal responses. Different organisations at various locations in the country undertook experiments on watershed basis. There are five different programs operating, which differ in terms of techniques, administration, planning and system composition. The first group consists of the Operational Research Projects (ORP) taken up by the Indian Council of Agricultural Research (ICAR) at different locations in the country. Secondly, World Bank financed watershed projects. These were undertaken with active participation of agricultural Universities. Thirdly, the State Governments like Karnataka and Maharashtra have taken up such programmes either with elaborate or existing administrative machinery. Fourthly, the Central Government activated National Watershed Development Programme (NWDP), which was implemented by each States with some modifications. Lastly, there are projects undertaken by voluntary agencies and NGOs, which have relatively less scientific input and manpower but results are exemplary.

Major watershed development programmes taken up in India include;

- # 47 model watershed projects of the ICAR;
- # a centrally sponsored scheme of integrated watershed management in the catchments of flood-prone rivers;
- # World Bank funded watershed development projects in the States of Andhra Pradesh, Karnataka, Madhya Pradesh;
- # district watershed development programmes of Karnataka; and
- # a centrally sponsored scheme of National Watershed Development programme for rainfed areas.

During the Seventh Five Year Plan, the NWDP has been envisaged which was having the primary objective of increasing and stabilizing agricultural productivity of rainfed areas by significantly stepping up investments for the development of dry land agriculture. The salient features of NWDP are;

- # taking watershed as a unit for planning, conservation, and upgradation of the land and water resources as a viable natural resources for agricultural production
- # analysis of historical rainfall data, and using this information for improving crop management and planning

introduction of land management systems for soil and moisture conservation
introduction of efficient cropping systems

The International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) has developed a micro watershed based technology for semi-arid tropics of India. In this micro watershed based technology, an area of 3-25 ha is being developed to enable farmers within the watershed to improve their management of soil, water, and crops. On the watershed, broadbed and furrows are made with a constant grade of 0.4 to 0.6 % across the natural slope to increase the moisture storage capacity of soil, facilitate runoff of excess water, improve drainage, and reduce soil erosion and degradation. The area in India for which this watershed based technology may be suited is estimated between 5 and 12 million hectre spread in the States of Karnataka, Andhra Pradesh, Maharashtra, Madhya Pradesh, and Gujarat.

3.0 Project Components

3.1.Soil and Moisture Conservation:

Farm land development including soil and moisture conservation and water harvesting should be a basic project activity. The main emphasis is that the insitu moisture conservation and the designs used should help in minimising the need for drainage. Both engineering and vegetative conservation measures have to be employed.

The major conservation components to be adopted in a project are the following:
contour bunds
graded bunds
bench terraces
interbund management practices
zing terraces
vegetative strips
water ways
diversion ditches
gully management
stream bank protection
runoff conservation structures
nalla bunds
check dams
farm ponds

3.2 Afforestation:

Afforestation activities to be done in a project area are as follows:
plantation on Government waste lands
plantation on private waste lands

strip plantation on nalla banks and road sides
planting on contour bunds and tank shores

For all these types of plantations, the consent of the local people has to be taken. It is required to consult them regarding their needs for fodder, fuel, fruits, timber, and other tree products, as well as about their preference for each area.

3.3 Horticulture:

The scope for horticulture is two fold. First is planning and maintaining improved tree crops of horticultural importance in private holdings, in nearby waste lands, and home yards. Next one is the support for the traditional rainy season vegetables by introducing improved varieties and better practices of production.

3.4 Training and Demonstration:

Various youth groups and agricultural assistants have to be trained by the concerned project authorities. They should be given specialised training in practical social forestry and horticulture, including the importance of tree crops, features of different tree species, raising and care of seedlings, plant selection, planting techniques, maintenance of tree crops and handling tree products. Similarly, they should be trained in establishing and maintaining as well as regulating the use of grass lands and other fodder crops. They should also be trained in communication skills and utilisation of existing service systems including extension, credit, and market services.

Project staff should be given orientation training in watershed development, their respective roles as well as team work. The agricultural staff should be trained in soil and moisture conservation techniques during the pre-project period and during the first year of the implementation period, by conducting seminars and workshops.

3.5 Surveys, Studies, and Research:

A survey, socio-economic and technical in content, has to be initiated during the pre-project period. The objective of this survey is to collect gender specific baseline data in the watersheds, and to analyse this data with a view to proposing project activities that are socially and economically feasible.

The objectives of surveys and studies are to,

a) monitor the quality and quantity of components before and after the project implementation. These are crop specific average yields for arable lands, output of fodder and fuel, and changes in cropping pattern during the project period. Rainfall intensities and amounts are recorded in order to develop a picture of crop security within the introduced cropping system compared to old practices.

b) assess the soil conservation works carried out with the purpose of determining whether any of the methods employed are inadequate or impractical to the farmer.

c) conduct an overall time study in order to discover changes in work loads for men and women, caused by the introduction of new technology.

d) assess the economic effects of the new practices on the household economy, in co-operation with a socio-economist.

A research component has to be built in a project. Among other things, it should monitor the quantity and quality of the biomass components before and after the project implementation, and continuously assess the effects of technologies introduced. Records should be kept on rainfall amounts and intensities within the selected watersheds.

4.0 Hydrological Studies for Watershed Management

In the preceding discussions, watershed management components, except the hydrological aspects, have been mentioned. But a basic knowledge of hydrology and hydrologic behaviour of watershed to various management activities is fundamental for any successful watershed management programmes. The hydrologic processes of the biosphere and the effects of vegetation and soil on these processes are of particular interest in watershed management. Precipitation, and the movement of water into, through, and out of a watershed can all be affected by land use and management activities. A thorough hydrological study makes it possible to examine the existing watershed system, quantify the effects of management on the hydrologic cycle and in some cases predict or estimate hydrologic consequences of proposed activities.

Watershed is an open system. It has boundaries, energy inputs to regulate the hydrologic system and hydrological responses or outputs. The energy inputs of the watershed are divisible into two groups. These are, climate above the surface and tectonic activities below its surface. The hydrological responses of a watershed are also divisible into two groups. These are hydrological responses through the watershed mouth (channel runoff; suspended, dissolved and bed sediment load; quality of water; etc.) and through the watershed surface (evaporation, transpiration, overland flow, infiltration, erosion, etc.).

Responses of a watershed always depend on the watershed personality or the watershed characteristics. The watershed characteristics are divisible into two groups. These are natural (lithology, geology, soils, vegetation type and density, land forms of different genetics, etc.) and anthropogenic or man made (agricultural, barren land, population density, dams, irrigation tanks, rural and urban settlements, and other built up structures). A geomorphological study is also useful where the land forms, the slopes, the stream network, and the natural processes are dealt with.

Without a thorough understanding of controlling geographical factors and operating hydrological cycle, it is not possible to develop a model of water resources

management in particular, and watershed management in general. The watershed functions as a hydrologic system in which the relationship between the input (rainfall) and output (stream flow) is determined by the intermediate processes (evapo-transpiration, infiltration, soil moisture storage, etc.) and the characteristics of the watershed surface (topography, soils, land use pattern, geology, etc.).

A schematic representation of watershed system with its energy inputs and energy outputs is given in Figure 1. In general, small first and second order watersheds are preferred for research studies where it is desirable to measure the hydrologic response to a changed land use practice, or determine the water balance of a particular soil-vegetation type. Large fourth or fifth order watersheds may be appropriate for integrated watershed management projects.

Various hydrological aspects of a watershed management programme can be broadly explained as;

a) Delineation of a watershed, in which boundaries of the watershed are determined. This requires topographical maps of the area, which contains the watershed.

b) Defining a watershed - Characteristics of a watershed has to be closely studied for evaluating the extent of management required for that watershed and to finalise the types of management activities suitable for it. These include geology of the watershed, types of vegetation, land use pattern, soil characteristics, etc.

c) Defining energy inputs to the watershed

inputs from the climate above the surface (exogenic), which include precipitation, temperature, and humidity.

endogenic processes which include tectonic history, morpho -tectonics, neotectonics, etc.

d) Defining watershed outputs/responses

at the outlet which include water discharge, sediment load, water quality, etc.

from watershed surface which include evaporation, overland flow, subsurface flow, deep percolation, underground water storage, erosion, etc.

e) Correcting the watershed

After closely monitoring and analysing the inputs and outputs of a watershed, one should evaluate whether some sort of management is required or not and if required, the extent and type of management.

5.0 Hydrologic Monitoring of Watershed

The data pertaining to climate, land use pattern, socio-economic conditions of farmers, perceptions of farmers towards new dry land technologies, etc. are to be collected at the time of initiation of the project. Data pertaining to cultivation of crops, cropping

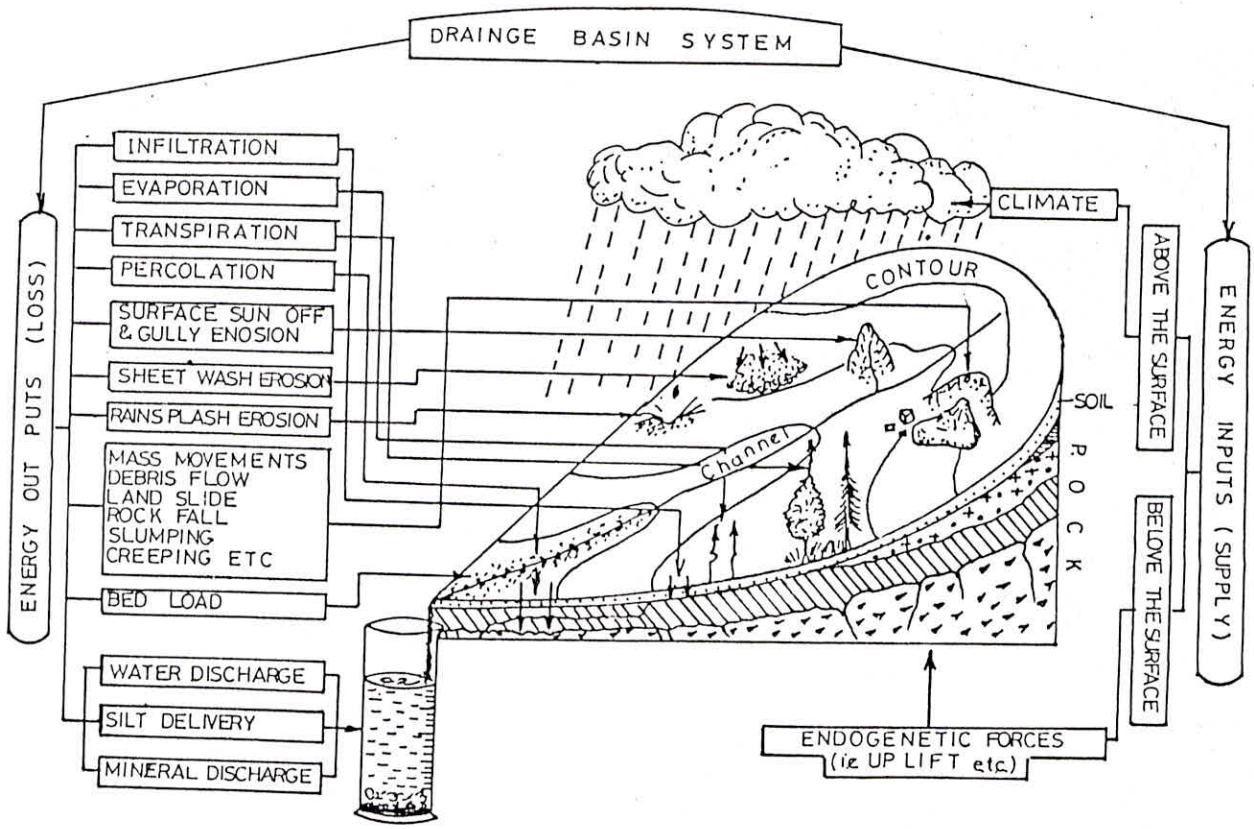

Fig. 1: Watershed System

programmes and land use pattern, labour employment, flow of income and expenditure, family budget etc, are to be collected during the period of the project to evaluate periodical development due to the implementation of watershed programme. After completion of the programme, it is again necessary to have an evaluation of the watershed programme.

Monitoring of a watershed is defined as measuring parameters (hydrologic, agronomic, socio-economic) through technical means to determine the changes caused by the development. These technical observations are taken over a period of time and will be used for evaluation of management activities like soil and water conservation practices. The evaluation process requires the development of data acquisition system commencing before the project is implemented (bench mark survey) and continuing beyond the completion of the project development. So a detailed knowledge of meteorological inputs and watershed responses are absolutely necessary. It requires a well-covered instrumentation network in the watershed. So the first step in any watershed studies is the installation of proper instrumentation and the monitoring of inputs and outputs. A typical instrumentation strategy for effective monitoring of inputs to and responses from a micro watershed is as shown in Figure 2.

Monitoring is also essential for studying the effects of management activities on the watershed. For this, an experimental watershed can be taken up. Experimental watershed (area less than 4 km^2) is one where one or more of the catchment characteristics is deliberately modified. Studies in an experimental watershed involve both observation and deliberate experimental procedures to introduce changes and to measure their effects. If a single basin is considered, it should be calibrated over a number of years against climatic changes, the treatment is carried out, and the deviation occurred from the predicted responses are assessed. But this requires a thorough knowledge of the natural responses of the watershed, which may not be available for most of the watersheds. So the paired watershed, comparative watershed, or control watershed procedure involves use of an untreated control watershed with similar characteristics to the experimental watershed can be used. The effects of treatment (management) are measured as departures from the behaviour of watershed, predicted from the control watershed.

The development of a watershed is a dynamic process meant for improvement in the long term and never really ends. To find out if watershed development programmes do generate both direct and indirect benefits, effective monitoring and evaluation of management activities should be conducted. This will eventually assist researchers, extension specialists, planners, and farmers in determining the progress of various development programmes. Long-term monitoring activities allow us to observe and analyse resource responses over a time to help identify problems. For example, precipitation and stream flow records need to be collected on a continuous basis for many years before floods, droughts, and erosion conditions can be modelled properly.

By considering the hydrological aspects, the specific objectives of a watershed programme can be listed as follows;

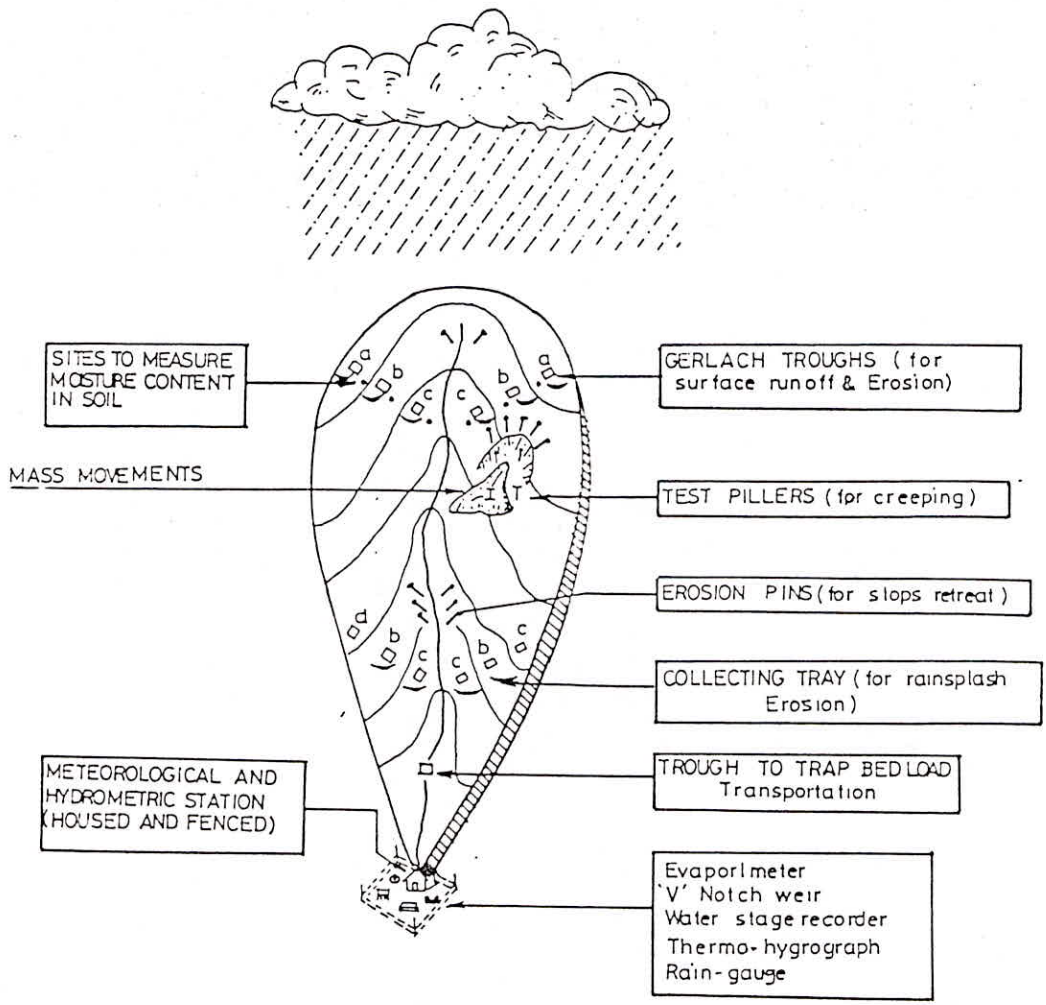

Fig. 2 : Watershed Instrumentation

a) To define the hydrological cycle of a watershed

to study meteorological input to the watershed - after defining the watershed completely (by its geology, vegetation, soil characteristics, land use pattern, etc.), the next step is to quantify the meteorological inputs to the watershed. This includes the measurement of temperature, rainfall, and humidity

to study hydrological outputs from the watershed - these can be classified into two - at watershed mouth (outlet) such as discharge, sediment load, water quality, etc. and from watershed surface such as evaporation, overland and subsurface flow, deep percolation, underground water storage, erosion, etc,

b) To define hydrological responses of different management activities in the watershed

an experimental watershed has to be identified, where certain management activities are going on regarding soil and water conservation (like check dams, gully plugging, contour bund, etc.). To study the hydrological responses of these, watershed outputs have to be monitored and compared with an undisturbed watershed.

c) To develop models and guidelines for integrated watershed development

to study input-output interaction - this step consists in developing a model for rainfall-runoff relationship, considering all the characteristics of the watershed

to develop guidelines for watershed management - in this final step, the detailed methodology for the management of the watershed has to be formulated for soil and water conservation, for improving productivity of the land, and for the improvement in the living conditions of people living within the watershed.

6.0 Conclusions

The focus on water and its inter-relationship with other natural resources and their use is what distinguishes watershed management from natural resource management activities. With the perspective of a watershed and a clear awareness of the hydrological behaviour of the watershed, it is possible to plan and develop long term solutions to many natural resources problems and to avoid many kinds of environmental degradations.

A basic understanding of hydrology is essential to the planning and management of renewable natural resources for sustainable use on a watershed. Ignoring the effects of land management activities on soil and water resources is short sighted and can lead to unwanted effects. Hydrologic information is necessary for watershed management assessment and it requires some type of field research and monitoring methods.

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