SYLLABUS:

UNIT-I

Introduction: Concept of watershed development, objectives of watershed development, need for watershed development, Integrated and multidisciplinary approach for watershed management.

UNIT-II

Characteristics of Watersheds: Size, shape, physiographic, slope, climate, drainage, land use, vegetation, geology and soils, hydrology and hydrogeology, socio-economic characteristics, basic data on watersheds.

UNIT-III

Principles of Erosion: Types and causes of erosion, factors affecting erosion, estimation of soil loss due to erosion- Universal soil loss equation.

Measures to Control Erosion: Contour techniques, ploughing, furrowing, trenching, bunding, terracing, gully control, check dams , rock-fill dams, brushwood dam, Gabion.

UNIT-IV

Water Harvesting: Techniques of rain water harvesting- rain water harvesting from roof top, surface flow harvesting, subsurface flow harvesting, stop dams, farm ponds and dugout ponds, percolation tanks.

UNIT-V

Land Management: Land use and Land capability classification, management of forest, agricultural, grassland and wild land, land grading operation, Reclamation of saline and alkaline soils.

UNIT-VI

Watershed Modelling: Data of watershed for modelling, application and comparison of watershed models, model calibration and validation, advances of watershed models.

TEXT BOOKS:

1. ‘Watershed Management’ by Das MM and M.D Saikia, PHI Learning Pvt. Ltd, 2013.
2. ‘Land and Water Management’ by Murthy.VVN, Kalyani Publications, 2007.
3. ‘Watershed Management’ by Murthy J V S, New Age International Publishers, 2006.

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1. ‘Water Resource Engineering’ by Wurbs R A and James R A, Prentice Hall Publishers, 2002.
2. ‘Watershed Hydrology’ by Black P E, Prentice Hall, 1996.

UNIT-I

Introduction: Concept of watershed development, objectives of watershed development, need for watershed development, Integrated and multidisciplinary approach for watershed management.

Concept of watershed development

A **watershed** is an area of land that forms the drainage system for a stream or river (it is an area draining the rain water into a streams). This area collects surface water from land within specific topographic boundaries (such as hills, valleys, mountains, and other landscape characteristics).
Watersheds are characterized by the location of the pour-point, or mouth, of the main flow of water to which all the other points of flow join and eventually drain from the watershed. Some of the rainfall in the area of a watershed will flow on top of the ground or find its way via underground water paths to the stream in the watershed. Some of the water will evaporate into the atmosphere, be used by people or plants, or be held in the soil or underground. Watersheds are very dynamic places becoming alternately wet and dry, due to high water and low rainfall conditions, with many differences in quality and flow depending upon the season, the year, and even with what happens during an individual storm. This is best illustrated by examining the components of the **hydrologic cycle.**

Within a watershed, activities on the land interact with the natural hydrologic cycle. Important nutrients and chemicals are circulated throughout the watershed's system and supply a basic nutritional source for both aquatic (fish, aquatic insects, etc.) and terrestrial (birds, small mammals, etc.) species. People also use these environments to grow food, build their homes and businesses, and travel from one place to another. Where and how these human activities occur have major impacts on the movement of water, water quality, and the quality of the natural habitat which remains. Ideally, we wish to have watersheds that continue to function as healthy ecosystems and serve as productive systems for people.

History of Watershed Development Program in India

About 60 per cent of total arable land (142 million ha) in India is rain-fed, characterized by low productivity, low income, low employment with high incidence of poverty and a bulk of fragile and marginal land (Joshi et al. 2008). Rainfall pattern in these areas are highly variable both in terms of total amount and its distribution, which lead to moisture stress during critical stages of crop production and makes agriculture production vulnerable to pre and post production risk. Watershed development projects in the country has been sponsored and implemented by Government of India from early 1970s onwards. The journey through the evolution of watershed approach evolved in India is shown in Figure-1 (Wani et al. 2005 and 2006). Various watershed development programs like Drought Prone Area Program (DPAP), Desert Development Program (DDP), River Valley Project (RVP), National Watershed Development Project for Rain-fed Areas (NWDPRA) and Integrated Wasteland Development Program (IWDP) were launched

subsequently in various hydro-ecological regions, those were consistently being acted by water stress and draught like situations. Entire watershed development program was primarily focused on structural-driven compartmental approach of soil conservation and rainwater harvesting during 1980s and before. In spite of putting e/orts for maintaining soil conservation practices (example, contour bunding, pits excavations etc.), farmers used to plow out these practices from their 1elds. It was felt that a straight jacket top-down approach cannot make desired impact in watersheds and mix up of individual and community based interventions are essential. The integrated watershed development program with participatory approach was emphasized during mid 1980s and in early 1990s. This approach had focused on raising crop productivity and livelihood improvement in watersheds (Wani et al.2006) along with soil and water conservation measures. The Government of India appointed a committee in 1994 under the chairmanship of Prof. CH Hanumantha Rao. The committee thoroughly reviewed existing strategies of watershed program and strongly felt a need for moving away from the conventional approach of the government department to the bureaucratic planning without involving local communities (Raju et al. 2008). The new guideline was recommended in year 1995,which emphasized on collective action and community participation, including participation of primary stakeholders through community-based orgnizations, non-governmental organizations and *Panchayati Raj* Institutions (PRI) (GoI, 1994, 2008; Hanumantha Rao et al. 2000; DOLR, 2003; and GoI, 2008; Joshi et al. 2008). Watershed development guidelines were again revised in year 2001 (called Hariyali guidelines) to make further simpli1cation and involvement of PRIs more meaningful in planning, implementation and evaluation and community empowerment (Raju et al. 2008) and guidelines were issued in year 2003 (DOLR, 2003). Subsequently, Neeranchal Committee (in year 2005) evaluated the entire government-sponsored, NGO and donor implemented watershed development programs in India and suggested a shift in focus "away from a purely engineering and structural focus to a deeper concern with livelihood issues" (Raju et al. 2008). Major objectives of the watershed management program are: 1) conservation, up-gradation and utilization of natural endowments such as land, water, plant, animal and human resources in a
harmonious and integrated manner with low-cost, simple, replicable technology; 2) generation of massive employment; 3) reduction of inequalities between irrigated and rain-fed areas and poverty alleviation.

Watershed Management Mechanism

- Watershed Management must be undertaken within the framework of integrated development planning and national goals and priorities
- operate within a holistic framework (research, policy, mitigative interventions)
- be intersectoral
- include stakeholder participation in the planning and decision making process
- Be supported by public awareness programs and public education, institutional
- strengthening and capacity building and application of appropriate technology
- Include data collection, monitoring, feedback and refinement of the management plan

Objective Watershed Management

• Raise public awareness of the Watershed and encourage participation in management and protection of our watershed resources.
• Identify problems and issues of importance to local citizens, groups, and users of the watershed.
• Diminish and eliminate further degradation of the watershed and its resources through better management practices.
• Promote, preserve, and protect beneficial uses of the watershed.
• Restore and enhance ecological systems of the watershed.
• Increase the viability, diversity, and health of the watershed.
• Promote science-based methods for water quality and environmental impact assessment of the watershed.
• Develop an effective approach to meeting water quality regulations for the watershed.

Need for Watershed Management Plan

A sound watershed management plan will provide the frame for harmonizing economic development and environmental protection. It will also integrate socio-economic and cultural realities, institutional structures and the biological aspects into upland protection and conservation in order to attain sustainable development.

A watershed management plan provides actions to
- protect a watershed or prevent damage to it
- mitigate the effects of land use to an acceptable level
- restore degraded environments
- optimize the availability of water resources

Integrated watershed plans have to be based on a complete inventory of the country's physical and human resources. A multidisciplinary approach has to be followed and the objectives of the plan should not be limited to prevention of watershed degradation. Increased production from the land on a sustained basis and a general improvement of the standard of living for the people living in the catchments must be an integral part.

Definition of Watershed

A watershed, also called a drainage basin or catchment area, is de1ned as an area in which all water flowing into it goes to a common outlet.

Or

Watershed management is the comprehensive development of a watershed (basin) so as to make
Productive use of all its natural resources and protect them. This includes land improvements, rehabilitation and other technical works as well as the human considerations.

Or

Watershed management is defined as the analysis, protection, repair, utilization and maintenance of drainage basins for optimum control and conservation of water in relation to other resources.

People and livestock are the integral part of watershed and their activities affect the productive status of watersheds and vice versa. From the hydrological point of view, the different phases of hydrological cycle in a watershed are dependent on the various natural features and human activities. Watershed is not simply the hydrological unit but also socio-political-ecological entity which plays crucial role in determining food, social, and economical security and provides life support services to rural people (Wani et al. 2008).

Perspective of a Watershed

- A watershed can be described as the area of land that delivers runoff water, sediment and dissolved substances to a river.
- A watershed is a hydrological unit that catches stores and releases water through networks of streams into the main rivers, which finally end in their estuaries by the sea.
- A watershed is also an integration of ecosystems of flora and fauna, land and water and their mutually interacting elements.

Characteristics are critical for a healthy watershed

- Riparian Habitat & Protected Banks

Riparian areas, areas along stream banks, are covered by transitional vegetation and act as buffers between a waterway and the surrounding area. These grasses, forbs, and trees reduce bank erosion by anchoring the soil.
These buffer areas also function as a wildlife corridor and enable safer and more efficient wildlife migrations.

- Good Water Quality

Good watersheds usually function best with low turbidity, minimal suspended sediment in the water, and infrequent shifts in water levels. Frequency and intensity of fluctuating water levels are also very important considerations.

- Adequate Shade

A riparian canopy provides structure and shade, which decreases the amount of penetrable sunlight. This decrease results in less extreme temperature gradients of the surface and sub-surface water. Cooler water can hold more oxygen for aquatic species to use.

- Meanders

Meanders in a river are turns in the banks that result in a winding course for the waterway. These meanders slow the water down and allow for deposition of sediment and other suspended material on their banks. As healthy rivers and streams age, they will naturally form more meanders.

- Biological Diversity

Biodiversity is extremely valuable to both the natural order of the system and human recreation and non-consumptive uses. Different types of internal habitat and structure diversity, such as pool and riffle sequences and vegetation, also help to diversify the system and provide for increased stability.

Components of Watershed Management

Entry Point Activity (EPA)

Entry Point Activity is the 1rst formal project intervention which is undertaken after the transect walk, selection and 1nalization of the watershed. It is highly recommended to use knowledge-based entry point activity to build the rapport with the community. Direct cash-based EPA must be avoided as such activities give a wrong signal to the community at the beginning for various interventions. Details of the knowledge-based EPA to build rapport ` the community ensuring tangible economic bene1ts to the community members are described here.

Land and Water Conservation Practices

Soil and water conservation practices are the primary step of watershed management program. Conservation practices can be divided into two main categories: 1) *in-situ* and 2) *ex-situ* management. Land and water conservation practices, those made within agricultural fields like construction of contour bunds, graded bunds, field bunds, terraces building, broad bed and furrow practice and other soil-moisture conservation practices, are known as in-situ management .These practices protect land degradation, improve soil health, and increase soil-moisture availability and groundwater recharge. Moreover, construction of check dam, farm pond, gully control structures, pits excavation across the stream channel is known as *ex-situ* management (Figure 4). *Ex-situ* watershed management practices reduce peak discharge in order to reclaim gully formation and harvest substantial amount of runoff, which increases groundwater recharge and irrigation potential in watersheds.

Integrated Pest and Nutrient Management

Water only cannot increase crop productivity to its potential level without other interventions. A balanced nutrient diet along with adequate moisture availability and pest and disease free environment can turn agricultural production several folds higher compared to unmanaged land. Integrated nutrient management (INM) involves the integral use of organic manure, crop straw, and other plant and tree biomass material along with little application of chemical fertilizer (both macro and (micro-nutrients). Integrated pest management (IPM) involves use of different crop pest control practices like cultural, biological and chemical methods in a combined and compatible way to suppress pest infestations. Thus, the main goals of INM and IPM are to maintain soil fertility, manage pest and the environment so as to balance costs, bene1ts, public health, and environmental quality.

Crop Diversification and Intensification

The crop diversi1cation refers to bringing about a desirable change in the existing cropping patterns towards a more balanced cropping system to reduce the risk of crop failure; and crop intensi1cation is the increasing cropping intensity and production to meet the ever increasing demand for food in a given landscape.

Watershed management puts emphasis on crop diversi1cation and intensi1cation through the use of advanced technologies, especially good variety of seeds,
balanced fertilizer application and by providing supplemental irrigation.

Use of Multiple Resources

Farmers those solely dependent on agriculture, hold high uncertainty and risk of failure due to various extreme events, pest and disease attack, and market shocks.

Therefore, integration of agriculture (on-farm) and non-agriculture (o/-farm) activities is required at various scales for generating consistent source of income and support for their livelihood. For example, agriculture, livestock production and dairy farming, together can make more resilient and sustainable system compared to adopting agriculture practice alone. Product or by-product of one system could be utilized for other and vice-versa. In this example, biomass production (crop straw) after crop harvesting could be utilized for livestock feeding and manure obtained from livestock could be applied in 1eld to maintain soil fertility. It includes horticulture plantation, aquaculture, and animal husbandry at indivisible farm, household or community scale.

Capacity Building

Watershed development requires multiple interventions that jointly enhance the resource base and livelihoods of the rural people. This requires capacity building of all the stakeholders from farmer to policy makers. Capacity building is a process to strengthen the abilities of people to make effective and efficient use of resources to achieve their own goals on a sustained basis (Wani et al. 2008). Unawareness and ignorance of the stakeholders about the objectives, approaches, and activities are the reasons that a/ect the performance of the watersheds (Joshi et al. 2008). Capacity building program focuses on construction of low cost soil and water conservation methods, production and use of bio-fertilizers and bio-pesticides, income generating activities, livestock based activities, waste land development, market linkage for primary stakeholders. Clear understanding of strategic planning, monitoring and evaluation mechanism and other expertise in 1eld of science and management is essential for government officials and policy makers. The stakeholders should be aware about the importance of various activities, their bene1ts in terms of economics, social and environmental factors. Therefore, organizing various training at different scales are important for watershed development.

Watershed Management Approaches

Integrated Approach

This approach suggest the integration of technologies within the natural boundaries of a drainage area for optimum development of land, water, and plant resources to meet the basic needs of people and animals in a sustainable manner. This approach aims to improve the standard of living of common people by increasing his earning capacity by offering all facilities required for optimum production (Singh, 2000). In order to achieve its objective, integrated watershed management suggests to adopt land and water conservation practices, water harvesting in ponds and recharging of groundwater for increasing water resources potential and stress on crop diversi1cation, use of improved variety of seeds, integrated nutrient management and integrated pest management practices, etc.

Consortium Approach

Consortium approach emphasizes on collective action and community participation including of primary stakeholders, government and non-government organizations, and other institutions. Watershed management requires multidisciplinary skills and competencies. Easy access and

timely advice to farmers are important drivers for the observed impressive impacts in the watershed. These lead to enhance awareness
of the farmers and their ability to consult with the right people when problems arise. It requires multidisciplinary pro1ciency in 1eld of engineering, agronomy, forestry, horticulture, animal husbandry, entomology, social science, economics and marketing. It is not always possible to get all the required support and skills-set in one organization. Thus, consortium approach brings together the expertise of different areas to expand the effectiveness of the various watershed initiatives and
interventions.

Preparation of the Integrated Watershed Development Plan

- An integrated watershed plan, including technical as well as the human aspects is drawn up on the basis of the inventory.

The analysis for each parameter normally should describe:

- The present status or conditions (e.g. good, poor, etc.)
- The present trend
- The potential (development opportunity for the resource, likely future trends, potential problems, etc.)
- The purpose of the watershed analysis should be to develop and interpret memory data in a form that will permit selection of appropriate alternative methods of managing the watersheds.
- Integrated planning should be a multi-disciplinary effort.

Some of the base maps, which should be used to prepare a watershed plan, are as follows:

- A topographic map prepared from aerial photographs (a suitable scale is usually 1:10,000)
- A slope map with, say, 0-5, 5-15, 15-35, 35-85 and greater than 85 percent slope intervals
- A soil and land capability map which may include soil types, depths or other details with slope scale and degree of soil management intensity
- An erosion and site degradation map showing the degree, size and stage of degradation as well as the courses, if possible
- A vegetative cover map, including the type of (nature) vegetation and permanent, perennial and annual crops.
- A land use and ownership map. A land use planning map should show the potential land uses as well as the existing land uses.
- A watershed development plan is drawn up from this information and it should give priority to
- sustainable use and development of the natural resources and simultaneously facilitate socio
  economic development.
- Overall the objective must be a better standard of living for the present and future generations.

UNIT-II

Characteristics of Watersheds: Size, shape, physiographic, slope, climate, drainage, land use, vegetation, geology and soils, hydrology and hydrogeology, socio-economic characteristics, basic data on watersheds.

A watershed is a geographical unit in which the hydrological cycle and its components can be analyzed. The equation is applied in the form of water-balance equation to a geographical region, in order to establish the
basic hydrologic characteristics of the region. Usually a watershed is defined as the area that appears, on the basis of topography, to contribute all the water that passes through a given cross section of a stream.
The surface trace of the boundary that delimits a watershed is called a divide. The horizontal projection of
the area of a watershed is called the drainage area of a stream at that cross section. The location of the stream cross section that defines the watershed is determined by the analysis.

Delineation

If a permeable soil covers an impermeable substrate, the topographical division of watershed will not always Correspond to the line that is effectively delimiting the groundwater.
Thus the watershed is different from the topographically delimited watershed. In this case it is called a real watershed. This difference between the two kinds of watershed is of particular importance in the karst areas.
In the delineation of a watershed artificial barriers (e.g. roads, railways) must also be taken into consideration.

The hydrological process takes place especially on the surface, and it can be modified by artificial inflow (e.g. artificial derivation, drinking and wastewater networks, roads, pumps, reservoirs). The conventional method of watershed delineation requires a topographic map. To start the divide we should start from the location of the chosen stream cross section, and then we draw a line away from the left bank or the right bank always maintaining an angle of 90° to the contour lines. We continue the line until it is generally above the headwaters of the stream network. Finally we return to the starting point and we trace the divide from the other bank, eventually connecting it with the first line.

Watershed characteristics

Physical characteristics

The physiographical characteristics of a watershed influence to a large degree its hydrological responses and especially the flow regime during floods and periods of drought.
The concentration time, which characterizes the speed and intensity of the watershed's reaction to stress (rainfall), is influenced by the different morphological characteristics.

Watershed Size

The size of a watershed forms a basis for further classification into different categories.

- Sub-Watershed (100-500 sq.km)
- Milli-Watershed (10-100 sq.km)
- Micro- Watershed (1-10 sq.km)
- Mini-Watershed(less than 1 sq.km).

Use: Computing many parameters like precipitation received, retained and drained off.

Geomorphology

A watershed is the area of reception of the rainfalls and of supplying the watercourse; the outlet flows depending thus on its surface. The surface of a watershed can be measured using a variety of methods:
Superposing a grid over the watershed map, using a Planimeter or digitalizing methods

Use: it is useful to compute, identification and analysis the type of surface and its feature.

Watershed Shape

The shape of a watershed influences the shape of its characteristic hydrograph and morphmetric parameters (geology and structure).
For example, a long shape Watershed generates, for the same rainfall, a lower outlet flow, as the concentration time is higher. A watershed having a fan-shape presents a lower concentration time, and it generates higher flow.
Different geomorphologic indices can be used for the analysis of a watershed if its shape is taken into consideration. The most frequently used index is the Gravelius's index *KG*, which is defined as the relation between the perimeter of the watershed and that of a circle having a surface equal to that of a watershed.

$K_{G=}$ P

—

where:

KG Gravelius's shape index
A watershed area [km2]
P watershed perimeter [km]
Several values of the Gravelius's index for various shapes of watershed

Uses: It is useful to determine the length –width ratio , run off-time.

Watershed orientation

The orientation of a watershed influences the melting speed of snow. Watersheds developed especially in North-South direction have an alternative exposure to sunrays; the melting speed of snow thus being smaller than in cases of watersheds developed towards East-West.
For a precise determination of the influence of watershed orientation, it is necessary to know the direction and frequency of the dominant wind.

Use: it is useful to know about the effect of orientation **of** the watershed.

Physiography
Type of land, its altitude and physical disposition immensely speak about a watershed as to be the climate and planning the activities in greening. For ex: a hilly tract could be useful mainly for forestry and plains of populated areas could be utilized only for the crops.
Watershed average slope
It controls the rainfall distribution and movement, land utilization and water shed behaviour .The degree of the affects the velocity of overflow and runoff, infiltration rate, thus soil transportation.

Watershed average slope offers information about the watershed topography. It is considered an independent variable. The average slope of a watershed influences radically the value of the time of concentration and, directly, the runoff generated by a rainfall.

Series of methods have been developed to estimate the average slope of the watershed. The method proposed by Carlier and Leclerc (1964) consists of calculating the weighted mean of all the elementary surfaces that exist between two contour lines. [Musy, 2001]

where:
ia average slope of the watershed [m/km] or [‰]
D the equidistance between two consecutive contour lines [m]
L total length of the contour lines [km]
A surface of the watershed [km^2]

Use: it is used to measure the slope of a watershed

Climate
Meteorological parameters like precipitation, temperature, wind velocity, humidity and evaporation decide a quantitative approach for arriving at water availability in a watershed. Climate is a determining factor for the management of all aspects of watershed. For ex: the entire planning of greenery depends on climate.

Drainage

The order, pattern and density of drainage have a profound influence on water shed as to runoff, infiltration, land management etc.
Use: It is useful to determine the flow characteristics and thus erosional behaviour**.**

Agro-pedo-geological characteristics

Soil types and vegetal covering
Crops depend upon the different parameters like depth, nature, moisture and fertility of the soils. The type of soil influences the infiltration rate, the retention capacity and the runoff coefficient. The humidity degree of the soil is one of the main factors that determine the concentration time. It is very difficult to measure this parameter because it has great variations in time and space. Most often other parameters are used. They reflect the soil moisture and can be obtained more easily. One of these is the antecedent precipitation index (API), expressed by the relation:

where:
API0 the API initial values [mm]
APIt API values after t days [mm]
t time [days]
K regression factor (*K*<1), characteristic for each watershed and varies from one season to another [km]

The type and density of vegetal covering directly determines the quantity of water intercepted and retained
by the soil. For example, the forest retains a certain part of the precipitation by the tree canopy. Vegetation regularizes the runoff in conditions that are meteorologically normal. Its action in extreme conditions (floods and droughts) is relatively reduced. In cases of soils without vegetation the capacity of water retention is
reduced, which leads to torrential runoff and to apparition of riverbed erosion phenomena. For estimating the influence of vegetal covering, a coefficient for various cultures must be calculated:

Use: It is used to determine the movement and infiltration of water.

Land Use
It is a pattern is vital for planning, programming and implementing a management project on a watershed. It is an important statistic for ascertaining the background, appreciating the status and planning the programmes in management. It portrays man’s impact on the specific watershed and forms a basis for categorizing the land for the formulation of a pragmatical action plan.

Watershed geology

The geology of the watershed must be known in order to estimate the watershed hydrological reaction. The geology of the watershed substrate influences both the runoff and the groundwater flow. For the runoff the main geologic characteristic is the permeability of the soil substrate. In case of rainfall a watershed that has an impermeable substrate presents a faster and more violent increase of the runoff in comparison to a watershed with a permeable substrate. A watershed with a permeable substrate will provide a base runoff during dry periods that will last longer. Watershed geology is essential for groundwater flow, through the identification of the karst areas. These karst areas may modify even the real watershed delimitation.

Hydrological characteristics

The analysis of the hydrologic behaviour of a watershed is done in order to study the hydrologic reaction of the watershed in relation to rainfall. This reaction is measured by observing the quantity of water that is drained from the system. The graphical representation of the evolution of the discharge Q versus time is called a hydrograph. The hydrologic reaction of a watershed to a particular rainfall is characterized by its speed and its intensity. **Hydrograph**

The hydrographic network is defined as the sum of all the watercourses, natural or artificial, permanent or temporary, which contribute to the runoff. The characteristics of a hydrographic network of a watershed are influenced by four main factors: geology, climate, relief and environment. The hydrographic network is one of the most important characteristics of a watershed.

Hydrographic network topology

The classification of the watercourses was introduced by Strahler (1957). The order of the watercourses reflects the degree of ramification of the hydrographic network from upstream to downstream and it is based on the following principles: [Musy, 2001]

- All watercourses without tributaries are of 1st order;
- The watercourse formed by the confluence of two watercourses of different order is going to keep the highest order of the two;
- The watercourse formed by the confluence of two watercourses of same order is going to have an order higher with one than the other two.

Characteristic slopes and length for hydrographic network

The steep slope of a watercourse favors and accelerates the runoff, while a small slope gives the water the necessary time to infiltrate totally or partially into the soil. The calculation of the average slope is obtained from the longitudinal profile of the main stream and its tributaries.

The most frequent method used to calculate the longitudinal slope of a watercourse consists of correlating the difference of altitude of the extreme points of the stream with its length.

where:

s1 longitudinal slope of stream [m/km] or [% $^{\circ}$]

ΔH difference of altitude of the extreme points of the stream [m]

L total length of the stream between its extreme points [km]

The degree of development of the hydrographic network

The degree of development of the hydrographic network, introduced by Horton, is given by the rapport between the total length of the hydrographic network and the watershed surface.

where:
Dd degree of development of the hydrographic network [km/km^2]
Li length of the stream [m]
A watershed surface [km]

The stability constant of a stream, introduced by Schumm, represents the opposite of the development degree of the hydrographical network.

Use: It is used to determine the location and design of conservation structures.

Topography

The relief influences the reaction of the watershed through the following characteristics:

- Watershed hypsographical curve gives a general synthetic view of the watershed relief.
- This curve represents the repartition of the watershed, taking its altitude into consideration.

Hypsographical curve of a watershed
The hypsographical curve has practical utility in the comparison of watersheds or of different sections of a
watershed. The hypsographical curve also helps to establish the average amount of precipitation over the
watershed, and can give information about the hydrologic and hydraulic behaviour of the watershed, and about its hydrographic network.

Characteristic altitudes for watershed
a) The extreme altitudes of the watershed, such as minimum and maximum, are obtained as a starting step
for topographic maps. The maximum altitude is the elevation of the highest point of the watershed, while the
minimum altitude is the elevation of the lowest point, this being generally the outlet section of the watershed.
These values determine the altimetry amplitude of a watershed and help to calculate the slope.
b) The average altitude of a watershed - can be deduced directly from the hypsographical curve or from
reading the topographical map. The average altitude of a watershed is often used in the evaluation of
certain hydro-meteorological parameters and

where:
Ha average altitude of the watershed [m]
Ai;i+1 area between two consecutive contour lines [km2]

hi ; hi+1 altitudes of the contour line [m]
A watershed area [km2]
c) The medium altitude of a watershed, represents the arithmetic mean of the values of maximum and
minimum altitudes of a watershed, and is expressed by the following relation:

where:
Hm medium altitude of the watershed [m]
Hm ax maximum altitude of the watershed [m]
Hm in minimum altitude of the watershed [m]

Concentration time

The concentration time *tc*, of the water in a watershed is defined as being the maximum of duration necessary for a water drop falling on the watershed surface to reach the outlet section of the watershed.
The concentration time is made up of three different terms:

th - humidification time - the time necessary for the soil to absorb the water;
tr - runoff time - the time that corresponds to the water flow from the surface or from the first soil horizon to a hydrographical network;
ta - moving time - the time necessary for the water drop to move through the hydrographical network
to the outlet section of the watershed.
Concentration time is thus equal to the maximum sum of the three elements:
The concentration time may be deduced through field measurements or may be estimated with empirical
formulas. [Musy, 2001]

Socioeconomics

Statistics on people and their health, hygiene, wants, wishes, cattle, farming practices and share of participation.

Isochrones

The isochrone is a contour joining points of equal concentration time of the water in a watershed. The farthest isochrones from the outlet section represent the time passed for which the whole watershed surface contributes to the flow towards the outlet section after a uniform rainfall.
Thus, the tracing of the isochrones network allows partial the comprehension of the hydrologic behaviour of a watershed and the relative importance of each of its sub watersheds. [Musy, 2001]
These curves allow, for different hypotheses, the determination of the hydrograph resulting from rainfall over the watershed.

Basic data on watersheds

Master Plan

An effort is made here in to present some details on preparation of a plan for a possible understanding of the list disciplines and their interrelationship.

Goals of Watershed Management Master Plan

- Protect and enhance water quality
- Conserve, reuse, and recharge water supply.
- Protect, enhance, and restore native habitats and biological resources.
- Promote public awareness and involvement in watershed management.

Survey for the Master Plan

Erosion

The uppermost weathered and disintegrated layer of the earth's crust is referred to as soil. The soil layer is composed of mineral and organic matter and is capable of sustaining plant life. The soil depth is less in some places and more at other places and may vary from practically nil to several meters. The soil layer is continuously exposed to the actions of atmosphere. Wind and water in motion are two main agencies which act on the soil layer and dislodge the soil particles and transport them. The loosening of the soil from its place and its transportation from one place to another is known as soil erosion.

The word erosion has been derived from the Latin word 'erodere' which means eating away or to excavate. The word erosion was first used in geology for describing the term hollow created by water. Erosion actually is a two phase process involving the detachment of individual soil particle from soil mass, transporting it from one place to another (by the action of any one of the agents of erosion, viz; water, wind, ice or gravity) and its deposition. When sufficient energy is not available to transport a particle, a third phase known as deposition occurs. In general, finer soil particles get eroded more easily than coarse particles (silt is more easily eroded than sand). Hence soil erosion is defined as a process of detachment, transportation and deposition of soil particles (sediment). It is evident that sediment is the end product of soil erosion process. Sediment is, therefore, defined as any fragmented material, which is transported or deposited by water, ice, air or any other natural agent. From this, it is inferred that sedimentation is also the process of detachment, transportation and deposition of eroded soil particles. Thus, the natural sequence of the sediment cycle is as follows:

Soil ⟶ **detachment** ⟶ **Transportation** ⟶ **Deposition**

Detachment is the dislodging of the soil particle from the soil mass by erosive agents. In case of water erosion, major erosive agents are impacting raindrops and runoff water flowing over the soil surface. Transportation is the entrainment and movement of detached soil particles (sediment) from their original location. Sediments move from the upland sources through the stream system and may eventually reach the ocean. Not all the sediment reaches the ocean; some are deposited at the base of the slopes, in reservoirs and flood plains along the way. Erosion is almost universally recognized as a serious threat to human well being. Erosion reduces the productivity of crop land by removing and washing away of plant nutrients and organic matter. Distribution of global sediment load is presented in Fig. 1.2.

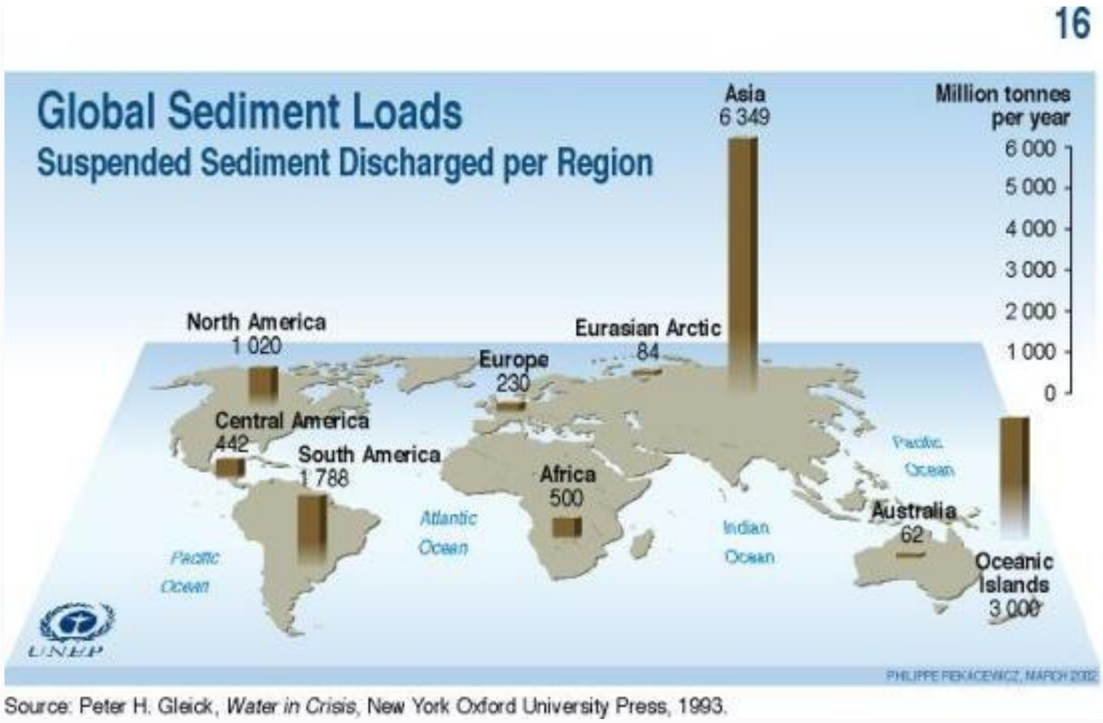


Fig. 1.2. Global sediment loads. Due to high monsoon rainfall, Asia has the highest suspended sediment discharge. (Source: Peter H.G., 1983)

1.1.2 Problems Arising due to Soil Erosion

Balanced ecosystems comprising soil, water and plant environments are essential for the survival and welfare of mankind. However, ecosystems have been disturbed in the past due to over exploitation in many parts of the world, including some parts of India. The resulting imbalance in the ecosystem is revealed through various undesirable effects, such as degradation of soil surfaces, frequent occurrence of intense floods etc.

infertile surfaces due to accelerated soil erosion caused by the above and other factors. These degraded land surfaces have also become a source of pollution of the natural water. Deposition of soil eroded from upland areas in the downstream reaches of rivers has caused aggradation. This has resulted in an increase in the flood plain area of the rivers, reduction of the clearance below bridges and culverts and sedimentation of reservoirs. Severity of land degradation at a continental scale is shown in Fig. 1.3.

The major land degradation problems due to sedimentation are briefly discussed as below:

- **Erosion by wind and water:** Out of 144.12 M-ha areas affected by water and wind erosion. About 69 M-ha is considered to be critical and needs immediate attention. Wind erosion is mainly restricted to States of Rajasthan, Gujarat and Haryana. The severity of wind erosion is inversely related to the rainfall amount, lesser is the rainfall more would be the wind erosion.
- **Gullies and Ravines:** About 4 M-ha is affected by the problem of gullies and ravines in the country covering about 12 states. Ravines are mostly located in the states of Uttar Pradesh, Madhya Pradesh, Rajasthan and Gujarat. Gullies on the other hand are seen in the plateau region of Eastern India, foot hills of the Himalayas and areas of Deccan Plateau.

- **Torrents and Riverine Lands**: Problem of Riverine and torrents is spread over an area of 2.73 M-ha in the country. Torrents are the natural streams which cause extensive damage to life and property as a result of frequent changes in their course and associated flash flows with heavy debris loads. The unfertile material or debris transported by torrents is sometimes deposited on the fertile plains, thus ruining the land for ever.
- **Water logging:** Water logging is caused either by surface flooding or due to rise of water table. An area of 8.53 M-ha has been estimated to be affected by water logging. Water logging due to surface flooding is predominant in the states of West Bengal, Assam, Bihar, Orissa, Andhra Pradesh, Uttar Pradesh, Kerala, Punjab and Haryana.
- **Shifting Cultivation:** Shifting cultivation, also known as ‘jhuming’ is a traditional method of growing crops on hill slopes by slash and burn method. The method involves selection of appropriate site on hill slopes, cleaning of forest by cutting and burning, using the site for cultivation for few years and later on abandoning it and moving to a fresh site. The jhum cycle has gradually declined from 20-30 years to 3-6 years due to increasing population pressures. The problem is more serious in North Eastern region and in the states of Orissa and Andhra Pradesh.

- **Saline soil including coastal areas**: Saline soils are prevalent both in inland as well as coastal areas. About 5.5 M-ha area is affected by this problem in the country which includes arid and semi-arid areas of Rajasthan and Gujarat, black soil region and coastal areas. This problem is causing serious damage to agricultural lands, rendering fertile soil unproductive and turning groundwater brackish in the States of West Bengal, Tamil Nadu, Orissa, Maharashtra, Kerala, Karnataka, Gujarat and Andhra Pradesh as well as Union Territories of Pondicherry and Goa, Daman and Diu.
- **Floods and Droughts:** In India, among the major and medium rivers of both Himalayas and non-Himalayas catagories, 18 are flood prone which drain an area of 150 M-ha. In recent years, flash floods have caused extensive damage even in the desert areas of Rajasthan and Gujarat.

1.1.3 Importance of Soil Conservation

In India, out of the total geographical area of 329 M-ha, an area of about 150 M-ha is subjected to either water or wind erosion. A net area of about 140 M-ha is cropped at present. An area of 40 M-ha is considered to be flood prone. Area lost through ravines and gullies is estimated to be about 4 M-ha. As a whole, it is estimated that about 175 M-ha i.e., 53.3% of the total geographical area of the country is subjected to various soil and land degradation problems like saline-alkali soils, waterlogged areas, ravine and gullied lands, area under shifting cultivation, and desertification. By the year 2100 A.D, the projected population of the country is expected to be two billion, whereas the food grain production is almost stagnant at 211 million tons for the last 5 years. The per capita cropped area is shrinking every day; in the year 1950, it was 0.33 ha/capita, 0.2 ha in 1980 and it was 0.15 ha by 2000. This clearly shows that the limited land resource has to be managed very carefully by adopting total conservation measures for the survival of the huge population. A few suggestions to conserve soil and water resources in Indian context are discussed below.

- To prevent erosion of bare soil, it is important to maintain a vegetation cover, especially in the most vulnerable areas e.g. those with steep slopes, in a dry season or periods of very heavy rainfall. For this purpose, only partial harvesting forests (e.g. alternate trees) and use of seasonally dry or wet areas for pasture rather than arable agricultural land should be permitted.
- Where intensive cultivation takes place, farmers should follow crop rotation in order to prevent the soil becoming exhausted of organic matters and other soil building agents. Where soils are ploughed in vulnerable areas, contour ploughing (i.e. round the

hillside rather than down the hillside) should be used. Careful management of irrigation, to prevent the application of too much or too little water will be helpful to reduce the problem of soil salinity development. Livestock grazing must be carefully managed to prevent overgrazing.

- Construction of highways and urbanization should be restricted to areas of lower agricultural potential. With extractive industries, a pledge must be secured to restore the land to its former condition before permission for quarries or mines is granted.

1.1.4 History of Soil Erosion and Soil Conservation Programs in India

To meet the demand for food, fiber, fuel wood and fodder owing to increasing population pressures, the forest areas have been indiscriminately cleared resulting in enormous soil loss in many parts of the country. The human activities such as urbanization, road construction, mining etc. have further aggravated the problem. In the early years, the problem was more localized but now it has become more serious due to over exploitation of natural resources. However, various governmental plans have been implemented in the field of conservation of land, water and plant resources since pre-independence days.

(1) The Pre-Independence Era

In 1882, Sir Dietrich Brands, the Inspector General of Forests, commented on the possibility of soil erosion taking place and the need to counter it in the denuded slopes of the Nilgiri District of Madras Province of pre-independence India. He suggested planting of belts of trees in the midst of cultivation on hill slopes. Protection of land from the menace of 'Cho' (mountain torrents) also received early attention and one of the first enactments for prevention of soil deterioration was passed in Punjab in 1900 as Land Preservation Act. It provided for such measures as Wat Bandi (ridge formation), contour trenching, gully plugging, terracing, tree planting etc. for preventing the havoc caused by Chos. Soil conservation research in India was initiated during 1933-35 when the then Imperial (now Indian) Council of Agricultural Research decided to establish its regional centres for research in dry farming at Sholapur (Maharashtra), Bijapur, Raichur, Bellary (Karnataka) and Rohtak (Haryana). Holding rain water by construction of bunds, green manuring, cultivation of kharif crops on shallow soils and fallowing in deep black soils were important measures recommended by the research stations.

A real push to soil conservation was given when a separate Soil Conservation Wing in Agricultural Department was established in Maharashtra during 1940's and massive contour bunding programme was taken up following scientific guidelines and specifications. Field bunding was also practiced as part of famine relief programmes in the Deccan plateau during 1930's and 40's. Soil conservation was not confined to contour bunding alone but also included nala bunding (check dams of loose stones) and percolation dams for water harvesting.

A commission was appointed by the Gwalior State as far back as 1919 to consider ways and means of arresting further extension of ravines and suggest methods for improving production of economic plants in these areas. In the 1930's, ravine reclamation practices were applied in the Chambal ravines of the erstwhile state of Gwalior. In 1953, Board of Agriculture made a proposal for a systematic reconnaissance survey of Indian soils to assess the damage caused by erosion. The Bombay Land Improvement Act of 1942 provided for setting up in each division a Land Improvement Board for conservation, improvement and regulation of agriculture, forest and pasture lands.

In 1945, the Central Government obtained the services of Dr. Donald V. Shuhart of Soil Conservation Service, USDA to report on soil erosion problems in India and suggest remedial measures. A high powered seven member team visited United States in May, 1947 for exhaustive study of soil conservation practices and submitted a report to Government of India taking due cognizance of the conditions peculiar to the Indian Agriculture. The team suggested that the unit of planning should be a village or a group of villages or a watershed. The report also emphasized that there should be a close cooperation between the Department of Forest, Agriculture and Irrigation at the centre and in the provinces in initiating and developing different phases of the conservation programme.

(2) Post-Independence Period

A conference of state Ministers in-charge of agriculture and cooperation was held in New Delhi in September, 1953. The conference considered that at the state level, existing organizations and state development committees should be entrusted with the task of formulating soil conservation programmes. It also suggested that any state problem with regard to soil conservation should be concern of the Central Soil Conservation Board. The central Government in the Ministry of Food and Agriculture set up a Central Soil Conservation Board in 1953. Maharashtra state did pioneering work on problems of soil erosion and conservation measures in cultivated lands. It was realized that ultimate aim of soil conservation was not only to control erosion but also to maintain the productivity of soil.

(3) First Five Year Plan (1951-56)

During the First Five Year Plan (1951-56), considerable attention was given to soil and moisture conservation. With a view to develop a research base for soil conservation, a Soil Conservation Branch and a Desert Afforestation

Research Station at Jodhpur were established under the control of Forest Research Institute, Dehra Dun. Consequently, the Central Soil Conservation Board established a chain of nine Soil Conservation Research, Demonstration and Training Centers at Dehra Dun, Chandigarh, Bellary, Ootacamund (now Udhagamandalam), Kota, Vasad, Agra, Chatra (Nepal) and Jodhpur during the late First Five Year Plan and early Second Five Year Plan.

(4) Second Five Year Plan (1956-61)

In this plan, the Desert Afforestation and Soil Conservation Centre at Jodhpur were developed into the Central Arid Zone Research Institute (CAZRI) in 1959 with collaboration of UNESCO. A Centre was set up at Chatra in Nepal to take-up research on soil conservation problems of Kosi River Valley Project. The All India Soil & Land Use Survey Organization was established at central level.

(5) Third Five Year Plan (1961-66)

A centre at Ibrahimpatnam (Hyderabad) in the semi-arid red soil region was established in the third five year plan in 1962. The Government of India reorganized the Soil Conservation Division in the Ministry of Agriculture and redesignated the Senior Director as Advisor and entrusted him with the responsibility of coordinating the soil and water conservation development. After the reorganization of Agricultural Research and Education in India, all the Soil

Conservation Research, Demonstration and Training Centres of the Government of India except Chatra (Nepal) were transferred to the Indian Council of Agricultural Research (ICAR) on the 1st October, 1967.

(6) Fourth Five Year Plan (1969-74)

Under this plan, All India Soil & Land Use Survey prepared a detailed analysis of different watersheds of the country. The concept of Integrated Watershed Management was successfully introduced at field level in different parts of the country.

(7) Fifth Five Year Plan (1974-79)

In this plan, the Government of India introduced many centrally sponsored programmers, viz; Drought Prone Area Programme (DPAP), Flood Prone Area Programme (FPAP), Rural Development Programme (RDP), and Desert Development Programme (DDP). In DPAP and DDP, the focus was on planting of trees on degraded lands and to drill tube wells to extract groundwater.

(8) Sixth Five Year Plan (1980-85)

In this plan period, more emphasis was given on the treatment of small watersheds varying in size up to 2000 hectare. An intensive programme for integrated management of about 200 sub-watersheds of 8 flood prone catchments of Ganga river basin was undertaken during this plan.

(9) Seventh Five Year Plan (1985-90)

In this plan, DDP in hot and cold desert areas took a major establishment and aforestation practices were adopted on a large scale following integrated watershed management approach. On the basis of the experience gained in various schemes, National Watershed Development Programme for Rainfed Areas (NWDPRA) was launched in the 7^{th} Plan in 99 selected districts in the country. NWDPRA was implemented in about 2550 watersheds in 357 districts of 25 states and two Union Territories, viz; Andaman and Nicobar Islands and Dadra and Nagar Haveli. The watershed approach has the advantage of serving the twin objectives of restoration of ecological balance and socio-economic welfare of watershed community.

(10) Eighth Five Year Plan (1990-95)

During this period, Ministry of Agriculture, Department of Agriculture and Cooperation, New Delhi formulated the guidelines for the implementation of NWDPRA and published it in the form of a document commonly known as WARASA (Watershed Areas Rainfed Agriculture System Approach). The Ministry of Rural Development also brought out common guidelines for the implementation of

DPAP, DDP and Integrated Wasteland Development Programme (IWDP) in the country so as to maintain uniformity in objectives, strategies and expenditure norms for various watershed development projects.

(11) Ninth Five Year Plan (1997-02)

The centrally sponsored scheme for reclamation of alkali soils was launched during the Seventh Five Year Plan in the states of Haryana, Punjab and Uttar Pradesh. It continued during the Eighth Five Year Plan and was extended to the states of Gujarat, Madhya Pradesh and Rajasthan. During 2000-01, it was extended to all other states where alkali soil problem exists. The scheme aimed at improving physical conditions and productivity status of alkali soils for restoring optimum crop production. The major components were assured irrigation water, on-farm development works like land leveling, bunding and ploughing, community drainage system, application of soil amendments, organic manures etc. During IX Plan, an area of 0.97 lakh ha, mostly occurring in isolated patches, was reclaimed at a cost of Rs. 14.99 crores (Govt. of India share).

Up to IX plan (1997-02), an area of 426 lakh ha had been covered under Priority Delineation Survey (PDS) and about 13.1 lakh ha under Detailed Soil Survey (DSS) by the All India Soil and Land Use Survey.

(12) Tenth Five Year Plan (2002-07)

The Tenth Five Year Plan (2002-2007) has put emphasis on natural resource management through rainwater harvesting, groundwater recharging measures and controlling groundwater exploitation, watershed development, treatment of waterlogged areas. The Government of India fully funded the Western Ghats Development Programme (WGDP), area affected due to erosion and water problem. In this programme, the State Governments were directed to adopt Integrated Watershed Approach in implementing the activities such as soil conservation, agriculture, horticulture, afforestation, fuel and fodder development, minor irrigation, animal husbandry etc. various soil conservation measures (engineering and agricultural) like construction of check dams, gully plugging, plantation of mixed species and contour trenching etc were taken up in sensitive Western Ghats areas of Sattari, Canacona and Sanguem talukas.

(13) Eleventh Five Year Plan (2007-12)

Watershed development projects, for the purpose of conserving soil and water, were funded through various schemes including National Watershed Development Projects in Rainfed Areas (NWDPRA), River Valley Projects (RVP), and Integrated Wasteland Development Programme (IWDP). Emphasis has been given to increase the water resources availability and their efficient use. Responsibility for ensuring adequate availability of water for agricultural use was divided between the Ministry of

Water Resources (MoWR), which was responsible for major, medium, and minor irrigation, the Department of Land Resources, which was responsible for watershed management, the Department of Rural Development, which was responsible for the Mahatma Gandhi Rural Employment Guarantee Act (MGNREGA) and strongly oriented to deal with water conservation issues, and the Department of Agriculture, which deals with water use efficiency

Causes of Soil Erosion

No single unique cause can be held responsible for soil erosion or assumed as the main cause for this problem. There are many underlying factors responsible for this process, some induced by nature and others by human being. The main causes of soil erosion can be enumerated as:

(1) Destruction of Natural Protective Cover by

(i) indiscriminate cutting of trees,

(ii) overgrazing of the vegetative cover and

(iii) forest fires.

(2) Improper Use of the Land

(i) keeping the land barren subjecting it to the action of rain and wind,

(ii) growing of crops that accelerate soil erosion,

(iii) removal of organic matter and plant nutrients by injudicious cropping patterns,

(iv) cultivation along the land slope, and

(v) faulty methos of irrigation.

2.2 Types of Soil Erosion

2.2.1 According to Origin: Soil erosion can broadly be categorized into two types i.e. geologic erosion and accelerated erosion.

2.2.2 Geological Erosion: Under natural undisturbed conditions an equilibrium is established between the climate of a place and the vegetative cover that protects the soil layer. Vegetative covers like trees and forests retard the transportation of soil material and act as a check against excessive erosion. A certain amount of erosion, however, does take place even under the natural cover. This erosion, called geologic erosion, is a slow process and is compensated by the formation of soil under the natural weathering process. Their effects are not of much consequence so far as agricultural lands are concerned.

2.2.3 Accelerated Erosion: When land is put under cultivation, the natural balance existing between the soil, its vegetation cover and climate is disturbed. Under such condition, the removal of surface soil due to natural agencies takes places at faster rate than it can be built by the soil formation process. Erosion occurring under this condition is referred to as accelerated erosion. Its rates are higher than geological erosion. Accelerated erosion depletes soil fertility in agricultural land.

2.2.4 According to Erosion Agents: Soil erosion is broadly categorized into different types depending on the agent which triggers the erosion activity. Mentioned below are the four main types of soil erosion.

(1) Water Erosion: Water erosion is seen in many parts of the world. In fact, running water is the most common agent of soil erosion. This includes rivers which erode the river basin, rainwater which erodes various landforms, and the sea waves which erode the coastal areas. Water erodes and transports soil particles from higher altitude and deposits them in low lying areas. Water erosion may further be classified, based on different actions of water responsible for erosion, as : (i) raindrop erosion, (ii) sheet erosion, (iii) rill erosion, (iv) gully erosion, (v) stream bank erosion, and (vi) slip erosion.

(2) Wind Erosion: Wind erosion is most often witnessed in dry areas wherein strong winds brush against various landforms, cutting through them and loosening the soil particles, which are lifted and transported towards the direction in which the wind blows. The best example of wind erosion are sand dunes and mushroom rocks structures, typically found in deserts.

(3) Glacial Erosion: Glacial erosion, also referred to as ice erosion, is common in cold regions at high altitudes. When soil comes in contact with large moving glaciers, it sticks to the base of these glaciers. This is eventually transported with the glaciers, and as they start melting it is deposited in the course of the moving chunks of ice.

(4) Gravitational Erosion: Although gravitational erosion is not as common a phenomenon as water erosion, it can cause huge damage to natural, as well as man-made structures. It is basically the mass movement of soil due to gravitational force. The best examples of this are landslides and slumps. While landslides and slumps happen within seconds, phenomena such as soil creep take a longer period for occurrence.

2.3 Agents of Soil Erosion

Soil erosion is the detachment of soil from its original location and transportation to a new location. Mainly water is responsible for this erosion although in many locations wind, glaciers are also the agents causing soil erosion. Water in the form of rain, flood and runoff badly affects the soil. Soil is in fact a composite of sand, silt and clay. When the rain falls along the mountains and bare soil, the water detaches the soil particles, and takes away the silt and clay particles along with the flowing water. Similarly, when wind blows in the form of storms, its speed becomes too high to lift off the entire soil upper layer and causes soil erosion.

Other factors responsible for soil erosion are human and animal activities. Vegetation is the natural cover of soil. When the animals continuously graze in the pastures, the vegetation is removed due to their walking and grazing. Bare lands left behind are easily affected by soil erosion. Activities of human like forest cutting, increased agriculture, and clearing of land for different purposes are the other agents that cause erosion of the soil. The soil erosion agent can be classified and summarized as shown in Fig. 2.1.

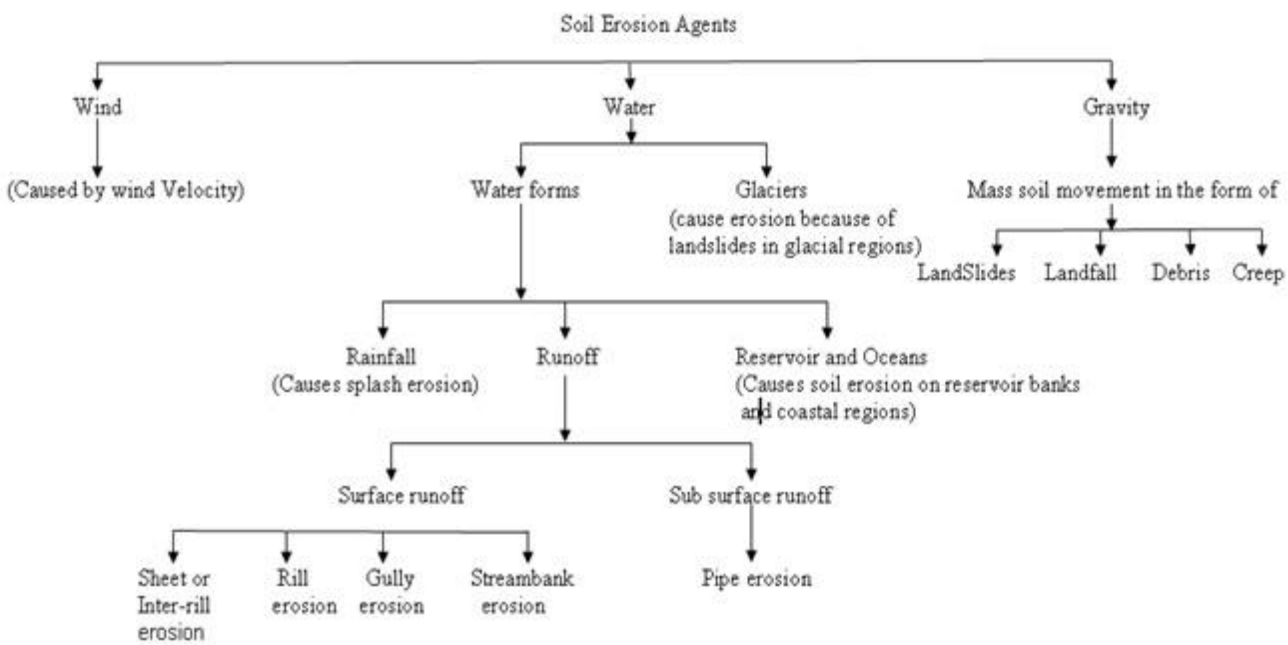


Fig. 2.1. Soil erosion agents, processes and effects. (Sources: Das, 2000)

2.4 Factors Affecting Soil Erosion

Soil erosion includes the processes of detachment of soil particles from the soil mass and subsequent transport and deposition of those soil/sediment particles. The main factors responsible for soil erosion, in India, are excessive deforestation, overgrazing and faulty agricultural practices. Soil erosion is a very complicated problem as many complex factors affect the rate of erosion and therefore it is difficult to solve. These factors include:

1. Climatic Factor: The climatic factors that influence erosion are rainfall amount, intensity, and frequency. During the periods of frequent or continuous rainfall, high soil moisture or saturated field conditions are developed, a greater percentage of the rainfall is converted into runoff. This in turn results in soil detachment and transport causing erosion at high rate.

2. Temperature: While frozen soil is highly resistant to erosion, rapid thawing of the soil surface brought about by warm rains can lead to serious erosion. Temperature also influences the type of precipitation. Although falling snow does not cause erosion, heavy snow melts in spring can cause considerable runoff damage. Temperature also influences the amount of organic matter that get collected on the ground surface and get incorporated with the topsoil layer. Areas with warmer climates have thinner organic cover on the soil. Organic matter cover on the surface protects the soil by shielding it from the impact of falling rain and helping in the infiltration of rainfall that would otherwise cause more runoff. Organic matter inside the soil increases permeability of the soil to cause more percolation and reduce runoff.

3. Topographical Factors: Among the topographical factors, slope length, steepness and roughness affect erodibility. Generally, longer slope increases the potential for erosion. The greatest erosion potential is at the base of the slope, where runoff velocity is the greatest and runoff concentrates. Slope steepness, along with surface roughness, and the amount and intensity of rainfall control the speed at which runoff flows down a slope. The steeper the slope, the faster the water will flow. The faster it flows, the more likely it will cause erosion and increase sedimentation. Slope accelerates erosion as it increases the velocity of flowing water. Small differences in slope make big difference in damage. According to the laws of hydraulics, four times increase in slope doubles the velocity of flowing water. This doubled velocity can increase the erosive power four times and the carrying (sediment) capacity by 32 times.

4. Soil: Physical characteristics of soil have a bearing on erodibility. Soil properties influencing erodibility include texture, structure and cohesion. Texture refers to the size or combination of sizes of the individual soil particles. Three broad size classifications, ranging from small to large are clay, silt, and sand. Soil having a large amount of silt-sized particles is most susceptible to erosion from both wind and water. Soil with clay or sand-sized particles is less prone to erosion.

Structure refers to the degree to which soil particles are clumped together, forming larger clumps and pore spaces. Structure influences both the ability of the soil to absorb water and its physical resistance to erosion. Another property is the cohesion which refers to the binding force between the soil particles and it influences the structure. When moist, the individual soil particles in a cohesive soil cling together to form a doughy consistency. Clay soils are very cohesive, while sand soils are the least cohesive.

5. Vegetation: Vegetation is probably the most important physical factor influencing soil erosion. A good cover of vegetation shields the soil from the impact of raindrops. It also binds the soil together, making it more resistant to runoff. A vegetative cover provides organic matter, slows down runoff, and filters sediment. On a graded slope, the condition of vegetative cover will determine whether erosion will be stopped or only slightly halted. A dense, robust cover of vegetation is one of the best protections against soil erosion.

6. Biological Factors of Soil Erosion: Biological factors that influence the soil erosion are the activities like faulty cultivation practices, overgrazing by animals etc. These factors may be broadly classified into following three groups:(i) Energy factors, (ii) Resistance factors, and (iii) protection factors.

(i) Energy Factors: They include such factors which influence the potential ability of rainfall, runoff and wind to cause erosion. This ability is termed as erosivity. The other factors which directly reduce the power of erosive agents are reduction in length/degree of slope through the construction of terraces and bunds in case of water eroded areas and creation of wind breaks or shelter belts in case of wind eroded areas.

(ii) Resistance Factors: They are also called erodibility factors which depend upon the mechanical and chemical properties of the soil. Those factors which enhance the infiltration of water into the soil reduce runoff and decrease erodibility, while any activity that pulverizes the soil increases erodibility. Thus, cultivation may decrease the erodibility of clay soils but increases that of sandy soil.

(iii) Protection Factors: This primarily focuses on the factors related to plant cover. Plant cover protects the soil from erosion by intercepting the rainfall and reducing the velocity of runoff and wind. Degree of protection provided by different plant covers varies considerably. Therefore, it is essential to know the rate of soil erosion under different land uses, degrees of length and slope, and vegetative covers so that appropriate land use can be selected for each piece of land to control the rate of soil erosion. The quantity of soil moved past a point is called soil loss. It is usually expressed in unit of mass or volume per unit time per unit area.

2.5 Mechanics of Soil Erosion

Soil erosion is initiated by detachment of soil particles due to action of rain. The detached particles are transported by erosion agents from one place to another and finally get settled at some place leading to soil erosion process. Different soil erosion processes are shown in Fig. 2.2.

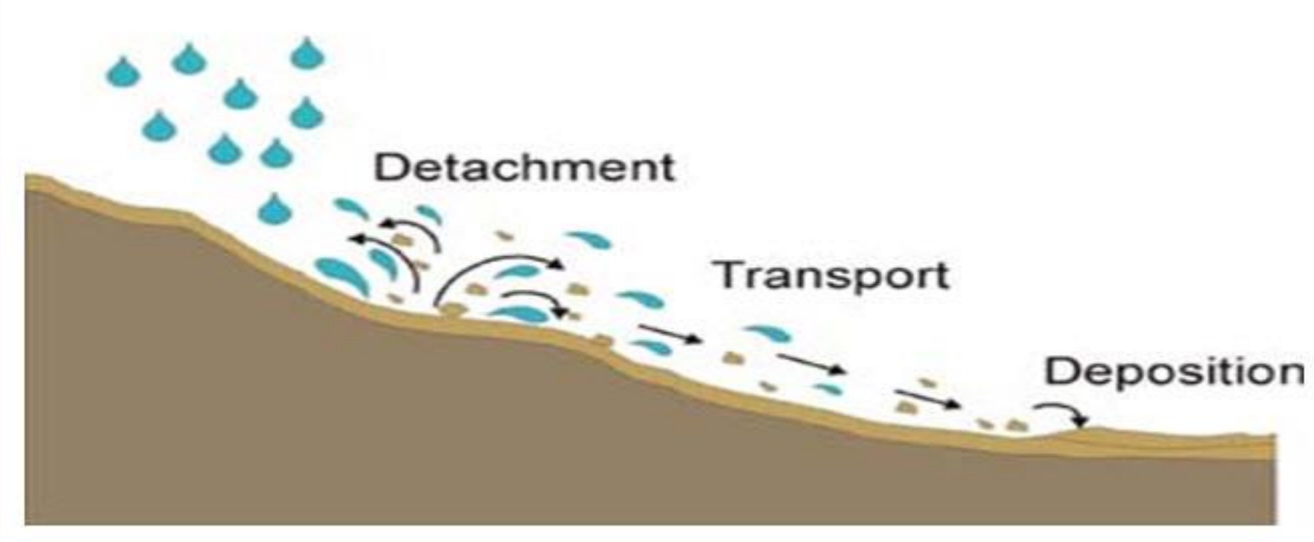


Fig. 2.2. Process of water erosion by the impact of raindrops.

(Source: www.landfood.ubc.ca)

Mechanics of soil erosion due to water and wind is discussed below.

2.5.1 Mechanics of Water Erosion

There are three steps for accelerated erosion by water:

i) Detachment or loosening of soil particles caused by flowing water, freezing and thawing of the top soil, and/or the impact of falling raindrops,

ii) Transportation of soil particles by floating, rolling, dragging, and/or splashing and

iii) Deposition of transported particles at some places of lower elevation.

Rain enhances the translocation of soil through the process of splashing as shown in Fig.2.2. Individual raindrops detach soil aggregates and redeposit them as particles. The dispersed particles may then plug soil pores, reducing water intake (infiltration). Once the soil dries, these particles develop into a crust at the soil surface and runoff is further increased.

2.5.2 Mechanics of Wind Erosion

Wind erosion occurs where soil is exposed to the dislodging force of wind. The intensity of wind erosion varies with surface roughness, slope and types of cover on the soil surface and wind velocity, duration and angle of incidence. Fine soil particles can be carried to great heights and for (may be) hundreds of kilometers. The overall occurrence of wind erosion could be described in three different phases. These are initiation of movement, transportation and deposition.

1. Initiation of Movement: The initiation of the movement of soil particles is caused by several factors acting separately in combination. In the course of collision of grains rolling and bumping on the surface, some particles may be bounced up. It occurs when the wind force or the impact of moving particles is strong enough to dislodge stationary soil particles.

2. Transportation: The transportation of the particles once they are dislodged take place in three ways:

i) Saltation – In saltation soil particles of medium size (0.10-0.15 mm diameter) are carried by wind in a series of short bounces. These bounces are caused by the direct pressure of the wind on soil particles.

ii) Soil Creep – saltation also encourages soil creep (rolling or sliding) along the surface of the particles (0.5-1.0 mm diameter). The bouncing particles carried by saltation strike the large aggregates and speed up their movement along the surface.

iii) Suspension – When the particles of soil are very small (less than 0.1 mm) they are carried over long distances. Finer suspended particles are moved parallel to the ground surface and upward.

3. Deposition: Deposition of the particles occurs when the gravitational force is greater than the forces holding the particles in air. Deposition could occur when the wind velocity is decreased due to surface obstructions or other natural causes

Erosion Due to Water

Erosion of soil by water is caused by its two forms: liquid as the flowing water, and solid as the glaciers.

3.1 Forms of Water Erosion

The impact of rainfall causes splash erosion. Runoff water causes scraping and transport of soil particles leading to sheet, rill and gully erosion. Water waves cause erosion of bank sides of reservoirs, lakes and oceans. The subsurface runoff causes soil erosion in the form of pipe erosion, which is also called tunnel erosion. The glacial erosion causes heavy landsides. In India, glacial erosions are mainly confined to Himalayan regions. The various forms of water erosion are given below.

3.1.1 Hydraulic Action: The hydraulic action takes place when water runs over the soil surface compressing the soil, as a result of which the air present in the voids exerts a pressure on the soil particles and this leads to the soil detachment. The pressure exerted by the air voids is called hydraulic pressure. The soil particles so detached from their places, are scoured by the running water. The hydraulic action is more effective when the soil is in loose condition.

3.1.2 Abrasion: Soil particles mixed with the running water create an abrasive power in the water which increases the capacity of flowing water to scour more soil particles. Due to this effect, larger soil particles are eroded by the flowing water.

3.1.3 Attrition: This form includes mechanical breakdown of loads running along the moving water due to collision of particles with each other. The broken particles are moved along with the flow velocity, which generate abrasion effect on the bottom and banks of the water course. This effect pronounces the water erosion.

3.1.4 Solution: This form is associated with the chemical action between running water and soil or country rocks. This type condition is observed in areas where existing rocks or soils are easily dissolved in the running water.

3.1.5 Transportation: The process of soil transportation by running water is completed under the following forms:

1) **Solution:** the water soluble contents present in the water are transported by the water in solution form.

2) **Suspension:** it involves the transportation of finer soil particles, which are present in suspension form in the flowing water.

3) **Saltation and Surface Creep:** it involves transportation of medium size soil particles that are not able to stand in suspension form, but are mixed in water and flow over the stream bed in the form of mud. The surface creep action is responsible for transporting the coarser soil particles.

3.2 Factors Affecting Water Erosion

Water erosion is due to dispersive and transporting power of the water; as in case of water erosion first soil particles are detached from the soil surface by the raindrop force and then transported with surface runoff. There is a direct relationship between the soil loss and surface runoff volume. The water erosion process is influenced primarily by climate, topography, soils and vegetative cover. The factors influencing the water erosion are discussed below.

3.2.1 Climatic Factors: Climate includes rainfall, temperature and wind. The frequency, intensity and duration of rainfall are the principal aspects of rainfall influencing the volume of runoff, erosion and sediment (potential) from a given area. As the volume and intensity of rainfall increase, the ability of water to detach and transport soil particles increases. When storms are frequent, intense, and of long duration, the potential for erosion of bare soils is high. Temperature has a major influence on soil erosion. Frozen soils are relatively erosion resistant. However, bare soils with high moisture content are subject to uplift or “spew” by freezing action and are usually easily eroded upon thawing. Wind contributes to the drying of soil and increases the need for irrigation for new plantings and for applying wind erosion control practices.

3.2.2 Soil Characteristics: Soil characteristics include texture, structure, organic matter content and permeability. In addition, in many situations, compaction is significant. These characteristics greatly determine the erodibility of soil. Soils containing high percentages of sand and silt are the most susceptible to detachment because they lack inherent cohesive characteristics. However, the high infiltration rates of sands either prevent or delay runoff except where overland flow is concentrated. Clearly, well-graded and well-drained sands are usually the least erodible soils in the context of sheet and rill erosion. Clay and organic matter act as a binder to soil particles, thus reducing erodibility. As the clay and organic matter content of soils increase, the erodibility decreases. However, while clays have a tendency to resist erosion, they are easily transported by water once detached. Soils high in organic matter resist raindrop impact, and the organic matter also increases the binding characteristics of the soil. Sandy and silty soils on slopes are highly susceptible to gully erosion where flow concentrates because they lack inherent cohesiveness. Small clay particles, referred to as colloids, resist the action of gravity and remain in suspension for long periods of time. Colloids are potentially a major contributor to turbidity where they exist.

3.2.3 Vegetation Cover: Vegetative cover is an extremely important factor in reducing erosion at a site. It absorbs energy of raindrops, binds soil particles, slows down the velocity of runoff water, increases the ability of a soil to absorb water, removes subsurface water between rainfall events through the process of evapotranspiration and reduces off-site fugitive dust. By limiting the amount of vegetation disturbance and the exposure of soils to erosive elements, soil erosion can be greatly reduced. Vegetations create a surface obstruction for direct falling of raindrops on the land surface as well as in the flowing path of surface runoff. A good vegetative cover completely negates the effect of rainfall on soil erosion.

3.2.4 Topographic Effect: The main topographic factors which influence the soil erosion are land slope, length of slope and shape of slope. The land slope or slope inclination affects the erosion predominantly. As the slope increases, the runoff coefficient, kinetic energy and carrying capacity of surface runoff also increase thereby decreasing the soil stability. Critical slope length is the slope length at which the soil erosion begins. It is related to the critical land inclination. Lower the critical inclination larger will be the critical slope length. The slope shapes have greater bearing on erosion potential. The base of a slope is more susceptible to erosion than the top, because runoff has more momentum and is more concentrated as it approaches the base of slope. The slopes may be roughly convex or concave. On convex slope the above phenomena is magnified, whereas on concave slope it is reduced. It is because in convex slope, the steepness increases towards bottom, while it is flattened towards bottom in case of concave slope.

3.3 Types of Water Erosion

Water erosion can be classified as splash erosion, sheet erosion, rill erosion, gully erosion, stream bank erosion, sea-shore erosion and land slide erosion. They are discussed as follows.

3.3.1 Splash Erosion: It is also known as raindrop erosion (Fig. 3.1) because it is caused by the impact of raindrops on exposed soil surface. The process of raindrop erosion can be described as: when raindrop strikes on open soil surface it forms a crater. This is accomplished by forming a blast which bounces the water and soil up and returns back around the crater. The soil may be splashed into the air up to a height of 50 to 75 cm depending upon the size of rain drops. At the same time the soil particles also move horizontally as much as 1.50 m on level land surface. On sloping land, more than half of the splashed particles move down with the runoff.

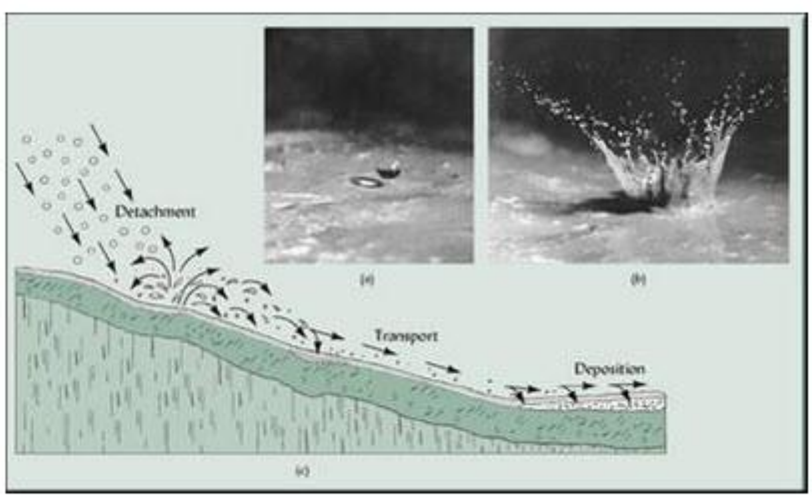


Fig. 3.1. Splash erosion.
(Source: www.bierbrauerf.weebly.com)

3.3.2 Sheet Erosion: Sheet erosion may be defined as more or less uniform removal of soil in the form of a thin layer or in "sheet" form by the flowing water form a given width of sloping land (Fig. 3.2). It is an inconspicuous type of soil erosion because the total amount of soil removed during any storm is usually small. In the sheet erosion two basic erosion processes are involved. First process is the one in which soil particles are detached from the soil surface by falling of raindrop and in the second one the detached soil particles are transported away by surface runoff from the original place. The detached process is referred to as the splash erosion and transportation of detached particles by flowing water is considered as the wash erosion. When the rate of rainfall exceeds the infiltration rate of the soil, the excess water tends to flow over the surface of sloping land. This flowing water also detaches soil particles from the land surface and starts flowing in the form of thin layer over the surface. The erosion during these processes is called sheet erosion. The eroding and transporting power of sheet flow depends on the depth and velocity of flowing water for a given size, shape and density of soil particles.

Fig. 3.2. Sheet erosion.
(Source: www.soer.justice.tas.gov.au)

3.3.3 Rill Erosion: This type of water erosion is formed in the cultivated fields where the land surface is almost irregular. As the rain starts, the water tends to accumulate in the surface depressions and begins to flow following least resistance path. During movement of water large amount of soil particles are eroded from the sides and bottom of the flow path, which are mixed in the flowing water. This surface flow containing soil particles in suspension form moves ahead and forms micro channels and rills (Fig. 3.3).

Fig. 3.3. Rill erosion. (Source: http://www.kalkaskacounty.net)

3.3.4 Gully Erosion: Rills are small in size and can be leveled by tillage operations. When rills get larger in size and shape due to prolonged occurrence of flow through them and cannot be removed by tillage operation, these are called gullies (Fig. 3.4). Large gullies and their network are called ravines. It is the advanced and last stage of water erosion. In other words it is the advanced stage of rill erosion. If the rills that are formed in the field are overlooked by the farmers, then they tend to increase in their size and shape with the occurrence of further rainfall. Some of the major causes of gully erosion are: steepness of land slope, soil texture, rainfall intensity, land mismanagement, biotic interference with natural vegetation, incorrect agricultural practices, etc. Gully erosion gets initiated where the longitudinal profile of an alluvial land becomes too steep due to sediment deposition.

Gullies advance due to the removal of soil by the flowing water at the base of a steep slope, or a cliff at the time of fall of stream. High intensity of flow of the runoff increases the gully dimensions. In the absence of proper control measures, slowly the gullies extend to nearby areas and subsequently engulf the entire region with a network of gullies of various sizes and shapes.

Fig. 3.4. Gully erosion. (Source: www.soilsurvey.com.au)

3.3.5 Stream Bank Erosion: Stream bank erosion is defined as the removal of stream bank soil by water either flowing over the sides of the stream or scouring from there (Fig.3.5). The stream bank erosion due to stream flow in the form of scouring and undercutting of the soil below the water surface caused by wave action is a continuous process in perennial streams. Stream bank erosion is mainly aggravated due to removal of vegetation, over grazing or cultivation on the area close to stream banks. Stream bank erosion is also caused by the occurrence of flood in the stream. Apart from scouring, the sloughing is also a form of stream bank erosion which is caused when the stream water subsides after reaching the peak. Sloughing is mainly due to movement of underground water from side into the stream due to pressure difference.

Fig. 3.5. Stream bank erosion. (Source: www.sswc.org)

3.3.6 Sea-shore Erosion: It is also called coastal erosion. Sea shore erosion is the wearing away of land and the removal of beach or dune sediments by wave action, tidal currents, wave currents, or drainage (Fig. 3.6). Waves, generated by storms, wind or fast moving motor craft, cause coastal erosion which may take the form of long-term losses of sediment and rocks, or merely the temporary redistribution of coastal sediments. It may be caused by hydraulic action, abrasion, impact and corrosion.

Fig. 3.6. Sea-shore/ coastal erosion.
(Source: www.climatide.wgbh.org)

3.3.7 Landslide Erosion: When gravity combines with heavy rain or earthquakes, whole slopes can slump, slip or slide (Fig. 3.7). Slips occur when the soil (topsoil and subsoil) on slopes becomes saturated. Unless held by plant roots to the underlying surface, it slides downhill, exposing the underlying material.

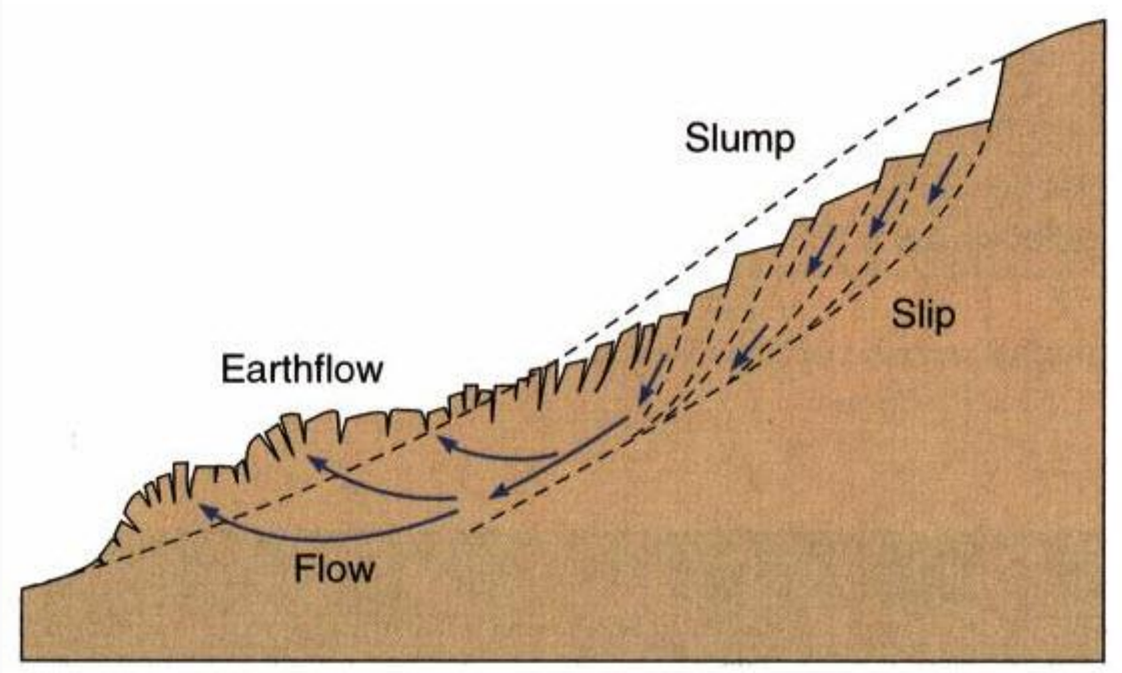


Fig. 3.7. Cross-section of landslide characteristics

Measures of Water Erosion Control

Soil conservation is a preservation technique, in which deterioration of soil and its losses are eliminated or minimized by using it within its capabilities and applying conservation techniques for protection as well as improvement of soil. In soil and water conservation, the agronomical measure is a more economical, long lasting and effective technique. Agronomic conservation measures function by reducing the impact of raindrops through interception and thus reducing soil erosion. They also increase infiltration rates and thereby reduce surface runoff. Widely used agronomic measures for water erosion control are listed below.

4.2.1 Contour Cropping

Contour Cropping is a conservation farming method that is used on slopes to control soil losses due to water erosion. Contour cropping involves planting crops across the slope instead of up and down the slope (Fig. 4.1). Use of contour cropping protects the valuable top soil by reducing the velocity of runoff water and inducing more infiltration. On long and smooth slope, contour cropping is more effective as the velocity of flow is high under such situation and contour cropping shortens the slope length to reduce the flow velocity. Contour cropping is most effective on slopes between 2 and 10 percent.

Fig. 4.1. Contour cropping.)

4.2.2 Strip Cropping

Strip cropping is the practice of growing strip of crops having poor potential for erosion control, such as root crop (intertilled crops), cereals, etc., alternated with strips of crops having good potentials for erosion control, such as fodder crops, grasses, etc., which are close growing crops (Fig. 4.2). Strip cropping is a more intensive farming practice than contour farming. The farming practices that are included in this type of farming are contour strip farming, cover cropping, farming with conservation tillage and suitable crop rotation. A crop rotation with a combination of intertilled and close growing crops, farmed on contours, provides food, fodder and conserves soil moisture. Close growing crops act as barriers to flow and reduce the runoff velocity generated from the strips of intertilled crops, and eventually reduce soil erosion. Strip cropping is laid out by using the following three methods:

Fig. 4.2. Strip cropping.

i) **Contour strip cropping:** In contour strip cropping, alternate strips of crop are sown more or less following the contours, similar to contouring. Suitable rotation of crops and tillage operations are followed during the farming operations.

ii) **Field strip cropping:** In a field layout of strip cropping, strip of uniform width are laid out across the prevailing slope, while protecting the soil from erosion by water. To protect the soil from erosion by wind, strips are laid out across the prevailing direction of wind. Such practices are generally followed in areas where the topography is very irregular, and the contour lines are too curvy for strict contour farming.

iii) **Buffer strip cropping:** Buffer strip cropping is practiced where uniform strip of crops are required to be laid out for smooth operations of the farm machinery, while farming on a contour strip cropping layout. Buffer strip of legumes, grasses and similar other crops are laid out between the contour strips as correction strips. Buffer strips provide very good protection and effective control of soil erosion

Estimation of Soil Loss

The control of erosion is essential to maintain the productivity of soil and to improve or maintain downstream water quality. The reduction of soil erosion to tolerable limits necessitates the adoption of properly planned cropping practices and soil conservation measures. Several methods exist for the measurement of soil loss from different land units. These include the measurements from runoff plots of various sizes for each single land type and land use, small unit source watersheds, and large watersheds of mixed land use. However, to estimate soil erosion, empirical and process based models (equations) are used. Universal Soil Loss Equation (USLE) is an empirical equation. It estimates the average annual mass of soil loss per unit area as a function of most of the major factors affecting sheet and rill erosions. Estimating soil loss is considerably more difficult than estimating runoff as there are many variables, both natural such as soil and rainfall and man-made such as adopted management practices. The soil loss considerably depends on the type of erosion. As a result, models, whether empirical or process-based, are necessarily complex if they are to include the effect of all the variables.

For some purposes, meaningful and useful estimates of sediment yield can be obtained from models, and the best example is the estimation of long-term average annual soil loss from a catchment by using the Universal Soil Loss Equation (USLE).

16.2 The Universal Soil Loss Equation (USLE)

The filed soil loss estimation equations development began in 1940 in USA. Zing (1940) proposed a relationship of soil loss to slope length raised to a power. Later in 1947, a committee chaired by Musgrave proposed a soil-loss equation having some similarity to the present day USLE. Based on nearly 10,000 plot year runoff plot data, Wischmeier and Smith (1965) developed the universal soil loss equation, which was later refined with more recent data from runoff plots, rainfall simulators and field experiences. It is the most widely used tool for estimation of soil loss from agricultural watersheds for planning erosion control practices. The USLE is an erosion prediction model for estimating long term averages of soil erosion from sheet and rill erosions from a specified land under specified conditions (Wischmeier and Smith, 1978).

It provides an estimate of the long-term average annual soil loss from segments of arable land under various cropping conditions. The application of this estimate is to enable farmers and soil conservation advisers to select combinations of land use, cropping practice, and soil conservation practices, which will keep the soil loss down to an acceptable level. The equation (USLE) is presented as below.

$$A = R \times K \times L \times S \times C \times P \qquad (16.1)$$

where, A = soil loss per unit area in unit time, t ha^{-1} yr^{-1}, R = rainfall erosivity factor which is the number of rainfall erosion index units for a particular location, K = soil erodibility factor - a number which reflects the susceptibility of a soil type to erosion, i.e., it is the reciprocal of soil resistance to erosion, L = slope length factor, a ratio which compares the soil loss with that from a field of specified length of 22.6 meters, S = slope steepness factor, a ratio which compares the soil loss with that from a field of specified slope of 9%, C = cover management factor

- a ratio which compares the soil loss with that from a field under a standard treatment of cultivated bare fallow, and P = support practice factor - a ratio of soil loss with support practice like contouring, strip cropping or terracing to that with straight row farming up and down the slope.

The factors L, S, C and P are each dimensionless ratios which allow comparison of the site for which soil loss is being estimated with the standard conditions of the database. Knowing the values of rainfall erosivity, soil erodibility and slope one can calculate the effectiveness of various erosion control measures with the purpose of introducing a cultivation system in an area with soil loss limited to the acceptable value.

Various factors associated with the above equation are discussed below.

- **Rainfall Erosivity Factor (R)**

It refers to the rainfall erosion index, which expresses the ability of rainfall to erode the soil particles from an unprotected field. It is a numerical value. From the long field experiments it has been obtained that the extent of soil loss from a barren field is directly proportional to the product of two rainfall characteristics: kinetic energy of the storm and its 30-minute maximum intensity. The product of these two characteristics is termed as EI or EI_{30} or rainfall erosivity. The erosivity factor, R is the number of rainfall erosion index units (EI_{30}) in a given period at the study location. The rainfall erosion index unit (EI_{30}) of a storm is estimated as:

$$EI_{30} = \frac{KE \times I_{30}}{100} \quad EI_{30} = KE \times I_{30} \qquad (16.2)$$

where, KE = kinetic energy of storm in metric tones /ha-cm, expressed as

$$KE = 210.3 + 89 \log I \quad KE = 210.3 + 89 \log I \qquad (16.3)$$

where, I = rainfall intensity in cm/h, and I_{30} I_{30} = maximum 30 minutes rainfall intensity of the storm.

The study period can be a week, month, season or year and this I_{30} values are different for different areas. The storm EI_{30} values for that length of period is summed up. Annual EI_{30} values are usually computed from the data available at various meteorological stations and lines connecting the equal EI_{30} values (known as *Iso-erodent lines*) are drawn for the region covered by the data stations for ready use in USLE.

- **Soil Erodibility Factor (K)**

The soil erodibility factor (K) in the USLE relates to the rate at which different soils erode. Under the conditions of equal slope, rainfall, vegetative cover and soil management practices, some soils may erode more easily than others due to inherent soil characteristics. The direct measurement of K on unit runoff plots reflect the combined effects of all variables that significantly influence the ease with which a soil is eroded or the particular slope other than 9% slope. Some of the soil properties which affect the soil loss to a large extent are the soil permeability, infiltration rate, soil texture, size and stability of soil structure, organic content and soil depth. These are usually determined at special experimental runoff plots or by the use of empirical erodibility equations which relate several soil properties to the factor K. The soil erodibility factor (K) is expressed as tons of soil loss per hectare per unit rainfall erosivity index, from a field of 9% slope and 22 m (in some cases 22.13 m) field length. The soil erodibility factor (K) is determined by considering the soil loss from continuous cultivated fallow land without the influence of crop cover or management.

The formula used for estimating K is as follows:

$$K = \frac{Ao}{S \times (\Sigma EI)} \quad K = \frac{A_o}{S \times (\Sigma EI)} \qquad (16.4)$$

where, K = soil erodibility factor, A_0 = observed soil loss, S = slope factor, and ΣEI = total rainfall erosivity index.

Based on runoff plot studies, the values of erodibility factor K have been determined for use in USLE for different soils of India as reported by Singh *et al*. (1981). Values of K for several stations are given in Table 16.1.

Table 16.1. Values of K for Several Stations (Source: K. Subramanya, 2008)

Station	Soil Type	Computed Values of K
Agra	Loamy sand, alluvial	07
Dehradun	Dhulkot silt, loam	15
Hyderabad	Red chalka sandy loam	08

Kharagpur	Soils from laterite rock	04	
Kota	Kota clay loam	11	
Ootakamund	Laterite	04	
Rehmankhera	Loam, alluvial	17	
Vasad	Sandy loam, alluvial	06	

Topographic Factor (LS)

Slope length factor (L) is the ratio of soil loss from the field slope length under consideration to that from the 22.13 m length plots under identical conditions. The slope length has a direct relation with the soil loss, i.e., it is approximately equal to the square root of the slope length ($L^{0.5}$), for the soils on which runoff rate is not affected by the length of slope (Zing, 1940).

Steepness of land slope factor (S) is the ratio of soil loss from the field slope gradient to that from the 9% slope under otherwise identical conditions. The increase in steepness of slope results in the increase in soil erosion as the velocity of runoff increases with the increase in field slope allowing more soil to be detached and transported along with surface flow.

The two factors L and S are usually combined into one factor LS called ***topographic factor***. This factor is defined as the ratio of soil loss from a field having specific steepness and length of slope (i.e., 9% slope and 22.13 m length) to the soil loss from a continuous fallow land. The value of LS can be calculated by using the formula given by Wischmeier and Smith (1962):

$$LS = \frac{\sqrt{L}}{100}\left(0.76 + 0.53S + 0.076S^2\right)$$

$$LS = \frac{\sqrt{L}}{100}(0.76 + 0.53\,S + 0.076\,S^2) \qquad (16.5)$$

where, L = field slope length in feet and S = percent land slope.

Wischmeier and Smith (1978) again derived the following equation for LS factor in M.K.S. system, based on the observations from cropped land on slopes ranging from 3 to 18% and length from 10 to 100 m. The derived updated equation is:

$$LS = \left(\frac{\lambda}{22.13}\right)^m [65.41\, Sin^2\theta + 4.56\, Sin\theta + 0.065] \qquad (16.6)$$

where, λ = field slope length in meters, m = exponent varying from 0.2 to 0.5, and θ = angle of slope.

Crop Management Factor (C)

The crop management factor C may be defined as the expected ratio of soil loss from a cropped land under specific crop to the soil loss from a continuous fallow land, provided that the soil type, slope and rainfall conditions are identical. The soil erosion is affected in many ways according to the crops and cropping practices, such as the kind of crop, quality of cover, root growth, water use by plants etc. The variation in rainfall distribution within the year also affects the crop management factor, which affects the soil loss. Considering all these factors, the erosion control effectiveness of each crop and cropping practice is evaluated on the basis of five recommended crop stages introduced by Wischmeier (1960). The five stages are:

Period F (Rough Fallow): It includes the summer ploughing or seed bed preparation.

Period 1 (Seed Bed): It refers to the period from seeding to 1 one month thereafter.

Period 2 (Establishment): The duration ranges from 1 to 2 months after seeding.

Period 3 (Growing Period): It ranges from period 2 to the period of crop harvesting.

Period 4 (Residue or Stubble): The period ranges from the harvesting of crop to the summer ploughing or new seed bed preparation.

For determining the crop management factor the soil loss data for the above stages is collected from the runoff plot and C is computed as the ratio of soil loss from cropped plot to the corresponding soil loss from a continuous fallow land for each of the above five crop stages separately, for a particular crop, considering various combinations of crop sequence and their productivity levels. Finally, weighted C is computed. This factor reflects the combined effect of various crop management practices. Values of factor C for some selected stations of India are given in Table 16.2.

Table 16.2. Values of Crop Management Factors for Different Stations in India (Source: K Subramanya, 2008)

Station	Crop	Soil Loss, t ha $^{-1}$y $^{-1}$	Value of C
Agra	Cultivated fallow	3.80	1.0
	Bajra	2.34	0.61
	Dichanhium annualtu	0.53	0.13
Dehradun	Cultivated fallow	33.42	1.0
	Cymbopogon grass	4.51	0.13
	Strawberry	8.89	0.27

Hyderabad	Cultivated fallow	5.00	1.0
	Bajra	2.00	0.40

Support Practice Factor (P)

Station	**Practice**	**Factor P**
Dehradun	Contour cultivation of maize	0.74
	Up and down cultivation	1.00
	Contour farming	0.68
	Terracing and bunding in agricultural watershed	0.03
Kanpur	Up and down cultivation of Jowar	1.00
	Contour cultivation of Jowar	0.39

Ootacamund	Potato up and down	1.00
	Potato on contour	0.51

This factor is the ratio of soil loss with a support practice to that with straight row farming up and down the slope. The conservation practice consists of mainly contouring, terracing and strip cropping. The soil loss varies due to different practices followed. Factor P for different support practices for some locations of India is presented in Table 16.3.

Table 16.3. Different Values of Support Practice Factor (P) for Some Indian Locations (Source: K. Subramanya, 2008)

16.3 Use of USLE

There are three important applications of the universal soil loss equation. They are as follows:

- It predicts the soil loss;
- It helps in identification and selection of agricultural practices; and
- It provides the recommendations on crop management practices to be used.

USLE is an erosion prediction model and its successful application depends on the ability to predict its various factors with reasonable degree of accuracy. It is based on considerably large experimental data base relating to various factors of USLE.

Based on 21 observation points and 64 estimated erosion values of soil loss obtained by the use of USLE at locations spread over different regions of the country, soil erosion rates have been classified into 6 categories. Areas falling under different classes of erosion are shown in Table 16.4.

Table 16.4. Distribution of various erosion classes in India (Source: K Subramanya, 2008)

Range (Tones/ha/year)	Erosion Class	Area (km^2)
0-5	Slight	801,350
5-10	Moderate	1,405,640
10-20	High	805,030
20-40	Very high	160,050

40-80	Severe	83,300
>80	Very severe	31,895

16.4 Limitations of Universal Soil Loss Equation

The equation involves the procedure for assigning the values of different associated factors on the basis of practical concept. Therefore, there is possibility to introduce some errors in selection of the appropriate values, particularly those based on crop concept. Normally R and K factors are constants for most of the sites/regions in the catchment, whereas, C and LS vary substantially with the erosion controlled measures, used. The following are some of the limitations of the USLE:

- **Empirical**

The USLE is totally empirical equation. Mathematically, it does not illustrate the actual soil erosion process. The possibility to introduce predictive errors in the calculation is overcome by using empirical coefficients.

- **Prediction of Average Annual Soil Loss**

This equation was developed mainly on the basis of average annual soil loss data; hence its applicability is limited for estimation of only average annual soil loss of the given area. This equation computes less value than the measured, especially when the rainfall occurs at high intensity. The storage basin whose sediment area is designed on the basis of sediment yield using USLE should be inspected after occurrence of each heavy storm to ensure that the sedimentation volume in the storage basin is within the limit.

- **Non-computation of Gully Erosion**

This equation is employed for assessing the sheet and rill erosions only but can not be used for the prediction of gully erosion. The gully erosion caused by concentrated water flow is not accounted by the equation and yet it can cause greater amount of soil erosion.

- **Non-computation of Sediment Deposition**

The equation estimates only soil loss, but not the soil deposition. The deposition of sediment at the bottom of the channel is less than the total soil loss taking place from the entire watershed. Nevertheless, the USLE can be used for computing the sediment storage volume required for sediment retention structures., Also the USLE equation can be used as a conservative measure of potential sediment storage needs, particularly where sediment basins ranges typically from 2-40 ha and runoff has not traveled farther distance and basin is intended to serve as the settling area. Again, if the drainage on any site is improperly controlled and gully erosion is in extensive form, then this equation underestimates the sediment storage requirement of the retention structure.

During the estimation of contribution of hill slope erosion for basin sediment yield, care should be taken as it does not incorporate sediment delivery ratio. This equation cannot be applied for predicting the soil loss from an individual storm, because the equation was derived to estimate the long term mean annual soil loss. The use of this equation should be avoided for the locations, where the values of different factors associated with the equation, are not yet determined.

16.5 Revised Universal Soil Loss Equation (RUSLE)

Over the last few decades, a co-operative effort between scientists and users to update the USLE has resulted in the development of RUSLE. The modifications incorporated in USLE to result the RUSLE are mentioned as under (Kenneth *et.al.* 1991):

- Computerizing the algorithms to assists the calculations.
- New rainfall-runoff erosivity term (R) in the Western US, based on more than 1200 gauge locations.
- Some revisions and additions for the Eastern US, including corrections for high R-factor areas with flat slopes to adjust splash erosion

associated with raindrops falling on ponded water.

- Development of a seasonally variable soil erodibility term (K).
- A new approach for calculating the cover management term (C) with the sub-factors representing considerations of prior land use, crop canopy, surface cover and surface roughness
- New slope length and steepness (LS) algorithms reflecting rill to inter-rill erosion ratio
- The capacity to calculate LS products for the slopes of varying shapes
- New conservation practices value (P) for range lands, strip crop rotations, contour factor values and subsurface drainage.

16.6 Modified Universal Soil Loss Equation (MUSLE)

The USLE was modified by Williams in 1975 to MUSLE by replacing the rainfall energy factor (R) with another factor called as ‘runoff factor’. The MUSLE is expressed as

$$Y = 11.8\left(Q \times q_p\right)^{0.56} K(LS)CP$$ $Y = 11.8\,(Q \times q_p)^{0.56} K(LS)CP$ (16.12)

where, Y = sediment yield from an individual storm (in metric tones), Q = storm runoff volume in m^3 and q_p = the peak rate of runoff in m^3/s.

All other factors K, (LS), C and P have the same meaning as in USLE (equation 16.1). The values of Q and q_p can be obtained by appropriate runoff models. In this model Q is considered to represent detachment process and q_p is the sediment transport. It is a sediment yield model and does not need separate estimation of sediment delivery ratio and is applicable to individual storms. Also it increases sediment yield prediction accuracy. From modeling point of view, it has the advantage that daily, monthly and annual sediment yields of a watershed can be modeled by combining appropriate hydrological models with MUSLE.

Terraces for Water Erosion Control

One of the most effective actions that can take to mitigate the problem of an eroding slope is to break up the rate of water decent by constructing terraces. The terraces for water erosion control consist of some mechanism to protect land surface as well as to reduce the erosive velocity of runoff water. It involves some land surface modification for retention and safe disposal of rainfall

5.1 Terraces and their Design

A Terrace is an earth-embankment, constructed across the slope, to control runoff and minimize soil erosion. A terrace acts as an intercept to land slope, and divides the sloping land surface into strips. In limited widths of strips, the slope length naturally available for runoff is reduced. It has been found that soil loss is proportional to the square root of the length of slope; i.e. by shortening the length of run, soil erosion is reduced. The soil eroded by the runoff scour and the raindrop splash flows down the slope, and gets blocked up by terraces. The scour of soil surface because of runoff water is initiated by the runoff at a velocity above the critical value, attained during a flow on long length of the sloping run. Thus, by shortening the length of run, the runoff velocity remains less than the critical value and therefore soil erosion owing to scour is prevented.

Terraces are classified into to two major types: broad-base terraces and bench terraces. Broad-base terraces are adapted where the main purpose is either to remove or retain water on sloping land suitable for cultivation whereas, the purpose of bench terraces is mainly to reduce the land slope. The classification of the terraces is given in Fig. 5.1.

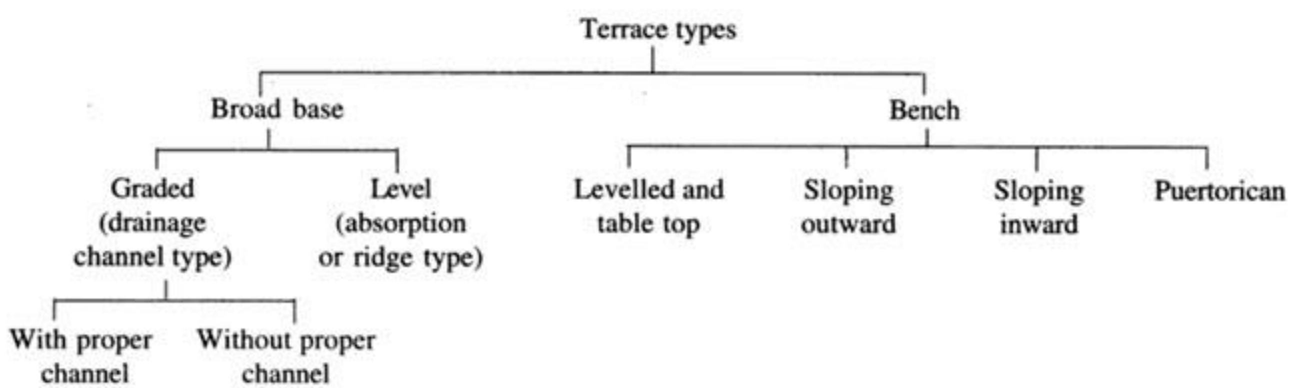


Fig. 5.1. Types of terraces.

5.2 Bench Terracing

The original bench terrace system consists of a series of flat shelf-like areas that convert a steep slope of 20 to 30 percent to a series of level, or nearly level benches (Fig. 5.2). In other words, bench terracing consists of construction of series of platforms along contours cut into hill slope in a step like formation. These platforms are separated at regular intervals by vertical drop or by steep sided and protected by vegetation and sometimes packed by stone retaining walls. In fact, bench terrace converts the long un-interrupted slope into several small strips and make protected platform available for farming. In several hilly areas bench terraces have been used for the purpose of converting hill slopes to suit agriculture. In some areas where the climatic conditions favour the growing of certain cash crops like potato, coffee etc., the hill slopes are to be bench terraced before the area is put for cultivation of these crops. Bench terraces have also been adopted for converting sloping lands into irrigated fields or for orchard plantations.

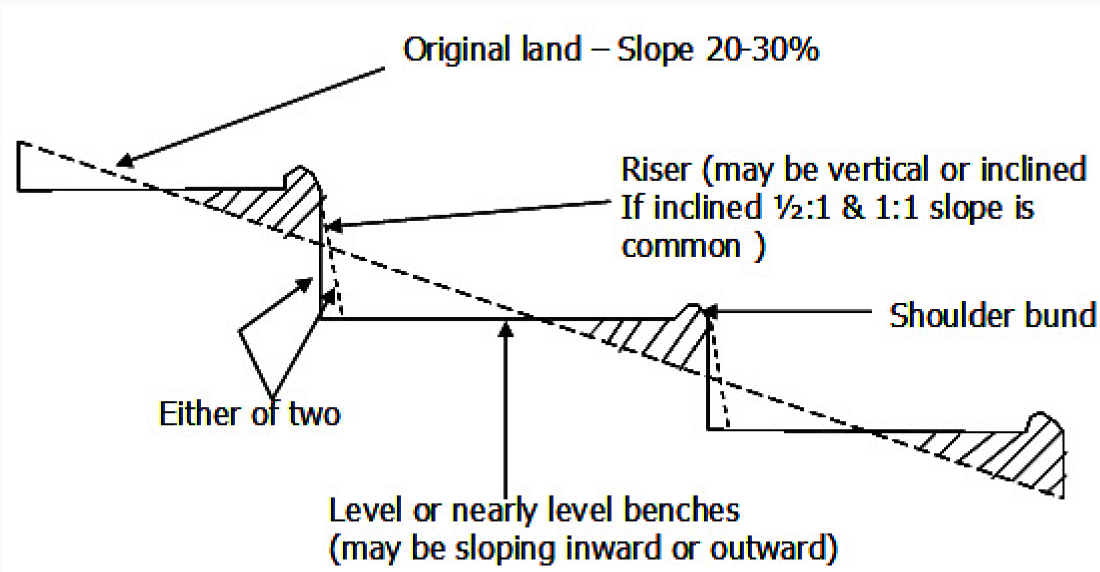


Fig. 5.2. Bench terrace and its different components.

5.3 Types of Bench Terraces

Depending on the purpose for which they are used, bench terraces are also classified as follows:

1. Hill-type bench terraces: used for hilly areas with a grade reversely towards the hill.

2. Irrigated bench terraces: level benches adopted under irrigated conditions.

3. Orchard bench terraces: narrow width terraces for individual trees. These are also referred to as intermittent terraces and step terraces.

The conversion of land into bench terraces over a period of time is referred to as gradual bench terracing. Bench terraces are classified depending upon the slope of benches. The different types are: (i) bench terraces sloping outward; (ii) bench terraces sloping inward and (iii) bench terraces with level top.

Bench terraces with slopes inside are to be adopted in heavy rainfall areas where a major portion of the rainfall is to be drained as surface runoff. In the case of these terraces, a suitable drain at the inward end of each of these terraces is to be provided to drain the runoff. These drains ultimately lead to a suitable outlet. These are also known as hill-type terraces. Bench terraces with level top are suitable for areas of medium rainfall, evenly distributed and having deep and highly permeable soils. Due to the fact that no slope is given to the benches it is expected that the most of the rainfall coming over the area is to be absorbed by the soil and very little water is to go as surface drainage. These types of terraces are also used where irrigation facilities are available and referred to as irrigated bench terraces. Bench terraces sloping outward are to be used in low rainfall areas with permeable soils. For bench terraces sloping outward a shoulder bund is essential even though such a bund is provided in the other two types also for giving stability to the edge of the terrace. In these terraces the rainfall thus conserved will have more time for soaking into the soil. Bench terraces with narrow width (about 1 m) are sometimes constructed for orchards bench terraces. These terraces are referred to as step terraces when a series of step like formations are made.

5.4 Design of Bench Terraces

For the designing of the bench terraces for a particular tract the average rainfall, the soil type, soil depth and the average slope of the area should be known. In addition the purpose for which the terraces are to be constructed should also be known.

The design of bench terraces consists of determining the (1) type of the bench terrace, (2) terrace spacing or the depth of the cut, (3) terrace width, and (4) terrace cross section.

Selection of the type of bench terrace among the three types, described earlier, depends upon the rainfall and soil conditions.

Terrace spacing is generally expressed as the vertical interval between two terraces. The vertical interval (D) is dependent upon the depth of the cut and since the cut and fill are to be balanced, it is equal to double the depth of cut. The factors that limit the depth of cut are the soil depth in the area and the slope. The depth of cut should not be too high as to expose the bed rock which makes the bench terraces unsuitable for cultivation. In higher slopes greater depth of cuts result in greater heights of embankments which may become unstable.

The width of the bench terraces (W) should be as per the requirement (purpose) for which the terraces are to be put after construction. Once the width of the terrace is decided, the depth of cut required can be calculated using the following formulae.

Case 1: When the terrace cuts are vertical

$$D = \frac{WS}{100} \qquad (5.1)$$

S is the land slope in percent; D/2 is the depth of cut and W is the width of terrace.

Case 2: When the batter slope is 1:1

$$\frac{D/2}{W/2 + D/2} = \frac{S}{100}$$

$$D = \frac{WS}{(100 - S)} \qquad (5.2)$$

Case 3: When the batter slope is ½: 1

$$\frac{D/2}{W/2 + D/4} = \frac{S}{100}$$

$$D = \frac{2WS}{(200 - S)} \qquad (5.3)$$

After deciding the required width, the depth of cut can be calculated from one of the above formulae.

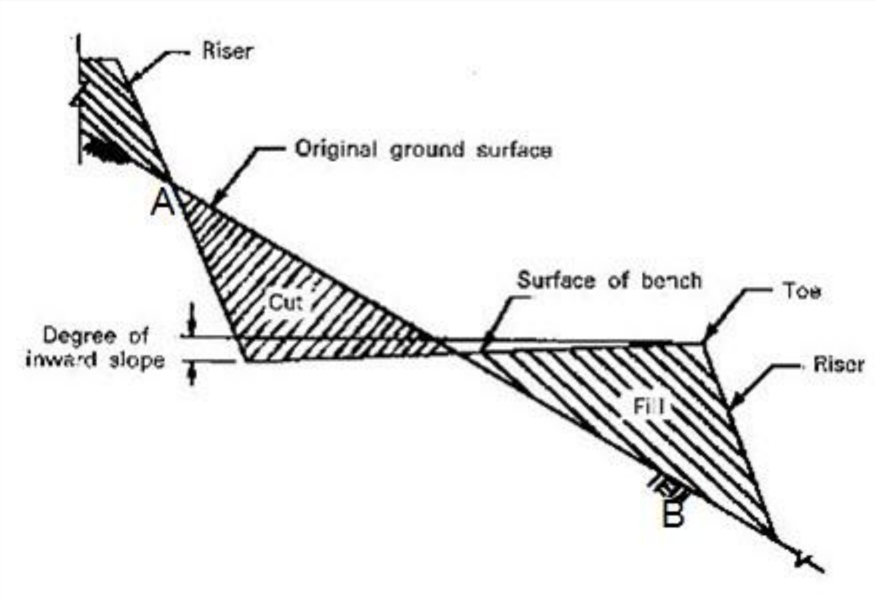


Fig: 5.3 Cross section of bench terraces.

The design of the terrace cross section consists of deciding (1) the batter slope, (2) dimensions of the shoulder bund, (3) inward slope of the terrace and the dimensions of the drainage channel in case of terraces sloping inward, and (4) outward slope in case of terraces sloping outward (Fig. 5.3). The batter slope is mainly for the stability of the fill or the embankment. The flatter the batter slope, the larger the area lost due to bench terracing. Vertical cuts are to be used in very stable soils and when the depth of the cut is small (up to 1 m). Batter slopes of ½: 1 can be used in loose and unstable soils. The size of the shoulder bunds in case of terraces sloping inward is nominal. In case of terraces with flat top and sloping outwards, larger sections of shoulder bunds are required as water stands against these bunds. The bund cross section depends upon the terrace width and soil conditions. The inward slope of the terrace may be from 1 in 50 to 1 in 10 depending upon the soil conditions. For these terraces a drainage channel is to be provided at the inner edge of the terrace to dispose of the runoff.

5.5 Alignment of Bench Terraces

Alignment of bench terraces should start from the ridge and progress towards the valley. The average land slope of the area to be terraced should be determined by taking levels and then the specifications of the terrace should be worked out. Contour lines may be marked with the help of a leveling instrument. Taking a contour line as the centre line, the terrace width may be marked on the ground. The alignment may now be examined and suitable adjustments should be made wherever necessary taking into considerations the local conditions like depressions, sharp turns, field boundaries etc. that exist at the site.

Construction of the bench terraces may be started from the highest terrace and proceeded downwards. By this method, the top soil and the subsoil get mixed up and the top soil may not be available for the terrace surface. In cases where the subsoil condition is not good, it is necessary to keep the top soil apart and again spread it on the terrace. This can be accomplished by starting the construction of the terraces from the lower most one. After the construction of the first terrace, the top soil from the second terrace may be spread on the first terrace and the process continued for subsequent terraces. In bench terraced areas, suitable outlets should be provided to dispose of the runoff safely. In most of the cases one of the sides of the hill slope where vegetation is well established can be used as the outlet. Where such outlets are not available or feasible, waterways are to be formed to dispose of the runoff.

5.6 Area Lost for Cultivation due to Bench Terracing

The area lost for cultivation due to bench terracing of a slope can be calculated as follows.

Consider a batter slope of 1:1. Let D be the vertical interval of the benches to be laid out on a land with a slope of S %, along AB in Fig. 5.3 and the batter of the risers is 1:1. L is the horizontal interval between the benches i.e., projected length of AB on horizontal plane. Actual distance of AB is given by:

$$AB = \sqrt{L^2 + D^2}$$

$$= L\left[1 + \frac{D^2}{2L^2} + \frac{D^4}{8L^4} + ...\right] \qquad (5.4)$$

$$AB = L + \frac{D^2}{2L}$$

$$L = \frac{100D}{S}$$

$$AB = \frac{100D}{S} + \frac{D^2}{2} \cdot \frac{S}{100D}$$

$$= \frac{100D}{S} + \frac{DS}{200} \qquad (5.5)$$

If W is the width available for cultivation after terracing:

$$W + D = L = \frac{100D}{S}$$

$$W = \frac{100D}{S} - D = \frac{100D - DS}{S} \qquad (5.6)$$

Width not available for cultivation after terracing (from equations 5.5 and 5.6)

$$= AB - W$$

$$= \frac{100D}{S} + \frac{DS}{200} - \frac{100D}{S} + \frac{DS}{S}$$

$$= \frac{DS}{200} + \frac{DS}{S}$$

Width loss in percentage of original inclined width AB

$$= \frac{\frac{DS}{200} + \frac{DS}{S}}{\frac{100D}{S} + \frac{DS}{200}} * 100$$

$$= \frac{\frac{S}{200} + 1}{\frac{100}{s} + \frac{S}{200}} * 100 = \frac{(S + 200)S}{20000 + S^2} * 100$$

By dividing the numerator and the denominator by 100 width lost in percentage of the original width

$$= \frac{S + 200}{\frac{200}{S} + \frac{S}{100}}$$

The percentage width lost can be taken as the percentage area lost. When the batter is vertical, the length of bench terrace per hectare in metres will be 10000/W where W is in metres. When the batter slope is 1:1 the length per hectare in metres will be 10000/W + D; D and W being in meters.

5.7 Maintenance of Bench Terraces

New terraces should be protected at their risers and outlets and should be carefully maintained, especially during the first two years. After cutting a terrace, its riser should be shaped and planted with grass as soon as possible. Sod-forming or rhizome-type grasses are better than those of the tall or bunch-type.

Although tall grasses may produce considerable forage for cattle, they require frequent cutting and attention. The rhizome-type of local grass has proved very successful in protecting risers. Stones, when available, can also be used to protect and support the risers. An additional protection method is hydro-seeding. The outlet for drainage-type terraces is the point where the run-off leaves the terrace and goes into the waterway. Its gradient is usually steep and should be protected by sods of earth. A piece of rock, a brick, or a cement block, is sometimes needed to check the water flow on steeper channels. Similar checks on water flow are required for level bench terraces where the water falls from the higher terraces onto those below. A piece of rock should be placed on the lower terrace to dissipate the energy of the flowing water. The shoulder bund should be planted with permanent vegetation and ploughing of the toe of bund should be avoided. The batter slope of the terraces should be stabilized and protected by establishing deep rooted and soil binding spreading type of grasses.

5.7.1 Benches

The toe drains should be always open and properly graded; water must not be allowed to accumulate in any part of the terrace. All runoff should be allowed to collect at the toe drains for safe disposal to the protected waterway. Obstacles such as continuous mounds or beds must be removed at regular intervals to allow water to pass to the toe drain. Grasses and weeds should be removed from the benches. Correct gradients should be maintained and reshaped immediately after crops are harvested. Ploughing must be carried out with care so as not to destroy the toe drains and the grade.

5.7.2 Risers

Grasses should be grown well on the risers. Weeds and vines which threaten the survival of the grasses should be cut down or uprooted. Grasses should not be allowed to grow too high. Any small break or fall from the riser must be repaired immediately. Cattle should not be allowed to trample on the risers or graze the grasses. Runoff should not be allowed to flow over the risers on reverse-sloped terraces.

5.7.3 Outlets for Drainage Types of Terrace

The outlets should be checked to see whether they are adequately protected. Make sure that the water flows through the outlets instead of going around them. Any breaks must be mended immediately.

5.7.4 Soil Productivity

Deep ploughing, ripping or sub-soiling is needed to improve the structure of the soils on the cut part of the bench terraces. Green manuring, compost or sludge is needed in the initial period in order to increase soil fertility. Soil productivity should be maintained by means of proper crop rotation and the use of fertilizers.

5.8 Solved Example of Terrace Design

On a 20% hill slope, it is proposed to constructed bench terraces. If the vertical interval of terrace is 2 m, calculate (i) length of terrace per hectare, (ii) earth work required per hectare, and (iii) area lost per hectare both for vertical cut and batter slope of 1:1. The cut should be equal to fill.

Solution

Using the equation for vertical cut, and estimating the width of bench terrace (W

$$W = \frac{100D}{S} = \frac{100 * 2}{20} = 10 \text{ m}$$

$$\text{Length of terrace per hectare} = \frac{10000}{10} = 1000 \text{ m}$$

$$\text{Earthwork} = \frac{1}{2} * 5 * \frac{2}{2} * 1000 = 2500 \text{ m}^3.$$

$$\text{Area lost} = \frac{\sqrt{D^2 + W^2} - W}{\sqrt{D^2} + W^2} * 100 \text{ nearly } 2\%$$

When the batter slope is 1:1, using equation

$$W = \frac{D(100 - S)}{S}$$

$$= \frac{2(100-20)}{20}$$

$$= 8 \text{ m}$$

Length per hectare $= \dfrac{10000}{8+1+1}$

$= 1000$ m

Earthwork per hectare =0.5(5*1-1*1)*1000

= 2000 m^3.

Area lost for cultivation using equation

$$= \frac{S+200}{\frac{200}{S}+\frac{S}{100}} = \frac{20+200}{\frac{200}{20}+\frac{20}{200}} = 21.57\%$$

Gully Erosion

Gully erosion is an advance stage of rill erosion as rill erosion is the advanced stage of sheet erosion. It is the most spectacular form of erosion. Any concentration of surface runoff is a potential source of gully erosion. The Soil Conservation Society of America defines a gully as “a channel or miniature valley cut by concentrated runoff but through which water commonly flows only during and immediately after heavy rains. It may be dendritic or branching or it may be linear, rather long, narrow and of uniform width”. In India, the rate of soil erosion from gullies is 33 t/ha/yr in ravine regions (Shekinah and Saraswathy, 2005). The distinction between ravine, gully and rills is that of size. A gully is too large to be filled by normal tillage practices. A ravine is a deep narrow gorge. It is larger than a gully and is usually worn down by running water. It is estimated that about 4 million ha of land in India are affected by gully erosion (Michael and Ojha, 2012).

7.1 Development of Gullies

The main processes in the development of gullies are waterfall erosion and channel erosion. These two erosions are commonly found in the same gully. The extension of the gully head is usually by waterfall erosion; while the scouring of bottom and sides which enlarges the depth and width of gullies is by channel erosion. Gullies usually start with channel erosion. When an overfall develops at the head of the gully, the gully continues to develop by waterfall erosion. The waterfall erosion at gully head and advancement of the gully towards the upper edge of the watershed is shown in Fig. 7.1.

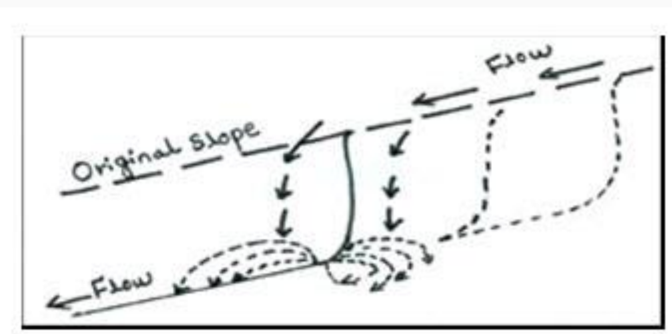


Fig. 7.1. Waterfall erosion at gully head.

The gully development is recognized in four stages:

Formation Stage: Scouring of top soil in the direction of general slope occurs as the runoff water concentrates. It normally proceeds slowly where the top soil is fairly resistant to erosion.

Development Stage: Causes upstream movement of the gully head and enlargement of the gully in width and depth. The gully cuts to the C-horizon of soil, and the parent materials are removed rapidly as water flows.

Healing Stage: Vegetation starts growing in the gully.

Stabilization Stage: Gully reaches a stable gradient, gully walls attain a stable slope and sufficient vegetation cover develops over the gully surface to anchor the soil and permit development of new topsoil.

7.2 Classification of Gullies

Gullies can be classified based on three factors viz. their size, shape (cross section) and formation of branches or continuation. The detailed classification is discussed below.

7.2.1 Based on Size (depth and drainage area)

Gully classification based on the size is presented in Table 7.1.

Table 7.1. Gully classification based on size

Classification	Depth (m)	Drainage area (ha)
Small	< 1	< 2
Medium	1 to 5	2 to 20
Large	> 5	> 20

7.2.2 Based on Shape

The classification of gullies based on shape is shown in Fig 7.2.

U-Shaped: These are formed where both the topsoil and subsoil have the same resistance against erosion. Because the subsoil is eroded as easily as the topsoil, nearly vertical walls are developed on each side of the gully.

V-Shaped: These gullies develop where the subsoil has more resistance than topsoil against erosion. This is the most common form of gully.

Trapezoidal: These gullies are formed where the gully bottom is made of more resistant material than the topsoil. Below the bottom of gully, the subsoil layer has much more resistance to get eroded and thus the development of further depth of gully is restricted.

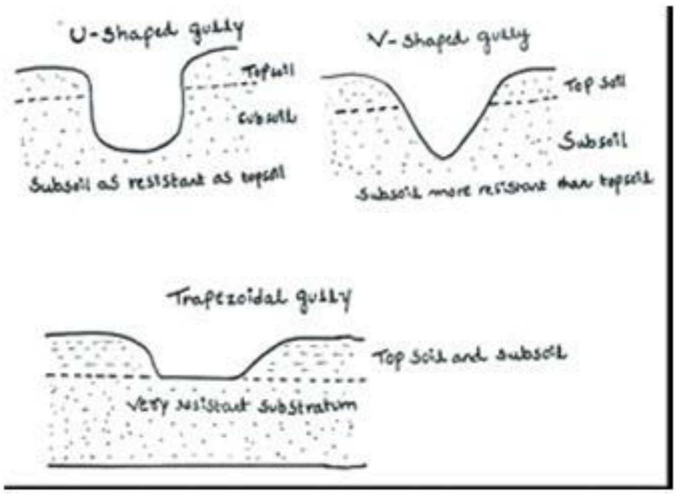


Fig. 7.2. Gully classes based on the shape of gully cross-section.

7.2.3 Based on the Formation of Branches or Continuation

Continuous Gullies: These gullies consist of many branches. A continuous gully has a main gully channel and many mature or immature branch gullies. A gully network is made up of many continuous gullies. A multiple-gully system may be composed of several gully networks.

Discontinuous Gullies: These may develop on hillsides after landslides. They are also called independent gullies. At the beginning of its development, a discontinuous gully does not have a distinct junction with the main gully or stream channel. Flowing water in a discontinuous gully spreads over a nearly flat area. After some time, it reaches the main gully channel or stream. Independent gullies may be scattered between the branches of a continuous gully, or they may occupy a whole area without there being any continuous gullies.

7.3 Principles of Gully Control

Generally, gullies are formed by an increase in surface runoff. Therefore, minimizing surface runoff is essential in gully control. The rate of gully erosion depends primarily on the runoff producing characteristics of the watershed, the watershed area, soil characteristics, size-shape and slope of gully etc. Watersheds deteriorate because of misuse of the land (man made changes), short intensive rainstorms, prolonged rains of moderate intensity, and rapid snow melts. The precipitation factors which turn into high runoff, develop flooding and form gullies. In gully control, the following three methods should be applied according to the order given:

- Improvement of gully catchments to reduce and regulate the runoff rates (peak flows).
- Diversion of surface water above the gully area.
- Stabilization of gullies by structural measures and accompanying re-vegetation.

When the first and/or second methods are applied in some regions of the countries with temperate climates, small or incipient gullies may be stabilized without having to use the third method. On the other hand, in tropical and subtropical countries which have heavy rains (monsoons, typhoons, tropical cyclones, etc.); all three methods have to be applied for successful gully control.

7.4 Gully Control Measures

Preventing the formation of gully is much easier than controlling it once it has formed. One of the major steps in a gully control programme is to plan the control of runoff from the drainage area. The various methods employed for controlling runoff may be considered in the following order:

- **Retention of Runoff on the Drainage Area:** It is possible through good crop management and applicable conservation practices such as contouring, strip cropping, bunding, terracing etc. Where contour bunds are used, runoff is greatly reduced. On cultivated areas, small and medium sized gullies can also be reclaimed by placing a series of earthfills across the gully.
- **Diversion of Runoff Around the Gullied Area:** The most effective control of gullies is by complete elimination of runoff from the gullied area. This can be obtained by diverting runoff from the gully, causing it to flow at a non- erosive velocity to a suitable outlet. Terraces and diversion ditches are generally used for diverting runoff from its natural outlet. Terraces are very effective in the control of small gullies on cultivated fields or even medium

size shallow gullies. If the slope above a gully is too steep for terracing, or if the drainage area is pasture or woodland, diversion ditches may be used to keep the runoff out of the gully.

- **Conveyance of Runoff through the Gully:** If it is not possible to either retain or divert the runoff, then runoff must be conveyed through the gully itself. This is possible only if vegetation can be established in the gullies, or if soil conservation structures are built at critical points to give primary control.

7.5 Classification of Gully Control Measures or Structures

Basically gully control structures are used to reduce soil erosion, control sedimentation, and harvesting water. Gully control measures are mainly of two types.

7.5.1 Biological or Vegetative Measures

7.5.1.1 Anti-Erosion Crops

These crops stabilize gully. Crops produced provide supplementary income.

7.5.1.2 Changing Gully into Grassed Waterway

Small and medium size gullies can be converted into grassed waterways. In practice, gully is shaped and suitable species of grasses are grown. Channel cross-section should be broad and flat, to keep water spread uniform over a wide area.

7.5.1.3 Sod Flumes

It may be successfully used to control overfall in gullies with head < 3 m and area <10 ha. The design of sod flume is shown in Fig 7.3. It serves the purpose of preventing further waterfall erosion by providing a protected surface over which the runoff may flow into the gully. Slope varies with the soil type, size of watershed, height of overfall and type of sod used. 4:1 is the steepest slope considered for its design. To maintain a non-erosive velocity, flume should be wide enough. The maximum depth of flow over the flume should not exceed 30 cm.

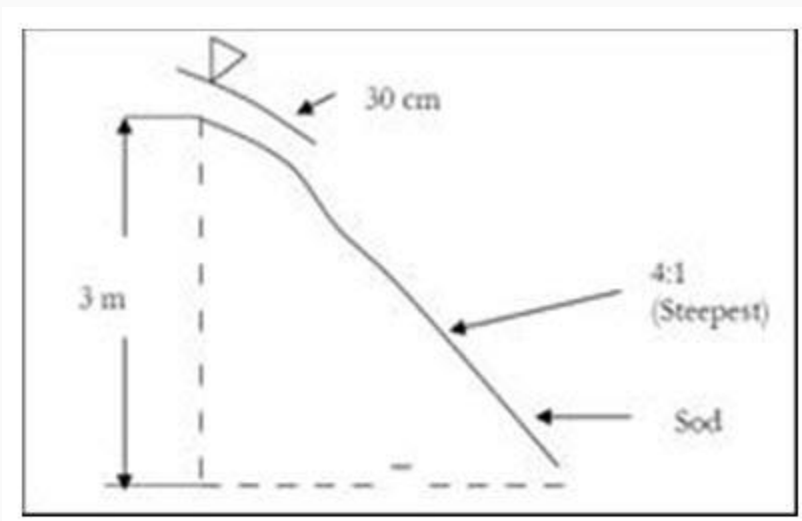


Fig. 7.3. Sod flume.

7.5.1.4 Sod Strip Checks

These checks are best adapted to small gullies with small to medium sized watersheds. These checks cannot be used in gullies with very steep grades. Strips are laid across gully channel (Fig. 7.4). Strips should have a minimum width of 30 cm and should extend up to gully sides at least 15 cm. Strip spacing usually varies from 1.5 to 2.0 m.

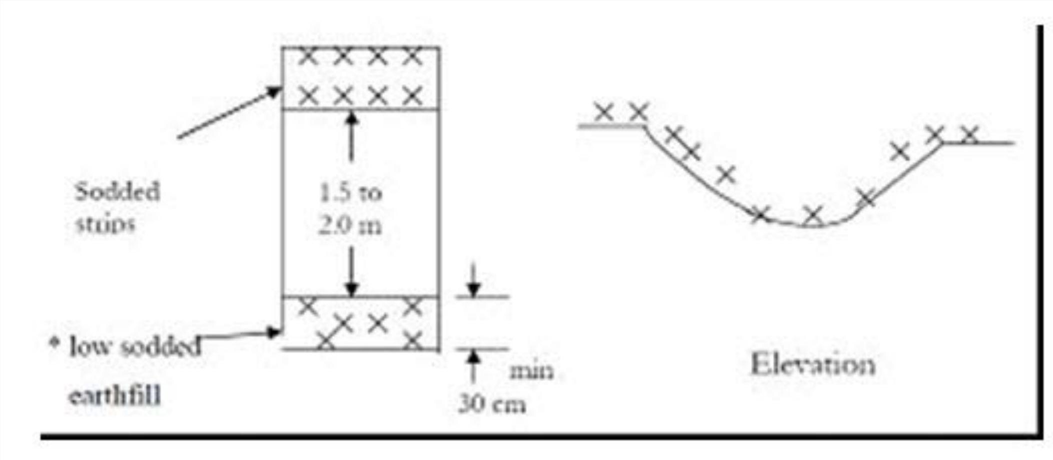
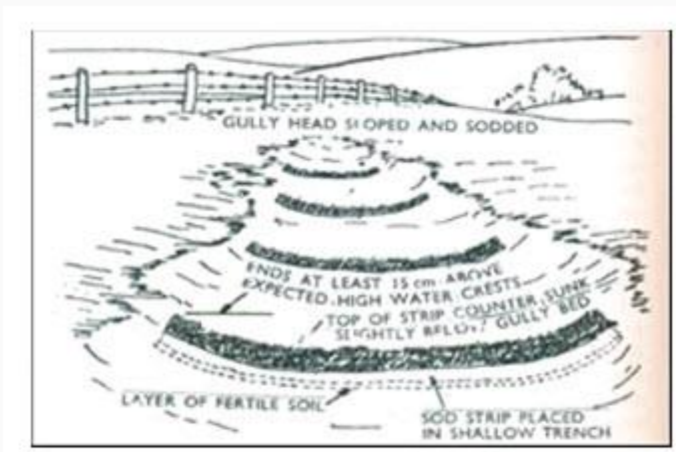


Fig. 7.4A. Sod strip checks.



.A series of sod-strip checks in a small gully.

Low Sodded Earthfills

These are used as substitutes for temporary gully controlled structures in small and medium sized gullies. Already growing sods are cut along with soil mass and combined together to form earth fill dams (Fig. 7.5). They are constructed with a maximum height of 45 cm, upstream (u/s) side slope of 3:1 and downstream (d/S) side slope of 4:1.

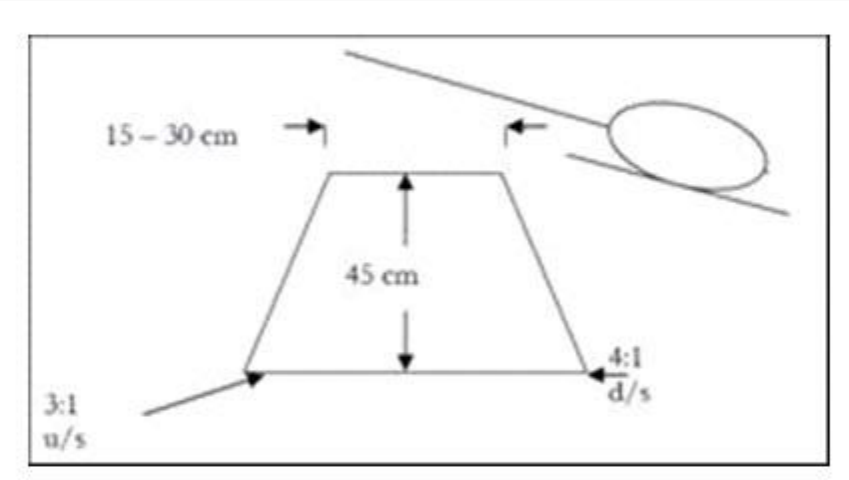


Fig. 7.5 Low sodded earthfills.

Trees, Shrubs etc.

Trees, shrubs etc. are used to stabilize severely eroded gullied area. Generally gullied area is fenced and trees are grown. A plant spacing of 1 × 1 m, 1.2 × 1.2 m or a maximum of 2 × 2 m should be maintained.

Engineering Measures (Temporary and Permanent)

Temporary Gully Control Structures (TGCS)

TGCS have a life span of 3 to 8 years and they are pretty effective where the amount of runoff is not too large. These are made of locally available materials. Basic purposes they serve are to retain more water as well as soil for proper plant growth and prevent channel erosion until sufficient vegetation is established on the upstream side of the gully. TGCS are of many types:

- Woven wire check dams
- Brush dams
- Loose rock dams
- Plan or slab dams
- Log check dams
- Boulder check dams

Permanent Gully Control Structures (PGCS)

If the erosion control programmer requires bigger structure, then PGCS are used. They include:

- Drop spillway
- Drop-inlet spillway
- Chute spillway
- Permanent earthen check dams

Design Criteria of TGCS

- The overall height of a temporary check shouldn’t ordinarily be more than 75 cm. An effective height of about 30 cm is usually considered sufficient. Also, sufficient freeboard is necessary.

- Life of the check dams under ordinary conditions should be in between 3 to 8 years.
- Spillway capacity of check dams is generally designed to handle peak runoff that may be expected once in 5 to 10 year return period.
- Since the purpose of check dams in gully control is to eliminate grade in the channel, check dams theoretically should be spaced in such a way that the crest elevation of one will be same as the bottom elevation of the adjacent dam up-stream.
- As an integral part of most of the checks dams, an apron or platform of sufficient length and width must be provided at the down-stream end to catch the water falling over the top and to conduct it safely without scouring.

Woven Wire Check Dams

Woven-wire check dams are small barriers which are usually constructed to hold fine material in the gully (Fig. 7.6).

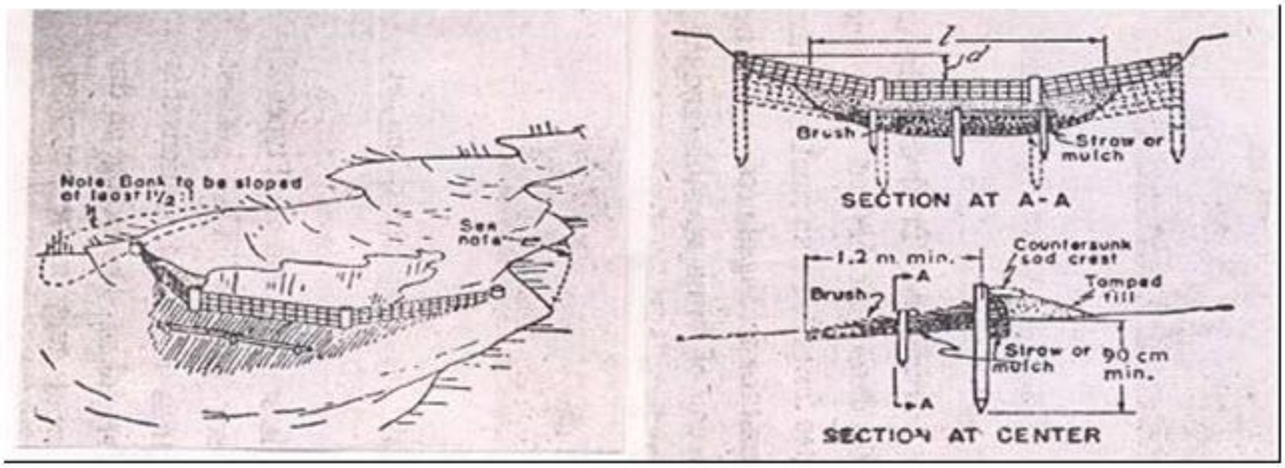
General:

- Used in gullies of moderate slopes (not more than 10 percent) and small drainage areas that do not have flood flows which carry rocks and boulders.

- Help in the establishment of vegetation for permanent control of erosion.
- Dam is built in half-moon shape with the open end up-stream.
- The amount of curvature is arbitrary: but an off-set equal to $1/6^{th}$ of the width of gully at the dam site is optimum.

Construction:

- To construct a woven-wire dam, a row of posts is set along the curve of the proposed dam at about 1.2 m intervals and 60-90 cm deep.
- Heavy gauge woven wire is placed against the post with the lower part set in a trench (15-20 cm deep), and 25-30 cm projected above the ground surface along the spillway width.
- Rock, brush or sod may be placed approximately up to a length of 1.2 m to form the apron.
- For sealing the structure, straw, fine brush or similar material should be placed against the wire on the upstream side upto the height of spillway.



Woven wire check dams.

7.6.2 Brush Dams

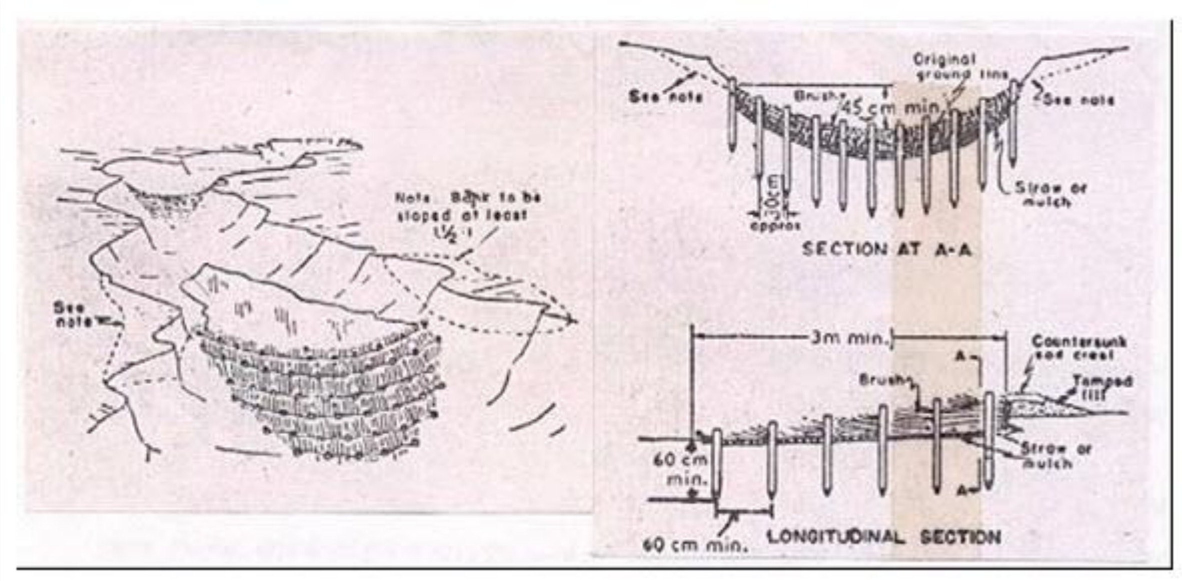
General:

- Cheap and easy to build, but least stable of all types of check dams.
- Best suited for gullies with small drainage area.
- Center of the dam is kept lower than the ends to allow water to flow over the dam rather than around it (Fig. 7.7).

Construction:

- For a distance of 3-4.5 m along the site of the structure, sides and bottom of the gully are covered with thin layer of straw or similar fine mulch.

- Brushes are then packed closely together over the mulch to about one half of the proposed height of dam.
- Several rows of stakes are then driven crosswise in the gully, with rows 60 cm apart, and stakes 30-60 cm apart in the rows.
- Heavy galvanized wire is used to fasten the stakes in a row, as well as to firmly compress the brushes in places.
- Sometimes large stones are also placed on top of brush to keep it compressed and in close contact with the bottom of the gully.
- Major weakness is the difficulty of preventing the leaks and constant attention is required to plug openings of appropriate size with straw as they develop.



Brush dam.

Loose Rock Dams

Loose rock dams made of relatively small rocks are placed across the gully (Fig. 7.8). The main objectives for these dams are to control channel erosion along the gully bed, and to stop waterfall erosion by stabilizing gully heads. Loose stone check dams are used to stabilize the incipient and small gullies and the branch gullies of a continuous gully or gully network. The length of the gully channel is not more than 100 m and the gully catchment area is 2 ha or less. These dams can be used in all regions.

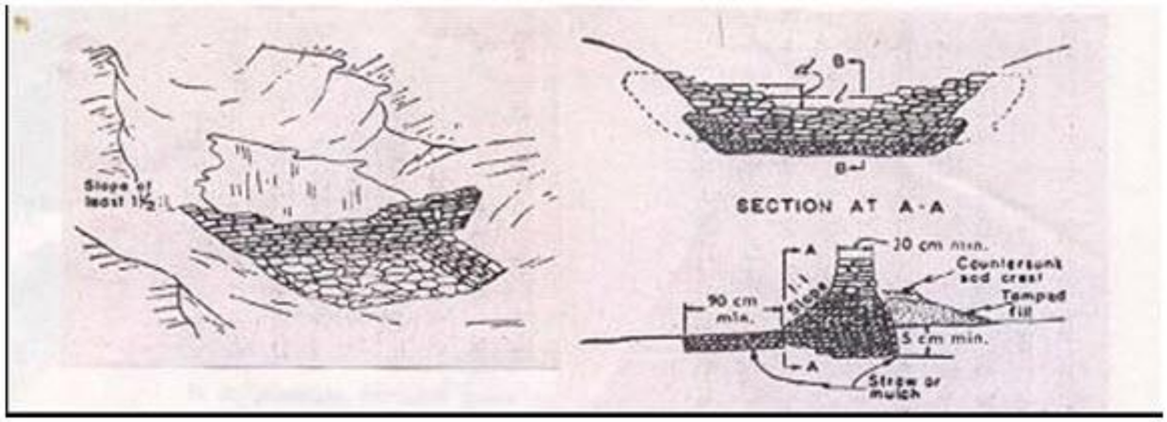
General:

- Suitable for gullies with small to medium size drainage area.

- Used in areas where stones or rocks of appreciable size and suitable quality are available.
- Flat stones are the best choice for dam making.
- Stones can be laid in such a way that the entire structure is keyed together.
- If round or irregular shaped stones are used, structure is generally encased in woven-wire so as to prevent outside stones from being washed away.
- If the rocks are small, they should be enclosed in a cage of woven-wire.

Construction:

- A trench is made across the gully to a depth of about 30 cm. This forms the base of the dam on which the stones are laid in rows and are brought to the required height.
- The center of the dam is kept lower than the sides to form spillway.
- To serve as an apron, several large flat rocks may be countersunk below the spillway, extending about 1 m down-stream from the base of the dam.



Loose rock dam.

Plank or Slab Dam

General:

- These dams are suitable in areas where timber is plentiful, and dam can be constructed with much less labor as compared to other types of temporary structures.
- These dams can generally be used in gullies with larger drainage area.

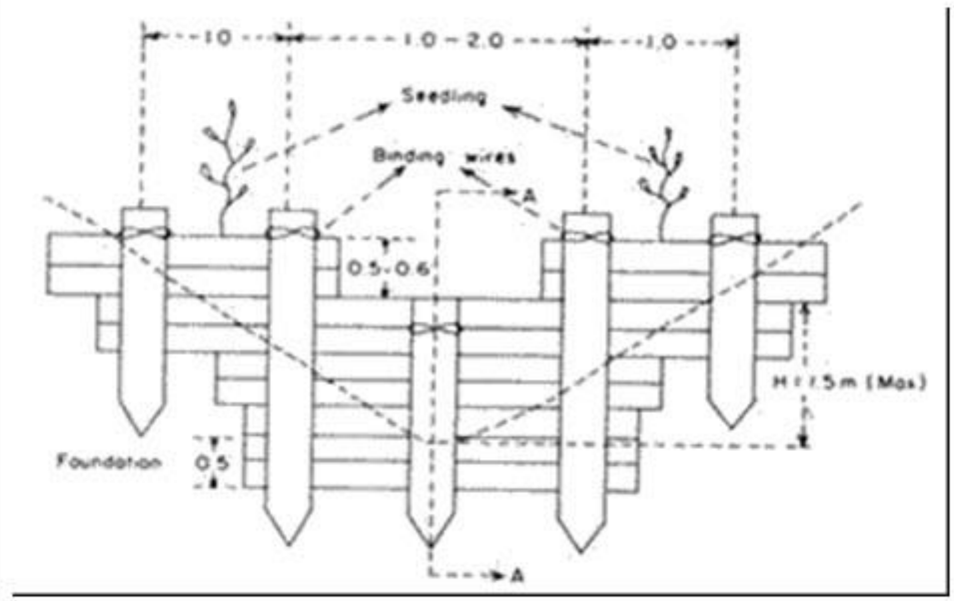
Construction:

- The planks are placed across the gully to form the dam. If the planks are not close fitting, straw or grass may be used for sealing purposes.
- A suitable opening for the spillway notch is made over the headwall. On the up-stream face, a well tempered earth fill is made.

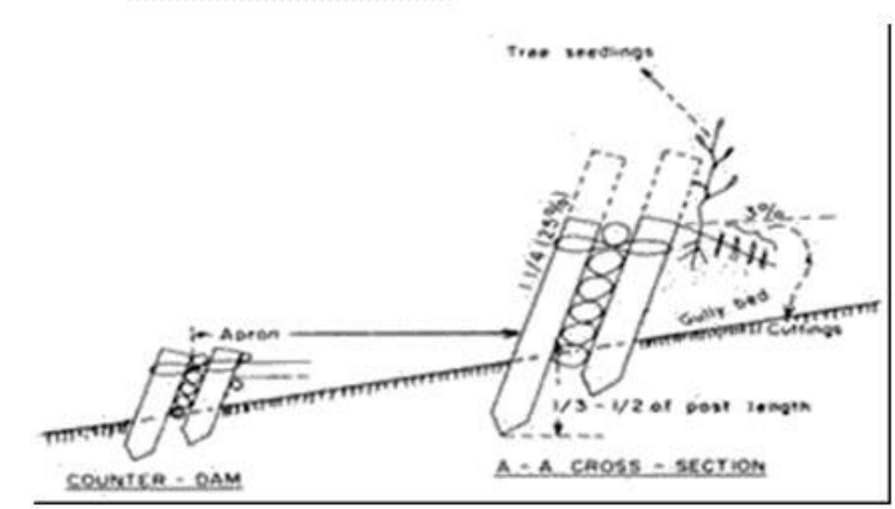
- On the down-stream, the apron may be made of loose rock, brush, sod or planks.

Log Check Dam

They are similar to plank or slab dams. Logs and posts used for the construction are placed across the gully. They can also be built of planks, heavy boards, slabs, poles or old railroad ties. The main objectives of log check dams are to hold fine and coarse material carried by flowing water in the gully, and to stabilize gully heads. They are used to stabilize incipient, small and branch gullies generally not longer than 100 m and with catchment areas of less than two hectares. The maximum height of the dam is 1.5 m from the ground level. Both, its downstream and upstream face inclination are 25 percent backwards. The spillway is rectangular in shape. In general, the length and depth of spillway are one to two meters and 0.5 to 0.6 m respectively (Fig. 7.9).



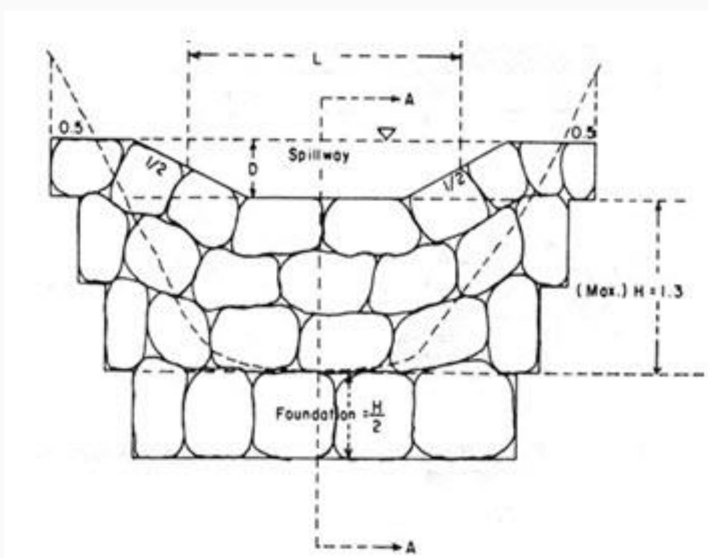
Front view of the first log check dam.



A-A cross-section of the first log check dam and counter dam.

Boulder Check Dams

Boulder check dams placed across the gully are used mainly to control channel erosion and to stabilize gully heads. In a gully system or multiple-gully system all the main gully channels of continuous gullies (each continuous gully has a catchment area of 20 ha or less and its length is about 900 m) can be stabilized by boulder check dams. These dams can be used in all regions. The maximum total height of the dam is 2 m. Foundation depth must be at least half of the effective height. The thickness of the dam at spillway level is 0.7 to 1.0 m (average 0.85 m), and the inclination of its downstream face is 30 percent (1:0.3 ratio); the thickness of the base is calculated accordingly. The upstream face of the dam is usually vertical. If the above-mentioned dimensions are used, it is not necessary to test the stability of the dam against overturning, collapsing and sliding. The dimensions of the spillway (Fig. 7.10) should be computed according to the maximum discharge of the gully catchment area. The form of the spillway is generally trapezoidal.



Front view of the boulder check dam.

Problem : Design the notch dimensions of a wooden slab dam to carry a peak flow of 0·6 m^3/sec. The notch has rectangular opening. Width of gully channel is 2·5 m.

Solution

Q = 0·6 m^3/sec = 600 litres/sec

Length, L, of notch = width of gully channel

= 2·5 m = 250 cm

$Q = 0{\cdot}0171\ LH^{3/2}$

Substituting the values in the formula,

$600 = 0{\cdot}0171 \times 250 \times H^{3/2}$

H = 27·01 cm, say 27 cm

Assume a freeboard of 5 cm

Total depth of notch = 27 + 5 = 32 cm

The design dimensions of the notch are: length 2·5 m; total depth 32 cm

RAINWATER HARVESTING

ATTRIBUTES OF GROUND WATER:

There is more ground water than surface water.
Ground water is less expensive and economic resource.
Ground water is sustainable and reliable source of water supply.
Ground water is relatively less vulnerable to pollution
Ground water is usually of high bacteriological purity.
Ground water is free of pathogenic organisms.
Ground water needs little treatment before use.
Ground water has no turbidity and color.
Ground water has distinct health advantage as alternative for lower sanitary quality surface water.
Ground water is usually universally available.
Ground water resource can be instantly developed and used.
There are no conveyance losses in ground water based supplies.
Ground water has low vulnerability to drought.
Ground water is key to life in arid and semi-arid regions.
Ground water is source of dry weather flow in rivers and streams.

RAINWATER HARVESTING is a process involving collection and storage of rain water (with the help of artificially designed system) that runs off natural or man-made catchment areas e.g. roof top, compounds, rock surface or hill slopes or artificially repaired impervious/semi-pervious land surface. Undoubtedly a number of factors contribute to the amount of water harvested e.g. the frequency and the quantity of rainfall, catchments characteristics, water demands and the quantum of runoff, and above all speed and ease with which the rainwater percolates through the subsoil to recharge the ground water.

Why harvest rainwater?

This is perhaps one of the most frequently asked questions, as to why one should harvest rainwater. There are many reasons but following are some of the important ones.

- To arrest ground water decline and augment ground water table
- To beneficiate water quality in aquifers
- To conserve surface water runoff during monsoon
- To reduce soil erosion
- To inculcate(teach) a culture of water conservation.

RAIN WATER HARVESTING TECHNIQUES :
There are two main techniques of rain water harvestings.
1. Storage of rainwater on surface for future use.

2. Recharge to ground water.

The storage of rain water on surface is a traditional techniques and structures used were underground tanks, ponds, check dams, weirs etc. Recharge to ground water is a new concept of rain water harvesting and the structures generally used are :-

Pits :- Recharge pits are constructed for recharging the shallow aquifer. These are constructed 1 to 2 m, wide and to 3 m. deep which are back filled with boulders, gravels, coarse sand.

Trenches:- These are constructed when the permeable stream is available at shallow depth. Trench may be 0.5 to 1 m wide, 1 to 1.5m Deep and 10 to 20 m long depending up availability of water. These are back filled with filter Materials.

Dug wells:- Existing dug wells may be utilized as recharge structure and water should pass through filter media before putting into dug well.

Hand pumps :- The existing hand pumps may be used for recharging the shallow/deep aquifers, if the availability of water is limited. Water should pass through filter media before diverting it into hand pumps.

Recharge wells :- Recharge wells of 100 to 300 mm. diameter are generally constructed for recharging the deeper aquifers and water is passed through filter media to avoid choking of recharge wells.

Recharge Shafts :- For recharging the shallow aquifer which are located below clayey surface, recharge shafts of 0.5 to 3 m. diameter and 10 to 15 m. deep are constructed and back filled with boulders, gravels & coarse sand.

Lateral shafts with bore wells :- For recharging the upper as well as deeper aquifers lateral shafts of 1.5 to 2 m. wide & 10 to 30 m. long depending upon availability of water with one or two bore wells are constructed. The lateral shafts is back filled with boulders, gravels & coarse sand.
Spreading techniques :- When permeable strata starts from top then this technique is used. Spread the water in streams/Nalas by making check dams, nala bunds, cement plugs, gabion structures or a percolation pond may be constructed.

Types of harvest rainwater

Broadly there are two ways of harvesting rainwater:

(i) Surface runoff harvesting
(ii) Roof top rainwater harvesting

Surface runoff harvesting:

In urban area rainwater flows away as surface runoff. This runoff could be caught and used for recharging aquifers by adopting appropriate methods.

Roof top rainwater harvesting (RTRWH):

It is a system of catching rainwater where it falls. In rooftop harvesting, the roof becomes the catchments, and the rainwater is collected from the roof of the house/building. It can either be stored in a tank or diverted to artificial recharge system. This method is less expensive and very effective and if implemented properly helps in augmenting the ground water level of the area.

Components of the roof top rainwater harvesting system

The system mainly constitutes of following sub components:

- Catchment
- Transportation
- First flush
- Filter

Catchment

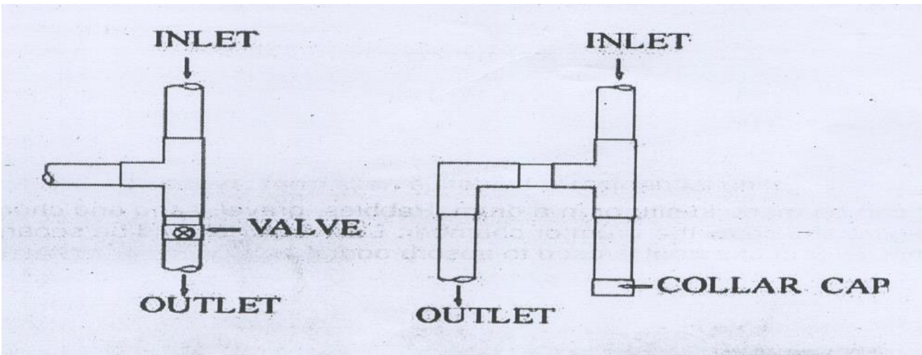
The surface that receives rainfall directly is the catchment of rainwater harvesting system. It may be terrace, courtyard, or paved or unpaved open ground. The terrace may be flat RCC/stone roof or sloping roof. Therefore the catchment is the area, which actually contributes rainwater to the harvesting system.

Transportation

Rainwater from rooftop should be carried through down take water pipes or drains to storage/harvesting system. Water pipes should be UV resistant (ISI HDPE/PVC pipes) of required capacity. Water from sloping roofs could be caught through gutters and down take pipe. At terraces, mouth of the each drain should have wire mesh to restrict floating material.

First Flush

First flush is a device used to flush off the water received in first shower. The first shower of rains needs to be flushed-off to avoid contaminating storable/rechargeable water by the probable contaminants of the atmosphere and the catchment roof. It will also help in cleaning of silt and other material deposited on roof during dry seasons Provisions of first rain separator should be made at outlet of each drainpipe.

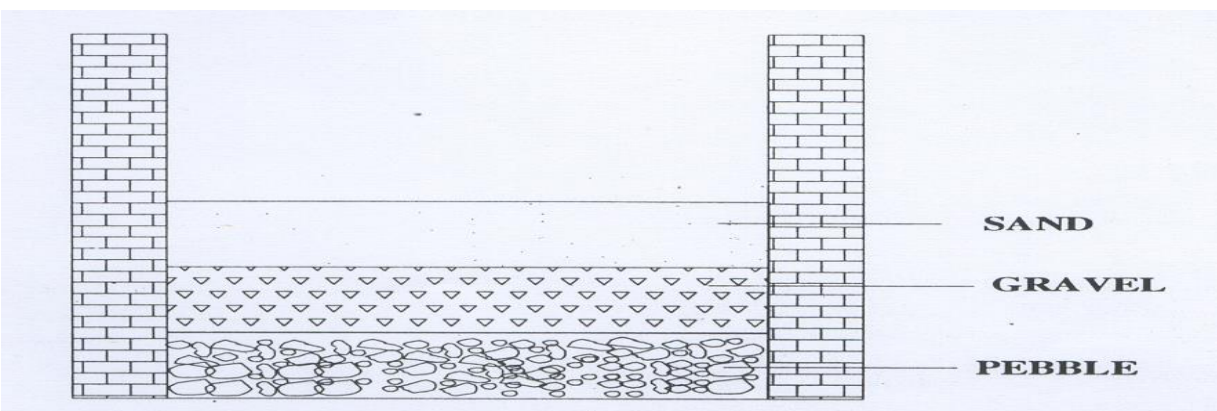


Filter

There is always some skepticism regarding Roof Top Rainwater Harvesting since doubts are raised that rainwater may contaminate groundwater. There is remote possibility of this fear coming true if proper filter mechanism is not adopted. Secondly all care must be taken to see that underground sewer drains are not punctured and no leakage is taking place in close vicinity. Filters are used fro treatment of water to effectively remove turbidity, color and microorganisms. After first flushing of rainfall, water should pass through filters. There are different types of filters in practice, but basic function is to purify water.

SandGravelFilter

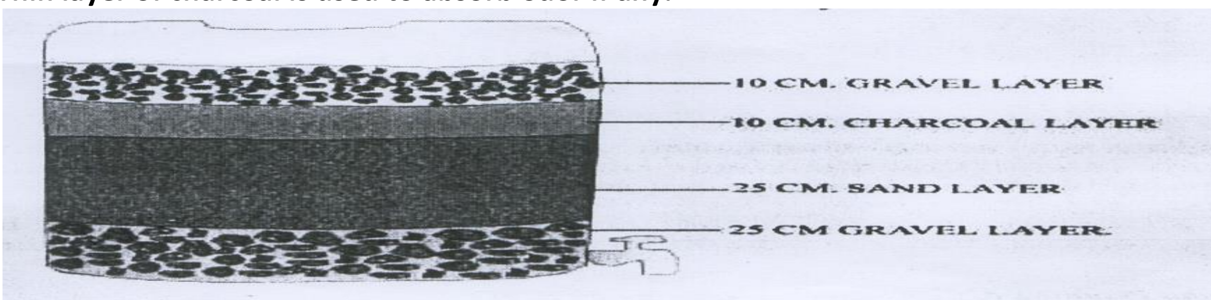
These are commonly used filters, constructed by brick masonry and filleted by pebbles, gravel, and sand as shown in the figure. Each layer should be separated by wire mesh.



SAND GRAVEL FILTER

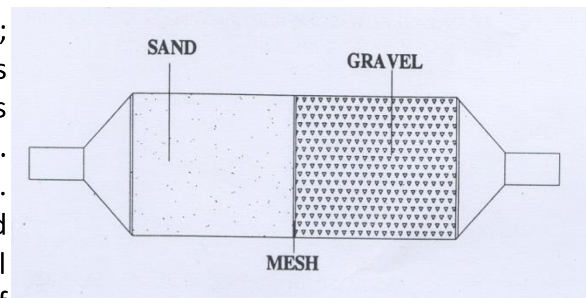
Charcoal Filter

Charcoal filter can be made in-situ or in a drum. Pebbles, gravel, sand and charcoal as shown in the figure should fill the drum or chamber. Each layer should be separated by wire mesh. Thin layer of charcoal is used to absorb odor if any.



PVC- Pipe filter

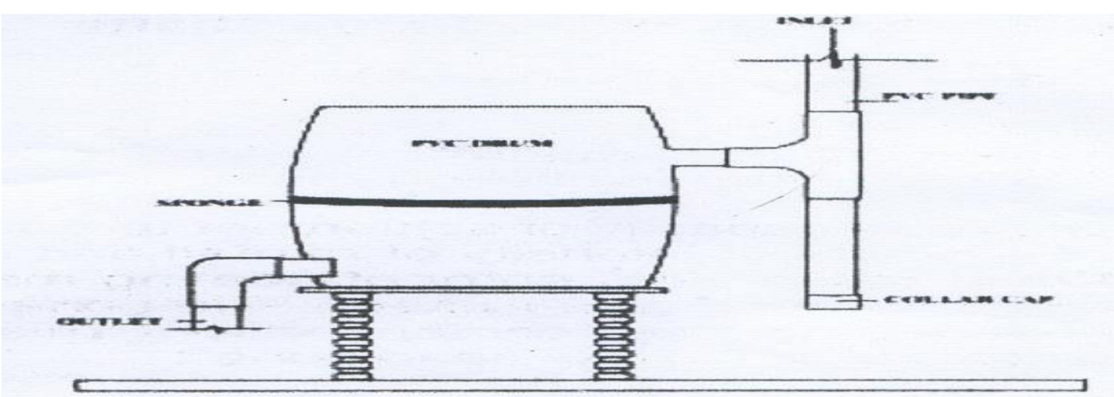
This filter can be made by PVC pipe of 1 to 1.20 m length; Diameter of pipe depends on the area of roof. Six inches dia. pipe is enough for a 1500 Sq. Ft. roof and 8 inches dia. pipe should be used for roofs more than 1500 Sq. Ft. Pipe is divided into three compartments by wire mesh. Each component should be filled with gravel and sand alternatively as shown in the figure. A layer of charcoal could also be inserted between two layers. Both ends of filter should have reduced of required size to connect inlet and outlet. This filter could be placed horizontally or vertically in the system.



PVC PIPE FILTER

Sponge Filter

It is a simple filter made from PVC drum having a layer of sponge in the middle of drum. It is the easiest and cheapest form filter, suitable for residential units.


SPONGE FILTER

Methods of Roof Top Rainwater Harvesting

Storage of Direct use

In this method rain water collected from the roof of the building is diverted to a storage tank. The storage tank has to be designed according to the water requirements, rainfall and catchment availability. Each drainpipe should have mesh filter at mouth and first flush device followed by filtration system before connecting to the storage tank. It is advisable that each tank should have excess water over flow system.

Excess water could be diverted to recharge system. Water from storage tank can be used for secondary purposes such as washing and gardening etc. This is the most cost effective way of rainwater harvesting. The main advantage of collecting and using the rainwater during rainy season is not only to save water from conventional sources, but also to save energy incurred on transportation and distribution of water at the doorstep. This also conserves groundwater, if it is being extracted to meet the demand when rains are on.

Recharging ground water aquifers

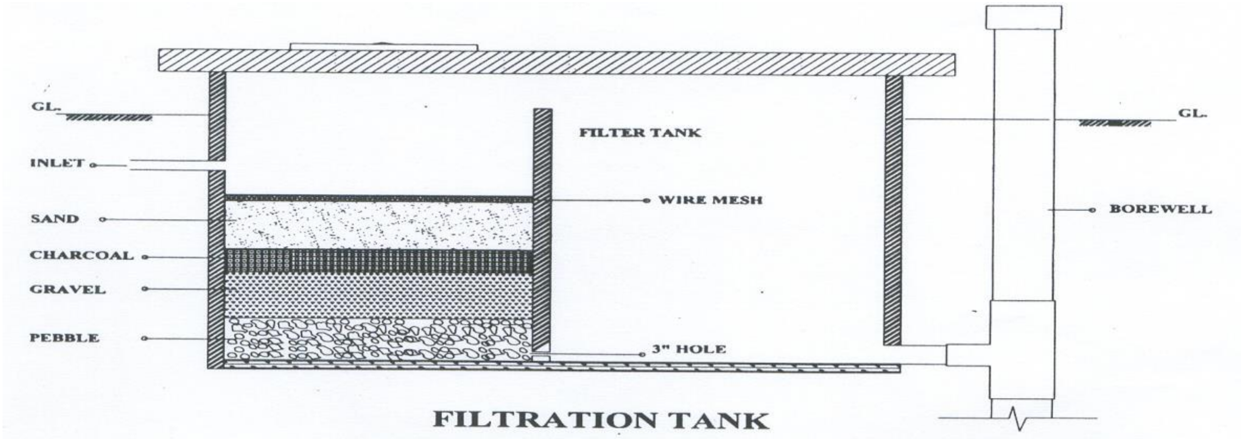
Ground water aquifers can be recharged by various kinds of structures to ensure percolation of rainwater in the ground instead of draining away from the surface. Commonly used recharging methods are:-

a) Recharging of bore wells
b) Recharging of dug wells.
c) Recharge pits
d) Recharge Trenches
e) Soak ways or Recharge Shafts
f) Percolation Tanks

Recharging of bore wells

Rainwater collected from rooftop of the building is diverted through drainpipes to settlement or filtration tank. After settlement filtered water is diverted to bore wells to recharge deep aquifers. Abandoned bore wells can also be used for recharge.

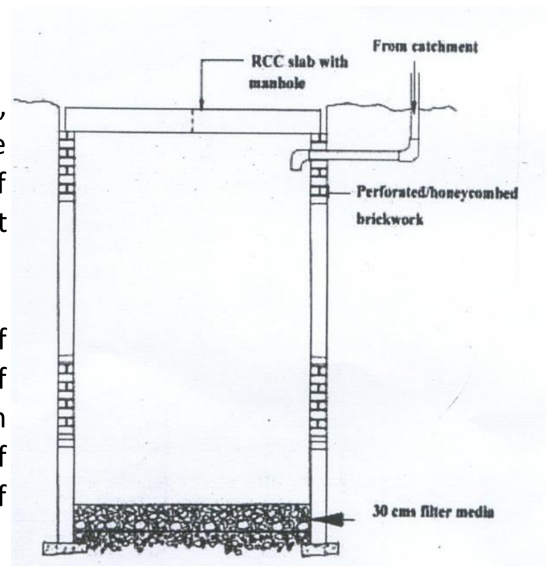
Optimum capacity of settlement tank/filtration tank can be designed on the basis of area of catchement, intensity of rainfall and recharge rate as discussed in design parameters. While recharging, entry of floating matter and silt should be restricted because it may clog the recharge structure. "First one or two shower should be flushed out through rain separator to avoid contamination. This is very important, and all care should be taken to ensure that this has been done."



Recharge Pits

Recharge pits are small pits of any shape rectangular, square or circular, contracted with brick or stone masonry wall with weep hole at regular intervals. top of pit can be covered with perforated covers. Bottom of pit should be filled with filter media.

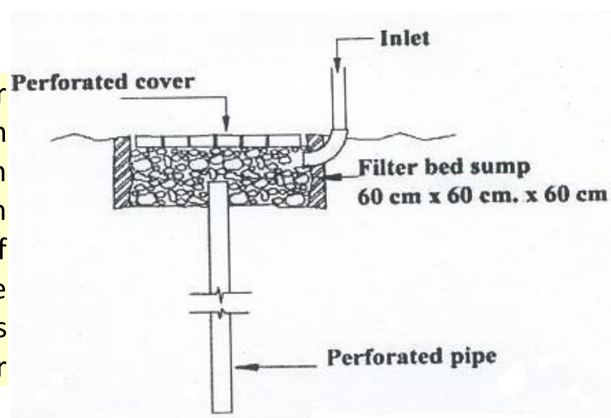
The capacity of the pit can be designed on the basis of catchment area, rainfall intensity and recharge rate of soil. Usually the dimensions of the pit may be of 1 to 2 m width and 2 to 3 m deep depending on the depth of pervious strata. These pits are suitable for recharging of shallow aquifers, and small houses.



Typical recharge pit

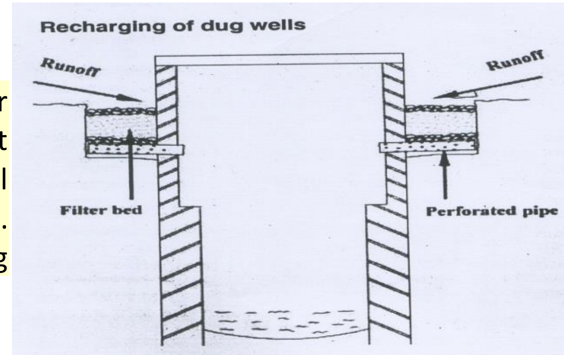
Soak away or Recharge Shafts

Soak away or recharge shafts are provided where upper layer of soil is alluvial .These are bored hole of 30 cm dia. up to 10 to 15 m deep, depending on depth of infiltration layer. Bore should be lined with slotted/perforated PVC/MS pipe to prevent collapse of the vertical sides. At the top of soak away required size sump is constructed to retain runoff before the filters through soak away. Sump should be filled with filter media.



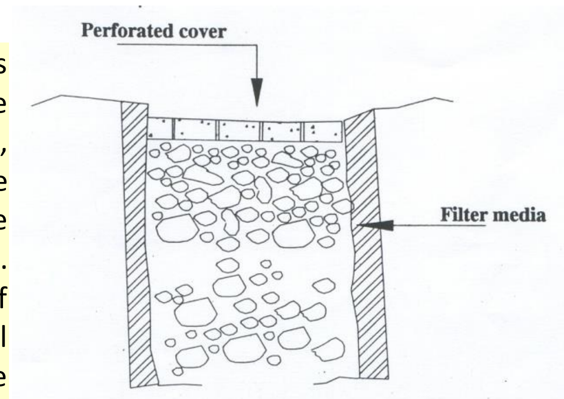
Recharging of dug wells

Dug well can be used as recharge structure. Rainwater from the rooftop is diverted to dug wells after passing it through filtration bed. Cleaning and desalting of dug well should be done regularly to enhance the recharge rate. The filtration method suggested for bore well recharging could be used.



Recharge Trenches

Recharge trench in provided where upper impervious layer of soil is shallow. It is a trench excavated on the ground and refilled with porous media like pebbles, boulder or brickbats. it is usually made for harvesting the surface runoff. Bore wells can also be provided inside the trench as recharge shafts to enhance percolation. The length of the trench is decided as per the amount of runoff expected. This method is suitable for small houses, playgrounds, parks and roadside drains. The recharge trench can be of size 0.50 to 1.0 m wide and 1.0 to 1.5 m deep.



Recharge Trenches

Percolation tanks

Percolation tanks are artificially created surface water bodies, submerging a land area with adequate permeability to facilitate sufficient percolation to recharge the ground water. These can be built in big campuses where land is available and topography is suitable.

Surface run-off and roof top water can be diverted to this tank. Water accumulating in the tank percolates in the solid to augment the ground water. The stored water can be used directly for gardening and raw use. Percolation tanks should be built in gardens, open spaces and roadside green belts of urban area

Recharge structures

Rainwater may be charged into the groundwater aquifers through any suitable structures like dugwells, borewells, recharge trenches and recharge pits.

Various recharge structures are possible - some which promote the percolation of water through soil strata at shallower depth (e.g., recharge trenches, permeable pavements) whereas others conduct water to greater depths from where it joins the groundwater (e.g. recharge wells). At many locations, existing structures like wells, pits and tanks can be modified as recharge structures, eliminating the need to construct any structures afresh. Here are a few commonly used recharging methods:

1. Recharging of dugwells and abandoned tubewells.

In alluvial and hard rock areas, there are thousands of wells which have either gone dry or whose water levels have declined considerably. These can be recharged directly with rooftop run-off. Rainwater that is collected on the rooftop of the building is diverted by drainpipes to a settlement or filtration tank, from which it flows into the recharge well (borewell or dugwell).

If a tubewell is used for recharging, then the casing (outer pipe) should preferably be a slotted or perforated pipe so that more surface area is available for the water to percolate. Developing a borewell would increase its recharging capacity (developing is the process where water or air is forced into the well under pressure to loosen the soil strata surrounding the bore to make it more permeable).

If a dugwell is used for recharge, the well lining should have openings (weep-holes) at regular intervals to allow seepage of water through the sides. Dugwells should be covered to prevent mosquito breeding and entry of leaves and debris. The bottom of recharge wells should be desilted annually to maintain the intake capacity.

Providing the following elements in the system can ensure the quality of water entering the recharge wells:

1.Filter mesh at entrance point of rooftop drains

2. Settlement chamber

3. Filter bed

A settlement chamber

2. Settlement tank

Settlement tanks are used to remove silt and other floating impurities from rainwater. A settlement tank is like an ordinary storage container having provisions for inflow (bringing water from the catchment), outflow (carrying water to the recharge well) and overflow. A settlement tank can have an unpaved bottom surface to allow standing water to percolate into the soil.

In case of excess rainfall, the rate of recharge, especially of borewells, may not match the rate of rainfall. In such situations, the desilting chamber holds the excess amount of water till it is soaked up by the recharge structure. Thus, the settlement chamber acts like a buffer in the system.

Any container, (masonry or concrete underground tanks, old unused tanks, pre-fabricated PVC or ferrocement tanks) with adequate capacity of storage can be used as a settlement tank.

3. Recharging of service tubewells.: In this case the rooftop runoff is not directly led into the service tubewells, to avoid chances of contamination of groundwater. Instead rainwater is collected in a recharge well, which is a temporary storage tank (located near the service tubewell), with a borehole, which is shallower than the water table. This borehole has to be provided with a casing pipe to prevent the caving in of soil, if the strata is loose. A filter chamber comprising of sand, gravel and boulders is provided to arrest the impurities.

4 Recharge pit :A recharge pit is 1.5m to 3m wide and 2m to 3m deep. The excavated pit is lined with a brick/stone wall with openings (weep-holes) at regular intervals. The top area of the pit can be covered with a perforated cover. Design procedure is the same as that of a settlement tank.

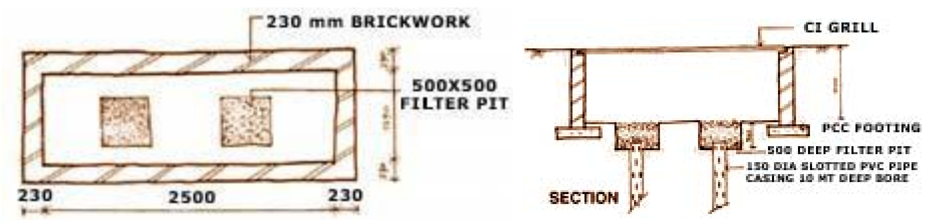
5. Soakaways / Percolation pit

Filter materials in a soakaway

Percolation pits, one of the easiest and most effective means of harvesting rainwater, are generally not more than 60 x 60 x 60 cm pits, (designed on the basis of expected runoff as described for settlement tanks), filled with pebbles or brick jelly and river sand, covered with perforated concrete slabs wherever necessary.

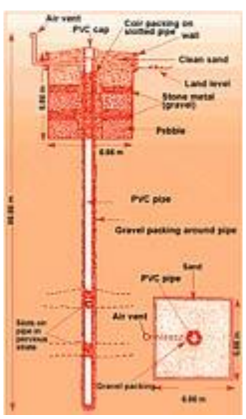
6.Recharge trenches :A recharge trench is a continuous trench excavated in the ground and refilled with porous media like pebbles, boulders or broken bricks. A recharge trench can be 0.5 m to 1 m wide and 1 m to 1.5 m deep. The length of the recharge trench is decided as per the amount of runoff expected. The recharge trench should be periodically cleaned of accumulated debris to maintain the intake capacity. In terms of recharge rates, recharge trenches are relatively less effective since the soil strata at depth of about 1.5 meters is generally less permeable. For recharging through recharge trenches, fewer precautions have to be taken to maintain the quality of the rainfall runoff. Runoff from both paved and unpaved catchments can be tapped.

7. Recharge troughs



Source: A water harvesting manual for urban areas

To collect the runoff from paved or unpaved areas draining out of a compound, recharge troughs are commonly placed at the entrance of a residential/institutional complex.These structures are similar to recharge trenches except for the fact that the excavated portion is not filled with filter materials. In order to facilitate speedy recharge, boreholes are drilled at regular intervals in this trench. In design part, there is no need of incorporating the influence of filter materials.
This structure is capable of harvesting only a limited amount of runoff because of the limitation with regard to size.



8. Modified injection well

In this method water is not pumped into the aquifer but allowed to percolate through a filter bed, which comprises sand and gravel. A modified injection well is generally a borehole, 500 mm diameter, which is drilled to the desired depth depending upon the geological conditions, preferably 2 to 3 m below the water table in the area. Inside this hole a slotted casing pipe of 200 mm diameter is inserted. The annular space between the borehole and the pipe is filled with gravel and developed with a compressor till it gives clear water. To stop the suspended solids from entering the recharge tubewell, a filter mechanism is provided at the top.

.ARTIFICIAL RECHARGE

The artificial recharge to ground water aims at augmentation of ground water reservoir by modifying the natural movement of surface water utilizing suitable civil construction techniques. Artificial recharge techniques normally address to following issues –

(i) To enhance the sustainable yield in areas where over-development has depleted the aquifer.
(ii) Conservation and storage of excess surface water for future requirements, since these requirements often changes within a season or a period.
(iii) To improve the quality of existing ground water through dilution.
(iv) To remove bacteriological and other impurities from sewage and waste water so that water is suitable for re-use.

The basic purpose of artificial recharge of ground water is to restore supplies from aquifers depleted due to excessive ground water development.

The artificial recharge techniques inter relate land integrate the source water to ground water reservoir. Two effects are generated by artificial recharge in ground water reservoir namely –

(a) Rise in water level and

(b) Increment in the total volume of the ground water reservoir.

ARTIFICIAL RECHARGE TECHNIQUES AND DESIGNS

A wide spectrum of techniques is in vogue to recharge ground water reservoir. Similar to the variations in hydro geological framework, the artificial recharge techniques too vary widely. The artificial recharge techniques can be broadly categorized as follows:-

a. Direct surface techniques

• Flooding

• Basins or percolation tanks

• Stream augmentation

• Ditch and furrow system

• Over irrigation

b. Direct sub surface techniques

• Injection wells or recharges wells

• Recharge pits and shafts

• Dug well recharge

• Bore hole flooding • Natural openings, cavity fillings.

c. Combination surface – sub-surface techniques

• Basin or percolation tanks with pit shaft or wells.

d. Indirect Techniques

• Induced recharge from surface water source.

• Aquifer modification.

Besides above, the ground water conservation structures like ground water dams, sub-surface dykes or locally termed as Bandharas, are quite prevalent to arrest sub-surface flows. Similarly in hard rock areas rock fracturing techniques including sectional blasting of boreholes with suitable techniques has been applied to inter-connect the fractures and increase recharge. Cement sealing of fractures, through specially constructed bore well has been utilized in Maharashtra to conserve sub-surface flow and augment bore well yield.

Artificial Recharge Structures

Ditch and Furrow Method:

In areas with irregular topography, shallow, flat bottomed and closely spaced ditches or furrows provide maximum water contact area for recharge water from source stream or canal. This technique requires less soil preparation than the recharge basins and is less sensitive to silting. a typical plan or series of ditches originating from a supply ditch and trending down the topographic slope towards the stream. Generally three patterns of ditch and furrow system are adopted.

Lateral Ditch Pattern

The water from stream is diverted to the feeder canal/ditch from which smaller ditches are made at right angles. The rate of flow of water from the feeder canal to these ditches is controlled by gate valves. The furrow depth is kept according to the topography and also with the aim that maximum wetted surface is available along with maintenance of uniform velocity. The excess water is routed to the main stream through a return canal along with residual silt.

Dendritic Pattern

The water from stream can be diverted from the main canal to a series of smaller ditches spread in a dendritic pattern. The bifurcation of ditches continues until practically all the water is infiltrated in the ground.

Contour Pattern

The ditches are excavated following the ground surface contour of the area. When the ditch comes closer to the stream a switch back is made and thus the ditch is made to meander back and forth to traverse the spread are repeatedly. At the lowest point downstream, the ditch joins the main stream, thus returning the excess water to it.

Check Dams Cement Plug nala bunds

Check dams are constructed across small streams having gentle slope and are feasible both in hard rock as well as alluvial formation. The site selected for check dam should have sufficient thickness of permeable bed or weathered formation to facilitate recharge of stored water within short span of time. The water stored in these structures is mostly confined to stream course and the height is normally less than 2 m. These are designed based on stream width and excess water is allowed to flow over the wall. In order to avoid scouring from excess run off, water cushions are provided at down streamside. To harness the maximum run off in the stream, series of such check dams can be constructed to have recharge on regional scale. A series of small bunds or weirs are made across selected nala sections such that the flow of surface water in the stream channel is impeded and water is retained on pervious soil/tock surface for longer body. Nala bunds are constructed across bigger nalas of second order streams in areas having gentler slopes.

For selecting a site for Check Dams/Nala bunds the following conditions may be observed.

1. The total catchment of the nala should normally be between 40 to 100 Hectares. though the local situations can be guiding factor in this.

2. The rainfall in the catchment should be less than 1000 mm/annum.

3. The width of nala bed should be atleast 5 metres and not exceed 15 metres and the depth of bed should not be less than 1 metre.

4. The soil down stream of the bund should not be prone to water logging and should have pH between 6.5 to 8.

5. The lands downstream of Check Dam/bund should have irrigable land under well irrigation.

6. The Nala bunds should be preferable located in area where contour or graded bunding or lands have been carried out.

7. The rock strata exposed in the ponded area should be adequately permeable to cause ground water recharge through ponded water.

8. Nala bund is generally a small earthen dam, with a cut off core wall of brick work, though cement bunds/plugs are now prevalent.

9. For the foundation for core wall a trench is dug 0.6 m wide in hard rock or 1.2 meters in soft rock of impervious nature. A core brick cement wall is erected 0.6 m wide to stand atleast 2.5

meters above nala bed and the remaining portion of trench is back filled on upstream side by impervious clay. The core wall is buttressed on both sides by a bund made up of local clays and on the upstream face, stone pitching is done.

10. Normally the final dimensions of the Nala bund are; length 10 to 15 meters, height 2 to 3 meters and width 1 to 3 meters, generally constructed in a trapezoidal form. If the bedrock is highly fractured, cement grouting is done to make the foundation leakage free.

The check dams are also popular and feasible in Bhabar, Kandi and talus scree areas of Uttar Pradesh, Punjab, and Maharashtra and have substantial impact on augmentation of ground water.

Gabion Structure

This is a kind of check dam being commonly constructed across small stream to conserve stream flows with practically no submergence beyond stream course. The boulders locally available are stored in a steel wire. This is put up across the stream's mesh to make it as a small dam by anchoring it to the streamside. The height of such structures is around 0.5 m and is normally used in the streams with width of about 10 to 15 m. The cost of such structures is around Rs.10 to 15000/-. The excess water overflows this structure storing some water to serve as source of recharge. The silt content of stream water in due course is deposited in the interstices of the boulders to make it more impermeable. These structures are common in the State of Maharashtra, Madhya Pradesh, Andhra Pradesh etc.

Percolation Tanks (PT) / Spreading Basin

These are the most prevalent structures in India as a measure to recharge the ground water reservoir both in alluvial as well as hard rock formations. The efficacy and feasibility of these structures is more in hard rock formation where the rocks are highly fractured and weathered. In the States of Maharashtra, Andhra Pradesh, Madhya Pradesh, Karnataka and Gujarat, the percolation tanks have been constructed in plenty in basaltic lava flows and crystalline rocks. The percolation tanks are however also feasible in mountain fronts occupied by talus scree deposits. These are found to be very effective in Satpura Mountain front area in Maharashtra. The percolation tanks can also be constructed in the Bhabar zone. Percolation tanks with wells and shafts Percolation tanks are also constructed to recharge deeper aquifers where shallow or superficial formations are highly impermeable or clayey with certain modification. Recharge wells with filter are constructed in the Percolation Tanks and the stored water is Moti Ranjan and Bhujpur, Mandvi Kutch district, Gujarat.

Important Aspects of Percolation Tanks:

a. A detailed analysis of rainfall pattern, number of rainy days, dry spells, and evaporation rate and detailed hydro geological studies to demarcate suitable percolation tank sites.

b. In Peninsular India with semi arid climate, the storage capacity of percolation tank be designed such that the water percolates to ground water reservoir by January since the evaporation losses would be high subsequently.

c. Percolation tanks are normally constructed on second to third order stream since the catchment so also the submergence area would be smaller.

d. The submergence area should be in uncultivable land as far as possible.

e. Percolation tank be located on highly fractured and weathered rock for speedy recharge. In case of alluvium, the boundary formations are ideal for locating Percolation Tanks.

f. The aquifer to be recharge should have sufficient thickness of permeable vadose zone to accommodate recharge.

g. The benefitted area should have sufficient number of wells and cultivable land to develop the recharge water.

h. Detailed hydrological studies for run off assessment be done and design capacity should not normally be more than 50% of total quantum of rainfall in catchment.

i. Waste weir or spillway be suitably designed to allow flow of surplus water based on single day maximum rainfall after the rank is filled to its maximum capacity.

j. Cut off trench be provided to minimize seepage losses both below and above nallah bed.

k. To avoid erosion of embankment due to ripple action stone pitching be provided upstream up to HFL.

l. Monitoring mechanism in benefitted as well as catchment area using observation well and staff gauges be provided to assess the impact and benefits of percolation tank.

RECHARGE PITS

Recharge pits are normally excavated pits, which are sufficiently deep to penetrate the low permeability layers overlying the unconfined aquifers. They are similar to recharge basins in principle, with the only difference being that they are deeper and have restricted bottom area. In many such structures, most of the infiltration occurs laterally through the walls of the pit as in most layered sedimentary or alluvial material the lateral hydraulic conductivity is considerably higher than the vertical hydraulic conductivity. Abandoned gravel quarry pits or brick kiln quarry pits in alluvial areas and abandoned quarries in basaltic areas can also be used as recharge pits wherever they are underlain by permeable horizons. Nalah trench is a special case of recharge pit dug across a streambed. Ideal sites for such trenches are influent stretches of streams.

Design Guidelines

• The recharging capacity of the pit increase with its area of cross section. Hence, it is always advisable to construct as large a pit as possible.

• The permeability of the underlying strata should be ascertained through infiltration tests before taking up construction of recharge pits.

• The side slopes of recharge pits should be 2:1 as steep slopes reduce clogging and sedimentation on the walls of the pit.

• Recharge pits may be used as ponds for storage and infiltration of water or they may be backfilled with gravel sand filter material over a layer of cobbles/boulders at the bottom. Even when the pits are to be used as ponds, it is desirable to provide a thin layer of sand at the bottom to prevent the silt from clogging permeable strata.

• As in the case of water spreading techniques, the source water being used for recharge should be as silt-free as possible.

• The bottom area of the open pits and the top sand layer of filter-packed pits may require periodic cleaning to ensure proper recharge. Recharge pits located in flood-prone areas and on streambeds are likely to be effective for short duration only due to heavy silting. Similar pits by the sides of streambeds are likely to be effective for longer periods

. • In hard rock areas, streambed sections crossing weathered or fractured rocks or sections along prominent lineaments or intersection of lineaments form ideal locations for recharge pits.

farm pond

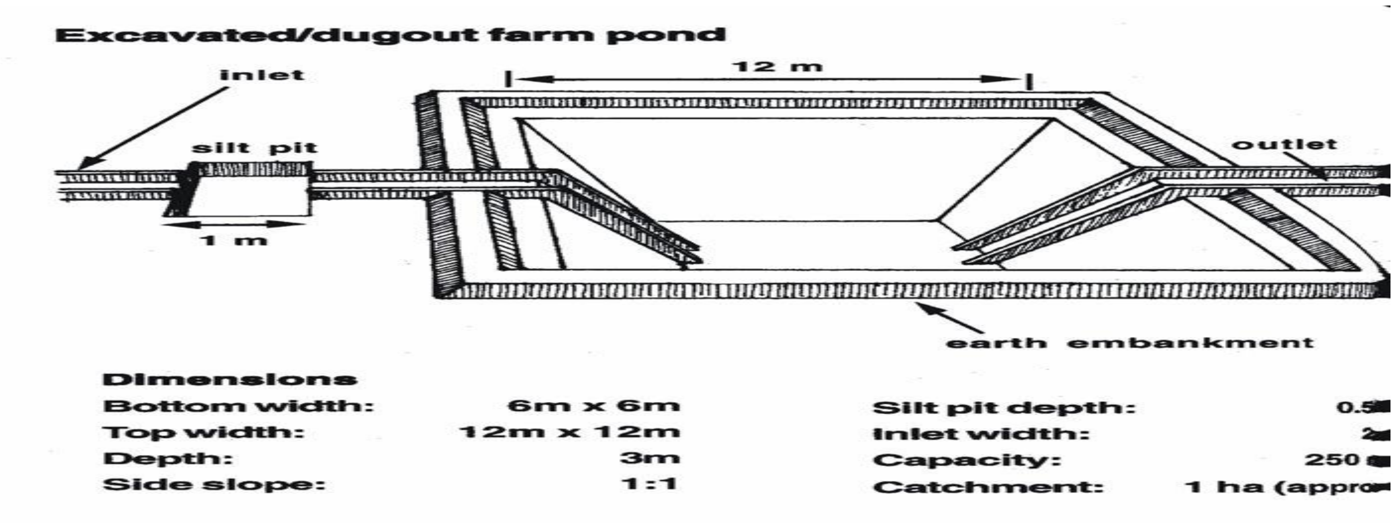
A farm pond is a large hole dug out in the earth, usually square or rectangular in shape, which harvests rainwater and stores it for future use. It has an inlet to regulate inflow and an outlet to discharge excess water. The pond is surrounded by a small bund, which prevents erosion on the banks of the pond. The size and depth depend on the amount of land available, the type of soil, the farmer's water requirements, the cost of excavation, and the possible uses of the excavated earth. Water from the farm pond is conveyed to the fields manually, by pumping, or by both methods.

Location

The selection of a site for a farm pond is critical in maximizing its storage capacity. . The pond must be located in a corner of a plot of land so that it does not disturb farm operations like plowing. It must be located at least 3m away from other farmers' fields common lands. The slope of the land and the slope's direction must also be carefully evaluated.

Excavation

A test pit is dug out before finalizing the location and depth of excavation. The excavation and transportation of earth can be accomplished with a combination of manual labour or with machines like excavators and tractors.



Soil conditions must be carefully considered. Excavation in areas with hard clay soil, such as Ramnad district, is very difficult and expensive using manual labour.

Use of machines for excavation and transportation is the best method in this context, with human labour used for leveling, bund formation, and construction.

Advantages of Farm Ponds

- They provide water to start growing crops, without waiting for rain to fall.
- They provide irrigation water during dry spells between rainfalls. This increases the yield, the number of crops in one year, and the diversity of crops that can be grown.
- Bunds can be used to raise vegetables and fruit trees, thus supplying the farm household with an additional source of income and of nutritious food.
- Farmers are able to apply adequate farm inputs and perform farming operations at the appropriate time, thus increasing their productivity and their confidence in farming.
- They check soil erosion and minimizes siltation of waterways and reservoirs.
- They supplies water for domestic purposes and livestock
- They promote fish rearing.
- They recharge the ground water.
- They improve drainage.
- The excavated earth has a very high value and can be used to enrich soil in the fields, leveling land, and constructing farm roads.

Limitations of Farm Ponds

- They reduce the water flow to other people’s tanks and ponds situated in lower-lying areas.
- They occupy a large portion of farmers’ lands. However, this can be compensated for by rearing fish in the pond, effectively utilizing the bunds for vegetable and/or tree plantations, etc.

Problem:

The storage capacity needed should be calculated to take into consideration the length of any dry spells, the amount of rainfall, and the per capita water consumption rate. In most of the Asian countries, the winter months are dry, sometimes for weeks on end, and the annual average rainfall can occur within just a few days. In such circumstances, the storage capacity should be large enough to cover the demands of two to three weeks. For example, a three person household should have a minimum capacity of 3 (Persons) x 90 (l) x 20 (days) = 5 400 l.

Land

Land is a physical entity in terms of its topography and spatial nature thus including natural resources like the soil, minerals, water and biota existing on the land.

These components provide a variety of services essential to the maintenance of life-support systems and the productive capacity of the environment.

Land Use Classification

a)Classification of Land according to Area

• **Land Cover Classification -** physical appearance,

• **Agro-Climatic / Agro-Ecological Classification -** technical attributes like soil profile, soil texture agro -climatic conditions etc.

• **Land Use Classification -** purpose for which it is being used.

b)Classification of Land according to use/cover

Class 1: **Conservation and Natural Environments**
Land used primarily for conservation purposes or land uses with minimal impact, based on the maintenance of the essentially natural ecosystems present. Examples include Gregory National Parks.

Class 2: **Production from relatively natural environments**

Land used primarily for primary production based on limited change to the native vegetation. Examples include pastoralism on native vegetation.

Class 3:**Production from dry land agriculture and plantations**

Land used mainly for primary production, based on dry land farming systems. For example, pastoralism on improve pastures

Class 4 : **Production from irrigated agriculture and plantations**

Land used mostly for primary production based on irrigated farming. Examples include irrigated mangoes and vegetables and broad scale centre pivot crops.

Class 5 : **Intensive uses**

Land subject to extensive modification, generally in association with closer residential settlement, commercial or industrial uses.

Class 6 : **Water**

Water features. Water is regarded as an essential aspect of the classification, but it is primarily a cover type. For example Darwin River Dam.

LAND-CAPABILITY CLASSIFICATION

The standard soil-survey map shows the different kinds of soil that are significant and their location in relation to other features of the landscape. These maps are intended to meet the needs of users with widely different problems and, therefore, contain considerable detail to show important basic soil differences.

The information on the soil map must be explained in a way that has meaning to the user. These explanations are called **interpretations**. Soil maps can be interpreted by

(1) the individual kinds of soil on the map, and

(2) the grouping of soils that behave similarly in responses to management and treatment.

The capability classification is one of a number of interpretive groupings made primarily for agricultural purposes. As with all interpretive groupings the capability classification begins with the individual soil-mapping units, which are building stones of the system (table 1). In this classification the arable soils are grouped according to their potentialities and limitations for sustained production of the common cultivated crops that do not require specialized site conditioning or site treatment.

Nonarable soils (soils unsuitable for longtime sustained use for cultivated crops) are grouped according to their potentialities and limitations for the production of permanent vegetation and according to their risks of soil damage if mismanaged.

The capability grouping of soils is designed

(1) to help landowners and others use and interpret the soil maps,

(2) to introduce users to the detail of the soil map itself, and

(3) to make possible broad generalizations based on soil potentialities, limitations in use, and management problems.

The capability classification provides three major categories of soil groupings:

(1) Capability unit,

(2) capability subclass,

(3) capability class.

Soil-mapping unit	Capability unit	Capability subclass	Capability class

A soil mapping unit is a portion of the landscape' that has similar characteristics and qualities and whose limits are fixed by precise definitions. Within the cartographic limitations and considering the purpose for which the map is made, the soil mapping unit is the unit about which the greatest number of precise statements and predictions can be made. The soil mapping units provide the most detailed soils information. The basic mapping units are the basis for all interpretive groupings of soils. They furnish the information needed for developing capability units, forest site groupings, crop suitability groupings, range site groupings, engineering groupings, and other interpretive groupings. The most specific management practices and estimated yields are related to the	A capability unit is a grouping of one or more individual soil mapping units having similar potentials and continuing limitations or hazards. The soils in a capability unit are sufficiently uniform to (a) produce similar kinds of cultivated crops and pasture plants with similar management practices, (b) require similar conservation treatment and management under the same kind and condition of vegetative cover, (c) have comparable potential productivity. The capability unit condenses and simplifies soils information for planning individual tracts of land, field by field. Capability units with the class and subclass furnish information about the degree of	Subclasses are groups of capability units which have the same major conservation problem, such as— e—Erosion and runoff. w—Excess water . s—Root-zone limitations. c—Climatic limitations. The capability subclass provides information as to the kind of conservation problem or limitations involved. The class and subclass together provide the map user information about both the degree of limitation and kind of problem involved for broad program planning, conservation need studies, and similar purposes.	Capability classes are groups of capability subclasses or capability units that have the same relative degree of hazard or limitation. The risks of soil damage or limitation in use become progressively greater from class I to class VIII. The capability classes are useful as a means of introducing the map user to the more detailed information on the soil map. The classes show the location, amount, and general suitability of the soils for agricultural use. Only information concerning general agricultural limitations in soil use are obtained at the capability class level.

individual mapping unit.	limitation, kind of conservation problems and the management practices needed.		

Capability classes, the broadest groups, are designated by the numbers 1 through 8. The numbers indicate progressively greater limitations and narrower choices for practical use. The classes are defined as follows:

Class 1 soils have slight limitations that restrict their use.

Class 2 soils have moderate limitations that restrict the choice of plants or that require moderate conservation practices.

Class 3 soils have severe limitations that restrict the choice of plants or that require special conservation practices, or both.

Class 4 soils have very severe limitations that restrict the choice of plants or that require very careful management, or both.

Class 5 soils are subject to little or no erosion but have other limitations, impractical to remove, that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat.

Class 6 soils have severe limitations that make them generally unsuitable for cultivation and that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat.

Class 7 soils have very severe limitations that make them unsuitable for cultivation and that restrict their use mainly to grazing, forestland, or wildlife habitat.

Class 8 soils and miscellaneous areas have limitations that preclude commercial plant production and that restrict their use to recreational purposes, wildlife habitat, watershed, or esthetic purposes.

Capability subclasses are soil groups within one class. They are designated by adding a small letter, *e, w, s,* or *c,* to the class numeral, for example, 2e. The letter *e* shows that the main hazard is the risk of erosion unless close-growing plant cover is maintained; *w* shows that water in or on the soil interferes with plant growth or cultivation (in some soils the wetness can be partly corrected by artificial drainage); *s* shows that the soil is limited mainly because it is shallow, droughty, or stony; and *c,* used in only some parts of the United States, shows that the chief limitation is climate that is very cold or very dry.

In class 1 there are no subclasses because the soils of this class have few limitations. Class 5 contains only the subclasses indicated by *w, s,* or *c* because the

soils in class 5 are subject to little or no erosion. They have other limitations that restrict their use to pasture, rangeland, forestland, wildlife habitat, or recreation.
Capability units are soil groups within a subclass. The soils in a capability unit are enough alike to be suited to the same crops and pasture plants, to require similar management, and to have similar productivity. Capability units are generally designated by adding an Arabic numeral to the subclass symbol, for example, 2e-4 and 3e-6. These units are not given in all soil surveys.
The capability classification of map units in this survey area is given in the table "Land Capability and Yields Per Acre of Crops and Pasture".

Grassland

A large open area of country covered with grass, especially one used for grazing.

Benefits of grassland:

A) Environmental benefits

- Prevents grassland from turning into brush land
- Maintains or enhances the soil erosion, water quality, soil quality and carbon sequestration benefits of existing grassland
- Protects restored habitat for many plants and animals including pheasant, ducks, songbirds and endangered species

b) Practical benefits

- Improves the quality and yield of forage, biomass or native seed production
- Keeps unwanted species from getting established and becoming a nuisance
- Provides opportunities for hunting, birding and wildlife watching
- Keep grass-based conservation practices working properly
- May support nearby crop health by providing long-term habitat for animals that eat insect pests and habitat for pollinator species that many crops rely upon, such as bees.

- Helps prevent gully formation that requires expensive corrective measures
- Provides a low-cost alternative to growing crops on marginal land.

Components of Grasslands

Grassland ecosystems have both **biotic** and **abiotic** components. The biotic components of an ecosystem are the living organisms that exist in the system and can be classified as producers (including grasses, shrubs and trees), consumers (including grazing ungulates, birds and insects) or decomposers (including fungi, insects and bacteria). Abiotic components of the ecosystems are the non-living components on which the living components depend, including climate, soil and topography.

Grassland management keeps grass stands healthy so they continue to provide long-term conservation benefits. It is important for native as well as non-native (introduced) grassland ecosystems. Well established native grasslands, however, typically do not need ongoing insecticide or herbicide treatment for weed control.

Grassland management, especially weed control, is critical in the first few years after grass is planted. Removing dead plant residues through, mowing, clipping, grazing or controlled burning invigorates grassland by creating open soil for new grass growth. Burning is especially useful in killing weed seeds, insects and other pests as well as recycling nutrients to promote vigorous plant growth.

Common additional grassland management activities include long-term invasive species management and re-seeding problem areas. Other aspects of grassland management vary depending on whether and how the grassland is used, e.g., for habitat, pasture, hay, biomass for bio-fuels or native seed production.

forest

A large area covered chiefly with trees and undergrowth.

Types of forest:

Tropical Rainforest

Location: The tropical rainforests contain the greatest diversity of species of all biomes on earth. They are found around the equator, between 23.5 degrees N latitude and 23.5 degrees S latitude.

Climate: Temperatures in tropical rainforests remain between 68 and 77 degrees Fahrenheit all year long. Winter is absent in these forests. Most tropical rainforests receive 100 inches of rain per year.

Soil: Because the temperature is warm and the air moist, decomposition happens at a very fast rate in tropical rainforests. High levels of rainfall often lead to leaching of nutrients from the soil, creating soils that are nutrient poor.

Plants: Trees in the tropical rainforests grow between 82 and 115 feet tall and are typically broad-leafed trees. Other plants include ferns, vines, mosses, palms and orchids.

Animals: Dense growing trees create a thick canopy layer in tropical rainforests that keep the sun from penetrating to the lower layers of the forest. This means that most animals that live here must be adapted to living in the trees. A variety of birds, bats, monkeys, snakes and other animals can be found in tropical rainforests.

Threats: The biggest threat to tropical rainforests is unsustainable forestry practices. Other threats include road construction, clearing land for agriculture and other development activities and climate change.

Temperate Deciduous Forest

Location: Eastern United States and Canada, Western Europe and parts of Russia, China and Japan.

Climate: There are four distinct seasons in temperate deciduous forests and precipitation falls throughout the year, as rain in the spring, summer and fall and snow in the winter. Temperate deciduous forests receive 30-60 inches of rain per year.

Soil: The soil in these forests is very fertile.

Plants: The forest floor in temperate deciduous forests supports mosses, ferns and wildflowers and the understory supports a variety of shrubs and ferns. Maple, oak and birch trees are some examples of the deciduous trees that dominate these forests. There are also small numbers of evergreen trees such as pines and fir.

Animals: Animals living in temperate deciduous forests must be adapted to cold winters. Common species found in temperate deciduous forests include, red fox, hawks, woodpecker and cardinals.

Threats: Acid rain caused by industrial and vehicular emissions poses the biggest threat to temperate deciduous forests. Over time, acid rain damages tree leaves, causes trees to produce fewer and smaller seeds and reduces resistance to disease. Other threats include unsustainable forestry, strip mining and the spread of invasive, non-native species that compete for space and food. Climate change is also a threat.

Temperate Coniferous Forest

Location: Temperate coniferous forests are typically found in coastal areas with mild winters and heavy rainfall or in in-land mountainous areas with mild climates. Examples of where these forests are found are Pacific Northwestern United States and Canada, southwestern South America, Southern Japan, New Zealand and small parts of northwestern Europe (Ireland, Scotland, Iceland and Norway).

Climate: Temperate climate with temperature that fluctuates little throughout the year. High levels of precipitation (50-200 inches per year) cause a moist climate and a long growing season.

Soil: Soils are generally rich with a thick layer of decaying material.

Plants: Evergreen conifers dominate these forests. Due to the high levels of precipitation and moderate temperatures, there is a long growing season, resulting in trees that grow very tall. Dominant tree species found in temperate coniferous forests include cedar, cypress, Douglas fir, pine, spruce and redwood. There are some deciduous trees such as maple, and mosses and ferns are common.

Animals: Examples of animals that live in temperate coniferous forests are, deer, marmot, elk, black bear, salmon, spotted owl, marbled murrelet

Threats: Unsustainable forestry, road construction and other development related activities are the biggest threat to temperate deciduous forests.

Boreal (taiga) Forest

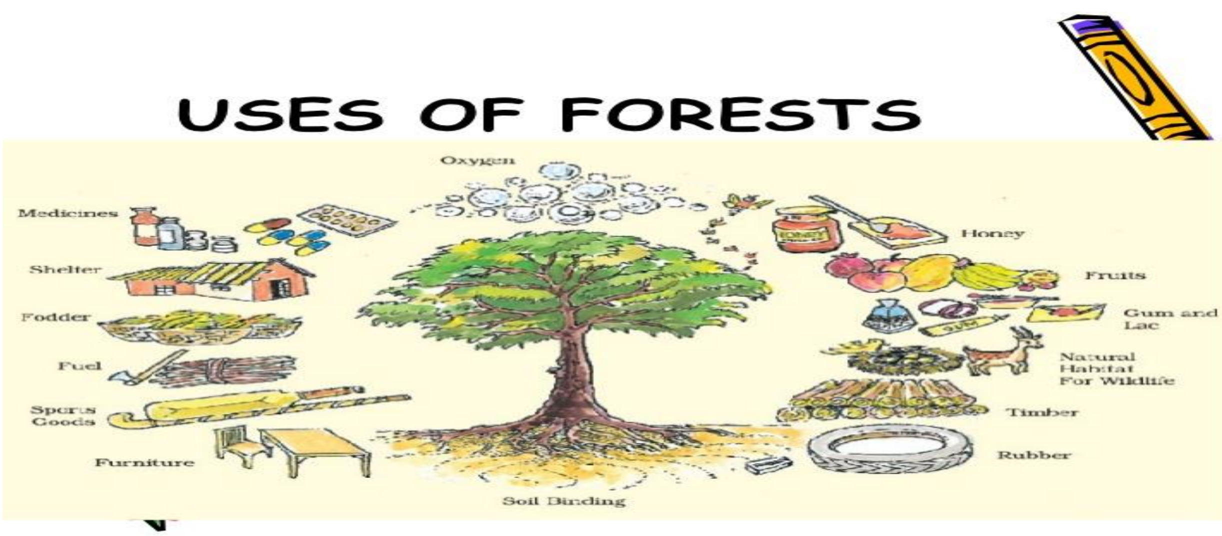
Location: This is the northern most forest type and is found between 50 and 60 degrees N latitude. Boreal forests are found in Canada, northern Asia, Siberia and Scandinavia (Denmark, Norway, Sweden, Finland). About two-thirds of the world's boreal forests are found in Scandinavia.

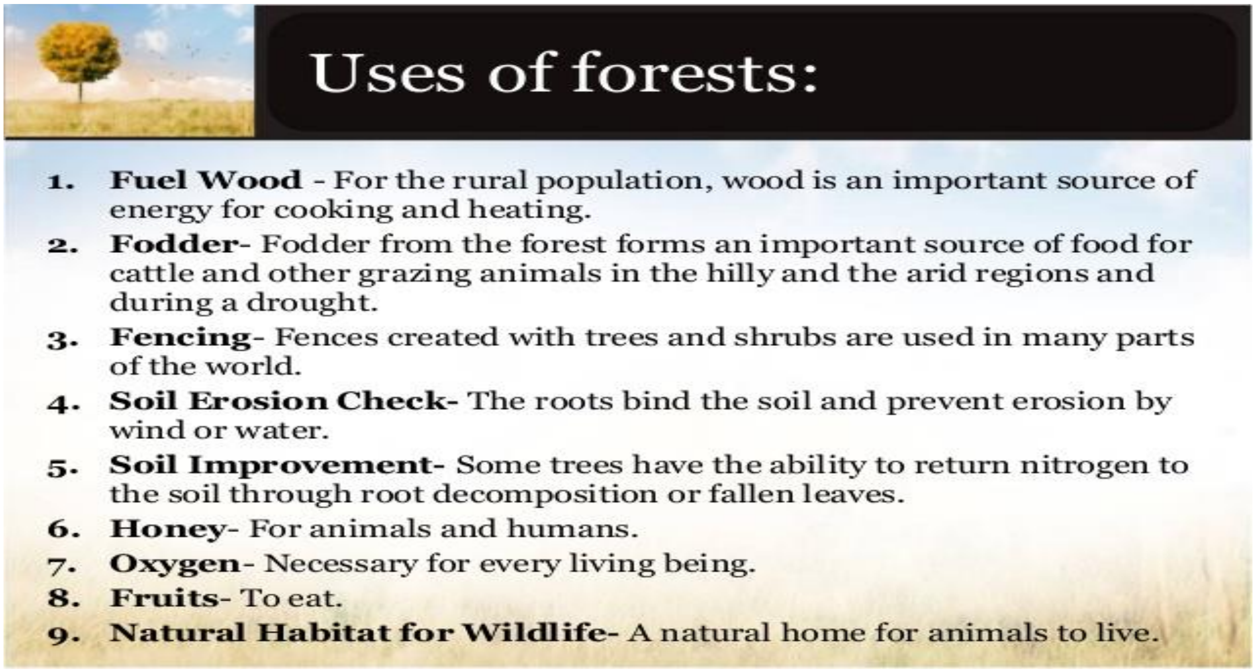
Climate: Boreal forests are characterized by long winters and short summers. Most precipitation is in the form of snow and these forests receive between 15 and 40 inches of precipitation per year.

Soil: Because of cold temperatures, decomposition takes a long time, resulting in thin soil.

Plants: Trees are mostly evergreen and include species such as spruce, fir and pine. The understory is limited because the canopy is so dense.

Animals: Animals found here must be adapted to long, cold winters and usually have thick fur. Deer, moose, elk, caribou, snowshoe hare, wolves, grizzly bears, lynxes and wolverines are some examples





FOREST MANAGEMENT

Forest management is a branch of **forestry** concerned with overall administrative, economic, legal, and social aspects, as well as scientific and technical aspects, such as protection, and **forest** regulation.

1. The role and the meaning of forest management
2. Management - the development of different approaches
3. The principles of sustainable management
4. Technical requirements
5. Final general remarks

What is Grassland Management?

Grassland management refers to the manipulation of natural vegetation in order to achieve some predetermined goals. Grasslands are often managed to improve productivity and to maximize benefits for human use. An understanding of the relationships between environmental forces and the plants and animals that make up grassland ecosystems is key to ensuring the proper balance of rest and disturbance.

Grassland management science includes the study of the various plants and animals that live in BC's grasslands and the interactions between them. As we gain more knowledge about grassland ecosystems and how they function, we are better able to make management decisions to ensure their long-term health.

Proper grazing management also maintains wildlife habitats, conserves the soil upon which we all depend, and preserves the natural beauty of grassland landscapes.

Ecological System

Ecological systems (ecosystems) consist of all the living organisms in an area and their physical environment (soil, water, air). Ecosystems are influenced over time by the local climate, variations in the local landscape, disturbances such as fire and floods, and the organisms that inhabit them. Grassland ecosystems in British Columbia generally occur in areas where the climate is hot and dry in summer and cool to cold and dry in winter, where the parent material is composed of fine sediments, and in valley or plateau landscapes. The organisms that live in grasslands include plants and animals that have adapted to the climatic conditions in a variety of ways. Differences in elevation, climate, soils, aspect and their position in relation to mountain ranges have resulted in many variations in the grassland ecosystems of British Columbia. The mosaics of ecosystems found in our grasslands, including wetlands, riparian areas, aspen stands and rocky cliffs, allow for a rich diversity of species.

Components of Grasslands

Grassland ecosystems have both biotic and abiotic components. The biotic components of an ecosystem are the living organisms that exist in the system and can be classified as producers (including grasses, shrubs and trees), consumers (including grazing ungulates, birds and insects) or decomposers (including fungi, insects and bacteria). Abiotic components of the ecosystems are the non-living components on which the living components depend, including climate, soil and topography.

Grassland Vegetation

Approximately 1,990 of types of vascular plants are found in plant communities that are dominated by steppe vegetation, which includes our native Bunchgrass Zone. This wide diversity of plant species requires managers to have a thorough understanding of plant physiology and morphology. Plants are generally grouped into six classes:

- trees
- shrubs
- grasses
- grass-like plants (sedges and rushes)
- forbs (broad-leaved herbaceous plants)
- cryptogams (mosses and lichens).

Trees

Trees can be either coniferous or deciduous. Coniferous trees, including Douglas fir and ponderosa pine, have needle-like leaves and seeds borne in cones. Coniferous trees are often referred to as “evergreens” because they retain their leaves throughout the year. Ponderosa pine is common as scattered trees on BC’s open grassland landscape or as semi-open stands. Douglas fir is abundant in swales and ravines, or in semi-open stands at higher elevations. On the upper grassland slopes, fire kept coniferous trees from encroaching and foresting the landscape. In recent decades as a result of fire suppression, vast acreages of the upper grasslands have been lost to forest.

Deciduous trees, such as trembling aspen, generally have broad, net-veined leaves and seeds that are produced from flowers. The leaves of deciduous trees usually change colour before they are shed in the autumn. Shrubs, such as Saskatoon and snowberry, are woody plants that have shorter, bushier appearances than trees. Aspen groves or ‘copses’ on the open grasslands and shrubby ravines or draws provide valuable food and cover habitat for wildlife and birds. Heavy grazing by cattle on these species competes with wild animals, such as deer, for forage. Cattle preference for browsing small aspen and deciduous shrubs in fall months can occur when protein levels in grasses are low.

Grasses

Grasses are herbaceous plants, which mean that they die back to ground level each year. The flowers and seeds of grasses can vary greatly and are used to distinguish between different grass species. Bluebunch wheatgrass and Rough fescue (found in steppe vegetation of the Southern Interior), pinegrass (found beneath forest canopies throughout central and southern BC) and Altai fescue (found in northern BC) are some common grasses of BC's rangelands. The most palatable grass species for cattle and wildlife are more sensitive to grazing than weedy or annual grass species. Continued, heavy grazing can negatively impact the desirable grasses reducing their ability to compete with unglazed plants.

Grass-like plants

Sedges and rushes are similar to grasses in that they have slender, parallel-veined leaves, but their stems are unjointed and solid. Rushes have round stems and sedges usually have three-sided stems. Both sedges and rushes are associated mainly with wetlands but a number of sedges are also found in grasslands, forests and alpine areas throughout BC's rangelands. Grazing values of sedges and rushes are quite high in spring months; however, this timing conflicts with the value of these species in the wetlands for nesting waterfowl habitat.

Forbs

Forbs are generally small plants that produce flowers. They flower at different times throughout the growing season and die back after flowering. Forbs are broad-leaved plants with fleshy stems and net-veined leaves. Yarrow, low pussytoes, lupines, arrow-leaved balsamroot and heart-leaved arnica are some of the common forbs in BC grasslands. The amount of forbs on the grassland landscape varies with site aspect, moisture and elevation. Although a seasonally spectacular when in flower, a high abundance of forbs can indicate that the sensitive grasses have disappeared from overgrazing.

Hazardous Plants

Plants that are either poisonous or injurious to livestock naturally exist in BC's grasslands. Five species are considered to be major poisonous plants in BC: Seaside arrow-grass, tall larkspur, low growing larkspur, timber milk-vetch, and Douglas's water hemlock. Poisonous plants are often unpalatable however grazing animals sometimes will be addicted to plants such as timber milk-vetch if animals are hungry and little good quality forage is available. The best way to avoid livestock poisonings is to be aware of the location and extent of poisonous plants in grazing areas. In addition to those poisonous, plants may also injure animals mechanically, such as the awns of cheatgrass and needlegrasses.

Cryptogams

Cryptogams are rather complex and have both visible and microscopic components that grow over the surface of soils. The visible part includes lichens, mosses and liverworts, while the microscopic component is made up of algae, fungi and bacteria. Because of this complexity, cryptogams are more commonly referred to as the microbiotic crust of soil surfaces. Some common lichens and mosses on BC's bunchgrass ranges include pixie-cup lichens and rusty steppe moss. Crypotrams, or microbiotic crust, is sensitive to disturbance that occurs from motorized and non-motorized vehicles, human foot traffic, and animal hoof action. Overgrazing or recreational disturbances can result in a substantially reduced cover of cryptograms, reducing the soils nutrient and water functions. A lack of cryptogram crust and evidence of surface soil erosion indicates past soil disturbance or continued heavy use.

Detailed information on ecosystem processes such as nutrient cycling and energy flow, on the Understanding Grasslands pages.

Plant Communities

Plant communities consist of groups of plants that are adapted to similar combinations of climatic conditions and soils. Each different plant community by itself, or with other communities, provides a variety of habitats that are used by animals for food and shelter. Vegetation in British Columbia's grasslands is very diverse due to the wide variations in climate, soils and topography throughout the province. Biogeoclimatic zones, defined as the broadest vegetation complexes that reflect the same regional climate, are used for range classification and management. The zones are generally named after one or two dominant plant species that are present over a wide range of conditions. Biogeoclimatic zones can be further broken down into subzones, which have less climatic variability and narrower geographic distribution than zones. Biogeoclimatic phases are areas within a zone that contain non-zonal ecosystems. In the Southern Interior, the most important zones in terms of area and forage production potential for livestock and wildlife are Bunchgrass, Ponderosa Pine, Interior Douglas-fir and Montane Spruce.
Different communities are present on north-facing slopes as compared with south-facing slopes and still others in swales as compared with knolls. Some plants are more sensitive than others to factors in the environment, such as grazing pressure. Overgrazing can change the plant species present and total forage production.

Bunchgrass Zone

The Bunchgrass Zone is located in the hot, dry valley bottoms of southern BC. It is found in the Okanagan Valley south of Summerland, the Similkameen River Valley to Keremeos, the Thompson River Valley from Spences Bridge to Pritchard, the Nicola Valley, and the Middle Fraser and Lower Chilcotin River valleys from the Farwell Canyon to Big Bar. In BC, this biogeoclimatic zone usually occurs at lower elevations, 300 to 1000 meters. In BC, grasslands cover about 1.2 million hectares but only 300,000 hectares are classified as bunchgrass.

The climate of the Bunchgrass Zone is characterized by hot, dry summers and moderately cold winters often with little snowfall. Winter moisture is critical to plant growth because of heavy evaporation losses with spring and summer rains. The lowest elevation and hottest grasslands at 300 to 700 m are typically dominated by wide-spaced bluebunch wheatgrass with big sagebrush. Antelope-brush survives the slightly warmer winters in the southern areas. At elevations from 700 to 100 meters elevation in the dry warm bunchgrass, big sagebrush is absent and bunchgrass plants are closer spaced.

Bluebunch wheatgrass along with big sagebrush are the dominant species found throughout the zone, along with well-developed lichen crusts. Dominant grasses vary with site latitude, elevation and aspect, with porcupine grass being common at the north end of the zone, while Idaho and Rough fescue can dominate on north and east facing slopes in the south. As sites are modified by heavy grazing pressure, other plants become common include prairie sagewort, rabbit-brush, junegrass, Sandberg's bluegrass, needle-and-thread grass and yarrow. Past grazing history has influenced the bunchgrass zone in BC and many hectares are dominated with weedy annual species from disturbance and prolonged misuse. Moisture and range condition cause wide fluctuations in forage production in the bunchgrass zone from 200 to 1000 kg/ha. Employing cattle grazing practices to ensure proper use and rests are critical in this zone.

Despite the arid climate, a variety of wetlands occur in the bunchgrass. They include cattail marshes, saline meadows, and riparian zones lined with shrubs. These wetlands are important sources of water for livestock as well as habitat for wildlife, supporting a high density and diversity of reptiles, birds, small mammals, and large ungulates. The majority of the Bunchgrass Zone occurs on private land and is extensively used for cultivated crops or non-agricultural purposes. The remaining grasslands are critical to the livestock industry in BC because they provide spring, fall and winter range.

Ponderosa Pine Zone

The Ponderosa Pine Zone is characterized by open, savannah-like stands of ponderosa pine with a well developed ground cover of grasses and forbs. This zone occupies 0.3% of the province or about 300,000 ha, and occurs at higher elevations than the Bunchgrass Zone and below the Douglas-fir Zone on the lower slopes and terraces of the driest, warmest valleys of the Southern Interior, typically between 300 to 900 m. This zone is the warmest and driest forest zone in the province.

The zone most frequently exists as a mixture of open forest and grassland. Plants found under the pine canopy are similar to those found in the Bunchgrass zone. Ponderosa pine is the dominant tree throughout the zone but Douglas-fir can also be found in the moist areas and gullies, as well as on drier sites in cooler northern areas. Few shrubs are present in the Ponderosa Pine Zone except for big sagebrush and rabbit-brush, and scattered plants of wild rose and Saskatoon in swales. Antelope-brush contributes to the understory in the southerly portions of the zone. Bluebunch wheatgrass, big sagebrush, and rough fescue or Idaho fescue dominate sites in good range condition. Fescues may replace bluebunch weheatgrass or become a co-dominant with it in the southern part of the zone. As in the Bunchgrass zone, grazing history has played a role in determining the composition of plants present. Under heavy grazing, less bluebunch wheatgrass and fescues are present, and more Sandberg's bluegrass, needlegrass, cheatgrass and low-growing weeds.

The Ponderosa Pine Zone is an important source of early spring and late-fall range for cattle in the Southern Interior Forest Region. In most years there is sufficient fall regrowth to provide supplemental forage. Ponds, which occur in depressions, provide water for livestock and wildlife in the spring, but often dry up during the summer.

These middle elevation grasslands have lesser big sagebrush and an increased dominance of bunchgrass than the Bunchgrass zone. Bluebunch wheatgrass is the primary forage plant on excellent condition range in both subzones and can account for 25 to 65% of the total forage production. Rough fescue and Idaho fescue are also important forage species in some areas. Forage production is influenced by soil type, range condition and tree canopy closure but can range from 480 to over 800 kg/ha.

The Ponderosa Pine Zone has relatively light snowfall and short winters, so it provides winter and spring forage for deer, big-horn sheep and Rocky Mountain Elk. The conifers also provide food and cover for many birds and small mammals. Rugged cliffs and talus slopes, which are common to the zone, can provide lambing grounds for bighorn sheep.

Interior Douglas-fir Zone

The Interior Douglas-fir Zone occupies most of the low- to mid-elevation terrain in the Southern Interior plateau, the Southern Rocky Mountain trench and portions of the lee side of the Coast Mountains. Topography varies from nearly level to rolling and steep slopes.

The zone occurs over a wide range of elevations from 350m in some valley bottoms to over 1450m where it often joins with the Montane Spruce Zone. Cool winters, warm dry summers and a fairly long growing season characterize the climate of the Interior Douglas-fir Zone. Both moisture deficits and deep frosts during the growing season can limit plant growth. The landscape of the Interior Douglas-fir Zone includes grasslands, savannahs with open canopies and grass understories, as well as closed forests with a ground cover consisting of a mix of shrubs, forbs and grasses.

Douglas-fir is the dominant tree species in the forested parts of this zone. Lodgepole pine commonly occurs at higher elevations where it forms even-aged stands after disturbance such as fire. Trembling aspen also occurs, especially on deep, rich soils. Generally the understory is well developed in Douglas-fir forests but few plants other than Saskatoon, birch leaved spirea, pinegrass, and feathermoss occur constantly across all subzones. Common shrubs and forbs include rose, willow, timber milk-vetch, creamy peavine and lupine.

The upper grasslands, as grassland phases in the Interior Douglas-fir Zone are commonly known, are important forage resources for livestock and wildlife. These grasslands occur due to a combination of soil, topographic conditions and fire. Grassland plant communities in the Interior Douglas-fir Zone share common species with the lower elevation grasslands in the Bunchgrass and Ponderosa Pine zones. In comparison with the lower grasslands however, they are characterized by the absence of big sagebrush and by having more forbs, taller grass growth, and denser plant cover. Under prolonged periods of heavy grazing, grasses can be replaced by forbs.

Bluebunch wheatgrass can be the sole dominant species on dry grassland sites throughout the zone, but with different moisture conditions it often co-dominates with rough fescue, Idaho fescue, or needlegrasses.

Many of these grasslands are like those found at lower elevations and contain plant communities altered by past grazing practices. Species composition on these sites generally contain less bluebunch and rough fescue, more Kentucky bluegrass and smaller bunchgrasses such as needle-and-thread, junegrass, and Columbia needlegrass.

The Interior Douglas-fir Zone is one of the most important zones for cattle and wildlife in BC. The open grasslands provide important range for livestock grazing in spring and fall months, as well as extensive grazing in semi-open forests and cut blocks in the summer. Pinegrass comprises 40 to 60% of the ground cover under the forest canopy and provides 50 to 65% of the available livestock forage. In open forest stands and grasslands, bluebunch wheatgrass, rough fescue or Idaho fescue can be the principal forage speices. Forage yields can range from 270 to 800 kg/ha in forest, and up to 1120 kg/ha in grasslands.

Plant Responses to Grazing

Rangeland plants have evolved with a long history of grazing and browsing, although there are considerable differences in resistance to grazing among species. Plants have either positive or negative responses to grazing depending on the intensity of defoliation. Studies have indicated that degree and season of defoliation are the primary indicators that determine the level of damage.

Proper grazing management can stimulate plant growth, enhance nutritive value, remove excessive litter, and accelerate nutrient cycling. Positive impacts are typically associated with light to moderate grazing. Grasses that have been lightly defoliated usually show increased tillering and leaf growth. They tend to be shorter but leafier and cover more ground surface than ungrazed grasses. The new leaves also have higher nitrogen and nutritional content than those of ungrazed grasses. The effect of defoliation on forage plants also depends on the season of grazing. Generally, plants are little affected if defoliation occurs during dormancy because photosynthesis has already ceased. Plants may also quickly recover from defoliation early in the growing season because there is still time for the plant to produce new growth while moisture and temperature levels remain favourable. Browsing of shrubs removes the terminal bud causing an increase in the growth of lateral buds. This leads to increased sprouting and bushier shrub growth. Antelope-brush that has not been browsed shows a decline in annual branch and leaf growth. The amount of forage and nutrient content of forage plants can often be enhanced with certain levels of grazing.

Negetive Impacts of Over Grazing

Heavy grazing negatively impacts range plants by causing decreased photosynthesis, reduced root growth and seed production, and a reduced ability to compete with plants that are ungrazed. Plants are considered to be most vulnerable to grazing damage when carbohydrates in the roots are not sufficient enough to initiate regrowth. With intense defoliation, the entire root system becomes smaller, shallower, and less branched. This affects the plant’s ability to absorb water and nutrients from the soil. Eventually, with continued heavy grazing, the plant’s health declines to the point where death may occur.

The most critical time for defoliation of grasses usually occurs just before the plants begin flowering and setting seeds. This is because carbohydrate stores are still recovering from winter dormancy, and the rapid part of the growing season is coming to an end because of declining soil moisture. If heavy defoliation occurs every year during early bloom, bluebunch wheatgrass decreases as a proportion of the plant cover, and may virtually disappear from the plant community after only a few years.

This illustrates how changes in the plant community will occur if heavily grazed in spring months year after year. Grazed plants are replaced by weedy species that are more resistant to grazing. These weedy plants are generally less productive and palatable than those with low grazing resistance. This overgrazed state generally reduces the value of grasslands for forage, livestock, and wildlife production. Overgrazed plant communities also bring about changes in the physical micro-environment of forage plants. As there is less plant leaf material to intercept rang and trap snow, more moisture is lost to the system by runoff and erosion.

Effects on Succession

Succession is the replacement of one plant community by another. The changes may come about as a result of the natural development of a community or as a result of disturbance caused by animals or man, or climate and soil changes. Overgrazing can force the grassland to shift the successional pattern and move down in productivity. The goal of the grassland manager is to maintain or restore the desirable plant species.

Proper Range Management

BC’s grasslands are valuable spring and fall forage grazing areas. Proper range management commonly focuses on 2 objectives: leaving sufficient leaf area for plants to photosynthesize; and maintaining carbohydrate reserves of perennial forage plants. These goals can be achieved with a variety of techniques:

- Graze the previous years’ forage production early before spring growth begins;
- When used in spring, graze for short periods so that leaf re-growth occurs afterwards;
- Make sure grazing is ceased while there is sufficient leaf material to maintain photosynthesis;
- Avoid grazing spring ranges in the autumn to allow for fall re-growth so that carbohydrate reserves continue to build.

Wild Animals

Grasslands have evolved with grazing. Even before European settlement, native herbivores such as deer, elk, pronghorn and bison applied grazing pressure. Some wildlife species require grazing for their existence - a prime example of this is the endangered Burrowing Owl which prefers shorter vegetation so it can see predators. For more information on grassland wildlife in BC, see Species at Risk.

Rocky Mountain elk were in much greater abundance than they are today. Elk numbers dropped dramatically during the late 1880s, possibly due to very severe winters. Elk began to increase in the Kootenays by the turn of the century but remain sparse and scattered in the Okanagan and Thompson River areas, and the Central Interior. Elk feed extensively on a variety of grasses, forbs, sedges, and ferns. When these preferred foods are unavailable or in short supply they turn to shrub species and deciduous tress such as willow, red-osier dogwood, trembling aspen, alder and Douglas maple. Nearby coniferous forests provide cover from harsh winter conditions and protection from predators. Elk required low-elevation open parkland containing deciduous tree/ grassland associations for feeding in winter and spring months, frequently sharing the same ranges as cattle. Competition for food between elk and cattle requires integrated wildlife and cattle management in elk-populated grasslands, as in the Kootenays.

Deer are known to be grazers of grasses and forbs in early spring months, but are primarily browsers throughout the year feeding extensively on aspen, willow, Saskatoon, snowbrush, red-osier dogwood, antelope brush, and big sagebrush. They utilize shrubby ravines and aspen copses on the grasslands for forage and cover, and populate the fringe areas between grassland and dense coniferous forest.

Mule deer are plentiful the mixed grass and open forests of the Interior and Kootenays of BC. They prefer grasslands and low-elevation shrublands close to cover, open forests of ponderosa pine and Douglas fir, and aspen parklands. Mule deer also thrive in logged forests where blocks of mature timer remain adjacent to early successional stages of shrub, grass and forb vegetation. The critical areas for mule deer are the low-elevation winter ranges. Mule deer remain on their winter ranges until early spring green-up occurs on nearby grasslands. Heavy grazing, particularly in fall or winter months, can cause livestock to switch from grass to shrubs directly competing with mule deer. Managed cattle grazing may benefit mule deer if the growth of palatable shrubs is stimulated or where the mature growth of large bunchgrasses is removed to make new growth available.

White-tailed deer are numerous in the Kootenays and Peace River regions, and, because they are migratory, are spreading through much of the Southern and Central Interior. White-tailed deer are more adaptable than mule deer, co-existing with humans and agriculture, and making greater use of dense forests for wintering. As with mule deer, heavy cattle grazing during late fall and winter may reduce the available forage for white-tailed deer, but alternatively, heavy spring use of grass by white-tails, such as in cultivated fields, may result in a shortage of forage for cattle.

Wild sheep are primarily grazers and rely more on grasslands than any other wild ungulate. Historically, wild sheep were important to the First Nations diet, their mythology, and in tool-making. Today, the majority of Ricky Mountain bighorn sheep are found in the southern Rocky Mountains and Rocky Mountain Trench east of the Columbia River. Successful transplants have resulted in small bands from Castlegar, Kamloops to Spences Bridge. California bighorns are present in scattered herds on the mountains and grassland of the Similkameen, Okanagan and Fraser basin north of Lillooet. Sheep numbers fluctuate due to die-offs from disease, and competition with domestic livestock for forage and disease transfer from domestic sheep have been concerns to wildlife managers over the last century. Winter range is critical to maintaining bighorn sheep numbers. In the winter, the majority of bighorns move to low-elevation grasslands on south- and west-facing slopes with relatively warm temperature and little snow. Preferred foods are grasses, particularly bluebunch wheatgrass, and several species of bluegrasses and fescues. Heavy cattle grazing, and any other disturbance that impacts the abundance of these species, affects the value of the grassland to wild sheep.

Horses arrived in BC in the late 1700s. They became prominent for transporting furs after 1821 and later in the mid-1800s in the mining areas, for road, trail and railway construction. Although horse numbers in the 1800s is poorly documented, there were a reported five or six thousand head at Fort Kamloops alone by the 1948. Horse numbers in the last half of the nineteenth century and the first few decades of the twentieth century likely contributed to overgrazing the grasslands. Between 1950 and 1970, the ranchers and BC Forest Service made a concentrated effort to remove horses from Crown land. Horses are presently used by most cattle ranchers, guides and outfitters and for recreational riding, but are mostly confined to private lands.

Following horses, cattle and domestic sheep were introduced into southern BC about 1840 by the Hudson's Bay Company. The first large imports of cattle were the result of the Cariboo gold rush. Between 1858 and 1868 approximately 22,000 head of cattle entered BC from the United States at Osoyoos. Most of these cattle were destined for consumption by the gold miners, but some became the nucleus for ranches which sprang up between Osoyoos and Quesnel. Another gold rush at Wild horse Creek in the East Kootenay in 1864 resulted in cattle being driven there from Montana. Cattle numbers in BC increased very rapidly after 1860 and the establishment of the ranching industry.

In early days, cattle grazed year round on the lower elevation grasslands. Since the introduction of fencing in the early 1900s, grasslands are used primarily for spring and fall grazing, with cattle utilizing higher elevation forested ranges on Crown land in summer months.

Sheep arrived in the Southern interior a few years after cattle. Sheep numbers increased in the 1920s with the use of high elevation alpine ranges for summer grazing. Following decades of a reduced sheep industry, numbers have again risen in parts of the province and are frequently used on forested Crown lands to remove shrub and vegetation from tree plantations.

System Responses to Humans

Throughout history, humans have interacted with grassland ecosystems causing change. For thousands of years before European settlement, the grassland ecosystems provided food, clothing, fuel, and shelter for aboriginal people. From the 1800s through the 1900s, the grasslands provided forage to support livestock for growing communities and the building of BC's ranching industry. Today, pressures from population growth are impacting our remaining grasslands.

An additional 70,000 individuals are predicted to move into the Central Okanagan over the next 20 years. Steady growth is also predicted for the North Okanagan, Thompson and Nicola regions. As communities grow, they expand onto adjacent remaining grasslands. Housing and development results in loss of the grassland land base, and fragmentation of remaining grassland parcels impeding wildlife travel and isolating populations. Urban sprawl is only part of the problem - fragmentation of grassland for development of recreational properties, resorts or other tourism developments also impact grasslands. Along with community growth and development on the grassland, comes increased recreation on the remaining adjacent grassland parcels.

Mapping currently underway by the GCC will show the location and extent of remaining priority grassland areas. With development pressure on remaining natural ecosystem being intense and increasing, this mapping information will be of use to local governments struggling to find a balance between managing growth and protecting natural values. The majority of land use decisions in areas of human settlement are made at the local government level, and local governments have been empowered in recent years to enact legislation to protect sensitive ecosystems within their jurisdictions.

Recreation

The grasslands of BC offer great opportunities for recreation, from bird watching to all terrain vehicle (ATV) use. In more recent years, mountain biking through grasslands near communities has increased. For all users that travel off trails, or build new networks of trails, impacts on the grassland ecosystem are realized. Soil disturbance and trampled microbiotic crust lead to erosion, weed infestations, and reduced forage production. Some recreational uses have minimal impact on the grassland ecosystem, but heavy foot or mechanical traffic can cause changes to the cryptogrammic crust, individual plants and animals, and ultimately threaten plant communities.

Grassland recreation is becoming increasingly popular as more people settle in grassland communities. Well-managed recreational activities can minimize impacts to sensitive grasslands and the species they support. In order to ensure that grasslands are used in a sustainable manner, recreationists must take responsibility for grassland stewardship and adopt appropriate management practices. The GCC in partnership with the Ministry of Environment developed the Best Management Practices for Recreational Activities on Grasslands in the Thompson and Okanagan Basins document. Developed with input form more than 40 organizations, this comprehensive code of practices was created by the user, for the user.

Agriculture

Cultivation of the native plant communities in grasslands results in loss of natural values and long-lasting modification of soil and plant ecosystem function. In the later 1800s and early 1900s, significant acreages of grasslands were cultivated by European settlers. Many acreages remain in hay production throughout the 1900s to support the ranching industry by producing winter feed. Increasing agricultural pressures on the remaining grassland parcels throughout the Southern and Central Okanagan is realized for orchard and vineyard production. Much of the grassland landscape dominated by antelope brush in the South Okanagan is known to be also ideal for grape production. Most remaining grassland parcels in this region are fragmented, limiting their values for threatened wildlife populations.

Fire

Fire, or the absence of fire, has affected the extent of BC grasslands. First Nations peoples used fire to remove brush for improving travel and attracting wild game to new growth. By the late 1960s, the BC Forest Service had effectively began to control large wildfires. With the absence of fire the forest vegetation is creeping into the grasslands and replacing the bunchgrass with Douglas fir and lodgepole pine.

Before European contact, interior forests and grasslands experienced frequent, low intensity fires, possibly every five to 20 years, many probably set by the native inhabitants. In the twentieth century, preventing fires was taken more seriously because of the economic value of forests, ranches and the increasing threat to public safety.

The GCC supports a balanced approach to restoring and maintaining grassland and dry open forest ecosystems. The GCC's position with respect to fire as a management tool is as follows:

- prescribed fire is an important tool for restoring and maintaining grassland and dry open forests.
- prescribed fire should be applied with clearly defined ecological and social objectives, and in combination with other appropriate tools

Fire science should continue to improved our understanding of the historic role of fires in BC and simulate as much as feasible, its past role in restoring and maintaining our grasslands and dry open forests

Grassland Monitoring

Change is part of every ecosystem. Fire, grazing, disease, drought, and earthquakes are examples of variable forces that cause change. Grassland vegetation changes over time in response to these forces. Grassland managers are usually interested in successional changes, which are changes to the plant community that may have resulted from a management action. Assessment and monitoring is required to understand the impact of use and management on changes in the grassland ecosystem.

In 2003, the Grasslands Conservation Council of British Columbia, in partnership with other non-government and government organizations, took the initiative to develop an assessment and monitoring tool that would provide a basic level of grassland evaluation. While the procedure is primarily intended for ranchers to use on their private land, the tool will be consistent with government objectives and can be applied to grasslands anywhere. The simple and rapid procedure allows users to make visual assessments of five principal indicators that determine the relative condition of grasslands compared to reference conditions.

What is Grassland Assessment and Monitoring?

Grassland assessment is simply a process for comparing the present condition of a site to its ecological potential. Monitoring is a process of collecting information from several assessments to detect changes over time. Both assessment and monitoring provide valuable information that determines if management programs are achieving their goals and objectives.

Most grassland assessments compare the present condition of a site to a reference that would exist with little or no disturbance. Generally, the climax plant community, which is primarily controlled by climate, soils and topography, serves as the best benchmark for a site. These communities represent the most stable combination of plant, water and soil factors, and are only minimally disturbed by outside influences. Disturbances such as fire, grazing and recreational activities sometimes cause significant changes in plant communities depending on their intensity, frequency and duration. These events can not only change the composition and structure of plant communities, but they also affect water relations and soil stability.

How is Grassland Status Assessed?

Ecological changes in grasslands are often complex and difficult to measure. Therefore, indicators are often used as indices to describe the status of an ecological factor or process that cannot be seen or measured. Grassland status indicators are visually estimated with this procedure, but scientific facts must support the decisions that will be made using each indicator. In order for these indicators to be effective, they must be easily observed, their present condition must be simple to describe, and changes in their condition must be conspicuous. The following five indicators are used to make grassland assessments:

- Species composition of the plant community
- Plant community structure
- Amount of litter present on the site
- Stability of soils and potential for erosion

- Presence and distribution of noxious weeds and invasive plants

Assessments of grassland sites evaluate each of the five indicators to determine how close, or how far, a site is from the Reference Condition. Changes in each indicator are determined using thresholds that relate the conditions on the site to a set of standards. Each indicator is evaluated and scored independently against the threshold information provided. The sum of the scores for each of the five indicators produces an overall score for the site. The relative status of the site is finally established by comparing this score to a set of standards as follows: Reference Conditions (75-100 percent), Slightly Altered (51-75 percent), Moderately Altered (25-50 percent), and Greatly Altered (<25 percent).

Trend in grassland condition can also be evaluated using this method by making repeat assessments over time. Monitoring for trend also uses a series of photographs that accompany the visual assessments to provide photographic documentation of conditions on the site over time.