सत्यमेव जयते

SOIL AND WATER CONSERVATION

বন বিভাগ
পশ্চিমবঙ্গ সরকার

DIRECTORATE OF FORESTS
GOVERNMENT OF WEST BENGAL

This edition is published by
Development Circle,
Directorate of Forests,
Government of West Bengal,
2016

Aranya Bhavan
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Salt Lake City, Kolkata,
West Bengal, 700098

PREFACE

Soil and water form two major components of a forest ecosystem and they directly influence the status, health and nature of the flora and fauna that such ecosystem is likely to support. It is obvious therefore that while managing the forests the forest officers have to deal with these components and make their best efforts for their conservation to sustain the plants and animals. As part of the JICA project on 'Capacity Development for Forest Management and Training of Personnel' being implemented by the Forest Department, Govt of West Bengal, these course materials on Soil and water conservation have been prepared for induction training of the Foresters and Forest Guards. The object of this training manual is to present the basic ideas of the science of soil and water conservation.

The subjects covered in these materials broadly conform to syllabus laid down in the guidelines issued by the Ministry of Environment of Forests, Govt of India, vide the Ministry's No 3 -17/1999-RT dated 05.03.13. In dealing with some of the parts of the course though, some topics have been detailed or some topics have been included to facilitate complete understanding of the subjects and to provide appropriate coverage of the field works that the trainees will be required to perform. The revised syllabus, with such modifications,is appended.

As the materials are meant for the training of frontline staff of the Department, effort has been made to present the subject in simple and easy language and to avoid complex engineering calculations and design, except to an extent which is unavoidable.

The contents of the course materials have been compiled and edited by A Basu Ray Chaudhuri, IFS (Retd). Many books and literature including those available in internet have been made use of in preparing these course materials. Besides the books and documents that have been cited in the respective topics, the contents of these study materials owe heavily to the following sources, namely, (1) Soil and water conservation engineering by Frevert, Schwab, Edminster, Barnes, (2) Manual of soil and water conservation practices by Gurmel Singh, C. Venkataramanan, C Sastry and B.P Joshi, (3) Soil Conservation manual of Soil Conservation Circle of WB Forest Directorate, (4) Papers presented in Staff training on soil conservation held in 1993 and (4) Forest Ecology by Barnes, Zak, Denton and Spurr. Shri A Basu Ray Chaudhuri is indebted to many forest officers who have helped in the preparation of these materials. Special word of thanks goes to Shri S Palit IFS (Retd) for providing a copy of Soil conservation Manual, Shri S Barari, IFS for providing the book by Shri Gurmel Singh et.al, and Shri Prabir Kr Guha Roy, Retd forest officer, for providing the collection of papers presented in the staff training on soil Conservation.

Efforts that have gone into making of these course materials will be best rewarded if the frontline staff of the forest department find these materials useful in their day-to-day works.

Kolkata, May 2015

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For IBRAD (Consultant)

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Govt of West Bengal

SYLLABUS

Soil and Water Conservation (10 hours), Excursion 1 day, Tour 2 days		
1. Introduction	Concept and definition of watershed Concept and objective of Integrated watershed management* Watershed approach for development Need for SWC for forest development	1 hour
2. Hydrology	Hydrological cycle Hydrological Cycle in a Forested Eco-system* Rainfall distribution and measurement Water balance	1 hour
3. Soil Erosion	Causes Factors involved Effects of erosion Types of erosion Water and wind erosion	2 hours
4. Soil and Water Conservation Measures	Vegetative measures. • Contour ploughing and cultivation • Strip Cropping • Vegetative barriers / checks Engineering measures • Contour bunding, • graded bunding • Contour trenches • Contour stone walls • Earthen Dam* • Nala bunding • Sunken gully pits • Silt traps River training • Retaining wall • Gabion wall • Revetment Water harvesting -Farm ponds. Gully Control* Check dams • Temporary • Brushwood • Boulder • Loose stone • Permanent • Masonry Sediment movement in stream channel and Measurement* Combating spread of desert	6* hours

	• Sand dune fixation Shelterbelts	
Field Study	Study of available SWC measures during tours/excursions.	

* These are modifications to the course contents which were prescribed by MoEF, indicating addition of topics and change in lesson hours.

Lesson 1 **1 hour**

Lesson Plan:

Objective:

- To introduce the concept of watershed management
- To study objectives and components of watershed management.
- To go through evolution of watershed projects in India
- To study the need for soil and water conservation for forest development.

Forward Linkage:

- During tour the trainees may be shown watershed projects and soil-moisture conservation works in forest plantations.

Training materials required:

- Copy of lesson 1 to be circulated beforehand.

Allocation of time:

- Concept and Definition of Watershed – 10 mts
- Watershed Deterioration – 5 mts
- Concept and objectives of Integrated Watershed Management – 10 mts
- History of Watershed Projects – 5 mts
- Components of Watershed Management – 10 mts
- Need for Soil and Water Conservation (SWC) for Forest Development – 10 mts
- Discussion/miscellaneous – 10 mts

1.1. Concept and Definition of Watershed:

A watershed is a drainage basin or catchment area of a particular stream or river. Watershed is defined as a hydro-geological unit of area from which the rainwater drains through a single outlet. Simply put, it refers to the area from where the water to a particular drainage system, like a river or stream, comes. Watersheds are considered appropriate units for both surveys and assessment of soil and land resources as well as for planning and implementation of various developmental programmes. People and livestock are an integral part of watershed and their activities affect the productive status of watersheds and vice versa. Every stream, tributary, or river has an associated watershed, and small watersheds aggregate together to become larger watersheds. In other words, watersheds of small streams are the sub-watersheds of the watershed of a larger stream.

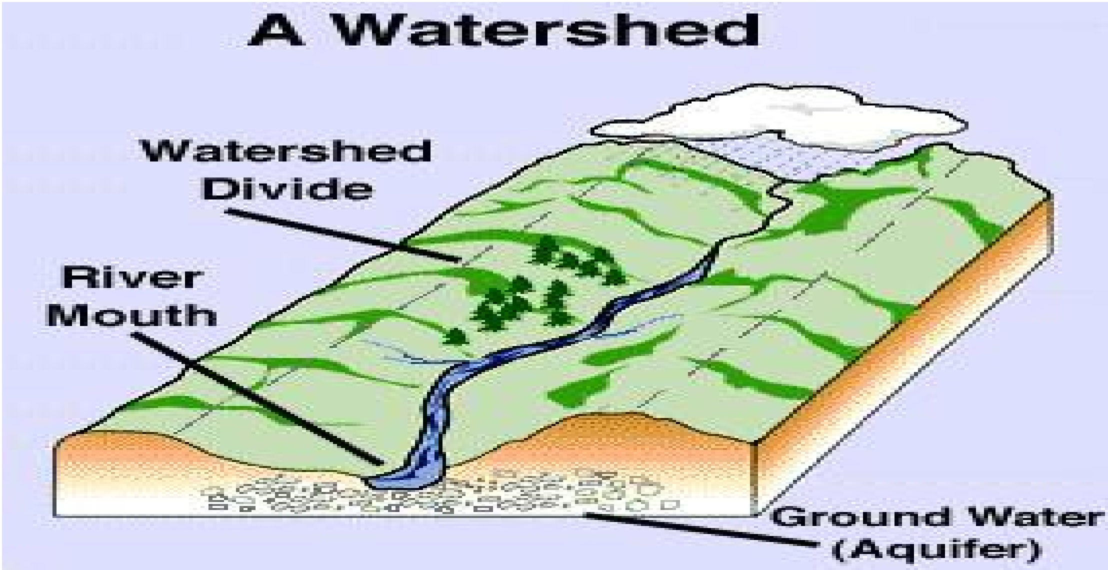


Figure. 1.1. Watershed

1.2. Watershed Approach for development:

1.2.1 Watershed Deterioration: Deterioration of a watershed means decline in the status and productivity of the natural resources – land, vegetation and water – that comprise the watershed. The deterioration may occur due to many factors. These include:

- Faulty agricultural, forestry, and pasture management leading to degradation of land;
- Fire;
- Unscientific mining and quarrying;
- Faulty road alignment and construction;
- Industrialization;
- Lack of awareness of the people.

1.2.2 Results of watershed deterioration

- Poor returns from agriculture, forests, grass lands, fruit orchards due to degradation of land;
- Increased erosion hazards resulting in decreased biomass production;
- Quick siltation of reservoirs, lakes and riverbeds;
- Poor water yield in terms of quantity and quality;

- Poverty

(Source: Reading material 'Forest Conservation & Management' for Dy ranger/Forester Course, April 2003, WB Forest School)

1.2.3 Why is Watershed Management so important?

- To maintain a sufficient and quality water supply
- To avoid and contain erosion
- To improve planning and reduce risk of floods and droughts
- To be prepared for the impacts of climate change

1.2.4 Concept of Integrated Watershed Management

Integrated watershed management involves integration of technologies within the natural boundary of drainage area for optimum development of land, water and plant resources to meet the basic minimum needs of people in a sustained manner. Integrated Watershed Management is thus

- Multi-technology initiative – technologies relating to forests, agriculture, land management, management of water resources, management of animal resources etc.
- Management by Multi-stakeholder – appropriate departments of the government, local bodies, Panchayet Institutions, local people.
- Multi-subjects of focus – land, water and plant resources within the watershed area.

1.2.5 Objectives of Integrated Watershed Management Plan

The objectives of Integrated Watershed Management plan are-

(a) To adopt optimum agricultural cropping system for all culturable land backed by an appropriate package of inputs (seeds, fertilizer etc.)

(b) To adopt appropriate planting technique for the non-agricultural land in the watersheds to ensure control of erosion, improvement of moisture regime and production of fuel wood, fodder, small wood as an additional component. This includes management of forests and afforestation of degraded lands.

(c) To reduce runoff by ensuring extensive absorption and percolation of rain water and consequent better recharge of wells for domestic uses and for irrigation, wherever possible.

(d) To adopt corrective measures on land to prevent erosion by water and wind, gully formation etc.

(e) To provide for storage of available rain water in situ and re-use it within watershed for crop production.

(f) To prepare land and a drainage system for optimum use of scarce water.

(g) To reclaim eroded land and restore it to productive use.

(h) To generate adequate employment opportunities through improved crop and plant management and also through animal husbandry.

(Source: Soil Conservation Manual, WB Forest Directorate)

1.2.6 History of Watershed Projects

In order to combat the frequent recurrence of drought in the States, Drought Prone Area Programme (DPAP) was introduced during the year 1975, as a Centrally Sponsored Scheme (CSS) with matching state share of 50:50 and watershed approach was adopted the in 1987. The Drought Prone Area Programme concentrated on non-arable lands. Drainage lines for in-situ soil and moisture conservation, agro-forestry, pasture development, horticulture and alternate land use were its main components. Integrated Wasteland Development Programme (IWDP) was introduced during 1992 with 100% Central assistance. The Integrated Wasteland Development Programme made afforestation and soil and moisture conservation in waste lands under Government or community or private control as its predominant activity, without much focus on saturation of complete micro watershed and participation of people. 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 new guidelines were 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 I*nstitutions (PRI). Hariyali guidelines were issued in 2003-04 for implementation of watersheds through Gram Panchayats. Under these guidelines, the Grama Panchayats were vested with the total responsibility of implementation of watershed programmes.

1.2.6.1 Integrated Watershed Management Programme (IWMP) was launched by the Government of India in the year 2008. The main objectives of the IWMP are to restore the ecological balance by harnessing, conserving and developing degraded natural resources such as soil, vegetative cover and water. The envisaged outcomes are prevention of soil run-off, regeneration of natural vegetation, rain water harvesting and recharging of the ground water table. This enables multi-cropping and the introduction of diverse agro-based activities, which help to provide sustainable livelihoods to the people residing in the watershed area. In addition, there is a Scheme of Technology Development, Extension and Training (TDET). It is also being implemented to promote development of cost effective and proven technologies to support watershed management. The IWMP was to be implemented under Common Guidelines on Watershed Development, 2008. The salient features of these guidelines are as following.

- Cluster of micro watersheds covering an area of 1000-5000 ha will be treated as a project.
- Unit cost is raised from Rs.6000/ha to Rs.12000/ha.
- Fund allocation for Livelihoods and Productivity Enhancement of Agriculture & Livestock.
- Project period is 4-7 years.
- Funding pattern is 90:10 (Central & State share).
- All new watersheds from 2008-09 onwards will be implemented under a single programme called IWMP

1.2.7 Components of Watershed Management

Entry Point Activity (EPA)

Entry Point Activity is the first formal project intervention which is undertaken after the transect walk, selection and finalization of the watershed. It is highly recommended to use knowledge-based entry point activity to build the rapport with the community.

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 or young forest plantations, like construction of contour bunds/trenches, 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. *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 alone 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 crop 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 a little application of chemical fertilizer. 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.

Crop Diversification and Intensification

The crop diversification 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 provide yields of multifarious products. For forest crop it is always advisable to try judicious mixture of indigenous species suitable for the agro-climatic zone in question. Crop intensification is the increasing cropping intensity and production to meet the ever increasing demand for food and forest products in a given landscape. Watershed management puts emphasis on crop diversification and intensification through the use of advanced technologies, especially good variety of seeds and planting stock, balanced fertilizer application and by providing supplemental irrigation.

Use of Multiple Resources

Those farmers who are solely dependent on agriculture face high uncertainty and risk of failure due to various extreme events, pest and disease attack, and market shocks. Therefore, integration of agriculture (off-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, dairy farming, suitable models of agro-forestry, 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..

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 in order to achieve their own goals on a sustained basis. 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 and so on.

1.3. . Need for Soil and Water Conservation (SWC) for Forest Development:

Soil and water conservation measures are absolutely essential for forest development particularly in degraded sites where availability of moisture in soil is very low and the top soil is either eroded or prone to erosion. Such sites are very common in the forests of south west Bengal. Tree growth responds more to water stress than any other perennial factors of the forest site. Thus soil water is the key to forest site productivity for many species. It has been experienced that artificial regeneration of Sal in south Bengal forests is difficult to achieve in rain-fed sites though raising Acacia species and Eucalyptus in the same sites under the same management practice has been a success. Soil water that is available in most of the South West Bengal forests is not enough to meet water requirement of Sal seedlings and carry it through the first dry season after planting. Mortality of Sal seedlings in the very first year has been very high. However, since mid 1990s a remarkable rate of success in Sal plantation was achieved in south West Bengal when plantation site was irrigated, though on a low scale, during the dry season.

1.3.1 Soil-water stress plays an equally important role in the radial growth of trees. It affects the annual growth, and thus forest productivity, and various wood properties, particularly, wood specific gravity.

1.3.2 Forest floor, if denuded and subjected to heavy erosion, loses the top layers of the soil. The topmost layer, unique to forest soils, contains organic matter, partly or well decomposed, and the next horizon in the soil profile is that of mineral soil mixed with organic matter. These are the layers that supply nutrients to plants and contribute to forest growth. Thus once these layers are removed due to erosion, the forest plants suffer from lack of food and become dependent on supply of fertilizers for survival and growth. Sustaining forest growth by external application of fertilizers is not an economic measure. Heavy erosion of the forest soil also destroys its physical properties like soil texture, structure, porosity etc. The physical properties of the solid, liquid, and gaseous phases of soil have a substantial influence on the supply of water, nutrients and oxygen for metabolism, and the availability of physical space to anchor the underground plant structures. Providing physical support for above ground tissues is of particular importance, because plants must properly orient themselves to capture sun's energy for use in photosynthesis. In shallow and poorly drained soils, wind throw is common because of limited physical space in the former case, and anoxic (without oxygen) condition in the latter. Thus arrest of soil erosion in forest floor is essential for survival and growth of forest trees.

1.3.3 The most common and economic soil-water conservation measure adopted in south West Bengal forests is digging of interrupted contour trenches in the current year plantations and young forests.

(Source:http://www.westgodavari.org/neeru%20website/watershed.htm; Watershed Management Concept and Principles Suhas P Wani and Kaushal K Garg; http://dolr.nic.in/iwmp_main.htm ; www.rd.ap.gov.in/iwmp/IWMP_Note_Jan_2010.pdf; Soil Conservation Manual. WB Forest Directorate; Burton V. Barnes et.al Forest Ecology, 4th Edition)

Lesson 2 **1 hour**

Lesson Plan:

Objective:

- To introduce the concept of hydrological or water cycle
- To study the concept of water balance
- To study distribution of rainfall
- To study methods of rainfall measurement.

Backward Linkage:

- Concept of watershed management dealt with in Lesson 1

Forward Linkage:

- During tour the trainees may be shown watershed projects and rain gauge stations.

Training materials required:

- Copy of lesson 2 to be circulated beforehand.

Allocation of time:

- Hydrological Cycle – 10 mts
- Hydrological Cycle in a Forested Eco-system – 10 mts
- Water Balance – 5 mts
- Rainfall Distribution – 10 mts
- Gauge for rainfall measurement – 15 mts
- Discussion/miscellaneous – 10 mts

2.1 Hydrological cycle – also known as **Water cycle** is the journey water takes as it circulates from the earth's surface to the sky and back again. **The major storages of water** on the earth are the **oceans** and the **atmosphere. Others include ground water, streams, lakes and plants.** While the total amount of water on the earth remains fairly constant, the partitioning of the water into the major storages varies depending on a wide range of climatic variables. In a never ending cycle, the water moves from one reservoir to another by the physical processes of **evaporation**, **condensation**, **precipitation**, **transpiration**, **infiltration, run-off**, and **subsurface flow**. In so doing, the water goes through different phases: liquid, solid (ice), and gas (vapour).

This circulation and conservation of earth's water as it circulates from the land to the sky and back again is called the 'hydrological cycle' or 'water cycle'.

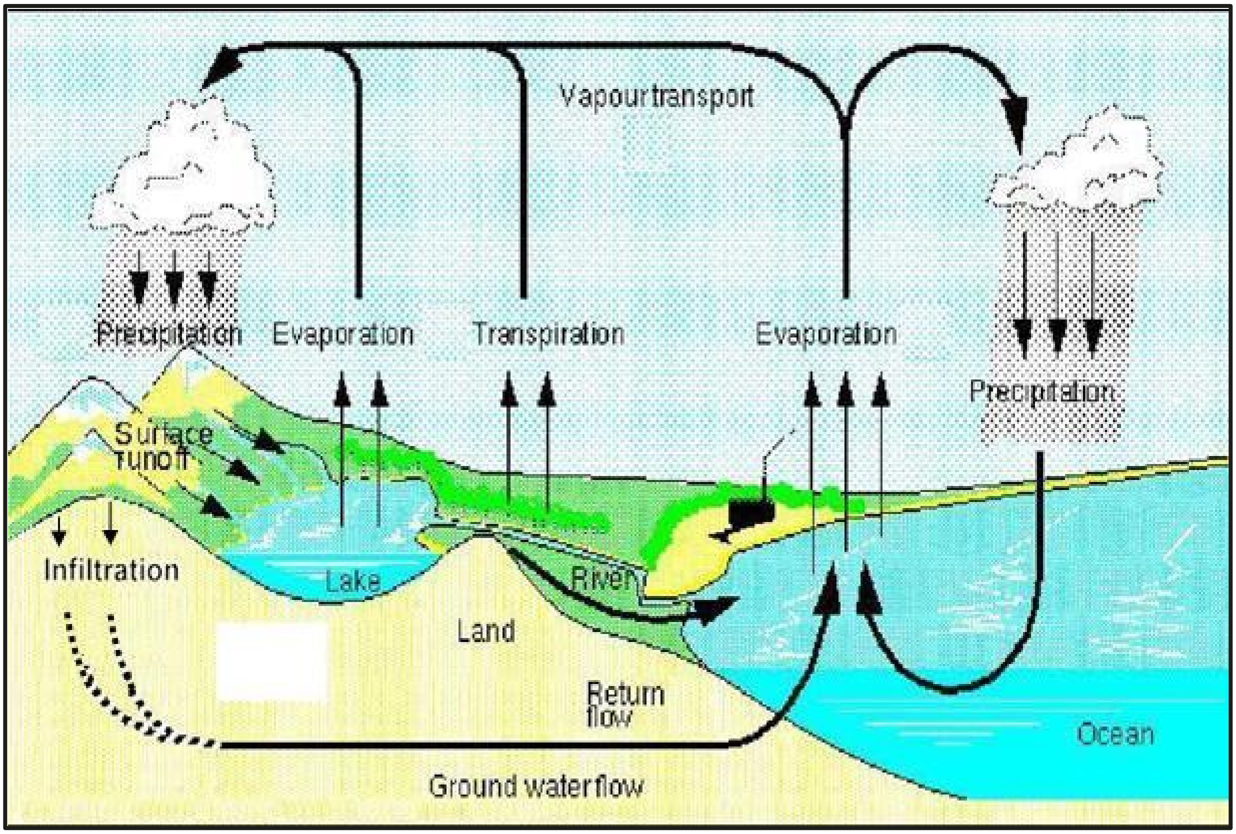


Fig. 2.1. Hydrological cycle (Source : http://www.euwfd.com/html/hydrological_cycle.html)

2.1.1 A hydrological cycle, in a simple form, is illustrated in Fig.2.1. Earth's surface, both land and ocean, receives water from the atmosphere through precipitation. A part of the precipitation reaching the land infiltrates the ground, adds to ground water and seeps slowly as ground water flow to streams and oceans. Another part of land precipitation after filling the depressions of land surface begins to move over the land surface as **runoff** which eventually meets the water storage in lakes and rivers. The rivers again meet the oceans. Water goes back to the atmosphere as vapour through evaporation from the ocean and the land, and transpiration from the vegetation. The vapour in the atmosphere forms clouds and lead to precipitation. That is how the water or hydrological cycle continues.

2.1.2 Hydrological Cycle in a Forested Eco-system

Forest Ecosystems participate in the above processes of water movement from one storage to the other, both depending on those processes and influencing them as illustrated in Fig. 2.2.

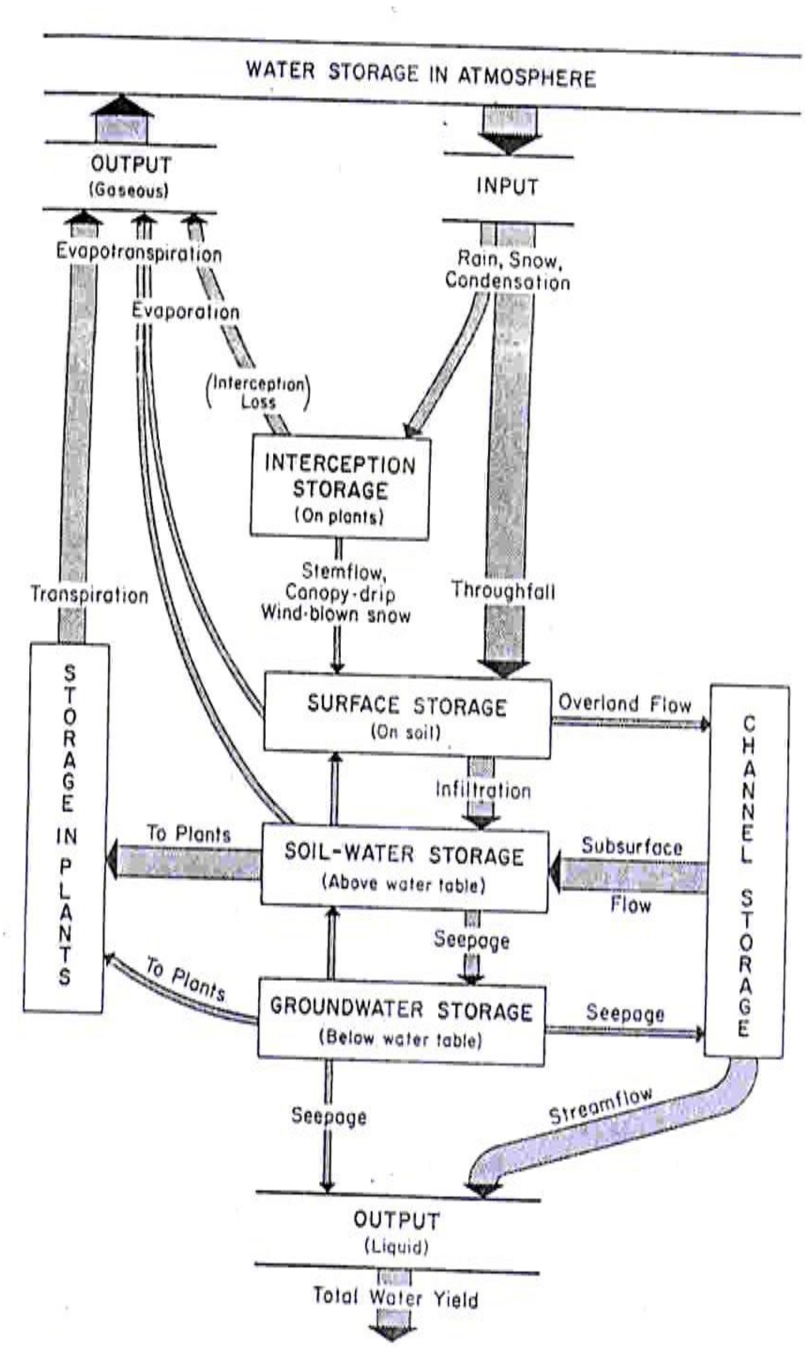


Figure 2.2. The Hydrological cycle of a Forested Ecosystem showing inputs from the atmosphere and outputs to groundwater, streams, and the air.(Source: Burton V. Barnes Forest Ecology 4th Edition).

- Precipitation in a forest ecosystem partly reaches surface storage as **through-fall** and partly intercepted by vegetation.
- Water may be stored briefly on the plant surfaces or in the soil. From there it can evaporate back into the atmosphere, or move to other surfaces by dripping from the canopy, running down stems (stem-flow), or being blown by wind.
- When water reaches the soil, it can evaporate to the atmosphere, infiltrate the soil to be absorbed by roots, or percolate downward to groundwater.
- Water in excess of that which infiltrates the soil may flow overland toward streams, lakes or oceans as runoff.
- Water is evaporated back into the atmosphere from the following sources:
    - Interception storage on plants;
    - Surface storage on soil
    - Soil water storage above water table
    - Water storage in plants through transpiration
- Evapotranspiration, which is the combination of evaporation from surface water, land and plant surfaces, and transpiration, accounts for 70% of water returned to the atmosphere. Evaporation from oceans accounts for remaining 30%.

2.2 Water Balance

A catchment/watershed water balance is the process by which precipitation is separated into its components and thus water inputs from the atmosphere is balanced against the outputs. Water balance in a forested watershed can be described by the following equation.
For a given study period

$$P + W_{sn} = E_{for} + R + dV + dS_{gr} ,$$

where ($P + W_{sn}$) are precipitation and water equivalent of snow, that is the water income or input,
E_{for} is total evapotranspiration,
R is total runoff (overland and ground) into rivers,
dV and dS_{gr} are the changes in moisture storage in the unsaturated zone and ground water, which are determined by the difference between the respective values at the start and end of the study period.
For a long-term period (over 10 years) one may assume that:
$\bar{P} = \bar{E}_{for} + R$, **where the symbols indicate long term mean values of the respective quantities.**
Over a long period if the soil moisture and ground water storage do not undergo any change, the precipitation will be divided between evapotranspiration and runoff.

It has been experimentally found that E_{for} is closely related to the biological productivity of forests and especially to the annual increment of timber and to the phytomass of the canopy (leaves, needles). **Thus nature of the crop, age of the crop and management practices will all have an impact on the evapotranspiration and runoff, the output quantities of the water balance equation.**

2.3 Rainfall Distribution

Rainfall is an important element of Indian economy. Even as monsoons effect most part of the country, the amount of rainfall varies over a wide range from heavy to scanty in different parts. There is great regional and temporal variation in the distribution of rainfall. Over 80% of the annual rainfall is received in the four rainy months of June to September. The average annual rainfall is about 125 cm, but it has great spatial variations.

a. Areas of **Heavy Rainfall (Over 200cm)** : The highest rainfall occurs in west coasts, on the western Ghats as well as the Sub-Himalayan areas in North East and Meghalaya Hills. Assam, West Bengal, West Coast and Southern slopes of eastern Himalayas.
b. Areas of **Moderately Heavy Rainfall (100-200 cm)** : This rainfall occurs in Southern Parts of Gujarat, East Tamil Nadu, North-eastern Peninsular, Western Ghats, eastern Maharashtra, Madhya Pradesh, Orrisa, the middle Ganga valley.
c. Areas of **Less Rainfall (50-100 cm**) : Upper Ganga valley, eastern Rajasthan, Punjab, Southern Plateau of Karnataka, Andhra Pradessh and Tamil Nadu.
d. Areas of **Scanty Rainfall (Less than 50 cm**) : Northern part of Kashmir, Western Rajasthan, Punjab and Deccan Plateau.
e. The two significant features of India's rainfall are:
f. i. in the north India, rainfall decreases westwards and ii. in Peninsular India, except Tamil Nadu, it decreases eastward.
(Source:http://www.facts-about-india.com/distribution-of-rainfall-in-india.php)

2.3.1 Distribution in West Bengal

(Source: Weather and Climate of West Bengal by Dr. Swadesh Mishra file:///C:/Documents%20and%20Settings/S.%20B.%20Roy/My%20Documents/Downloads/Chap-Wcw_17.PDF), http://www.imd.gov.in/section/hydro/distrainfall/webrain/wb/jalpaiguri.txt , www.indiawaterportal.org)

Like other parts of the country southwest monsoon is the main feature in the climate of West Bengal as well as the principal denominator of the prosperity of the state and its agro-economy. Like a greater part of the Indian sub-continent the season of south west monsoon (June-September) is the principal 'rainy season' in the state which contributes 73 to 80 per cent of the average annual rainfall of the districts. The amount of rainfall of the season varies considerably over the regions. District wise monthly and annual rainfall for the period from 2004 to 2012 (period for which data are available) may be seen in Appendix 1. It will be seen that the three northern districts of Darjeeling, Jalpaiguri and Cochbehar form the highest rainfall zone followed by the coastal districts of Medinipur and Dakshin 24 Parganas. The region in the south west and central part of the state receive less rainfall in the range of 1200 to 1500 mm. Appendix 2 shows the district wise average annual rainfall over the period from 2004 to 2012(period for which data are available) in the descending order.

2.3.2 Rainfall measurement

(Source: Paper titled "Rainfall Measurement" by Shri S. Barari, IFS, presented in the staff training on soil conservation at forestry training centre in 1993; http://www.imdpune.gov.in/surface_instruments/Specs%20of%20SurfaceInsrtuments.pdf ; soil and water conservation Engineering by Frevert. Schwab et.al.)

Rainfall is the most important hydrological function and is used in almost all hydrological computations, which are frequently required for designing of various structures connected with runoff and water yield from a catchment. The measurement of precipitation (i.e, rain, snow, sleet or hail) is a process of sampling wherein the gauges are located at predetermined points in the watershed area and their average value determined.

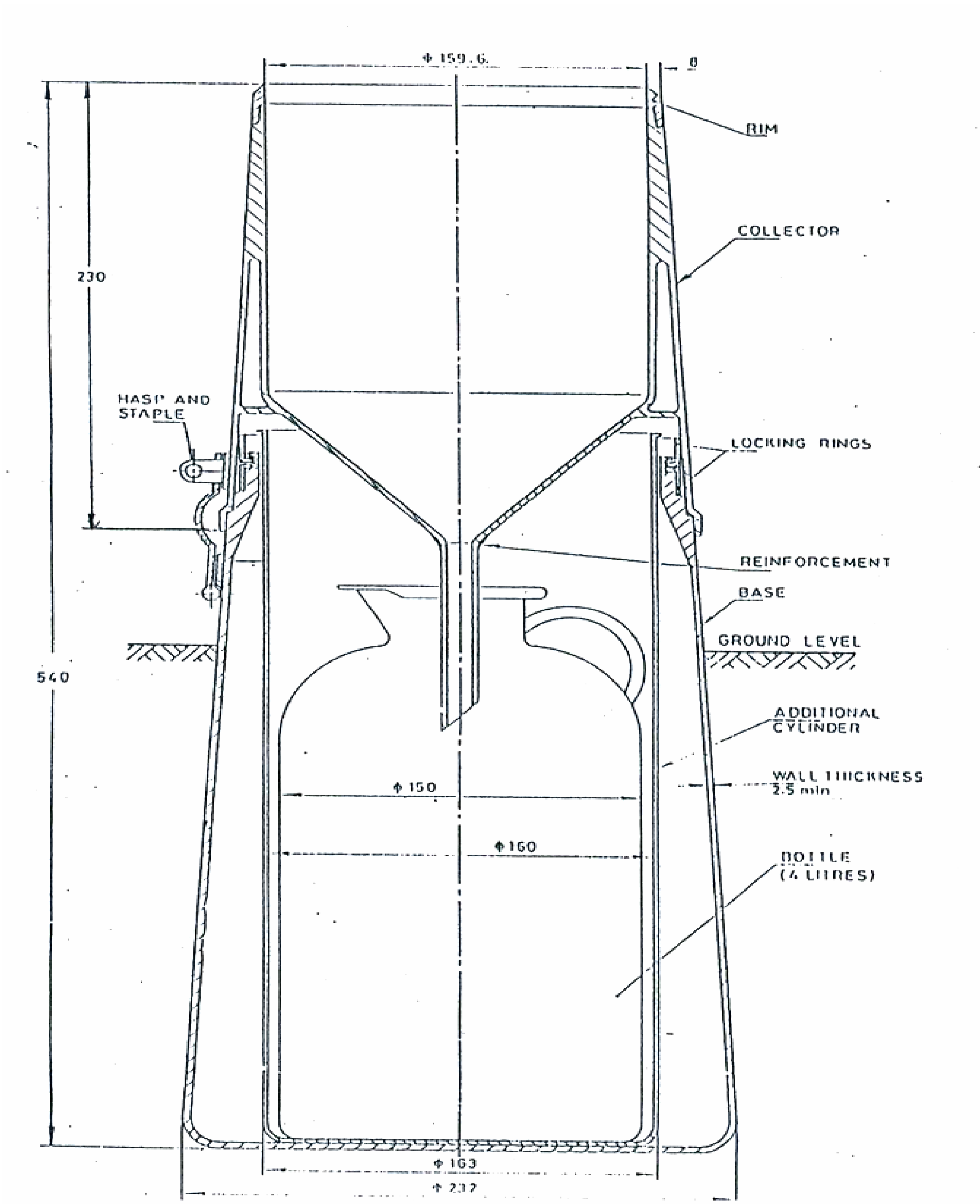
2.3.2.1 Rainfall Terminologies:

a) **Rainfall duration**: It is the time during which the rainfall occurs.
b) **Rainfall intensity**: It is the amount of rainfall in unit of depth (i.e. in inch or mm) per unit time (i.e. in hour). In other words, it is the ratio of total amount of rain to the length of the period in which this rain falls.
c) **Rainfall recurrence interval**: This is the average time interval between the occurrence of rainfall of given intensity and that of an equal or greater intensity. This is also termed as **rainfall intensity frequency**.

2.3.2.2 Gauge for rainfall measurement

The purpose of the rain gauge is to measure the depth and intensity of rain falling on a flat surface, without considering infiltration, evaporation or run-off. The amount of rainfall is expressed in terms of depth of water over the area in inches or m.m. Rain gauge may be classified as recording or non-recording.

a) Standard or non-recording: This works on the principle of collecting rainfall through an opening of regular dimension and working out the depth of rainfall. Please see Fig.2.3 which shows the different components and specifications of non-recording rain gauge prescribed by the Indian Meteorological Department.



All dimensions in millimeters

Fig.2.3 Rain gauge, Non- Recording (200 cm^2), General Assembly

(Source :
http://www.imdpune.gov.in/surface_instruments/Specs%20of%20SurfaceInsrtuments.pdf)

The non-recording rain gauge is a cylindrical can, open at the top, the rigid rim of the opening defining a collecting area of 100 sq.cm. or 200 sq. cm. The collector which intercepts the sample of rainfall to be measured is exposed above ground level. The water intercepted by the collector is funneled into the receiver which consists of a base and a bottle. The receiver is fixed partially below ground level. The amount of precipitation caught in a gauge is measured using rain measures. The rain measure is usually of 20 mm capacity suitable for 100 cm^2 or 200cm^2. The material for collector and the receiver should preferably be fibre glass reinforced polyester. However any material, except galvanized iron sheet, which is rigid and strong but light in weight and capable of withstanding exposure to climatic conditions will be suitable. The rim of the collector should be of gun metal or aluminium alloy. The diameter of collector rim should be 159.6 mm for 200^2 cm rain gauge and 112.9 mm for 100^2 cm rain gauge. Each non-recording rain gauge shall be provided with a rain measure. There are specified types of measure corresponding to the collectors of 200 cm^2 and 100 cm^2 area. Made of colourless and transparent glass the rain measures shall be cylindrical flat bottomed containers having a uniform diameter. The open end shall be splayed and provided with a lip, the edges being well rounded off. The graduation marks on the measures shall be horizontal lines lying in planes perpendicular to the axis of the rain measures. The graduations shall be marked for every 0.1 mm or 0.2 mm. In a rain measure for 200 cm^2 collector a rainfall measure of 0.2 mm will be equivalent to an actual collection of 4cm^3 of rainwater.

b) Recording rain gauge

Recording rain gauge is used to collect information on intensity of rainfall also in addition to the total rainfall of an area. The chart of recording rain gauge gives us the following information:

i) Total amount of rainfall;
ii) Times of start and ceasation of rainfall
iii) Duration of rainfall
iv) Rainfall intensity

The most common design of recording rain gauge is the siphon type. It consists of a collector and a rainfall recording mechanism mounted on a base. The rainfall measuring unit consists of a float chamber containing a light metal float and siphon chamber. Rain from the collector is led into the float chamber through an inlet tube and as the float rises, a pen fixed to the float rod draws a line on a chart wound on a rotating drum driven by clock-work. The water is emptied by the siphon chamber as soon as a pre-determined level is reached by the float chamber and the process repeats. Recording range is 0 to 10 mm with collector area of 325cm^2 and 0 to 25 mm with collector area of 130 cm^2.

Rainfall analysis:

1) "X" axis of the drum chart gives the time in hrs. and "Y" axis the depth of rainfall.
2) For each bout of rainfall during a 24 hour cycle the duration (in hr.) of rainfall is found out and also the depth (in m.m.). This gives the intensity for each bout of rainfall.
3) The cumulative rainfall depth for all the rainfall bouts during the 24 hours time is found out by adding up the depths together. Similarly, the cumulative time of rainfall is found out by summing up the period of rainfall of each bout. The cumulative intensity is thus measured.

Average rainfall determination

i) **Arithmetic mean method**: When one gauge is used, the rainfall recorded is applied over the entire area. When more than one, say n number, gauge is used, the simplest method is to take arithmetic mean of the rainfall in the gauges. This is determined by the formula

$$P_{av} = \frac{P_1+P_2+P_3+\dots\dots\dots+P_n}{n}$$

Where P1, P2, P3…P_n are rainfall recorded in the respective gauges in the watershed and n is the total no. of gauges.

ii) Thiessen polygon method: The use of this method has been illustrated in Fig.2.4. The location of the rain gauges is plotted on a map of the watershed. The points representing the location of the gauges are joined by lines. Perpendicular bisectors are drawn on these connecting lines in such a way that those bisectors enclose areas referred to as Thiessen Polygons. For each gauge there will be a corresponding polygon. All points within one polygon will be closer to its gauge than any of other gauges. The polygons may lie wholly or partly within the watershed. The fig.2.4 shows one polygon lying completely within the watershed and others falling partly within the watershed.

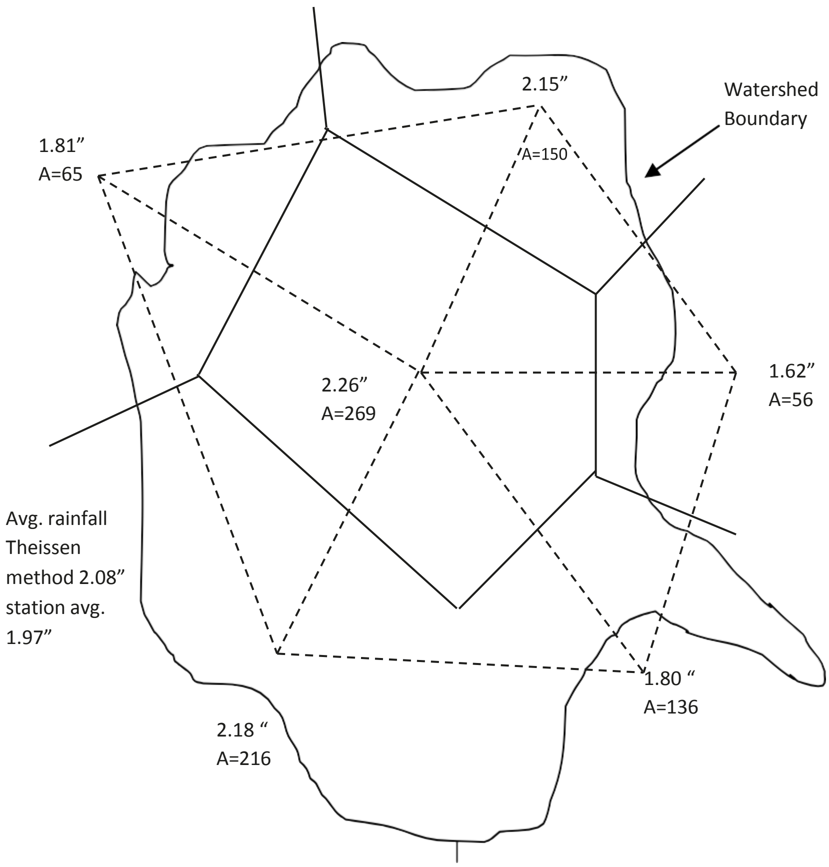


Fig.2.4. Thiessen Network

(Source: Redrawn from Soil & Water conservation Engineering by Frevert. Schwab et.al)

The average precipitation over a watershed can be determined by using the following equation:

$$P_{av} = \frac{P_1A_1+P_2A_2+P_3A_3+.....+P_nA_n}{A_1+A_2+A_3+.....+A_n}$$

$$= \frac{\sum AP}{A}$$

Where P_{av} represents the average depth of rainfall in a watershed of area A, and P_1, P_2, P_3, ... P_n represent the rainfall depth in the polygon having areas A_1, A_2, A_3, ... A_n within the watershed.

The data given in Fig. 2.4, give rainfall depth recorded in the various gages and the areas of the respective polygons falling within the watershed. It may be noted that except one polygon (area: 269) which appears in full, part area of the polygons lying within the watershed is to be taken into account for applying the above formula. Working with the given data, the average depth of rainfall by arithmetic mean comes to 1.97 inches. However, by the Thiessan method after working out the areas of the Polygons falling within the watershed from the watershed map. The average rainfall value comes to 2.08 inches.

iii) Isohyetal method:

In this method depth of rainfall recorded at the location of the various gauges is plotted on a graph. Then isohyetals (lines of equal rainfall) are drawn by the method used in drawing topographic maps. The area between the hyetals may be planimetered and average rainfall depth may be calculated by the above equation applied in Thiessen polygon method.

APPENDIX - I Soil and Water Conservation

Districtwise Rainfall in West Bengal

Source : www.indiawaterportal.org and http://www.imd.gov.in/section/hydro/distrainfall/webrain/wb/jalpaiguri.txt

District	Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total (mm)	Average Annual Rainfall (mm)
BANKURA	2004	0.3	0	14	46	83.2	228	271	529	239	149	0	0.2	1559.8	1471.4
	2005	31	36	53	53	62.2	195	261	238	193	198	0	23	1343.6	
	2006	0	0	2.3	48	114	238	383	293	288	15	13	0	1394.4	
	2007	0	45	43	32	97.6	211	623	303	418	11	31	0	1814.6	
	2008	26	5.4	3.3	39	93.4	399	439	303	232	19	0	0	1557.9	
	2009	4.8	0	28	0.7	197	56.8	307	326	312	55	13	0	1300.1	
	2010	4.8	34	31	31	118	189	181	136	200	71	7.4	38	1040.6	
	2011	5.1	0.7	34	122	146	544	184	394	417	30	3.8	0	1880.6	
	2012	44	16	7.9	86	44.6	173	301	346	243	36	38	15	1350.7	
BIRBHUM	2004	7	1.8	52	59	111	225	208	365	388	247	0	2.8	1664.5	1442.1
	2005	52	21	77	77	69.2	180	482	221	107	219	0	5.8	1512.1	
	2006	0	0	21	56	93	310	622	224	467	25	15	0	1831.1	
	2007	0	55	60	47	69.6	214	508	285	427	43	4.5	0	1712.4	
	2008	15	6.3	9.1	25	96.8	294	397	300	202	54	0	0	1399.3	
	2009	1.8	9	7.8	0	231	75.9	231	304	283	93	2	0	1238.6	
	2010	1.8	12	9.2	26	66.2	215	224	122	222	68	8.8	50	1023.9	
	2011	8.1	1.8	36	63	82.5	411	196	490	234	21	0.5	0	1544	
	2012	17	5.5	7.7	30	46.9	123	325	197	139	85	71	6	1052.8	
BURDWAN	2004	7.5	0	24	53	92.8	227	182	310	240	142	0	3.3	1282.2	1391.9
	2005	31	24	46	46	51.4	171	310	199	133	242	0	9.6	1265.1	
	2006	0	0	5.7	72	113	175	517	283	306	26	9.2	0	1506.6	
	2007	0	48	41	27	71.7	246	497	289	451	51	34	0	1754.8	
	2008	23	13	21	37	125	376	420	298	268	56	0	0	1638.3	
	2009	0	0	21	0.3	229	48.6	254	371	303	69	0.2	0	1296.6	
	2010	0	8.2	10	13	110	223	191	123	209	50	8.3	44	989.2	
	2011	0	0.7	27	55	117	417	260	349	240	51	0.6	0	1517.6	
	2012	31	7.8	3.2	63	39.4	134	425	278	195	57	38	6.2	1276.6	

COOCH BEHAR	2004	6.8	1	5.1	195	338	549	1100	264	519	179	6.5	0	3162.4	2790.7
	2005	25	6.8	66	185	347	676	631	651	276	421	0.2	0	3285	
	2006	0.2	2.2	6	45	343	589	653	139	390	157	16	5.3	2344.1	
	2007	0	50	22	185	221	418	613	394	430	88	0	0.1	2420.3	
	2008	41	8.6	64	136	220	447	623	855	275	162	0	0.1	2830.6	
	2009	0	0	41	190	263	418	357	599	171	275	2.2	0.2	2316.1	
	2010	0	0	64	287	442	688	815	500	479	58	5.8	0	3338.9	
	2011	0.8	11	89	161	270	387	788	421	475	15	8.2	3.3	2627.8	
	2012	4	11	5.9	152	341	919	731	408	561	222	N.A.	0	N.A.	
DARJEELING	2004	17	17	46	151	233	593	800	352	480	121	9	1.6	2820.3	3029.4
	2005	15	5.6	103	70	131	417	608	596	116	162	6.1	0	2230.1	
	2006	0	5	6.8	115	226	449	667	447	659	172	6.9	4.1	2757.4	
	2007	0	106	40	99	220	392	1065	567	724	69	1.3	2.6	3285.3	
	2008	20	2.9	49	67	192	915	739	875	292	138	27	0	3316.1	
	2009	0	0	13	147	398	350	765	760	266	307	0.5	1.8	3009.1	
	2010	0	3.4	6.8	73	304	636	981	914	469	136	15	0	3538.6	
	2011	3.7	8.2	20	99	233	620	1070	645	589	30	16	4.2	3338.5	
	2012	7.2	2.8	2.2	142	152	628	902	479	588	67	0	0	2969.5	
HOOGHLY	2004	2	0	13	42	87.2	252	195	289	287	197	0	0	1363.2	1315.2
	2005	26	11	60	33	32.3	189	210	221	151	321	0	0.9	1254.6	
	2006	0	0	1.3	92	146	167	326	269	236	33	0.1	0	1270.4	
	2007	0	45	14	53	106	278	473	235	420	49	87	0	1759.7	
	2008	55	9.2	22	54	95.8	356	340	216	238	39	0	0	1424.3	
	2009	0	0	25	0	195	79.8	203	332	243	72	6.2	0	1156	
	2010	0	31	4	18	171	186	136	190	210	65	4.2	19	1033.5	
	2011	1.9	0.4	43	38	122	351	246	429	235	21	0.1	0	1485.2	
	2012	41	15	1.8	41	56	170	273	200	184	48	52	9.6	1089.8	
HOWRAH	2004	0	1	2	9	86	224	185	277	274	261	0	0	1319.2	1427.9
	2005	43	0	110	106	74.7	161	288	228	238	451	0	1.8	1701.1	
	2006	0	0	1	41	89.4	108	627	292	308	244	2.8	0	1714.1	
	2007	4.8	54	24	53	64.8	240	758	365	416	53	46	N.A.	N.A.	
	2008	N.A.	N.A.	1.8	50	90.4	563	313	258	362	70	0	0	N.A.	
	2009	0	0	4	0	328	43.9	371	196	299	66	0	0	1307.3	
	2010	0	11	0	2.2	107	175	213	351	204	160	3	19	1244.9	
	2011	4.9	5.3	29	38	127	293	256	434	252	24	0	0	1462.5	
	2012	81	15	0	34	18.3	267	241	155	257	112	26	40	1245.9	
JALPAIGURI	2004	21	14	40	150	462	689	125	474	659	173	15	6.9	3952.8	3520.7

								1							
	2005	28	5.2	201	216	242	487	834	723	296	365	8	0	3405.8	
	2006	0	15	16	99	386	664	741	300	673	200	22	5.6	3120.7	
	2007	0	68	25	209	260	584	919	676	690	74	2.8	0.6	3507.8	
	2008	14	5.5	65	135	227	672	959	1046	322	99	13	3.7	3559.3	
	2009	0	0	34	154	258	656	699	746	264	323	2.5	2.4	3137.8	
	2010	0	3.1	43	226	421	873	1165	784	553	74	5.6	0	4146.2	
	2011	2.3	8.2	44	162	277	531	925	544	491	40	9.5	2.8	3035.1	
	2012	5.4	3.8	5.8	164	264	1057	1111	456	598	155	0	0.1	3820.8	
MALDA	2004	29	0	4.1	27	83.3	318	430	240	126	510	0	0	1766.5	1364.7
	2005	12	5.8	36	18	86.2	69.4	567	292	183	167	0	0	1435.6	
	2006	0	0	9.6	97	85.9	158	189	227	355	90	9.7	0	1221.3	
	2007	0	36	36	0	111	403	547	160	184	76	1.6	0	1554.1	
	2008	61	0.6	3.6	12	37.5	395	456	256	233	48	0	0	1503.4	
	2009	1.1	6.8	0.3	0	297	29.9	262	320	136	269	3.8	0	1325	
	2010	1.1	2.2	0.1	38	184	218	213	204	220	92	11	5.9	1189.8	
	2011	0.4	4.6	3.9	24	127	332	243	436	203	22	0.1	0	1395.2	
	2012	9.3	0	3.3	48	23	120	277	112	168	86	46	0	891.3	
MIDNAPORE	2004	0	2.1	9.7	65	65.2	315	264	378	187	201	0	0.1	1487.4	1650.3
	2005	17	2.2	91	47	140	188	333	296	371	491	0.1	1.9	1978.5	
	2006	0	0	13	40	145	171	424	394	368	40	9	0	1603.2	
	2007	11	69	59	46	58.8	299	792	411	457	26	37	0	2264.9	
	2008	85	13	18	72	99.4	709	285	270	286	69	0	0	1904.9	
	2009	0.1	0	18	4.3	308	65.7	281	285	255	88	16	0.3	1320.7	
	2010	0.1	9	3.4	0	95.2	180	286	372	283	158	6.9	19	1412.8	
	2011	3.7	7.4	22	60	133	271	295	372	297	28	2.3	0	1490.8	
	2012	63	1.2	0.1	35	44.1	109	277	276	463	62	25	34	1389.5	
MURSHIDABAD	2004	3.3	0	24	26	51	223	166	136	264	219	0	0	1112.6	1247.2
	2005	26	38	45	45	4.3	127	339	152	133	140	0	2	1051.4	
	2006	0	0	6	45	182	261	410	227	440	47	9.6	0	1626.9	
	2007	0	61	23	0	N.A.	334	479	268	418	143	N.A.	N.A.	N.A.	
	2008	6.2	2.1	2.3	7.8	32.9	248	379	210	220	66	0	0	1173.8	
	2009	0.2	0	24	0	177	73.8	186	359	382	151	0	0	1351.3	
	2010	0.2	0.1	0	0	88	264	101	171	174	90	2	50	940.7	
	2011	4.7	1.3	53	155	117	517	246	397	224	25	0.2	0	1741.3	

	2012	16	0.5	10	56	35	104	293	110	174	109	68	4.1	979.5	
NADIA	2004	0	0	1	38	87.4	209	147	216	415	141	0	9	1262.3	1300.7
	2005	20	6	104	104	59.9	145	274	144	140	351	0	7.2	1355.6	
	2006	0	0	0	6	144	95.9	353	219	427	52	0.5	0	1297.1	
	2007	0	81	36	20	71.8	205	471	209	454	107	38	0	1692.9	
	2008	71	35	10	92	96.4	260	301	220	314	82	0	0	1480.2	
	2009	0	0	33	0.4	250	87.7	234	507	304	60	21	0.2	1496.5	
	2010	0	15	0	29	94.2	173	107	87.9	181	110	6.8	42	846.2	
	2011	0	0.4	36	99	122	325	238	363	197	30	3.4	0	1413.4	
	2012	20	0.4	0.4	27	74.3	95.6	207	163	162	72	38	3.7	862	
NORTH 24 PARGANAS	2004	0.6	0.1	6.9	70	61.3	286	245	334	352	234	0	0	1589.7	1495.3
	2005	21	0.6	88	41	123	177	353	271	122	399	0	0	1595.3	
	2006	0	0	13	58	140	121	427	309	414	99	3.9	0	1584.6	
	2007	1.1	57	17	64	101	276	428	228	433	71	76	N.A.	N.A.	
	2008	60	39	29	50	193	238	306	128	314	127	0	0	1484.7	
	2009	15	5.6	31	0	214	113	175	301	301	68	23	0	1246.6	
	2010	15	10	5.3	25	152	220	217	214	203	168	4.9	20	1254.3	
	2011	0	0.3	46	46	145	376	408	545	309	40	0	0	1915.3	
	2012	43	16	0	99	87.2	148	249	212	254	115	56	14	1291.6	
NORTH DINAJPUR	2004	N.A.	N.A.	N.A.	N.A.	N.A.	44.5	634	249	258	81	0	0	N.A.	1227.8
	2005	N.A.	N.A.	N.A.	N.A.	N.A.	282	459	385	241	295	N.A.	N.A.	N.A.	
	2006	N.A.	N.A.	N.A.	N.A.	N.A.	117	343	234	264	54	N.A.	N.A.	N.A.	
	2007	N.A.	N.A.	N.A.	N.A.	N.A.	439	474	414	221	N.A.	N.A.	N.A.	N.A.	
	2008	N.A.	N.A.	N.A.	N.A.	N.A.	294	512	334	21.3	N.A.	N.A.	N.A.	N.A.	
	2009	N.A.	N.A.	N.A.	N.A.	N.A.	221	320	464	43.7	262	N.A.	N.A.	N.A.	
	2010	N.A.	N.A.	N.A.	N.A.	N.A.	364	357	343	370	70	N.A.	0	N.A.	
	2011	1.3	11	N.A.	N.A.	205	355	421	325	362	6.7	17	0	N.A.	
	2012	6.2	1.9	6.4	68	3	248	531	140	164	60	0	0	1227.8	
PURULIA	2004	N.A.	N.A.	N.A.	N.A.	N.A.	92.2	295	476	174	98	0	0	N.A.	1399.8
	2005	N.A.	N.A.	N.A.	N.A.	N.A.	144	209	226	137	235	25	N.A.	N.A.	
	2006	N.A.	N.A.	N.A.	N.A.	N.A.	271	412	326	271	13	26	0	N.A.	

	2007	0	39	53	31	78.4	127	588	445	373	33	17	0	1783.8	
	2008	24	3.1	3.9	17	63	403	385	203	271	11	0	0	1383.4	
	2009	8.9	0	11	1.3	113	55.4	294	337	263	73	9.6	0	1165.8	
	2010	8.9	30	5.7	12	87.7	102	140	218	175	59	11	53	901.3	
	2011	1.2	0.2	44	75	98	523	222	405	375	20	0	0	1763.3	
	2012	38	26	6.3	75	37.6	146	329	317	319	38	52	17	1400.9	
	2004	1.5	3.6	17	85	42.7	304	357	511	236	305	1.8	0	1863.3	
	2005	32	0.1	116	79	84.2	209	532	283	305	507	0	0.5	2148.5	
	2006	0	0	13	47	113	148	632	373	476	72	6.5	0	1878.8	
	2007	4.9	59	12	37	181	239	736	360	479	86	61	0	2252.9	
SOUTH 24 PARGANAS	2008	99	11	8	51	76.4	400	245	298	285	150	0	0	1622.6	1752.1
	2009	0	0	21	6	235	78.3	410	318	316	88	32	0	1502.8	
	2010	0	6.7	1.4	11	151	251	247	253	222	148	3.4	14	1309.7	
	2011	0.1	3.3	29	140	94	419	203	567	268	42	0	0	1765.4	
	2012	45	18	5.5	43	42.8	140	345	328	318	67	39	34	1424.8	
	2004	46	0	0	0	4	169	433	112	1.2	397	0	0	1162	
	2005	N.A.	0	N.A.	0	0	43.8	409	407	224	740	0	0	N.A.	
	2006	0	0	0	35	3.5	162	294	196	419	23	0	0	1133.1	
	2007	0	14	0	0	109	524	435	197	292	11	0	0	1582.2	
SOUTH DINAJPUR	2008	0	0	0	0	1.2	287	464	304	198	43	0	0	1296.8	1305.7
	2009	0	0	0	0	59.4	42.7	314	376	14.7	175	0	0	982.5	
	2010	0	0	0	85	121	384	139	336	192	119	16	0.6	1393	
	2011	0	9.3	33	167	192	325	176	334	249	3.7	1.1	0	1489.1	
	2012	8	0	0	28	139	353	371	207	234	65	2.2	0.4	1407.1	

Note: 1.N.A. means data not available

2. Average figures in last column have been computed on the available data.

Appendix - II Soil and water conservation	
District wise average annual rainfall	
District	Average Annual Rainfall (mm)
JALPAIGURI	3520.7
DARJEELING	3029.4
COOCH BEHAR	2790.7
SOUTH 24 PARGANAS	1752.1
MIDNAPORE	1650.3
NORTH 24 PARGANAS	1495.3
BANKURA	1471.4
BIRBHUM	1442.1
HOWRAH	1427.9
PURULIA	1399.8
BURDWAN	1391.9
MALDA	1364.7
HOOGHLY	1315.2
SOUTH DINAJPUR	1305.7
NADIA	1300.7
MURSHIDABAD	1247.2
NORTH DINAJPUR	1227.8

Note : 1.Average annual rainfall computed over the period 2004-2012 or period for which data are available.

2. Figure for North Dinajpur is of 2012 only.

Lesson 3 **1 hour**

Lesson Plan:

Objective:

- To study the concept of Run off
- To study the runoff process, expression of runoff and factors affecting runoff
- To study the concept and computation of peak runoff
- To study soil erosion-types, agencies and factors

Backward Linkage:

- Concept of Hydrological cycle and water balance dealt with in Lesson 2

Forward Linkage:

- During tour the trainees may be shown sites demonstrating accelerated erosion
- Description of different types of erosion covered in lesson 4

Training materials required:

- Copy of lesson 3 to be circulated beforehand.

Allocation of time:

- Runoff and runoff process –5 mts
- Expression of runoff –5 mts
- Factors affecting runoff -10 mts
- Peak runoff –20 mts
- Soil erosion-types, agencies and factors–10 mts
- Discussion/miscellaneous – 10 mts

3.1 Runoff

Runoff is that portion of the precipitation that makes its way toward stream channels, lakes or oceans as **surface or subsurface flow**. When the term “runoff” is used alone, surface runoff usually is implied. The engineers designing channels and structures to handle natural surface flows are concerned with peak rates of runoff, runoff volume and with temporal (over time) distribution of runoff rates and volumes.

3.1.1 The Runoff Process

Runoff occurs after precipitation satisfies the demands of evaporation, interception, infiltration, surface storage, surface detention, and channel detention. For runoff to occur the rate of precipitation has to be in excess over the rate at which water may infiltrate into the soil. The process takes place in the order that may be described as follows.

- First, the infiltration rate is satisfied.
- Then water begins to fill the depression, small and large, on the soil surface;
- After the depressions are filled overland flow or runoff begins;
- The depth of water builds up on the surface until the head is sufficient to result in runoff in equilibrium with the rate of precipitation less infiltration and interception.

3.1.2 Mathematical Expresssion of Runoff

In a watershed, after surface or depression storage has been filled, runoff over a period of time may be defined by the following equation:

Runoff R = Precipitation – (Evapotranspiration + change in soil moisture
+ change in ground water storage).

The above expression follows from the water balance equation. In a simple expression, surface runoff is that part of precipitation that remains after evapotranspiration (to atmosphere) and infiltration (into ground). This is the part of precipitation that flows overland.

When observation is made over a short period where overland part of precipitation has also components of surface or depression storage and interception storage, the above equation for surface runoff is further refined as follows.

Runoff R = Precipitation – (Evapotranspiration + change in soil moisture + change in ground water storage + interception + depression storage).

3.1.3 Factors affecting Runoff

There are two kinds of factors that affect Runoff – (1) those associated with precipitation or rainfall; and (2) those associated with watershed. The factors are described below.

Rainfall factors -

- **Rainfall duration** – A storm of short duration may produce no runoff, but a storm of same intensity but of long duration will result in runoff.
- **Rainfall intensity** – rainfall intensity, that is, amount of precipitation per unit time, influences both the rate and the volume of runoff. An intense storm exceeds the infiltration capacity by a grater margin than does a gentle rain. Thus total volume of runoff will be grater for the intense storm even if total precipitation for both is the same.
- **Areal distribution of rainfall** – Rate and volume of runoff from a given watershed are influenced by the distribution of rainfall and of rainfall intensity over the watershed. The rate and volume of runoff reach maximum when the entire watershed contributes.

Watershed factors -

- **Size –** runoff increases with size.
- **Shape** – Long narrow watersheds are likely to have lower runoff than more compact watershed of same size.
- **Orientation –** orientation of the watershed with reference to storm path affects runoff.
- **Topography –** slope of upland areas, gradient of channels etc. affect runoff
- **Geology –** geology of soil materials influences infiltration rate and thus affects runoff.
- **Surface culture –** nature of vegetation (agriculture or forests etc.) and its management practice affect runoff.

3.2 Peak Runoff

(Source: Paper titled "Calculation of Peak Runoff in a watershed for Designing Soil Conservation Structures" by Shri P.K.Das. IFS(Retd.), prescuted in the Staff Training on Soil Conservation at Forestry Training Centre in 1993).

Structures and channels are planned to carry runoff which occurs with a specified recurrence interval. Vegetated controls and temporary structures are designed for a peak runoff that may be expected to occur once in 10 years. Permanent structures, which are expensive, are constructed for peak runoffs expected to occur once in 50 or 100 years. The **Rational Method** of predicting a design peak runoff rate is expressed by the equation

$$Q = \frac{C I A}{360}$$

Where Q = Peak value of runoff in cumec (cubic metre per sec)

C = Runoff Coefficient, which is dimensionless, and which depends on slope, cover, soil material and land use;

I = Peak Intensity of rainfall in mm/hour for the recurrence interval assumed for the design purpose;

A = Total area of the watershed in hectare.

The runoff coefficient C can be taken from the table below.

Sl No	Soil Type	Cultivated	Pasture	Forest
1	Sandy or gravelly soil	0.29	0.15	0.10

2	Loamy soil	0.40	0.35	0.30
3.	Clay soil	0.50	0.45	0.40

If the land is barren, the value of the coefficient will be increased by 10%.

If the watershed is comprised of areas under different land use of different soil type, the average value of C for the watershed is computed as given below.

$$C = \frac{A_1C_1 + A_2C_2 + A_3C_3 + \text{.........} + A_nC_n}{A}$$

Where A_1 is the area with coefficient C_1, A_2 the area with coefficient C_2 and so on.

The peak intensity I is given by the formula

$$I = \frac{kT^a}{(t+b)^n}$$

Where T = the design recurrence interval in years

t = the time of concentration for the watershed in hour

k, a, b, n = constants which depend on the agro-climatic characteristics of the region.

The values of k, a, b and n are available for different regions, such as Northern India, Southern India, Eastern India etc., and more accurately for certain research stations located all over India. The figures for Eastern Zone are as below.

k = 6.933

a = 0.1353

b = 0.50

n = 0.8801

3.2.1 The Recurrence Interval T is the number of years which is expected to elapse between two successive occurrences of similar storms of high intensity. It means when a structure is expected to last for a certain number of years, it should be so designed as to withstand such high intensity storms likely to occur within the designed life of the structure.

3.2.2 Time of concentration

It should be understood that flow at the lowest point of the watershed does not reach the peak value as soon as the rain starts. Time of concentration t is the time in which water from every point of the watershed reaches the point of construction of the structure in question and it is after lapse of this time t that the peak value of the flow is attained. The structure must be designed on the basis of this peak value of flow which depends on the time of concentration. The time of concentration to the site of construction of a structure in a watershed is calculated by the formula

$$t = \frac{0.01947 \cdot K^{0.77}}{60},$$

where $K = \sqrt{\frac{L^3}{H}}$

L = maximum length of travel in the watershed in metres, and

H = difference in elevation in metre between the farthest point in the watershed and the point where the structure is constructed.

Following is a table giving values of $10kT^a$ based on values of 'k' and 'a' for Eastern Region indicated above.

Life in year T	Value of $10kT^a$	Life in year T	Value of $10kT^a$	Life in year T	Value of $10kT^a$	Life in year T	Value of $10kT^a$
5	86.20	30	109.84	55	119.23	80	125.43
10	94.67	35	112.16	60	120.64	85	126.47
15	100.01	40	114.20	65	121.96	90	127.45
20	103.98	45	116.04	70	123.19	95	128.38
25	107.17	50	117.70	75	124.34	100	129.28

3.2.3 Example

Calculate the peak runoff for designing an earthen dam in a small sub-watershed in the district of Bankura in West Bengal. The basic data in the watershed are as below.

Recurrence Interval for design = 25 years.

Area under agriculture	Loamy soil	60 ha
Area under forest	(a) Clay soil	20 ha
	(b) sandy soil	25 ha
Barren pasture	Clay soil	45 ha
Total Area		150 ha

Maximum length of travel in the watershed to the point of construction of the structure = 2704 metre;

Difference in elevation between the remotest point and the pint of construction of the structure = 49 metre.

Calculation:

$$C = \frac{60*0.40+20*0.40+25*0.10\ +45*0.45*1.1}{60+20+25+45}$$

$$= 0.3785$$

$$K = \sqrt{\frac{(2704)^3}{49}} = 20087 \quad , K^{0.77} = (20087)^{0.77} = 2057$$

$$t = \frac{0.01947 \ast \text{�}^{0.77}}{60} = \frac{0.01947 \ast 2057}{60} = 0.667 \text{ hour}$$

Now from the table , $10kT^a$ (for T =25 years) = 107.17, and we also have b = 0.5 and n = 0.8801.

$$\text{Therefore, } I = \frac{10kT^{\text{�}}}{(t+\text{�})^n} = \frac{107.17}{(0.667+0.5)^{0.8801}} = \frac{107.17}{1.14} = 94 \text{ mm/hour}$$

We have A = 150 ha

$$\text{Therefore } Q = \frac{C.\text{�}A}{360} = \frac{0.3785 \ast 94 \ast 150}{360} = 14.82 \text{ cusec.}$$

3.3 Soil Erosion

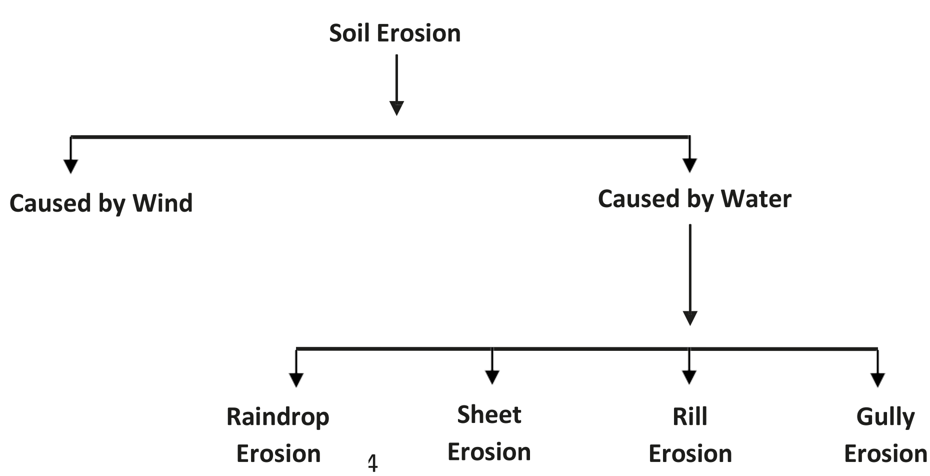
There are two major types of erosion, namely Geological Erosion and Accelerated Erosion.

3.3.1. Geological Erosion:

The wearing away of the land surface by running water , wind, waves, and moving ice generally has been looked upon as a normal geological process. Geological erosion is sometimes referred to as normal erosion or Natural erosion that represents the erosion characteristic of the land in its natural environment, undisturbed by human activity. Geological erosion has contributed to the formation of our soils and their distribution on earth. This long term eroding process has given rise to most of our present topographic features like stream channels, valleys etc.

3.3.2 Accelerated Erosion:

Accelerated Erosion or what is normally referred to soil erosion represents the soil loss in excess of geological erosion. Soil erosion means the process of detachment of particles from the soil surface and their transportation to other areas through the agencies of water, wind or gravity. Soil erosion is caused primarily by two agencies- water and wind. Water erosion is further subdivided into Raindrop, Sheet, Rill and Gully erosion.



In our country the interaction between water and soil is the main cause of erosion.

3.3.3 Factors involved in Erosion:

The major factors affecting soil erosion are –

- Climate
- Soil
- Vegetation
- Topography

Of the above factors, vegetation and to some extent soil may be manipulated or controlled. However, the climatic and topographic factors remain beyond human control.

3.3.3.1. The factors affecting erosion are further described below.

Climate – Climatic factors affecting erosion are precipitation, temperature, wind, humidity and solar radiation. The influence of temperature and wind is most evident through their effects on evaporation and transpiration. Precipitation has a direct impact on runoff, as has been explained earlier. As the runoff increases, so does the soil erosion or soil loss.

Soil- Physical properties of soil, namely soil structure, texture, organic matter, moisture content, density or compactness as well as chemical and biological characteristics influence the infiltration capacity and extent to which soil is likely to be dispersed or transported.

Vegetation-The major effects of vegetation in reducing erosion are –

- Interception of rainfall and thus reducing runoff
- Retardation of erosion by decreased surface velocity
- Physical restraint of soil movement
- Improvement of aggregation and porosity of the soil by roots and plant residue
- Increase biological activity in the soil and
- Transpiration which decreases soil moisture ,resulting in increased storage capacity

It may, however be noted that the above influences of vegetation on erosion will vary with the season, crop , age of the crop, climate and nature of the vegetative material, i.e, roots, plant tops/crown and plant residues.

Topography –Topographic features influencing the erosion are degree of slope, length of slope, and size and shape of the watershed.

Accelerated erosion is attributable to the following causes –

- Faulty agricultural practices
- Faulty silvicultural practices
- Inadequate soil cover
- Uncontrolled grazing
- Large scale deforestation
- Fire
- Road construction on hills without adequate arrangements for drainage of water.

Lesson 4

1 hour

Lesson Plan:

Objective:

- To study various types of Water Erosion
- To study in detail the Gully erosion
- To study wind erosion
- To study conservation measures for water erosion

Backward Linkage:

- Concept of Runoff , soil erosion and its types dealt with in Lesson 3

Forward Linkage:

- During tour the trainees may be shown sites demonstrating accelerated erosion
- Conservation measures covered in subsequent lessons

Training materials required:

- Copy of lesson 4 to be circulated beforehand.

Allocation of time:

- Raindrop, Sheet and Rill erosion –10mts
- Gully erosion–15 mts
- Wind erosion–10 mts
- Soil conservation measures –15 mts
- Discussion/miscellaneous –10 mts

4.1. Water Erosion:

Water Erosion is basically of four types:

i) Raindrop Erosion: Soil splash resulting from the impact of raindrops directly on soil particles or on thin water surfaces is called raindrop erosion. On soil protected with vegetation or plant residues, raindrop erosion may be insignificant, but on bare soil as much as 100 tonnes per acre are splashed into the air during a heavy rain. Size of raindrop and its velocity are two characteristics of raindrop that affect erosion. Large drops increase sediment carrying capacity of runoff. The velocity of rainfall also greatly affects the soil splash and erosion. The soil characteristics that determine the ease with which soil particles may be detached and transported are soil detachability and soil transportability. In general soil detachability increases with the increase in size of soil particles and soil transportability increases with decrease in particle size. It means that clay particles are more difficult to detach than sand, but clay is more easily transported. The effect of raindrop splash is more pronounced on sloping fields than on level land.

ii) Sheet Erosion: The uniform removal of soil in thin layers from slopping land is called sheet erosion. The beating action of raindrops combined with surface slope causes the major portion of sheet erosion. From the energy point of view raindrop erosion is far more important because raindrops have velocities of about 20 to 30 fps whereas overland flow velocities are about 1 to 2 fps.

iii) Rill Erosion: Soil removes from small but well defined channels (rills) resulting from concentration of surface flow is called rill erosion. Rill erosion is more serious because runoff moves faster in these small channels than in surface slope.

iv) Gully Erosion: Rills are small enough to be removed by normal tillage operations. Gullies are defined as large channels that cannot be filled except by earth moving machines in addition to normal tillage. Gully erosion takes place when concentrated runoff from a vast slopping land in sufficient volume and velocity continues cutting the soil in the form of channels. Gullies are the spectacular results of erosion. The area under gully is lost for cultivation. The gully erosion is an advanced stage of rill erosion much as rill erosion is an advanced stage of sheet erosion.

4.2. Process of Gully erosion:

The rate of gully erosion depends on runoff producing characteristic of watershed. These are:

- Drainage area
- Soil characteristics
- Alignment, Size and shape of the gully
- Slope in the channel

Development of a gully is combination of a number of processes occurring simultaneously or in different stages. These processes are:

- Waterfall erosion at the gully head (See Fig.4.1)
- Channel erosion caused by water flowing through the gully or by raindrop splash
- Slides or mass movements of soil in the gully

4.3. Stages of gully development:

Following four stages of gully development are generally recognizable on ground.

- Stage 1- Channel erosion by downward scour of the top soil.
- Stage 2 – Upstream movement of the gully head and enlargement of the gully in width and depth.
- Stage 3 – Healing stage with vegetation beginning to grow in the channel
- Stage 4 – Stabilization of the gully. At this stage the channel attains a stable gradient, gully walls reach a stable slope, and vegetation comes in abundance.

During the time of stage 3 and 4 the gully head has progressed to the upper end of the watershed. As a result the runoff to the gully head decreases since the drainage area is reduced. The remainder of the runoff enters at many points along the length of the gully.

4.4. Classification of gullies

(Source: http://www.fao.org/docrep/006/ad082e/ad082e01.htm)

Gullies are classified under several systems based on their different characteristics.

4.4.1. Gully classes based on size

One gully classification system is based on size - depth and drainage area. Table 1 describes small, medium and large gullies and is commonly used in manuals on erosion.

Table 1

Gully classes based on size

Gully classes	Gully depth in metre	Gully drainage area in ha
(a) Small gully	less than 1	less than 2
(b) Medium Gully	1 to 5	2 to 20
(c) Large gully	more than 5	more than 20

Source: (Frevert et., al., 1955).

4.4.2. Gully classes based on shape

This system classifies gullies according to the shape of their cross-sections (Fig. 4.1).

(a) U-Shaped gullies 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.

(b) V-Shaped gullies develop where the subsoil has more resistance than topsoil against erosion. This is the most common gully form.

(c) Trapezoidal gullies can be formed where the gully bottom is made of more resistant material than the topsoil and

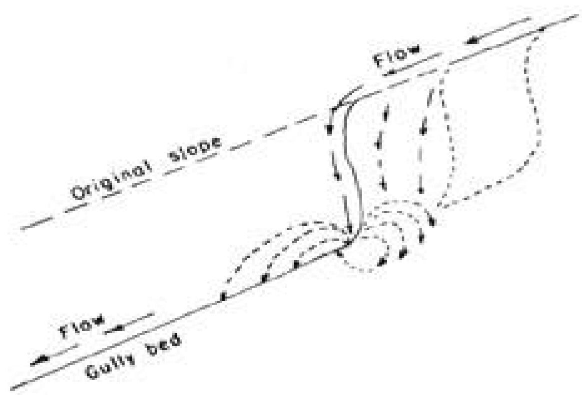


Fig.4.1. Waterfall erosion at gully head and advancement of the gully to the upper edge of the watershed. (Source: Weidelt, 1976)

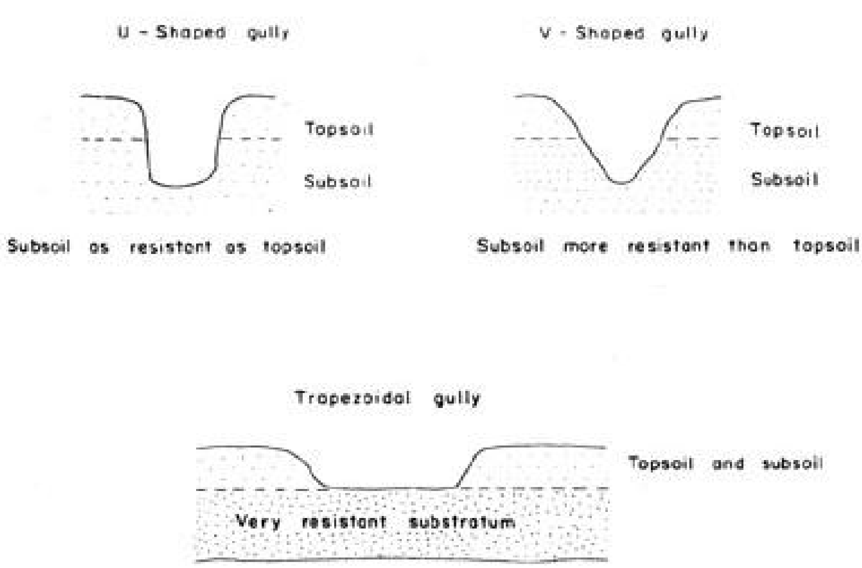


Fig.4.2. Gully classes based on shape of gully cross-section.
(Source : Weidelt, 1976)

4.5. Wind Erosion

Wind is one of the active forces causing soil erosion particularly in tracts subjected to frequent and heavy gales. The wind picks up lighter particles and transports them to great distances. This is particularly seen in the coastal and desert areas. Like water erosion, the loss of soil by wind involves two processes, namely, (a) detachment; and (b) transportation. The abrasive action of the wind results in some detachment of tiny soil grains from the granules or clods of which they are a part and transportation of the particles takes place in many ways.

4.5.1 Factors involved in wind erosion:

The major factors affecting wind erosion are

- Climate
- Soil
- Vegetation

Topography is relatively unimportant; though the length of the eroding surface greatly influences soil movement.

Climatic factors – factors influencing wind erosion are –

- Precipitation (Amount and distribution of rainfall and its effect on soil moisture);
- Temperature;
- Wind (velocity, direction, duration and turbulence) ;
- Humidity, viscosity and density of the air
  (Temperature, wind and humidity influence evaporation and transpiration which deplete soil moisture. Depletion of soil moisture makes it more vulnerable to wind erosion.)

Soil factors - factors influencing wind erosion are –

- Texture
- Structure
- Density of particles
- Density of soil mass
- Organic matter
- Moisture content
- Surface roughness
  Moisture content is the most significant factor, as relatively dry soil is more prone to wind erosion.

Vegetation - factors influencing wind erosion are –

- Height and density of vegetation cover
- Type of vegetation
- Seasonal distribution

  (Living plant roots and crown are more effective in retarding erosion than crop residues.)

4.5.2 Types of soil movement

- Suspension (where soil particle remains in suspension in air for some period of time without contact with soil surface.)
- Saltation (movement where the particle skip and bounce off the soil surface)
- Surface creep (where soil particles move while remaining in constant touch with the soil surface)

  The three types of movement usually occur simultaneously. Investigations have shown that at heights above approximately 3 feet from the surface, the only movement is normally the suspension, where all three types of movement occur near the surface.

4.6 Effects of Soil Erosion:

- The fertile top soil is removed and along with it the plant nutrients are lost and less productive sub soil is exposed.
- Drought becomes more severe as the water is not stored in the sub soil to be used by the plants in the dry season.
- Erosion reduces cultivable area by cutting deep gullies; makes farming difficult and uneconomic.
- Fertile lands go out of cultivation due to formation of sand dunes by wind erosion.
- Erosion in reservoirs and tank catchments causes silting of those irrigation structures and reduces their capacity and finally render them to be abandoned.
- Erosion in river catchment results in silting up of the rivers. Consequently the bed is raised, thereby causing overflowing of rivers and flood.
- Soil erosion prevents replenishment of ground water supply and springs and wells.

4.7. Soil and Water Conservation Measures – Brief Outline

Erosion control measures are of two types structural and biological.

4.7.1 **Splash erosion** - Splash erosion may be checked by growing vegetal cover. Grass and shrubs are best vegetal cover. Dub grass (*Cynodon dactylon*), Cenchrus spp., Pennisetum, Spear grass(Heteropogon spp. in dry areas), trailers like Ipomea biloba, sabai grass etc.are good ground cover. In the hills Kudzu vine, Amlisho etc. are good cover.

4.7.2 **Sheet Erosion** - Areas under sheet erosion should be closed to grazing. If the area is closed to grazing and fire, chances and extent of erosion are much less .This may be done by erecting fencing or cutting cattle proof trenches etc. In the areas with moderately loamy soil contour trenches may be dug at suitable intervals depending on slope. This will intercept run off and help infiltration. In the south western region (Bankuara, Purulia, Birbhum) the major soil is laterite red loam having moderately heavy sub soil. The size of the contour trench should be sufficient to intercept at least 12 hours continuous run off. Staggered contour trenches with intermediate spaces are more effective than continuous contour trenches. The dug out soil is neatly piled the shape of a bundh.

In the agricultural fields, contour bundhs are erected. Spillways are provided in staggered manner to drain out excess water. Please see Fig. 4.3

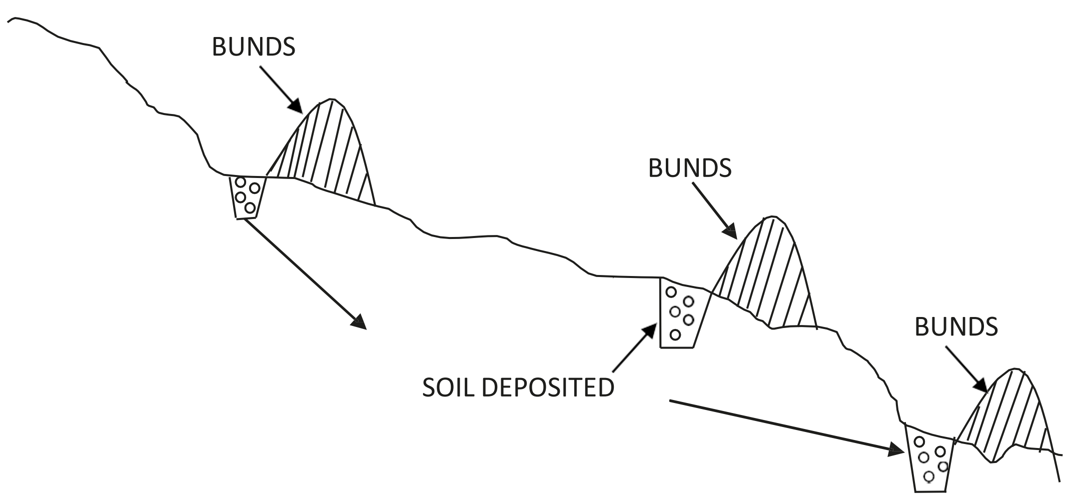


Fig.4.3. Bunds to Control Run Off Flow

4.7.3. Vegetative Measures:

(Source: Soil conservation by Hough Hammond Bennet ; Soil Conservation Manual of WB Forest Directorate))

Soil completely covered with vegetation is in an ideal condition to absorb moisture and resist the inroads of erosion, provided the cover is continuous and the soil is well penetrated with roots. Under such conditions, erosion is limited to a normal, harmless rate. Close-growing vegetation serves to reduce or eliminate direct impact of rain on the soil. In open forest areas, species with low crown like Kaju, Akashmoni, Mahua , Neem etc may be planted. Growth of grass need be encouraged. Perennial shrubs like Croton, Indigofera, Zizyphus etc. may be raised. In fact, shrubs are more effective to check erosion than trees. Even on steep slope, soil erosion is minimum in tea gardens with thick tea crop.

4.7.4. In agricultural land, erosion promoting and erosion retarding crop may be planted in alternate strips. Maize, Bazra, potato etc are erosion promoting crops, whereas legumes (pulses) are erosion retarding crops.

4.7.5. In the pasture land, rotational and regulated grazing need be practiced.

4.7.6. Rill Erosion – Rills should be closed by ploughing the land. Other measures prescribed for sheet erosion need be adopted.

4.7.7. Gully Erosion – Principal steps of control measures are given below. The measures in detail will be discussed in subsequent lessons. The major steps are

- To arrest water from coming into gullies. This is done by cutting diversion drains, catch water drains or ring bundhs.
- To smoothen the slope of gully head. It is done by cutting in slpoe of 1 in 2. The slope is grass sodded or pitched with stone masonry.
- To check the velocity of water flowing over the gully. For shallow gullies, this is effectively done by raising brushwood dams. Small barriers with thickly placed branches of Vitex negundo, Ipomea supported by live posts etc may be raised.
- To control velocity by constructing engineering structures. Rock check dams are constructed in small gullies.
- Storage in lower reaches. Earthen dam is constructed at lower reaches for storage purpose. It checks the velocity of water and arrests the soil. Earthen dams are provided with spillways.

Lesson 5 1 hour

Lesson Plan:

Objective:

- To study vegetative measures of conservation like Contour Cultivation and Strip Cropping.
- To study the engineering measures - contour bunding, graded bunding and Contour stone wall.

Backward Linkage:

- Concept of Runoff and water erosion of soil dealt with in Lesson 3 and 4.

Forward Linkage:

- During tour the trainees may be shown sites demonstrating contour cultivation and contour / graded bunding.
- Conservation measures covered in subsequent lessons

Training materials required:

- Copy of lesson 5 to be circulated beforehand.

Allocation of time:

- Contour ploughing and cultivation –5mts
- Strip cropping – 5 mts
- Vegetative Checks or Barriers – 5 mts
- Contour bunding –20 mts
- Graded bunding – 10
- Contour Stone wall -5 mts
- Discussion/miscellaneous –10 mts

Soil and Water Conservation Measures

5.1. Vegetative Measures

Under this topic some farming methods suitable for lands of moderate slope will be discussed. The farming methods, namely, **contour ploughing, strip cropping** etc are effective conservation practice on slopes. They all work on the same principle which is described below.

5.1.1. Principle

Water flowing down a denuded slope gathers both volume and speed as it moves. As a result, the erosive power of runoff increases with the length of the slope over which it flows. In the practices mentioned above, the furrows, or strips, in effect, divide a long slope into a series of shorter ones, and thus check the downhill flow of water. Consequently, the capacity of runoff to pick up soil particles and carry them in suspension is reduced. The furrows or strips also desilt the water flowing over them and enhance infiltration of water into the ground.

5.1.2 Contour ploughing and cultivation

Contour ploughing is the practice of ploughing across a slope following its elevation contour lines. When plough furrows and planter furrows run uphill and downhill, they form natural channels in which runoff accumulates. However, furrows or pits along contour lines create a water break which reduces the formation of rills and gullies during times of heavy water run-off; which is a major cause of top soil loss and soil erosion. The water break also allows more time for the water to settle into the soil.

In contour ploughing or cultivation

- The pits or furrows made by the plough run perpendicular rather than parallel to slopes,
- Furrows curve around the land and are level.
- Negative effects associated with soil erosion such as reduced crop productivity, worsened water quality, lower effective reservoir water levels, flooding, and habitat destruction are considerably reduced.

In regions of low rainfall, the primary purpose of contour farming is to provide maximum conservation and distribution of rainfall, in humid regions; on the other hand, the primary purpose is to reduce soil loss by erosion.

5.1.3 Strip cropping – Strip cropping consists of a series of alternate strips of various types of crops laid out so that all tillage and management practices are performed across the slope or on the contour. In strip cropping ordinary farm crops are planted in relatively narrow strips, across the slope of land, and are so arranged that strips of non-erosion-resistant crops are always separated by strips of close growing, erosion-resistant crops.

5.1.3.1 Types of strip cropping - The three general types of strip cropping are

- Contour Strip Cropping – It consists of a layout where strips are planted closely on the exact contours with the crops following a definite rotational sequence.
- Field Strip Cropping – It consists of strips of a uniform width placed across the general slope, but not necessarily on the exact contour.

- Buffer strip cropping – It consists of strips of some grass or legume crop laid out between contour strips of crops in the regular rotations. The buffer strips may be even or irregular in width.

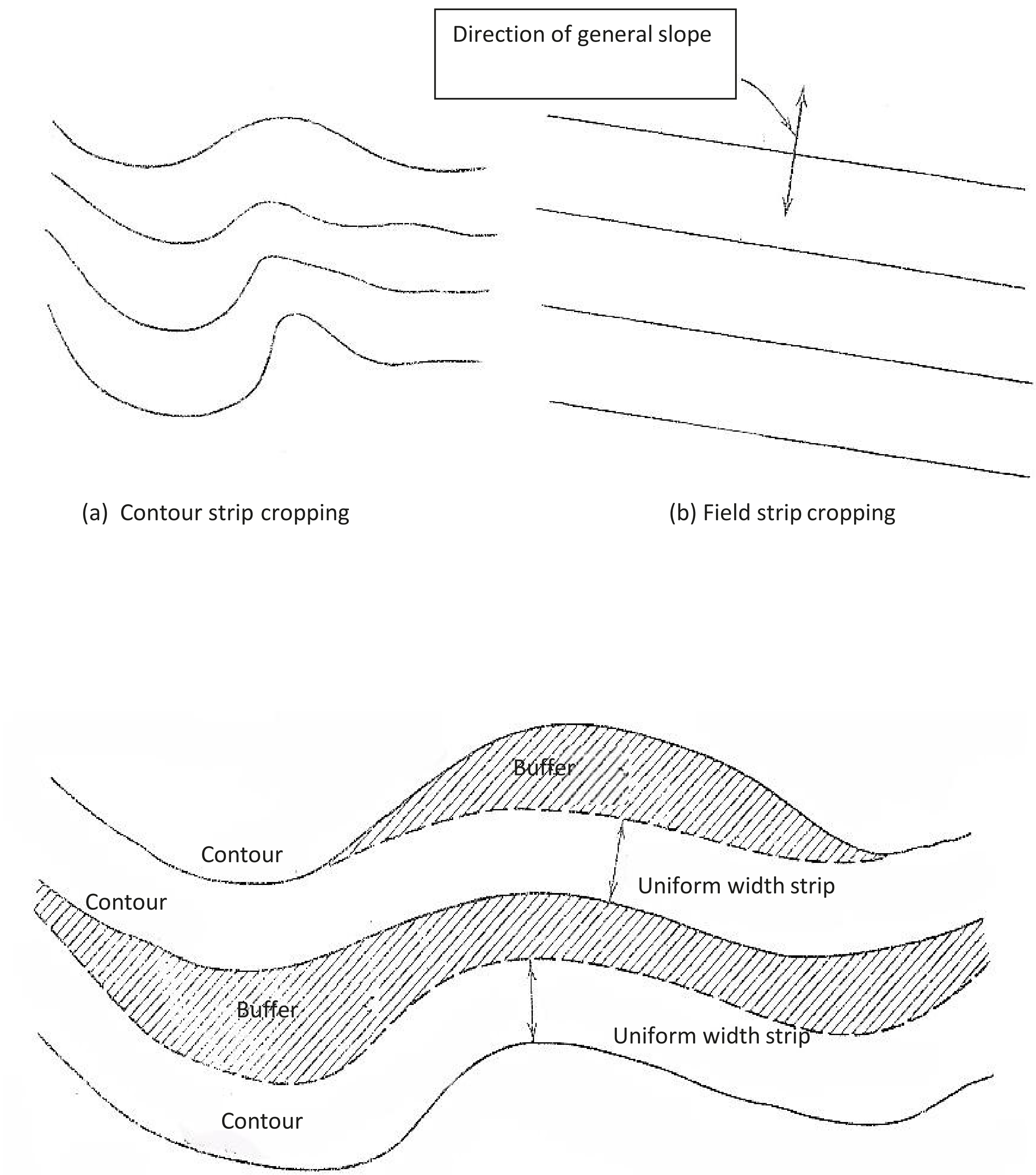


Fig.5.1 Three types of strip cropping: (a) contour (b) field, and (c) buffer.
(Redrawn from Soil and water Conservation Engineering by Richard K Frevert et.al)

5.1.4 Vegetative Checks or Barriers

Vegetative barriers are narrow, parallel strips of stiff, erect, dense grass hedges, or suitable shrubs, planted close to the contour.

5.1.4.1 Purposes

Vegetative barriers control soil erosion and conserve water in the following manner.

- can retard and reduce surface runoff by promoting detention and infiltration.
- can divert runoff to a stable outlet.
- can trap sediment, and facilitate benching of sloping cropland.
- can improve the efficiency of other conservation practices, like contour farming.

5.1.4.2 Function

Coarse, stiff, hedge-forming grasses can withstand high water flows that would bend and overtop finer vegetation. They retard flow velocity and spread out surface runoff. Reduced velocity prevents scouring, causes deposition of eroded sediment, and lessens ephemeral gully development. Vegetative barriers can disperse flow where water enters other types of conservation buffers.

5.2 Engineering Measures

We now describe some of the engineering measures that are in practice for the purpose of soil and water conservation. The problem related to runoff and accompanying soil erosion becomes more prominent and acute as slope of the ground being dealt with increases. On flat land or terrain of gentle slope, a good vegetation cover alone can contain runoff within tolerable limits. However, where we deal with grounds of steep gradient or where grounds of gentle slope are located in a heavy rainfall zone, runoff becomes so high that vegetative measures alone cannot arrest the soil erosion and water loss. In such cases of high runoff, engineering measures are taken recourse to, or more ideally, a judicious combination of engineering and vegetative measures is adopted.

5.2.1 Contour Bunding

It is a series of mechanical barriers across the land slope to break the slope length and also to reduce the slope degree wherever necessary. Contour Bunds are constructed along contours or with permissible deviations from contours.

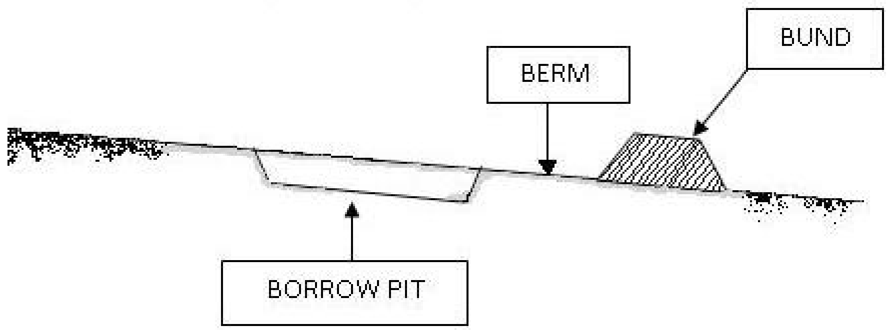


Fig. 5.2 Contour Bund

5.2.1.1 Function

In rolling (slope less than about 6%) and flatter lands with scanty and erratic rainfall contour bunding is practiced to intercept the runoff by a series of parallel embankments running along contours. To achieve better results, it is necessary that the land between the bunds is given treatment like contour cultivation which is favourable to moisture conservation. It is also necessary to have arrangement for removal of excessive runoff resulting from high intensity storms.

5.2.1.2 Suitable Soil

All types of relatively permeable soils, e.g alluvial, red, laterite, brown soil, shallow and medium black soil, except the clayey or deep black cotton soil are suitable for contour bunding.

5.2.1.3 Spacing of Contour Bund

The main criterion of spacing of contour bund is to intercept the water before it attains the erosive velocity. The spacing is determined by many factors like slope, soil, rainfall, cropping programme, conservation practices etc.

Ramser's Formula- Taking into consideration the factor of only slope, C.E Ramser established the following general equation. The equation is based on field observations and experiments for sub-humid areas and soils with good infiltration rates.

$$\mathbf{VI} = 0.\text{�}\frac{\text{�}}{\text{�}} + \text{�}$$

Where, VI = vertical interval in metre between two consecutive bunds; and

S = degree of slope in percent.

As much as 25% extra spacing can be provided above the mean VI in soils having high infiltration and permeability. Again a decrease in spacing to the tune of 15% may be done where soils are of low rates of infiltration or permeability, particularly when coupled with unfavourable cropping conditions.

5.2.1.4 Grade of contour bund

Contour bunds are made on same elevation, i.e. on contour and therefore the **grade is zero**. However, in the field, given the undulations the contour bunds cannot be laid on exact contour. Some **deviations** are likely to occur and these deviations lead to uneven impounding of water. This may result in less storage capacity of the bund as well as may increase the potential danger of breach.

5.2.1.5 Cross-section

The cross section of the bund defines the height, and the top and bottom width. The shape of the bund is trapezoidal (two opposite lines of the quadrilateral are parallel and the other two are not).

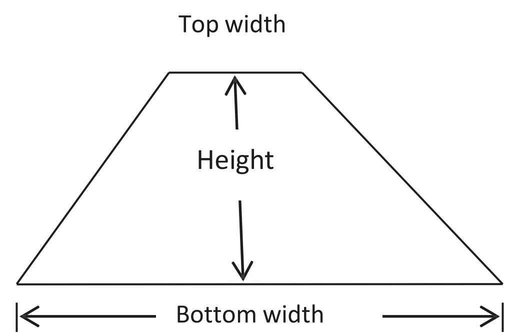


Fig. 5.3

Cross section of the bund

Cross-sectional area = Ba� �v� ���� ��� ��� / � **X height**

5.2.1.6 Height of the Bund

The height of the bund is governed by the following factors.

- Depth of water to be impounded (FSL)
- Design depth of flow over weir (HFL over the sill)
- Freeboard
- Rate of infiltration in soils (lesser the rate, more is the depth of water impounded)
- Vertical Interval (more the VI, more the depth of water impounded)

An illustrative section of contour bund is shown below for 30 cm depth of impounding (usu practice in many states)

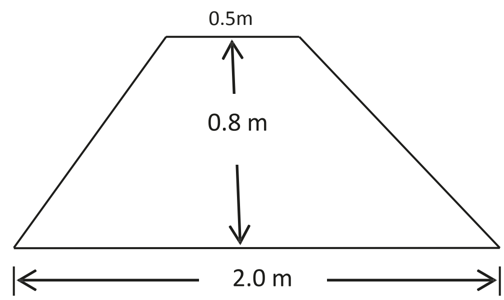


Fig.5.4
A typical section of contour bund

- Designed depth of impounding = 30cm
- Depth of flow over the outlet (an outlet or weir is provided with bund to allow pas of excess water) = 30 cm
- Freeboard (distance between the designed HFL and the top of the bund) = 20 cm.
- Given the above designed plan, the height of the bund comes to 80 cm.
- With top width of 50 cm, height of 80 cm, and bottom width of 2 m, the side slope works out to approximately 1:1.
- The cross sectional area works out to 1 sq.m.

The cross sectional area of 1 sq. m for an arbitrary depth of impounding of 30 cm is usuall adopted.

5.2.1.7 Contour bund to store runoff from 24 hour rain storm of a given frequency

Ideally, a contour bund should be designed so as to store runoff expected from the ind bunded area. It is thus necessary to know how to calculate the storage capacity of a c bund.

Please see the Fig. 5.5. The runoff volume of from one metre wide strip will be equal to

$$Q_v = \frac{R_e}{100} \text{ x HI}$$

Where Q_v = runoff volume in m^3;

HI and VI are related by the following formula:

$$HI = \frac{VI}{Slope\ (\%)} x100$$

The storage capacity of the bund, assuming it to be a triangle is obtained by the following equation (neglecting the minor effect of the side slope of the bund)

$$Q_c = \frac{W_s}{2} \times h$$

Where Q_c = capacity of contour bund 1 metre long in m^3;

W_s = water spread length in metre impounded by bund

H = depth of impounding in m near the bund.

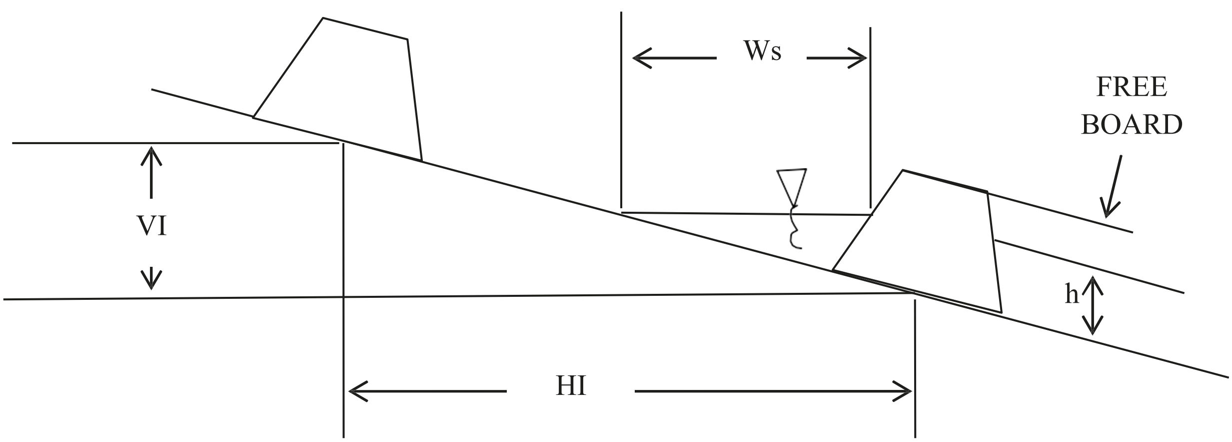


Fig.5.5, Determination of height of Contour bund
(Redrawn from: Manual of Soil & Water Conservation practices by Gurmel Singh et.al)

Equating Qc = Q_v ,

$$\frac{W_s}{2} \times h = \frac{R_e}{100} \times HI,$$

Or, h = $\frac{R_e}{50}$ x ��/�

Now from the properties of plane geometry,

��/� = ��/h

Substituting this value of ��/� in the previous equation,

h = $\frac{R_e}{50}$ x ��/h

or,

$$h = \sqrt{\frac{Re \times VI}{50}}$$

Thus using the above equation the height of impounding water h can be determined for 10 years frequency or any other frequency, provided R_e can be estimated. One has to add to this value of h (i) depth of flow over the outlet and (ii) freeboard of 25% to determine the height of the bund. Once the height is known, then taking minimum top width as 50 cm and side slopes of 1:1, the bottom width can be found out.

5.2.1.8 Construction

Bunds are constructed out of earth excavated from borrow pits 2.5 m wide and 0.3 m deep cut at a distance of 3 m from the toe of the proposed bunds. These borrow pits are taken on the upstream side of the bund. The width of the borrow pits can be changed without changing the depth as per requirement of the volume of earth work to make the bund.

5.2.1.9 Surplussing Arrangement

To protect the contour bund from breaching, masonry outlet structures which can drain away excess water, are constructed in the lowest spaces in a holding where due to deviation (from contour) of the bund to conform field boundary, stagnation of water takes place in excess of 0.3 m (depth of impounding) and requires to be drained rapidly.

5.2.2 Graded Bunding

Graded bunds or graded terraces or channel terraces are laid along a pre-determined longitudinal grade instead of along contour.

5.2.2.1 Function

Graded bunds consist of constructing wide and relatively shallow channels across the slope very near to contour ridges and at critical intervals. These terraces act primarily as drainage channels. They drain the excess runoff water with a mild and non-erosive velocity.

5.2.2.2 Suitable site

Graded bunds are adopted in areas where annual rainfall exceeds 80 cm and particularly in clayey soil (soil with poor infiltration) even with lesser rainfall.

5.2.2.3 Location of outlets

The foremost factor to be considered in field planning is the most desirable location of the outlets. Short terraces with a number of outlets in natural water courses are preferred to having long terraces and a single outlet.

5.2.2.4 Vertical Interval

The vertical interval and the horizontal spacing of the graded bunds may be designed in the same way as the contour bunds.

5.2.2.5 Grade

In general, a grade of 0.2 to 0.4% (longitudinal grade) is provided depending on the soil type. In permeable soils, the grade may vary from 0% at upper end to 0.5% at the outlet end. In case of impervious soils, the grade may start from 0.2% at the upper end and end up to 0.4% at the outlet. It is customary to change the grades at intervals of 100 to 150m. For example, a 400 m long terrace may have 0% grade for the first 100 m, 0.1% grade in the next 100 m, 0.2% in the third 100 m, and 0.3% in the last 100 m. As regards selection between uniform and variable grade, the choice depends on which will provide better alignment.

5.2.2.6 Cross section

The main prerequisites of suitable cross-section are (i) ample channel capacity and (ii) flat side slopes to permit farming operations without causing damage to cross section. Usually the channel depth of a settled terrace from the bottom of the terrace to the top of the ridge should be at least 0.45 m. Normally, terraces are made a minimum of 1sq.m in cross section.

5.2.3 Contour Stone Wall

Contour stone wall is constructed across the hill slope with cut stones of size around 20 cm. The function of the stone wall is to intercept runoff, and thus retard soil loss and conserve soil moisture. They are constructed in lands having slopes between 10 and 16% and above. Spacing ranging from 10 m to 30 m between two successive stone walls can be adopted depending upon slope of the terrain.

5.2.3.1 Construction

A shallow foundation trench is dug along contour and stones are packed directly in the foundation and the superstructure to form the wall. A longitudinal slope of 1 in 500 or 0.2% is provided towards the safe outlet. The stones should be properly interlocked to make the wall stable. Each stone wall must end in an outlet either natural or artificial. The soil obtained out of excavation is used to form small bund on the upstream side. The bund may be planted or sown with proper vegetation to add to the stability of the wall.

Lesson 6

Time 1 hour

Lesson Plan:

Objective:

- To study engineering measures of conservation like Contour Trench and Earthen Dam.

Backward Linkage:

- Concept of Runoff and water erosion of soil dealt with in previous lessons.

Forward Linkage:

- During tour the trainees may be shown sites demonstrating contour trench and earthen dam.
- Conservation measures covered in subsequent lessons

Training materials required:

- Copy of lesson 6 to be circulated beforehand.

Allocation of time:

- Contour trench –15mts
- Earthen dam – 25 mts
- Discussion/miscellaneous –10 mts

Engineering Measures (Continued)

6.1 Contour Trenches

This is a common conservation measure adopted in forest plantation and eroded forest lands having wide range of slope. Contour trenches are shallow excavated trenches along a uniform level, that is, along contour, across the slope of the land in the upper portion of the catchment. Bunds are formed on the downstream side of the trenches with material taken out of trenches. The object is to create more favourable moisture conditions and accelerate the growth of the plants. Please see Fig.6.1 for a typical section of a contour trench.

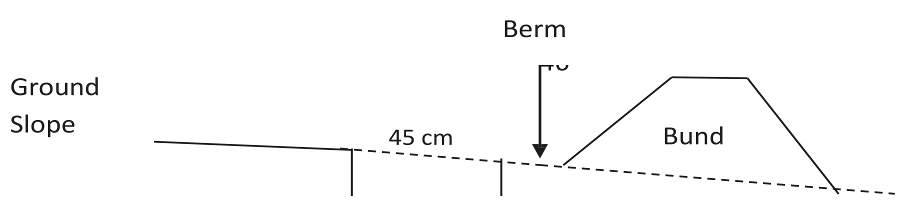


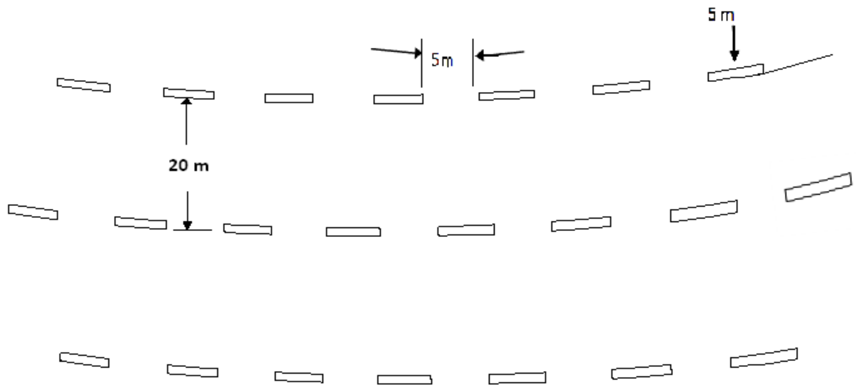
Fig.6.1 Typical section of a trench

6.1.1 Function

Contour trenches break the ground slope and thus reduce the velocity of the runoff . At the same time the trenches impound part of the rain water and capture part of the soil that is carried by the runoff. The rainwater infiltrates the soil and enriches the ground water storage and soil moisture, particularly in the middle and lower sections of the catchment. Where the lower fields are bunded these contour trenches also protect the bunds from being breached due to runoff from the upper portion of the catchment. Contour trenches are beneficial in all terrain regardless of slope and rainfall, but are particularly useful in low rainfall regions and where major part of rain is lost as runoff, that is, infiltration is low because of lack of vegetation or topographic features.

6.1.2 Alignment and Dimensions

Contour trenches are dug along contours. They may be continuous or interrupted. However, it is advisable to have interrupted trenches, as in case of wrong alignment of contour lines, a continuous trench excavated along such wrong alignment may virtually act as a nala or an easy outlet of the runoff. The interrupted trenches are dug in staggered manner. Please see a typical alignment of staggered trenches in Fig.6.2. Staggered trenches are short trenches, 5 to 10 metres long (in South West Bengal forests, normally 5 metres long trenches are prescribed) laid in rows along contours with interspace between them. Usually, between two 5-metre long trenches in a row, an interspace of 5 metres is left (Please see Fig. 6.2). The trenches in successive rows will be staggered in such a manner that the interspaces in the upper row are directly above the trenches in the lower row. It ensures that even though the trenches are not continuous, runoff from any part of catchment area cannot move down without being intercepted by the trenches. The optimum spacing or the distance along ground between two successive rows depends on the slope and the rainfall. Usually, in South West Bengal forests, the rows are laid 1 chain or 20 metres apart. The section of the trench may be trapezoidal or square depending on the nature of the soil. In south West Bengal forests, the trench section of 45cm x 45 cm is prescribed..



Distances are not upto scale

Fig.6.2 Alignment of staggered trenches

6.2 Earthen Dam

Earthen dam, a common water harvesting structure, harvests the runoff water and arrests soil erosion in the lower section of a gully.

6.2.1 Benefits

- Arrests silts coming from the upper section of the catchment
- Recharges ground water
- Provides water for agriculture, pisciculture and domestic purposes.

6.2.2 Selection of site

- Earthen dams are constructed across the gully where the slope is easier and the sides are more stable.
- From economic point of view, the site should provide large storage volume with minimum fill of earth. This condition is generally satisfied where the valley is narrow and will permit a large deep basin.
- While site of shallow water is to be avoided, the desirable site at a narrow valley should primarily have easy slope and stable side embankment.

6.2.3 Types

There are three types of Earthen dam, depending on the types of earth fill –

(1) Simple embankment type constructed of relatively homogeneous soil material which is keyed into an impervious stratum (Please see Fig. 6.3)

(2) Core type of design utilizing within the dam a central core wall of highly impermeable or puddled soil materials extending from above the water line to an impermeable stratum in the foundation (please see Fig.6.4);

(3) Diaphragm embankment type, which uses a thin wall of concrete or wood to form a barrier against seepage through the fill.

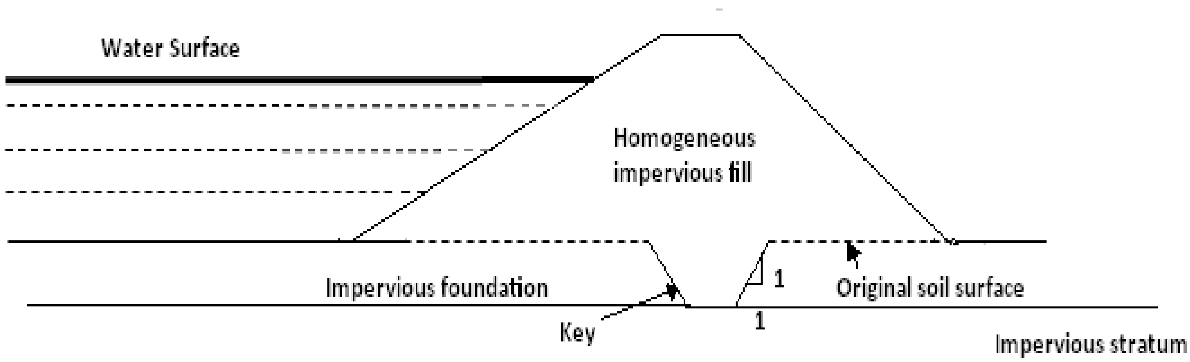


Fig.6.3

(Redrawn from Soil and Water Conservation Engineering by R.K.Frevert et.al)

6.2.4 Foundation

The most satisfactory foundation is one that consists of or is underlain at a shallow depth by a thick layer of relatively impervious consolidated material. Such foundation causes no stability problems. It is sufficient to remove the top soil and scarify or disk the area to provide a bond with the material in the dam. However, when the foundation consists of pervious materials at or near the surface, and the rock or impervious stratum is at a depth, a cut-off or key trench joining the impervious stratum in the foundation with the base of the dam is needed (please see Fig.6.3 and 6.4).

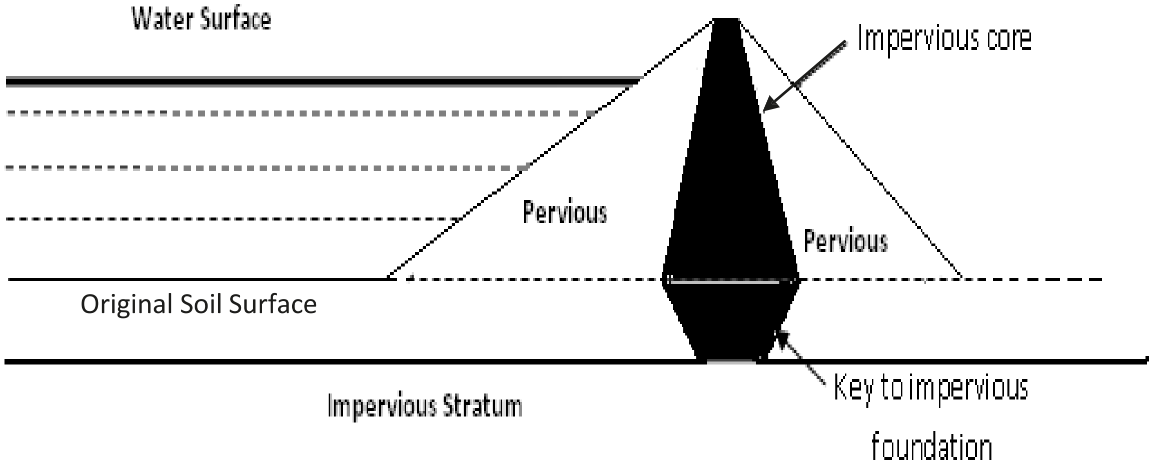


Fig.6.4

(Redrawn from Soil and Water Conservation Engineering by R.K.Frevert et.al)

6.2.4.1 Key Trench

A key trench is a trench cut parallel to the centre line of the dam to a depth that extends well into the impervious layer. The trench is extended into and carried up the abutments of the dam as far as the pervious material exists that might allow seepage under the embankment. **The trench should have a bottom width of not less than 1.2 metre** and adequate to allow use of equipment necessary to obtain proper compaction. **Its side should not be steeper than 1:1**. The trench should be filled with successive thin layers of relatively impervious material, each layer being thoroughly compacted at near optimum moisture condition before the succeeding layer is placed. Any water collected in the trench should be removed before back fill operations are started.

6.2.5 Core wall

It is a centrally provided impervious wall in the dam (Fig.6.4). It checks the flow of water across the section of the dam. Generally, the core wall extends from the ground level to High Flood Level (H.F.L) or top level of the dam. It is generally made of puddle clay.

6.2.6 Borrowpit

Borrow areas within the reservoir area should be given first preference, followed by those located on the valley sides close to the proposed embankment. Borrow pits in the reservoir have the advantage of increasing the upstream storage capacity and require no remedial work once the dam is completed. Borrow pits should never be located close to the downstream toe area of the dam, the spillway or outfall or in any area prone to erosion. Borrow pits located some distance from the dam site will increase construction costs, wear and tear on plant and machinery and the timing of the construction.

6.2.7 Earth Fill

Earth fill material should be preferably impervious and have enough body to remain stable under the loads imposed. A sandy clay soil is most desirable. In the event of variation in the fill material, the more impervious material should be placed in the upstream two-third and the more pervious be used in the downstream one-third. Earth fill material should be free from sod, roots, brush etc. The fill material should be spread in layers not exceeding 20 cm in thickness, and then compacted at optimum moisture until maximum density is achieved.

6.2.8 Embankment Top Width

(Source: Manual of Soil and water Conservation Practices by Gurmel Singh et-al.)

Normally, the top width of the embankment (W) is determined by the equation

$$W = \frac{}{5} + 3$$

Where, W = top width or width of crest in metre;

and Z = Height of embankment above the stream bed in meter.

Recommended top width for earthen embankments.

Height of dam (m)	Top width (m)
Under 4	3.25
4 to 6	3.50
6 to 8	3.75

Prescriptions of FAO Manual on Small earth dams
(Source: http://www.fao.org/docrep/012/i1531e/i1531e.pdf) in this regard are as follows.

The crest width of an embankment is selected taking into account the size of the dam, the catchment characteristics and topography and whether road or other access will be required across the embankment. In all cases, the embankment crest width should be designed to allow the safe passage of plant and equipment to be used in the dam construction and **should be no less than 2 m wide.** Alternatively, and most appropriate to small dams exceeding 5 m in height, a standard crest width of 3 m can be adopted or the formula below can be used:

W (in m) = 0.4Z + 1

where W is the crest width and Z is the maximum height of the dam in metres. Always adopt the widest crest width possible (and flatter embankment slopes) where foundations or construction materials are suspect. To reduce erosion, all crests should be given a 2.5 percent crossfall to drain rainwater to the reservoir via the upstream slope of the embankment.

6.2.9 Side slopes of embankment

The side slopes of an embankment depend primarily on the stability of the material in the embankment. The greater the stability of the fill material, the steeper could be the side slopes.

Recommended side slopes for earthen dams are as follows:-

Soil type	Up stream	Down stream
1) Clayey gravels, silty gravels, gravel sand clay mixtures and gravel sand silt mixtures.	2 .5 : 1	2 : 1
Sandy clays, silty clays, lean clays, inorganic silts and clays.	3 : 1	2.5 : 1
Inorganic clays of high plasticity and inorganic silts	3.5 : 1	2 .5 : 1

6.2.10 Free Board

Free board is the added height of the dam provided as a safety factor to prevent wave or run off from storms greater than the design frequency for topping over the embankment. It is the vertical distance between the elevation of the high flood-level and top of embankment after all settlement has taken place. Normally, 15% is adopted as free board. According to FAO Manual on Small earth dams (Source: http://www.fao.org/docrep/012/i1531e/i1531e.pdf), Freeboard for small dams should never be less than 0.5 m with 0.75 m to 1.0 m preferred.

6.2.11 lowance for settlement

Settlement includes the consolidation of the fill materials and that of foundation materials due to the self-weight of fill materials and the increased moisture caused by the storage of water. Settlement or consolidation depends on the character of the materials in the dam and foundation and on the methods and speed of construction. The design height of earthen dam should be increased by an amount equal to 5% of the design height.

6.2.12 Seepage /Saturation Line

The characteristics of the soil materials in both the foundation and the fill affect the degree of seepage that passes through and under the dam. All earthen structures that impound water develop a seepage line that is essentially the line of saturation. As water is impounded on the upstream side, there is a head of water equal to the height of water stored. Under this head, water seeps in and percolates through the dam, and as this percolation of water proceeds, it loses head enroute, till the head of water meets the base of the dam at some point. The head of water proceeds along what is called seepage or saturation line. It is the line of demarcation between saturated soil and unsaturated soil in the dam section. For stability of dam , it is essential that the saturation line meets the base within the dam section.

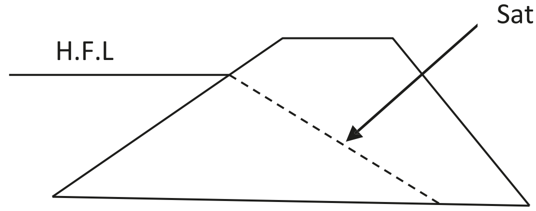


Fig. 6.5 Saturation Line

6.2.13 Stone Pitching

Stone pitching is done on the upstream sloping face of the dam. Pitching extends from the natural ground surface to about one metre above the H.F.L. It bears the brunt of water pressure and protects the upstream slope. Thickness of pitching varies from 30 cm to 60 cm. Pitching is laid over a layer of murrum or gravel of 15 cm thickness.

6.2.14 Sod

It is a grass turf maintained on the downstream sloping face of a dam to protect it from heavy rainfall etc.

6.2.15 Earthwork Computation

(Source: http://www.fao.org/docrep/012/i1531e/i1531e.pdf)

The volume of earthwork can be estimated as follows:
V = 0.216 HL (2C+HS)
Where:
V is the volume of earthworks in m3.
H is the crest height (FSL+ freeboard) of the dam in m. (FSL means Full Supply level or H.F.L)
L is the length of the dam, at crest height H, in m (including spillway).
C is the crest width in m.
S is the combined slope value. For example, if the slopes of the embankment are 1: 2 and 1:1.75, S = 3.75.
This formula is based on real equations for the cross-section and longitudinal section with the inclusion of an empirically developed adjustment factor. Again, it presents an idealized solution and as

for the capacity, the formula should only be used at the preliminary survey stage. The formula is, however, reasonably accurate and if a general average figure is known for costs of earthworks, a guide cost for the total embankment can be derived.

6.2.16 Computation of Storage Capacity

(Source: http://www.fao.org/docrep/012/i1531e/i1531e.pdf)

Storage capacity is worked out as follows:

$$Q = \frac{LTH}{6}$$

Where:

Q is the storage capacity in m3 and should not exceed catchment yield in an average year.

L is the length of the dam wall at full supply level (FSL) in m.

T is the throwback, in m and approximately in a straight line from the wall.
H is the maximum height of the dam, in m, at FSL.
6 is a factor (conservative generally) that can be adjusted (to 5 or 4) with experience and local knowledge. All the above measurements can be determined by the use of a level or theodolite (or accurate GPS equipment) at the site, either in the form of a cross-section survey at the centre line of the proposed dam or, more accurately and with more time (but more useful where comparison of similar sites is involved), by a contour survey followed by a survey or estimate of the throwback.

6.2.16.1 The capacity estimated in this way is accurate to within about 20 percent. The formula considers the water volume to be an inverted pyramid with a triangular surface area (LT/2) and H/3 for the height/depth, and is a simplification of reality. With experience, one is able to judge fairly accurately how an individual valley will compare with such an idealized picture and, therefore, to adjust the resulting conclusions.

6.2.17 Advantages of earthen dam over masonry dam

(1). Its construction is easy, quick and less costly.
(2). IT can be constructed on any kind of foundation.
(3). It does not require many skilled labours.

6.2.18 Causes of failure of earthen dam

(1) Overtopping: - Earthen dams are designed for no overtopping and they might fail if water overtops it. Therefore it is important that the maximum flood level should be properly established.

(2) Wave erosion: - Precaution should be taken against it. Otherwise such erosion by waves may waken the section of the dam causing damage to it.

(3) Toe erosion: - Due to continuous seepage of water at the base, the dam may collapse due to formation of rill or sheet erosion. So, rock toe with filter drain may be provided, if necessary. The sides of bank should also be provided with bank protection.

(4) Piping or Seepage failure: - Piping takes place due to holes made by some animal which is dangerous for any dam. So necessary bank protection should be taken. Design should be such that compaction is more and seepage is less and necessary Toe protection should be taken.

(5) Slide of upstream slope: - Sometimes as water level goes down, the portion of the slope which was in contact with water slides down, causing collapse of dam.

(6) Downstream side slides due to seepage: - Protection against seepage should be taken.

(7) Failure of foundation: - Presence of sand at the foundation through which water passes can cause collapse.

(8) Failure due to earthquake

Lesson 7

Time 1 hour

Lesson Plan:

Objective:

- To study outlet works of earthen dam.
- To study nala bunding.
- To know some gully control measures

Backward Linkage:

- Earthen dam in lesson 6.

Forward Linkage:

- During tour the trainees may be shown sites demonstrating gully control structures and nala bunding.
- Conservation measures covered in subsequent lessons

Training materials required:

- Copy of lesson 7 to be circulated beforehand.

Allocation of time:

- Earthen dam – oulet structures –30 mts
- Nala Bunding – 10 mts
- Sunken gully pits, Silt traps – 10 mts
- Discussion/miscellaneous –10 mts

Engineering Measures (Continued)

Earthen dam (Continued)

(Source: FAO Manual on small earth dams at
http://www.fao.org/docrep/012/i1531e/i1531e.pdf)

7.1. . Outlet works - Spill way

The spillway is the most important outlet associated with a dam. It allows excess water to pass through and disposes it off safely. It is to be designed to accommodate the anticipated peak flood. It has to be a permanent structure that will not erode and is located at a level that allows for the required water depth and freeboard ascertained at the site selection and investigations stage. Critical items are the entrance width ‘b’ (dependent on the peak flood), the outfall (dependent usually on ‘b’ and the material the of spillway.

7.1.1 Catchment Area and Spillway Dimensions

A fairly accurate estimation of catchment area, either from an aerial photograph or a large-scale topographic map, is essential in the calculation of catchment yield and peak runoff (flood). Also essential are the hydrological data (mainly rainfall and runoff), topographical factors and the shape of the catchment. The maximum design capacity of the reservoir is directly related to the catchment yield multiplied by a design factor that has usually been derived locally from the history of other dams.

In the case where a series of small dams is built in a catchment,

- Consider the size of the catchment area for each dam to find the total catchment area above the dam under consideration;
- Do not take only the area between the dam under consideration and the one above it.
- It is to be assumed that the peak flood will occur when all the dams above are full and therefore presence of dams above will not have significant retardation or retention effects on the flood.

7.1.2 Catchment Yield

The catchment yield, 'Y', is based on the expected annual runoff from a catchment and is an important factor in assessing the feasibility of a dam and in determining the required height of the embankment.

It is estimated as follows (Source: http://www.fao.org/docrep/012/i1531e/i1531e.pdf):

- Where the average percentage of runoff is not known, use, as a guide, a figure of 10 percent of the mean annual rainfall for the catchment area. If more information is known, take the rainfall on a return period of 1 in 10 years as a guideline.
- Calculate the annual runoff for the catchment, in mm, based on the percentage determined above. This is 'Rr'.
- Measure the catchment area 'A' in km^2, upstream of the proposed embankment. Ignore any upstream dams (as these may already be full at the time of a flood event; refer paragraph 7.2)) and calculate the area of the whole catchment.
- The annual runoff for the catchment (the catchment yield in an average year), Y, in m3, is given by:

$$\mathbf{Y = Rr \times A \times 1\,000}$$

7.1.3 Peak Runoff

The **peak runoff** or peak flood is the **probable maximum flood (PMF)** to be expected from a catchment following a rainfall of estimated intensity and duration for a selected return period taking into account the hydrological characteristics of the catchment (Please refer to lesson 3) .

Often the relevant hydrological information is not available. Where the detailed hydrological information is unavailable, the **Rational Method** (**please refer to paragraph 3.2 of Lesson 3)**– based on catchment area and an assumed uniform rainfall intensity and runoff – is a useful tool for the estimation of peak floods on small catchments. The Rational Method is most appropriate for catchments under 15 km^2 and requires the planner to know the catchment area and the maximum daily rainfall. Other factors such as topography (especially the slope), the shape of the catchment and the vegetation cover may also require consideration. These are generally taken into account in the calculation of the 'Time of concentration'.

7.1.3.1 Where no detailed data are available

Where no detailed data except catchment area and rainfall figures are available, a very approximate peak flood estimate can be made by taking the highest daily rainfall figure for the catchment and assuming that all dams in the same catchment are 100 percent full, the ground is saturated and that 100 percent runoff will occur.

- For example, if a daily rainfall of 223 mm (I) fell on a catchment area of 19 km^2 (A), the estimated peak flood would be in the region of 49 m^3/s (= $\frac{\text{I in mm x A in sq km x 1000 x 1000}}{\text{24 x 60 x 60 x 1000}}$) over a 24 hour period.
- It is advisable to stay on the conservative side when using approximations or estimates for peak floods;
- 2-4 m3/s per km^2 of catchment area per 24 h period is a guide but this figure should always be adapted bearing in mind local topographic and climatic conditions.

(Source: FAO manual on small earth dams)

7.1.4 Spillway Width

Once the peak runoff or PMF (**Q_p**) has been estimated, the spillway width can be calculated using the formula:

$$\mathbf{Q_p = 1.7\, b\, D^{1.5}}$$

In the above formula -

- b and D are in m and Q_p is in m^3/s
- '1.7' is a factor derived for concrete ogee type crests and can vary up to 2.25 according to site conditions and factors of safety. 1.7 is generally used for spillways for small dams on small catchments.

- ‘b’ is the minimum width (‘breadth’) of the spillway and is calculated by introducing the values for Q_p (estimated using the options above) and $D^{1.5}$. It is assumed that b is large when compared to D and that the spillway channel will thus be rectangular.
- ‘D’ is the depth of the spillway at the crest and will comprise all or part of the design freeboard. D is normally in the range 0.75 m to 1.5 m for small dams and comprises the total freeboard.
- However, where wave action or backing up of floods may affect the dam, an additional ‘dry’ freeboard of up to 0.75 m. should be added to the figure above for safety reasons.
- Once all the other values are known, ‘b’ can then be calculated and the best option for varying depths, ‘D’, can be chosen.

The width ‘b’ is the minimum width for the spillway to accommodate the design flood. It assumes that there is no constriction downstream of the spillway. The width and depth may have to be adjusted to suit the local topography and spillway bed material later in the design process.

7.1.5 Guidelines

For grass spillways, the erosion hazard is an important consideration. Therefore,

- Grass spillway should be horizontal at its entrance, ideally with a concrete or masonry sill to level the entrance and control velocities and erosion.
- It can have a slight cross fall (but no more than 5 degree) across the spillway; and
- Must have a safe outfall to return floodwaters to the stream.
- Allowable flow velocities will depend upon depth of flow (and in turn affect the freeboard) and the floor material of the spillway.

Guidelines to follow are presented in the following Table 7.1. The guidelines assume that an earth spillway is level and grassed with good, mat-forming creeping grass. Calculations of minimum spillway width based on hydrological grounds (please see paragraph 7.1.4) should, be modified to meet these guidelines. It is always advisable to adopt the more conservative value – to thus increase spillway width – where dimensions vary.

Table 7.1

(Source: FAO Manual on small earth dams at http://www.fao.org/docrep/012/i1531e/i1531e.pdf)

Type of surface	**Sand to sandy**	**Sandy loam to sandy**	**Sandy clay**	**Light clay**	**Heavy clay gravel**	**Hard rock**

	loam	clay loam	loam		friable rock	
Max velocity (m/s)	0.30	0.60	0.75	1.00	1.25	1.50
Flow depth (m) at spillway entrance	0.15	0.30	0.50	0.60	0.75	1.50
Discharge (m3/s per m width)	0.05	0.20	0.35	0.60	1.00	2.50

7.2 Other outlet works (Source: FAO Manual on small earth dams at http://www.fao.org/docrep/012/i1531e/i1531e.pdf)

Trickle flow outlets are necessary where there would be perennial stream flow on grass spillways, as these will protect the earth spillway from the hazards of rills formed by a continuous low flow. The trickle flow can be passed out of the dam by either a drop-inlet overflow in the embankment or a trickle flow channel in the spillway. This may involve the use of reinforced concrete and /or masonry work.

7.2.1 Drop inlet overflows

A drop inlet overflow consists of a pipe (or pipes) installed at the time of construction and set to an upstream level just below spillway (full supply) level. It is of a diameter large enough to carry all but the flood flows. Depending on the design discharge, the pipe can either protrude directly from the wall (for smaller flows) or have an inlet chamber (for larger flows) located adjacent to the wall but designed to prevent vortex and possible erosion of the upstream face of the embankment. The idea is that the main spillway can be reserved for flood flows and problems of gullying will thus be avoided.

7.2.1.1 Please refer to Fig.7.1 which illustrates a drop inlet overflow showing its elevation and section. The pipe made of steel or concrete should be carefully laid, true to line and level. The pipe should be laid in a trench cut in original ground on the valley sides before the embankment is built. Steel pipes should be flanged and concrete pipes should have staunching rings (anti-seepage collars) to prevent seepage of water along the outside of the pipe. If stream flows are not known, the minimum diameters of pipe are as follows:

– 300 mm for very small catchments.
– 375 mm for catchments up to 5 km^2.
– 450 to 550 mm for catchments between 5 and 8 km^2

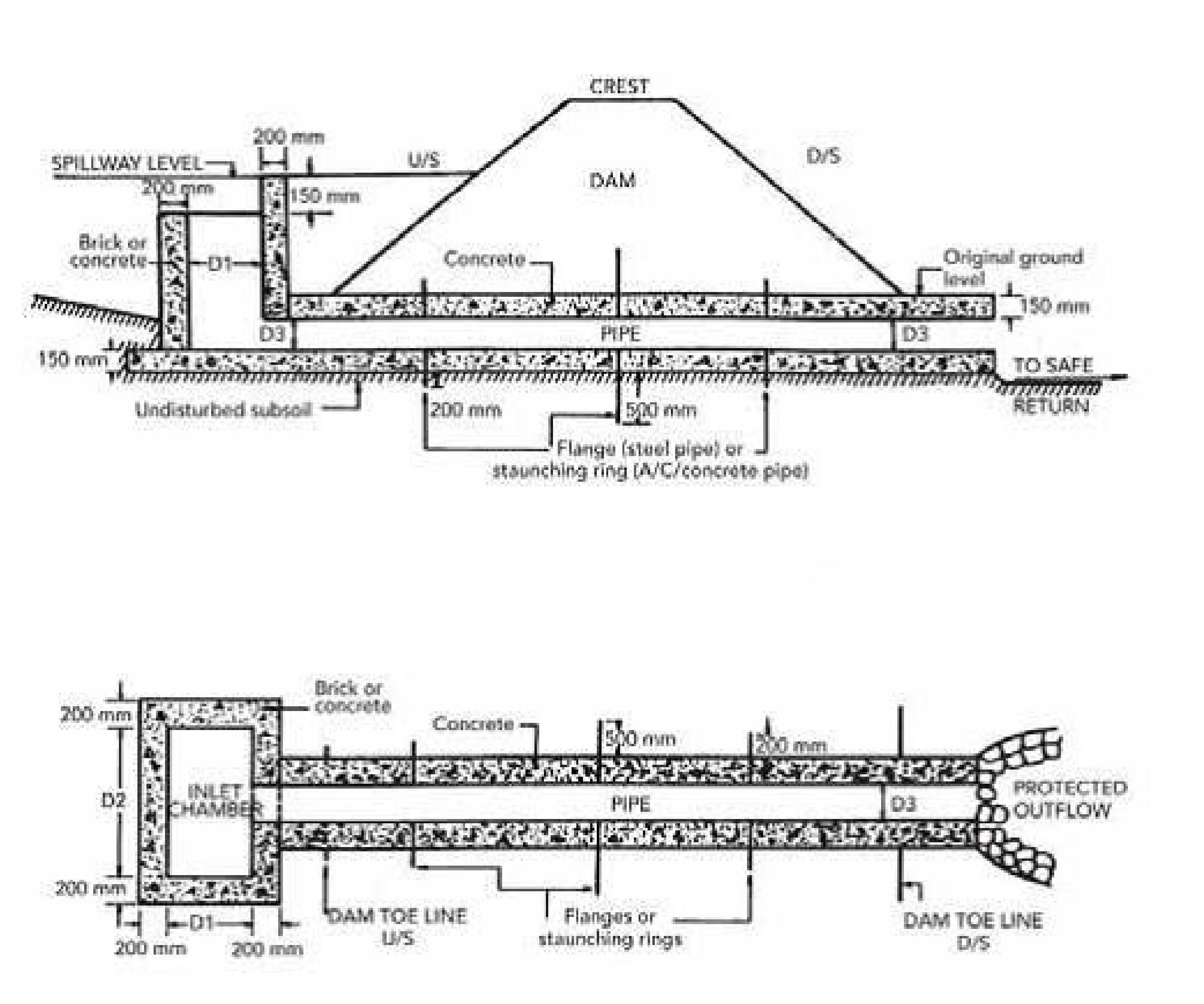


Fig. 7.1

(Source: FAO Manual on small earth dams at http://www.fao.org/docrep/012/i1531e/i1531e.pdf)

Please note that

- **Dimensions D_1 and D_2 depend on D_3.**
- **A gradient of 2% is recommended.**
- **The drop inlet overflow should be located at the other end of embankment to spillway.**
- **Brick wall of chamber is built 150 mm higher to suppress vortex.**

7.2.2 Trickle flow spillways (Source: FAO Manual on small earth dams at http://www.fao.org/docrep/012/i1531e/i1531e.pdf)

Where normal flows are small or a drop-inlet overflow was not installed at the time of construction, a trickle flow spillway can be constructed within the existing grass spillway(s). A well founded stone-pitched or brick-lined channel designed to carry average stream flow can avoid subsequent erosion of the main spillway. A concrete or masonry sill placed across the entrance and exit of the grassed spillway will also reduce risk of erosion as well as allowing for control of the full supply level in conjunction with a drop-inlet pipe. Maintenance (de-silting and repair works) may be required after major floods or at the end of each rainy season.

7.3 Training banks and spillway outfall (Source: FAO Manual on small earth dams at http://www.fao.org/docrep/012/i1531e/i1531e.pdf)

Whether the spillway be grass, rock, drop-inlet, or trickle flow, an essential requirement will be a safe return to flow downstream of the embankment. Please note –

- For any spillway the bends or constrictions to the channel must be avoided.
- Grass, and occasionally rock spillways, may require the construction of training banks (stone pitched if necessary) to guide the flood flows away from the steeper slopes and the downstream toe of the dam.
- A maximum slope of about 5 percent for the return should be the goal and this should only be exceeded where rock is to be used for the return.
- The actual outfall should be designed to be non-erosive and, as a rule of thumb, the final width should be 1.5 to 2 times the entrance width 'b' thus reducing velocities of flow to manageable levels.
- For drop inlet overflows the construction of a channel of brick or stone from pipe outlet should be sufficient and this can then be led to a safe dissipation point downstream.

7.4 Nala Bunding

Nala bunding means construction of bunds of suitable dimensions across a nala or gully with surplussing arrangement at suitable intervals to drain the water.

7.4.1 Function

- To hold runoff water to cause flooding of upstream area for a temporary period (days or weeks);
- To trap the silt carried by runoff
- To drain off water in a controlled manner;

7.4.2 Benefits

- Provides water in upstream area;
- Impounding of water facilitates percolation of water down the deeper layers of soil profile;
- Water is released from bunds with non-erosive velocity and is free from silt; before water acquires erosive velocity, it is intercepted by the next bund below in the catchment;
- The basin at the upstream side is enriched with silt deposited progressively and the process facilitates reclamation of gullied lands;
- Helps in recharging ground water.

7.4.3 Location

Bunds are useful in arid and semi-arid regions with low rainfall. Bunds should be provided from top of the catchment to the valley at regular intervals. They are suitable in nalas with slope less than 3.5%.

7.4.4 Execution

Execution of nala bunds comprises –

- Fixing the position of nala checks;
- Laying out foundation after fixing the different points such as full storage level, HFL and cut outlets;
- Excavation of required puddle trench;
- Construction of core wall;
- Excavation of cut out
- Digging and filling of embankment portion;
- Construction of earthen embankment over core wall;
- Stone pitching on the upstream side of the bund.

7.5 Sunken Gully pits

(Source: www.apforests.gov.in/Circulars%20Vol%20I/Circular%20No%205.htm)

Sunken Gully Pits are trenches excavated across the Gullys of 1st order and 2ndorder streams in order to impound water in the trenches. (Note: The 1st order stream is one which begins at the upper slope of the watershed area and generally the depth of it is quite shallow whereas the 2nd order stream is the confluence of two 1st order streams.) These pits serve as water percolation tanks. The dug out earth may be kept in the trapezoidal shape at a distance of 50 cm (berm) from the trench giving a passage of water. Seeds of suitable species may be sown on the dug out earth. The frequency or the interval between two Sunken Gully Pits will depend on the slope – more the slope more the number of such Sunken Pits. De-silting of these Gully Pits at regular intervals is necessary.

7.6. Silt Traps:

(Source : http://www.wisegeek.com/what-is-a-silt-trap.htm)

Despite adoption of the best conservation measures, soil erosion to an extent is inevitable. This leads to the concept of having sediment retention structures. These structures do not stop erosion but trap the eroded soil before it reaches a water body. A silt trap, a sediment retention structure, is a designated area where water that is contaminated with suspended sediment as a result of construction activity or water runoff is contained. While the water is in the trap, the sediment can settle to the bottom of the trap until it can be removed. These devices can be made using silt curtains, silt fences or a series of shallow ponds or trenches across the slope of the channel to naturally filter the sediment from the water before it reaches a stream or clean body of water. Environmental protection efforts, such as the silt trap, are often seen in conjunction with mining or construction. Activity from these industries can result in the production of grain-size particles, stone dust and other components that create suspended sediment when caught up in water runoff during rainfall. As the rainwater carries these particles and other pollutants to streams, rivers and lakes, the suspended sediment can cause a serious issue for the fish and other wildlife that inhabit these waters. Using the laws of gravity and the physics associated with liquid suspensions, the trap allows the denser, heavy particles of the suspended sediment to drop out of the suspension by creating an artificial break in the current. These particles are easily picked up by water runoff moving with a certain amount of speed, but when the water's current is slowed by the silt trap, the heavier particles of sediment naturally drop to the bottom of the trap.

Lesson 8

1 hour

Lesson Plan:

Objective:

- To study various measures for river training.
- To study water harvesting.

Backward Linkage:

- Earthen dam in lesson 6; runoff in lesson 3.

Forward Linkage:

- During tour the trainees may be shown sites demonstrating river training works.

Training materials required:

- Copy of lesson 8 to be circulated beforehand.

Allocation of time:

- River training and methods of control –5 mts
- Revetment – 5 mts
- Spurs and groynes – 8 mts
- Retaining structures – concept and use – 5 mts
- Gravity wall – different types – 15 mts
- Water harvesting – concept and need – 4mts
- Farm pond – 8 mts
- Discussion/miscellaneous –10 mts

8.1. River Training

Erosion of river or stream banks occurs when the forces of flowing water exceed the ability of the soil and any vegetation present to bind together and resist detachment. The soil particles disaggregate and the bank of the river collapses. Under normal flow conditions a balance is struck as the bank geometry and the natural vegetation adapt to the regime. Most soil erosion occurs in rare flood events or in man- induced events when the increase in flow pattern upsets the balance. Three functions are balanced in a river system - erosion, transportation and deposition. In very general terms erosion takes place in the upper steeper reaches and deposition in the lower reaches but a river is a dynamic environment and all three mechanisms can be taking place in the same locality, but in different parts of the channel.

8.1.1 Methods of control

In theory, protection and stabilization of streambeds is achieved either by reducing the velocity of the flowing water or by increasing the resistance to erosion of the bank. In practice most measures involve increasing the erosion resistance of the bank and these fall into two main groups – revetments and spurs.

8.1.2 Revetment on Bank Protection:

There are three ways of revetment:-

(i) Protection of bank by vegetative cover either by turfing or sodding, low growth shrubs and willows is by far very effective cover. The method should be used if the slope is not subjected to high current.

(ii) Pavement of bank slopes by such materials which can resist quick erosion. Along with the pavement, the slope is given a temporary covering of brushwood or lumber mattresses, weighted down by stone. please see Fig 8.1

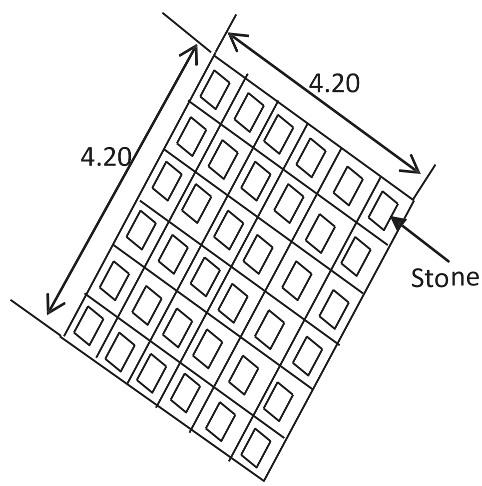


Fig.8.1. Brushwood structure with stone weights

(iii) When the current is very strong, protection is provided by stone revetment or by any other such device, say concrete, brick etc. Thickness of stone /concrete pitching may be kept at 30-40 cm. Please see Fig 8.2.

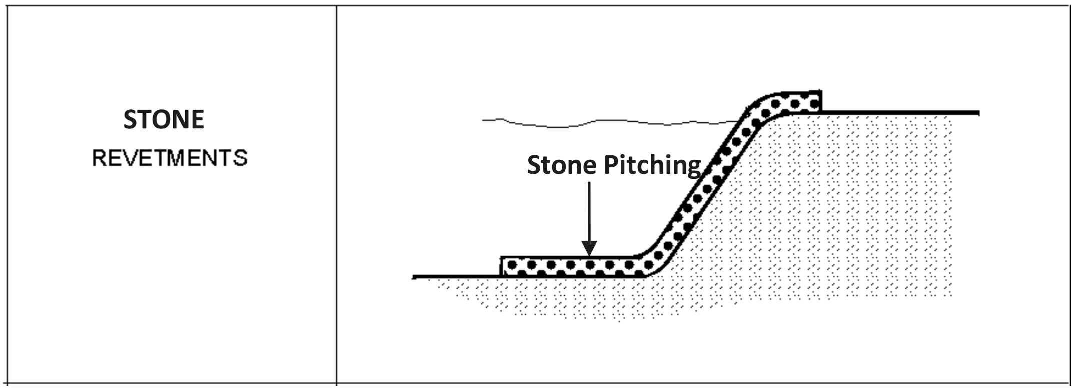


Fig.8.2.Revetment by stone

8.1.3 Spurs and Groynes

(**Source:** Methods and Materials in Soil Conservation- A manual by Jhon Charman).

Spurs and groynes are structures that project into the riverbed from the bank to prevent lateral erosion. The orientation of the spur in relation to the riverbank is important. If it is constructed at right angles (protection spur) it serves to protect the status quo. If it is inclined upstream (aggradation spur), it encourages sediment to accumulate in the area between successive spurs. If it is inclined downstream (deflection spur) it deflects the stream flow to the opposite bank. Please see **Fig 8.3**.The spacing of successive spurs is also important to prevent erosion of the bank between them. The separation distance is calculated using the following:

$D = \cot 15^0 * L = 3.73L$

Where: L = length of the spur

D = distance between spurs.

8.1.3.1. Spurs interrupt flow and therefore water velocities increase around them causing local scour. Design against scour is imperative if the structures are to survive for their intended design life. The structures should ideally be trenched into the stream bed to a depth greater than the predicted scour depth but this is practically often difficult. Alternatively a protective gabion apron should be laid on the streambed and incorporated into the structure to protect the toe.

8.1.3.2. Spurs or groynes are of two types –

- Permeable type – They permit the flow of water through them, while reducing the velocity of flow. They can be made with materials that are easily available, e.g. waste wood, tree branches, ropes, empty drums etc. The aim is to pose some kind of obstruction to water flow. They are very effective if the river is narrow and the current is strong, as they permit flow of water through them.

- Impermeable type- These spurs consist of impermeable embankment with easy slopes. They do not allow flow of water through them. They rather intercept the flow and protect the bank from the direct impact of water flow. Height of these spurs depends upon the amount of river training required, velocity of flow etc.

8.1.4 Retaining Structures

(Source: Methods and Materials in Soil Conservation – A Manual by John Charman - ftp://ftp.fao.org/agl/agll/docs/mmsoilc.pdf)

When the slope of the bank becomes unstable and may cause movement of earth in the form of landslips or landslides, it is necessary to take up multiple measures to stabilize the bank. These measures include (1) regrading the bank slope, (2) manipulation of the surface drainage, (3) diversion and training of waterways, (4) erecting retaining structures, etc. Some common retaining structures are discussed here. Even when the existing slope is more or less stable, if the existing slope has to be steepened to allow a track, road or an irrigation canal to be constructed across it and the new profile results in an unacceptably low factor of safety, retaining structures can be used to support the new steep cut slope or to support fill placed behind them to carry the new road. Among many types of retaining structures, only gravity walls are discussed here.

8.1.4.1 avity walls

The gravity walls resist the earth pressure exerted by the backfill (material retained or supported by the wall) by its own weight (dead load). It is usually built in stone masonry and occasionally in mass or reinforced concrete. The building materials of the wall define the various types of gravity walls that are normally used. Local availability of materials and cost of procurement often govern the selection of the materials. Reinforced concrete and mass concrete structures are rigid and durable, but they require specialized skill and are cost intensive, and therefore are not suitable for simple design. In forest and remote areas and in dealing with small landslips, suitable and common walls are –

- Drystone walls – simple to build with local labour force; however having restriction in height to which they can be built; would require regular maintenance.
- Crib structures using interlinked timber or concrete stringers and ties to form a structural

framework encasing a fill material.

- Gabion structures that use wire baskets, usually 1m x 1m x 2m in size, filled with stone.

Gravity wall of another type, made of reinforced earth, is becoming popular. In this wall the excavated soil material is re-used and reinforcing elements are added to strengthen it. The different types of gravity retaining walls are illustrated in **Fig.8.4.**

8.1.4.2. Design of Gravity Retaining wall:

The design of gravity retaining walls requires the following conditions to be satisfied:

- The structure should not overturn about the toe;
- The structure should not slide forward on its base
- The structure must not exceed the bearing capacity of the foundation soil
- The earth pressure generated behind the wall should not overstress any part of the Structure.
- The resultant of the major forces – the horizontal thrust exerted by backfill and vertical force due to weight of the wall – acting on the base of the wall should fall in the middle third of the wall base.

8.1.4.3 Drystone walls

Drystone walls are cheap and easy to build, and often very suitable in rural areas. However, they are the least durable form of wall. Care in the following aspects of construction will considerably improve their performance:

· Excavation for placing the base of the wall should be extended to a firm foundation.
· It is preferable to slope the base back into the slope at about 10°.
· Drystone walls should not be higher than 3.5 m.
· The width of the base (front to back) should be at least half of the height.
· Only strong unweathered and angular stone should be used.
· The stone should be carefully packed to maximise interlocking between individual pieces.
· Preferably the stone should not be of equal dimension and should be packed with the longest dimension extending back to front into the slope.
· Any gap between the slope and the rear of the wall should be hand-packed with granular material.

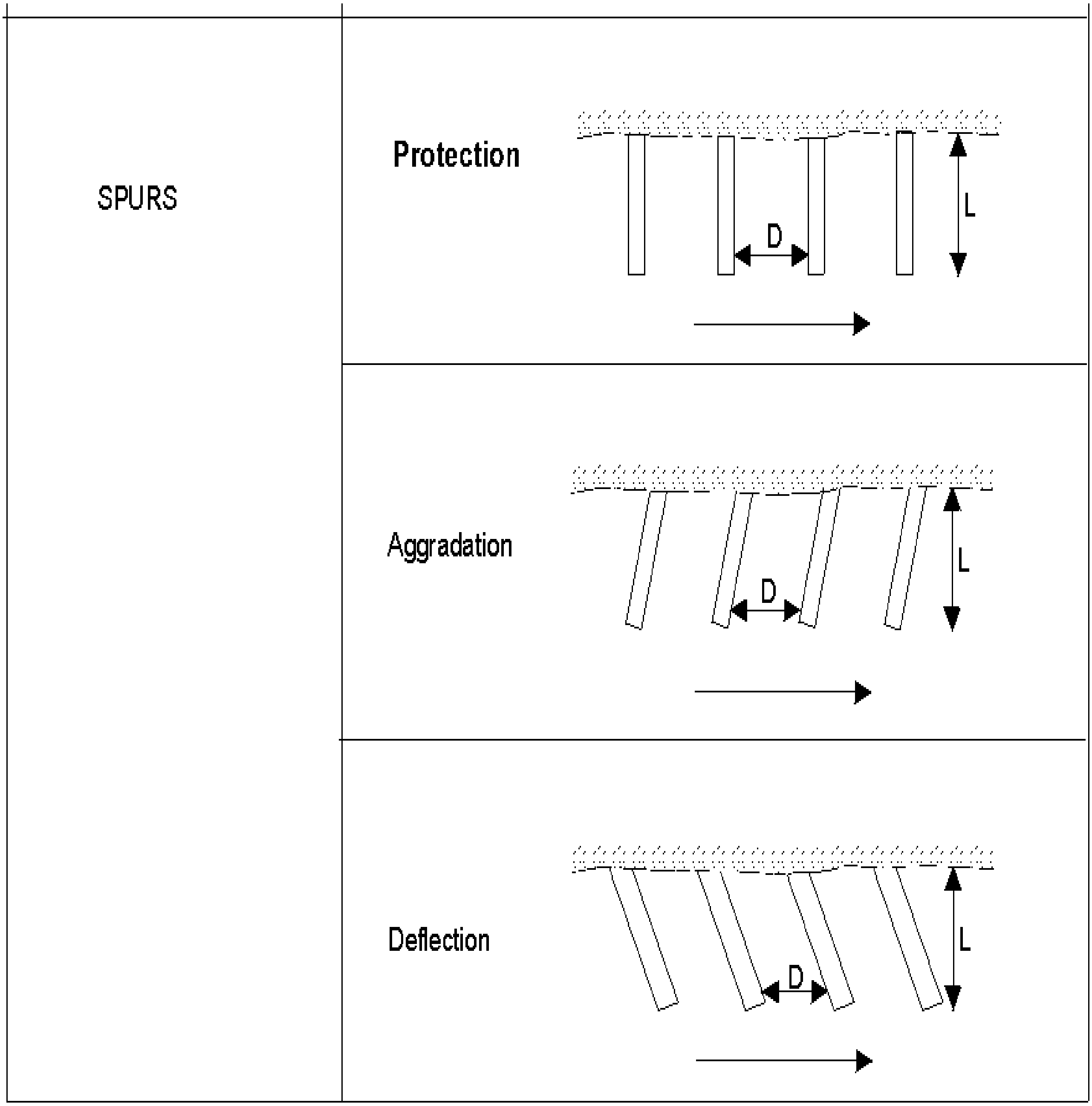


Fig.8.3 River bank protection works by Spurs

(Source: Methods and Materials in Soil Conservation – A Manual by John Charman - ftp://ftp.fao.org/agl/agll/docs/mmsoilc.pdf)

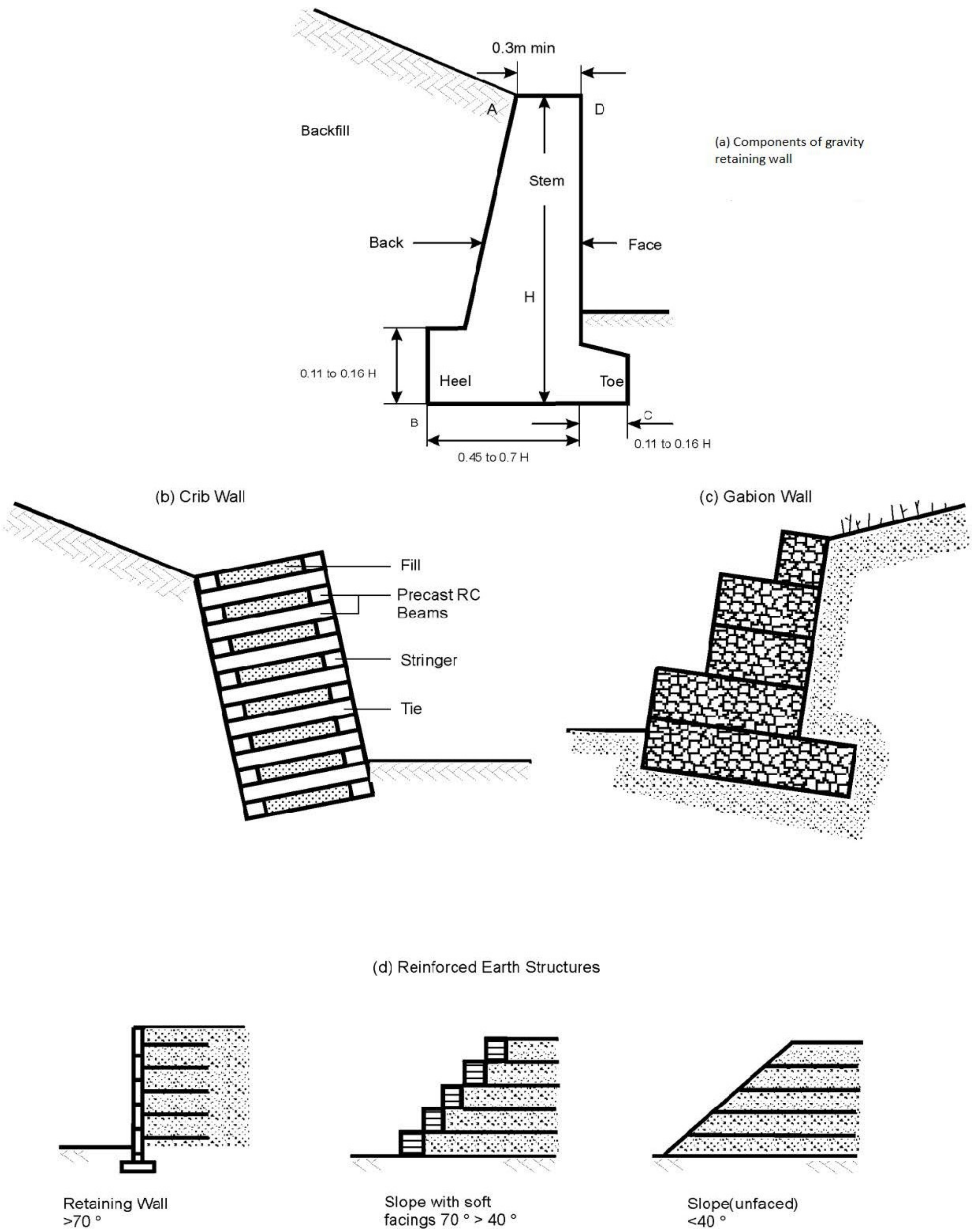


Fig.8.4 Types of Gravity Retaining Walls

(Source: Methods and Materials in Soil Conservation – A Manual by John Charman - ftp://ftp.fao.org/agl/agll/docs/mmsoilc.pdf)

With introduction of bands of cement bonded masonry at regular intervals of height, the overall height can be increased. However, height more than 6 m should not be attempted without detailed analysis.

8.4.1.4 Reinforced earth retaining wall

Reinforced earth comprises a series of compacted soil layers separated by sheets or strips of a reinforcing medium, which may be a sheet geotextile, a sheet of woven gabion wire, a timber grid, or metal strips. A sub-vertical structure, face slope angle greater than about 70^0, is generally referred to as a reinforced earth retaining wall and can be built from reinforced soil if facing units are used to hold the soil in place. For slopes with an angle of less than 70^0 it is possible to use 'soft' facings, such as soil filled jute bags, to form the face of the slope and the natural soil is compacted behind this face. For slopes of less than about 40^0 no special facing is necessary but vegetation should be established soon after construction {**Figure 8.4**}.

8.4.1.5 Gabion Wall:

Gabions are boxes or mats formed out of wire mesh and filled with durable stone. Structures are formed by linking the boxes. Gabion boxes and mattresses can utilize local resources of stone and can be built by local unskilled and skilled labour. They are flexible, easy to move and can be repaired by the local workforce.

8.4.1.5.1 Some basic rules to be followed for gabion construction -

- The gabion stone should be ideally between 100 mm and 200 mm in size and should normally be at least 1.5 times the size of the mesh;
- Stone should be hard and durable and may be from a quarried source or naturally occurring rounded river stone. River boulders are generally very durable.
- It is necessary to use variable sized stones to pack the voids between the larger stone.
- Th*e gabion wire* should be at least 2.5mm in diameter and should be woven into a mesh. It is important that the wires forming the mesh are double twisted so that if a wire is broken it is prevented from unraveling and progressively weakening the structure. The mesh is formed into panels, usually of size 1m x 1m or 1m x 2m etc., or into rolls 2m to 4m wide.
- The gabion boxes (0.5 m or 1m high) are formed by lacing the mesh panels together using a lacing wire of at least 2 mm diameter.

8.4.1.5.2 The boxes should be placed on a prepared flat surface, sloping back into the slope at 10° and preferably keyed into the ground to a depth of at least 0.5m. Each box should be laced to all adjacent boxes.

8.5 Water Harvesting:

(Source:http://www.fao.org/docrep/u3160e/u3160e03.htm#1.2%20definitions%20and%20classification; Manual of Soil and Water Conservation practices by Gurmel Singh et.al)

Water harvesting is defined as the collection of runoff for its productive use. Runoff may be harvested from roofs and ground surfaces as well as from intermittent or ephemeral watercourses. Water harvesting techniques which harvest runoff from roofs or ground surfaces fall under the term, **rainwater harvesting,** while all systems which collect discharges from watercourses are grouped under the term, **floodwater harvesting.** Scarcity of water or drought is not a characteristic of low rainfall area alone. Occurrence of dry spells even during monsoon in high rainfall areas is not uncommon. Thus while on the one hand high rainfall areas are in general prone to floods, on the other, irregular rainfall or occasional dry spell in critical times may create a condition of drought even in high rainfall areas. Needless to say, that drought prone areas or areas of low rainfall are the regions worst affected by scarcity of water. In drought condition, water becomes scarce not only for irrigation but also for drinking and household purposes. However, for most of the drought affected regions of our country, low rainfall is not the only or major reason of drought. Scarcity of water for use is more attributable to lack of arrangement for harvesting runoff water. It is essential that runoff water is harvested, stored and put to optimum use.

8.5.1. Benefits of Water harvesting

- Mitigates drought condition
- Moderate floods;
- Develops water resources

8.5.2 Storage of harvested runoff water

We discuss here harvesting of rain water and flood water in external catchments. Harvesting of rain water in micro catchment like roof top, terrace or courtyard – very useful for domestic purpose – is not dealt with in this lesson. Depending on requirements and topography, water harvesting and storage can be done in the reservoirs.

- Small earthen dams / embankments (dealt with in lesson 6 and 7);
- Dug-out farm ponds;
- Embankments-cum-dug out farm ponds.

We discuss below dug-out farm ponds.

8.5.3 Dug-out Farm Ponds

Farm ponds are dug out or excavated in flat terrain where topography does not permit construction of embankment. Farm pond, because of its depth, exposes less water surface for a given volume than an earthen dam and thus causes less evaporation loss.

8.5.3.1 election of site

Following aspects should be examined for selection of site.

- Annual runoff from the watershed should be adequate to fill the dug-out;
- The soil type at the site should be investigated. Soil which is highly permeable is not suitable for the bottom and sides of the dugout. In case of excessive seepage, the pond should be provided with suitable lining (puddling compacted to bulk density). Again very hard soil where excavation is difficult may be avoided.
- Soil underlain by limestone containing crevices, sinks or channels may be avoided.

8.5.3.2 Construction

The pond site is cleared of all vegetation. The pond is excavated by step method by employing manual labour. The excavated material should be placed in such a manner that its weight does not destabilize the pond and the material does not get washed back to the pond by rain water. The excavated material may be stacked in bunds of easy slope away from the pond leaving a berm space equal to the depth of the pond.

8.5.3.3 Estimation of Volume of a pond

The volume of excavation required can be estimated by the following prismoidal formula.

$$V = \frac{A+4B+C}{6} \times D$$

Where V = Volume of excavation (m^3)

A = Area of excavation at the ground surface (m^2)
B = Area of excavation at the mid-depth point (m^2)
C = Area of excavation at the bottom of pond (m^2)
D = Average Depth of the pond (m)

Lesson 9

I hour

Lesson Plan

Objective:

- To study gully control – approach and measures.
- To study function of various check dams.

Backward Linkage:

- Earthen dam in lesson 6 and 7; gully erosion in lesson 4.

Forward Linkage:

- During tour the trainees may be shown sites demonstrating gully control works.

Training materials required:

- Copy of lesson 9 to be circulated beforehand.

Allocation of time:

- Gully control –approach and methods –10 mts
- Various check dams – 40 mts
- Discussion/miscellaneous –10 mts

9.1 Gully Control - Approach

The causes of gully erosion, the various stages of development of gullies and outline of gully control measures have been discussed in lesson 4. This lesson now devotes to details of measures of gully stabilization. One should know that formation of gully is a symptom of improper land use. Prevention of gully formation by removing the causal factor, that is, by taking recourse to proper land use of the catchment that contributes water flow to the gully channel is the first step to be taken. However, when gullies have already been formed, it becomes necessary to take control measures in the gully in addition to preventive measures in the upper catchment. The control approach consists of (1) reduction of peak flow rates through the gully, and (2) provision of a stable channel for the flow that is to be handled.

9.2 Methods of Gully Stabilization

The best way to accomplish gully stabilization is –

- To provide a vegetal protection for the gully channel;
- To modify the cross section and the grade of the channel to limit the flow velocity that the vegetation can withstand
- To apply conservation measures to the contributory watershed. Construction of terraces or diversions may completely remove the flow from some of the gullies.

9.2.1 Vegetation

Planting of trees or vines and creating conditions that encourage natural regeneration is very effective to control even large gullies. If the runoff causing gully is diverted and the area is fenced to remove grazing or other biotic damage, natural regeneration begins to come in automatically. Given a favourable situation, a gradual succession of plant species will cover the gullied area with grasses, vines, shrubs and trees native to the area in question. The vegetation may be further enriched by taking recourse to artificial regeneration. Grasses, shrubs and trees suitable for the area may be planted. Selection of species may be made keeping in view the future use of the area. For example, if the vegetation is to be used for pasture or hay, grasses and legumes may be planted, shrubs would be desirable if the gullied areas on reclamation be made a wildlife refuge. Above all, some local species, effective to control soil erosion, and easy to propagate by natural regeneration or coppicing may be given preference.

9.2.2 Sloping Gully banks

Sloping banks should be done only to the extent required for establishment for vegetation. To establish trees and shrubs, a 1:1 slope is sufficient. If the gullies are to be reclaimed as grassed waterways, banks of slope 4:1 or so may be created.

9.2.3 Diversion

The most effective control is done by complete elimination of the runoff coming into the gully. It is often done by diverting runoff from above the gully and causing it flow through suitably protected outlet. A diversion is a channel or waterways constructed across the slope with a slight grade to divert the flow to the desired outlet. The capacity of the diversion will be guided by the peak runoff for the 10-year recurrence interval. They should be located far enough above gully overfall. Bottom width and side slopes vary with soil and land slope. However, side slope of 4:1 and bottom widths sufficient to permit mowing are desired.

9.2.4 Control Structures

Providing a stable channel for runoff is the fundamental step of gully control. With this object the control structure is constructed. Its function is to reduce the channel gradient and maintain the water velocity below the erosive level. The structure intercepts a large part of the fall in the gully and dissipates the energy of falling water.

9.2.5 Check dams

The function of the check dams is to flatten the steep gradient of the gully by constructing a series of checks. The check dams convert the longitudinal gradient into a series of steps with low risers and long flat treads.

9.2.6 Temporary Check dams

They are constructed in small and medium gullies and intended to function until the vegetation cover in the gully gets established and provides permanent protection. The temporary dams trap water and soil and thus facilitate vegetation growth. They are usually made of brush, wire, poles or loose rock.

9.2.6.1 Series of check dams, spacing, spillway.

(Source: FAO watershed management field manual - Gully control.)

To obtain satisfactory results from structural measures, a series of check dams should be constructed for each portion of the gully bed. Because they are less likely to fall, low check dams are more desirable than high ones. After the low dams silt up and rot away, vegetation can control the low overfalls much more easily than on high dams. Please note –

- The spacing between check dams can be determined according to the compensation gradient and the effective height for the check dams.
- "Compensation gradient" is the future or final gradient of the gully channel between the top of the lower check dam and the bottom of the upper . It is formed when material carried by flowing water fills the check dams to spillway level. Field experience has demonstrated that the compensation gradient of gullies is not more than 3 percent.
- The first check dam should be constructed on a stable point in the gully such as a rock outcrop, the junction point of the gully to a road, the main stream or river, lake or reservoir. If there is no such stable point, a counter-dam must be constructed. The distance between the first dam and the counter-dam must be at least two times the effective height of the first check dam.
- The points where the ensuing check dams are to be built are determined according to the compensation gradient and the effective height of the check dams. Please see Fig.9.1 which illustrates how to locate the position of second check dam for a given height of the first dam and an envisaged compensation gradient, with the help of a clinometer, clinometer stand and a target.
- The width of the spillway b may be determined from the following formula

$$Q = CbD^{3/2}$$

Where

C is the Coefficient which is 3.0 for loose rock, boulder, log and brushwood check dams;

b is the minimum width or breadth of spillway in meters;

D is the depth of spillway in meters;

Q is the maximum discharge of the gully catchment at the proposed check dam point, in cubic meters/second.

(Please see Lesson 7 for spillway of earthen dam)

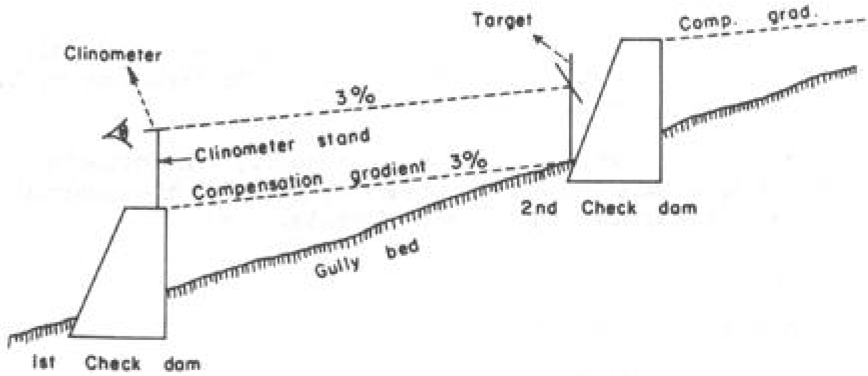


Fig.9.1 Locating position of second check dam

9.2.6.2 Brushwood check dams

(Source: http://www.fao.org/docrep/006/AD082E/AD082e03.htm)

Brushwood check dams made of posts and brush are placed across the gully. The main objective of brushwood check dams is to hold fine material carried by flowing water in the gully. Small gully heads, no deeper than one meter, can be stabilized by brushwood check dams. Brushwood check dams are temporary structures and should not be used to treat ongoing problems such as concentrated run-off from roads or cultivated fields. They can be employed in connection with land use changes such as reforestation until vegetative and slope treatment measures become effective. *Please see Fig. 9.2, 9.3, and 9.4*

9.2.6.3 Brushwood check dams are suitable for use in all regions provided the soil is deep enough. It is compatible with a range of gully gradient from 5 to 12 percent, but the length of the gully channel, beginning from the gully head, should not be more than 100 meters. The gully catchment area should be one ha or less. There are many types of brushwood check dams. The type chosen for a particular site depends on the amount and kind of brush available. Whatever sort is used, the spillway crest of the dam must be kept lower than the ends, allowing water to flow over the dam rather than around it. The maximum height of the dam is one meter from the ground (effective height). Both the upstream and downstream face inclination is 30 percent backwards. The spillway form is either concave or rectangular.

9.2.6.4 Other specifications for brushwood check dams

- Posts are set in trenches (0.3 by 0.2 m in size) across the gully to a depth of about 1/3 to 1/2 of the post length, and about 0.3 to 0.4 m apart. The length of the posts is 1.0 to 1.5 m and their top-end diameter is 3 to 12 cm.
- Any tree or shrub species, such as alnus, pine, bamboo, salix, poplar, etc., can be used as posts.

- The flexible branches of trees (Salix, Poplar, Cassia, etc.), flexible stems of shrubs and the strips made of bamboo stems may be used as interlink material. These materials are woven between wooden posts driven into the ground.

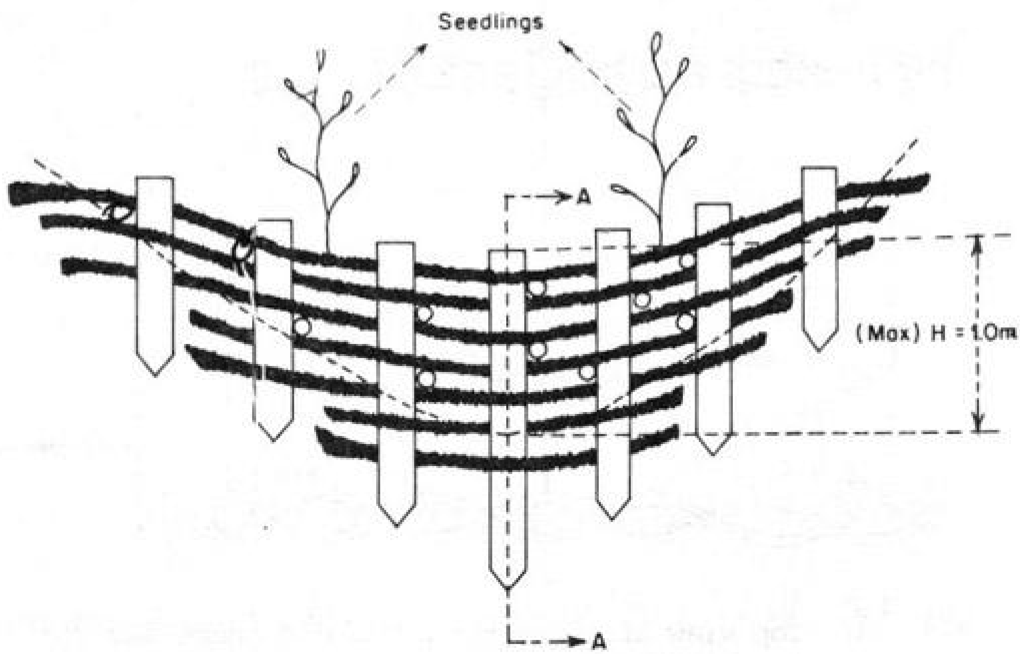


Fig.9.2 Brushwood Dam

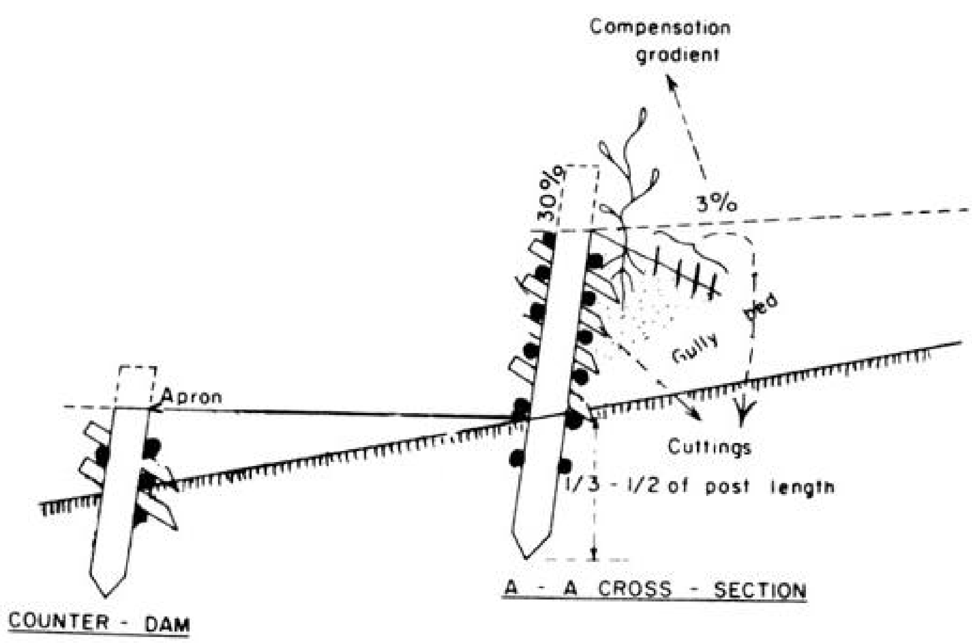


Fig 9.3 A-A Cross section of Brushwood Checkdam

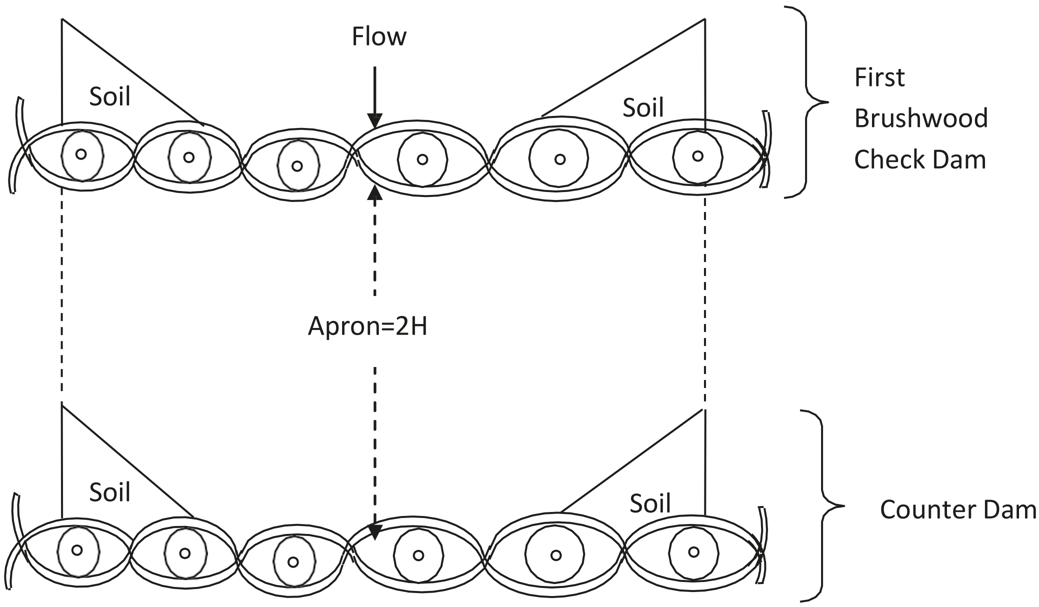


Fig.9.4 Top view of brushwood Check dam and the counter dam

- The ends of interlink materials should enter at least 30 cm into the sides of the gully.
- The space behind the brushwood check dams must be filled with soil to the spillway.
- If sprouting species (Salix, Poplar etc.) are selected as posts and interlink materials, brushwood check dams should be constructed when the soil in the gully is saturated or during the early rainy season.
- If non-sprouting species (pine and alnus as posts, bamboo strips as interlink materials) are used, brushwood check dams can be constructed during any season.

9.2.6.5 Boulder Checkdams:

(Source: http://www.fao.org/docrep/006/AD082E/AD082e03.htm)

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 two m. Foundation depth must be at least half of 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. The above-mentioned dimensions can ensure stability of the dam against overturning, collapsing and sliding. But, the dimensions of the spillway should be computed according to the maximum discharge of the gully catchment area. The form of the spillway is generally trapezoidal. *Please see Fig. 9.5, 9.6 and 9.7*

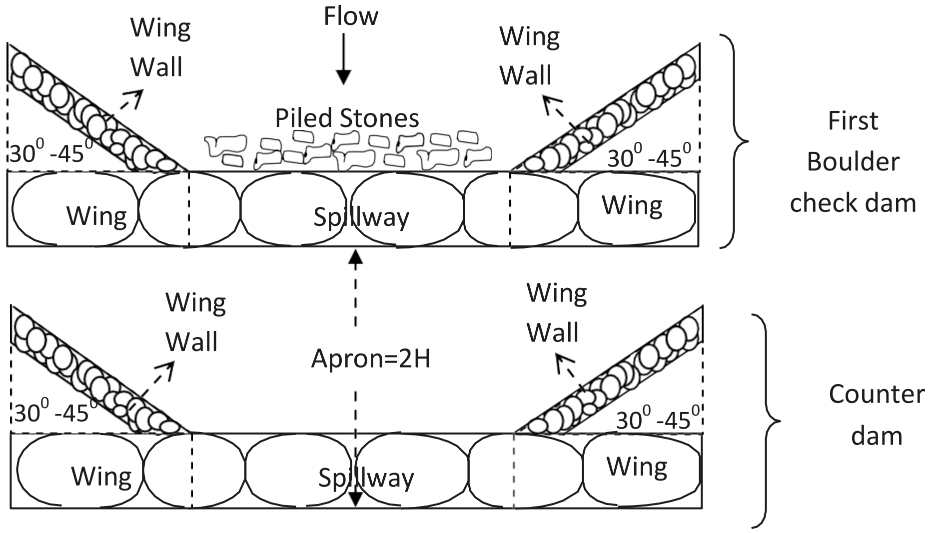


Fig.9.5 Top view of Boulder Check Dam

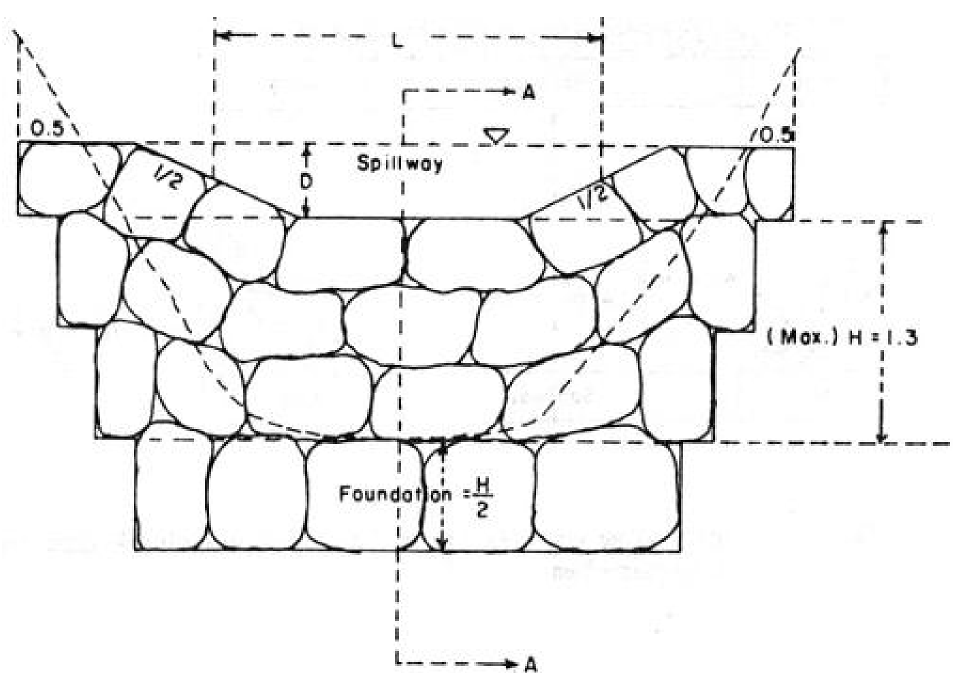


Fig. 9.6 Boulder Check Dam - Elevation

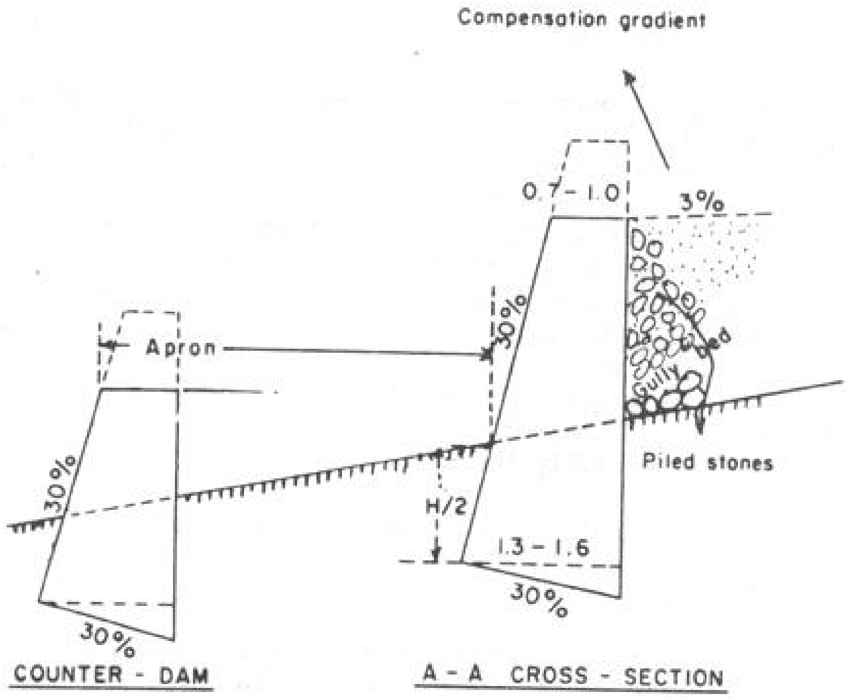


Fig. 9.7 A-A cross section of the first boulder check dam and Counter dam

9.2.6.6 Loose stone check dams

(Source: http://www.fao.org/docrep/006/AD082E/AD082e03.htm)

Loose stone check dams made of relatively small rocks are placed across the gully. 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 two ha or less. These dams can be used in all regions. The maximum effective height of the dam is 1.0 m and its foundation depth is at least 0.5 m. The thickness of the dam at spillway level is 0.5 to 0.7 m and the inclination of its downstream face is 20 percent; the thickness of the base is computed accordingly. The upstream face of the dam is generally vertical. Please see Fig. 9.8,9.9 and 9.10.

Other specifications for loose stone check dams

- The foundation of the dam is dug so that the length of the foundation will be more than the length of the spillway. The foundation of the wings should be dug in such a manner that the wings will enter at least 50 cm into each side of the gully.
- The crest and middle part must be constructed with bigger rocks than the rest of the dam.

- The wings of the dam should be protected against flash water by wing walls. The angle between the wing wall and the wing is 30 to 45 degrees. The wing wall's height must be equal to the depth of the spillway. Fill the space behind the wing walls with soil.
- The space behind the dam should also be filled to spillway level with soil excavated for the foundation, and from the gully bed.
- The form of the spillway is concave.

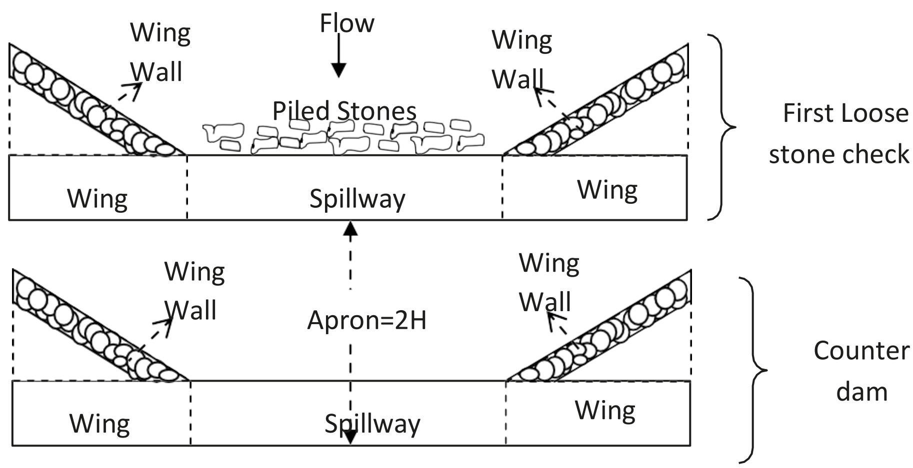


Fig.9.8 Top view of Loose Stone Check Dam and the Counter Dam

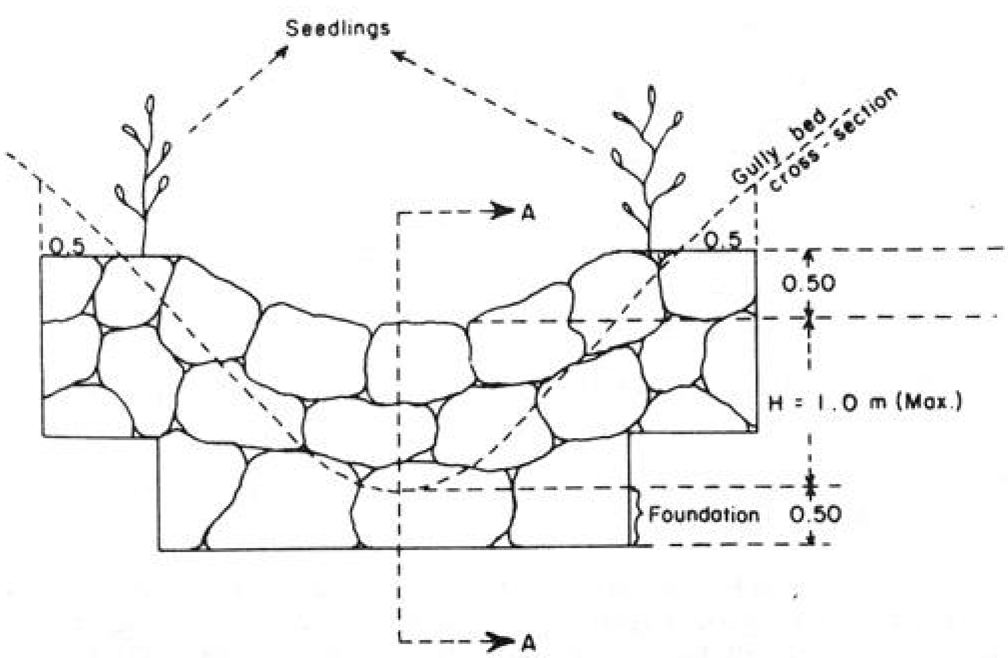


Fig.9.9 Front View of Loose Stone Check Dam

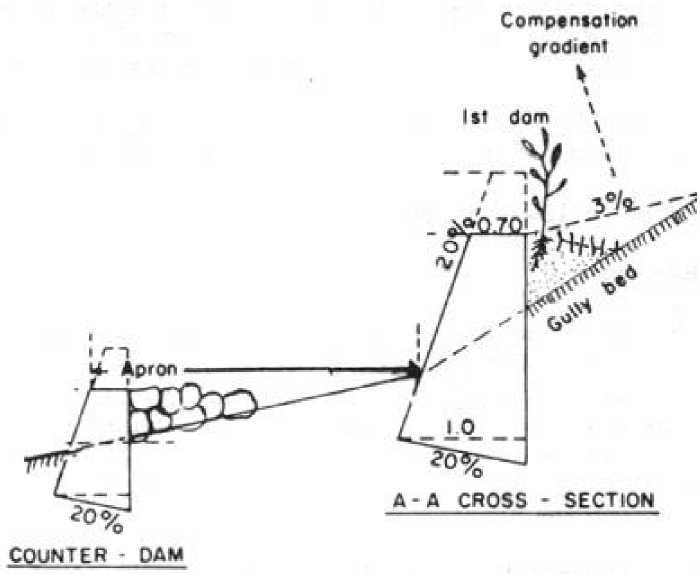


Fig.9.10 A-A Cross section of the loose stone check dam and counter dam

9.2.7 Permanent check dams:

Permanent control structures are generally required to control the overfall at the head of a large gully, to drop the discharge from a vegetated waterway into a drainage ditch, and to take up the fall at various points in a gully channel. In short, when a control structure demands a high degree of safety and permanence, masonry or concrete structures are unavoidable.

9.2.7.1 Types of structures

There are three principal types of spillways.

- Drop spillway
- Drop inlet spillway
- Chute (meaning inclined channel) spillway - useful in high over falls where a full flow structure is required and where site condition do not permit the use a detention type of structure.

9.2.7.2 Component parts of structure

Commonly used control structures consist of four major components, namely–

- Embankment / dam
- Spillway inlet
- Conduit
- Spillway outlet

Major function of the control structures is to reduce the gradient of the channel and maintain velocities below erosive level. Much of the fall in the gully being treated is taken up at the structures which are designed to dissipate the energy of falling water.

Embankment / dam

The embankment intercepts the flow of water and diverts it through spillway. The embankment for a drop spillway or chute (inclined) generally extends from the spillway to the high ground or to a vegetative spillway.

Spillway inlet

The inlet through which water enters the spillway may be in the form of a box, a weir in a wall or a culvert-type entrance. The box may be straight or flared while the wall may be straight, flared or curved. The culvert type entrance may be round, square edge, hood or flared entrance. Vertical walls extending into soil foundation under the inlet serve as cutoff walls to prevent the seepage of water under the structure. Similar vertical walls extending laterally from the inlet to prevent seepage and erosion around the ends of the structure, are called headwall extensions.

Spillway conduit

The function of the conduit is to receive water from the inlet and conduct it through the structure. The conduit may be closed in the form of a box or pipe, or may be open like a rectangular channel. Cutoff walls or anti-seep collars are usually constructed as part of conduit to prevent seepage along length of conduit.

Spillway outlet

Water leaves the structure through the outlet. Its function is to discharge the water into the channel below at a safe velocity. The outlet may be of the cantilever (propped) type, a plain apron outlet, or an apron with any type of energy dissipater. Vertical walls known as toe walls are extended below at the front of the apron to prevent undercutting. Vertical walls known as wing walls are constructed, which extend from the outlet to the channel banks to protect against the swirling action of water when it leaves the structure.

9.2.8. Masonry check dams

(Source: http://www.fao.org/docrep/006/AD082E/AD082e03.htm)

Masonry check dams constructed with cement mortar and non-disintegrating stones are generally used in torrent control. The main objective of the dam is to hold fine and coarse material carried by flowing water in the gully or torrent. From a technical and economical point of view, it is normally not necessary to build masonry check dams to control channel erosion in gullies. Every kind of gully that is about 1 000 m long and covers an area of 20 ha or less can be stabilized easily by boulder check dams. In a series of boulder check dams, the first dam can be built with cement masonry as well as those above and below a road at the junction points where the gully crosses it.

9.2.8.1 Calculating the dimensions of masonry check dams

1. For dams less than two m high:

If a masonry check dam is less than two m high, its crest thickness should be 0.4 m. The base thickness is calculated according to the height and inclination of the dam's downstream face.

2. For dams two to six m:

If the height of a masonry check dam is two to six m, the base thickness can be computed by using the following "Hoffman" formula:

$$d = 0.462\ H$$

d : thickness of the base

H : total height of the dam

The crest thickness can be computed by taking into account the inclination of the downstream face, and the height of the dam.

9.2.8.2 Other specifications and construction procedures for masonry check dams *(Please see Fig. 9.11, 9.12 and 9.13)*

- The dams must not be constructed on points where there is mass movement of soil blocks. They should be built on a gully bed or torrent channel's stable points just below the sliding area to hold debris and material as well as to stop the movement of soil blocks.
- The foundation of the first dam must be dug to a durable layer below, such as solid rock.
- The foundation of the other dams must be at least one meter deep, if they are not constructed on solid rock.
- The wings should enter at least one meter into the sides of the gully.
- The foundation is longer than the spillway.

- An aqueduct (diameter 20 to 50 cm) must be built on ground level and drainage holes (diameter of each hole at least 10 cm) must be made during the construction of the dam. The gradient of the aqueduct and drainage holes is five percent.
- The upstream face of the dam is vertical, whereas its downstream face inclination is 20 percent (1:1/5 ratio).
- The stones must be piled behind the mouth of the aqueduct. If possible, the space behind the dam should be filled to the spillway with soil excavated for the foundation and from the gully bed.
- Wing walls should be built behind the wings of the dam to protect them against flash water. The angle between the wing and wing wall is 30 to 45 degrees. The space behind the wings should be filled with soil. The height of the wing walls is equal to the depth of the spillway.
- The stones used in constructing masonry check dams must be hard enough to withstand abrasion, non-disintegrating, and resistant to weathering.
- A counter-dam must be constructed in front of the first masonry check dam. It also is built as cement masonry work.

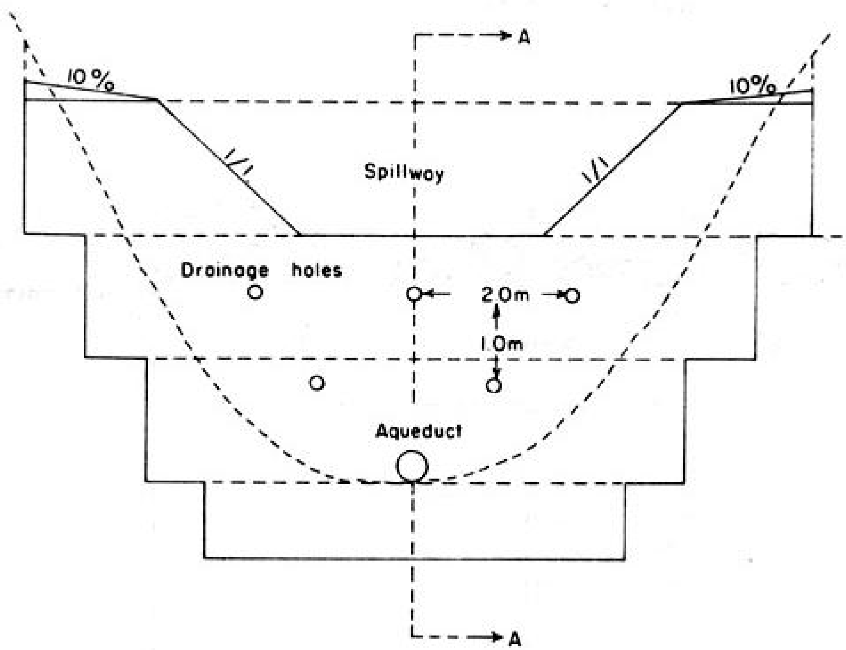


Fig.9.11 Front View of the first Masonry Check dam

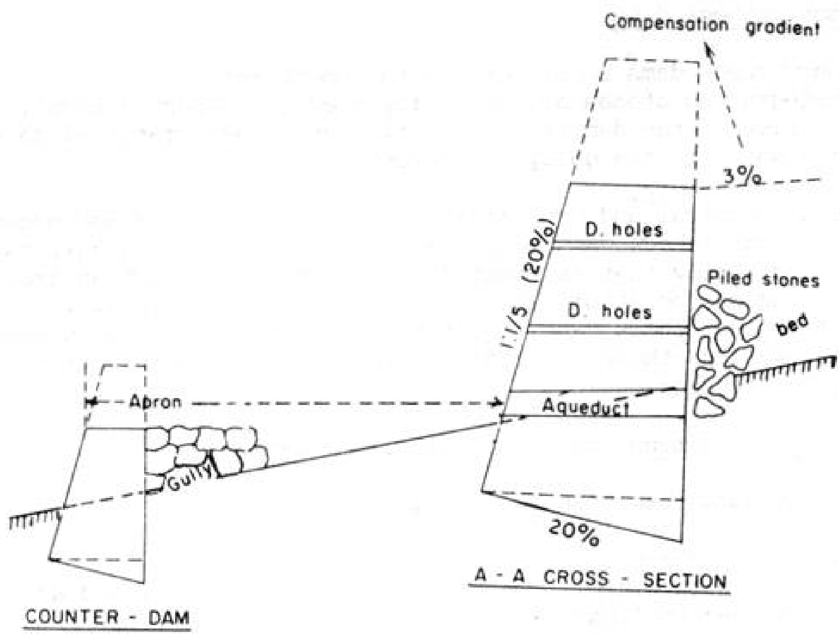


Fig.9.12 A-A cross section of the first masonry check dam and Counter dam

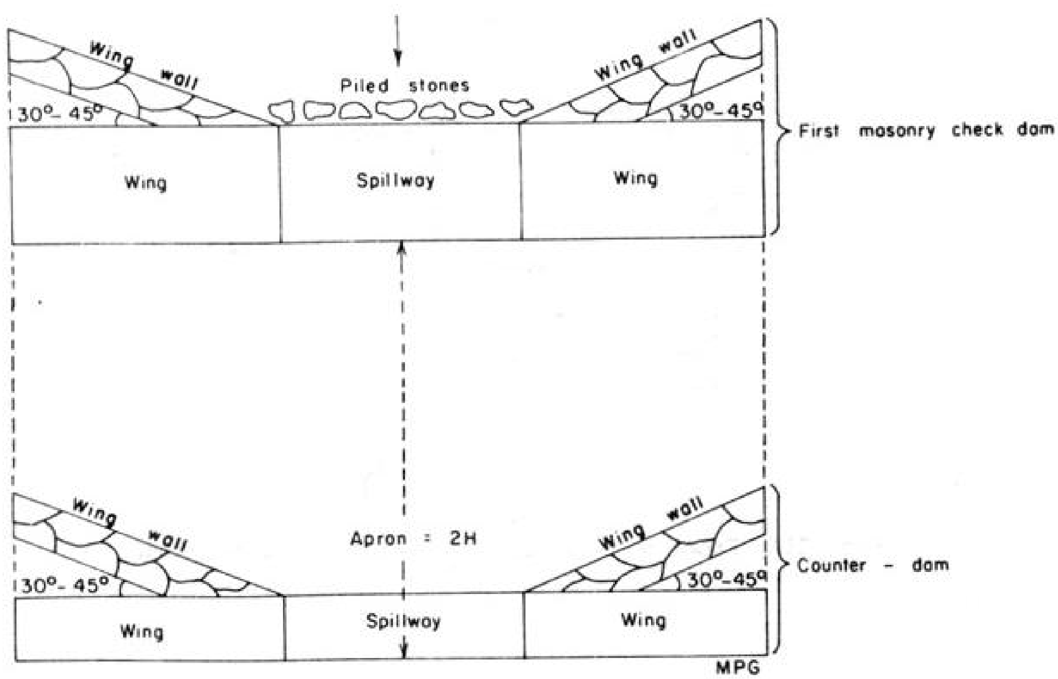


Fig.9.13 – Top view of the first Masonry Check dam and Counter dam

Lesson 10

Time 1 hour

Lesson Plan

Objective:

- To study sediment movement in stream channel and sediment measurement.
- To study sand dune stabilization and shelterbelt.

Backward Linkage:

- Stream bank erosion in Lesson 8.
- Wind erosion in Lesson 4.

Forward Linkage:

- During tour the trainees may be shown sediment monitoring station and treatment of coastal areas.

Training materials required:

- Copy of lesson 10 to be circulated beforehand.

Allocation of time:

- Sediment movement in channel and measurement of sediment load –25 mts
- Sand dune stabilization and shelterbelt – 25 mts
- Discussion/miscellaneous –10 mts

10.1 Stream Channel Erosion

Stream channel erosion consists of soil removal from stream banks and soil movement in the channel. Primary distinction of stream channel erosion from gully erosion is that –

- Channel erosion applies to lower end of headwater tributaries , whereas gully erosion occurs near the upper ends of tributaries;
- Channel erosion applies to streams that have nearly continuous flow and flat gradients, whereas gully erosion occurs in intermittent streams and at steeper slopes.

10.1.1 Sediment movement in channels

(Source: Soil and Water Conservation Engineering by R.K. Frevert et al)

Sediment in stream is transported by suspension, saltation and by bed load movement. Many theoretical and empirical relationships have been developed between the sediment transporting capacity of a stream and certain parameters of flow. But it is very difficult to predict sediment loads with a degree of accuracy. Variables affecting sediment movement include:

- Velocity of flow;
- Turbulence;
- Size distribution, cohesiveness and specific gravity of transported materials;
- Channel roughness;
- Obstruction to flow;
- Availability of materials for movement

10.1.2 Impact of Stream Channel Erosion (Source: World meteorological organization, Operational hydrology report no. 47, Manual on sediment management and Measurement at http://whycos.org/IMG/pdf/948_E.pdf)

Deposit and scour are common in channels because of the difference between sediment load and the real sediment transportation capacity of flow. Deposition in stream channels raises the elevation of channel beds. Consequently, it enhances the water level at the same discharge, and increases the occurrence and the damage of floods. On the other hand, scour brings some safety problems for river training works, lowers water levels, and therefore affects water supply and navigation along rivers.

10.1.3 Type of sediment load

Sediment load may be classified as suspended load or bed load according to the mode of movement in the river. Suspended load is the sediment that moves in suspension in water under the influence of turbulence. Bed load is the part of sediment load that moves in almost continuous contact with the streambed by saltation and traction, that is, by bouncing, sliding and rolling on or near the streambed by the force of water.

10.1.4 Measurement of Sediment Load

(Source:http://www.britannica.com/EBchecked/topic/504801/river/29094/Sediment-yield-and-sediment-load#toc29095)

The sediment load can be measured in different ways. Collection of water samples from a river and measurement of the sediment contained in each unit of water will, when sufficient samples have been taken and the water discharge from the system is known, permit calculation of annual sediment yield. Because sediment in a stream channel is transported in suspension, in solution, and as material rolling or moving very near the bed, the water samples will contain suspended and dissolved load and perhaps some bed load. Much of the bed load, however, cannot be sampled by existing techniques, as it moves too near the bed of a stream. It is fortunate, therefore, that the greatest part of the total sediment load is in the form of suspended load.

When a dam is constructed, the sediment transported by a stream is deposited in the still waters of the reservoir. In this case, both bed load and suspended load are deposited, but the dissolved load eventually moves out with the water released from the reservoir. Frequent, precise surveys of the configuration of the reservoir provide data on the volume of sediment that accumulates in the reservoir. Water samples can be taken to provide data on the dissolved load transported into the reservoir; and when this quantity is added to the measurements of suspended and bed load, a reasonably accurate measure of sediment yield from the drainage basin above the reservoir can be obtained.

All of the techniques utilized to measure sediment yield are subject to considerable error, but data sufficiently accurate for the design of water-regulatory structures can be obtained by sampling or by reconnaissance surveys of the drainage systems.

10.1.5 Devices and instruments for measuring sediments

(Source: http://www.fao.org/docrep/x5302e/x5302e0a.htm)
A great number of apparatus and instruments have been developed in attempting to measure each process of the erosion-sediment transport sequence. However, at present, none has proved to be fully satisfactory, reliable and free from disturbing secondary phenomena. Some critical interpretation of the sample analysis by a specialist is always desirable.

10.1.5.1 ended sediment samplers

Several types of samplers of suspended-sediment have been developed such as trap samplers, direct pumping, integrating samplers, etc. However, only few of them are designed so that the intake velocity into the sampler is equal to the actual stream velocity. This characteristic is essential for the samples to be representative of the suspended-sediment concentration of the stream at the point of measurement. A well-designed sampler faces the approaching flow and its intake extends upstream from the zone of disturbance caused by the presence of the sampler itself.

- Instantaneous samples are usually taken by **trap samplers** consisting of a piece of horizontal cylinder equipped with end valves which can be closed suddenly to trap a sample at any desired time and depth.
- The **pumping sampler** sucks water-sediment mixture through a pipe or hose, the intake of which is placed at the sampling point. Regulating the intake water velocity in order to be equal of that of the stream, the operator can obtain a sample that is representative of the sediment concentration at the point of measurement.
- The **integrating sampler** consists of a metallic streamlined body equipped with tail fins to orient it in the flow. An intake nozzle of an appropriate diameter projects into the

current from the sampler head. An exhaust tube, pointing downstream, permits the escape of air from the container which is located in the sampler body. Valve mechanisms enclosed in the head are electrically operated by the observer to start and stop the sampling process.

- A new method of *in situ* determination of suspended-sediment concentration is the application of **optical, ultra-sonic or nuclear gauges**. The working principle of these instruments is that a beam of light, x-ray, ultrasound or nuclear radiation emitted by a source with constant intensity is scattered and/or absorbed by the suspended-sediment particles. The decrease of intensity of the beam measured by an appropriate detector or sensor situated at constant distance from the source, is proportional to the sediment concentration, provided other relevant characteristics of water and sediment (chemical, mineral composition, etc.) remain unchanged.
- The **single stage suspended sediment sampler** operates on the siphon principle. It is used to automatically collect suspended sediment samples from flash floods in intermittent streams at remote locations. The sampler consists of a bottle or other suitable container with about 5 mm copper tubes that are formed to a siphon shape and inserted through taps which fit tightly into the tops of the bottles. Several samplers are mounted at various depths on a support that is fixed on the side of the stream so that samples are obtained at several water surface elevations as the water level of the stream rises.

10.1.5.2 Samplers for bed-material discharge

Field measurement of bed-material discharge is difficult due to the erratic sediment movement which takes place in the form of moving ripples, dunes, bars, etc. No instruments have proved to be reliable for trapping the large and small sediment particles with the same efficiency, while remaining in a stable and flow-oriented position on the streambed and not altering the natural flow pattern and sediment movement. Because of several uncertainties involved in sampling bed-material discharge, it is necessary to determine an efficiency coefficient for each type of sampler. The calibration takes place generally in a laboratory flume, where the bed-material discharge can be directly measured in a sump at the end of the flume, although uniform transport conditions over the width and length of the flume are difficult to maintain.

[A pilot study of sediment monitoring in Rupnarayan catchment (source: paper presented by Shri AB Mahato, former DFO, Panchet Soil Conservation Division in Staff training on Soil Conservation held in 1993)

A pilot study to assess the effect of soil and water conservation measures carried out in watershed No Rd 7d (part) of Rupnarayan catchment was carried out. A rainfall gauging station and a sediment monitoring centre were installed in river Purandar, a drainage line of the said watershed, in 1986. Assessment of sediment load was done in 1986 (pre-conservation stage) and in 1991 (post-conservation stage). According to the study made, the sediment outflow was reduced considerably due to soil conservation measures that were carried out.

Procedure followed –

To determine velocity – The paper refers to two methods as described below.

Current meter method – The velocity v of 'A' area of water section is determined by a current meter which has a wheel that turns round due to force of current. The revolution of the wheel is recorded by an electrical device.

Float method – A float, say a closed bottle or a rubber ball is allowed to float through the current line of the river. The time taken by the float to cover a known length of distance is noted. Surface Velocity is determined by the formula –

$$\text{Surface Velocity} = \frac{\text{Known length}}{\text{time taken}}.$$

A number of observations give a fairly accurate value of surface velocity. Mean velocity v is taken as 0.8 to 0.9 of the average surface velocity.

To determine discharge –

Discharge Q = A x v; where A is area of water section and v is velocity.

If A is expressed in m^2 and v in m/sec, the discharge Q is expressed in m^3 / sec.

Total discharge in m^3 per day V = Average discharge Q in m^3 / sec x 60 x 60 x 24

Collection of water sample – samples of water containing sediment were collected from the site of monitoring station in 1-litre bottle three times daily from different depths – 0.2 m, 0.4 m and 0.6 m below water surface. Samples were dispatched to laboratory.

Laboratory works – To help quick settlement of sediment in suspension, alum dust is added. Water samples are left undisturbed till all the particles settle. The clear water above is siphoned off carefully, and the sediment is transferred to a beaker. The contents of the beaker are then transferred on to a filter paper fitted in a funnel. When water is drained off completely, the filter paper with the residue is placed in a desiccator and dried completely.

Estimation of sediment –

W = weight of dry filter paper in gm

W_1 = weight of dry sediment and filter paper.

Ws = weight of sediment = W_1 – W in gm per litre.

Volume of sediment in cc per litre X = $\frac{W\text{[illegible]}}{D\text{[illegible]}}$

Sediment yield S = X . V . 10^{-3} m^3 per day, where X is volume of sediment in cc per litre and V is discharge in m^3 per day.

= X . V . 10^{-7} ha.m per day.

Suspended sediment rate = $\frac{S}{w\text{[illegible]}}$ ha.m/km^2/day]

10.2. Wind erosion - Sand Dunes:

We have discussed wind erosion and mechanics of the process in Lesson 4. The desert and the coastal sandy lands are the areas which are most affected by wind erosion. The desert areas are distributed over the states of Rajasthan, Gujarat and Haryana. Coastal sandy lands fall mostly in the states of West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, Karnataka, Kerala, Maharashtra and Gujarat. Sand dunes are common features of shoreline and desert environments. Dunes provide habitat for highly specialized plants and animals, including rare and endangered species. However, when subjected to wind erosion shifting of sand dunes takes place and the resulting problems manifest most in the interfaces where deserts, arable lands and man meet. In view of growing population and increasing demand of food, it is apparent that fixing of sand dunes and afforestation will become a priority task for us.

10.2.1 Dune fixation: a tool for desertification control

(Source : http://www.fao.org/wairdocs/x5309e/x5309e06.htm; Mulching Technique of Dune Fixation by B. Ben Salem; Sand dune Fixation and Afforestation, Traditional Procedures for dune Fi xation by R.N Kaul)

Sand dune fixation is designed to prevent the movement of sand long enough so that vegetation, either natural or planted, becomes established. The technique of dune fixation is therefore based on reducing the threshold velocity of wind at the dune surface by

- establishing a pre-planting mechanical system; followed by
- establishing a vegetal cover over the dunes.

Sites that are prone to periodic shifting of sand dunes cannot be stabilized straight away by vegetation alone because of the following factors –

(1). Possible exposure of root system of the transplants by the blowing of sand;

(2). Injury to young seedlings caused by abrasive action of blowing sands;

(3). Chances of young seedlings getting buried under the sand.

10.2.1.1 Mechanical means

The mechanical means for stabilizing sand dunes normally consist of creating artificial physical barriers to wind. These are done by the following techniques.

(i) The fencing technique

The fence is a linear obstacle placed across the direction of the prevailing wind. It reduces wind speed and causes the moving sand to accumulate in front of it, finally forming a man-made protection dune. Low fences (hedges/windbreakers) are erected with the help of vegetative materials like twigs of trees, brushwood, reeds, palm leaves etc. and other substances like old railway sleepers, telephone poles, used oil drums, earth ridges etc. Rows of these materials when inserted into ground are called 'palisades" or 'micro windbreaks". In cases where the wind blows from only one direction, the fences may be erected along parallel lines. But if the wind blows from different directions, a checkerboard system may be resorted to. As a thumb rule, the fences or the windbreaks should be closer on the tops of the dunes and the windward sides, and spaced wider on the low dunes and depressions.

(ii) The mulch technique: This involves covering the sand with an even, protective layer of mulch in order to stop wind action at ground level and prevent saltation. Mulch consists of several materials: soil, water, oil and chemical products.

10.2.1.2 Vegetative methods :

The most durable and economic approach to controlling of shifting of sand dunes is through establishment of vegetation. Once the dunes have been fixed by one of the mechanical procedures described above, they can then be fixed definitively. For this we need to establish perennial tree or shrub cover. There is no longer the risk of these being destroyed by moving sands that might otherwise have exposed plant roots or damaged their aerial parts through abrasion. Despite the apparent similarity between sand dune areas, it has been experienced that growth and performance of plants vary as the same is influenced by many ecological factors like climatological, edaphic, hydrological etc.

10.2.1.2.1 Choice of species

The species suitable for planting in sand dunes must be drought resistant and should have well developed root system capable of deep vertical penetration to reach the lower moisture level of the soil or have considerable horizontal spread to take maximum advantage of the scanty precipitation and dew. In addition the species should be capable of withstanding frost and high temperature or both and abrasive action of moving sand. Further, the species should preferably be capable of regenerating naturally. Examples of species suitable for coastal sand dune fixation in our country are given below.

Grasses and creepers: Spinifex spp, *Ipomea biloba;*
Trees*: Casuarina equisetifolia, Anacardium occidentale, Acacia auriculiformis, Acacia tortilis, Prosopis juliflora, Zizyphs mautitiana*
Shrubs*: Acacia nubica, Acacia victoriae, Dichrostachys nutans, Calligonum polygonoides, Crotolaria burhia, Aerva javanica.*

In Rajasthan's inland sand dune areas some of the species recommended are as follows.
Acacia tortilis, prosopis juliflora, P. cineraria, Ailanthus excels, Dalbergia sissoo, Albizzia lebbek, Dichostachys glomerata syn nutans, Calligonum polygonoides, Saccharum bengalensis.

10.3 Shelterbelt

(Source: "An introduction to agroforestry" by World Agroforestry Centre at http://www.worldagroforestry.org/units/library/books/Book%2032/an%20introduction%20to%20agroforestry/html/18_5_trees.htm?n=106)

Windbreaks are narrow strips of trees, shrubs and/or grasses planted to protect fields, homes, canals, and other areas from the wind and blowing sand. Shelterbelts, a type of windbreak, are long, multiple rows of trees and shrubs, usually along sea coasts, to protect agricultural fields from inundation by tidal waves as well as from wind erosion, where wind is a major cause of soil erosion and moisture loss. Shelterbelts have been traditionally used for a long time in several places, most notably on the Bay of Bengal coast of India and Bangladesh.

10.3.1 When properly designed and maintained, a windbreak reduces the velocity of the wind, and thus its ability to carry and deposit soil and sand. It can improve the microclimate in a given protected area by decreasing water evaporation from the soil and plants. It can also protect crops from loss of flowers, as well as reduce crop loss due to sand-shear of seedlings. In many cases windbreaks have been shown to increase the productivity of the crops they protect. In addition to these soil- and water-conservation effects, windbreaks can also provide a wide range of useful products, from poles and fuelwood to fruit, fodder, fiber, and mulch.

10.3.2 Structure of Shelterbelt

A typical shelterbelt is a planting consisting of several rows – at least three - of trees and shrubs of varying heights. The shelterbelts are placed on the windward side of the land to be protected, and are most effective when oriented at right angles to the prevailing winds. Small living fences and hedgerows can also act as windbreaks for small sites such as home-gardens and nurseries. However, windbreaks or shelterbelts are distinguished from boundary plantings and living fences by their orientation, which must face the wind, and by their multistory, semi-permeable design. Very dense windbreaks may do more harm than good since they will tend to create strong turbulence that will scour the soil on the windward side and damage crops on the leeward side. Conversely, gaps in the trees will channel the wind, actually increasing the velocity on the leeward side and promoting soil erosion and damaging crops.

10.3.3 Protection by Shelterbelt

The protected zone created by windbreaks is defined as the area, on both leeward and windward sides, where wind speed is reduced by 20% below incident wind speed. The effective distance of protection is expressed as multiples of the height (H) of the tallest rows of trees. Windbreak effects extend to a distance of 15-20 H leeward and 2-5 H windward of the windbreak; but usually a common calculation of the extent of protected area is 10 H leeward. This means if the trees are 10m tall, crops up to 100 m in the leeward direction will be protected. The protective influence will diminish with increasing distance from the windbreak. A permeable windbreak will shelter a longer stretch of cropland than a dense windbreak.

10.3.4 Planting shelterbelt along the east coast of India under different names like bio-shield, bio-wall etc has been continuing since long. Until recently, stress had been on raising mono-crop of Casuarina equisetifolia. The utility of shelterbelt received much attention after the recent tsunami which played havoc in the coastal region. In West Bengal's coastal districts of South 24 Parganas and East Medinipur, Forest Department successfully raised multi-row shelter belt with diverse species including mangroves.

10.3.5 Composition of Shelterbelt

A typical shelterbelt may consist of a central core of a double-row planting of fast -and tall -growing species such as *Eucalyptus* spp., *Casuarina* spp., or neem (*Azadirchta indica*), and two rows each of shorter spreading species such as *Cassia* spp., *Prosopis* spp. or *Leucaena* spp. on both sides of the central core. *Agave* spp. are also used, especially on the outer rows (away from crop fields). Since tree shapes vary with age, it is usually necessary to mix several species of different growth rates, shapes and sizes in multiple rows. Fast- and slow-growing species as well as trees with longer and shorter life-spans should be mixed to extend the useful life of the windbreak. Mixing species also provides protection against attack from diseases or insects that can easily destroy single-species stands. Diversifying the species in the windbreak can also bring a wider variety of useful products to local users.

10.3.6 Coastal Shelterbelt at Dakshin Kadua near Contai in East Medinipur Division

An experimental plantation of shelter belt at Dakshin Kadua in the coastal area of Contai was established by Silviculture South Division in 2003. The area comprising semi-stable sand dune and mud flat was first of all fenced to eliminate chances of biotic interference and to allow natural regeneration of local species. Artificial regeneration was then resorted to by way of sowing and transplanting. A number of species were tried over the years to judge their suitability and it was monitored which of the species were favoured under the local conditions for establishment through process of natural and artificial regeneration. Excerpt of tour note (03-05 jan, 2007) of Shri A Basu Ray Chaudhuri, former CCF Research and Monitoring is reproduced below to give an insight into the status of the plantation after about four years. The note will also indicate which species had performed well in the area.

"2003 coastal shelter belt (2.6 ha.) at Dakshin Kadua – The area was taken up to study and standardize a protocol for management of coastal areas with special emphasis on regeneration of mangroves. In the stable sand dune, Casuarina and Akashmani have grown very tall and healthy. Elimination of biotic interference has helped to produce a dense vegetation which otherwise is not found in the adjoining areas. The leeward side has harboured natural colonization of *Azadirachta* indica (Neem) and *Pongamia pinnata* (Karanj). It was interesting to see that a number of medicinal plants tried on the leeward side have established very well. These included *Hemidesmus indicus* (Anantamul), *Ocimum tenuiflorum* (Kalotulsi), *Ocimum sanctum* (Sada Tulsi), *Tylophora indica* (Antamul), *Andrographis paniculata* (Kalmegh), *Cissus quadrangularis* (Harjora), *Calanchoe pinnata* (Patharkuchi), *Withania somnifera* (Ashwagandha), Solanum torvum (Gothbegun), *Abrus precatorious* [Kuch(Red)] etc. Dibbling of seeds has also produced Tal and Khejur plants. In the unstable sand dune, the species which had established earlier were still surviving. They are Prosopis juliflora (Saibabla), Karanj, Subabul, Babla, *Pandanus odoratissimus* (Keya), *Ricinus communis* (Rerhi) etc. The wave action zone that is the mudflat area below the second line of Keya still remains a difficult area. While floor vegetation is slowly coming up, the tree species that were tried did not establish. *Avicennia* species is surviving, though not promising at all. During 2006 infilling by Gneoa has been tried. It is suggested that the area remains closed so as to facilitate colonization of mangroves. Over and above, planting of a number of estuarine species may be tried."