Technical Manual

Integrated Watershed Management Programme

GSWMA

Gujarat State Watershed Management Agency

Commissionerate of Rural Development, Gandhinagar

Government of Gujarat

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Executive Summary

This Technical Manual for Integrated Watershed Management Programme is prepared by experienced technical officials of Gujarat State Watershed Management Agency (GSWMA), in consultation with various professional research institutes i.e. Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Vasad (Anand), Central Ground Water Board (CGWB), West Central Region, Ahmedabad, Narmada, Water Resources, Water Supply and Kalpsar Department, Govt. of Gujarat, Gujarat Land Development Corporation (GLDC) and referred various technical books and reports on watershed Development. This manual will act as a key tool to all the field engineers of integrated Watershed Management Programme (IWMP) for practical guidance. Comprehensive details is written for all types of possible soil and water conservation engineering structures in ridge to valley principle under IWMP, as per the new common guidelines 2008 issued by Ministry of Land Resources, Government of India.

The appropriate design and proper selection of site is very important for ridge to valley treatment. This manual gives systematically ridge to valley treatment with details engineering activities with appropriate design, drawings, estimation example and photograph of each structure. Chapter-1 involves watershed concept and its related terminology. Chapter-2 involves soil and moisture conservation activities for upper catchment area treatment that covers contour bunding, contour trenching, bench terracing, nala plug, loose boulder checks, chute spill way, etc. Chapter-3 involves land development activities for middle catchment area treatment that covers land leveling, farm bund, farm pond and waste weir. Chapter-4 involves soil and water conservation activities for lower catchment area treatment covers gabion structures, earthen dams, masonry check dams, earthen dam, sub-surface check dams/dykes. Chapter-5 involves measures for soil acidity and soil salinity covers its causes and management. Chapter -6 involves measures for water logging that covers on farm water management, surface drainage and sub-surface drainage methods. Chapter-7 involves various techniques of groundwater recharge, covers artificial recharge to ground water through recharge pits, recharge trenches, existing tube wells, percolation tanks, recharge shafts and through existing dug wells. Chapter-8 involves details of roof top rain water harvesting structures.

Abbreviations

AKF	Aga Khan Foundation
AKRSP	Aga Khan Rural Support Programme
BAIF	Bharatiya Agro-Industries Foundation
BCR	Benefit-Cost Ratio
BDO	Block Development Office
BPL	Below Poverty Line
CAPART	Council for Advancement of People's Action and Rural Technology
CAZRI	Central Arid Zone Research Institute
CBO	community-Based organisation
CDS	Current Daily Status
CEO	Chief Executive Officer
CESS	Centre for Economic and Social Studies
CGWB	Central Ground Water Board
CIDA	Canadian International Development Agency
CSWCRTI	Central Soil and Water Conservation Research and Training Institute
DDP	Desert Development Programme
DLR	Department of Land Resources
DPAP	Drought Prone Areas Programme
DRDA	District Rural Development Agency
DSC	Development Support Centre
DWDU	District Watershed Development Unit
EAP	Externally Aided Project
EAS	Employment Assurance Scheme
FAO	Food and Agricultural Organisation of the United Nations
FPR	Flood Prone Rivers
FRL	Full Reservoir Level
GIA	Gross Irrigated Area
GIS	Geographical Information System
GLDC	Gujarat Land Development Corporation
GPS	Global Positioning System
GSWMA	Gujarat State Watershed Management Agency
GWD	Ground Water Development

GWT	Ground Water Table
HM	Hhard Mooram
HST	Hind Swaraj Trust
IARI	Indian Agricultural Research Institute
ICAR	Indian Council of Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
IGWDP	Indo-German Watershed Development Programme
IIM	Indian Institute of Management
I-JRY	Innovative Jawahar Rozgar Yojana
IRR	Internal Rate of Return
IT	Information Technology
IWDP	Integrated Wastelands Development Programme
IWMI	International Water Management Institute
IWMP	Integrated Watershed Management Programme
LCC	Land Capability Class
LEISA	Low External Input Sustainable Agriculture
LGP	Length of Growing Period
MDT	Multi-Disciplinary Team
MGNREGS	Mahatma Gandhi National Rural Employment Guarantee Scheme
MIS	Management Information System
MoRD	Ministry of Rural Development
MoU	Memorandum of Understanding
MTO	Master Trainer Organisation
NABARD	National Bank for Agriculture and Rural Development
NASDORA	National Authority for Sustainable Development of Rainfed Areas
NBSS-LUP	National Bureau of Soil Survey and Land Use Planning
NCMP	National Common Minimum Programme
NDDB	National Dairy Development Board
NGO	Non-Government Organization
NRM	natural resource management
NRSA	National Remote Sensing Agency
NSS	National Sample Survey
NTFP	Non-Timber Forest Produce
NWDPRA	National Watershed Development Programme for Rainfed Areas

PE	Professional Expert
PET	Potential Evapo-Transpiration
PIA	Project Implementing Agency
PM	Project Manager
PMES	Participatory Monitoring and Evaluation Systems
PNP	Participatory Net Planning
PRA	Participatory Rural Appraisal
PRADAN	Professional Action for Development and Networking
PRI	Panchayati Raj Institution
PRM	Participatory Resource Mapping
PSI	People’s Science Institute
RDT	Rural Development Trust
RVP	River Valley Projects
SC	Scheduled Caste
SHG	Self-Help Group
SIDA	Swiss International Development Agency
SIDBI	Small Industries Development Bank of India
SMC	Soil and Moisture Conservation
SoR	Schedule of Rates
SPS	Samaj Pragati Sahayog
ST	Scheduled Tribe
SVO	Support Voluntary Organisation
TE	Technical Expert
VRTI	Vivekananda Research and Training Institute
VWC	Village Watershed Committee
WA	Watershed Association
WASSAN	Watershed Support Services and Activities Network
WC	Watershed Committee
WDF	Watershed Development Fund
WDT	Watershed Development Team
ZP	Zilla Panchayat

Chapter- 1

Watershed Concept

1.1 Introduction

The stress on water resources started in Gujarat due to green revolution (in early Sixties), fast development in industrial sector and change in health and hygiene habits of people of Gujarat. Hectic exploration and exploitation of ground water for drinking, agricultural and industrial purposes has been practiced all over the Gujarat state for past few decades, which has resulted in dwindling of water levels. Ground water was being used by means of shallow wells in 1960-61, a practice, which turned, gradually from wells to bores and tube wells to deeper tube wells. Exploration has already reached to the levels of almost 600 Mts. in hard rock areas and 400 Mts. in alluvium areas.

This phenomenon has activated minds of many scientists and engineers working in water sector, to dedicate their professional lives to study water for its proper use and management for future needs. Land degradation is a major cause of productivity losses and soil erosion is the most serious one among the various factors affecting land degradation. Therefore soil conservation is of primary importance in any land development work. Also, in dry lands, soil water (moisture) conservation is of vital importance for successful crop production. There are many time-tested technologies for soil and water conservation that can be adopted for alternate land use systems whether it is crop production, horticulture, agro-horticulture systems, agro-forestry, silvi-pasture system or any other. The type of soil and water conservation measure will depend on the size and shape of the areas to be developed for cropping, its location within the watershed of which this area is a part, the kind of plantation being taken up etc. For small areas, in situ conservation practices such as formation of basins, or micro relief systems and agronomic conservation practices may suffice whereas for large plantations, watershed scale development work may have to be taken up.

Since 1996, Government of India has issued guideline for the implementation of area development programme adopting watershed approach. Watershed approach aims at restoration of ecological balance preserving environment and stabilizing the income of village community both farmers, asset less and landless agricultural labour. The importance of watershed development cannot be underestimated. On one hand is the need to increase food productivity and hence productivity from soil and the other increasing soil erosion and depleting water availability.

Water is almost a dual edge sword, in the form of rain, if allowed to fall and flow unabated and unchecked. If instead it can be captured allowed percolation time, it can deplete reservoir and half soil erosion to a certain extent. It thus makes sense to adopt soil and water conservation method together through watershed management and development. Watershed management discusses the impact of watershed on people, the need for people participation and how this can be achieved and most considerably provides a format for watershed planning.

1.2 Watershed Approach for National Resources Conservation

The scope of soil conservation is very wide and encompasses much more than physical work for erosion control. The concept of soil conservation, now-a-days has been expanded to mean protection of the soil against physical loss by erosion or against chemical deterioration. Thus, the effective conservation and management of land, water and vegetation resources aimed at obtaining optimum and sustained return from these resources without degrading them can be achieved by adopting watershed as basic unit of development. Watershed being a natural hydrological entity, it responds most effectively to various engineering, biological and cultural treatments. Monitoring of runoff and silt at the outlet of the watershed can help assess the impact of various treatments aimed at conserving soil and water, and protecting vegetation.

Watershed management involves protection of land against all forms of degradation, restoration of degraded land, sediment control, pollutants control, and prevention of floods, etc. A workable size of the watershed can be decided in accordance with the aim and objective of the particular system as well as the size of the stream for which it forms a catchment. Watershed of smaller size has distinct advantage of involving a smaller number of families within a resource unit with a common social and economic pattern. Demarcation of watershed and subsequently sub watersheds can be done either by using toposheet of the area available with Survey of India or by interpretation of remotely sensed imagery of the area. Prioritization of sub watershed should be done on the basis of sediment yield and pollutants concentration in the runoff from the sub watershed. The entire watershed can be treated gradually over a number of years as per the availability of financial and other resources.

Numerous treatment technologies in the form of engineering measures and agronomic practices are available. But identification of most suitable technologies as per the site condition and their application in correct way is most important to achieve the desired results. These technologies when adopted within the boundary of watershed, facilitates favorable interaction among various watershed factors such as physiography, land slope, soil characteristics, land use, hydrological behavior etc, land and water resources to produce food, fodder, fuel and fiber on sustainable basis. In this manual only engineering measures suitable for the region are discussed. Engineering measures are also called mechanical measures. These measures are aimed at arresting the movement of eroded soil by reducing the slope length and / or slope steepness or gradient and conserving water by different methods. Some of these measures suitable for agricultural lands and their design and potential land use models are discussed.

This manual "Technical Manual for Watershed" aims to attempt development of watershed in the Indian context and particularly considering the need of Gujarat. It aims at actual identifying ideal soil conservation structures, water harvesting structures and their design situated to a particular topography. It is meant for those individuals like Multi Disciplinary Team (MDT)/Watershed Development Team (WDT) member, Line Departments and organizations who will be involved in planning, implementing and/or monitoring of watershed programme. It will be helpful as they will work out how structures are built and cost estimated.

1.3 Objectives of the Manual

The manual will play a key tool of practical guidance to the field engineers at village level as well as district levels. Many of field engineers are joining as fresh without any practical experience and many field engineers not having relevant field experiences will get the benefited from this manual. This manual is prepared in comprehensive for all types of possible soil and water conservation engineering structures applicable in integrated watershed management programme as per the new common guidelines 2008 issued by Government of India. The proper design and proper selection of sites have discussed in this manual systematically in ridge to valley development approach with drawings and example photographs of each structures. This manual covers complete engineering treatments starting with basics and concept of watershed development and management, various factors and terminology used in watershed development programme, then upper catchment area treatment, lower catchment area treatment, land development activities, acidity and salinity controls, treatments for partial water logging areas, ground water recharging techniques and roof rain water harvesting techniques. The stake holders will be able to:

i) Apply integrated approach to watershed.
ii) Apply techniques of soil and water conservation in watershed management.
iii) Use rainwater-harvesting techniques.
iv) Reclamation of soil acidity and salinity.

1.4 Watershed Management

A watershed is an area from which runoff, resulting from precipitation, flows past a single common outlet point into a large stream, a river, lake or a reservoir. In other words a watershed is a topographically delineated area that is drained by a stream system through single outlet. A watershed is made up of its physical and hydrological natural resources as well as human resources. Watershed management implies the proper use of all land and water resource of a watershed for optimum production with minimum hazard to natural resources. A watershed may be only a few hectares as in case of small ponds or hundreds of square kilometers as in case of rivers. All watersheds can be divided into smaller sub watersheds.

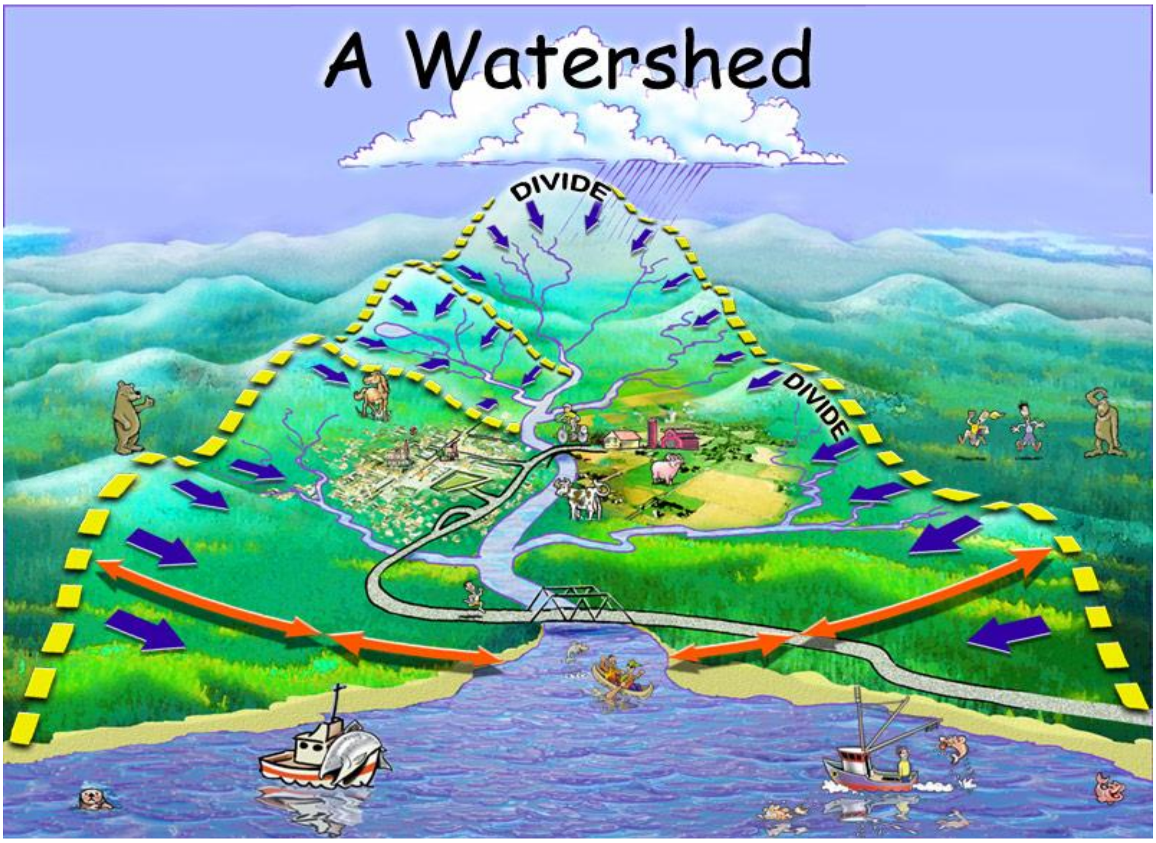


Fig 1: A watershed

Table 1: Hierarchy of Watersheds

Category	Size (ha)
Basin	30,00,000-300,00,000
Catchment	10,00,000-30,00,000
Sub-catchment	2,00,000-10,00,000
Watershed	50,000-2,00,000
Sub-watershed	10,000-50,000
Milli-watershed	4000-10,000
Mini watershed	1000-4000
Micro-watershed	100-1000

The objectives of watershed management are:

i) To control damaging runoff
ii) To manage and utilize runoff for useful purposes
iii) To control erosion
iv) To moderate floods in the downstream areas
v) To enhance groundwater storage and
vi) To decide use of appropriate of the land resources in the watershed.

The factors which affect the watershed behavior and which need to be studied in management programmes are (i) size and shape of the watershed (ii) topography (iii) soil and their characteristics, (iv) precipitation (v) land use and (vi) vegetative cover.

Data to be collected for planning of watershed programmes are (i) hydrological information - precipitation, climate data, flow data and sediment flow. (ii) Soil and land use data - land use, soil data, topography, geology and vegetation and (iii) Socio-economic data as per needs of the people to work out cost benefit of the project.

Chapter-2

2 Terminologies related to Watershed

2.1 Precipitation

It is nothing but the all atmospheric moisture that reaches to earth surface in liquid, vapor or solid forms. The liquid form of precipitation that is rainfall is used for various purposes such as land use planning, identification of crop growth period, choice of cropping pattern, resources allocation, etc.

2.1.1 Rainfall Parameters

Rainfall parameters which are important from soil conservation and hydrological point of view are rainfall amount, duration, intensity and rainfall frequency.

2.1.2 Rainfall Amount

Rainfall amount is the depth to which rainwater would collect on horizontal surface under conditions of no infiltration, no runoff and no evaporation. In other words, it is vertical depth to which rainwater would collect if water remains where it falls. It is measured in terms of linear unit i. e. in mm or cm.

2.1.3 Rainfall Duration

The period during which the rainfall occurs is known as the duration of rainfall. It has the unit of time, viz; second, minutes or hours.

2.1.4 Rainfall Intensity

Rainfall Intensity is defined as the rate at which rainfall takes place or it is the amount of rainfall occurring per unit of time. It is expressed in units of mm/hr or cm/hr. It is one of the most important parameter which is used for the design of soil and water conservation structures. A high intensity rainfall occurring over a short period is more harmful for the unprotected soil as compared to low intensity rainfall occurring over a longer period, the total amount of rainfall remaining the same.

2.1.5 Rainfall Frequency

Rainfall frequency and return period are synonymous terms and denote the period in years during which a storm of given intensity and duration can expected to occur. Thus, if at a given station the maximum daily precipitation of 30 cm has got recurrence interval of 10 years, it means that on this station, the chances of rainfall are such that once in 10 years, rain is likely to equal or exceed 30 cm.

2.2 Measurement of Rainfall

Measurement of rainfall is a process of sampling wherein the rainfall measuring devices are located at predetermined points in the watershed and then the average value is determined for the area. Rain gauge is the device/instrument used for the measurement of rainfall. Two types of rain gauges are used for measurement of rainfall, viz; non-recording or standard rain gauge and recording rain gauge. Rainfall can be measured simply by installing a rain gauge. A simple manual rain gauge (non-recording type) can be easily installed in an open area and the accumulated rainfall measured regularly i.e once in a day. All forms of precipitation shall be measured on the basis of vertical depth of water.

Pour the water collected from bottle (from inside the gauge) into the glass-measuring cylinder (IS: 4849-1968) placed on level surface. Need to take care to avoid spilling of the collected water. Take the reading at the bottom of curved surface of the water and estimate it to the nearest 0.1 mm

If there is more water in the bottle than the measuring glass can hold, fill the glass nearly up to the top graduation mark, take the reading and throw away the water. Repeat till all the collected water has been individually measured and noted. The total rainfall is the sum of all these measurement.

Measurement must be taken daily at 8.30 hr Indian Standard Time. Examine the raingauge daily at this hour even if there is no rainfall.

Use a rain gauge of appropriate capacity as specified in IS:5225-1969 for measuring very heavy rainfall

If rainfall is very heavy at the time of observation, place a spare bottle immediately after the bottle inside the receiver is taken out so that no record is missed during the interval. Replace the bottle quickly and pour the rainfall collected in spare bottle in it.

2.3 Installation of Rain gauge

The base of rain gauge should be masonry or concrete foundation of size 600 X 600X600 mm, sunk into the ground in such a manner that the rim of the rain gauge is exactly 300 mm above the ground level. This height is necessary to prevent water splashing into the gauge.

Keep the top of the gauge perfectly level and true to shape, as change in the effective area of the collector changes the amount of rain collected.

In flood-prone areas, maintain the level of rain gauge 300 mm above the maximum flood level.

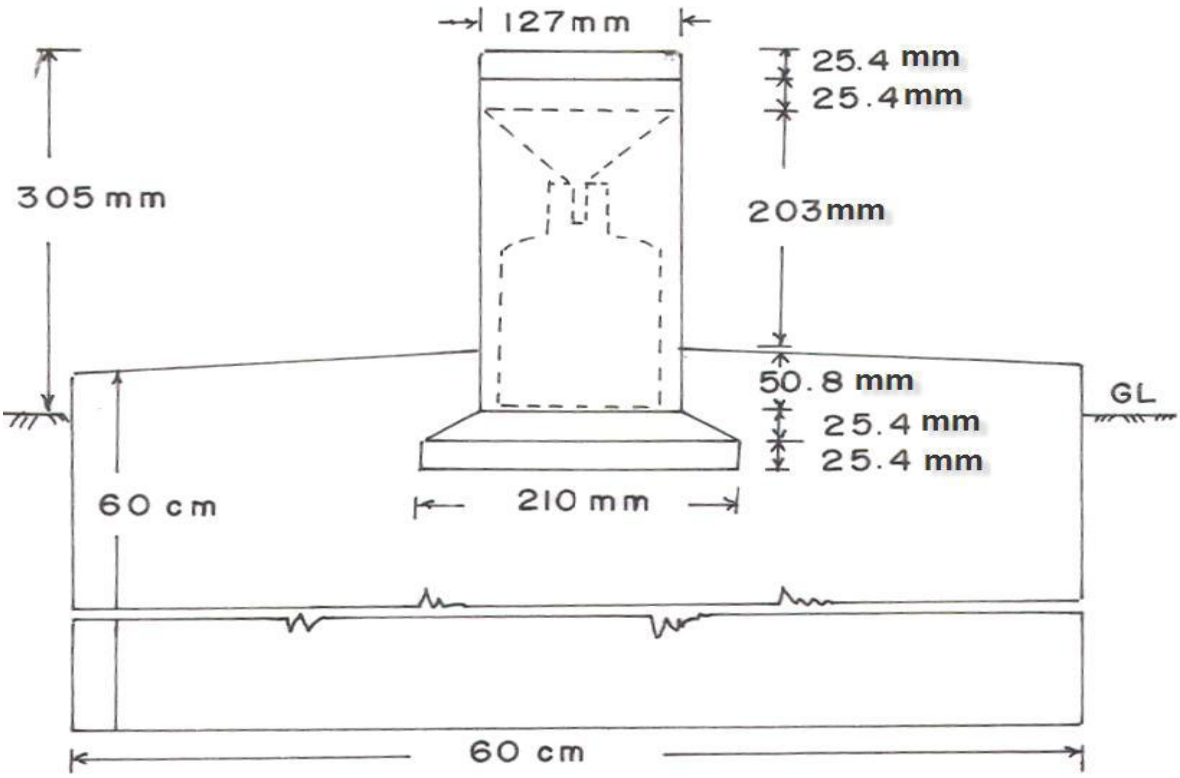


Fig 2: Non-recording type Rain Gauge

2.4 Outflow from the Watershed

Outflow from the watershed means, the amount of water that leaves the watershed surface area. It takes into account various parameters, which help in calculating the actual outflow that has occurred from the watershed. These parameters include evaporation, evapo-transpiration, subsurface outflow, ground water recharge, soil moisture, surface runoff and surface storage.

2.5 Evaporation

Water that lost as vapour from soil or open surface is called evaporation. There are various methods to calculate the evaporation within the area. The pan evaporation method is the most commonly used method. Imagine the open container, with a depth of 15 mm of water in it, leave the container in the field for 24 hr and make sure that it does not rain during those 24 hr. After 24 hr, a part of the water originally in the container will have evaporated. If only 9 mm of water depth remains in the container, then the evaporation during that day was 15-9 = 6 mm.

2.6 Evapotranspiration (ET)

Evapotranspiration of the particular area is the water lost from soil by evaporation and water lost from plant leaves by transpiration. The evapotranspiration of crop is the total amount of soil water used for transpiration by plants and evaporation from the surrounding soil surface. Evapotranspiration is commonly expressed in mm of water used per day (mm/day)

2.7 Subsurface Outflow or Subsurface Runoff

It is the part of rainfall, which leaches into the soil and moves laterally without joining the water table, to the streams, rivers or ocean. This parameter is one of the major components in measuring the water balance. This is collected in stream and can be observed in the forms of a flow in stream in the month of January to May. Subsurface flow could be calculated using the simple method of calculating the discharge of seepage in the streams or any outlet.

2.8 Surface Storage

Surface storages include all the surface water storages existing in the watershed. For accurate calculation of the amount of water in each structure, a contour survey of the site is necessary. Based on the contours, one can accurately define the storage capacity of the structure. To calculate the storage capacity of surface water, thumb rule equation can be used as Storage= 0.4 x Length of spread x Breadth of dam x Height of water near the dam.

2.9 Surface Runoff

It is that portion of rainfall, which enters the stream immediately after the rainfall. It occurs when all losses are satisfied and if rain is still continued, with the rate greater than infiltration rate, at this stage water starts flowing over the land as overland flow. For the design of any soil and water conservation structures and waterways or channels, runoff volume and peak rate of runoff are required to be estimated. Runoff rate is expressed in cubic meter per seconds and runoff volume or water yield from watershed is generally expressed as m^3.

2.10 Factors affecting Surface Runoff

2.10.1 Climatic Factors

The climatic factors of the watershed affecting the runoff are mainly associated with the characteristics of precipitation, which include:

i) Type of precipitation
ii) Rainfall intensity
iii) Duration of precipitation
iv) Rainfall distribution
v) Direction of prevailing wind

2.10.2 Physiographic Factors

Physiographic factors of watershed consist of both, the watershed as well as channel characteristics. The different characteristics of watershed and channel, which affect the runoff, are listed below:

2.10.3 Area of the Watershed

The area of watershed is also known as the drainage area and it is the most important watershed characteristic for hydrologic analysis. It reflects the volume of water that can be generated from a rainfall. The total volume and rate of runoff depends on the area of the watershed. However, per unit area values decreases due to longer opportunity time.

2.10.4 Length of Watershed

This is the distance traveled by the surface drainage and sometimes more appropriately labeled as hydrologic length. This length is usually used in computing a time parameter, which is a measure of the travel time of water through a watershed. The watershed length is therefore measured along the principal flow path from the watershed outlet to the basin boundary. As the length of watershed is more, runoff takes more time to reach at its peak value.

2.10.5 Slope of watershed

Watershed slope affects the momentum of runoff. Watershed slope reflects the rate of change of elevation with respect to distance along the principal flow path. It is usually calculated as the elevation difference between the endpoints of the main flow path divided by the length. Higher slope causes high runoff rate within short period of time. Therefore in watershed development principle, we try to reduce the slope so that runoff takes more time to reach the outlet and during that period a part of it recharges ground water.

2.10.6 Land Use

Land use pattern, local crop management practices; forest or grass land determines the runoff producing characteristics of the watershed. Vegetated watershed produces less runoff than the bare watershed due to induced opportunity time. During a rainstorm, flow from an impervious steeply sloped and smooth surface make a little retardation and no loss to the flow. In comparison, flow along a pervious grassy hill of the same size will produce retardation and significant loss to the flow due to infiltration.

2.10.7 Drainage Density

The drainage density (D_d) is defined as the ratio of total length (L) of channel in the watershed to the total watershed area (A). The drainage density and its pattern affects the runoff, greater the drainage density, more would be the runoff due to efficient drainage. $D_d = L/A$

2.10.8 Soil type

In the watershed, the surface runoff is mainly influenced by soil type, soil structure and soil texture as the infiltration and permeability depend upon the soil characteristic. More runoff is expected from a layered soil, as compared to homogeneous profile.

2.10.9 Basin Shape

Basin shape is not used directly in hydrologic design methods; however, parameters that reflect basin shape are used occasionally and have a conceptual basis. Watersheds have an infinite variety of shapes, and the shape supposedly reflects the way that runoff will “bunch up” at the outlet. A circular watershed would result in runoff from various parts of the watershed reaching the outlet at the same time. An elliptical watershed having the outlet at one end of the major axis and having the same area as the circular watershed would cause the runoff to be spread out over time, thus producing a smaller flood peak than that of the circular watershed.

2.10.10 Stream Order

Horton (from Horton’s infiltration equation fame) developed a set of “laws” that are indicators of the geomorphologic characteristics of watershed. The stream order is a measure of the degree of stream branching within a watershed. Each length of stream is indicated by its order (for example, first-order, second-order, etc.). A first-order stream is an un-branched tributary, a second-order stream is a tributary formed by two or more first-order streams. A third-order stream is a tributary formed by two or more second-order streams and so on. In general, an n^{th} order stream is a tributary formed by two or more streams of order (n-1) and streams of lower order. The stream through which all discharge of water and sediments pass in the stream is known as highest order stream of that watershed. For a watershed, the principal order is defined as the order of the principal channel. Usefulness of the stream order is based on the premise that the order is directly proportional to size of the contributing watershed, to channel dimensions and to stream discharge at that place in the system. The figure below gives an example of stream ordering. The concept of stream order is used to compute other indicators of drainage character. The **bifurcation ratio** (R_b) is defined as the ratio of the number of streams of any order to the number of streams of the next highest order. Values of R_b typically range from the theoretical minimum of 2 to around 6. Typically, the values range from 3 to 5. The bifurcation ratio is calculated as

$R_b = N_i/N_{i+1}$

From this, Horton developed the Law of Stream Numbers_which relates the number of streams of order I (N_i) to the bifurcation ratio and the principal stream order (k)

$N_i = R_b^{k-1}$

Example: The bifurcation ratio of a watershed is the average of the bifurcation ratios of each stream order. For a watershed with a bifurcation ratio of 2.6 and a fourth-order principal stream,

$N_i = 2.6^{4-I}$

This would predict 18, 7, and 3 streams of order 1, 2, and 3, respectively. In addition to this Horton proposed a Law of Stream Lengths, in which the average lengths of the streams of successive orders are related by a length ratio R_L:

$R_L = L_{i+1}/L_i$

$L_i = L_1 r_L^{i-1}$

By similar, Schumm (1956) proposed a **Law of Stream Areas** to relate the average areas A_i drained by streams of successive order

$R_A = A_{i+1}/A_i$

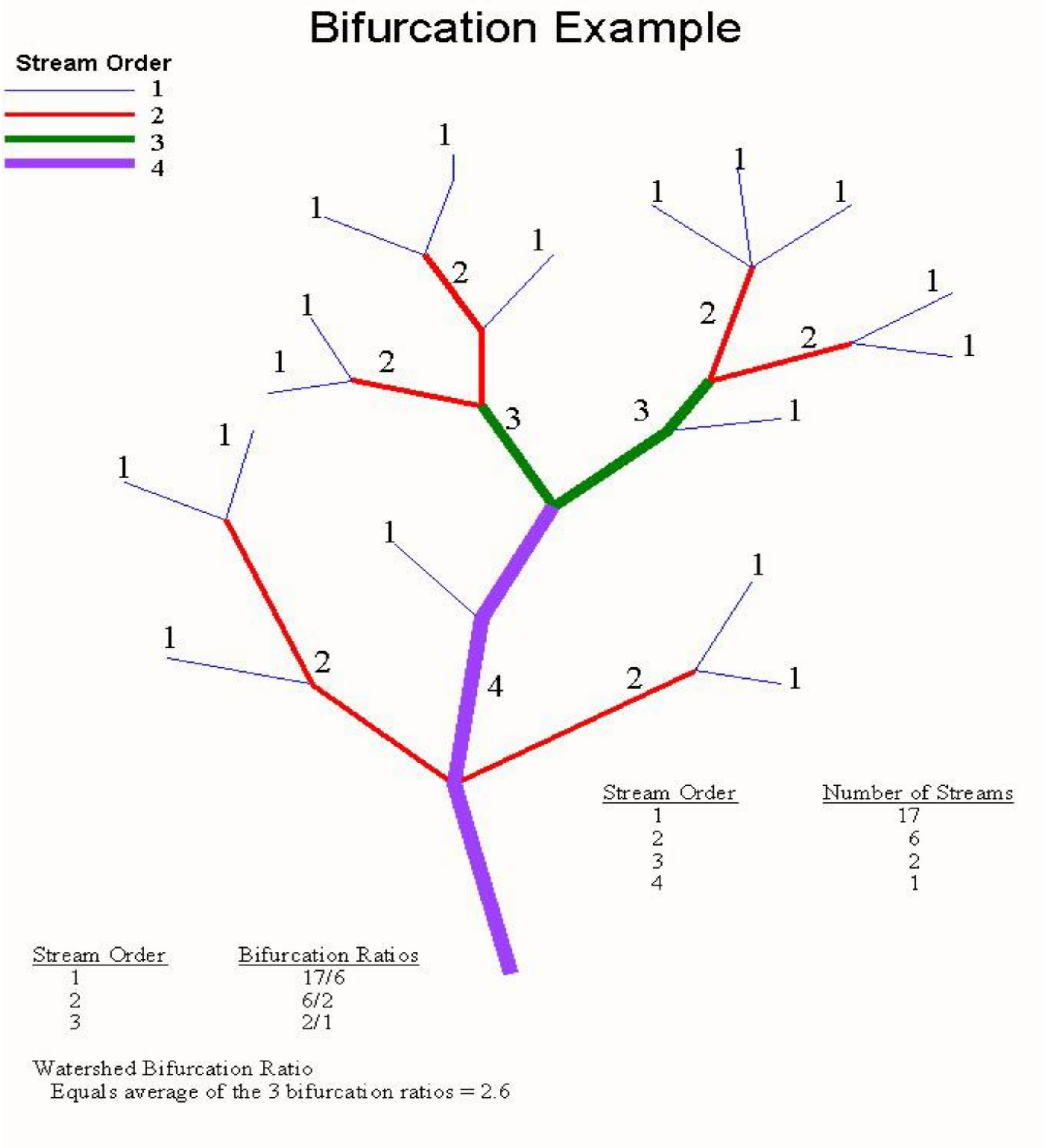


Fig 3: Stream order

2.10.11 Drainage Patterns

Geomorphologists and hydrologists often view streams as being a part of drainage pattern. Over time, a stream system will achieve a particular drainage pattern to its network of stream channels and tributaries as determined by local geologic factors. Drainage patterns are classified on the basis of their form and texture. Their shape or pattern develops in response to the local topography and subsurface geology. Drainage channels develop where surface runoff is enhanced and earth materials provide the least resistance to erosion. The texture is governed by soil infiltration, and the volume of water available in a given period of time to enter the surface.

A **dendrite drainage pattern** is the most common form and looks like the branching pattern of tree roots. It develops in regions underlain by homogeneous material. That is, the subsurface geology has a similar resistance to weathering so there is no apparent control over the direction the tributaries take. Tributaries are joining larger streams at acute angle (less than 90 degrees).

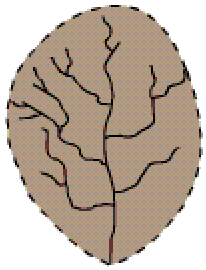


Fig 4: Dendrite drainage pattern

Parallel drainage patterns form where there is a pronounced slope to the surface. A parallel pattern also develops in regions of parallel, elongate landforms like outcropping resistant rock bands. Tributary streams tend to stretch out in a parallel-like fashion following the slope of the surface. A parallel pattern sometimes indicates the presence of a major fault that cuts across an area of steeply folded bedrock. All forms of transitions can occur between parallel, dendritic, and trellis patterns.

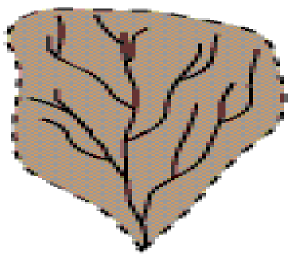


Fig 5: Parallel drainage patterns

Trellis drainage patterns look similar to their namesake, the common garden trellis. Trellis drainage develops in folded topography like that found in the Appalachian Mountains of North America. Down-turned folds called synclines form valleys in which resides the main channel of the stream. Short tributary streams enter the main channel at sharp angles as they run down sides of parallel ridges called anticlines. Tributaries join the main stream at nearly right angles.

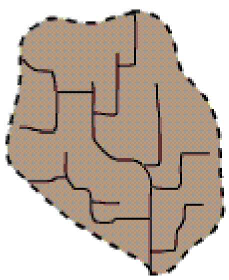


Fig 6: Trellis drainage pattern

Deranged or contorted patterns develop from the disruption of a pre-existing drainage pattern. Fig. 7 began as a dendritic pattern but was altered when overrun by glacier. After receding, the glacier left behind fine grain material that forms wetlands and deposits that dammed the stream to impound a small lake. The tributary streams appear significantly more contorted than they were prior to glaciation.

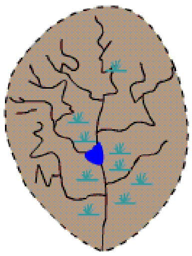


Fig 7: Deranged or contorted pattern

2.11 Runoff Estimation

There are number of methods and empirical formulae employed for the estimation of runoff. The two commonly used methods of runoff computation from small watershed are rational method and Empirical formulae method.

2.11.1 Rational Method

For urban watersheds of less than 100 acres that are not complex and do not have significant storage areas, it is acceptable to use the Rational Method to determine peak flow rates only. Due to its simplicity and inherent assumptions, it may not be appropriate for some applications. Different components of the Rational Method are explained below

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

Where,

Q = Peak rate of runoff, m^3

C = Runoff Coefficient (constant value ranges from 0 to 1)

I = Rainfall intensity for design frequency and duration equal to time of concentration, mm/hr

A = Area of watershed, Ha

The general procedure for Rational Method calculations for a single watershed is as follows:

Delineate the watershed boundary and calculate its area.

Define and measure the flow path from the upper-most portion of the watershed to the deign point.

i) Calculate the slope for the flow path.
ii) Calculate time of concentration, *Tc*
iii) Find the rainfall intensity I, for the design storm using the calculated *Tc* as the duration.
iv) Determine the runoff coefficient, *C*
v) Calculate the peak flow rate from the watershed using above equation

Table 2: Value of runoff coefficient, C

Vegetative cover	Slope (%)	Soil Texture		
		Sandy Loam	Clay and slit Loam	Stiff clay
Cultivated land	0-5	0.3	0.5	0.6
	5-10	0.4	0.6	0.7
	10-30	0.52	0.72	0.82
Pasture land	0-5	0.1	0.3	0.4
	5-10	0.16	0.36	0.55
	10-30	0.22	0.42	0.60
Forest land	0-5	0.1	0.3	0.4
	5-10	0.25	0.35	0.50
	10-30	0.3	0.50	0.6

(Source: "Soil and Water Conservation Engineering" book by R. Suresh)

2.11.1.1 Time of Concentration

The time of concentration, Tc, is defined as the time required for water to travel from the most hydraulically remote point in a watershed to the point of outlet. When using the Rational Method, the rainfall duration used to determine intensity should typically equal the time of concentration of the drainage area. If a highly developed portion of the watershed produces a higher rate of runoff than the overall drainage area, then calculations should be based upon the flow length and path that results in a Tc for the highly developed portion of the drainage area only.

Computation of Time of Concentration

There are several empirical relations available for computing the time of concentration, Kirpich (1940) developed an equation for computing the T_c on the basis of channel length and its average slope. The equation is given below

$Tc = 0.0195\ L^{0.77} \times S^{-0.385}$

Where,

Tc = time of concentration, minutes

L = length of channel reach, m

S = average slope of channel, m/m

One Hour rainfall : The intensity of severest rainfall during a given recurrence interval of particular region, during the time interval of one hour is called as one hour rainfall for that return period/frequency. In the rational method, for computing peak runoff, the intensity of rainfall should be equal to the time of concentration; in this case one hour rainfall intensity is converted accordingly with T_c value.

Rainfall intensity for design frequency and duration equal to time of concentration, **cm/hr** is given by following formula

$$I = \frac{K.T^a}{(Tc+b)^n}$$

Where,

L= longest length, m

S= average slope of channel, m/m

T= return period in years

K,a, b and n are constant as per zone.

T_c = time of concentration, minutes

Table 3: Intensity-duration-return period relationship, India

Zone	Station	K	a	b	n
Eastern Zone	Aearthala	8.097	0.1177	0.50	0.8191
	Dumdum	5.940	0.1150	0.15	0.9241
	Gauliati	7.206	(1.1557	0.75	0.9401
	Gava	7.176	0.1483	0.50	0.9459
	Imphal	4.939	0.1340	0.50	0.9719
	Jamshedpur	6.930	0.1307	0.50	9.8737
	Jharsitguda	8.596	0.1392	0.75	0.8740
	Noltll Lakhimpur	14.070	0.1256	1.25	1.0730
	Sagar Island	16.524	0.1402	1.50	0.9635
	Shilons	6.728	0.1502	0.75	0.9575
	Eastern Zone	6.933	0.1353	0.50	0.8801

Zone	Station	K	a	b	n
Southern Zone	Bangalore	6.275	0.1262	0.50	1.1280
	Hyderabad	5.250	0.1354	0.50	1.0295
	Kodaikanal	5.914	0.1711	0.50	1.0086
	Madras	6.126	0.1664	0.50	0.8027
	Mangalore	6.744	0.1395	0.50	0.9374
	Tinichiapalli	7.135	0.1638	0.50	0.9624
	Trivandrurn	6.762	0.1536	0.50	0.8158
	Visakhapatnam	6.646	0.1692	0.50	0.9963
	Southern Zone	6.311	0.1523	0.50	0.9465

Zone	Station	K	a	b	n
Central Zone	Bagra-tawa	8.5704	0.2214	1.25	0.9331
	Bhopal	6.9296	0.1892	0.50	0.8767
	Indore	6.9280	0.1394	0.50	1.0651
	Jabalpur	11.379	0.1746	1.25	1.1206
	Jagdalpur	4.7065	0.1084	0.25	0.9902
	Naapur	11.45	0.1560	1.25	1.0324
	Puuasa	4.7011	0.2608	0.50	0.8653
	Raipur	4.683	0.1389	0.15	0.9284
	Thin	6.088	0.1747	1.00	0.8587
	Central Zone	7.4645	0.1712	0.75	0.9599

Zone	Station	K	a	b	n
Western Zone	Aiiransabad	6.081	0.1459	0.50	1.092.3
	Bhuj	3.823	0.1919	0.25	0.9902
	Mahabaleshvar	3.483	0.1267	0.00	0.4853
	Nandurbar	4.254	0.2070	0.25	0.7704
	Veneurla	6.863	0.1670	0.75	0.8683
	Veraval	7.787	0.2087	0.50	O.S908
	Western zone	3.974	0.1647	0.15	0.7327

Zone	Station	k	a	b	n
Northern Zone	Aera	4.911	0.1667	0.25	0.6293
	Allahabad	8.570	0.1692	0.50	1.0190
	Arnristar	14.41	0.1304	1.40	1.2963
	Dehradun	600	0.22	0.50	0.8000
	Jaipur	6.219	0.1026	0.50	1.1172
	Jodlipur	4.098	0.1677	0.50	1.0369
	Lucknow	6.074	0.1813	0.50	1.0331
	New Delhi	5.208	0.1574	0.50	1.1072
	Srinasar	1.503	0.2730	0.25	1.0636
	Northern Zone	5.914	0.1623	0.50	1.0127

(Source: Technical paper for SMC works by Forest dept. Andhra Pradesh)

Table 4: Recommended maximum runoff frequencies for various types of structures.

Type of structures	Frequency, year
Storage arid diversion dams having permanent spillways	50-100
Earthen dams-storage having natural spillways	25-50
Stop dams/Check dams	25
Small permanent masonry gully control structures.	10-15
Terrace outlets and vegetated waterways	10
Field diversions	15

(Source: Training manual vol. II Soil and Water Conservation Engineering (CSWCRTI)

2.11.2 Runoff Estimation by Empirical Formulae

Empirical Formulae have been derived by Hydrologist and soil conservationists to derive relationship between rainfall over catchment area and resulting runoff for application to ungauged watersheds. The application of such relationship may, however be limited due to variations in factors such as antecedent moisture conditions, infiltration rates and runoff responses. For smaller areas with fairly uniform and evenly distributed rainfall, these relationships may be very simple. However, complexity arises in larger areas having varying conditions of topography, landuse, geological composition and uneven distribution of rainfall. Hence these relationships must be extrapolated with great caution to ungauged watershed under identical agro climatic situations.

2.11.3 *Runoff Co-efficient Method*

In this method runoff is computed simply multiplying the runoff coefficient to the rainfall amount, given as under

R = K. P.

Where, R = Runoff, cm

K = runoff coefficient

P = Rainfall Depth, cm

The values of runoff coefficient for different land use condition are given below.

Table 5: Values of runoff coefficient (K)

Sr. No.	Area	K
1	Urban Area covered by residential Buildings Garden apartments	 0.3 0.5
2	Commercial and industrial area	0.9
3	Forest area	**to 0.2**

2.11.4 Dicken's Formula

$Q = C. A^{3/4}$

Where, Q = flood discharge in m^3/s

A = Catchment area in sq km

C = 11.45 for areas with annual rainfall of 600 mm to 1200 mm.

2.12 Hydrograph

A hydrograph is a graph showing changes in the discharge of a river over a period of time. It can also refer to a graph showing the volume of water reaching a particular outfall, or location in a sewerage network, related to time.

The discharge is measured at a certain point in a river and is typically time variant.

2.12.1 Rising limb

The rising limb of hydrograph, also known as concentration curve represents the increase in discharge due to the gradual building up of storage in channels and over the catchment surface.

2.12.2 Falling limb

The recession limb extends from the point of inflection at the end of the crest segment to the commencement of the natural groundwater flow (base flow). It represents the withdrawal of water from the storage built up in the basin during the earlier phases of the hydrograph.

2.12.3 Peak discharge

The highest point on the hydrograph when there is the greatest amount of water in the river

2.12.4 Lag time

Lag time is the amount of time it takes from when precipitation falls within the river basin to when it reaches the river.

2.12.5 Discharge

Volume of water in a river at a given time

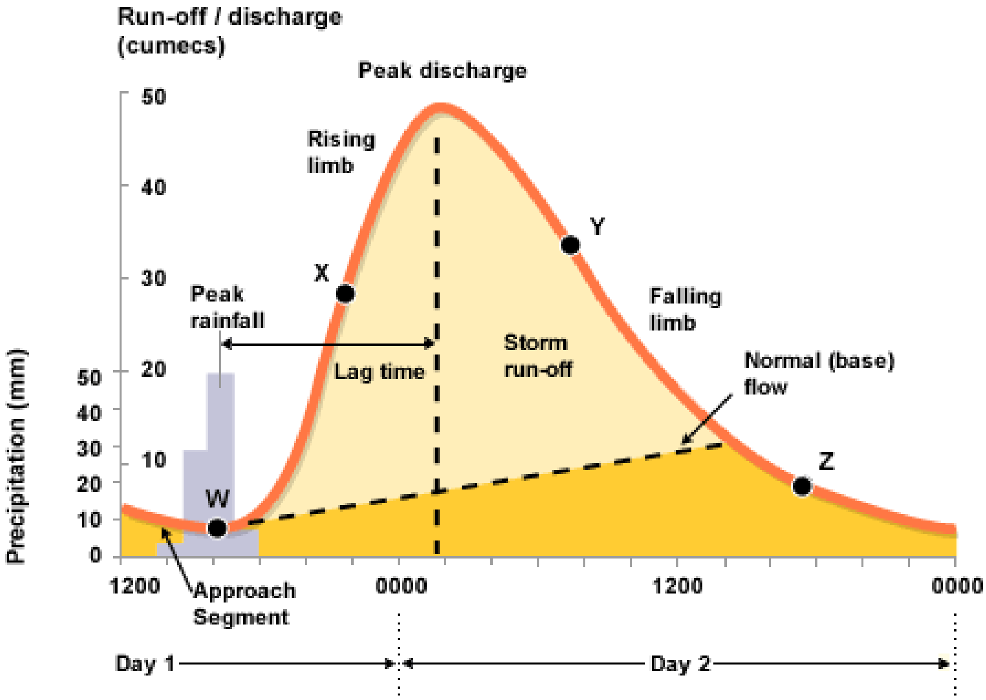


Fig 8. Hydrograph

2.13 Factors affecting the Hydrograph

Soil saturation is dependent on previous rainfall, or otherwise known as Antecedent rainfall. The surroundings; Rural or Urban (Could be less impermeable surface, or the surface type could vary)

i. Vegetation type (Deforestation and amount of interception)
ii. Steepness of surrounding land, or 'relief' land
iii. Drainage density (Number of tributaries)
iv. Geology (Rock Type; Impermeable=flashier hydrographs. Or Permeable)
v. Season dependant; Very dry weather creates a crust on the river bed. Wet winters create increase in discharge.
vi. Soil Type (Clay, sand etc.) Clay would create a flashy hydrograph,
vii. Shape of drainage basin (circular or elongated).
viii. Precipitation (distribution of rainfall rates and locations)

2.14 Soil Properties

For the design of any soil and water conservation structures, soil properties are very important. These properties play significant role in deciding the stability and strength of the structure. Soil properties break down into three categories: impervious, pervious (drains), and semi-pervious (usually unlabelled, general fill). This refers to the soil's ability to drain or retain water. This is an important feature in a soil. The other feature of the soil that will be needed is the strength of the soil. The properties that effect both permeability and strength are numerous and complex. But, they do not have to be understood completely to perform some simple tests to determine if a soil is suitable for a certain application

2.14.1 Soil Classification

Soil can be broken down in to two basic categories: organic soils (such as peat) and nonorganic soils (sand, gravel, silt, and clay). Organic soils are formed from rotting and de-composing plant and animal mater and are characterized by high compressibility, dark colour and occasionally an organic smell. Because of their instable nature and extreme variability it is considered to be completely useless for foundations, embankments, and other forms of en-gineering. Soils with small amounts of organic matter don't have to be discarded completely, but the amount should be as little as possible. Non-organic soils have been produced through erosion and other geologic processes. The four basic soil particles types are: clay, silt, sand, and gravel. The differences between these types of soils are the size of the grain. Clay and silt also have chemical and shape properties that separate them, but since neither can be seen with the naked eye they must be differentiated based on feel and other factors. Since almost all soils contain a combination of these grain sizes, soils can be classified based on how much of each type is present.

Soil texture refers to the relative proportion (by weight) of sand, silt and clay present in soil. This is differentiated from **soil structure,** which is the physical arrangement or grouping together of the individual soil mineral particles. Soil texture is very important in that it effects: 1) soil structure, 2) water holding capacity, 3) nutrient holding capacity, 4) aeration, 5) drainage, and 6) root penetration and growth.

Table 6: Description of Basic Soil Grains

Grain Type	Size	Comments
Clay	0.0005-0.002 mm	Sticky and gooey when wet. Can be molded and rolled without breaking apart. Very hard when completely dried as in an oven.
Silt	0.002-0.06 mm	Very fine material, individual grains can't be seen with the naked eye. When dry silt feels like talcum powder. When wet, clumps break apart and disperse.
Sand	0.06-2 mm	Loose grains over a range of sizes. Even the smallest sand grains can be seen with the naked eye. The soil will feel gritty.
Gravel	2-64 mm	Large grains, easily distinguished.

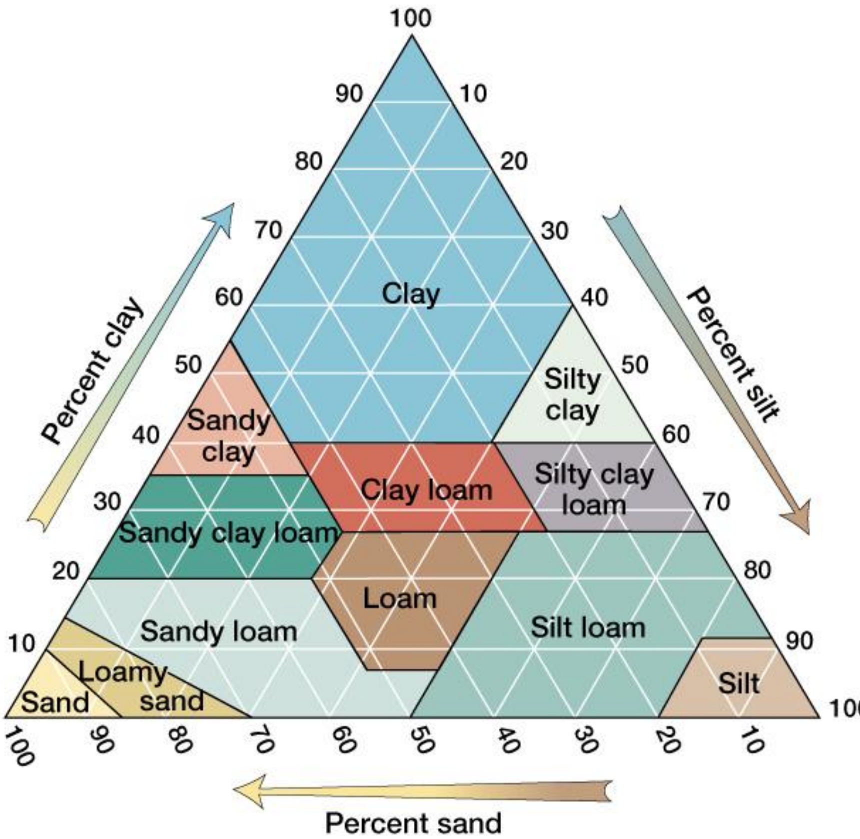


Fig 9. Soil texture triangle

The soil texture triangle shows the percentage (by weight) sand, silt and clay in the various textural classes of soils. The various textural classes denote a range of texture combinations which have similar chemical and physical properties, and yield similar plant growth. Generally, a loam soil is considered the best for overall plant growth. For example, a soil that was found to contain 20% sand, 20% clay and 60% silt would be classified as a silt loam.

2.14.2 Soil Erosion

Erosion is the transport of soil from one place to another. Climatic factors such as wind and rain can cause erosion, but also under irrigation it may occur.

Over a short period, the process of erosion is almost invisible. However, it can be continuous and the whole fertile top layer of a field may disappear within a few years.

Soil erosion by water depends on:

i. The slope: steep, sloping fields are more exposed to erosion;
ii. The soil structure: light soils are more sensitive to erosion;
iii. The volume or rate of flow of surface runoff water: larger or rapid flows induce more erosion.

2.14.3 Soil Erosion Principle

The soil erosion may be defined as a process of detachment, transportation and deposition of soil particle from one place to another place under the influence of wind, water or gravity forces. Detachment is the dislodging of the soil particle from soil mass by erosive agents. Erosion is a function of the eroding power of raindrops, running water, and sliding or flowing earth masse, and the erodibility of the soil or Erosion=f (Erosivity, Erodibility). In case of water erosion, major erosive agents are impacting raindrop and runoff water flowing over soil surface. Transportation is the movement of detached soil particles from their original position. The severity of soil erosion depends upon the quantity of material supplied by detachment process and capacity of eroding agents to transport them. Soil erosion is the major soil conservation problem and almost recognized as a serious threat to human well being.

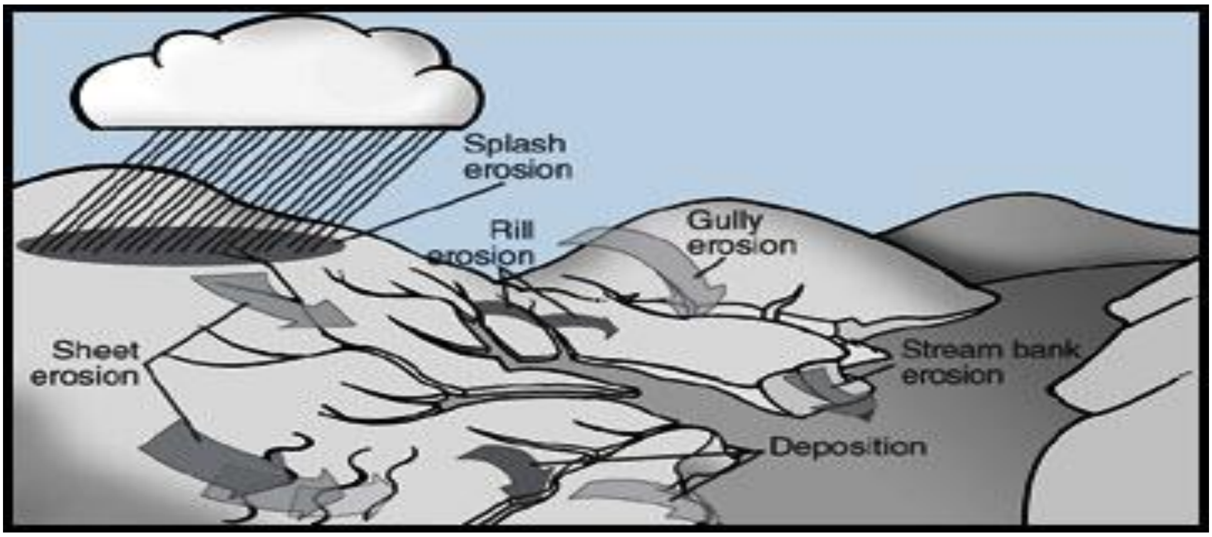


Fig 10: Different forms of water erosion

2.14.4 Factors Affecting Erosion

Climate and geology are the most important influences on erosion with soil character and vegetation being dependent upon them and interrelated with each other.

2.14.4.1 Climate Factor

The major climatic factors which influence runoff and erosion are precipitation, temperature, and wind. Precipitation is the most important factor among them. Temperature affects runoff by contributing to change in soil moisture between drains, it determines whether the precipitation will be in the form of rain or snow and it changes the absorptive properties of the soil by causing the soil to freeze. Ice in the soil, particularly needle ice, can be very effective in raising part of the surface of bare soil and thus making it more easily removed by runoff or wind. The wind effect includes the power to pick up and carry fine soil particles, the influence it exerts on the angle and impact of raindrops and, more rarely, its effect on vegetation, especially by wind-throw of trees.

2.14.4.2 Soil Feature Factor

The soil factor is expressed as the erodibility of the soil. Erodibility, unlike the determination of erosivity of rainfall, is difficult to measure and no universal method of measurement has been developed. The main reason for this deficiency is that into two groups: those which are the actual physical features of the soil and those which are the result of human use of the soil. The resistance of soil to detachment by raindrop impact depends upon its shear strength, that is its cohesion (c) and angle of friction. It is difficult in practice to measure the appropriate values of c and for grains at the surface of a soil or soil crust, partly because of variability in the size, packing and shape of particles and partly because of the varying degrees of wetting and submergence of grains by water.

2.14.4.3 Geological Factor

This factor is evident in the steepness and length of slope. Nearly all of the experimental work on the slope effect has assumed that the slopes are under cultivation. In such conditions rain-drop splash will move material further down steep slopes than down gentle ones, there is likely to be more runoff, and runoff velocities will be faster. Because of this combination of factors the amount of erosion is not just proportional to the steepness of the slope, but rises rapidly with increasing angle. The length of slope has a similar effect upon soil loss, because on a long slope there can be a greater depth and velocity of overland flow, and rills can develop more readily than on short slopes. Because there is a greater area of land on long than on short slope facets of the same width, it is necessary to distinguish between total soil loss and soil loss per unit area.

2.14.4.4 Biological Factor

Vegetation offsets the effects on erosion of the other factors-climate, topography, and soil characteristics. The major effects of vegetation fall into at least seven main categories:

(1) The interception of rainfall by the vegetation canopy.

(2) The decreasing of velocity of runoff, and hence the cutting action of water and its capacity to entrain sediment.

(3) Root effects in increasing soil strength, granulation, and porosity.

(4) Biological activities associated with vegetative growth and their influence on soil porosity.

(5) The transpiration of water, leading to the subsequent drying out of the soil.

(6) Insulation of the soil against high and low temperatures which cause cracking or frost heaving and needle ice formation.

(7) Compaction of underlying soil.

2.15 Types of Erosion

2.15.1 Raindrop Splash and Sheet Erosion

The first step in the erosion process begins as raindrops impact the soil surface. The detachment and splash or transport of the soil particles occurring as a result of impact of falling rain drops is called rain drop erosion. Raindrops typically fall with a velocity of 6-10 meter per second. The energy of these impacts is sufficient to displace soil particles as high as two feet vertically. In addition, the impact of a rainfall on a bare soil can compact the upper layer of soil, creating a hard crust that inhibits plant establishment.

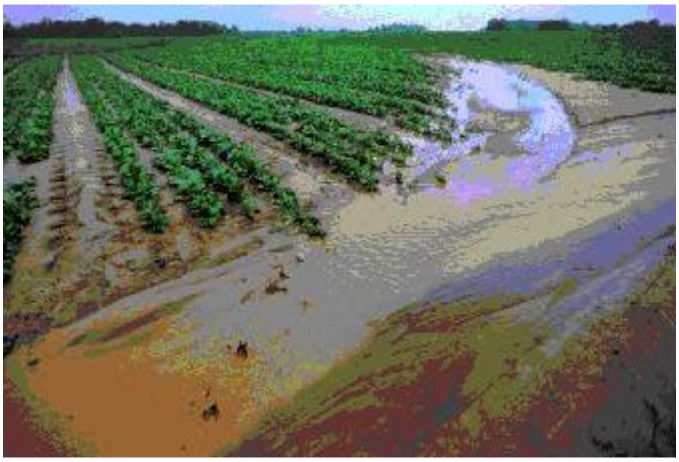


Fig.11. Sheet erosion

Sheet erosion occurs as runoff travels over the ground, picking up and transporting the particles dislodged by raindrop impacts. The removal of more or less uniform thin layer or sheet of soil by running water from sloping land is known as sheet erosion. The process of sheet erosion is uniform, gradual and difficult to detect until it develops into rill erosion.

The method used to prevent erosion from raindrop splash and sheet erosion is stabilization. Stabilizing techniques such as temporary and permanent vegetation, sodding, mulching, compost blankets, and rolled erosion control products absorb the impact of raindrops and protect the ground surface. By protecting the surface, soil particles are not dislodged and transported by sheet flow. Typically, sheet flow does not have sufficient volume or velocity to dislodge soil particles from a bare surface by itself. It is dependent on raindrop impacts to disturb the surface. Therefore, stabilizing a surface, protects the ground from both raindrop and sheet erosion.

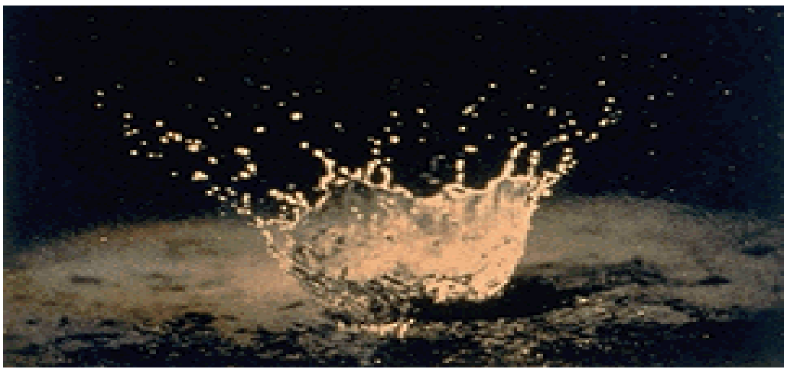


Fig 12: Rain drop erosion

2.15.2 Rill Erosion

Rill erosion occurs as runoff begins to form small concentrated channels. As rill erosion begins, erosion rates increase dramatically due to the resulting concentrated higher velocity flows. Rill can be repaired by tilling or normal cultivation operation and should be repaired as soon as possible in order to prevent gullies from forming.

Fig 13: Rill Erosion from the field.

2.15.3 Gully Erosion

Gully erosion results from water moving in rills, which concentrate to form larger channels. When rill erosion can no longer be repaired by merely tilling or discing, it is defined as gully erosion. The advanced stage of gully erosion leads to formation of ravines near the river systems. It is however noted that deep gullies are formed normally in lands having relatively thick soil depth.

Fig 14: Gully Erosion in the field.

Table 7: Types of Gully

Description	Gully depth	Catchment area
Small	1 m or less	2 ha or less
Medium	1 to 5 m	2 to 20 Ha
Large	Greater than 5 m	Greater than 20 ha

2.15.4 Stream Bank Erosion

Stream channel erosion consists of both stream bed and stream bank erosion. Stream bed erosion occurs as flows cut into the bottom of the channel, making it deeper. This erosion process will continue until the channel reaches a stable slope. The resulting slope is dependent on the channel materials and flow properties. As the stream bed erodes, and the channel deepens, the sides of the channel become unstable and slough off, resulting in stream bank erosion. Stream bank erosion can also occur as soft materials are eroded from the stream bank or at bends in the channel. This type of stream bank erosion results meandering waterways. One significant cause of both steam bed and stream bank erosion is due to the increased frequency and duration of runoff events that are a result of urban development.

2.15.5 Stream Bank Erosion Control

It is often necessary in areas where development has occurred in the upstream watershed and full channel flow occurs several times a year. Stream bank protection can be vegetative, structural or a combined method where live plant material is incorporated into a structure (bioengineering). Vegetative protection is least costly and the most compatible with natural stream characteristics. Additional protection is required when hydrologic conditions have been greatly altered. Because each reach of channel is unique, measures for stream bank protection should be installed according to a plan developed for the specific site and watershed.

2.15.5.1 Supplementary Agronomic Measures

Several agronomical measures are adopted, supplementing the mechanical measures in the treated lands, the process of soil erosion (detachability and transportability) will continue resulting fluctuating crop fields.

These measures include: -

Contour Farming. - planting on contours

Mulching – using various techniques that will increase the water retention capacity of the soil, for instance mixing straw and breaking clods. Mulching is particularly helpful in vegetable cultivation, where assured soil moisture is a necessity.

Use of dense growing crops/ cover crops – for instance cowpea, pulses, paddy, wheat. These will reduce splash erosion.

Mixed cropping. – increasing the capacity to retain water

Inter – cropping or strip cropping, alternating either blocks or strips with different crops.

Use of organic manure or green manuring with legumes, such as cowpea, dhaincha, pulses. This improves water-holding capacity.

2.15.5.2 Vegetative Protection

Provide vegetative protection in zones where the location of each zone depends on the elevations of the mean high water level, the mean water level and the mean low water level. Vegetative protection usually works for stabilization only when a channel has become unstable because vegetation has been removed.

Aquatic Zone The aquatic plant zone includes the stream bed and is normally submerged at all times. No artificial planting is required in the aquatic plant zone.

Shrub Zone The shrub zone lies on the bank slopes above the mean water level and is normally dry, except during floods. Willows, silver maple and poplar can be planted (staked) from top-of-bank to waterline. They are preferred because they have high root densities, root shear and tensile strength is higher than that of most grasses or forbs, and they can transpire water at high rates. Some grasses can be planted in the shrub zone if velocities are not too high and plants are not submersed frequently or for long periods of time. Plant grasses in the spring or the fall.

Tree Zone Plant upland trees along the banks of the stream and not on the slopes. If trees provide shade to the stream bank, grasses should be planted which will thrive in shady conditions.

2.15.5.3 Structural Protection

Structural protection should be provided in locations where velocities exceed 6 feet per second, along bends, in highly erodible soils and in steep channel slopes. Common materials include riprap, gabions, fabric- formed revetments and reinforced concrete. Grouted riprap is not recommended, because grouted rock does not move with freeze/thaw and wetting/drying cycles. Voids quickly form under grouted rock, allowing erosion. The upstream and downstream ends of the structural protection should begin and end along stable reaches of the stream.

Riprap is the most commonly used material for stream bank protection. Properly sized, graded, bedded and placed riprap rises and settles with soil movement. Stream banks should be sloped at 2:1 or flatter. Place filter fabric or a granular filter between the riprap and the natural soil. Construct the riprap layer with sound, durable rock. Refer to plan for gradation and layering. Place the toe of the riprap at least 1 foot below the stream channel bottom or below the anticipated scour depth. Install toe walls as specified in plan. Extend the top of the riprap layer at least up to the 2-year water surface elevation.

Gabions are rock-filled wire baskets. They are very labor intensive to construct but are semi-flexible, permeable and can be used to line channel bottoms and stream banks.

Fig 15: Stream Bank Erosion control by gabion structure

Reinforced concrete may be used to stabilize the stream bed or the stream bank. Reinforced concrete retaining walls and bulkheads provide good erosion protection for stream banks. Anchor the foundation for these structures to a stable, non erodible base material such as bedrock. Place filter fabric or a granular filter between stream bank material and the retaining wall or bulkhead. Construct water stops at all joints in concrete retaining walls. Construct the top of the retaining wall or bulkhead up to the design water surface elevation plus freeboard, and vegetate the rest of the stream bank.

2.16 Estimation of Soil Erosion

The erosion risk (A=annual soil loss) is calculated from a number of factors that have been measured for all climates, soil types, topography and kinds of land used in the state. The amount of soil erosion is, therefore depends on a combination of power of rain to cause erosion and ability of soil to withstand the rain. In mathematical terms, erosion is a function of erosivity of rain and erodibility of the soil.

Erosion = f (Erosivity, Erodibility)

The factors are combined in a number of formulas of the 'Universal Soil Loss Equation', which returns a single number, the tolerance factor, equivalent to predicted erosion in ton/ha

A = R.K.L.S.C.P

Where:

A = Average annual soil loss: the predicted erosion or tolerance factor in ton/ha, calculated from all others.

R = Rainfall erosivity factor: a factor dependent on climate and likelihood of extreme events.

K = Soil erodibility factor: an estimate made from soil properties as catalogued in the National Resources Inventory. It depends on the particle sizes and proportions of sand, silt and clay, oganic matter, granularity and profile permeability to water.

L = Slope length factor: the slope length is the length of the field in a down-slope direction. The larger slope length, the more water accumulates at the bottom of the field, increasing erosion. It also depends on the land's slope.

S = Slope steepness factor: calculated from the slope of the land in %.

C = Crop management factor: depends on crop growth rate in relation to the erosivity variation in the climate.

P = Supporting practice factor: reflects the use of contours, strip cropping and terracing.

Table 8: Computed value of soil Erodibility factor (K) from various research station

Research Station	**Soil type**	**Erodibility factor (K)**
Agra (U.P.)	Loamy sand, alluvial	0.07
Dehra Dun	Dhulkot silt loam	0.15
Hyderabad (A.P)	Red chalka sandy loam	0.08
Kharagpur (W.B.)	Soil from lateritic rock	0.04
Kota (Rajastan)	Clay loam (black soil)	0.11
Udhagamandalam (T.N.)	Deep lateritic	0.04
Rehmankhera (U.P)	Loam alluvial	0.17
Vasad (Gujarat)	Sandy loam alluvial	0.059

(Source: Training manual vol. II Soil and Water Conservation Engineering, CSWCRTI)

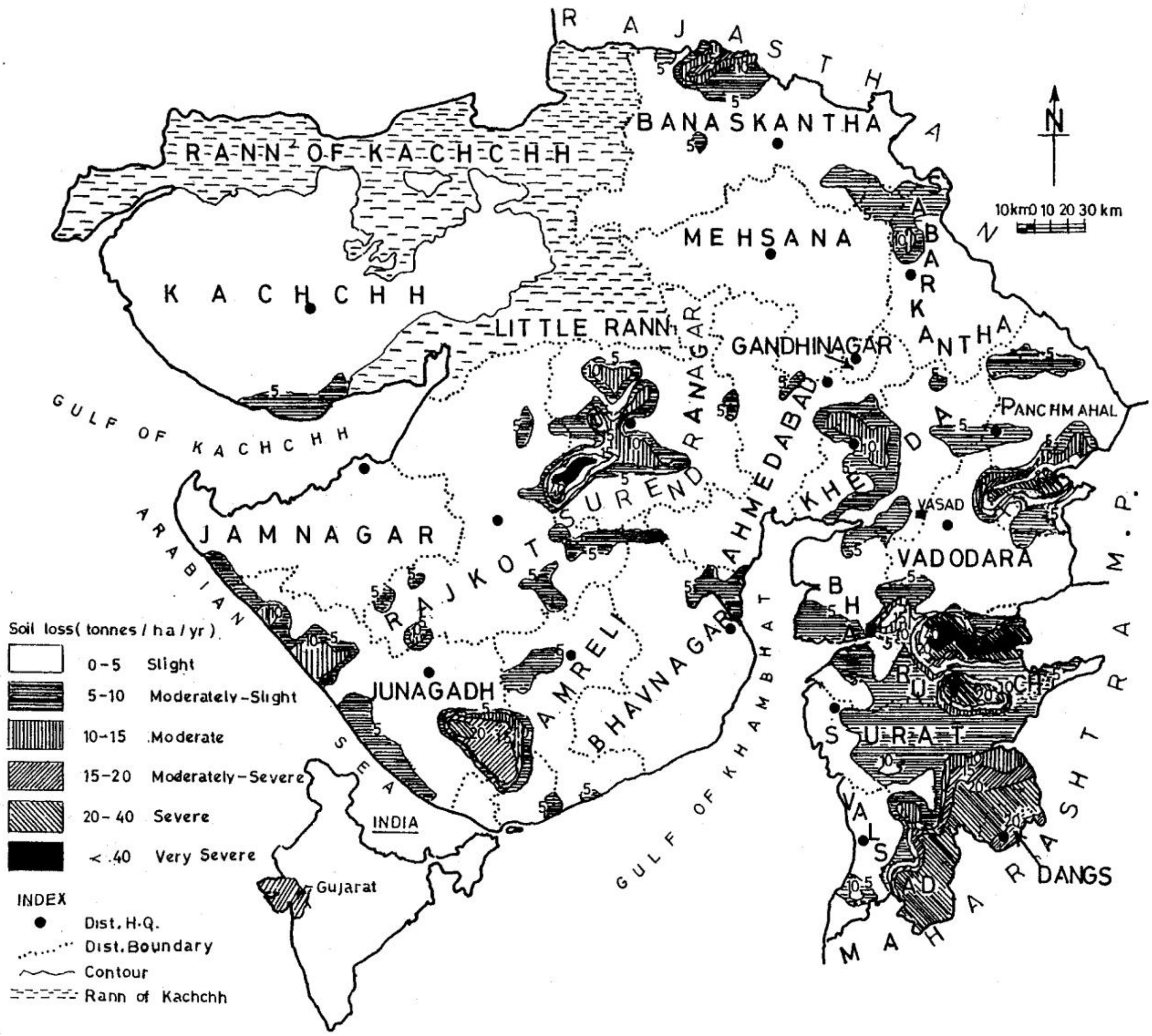


Fig. 16: Soil Erosion map of Gujarat

(Source: Indian Journal of Soil Conservation, 25 (1); 9-13, 1997)

Slope length factor (L)

The slope length factor (L) is the ratio of the soil loss from field slope length to that from 22 m length plot under identical conditions. The factor can be calculated from following equation:

$$L = (l/22)^m$$

Where, L = slope length factor,

l = slope length in meters

m = dimension less exponent

The value of exponent m varies with slope and given as below:

Table 9: Variation of 'm' with slope

Slope gradient (%)	Value of m
Less than 1	0.2
1 – 3	0.3
3 – 5	0.4
More than 5	0.5

Source: Training manual vol. II Soil and Water Conservation Engineering (CSWCRTI)

Slope gradient factor (S)

The slope gradient factor is the ratio of soil loss from the field slope gradient to that from 9% slope gradient. Wischmeir and smith (1978) have given following relationship for computation of S:

$$S = 65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065$$

Where, θ is the angle of slope

Chapter-3

3 Upper Catchment Area Treatment

3.1 Introduction

The treatment measure for watershed development starts from a ridge and proceeds to the valley. If done in reverse order, runoff velocity from the untreated top part can damage the structure on lower catchments. This approach helps to conserve soil first and to retain moisture in the area for longer periods.

3.2 Biological Measures

It is also important to adopt biological measures for stream bank protection so that it facilitates recharge, in-stream habitat restoration and enriches the overall ecosystem.

3.2.1 Riparian Habitat

Riparian vegetation should be allowed to grow and regenerate on both the banks, throughout the stretch of the stream. Indigenous grasses and plants may be selected for creating vegetation cover along the banks. Depending upon whether plantation is below or above the line of submergence, appropriate aquatic and non-aquatic species may be selected. The vegetation created will absorb floods, protect agriculture, build up hyporheic zone to increase soil moisture holdings capacity and provide habitat to invertebrates and higher animals.

3.2.2 Live Hedge

A barrier created by planting grass, shrubs and trees across the rills to stop soil erosion is called live hedges. It is done at a location where the gully/rill originates. Following points should be kept in mind while designing and constructing live hedges.

3.2.2.1 Construction

Clean the site first

Excavation up to 0.15 to 0.23m depth needed.

Then plant two lines of grasses like vertiver or any other local soil binding grass.

On the downstream of the grass line, plant one line of shrubs such as pandanus, thor or agave.

Functions

i. To check soil erosion
ii. To reduce runoff velocity
iii. To control further deepening of gullies

3.3 Engineering measures

3.3.1 Contour Bunding

This measure involves construction of horizontal lines of small earthen or boulder bunds across the sloping land surface. Contour bunding is practiced to intercept the runoff flowing down the slope by an embankment with either open or closed ends to conserve moisture as well as to reduce erosion. The land treatment in between the bunds is desirable for uniform conservation of moisture. The practice of contour bunding is found to increase crop yield by about 15-20 per cent.

3.3.1.1 Objectives

i. To increase the time of concentration of rainwater where it falls and thereby allowing rainwater to percolate into the soil
ii. Converting a long slope into several ones as to minimize velocity and thereby reducing the erosion by runoff water
iii. To divert runoff for water harvesting purposes

The term contour bunding used in India is same as “level terraces” and “ridge type terraces”. The bund acts as barrier to the flow of water and at the same time impound water to build up soil moisture storage. The spacing of bunds is so arranged that the flowing water is intercepted before it attains the erosive velocity. The vertical interval between the two bunds is determined by the following formula:

3.3.2 Ramser’s formula

V.I. = 0.3 (S/3 + 2)

Where,

S = Degree of slope in percent

V.I. = Vertical interval between two bunds, m

3.3.3 COXS' Formula

VI = (XS + Y) 0.3

Where, X = Rainfall factor

Y = Infiltration and crop cover factor

S = Slope %

VI = Vertical Interval (m)

Table 10: Value of "X" in COXS' Formula

Rainfall	Annual Rainfall (cm)	Rainfall Factor "X"
Scanty	64	0.8
Moderate	64-90	0.6
Heavy	Over 90	0.4

Source: Training manual vol. II Soil and Water Conservation Engineering (CSWCRTI)

Table 11: Value of "Y" in COXS' Formula

Intake rate	Crop cover during erosive period of rains	Value of "Y"
Below average (e.g. black soils)	Low coverage	1.0
Average or above	Good coverage	2.0
One of the above factors favorable and the other unfavorable		1.5

Source: Training manual vol. II Soil and Water Conservation Engineering (CSWCRTI)

The spacing is increased by 25% in highly permeable soils and decreased by 15 percent in poorly permeable soils. It is always desirable to remove local ridges and depressions before building contour bunds. Dimensions of contour bunding with different height and side slope, is recommended as given below.

By knowing the cross section area of the bund, the volume of earthwork per hectare and the cost of earthwork per hectare can be determined. The design of cross-section of contour bund, which can store runoff excess from 24 hrs rainstorm, can be done with the help of the following equation.

Table 12: Dimensions of the Contour Bund

Type of soil	**Bottom width (m)**	**Top width (m)**	**Height (m)**	**Side slope**
Gravel soils	1.2	0.3	0.6	0.75:1
Red soils	2.1	0.3	0.6	1.5:1
Shallow to medium black soil	2.4	0.45	0.75	1.3:1
Deep soils	3.3	0.60	0.675	2:1

$$h = \sqrt{\frac{Re\,xVI}{50}}$$

Where, h = Depth of impounding in meter near the bund, Re = Maximum 24 hours rainfall in cm, VI = Vertical interval in meter

Using the above equation, height of impounding required for 10 years frequency (or any other frequency) can be obtained which will not cause any spill over. To the depth of impounding 'h', the free board of 25 to 30% may be added.

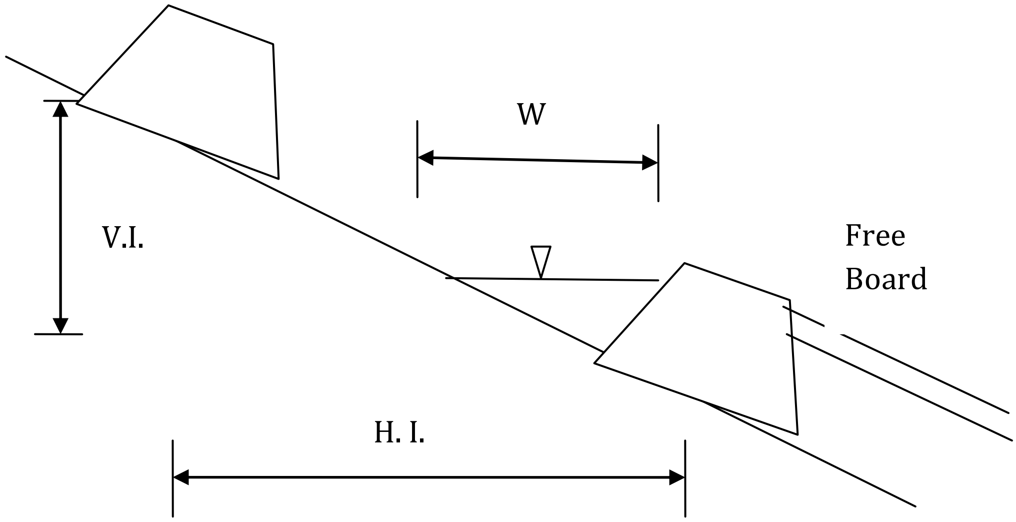


Fig 17. Sketch of Contour Bund

Example

A piece of land mea[illegible] 250 m across the slope has uniform slope of 2%. The maximum 24 hr rainfall for 10 year recurrence interval is 200 mm. The soils are sandy loam in texture. The side slope for bund 1.5:1. Design cross section of the main bund if the top width of the bund is 0.5 m. Find the cost of bunding if the rate of earth work is Rs. 41 per cum.

Solution: V. I. = $\left(\frac{S}{3}+2\right)0.3 = \left(\frac{2}{3}+2\right)0.3 = 0.8m$

H.I. = $\frac{100x0.8}{2} = 40m$

No. of bunds = $\frac{1350}{40} = 34Nos$

Height of bund, h = $\sqrt{\frac{Re\,xV.I.}{50}}$

Where, Re is maximum 24 hr rainfall in cm and V.I. is vertical interval in m

$$h = \sqrt{\frac{0.80x20}{50}} = 0.57m$$

Free board (15 % of h)= (0.57X15)/100 = 0.1

Actual height of bund after adding the free board = 0.57 +0.1 = 0.67 or 0.7 m

Cross sectional area of bund if top width is 0.5m and side slope as 1.5:1

$$= \frac{(2.60 + 0.5)}{2} x 0.70 = 1.085 sq.m.$$

Length of the bund = 10000/H.I. = 10000/40 = 250 m/ha

Total Area = (1350x 250)/10000=33.75 Ha

Total length of the bund for given area= 250 X 33.75 = 8437.50 m

Volume of earth work for main bund = L x A = 8437.50 X 1.085 = 9154.69 or 9155 cum

Cost estimate = 41 X 9155 = Rs 375355/-

Fig 18: Contour Bunds in a hill

3.3.4 Contour Bunds: DO's and DONT's

i. Always provide a berm (distance from excavated portion to bund) of minimum 30 cm.
ii. Always provide a settlement allowance of 10-15% depending on soil type.
iii. Exit must be provided in sloping land and in impermeable soils , depending on site conditions.
iv. In impermeable soils increase the cross section area of bunds.
v. Do not start the lay-out of bunds from the shorter section. Always begin from the longest section within the largest area of uniform slope.
vi. Do not make bunds on slopes higher than 10%.

vii. On relatively high slopes do not make bunds closer than 30 m.

viii. On low slopes do not make bunds farther than 60 m.

ix. Do not construct bunds where there is already dense vegetation.

x. Do not excavate if roots of a tree are encountered

xi. Do not excavate soil continuously in permeable soils.

3.3.5 Marking Contour Lines by field method

Contour Lines are imaginary lines across a slope, which are the same height at all places along the slope. Water cannot flow along a contour line - it is completely level. Most soil erosion control methods are built along the contour lines to have maximum effect. Contour lines cannot be guessed - they need to be measured. An A-Frame can be made at no cost, from material readily available to every farmer and used by one or two people. The Hose Level needs materials which cost a small amount of money and it needs either two or three people for marking contours, but it is quicker to use.

"A" Frame

An A frame is a simple device used for demarcation of the contours on the ground. Soil and water conservation measures such as bunding, trenching is laid along the contours. Hence each contour line needs to be demarked.

Materials needed

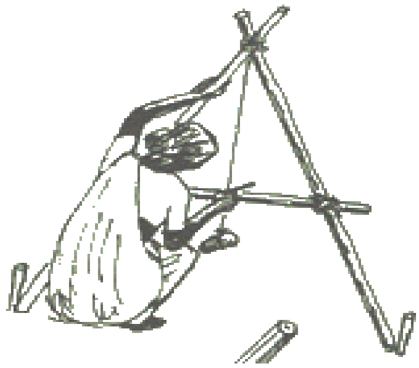
i) Poles about 2 meters long
ii) 1 shorter pole about 1 meter long
iii) some string
iv) a stone or plum bob

Step 1

Tie the poles very tightly together to make the shape of a letter A. Hang the stone/plum bob from the top of the A-Frame, making sure the stone hangs below the cross bar.

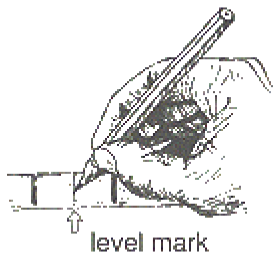
Step 2

Holding the frame upright, mark with two sticks exactly where the poles touch the ground. When the stone or plum bob stops moving, mark on the cross bar. Turn the A-Frame around, placing the poles in exactly the positions marked by the two sticks. Again mark where the string crosses the cross bar.



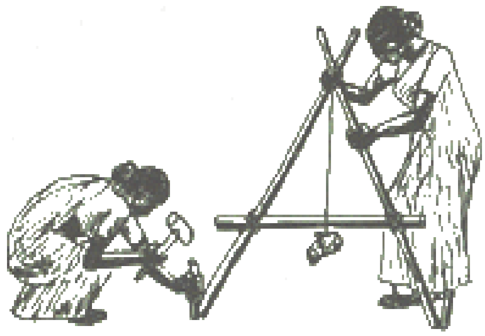
Step 3

Mark the level mark on the cross bar - exactly half way between the previous marks. If the first two marks happen to be on the same place - this is the level mark.



Step 4

Before using the A-Frame, collect a number of sticks. Begin ideally with, one side of the field where the first contour line is needed. Hold one pole firmly on the ground. Move the other pole until both poles are on the ground with the string touching the level mark. Place a stick into the soil by each pole. Move the A Frame along, by turning it around (pivoting), keeping pole 1 in exactly the same place. Move pole 2 until the string touches the level mark and place another stick into the ground by pole 2. Carry on in this way, pivoting the A-Frame across the field.



The Water Tube Level

The Water Tube Level is more popular equipment in demarcating contours in watershed area and is simple equipment that can be prepared locally.

Materials needed

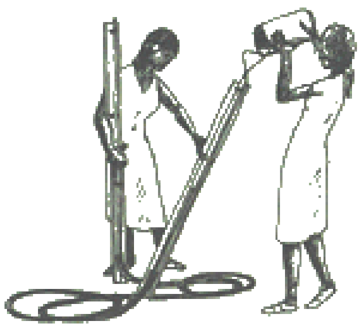
Two poles about 2 metres long

Length of clear plastic tubing 10-25 metres long and about 1 cm in diameter

Small amount of string or adhesive tape

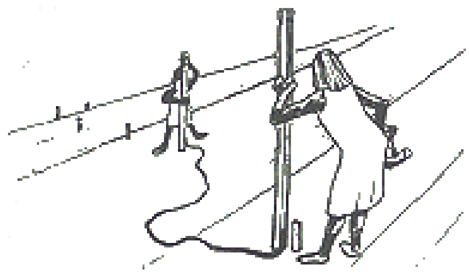
Step 1

Tie the ends of the tubing securely to the two poles in several places. Carefully fill the tubing with clean water, making sure no air bubbles are trapped inside, until nearly full. Hold the poles side by side, with their lower ends resting on the ground, until the water level settles at exactly the same level on each pole (ideally where it is easy to see without bending). Mark this level clearly on each pole.



Step 2

When moving the poles, either use a thumb or fit some kind of plastic stopper to stop water spilling - these should be removed before measuring. Begin at one side of the field. One person stands still while the other moves their pole until the level mark is reached in both poles. As with the A-Frame, use marker sticks and move alternate poles so that any slight faults with the Hose Level do not affect the contour line.



Marking the Line

Whatever method has been used, the end result will be a line marked across the land with a series of sticks. If there are sharp bends in the line, then move a stick a little to make a smoother line. Such sharp bends are usually due to rocks or small holes which have affected one measurement. The contour line is now ready for whatever control measures are planned.

3.3.6 Contour Trenching

Construction trenches are constructed on contours to detain water and sediment transported by water. Contour trenches are ditches dug along a hillside in such a way that they follow a contour and run perpendicular to the flow of water. The soil excavated from the ditch is used to form a small bund on the downhill edge of the ditch. The bund is planted with permanent vegetation (native grasses, legumes) to stabilize the soil and for the roots and foliage in order to trap any sediment that would overflow from the trench in heavy rainfall events.

3.3.6.1 Objectives

Contour trenches are used to break up the slope surface, to slow runoff and allow infiltration, and to trap sediment. Rills are stopped by the trenches. Trenches or terraces are often used in conjunction with seeding. It improves soil moisture profile by checking soil erosion. They can be constructed with machinery (deeper trenches) or by hand (generally shallow). Width and depth vary with design storm, spacing, soil type, and slope.

3.3.6.2 Specifications

Trenches can be continuous or interrupted. The interrupted one can be in series or staggered, continuous one is used for moisture conservation in low rainfall areas and require careful layout. Intermittent trenches are adopted in high rainfall areas. The trenches are to be constructed strictly on contours irrespective of the category.

3.3.6.3 Layout

The size of the trench depends upon the soil's depth. Normally 1,000 sq cm to 2,500 sq cm. in cross section are adopted. The trench may be of 30 cm base and 30 cm top width and square in cross section or it can be trapezoidal with side slopes 1:1. Based on the quantum of rainfall to be retained, it is possible to calculate the size and number of trenches.

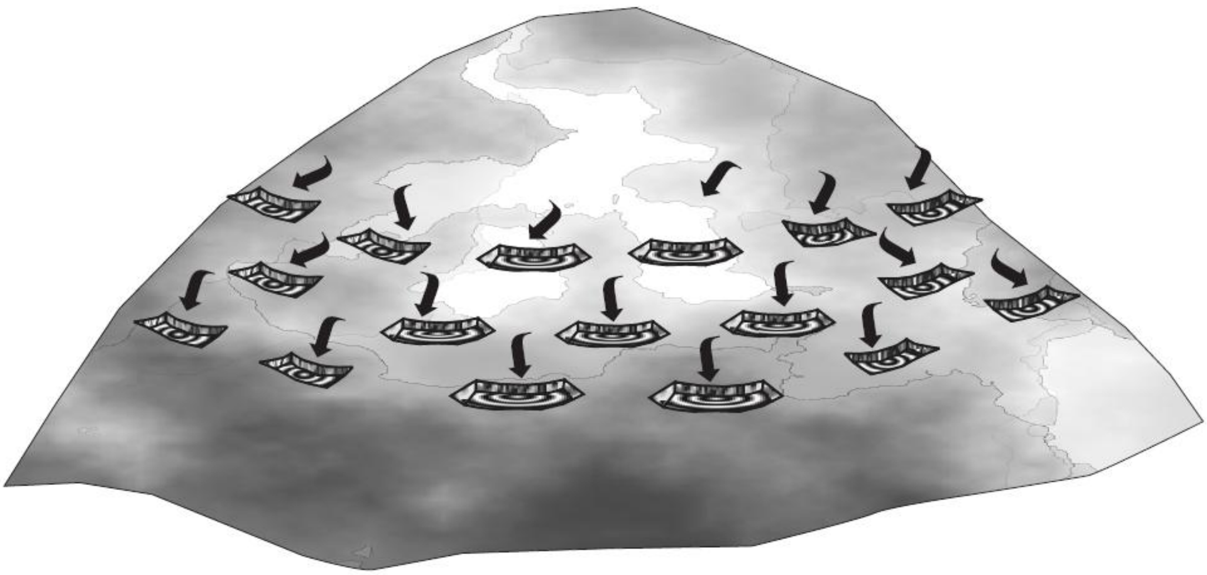
3.3.7 Types of Trenches

3.3.7.1 Continuous Contour Trenches

Continuous contour trenches (CCT) are the ones when there is no break in their length and they can be 10 to 20 m long across the slope depending on the width of the field. The cross section of the trench generally varies from 30 x 30 cm to 45 x 45 cm .They are constructed for moisture conservation in low rainfall areas receiving storm of mild intensities. It has been observed that CCT are prone to breaching if they are not constructed perfectly on contours hence it demands high skill for construction.

3.3.7.2 Staggered Contour Trenches

In medium rainfall areas with highly dissected topography, Staggered Contour Trenches are adopted. The length of the trenches is kept short around 2-3 m and the spacing between the rows may vary from 3-5 m. The chances of breaches of SCT are less as compared to CCT. Over time, experience of watershed programs has shown that it is better to stagger the digging of contour trenches. This is because it has been found that invariably errors have been made in contouring over long distances. If the contour trench is not level and by mistake sloped, then water starts to flow from the high point to the low point, cutting a path and increasing soil erosion. Therefore, instead of making trenches continuously, they should be made in a staggered, discontinuous manner.



Staggered trenches minimise the risk of going off the contour and are therefore safer

(Source: Watershed works manual: Samaj Pragati Sahayog)

Fig 19: Staggered contour trenches

Fig 20: Staggered contour trenches in a hillock

3.3.8 Design of Contour Trenches

Design of contour trenches involve the determination of cross sectional area and spacing of trenches to collect desired amount of runoff generated from the catchment area. Steps involved in design of contour trenches are as follows:

3.3.8.1 Determination of direct runoff volume

Trenches are designed to hold part of the runoff expected from a storm of 4 years recurrence interval and 6 hr duration. Trenches are designed to store 60-70 % of runoff. The volume of run-off from the design storm is computed by the following formula.

$Q = C \times R \times A$

Where, C = runoff coefficient, R = quantum of daily rainfall

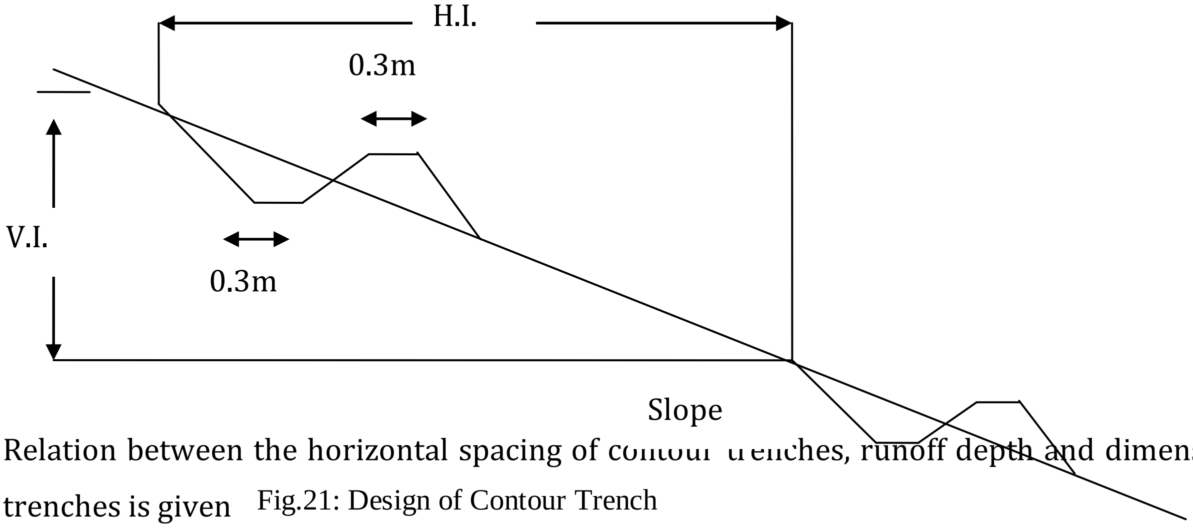
A = catchment area for that particular structure

3.3.8.2 Determination of cross sectional area and volume of trench

The cross section of trench can be of square, rectangle, trapezoidal or triangular V-shape. The size of trenches depends upon the soil depth available at site. In relatively deeper soils, trench depth is generally fixed at 40-50 cm while for shallow soil, trench depth may reduce to about 15-20 cm. As far as length of trench is considered, shorter lengths 3 to 7 m are adopted for convenience of layout and construction.

3.3.8.3 Determination of spacing

Spacing is expressed in terms of horizontal and vertical interval. Vertical interval is defined as the elevation difference between the upper or lower edge of successive contour trenches. A definition sketch of contour trenching is given below.



Relation between the horizontal spacing of contour trenches, runoff depth and dimension of trenches is given

Fig.21: Design of Contour Trench

H.I. =Cross sectional Area/Runoff depth= A/Q

Assuming trench to be rectangular, $H.I. = \frac{WxD}{100xQ}$

Where, H.I. = Horizontal spacing

W = width of trench, cm

D = depth of trench, cm

Q = Runoff depth, cm

3.3.8.4 Contour Trenches: DON'Ts

i. Do not make trenches on slopes higher than 25%. Instead adopt vegetative measures
ii. Do not make trenches on slopes less than 10%. Instead construct contour bunds
iii. Do not excavate trenches where there is already dense vegetation
iv. Do not plant inside the trench
v. Do not excavate if roots of a tree are encountered
vi. Do not excavate trenches across large streams or drainage lines
vii. Do not start the lay-out of trenches from the shorter section. Always begin from the longest section within the largest area of uniform slope

3.3.9 Bench Terracing

Bench terracing means construction of nearly level steps like fields along contours usually by half cutting and half filling procedure. It is an earthen embankment or a ridge and channel, constructed across the slope at a suitable location to intercept surface runoff water.

It may be constructed with an acceptable grade to an outlet or with a level channel and ridge. By adopting bench terracing, both degree and length of slope are reduced which help in soil moisture conservation for enhanced crop production. Bench terracing is recommended for slopes from 10 to 30%.

3.3.9.1 Functions

Terraces are constructed

i. To reduce erosion by shortening the length of slope and conducting the runoff water on a non-erosive grade to a stable slope.
ii. To conserve moisture
iii. To reduce floods by means of level closed terraces, or by increasing the time of concentration with graded terraces, and
iv. Controlling gully heads downstream (by checking water fall erosion).

3.3.9.2 Functions of Terracing in the Conservation Programme

i. One of the best mechanical measures
ii. Properly located, constructed and maintained terraces
iii. Reduce runoff and soil losses
iv. Prevent the formation of rills and gullies and
v. Assist in reclaiming badly eroded gullied fields by intercepting the runoff before it becomes concentrated and attains an eroding velocity.
vi. To be effective, they must be used in combination with other practices, such as stubble mulching, contouring and strip cropping.
vii. Over a period of years, better crops may be expected on terraced land because of the soil and moisture they conserve.

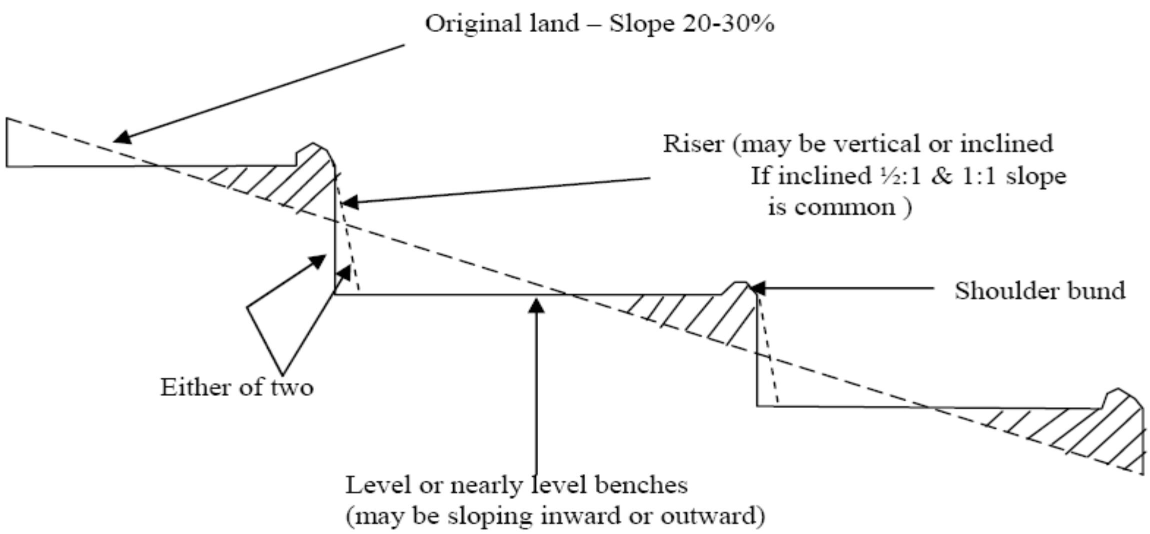


Fig 22: Different types of bench terraces

3.3.9.3 Limitations

Terraces can be constructed on practically all soils except those are too stony, sandy or shallow to permit practical and economical construction and maintenance.

It is not advisable to terrace some lands where the slope of the land is either too slight or excessive, or the topography is extremely irregular.

The steepness of the land is one of the factors that determine the practicability of terraces.

As the slope increases, soil loss from erosion increases. However, the cost of construction and maintenance of terraces and the difficulty of farming them also increase with the degree of slope to the point that these factors may eventually outweigh the benefits derived. When this point is reached, terracing is not advisable.

3.3.10 Types of Bench Terraces

3.3.10.1 Level Bench Terraces

This type of terraces consists of level top surface. They are generally used in the areas which receive medium rainfall and have highly permeable soils. Since it is expected that most of surface runoff passing through these terraces are absorbed by the soil and remaining portion is drained into drain. These are used for paddy cultivation for providing uniform impounding.

3.3.10.2 Bench Terraces Sloping Outward

Such terraces are adopted in low rainfall areas with permeable soil. For these terraces a shoulder bund is essential to provide the stability to the outer edge of terrace. Bench terraces sloping outward are also known as orchard type bench terrace.

3.3.10.3 Bench Terraces Sloping Inward

Bench terraces sloping inward are preferred to construct in the areas of heavy rainfall and less permeable soils, from where large portion of rain water is drained as surface runoff. Such type of terraces has a provision to drain the runoff from their inner side by constructing a drainage channel. These types of terraces are usually preferred for those crops, which are extremely susceptible to water logging such as potato.

3.3.10.4 Design of Bench Terraces

The following factors have direct bearing on design of bench terraces:

i. Soil depth and uniform spreading of top soil.
ii. Slope of land
iii. Rainfall amount
iv. Farming practices and proposed crops to be grown

3.3.10.5 Basic design parameters

v. Terrace spacing

vi. Terrace grade along the width & length

vii. Terrace cross section

3.3.10.6 Terrace spacing

Terrace spacing is the vertical distance between two successive bench terraces. It is equal to the double the depth of cut. It depends on the soil depth and land slope. The width of terrace should be such that it enables convenient and economic agriculture operations.

Step I: Find out the maximum depth of productive soil range (D). Lesser the depth of cutting, the greater will be the depth of productive soil available for cultivation.

Step II: Find out the maximum admissible cutting (d) for desirable land slope (S) and the crop to be grown. This depth of cutting should enable the construction of terrace with convenient width.

Step III: The width of terrace (W) can be computed for a given slope (S) by the formula

$$W = \frac{200.d}{S}$$

Where, W and d are in meters and S in percent

Step IV: Determine the vertical interval using following formula

$$V.I. = \frac{WS}{100 - S}$$

3.3.10.7 Terrace Grade along the Width & Length

Suitable terrace gradient has to be provided in new terraces in high rainfall areas for safe and quick disposal of the excess water.

Step I: Use Rational formula to estimate peak rate of runoff in cumec from bench terrace as given by

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

Step II: Calculate the area drained in ha by the formula

$$A = \frac{L.W}{10000}$$

Where, L= length of terrace, m

W=Average width of terrace, m

Step III: Find out the approximate value of cross sectional area of the channel, using following relation as

$$Q = A \times V$$

Where, Q is runoff computed in step I, and "A" is the cross sectional area of channel and "V" is the permissible velocity of runoff water in channel.

Step IV: Calculate the mean hydraulic radius, R as follows

$$R = A / P$$

Where, P is wetted perimeter of channel

Step V: Calculate the value of terrace grade, using Manning's formula, given as under

$$V = \frac{R^{2/3} . S^{1/2}}{n}$$

In this formula value of R is taken from step IV and velocity V from step III.

The value of n= 0.02 to 0.04 and S = Slope of channel

3.3.10.8 Terrace Cross Section

In bench terrace construction, the earth excavated from the upper half is deposited over the lower slope and this forms an embankment which should be properly and safely secured on the slope.

Earth work in bench terracing is given as

$$E = \frac{W.S.100}{8}$$

Where, E = Volume of earthwork, cum

W = width of terrace, m

S = land slope, %

Area available for cultivation= 100 (100-NS)

Where, N = Batter slope, %

S = land slope, %

Fig 23: Farming on bench terraces in a hilly area

Example

It is proposed to construct bench terraces in hilly region over an area of 1 ha having slope of 25 % the average soil depth is 1 m. The crops to be raised after making the terrace require minimum soil depth of 0.3m. The riser is to be laid on 1:1 gradient and local species of grasses will be planted on them. The critical length of terrace is approx. 100 m. Calculate the cost of bench terrace assuming earth work @ Rs 41/- per cum. Cost of grass plantation @ Rs 30 per 100 m length of riser. Total cost of bench terracing.

Solution

Cost of bench terrace

Assume depth of cut 65 %, hence

Depth of cut = 0.65 x 1 m = 0.65 m

Still soil depth available for plantation = 1- 0.65 = 0.35 m which is > 0.3 m

Bench width, $W = \frac{200.d}{S}$

$$W = \frac{200x0.65}{25} = 5.2 \text{ m}$$

Vertical Interval, $V.I. = \frac{WS}{100 - S}$

$$V.I. = \frac{5.2x25}{100 - 25} = 1.73 \text{ m}$$

H.I. = W + V.I. = 5.2 + 1.73 = 6.93 m

Earth work, $E = \frac{W.S.100}{8}$

$$E = \frac{5.2x25x100}{8} = 1625 \text{ cum.}$$

Cost of earth work @ Rs. 41/- per cum = 1625 x 41 = Rs 66,625/-

ii) Cost of grass plantation @ Rs 30/- per 100 m

Critical length of terrace (K) = 100 m

Length of terrace per Ha = 10000/H.I = 10000/6.93 = 1443 m

Cost of grass plantation @ Rs 30/- per 100 m

= (30/100) x 1443 = 432.90 or Rs 433/-

iii) Total cost of bench terracing

= 66625 + 433

= Rs. 67058/-

3.3.11 Vegetative Grassed Waterways

Vegetative waterways are natural or constructed waterways shaped to require dimensions and vegetated for safe disposal of runoff from a field, diversion, terrace or other structures. Satisfactory performance of vegetated waterways depends on its having the proper shape, as well as the preparation of the area in a manner to provide conditions favourable to vegetation growth. The grass in the waterways should be established before any water turned into it. The velocity in the grassed waterways should be kept within the permissible limit for different types of soil and these limits are presented below table.

Table 13: Permissible velocity in grassed waterways for different soil types

Type of soil	Maximum permissible velocity (cm/sec)
Sand and silt	45
Loam, sandy loam and silt loam	60
Clay loam	65
Clay	70
Gravelly soil	100

(Source: Paper on treatment technologies for watershed development and management in north east hill region by R. K. Singh)

Design

Vegetative waterways are generally designed to carry the maximum runoff from a storm of 10-year recurrence interval. Runoff can be estimated by the Rational Method.

Shape

Vegetated waterways may be built to three general shapes or cross-sections, namely, parabolic, trapezoidal or V-shaped. Parabolic waterways are most common and generally are the most satisfactory. It is the shape ordinarily found in nature. V-shaped channels can be easily constructed with a V-ditcher and trapezoidal channels with a V-ditcher and a buck scrapper, and hence these sections are preferred constructed channels. Broad-bottom trapezoidal channels require less depth of excavation than parabolic or V-shapes for the same capacity. Thus there are number of factors which govern the selection of shape.

Table 14: Basic equations for Trapezoidal, V-shaped and Parabolic Channels

Cross-section	Area (A)	Wetted perimeter (P)	Top width (t)	Top width with freeboard (T)
Trapezoidal	$A = bd + zd^2$	$P = b + 2d (z^2 + 1)^{0.5}$	$t = b + 2zd$	$T = b + 2 zD$
V-shaped (triangular)	$A = zd^2$	$P = 2d (z^2 + 1)^{0.5}$	$t = 2zd$	$T = tD/d$
Parabolic	$A = 2td/3$	$P = t + (8d)/3t$	$t = A/(0.67d)$	$T = t (D/d)^{0.5}$

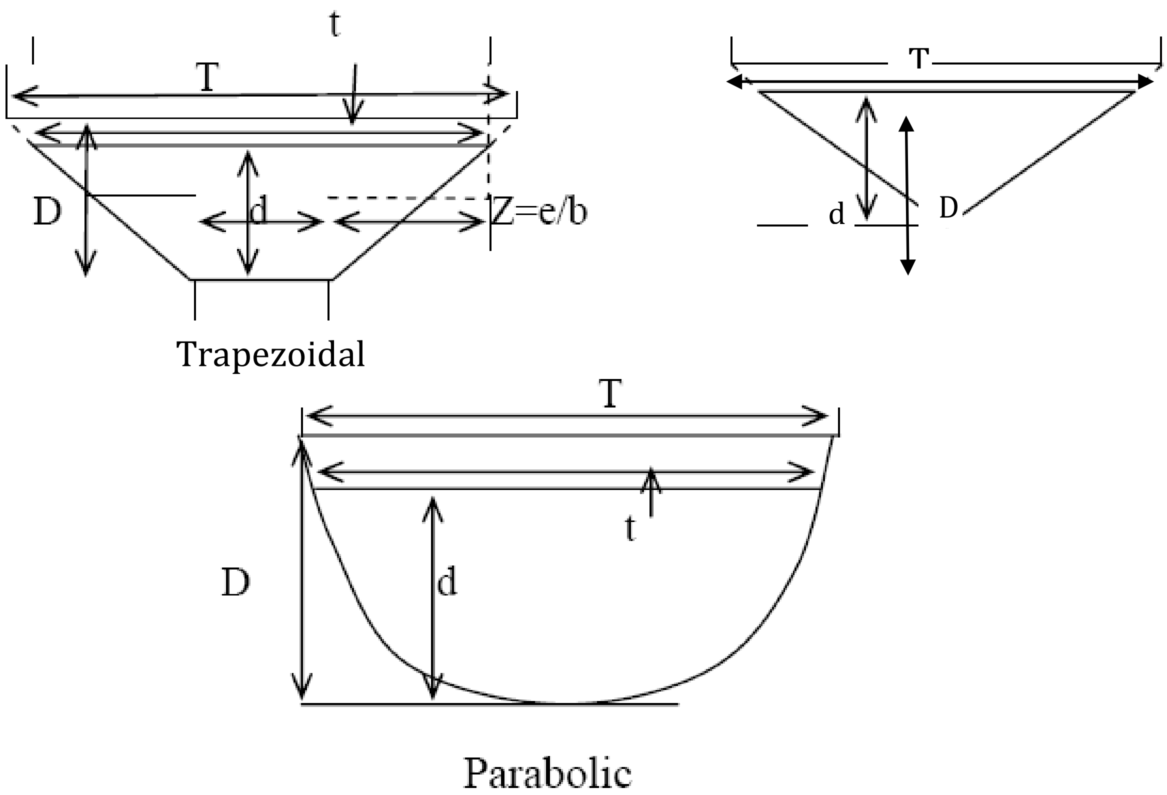


Fig 24: Different Shape of waterways

Channel Grades

Grassed waterways generally run down the slope and the channel grade is usually governed by land slope. In any case, channel slope should not exceed 10% while it is normally desirable to keep the grade within 5%.

Channel Dimensions

After the runoff, channel grade and design velocity have been determined, the next step is to decide on the channel dimensions. Design of vegetated waterways is based on the Manning's formula. The coefficients of roughness (n) usually assumed in grassed waterways design is 0.04. Side slopes of channel should be 4:1 or flatter to facilitate crossing of farm equipment. A freeboard of 10 - 15 cm should be provided to take care of the sediment deposition and variation in the value of 'n'.

Example:

Determine the dimension of trapezoidal shaped grassed waterways to carry the peak runoff rate of 4.0 m^3/s and slope of the waterway is 0.3 %. Assume flow velocity as 0.9 m/s and manning's coefficient n= 0.045.

Solution

Let the side slope of trapezoidal channel be 2:1

Bottom width = 2m

Flow depth = 1 m

Area of cross section:

$A = bd + zd^2$

$= (2x1) + (2x1^2)$

$= 4\ m^2$

Wetted Perimeter (p) $= b + 2d\sqrt{1+z^2}$

$= 2 + 2x1\sqrt{1+2^2}$

= 6.47 m

Hydraulic radius (R) = A/P = 4/6.47 = 0.62 m

$$\text{Velocity, } V = \frac{R^{2/3} . S^{1/2}}{n}$$

$$= \frac{1}{0.045}(0.62)^{2/3} x \left[\frac{0.3}{100}\right]^{1/2}$$

= 0.885 m/s

Q = A x V = 4 x 0.885 = 3.54 m^3/s

The discharge computed above is less than the given value, therefore, another trial with bottom width 2.5 m and with the same side slope may be attempted.

Then by same formula mentioned above, cross section area A = 4.5 m^2

and perimeter P= 6.97 m

Hydraulic Radius R = A/P = 4.5/6.97 = 0.645 m

Velocity, $V = \frac{1}{0.045}(0.645)^{2/3} x \left[\frac{0.3}{100}\right]^{1/2}$

= 0.91 m/s

Therefore Discharge Q = A.V = 4.5 x 0.91 = 4.09 m^3/s

The discharge capacity of waterway obtained is about equal to the discharge rate to be handled by waterway. Hence, the selected dimensions i. e. bottom width as 2.5 m, depth of flow as 1.0 m and side slope 2:1 can be used for construction of grassed waterway.

3.3.12 Gully plugging Measures

Gullies are a symptom of functional disorder of the land, improper land use and are the most visible result of severe soil erosion. They are small drainage channels, which cannot be easily crossed by agricultural equipment. The gully plugging measures include vegetative plantings and brushwood check dams, boulder checks, earthen bunds or a combination of both and sand bag plugs etc.

Gully plugs can be defined as stones placed across gullies or valleys, so as to capture nutrients, silt and moisture. Stones are often embedded into the upper surface of spillway aprons and wells to provide support for the next layer. The principle is to capture runoff from a broad catchment area, thus transferring low rainfall into utilizable soil moisture, and to prevent soil erosion. Slowing of the flow of water helps in settling down organically rich soil. A well maintained gully plug creates a flat, fertile and moist field, where high value crops and trees can be grown.

Table 15: Recommended Vertical interval for different types of gully

Slope of Gully Bed %	Width of Gully Bed (m)	Location	Type of Gully Plug	Vertical Interval
0-5	4.5	Gully bed	Brush wood	3.0
	4.5-10.5	Gully bed	Earthen	2.25-3.0
	7.5-15.0	At the confluence of two Gullies	Sand bag	2.25-3.0
	7.5-15.0	At the confluence of all branches of a compound gully	Brick masonry	2.25-3.0
5-10	4.5	Gully bed	Brush wood	3.0
	4.5-6.0	Gully bed and side branch	Earthen	1.5-3.0

3.3.12.1 Nala Plug

It is creating obstruction by placing used bags filled with sand. Nala Plug (Bori Bandh) is the effective method to slow down the speed of flowing water of the stream in any area. Bori Bandh is a kind of stop made of empty cement bags filled with sand, clay and such other material and placed in the course of stream. Usually, there is erosion due to flow of water in hilly terrain but Bori Bandh can check it effectively. In case of Bori Bandh, the empty cement bags are filled with sand, clay and small pebbles. Such bags are then stacked one over the other in the channel of the stream which are not more than 15 meter in width. This method is effective where the depth of the stream is not more than one and a half meter and the sides of the stream are of clay. On the upstream side of masonry check dam at two to three places if Bori Bandhs are constructed then they prevent land erosion. Moreover they check sediments from entering into the dams and increase the lifespan of downstream structures.

Fig. 25: Nala Plug (Boribandh)

3.3.12.2 Loose Boulder Checks

Boulder checks are loose rock dams made on small drainage lines or seasonal streams which have a catchment area of less than 50 ha.

Objectives

In active gullies the objective of gully control should be to reduce the gradient and dissipate the energy of the flowing water. In nature, this is achieved through erosion down to base levels. To control a gully, a series of local base levels can be established through check-dams. The difference in height between the crests of successive check-dams should be such that the filled-up basins form steps with a mild slope. In this way, a steep erosive gradient is replaced by a stairway of gentle and non-erosive steps. By reducing the velocity of runoff, boulder checks help in:

i. Reducing soil erosion;
ii. Trapping silt which slows the rate of siltation in water harvesting structures in the lower reaches of the watershed.
iii. Creating a hydraulic head locally which enhances infiltration of surface runoff into the groundwater system.
iv. Increasing the duration of flow in the drainage line. Therefore, the capacity of the water harvesting structures created downstream on the drainage line is utilized more fully as they get many more refills.

Location

Boulder checks should be made as a series on a drainage line, with each structure dividing the overall catchment of the drainage line into smaller sections.

1. The independent catchment of each boulder check should not be more than 1 to 2 ha.
2. Boulder checks should not be made where the bed slope of the drainage line at that point is above 20% because the check will not be able to withstand the high velocity of water flow. However, on a drainage line with an overall high bed slope, loose boulder checks can be constructed in sections where the local bed slope is less than 20%.
3. Boulder checks should be made where boulders are available in large quantities in the requisite size.
4. A high enough to accommodate peak flows even after the check has been made, thereby preventing water from rising over and cutting the banks. The height of the embankment at the location of the structure must at least equal the maximum depth of flow in the stream plus the design height of the structure in the central portion of the drainage line. This rule is applicable to all structures in which overtopping is permissible boulder check should be made where the embankments are well defined and stable.
5. Even though storage is not a primary consideration in the case of loose boulder checks, enhanced water retention and groundwater recharge is a desirable objective. Hence, locating the structure in those sections in the drainage line where the upstream slope is flatter may be advantageous. The flatter the upstream slope, the more would be the storage per unit height of the structure.

Laying out Boulder Checks on a Stream

Since loose boulder checks are not reinforced, the angle of rest of the rock should determine the slopes of the dam sides. This angle depends on the type of rock, the weight, size and shape of the individual rocks and their size distribution. If the dams are constructed at an angle steeper than that of rest of the rock, the structure will be unstable and may lose its shape during the first heavy runoff. Loose rock has proved to be a very suitable construction material if used correctly. Often it is found on the land and thus eliminates expenditure for long hauls.

There will be a series of loose boulder checks on each drainage line. The minimum vertical interval between two successive checks on a drainage line should equal the height of the structure, so that the water temporarily stored in one check will reach the toe of the check upstream. Any interval below this limit would mean under utilization of the capacity of the downstream boulder check. What interval we keep above this limit would require a balance to be struck between cost considerations and volume of water to be stopped. Once this vertical interval is fixed, the horizontal interval between two successive checks would depend on the bed slope of the drainage line: for instance, with a constant vertical interval of 1m, the boulder checks would be spaced at a horizontal interval of 20m on a 5% slope and 10m on a 10% slope. In general the relationship can be expressed as follows:

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

Where, HI is the Horizontal Interval and VI the Vertical Interval. However, one must not follow this rule blindly without taking into account the catchment area that each boulder check has to handle. For example, on high slopes one may end up making too many checks even though there is very little water which each check needs to handle. In practice, one must fix the maximum and minimum horizontal interval between two successive loose boulder checks:

1. On high slopes, loose boulder checks should be spaced close but not closer than 10m;
2. As the slope decreases, boulder checks must be spaced farther, but not farther than 50m.

3.3.12.2.1 Design of Loose Boulder check

Through years of experience in watershed development, the maximum height generally accepted for loose boulder checks is 1m. The design height of 1m means that the top of the check in the middle of the stream is 1m above ground level. The top width of the boulder check is usually 0.4-0.5 m. As the material used in the check has a high angle of repose, the upstream slope of the check should be fixed at 1:1in general, to be varied only in exceptional cases where the structure has to handle very high volume of runoff of high velocity.

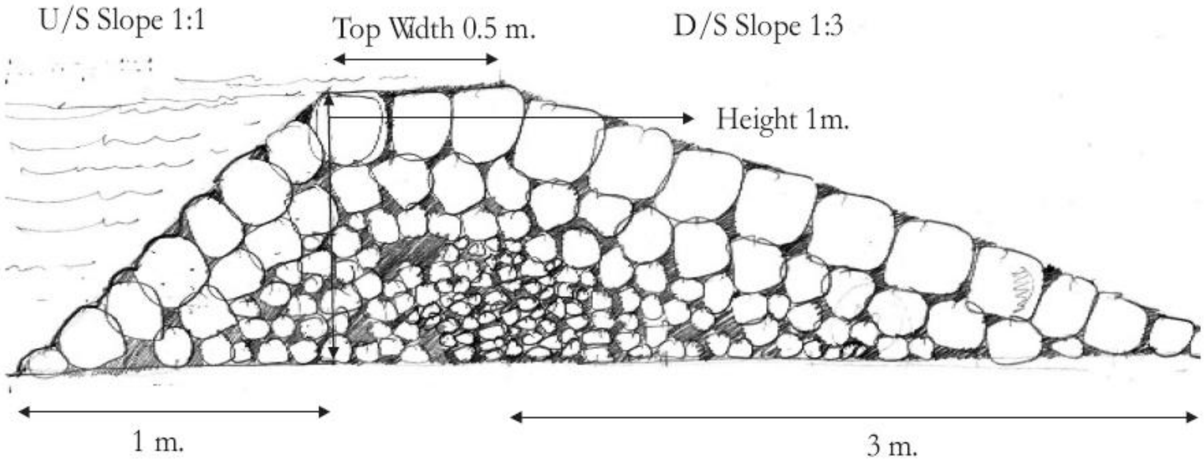


Fig 26: Cross section of loose boulder check

The downstream slope of the boulder check can vary from 1:2 to 1:4 depending on the volume and velocity of runoff. The higher the volume and velocity of runoff, flatter the slope.

Since the boulder check is composed of highly porous material it is not expected to hold water for a long period.

Example 1:

Find out the number of loose boulder check in the micro-watershed, if there is a stream 2000m long, with a slope of 8%, then how many 1m high loose boulder checks.

Solution: We know that,

Slope S = 8%

Length of the Stream L = 2000 m

Height of the Boulder Check VI = 1 m

Horizontal interval, $HI = \frac{VI}{Slope\%} x100$ **=** (1/8) x 100 = 12.5 m

Also, the base of the boulder check itself will occupy 5m. Therefore the effective width of a boulder check, w = 12.5 m + 5 m = 17.5 m.

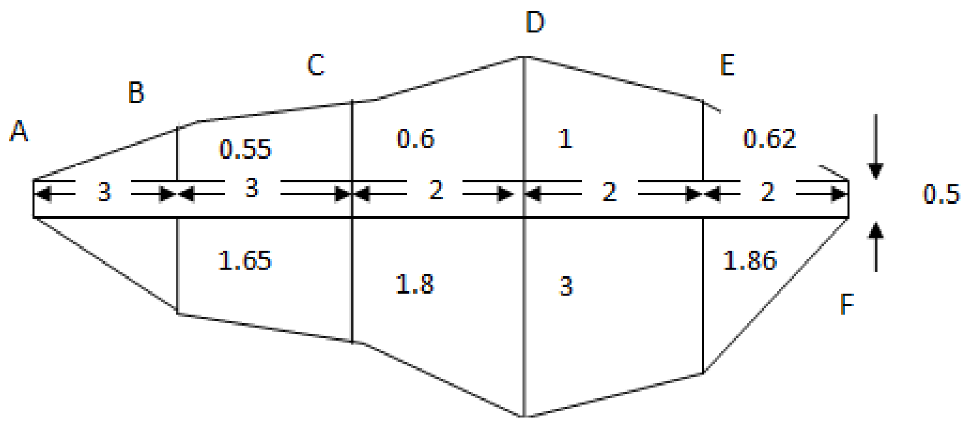
Therefore, Number of boulder check = (Total length of stream)/(Effective width of 1 boulder check)

= 2000/17.5

= 114.2 means 114 numbers

Example 2

Cross section of the boulder check is shown below. Find the cost of the loose boulder check.



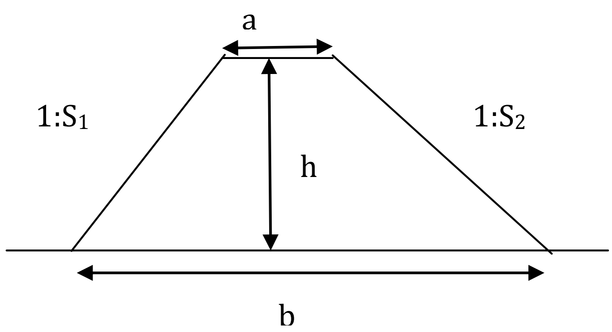


Fig 27: Cross section of loose boulder check

Point	Chainage (between points)	Height
A	0	0.00
B	3	0.55
C	6	0.60
D	8	1.00
E	10	0.62
F	12	0.00

Solution

Area of a trapezium = Average of parallel sides × Distance between two parallel sides

$$A=\left(\frac{a+b}{2}\right)\times h$$

where, a = Top width, b = Base width, h = Height

Base width (b) = Upstream Slope (S_1) × Height + Downstream Slope (S_2)× Height + Top width(a), $b = hxS_1 + a + hxS_2$

Area of trapezium (cross section between two points) = a x h + h^2 x (S1 + S2) /2

Volume of boulders required can be found out by multiplying the distance between points with area. Here we know Top width (a) = 0.5 m, Upstream slope S_1=1 and Downstream slope S_2=3.Using the above equation quantities of boulders required can be found out.

	Boulder check- Quantities					
Point	**Chainage**	**Height**	**Area of X-Section**	**Av. Area of x-Section**	**Distance**	**Quantity**
A	0	0.00	0.00	-	-	-
B	3	0.55	0.88	0.44	3	1.32
C	6	0.60	1.02	0.95	3	2.85
D	8	1.00	2.50	1.76	2	3.52
E	10	0.62	1.08	1.79	2	3.58
F	12	0.00	0.00	0.54	2	1.08
Total					**12**	**12.35**

Add 15% for keying and smooth exit of boulder check. Volume of boulder required for keying = 12.35 x 0.15 = 1.82 m^3

Total Volume of boulder required for boulder check = 12.35 + 1.82 = 14.20 m^3

Unit Rate for collection & stacking of boulders = Rs 250 (From rate analysis). So, total cost of boulder check =14.20x250= Rs 3550

3.3.13 Chute Spillway

Chute spillways are paved sloppy channels usually carrying high run-off discharges. In addition, these help in controlling high falls in gullies. Chute spillway ordinarily consists of an entrance channel either straight or curved in alignment, a control structure, a terminal structure, and an outlet channel. The main design consideration would be to fix the longitudinal bed profile of the channel and its sectional dimensions. The energy of the flow has to be suitably dissipated at the outlet, before the flow enters the downstream channel.

Objectives

i) To serve as a spillway for surplus water from farm ponds/reservoirs over earthen embankments.

ii) To serve as gully control structures for safely accommodating flash flow coming from upper catchment and causing deep gullies.

Specific Site Conditions

Chute spillways are generally used to drop water at reaches which are much farther and lower than that of a drop structure. In gully control, they can be used for the control of gully drops up to 6 m. Where there is no opportunity for providing temporary storage above the structure and where high discharges are required, the flume with its inherent high capacity is preferred over the drop inlet spillway. In situations where construction of a drop spillway or drop inlet spillway is going to be costly, chute spillway structures, which are relatively cheaper, are adopted. However, there is the danger of the structure being undermined by rodents and in locations with poorly drained soil; foundations may be threatened by seepage.

Design

The chute spillway structure also has the following main components.

(i) Inlet or control section

(ii) Conduit or Chute Discharge Carrier

(iii) Outlet or Energy Dissipator

Control Section

The control structure should have a proper approach channel. It is usually located on the flanks where the height of body wall either of masonry or concrete of spillway is considerably small. The Crest gates for flood control if necessary may be provided. Water overflowing the spillway is let into the chute. The common type of inlets used in chute spillways are the straight inlet, box inlet and the side channel inlet. The design procedures for inlets are more or less the same as drop spillways.

Conduit or Chute Discharge Carrier

The Chute portion will be a steep channel to convey water from a higher to lower elevation (i.e. to the natural river course at very high velocity. The cross section of the Chute may be rectangular or trapezoidal). Usually the conduit section is adopted considering the dimensions of the inlet section. Sometimes, more or less same section as that of inlet is used for the conduit also.

Outlet

These are located at the downstream end, after the fall is completely negotiated and in the vicinity of the natural stream. It may include Chute blocks, baffle blocks, stilling basin, end sill and side (training) walls. It is preferable to keep them vertical on water side for the satisfactory formation of hydraulic jump. When the velocity at entry of stilling basin is high, chute and baffle blocks are omitted. The outlet's capacity is verified by different considerations of critical depth of flow. Straight apron can also be used for small structures. Scour at the outlet is one of the important factors leading to failure of an over fall structure. Scour may be controlled by giving proper consideration in the design to the:

i. Stability of the grade below the structure.
ii. Velocities occurring in the downstream channel.
iii. Tail water elevations for different flow stages.
iv. Dissipation of water energy in the outlet.

Scour below drop spillways or chutes usually are reduced as the tail water elevation is increased.

Cost Estimate

Cost estimates of the chute structures may involve the earth work in embankment or shaping the existing gully head or pond fill to accommodate the components of chute structures. The cost of inlet, paved channel and outlet are worked out based on the standard procedure of weir.

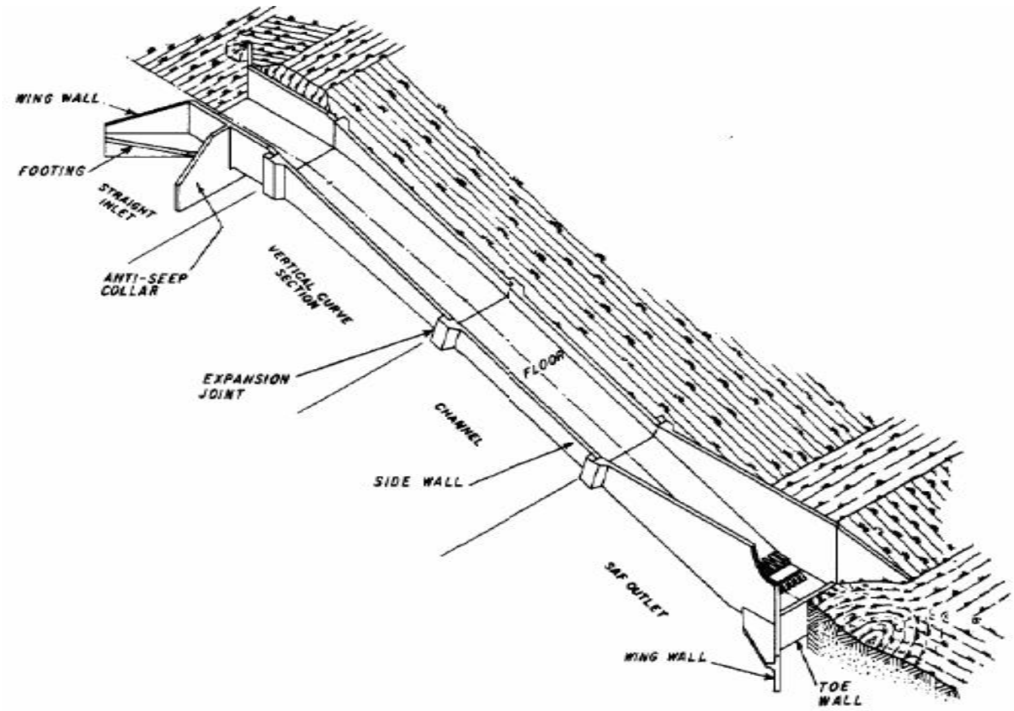


Fig. 28: Chute Spillway

The type of foundation for any proposed site may determine the type and size of structure to be constructed. Wet, seepy foundations are not suitable for large concrete structures unless the design includes expensive corrective measures. This may be the place where a drop inlet structure is needed. Dry, unstratified foundations are suitable for almost any type of structure. Where there are wet areas on the structure site, drop spillways or chutes can be constructed in a drier area and the water flow diverted to them.

Chapter-4

4 Middle Catchment Area Treatment

4.1 Introduction

This chapter involves land development activities for middle catchment area treatment covers land leveling, farm bund, farm pond and waste weir.

4.2 Land Levelling

Land levelling is a process of smoothing and grading the land surface to provide a suitable surface for efficient application of irrigation water and uniform leaching of salts. It may be defined as the process of changing the natural topography in such a way so as to control the movement of water on to or from the land surface. Land levelling could be considered under the two heads namely development of barren uncultivated lands and levelling of currently irrigated lands. In the first case, land levelling would be a package of land development consisting of reconnaissance survey, land clearing, topographic and soil survey and land levelling. In the second case where fields are already cultivated, land levelling is usually accomplished, on a field-to-field basis. In large area planning, a complete design of the land levelling operation in blocks of economically feasible sizes is necessary. Before doing so, it would be beneficial to complete rough grading with the help of bulldozer. For hauls exceeding 100 m, the efficiency of a bulldozer is reduced significantly. In such cases, use of scraper with a pick up and carry operation could be employed. In the second instance for small areas, the tractors usually do levelling operation and the driver's judgment is sufficient to achieve the desired level. In establishing the land-grading plan in both the cases, the designer has to consider factors like soil profile limitations, prevailing land slopes, rainfall characteristics, crops to be grown and irrigation methods to be practiced. For example, in sprinkler and drip irrigation levelling could be quite rough and could even be dispensed with. Levelling is usually limited to lands, which can be graded economically to slopes, which do not ordinarily exceed 2%. The depth of top soil that can be disturbed without reducing productivity often limits the extent of levelling that is practicable, especially in shallow soils.

4.2.1 Design Methods for Land Levelling

There are four basic methods of land levelling. Each method has some advantages and disadvantages, but when intelligently used, all will provide satisfactory results.

i. Plane method
ii. Profile method
iii. Plan inspection method

iv. Contour adjustment method

v. Out of above four methods, the first one is most commonly used.

4.2.1.1 Plane Method

It is the most widely used and very useful method for developing a good quality levelling job. It is so called because the resulting land surface has a uniform field slope and a uniform cross slope. Thus, true plane surface results. Following are the steps for design procedure using plane method:

Determination of centroid: The distance of the centroid of the field from any line of reference is equal to the sum of the products obtained by multiplying the area of each part times the distance from the line of reference to its centroid, divided by the area of the entire field.

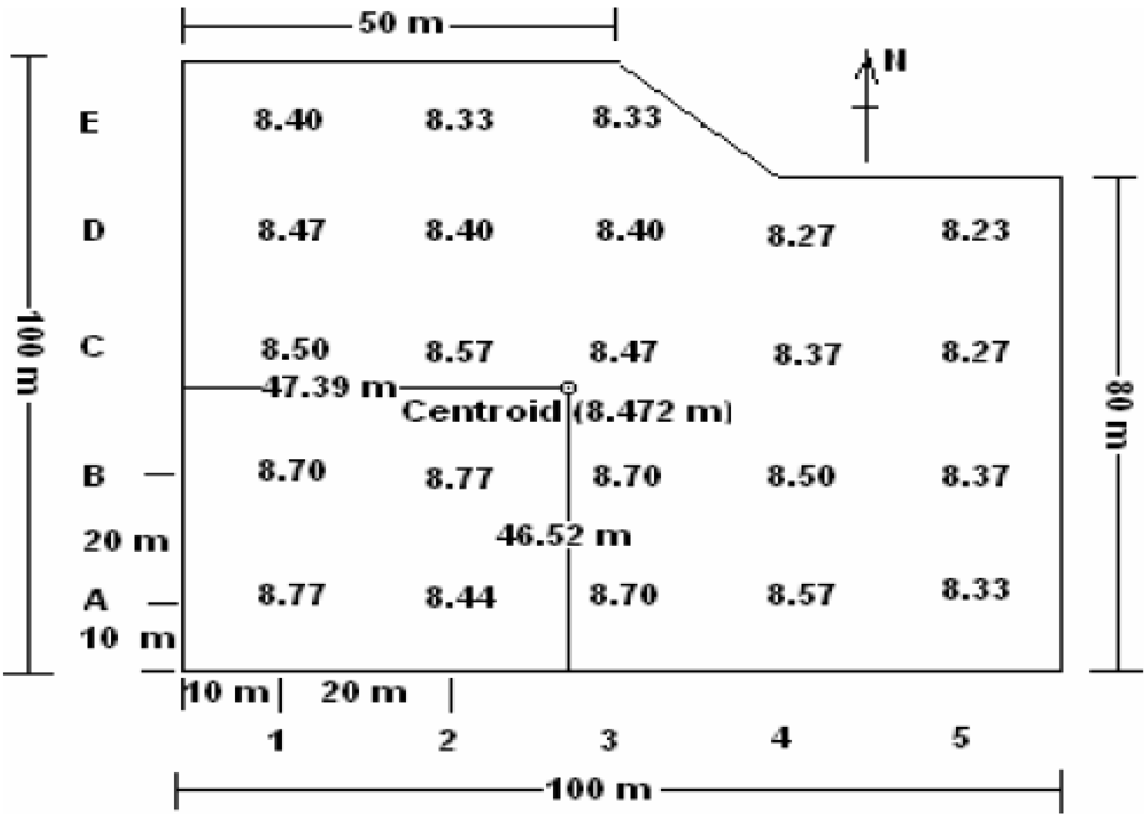


Fig 29: Location of centroid using plane method

4.2.1.2 Centroid with respect to Reference Line

South of row A = [(10x5) + (30x5) + (50x5) + (70x5) + (90x3)]/23 = 46.52 m

Left of line 1 = [(10x5) + (30x5) + (50x5) + (70x4) + (90x4)] / 23 = 47.39 m

(ii) Determination of average elevation: It is obtained by adding the elevations of all grid points in the field and dividing the sum by total number of grid points.

Elevation of centroid = 194.86 / 23 = 8.472 m *(iii) Computing the cut and fills for levelled field:* Taking elevation of the centroid (8.472 m) as formation level for levelled field, the cuts and field for all grid points are calculated as given in Table 24.

(iv) Computing the formation level and cuts and fills for 0.2% slope: Taking 0.2% slope in east-west direction, the formation level and the cuts and fills for different grid points are given in Table 25.

Table 16: The cuts and fills for levelled field

	1	2	3	4	5
A	-0.298	+0.032	-0.228	-0.098	+0.142
B	-0.228	-0.298	-0.228	-.028	+0.102
C	-0.028	-0.098	+0.002	+0.102	+0.202
D	-0.002	+0.072	+0.072	+0.202	+0.242
E	-0.072	+0.142	+0.142	-	-

(- sign indicates cut and + indicates fill: check: ∑ cut = ∑ fill = 1.530 m)

Table 17: The cuts and fills for field with 0.2% slope (east-west direction)

	1	2	3	4	5
Level	8.397	8.437	8.477	8.517	8.557
A	-0.373	-0.003	-0.223	-0.053	+0.227
B	-0.303	-0.333	-0.223	+0.017	+0.187
C	-0.103	-0.133	+0.007	+0.147	+0.287
D	-0.073	+0.037	+0.077	+0.247	+0.327
E	-0.003	+0.107	+0.147	-	-

(- sign indicates cut and + indicates fill: check: ∑ cut = ∑ fill = 1.820 m)

4.2.1.3 Earth Work Estimations

The "average end area" or the "prismoidal" formulae are suitable for making earthwork computations. A better procedure known as "the four point method" is generally employed and is quite accurate for land grading:

$$Vc = \frac{L^2\left(\sum C\right)^2}{4\left(\sum C + \sum F\right)} \quad \text{and} \quad V_f = \frac{L^2\left(\sum F\right)^2}{4\left(\sum C + \sum F\right)}$$

Where, Vc = volume of cut, cum

V_f = volume of fill, cum

L = grid spacing, m

C = cut on the grid, m

F = fill on the grid, m

4.2.2 Profile Method

With this method, ground profiles are plotted and a grade is established that will provide an appropriate balance between cuts and fills as well as reduce haul distances to reasonable limits. It is usually well adapted to levelling design for very flat land with undulating topography on which it is desired to develop a fairly uniform surface relief. There are many variations of the profile method, but essentially it is a trial and error method of adjusting grades on plotted profiles until the irrigation criteria are met with and the earthwork balance is attained. Experienced workers frequently use this method, as it is relatively easy to select grades on a profile that will provide balanced cut and fill with a relatively short haul distance.

4.2.3 Plan Inspection Method

In this method, the grid point elevations are recorded on the plan and the design grade elevations are determined by inspection after a careful study of the topography. It is largely a trial and error procedure keeping in mind down field slope and cross slope limitations. Although this method does not ensure minimum cuts and fills or the shortest length of haul, it is a rapid method. This method is adopted for moderate to flat land slopes. Usually it is necessary to assume trial elevations for one or two lines of stakes. In selecting the formation level, the designer must simultaneously consider the down field slope, cross slope, earthwork balance and haul distance.

4.2.4 Contour Adjustment Method

To apply this method, a contour map is drawn and the proposed ground surface is shown on the same map by drawing new contour lines. The uniformity of slope is controlled by properly spacing the new contours. As with the plan inspection method, it is largely a trial and error procedure. The proper balance of cuts and fills is estimated graphically at the grid points by interpolating between contour lines and by new surface. This method is adapted to smoothening of steep lands that are to be irrigated. This method demands considerable judgment on the part of designer to keep the earthwork and haul to a minimum.

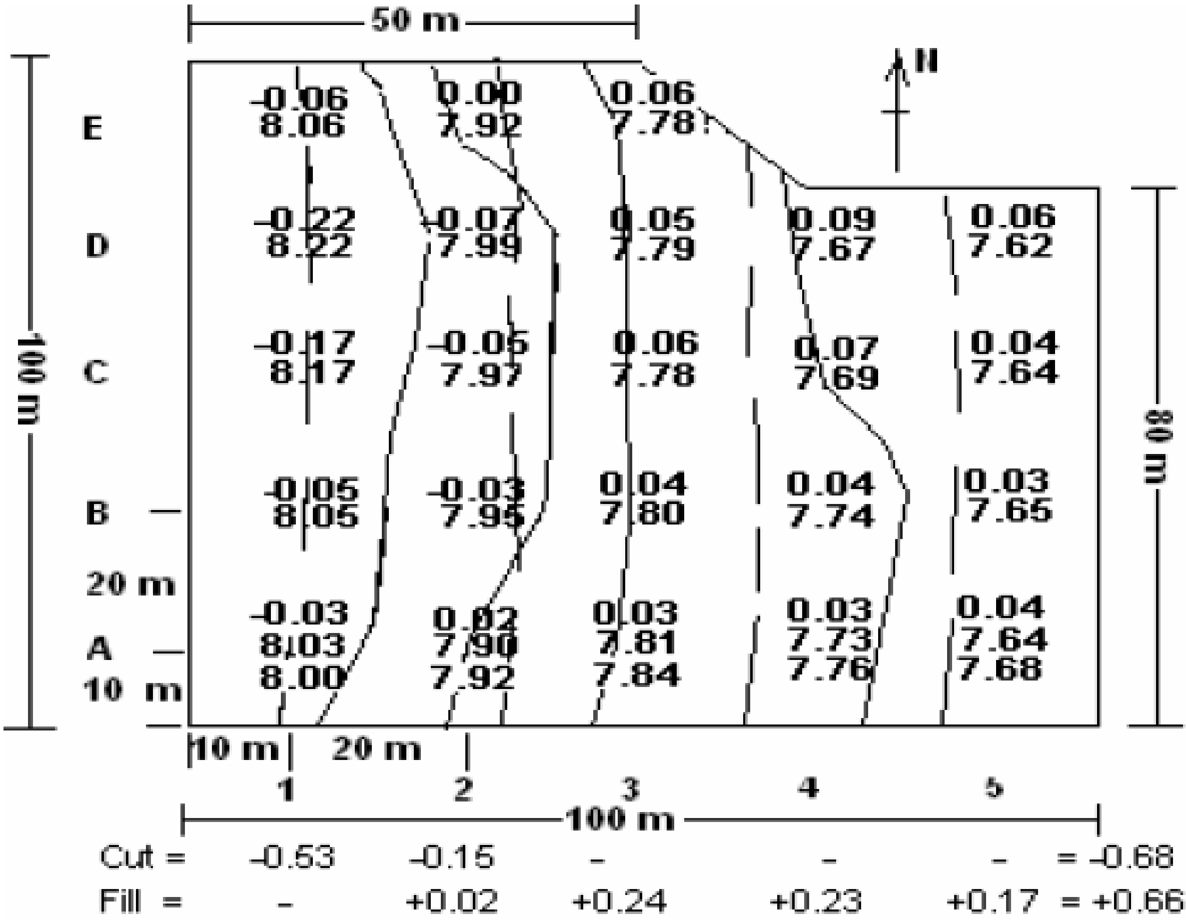


Fig. 30: Land Levelling using contour adjustment method

4.3 Farm Bund

Farm bunds are constructed on agricultural land with the aim of arresting soil erosion and improving the soil moisture profile. Ideally, bunds on farms should be made on the contour line. But this creates several problems for farmers. These bunds divide the field into irregular sections. In such a situation, it becomes inconvenient to maneuver bullocks for operations such as ploughing and line-sowing.

(Source: Capacity Building Manual for IWMP, GSWMA)

Fig. 31: Farm Bund

4.3.1 Objectives

4.3.1.1 Control of Soil Erosion

In our country, rain falls in a few hours on a few days in a few months. After falling on the ground, rainwater carries off with it precious top soil. Due to this action of rainwater, rills are formed in fields, which soon become small drains. It must be remembered that every year in our country 6.6 billion tonnes of top soil and 5-8 million tonnes of nutrients are lost due to soil erosion. India is losing soil 30 to 40 times faster that the natural replenishment rate. We should also keep in mind that it takes over ten thousand years to form a cm thick layer of fertile soil. It is estimated that if these soil losses are prevented the productivity of agricultural can rise by 30-40%. By dividing the field into several units, bunds control the volume and velocity of runoff in each such unit. The water in the field and the soil it is carrying are stopped at each bund. Thus, by not allowing water a long stretch of free flow, bunds break the momentum of water.

Improvement of the Soil Moisture Profile

Bunding improves and stabilises the soil moisture profile. The definition changes with changing local conditions:

In permeable soils (sandy or alluvial), the main aim of bunding is to stop runoff.

In impermeable soils (black or clayey), the purpose of bunding is to make arrangements for the safe exit of water out of the field. On the one hand, we aim to reduce the velocity of runoff. But since the soil is impermeable, this water will collect in the field and harm the standing crops. Thus, we also aim to provide an outlet to this water.

In fields with crops such as paddy, the purpose of bunding is to stop water in the field, regardless of the permeability or impermeability of the soil.

Planning

A plan for farm bunding can never be made for one field alone. Because, in any field water flows the fields above it and water flows out to the fields below it. Thus, it is important to plan for the entire stretch between the up-lying fields to the drainage line as a single unit. Therefore, it is crucial to involve all farmers in the village in the planning process. They must be informed about the proposed plan and its objectives. Only with their complete participation bunding should be finalised. Even so, it may happen that farmers in the uplying fields may not agree to get their fields bunded. In such a case, if bunding has to be done on low-lying fields, a diversion channel will have to be dug for the exit of water coming in from the fields above.

Spacing

The distance between bunds must be 30-80 m. This decision depends on the slope of the field. That is,

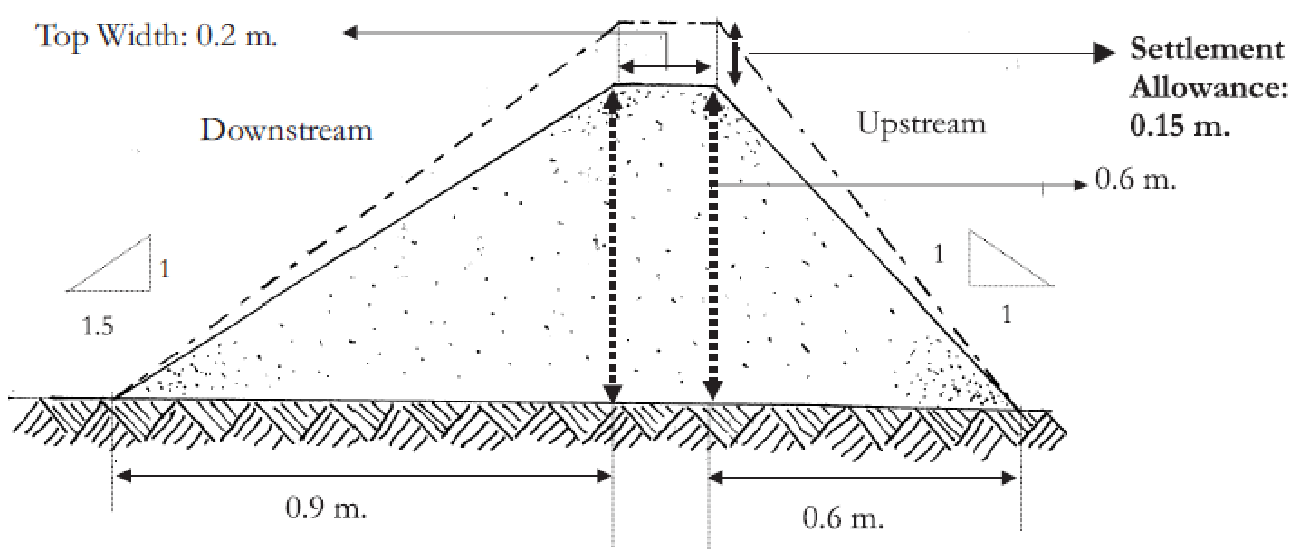
The greater the slope, the lesser the distance

The lesser the slope, the greater the distance

In highly sloping land, water will run off very fast. Thus it will have to stop more frequently.

Design

Situation 1: In Relatively Permeable Soils



(Source: Watershed works manual: A source book for Soil and Water Conservation Measures,FES)

Fig. 32: Cross section of a farm bund in permeable soil

1. Height: 60 cm (refer to Figure 32)

2. Settlement Allowance: 25%

3. Thus, height of bund at time of construction: 60 x 1.25 = 75 cm. In gravelly soils, the settlement allowance can be lowered to 10%

4. Top Width: 20-30 cm

5. Upstream Slope: 1:1

6. Downstream Slope: 1:1.5.

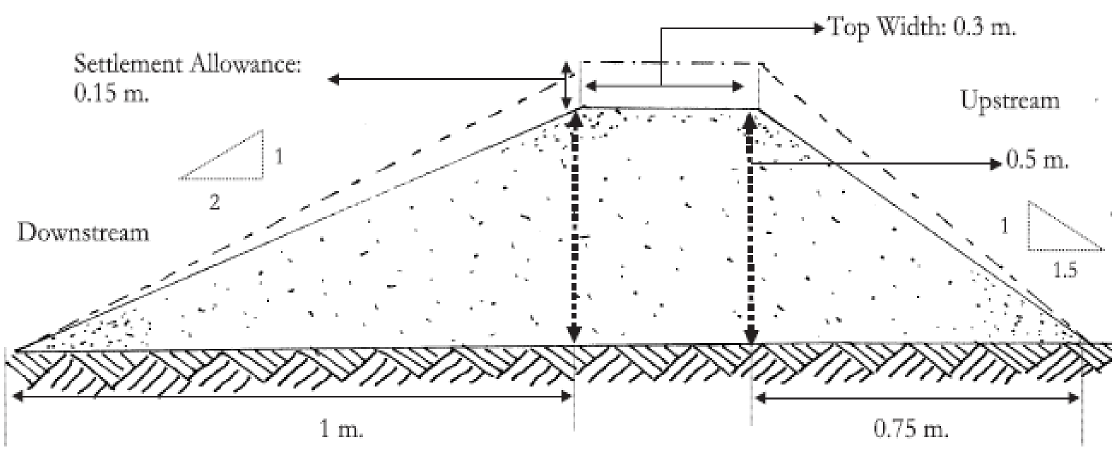
7. Exit: On relatively flat permeable fields, an exit need not be given. However, in sloping lands, there is every danger of the bund breaking without an exit. Therefore, provision of a stone exit becomes imperative. From the point of view of safety, it is best to provide an exit at the lowest point of the bund but in such a case no water will stop at the bund, rendering the bund meaningless. The exit should, therefore, be made a little above the lowest point of the bund. The water will stop at the bund for a short time and then flow out of the exit.

Situations 2: In Relatively Impermeable Soils

In such soils, there is a danger of water collecting in the field.

Height: 50 cm in impermeable soils, water takes a longer time to percolate below the ground. Therefore, there is always a danger of it overtopping the bund and breaching it. Thus, an argument can be made that bunds in such soils should be higher. However, in black clayey soils, this may create waterlogging and may also endanger the bund. In order to get around this dilemma, the bunds should be kept at a lower height, but in order to avoid waterlogging, an exit should be provided. In black, clayey soils, provision of such an exit is a must. In addition, the distance between bunds should be reduced (20 to 50 m) so that no unnecessary pressure is created on any one bund.

Settlement Allowance: The fine particles of clay have a natural tendency to settle.



(Source: Watershed works manual: A source book for Soil and Water Conservation Measures, FES)

Fig. 33: Cross section of farm bund in impermeable soil

Also, such soils are found as clods. Depending upon the shape of the clods, it is important to give a settlement allowance of at least 25%. As much as possible, the clods should be broken down, since the bigger the clods, the greater are the chances of the bund subsiding. The clods are best broken when they are dry.

3. Top Width: 30-40 cm. The width of bunds made of clayey soils has to be greater because when the clay dries up, it cracks. Moreover, on such bunds it is very important to plant grass etc. whose roots stabilise the bunds.

4. Upstream Slope: 1:1.5

5. Downstream Slope: 1:2 since clayey soils have a greater tendency to settle, bunds made from them should have lower slopes than those made on permeable soils. In particular, special care has to be taken to prevent water from seeping through the cracks in the bund and emerging across on the other side. After some time, the water starts forming wide channels downstream of the bund. To prevent this, the downstream slope of the bund must be lower than its upstream slope. Its base width can be kept at 2.5 m. This will prevent the seepage of water through the bund since it will be difficult for the water to seep through a broad bund. Another way is to give a gentle grade to the bund. The water will flow along the bund and out of the exit.

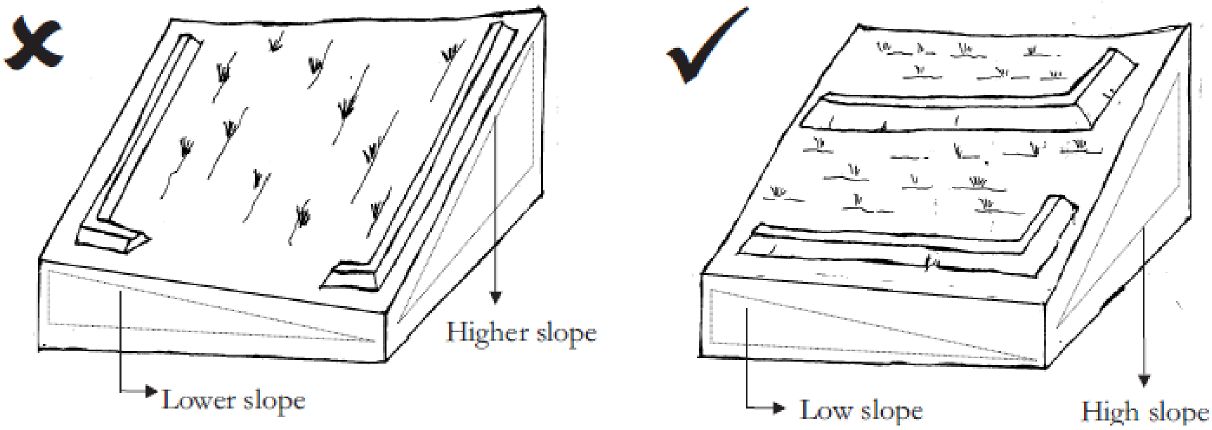
6. Exit: In black soils, exits must be provided, depending on local conditions. If the slope permits, a channel should be dug upstream of the bund for the exit of water. The water flowing out of each field should be given a channel, which uses the natural slopes to conduct water into the main drainage line. Grass should be planted on such channels in order to prevent soil erosion. At every 10-20 m. interval, small trenches should be dug across these channels which should be filled with stones. These trenches will prevent soil erosion, without obstructing the flow of water.

Alignment of Bunds under Different Conditions

The alignment of bunds requires several improvisations on the spot, depending on local conditions:

Example 1: When a rectangular field slopes along one diagonal or towards one edge of the field

In such a situation, ideally, contour bunds should be constructed across the slope of the field. However, as mentioned earlier, contour bunds will divide the field into irregular sections. Therefore, the bund should be constructed parallel to one of the field boundaries. In this way, since the bund will have a gradient, water will flow along it *(Source: Watershed works manual: Samaj Pragati Sahayog).*

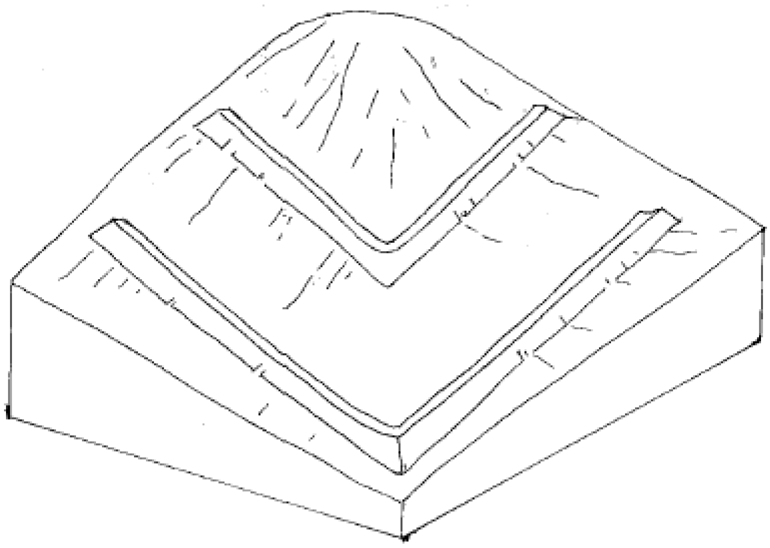


(Source: Watershed works manual: Samaj Pragati Sahayog)

Fig. 34: The wrong and the right way to layout bunds on sloping fields

Example 2: If the field has a two-way slope

If in such a situation, the bunds are aligned parallel to the boundaries, the velocity of runoff will only increase. Thus, first one bund should be constructed across one slope. Then the other bund should be constructed across the other slope. Both bunds should be joined in the middle. Such a bund will be almost like a contour bund. Remember to provide an exit in one or the other of the bunds *(Source: Watershed works manual: Samaj Pragati Sahayog).*



(Source: Watershed works manual: Samaj Pragati Sahayog)

Fig. 35: Farm bunds on a field with a two-way slope

4.4 Farm Pond

For many years farmers have been building ponds for irrigation and livestock. More will be needed in the future. The demand for water has increased tremendously in recent years, and ponds are one of the most reliable and economical sources of water. Ponds are now serving a variety of purposes, including water for livestock and for irrigation, fish production, field and orchard spraying, energy conservation, wildlife habitat, recreation, and landscape improvement. Harvesting of the water in pond, lakes, wells, tanks and reservoirs helps to preserve this water so that it can be put to varied uses later on. One of the most effective ways of water management is through pond. This technology developed due to the following reasons.

Dug out farm pond is most suitable water harvesting structure for semi arid black soils. Black soils constitute 23.1% of rainfed lands in India.

These areas receive low average annual rainfall ranging from 500 to 700 mm.

Due to low infiltration rate of these soils the storage losses will be minimum, which is good for storing water in dugout farm ponds.

The production of runoff in these areas ranges from 10 to 20%, which is higher than other soils.

The required storage capacity of a pond used for irrigation depends on these interrelated factors: water requirements of the crops to be irrigated, effective rainfall expected during the growing season, application efficiency of the irrigation method, losses due to evaporation and seepage, and the expected inflow to the pond.

4.4.1 Types of Ponds

Depending on the source of water and their location with respect to the land surface, farm ponds are grouped into four types. These are (1) Dugout ponds (2) Surface ponds (3) Spring or Creek fed ponds and (4) Off-stream storage ponds.

Dugout Ponds are excavated at the site and the soil obtained by excavation is formed as embankment around the pond. The pond could either be fed by surface runoff or groundwater wherever aquifers are available. In case of dugout ponds, if the stored water is to be used for irrigation, the water has to be pumped out. Pond is made by digging a pit or dugout in a nearly level area. Because the water capacity is obtained almost entirely by digging, excavated ponds are used where only a small supply of water is needed. Some ponds are built in gently to moderately sloping areas and the capacity is obtained both by excavating and by building a dam. Excavated ponds are the simplest to build in relatively flat terrain. Because their capacity is obtained almost solely by excavation, their practical size is limited. The ease with which they can be constructed, their compactness, their relative safety from flood flow damage, and their low maintenance requirements make them popular in many sections of the country.

Surface water ponds are the most common type of farm ponds. These are partly excavated and an embankment is constructed to retain the water. Generally it is made by building an embankment or dam across a stream or watercourse where the stream valley is depressed enough to permit storing 6 feet or more of water. The land slope may range from gentle to steep.

Spring or creek fed ponds is those where a spring or a creek is the source of water supply to the pond. Construction of these ponds, therefore, depends upon the availability of natural springs or creeks.

Off-stream storage ponds are constructed by the side of streams which flow only seasonally. The idea is to store the water obtained from the seasonal flow in the streams. Suitable arrangements need to be made for conveying the water from the stream to the storage ponds.

If an excavated pond is to be fed by surface runoff, enough impervious soil at the site is essential to avoid excess seepage losses. The most desirable sites are where fine-textured clay and silty clay extend well below the proposed pond depth.

Although excavated ponds can be built to almost any shape desired, a rectangle is commonly used in relatively flat terrain. The rectangular shape is popular because it is simple to build and can be adapted to all kinds of excavating equipment. Rectangular ponds should not be constructed, however, where the resulting shape would be in sharp contrast to surrounding topography and landscape patterns. A pond can be excavated in a rectangular form and the edge shaped later with a blade scraper to create an irregular configuration.

Traits of a Good Pond Site

A good pond site should possess the following traits:

(i) It should be a narrow gorge with a fan shaped valley above: so that a small amount of earthwork gives a large capacity.

(ii) The capacity catchment area ratio should be such that the pond can fill up in about 2-3 months of rainfall. The capacity should not be too small to be choked up with sediments very soon.

(iii) The main factors in deciding the location of a farm pond are soil type, natural flow of water (runoff water), possibilities of siltation and the topography. It must be ensured that all the water from field and also water from catchment area can be diverted into the pond (i.e. point in depression). It is necessary to make a test pit to understand the strata.

(iv) It can be undertaken in any field (individual or common land) from where farmer can easily provide water to crops, nursery, animals, and vegetable crop or fishery.
(v) Junction of two tributary, depressions and other sites of easily available fill material and favorable geology should be preferred.
(vi)The site should not have excessive seepage losses.
(vii) The catchment area should be put under conservation practices.

Detailed Soil Investigation

Soils in the pond area: Suitability of a pond site depends on the ability of the soils in the reservoir area to hold water. The soil should contain a layer of material that is impervious and thick enough to prevent excessive seepage. Clays and silty clays are excellent for this purpose, sandy and gravelly clays are usually satisfactory. Generally, soils with at least 20 percent passing the No. 200 sieve, a Plasticity Index of more than 10 percent and an undisturbed thickness of at least 3 feet do not have excessive seepage when the water depth is less than 10 feet. Coarse-textured sands and sand-gravel mixtures are highly pervious and therefore usually unsuitable. The absence of a layer of impervious material over part of the ponded area does not necessarily mean to abandon the proposed site.

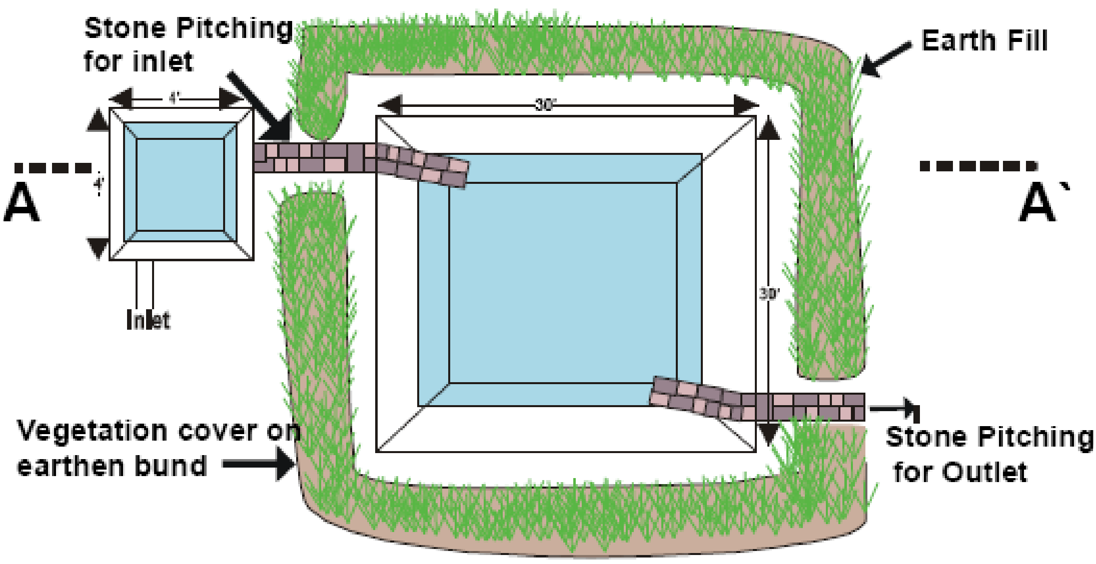
Some limestone areas are especially hazardous as pond sites. Crevices, sinks, or channels that are not visible from the surface may be in the limestone below the soil mantle. They may empty the pond in a short time. In addition, many soils in these areas are granular. Because the granules do not break down readily in water, the soils remain highly permeable. All the factors that may make a limestone site undesirable are not easily recognized without extensive investigations and laboratory tests. The best clue to the suitability of a site in one of these areas is the degree of success others have had with farm ponds in the immediate vicinity.

Selecting the Dimensions

The dimensions to be selected for a pond depend on the required storage capacity. Of the three dimensions of a pond, the most important is depth. If an excavated pond is fed from ground water, it should be deep enough to reach well into the water bearing material. The maximum depth is generally determined by the kind of material excavated and the type of equipment used. The type and size of the excavating equipment can limit the width of an excavated pond. For example, if a dragline excavator is used, the length of the boom usually determines the maximum width of excavation that can be made with proper placement of the waste material. To prevent sloughing, the side slopes of the pond are generally no steeper than the natural angle of repose of the material being excavated. This angle varies with different soils, but for most ponds the side slopes are 1:1 or flatter. If the pond is to be used for watering livestock, provide a ramp with a flat slope (4:1 or flatter) for access.

Depth: For the same volume of water stored, deeper the pond, lesser is the area occupied by the pond and also lesser are evaporation losses. However, with increased depth, the seepage losses also increase and hence the storage losses may even out. When the construction is done with human labour, any increase in depth beyond 2.5 to 3 m becomes uneconomical. It also becomes uneconomical and difficult for lifting devices operated with human and animal power. Hence, a depth of 2.5 to 3 m may be suitable in general for the ponds.

Side slopes: The side slopes are decided by the angle of repose of the sub-soil. The constant action of standing water may require relatively flatter side slopes to avoid slippage due to saturation. Generally, side slopes of 1:1 or flatter are adopted.



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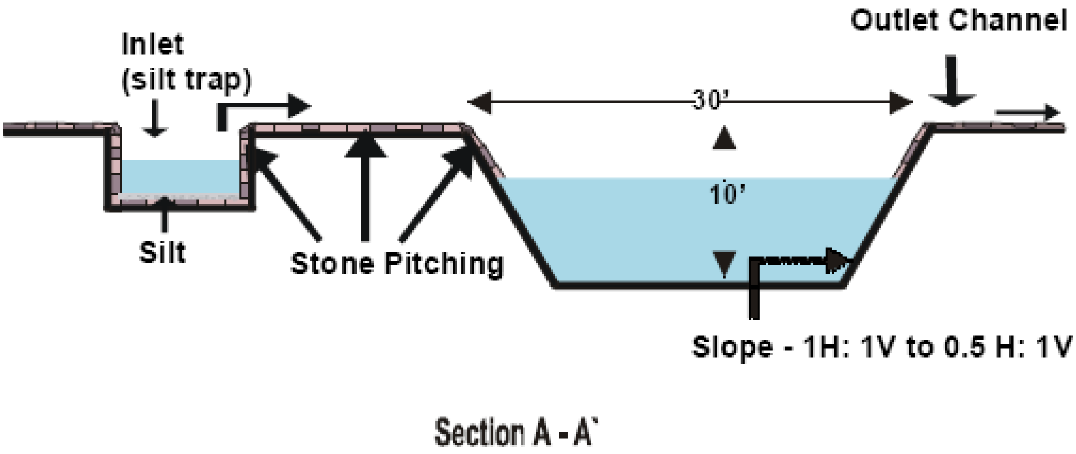

Fig. 36: Plan and Cross-Section of a Farm Pond

Bottom area: When the volume of the pond is known and the depth and side slopes are fixed, the side of the bottom square can be obtained from the following formula:

$$b=\frac{\sqrt{3V-d^3z^2}}{3d}-dz$$

Where, b = Side of bottom square, m,

V = Volume of pond, m^3,

d = Depth of pond, m, and

z = Side slope ratio (horizontal: vertical).

Bottom area (A_0) can be obtained by squaring the value obtained as above.

Top area: Once the bottom dimensions are known, the side of the top square can be obtained from the following formula:

B = b + 2 d.z.

Where, B is length of side of farm pond at the top in meter. Top area (A_2) can be obtained by squaring the value of 'B'

Inlet: The inlet is designed as chute spillway for conducting the runoff into the pond in a controlled manner. The entry section can be designed as a rectangular broad crested weir. The minimum size of inlet should be 1m x 1m in section and the length should be maintained as per the site condition. The pit of size 1.2 x 1.2 x 1.5 m (inlet chamber) should be provided to trap the incoming silt. Every year, the silt collected in the pit has to be removed.

Outlet: The outlet is constructed as a rectangular or square channel. The discharge capacity of the outlet can be assumed to be half as that of the inlet capacity as peak rate of runoff. Stone pitching for the outlet section has to be provided to avoid scouring of soil. If step cutting is adopted, step of 0.50m to 1m width and depth are more convenient.

Construction of the Pond

i. Site clearing
ii. Leveling
iii. Demarcating pond area.
iv. Establishing reference level
v. Stepping method of construction
vi. Formation of spoil bank
vii. Pitching
viii. Silt trap

Clear the pond area of all undesired vegetation. Mark the outside limits of the proposed excavation with stakes. In low-rainfall areas where water is unlikely to accumulate in the excavation, you can use almost any kind of available equipment. Tractor-pulled wheeled scrapers, dragline excavators, and track-type tractors equipped with a bulldozer blade are generally used. Bulldozers can only push the excavated material, not carry it; if the length of push is long, using these machines is expensive.

Fig. 37: Farm Pond

Pitching: Rock pitching is an effective method of control if a high degree of protection is required or if the water level fluctuates widely. Pitching should extend up to the flood reservoir level of the bund. Rock is dumped directly from trucks or other vehicles or is placed by hand. Hand placing gives more effective protection and requires less stone. Dumping requires more stone, but less labor. The layer of stones should be at least 12 inches thick and must be placed on a bed of gravel or crushed stone at least 10 inches thick. This bed keeps the waves from washing out the underlying embankment material that supports the pitching.

Establishing Vegetation

Trees, shrubs and grasses should be planted during or soon after construction of the bunds. Native varieties are preferred for new plantings.

Design example

A dugout pond is to be constructed in a semi-arid area having red soils. It is proposed to provide two supplemental irrigations of 10 cm depth (including losses) to an area of 1.5 ha. Design the pond and estimate the cost.

Solution

Water requirement for two irrigation times of 10 cm to 1.5 ha area,

= 1.5 x 10 = 15.0 ha-cm

Assuming 20 per cent of storage losses (evaporation and seepage),

Losses = 15 x 0.20 = 3 ha-cm

Designed capacity of the pond = 15.0 + 3.0

= 18.0 ha-cm = 1800 cu-m

It is presumed that the pond will have sufficient watershed area contributing runoff to fill the pond.

Depth of pond = 4.5 m (assumed)

Side slopes = 1:1

Shape = Rectangular

Assuming bottom width & length = 12 m x 25 m

Top length = 25 + (4.5 x 1) 2 = 34 m

Top width = 12 + (4.5 x 1) 2 = 21 m

Area of pond at top (A_2) = 34 x 21 = 714 m^2

Mid-length = 25 + (2.25 x 1)2 = 29.5 m

Mid-width = 12 + (2.25 x 1)2 = 16.5 m

Area of the pond at d/2 depth below the top of pond (A_1) = 29.5 x 16.5 = 486.75 m^2

Area of pond at bottom (A_0) = 12 x 25 = 300 m^2

Volume (V) using Equation

$$V=\frac{d}{6}(A_0+4A_1+A_2)$$

V= (300 + 4 x 486.75 + 714) 4.5/6 = 2220 ha-cm

Since, it is higher than the design capacity; the dimensions should be less than the previously assumed one. Now, assuming bottom dimensions = 12 m x 20 m (length changed from 25 to 20 m, keeping width as same).

Top length = 20 + (4.5 x 1) x 2 = 29 m, A_2 = 29 x 21 = 609 m^2

Mid-length = 20 + (2.24 x 1) 2 = 24.5 m

A_1 = 24.5 x 16.5 = 404.25 m^2, A_0 = 12 x 20 = 240 m^2

$V=\frac{d}{6}(A_0+4A_1+A_2)$, V= (240+4 x 404.25+240) x 4.5/6 = 1849.5 m^3

Therefore, these dimensions can be accepted as the design dimensions to store 18 ha cm ru-noff water.

Design dimensions (L x W) are:

Bottom = 20 m x 12 m, Top = 29 m x 21 m, Depth = 4.5 m, Side slopes = 1:1

Total estimated cost = cost of excavation/cubic meter of soil x Total Volume of Excavation

Assuming the cost of excavation per cubic meter of soil as Rs 43 (including lift), the estimated cost will be: 1849.50 x 43= Rs 79529/-

Design Example

Plan and Cross section of the dugout pond is shown in fig below. Find the cost of said dugout pond.

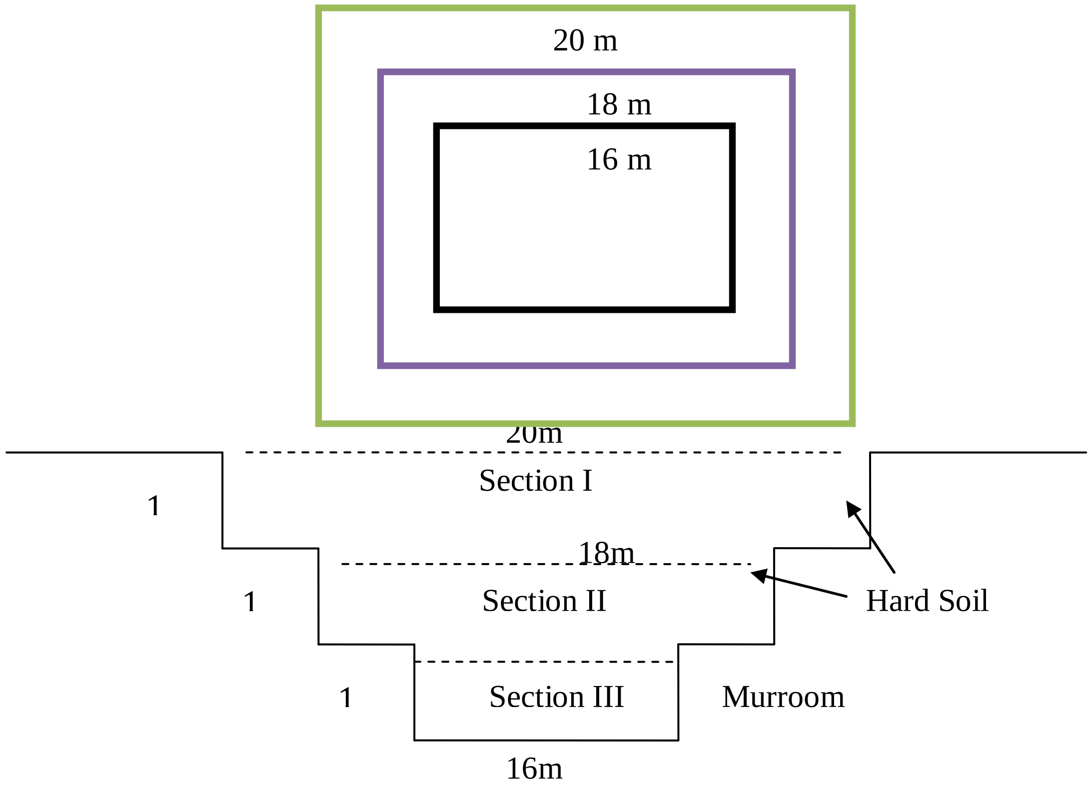

Fig. 39: Cross-section of pond

Volume of dugout pond in section I = Length x Width x Depth

= 20m x 20m x 1m = 400 m^3

Volume of dugout pond in section II = Length x Width x Depth

= 18m x 18m x 1m = 324 m^3

Volume of dugout in hard soil = 400 + 324 = 724 m^3

Volume of dugout pond in Section III = Length x Width x Depth

= 16m x 16m x 1m = 256 m^3

Volume of dugout in hard murrum = 256 cubic meter

Cost of excavation in hard soil = Volume x Rate

= 724 x 41 = Rs 29684

Cost of excavation in hard murrum = Volume x Rate

= 256 x 62 = Rs 15872

Lift charge: (it is a charge when the depth of excavation is more than 1.5 m.)

4.4.1.1 Volume of Lift

Volume of lift charge soil in section II = Length x Width x Depth

= 18 x 18 x 0.5 = 162 m^3

Volume of lift charge soil in section III = Length x Width x Depth

= 16m x 16m x 1m = 256 m^3

Total volume of lift charge soil = 162 + 256 = 418 cubic meter

Cost of Lift charge = Volume x Rate

= 418 x 2.50 = 1045

Total cost of dugout pond = 29684 + 15872 + 1045 = Rs 46601

4.5 Waste Weir

Waste weirs are structures with regular openings (to dispose of excess runoff) placed in the path of the water. They may be permanent or temporary. They are generally located within the structure in case of permanent structures and away from the structure or at safe locations in temporary structures. These are constructed also for giving a safe passage to the excess runoff from the field and also store some amount of water in the field. The water stored in these structures is mostly confined in field and height is normally less than 0.5 m. and excess water is allowed to flow over the head wall. They are usually located at the lowest point of the field forming the inter-bund area. Rectangular, triangular and trapezoidal weirs are commonly used in soil and water-conservation structures.

The rectangular weir is the most commonly used in agricultural lands. Weirs are typically installed in open channels such as streams to determine discharge (flow rate). The basic principle is that discharge is directly related to the water depth (h) in the figure above; h is known as the "head."

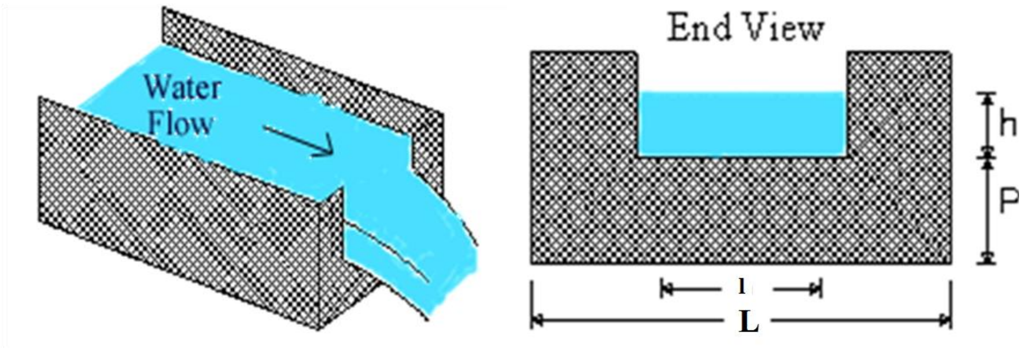

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Fig. 40: Waste weir

4.5.1 Design of Waste Weir

The weir can be made of wooden planks, sheet metal or concrete and the opening cut on the top of the edge. The weir has two design components namely its length (L) and the height (H) of water above the crest; these are variably related to the discharge (Q) according to the type of weir. The formulae expressing these relations are given below.

Rectangular weir:

$Q = 1.84\ LH^{3/2}$

Triangular weir:

$Q = 1.38\ H^{5/2}$

Trapezoidal weir (Cipoletti weir with side slopes of 1 horizontal to 4 vertical),

$Q = 1.86\ LH^{3/2}$

A depth of 0.3 m is mostly followed for computing the waste weir length at the beginning. The main components of a clear over fall weir are crest wall, side pitching and apron. A row of headers are also placed on the downstream side to hold the stones in position.

The discharge Q in all cases is calculated using the Rational formula described earlier. If H is assumed depending on the height of the water path, L can be calculated. Conversely, if the width of the waterway is known, L is assumed and H is derived for surplussing the excess water.

Fig. 41: Waste weir of a farm (farm outlet)

Design Example

To design a rectangular weir for disposing runoff from a catchment area (A) of 35 ha, having a runoff coefficient C of 0.5 with rainfall intensity (I) of 50 mm/hour

$$Q = \frac{CIA}{360} = 0.5 \text{ x } 50 \text{ x } 35 /360 = 2.43 \text{ cumec}$$

H is assumed to be 0.6 m, and then L is given by

$L = Q/ (1.84 H^{3/2})$

$= 2.43/ (1.84 \text{x} 0.6^{3/2}) = 2.43/ (1.84 \text{x } 0.465) = 2.84$ m.

The actual height of the weir should be 0.6 m + free board.

Chapter 5

5 Lower Catchment Area Treatment

5.1 Introduction

There are always strong links between soil conservation and water conservation measures. Many actions are directed primarily to one or the other, but most contain an element of both. Water harvesting in the lower catchment area or in drainage line is the collection, storage and recycling of rain water (surface/subsurface) for irrigation and other uses. Reduction of surface runoff can be achieved by constructing suitable structures or by changes in land management. Further, this reduction of surface runoff will increase infiltration and help in water conservation.

The engineering measures adopted differ with location, slope of the land, soil type, amount and intensity of rainfall. The principle of water harvesting techniques in the drainage line of lower catchment consists of three main components. First, the catchment area is where the part of the land contributes its share of rainwater. Second, the storage is the place where runoff water is held or collected. Third, the target or cultivated area is where the harvested water is used. Depending on these parameters, the methods commonly used are gabion, earthen dam, masonry check dam and subsurface check dams or dyke.

5.2 Gabion Structure

This is a kind of check dam being commonly constructed across small stream to conserve stream flows with practically low submergence beyond stream course with a catchment area of 30-150 ha. Small bund across the stream is made by putting locally available boulder in a mesh of steel of mesh wires. This is put up across the stream to make it as a small dam by anchoring it to the stream banks. This makes the structure strong and heavy. It acts as a single unit that can withstand a high velocity of runoff. The height of such structures is around 1 to 2 meter and is normally used in the streams with width of about 10 to 20 m. Gabion structures have a long life (20-25 years) almost similar to cement masonry permanent structures.

Concrete, masonry and brick work have good resistance to compression but fail easily under tensile loads resulting from settlement. A small settlement of the structure, can introduce stresses which the structure is ill equipped to withstand. The inherent flexibility of the gabions, the ability to bend without breaking seems to be the primary reasons for their success. Other important advantage are that i) they are permeable to water but retain soil, ii) they do not require water or cement for their construction, iii) the materials are re-usable if the baskets should break or if the structure should deform excessively, iv) gabions are also suitable where firm foundation is not available. They are also constructed to reinforce highly erodible stream embankments.

The excess water overflows this structure storing some water to serve as a source of recharge. The silt content of stream water in due course forms an impermeable layer and helps in retaining surface water runoff for sufficient time to recharge the ground water body.

5.2.1 Objectives

The main aim of constructing gabion structure is to reduce the velocity of water flowing through the drainage line. By reducing the velocity of runoff, gabion structures help in

i. Trapping silt, which reduces the rate of siltation in water harvesting structures in the lower reaches of the watershed.
ii. Soil conservation.
iii. Creating a hydraulic head locally which enhances infiltration of surface runoff into the groundwater system.
iv. Increasing the duration of flow in the drainage line. Therefore, the capacity of the water harvesting structures created downstream on the drainage line is utilized fully as they get many more refills.

(Source: Capacity Building Manual for IWMP, GSWMA)

Fig. 42: Gabion Structure

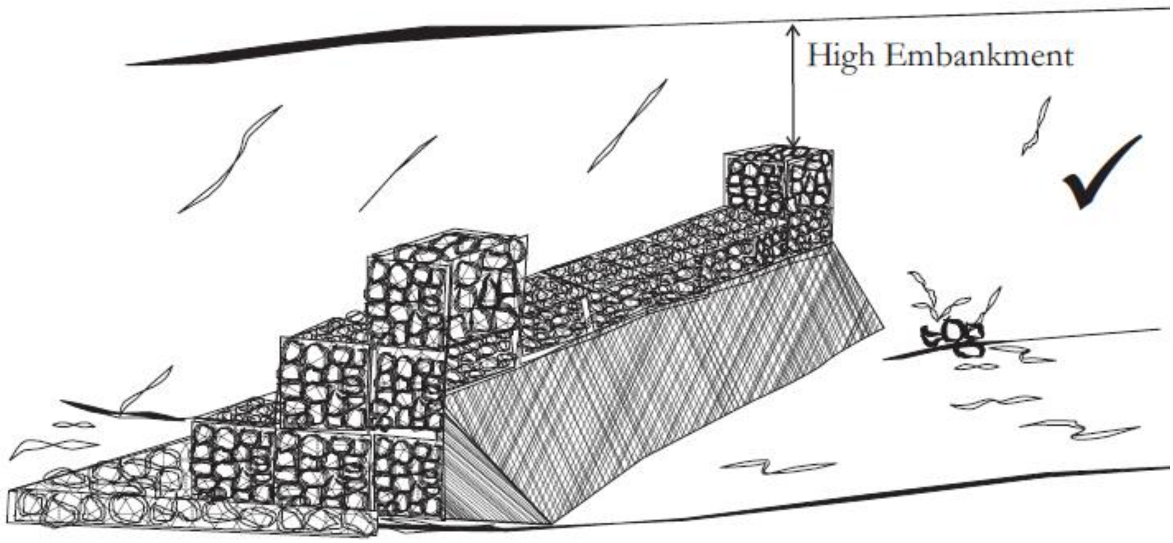


Fig. 43: Sketch of gabion structure in a drainage line

5.2.2 Site Selection

These are the structures constructed out of stones, where masonry and earthen structures are not feasible or uneconomical. Hence, the desired conditions are:

i. Straight stream flow.
ii. Stream bed should not be with loose material
iii. Stream banks should be stable and should have sufficient height on both sides.
iv. For maximizing storage in the structure, the bed slope of the upstream portion should be low. The flatter the upstream slope, the more will be the storage.
v. Structures should be at right angles to the stream flow.
vi. On the downstream of the structure at least 2m fairly level land should be available for apron work.

5.2.3 Spacing of the Gabions

Most common thumb rule is bottom of the upstream structure should be in the same level with top of downstream structure. If there is very mild slope say around 1% then spacing between two structures must be 50 m horizontally. In steep slopes spacing should be 5 to 10 m vertical interval or 10 to 20 m horizontal interval.

5.2.4 Brief Description of the Construction

Good quality galvanized wire of gauge 12-14 (chain link) must be used for constructing gabion structures. Ready-made mesh with a single twist is commercially available. In these meshes the gap should not be more than 7.5cm x 7.5cm. The prepared mesh should be combined together with 14 gauge wires. Box size of 1m length x 1 wide x 1m height is required to prepare and all the boxes have to be joined as a whole unit. After filling the box with rocks or boulders the top cover mesh is to be folded and all the corners are to be tightened with binding wire (14 gauge). Acceptable stone for gabion construction shall be hard, durable, equally graded, angular in shape, and shall not be less than 4" in any given dimension and no larger than 8" in any given dimension. The specific gravity required for the stone fill shall be determined by the design and specified by the design engineer. Specific gravity for stone fill shall be no less than 2.5. To increase the impermeability of the structure, a reverse filter should be constructed on its upstream face. This is made by placing layers of small boulders, gravel, sand and mud against the structure. The boulders are placed adjacent to the structure, with gravel, sand and mud being placed successively away from it.

Table 18: Unit weight of gabion stone fill

TYPE OF ROCK	LBS/CUBIC FT
Basalt	180
Granite	160
Sandstone	140

5.2.5 Specifications

Top width	:	1 to 2 m
Depth of foundation	:	0.30 to 0.6 or up to hard strata
Height above Ground Level	:	1-2 mt
Keying into bank	:	0.30 to 1.0 m into stable portion
Galvanized Iron chain link	:	size: 12 -14 gauge

5.2.6 Construction Methodology – Gabion structure

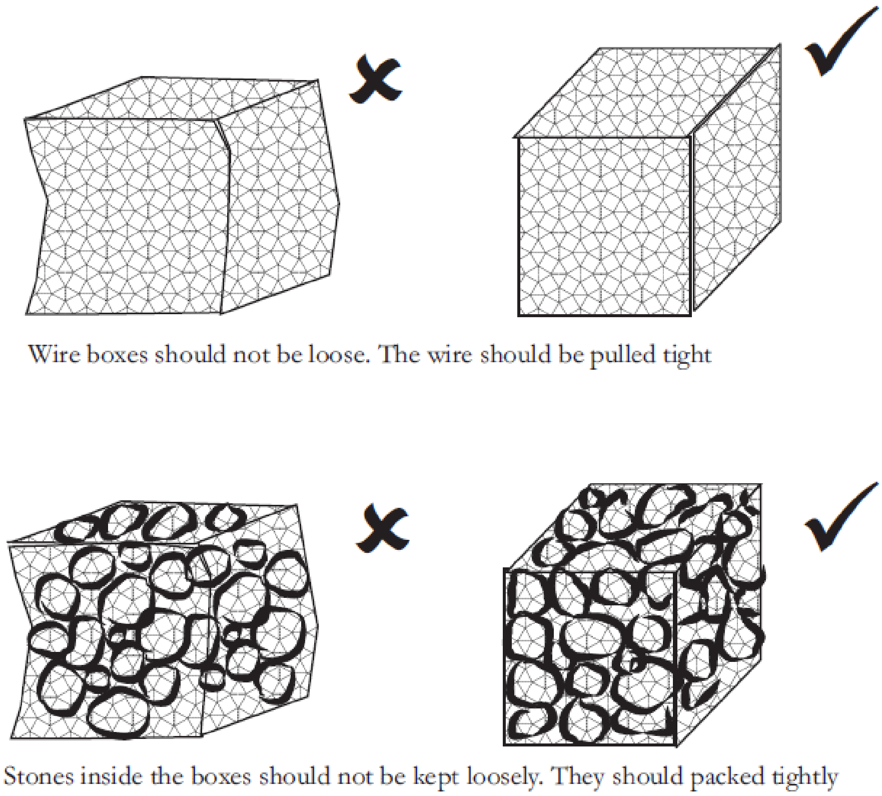
i. Clean the site first.
ii. Loose material should be removed from the construction site.
iii. Excavate the foundation trench to 0.30 to 0.60 m depth.
iv. Gabion box should be properly aligned along the foundation.
v. Layer by layer loose rock is to be kept. Bigger size rock should be kept at the bottom portion and smaller rocks (minimum size 4”) should be kept on the upper layer. The headwall as well as the sidewalls should be constructed as boxes of 1 to 2m length and 1to 2 m height. After filling up, the box should be closed tightly with the binding wire (14 gauges G.I. wire).
vi. Construct a stone bund with locally available stones.

vii. The whole structure should go (Head wall extension) up to 0.30 to 1.0 m into the stable portion of the gully side to prevent end cutting.

viii. The structure to the level equal to flood depth plus free board to prevent scouring of the stream banks.

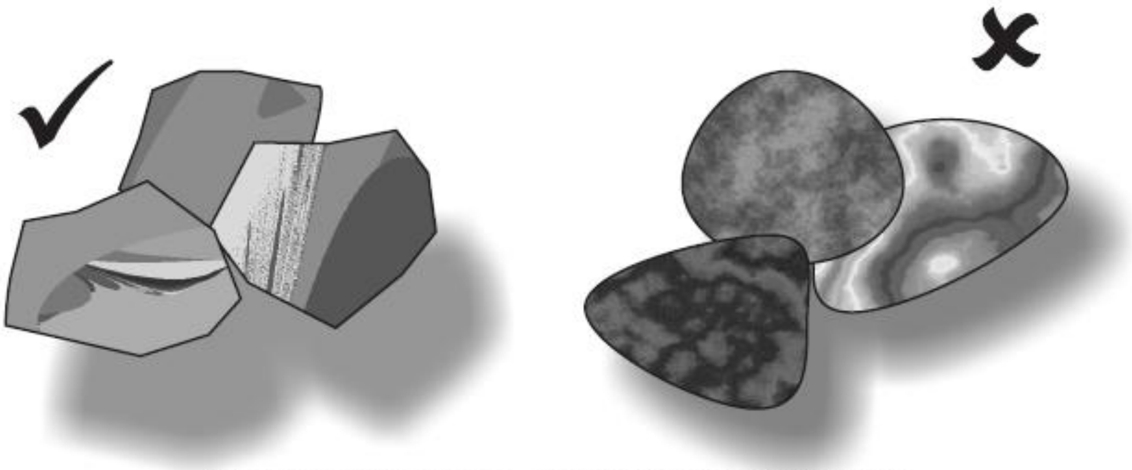
ix. On down streamside, provide 2 to 2.5m wide apron along the full length of the structure. Apron should be made by first excavating the trench and fill with boulders and enclosed in a wire mesh which is anchored under the boulders. This helps to prevent erosion of the down streamside of the structure.

x. To increase the impermeability of the structure, a reverse filter should be constructed on its upstream face.

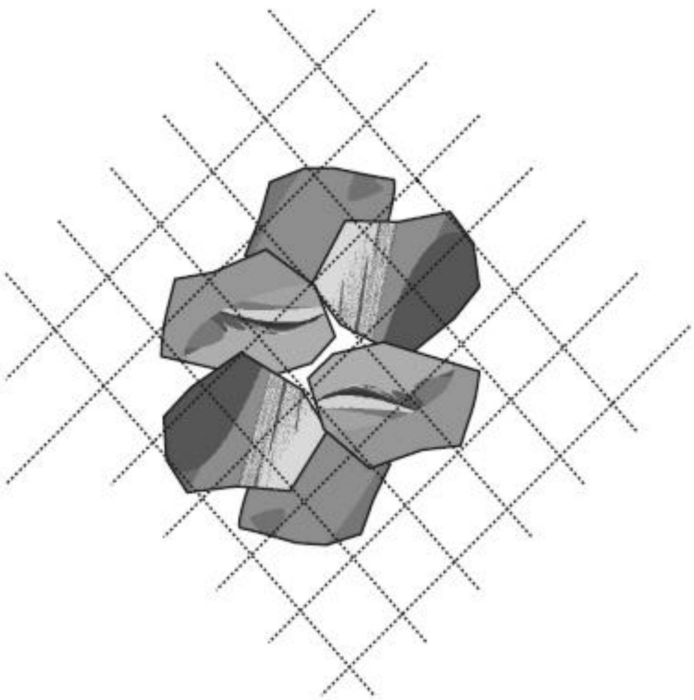


(Source: Watershed works manual: Samaj Pragati Sahayog)

Fig. 44: Design of stone box for gabion structure



Use angular stones in a gabion rather rounded ones

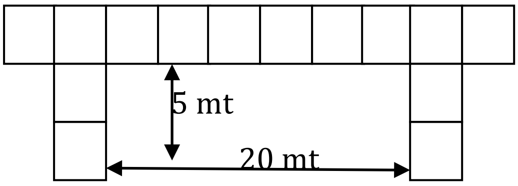


The smallest stone should be bigger than the hole in the wire mesh

Fig. 45: Selection of stones for gabion structure

Example

Find the cost of a Gabion Structure (GS) with the following parameter details: Length of gabion 20 m, Depth of foundation of headwall, headwall extension, sidewall and apron = 0.6 m, Height of head wall = 2.0 m, Length of headwall extension = 2 m, Height of sidewalls over headwall = 1m, Width of apron = 5m. Cross section of the gabion is shown in fig below. *(Source: Watershed works manual: A source book for Soil and Water Conservation Measures, FES)*



Step 1 Excavation

1. Excavation for head wall extension in hard soil

= 2 × Length ×Width × Depth

= 2 × 2 × 2 × 2 = 16 cum

2. Excavation for apron and main wall foundation in hard soil

= Length ×Width × Depth

= 20 × (5 + 1) × 0.60 = 72 cum

3. Boulder filling for apron and main wall foundation

= Length ×Width × Depth = 20 × (5 + 1) × 0.6 = 72 cum

Step 2 Area of wire mesh

Area of wire mesh

1. Area of wire mesh on apron and main wall foundation

= Length ×Width = 20 × (5 + 1) = 120 sqm

2. Area of wire mesh for keying of apron

= Length ×Width = (20 + 20 + 5 + 1 + 5 + 1) × 1 = 52 sqm

Total area of wire mesh apron: = 120 + 52 = 172 sqm

Step 3 Gabion Boxes

As we know the gabion is made with GI wire mesh cubical boxes of 1.0 m. filled with the boulders. For making one cubical box of 1 cum capacity:

Quantity of boulder required in 1 box= 1.00 cum

Quantity of wire mesh required = 5.00 sqm (As out of the six faces of cube two faces will remain common for joining the two boxes). For estimating the quantity of GS, we have to count the number of boxes in each part of the structure:

Total boxes for main wall = Number of boxes in the main wall c/s × Length of GS = 2 × 20 = 40 boxes

Total boxes for both sidewalls = Number of boxes in the side wall c/s × 2 = 6 × 2 = 12 boxes

Total boxes for both side head wall extensions = No. of boxes in the head wall extensions × 2 = 4 × 2 = 8 boxes

Total boxes for main wall + sidewall + head wall = 40 + 12 + 8 = 60 Boxes

Total quantity of wire mesh required for main wall + sidewall + extension wall = No. of boxes × 5 = 60 × 5 = 300 sqm

Quantity of reverse filter = Length x Base x height x 0.5

Volume of Reverse Filter = 20 x 1 x 2 x 0.5 = 20 cubic meter

Sr. No.	Particulars of work	Quantity	Rate	Amount
1	Excavation of foundation in hard soil	72	41	2952
2	Excavation for main wall extension in hard soil	16	41	656
3	Boulder filling in apron	72	250	18000
4	G.I. wire mesh for apron and its keying	172	90	15480
5	Boulder required for main wall, side wall & main wall extension	60	250	15000
6	G.I. wire mesh required for main wall, side wall & main wall extension	300	90	27000
7	Reverse filter	20	120	2400
	Total cost (Rs)		**81488**	

5.3 Earthen Dams

A dam exceeding 15m in height above deepest river bed level is defined as large dam. Also a dam in between 10 m to 15 m height is termed as large dam if volume of earth dam exceeds 0.75 million cubic meters and storage exceed one million cubic meters. A dam not satisfying the above criterion of large dam is termed as small dam and is an important structure in drainage line or in low catchment areas. Earthen dams are constructed across streams of having gentler slopes. An earthen dam may be homogeneous, zoned type and diaphragm type.

Fig. 46: Earthen Dam

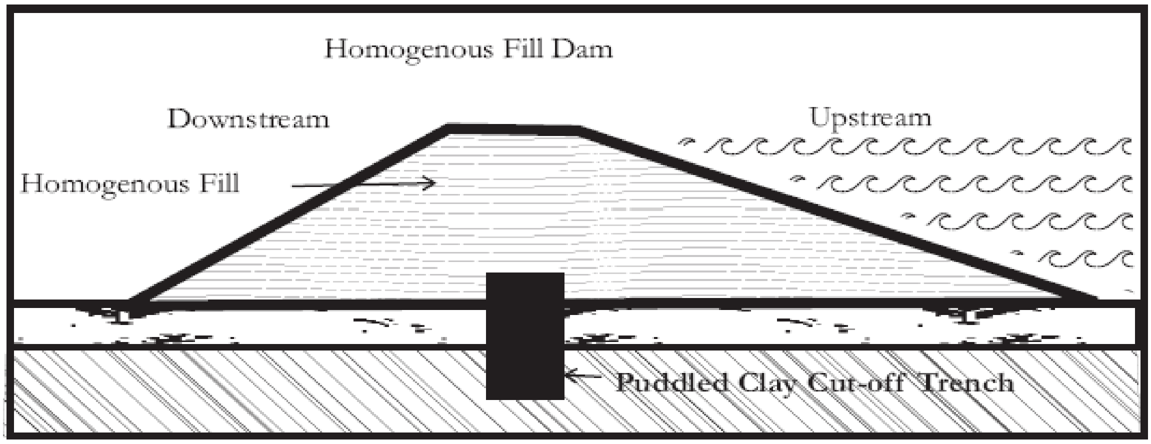


Fig 47: Homogeneous earthen dam

Homogeneous earth dam: A purely homogeneous type of dam is composed of a single kind of material. The purely homogeneous type of section has now been replaced by a modified homogeneous section, in which small amount of carefully placed pervious material control the action of seepage so as to permit much steeper slopes as compared to pure homogenous dam.

Zoned earth dam: In this type, a central highly impervious core is flanked by zones of material considerably more pervious. The core extends from above the water line to an impermeable stratum in the foundation. Sometimes an upstream blanket may also be used in conjunction with the central core or core wall to reduce the cost of fill material.

Diaphragm: In this type, the bulk of the embankment is constructed with pervious material (sand, gravel or rock) and a thin diaphragm of impermeable material like plastic, butyl, concrete, steel or wood to act as a barrier against seepage through the fill is provided. Depending on the length of wall, it could be "full diaphragm" or "partial diaphragm" type.

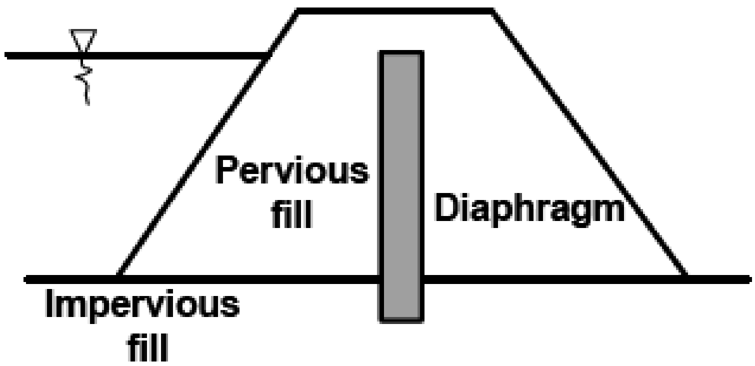


Fig 48: Diaphragm type earthen dam

An earth dam is composed of suitable soils obtained from borrow areas or required excavation and compacted in layers by mechanical means. Following preparations of a foundation, earth from borrow areas and from required excavations is transported to the site, dumped, and spread in layers of required depth. The soil layers are then compacted by tamping rollers, sheepsfoot rollers, tractors, or earth-hauling equipment.

5.3.1 Basic Requirements of an Embankment Dam

Dams are a critical and essential part of the Nation's infrastructure for the storage and management of water in watersheds. To meet the dam safety requirements, the design, construction, operation, and modification of an embankment dam must comply with the following technical requirements:

5.3.2 Selection of Embankment Type

Site conditions that may lead to selection of an earthen dam include a wide stream valley, lack of firm rock abutments, considerable depths of soil overlying bedrock, poor quality bedrock from a structural point of view. In order to be cost effective, the dam should be located where maximum storage volume is obtained through minimum volume of earth fill. Drainage line should have well-defined embankments where the dam is to be located so that it can be anchored.

Topography

Topography, to a large measure, dictates the first choice of type of dam. A narrow V-shaped valley with sound rock in abutments would favour an arch dam. A relatively narrow valley with high, rocky walls would suggest a rock fill or concrete dam (or roller-compacted concrete). Conversely, a wide valley with deep overburden would suggest an earth dam. Irregular valleys might suggest a composite structure, partly earth and partly concrete. Composite sections might also be used to provide a concrete spillway while the rest of the dam is constructed as an embankment section.

Geology and Foundation Conditions

The geology and foundation conditions at the dam site may dictate the type of dam suitable for that site. Competent rock foundations with relatively high shear strength and resistance to erosion and percolation offer few restrictions as to the type of dam that can be built at the site. Gravel foundations, if well compacted, are suitable for earth or rock-fill dams. Special precautions must be taken to provide adequate seepage control and/or effective water cutoffs or seals. Silt or fine sand foundations can be used for low concrete (or roller-compacted concrete) and earth dams but is not suitable for rock-fill dams. The main problems include settlement, prevention of piping, excessive percolation losses, and protection of the foundation at the downstream embankment toe from erosion. Non dispersive clay foundations may be used for earth dams but require flat embankment slopes because of relatively low foundation shear strength.

Materials available

The most economical type of dam will often be one for which materials can be found within a reasonable haul distance from the site, including material which must be excavated for the dam foundation, spillway and outlet works. Materials which may be available near or on the dam site include soils for embankments, rock for embankments and riprap, and concrete aggregate (sand, gravel, and crushed stone). Materials from required excavations may be stockpiled for later use. However, greater savings will result if construction scheduling allows direct use of required excavations. If suitable soils for an earth-fill dam can be found in nearby borrow pits, an earth dam may prove to be more economical. The availability of suitable rock may favor a rock-fill dam. The availability of suitable sand and gravel for concrete at a reasonable cost locally or onsite is favorable to use for a concrete exit weir.

Spillway/Exit weir

The spillway is a critical part of dam construction. An under-designed spillway will result in the dam overtopping or serious spillway erosion during peak runoff. These situations can cause major water losses, potential flooding and damage downstream, in addition to the costs to repair the dam. The size, type, and restrictions on location of the spillway are often controlling factors in the choice of the type of dam. When a large spillway is to be constructed, it may be desirable to combine the spillway and dam into one structure, indicating a concrete overflow dam. In some cases where required excavation from the spillway channel can be utilized in the dam embankment, an earth or rock-fill dam may be advantageous.

Environmental

Recently environmental considerations have become very important in the design of dams and can have a major influence on the type of dam selected. The principal influence of environmental concerns on selection of a specific type of dam is the need to consider protection of the environment, which can affect the type of dam, its dimensions, and location of the spillway and appurtenant facilities.

Economic Analysis

The final selection of the type of dam should be made only after careful analysis and comparison of possible alternatives, and after thorough economic analyses (cost benefit ratio) that include costs of spillway and foundation treatment.

Technical Requirements

i. The dam, foundation, and abutments must be stable under all static and dynamic loading conditions.
ii. Seepage through the foundation, abutments, and embankment must be controlled and collected to ensure safe operation. The intent is to prevent excessive uplift pressures, piping of materials, sloughing removal of material by solution, or erosion of this material into cracks, joints, and cavities. In addition, the project purpose may impose a limitation on allowable quantity of seepage. The design should include seepage control measures such as foundation cutoffs, adequate and non brittle impervious zones, transition zones, drainage material and blankets, upstream impervious blankets, adequate core contact area, and relief wells.
iii. The freeboard must be sufficient to prevent overtopping by waves and include an allowance for settlement of the foundation and embankment.
iv. The spillway and outlet capacity must be sufficient to prevent over-topping of the embankment by the reservoir.

5.3.3 Design of Earthen Dam

The various components of an earthen bund include (a) foundation including key trench or cut-off, (b) height of bund, (c) side slopes, (d) top width, (e) free board and (f) settlement allowance.

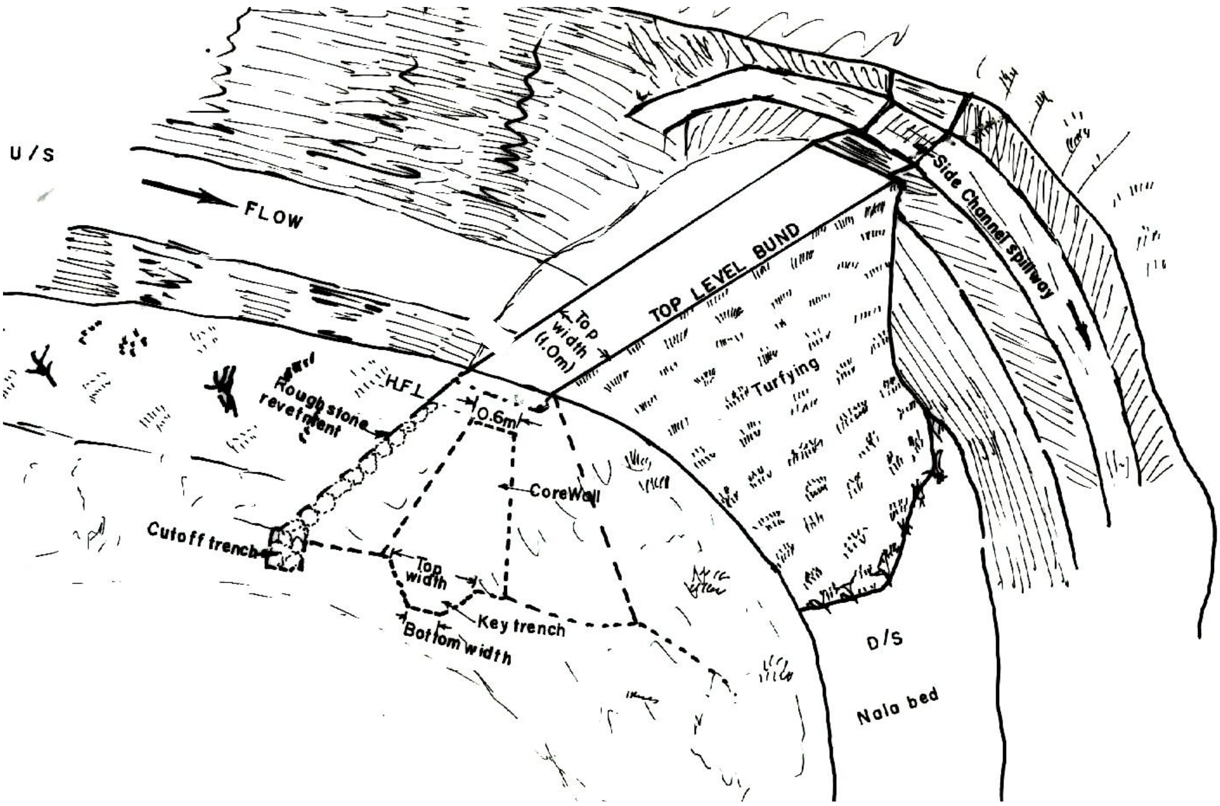


Fig. 49: Earthen Dam

It is possible to construct a stable and economical earthen bund on any foundation. Sites with foundation conditions requiring relatively expansive construction measures should be avoided. 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 foundations cause no stability problems. Where a suitable layer occurs at the surface no special measures are required. It is sufficient to remove the top soil (with vegetation and roots) and plough the area to provide a good bond with the new fill material of the bund.

Where the impervious layer is overlain by pervious material (sand), a compacted clay cut-off extending from the surface of the ground into the impervious is required to prevent excessive seepage and to prevent possible failure by piping.

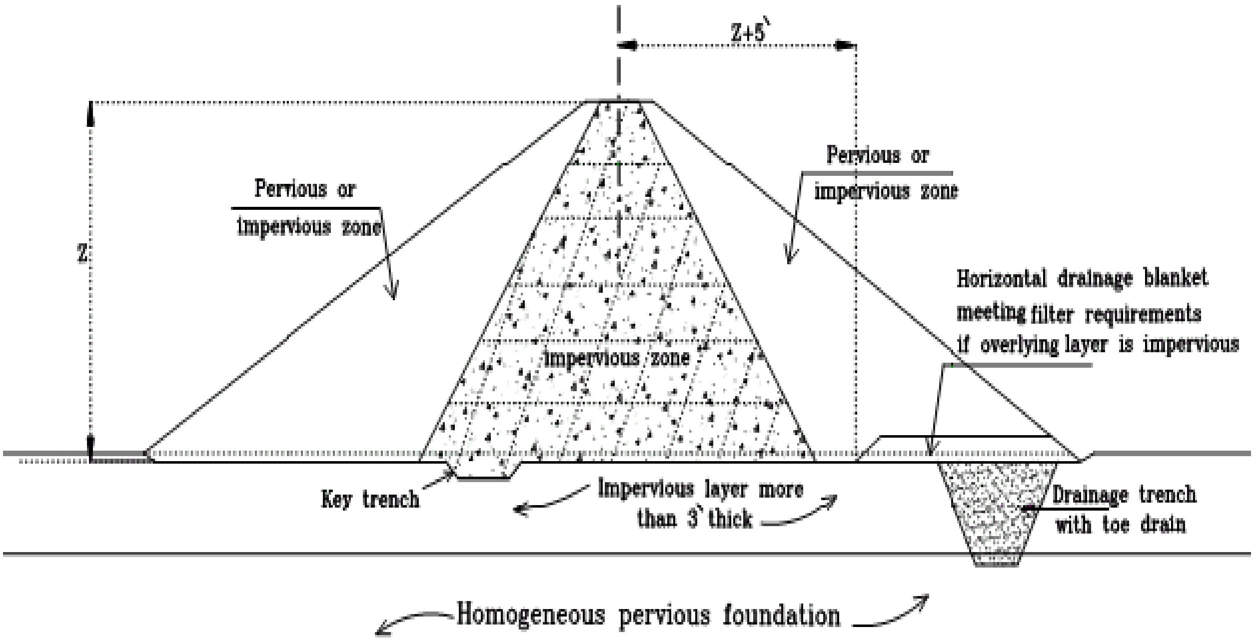


Fig. 50: Design of Earthen Dam

An earth dam often contains an impervious clay core to prevent water seeping through the face of the dam and causing erosion of the dam wall. Earth dams have a watertight core wall, formerly made of puddle clay. Their construction is very economical even for very large structures. Rock-fill dams are a variant of the earth dam in which dumped rock takes the place of compacted earth fill.

5.3.3.1 Foundation Cutoffs (Key trench)

A key trench (cutoff trench) is excavated below the base of the fill upstream of the centerline of the fill. The key trench is incorporated in the design for two reasons: to anchor the dam to the base material and to prevent piping (seepage under the fill). The key trench should be a minimum of three feet deep for a dam height of 10 to 12 feet. It should extend the full length of the dam and depth of about one third to one half of the height of the dam. Usually a cut-off joining the impervious stratum in the foundation with the base of the dam is needed. The most common type of cutoff is one constructed of compacted or puddled clay material. The trench should have a bottom width of not less than 1.5 meters but adequate to allow the use of mechanical equipment if necessary, to obtain proper compaction. The sides of the trench should be filled with puddled clay or with successive thin layers of relatively impervious material each layer being properly compacted.

5.3.3.2 Height of Embankment

The height of embankment will depend upon the volume of runoff to be stored and topography of the reservoir area. The height of the bund or embankment should also be selected in such a way that its cost per unit of storage (cum volume) is minimum. While calculating the cost corresponding to any height some allowance for settlement and free board, and temporary flood storage may be added to give the actual bund height or in other words the actual quantity of earth work.

5.3.3.3 Top Width of Embankment

Adequate top width especially when the crest is to be used as roadway for connecting adjoining villages or watersheds. Simple formula relating top width (W) with height (H) of dam (m) may be used:

$$W = \frac{H}{5} + 1.5$$

Up to 5 m height of dam, a minimum top width of 3 m is recommended. If the top is to be used as a road, width of 5 m or more is to be adopted.

5.3.3.4 Embankment Side Slopes

Embankment slopes are required for stability of the embankment on stable foundations. Pervious foundations may require the addition of upstream blankets for stability against seepage forces. Weak foundations may require the addition of stabilizing fills at either or both toes of the dam. The side slopes depend primarily on the stability of the material in the embankment. The greater the stability of the material, the steeper will be the side slopes or vice versa. The recommended side slopes for earthen embankments are presented.

Table19: Recommended side slopes for earthen dams

Type of material	Upstream slope	Downstream slope
Homogeneous well graded material	2.5:1	2:1
Homogeneous coarse silt	3:1	2.5:1
Homogeneous silty clay or clay (Height less than 15 m)	2.5:1	2:1
Height more than 15 m	3:1	2.5:1
Sand or sand and gravel with clay core	3:1	2.5:1

On embankments higher than 10 meters, berms are provided on downstream side of the dam. The berms are of 1-3 m width and have a mild inward slope for drainage.

5.3.3.5 Slope Protection

Upstream slope: The upstream slope protection is ensured by providing riprap. For design of riprap, IS 8237-1985 may be referred. A minimum of 300 mm thick riprap over 150 mm thick filter layer may be provided up to the top of dam.

Downstream slope: The downstream slope protection is ensured by turning or by local grass. It is usual practice to protect the downstream slope from rain cuts by providing suitable turfing on the entire downstream slope from top to toe. For details of downstream slope protection, IS 8237-1985 may be referred.

5.3.3.6 Free Board

It is the added height of the dam provided as a safety factor to prevent waves and runoff from storms greater than the design frequency from overtopping the embankment. It is the vertical distance between the elevation of the highest flood level and top level of the dam after all settlement has taken place. It depends upon the height as well as length of the dam. Normally, 10-15 percent is added as free board to the highest flood level of the dam. Minimum free board of 0.5 m is provided for length of pond upto 400 m, 0.75 m for length between 400 to 800 m and 1m for length more than 800 m.

5.3.3.7 Internal Drainage System

To ensure safety of dam, it is very important to handle the seepage water in the dam so as to maintain the original particles of soils in their place. The measures commonly adopted for safe disposal of seepage water through embankment dams are:

i. Inclined or vertical filter (chimney filter)
ii. Horizontal filter
iii. Rock toe
iv. Toe drain

As far as possible locally available sand, gravel etc should be used. Inclined or vertical filter is provided just on downstream slope of core. Its thickness is kept 1.0 meter (minimum). Horizontal filter collects the seepage from chimney filter & foundation, and carries to the rock toe & toe drain. Its thickness is kept minimum (as 1.0 meter). The standard filter criterion between filter and adjoining soil (casing or foundation) should be satisfied .In case of dam portions, where the head of water is 3 m or less it is not required to provide horizontal filter. Adequate toe protection shall however be provided. The height of rock toe is generally provided as 0.2 H, where H is the height of embankment. However minimum height of rock toe be kept as 1.0 metre. Rock toe is not necessary where height of embankment is 3 m or less. The toe drain is provided at the downstream toe of the earth dam to collect seepage from horizontal filter, rock toe & through foundation and to discharge it away from the dam by suitable surface or sub surface drains. The section of toe drain should be adequate enough to carry seepage. The bed of toe drain should be given a suitable slope to lead the seepage to natural drains. Depth of toe drain is usually provided as 1.5 m with bottom width of 1 m minimum and side slopes of 1:1 .For details IS 9429-1980 be referred.

The filter material should satisfy the following criteria with the base material:

a. $D_{15}\ (f) / D_{15}\ (b) > 4$ and < 20

b. $D_{15}\ (f) / D_{85}\ (b) < 5$

A filter that satisfies the above criteria may yet fail if it has an excess or lack of certain sizes or is not uniformly graded. The following criteria must be fulfilled.

$D_{50}\ (f) / D_{50}\ (b) < 25$

The gradation curve of the filter material should be nearly parallel to the gradation curve of the base material. The suffix 'f' stands for the filter material and 'b' for the base material. 15, 50, 85 percent particles, by weight, respectively are finer than D15, D50 and D85 particle size.

5.3.3.8 Design of Waste Weir

Water in excess of the Flood Reservoir Level (FRL) is drained out by a waste weir. After estimating the peak runoff from a catchment and the FRL of the structure, the dimensions of the waste weir are determined. The waste weir must have the capacity to safely drain out the peak runoff when the water is at FRL in the structure. Peak runoff from a watershed is estimated using the Rational formula:

Q=CIA/360,

Where Q=Peak runoff (cubic meter per seconds); C=runoff coefficient;

I = Intensity of rainfall (mm/hr); and A=watershed area (ha).

Wherever possible, it is better to have a broader waste weir for a given volume of excess runoff rather than a deeper one so as to maximize the storage capacity. The discharge capacity of the waste weir is given by the crested weir formula, $Q_p = 1.75LH^{3/2}$

So we need to arrive at the value of L, the length of the surplus weir.

$$L = Q_p / 1.75 \times H^{3/2}$$

Where, Q_p=discharge (cubic meter per second), L=weir width (m) and H=depth of flow (m). The waste weir should be designed with a wide base and a gentle slope, which will reduce water velocity and soil erosion. The base and sides should also be seeded to grass. The weir should be located away from the dam fill, not through or directly adjacent to the fill. This placement will reduce the risk of the dam washing out. Culverts are often used in waste weir design, and if undersized, they can restrict flow and result in project failure.

5.3.3.9 Causes of Failure of Earthen Dams

The most common causes of failure of earthen dams are:

i) Overtopping of the dam
ii) Wave erosion of the upstream
iii) Toe erosion of the downstream
iv) Rill and gullying downstream/upstream
v) Upstream slope failure due to caving/slipping.
vi) Downstream slope failure due to seepage
vii) Excessive settlement in embankment and foundation
viii) Inadequate spillway or blockage of spillway
ix) Sometimes, outlet pipe has to be taken through dam body. If, antiseep collars are not provided, water seeps along the pipe and leads to structure failures
x) Seepage failures:
    - Excessive seepage through the embankment
    - Excessive seepage through the foundation
    - Piping of fill and foundation due to seepage
    - Excessive creep flow around irrigation pipe outlet and pipe spillway.

Table 20: General Guidelines for Embankment section

Sl . No	Description	Height up to 5 m		Height above 5 m and up to 10 m		Height above 10 m and up to 15 m	
1.	Type of section	Homogene-ous/Modified homo-geneous section		Zoned / Modified homogeneous /Homogeneous section		Zoned / modified homo-geneous/ homogeneous section	
2.	Side slopes	U/S	D/S	U/S	D/S	U/S	D/S
(a)	Coarse grained soil						
	(i)GW,GP,SW,SP	Not Suitable		Not Suitable		Not suitable for core, Suitable for casing zone	
	ii)GC,GM,SC,SM	2:1	2:1	2:1	2:1	Section to be decided based upon stability analysis	
(b)	Fine grained soil						
	(i)CL,ML,CI,MI	2:1	2:1	2.5:1	2.5:1	-do-	
	(ii) CH, MH	2:1	2:1	3.75:1	3.75:1	-do-	
3.	Hearting zone	Not required		May be Provided		Necessary	
	a) Top width	--		3 m		3 m	
	b) Top Level	--		0.5m above MWL		0.5m above MWL	
4.	Rock toe height	Not necessary upto 3m height. Above 3m height, 1m ht. of rock toe may be provided		Necessary.H/5, where H is height of embankment		Necessary.H/5, where H is height of embankment	
5.	Berms	Not necessary		Not necessary		The berm may be pro-vided as per design. The minimum berm width shall be 3 m.	

Extract from Table 1 of IS: 12169 - 1987

Table 21: Suitability of soil for construction of dams

Relative suitability	Homogeneous Dykes	Zoned Dams		Impervious Blankat
		Impervious core	Pervious casing	
Very Suitable	GC	GC	SW, GW	GC
Suitable	CL,CI	CL,CI	GM	CL, CI
Fairly suitable	SP, SM, CH	GM, GC, SM, SC, CH	SP, GP	CH, SM, SC, GC
Poor	-	ML, MI, MH	-	-
Not suitable	-	OL, OI, OH, Pt	-	-

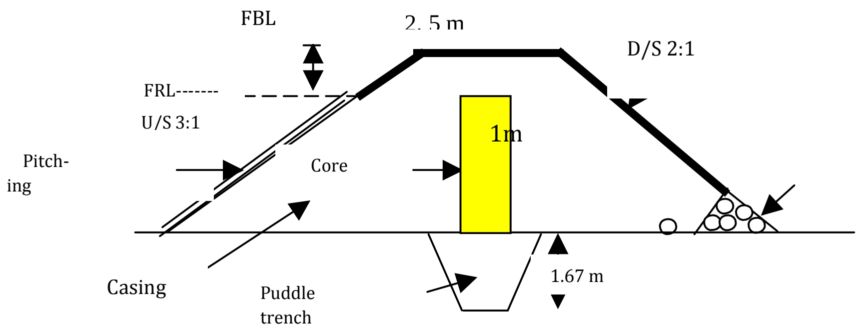
(Extract from Appendix A of IS 12169-1987)

5.3.3.10 Cost estimation of Earthen Dam

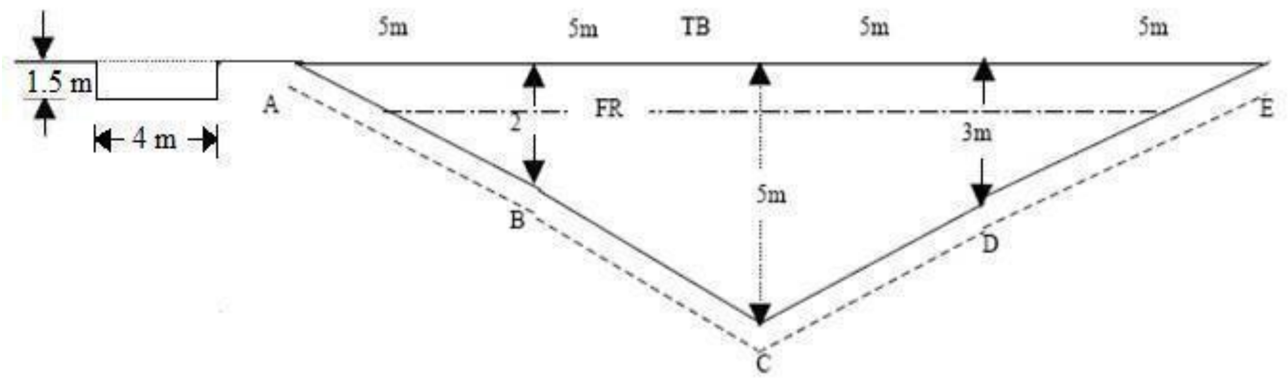
For working out the cost estimates of an earthen dam, following aspects are included.

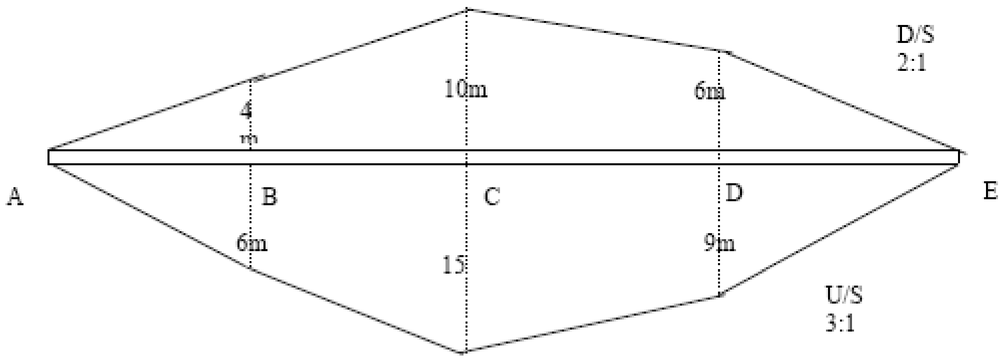
i. Cost of stripping/cleaning inside layout or plan section
ii. Earth work to erect the dam
iii. Excavation of cut-off trench
iv. Cost of core wall (if any)
v. Cost of pitching on upstream side
vi. Cost of toe wall
vii. Excavation for exit weir

Example: One earthen dam is proposed in a watershed in Rajkot dist of Gujarat. Length of earthen dam is 20 m and maximum height of bund is 5 m. Cross section of the dam is shown in fig below. Find the cost of the earthen dam. (Rates used in the examples are the SoR – 2008 of Irrigation Dept.)



X-section of the Embankment





Area of Trapezium = [(Top Width + Bottom Width) / 2] x Depth

$= [(B + H \times S_1 + B + H \times S_2) /2] \times H = [(2B + H \times S_1 + H \times S_2) /2] \times H$

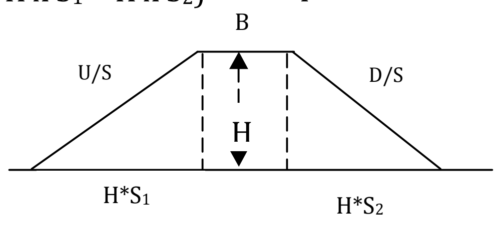
$= [\{2B + H \times (S_1 + S_2)\} /2]$

$= [\{2B /2\} + \{(H \times (S_1 + S_2)) /2\}] \times H$

$= [B + \{(H \times (S_1 + S_2)) /2\}] \times H$

$= [(B \times H) + \{(H^2 \times (S_1 + S_2)) /2\}]$

$= B \times H + H^2 \times (S_1 + S_2) /2$



Here, B = Top Width, H = Height, S_1 = U/S slope, S_2 = D/S slope

Cross sectional area of earthen dam $= B \times H + H^2 \times (S1 + S_2) /2$

As per drawing we knows, B = 2.5 m, S1= 3, S_2 = 2

Cross sectional area of earthen dam $= 2.5 \times H + H^2 \times (3 + 2) /2 = 2.5 \times H + H^2 \times 2.5$

Volume of Overall Bund

Point	Chainage	Height	X-sectional area	Average X-sectional area	Length Between two points	Volume (m^3)
A	0	0	0	-	-	-
B	5	2	15	7.5	5	37.50
C	10	5	75	45	5	22.50
D	15	3	30	52.50	5	262.50
E	20	0	0	15	5	75
Total						600

Total volume of bund = 600 cubic meter.

Volume of Core Wall

X-sectional area = width x height **=** W x (H – free board)

We know that, W = 2.5 m, Freeboard = 1 m (assumed).

X-sectional area = W x (H – free board) = 2.5 x (H - 1)

Point	Chainage	Height	X-sectional area	Average X-sectional area	Length between two points	Volume (m^3)
A	0	0	0	-	-	-
B	5	2	1	0.5	5	2.50
C	10	5	4	2.50	5	12.50
D	15	3	2	3	5	15
E	20	0	0	1	5	5
Total						35

Volume of core wall = 35 cubic meter.

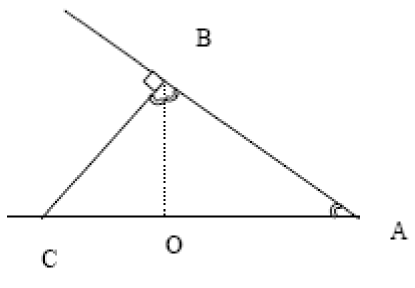
Volume of cut-off trench

Volume= Length x (Top width + Bottom width)/2 x Depth

= 20 x (2 + 1)/2 x 1.67

= 50.10 m^3

Volume of Rock toe



In triangle AOB,

Angle BAO = 180 - 90 – angle ABO

= 90 - angle ABO

Angle CBO = 90 - angle ABO

So, Angle BAO = angle CBO

If the slope of line AB is 2:1 then slope of line CB will be 2:1

Cross sectional area of rock toe = 1/2 x Base x Height

$= 1/2 \times \{(H/ 4S_2) + (H \times S_2/4)\} \times H /4$

$= H/8 \times \{(H/ 4 S_2) + (H \times S_2/4)\}$

$= H/32 \times \{(H/ S_2) + (H \times S_2)\}$

$= H/32 \times \{(H + (H \times S_2^2)/ S_2\}$

$= H^2 \times (1 + S_2^2)/(32 \times S_2)$

$S_2 = 2$

Cross sectional area $= H^2 \times (1 + S_2^2)/(32 \times S_2)$

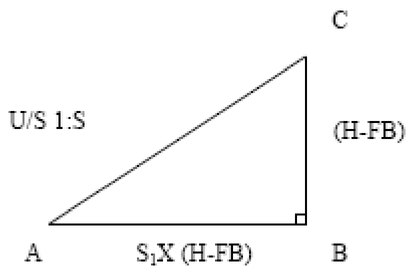
$= H^2 \times (1 + 2^2)/32 \times 2 = H^2 \times (5 /64)$

Estimation of volume of Rock Toe

Point	Chainage	Height	X-sectional area	Average X-sectional area	Length between two points	Volume (m^3)
A	0	0	0	-	-	-
B	5	2	0.31	0.16	5	0.78
C	10	5	1.95	1.13	5	5.66
D	15	3	0.70	1.33	5	6.64
E	20	0	0	0.35	5	1.76
Total						14.84

Volume of casing/outer cover should be calculated as in this case the dam has two sections namely ,a core wall section made with impervious or clayey soil and the casing/outer cover with more pervious material and rock toe filter on the downstream side.

Volume of casing/outer cover =Total volume of dam – (Volume of core wall + Volume of rock toe) = 600 – (35 + 14.84) = 550.16 cum



Area of Pitching

Cross sectional width (AC) = (H - freeboard) x (upstream slope $S_1{}^2 + 1)^{1/2}$

$= (H - 1) (3^2 + 1)^{1/2} = (H - 1) \times 3.16$

Point	Chainage	Height	Length of pitching	Average X-sectional area	Length between two	Area of Pitching
A	0	0	0	-	-	-
B	5	2	3.16	1.58	5	7.91
C	10	5	12.65	7.91	5	39.53
D	15	3	6.32	9.49	5	47.43
E	20	0	-	3.16	5	15.81
Total						110.68

Area of stripping:

Cross sectional width (AC) = (H x S1)+ B + (H x S2)

= B + H x (S1 + S2)

B = 2.5 m, S1= 3, S2 = 2

Cross sectional width (AC) = B + H x (S1 + S2) = 2.5 + H x (3 +2) = 2.5 + H x 5

Point	Chainage	Height	Width of strip-ping	Average Width of stripping	Length between two	Area of stripping
A	0	0	2.5	-	-	-
B	5	2	12.50	7.50	5	37.50
C	10	5	27.50	20.00	5	100.00
D	15	3	17.50	22.50	5	112.50
E	20	0	2.50	10.00	5	50.00
Total						300.00

Excavation for Exit

The exit is rectangular in shape and assumed length is 5 m.

Volume of excavation for exit = Length ×Width × Height= 5m × 4m× 1.5m = 30 cum

Sr.	Description	Quantity	Rate	Amount
1	Stripping	300	1.66	498
2	Excavation of cut-off trench in hard soil	50.10	41	2054.1
3	Cut-off trench filling with black cotton soil	50.10	140	7014

4	Casing construction in hard soil	550.20	53	29160.6
5	Construction of core wall	35	140	4900
6	Construction of rock toe on D/S side	14.80	290	4292
7	Construction of pitching on U/S side	110.68	153	16934.04
8	Excavation of exit in hard soil	30	41	1230
	Total cost Rs.			66082.74

5.4 Check Dam

It is an impermeable structure constructed across the drainage line having gentle slope and is feasible both in hard rock as well as alluvial formations for storage of water. The side of the dam where water is stored is called the upstream side and other side and other side of the dam is called downstream side. The water stored in these structures is mostly confined to stream course and the height is normally less than 3 m for watershed projects. These are designed based on stream width and excess water is allowed to flow over the wall. In order to avoid scouring from excess run off, water cushions are provided at downstream side. To harness the maximum run off in the stream, series of such check dams can be constructed to have recharge on regional scale. While constructing a series of check dams on along stream course, the spacing between two check dams should be beyond their water spread. The height of the check dam should be such that even during the highest flood, water does not spill over the banks. During the site selection for water harvesting structures under the watershed programmes, the cement masonry structures are usually preferred over the earthen structures. Watershed projects also focus on aspects that provide employment to the rural community but the construction of the cement masonry structure involves a very small component of unskilled labour cost. The proportion of wage cost and non-wage cost for the construction of the masonry structure is in the proportion of 40:60. Hence, these structures should be planned only on such sites that are not favorable for the construction of earthen structures.

Uses of check dam: The stored water may be used may be used for a variety of purposes that may be irrigation, drinking, electricity generation, and flood control etc.

Fig. 51: Masonry Check dam in drainage line

5.4.1 Classification of Check Dams

Dams are generally classified by three types:

5.4.1.1 On the basis of Use

Geographical location, storage capacity and location of the dam are the three main parameters for future classifying dams on the basis of use

Storage: The main purpose of this structure is to store the excess surface runoff during the rainy season. It can further be used for irrigation, electricity generation and the ground water recharge.

Irrigation: The main purpose of this dam is irrigation through canal network. All minor irrigation dams are the examples of this class.

Flood control structure: The main purpose of this structure is to protect a particular area from flooding by storing the water at flood times and releasing it during the normal period.

5.4.1.2 On the basis of overflow and non overflow

A dam where water flows over the dam body is called on overflow dam and otherwise it is called a non-overflow dam. All masonry structures are overflow dams and all earthen dams are the examples of non-overflow dams.

5.4.1.3 On the basis of construction material/shape

- RCC dam: It is constructed by concrete and steel bars hence it is called RCC dam.
- Concrete dam: Concrete is mainly used for construction of this structure.
- Masonry dam: UCR or Aron is mainly used.
- Steel dam: The dam constructed by steel thus, it is called steel dam.

5.4.2 Site Characteristic and Design Guidelines for Check Dams

Site of a dam is selected on the basis of its catchment area and the total amount of runoff generated from the catchment. Following points should be kept in mind while conducting survey for a dam:

i) The total catchment of the stream should normally be between 500 to 1000 Hectares though the local situations can be guiding factor in this.

ii) The width of nala bed should be at least 5 meters and the depth should not be less than 1 metre.

iii) The lands downstream of check dam should have irrigable land under well irrigation (This is desirable but not an essential requirement).

iv) The banks of the drain should be high and firm

v) Width of the drain at the site should be narrow and the slope of the drain bed should be gentle.

vi) The site should be approachable for an easy transportation of construction materials.

vii) The submergence area of the dam should be marked on the ground.

viii) Conduct cross section survey at regular intervals across the drain to estimate the storage capacity of the dam.

ix) Check the status of catchment area i.e. whether it is treated or untreated. If it is not treated then a plan for the same should be made and incorporated into the proposal of dam.

x) Selecting potential riverbeds based on field data regarding the physical and sociological aspects.

5.4.3 Design of Check Dams

During the preliminary survey, Following technical parameters have to be found out:

A = Catchment area in hectare from Toposheet/Drainage line maps.

H = Maximum height of the structure in meter

Step I: Calculate peak discharge, $Q = C*(A/100)^{3/4}$

Here, Q = Peak discharge in cusec

A = catchment in hectares

C = coefficient of runoff, the value of C is 11.45 for the areas with annual rainfall of 600 to 1200 mm and for Central India the value is 14.

Step II: Calculate peak runoff per running meter q = Q/L, where L is the length of the dam

Step III: Calculate depth of the flow considering peak discharge

$h = (q/1.71)^{2/3}$

Step IV: Calculate the hydraulic head "H_L"

$H_L = H + h$, where H is height of the dam

Step V: Calculate the top width of the dam "a"

$a = [H_L / (G+1)^{1/2}]$, where G is specific gravity of construction material

Step VI: Calculate the bottom width of the dam "b"

$b = [H_L / (G-1)^{1/2}]$, where G is specific gravity of the construction material

Step VII: Calculate the length of the downstream apron (L_a)

$L_a = 1.45 * K * (H_L/13)^{½}$, here K is coefficient of hydraulic gradient

Step VIII: Calculate the thickness of the downstream apron (t)

$t = 1.33 * [h/ (G+1)]$, where G is specific gravity of the construction material

Table 19: Specific gravity of different construction material

Sr. No.	**Construction material**	**Specific gravity (G)**
1	Plain cement concrete (PCC)	2.24
2	Reinforced cement concrete (RCC)	2.40
3	Stone masonry in cement mortar	2.54
4	Dry stone masonry	2.08
5	Random rubble masonry	2.32
6	Brick masonry	1.92
7	Reinforced brick masonry	2.00
8	Plum cement concrete	2.24

Table 20: Hydraulic gradient (K) for different situation of drain bed

Sr. No.	**Situation of drain bed**	**Safe hydraulic gradient (K)**
1	Coarse sand	12
2	Fine sand + mud	8
3	Sand + Boulder	5 to 9
4	Fine Sand	15
5	Boulder	5
6	Big Boulder	3.5 to 4.5

Step IX : Design of Baffle wall:

The downstream drain bed may get damaged by the water falling over the top of the dam, it is thus necessary that a baffle wall be constructed at the end of the downstream apron, so that an additional water cushion may be provided at the scour.

Calculate height of the baffle wall (h_b), $h_b = y_c - y_1$

Here = y_c is critical depth, $y_c = (q^2/g)^{1/3}$, where g is acceleration due to gravity, which is 9.81

And y_1 is pre-jump depth, $y_1 = 0.183 * q^{0.89} * H_L^{-0.35}$

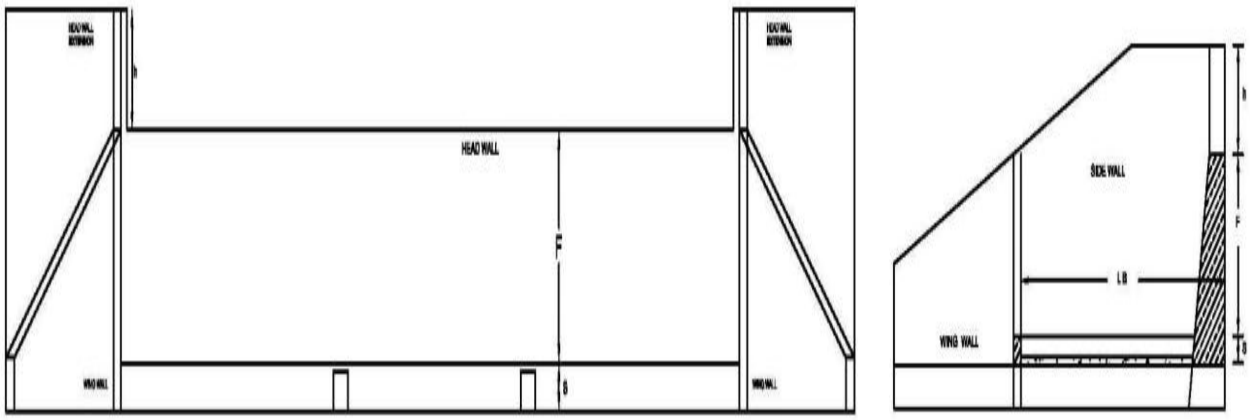
If the y_c - y_1 is less than 0.30 m then $h_b = y_c$

Thickness of baffle wall "t_b"

$t_b = 2/3 * h_b$

Distance of baffle wall from head wall (L_b)

$L_b = 5.25 * h_b$



Down Stream Elevation

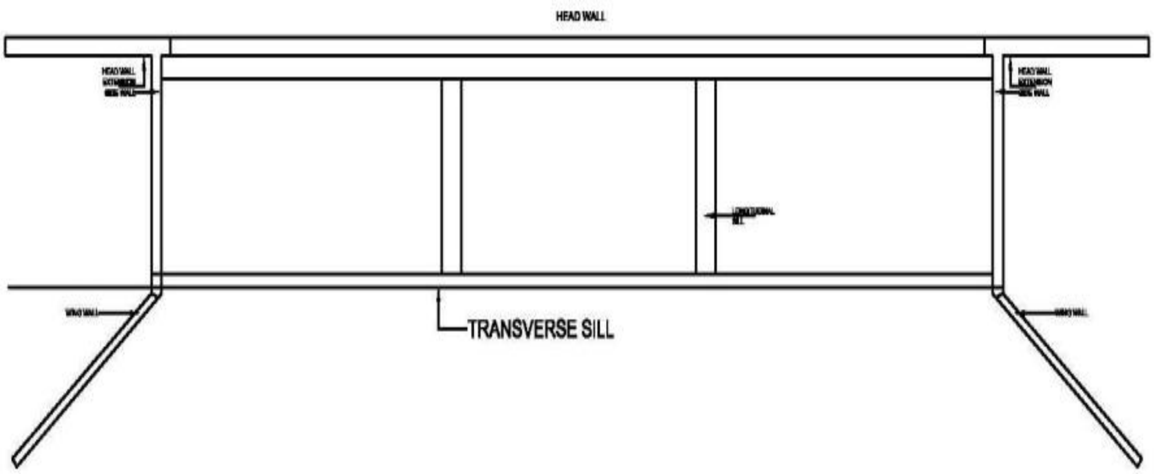


Fig. 52: Cross section and top view and components of Check Dams

Step X

Design of sidewall and wing-wall: These are constructed for protection of the structure, especially where the banks are weak. Weep holes should be provided in the wing wall for the drainage of excess water. Foundation depth of the sidewall and wing wall depends on the soil strata of foundation bed. It is an expensive measure, and thus it should be constructed only where it is necessary.

In certain cases, a gabion wall may be constructed instead of masonry wall depending on the bank condition and the catchment area. Height of the sidewalls at the dam section should be equal to the height of the structure plus the depth of the flow over dam plus the free board. Top width of the wing wall should be equal to 1/6 to 1/7th of the height of the wing wall. Bottom width of the wing wall should be equal to 1/3 to 1/4th of the height of the wing wall. Wing wall turns at the radius of 1.5 to 2 times of height of the dam.

Example

If peak discharge (Q) is = 18 cusec, length of dam (L) = 22m, height of the dam (H) = 1.8m, situation at drain bed is big boulder, construction material is concrete and site is in Gujarat. Design the structure.

Solution:

$q = Q/L = 18/22 = 0.81$ cusec/running meter

$h = (q/1.71)^{2/3} = (0.81/1.71)^{2/3} = 0.58$m

$y_c = (q^2/g)^{0.33} = (0.81^2/9.81)^{0.33} = 0.40$m

$y_1 = 0.183 * q^{0.89} * H_L^{-0.35} = 0.183 * 0.81^{0.89} * 2.38^{-0.35} = 0.30$m

$H_L = H+h$, $H_L = 1.8 + 0.58 = 2.38$ m

$h_b = y_c - y_1 = 0.4 - 0.3 = 0.10$ m, it very less so $h_b = y_c$, $h_b = 0.40$ m

Thickness of baffle wall (t_b) = $2/3 * h_b = 2/3 * 0.40 = 0.26$ m

Distance of baffle wall from head wall (L_b) = $5.25 * h_b = 5.25 * 0.40 = 2.1$ m

Length of downstream apron (L_a) = $1.45 * K * (H_L/13)^{1/2} = 1.45 * 4.5 * (2.38/13)^{1/2} = 2.79$ m

Thickness of downstream apron (t) = $1.33 * [h/(G+1)] = 1.33\ [0.58/(2.24+1)] = 0.62$m

Top width of dam (a) = $[H_L/(G+1)^{1/2}] = [2.38/(2.24+1)^{1/2}] = 1.11$ m

Bottom width of dam (b) = $[H_L/(G-1)^{1/2}] = [2.38/(2.24-1)^{1/2}] = 1.8$ m

5.4.4 Forces Acting on Dam Wall

- Stored water in upstream side of the dam body
- Self-weight of dam

- Uplift force of stored water
- Forces due to earthquake
- Ice force in cold terrain
- Wind force
- Force due to siltation

5.4.4.1 Horizontal forces due to stored water

Horizontal forces act on the dam body mainly due to the standing water column. Resultant of the forces acts at H/3 from the base of the dams. Formula for calculating horizontal force (P) on the dam body is

$P = \frac{1}{2} * w*H^2$, here w = specific unit weight of water = 1000 kg/m^3 and H is height of the stored water

5.4.4.2 Self Weight Force of the Check Dam

$W = 1/2 * w * H * b * G$

Where W is self-weight force in Kg,

w is specific unit weight of water,

H is depth of water column,

G is specific gravity of construction material and "b" is bottom width of dam

5.4.4.3 Uplift Force due to Standing Water Column

The standing water enters the foundation through small pores and the pore water would force upwardly from the dam body.

$U = 1/2 * \eta * w * b * H$

Here "U" is uplift force in Kg

η is a constant for uplift force, value of η varies from 0.60 to 0.75

5.4.5 Causes of Failure of Check Dam

- Overturning
- Crushing
- Shearing or sliding
- Sinking

Overturning

Resultant force of all forces except self weight force, acting on the dam body, causes the dam failure by overturning. If the summation of all negative moment divided by summation of all positive moment should be 1.5 to 2.5, then dam is safe from failure by overturning. Negative moment mainly occurs due to self-weight of the dam whereas positive moment occurs due to uplift force and the force due to standing water column. $\sum(-M)/\sum(+M)$ should be in between 1.5 to 2.5, means dam is safe

Crushing

The bearing capacity of the foundation strata should resist the forces occurring due to the dam body. On comparing the bearing capacity of the soil to the forces due to dam body, if the answer comes more than 1, it would mean that the dam is safe from crushing failure.

Bearing capacity of the soil per unit area divided by forces of dam on foundation per unit area should be more than 1.

Shearing or sliding

If the force of standing water is more than the force of self-weight of the dam then the dam may fail due to shearing or sliding. If summation of all vertical forces acting on the dam body divided by summation of all horizontal forces on the dam is more than 1, it would mean dam is safe from shearing or sliding failure. Friction constant is 0.75.

Example

Salient features of the dam are as follows: Length of the head wall = 32 m, location of the dam is in Central India with a catchment area of 200 ha. Design the dam.

Solution:

$Q = C * (A/100)^{3/4} = 14*(200/100)^{3/4} = 23.54$ cumec

Here, C = 14 ,A = 200 ha and H=3.2 m

$q = Q/L = 23.54/32 = 0.73$ m

$h = (q/1.71)^{2/3} = (0.73/1.71)^{2/3} = 0.54$ m

Hydraulic head (H_L) = H + h = 3.2 + 0.54 = 3.74 m

$y_c = (q^2/g)^{1/3} = (0.73^2/9.81)^{0.33} = 0.44$ m

$y_1 = 0.183 * q^{0.89} * H_L^{-0.35} = 0.183 * 0.73^{0.89} * 3.74^{-0.35} = 0.35$ m

$h_b = y_c - y_1 = 0.44 - 0.35 = 0.09$m, it is very less hence, $h_b = y_c$, $h_b = 0.44$ m

Thickness of baffle wall from head wall (t_b) = $2/3 * h_b = 2/3 * 0.44 = 0.29$ m

Distance of baffle wall from head wall (L_b) = $5.25 * h_b = 5.25 * 0.44 = 2.31$ m

Length of downstream apron (L_a) = $1.45 * K * (H_L/13)^{1/2} = 1.45 * 4.5 * (3.74/13)^{1/2} = 3.50$ m

Thickness of downstream apron (t) = $1.33 * [h/(G+1)] = 1.33 * [0.54/(2.24+1)] = 0.62$ m

Top width of dam (a) = $[H_L/(G+1)^{1/2}] = [3.74/(2.24+1)^{1/2}] = 2.07$ m

Bottom width of dam (b) = $[H_L/(G-1)^{1/2}] = [3.74/(2.24-1)^{1/2}] = 3.35$ m

Force of standing water (P) = $½ * w * H^2 = ½ * 1000 * 3.2^2 = 5120$ Kg

Self Weight of dam = $½ * w * H * b * G = ½ * 1000 * 3.2 * 3.35 * 2.24 = 12006$ Kg

Uplift force (U) = $½ * \eta * w * b * H = ½ * 0.75 * 1000 * 3.35 * 3.2 = 4020$ Kg

Negative moment due to self weight of dam = Self weight of dam x perpendicular distance from toe of the dam (b/2)

= 12006 * 3.35/2 = 201110 Kg-m

Positive moment due to force of water = force of water x perpendicular distance from toe of dam (H/3)

= 5120 * 3.2/3 = 5461 Kg-m

Positive moment due to uplift force of water = uplift force of water x perpendicular distance from toe of dam (b/2)

= 4020 * 3.35/2 = 6733.5 Kg-m

Shearing or Sliding Check

Summation of vertical forces acting on dam body divided by summation of horizontal forces acting on dam body should be more than 1.

$\mu = 0.75$

= (12006 – 4020) / 5120

= 1.56 > 1 hence OK

Check for overturning

$= \sum (- M)/\sum (+ M)$ should fall between 1.5 to 2.5

= 20110/12194

= 1.64>1.5 hence OK

Calculating the Quantities of Materials

I. Concrete

Mix Ratio – 1: a: b

Where: 1 = cement proportion: a = sand proportion: b = coarse aggregate proportion

If the amount of concrete needed is C, then:

Cement Quantity (Kg) = 1 * C * 1400 * 1.3 * 1.05/ (1+a+b)

Sand Quantity (m^3) = a * C* 1.3 * 1.15/ (1+a+b)

Gravel Quantity (m^3) = b * C * 1.3 * 1.15/ (1+a+b)

II. Stone Masonry

For water tight structures usually 65% of masonry body is proposed to be stone and 35% cement mortar. So, if the volume of stone masonry work is S, then

Volume of Stone (m^3) = 0.65 * S * 1.3

Volume of Mortar, M (m^3) = 0.35 * S

If mix ratio of mortar is 1: C,

Cement Quantity (Kg) = 1 * M * 1400 * 1.2 * 1.05/(1+C)

Sand Quantity (m^3) = C * M * 1.2 * 1.15/ (1+C)

III. Plastering

Follow the same formula used for mortar ingredients of stone masonry.

IV. Pointing

Pointing area is taken as 1/3 of plastering area and then follows the same way used for plastering.

V. Water

Water required for mixing, curing, washing dirty construction faces, workers construction and food preparation is roughly calculated from the total cement requirement of the site.

If Z Quintals of cement is required to complete the construction work,

Total volume of water = 280 * Z

5.5 Sub-Surface Check Dams/Dykes

Groundwater dams are structures that intercept or obstruct the natural flow of groundwater and provide storage for water underground. They have been used in several parts of the world, notably in India. Their use is in areas where flows of groundwater vary considerably during the course of the year, from very high flows following rain to negligible flows during the dry season. Sites for construction of subsurface dykes have to be located in areas where there is a great scarcity of water during the summer months or where there is need for additional water for irrigation.

5.5.1 Advantages

- The underground dam or dyke has following advantages:
- Since the water is stored within the aquifer, submergence of land can be avoided and land above reservoir can be utilized even after the construction of the dam.
- No evaporation loss from the reservoir takes place.
- No siltation in the reservoir takes place
- The potential disaster like collapse of dams can be avoided.

5.5.2 Construction and Design Guidelines

The basic principle of the groundwater dam is that instead of storing the water in surface reservoirs, water is stored underground. It is a sub-surface barrier across stream, which retards the base flow and stores water upstream below ground surface. The water level in upstream part of ground water dam rises saturating otherwise dry part of aquifer site where sub-surface dyke is proposed should have shallow impervious layer with wide valley and narrow outlet. The reservoir is recharged during the monsoon period and the stored water can be used during the dry season. Groundwater dams cannot be a universally applicable as these require specific conditions for functioning. The best sites for construction of groundwater dams are where the soil consists of sands and gravel, with rock or a permeable layer at a depth of a few meters. Ideally the dam should be built where rainwater from a large catchment area flows through a narrow passage.

After selection of site, a trench of 1-2 m wide is dug across the breadth of the stream down to impermeable bed. The trench may be filled with clay or brick / concrete wall up to 0.5 m below the ground level. In case of clay dykes, the width should be between 1.5 and 2m depending on the quality of clay used. The construction should be in layers and each fresh layer should be watered and compacted by plain sheet or sheep foot rollers of 1 to 2 ton capacity. In absence of roller, the clay should be manually compacted. Where the core wall is a masonry structure, the remaining open trench should be back-filled by impermeable clay. Dykes of 30 cm thick brick cement or stone cement, extending down to the compact bedrock, with mud or clay fillings in excavated portions on both sides of the wall provide a perfect impermeable barrier. Such dykes are also useful across the perennial streams. For ensuring total imperviousness, PVC sheets of 3000 PSI tearing strength and 400 to 600 gauge or low density polyethylene film of 200 gauge is also used to cover the cut out dyke faces. The underground structures should be keyed into both the flanks of stream for one meter length to prevent leakage from sides. In order to minimize or avoid problem of dewatering during construction, the work should be taken up by the end of winter and completed well before the onset of rains, as water table is at lower elevation in this period. These structures are preferred downstream of existing water supply structure to sustain availability during the summer.

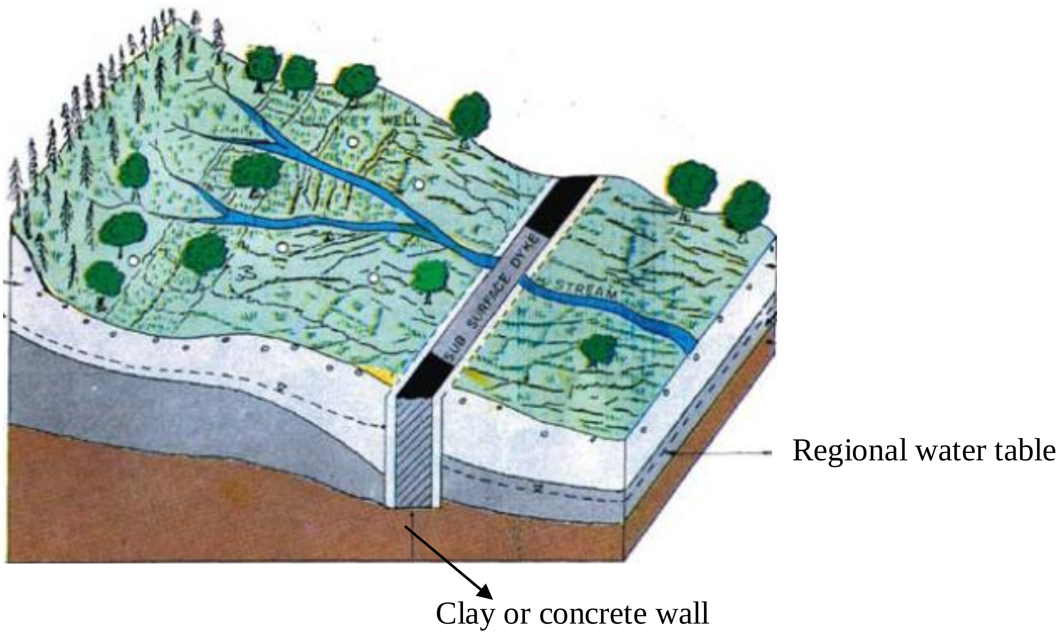


Fig. 53: Subsurface dam or Dyke

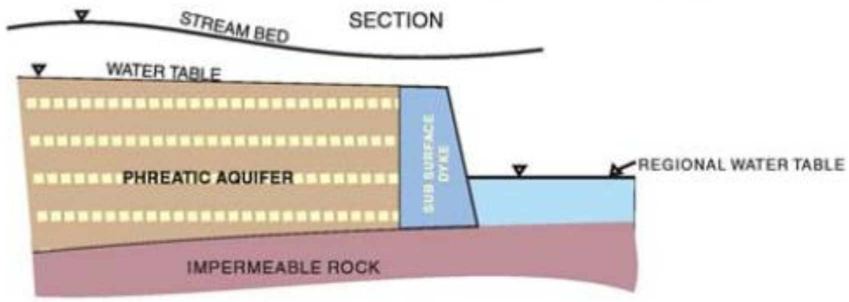


Fig. 54: Cross section of a Dyke

The main advantage of water storage in groundwater dams is that evaporation losses are much less for water stored underground. Further, risk of contamination of the stored water from the surface is reduced because as parasites cannot breed in underground water. The problem of submergence of land which is normally associated with surface dams is not present with sub-surface dams.

Design example

Find the cost estimate of an underground dyke for the following dimensions: Length of dyke = 20 m, Width = 1.5 m and Depth of 3 m.

Volume of Excavation for trench:

Volume= Length x Width x Depth

= 20 x 1.5 x 3 = 90 m^3

Cost of Excavation= Volume x Rate = 90 x41= Rs 3690

Laying of low density polyethylene sheet to cover the impermeable layer:

=Surface area of all the faces of the layer = 189 m^2 of sheet

Cost =189x 60 (assume for m^2 of polyethylene sheet) = Rs 11340/-

Construction of impermeable wall or Filling the trench with clayey soil:

Volume required is 90 m^3

Cost=Volume x Rate

=90 x140 (Assume) =Rs 12600/-

Total cost = Cost of Excavation + Cost of polyethylene sheet and laying+ Filling the trench

=3690+11340+12600=27630

Chapter-6

6 Measures for Soil Acidity and Soil Salinity

6.1 Introduction

This chapter involves measures for soil acidity and soil salinity covers its causes and management.

6.2 Soil Acidity

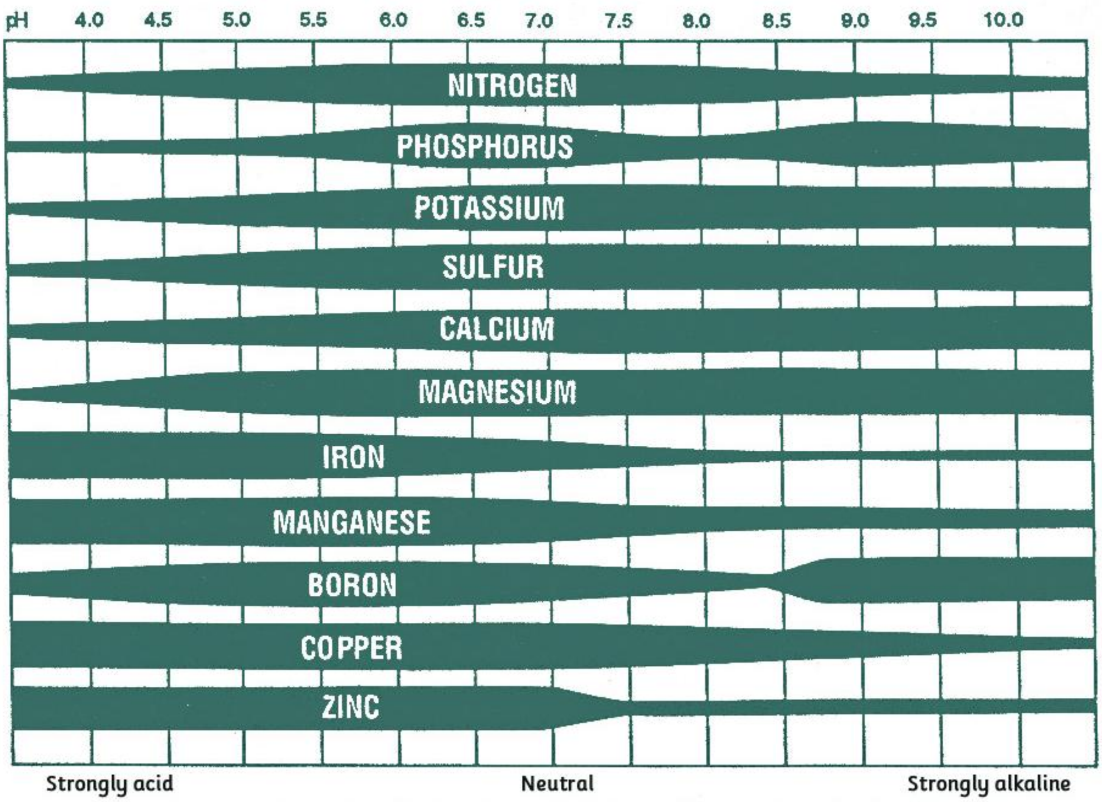
Soil acidity occurs when there is a build up of acid in the soil. The production of acid in the soils is a natural process and many soils in the high rainfall areas are inherently acidic. Acidification is a slow process but it is accelerated by agriculture. As soils become more acidic, plants intolerant of acidic conditions do not thrive and productivity declines.
Acid soils are found mainly in the eastern part of the Indo-Gangetic Plain, i.e. in West Bengal, Bangladesh and the mid-hills region of Nepal, where cropping is intensive and monsoonal precipitation is high. In many of these soils, organic matter is also quite low, resulting in poor buffering capacity and low nutrient contents

Soil acidity is one such limiting factor affecting adversely crop production to a considerable extent mainly in high rainfall and light texture conditions of soil. There are different types of problem lands where the constraints for optimum production are either unfavorable physico-chemical properties of the soil or some inherent land features and/or environmental conditions limiting optimum growth of crops. As such the productivity of these lands goes down to a considerable extent.

Table 21: Soil description based on pH

Soil Description	pH
Strongly acid	< 5.5
Medium acid	5.5 - 5.9
Slightly acid	6.0 - 6.4
Very slightly acid	6.5 - 6.9
Neutral	**7.0**
Very slightly alkaline	7.1 - 7.5
Slightly alkaline	7.6 - 8.0
Medium alkaline	8.1 - 8.5
Strongly alkaline	> 8.5

Table: 22: Effects of Soil Acidity/Alkalinity on Plant Nutrient Availability



The general relation of pH to the availability of plant nutrients in the soil: the thicker the bar, the more available the nutrient.

Generally, most plants require a soil pH in the range of 6.0 to 7.0. The pH of distilled water is 7.0 and is considered neutral. A pH of 6.0 is slightly acidic. While most plants do well in this range (6.0-7.0), some favor more acid conditions. Azaleas, rhododendrons and blueberries grow better in acid soils of pH 4.5 to 5.5. On the other hand, plants in the bean family (legumes) favor slightly alkaline conditions of 7.0 to 7.5 for good growth.

6.2.1 Causes of Soil Acidity

Major reasons for soils to become acidic are:

- (i) Rainfall and leaching,
- (ii) Acidic parent material,
- (iii) Organic matter decay
- (iv) Harvest of high-yielding crops
- (v) Removal of product from the farm or paddock
- (vi) Inappropriate use of nitrogenous fertilizers

Wet climates have a greater potential for acidic soils. In time, excessive rainfall leaches the soil profile's basic elements (calcium, magnesium, sodium, and potassium) that prevent soil acidity. Soils that develop from weathered granite are likely to be more acidic than those developed from shale or limestone. Organic matter decay produces hydrogen ions (H+), which are responsible for acidity (an ion is a positively or negatively charged element). Like that from rainfall, acidic soil development from decaying organic matter is insignificant in the short term. Harvest of high-yielding crops plays the most significant role in increasing soil acidity. During growth, crops absorb basic elements such as calcium, magnesium, and potassium to satisfy their nutritional requirements. As crop yields increase, more of this lime like nutrients is removed from the field. Compared to the leaf and stem portions of the plant, grain contains minute amounts of these basic nutrients. Therefore, harvesting high-yielding forages such as Bermuda grass and alfalfa affects soil acidity more than harvesting grain does. The natural rate of acidification is accelerated by agricultural practices like use of nitrogen fertilizers. The impact of nitrogen fertilizers on acidification depends on the type of fertilizer.

Acidity of soil creates unfavorable medium for the soil micro flora responsible for breaking down the complex organic as well as inorganic matter of the soil to more simple and soluble form. Useful micro organisms cannot grow well. It also makes primary, secondary and micro-nutrients to remain fixed or insoluble form, which cannot be taken by plants. "Phosphate fixation" in highly acid soils is an acute problem. The phosphate gets fixed with soluble iron present in acid soils. pH of the soil is the indicator of its Acidity, pH value 7 indicating neutral reaction and above 7 alkaline and below 7 acidic. Acidity and Alkalinity are relative terms. Highly acidic and alkaline soils both limit crop growth and should be ameliorated for optimum crop production. Strongly acid soils with pH less than 4.5 brings down the soil micro-flora activity and increases toxicity of elements like iron, copper and aluminum.

The acid soils are sedimentary in nature belonging to lateritic, ferruginous red and other red soil groups. They are developed mainly by the influence of relief, acidic parent material and wet climate. Under hot humid climate and heavy precipitation soils undergo drastic weathering of parent material and excess leaching of bases. In short, high rainfall with high temperature and heavy leaching is the main factor for the formation of acid soils.

6.2.2 Measures of Soil Acidity

Soil acidity is determined by a measurement of the hydrogen ion concentration of a particular soil. A pH meter is the instrument generally used by soil testing laboratories in measuring soil acidity. Generally, a small portion of the soil sample is mixed with water in a 1 to 1 or a 2 to 1 ratio and stirred. After the soil solution has set for approximately 30 minutes, a glass electrode and reference electrode are dropped into the soil-water mixture and the soil pH is determined. The measurement scale used in determining soil acidity is the pH scale which ranges from 0-14. A soil pH of 7.0 indicates a soil is neutral in reaction. Any number below 7.0 denotes soil acidity and numbers above 7.0 denote soil alkalinity. These measurements are a logarithmic factor. Therefore, a soil with a pH of 6.0 is 10 times more acid than a soil with a pH of 7.0. A soil having a pH of 5.0 is 100 times more acid than a soil pH of 7.0, etc.

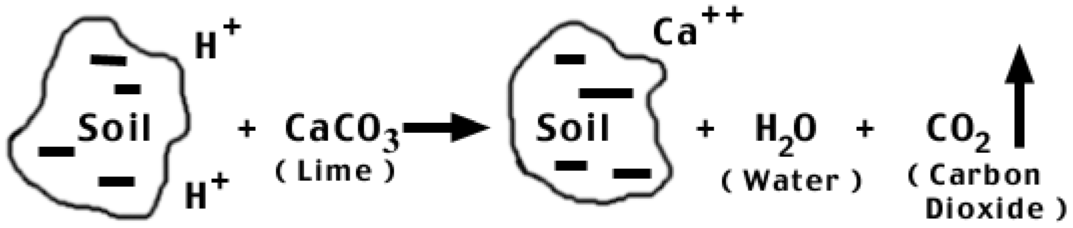
6.2.3 Management of Acid Soil

The management of acid soils aims at improving the production potential by addition of amendment to correct the acidity and manipulate the agricultural practices so as to obtain optimum crop yields under acid condition. One of the practices is to grow acid tolerant crops/ varieties and to supplement nutrients through suitable carriers. The pH level is a number that describes how acid or alkaline a soil is and from this it is calculated how much lime is needed to reduce soil acidity. A soil pH test measures the acidity or alkalinity of the soil. A pH 7.0 is considered neutral. Above pH 7.0, the soil is alkaline and below pH 7.0, the soil is acid.

Limiting is a desirable practice when the soil is highly acidic and where multi-cropping involving acid sensitive crops is adopted. Limiting improves base saturation and availability of Ca & Mg. Fixation of P and Mo is reduced by inactivating the reactive constituents. Toxicity arising from excess soluble Al, Fe and Mn is corrected and there by root growth is promoted and uptake of nutrients is improved. Liming also stimulates microbial activity and encourages N_2 fixation and nitrogen mineralization, and hence, legumes are highly benefitted from liming.

6.2.4 Treating Soil with Lime ($CaCo_3$)

In liming programme, the first and foremost thing is to assess the lime requirement of the soil for optimum yield of the crop/crops. Lime requirement is estimated on the basis of exchange acidity and percentage base saturation of soil. Among the various methods proposed to determine the lime requirement, buffer equilibration methods are most handy and accurate. Modified Woodruffs buffer method has been successfully used to assess the lime requirement of acidic soils in Orissa (2.02 to 6.08 tonnes/ ha.). However, it has been verified in a number of field trials that the full lime requirement dose as assessed by this method, which raise the pH to 7.0 or above, is not necessary for getting optimum yields of most crops. The desirable dose of lime for laterite soils was found to be one half of the lime requirement (LR) dose determined by Woodruffs buffer (pH 7.0) for maize and cotton. Scientists also recorded economic response to lime sludge applied at 0.5 LR dose in a variety of crops in red loam soils of Semiliguda with pH 5.0. When applied in high doses, much of the lime is lost by leaching from the top soil of light textured soils because of their low exchange capacity. Split application is recommended to minimize the leaching loss. Lime should preferably be applied in smaller doses more frequently (every alternate year) rather than in heavy dose one in three to four years. Application of full LR dose suppressed P availability and caused B deficiency. Hence, excess application is harmful.



- The lime requirement approximately ranges from 3.5 to 15 tonnes/ha.
- Lime application should be done in split doses.
- In smaller doses more frequently.
- Application of lime in furrows @ 3 Qtls/ha at the time of sowing.
- Application has to be done in every alternate year till the soil pH is brought to normal range.
- The programme may be taken up on area basis. (Block/Panchayat as unit).

6.2.4.1 Choice of Liming Material

The second important aspect is the choice of liming material. Lime should be less expensive and available within easy reach of the farmers besides suitability. Commercial lime stone or dolomite lime stone power is costlier. Several industrial wastes have been tried in the past as alternative sources of lime. Relative efficiencies of four sources i.e. lime stone, dolomite; basic slag and lime sludge were compared in lateritic soil taking three successive crops of maize. Crust formation and moisture stress during dry spells are the two major soil physical constraints under dry land situations in the red-lateritic acid soil zone, which also enhances soil erosion.

Application of organic amendments such as FYM or decomposable green leaf manures (Glyricidia) is quite effective in preventing crust formation and increasing moisture retentivity of the soil. Judicious application of lime, organic amendment and phosphate benefit the crop.

6.2.4.2 Lime Requirement for Different Soils

The lime requirement depends on soil texture (clay content), CEC and sesguioxide content of soil. In the absence of more accurate recommendation the following ready reckoner may be followed.

Table: 23: Lime Requirement (LR) for different soils

Soil pH	**Lime Requirement kg/ha**		
	Sandy loam	**Loam**	**Clay loam**
5.0	1,262	1,892	2,944

5.2	1,093	1,639	2,551
5.4	925	1,387	2,159
5.6	757	1,135	1,766
5.8	589	883	1,374
6.0	421	630	981

6.2.4.3 Cropping Pattern for Acid Soil Region

Rice has certain amount of tolerance to soil acidity; and flooding of the field also creates favorable condition (increase in pH and availability of P, Si and K) for growth of rice. Liming is desirable for raising the productivity of several crops. The acid sensitive crops like cotton, soybean, groundnut, french bean, pigeon pea etc. are better adaptable to acid soils with proper liming. Crops are classified according to their relative response to liming. This information can be utilised in fixing suitable cropping sequence. Under rainfed conditions, highly responsive crops like cotton, soybean, pigeon pea etc. may be grown in the first year of liming, followed by medium response crops like maize and wheat in the subsequent seasons. The low responsive crops like millets, rice, barley, linsed etc. may be grown when the effect of liming has been further reduced.

Soil erosion and shifting cultivation are major problems in hilly-tracts of ASR. Agri-horticultural and agro forestry systems need to be introduced in such tracts.

In general, regions receiving more than 900 mm rainfall and with a moisture storage capacity of 200 mm in the root zone, double cropping can be taken up.

Fig.24: Cropping Pattern in different elevation of Rain-fed Areas

Type of land	**Crops**	**Inter cropping / sequence cropping**
Higher elevation	Mesta, Pigeonpea, Maize, Groundnut	Inter cropping of pigeonpea + Groundnut
Medium land	Finger millet, Rice (Short duration)	Rice, Finger millet, Maize Horse-gram, Cowpea
Low	Rice	Rice-Pulse, Rice-Rapeseed

6.3 Soil Salinity

Soil salinity is a measure of the concentration of soluble salts in the soil. Sodium chloride is the most common salt; others include bicarbonates, sulphates and carbonates of calcium, potassium and magnesium. Some salts are useful (many fertilisers are in salt form), but too much salt of any kind is detrimental to plants and other organisms. However, a concentration of salts in the root zone that is too high can damage plant health and reduce crop yields. All soil contains some water soluble salts. Plant absorbs nutrients from the soluble salts. Sensitive crops lose their vigor already in slightly saline soils, most crops are negatively affected by (moderately) saline soils and only salinity resistant crops thrive in severely saline soils.

Measurement of soil salinity is generally required to determine the salt status of a soil. Soil salinity is measured as electrical conductivity (EC) in units of desi-siemens (dS/m). Salt is extracted from the soil using one of two methods, the most accurate and reliable of which is the saturation extract, although this method must be completed in a soil testing laboratory. The standard for the determination of soil salinity is from an extract of a saturated paste of the soil, and the EC is then written as ECe. The extract is obtained by centrifugation.

6.3.1 Classification of Soil Salinity

The salt affected soils have been grouped into three classes considering the nature of salts present in them, their physico-chemical characteristics and their ameliorative requirements. The two distinct classes are alkali and saline.

Table 25: Classification of salt affected soils (USDA system)

Type of soil	ECe (dS/m)	ESP	pHs
Saline	> 4.0	< 15	< 8.5
Sodic	< 4.0	> 15	> 8.5
Saline-sodic	> 4.0	> 15	< 8.5

(Source: Agriculture Land Drainage, Centra Soil Salinity Research Institute, 2007)

Where, ESP means Exchangeable Sodium Percentage

Table 26: Classification of salt affected soils (Indian system)

Soil characteristics	Saline soil	Alkali soil
pH	< 8.2	> 8.2
ESP	< 15	> 15
ECe (dS/m)	> 4	Variable, mostly < 4
Nature of salts	Neutral, mostly Cl and SO_4 of Na	Capable of alkaline

(Source: Agriculture Land Drainage, Centra Soil Salinity Research Institute, 2007)

In the Indian system, pH criterion for classification was reduced from 8.5 to 8.2 as the isoelectric pH for precipitation of $CaCO_3$. At this pH sodification process starts and mostly this pH is associated with ESP of 15 or more. The soils are classified in two categories. The saline sodic soil as classified by USDA, is to be classified either saline or alkali based upon pHs, ESP and ECe for which a separate criterion has been evolved as follows. If the ratio of $(2CO_3+HCO_3)/(Cl+2SO_4)$ and / or $Na/(Cl+2SO_4)$ expressed in mol/m^3 is more than 1, the saline sodic soil is treated as sodic and if less than 1, it is treated as saline.

6.3.2 Distinguishing Features of Saline and Sodic Soils

Table27: Distinguishing Features of Saline and Sodic Soils

Characteristics	Saline soils	Sodic soils
1. Chemical	a. Dominated by neutral soluble salts consisting of chlorides and sulphates of sodium, calcium and magnesium.	a. Appreciable quantities of neutral soluble salts generally absent. Measurable to appreciable quantities of salts capable of alkaline hydrolysis, e.g. Na_2CO_3, present.
	b. pH of saturated soil paste is less than 8.2.	b. pH of the saturated soil paste is more than 8.2.
	c. An electrical conductivity of the saturated soil extract of more than 4 dS/m at 25 °C is the generally accepted limit above which soils are classed as 'saline'.	c. An exchangeable sodium percentage (ESP) of 15 or more is the generally accepted limit above which soils are classed as 'sodic'. Electrical conductivity of the saturated soil extract is generally less than 4 dS/m at 25 °C but may be more if appreciable quantities of Na_2CO_3 etc. are present.
	d. There is generally no well-defined relationship between pH of the saturated soil paste and exchangeable sodium percentage (ESP) of the soil or the sodium adsorption ratio (SAR) of the saturation extract.	d. There is a well defined relationship between pH of the saturated soil paste and the exchangeable sodium percentage (ESP) of the soil or the SAR of the saturation extract for an otherwise similar group of soils such that the pH can serve as an approximate index of soil sodicity (alkali) status.

	e. Although Na is generally the dominant soluble cation, the soil solution also contains appreciable quantities of divalent cations, e.g. Ca and Mg.	e. Sodium is the dominant soluble cation. High pH of the soils results in precipitation of soluble Ca and Mg such that their concentration in the soil solution is very low.
	f. Soils may contain significant quantities of sparingly soluble calcium compounds, e.g. gypsum.	f. Gypsum is nearly always absent in such soils.
2. Physical	a. In the presence of excess neutral soluble salts the clay fraction is flocculated and the soils have a stable structure.	a. Excess exchangeable sodium and high pH result in the dispersion of clay and the soils have an unstable structure.
	b. Permeability of soils to water and air and other physical characteristics are generally comparable to normal soils.	b. Permeability of soils to water and air is restricted. Physical properties of the soils become worse with increasing levels of exchangeable sodium/pH.
3. Effect on plant growth	In saline soils plant growth is adversely affected:	In sodic soils plant growth is adversely affected:
	a. chiefly through the effect of excess salts on the osmotic pressure of soil solution resulting in reduced availability of water;	a. chiefly through the dispersive effect of excess exchangeable sodium resulting in poor physical properties;
	b. through toxicity of specific ions, e.g. Na, Cl, B, etc.;	b. through the effect of high soil pH on nutritional imbalances including a deficiency of calcium;
		c. through toxicity of specific ions, e.g. Na, CO_3, Mo, etc.
4. Soil improvement	Improvement of saline soils essentially requires removal of soluble salts in the root zone through leaching and drainage. Application of amendments may	Improvement of sodic soils essentially requires the replacement of sodium in the soil exchange complex by calcium through use of soil amendments and leaching and drainage of salts resulting from reaction of

	generally not be required.	amendments with exchangeable sodium.
5. Geographic distribution	Saline soils tend to dominate in arid and semi-arid regions.	Sodic soils tend to dominate in semi-arid and sub-humid regions.
6. Ground-water quality	Groundwater in areas dominated by saline soils has generally high electrolyte concentration and a potential salinity hazard.	Groundwater in areas dominated by sodic soils has generally low to medium electro-lyte concentration and some of it may have residual sodicity so has a potential sodicity hazard.

(Source: Salt-Affected Soils and their Management, FAO Soils Bulletin 39, Food and Agriculture Organization of the United Nations, Rome, 1988)

Although weathering of rocks and primary minerals is the chief source of all salts, salt-affected soils rarely form through accumulation of salts in situ.

6.3.3 Reclamation of Saline Soil

6.3.3.1 Chemical Method

Liming of acid soils is the most common and useful practice. Liming is done to raise the pH to some value so that the toxic effect of Al, Mn and Fe are suppressed or removed. It causes the displacement of Al & Mn ion from the permanent exchange sites of Colloids and thereafter the displaced Al & Mn are eventually precipitated as complexed compounds.

- Reclamation by addition of lime and phosphatic fertilizers
- Scrapping of the surface salts
- Keep the areas flooding to wash away the excess salt.
- Control water table
- Leach with proper drainage to remove salt
- Shallow ploughing

6.3.3.2 Biological Method

This method involves growing of variety of acid tolerant plantation crop like Pea, Cof-fee, Rubber, Cardamom, Cashew and some forest plant like Madhuca and Jack fruit etc. to manage the acidity of soils.

6.3.3.2.1 Planting Salt Tolerant Crops

Like waterlogged lands, differences occur in the tolerance of crops to soil salinity or soil alkalinity. Moreover, the problems of salinity /sodicity are dynamic in nature such that the degree of the problem would continue to increase unless some curative measures are adopted.

6.3.3.2.1.1 Crop Selection

In the management of waterlogged and/or saline lands, selection of crops is important. The following considerations should govern the crop selection for such areas. There are intra and inter-genic differences in tolerance to water logging. Crop tolerance would differ from the kind of the problem surface stagnation or high water table and/or soil salinity/alkalinity.

6.3.3.2.1.2 Shallow Rooted Crops

In waterlogged saline lands especially with high water table, shallow rooted crops should be preferred than the deep rooted ones. A shallow rooted crop will perform better than a deep-rooted crop for the same condition of the water table. Rice is preferred as the first crop in the first few years of reclamation of alkali lands since it is shallow rooted and its roots are mainly confined to reclaimed shallow layer.

Table 28: Tolerance of crops to high groundwater table (Groundwater at 50 cm)

Tolerance level	Crops
High tolerance	Sugarcane, potatoes, rice, willow, plum, broad beans, strawberries, some grasses
Medium tolerance	Sugar beet, wheat, oats, citrus, bananas, apple, barley, peas, cotton pears, Blackberries, onion
Sensitive	Maize, tobacco, peaches, cherries, olives, peas, beans, date palm

(Source: Agriculture Land Drainage, Centra Soil Salinity Research Institute, 2007)

6.3.3.3 Tillage Practices

Waterlogged saline lands are usually moist and need to be handled very carefully. Tillage of these lands at inappropriate moisture content could destroy the soil structure resulting in reduced infiltration rates and adverse root zone physical environment. Most agricultural operations should be performed at moisture content equivalent to the plastic limit of the soil. A viable option in such cases would be to resort to minimum tillage. Deep ploughing, if needed, could be done when the water table is deep and land is fallow. As far as possible, use of heavy machinery should be avoided.

6.3.4 Reclamation of Sodic Soils

In the reclamation of sodic soils, excess exchangeable Na+ is replaced by calcium. However gypsum, by virtue of its easy availability and low cost, is widely used to reclaim sodic soils. Na – (Clay) + $CaSO_4$ (gypsum) → Ca – Clay + $Na2SO_4$ + H_2O. The quantity of amendment depends upon the soil texture, soil depth, degree of sodicity and crops to be grown.

A package of practices for management of sodic soils includes,

i. Proper land levelling and bunding
ii. Ploughing salt surface crust deep in the soil
iii. Removal of Salt crust from surface
iv. Proper irrigation and water management
v. Good quality of irrigation water
vi. Application of Gypsum and green manures
vii. Application of appropriate fertilizer
viii. Selection of suitable crops, varieties and cropping sequences
ix. Suitable agronomic practices

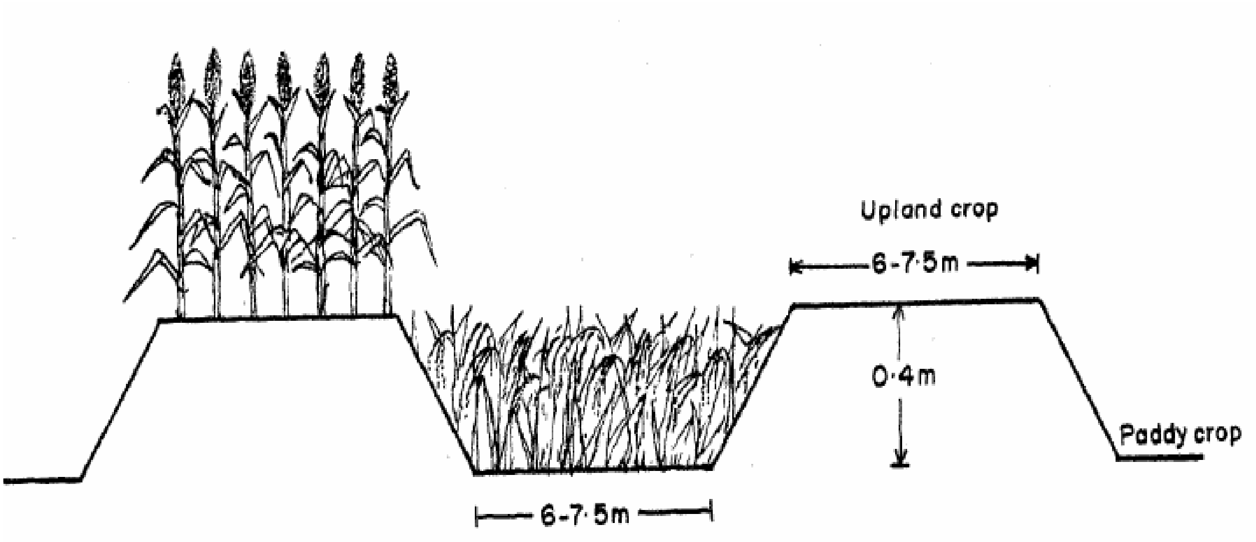
Table 29: Important crop varieties for cultivation in alkali soils

Crop	Varieties	Range of alkalinity tolerance
Rice	CSR10 CSR13, CSR27,CSR30	9. 8 to 10.2 9.4 to9.8
Wheat	KRL 1-4, KRL-19	9.2 to 9.4
Gram	Karnal Ghana 1	8. 5 to 9.0
Mustard	CS52	9.2 to 9.5

(Source: Agriculture Land Drainage, Centra Soil Salinity Research Institute, 2007)

6.3.4.1 Land Forming

Landforms which help in efficient surface drainage and that reduce the effect of shallow water table are helpful. Ridge cultivation in that way is most suited for waterlogged lands. It allows the plants to grow well at the same time provides surface drainage through the valleys. Raised and sunken bed technology is becoming quite popular and location specific versions of this technology are emerging from humid, subhumid and semiarid climates including salt affected soils. Raised bed planting of wheat is being recommended and popularized, which besides other benefits provide insurance against surface stagnation during the growing season of the crop. The landforms for saline soils and for use of saline water in agriculture have also emerged. Basic strategy in developing these landforms is to grow seeds at places where salt accumulation is minimum or away from the salt accumulation zone.



(Source: Agricultural Land Drainage, Reclamation of Waterlogged Saline Lands, CSSRI, Karnal 132001)

Fig 55: A raised and sunken bed model to manage drainage problem in sodic vertisols

6.3.4.2 Improved Irrigation Techniques

The irrigation water applied should be just sufficient to wet the root zone. Surface irrigation in that sense, unless managed properly, is inefficient. This can only be achieved through improved irrigation techniques. Improved irrigation techniques such as sprinkle or drip irrigation or some indigenously developed technique such as pitcher irrigation could be adopted to save water as well as to utilize saline/sodic waters. The drip irrigation system has become very popular in areas of acute water scarcity and places where commercial cultivation is undertaken mainly of cash or horticultural crops.

6.3.4.3 Application of Additional Dose of Plant Nutrients

Nitrogen uptake by the plants is reduced in waterlogged lands. Additional doses of nitrogen application therefore, have been found to be useful to reduce the harmful effects of waterlogging. Adverse effects of waterlogging are similar to the effects that are caused by low N-fertilizer in heavy soils. It has been conclusively proved that it is possible to compensate the effect of high water table by applying additional doses of nitrogen. As the effects of nitrogen application in waterlogged lands are a short-lived, it is recommended that applications of N-fertilizer should be increased but the full dose should be applied more frequently.

6.3.4.4 Leaching

Leaching is essentially a process in which water of low concentration (fresh water) is applied to displace the soil solution of relatively high concentration. The application of the excess water to pass through the root zone with the aim of pushing the salts below the root zone is defined as leaching. The leaching efficiency on the other hand is defined as the amount of salt drained as a fraction of the amount of salt present in the profile per unit pore volume after pre-decided pore volumes of water have been drained. The leaching of salts is carried out to meet one of the following objectives:

To remove or to reduce the salts in the root zone commonly known as one time leaching for reclamation. In alkali soils leaching also helps in transporting the exchanged ions below the root zone. To maintain the salt balance in the reclaimed or irrigated lands so that crops do not suffer due to excess salts at any time in future.

6.3.4.4.1 Amount of Water Required for Leaching

Drainage is an essential pre-requisite but not the end in itself in reclaiming water-logged saline soils. It is imperative to reduce the salts in the root zone to an acceptable level before the lands are cultivated. In an ideal soil system without bye pass, dissolution of pre-cipitated salts, salt diffusion constraints or hydrodynamic dispersion, the salt concentration of the soil water present in a given depth of the soil profile should drop to the concentration of the applied water when one pore volume of the water has passed through the profile. The ac-tual amount of water required in practice, however, depends upon factors such as: salt ini-tially present in the profile, desired level of salt in the root zone, soil texture, type of salts, soil depth to be reclaimed, efficiency of the drainage system and method of leaching.

Table 30: Leaching requirements of soils for one time reclamation

Soil type	Leaching requirement (cm/cm of soil depth)	Water requirement to leach 60 cm of soil profile (cm)
Coarse textured	0.5-0.6	30-36
Medium textures	0.6-0.8	36-48
Heavy textured	0.8-1.0	48-60

(Note: The above requirement is to leach down 80% of the salts initially present)

Source: Agriculture Land Drainage, Centra Soil Salinity Research Institute, 2007

In the monsoon season, leaching should preferably be carried out during the last week of June so that monsoon rains would be able to further leach down the salts making the land fit for cultivation in the first year itself. As far as possible, good quality water should be used for leaching.

Under conditions as exists in most farmlands, the rainwater utilization efficiency for leaching is in the range of 10-20%. If lands are appropriately levelled and bunded, rainwater efficiency for leaching could increase to 50%. If the land is also tilled before the onset of the monsoon season, the efficiency could go as high as 70%. Under appropriate management, about 1.85, 0.95 and 0.76 cm of rainwater would be required to leach 80% of the salt from each cm of the soil needing salt removal in the case of heavy, medium and coarse textured soils, respectively.

6.3.4.5 Mulching

Mulch is a protective covering, usually of organic matter such as leaves or straw, placed around plants. It prevents the evaporation of moisture, the growth of weeds and (in cold climates) it prevents freezing of roots. It can have a positive effect on the fertility of the soil. Salinity, an offshoot of water logging, adversely affects the crop yield. The rate of soil salinity is fastest during periods when soils are bare and potential evaporation is high. During such periods, mulching will be helpful in reducing rate of evaporation at the soil surface thereby curtailing accumulation of salts in the root zone.

Mulching films are most commonly used to save water, produce earlier, higher and healthier yields, and to produce plants with a better commercial appearance. Mulching has beneficial effects on soil, and on the environment. These include moisture retention, maintaining a proper structure, better use of fertilizers, protection of growing plants, less product damage and elimination of weeds when using opaque plastics.

All the plastics used for mulching increase soil temperature during the day, apart from the white and aluminised plastics which reflect light. Black plastic is best for preventing the growth of weeds. Inside greenhouses, white plastic is used as a reflective mulch to increase the quantity of light available for the plants.

Fig 56: Organic mulching

Chapter-7

7 Measures for Water Logging Area

7.1 Introduction

This chapter involves measures for water logging that covers on farm water management, surface drainage and sub-surface drainage methods.

7.2 Water Logging

Water logging is one of the major problems of land degradation in India. An irrigated area is said to be waterlogged when the surplus water stagnates due to poor drainage or when the shallow water table rises to an extent that soil pores in the root zone of a crop become saturated, resulting in restriction of the normal circulation of the air, decline in the level of oxygen and increase in the level of carbon dioxide. Excess water in the plant root zone restricts the aeration required for optimum plant growth. It may affect the availability of several nutrients by changing the environment around the roots. The actual depth of water table, when it starts affecting the yield of the crops adversely, may vary over a wide range from zero for rice to about 1.5 meters for other crops

7.2.1 Causes of Water Logging

Water logging may be a result of both natural and man-made factors. Natural factors may include poor natural drainage as a consequence of unfavorable sub-soil geology like existence of hardpan at shallow depths, spilling of rivers resulting in submergence of agricultural lands and heavy storm rainfall coupled with poor natural drainage etc. Water logging is, however, caused mainly because of manmade factors like deforestation and poor upkeep of watersheds, developmental activities such as construction of roads, bridges, railway lines and buildings resulting in choking of natural drainage, hydraulic pressure of water from upper irrigated areas resulting in seepage outcrop in low lying areas, introduction of irrigation without taking into account characteristics of soils and sub-soils for their irritability, seepage from canals, distributaries and watercourses, excess application of irrigation water particularly in the initial years when the command is not fully developed, poor "On Farm Water Management" resulting in poor water-application efficiencies, unrealistic cropping patterns tilted in favour of water intensive crops, lack of night irrigation in some commands, inadequate drainage and poor maintenance of existing drainage systems and outlets and lack of conjunctive use of surface and ground water etc.

7.2.2 Strategies for Prevention and Management of Water-logging

7.2.2.1 Lining of Water Distribution System

The effect of lining in canal distribution system shows that the system could result in substantial reduction in seepage. Lining the field channels alone followed by main canals and distributaries can help to derive the maximum benefits. Even in a particular component of the system need to be lined fully. The lining of ponds and reservoirs would be desirable although cost considerations would often limit the practicability of this proposition. A major difficulty with this option is the quality of work. If the quality is substandard, the lining or no lining does not matter. It is assessed that if 10% of the lining is defective, it might cause 70% of the seepage that is expected in an unlined system.

7.2.2.2 On Farm Water Management

Good irrigation water management lies in the efficient use of irrigation water once it reaches the field head. It is reported that as much as 50% of the water delivered at the field head goes as deep percolation losses and on an average, it is presumed that 1/3rd of the water is lost at the field level. Adding the earlier 25% of water lost in seepage, nearly 58% of water from canal irrigation system contributes to the groundwater naturally causing water-logging at an alarming rate than envisaged. To use this water through surface irrigation methods with minimum losses, on farm water management technology should include efficient land levelling and shaping, efficient design and layout of irrigation methods, scientific scheduling of irrigation under both adequate and deficit water supplies, crop planning for optimal water use and adequate provision of drainage. The water management must aim at optimum yield per unit of water applied and minimum loss of soil and plant nutrients. Proper control of the water delivered to the fields to avoid any misuse or over-use can result in water economy. The water thus saved can be used for intensive irrigation.

7.2.2.3 Conjunctive Use of Surface and Groundwater

Transport of water from one basin to another increases the input to the groundwater aquifer. Since natural drainage cannot take care of this additional input, the rise in water table is inevitable. Therefore, any approach to irrigation development should have an integrated use of surface and groundwater resources. Conjunctive use of groundwater serves as a corrective measure to remove the deficiencies of the distribution system and provide assurance of water availability urgently needed in modern agriculture. It also serves as an in-built insurance against water-logging.

7.2.2.4 Planting Trees in Vulnerable Reaches/Bio-drainage

An alternative option claimed to reduce water logging is bio-drainage, which is projected as the least expensive and more environmentally friendly method of land reclamation.

Bio-drainage relies on vegetation rather than mechanical means to remove excess water through consumptive use by the plants. Quick growing plants, which transpire water at a high rate, could be grown to dispose-off excess water. Eucalyptus is the most appropriate plant for this purpose. Exotic plants may be grown in areas prone to water logging to prevent or delay its appearance. These trees may be grown along the canal banks and also along the influent boundaries so as to check the incoming seepage from outside the area. This will curtail the input to the groundwater.

7.2.3 Surface Drainage

Surface drainage is the safe removal of excess water from the land surface through land shaping and improved or constructed channel. Surface drainage in agricultural land is needed to remove the excess rainfall as well as collection and disposal of excess surface irrigation. Low-lying flat areas, heavy soils with low permeability and lands in humid tropical or sub-tropical regions where high intensity storms are common, are subject to surface inundation and therefore, require surface drainage. Surface drainage uses the potential energy that exists due to overflow from rivers or natural channels sometime contribute to the drainage problem of an area. The following reasons could be ascribed to the problem:

Flat land surfaces causing hindrance in the natural runoff from the upper catchment area. The problem is severe in heavy textured soils and in humid climate.

Inadequate capacity of the drainage channels particularly during critical periods could cause surface stagnation. During intense storms the main drainage channels are full to the brim thereby reducing the capacity of the lateral and collector channels causing inundation upstream.

Inadequate outlet conditions partly due to developmental works, which obstruct the flow and partly due to choking of the outlet of the natural drainage systems.

No outlet due to backwater flow water. Surface stagnation is and would continue to be a major stress factor under monsoon climatic conditions. Although in monsoon, most agricultural lands climatic conditions are prone to short-term surface stagnation.

All lands in humid and subhumid regions and even lands in semiarid regions are prone to surface stagnation particularly during the *kharif* season.

Lands under rice-wheat system are prone to surface stagnation because of the development of plow sole/hard pan at the bottom of the plough layer impeding vertical movement of water.

Lands under irrigation with poor quality waters that is saline water with high Sodium Adsorption Ratio (SAR) or alkali waters with high Residual Sodium Carbonate (RSC) are prone to surface stagnation particularly during rain events.

Areas where drainage system with unrealistic drainage designs have been laid and/or the drainage systems are inadequately maintained.

Besides, the changing land use patterns, field-to-field irrigation, flood irrigation and poor on farm development; all favour short-term stagnation of water. It may be mentioned that there are large areas in the irrigation commands where field-to-field irrigation is still practiced. In such cases, irrigation water far in excess than required is applied such that short-term water stagnation is bound to occur particularly at low spots.

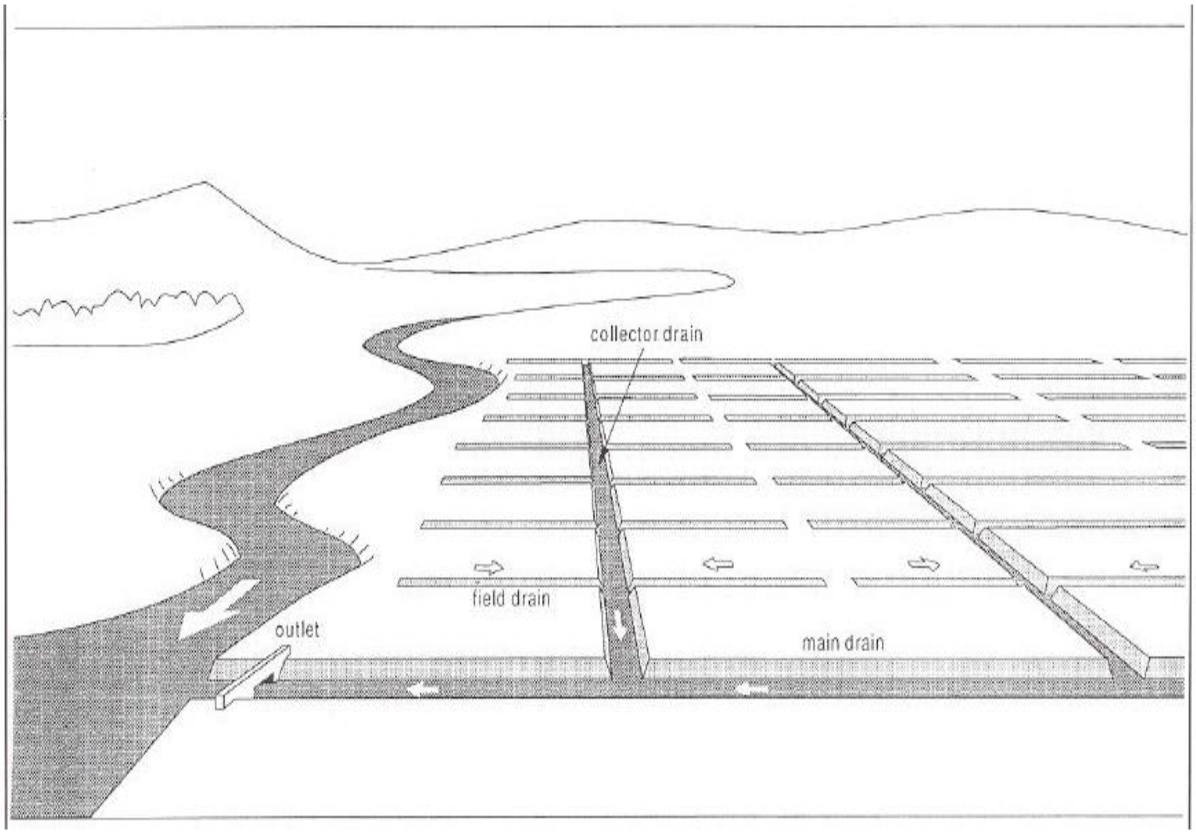


Fig. 57: Components of surface drainage

7.2.3.1 Types of Surface Drainage

There are three types of drainage systems used in flat area (less than 2 % slope)

7.2.3.1.1 Random Drain System

The random field drainage system is applied where there are a number of large but shallow depressions in a field, but where a complete land-forming operation is not considered necessary. The random field drainage system connects the depressions by means of a field drain and evacuates the water into a collector drain. The system is often applied on land which does not require intensive farming operations (e.g. pasture land) or where mechaniza-tion is done with small equipment.

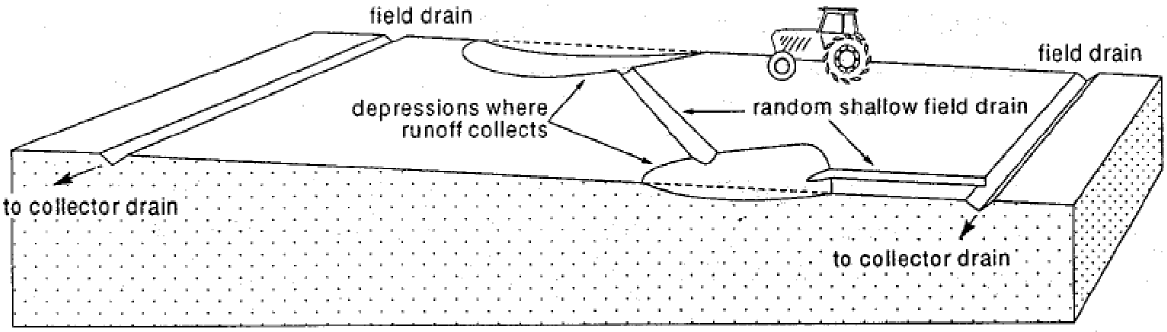


Fig 58: Random field drain system

7.2.3.1.2 The Parallel Field Drains

This system is most effective method of surface drainage and is well suited both for irrigated and rainfed areas. In his system individual fields are properly graded such that they discharge into the drain. Then each drain is connected to field lateral which further discharged into main outlet. Lateral and mains should be deeper than the field ditches to provide free outfall.

The parallel open ditch system is applicable in soil that requires both surface and subsurface drainage. It is similar to parallel field drain system, except the drains are replaced by open ditches which are comparatively deeper and have steeper side slope than the field drain. The open ditch cannot be crossed by farm machinery. The spacing of ditch depends upon the soil and watertable condition and may vary from 60 to 200 m.

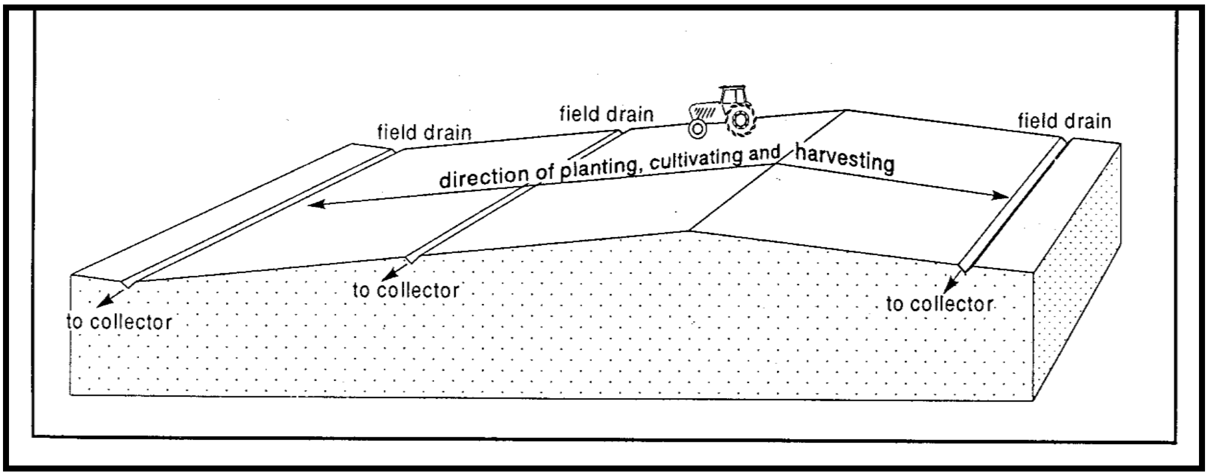


Fig. 59: The parallel field drain system

7.2.3.1.3 Bedding system

Bedding is a surface drainage method achieved by ploughing land to form a series of low beds, separated by parallel field drains. The bedding system for surface drainage is essentially a land forming process. The land is ploughed into beds, separated by dead furrow which run in the direction of prevailing slope. Ploughing is to be done parallel to the furrow and all other farming operation can be done either across the beds or parallel to the furrow. Bedding was proved to be successful on poorly drained soil and on flat lands having slope upto 1.5 per cent. The bedding system is normally used for grassland. In modern farming, bedding is not considered an acceptable drainage practice for row crops, because rows near the field drains will not drain satisfactorily. To overcome the disadvantages of the bedding system, the two other methods of land forming have been developed: land grading and land planning.

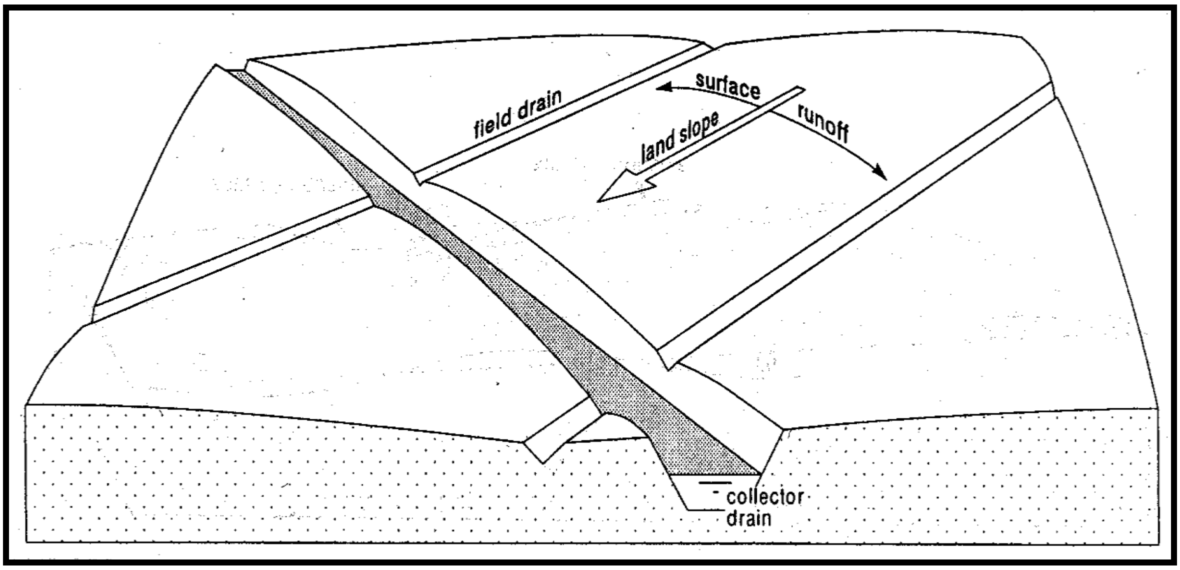


Fig. 60: Bedding system

Table 31: Recommended bed widths for different soils.

Permeability	Bed width
Very low with K = 0.5 cm/day	8- 12m
Low with K = 5 to 10 cm/day	15- 17 m
God with K = 10 to 20 cm/day	20-30 m

(Source: Agriculture land Drainage, Central Soil Salinity Research Institute, 2007)

7.2.3.2 Design of Surface Drainage System

Agricultural land drainage system may be categorised in to surface and subsurface drainage systems. The main objective of both the systems is to facilitate the removal of excess water (some times with presence of toxic soluble salts) from cropped land that may hinder the potential crop production. However, surface drainage may be defined as the removal of excess water over the ground surface through natural or constructed channels with adequate outlets for optimum crop production.

7.2.3.3 Design Criteria for Surface/Field Drainage

The very purpose of a good surface drainage system is to prevent the harmful effects of water logging on crops. Selection of an appropriate drainage coefficient is the key to design a successful surface drainage system. Drainage coefficient is defined as the amount of water that runs off from a given area and is to be removed in 24 hours. While designing surface drainage system, a low value of the drainage coefficient will lead to partial improvement in drainage though the cost of design may be relatively low, whereas a high value would increase the cost substantially without any additional gain in the removal of surface congestion. The water logging tolerance of a crop should be considered while estimating the drainage coefficient for a surface drainage project.

Example: Design a field drain for following parameters. Catchment area 10 Ha, land slope 1 %, soil type Clay loam, rainfall intensity 12.3 cm/hr (For Tc – 13.8 min rainfall intensity I= 21 cm/hr)

Solution

Assume side slope of drain 1:1 (depending upon soil type), Run off coefficient C= 0.35(for clay loam soil with 0-5 % slope)

Design Runoff, $Q = \frac{C.I.A}{360}$

$$Q = \frac{0.35x210x10}{360} \quad \text{where, (I= 210 mm/hr)}$$

= 2.05 cumsec

Design of Cross-section of Drain

For efficient cross section, bottom width B= 2d and R =0.6213d and A= $3d^2$

Where, d = depth of flow, R = Hydraulic Radius i. e. A/P

Now Velocity of flow $V = \frac{R^{2/3}.S^{1/2}}{n}$ (for clay loam n= 0.032)

$= 1/0.032 \times (0.6213d)^{2/3} \times (0.01)^{1/2}$

$= 1.94\ d^{2/3}$

Now, Q = A.V

$2.05 = 3d^2 \times 1.94\ d^{2/3}$

2.05 = 5.8 d 8/3

Therefore by solving d= 0.68 m

Hence, actual depth of channel after adding 10% free board d= 1.2 x 0.68 = 0.75 m

Bottom width = 2d =2x 0.75 = 1.5 m

Top width, T = B + (2 x z x d) where, z is side slope 1

= 1.5 + (2 x 1 x 0.75) = 3 m

The above designed channel is shown below

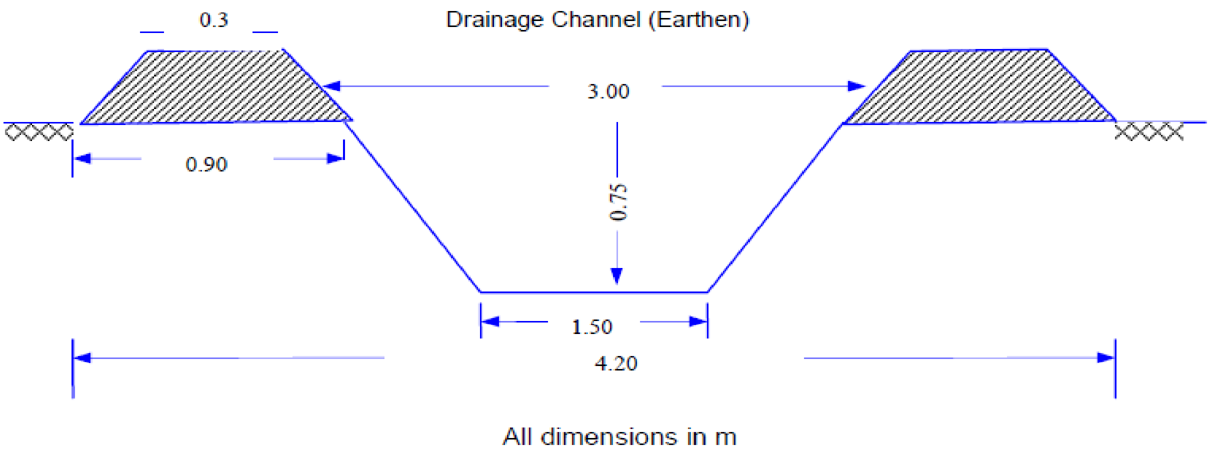


Fig. 61: Design of Earthen Drainage Cannel

7.2.4 Subsurface Drainage System

Irrigation induced water logging and soil salinity/alkalinity problems are observed in irrigation commands of large irrigation projects in many states of India. These problems adversely affect the production and productivity as well as threaten the sustainability of irrigated agriculture. Waterlogging is called as critical, if water table fluctuates between 0-2 m below ground surface. It is treated as semi-critical, if water table fluctuates between 2-3 m below ground surface. Besides coastal soil salinity, inland drainage problems in irrigated command and non-command areas in states of Gujarat, Maharashtra, Karnataka and Andhra Pradesh are observed mainly because of cultivation of water loving crops on heavy soils having low permeability.

Subsurface drainage refers to the removal of excess water present below the ground surface. Agriculture lands affected by high watertable generally need subsurface drainage. Subsurface drainage lowers the watertable and provides the better environment in the root zone.

7.2.4.1 Drainage Investigations

Drainage requirements and measures greatly vary depending upon factors such as soil, geo-hydrological and climatic conditions, irrigation and cropping practices and natural drainage. Drainage investigations are mainly conducted to understand different dimensions of the problem to search for a suitable solution. However, investigations are generally problem specific. It is always better to plan with minimum data obtained through best available means for a specific project. Information on hydraulic conductivity, drainable porosity, infiltration characteristics, soil salinity, soil alkalinity, depth of impermeable layer, aquifer parameters, groundwater fluctuations, groundwater quality, fresh water supplies, surface drainage network and availability of outlets, etc. is a pre-requisite for planning the drainage of waterlogged saline and alkali soils. In addition to above-mentioned information, knowledge on drainage requirement of different crops and criterion for drainage design is also needed. Information generated through drainage investigations is utilized effectively to design a drainage system, which would satisfy the limits related to drainage criteria.

7.2.4.2 Groundwater Conditions

The water table behaviour in drainage area needs to be studied on the basis of water table data during pre-monsoon period as well as post-monsoon period. Water table contour map is necessary to understand direction of groundwater flow. It also helps to assess whether interceptor drain is necessary and to decide the directions of main and lateral lines.

7.2.4.3 Subsurface Drainage Methods

In sub-surface drainage, water moves under influence of gravity to suitable outlets. This is accomplished using one of the following methods:

(1) Tile drain including perforated pipes

(2) Mole drain

(3) Drainage well

(4) Deep open drains and

(5) Combination of tile and open drains.

7.2.4.4 Design of Subsurface Drainage System

In the design of subsurface drainage system, following main items are considered:

- Drainage criteria
- Subsurface drainage coefficient
- Laterals: Depth and spacing of field laterals
- Size and slope of the laterals and collectors
- Drainage materials
- Layout and installation of drainage system
- Construction of sump and evaporation pond, if needed

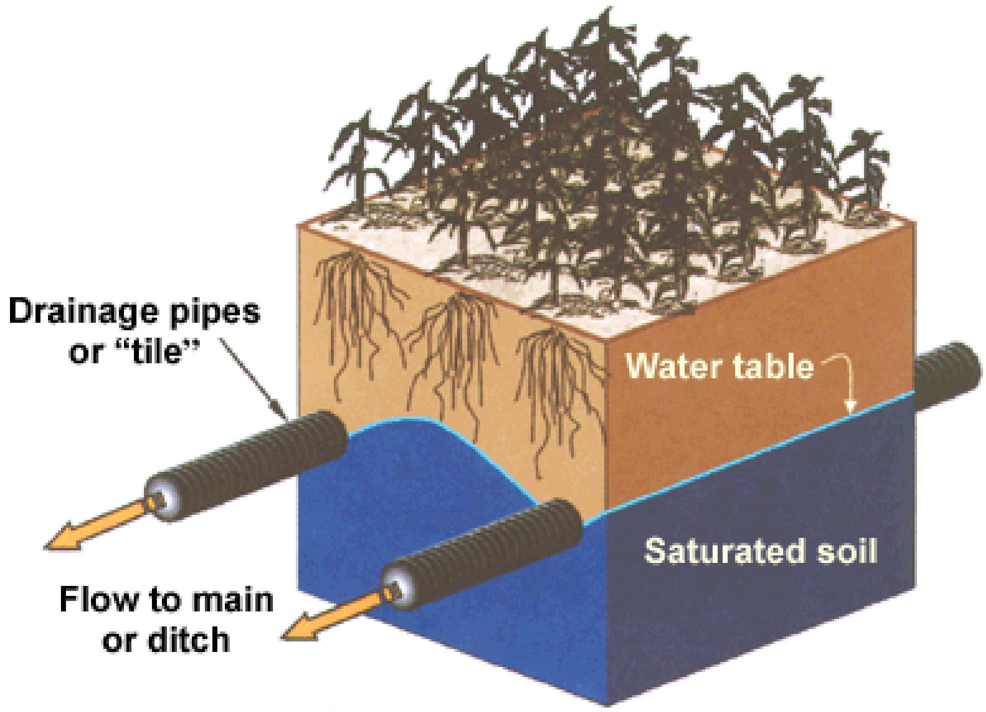


Fig. 62: Design of Subsurface Drainage System

7.2.4.5 Drainage Criteria

The agricultural drainage criterion is defined as the state to which the original waterlogging on or in the soil is to be reduced by a drainage system so that the maximum agricultural benefits are attained. In the definition of drainage, 'removal of excess water' indicates that land drainage is an action by man, who must know how much excess water should be removed. A groundwater balance of the drainage area is the most accurate tool to calculate the volume of the water to be drained. Before the water balance of the area can be made, number of the surveys must be undertaken to prepare hydrogeological and topographic maps. Further all surface and subsurface water inflows and outflows must be measured and estimated. Precipitation and relevant evapotranspiration data must be analysed and hydraulic properties of the soil should be determined.

7.2.4.6 Sub-surface Drainage Coefficient

Drainage coefficient is the most important parameter that decides the lateral drain spacing, size of the laterals and collectors and capacity of the pump to dispose off the drainage effluent. The drain spacing is less in cases where drainage coefficient is more as compared to a case where drainage coefficient is less. As such, the cost of the system depends largely upon this parameter. Therefore, the need to select an appropriate value for this parameter has always been emphasized. The drainage coefficients for some of the sites in India have been observed to be in the range of 1-5 mm

Table 32: Subsurface drainage coefficients for Gujarat as observed from test plots

Site	Rainfall (mm)	Rate (mm/d	Recommended range (mm/day)
Dabhou (Gujarat)	800	4.0	3.0-5.0
Muraj (Gujarat)	500	2.8	2.0-4.0

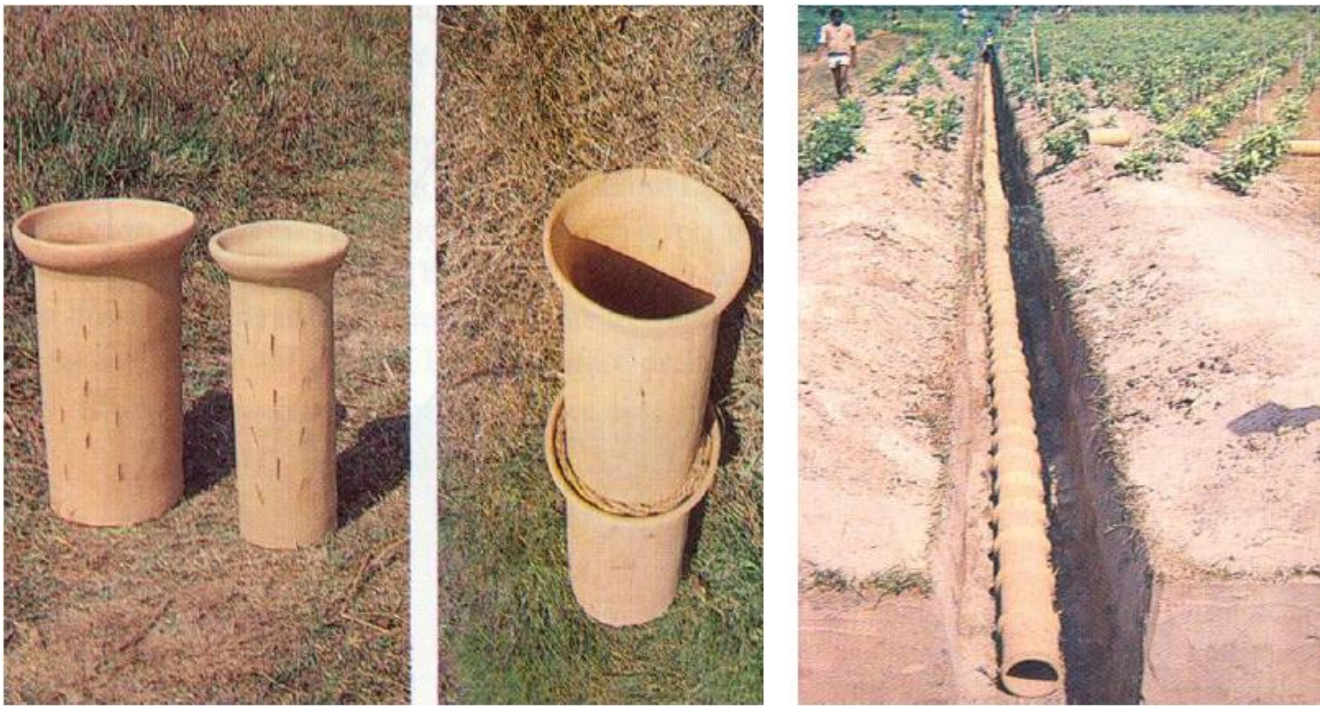
Variation in the range of 600-1400 mm (Source: Gupta and Gupta, 1997)

Table 33: Guidelines on drainage coefficient for subsurface drainage

Climatic conditions	Range (mm/day)	Optimum value (mm)
Arid	1-2	1
Semiarid	1-3	2
Subhumid	2-5	3

7.2.4.7 Installation of Subsurface Drainage System

The installation of subsurface drainage system begins with construction of outlet. In the absence of a natural outlet, pumped outlet is constructed. The installation of collectors and laterals follows the construction of outlet. Excavation of trenches, lying of lateral pipes along with filter material and immediate back filling of trenches are done to avoid any problem in the event of rainfall. Manholes (RCC pipe 2.5 m length and 0.6m diameter) can be installed and collectors and laterals are connected to manholes at 20-30 cm above their bottom levels so that manholes also act as sediment trap.



(Source: Agricultural Land Drainage, Reclamation of Waterlogged Saline Lands, Central Soil Salinity Research Institute, Karnal 132001)

Fig 63: Perforated clay tile drains and their fixing

7.2.4.8 Drainage Materials for Subsurface Drainage

Subsurface drainage aims at controlling the water table and to reduce the soil salinity. Several drainage techniques such as tube well drainage, open drains or subsurface drains could be employed to control the water table but leaching is most effective only through subsurface drains. On the other hand, efficient performance of a subsurface drainage system depends on the technically sound design and use of appropriate material in quality construction of the system. Major factors contributing towards satisfactory performance of the drainage are the structural strength, hydraulic properties and the type of pipe materials as well as the quality and hydraulic properties of envelope materials used in the system. The introduction of corrugated perforated polyvinyl chloride (PVC) and polyethylene (PE) pipes have resulted in the development of high powered, high speed trenching and trench less drainage machines and has prompted the use of cheaper and labour saving drainage envelope materials. In India, we are confronted with the problems of evolving a combination of artificial and locally available materials as well as combining the mechanized and manual methods of installation to efficiently utilize the skilled and unskilled manpower available. Due consideration should be given to existing conditions, availability and cost of materials while selecting the drainage materials.

7.2.4.9 Types of Drainage Materials

a) Drain pipes: The drain pipes could be (i) clay pipes (ii) concrete pipes and (iii) plastic pipes. The plastic pipes could further be characterized into corrugated perforated PVC or PE pipes and rigid PVC pipes.

b) Envelope material: is a common name given to filter and surrounds. Filters are classified into (i) geo-textile (ii) polypropylene (iii) coconut fiber (iv) polystyrene and (v) foam plastic. The common surrounds are gravel and coarse sand.

c) Pre-wrapped corrugated perforated pipes.

d) Miscellaneous materials: In this category pipe outlets, pipe connections, closing devices and outflow regulators, and drain bridges are included.

7.2.4.10 Tile Drain Method

It is consists of short length pies (30 to 90 cm) installed at particular depth from land surface. The pipes are made up of concrete or burnt clay. After digging the trench to desired depth the pipes are held end to end without any joining. They are covered with an envelope material in certain case and soil is backfilled. A network of tile line laid with a grade so that it removes the subsurface water easily.

7.2.4.10.1 Depth of Lateral Drains

Depth of the laterals should be planned according to agricultural drainage criteria. The drain depth is also decided by the construction method, the available machinery and drain specifications. Drains need to be installed at depths, where chances of damage due to agricultural operations are less. To protect the pipes against damage due to passage of heavy machinery, the minimum drain depths have been recommended, which vary from one soil type to another.

Table 34: Minimum soil cover required for pipe drains

Soil type	Minimum soil cover (cm)
Mineral	60
Deep peat and muck	120
Organic	75

(Source: Agriculture land Drainage, Central Soil Salinity Research Institute, 2007)

Table 35: Guidelines on drain depth

Outlet conditions	Depth of the drains	Optimum depth (m)
Gravity	0.9-1.2	1.1
Pumped	1.2-1.8	1.5

(Source: Agriculture Land Drainage, Centra Soil Salinity Research Institute, 2007)

7.2.4.10.2 Spacing of Lateral Drains

Assuming the steady state drainage criteria spacing between the laterals can be computed using

Hooghout's formula

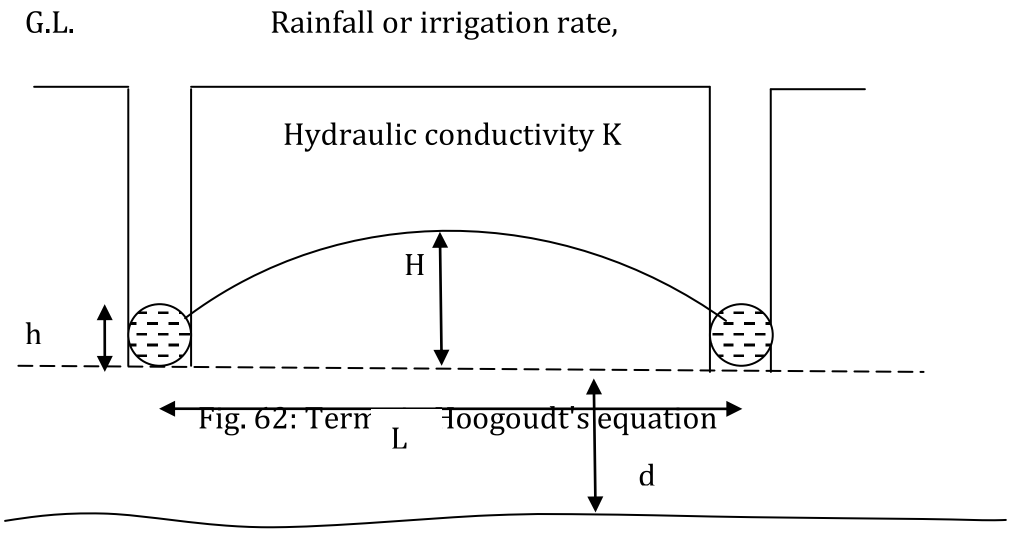


Fig. 62: Term[illegible] Hoogoudt's equation

$$L^2 = \frac{4KH}{R}(2d + H)$$

Where L= spacing between two drains, m

K= Hydraulic conductivity, m/day

H = the height of water table at midway between the drains, m

R = Rainfall m/day

d = the depth to impervious layer from drain, m

The discharge (m/day) through drain is given by:

$$q = \frac{4K(H^2 - h^2 + 2dH - 2dh)}{L^2}$$

Table 36: The average depth and spacing of tile drains (source: Schwab et al., 1993)

Soil type	Hydraulic class	Conductivity (m/day)	Spacing (m)	Depth (m)
Clay	Very slow	0.001	9 – 15	0.9 – 1.1
Clay loam	Slow	0.001 – 0.005	12- 21	0.9 – 1.1
Average loam	Moderately slow	0.005- 0.02	18- 30	1.1 – 1.2
Fine sandy loam	Moderate	0.02 – 0.06	30 – 37	1.2 – 1.4
Sandy loam	Moderately rapid	0.06 – 0.13	30 – 60	1.2 – 1.5
Peat and muck	Rapid	0.13 – 0.25	30 – 90	1.2 – 1.5
Irrigated soil	variable	0.025 - 25	45 - 180	1.5 – 3.0

7.2.4.10.3 Size of Tile Drain

The size of tile drain is determined using the maximum expected flow and the grade. Manning's formula is used for the design. The value of manning's constant recommended is 0.011 for concrete tiles and for other material value of 'n' is given in following table. Using manning's formula; the following relationship is developed for the size of the tiles flowing full

Q = A.V

Where, $V = \frac{R^{2/3} . S^{1/2}}{n}$

$$Q = A.V = \frac{\pi}{4}\frac{d^2}{n}\left(\frac{\pi r^2}{2\pi r}\right)^{2/3} S^{1/2}$$

Q = discharge through tile drain, m3/s

A = cross section of tile drain, m2

V= velocity m/s

d = tile diameter, m

r = tile radius, m

Table 37: Recommended values of n for various conduit materials:

Conduit Materials	Manning's n
Clay tile	0.011
Concrete pipe	0.011
Vitrified clay pipe	0.011
Perforated plastic pipe	0.017
Corrugated plastic tubing	0.017

Table 38: Capacity of corrugated pipe lateral drain

Internal Q dia (mm)	Drainage (m^3/day)		Area (ha) Slope (%)		Maximum length at 75 m spacing between laterals (m)	
	0.1	0.15	0.1	0.15	0.1	0.15
75	62.7	76.5	2.1	2.5	278	339
100	135.2	164.8	4.5	5.5	599	730
125	306.7	374.0	10.2	12.5	1359	1659
150	498.8	608.5	16.6	20.3	2212	2699

Example

In subsurface drainage system, the lateral were laid out 50 m apart and the 200 long and have grade of 0.3 m. if the drainage coefficient of the area is 2 cm, what size tiles have to be used? If drainage coefficient is increased to 3 cm, what will be the spacing of the laterals?

Solution:

Quantity of water to be drained by the lateral in 24 hr = 2/100 x 50 x 200 = 200 cu.m/day

Rate of flow = 200/(24 x 60 x 60) = 0.002315 cu.m/s

Consider the rate of flow through 10 cm dia tile

Wetted perimeter, P = π.r = 3.14 x 0.1 = 0.314 m

Hydraulic radius R = A/P = (π/4 x 0.1 x 0.1)/ π x 0.1 = 0.025 m

Velocity, $V = \frac{R^{2/3}.S^{1/2}}{n}$

$$V = \frac{0.025^{2/3}.(0.3/100)^{1/2}}{0.0108}$$

= 0.4335 m/s

Capacity of the tile, Q = A. V

$$=3.14/4 \times 0.1 \times 0.1 \times 0.4335$$

$$= 0.003405 \text{ cu.m/s}$$

Hence 10 cm dia tiles will be satisfactory.

Let the lateral be located at a distance of W and length kept at 200 m

Amount of water to be drain in 24 hr = W x 200 x 3/100

And this is nothing but the capacity of tile line = 0.003405 x 24 x 60 x 60 = 294.19 cu.m/day

Hence, W x 200 x 3/100 = 294.19

W = 49 m

Layout plan

The layout of subsurface drainage system is adjusted to utilize the natural slope and to minimize earthwork against slope. Collectors are generally laid along the natural slope and laterals are laid across the general slope. The details of position of lateral, gravel envelope, collector and main drain, junction boxes etc. are worked out to decide their exact locations.

7.2.5 Mole Drain

Mole drains are unlined channels formed in clay subsoil with a ripper blade with a cylindrical foot, often with an expander which helps compact the channel wall. Mole drains are used when natural drainage needs improving due to lack of slope or heavy clay subsoil prevents downward drainage. They are a more sophisticated drainage system than open drains. Mole drains do not drain groundwater but only water that enters from above.

Soils should have a minimum of 35% clay for best results. Clay gives the soil the ability to hold together and reduce the chances of collapsing after the mole is pulled. Sand content should be less than 30%. The soil should be free of stones at the mole drain depth.

7.2.5.1 Testing for Suitability for Mole Draining

Two simple tests can indicate a soil's suitability for mole drainage:

1. Test soil at mole draining depth by rolling out a pencil thick rod and try to form a 40 to 50 mm diameter circle. If this can be done without crumbling or cracking then it may be suitable for mole draining.
2. Another test is to find out if the soil at mole drain depth will slake or disperse. Small golf ball size balls of the soil are placed in distilled or rain water and observed over a day or two. If the water becomes cloudy and the ball becomes soft, then this indicates a dispersive soil. These soils are prone to tunnel erosion and should not be mole drained. If these ball falls apart quickly it is has a tendency to slake. Soils which tend to slake may be successfully gravel

mole drained (actually a gravel slot) albeit expensively. Gypsum may be useful in dispersive soils to suppress clay dispersal, but it can be difficult to get the gypsum into the subsoil.

7.2.5.2 Construct of Mole Drain

To achieve satisfactory results, the soil in the vicinity of the mole channel needs to be moist enough to form a channel, but not dry enough to crack and break up, and not soft enough to slough off and form slurry. These conditions usually occur on the drying cycle in late spring or early summer. The surface soil needs to be dry enough to form cracks at the time of mole draining and allow traction. If too moist then the cracks can heal over and reduce water intake. It is preferable for a drying period with no rain to allow the cracks to dry and the mole channel to harden. Usually when the clay at mole draining depth has a moisture content of 20-25%, conditions are satisfactory. Test the soil by kneading between the fingers. If you can roll out a ribbon without it sticking to your fingers the moisture content is right. Mole draining in autumn is not recommended, as the topsoil is wet and subsoil is too dry. The subsoil is difficult to mole and to dry out and it's difficult to achieve the desirable depth.

7.2.5.3 Gradient of Mole Drain

Recommended gradients for moles generally fall between 0.4% and 4%. A good gradient to aim for is 3%. This should enable relatively trouble free moles in that minor surface undulations won't block with negative gradients, and the risk from erosion is reduced. The flatter the gradient, the more even the soil surface has to be and more interceptor drains needed to achieve good results.

7.2.5.4 Depth of Mole Drain

Optimum mole depth depends on soil type and the conditions when moles are installed. Generally moles are pulled at 400–600 mm depth. Often when first mole draining, the shallow depth is used due to tractor limitations in tight soils. As the soil structure improves over time they can often be pulled deeper. Moles less than 400 mm deep are liable to be damaged by tractors and animals during or immediately after rain. A rule of thumb is that the expander to mole draining depth ratio is 1:7 i.e. 70 mm diameter expander should have mole depth 490 mm.

7.2.5.5 Spacing

In dairy areas spacing between moles is usually about 2 m. In grazing or less intensely used areas spacing may be up to 5 m apart but performance falls off with wider spacing.

7.2.5.6 Length

The generally accepted maximum effective length of moles is about 200 m. However moles up to 400m pulled have performed satisfactorily for a number of years. However shorter (80-100 m) moles should last longer, because they empty out quicker and are not likely to be overloaded.

7.2.5.7 Outfall/Outlet

The drain outfall or outlet is the most important part of the system. If this fails the whole system fails. Mole drains can discharge to open drains or into interceptor drains filled with gravel. This latter system protects the mole outlets and the only maintenance is required at the tile outlet, but does cost more to install. Open drain outlets should be fenced off from stock and kept clean so the outfall is above the drain water level. This prevents water backing up into the mole outlets and causing them to collapse. Short lengths of plastic pipe inserted in the ends can protect them better. Another advantage of gravel filled interceptor drains is that moles can be pulled both ways, instead of the one way trip from open drains. This speeds up the job.

Chapter-8

8 Artificial Ground Water Recharge

8.1 Introduction

Artificial recharge is becoming increasingly necessary to ensure sustainable ground water supplies to satisfy the needs of a growing population. The benefits of artificial recharge can be both tangible and intangible. The hydraulic effects generated by artificial recharge are measured both in qualitative and quantities terms. The water table rise depends on the geologic and hydraulic boundaries of the aquifer being recharge and type, location, yield and duration of recharge mechanism.

The artificial recharge to ground water by rain water harvesting is very important for the following objectives:

i. To overcome the inadequacy of waters to meet our demands.
ii. To arrest decline in ground water levels.
iii. To enhance availability of ground water at specific place and time and utilize rain water for sustainable development.
iv. To increase infiltration of rain water in the sub-soil; which has decreased drastically in urban areas due to paving of open area.
v. To improve ground water quality by dilution.
vi. To increase agriculture production.
vii. To improve ecology of the area by increase in vegetation cover, etc.

8.2 Prioritization of Area for Ground Water Recharge

Prioritization of area for artificial Ground water Recharge is normally done by overlying post-monsoon depth of water level maps with data of long term trend of groundwater levels. Normally, the area having deeper water levels in post monsoon period and decline water level trends should have higher priority for artificial recharge.

8.3 Conditions of Ground Water Recharge

i. Adequate space for surface storage is not available especially in urban areas.
ii. Water level is deep enough (> 8 m.) and adequate subsurface storage is available.
iii. Permeable strata are available at shallow / moderate depth.
iv. Where adequate quantity of surface water is available for recharge to ground water.

v. Ground water quality is bad and our aim is to improve it.
vi. Where there is possibility of intrusion of saline water especially in coastal areas.
vii. Where the evaporation rate is very high from surface water bodies.
viii. Where ground water levels are declining on regular basis.
ix. Where substantial amount of aquifer has been de-saturated.
x. Where availability of ground water is inadequate in lean months.
xi. Where due to rapid urbanization, infiltration of rain water into subsoil has decreased drastically and recharging of ground water has diminished.

8.4 Types of Ground Water Recharge Structure

- **Recharge Pits**

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

- **Recharge Trenches**

These are constructed when the permeable stratum is available at shallow depths. Trench may be 0.5 to 1 m. wide, 1 to 1.5 m. deep and 10 to 20 m. long depending upon availability of water. These are back filled with filter materials.

- **Dug wells**

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

- **Hand pumps**

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

- **Recharge wells**

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

- **Recharge Shafts**

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

- **Lateral shafts with bore wells**

For recharging the upper as well as deeper aquifers lateral shafts of 1.5 to 2 m. wide & 10 to 30 m. long depending upon availability of water with one or two bore wells are constructed. The lateral shafts are back filled with boulders, gravels & coarse sand.

- **Spreading techniques**

When a permeable stratum starts from top then this technique is used. Spread the water in streams / Nalas by making check dams, nala bunds, cement plugs, gabion structures or a percolation pond may be constructed.

N.B.: (i) All the recharge structures should have wire mess at water inlet to prevent entry of foreign materials in the filter and recharge system.

(ii) All the recharge system should have options for bypassing overflow water to the nearby drainage system.

8.4.1 Ground Water Recharge through Pit

i) In alluvial areas where permeable rocks are exposed on the land surface or at very shallow depth, roof top rain water harvesting can be done through recharge pits.

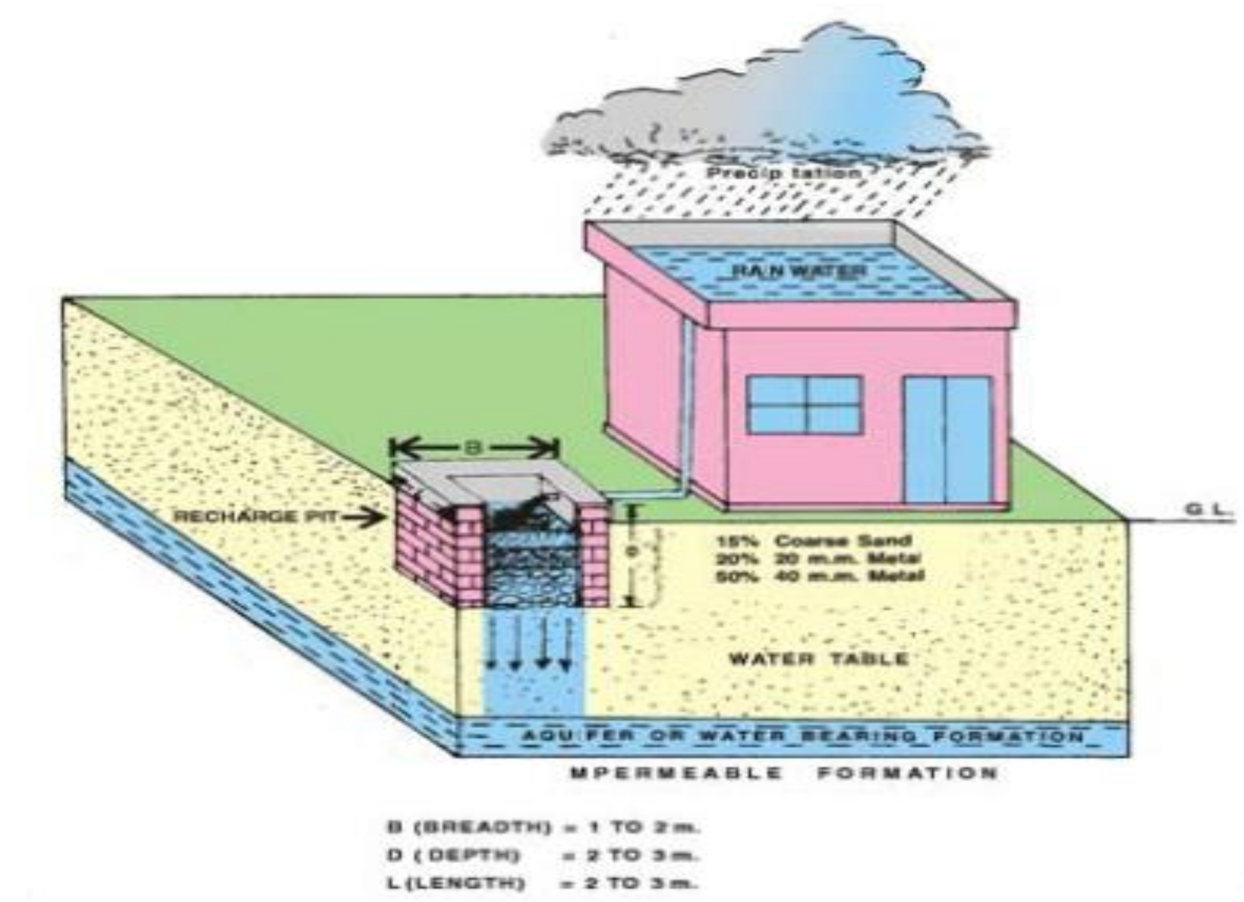
ii) The technique is suitable for buildings having a roof area of 100 sq.m and is constructed for recharging the shallow aquifers.

iii) Recharge Pits may be of any shape and size and are generally constructed 1 to 2 m. wide and 2 to 3 deep which are back filled with boulders (5-20 cm), gravels (5-10mm) and coarse sand (1.5- 2mm) in graded form. Boulders at the bottom, gravels in between and coarse sand at the top so that the silt content that will come with runoff will be deposited on the top of the coarse sand layer and can easily be removed. For smaller roof area, pit may be filled with broken bricks/ cobbles.

iv) A mesh should be provided at the roof so that leaves or any other solid waste / debris is prevented from entering the pit and a desilting /collection chamber may also be provided at the ground to arrest the flow of finer particles to the recharge pit.

v) The top layer of sand should be cleaned periodically to maintain the recharge rate.

vi) By-pass arrangement should be provided before the collection chamber to reject the first showers.



(Source: Rain water Harvesting Techniques to Augment Ground Water, CGWB, MoWR, GoI, Faridabad, 2003)

Fig. 64: Ground Water Recharge through pit

8.4.2 Ground Water Recharge through Trench

i) Recharge trenches are suitable for buildings having roof area of 200-300 sq. m. and where a permeable stratum is available at shallow depths.

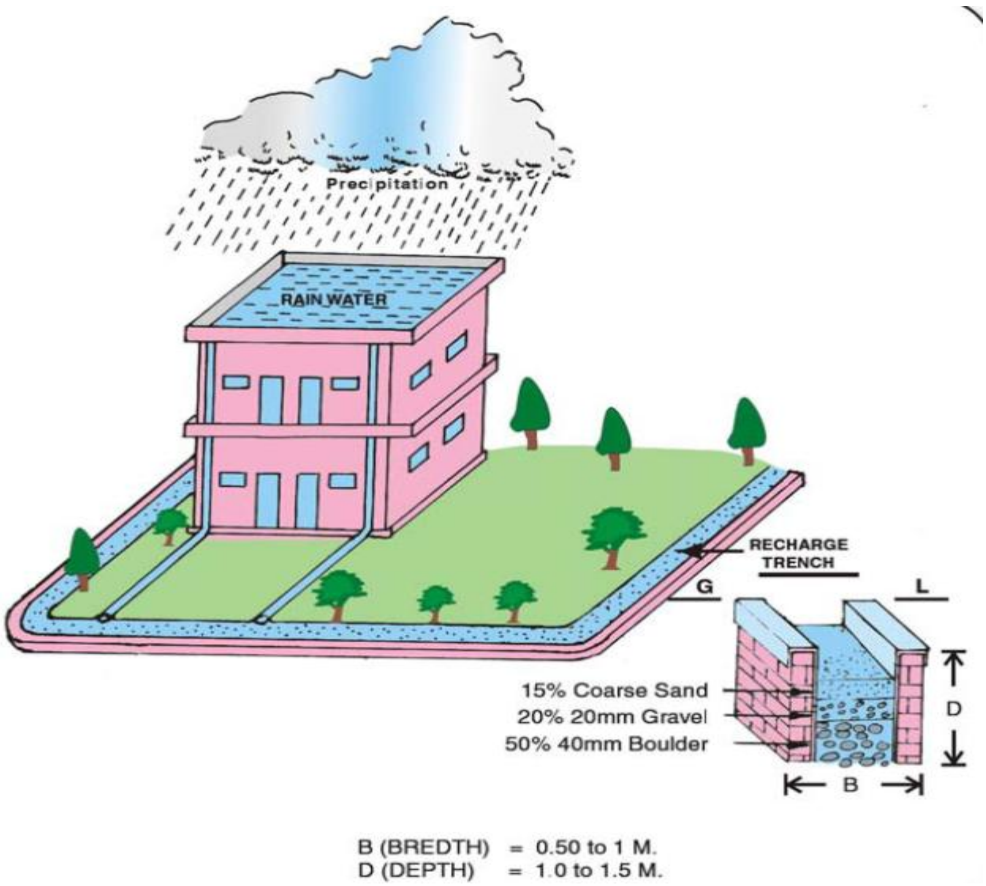
ii) Trench may be 0.5 to 1 m wide, 1 to 1.5m deep and 10 to 20 m. long depending upon availability of water to be recharge.

iii) These are back filled with boulders (5-20cm), gravel (5-10 mm) and coarse sand (1.5-2 mm) in graded form – boulders at the bottom, gravel in between and coarse sand at the top so that the silt content that will come with runoff will be coarse sand at the top of the sand layer and can easily be removed.

iv) A mesh should be provided at the roof so that leaves or any other solid waste/debris is prevented from entering the trenches and a desilting/collection chamber may also be provided on ground to arrest the flow of finer particles to the trench.

v) By-pass arrangement should be provided before the collection chamber to reject the first showers.

vi) The top layer of sand should be cleaned periodically to maintain the recharge rate.



(Source: Rain water Harvesting Techniques to Augment Ground Water, CGWB, MoWR, GoI, Faridabad, 2003)

Fig. 65: Ground Water Recharge through Trench

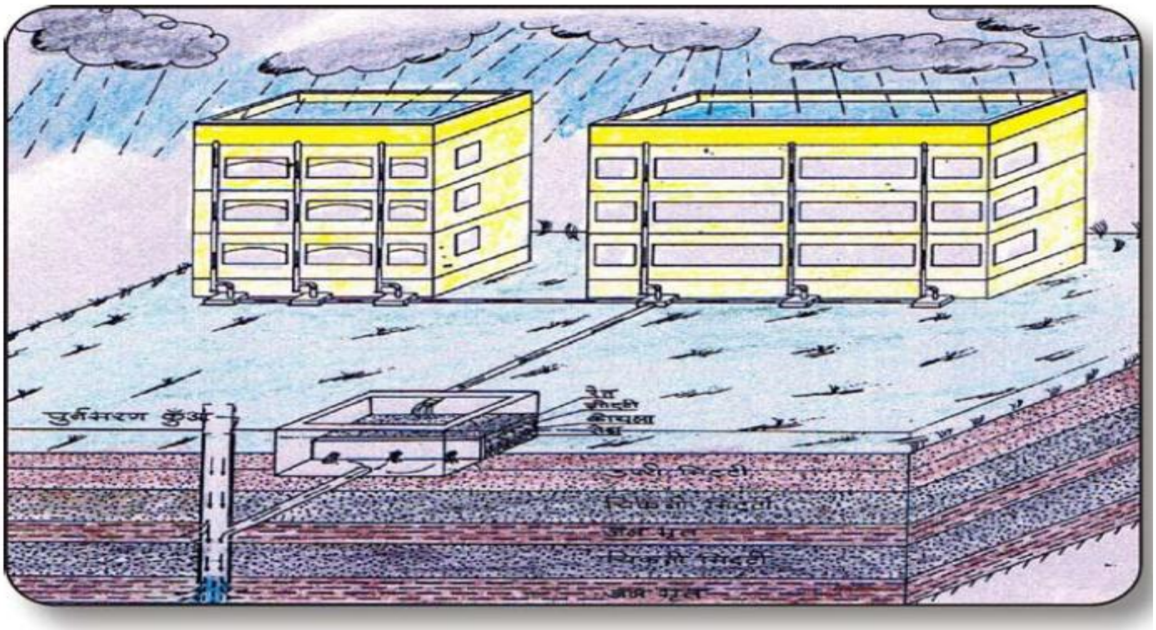
8.4.3 Ground Water Recharge through existing Tube Wells

i) In areas where the shallow aquifers have dried up and existing tube wells are tapping deeper aquifer, roof to rain water harvesting through existing tube well can be adopted to recharge the deeper aquifers.

ii) PVC pipes of 10 cm dia are connected to roof drains to collect rainwater. The first roof runoff is let off through the bottom of drainpipe. After closing the bottom pipe, the rainwater of subsequent rain showers is taken through a T to an online PVC filter. The filter may be provided before water enters the tube wells. The filter is 1 – 1.2 m. in length and is made up of PVC pipe. Its diameter should vary depending on the area of roof, 15 cm if roof area is less than 150 sq m and 20 cm if the roof area is more. The filter is provided with a reducer of 6.25 cm on both the sides. Filter is divided into three chambers by PVC screens so that filter material is not mixed up. The first chamber is filled up with gravel (6-10mm), middle chamber with pebbles (12-20 mm) and last chamber with bigger pebbles (20-40 mm).

iii) If the roof area is more, a filter pit may be provided. Rainwater from roofs is taken to collection/desilting chambers located on ground. These collection chambers are interconnected as well as connected to the filter pit through pipes having a slop of

1:15. The filter pit may vary in shape and size depending upon available runoff and are back-filled with graded material, boulder at the bottom, gravel in the middle and sand at the top with varying thickness (0.30-0.50m) and may be separated by screen. The pit is divided into two chambers, filter material in one chamber and other chamber is kept empty to accommodate excess filtered water and to monitor the quality of filtered water. A connecting pipe with recharge well is provided at the bottom of the pit for recharging of filtered water through well.



(Source: Rain water Harvesting Techniques to Augment Ground Water, CGWB, MoWR, GoI, Faridabad, 2003)

Fig. 66: Ground Water Recharge through existing Tube well

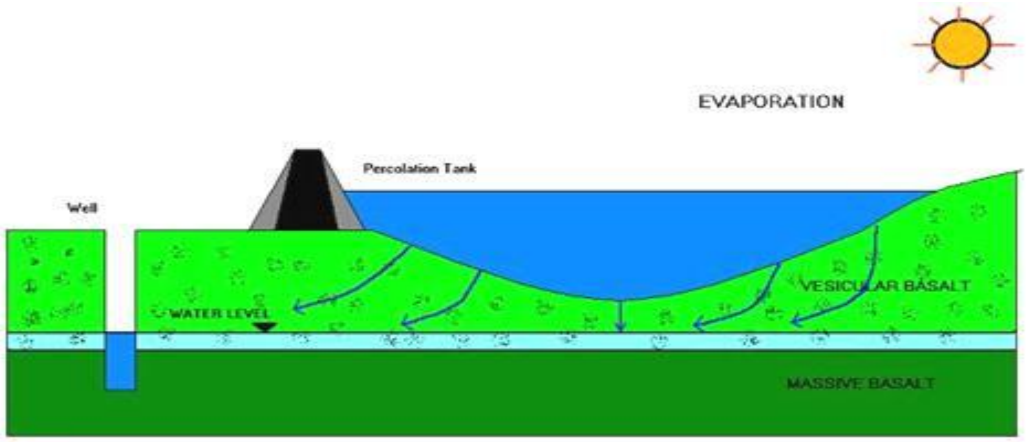
8.4.4 Ground Water Recharge through Percolation Tank

In rural areas, rain water harvesting is taken up considering watershed as a unit. Surface spreading techniques are common since space for such systems is available in plenty and quantity of recharged water is also large.

8.4.4.1 Percolation Tanks

Percolation tanks are artificially created surface water bodies, submerging a land area with adequate permeability to facilitate sufficient percolation of impounded surface runoff to recharge the ground water. These have come to be recognized as a dependable mode for ground water recharge in the hard rock terrain. The hard rock areas with limited to moderate water holding and water yielding capabilities often experience water scarce situations due to inadequate recharge, indiscriminate withdrawal of ground water and mismanagement. These are quite popular in the state of Gujarat. The percolation pond is a multipurpose conservation structure depending on its location and size. Percolation tanks are normally constructed on second order or third order steams since the catchment so also the submergence area would be smaller. Designed capacity should not normally be more than 50% of the total quantum of rainfall in catchment. It stores water for livestock and recharges the groundwater. In the Saurashtra region of Gujarat these tanks are constructed for recharging wells that support peanut production.

The design of percolation tank is similar to the design of earthen dams or nala bund with a fairly large storage reservoir. It is constructed by excavating a depression, forming a small reservoir or by constructing an embankment in a natural ravine or gully to form an impounded type of reservoir.



(Source: Rain water Harvesting Techniques to Augment Ground Water, CGWB, MoWR, GoI, Faridabad, 2003)

Fig. 67: Showing suitable location for a Percolation Tank

The cost of this type of structure is estimated at around 2 to 4 lakh. The capacity of these ponds or tanks varies from 5000 - 10000 m^3. This quantity of water, if it is used for irrigation, is sufficient to irrigate 4-6 hectares of irrigated dry crops (maize, cotton, pulse, etc.) and 2-3 hectares of cereal crop.

8.4.4.2 The Factors Considered for Selection of Site

i) It should not be located in heavy soils or soils with impervious strata; otherwise the top soil should be porous.

ii) Suitable and adequate soil should be available for forming embankments.

iii) The ideal location of the pond will be on a narrow stream with high ground on either side of the stream.

iv) Simple, economic and efficient surplus arrangement should be possible.

v) Pond size should be decided on the basis of the catchment area and the number of fillings possible for the pond in the area.

8.4.4.3 General Guidelines

i) Percolation tanks should normally be constructed in a terrain with highly fractured and weathered rock for speedy recharge. In case of alluvium, the bouldary formations are ideal. However, the permeability should not be too high that may result in the percolated water escaping in the downstream as regenerated surface flow.

ii) The aquifer to be recharged should have sufficient thickness of permeable Vadose zone to accommodate recharge. The Vadose zone should normally be about 3 m below the ground level to minimize the possibility of water logging.

iii) The benefited area should have sufficient number of wells, hand pumps etc. A minimum well density of 3 to 5 per square kilometres is desirable. The aquifer zone should extend upto the benefited area.

iv) Submergence area should be uncultivated as far as possible.

v) The nature of the catchment is to be evaluated based on Strange's Table for classification under Good, Average and Bad Category. It is advisable to have the percolation tank in a good/ average catchment.

vi) Rainfall pattern based on long-term evaluation is to be studied so that the percolation tank gets filled up fully during monsoon (preferably more than once).

vii) Soils in the catchment area should preferably be of light sandy type to avoid silting up of the tank bed.

viii) The location of the tank should preferably be downstream of runoff zone or in the upper part of the transition zone, with a land slope gradient of 3 to 5%.

ix) The yield of a catchment area is generally from 0.44 to 0.55 MCM/sq.km in a low catchment area. Accordingly, the catchment area for small tanks varies from 2.5 to 4 sq.km and for larger tanks from 5 to 8 sq.km.

x) The size of percolation tank is governed more by the percolating capacity of the formation under submergence rather than the yield of the catchment. Therefore, depending on the percolation capacity, the tank is to be designed. Generally, a percolation tank is designed for a storage capacity of 2.25 to 5.65 MCM. As a general guide the design capacity should normally not be more than 50 percent of the total quantum of utilizable runoff from the catchment.

xi) While designing, due care should be taken to keep the height of the ponded water column about 3 to 4.5 m above the bed level. It is desirable to exhaust the storage by February since evaporation losses become substantial from February onwards. It is preferable that in the downstream area, the water table is at a depth of 3 to 5 m below ground level during the post monsoon period, implying that the benefited area possesses a potential shallow aquifer.

xii) Construction-wise there is not much difference between a percolation tank and a minor irrigation tank, except for providing outlets for surface irrigation and the depth of the cut-off trench. The cut-off trench is to be provided below the earthen bund with depth limited to one fourth of the height between bed level and full storage level.

8.4.5 Ground Water Recharge through Shaft

i) This is the most efficient and cost effective technique to recharge unconfined aquifer overlain by poorly permeable strata.

ii) Recharge shaft may be dug manually if the stratum is of non-caving nature. The diameter of shaft is normally more than 2 m.

iii) The shaft should end in more permeable strata below the top impermeable strata. It may not touch water table.

iv) The unlined shaft should be backfilled, initially with boulders/ cobbles followed by gravel and coarse sand.

v) In case of lined shaft the recharge water may be fed through a smaller conductor pipe reaching up to the filter pack.

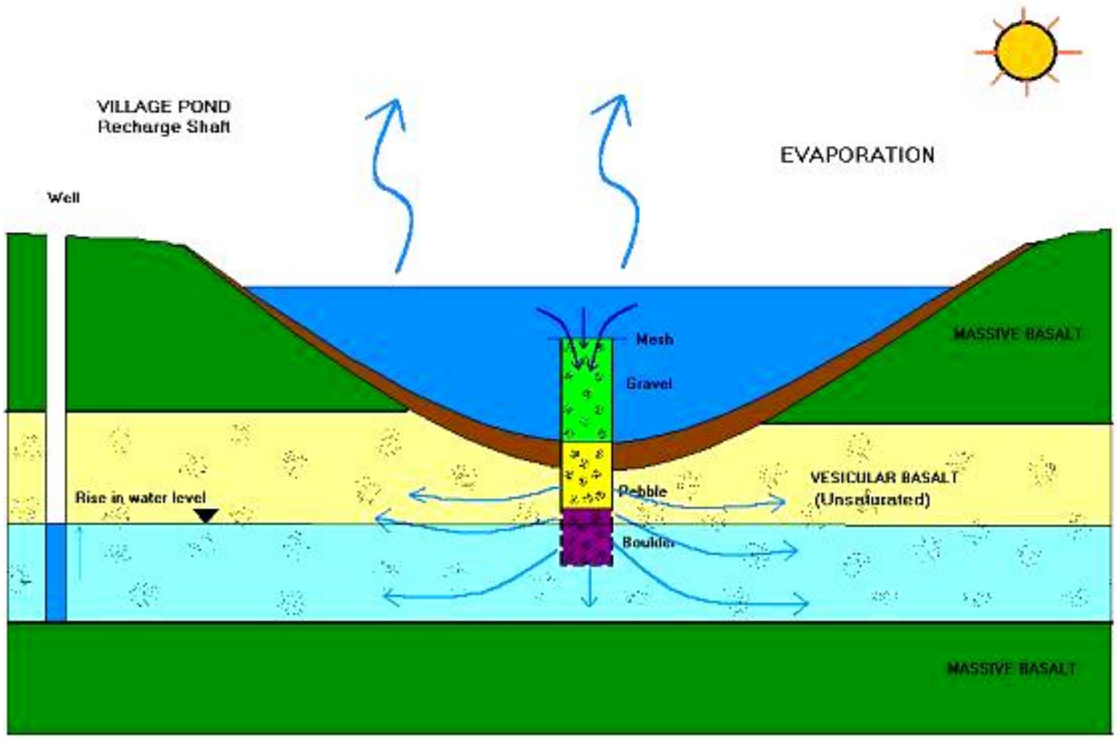
vi) These recharge structures are very useful for village ponds where shallow clay layer impedes the infiltration of water to the aquifer.

vii) It is seen that in rainy season village tanks are fully filled up but water from these tanks does not percolate down due to siltation and tubewell and dugwells located nearby remains dried up. The water from village tanks get evaporated and is not available for the beneficial use.

viii) By constructing recharge shaft in tanks, surplus water can be recharged to ground water. Recharge shafts of 0.5 to 3 m. diameter and 10 to 15 m. deep are constructed depending upon availability of quantum of water. The top of shaft is kept above the tank bed level preferably at half of full supply level. These are back filled with boulders, gravels and coarse sand.

ix) In upper portion of 1 or 2 m depth, the brick masonry work is carried out for the stability of the structure.

x) Through this technique all the accumulated water in village tank above 50% full supply level would be recharged to ground water. Sufficient water will continue to remain in tank for domestic use after recharge.



(Source: Rain water Harvesting Techniques to Augment Ground Water, CGWB, MoWR, GoI, Faridabad, 2003)

Fig. 68: Ground Water Recharge through Shaft

8.4.6 Ground Water Recharge through Dugwells

Artificial Recharge of Ground Water is one of the most efficient Ground Water Management tools for controlling decline in Ground Water levels, resource augmentation and increased sustainability of wells besides mitigation of Ground Water quality problems.

In this method Ground water is recharged through Scheme through existing dug wells using rainfall run-off from the agricultural fields to facilitate improvement in Ground Water situation in the affected areas which in turn will improve the overall irrigated agricultural productivity and help in improving the quality of Ground Water especially in the fluoride affected areas

8.4.6.1 Features of Artificial Dugwell Recharge Structures

i) Existing and abandoned dug wells may be utilized as recharge structure after cleaning and desilting the same.

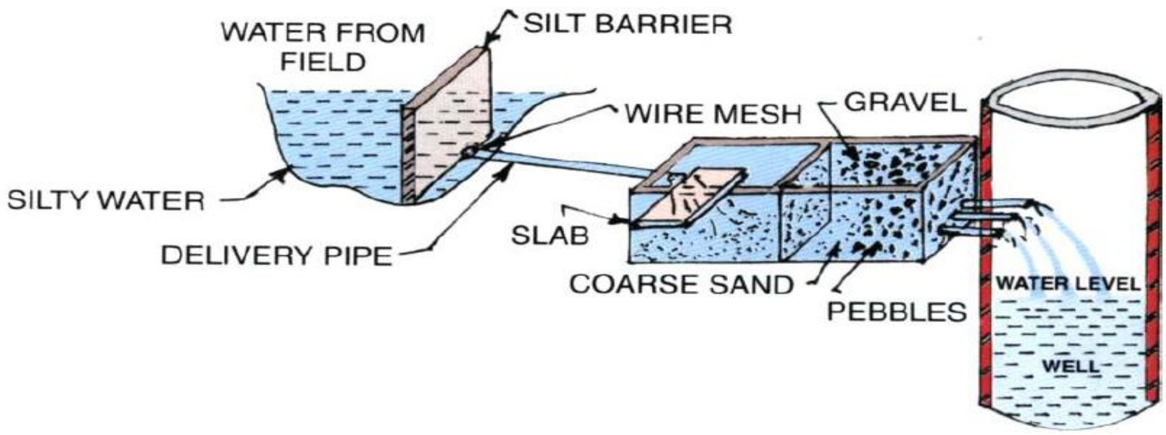
ii) The recharge water is guided through a pipe from desilting chamber to the bottom of well or below the water level to avoid scouring of bottom and entrapment of air bubbles in the aquifer.

iii) Recharge water should be silt free and for removing the silt contents, the runoff water should pass either through a desilting chamber or filter chamber.

iv) Periodic chlorination should be done for controlling the bacteriological contaminations.

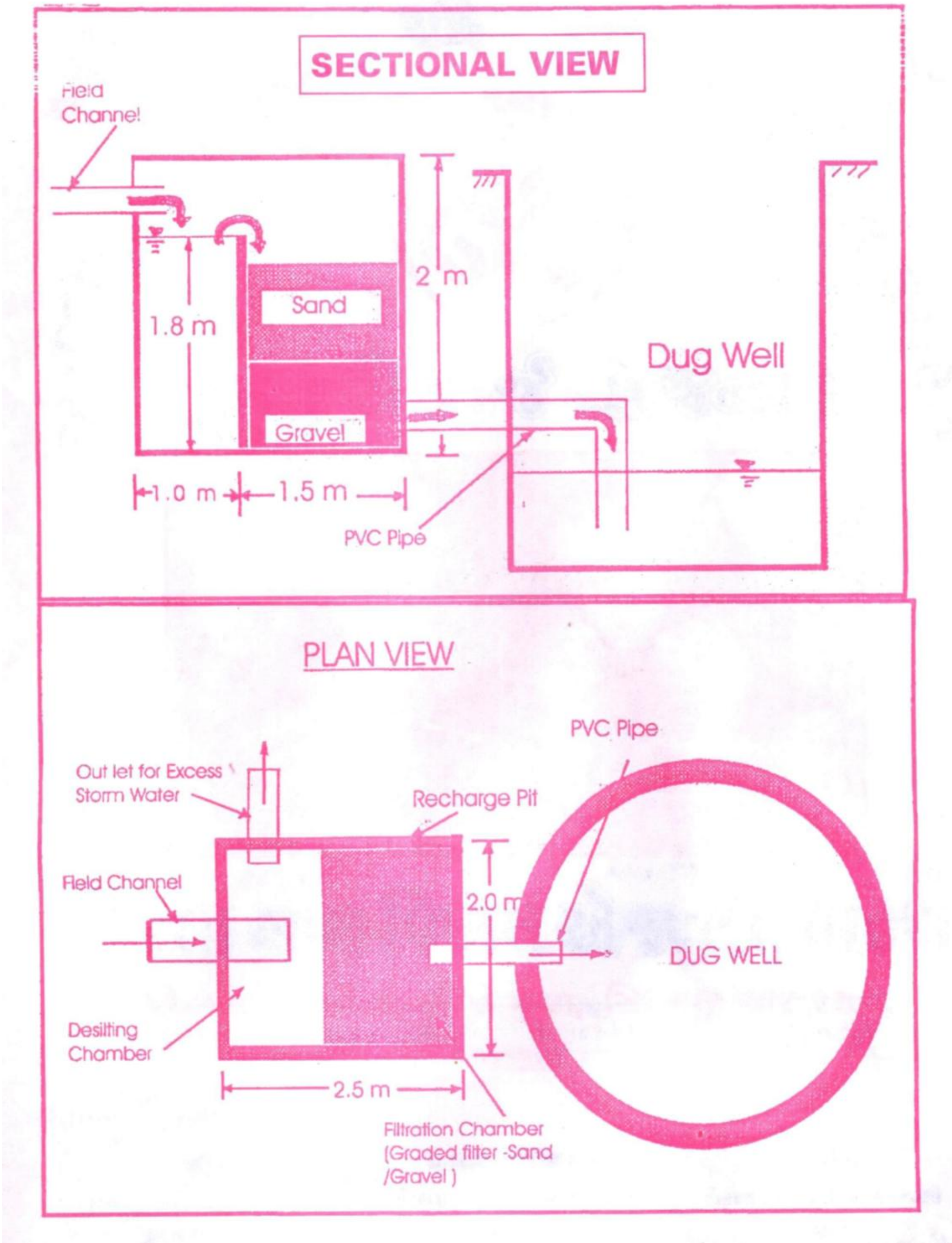
8.4.6.2 Benefits of Ground Water Recharge through Dugwells

The recharge of dugwell increases the sustainability of wells during lean period and will improve the overall irrigated agricultural productivity, drinking water availability, socio economic conditions and quality of life of the people in the affected areas. The recharge programme will also help improving the quality of ground water especially in the fluoride affected areas.



(Source: Rain water Harvesting Techniques to Augment Ground Water, CGWB, MoWR, GoI, Faridabad, 2003)

Fig. 69: Ground Water Recharge through Dugwells



(Source: Rain water Harvesting Techniques to Augment Ground Water, CGWB, MoWR, GoI, Faridabad, 2003)

Fig 70: Sketch of Dugwell Recharge Structure

7.3 Approximate cost of Ground Water Recharge Structures

The cost of each recharge structure varies from place to place. The approximate costs of the following structures are as under:-

Table 39: Approximate cost of Ground Water Recharge Structures

Sr. No.	Recharge Structure	Approximate cost (Rs)
1.	Recharge pit	2500 – 5000
2.	Recharge Trench	5000 – 10000
3.	Recharge through hand pump	1500 – 2500
4.	Recharge through dug well	5000 – 8000
5.	Recharge well	50000 – 80000
6.	Recharge shaft	60000 – 85000
7.	Lateral Shaft with Bore well Shaft per m.	Shaft per m. 2000 – 3000 Bore well 25000 - 35000

(Source: Rain Water Harvesting and Artificial Recharge to Ground Water, A Guide to Follow, CGWB, Ministry of Water Resources, and International Hydrological Programme (IHP) United Nations Educational, Scientific and Cultural Organization, September, 2000)

Chapter-9

9 Roof Top Rainwater Harvesting Structure

9.1 Introduction

This is an ideal solution of water problem where there is inadequate groundwater supply and surface sources are either lacking or insignificant. Rain water is bacteriologically pure, free from organic matter and soft in nature. Since the available roof area is usually limited, the system is used to meet water requirements during the summer months i.e. about 90 days. Such systems are usually designed to support the drinking and cooking needs of the family and comprise a roof, a storage tank and guttering to transport the water from the roof to the storage tank. In addition, a first flush system to divert the dirty water, which contains debris, collected on the roof during non-rainy periods and a filter unit to remove debris and contaminants before water enters the storage tank are also provided.

9.2 Design Considerations

i) Rooftop water harvesting systems can provide good quality potable water.

ii) Roof surfaces should be smooth, hard and dense since they are easier to clean and are less likely to be damaged and release materials/ fibers into the water.

iii) Roof painting is not advisable since most paints contain toxic substances and may peel off.

iv) No overhanging trees should be left near the roof.

v) The nesting of birds on the roof should be prevented.

vi) All gutter ends should be fitted with a wire mesh screen to keep out leaves, etc. A first-flush rainfall capacity, such as detachable down pipe section, should be installed.

vii) A hygienic soak away channel should be built at water outlets and a screened overflow pipe should be provided.

viii) The storage tank should have a tight fitting roof that excludes light, a manhole cover and a flushing pipe at the base of the tank (for standing tanks).

ix) There should be a reliable sanitary extraction device such as a gravity tap or a hand pump to avoid contamination of the water in the tank.

x) There should be no possibility of contaminated wastewater flowing into the tank especially for tanks installed at ground level).

xi) Water from other sources, unless it is reliable source, should not be emptied into the tank through pipe connections or the manhole cover.

In a typical domestic roof top rainwater harvesting system, rainwater from the roof is collected in a storage vessel or tank for use during periods of scarcity. Such systems are usually designed to support the drinking and cooking needs of the family and comprise a roof, a storage tank and guttering to transport the water from the roof to the storage tank. In addition, a first flush system to divert the dirty water, which contains debris, collected on the roof during non-rainy periods and a filter unit to remove debris and contaminants before water enters the storage tank are also provided.

9.3 Components of Roof Top Rain Water Harvesting

A typical Roof top Rainwater Harvesting System comprises following components:

- i) Roof catchment.
- ii) Drain pipes
- iii) Gutters
- iv) Down pipe
- v) First flush pipe.
- vi) Filter unit
- vii) Storage tank.
- viii) Collection sump.
- ix) Pump unit

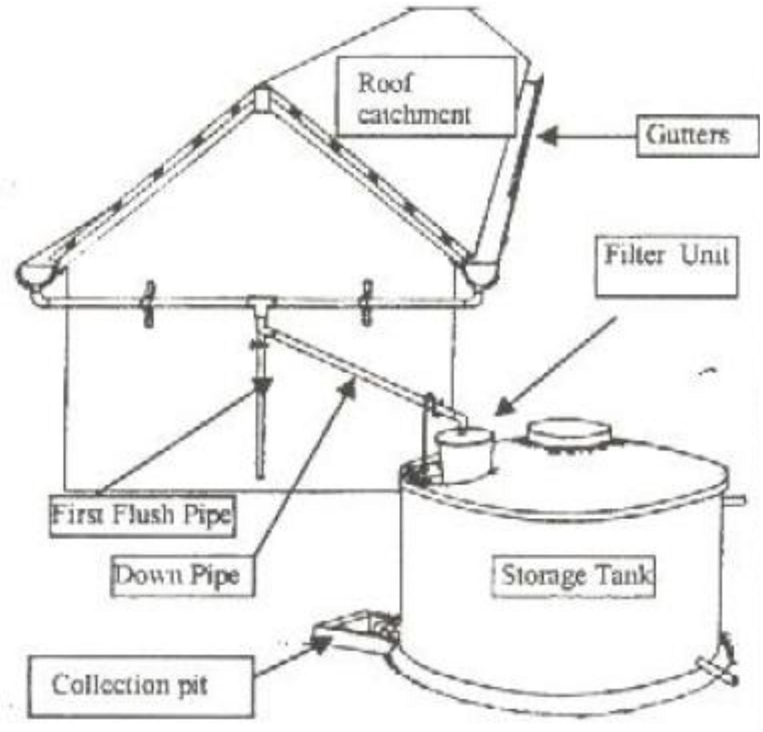
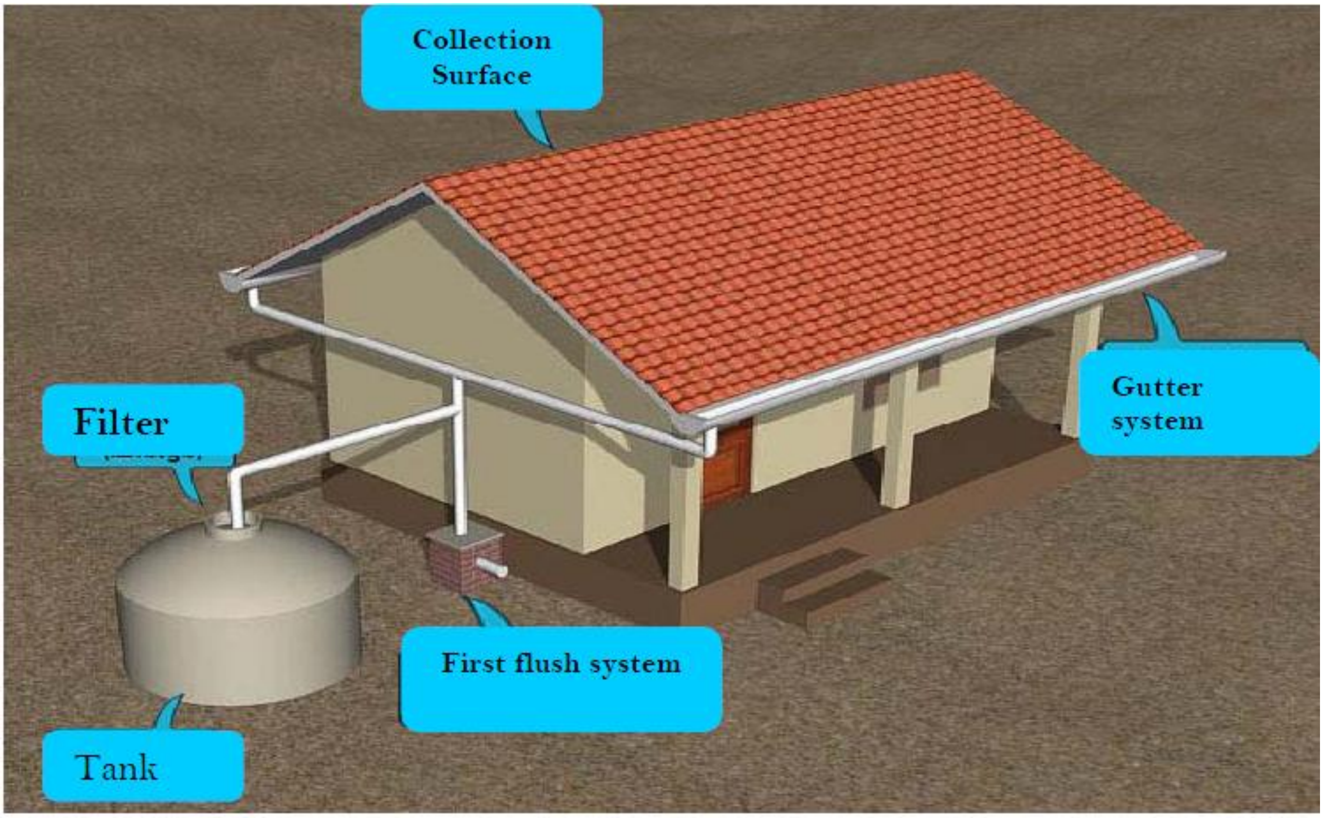


Fig 71: A Typical Rainwater Harvesting System



(Source: Rejuvenation of water bodies by adopting rain water harvesting by Samuel et all)

Fig. 72: Roof water Harvesting Structure

Among the above components, storage tank and filter unit are the most expensive and critical components. The capacity of the storage tank determines the cost of the system as well as its reliability for assured water supply whereas the filter unit assures the quality of the supplied water. Brief descriptions of each of the components are given below:

9.3.1 Roof Catchment

The roof of the house is used as the catchment for collecting the rainwater. The style, construction and material of the roof determine its suitability as a catchment. Roofs made of corrugated iron sheet, asbestos sheet, tiles or concrete can be utilized as such for harvesting rainwater. Thatched roofs, on the other hand, are not suitable as pieces of roof material may be carried by water and may also impart some colour to water.

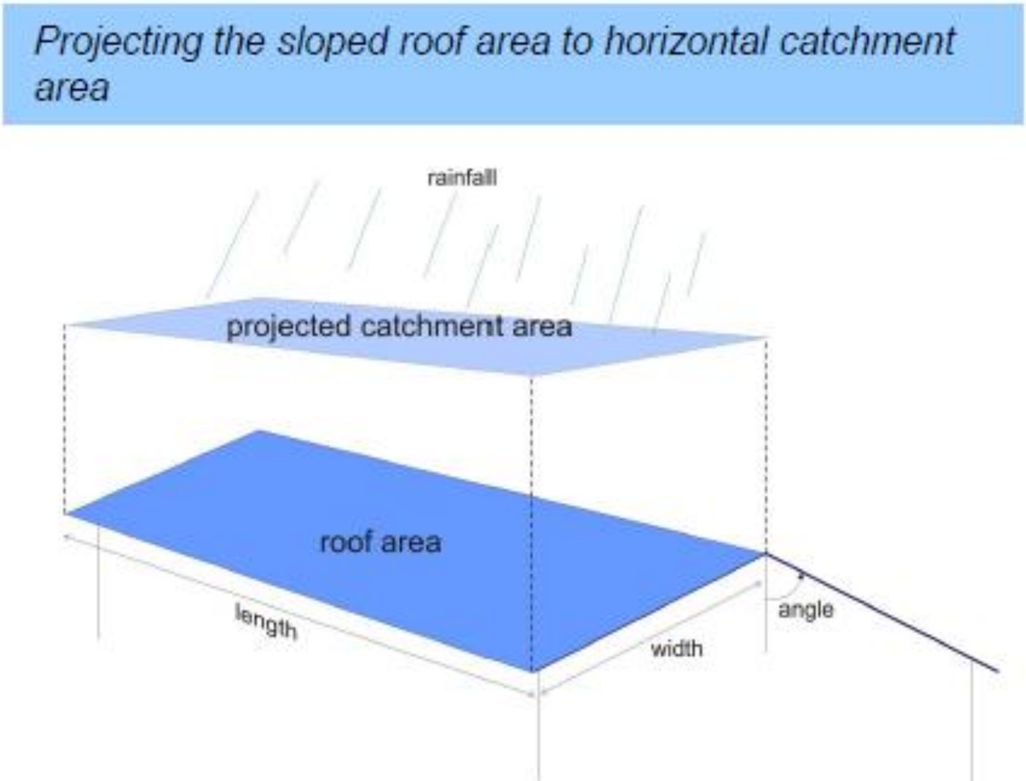


Fig. 73: Projected Roof Catchment Area

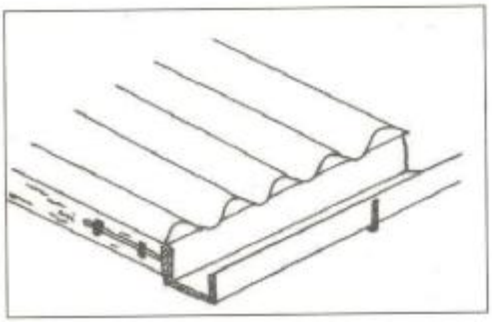
The type of roof determines the quality of water that is collected in the storage tank. Among the commonly seen roof types in rural areas, concrete, tiled, asbestos sheet and galvanized iron sheet are most suitable as roof catchments. The roof should be away from big trees to avoid accumulation of leaf litter and bird droppings. Thatched roofs are not suitable as roof catchments because the water collected from these roofs gets brownish colour and carries pieces of roof material. The slope and shape of the roof are also important in planning a roof top rain top rainwater harvesting system. Water flows with high velocity on steep-sloped roofs, causing overflow or wastage of water form gutters and filter. Gentle slopes in the range of 10 to 30 degrees are most suitable for smooth flow of water into the storage tank. Roofs having slope more than 30 degrees are to be avoided wherever possible. The size of roof is another important factor which determines the amount of water available for storage in the RRHS. Generally, a roof area of 15-20 square meters is required for collecting sufficient water required for a household. Roof catchments of lesser sizes could become a limiting factor in designing RRHS to the required capacity.

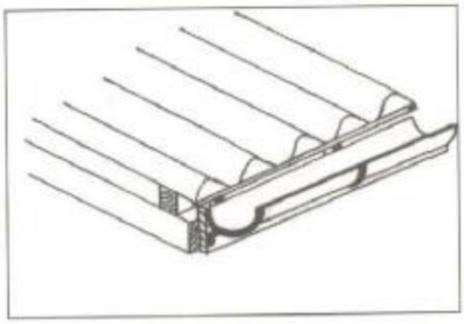
9.3.2 Drain Pipes

The drain pipes of suitable size, made of PVC / Stoneware are provided in RCC buildings to drain off the roof top water to the storm drains. They are provided as per the building code requirements.

9.3.3 Gutters

Gutters are channels fixed to the edges of roof all around to collect and transport the rainwater from the roof to the storage tank. Gutters can be prepared in rectangular shapes and semi-circular





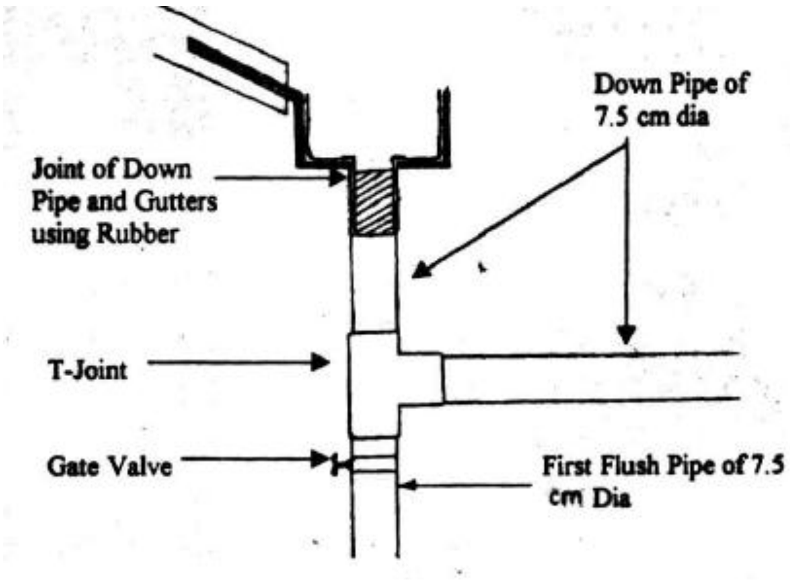
(Source: Manual on Artificial Recharge to Groundwater, CGWB, MoWR, Government of India,2003)

Fig. 74 (a) Rectangular Gutter and (b) Semi-circular Gutter

Gutters are channels made of either plain Galvanized Iron sheets or cut PVC pipes or split Bamboo. These channels are fixed to the roof ends to divert the rainwater into the storage tank. Semi-circular or rectangular shaped channels can be made using GI sheet. Cut PVC pipes and Bamboos will be semi-circular in shape. These channels are made at the site of construction and fixed to the roof by using mild steel supports. As the preparation of gutters from GI sheet involves cutting and bending the sheet to the required size and shape, certain amount of skill is required. Gutters from PVC pipes or bamboos are easily made. Use of locally available materials reduces the overall cost of the system.

9.3.4 Down Pipe

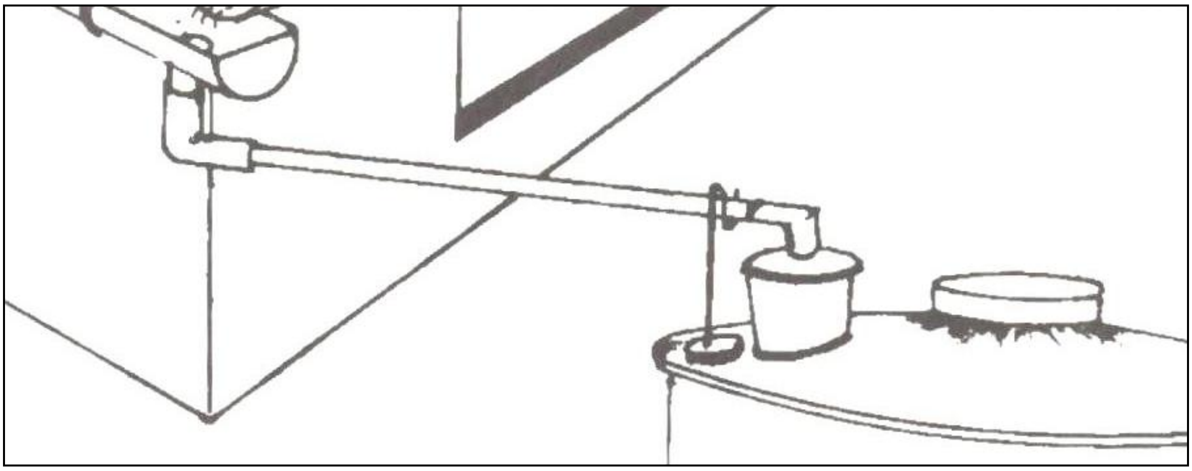
Down pipe is the pipe that carries the rainwater from the gutters to the storage tank. Down pipe is joined with the gutters at one end, whereas the other end is connected to the filter unit of the storage tank as shown below PVC or GI pipes of 50 mm to 75 mm (2 inch to 3 inch) diameter are commonly used for down pipe. In the case of RCC buildings, drain pipes themselves serve as down pipes. They have to be connected to a pipe to carry water to the storage tank. The down pipe and first flush pipe can be of either GI or PVC material of diameter 7.5 cm. Joining of pipes will be easy if both are of same material.



(Source: Manual on Artificial Recharge to Groundwater, CGWB, MoWR, Government of India,2003)

Fig. 75: Down pipe of Roof Water Harvesting Tank

The orientation and arrangement of the down pipe depends on relative locations of tank and roof. The shape of the roof and type of the roof also determine the arrangement of down pipes. The most common type of down pipe arrangement is shown in below fig.

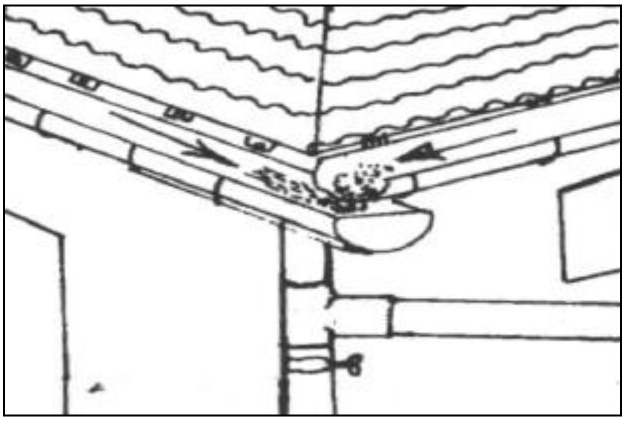


(Source: Manual on Artificial Recharge to Groundwater, CGWB, MoWR, Government of India,2003)

Fig.76: Most Common Arrangement of Down Pipe

9.3.5 First Flush Pipe

Debris, dirt and dust collect on the roofs during non-rainy periods. When the first rains arrive, these unwanted materials will be washed into the storage tank. This causes contamination of water collected in the storage tank, rendering it unfit for drinking and cooking purposes. A first flush system can be incorporated in the roof top rainwater harvesting systems to dispose off the 'first flush' water so that is does not enter the tank. There are two such simple systems. One is based on a simple, manually operated arrangement, whereby the down pipe is moved away from the tank inlet and replaced again once the first flush water has been disposed. In another semi-automatic system, a separate vertical pipe is fixed to the down pipe with a valve provided below the 'T' junction



(Source: Manual on Artificial Recharge to Groundwater, CGWB, MoWR, Government of India,2003)

Fig. 77: Flush Pipe

After the first rain is washed out through first flush pipe, the valve is closed to allow the water to enter the down pipe and reach the storage tank.

9.3.6 Filtration of Water

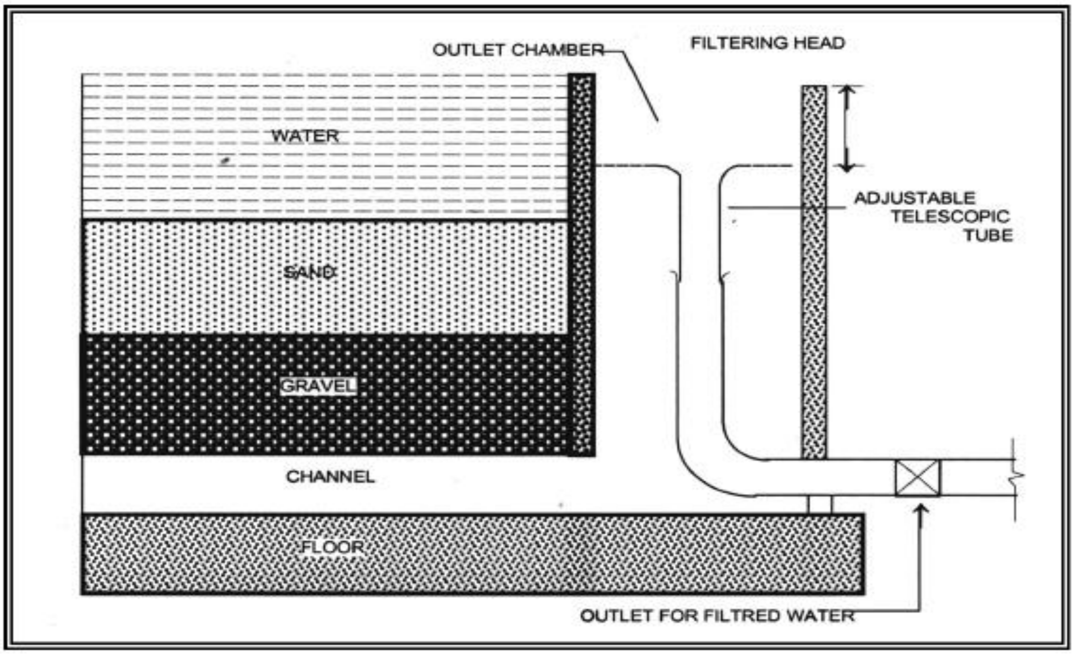
Filtration forms the most important process in the purification of water. It usually involves allowing water to pass through a filter media e.g. sand. Filtration essentially involves removal of suspended and colloidal impurities present in water. Depending on the type of filtration, the chemical characteristics of water may be altered and the bacterial content may be considerably reduced. These effects take place due to various processes such as mechanical straining, sedimentation, biological metabolism and electrolytic changes. Mechanical straining involves removal of suspended particles, which are unable to pass through the voids of the filter media. Sedimentation of particles of impurities occurs in the voids between sand grains in the filter unit. Such particles also adhere to the sand grains due to i) presence of a gelatinous film or coating developed on sand grains by previously trapped bacteria and colloidal matter and ii) physical attraction between particles. Biological metabolism in filter units involves the formation of a zoological jelly or film containing large colonies of bacteria around the sand grains, which feed on the organic impurities in the water and convert them into harmless compounds by complex biochemical reactions. Electrolytic changes involve the neutralization of ionic charges of particles of suspended and dissolved impurities when they come into contact with sand particles having opposite charge. When this happens, they neutralize each other, which ultimately results in the alteration of chemical characteristics of water.

9.3.7 Filter Sand

The sand being used for filter in roof top rainwater harvesting systems should be free from clay, loam, vegetable matter, organic impurities etc. and should also be uniform in nature and grain size. In place of sand, 'anthrafilt', made from anthracite (stonecoal) can also be used as filter medium. This material is found to possess many advantages such as low cost, high rate of infiltration and better efficiency. However, as sand is readily available almost everywhere, the usual practice is to use it as filter medium.

9.3.8 Rapid Sand Filters

Rapid sand filters (Gravity type) have been developed to achieve increased filtration rates by increasing the grain size of the filter media. These types of filters are preferred for rainwater harvesting schemes implemented over larger areas



(Source: Manual on Artificial Recharge to Groundwater, CGWB, MoWR, Government of India,2003)

Fig. 78: Cross section of a Slow Sand Filter

Screen filters or micro filters, which are readily available in the market, can also be used for filtration. Silt and other contaminants present in the roof top rainwater can be removed efficiently using these filters. The size of the filter can be decided based upon roof top area and the rainfall amount. Locally fabricated filters consisting of buckets or other containers filled with filter media such as coarse sand, charcoal, coconut fiber, pebbles and gravels may also be used to remove the debris and dirt form water that enters the tank in small scale domestic roof top rainwater harvesting systems. The container is provided with a perforated bottom to allow the passage of water. The filter unit is placed over the storage tank. Another simple way of filtering the debris and dust particles in the water is to use a fine cloth as filter media. The cloth, in 2 or 3 layers, can be tied to the top of a bucket or vessel with perforation at the bottom.

9.3.9 Storage Tank

Storage tank is used to store the water that is collected from the Roof tops. Common vessels used for small-scale water storage are plastic bowls, buckets, jerry cans, clay of ceramic jars, cement jars, old oil drums etc. For storing larger quantities of water, the system will usually require a bigger tank with sufficient strength and durability. Different types of storage tanks feasible for storing roof top rainwater are given below. Storage tanks are RCC, Masonry, Ferro, Cement and PVC There are unlimited numbers of options for the construction of these tanks with respect to the shape (cylindrical, rectangular and square), the size (capacity from 1,000 - 15,000 L. or even higher) and the material of construction (brick, stone, cement bricks, Ferro-cement, concrete and reinforced cement concrete). For domestic water needs, taking the economy and durability of tanks into consideration, ferrocement tanks of cylindrical shape in capacities ranging between 4,000 and 15,000 L are most suitable. Brick, stone or cement brick may be used for capacities ranging between 15,000 to 50,000 L. Cement concrete and reinforced cement concrete are used for tank capacities exceeding 50,000 L Storage tanks are usually constructed above ground level to facilitate easy detection of structural problems/leaks, easy maintenance and cleaning and easy withdrawal of stored water. They are provided with covers on the top to prevent contamination of water from external sources. They are also provided with pipe fixtures at appropriate places for drawing water, cleaning the tank and for disposal of excess water. They are called tap or outlet, drain pipe and over flow pipe respectively. PVC or GI pipes of diameter 20 to 25 mm are generally used for the purpose.

9.3.9.1 Size of Storage Tanks for Rural Areas

Size of the storage tank needs to be carefully selected considering various factors such as number of persons in the household, water use, and duration of water scarcity, rainfall, type and size of house roof and the status of existing water sources in the area. In general, the period of water scarcity for domestic purposes is found to be in the range of 90 days to 200 days depending upon the quantity and distribution of rainfall and water sources existing in the area. The water use of the household should first be studied, considering the local culture and habits of the people influencing the water use. Availability of water at the doorstep, as is the case with RRHS, is likely to increase the water use of the household. This results in increase in required size of storage tank and its cost. It is found that the per capita water use varies over a range of 3 litres to 10 litres per day. A per capita water consumption of 5 litres per day for the domestic drinking and cooking purposes is found optimum. Adding 20% towards additional water requirement for visitors, festivals and wastage, a per capita water requirement of 6 litres per day may be considered for selecting the size of water storage tank. The size of water storage tank may be determined using the following relation and approximating to the nearest thousand:

Size of Storage tank (in litres) = No. of persons in the household x Period of water scarcity (in days) x Per capita water requirement (in liters per day)

The capacity of storage tank, which reflects the total household water requirement during the period of water scarcity, need to be checked with the amount of water available from house rooftop during rains. If the amount of water available from roof is less than the required capacity of storage tank, then the household shall use the water available from roof only for a part of the water scarcity period.

Water available from roof is obtained from the following relation:

Water available (in litres) = Annual rainfall (in mm) x Roof area (in sq.m) x Runoff Coefficient

Area of a roof shall be measured as the area projected on a horizontal surface. For practical purpose, it is measured on the ground surface and the area calculated as the product of length and breadth. The coefficient of runoff varies depending on the type of roof and indicates the fraction of rainwater that can be collected from roof. Run-off coefficients for common types of roofs are shown in below Table

Table 40: Runoff Coefficients of Common Types of Roofs

Type of Roof	Runoff Coefficient
GI Sheet	0.9
Asbestos	0.8
Tiled	0.75
Concrete	0.7

Example: Selection of Size for Storage Tank

No. of persons in the selected household (4 adults and 4 children) = 8, period of water scarcity for the domestic needs = 120 days, per capita water requirement = 6 L/day Annual average rainfall = 1000 mm. Area of roof made of country tiles = 20 sq. m. Runoff coefficient for tiled roof = 0.75.

Solution: Size of storage tank (in litres) = No. of persons in the household x Period of water scarcity (in days) x Per capita water requirement (in lit/day)

= 8 x 120 x 6

= 5,760 L

Say 6,000 L

Check with water availability from roof top

Water available from roof top = Annual rainfall (in mm) X Area of roof (in sq.m) X Coefficient of runoff for the roof

= 1000 X 20 X 0.75 = 15000 liters

9.3.9.2 Space of Water Tank

Among all the components of roof top rainwater harvesting systems, storage tank is the component occupying most space, and hence the space required for the system depends on the size of the storage tank. For a typical 10,000 litre tank, the minimum space required is 3.0 x 3.0m. Therefore, assessment of availability of space adjacent to the house shall be done giving due importance to the preferences of the household. Storage tanks located near the roof reduce the cost of down pipes. The site should be clean, hygienic and away from cattle sheds to avoid contamination of stored water.

9.3.9.3 Collection Sump

A small pit is normally dug in the ground beneath the tap of the storage tank and constructed in brick masonry to make a chamber, so that a vessel could be conveniently placed beneath the tap for collecting water from the storage tank. A small hole is left at the bottom of the chamber, to allow the excess water to drain-out without stagnation. Size of collection pit shall be 60 cm x 60 cm x 60 cm.

9.3.9.4 Pump Unit

A hand pump or a power pump fitted to the storage sump facilitates lifting of water to the user. The size of the pump has to be decided depending upon the consumption of the stored water. In rural area, ponds, streams and wells have traditionally been used as sources of water for drinking and other domestic uses. In recent years, bore wells with hand pumps and small water supply schemes have almost replaced these traditional sources of water. Yet, in many rural habitations, these sources have not been able to supply water to the rural households round the year, due to various reasons. Domestic Roof top Rainwater Harvesting System (RRHS) provides a viable solution to bridge the gap between demand and supply of water in such areas, especially during periods of water scarcity.

9.3.9.5 Economic Viability

A typical domestic roof top rainwater harvesting system requires and investment of about Rs.12, 000/- to Rs.16, 000/-, depending on the capacity of the storage tank. This works out to Rs.2.34 to Rs.1.49 per litre of water stored. This is quite high when compared to the free water available through government-sponsored schemes, where community participation and labour are not required at the construction stage. Hence, investment to this extent is a costly option and may be unaffordable to many rural households. The cost of roof top rainwater harvesting systems could be brought down to a certain extent by using local materials such as bamboo for gutters, down pipe and first flush pipe. Contribution from users could be also be raised in terms of labour and materials to meet a part of the investment.

It is advisable to have the user household themselves meet a sizeable portion of the cost of RRHS to ensure its sustainability and reliability. This would also encourage ownership and appropriate maintenance of the system at the level of households. Extending soft loans repayable in easy instalments would be appropriate for this purpose. The existing Government schemes, which finance women self-help groups in rural areas such as the *Rashtriya Mahila Kosh* and NABARD self-help group schemes, could be utilized for extending such loan facilities to the rural households.

Design Example

A house has a sloping roof of G.I. sheet with an area of 50 sq m. The owner of the house has a family of 5 members. Design a roof water harvesting system. The 10 year rainfall for the areas is as follows:

Year	Rainfall (mm)	Year	Rainfall (mm)
Year 1	320 mm	Year 6	280 mm
Year 2	360 mm	Year 7	335 mm
Year 3	311 mm	Year 8	380 mm
Year 4	290 mm	Year 9	355 mm
Year 5	330 mm	Year 10	340 mm

The maximum rainfall intensity is 10 mm/hour. The lower edge of the roof is 3 m above the ground.

Solution

Arranging the rainfall in descending order, we get: 380, 355,340, 335, 330, 320, 311, 290, and 280. The highest rainfall of 380 mm is equalled or exceeded only once in 10 years. Therefore, it’s expected that the return period of this rainfall is 1 in 10 years, which is ‘rare’.

On the other hand, the lowest rainfall of 280 mm is equalled or exceeded in all the 10 years. Thus, this is the most reliable figure. So, the system may be designed for this rainfall.

For the roof area of 50 sq m and rainfall of 280 mm, the available water works out as

Q = Area x Rainfall Depth x Runoff coefficient

= 50 x 0.280 x 0.8 = 11.2 cu.m. i.e. 11200 lit

Allowing for a consumption of 10 lit/day/person, this water should be sufficient for 224 days or at least 7 months. As houses are of low height in rural areas, height of the tank may be limited to 1.6 m with water storage up to 1.4 m height.

Tank Diameter can be calculated as

Total water, $Q = \frac{\pi}{4} d^2 x h$

$$11.2 = \frac{3.14}{4} x d^2 x 1.4$$

d = 3.19 m

A tank of 3.2 m dia and 1.4 m height should be adequate for storing the water. However, an extra 0.2 m height may be provided to allow for fixing overflow pipe and dead storage below the outlet (tap). Thus, a tank having 3.2 m diameter and 1.6m height can be constructed for the purpose.

Size of Collector Channel (Gutter)

During heavy rains having intensity of 10 mm/hr or more, the runoff coefficient may be taken as 0.9 (assuming a net loss of 10% of rainfall).

Assuming instant generation of run-off, the maximum rate of runoff from the roof on either side from the roof area of 50 sq m is worked out as

Roof Area (m^2) x Rainfall intensity (m/sec) x Runoff coefficient

$$= 50 \text{ x } \frac{10}{(1000 \text{ x } 60 \text{ x } 60)} x 0.9 = 1.25 x 10^{-4} = 0.125 lps$$

Assuming the slope of the collector channel as 5 cm for 1 m, i.e. 1 in 200

Trial -1: Providing a collector channel of 0.1 m diameter with half circular

Cross sectional area of the channel (A) = $(\frac{\pi}{4} d^2)/2$ = 0.003925 sq m

Perimeter (P) = 0.157m

Hydraulic Mean depth (R) = 0.003925/ 0.157

= 0.25m

For slope of 1 in 200 for the collector channel,

Velocity of flow (V) = 0.24 m/sec

Discharge (Q) = AX V

= 0.003925 x 0.24

= 0.000942 cum/sec

As the design discharge is only 0.000125 cum/sec, the channel is oversized and hence, it is not acceptable.

Trial-II: Considering a channel of 0.05 m diameter

Area (A) = 0.00098 sq m

Perimeter (P) = 0.0785 m

Hydraulic Mean Depth, R = 0.00098/ 0.0785= 0.0125m

Velocity (V) = 0.152 m/sec

Discharge (Q) = A x V

= 0.00098 x 0.152= 0.000148 cum/sec.

As this corresponds well with the designed discharge, this channel diameter is acceptable. The channel may be made of plain Galvanized Iron (G.I) sheet. Width of the G.I. sheet required for channel is the perimeter of the channel

P = 0.0785 m = 78.5mm

Providing 25 mm extra for fixing with rafters / purlins,

Total width required = 78.5 + 25 = 103.5 mm, Say 104 mm

Tips for Maintenance of the RRHS

i) Always keep the surroundings of the tank clean and hygienic

ii) Remove algae from the roof tiles and asbestos sheets before the monsoon

iii) Drain the tank completely and clean the inside of the tank thoroughly before the monsoon

iv) Clean the water channels (gutters) often during rainy season and definitely before the first monsoon rain

v) Avoid first 15 or 20 minutes of rainfall depending on the intensity of rain. Use the first flush arrangement to drain off this first rainwater.

vi) Change the filter media every rainy season

vii) Cover all inlet and outlet pipes with closely knit nylon net or fine cloth or cap during non-rainy season to avoid entry of insects, worms and mosquitoes

viii) Withdrawal water from the system at the rate of 5 litres/head/day. This will ensure availability of water throughout the water scarcity period.

ix) Leakage or cracks in the storage tank should be immediately attended to. This will obviate the need for major repairs caused by propagation of cracks.

x) Heavy loads should not be applied on the lid.

xi) Water should not be allowed to stagnate in the collection pit

xii) The tap should have lock system to prevent pilferage or wastage of water

xiii) The filter material should be washed thoroughly before replacing in the filter bucket

xiv) In coastal areas, the outer side of the tank may be painted with corrosion-resistant paint at least once in 3 years and in other areas lime (Calcium Carbonate) based whitewash may be applied regularly.

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