A SOURCE BOOK FOR SOIL & WATER CONSERVATION MEASURES

June 2008

FOUNDATION FOR ECOLOGICAL SECURITY

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for

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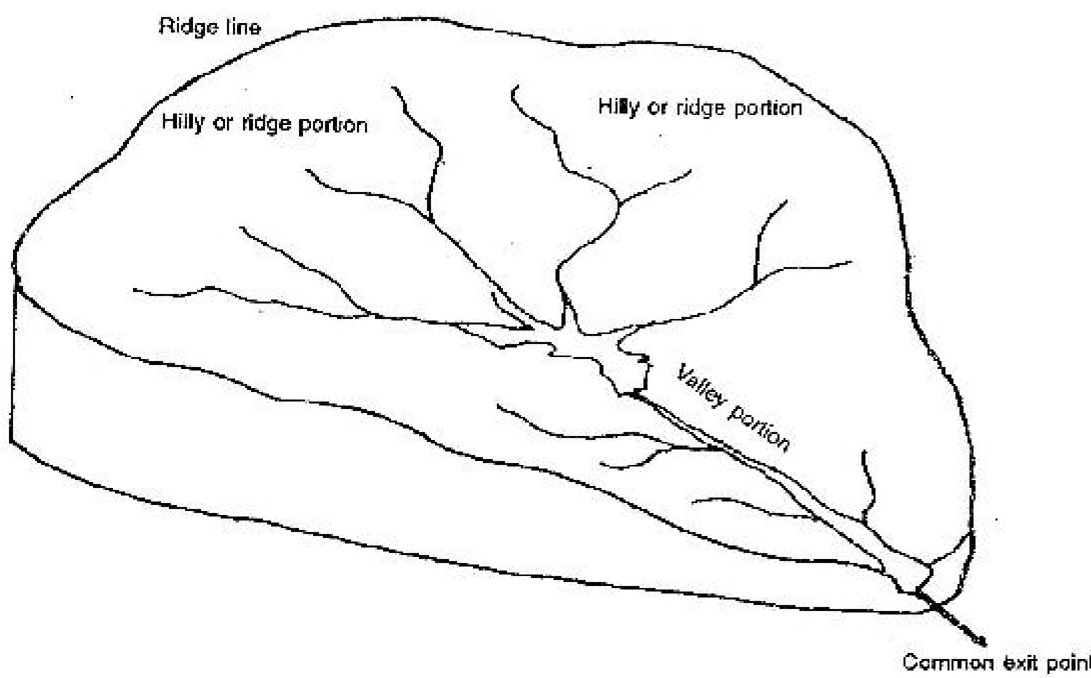
Index

Chapter I: Concept of Watershed

Watershed: The topography of any region may be subdivided into several ecological units, each of which drains to a common point. Each such ecological unit is referred to as watershed. Strictly speaking, the higher land that separates each such unit is called a watershed, and the unit itself being termed as the catchment area. However, it has become fairly common now to speak of catchment area and watershed in identical terms. The size of a watershed may vary from a few hectares to thousands of square kilometers. Table (following the diagram) provides a system of classifying watersheds at different levels of aggregation.



As may be seen from the Table, the total land area of India is divisible into 6 regions, consisting of 35 river basins, and further subdivided into 112 catchments, 500 sub-catchments and 3,237 watersheds. Each watershed can be further divided into sub-watersheds (10,000 to 50,000 ha.), milli-watersheds (1,000 to 10,000 ha.) and micro watersheds (up to 1,000 ha.). We, thus, have a progressive series of ecological units, each of them being a watershed at a particular level of aggregation (with a corresponding scale in mapping terms). While planning exercises need to be conducted at each level, the actual execution is usually done within the micro-watershed.

System of Classification of Watershed in India

Category	Number	Size Ranges (‘000 ha)
Regions	6	25000-100000
Basin	35	3000-25000
Catchments	112	1000-3000
Sub-Catchments	500	200-1000
Watersheds	3237	50-200
Sub-Watershed	12000	10-50
Milli-Watershed	72000	1-10
Micro- watershed	400000	0.5-1

Watershed management: is the rational utilization of land and water resources for gaining optimum production and with minimum hazards to natural resources. It essentially relates to the practice of soil and water conservation in the watershed, which means proper land use, protecting land against all forms of deterioration, building and maintaining soil fertility, conserving water for farm use, proper management of local water for drainage, flood protection and sediment reduction and increasing productivity from all prevailing land uses.

Causes of watershed deterioration:

Watershed deterioration takes place due to the uncontrolled, unplanned, and unscientific land use, and added to by the human interventions. These activities could be involving:

1. **Agricultural land:** Cultivation on sloping land without adequate precautions; cultivation along naala; cultivation of erosion permitting crops; over cropping areas without replenishing soil fertility.
2. **Forestland:** Clear felling on steep slopes; drastic thinning of plants along slopes; faulty logging roads and disturbance of forest floors during removal of the felled trees.
3. **Grasslands:** Excessive grazing resulting in disappearance of protective cover development of cattle tracts into channels; compaction of soil resulting in lower infiltration rates etc.
4. **Fire:** Intentional or accidental fire resulting in loss of vegetation, organic matter, and microorganisms.

5. **Shifting cultivation:** Destroying protective and productive vegetation in preference for a very brief period of immediate crop production and eventually resulting in soil loss.
6. **Unscientific Mining and Quarrying:** This practice results in exposure and digging up of slopes, which causes considerable damage to the landscape by destroying vegetation.
7. **Bad road alignment and construction:** These contribute largely coarse sediment to the drainage channels causing blockage of flow.
8. **Non-cooperation of the people:** this is the most important factor.

Consequences of watershed deterioration:

- Low productivity of land with respect to food, fuel, forge, fiber and fruits.
- Erosion and denudation within and adjoin watershed.
- Quick siltation of reservoir, lakes etc.
- Deterioration of water quality due to heavy sedimentation.
- Increased incidence of floods and droughts
- Poor health of people and cattle.

Principal factors influencing watershed operation:

I] Physiography: It includes the following aspects

(i) **Size:** Both runoff volume and runoff rate increases with the watershed size. However, both the rate and the volume per unit of watershed decrease with an increase in its area. The size of watershed is thus an important parameter in determining the peak rate of runoff.

(ii) **Shape:** Elongated and narrow watershed are likely to have longer time of concentration resulting in the lower runoff rates as compared to the square shaped watersheds of the same size. The time of concentration also affects the amount of water that will eventually infiltrate into the soil in the watershed.

(iii) **Land slope:** Slope also has a major implication for the land use. The speed and extent of runoff depends on slope of the land. The greater the slope, the greater the velocity of flow of the runoff water. Land slope cannot be directly changed but it can be modified by us through terraces and contour bunding.

The land slope in percent can be determined from a topographic map by the following formula:

S = (MN/A) X 100

Where: M = Total length of all contours within a watershed (m)

N = Contour interval (m)

A = Area of watershed (m^2)

(iv) **Drainage density and pattern:** The drainage density also affects the runoff pattern and intensity. High drainage density drains runoff water rapidly, decreases the lag time and also increases the peak of hydrograph.

Drainage density = total length of all stream (km)/catchments area (km^2)

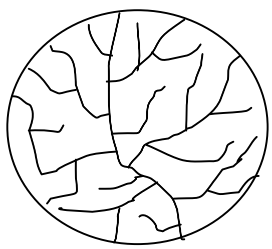


Fig.(a)

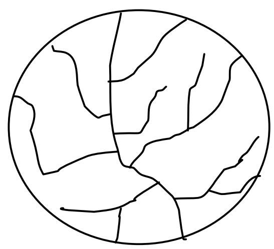


Fig.(b)

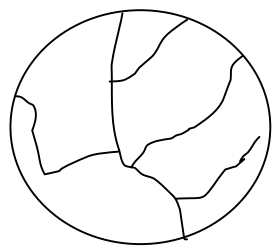


Fig.(c)

Fine drainage texture (fig. a) indicates that the rock formations are impervious and the permeability is low. Soil formed in such area is deep, heavy and with low degree of permeability.

Medium drainage texture (fig. b) is observed in rock formation characterized by fractures and joints. The soil is moderately deep, medium in texture and moderately permeable.

Coarse drainage system (fig. c) is observed where the soils are generally shallow, pervious and coarse in texture.

II] Soils and Geology: The soil and the geology of the watershed determines the amount of percolating water, and also governed by the corrective measures, which may be taken for improvement.

III] Vegetative cover: The type and quality of vegetative cover on watershed land has a substantial influence on runoff, infiltration rate, erosion and sediment production and also on the rate of evaporation. A dense cover of vegetation is a most powerful tool for reducing erosion.

IV] Peak runoff: It is the main design parameter for designing the soil and water conservation measures. It is described in a separate chapter.

V] Precipitation: The amount and nature of precipitation is the most important factor, which determines what will happen in a watershed. Rainfall evenly distributed throughout the year has a different impact as compared to sudden, sharp showers or seasonal rainfall.

Hydrological Cycle: All moisture results from the earth's unending moisture cycle, which has no beginning or end. Moisture is constantly rotating from the ocean to the sky, to the land, to the ocean. Water from the ocean evaporates into the atmosphere. This moisture in turn is lifted and is eventually condensed and falls back to the earth's surface as precipitation. About 200,000 cubic kilometers of water evaporates each year from the oceans. About 40,000 cubic kilometer is evaporated from the lakes and land surfaces of the continents. The total evaporation, however, is balanced by the total precipitation of which about 60,000 cubic kilometers falls on the earth's surface.

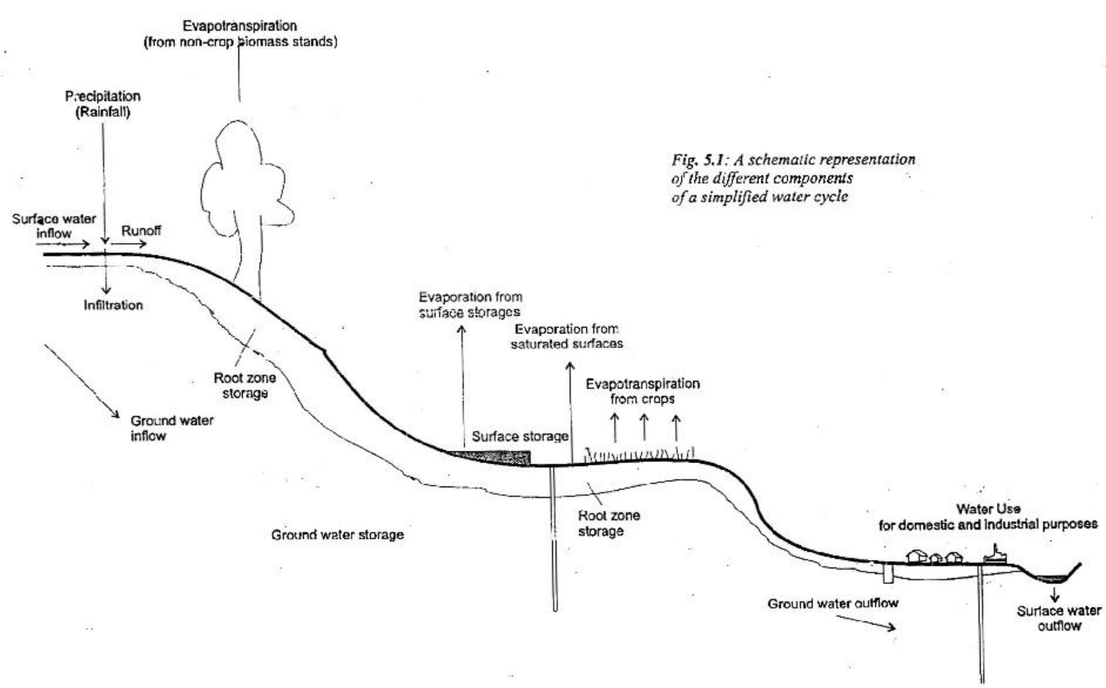


Fig. 5.1: A schematic representation of the different components of a simplified water cycle

Water Balance Identity: The natural resource base of a watershed may broadly be said to comprise land and water supporting a certain level of biomass. Biomass (from the Greek *bios*, meaning life) includes all plant life such as grasses, shrubs, trees, crops etc., their residues and human/ animal waste found in the watershed. The land and water components of a watershed together support a chain of organisms through which the nutrient and energy is transferred, this is referred to as the food chain. Each link in the food chain feeds on and obtains energy from the preceding one, and in turn, becomes the resource for the one following it. Organisms in the chain belong to different tropic (from the Greek *trophikos*, meaning pertaining to food) or energy levels, depending on whether they are producers, consumers or decomposers. Green plants are primary producers synthesizing water, carbon dioxide and solar energy into organic compounds. All other forms of life occupy the secondary producer or the consumer levels. The decomposers are bacteria, fungi and some protozoa (they may also be regarded as consumers that operate in decomposition at all levels).

The ultimate aim of any watershed project is to raise the biomass output of the agro-ecological system. Biomass is the cheapest and the most efficient technology to harvest solar energy known to man. Moreover, as biomass is a dispersed resource, its production can be managed without any centralized production and distribution patterns. The capability of an agro-ecological system to produce biomass is however constrained substantially by the soil moisture availability as necessary for the plant growth.

Rain, which falls on the soil medium, infiltrates into its pore spaces aided by its three dimensional structure, and is held as the stored soil moisture (ST). Soils of different texture have varying rates of infiltration and water holding capacity. Water in excess of the absorptive capacity of the soil goes out of the system as surface and sub-surface runoff (RO). Part of the rain percolates into the groundwater system (GW), which further complement the artificial replenishment of soil moisture through irrigation. Some moisture held in the soil profile is directly lost into the atmosphere as evaporation (E). Plants pick up a portion of soil moisture for their consumptive use and ultimately lose its major part to the atmosphere through evapotranspiration. The combined operation of evapo-transpiration (ET) has, thus, a drying effect on the soil profile. The water balance identity can be written as,

P = ST+GW+ET+RO,

where P is the total quantum of precipitation (rainfall).

Aim of Watershed Development:

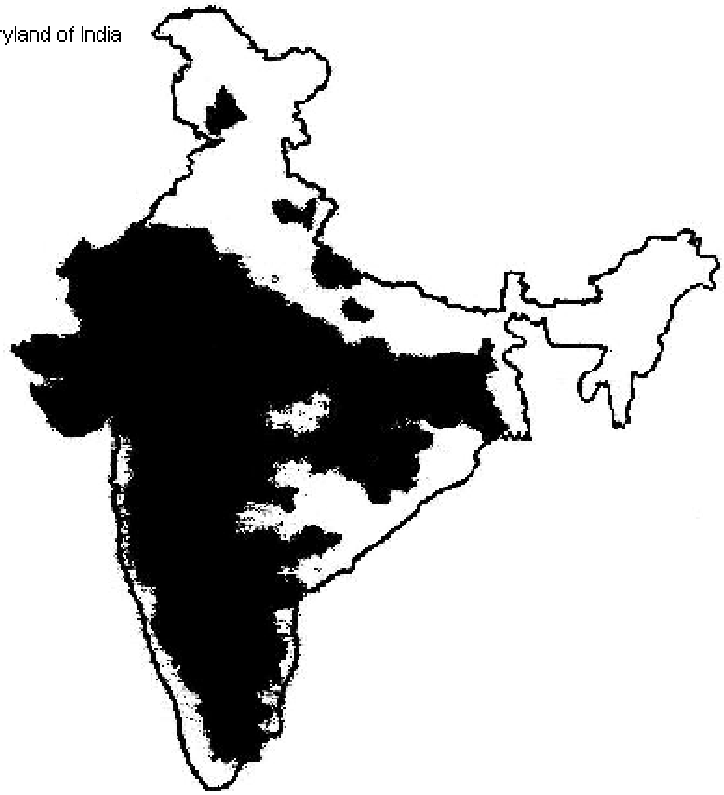
The aim of watershed development can be summarized as

- Conservation of soil moisture by reducing each of the losses (RO, E and GW) from the soil storage system; and
- To make available the moisture thus conserved to plants to maximize biomass production.

There is, of course, a significant difference in the status of RO and E, on the one hand, and GW, on the other, GW can be made available to plants through irrigation at a later date ('deferred loss'), but RO and E are irretrievable and absolute losses. Thus, either way, the variable to be maximized is the biomass productivity of the agro-ecological system (written as kg/ha-mm).

Distribution of Dry Districts and Area In States, 1989-90

State	*Area (%)*	*Districts (%)*
Andhra Pradesh	10	7
Arunachal Pradesh	0	0
Assam	0	0
Bihar	4	6
Goa	0	0
Gujarat	10	8
Haryana	0	1
Himachal Pradesh	0	0
Jammu and Kashmir	0	1
Karnataka	10	10
Kerala	0	0
Madhya Pradesh	19	23
Maharashtra	14	13
Manipur	0	0
Meghalaya	0	0
Mizoram	0	0
Nagaland	0	0
Orissa	3	2
Punjab	0	0
Rajasthan	18	14
Sikkim	0	0
Tamil Nadu	5	7
Tripura	0	0
Union Territories	0	0
Uttar Pradesh	4	7
West Bengal	2	2
Total	100	100



In our considered view, the traditional approach to watershed development has not paid adequate attention to the demand side. Irrespective of the amount of water we may harvest, unless we are able to ensure its sustainable and equitable use through active people's participation, the benefits of the programme would be nullified by a powerful minority. They may, moreover, utilise the water in a manner, which leads to its rapid exhaustion. This is particularly true of groundwater. In most watershed programmes these critical issues have not been addressed. Either an ostrich-like blind eye is turned to the overexploitation of groundwater, which is a widespread phenomenon in the country today, or no attempt is made to integrate sustainable groundwater use in the watershed programmes. Study of various watershed experiences in the field shows that many of them have performed below par because they have failed to effectively integrate soil moisture strategies with the sustainable and equitable exploitation of groundwater. It is only through above we can ensure that GW is neither allowed to lie underutilised nor is it subject to indiscrimate and unsustainable overexploitation.

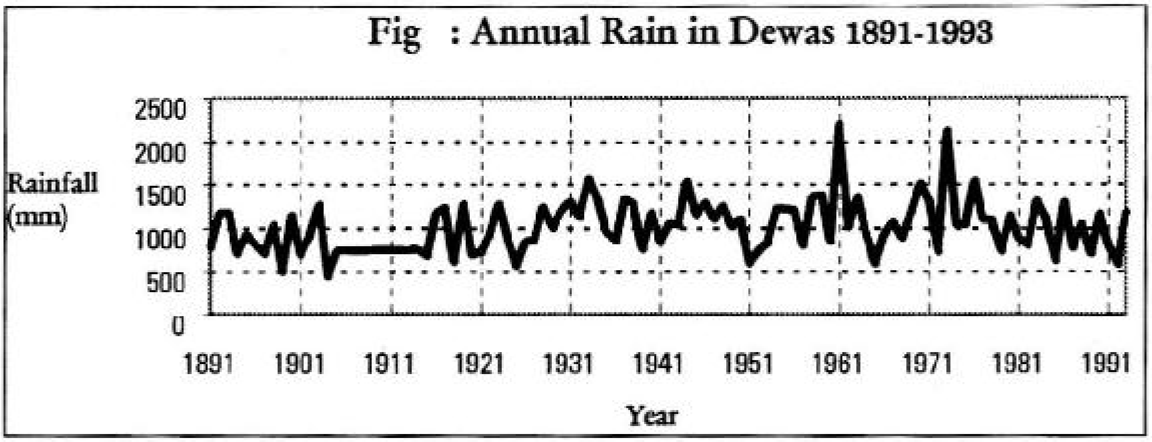
Net area Irrigated by Source, All –India, 1950-92 (%)						
Year	Canals	Tanks	Wells	Tube wells	Other	Total
1950-1	40	17	29	0	14	100
1960-1	42	19	29	0	10	100
1970-1	41	13	24	14	8	100
1980-1	39	8	21	25	7	100
1990-1	35	7	21	30	7	100

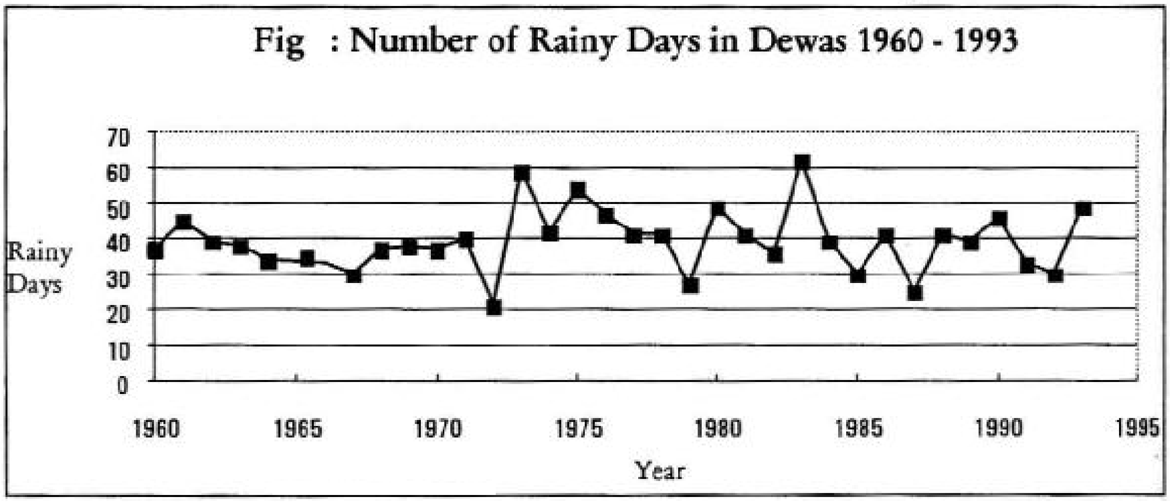
Water Resources in India:

The significance of stored soil moisture (ST) can be understood by casting a quick glance at the distribution of water resources in our country. It has been estimated that of the 400 million ha.m (mham) of water resources in India, 41% (165 mham) is in the form of soil moisture, while surface water and groundwater are only 29% and 13% respectively. Thus, the fundamental challenge of watershed development, especially in the drylands of India, is the efficient utilisation of soil moisture.

The Pattern of Rainfall:

Some people argue that the current water crisis facing the nation is a result of a decline in the quantum of rainfall in recent years. However, our analysis of rainfall data over the last 100 years shows that there has been no such decline. What can be observed are short and long term cycles, but no established linear trend in either direction. What has really happened is that with the growing demand for water there has been no change in our attitude or approach towards the use of water. This approach must be guided by the principle of balance - whatever we draw from mother earth; we must return it back to her. We must also observe a strict hierarchy in prioritizing the water usage, and should use: “the needs of the neediest first, sufficiency for all before superfluity for some” as the guiding principle.





The problem is actually not of the quantum but that of the variations in the intensity of rainfall in India. Typically in our country, rain falls very intensely within a few hours, within a few days, within a few months of every year. The number of rainy days does not average more than 40-50 days in most parts of the country. The real challenge is to find ways of using this water as and where it falls. For years, our planners have allowed the rain, which falls in every village of our country to flow out into the rivers as the runoff and then worked to bring this water back to the villages by building large and expensive dams and canal networks. The aim of watershed development is to precisely reverse this process. The aim is to store and conserve water where it falls, within every village, under the direction of the especially constituted village watershed committees.

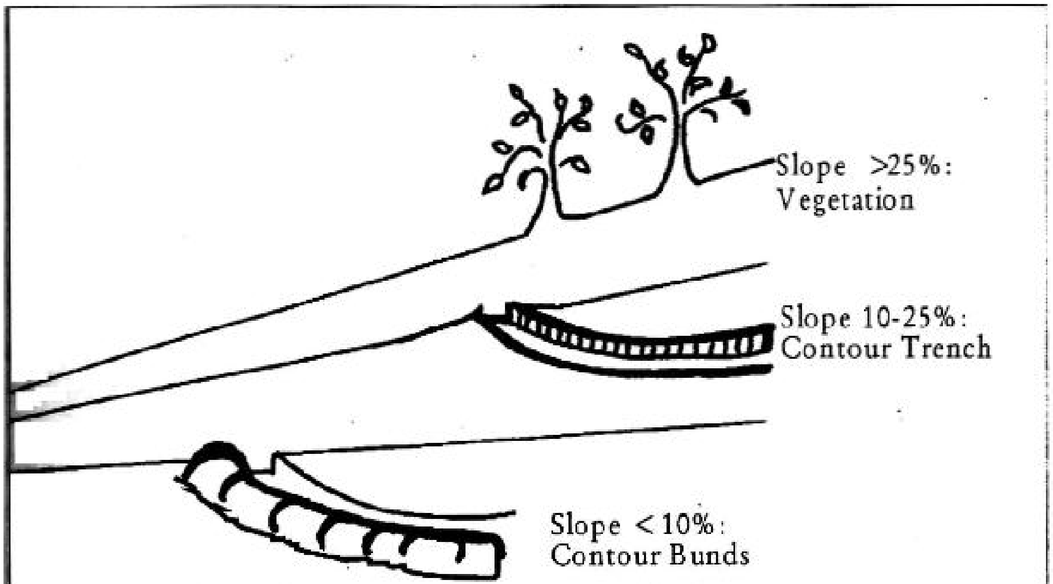
Watershed development tries to reduce the volume and the velocity of runoff through a series of interventions. The aim is to lower the water velocity, to make the water flow vertically downwards rather than horizontally across the village.

Interventions are made at different points in the village in a location-specific manner utilizing locally available materials and the vast knowledge of the local people regarding water flows and resource availability. Interventions are generally planned according to the ridge-to-valley principle. A usual mistake is to begin by constructing a water harvesting structure in the lowest part of the watershed without treating the upper part of the catchment. This results in rapid silting up of the storage capacity created because of the soil erosion-taking place in the upper part of the catchment. Thus, ideally we must begin with the treatment of the ridge area followed by the smallest drain, moving on to larger and larger drains in the watershed, arresting the runoff at each point.

The reduction in the volume and velocity of runoff confers the following benefits:

- Reduction in soil erosion;
- Trapping of silt which reduces the rate of siltation in water harvesting structures in the lower reaches of the watershed;
- Increasing the soil moisture profile locally, which provides a greater support to vegetation;
- Creating a hydraulic head locally which enhances infiltration of surface runoff into the groundwater system; and
- Increasing the duration of flow in the drainage line. Thus, the capacity of the water harvesting structures created downstream on the drainage line is utilized more fully as they get many more refills.

Interventions in the Ridge Area:



Measures for ridge area treatment vary with slope

Soil and water conservation measures undertaken in the ridge area will help recharge deeper aquifers in the discharge zone as well as regenerate the degraded forest cover.

- On slopes greater than 25%,
- Intensive plantation of grasses and shrubs
- Where boulders are available, contour bunding with boulders
- On slopes greater than 10% and less than 25%, contour trenching
- On slopes less than 10%, earth contour bunding
- Plantation of trees on barren patches and where the crown cover is less than 40%
- Encouraging natural regeneration by grazing control, stump dressing of freely coppicing varieties, micro-water harvesting structures and weeding around saplings, treating bamboo clumps by shoring them up with mud

Interventions in the Drainage Line

- Where the local bed slopes are above 20% and where thinning operation yields adequate raw material: **brushwood checks**
- Where local bed slopes are between 5-20%
  - If boulders are freely available **dry boulder checks**
  - If boulders are not freely available **boulder cum earth checks**
- Where local bed slopes are less than 5%
  - **Naala bunds,** which serve as percolation reservoirs in the upper catchment.These are to be located on pervious strata to improve vertical percolation
  - **Sand-filled bag structures** in order to check the velocity of stream flow and where sand is locally available
  - **Gabian structures** where velocity and volume of peak run-off is too high for loose boulder structures
- Where the stream embankments have been severely eroded
  - **Naala training,** including deepening of channels and raising embankments, along sections of streams; especially where during peak floods, the stream flows over its embankments and damages the fields alongside
  - **Embankment stabilisation through gabians or sand-filled bag structures** in stretches where the banks are particularly vulnerable and need reinforcement
- Where groundwater harvesting wells are located alongside
  - **Underground dykes** in the discharge zone where the impermeable strata are overlain by thin layer of permeable deposits

On-Farm Interventions

- **System of bunds and diversion channels** for a stretch of fields from local ridge to drain. While in permeable soils the bunds help increase soil-moisture profile, in waterlogged soils they act as drains to transport excess moisture out of the fields.

- **Seepage drains** on waterlogged fields which help vertical drainage of excess soil moisture into permeable strata underlying the top soil, simultaneously increasing groundwater recharge
- **Location-specific Grassland development** for ensuring adequate fodder supply Plantation of horticultural species around wells and along bunds

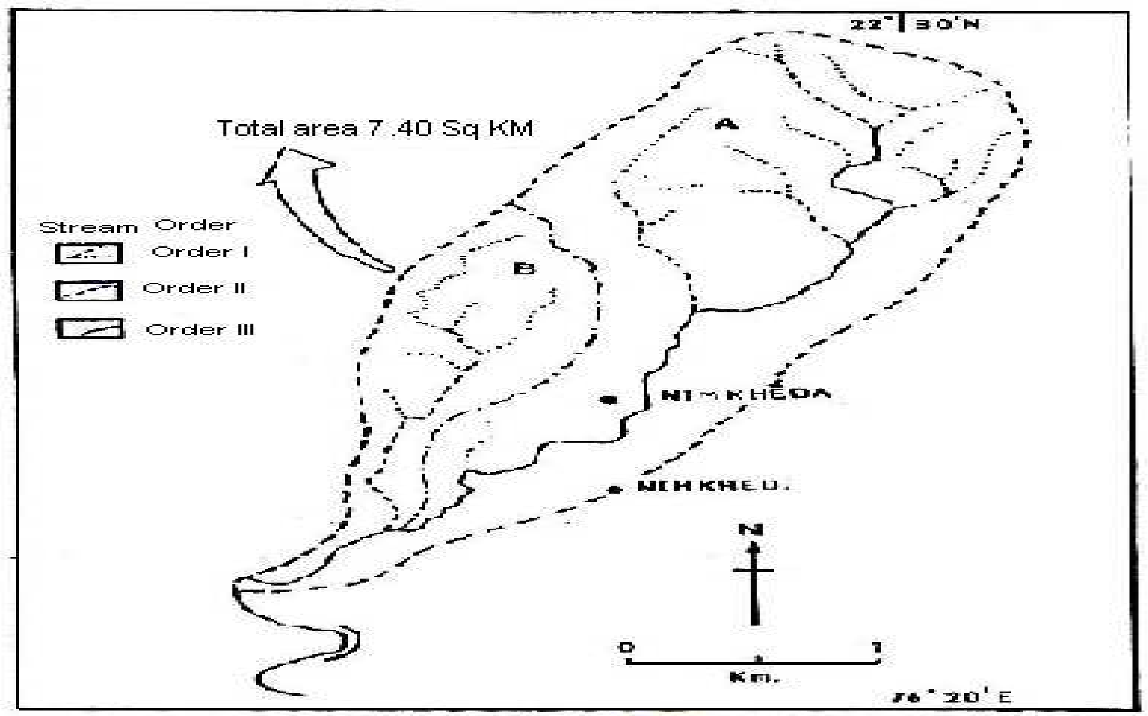
Water Harvesting Structures

- **Deepening and repair of traditional water harvesting structures.**
- **Farm ponds** to harvest runoff
- **Earthen water harvesting structures**
- **Cement masonry water harvesting structures**

Drainage Systems: Gully, Naali, Naala, and Nadi

As it is obvious from the definition of a watershed given above, watersheds can be defined at various levels, each level being contained within each successive higher level. The water flowing through a number of gullies joins up to make a naali, many naalis combine to make a naala, naalas flow into a nadi and so on. Since different watershed interventions take place in different size drainage lines, it is important to introduce a degree of rigour in our definitions of various drainages.

		Catchments in Hectares
Gully	I^{st} order drain	0 – 2
Naali	II^{nd} order drain	2 – 50
Naala	III^{rd} order drain	50 – 500
Nadi	Higher order drain	More than 500



Differences between Earthen and Boulder structures:

	Boulder structures	Earthen structures
Waste weir	At the top of the structure	Side of the structure
Side slope	US>D/S	U/S < D/S
Maximum height	At the sides	In the Middle
Primary Objective	Erosion control	Water Harvesting

Location of Structures:

Ridge Area:

While doing ridge area treatment, one must remember that we are trying to reduce soil erosion and not to increase it, or in another words the aim of watershed development is to reduce the slope of land and not to increase it.

- Special care should be taken not to disturb the existing vegetation.
- If boulders are to be used in any structure, they should never be dug out from the soil.
- If the Slope is > 25% vegetative measures, boulder contour bunds
- If the Slope is 10-25% contour trenching
- If the Slope is < 10% earth contour bunds should be promoted.

Drainage Line:

There are some general considerations, which should be borne in mind while selecting the site for locating structures on the drainage line:

- The width of the drainage line at that point should be narrow
- The width of the drainage line upstream of the point should be greater.
- The embankments at that point should be well defined, stable and high.
- The upstream bed slope of the drainage line should be low
- The upstream bed of the drainage line should be made up of impervious material if the principal aim is to harvest water for irrigation. On the other hand, if the main aim is to increase the rate of groundwater recharge, this material should be relatively pervious.
- Ideally in structures where waste weirs have to be constructed, the sub-strata of the naala banks should be hard enough so that the banks of the weir do not easily get eroded.
- In all those structures where overtopping is allowed, it is to be ensured that the height of the structure plus the depth of peak flow in the stream is always less than the height of the embankments.
- Always locate a structure at such a point, where the construction materials are of requisite size and quantity are adequately available.

Chapter II: Demarcation of watershed on toposheet

- **Definition of watershed:** A Geo-hydrological unit draining to a common point is called a watershed or the catchment area.
- **Why Demarcation is necessary:** Boundary of state, district, town, farms etc is demarcated on different maps but the boundary of any watershed has not been demarcated on any map. It is however demarcated on the toposheet when required. Demarcation of watershed depends on the selected point on the drainage line. Each selected points have different watershed boundary and size. Area of watershed depends on the location of the selected points on the drainage, area would increase if the points shift towards downstream and decreases when shift towards upstream.
- **Demarcation on what map:** Initially the demarcation of watershed should be done on toposheet and then this demarcation can be superimposed on other maps like cadastral maps, soil maps, geological maps etc.

Basic information regarding maps:

- Direction: North direction is always marked by an arrow on the corner of the maps so that it is easy to orient the map in the field.
- Scale: Proportion of distance marked on the map and actual distance on the field is called the scale of the map. Example 1: 100, 1:500, it means that the distance on the field is 100 to 500 times as marked on the map.
- Index: The information or symbol used on the maps is shown in the index table.
- Contour line: it is the line joining the points of equal elevation.

Important maps used in the planning of watershed:

- PRA maps: These are the maps prepared on the basic information available with the village community. These maps mainly show the problems of the village and the associated solutions for the problems.
- Cadastral map: It is a very important map, which shows the land record based on the survey numbers. Through this map, it is easy to know the

precise location of the lands of villagers. Normally the scale of the map is 1:4000. This map is used for the demarcation of watershed and the planning of interventions.

- Toposheet: It is prepared on the basis of earth's latitude and longitude. All the land of our country is marked on the toposheet. Each and every part of the land has specific toposheet number. It is available in three scale 1:250000, 1:50000, and 1:25000. The contour intervals of these toposheet being 100m, 20m and 10m respectively. Information like contour line, elevation of hilltop, drainage line, roads, villages and hamlets, power line, forestland, revenue land etc is also available on toposheet. From contour lines we can visualize the area in a three-dimensional view, as for example: Hillock, Pond, gentle slope, steeper slope, and valley etc that can be easily visualized by the contour lines.
- Demarcation of watershed boundary is possible only on toposheets because these are the only maps, which shows the contour lines and the drainage lines.
- The watershed boundary should be always marked on the color photocopy of the toposheet. It is easy to identify the contour and drainage line on the toposheet.
- Identification of drainage line on toposheet: When the lines join and does not cross and take the **Y** shape it means the line are drainage lines.
- Identification of contour lines on toposheet: Contour lines do not cross each other. Elevation of the lines is always shown on the contour lines and having equal contour intervals.
- If any two lines cross each other on the map, it means that one line is contour and other could be a drainage channel or a road or a power line or a forest demarcation line etc.

How to demarcate watershed on toposheet?

- Photocopy of toposheet on 100% scale is required for the demarcation of watershed. Select a point on drainage line on toposheet. Mark all the drainage line, which are joining at the selected point by using a color pen. It is easy to mark the drainage lines by drawing each drainage from destination to the origin point. It is very necessary to mark the drainage of nearby watershed by the pen of different color for the easy identification of the ridgeline. Use different color for the demarcation of ridgeline.

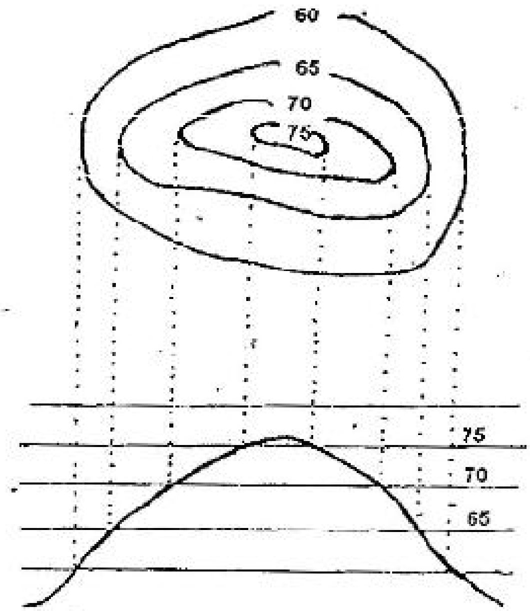


Fig. 9.4 (a): How a hill looks on a contour map. Note that the contours, lines joining points of equal height, get smaller and represent higher and higher points as we come in towards the hilltop. (Adapted from Mahanot and Singh)

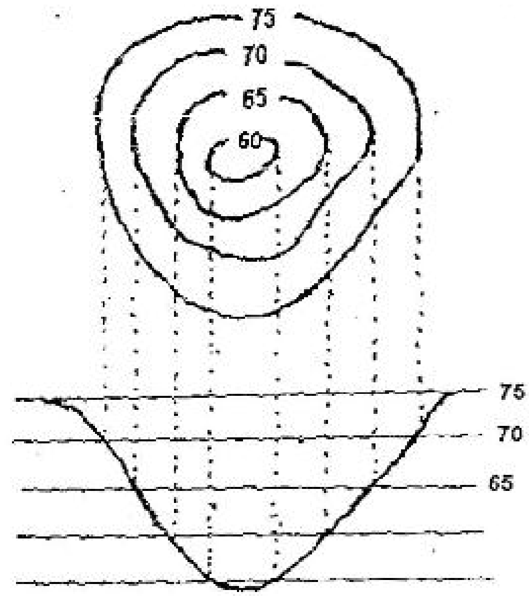


Fig. 9.4 (b): How a saucer type valley looks on a contour map. Here the contours represent smaller and smaller heights as we come in towards the shallow centre. (Adapted from Mahanot and Singh)

- Ridgeline: it is a line joining the points of higher elevation in a particular watershed. Ridgeline always divides the different watersheds.
- Demarcation of ridgeline: Start from the selected drainage point and join all the highest points on the boundary of watershed. Ridgeline should not cross any drainage line. Care should be taken while drawing the ridgeline in hilly terrain.

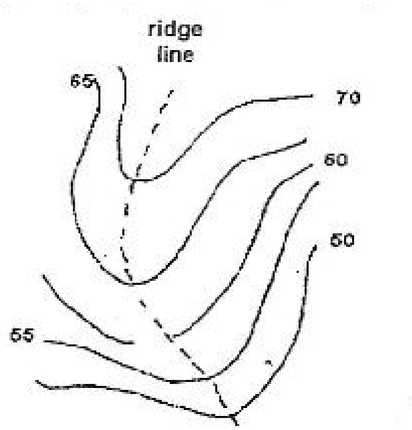


Fig. 9.4 (c): How a typical ridge line would look on a contour map. (Adapted from Mahanot and Singh)

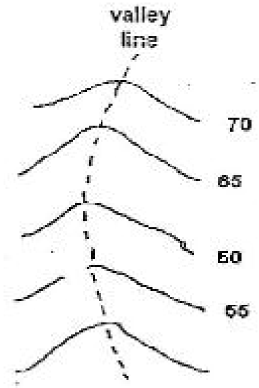


Fig. 9.4 (d): How a typical valley section would look on a contour map. (Adapted from Mahanot and Singh)

- Area calculation of demarcated watershed: procedure for calculating the watershed area is as follows:
    1. Trace the ridgeline on the transparent graph paper.
    2. Count the 1 sq cm box on the graph paper. Then count the 1 sq mm box in an incomplete box.

Example: Assuming that the scale of map is 1:50000 and the number of complete 1 sq cm box are 30. What is the area of the watershed?

Solution:

1 cm = 50000 cm = 500 m

1 x 1 sq cm = 500 x 500 sqm = 250000sqm = 25 hec

1 Sq cm = 25 hec

Area of watershed = 30 x 25 = 750 hec

Chapter III: Introduction to soil properties

Soil composition:

When the dry soil is crushed by hand, it can be seen that it is composed of all kind of particles of different sizes. Most of these particles, which originate from the degradation of rocks, are called mineral particles. Some of the particles, which originate from the residue of plants and animals, constitute the organic matter of the soil.

So we can divide soil into four parts:

- Mineral matter derived from rocks, but more or less altered by decomposition,
- Calcium carbonate and residual organic compounds derived from plants or organisms present at an earlier period,
- Residues of plants and organisms, recently added to the top soil, and
- The soil water, which is a solution of various salts present in the soil (this solution is dilute in areas of adequate rainfall but becomes more and more concentrated as we move to drier areas. It can even become crystals in the dry areas during droughts).

Soil profile:

If a pit, at least 1 m deep, is dug in the soil, various layers, different in color and composition, can be seen. These layers are called horizons. This succession of the horizons is called the soil profile.

Texture

The mineral constituents of a soil can be sorted out according to the size of the particles. Particles above 2mm in diameter are strictly speaking not regarded as part of soil. These are differentially classified as stones and gravel.

Different soils have different combinations of these constituents. We can roughly make this out even by feeling the soil with our fingers. Thus, soils with more sand are coarser and those with more clay feel finer. The relative proportions of different constituents in a soil give the soil its texture. A soil with a reasonable balance between sand, silt and clay is called a loam. It has a loamy texture. Experienced farmers can roughly estimate the relative proportions of these parts by feeling a soil when it is moist. They describe soils as light or heavy, and they also can foresee as how much cattle would be needed to plough the soil. Thus, clayey soils are heavier than sandy soils.

Generally, 10 types of soils are distinguished according to the proportion of sand, silt and clay. This leads to the development of exclusive soil properties as the movement and retention of water, circulation of soil air, adsorption of nutrients and microbial activity etc and this affects the choice of specific tillage practices, irrigation methods, crops etc.

Soil texture is mainly concerned with the size and shape of the mineral particles of the soil. The particles are sand, silt and clay and they have the following diameters:

Particle	**Size**	**Remark**
Sand	0.05-2 mm	Particles visible
Silt	0.002-0.05 mm	Particles hardly visible
Clay	<0.002 mm	Particles not visible
Clayey soil	>= 50% clay particles	
Silty soil	>= 50% silt particles	
Sandy soil	>= 50% sand particles	
Loams are soils with mixed particles of sand, silt and clay.		

Soil erosion depends greatly on the infiltration rate of a soil. The infiltration rate again depends on the soil texture. In sandy soil infiltration rate is comparatively higher than that of other soils.

How to identify the clayey, silty and sandy soil in the field:

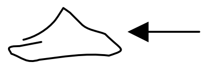
(i) Take a small handful of soil earth from the slope.

(ii) Slowly add small amounts of water and mix it thoroughly. Stop adding water as soon as the formed soil ball start to stick to your hand.

(iii) The soil texture can be roughly estimated with your moist soil sample. Try to form the sample into the different shapes you can form with your soil. If you cannot form it any further, stop at the previous picture and read the soil texture given alongside it. This is the texture of your soil.

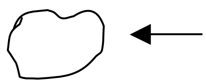
(iv) Form your sample according to each picture below until the next one is no more possible.

1. The soil remains loose and single grained and can only be heaped in to a pyramid.



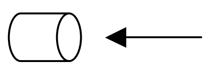
Sand

2. The soil contains sufficient silt and clay to become somewhat cohesive and can be shaped into a ball that falls apart easily.



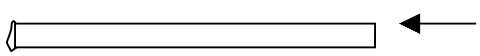
Loamy sand

3. The soil can be rolled into a short, thick cylinder.



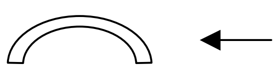
Silt loam

4. The soil can be rolled into a cylinder of about 15 cm length.



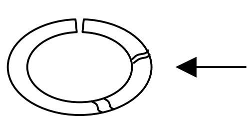
Loam

5. The cylinder can be bent into a U.



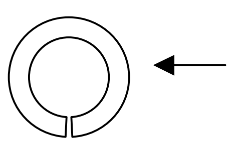
Clay loam

6. The U can be bent into a circle that shows cracks.



Light clay

7. The soil can be bent into a circle without showing cracks



Heavy clay

Soil Structure:

Soil structure refers to the grouping of soil particles (sand, silt, clay, organic matter and fertilizers) into porous compounds. These are called aggregates. Soil structure also refers to the arrangement of these aggregates separated by pores and cracks. The basic types of aggregate structure are granular, blocky, prismatic, and massive.

Infiltration:

When rain or irrigation water is supplied to a field, it seeps into the soil. This process is called infiltration

A range of values for infiltration rates is given below.

Low infiltration rate	< 15 mm/ hour
Medium infiltration rate	15 to 50 mm/ hour
High infiltration rate	> 50 mm/ hour

An infiltration rate of 15 mm/hour means that a water layer of 15 mm on the surface of the soil will take one hour to infiltrate. Factors influencing the infiltration rate are mainly soil texture, the soil moisture content and soil structure.

Soil moisture content:

It indicates the amount of water present in the soil. It is determined by

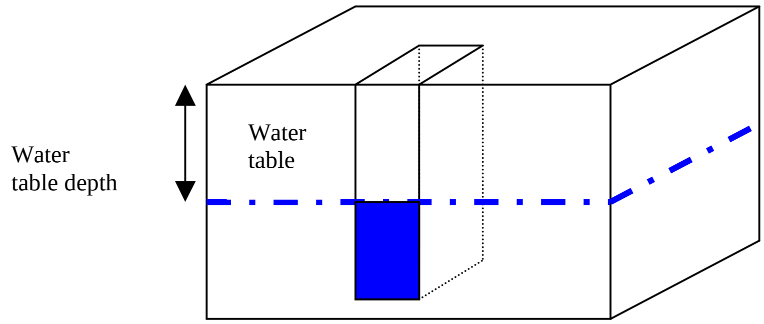
Soil moisture in % **=** [(total weight of water / total weight of soil) x 100].

Saturation:

During the rain shower or irrigation application, the soil pores fill with water. If all soil pores are filled with water the soil is said to be saturated. At this point there are no air voids left in the soil.

Ground water table

Part of the water applied to the soil surface drains below the root zone and feeds deeper soil layers, which are permanently saturated; the top of the saturated layer is called the ground water table or some time just water table. The depth of water table varies greatly from place to place, governed mainly by the variations in the topography of the area.



Capillary rise:

If a piece of tissue is dipped in water, the water is sucked upward by the tissue. The same process happens to the ground water table and the soil above it. The ground water can be sucked upward by the soil through very small pores that are called capillaries. This process is called capillary rise.

Natural Angle of Repose:

When a material (clay, loam, sand, gravel etc.) is left exposed to the action of natural forces for a certain period of time it will gradually attain a state of equilibrium with a definite slope having a considerable degree of stability. The angle this slope makes with the horizontal is called the natural angle of repose for that material.

The angle of repose is a concept of great significance in low cost mud-boulder engineering. In general, the slope of any watershed structure must always be less than the natural angle of repose of the material used in its construction. This is because allowance must be made for the safety of the structure, which is to continually come in contact with the harvested rainwater. The flatter a structure, the more safe it is. The natural angle of repose provides us with a quantitative basis for deciding how much flatter the structure is required to be made under safety considerations. The following table summarizes the natural angle of repose for various materials.

Natural Angles of Repose for Different Materials

Material	Angle of Repose (Degrees)
Clay, wet	15-20
Clay, dry	25-30
Clay, damp, well drained	30-45
Sand, wet	15-30
Sand, dry	25-35
Sand, moist	30-45
Earth, dry	30-40
Earth, loose	30-45
Earth, moist	45-49
Earth, rammed	50-65
Sand and clay, wet	18-20
Gravel	40-45
Gravel, wet	27
Gravel and clay, wet	18
Gravel, sand and clay, wet	19
Gravel and sand	25-30
Shingle	38-40
Shingle and earth, moist	40
Vegetable soil, dry	30
Vegetable soil, moist	45-50
Vegetable soil, wet	15-17
Peat	14-45
Silt, wet	10-20
Silt, dry	20
Rubble stone	45

Soils and Construction:

These soil properties have a fundamental bearing on the selection of materials for construction as well as on the design characteristics of structures using different soils. Thus, structures made of finer materials will have flatter slopes than those structures, which are made up of coarser materials, all other conditions being held constant. Finer materials will generally be placed towards the middle of structures, while coarser materials will be placed on outer surfaces, especially those coming into contact with water. Of course, this sequence is reversed when making reverse filters to serve various purposes.

Soil erosion:

Erosion may be defined as the detachment and transportation of soil. Running water, wind, sea waves and moving ice cause a certain amount of erosion called natural erosion. However, when natural vegetation and trees are cleared for agricultural purposes, the natural protection that the soil had is disturbed and the soil detachment and movement occurs at great speeds.

The forms of soil erosion by water are sheet and rill erosion (4 - 10 ton/ha/year in red soil, 17 - 43 ton/ha/year in black soil, and 4 -14 ton/ha/year in alluvial soils), gully erosion (about 33 ton/ha/year in ravine regions), hillside erosion (more than 80ton/ha/year in landslide, mine spoil area) and stream bank erosion.

Sheet erosion is the most serious of India's soil erosion problem since it poses a serious threat to red soils, covering an area of 69 million ha. the depth of these soils are, in many parts, only around 20 cm.

It is estimated that out of a total reported geographical area of 329 million ha, about 167 m ha are affected by serious problems of which about 127 m ha are subject to serious soil erosion and 40 m ha are degraded through gully and ravines, shifting cultivation, water logging, salinity, alkalinity, shifting of river courses and desertification.

In a recent analysis of annual soil erosion rates in India, it was estimated that about 5334 m-tons (16.35 ton/ha) of soil is detached annually due to agriculture and associated activities alone. The country's rivers carry about 2052 m-tons (6.26 ton/ha) of such soil. Nearly 1572 m-tons (29% of total eroded soil) are carried away by the rivers into sea every year and 480 m-tons (10% of the total eroded) are being deposited in various reservoirs, resulting in a considerable loss of storage capacity.

Types of erosion:

1. **Raindrop or splash erosion:** Raindrop or splash erosion result from soil splash caused by the impact of falling raindrops. It has been proved that raindrop splash is of major importance as a contribution to erosion. The falling raindrops detach soil particles. Raindrop may splash wet soil as much as 60 cm high and 150 cm from the spot where it falls.
2. **Sheet erosion:** Sheet erosion is a more or less even removal of a thin layer of soil. It is often unnoticed by the farmers because it occurs gradually and there is no appreciable change. The yield decreases slowly to the minimum.
3. **Rill erosion:** Sheet flow occurs only when the surface is smooth and has a uniform slope. This is however rare in cultivated fields. Consequently rainwater concentrate in depressions and then begins to flow taking the

path of least resistance, making rills which are small enough to be easily removed by normal tillage operations.

4. **Gully erosion:** Gully erosion is an advance stage of rill erosion. Unattended rills get deepened and widened every year to attain the form of gullies. The rate of gully erosion depends primarily on the runoff producing characteristics of the watershed, the watershed area, soil characteristics, size-shape and slope of gully etc.
5. **Other erosion:** Stream erosion, Landslide erosion and Erosion by waves etc, forms other important types of erosion by water.

Soil conservation

Soil conservation is the only known way to protect the productive land. In country like India, where droughts and floods cause chronic food scarcity, soil conservation not only increases crop yield, but also prevents further deterioration of land.

Chapter IV: Introduction to Ground water, rainfall &runoff

Groundwater:

Theoretical Introduction

Without a micro-level understanding of geological variations in the lateral and vertical sequences, there is a real danger of exhaustion of groundwater in an area already low in groundwater reserves. The spatial and temporal configuration of geological strata is of critical importance while assessing the hydrological response of a watershed. It determines the relationship between annual rainfall and runoff and hence influences the degree of usefulness of rain. On the other hand, it also has an important bearing on the existing microenvironment of the groundwater system. Groundwater resides in the geological strata and hence the capacity of litho-units to accept, hold and transmit subsurface water has a major role in determining the groundwater potential and recharge capacity.

The water that enters the ground may be subdivided as that which is:

- absorbed directly by vegetation;
- drawn by capillary action to the surface and gets evaporated;
- combines with molecules of minerals and is chemically fixed;
- flows directly into the sea (in coastal areas) through springs and underground channels;
- escapes at the surface through springs or by feeding rivers;
- retained in the ground.

Under the earth's surface, water exists in pores of soil and rocks. In the zone of saturation, the pores of rocks are full of water. This is what we call as groundwater and the upper limit of this saturation zone is called the water table, which is fundamentally the level below which rock pores are completely saturated with water. Groundwater can be divided into two zones-static and dynamic, on the criterion of renewability. It is very important to remember that it is only the groundwater in the zone of water level fluctuation, which is a renewable resource, being replenished periodically through rain, irrigation return flow and various seepages.

The water in the zone of saturation below the zone of fluctuation is called the static resource. In the language of an economist, we could say that the zone of fluctuation is the current account and the water below this zone is the capital account. Extracting water from the capital account is tantamount to the mining of groundwater.

Another way of defining a water table is to say that it is the level at which water pressure is exactly equal to the atmospheric pressure. Thus, groundwater is always at a pressure greater than atmospheric pressure. Contrastingly, in the zone of aeration, water is at a lesser pressure compared to the atmospheric pressure. In this zone, the pores contain some air and some water. Water in the capillary fringe is held in place by the molecular and surface tension forces, as the interconnected pores in granular rock materials behave like capillary tubes. Similarly, in the intermediate soil zones, water exists in the form of thin films (pellicles) surrounding rock and soil particles and lining the sides of the pores. This underground water component being held below atmospheric pressure, is strongly held by the force of suction around the rock grains and prevent it from draining under gravity. In this way, it resembles the capillary water.

These molecular effects and surface tension is important because they do not allow all the water in the pore space of an aquifer to be abstracted and utilized. The volume of water, V is in an aquifer and may be expressed as

$$V = A * h * p,$$

where A is the area of the aquifer, h its thickness and p its porosity. The percentage of the rock volume of an aquifer, which is void, is called its porosity, and it depends on the texture of the rocks found in the area, their composition and their relative stability. Porosity determines how much water the aquifer would be able to store. Mathematically, it may be expressed as

$$p = Vp/V,$$

where Vp is the volume of pores and V, the total volume of the rocks. Now if Vr is the volume of water that a saturated aquifer retains against the gravitational pull, then

$$Sr = Vr/V,$$

is referred to as the specific retention of the aquifer. The volume of water that drains from such an aquifer, Vy, is, therefore, given by

$$Vy = Vp - Yr.$$

Now the specific yield of the aquifer is expressed as

$$Sy = Vy/V.$$

Thus, the volume of water that will drain from an aquifer is

$$Vy = A^* h^* Sy.$$

We can easily see that porosity is the sum of specific retention and specific yield. Since,

$$Vy = Vp - Vr,$$

it follows that

$$Vy/V = Vp/V - Vr/V \text{ or } p = Sy + Sr.$$

When we try to assess the possibilities of groundwater development, we are interested in is not so much the porosity of rocks as their specific yield. For it can well happen that water is not able to flow easily even through a highly porous rock. This happens when the pores are very small in size and/or if they are not properly interconnected. Vesicular basalts are an example of poor interconnection of pores. Clay is an example, where the pores are very small. In this case the specific retention of the soil particles (due to molecular effects and surface tension) increases as grain size decreases. Clay can have a porosity of 50 per cent and the specific retention of 48 per cent, the specific yield being negligible.

On the other hand, in coarse-grained rocks with large pores, capillary films occupy only a small portion of the pore space-'the specific yield is then almost equal to the porosity, the specific retention being nearly zero. Again, a rock with very low porosity, although a poor storehouse of water, could allow water to pass through it easily if it has just one or two open cracks. This quality of a rock to be able to allow water to flow through it is called its permeability. Interconnections obviously must also occur across rocks. Thus, in assessing the specific yield of rock formations, their lithology (properties of primary rock materials), their stratigraphy (chronological order and vertical and lateral disposition of rock deposits) and their structural features (cracks, fissures, joints, folds and faults) have to be taken into consideration.

Groundwater in India

In India groundwater occurs mainly in three types of hydro-geological formations.

- **Unconsolidated alluvial formations:** covering over 30 per cent of the land area, primarily the Indo-Gangetic plain, comprising largely of sand, gravels and pebbles which can store large quantities of groundwater.
- **Semi-consolidated formations:** covering about 5 per cent of the land area and consisting of sandstone formations of Mesozoic and Tertiary age. These have highly variable yields of groundwater.
- **Consolidated formations:** covering 65 per cent of the land with relatively poor groundwater potential. 'Hard rock' is a generic term applied to consolidated formations with aquifers of low primary intergranular porosity.

The Report of the Groundwater Estimation Committee of the Ministry of Irrigation, Government of India (GOI) (1984) provides broad guidelines for the specific yield in different geological formations in the zone of water level fluctuation:

Specific Yields (%) for Geological Formations in India

Sandy Alluvial Area	12 to 18
Valley Fills	10 to 14
Silty/Clayey Alluvial Area	5 to 12
Highly Karstified Limestone	7
Limestone	3
Sandstone	1 to 8
Granites	2 to 4
Laterite	2 to 4
Basalts	1 to 3
Weathered phyllites, shales, schists and associated rocks	1 to 3

As can be seen from the table, the consolidated formations, which occupy the largest proportion of the area of the country, have the lowest groundwater potential. Thus, extreme care has to be exercised while extracting groundwater in such geological formations.

Rainfall and methods of runoff measurement:

Precipitation:

All forms of water received on earth from the atmosphere is called precipitation. If the precipitation had been occurring uniformly and well distributed throughout the year, many of the hydrological problems like floods and drought would not have arisen.

Forms of precipitation:

1. **Rain:** The term rain describes that form of precipitation where the size of water droplets is larger than 0.5 mm. The maximum size of a raindrop is about 6 mm.

Type	**Intensity mm/hr**
Light rain	< 2.5
Moderate rain	2.5 to 7.5
Heavy rain	> 7.5

2. **Snow:** In India snow occurs in the Himalayan regions. When the snowfall is fresh, it has an initial density varying from 0.06 to 0.15 gm/cm^3, with an average value of 0.1gm/ cm^3 (10mm snow = 1mm rain).
3. **Drizzle:** Drizzle is a form of rain when numerous water droplets of size less than 0.5mm with intensity less than 1 mm/ hr occur.
4. **Hail:** A hailstorm is when precipitation occurs in the form of irregular pellets or lumps of frozen rain, of size greater than 8 mm in diameter.

Rainfall pattern in India

The seasons in the Indian subcontinent can be divided into two major seasons and two transitional seasons:

1. Southwest Monsoon: From June to September.
2. Post Monsoon: From October to December.
3. Winter season: January to February.
4. Pre Monsoon: From March to May.

Rainfall Parameters

Adequate data on rainfall of an area provide the basic information required for management of land and water resources. The important parameters are:

1. **Amount of rainfall:** The height to which rain water would stand on a horizontal surface under conditions of no infiltration, no runoff and no evaporation is known as the amount of rainfall. It expressed in mm or cm.
2. **Duration:** The period during which the rainfall occurs is known as the duration of rainfall. It has the unit of time, viz. seconds, minutes, and hours.
3. **Intensity:** Rainfall intensity plays a great role in watershed planning. It is defined as the rate at which rainfall takes place that is the amount of rainfall occurring per unit time. It is expressed in units of mm/hr or cm/hr.
4. **Rainfall frequency:** Frequency or the return period or recurrence interval denotes the period in years during which a storm of given duration and intensity can be expected to recur. It is a better way to express this through 'percent chance', e.g. 50 year frequency has a 2% chance.

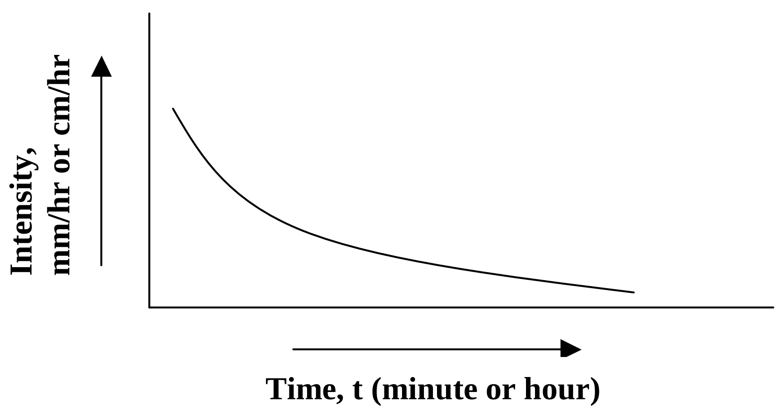
Runoff

The maximum rate at which water can enter the soil is known as its infiltration capacity. So long as the infiltration capacity exceeds the rate at which rain falls (intensity of rainfall), water will continue to be absorbed by the soil. There is, however, a definite limit to this process. Water in soils occurs as films around solid particles, held in the pores by surface tension and molecular forces. Initially, when rain falls on dry ground, these "pore-water suctions" assist gravity in drawing water down into the soil, because of which the infiltration capacity of the soil is high. As rainfall continues, there is a decline in the rate of infiltration due to a severe breakdown of soil structure leading to the formation of a thin compact layer on the surface. The beating action of the raindrops tends to close the pores and pore-water suctions decrease as the pores fill up. Water flowing on the surface also performs an assorting action, joining the finer particles around the larger ones to form a relatively impervious seal. Finally, we reach a point where the intensity of rainfall becomes greater than the infiltration capacity of the soil. At this point surface runoff is said to have started and this water no longer remains available for use within the area.

The estimation of runoff from a catchment is the first step in designing any watershed structure. The runoff coefficient gives the ratio of the runoff volume to per unit rainfall (mm) over the catchment area (ha). Value of the runoff coefficient depends upon the size and slope of the catchment area, the quantum and intensity of rainfall, the thickness and permeability of the soil and the extent of vegetative cover.

Intensity – Duration Relationship

If a small period is suitably selected within the total storm duration, the intensity of rainfall in that duration can be much higher than the intensity of the storm during its total duration. Intensity is an inverse function of its duration that is longer the duration of rainfall, the lower the intensity and vice versa.



The general form of the intensity –duration-return period is:

$I = [(K \times T^{a}) / (t + b)^{n}]$

Where, I = intensity (cm/hr)

T = return period (years)

t = time of concentration (storm duration) (hours)

Step I: For finding out the intensity of any particular place, select the values for K, a, b and n against corresponding place, which are provided in table.

Intensity –duration-return period relationship chart:

Zone	Station	K	a	b	N
North zone	Agra	4.911	0.1667	0.25	0.6293
	Allahabad	8.570	0.1692	0.50	1.0190
	Amritsar	14.41	0.1304	1.40	1.2963
	Dehradun	6.00	0.2200	0.50	0.8000
	Jaipur	6.219	0.1026	0.50	1.1172
	Jodhpur	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
	Shinagar	1.503	0.2730	0.25	1.0636
	Northen zone	5.914	0.1623	0.50	1.0127
Central zone	Bagra-tawn	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
	Nagpur	11.45	0.1560	1.25	1.0324
	Punasa	4.7011	0.2608	0.50	0.8653
	Raipur	4.683	0.1389	0.15	0.9284
	Thikri	6.088	0.1747	1.00	0.8587
	Central zone	7.4645	0.1712	0.75	0.9599
Western zone	Aurangabad	6.081	0.1459	0.50	1.0923
	Bhuj	3.823	0.1919	0.25	0.9902
	Mahabaleshwar	3.483	0.1267	0.00	0.4853
	Nandurbar	4.251	0.2070	0.25	0.7704
	Vengurla	6.863	0.1670	0.75	0.8683
	Veraval	7.787	0.2087	0.50	0.8908
	Western zone	3.974	0.1647	0.15	0.7327
Eastern zone	Agartala	8.097	0.1177	0.50	0.8191
	Dumdum	5.940	0.1150	0.15	0.9241
	Guwahati	7.206	0.1557	0.75	0.9401

	Gaya	7.176	0.1483	0.50	0.9459
	Imphal	4.936	0.1340	0.50	0.9719
	Jamshedpur	6.930	0.1307	0.50	0.8737
	Jharsguda	8.596	0.1392	0.75	0.8740
	Nor. Lakhimpur	14.070	0.1256	1.25	1.0730
	Sagar Island	16.524	0.1402	1.50	0.9635
	Shillong	6.728	0.1502	0.75	0.9575
	Eastern zone	6.933	0.1353	0.50	0.8801
Southern zone	Bangalore	6.275	0.1262	0.50	1.1280
	Hydrabad	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
	Manglore	6.744	0.1395	0.50	0.9374
	Tiruchinapalli	7.135	0.1638	0.50	0.9624
	Trivendrum	6.762	0.1536	0.50	0.8158
	Visakhapatnam	6.646	0.1692	0.50	0.9963
	South zone	6.311	0.1523	0.50	0.9465

Step II: The return period can be selected as per table below:

Type of structure	**Returning period in year**
Storage dam having permanent spillway	50-100
Earth fill dam having natural exit	25-50
Small permanent gully control structure	10-15
Terrace outlets and vegetated waterway	10
Field diversion	15

Step III: The time of concentration (t) of a watershed can be computed using the following equations:

$$t = 0.01947 \times K_c^{0.77}$$

Where, t = Time of concentration in minutes.

$K_c = [L^3/H]^{0.5}$

L = Maximum length of travel in meter

H = Difference in elevation between most remote point and outlet in m

Estimation of runoff

Runoff: Runoff occurs only when the rate of precipitation, i.e. its intensity, exceeds the rate of infiltration. Estimation of run off is required for the design of soil and water conservation structures. In designing spillway and outlets or waterways, estimates of peak runoff rates are required, while for assessing the storage in earthen dams, tanks and ponds, the estimates of total runoff volumes or water yield are required.

Rational method for calculation of peak runoff: The following basic assumptions are made in the this method:

- Rainfall occurs at a uniform intensity for a duration at least equal to the time of concentration of the watershed.
- Rainfall occurs with a uniform intensity over the entire watershed.

Due to above assumption, it is applied to watershed or catchments which are less than 1300 hectares. This is the most widely used method for the estimation of peak rate of run off from a small watershed. It is expressed by the equation:

$Q = CIA/360$

Where,

Q = Peak rate of runoff in cu.mt./sec for the given frequency of rainfall

C = rational runoff coefficient.

I = Intensity of rainfall in mm/hr

A = Area of watershed in hectares.

Value of coefficient of runoff {C} used in Rational method

Vegetative cover and slope	Soil Texture		
	Sandy loam	**Clay and silty loam**	**Stiff clay**
Cultivated land			
0 – 5%	0.30	0.50	0.60
5 – 10%	0.40	0.60	0.70
10 – 30 %	0.52	0.72	0.82
Pasture land			
0 – 5%	0.10	0.30	0.40
5 – 10%	0.16	0.36	0.55
10 – 30 %	0.22	0.42	0.60
Forest land			
0 – 5%	0.10	0.30	0.40
5 – 10%	0.25	0.35	0.50
10 – 30 %	0.30	0.50	0.60

Procedure of calculation:

Step I: Determine the areas under various land uses and the soils (A1, A2, A3…)

Step II: Determine the value of C from the table depending upon soil type and land use. In case watershed comprises of more than one land use or soil type, the average value of C is computed for the watershed as given below:

$$C = [A1C1 + A2\ C2 + A3C3 + \ldots\ An\ Cn] / A$$

Step III: Determine the time of concentration (t) in minutes by

$$t = 0.01947 \times (K_c)^{0.77}$$

Where, t = Time of concentration in minutes.

$K_c = [L^3/H]^{0.5}$

L = Maximum length of travel in meter

H = Difference in elevation between most remote point and outlet in meters

Step IV: Convert the one-hour intensity for design frequency for duration equal to time of concentration by using the formula:

$$I= [(KxT^{a}) / (t+b)^{n}]$$

Where, I = intensity (cm/hr)

T = return period (year)

t = time of concentration (storm duration) (hours)

Step V: Compute the peak rate of runoff by using the Rational formula:

$$Q = CIA/360$$

Where,

Q = Peak rate of runoff in cu.mt./sec for the given frequency of rainfall

C = rational runoff coefficient.

I = Intensity of rainfall in mm/hr

A = Area of watershed in hectares.

Example I: Estimate peak rate of runoff of 25 years frequency for a 25 ha watershed in medium black soil (clay) having 15, 5 and 5 ha under cultivation, forest and grassland, respectively. The watershed has a general slope of 2.5%. The area is located somewhere in the Central Zone. The maximum length of run is approximately 2500m and the elevations of the highest and outlet point are 250m and 200m, respectively.

Solution: Coefficient of runoff (C) from table

A1 (cultivated land) = 0.50

A2 (Pasture land) = 0.30

A3 (forest land) = 0.30

Weighted value of C for entire watershed

C = (15 x 0.50 + 5 x 0.30 + 5 x 0.30) / (15 + 5 + 5) = 0.42

The time of concentration (t)

$(t) = 0.1947 \times (K_c)^{0.77}$

Where, $Kc= [L^3/H]^{0.5}$

Maximum length of run (L) = 2500m

Difference in head (H) = 250 –200 = 50m

$Kc= [(2500)^3/50]^{0.5} = 17677$

$(t) = 0.1947 \times (K_c)^{0.77}$

$(t) = 0.1947 \times (17677)^{0.77}$ = 36 minutes = 36/60= 0.60hr.

The intensity of rainfall (I)

$I = [(K \times T^{a}) / (t + b)^{n}]$

The value of K, a, b and n can be obtained from table against central zone.

K = 7.4645, a = 0.1712, b = 0.75 and n = 0.9599

Recurrence interval as given 25 years, time of concentration (t) workout as 0.60hr.

$I = [(7.4645 \times 25^{0.1712}) / (0.60+0.75)^{0.9599}]$ = 9.71cm/hr or 97mm/hr

Substituting the values C = 0.42, I = 97 mm/hr and A = 25ha in the Rational formula:

Q = CIA/360 = (0.42 x 97 x 25) / 360 = 2.82 cu.mt./sec

Dickens formula: it is another method for calculating peak runoff. It is used for the catchments of more than 1300 hectares.

$$\mathbf{Q_p = C\,(A/100)^{0.75}}$$

Where, Q_p = peak discharge in cu.mt./sec

A = Catchments area in hectares

C = coefficient, for North India 11.5, for Central India 14 and for Western Ghat 22

Chapter V: Land capability classification

Introduction

It forms the basis of all the watershed management programmes. The basic principle of soil and water conservation is to use the land according to its capability and treat the land according to its needs. It indicates the most intensive, profitable, and safe use, which can be made of any piece of land.

Factors influencing the land capability classification

- **Soil profile characteristics:** The important soil properties which are interpreted for classifying lands under different land capability are: soil texture, effective soil depth, permeability and internal drainage, availability of nutrients, soil salinity, soil alkalinity, and soil toxicity.
- **External feature of the land:** Water logging, slope and erosion are the factors that determine land capability and limit the land for particular use only.
- **Climate factors:** Rainfall, temperature and wind velocity are important components that determine land capability class.

Land capability classes:

Group A: lands fit for cultivation

Class I: These lands are free from hazards. They are nearly level with deep soil depth and easily workable soil with medium fertility. These lands are not affected by any appreciable erosion, wetness, salinity etc. These lands are suitable for intensive cultivation without any restriction.

Class II: These lands have moderate soil depth, light or heavy texture, gentle slope, moderate slope and moderate soil fertility etc. There may be difficulty in soil working due to presence of pebbles and stones. There may be some climatic limitations. These lands are however suitable for permanent cultivation with moderate restrictions.

Class III: These lands have moderate to severe restriction for permanent cultivation. These lands may have moderately steep slope, shallow soil, severe erosion hazards, very poor and rapid drainage, etc.

Class IV: These lands are suitable only for occasional or limited cultivation because of unfavorable soil characteristics, slope, erosion, depth, drainage, adverse climate etc.

Group B: Lands not suitable for cultivation

Class V: This is the first in the category of the lands needing permanent vegetation. Class V lands have more or less the same characteristic as class IV except for one or more limitations of being rocky or humid or adverse climatic conditions.

Class VI: These lands are suitable for grazing and forestry with moderate restriction. Some of the characteristics of such lands are susceptibility to severe erosion by water and wind, steep slope, and very shallow soil.

Class VII: These lands are usually very shallow with very steep slopes, rough, stony or very severely eroded, infested with gullies or highly susceptible to wind erosion. They have severe restriction and require extreme care.

Class VIII: These lands are absolutely barren and unfit for economic use even for grassland and forestry. Lands which are rocky, marshy, lakes and ponds that are permanently wetlands and cannot be drained, and sand dunes in the desert.

Land capability rating table

	Class I	**Class II**	**Class III**	**Class IV**	**Class V**	**Class VI**	**Class VII**	**Class VIII**
1. Colour on map	Green	Yellow	Red	Blue	Dark green or uncolored	Orange	Brown	Purple
2. Degree of limitations for use	Few	Moderate	Severe	Very severe	Few	Moderate	Severe	Very severe
3.Texture of soil	Loams	Loams	Clay &loamy sands	Clay & sand	No limitations, except that the soils are rocky or stony	No limitations, except that the soils are rocky or stony	Soil limitations are more severe than class VI	Soil and land forms in this class cannot be used for commercial plants.
4. Soil depth	Very deep d5	Deep d4	Moderate d3	Shallow d2	Very deep d5	Very shallow d1	Very shallow d1	Rock, very shallow d1
5.	Moderate	Moderate	Slow	Very slow				

Permeability		slow Moderate rapid	rapid	Very rapid				
6. Response to application of fertilizer	High	Medium to low	Low	Low	High	Medium		
7. salinity and alkalinity conductivity	Free 0-2	Slight 2-4	Moderate 4-8	Strong 8-16		Very strong >16		
8.Slope (%)	Nearly level <1	Gentle 1-3	Moderate 3-5	Strong 5-15	Nearly level <1	Steep 15-25	Very steep >25	Precipitous
9. Effect of past erosion or susceptibility to erosion	None to slight sheet erosion e1	Slight sheet erosion e1	Moderate rill erosion e2	Severe small gullies e3	None to slight	Very severe gullied land or sand dunes	Very severe gullied land	
10. Drainage	Good	Wetness which can be corrected by drainage	Wetness which continue after drainage	Excessive wetness	Excessive wetness	Excessive wetness	Excessive wetness	
11. Damaging overflow	None	Occasional	Frequent with some damage	Frequent with damage	Frequent overflows	Excessive overflows	Excessive overflows	
12. Climatic limitations on soil use and management	Favorable for growing many common field crops	Slight limitations for field crops	Moderate limitations for field crops	Moderately adverse for field crops	Adverse for field crops	Adverse for field crops	Adverse for field crops	

Determination of the land capability class

The land is classified in to different capability classes according to each parameter with the help of rating table. The capability class will be the highest number given to any properties according to the severity of limitations. Example:

Parameters	**Land capability class**
1 = Loam (medium)	I
d4 = Soil depth	II
A = Slope, level (0-1%)	I
e1= Erosion absent or very slight	I

In this case the highest value is II so the land capability class will be II. The mapping symbol (1-d4/A-e1) will fall under this class.

Soil depth class		
Symbol	**Name**	**Depth range (cm)**
d1	Very shallow	0 – 7.5
d2	Shallow	7.5 – 22.5
d3	Moderate deep	22.5 – 45
d4	Deep	45 – 90
d5	Very deep	> 90

Permeability class		
Symbol	**Permeability class**	**Rate of flow (cm/hr)**
1	Very slow	< 0.13
2	Slow	0.13 – 0.5
3	Moderately slow	0.5 – 2.0
4	Moderate	2.0 – 5.0
5	Moderately rapid	5.0 – 13.0
6	Rapid	13.0 – 25.0
7	Very rapid	> 25.0

Slope classes			
Symbol	**Slope class**	**Slope %**	**Reading of Abney's Level**
A	Nearly level	0 - 1	0 – 35'
B	Gently sloping	1 – 3	35' – 1^0 44'
C	Moderately sloping	3 – 5	1^0 44' -$2^0$52'
D	Strongly sloping	5 – 10	$2^0$52' - $5^0$43'
E	Moderate steep	10 – 15	$5^0$43' - $8^0$32'
F	Steep	15 – 25	$8^0$32' - $14^0$03'
G	Very steep	25 – 33	$14^0$03'- $18^0$16'
H	Very very steep	> 33	$18^0$16' - $26^0$34'

Soil erosion phases		
Symbol	**Erosion phase**	**Characteristics**
e1	Not apparent or slight (sheet erosion)	0 – 25% top soil or original plough layer within a horizon removed
e2	Moderate (sheet and rill)	25 –75% top soil removed
e3	Severe (sheet, rill and small gullies)	75 – 100% top soil and up to 25% sub soil removed
e4	Very severe (shallow gullies)	Gullied land
e5	Very, very severe (shallow gullies)	Very severely gullied land or sand dunes

Table (E) Land Use pattern:

Symbol	Description
CC	Crop cultivation
GT	Grass land with trees
HP	Horti-pasture
AF	Agro forestry (afforestation)
C1R	Single crop rainfed
C2R	Double crop rainfed
C1I	Single crop irrigated
C2I	Double crop irrigated
W1	Wasteland (cultivable)
W2	Wasteland (uncultivable)

Chapter VI: Topographic surveying

Leveling: Surveying or survey leveling is practiced to determine the difference in elevation between various points in the field, to measure distances and to set out contour lines. Dumpy is a useful instrument for the survey of watershed. It is mainly used for the survey of drainage line intervention.

Slope and Vertical/Horizontal Intervals:

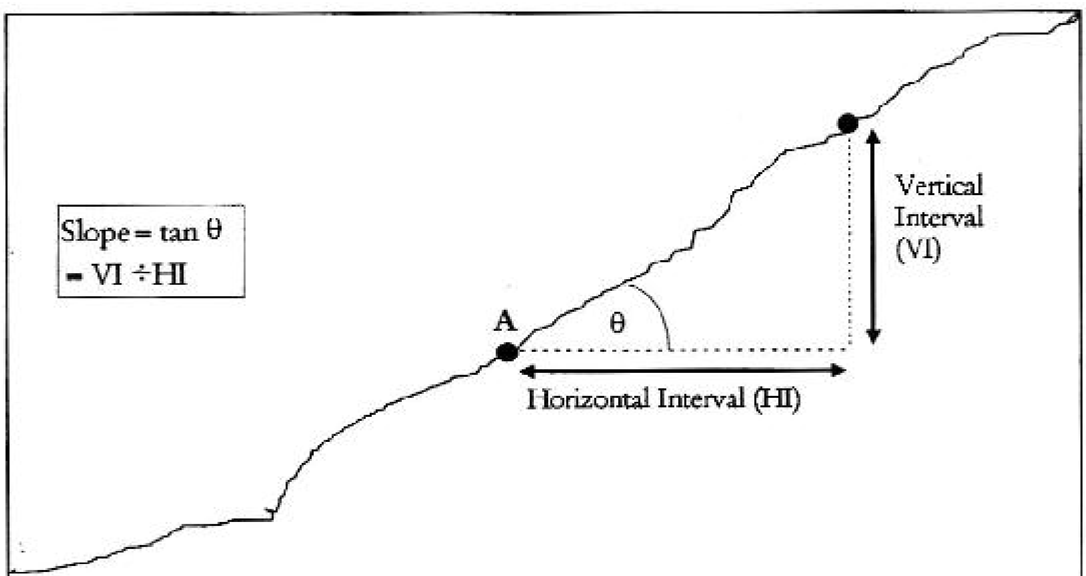
The distance between two points in the watershed can be expressed in two ways:

a) the horizontal interval (HI) and;

b) the vertical interval (VI) or the difference in elevation.

The ratio of the vertical interval to the horizontal interval gives us the slope of the land separating the two points (tan θ), which can be expressed as a percentage, ratio or in degrees. Thus,

slope= tan θ = perpendicular / base = VI /HI



The Vertical Interval is the difference in elevation between 2 points A and B. The Horizontal Interval measures the distance between the 2 points as if they were on the same elevation. The slope is the ratio between the Vertical and the Horizontal Interval.

While planning watershed structures, it is a common practice to fix the vertical interval and let the horizontal interval be determined according to the slope of the land. For instance, with a constant vertical interval of 1m, the contour trenches would be spaced at a horizontal interval of 20m on a 5% slope and 10m on a 10% slope.

However, one must not follow this rule blindly without taking into account the catchment area that each structure has to handle. It must be remembered that as the horizontal interval gets reduced, the independent catchment area of the structure also falls, leading to a reduction in runoff volume. Thus, following this rule on high slopes one may end up making too many contour trenches, very closely spaced, which will never get filled. On lower slopes, on the other hand, following this rule would imply that the horizontal interval and hence the independent catchment of each structure will increase to such an extent that the runoff volume will become very large in relation to the storage capacity of the trenches. To get around this problem in practice, one must fix in prior the maximum and minimum horizontal interval between two successive structures.

Topographic Surveying by Dumpy Level:

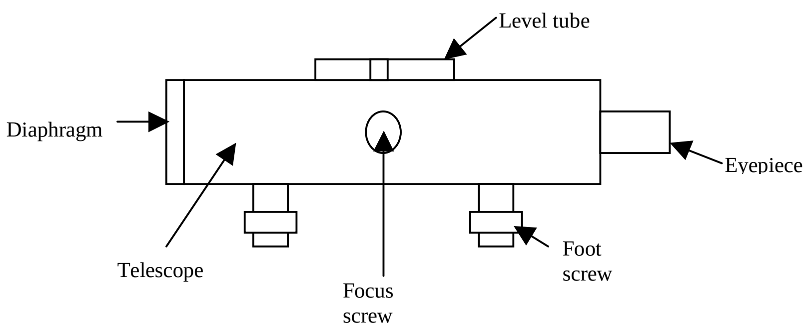
Benchmark:

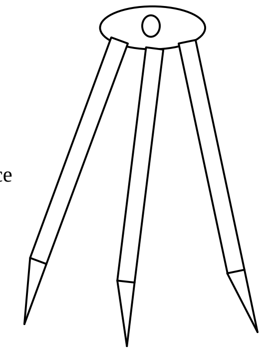
It is a permanent point, which shows the elevation with respect to the mean sea level.

Types of benchmark:

- **G.T.S. bench mark**- It is established carefully at safe location with correction for curvature and refraction. It is established by Great Trigonometrical Survey Department of India.
- **Permanent bench mark**- It is established at a safe location by Govt. department like P.W.D., Irrigation etc. and transferred from the G.T.S. benchmark.
- **Temporary benchmark**- It is established for the survey of any specific work by the concern survey team. Example: a benchmark established by an N.G.O. for the watershed survey work is called temporary benchmark.
- **Arbitrary benchmark-** It is an imaginary benchmark in which elevation of any point is assumed without being transferred from any benchmark. Example: For a survey of any dam, if an elevation of nearby stone is assumed to be as 100 m, that stone is called arbitrary benchmark.

Part of Dumpy Level:



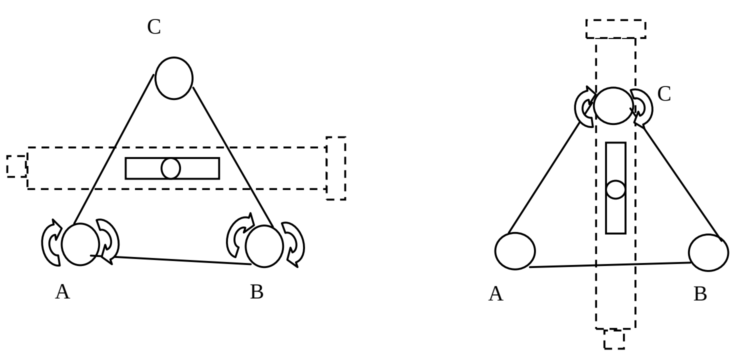


Tripod

- **Tripod**- it is a stand of dumpy level.
- **Foot screw-** it is used for temporary setting of dumpy level.
- **Focus screw-** it is used for focusing object for clear vision.
- **Eye piece-** it is used for focusing cross hairs for clear vision.
- **Level tube -** it is used for temporary setting of dumpy level.
- **Telescope-** it is used for clear vision of farther objects.
- **Staff-** it is a scale, which is used for reading of a point for calculation of reduced level.

Temporary setting of dumpy level:

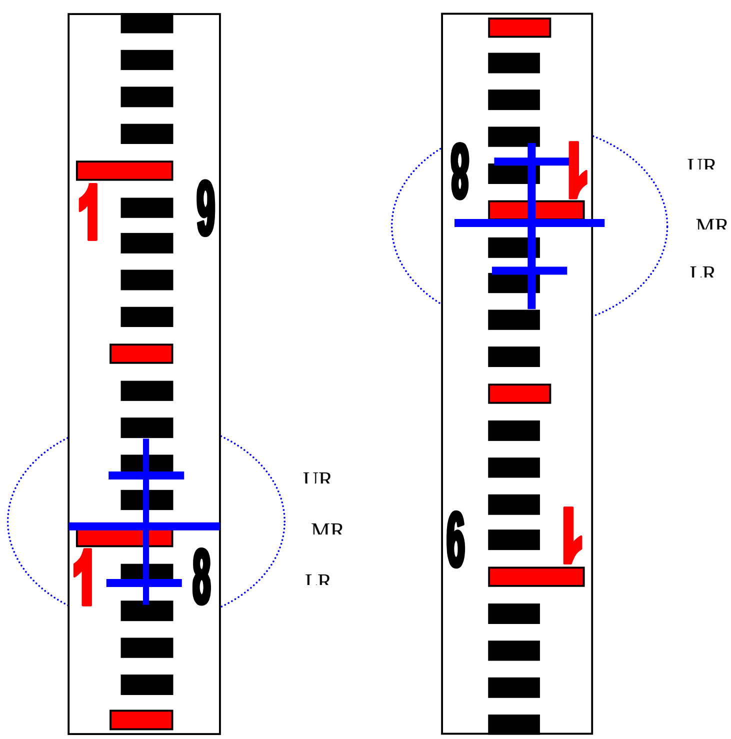
- To set the tripod, if the bubble of tripod comes at center it means tripod is set. Fix the legs of tripod into the ground.
- Fix dumpy over tripod with the help of screw.
- Loosen the foot screw.
- Set the telescope parallel to any two-foot screw then move both the screw, one in clockwise and the other one in an anticlockwise direction. This procedure is continued until bubble of level tube comes at center. It should be remembered that the moment of both the screws should always be equal.



- Set the telescope perpendicular to the selected screw and then move the third screw in clockwise or anticlockwise until bubble of level tube comes at center
- Now again set the dumpy to first step and set the bubble at the center of the bubble tube as described earlier.
- Now set the dumpy to second step and set the bubble at the center of the bubble tube as described earlier.
- First and second step of setting is continuous until bubble is not disturbed at the center of the level tube.
- Now the dumpy is ready for taking the readings.

Procedure of reading staff reading:

Least count of staff is 5 mm. Four meter, five meter & six meter long staff is available in the market. Five mm black and five mm white strip is marked on the staff. In the left of staff black color number 1,2,3… shows completion of 10 cm, 20 cm, 30 cm… In the right of staff red color number 1,2,3… shows completion of 1 m, 2 m, 3 m…



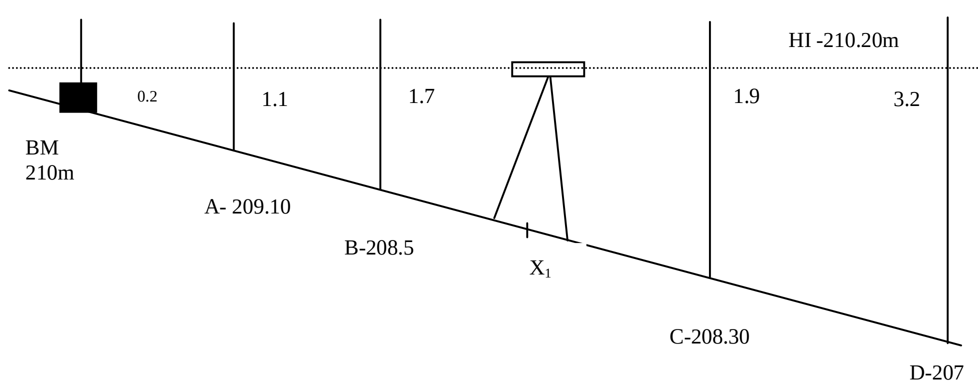
- Set the dumpy through foot screw.
- Set the cross hair for clear vision through eyepiece.
- Align the telescope in the direction of object.
- Focus the staff through focusing screw.
- Now read the staff as described earlier. We can read three reading- upper reading, lower reading & middle reading.

Example: Upper reading is 1m and 81.5 cm means 1.815 m. Middle reading is 1m and 80 cm means 1.80 m. Lower reading is 1m and 78.5 cm means 1.785 m.

Procedure of filling survey readings in field book:

- **Back sight reading-** It is first reading taken at a point of known elevation from a survey station. Whenever the dumpy is shifted to new position first reading should be always noted in back sight.
- **Intermediate sight reading-** Excluding the first and the last readings other readings, which are taken from a survey station, are known as intermediate sight-reading.
- **Foresight reading -** It is last reading taken from a survey station. Whenever the dumpy is shifted to a new position the last reading should always be noted in back sight.

Example 1: the dumpy is at station X1. First reading is taken 0.2m on benchmark from dumpy station. R.L. of benchmark is 210m. Then reading of location A, B, C and last D is 1.1, 1.7, 1.9, and 3.2m taken from the same dumpy station. Fill the reading in the field book and calculate the R.L. of point A, B, C &D.



Dumpy location	Station	Back sight	Intermediate sight	Fore sight	H.I.	R.L.
X1	BM	0.2			210.2	210
	A		1.1		210.2	209.1
	B		1.7		210.2	208.5
	C		1.9		210.2	208.3
	D			3.2	210.2	207
		ΣBS=0.2		ΣFS=3.2		

- Fill up the name of dumpy positions in column no 1.
- Fill up the name of staff position in column no 2.
- First reading is taken on BM and hence entered in the back sight, column no3.
- Readings of station A, B & C are the readings between the first and the last readings taken from dumpy location X1, so these are entered in the intermediate sight, column no 4.
- The reading of station D is taken at the end of survey so is entered in the column no 5.
- Calculate the Height of Instrument (H.I.) by using this formula:

  HI = BS + R.L.

  HI = 210 +0.2 = 210.20 M
- Now calculate the R.L. of station A, B, C, D by using this formula:

  R.L. = H.I. –I.S. or F.S.
- Procedure of arithmetic check for R.L. calculation:

  If, ΣBS-ΣFS = Last R.L.-fist R.L.

  ΣBS- Summation of back sight column.

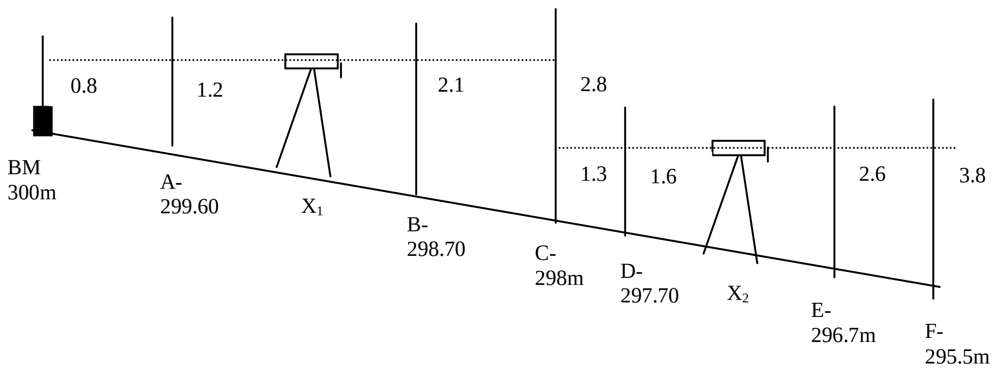
  ΣFS- Summation of fore sight column.

  0.2 –3.2 = 207 – 210

  -3 = -3

If both are equal, it means calculated R.L. is correct.

Example 2-From dumpy position X1, following reading are taken on BM, A, B, C are 0.8, 1.2, 2.1 &2.8.Dumpy shifted to other position X2, following reading are taken on C, D, E, F are 1.3, 1.6, 2.6 & 3.6. Fill the reading in the field book and calculate the R.L. of point A, B, C, D, E & F. R.L. of BM is 300m.



Dumpy location	Station	Back sight	Intermediate Sight	Fore sight	H.I.	R.L.
X1	BM	0.8			300.8	300
	A		1.2		300.8	299.6
	B		2.1		300.8	298.7
	C			2.8	300.8	298
X2	C	1.3			299.3	298
	D		4.6		299.3	297.7
	E		2.6		299.3	296.7
	F			3.8	299.3	295.5
		ΣBS=2.1		ΣFS=6.6		

If, ΣBS-ΣFS = Last R.L.-fist R.L.

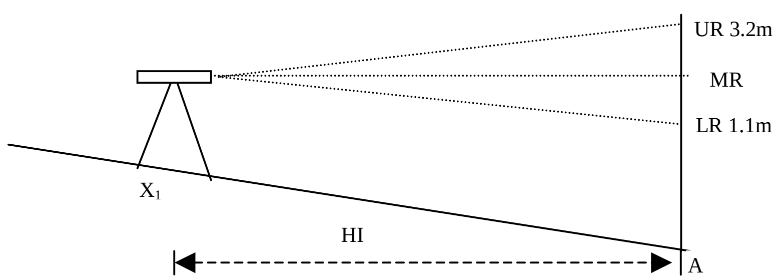
2.1 – 6.6 =295.5 – 300

-4.5 = -4.5

- First reading 0.8m is taken from dumpy location X1 is on BM, so this will enter in back sight column.
- Readings 1.2m & 2.1m are taken from dumpy locations X1 are on stations B & C, so these will be entered in the intermediate sight column.
- Last reading 2.8m is taken from dumpy location X1 is on C, so this is entered in the fore sight column.
- Now dumpy is shifted to an other location X2, First reading 1.3m is taken from dumpy location X2 is on C, so this will be entered in back sight column.
- Readings 1.6m & 2.6m are taken from dumpy locations X2 are on station D & E, so these are entered in the intermediate sight column.
- The last reading 3.8m is taken from dumpy location X2 is on F, so this is entered in the fore sight column.
- H.I. always remains the same until dumpy is shifted to other location.

Horizontal Interval measurement at field by dumpy level:

Upper Reading and lower reading taken from a dumpy level are mainly used for calculating horizontal intervals between the dumpy level station and the staff station. Following formula is used for calculation of Horizontal Interval.



Horizontal interval between dumpy station X_1 to staff station A =

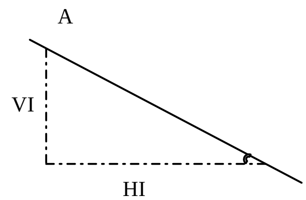
(UR – LR) x 100

If UR = 3.2 and LR = 1.1, then

Horizontal interval between dumpy station X_1 to staff station A =

(3.2 – 1.1) x 100 = 20 m.

Slope: Slope between any two stations is the ratio of vertical interval (V.I.) and horizontal distance (H.I.)



Dumpy Location	Station	BS	IS	FS	HI	RL	Bearing	UR	LR	Distance from X_1
X_1	BM	1.5			251.5	250				
	A		2.2		251.5	249.3		2.4	2.0	40
	B			3.4	251.5	245.1		4.0	2.8	120

VI between station A & station B = RL of station A - RL of station B

Slope can be described in three ways:

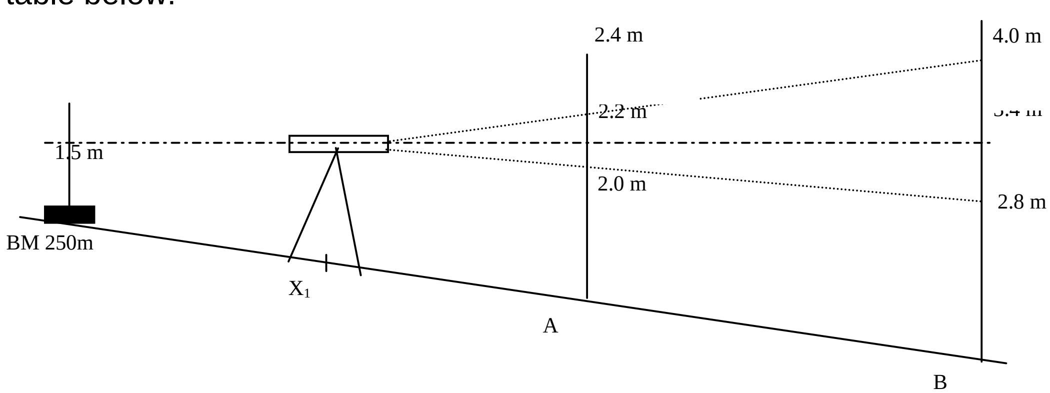
- Proportion of VI and HI, example: 1:2, 1:3 etc.
- In percentage, example: 10%, 20% etc.

  $S = (VI/HI) \times 100$

- In angle, example: 10^0, 20^0etc.

  $\text{Tan } \theta = VI/HI$

Example 1: Calculate slope between station A and station B, both staff stations are in front of dumpy station $X_{1.}$ Position of dumpy level station and staff station are in straight line. From dumpy level middle reading is taken on BM and RL of BM is 250 m then UR, LR, and MR taken on A & B. Detail of the readings are in the table below:



VI between A & B = RL of A – RL of B

VI between A & B = 249.3 – 248.1 = 1.2 m.

HI between A & B = Distance between X_1 to A - Distance between X_1 to B

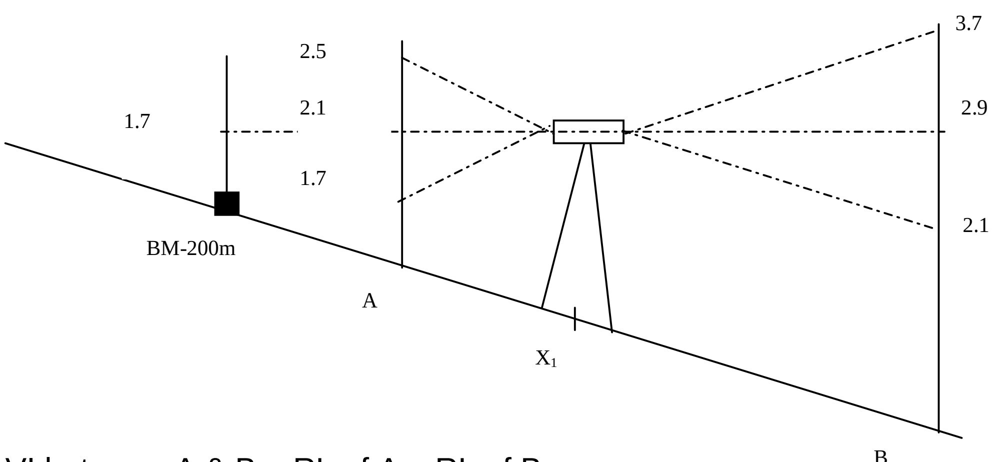
HI between A & B = 120 – 40 = 80 m.

Slope = (VI/HI) x 100

Slope = (1.2/80) x 100 = 1.5%

Example 2: Calculate slope between stations A & B. Position of dumpy level station X_1 is between staff stations A & B. Location of dumpy X_1 and staff stations A & B are in straight line. First middle reading is taken on BM then MR; UR & LR taken on A & B. Detail of the readings are as follows.

Dumpy Location	**Station**	**BS**	**IS**	**FS**	**HI**	**RL**	**Bearing**	**UR**	**LR**	**Distance from X_1**
X_1	BM	1.7			201.7	200				
	A		2.1		201.7	199.6		2.5	1.7	80
	B			2.9	201.7	198.8		3.7	2.1	160



VI between A & B = RL of A – RL of B

VI between A & B = 199.6 – 198.8 = 0.8m.

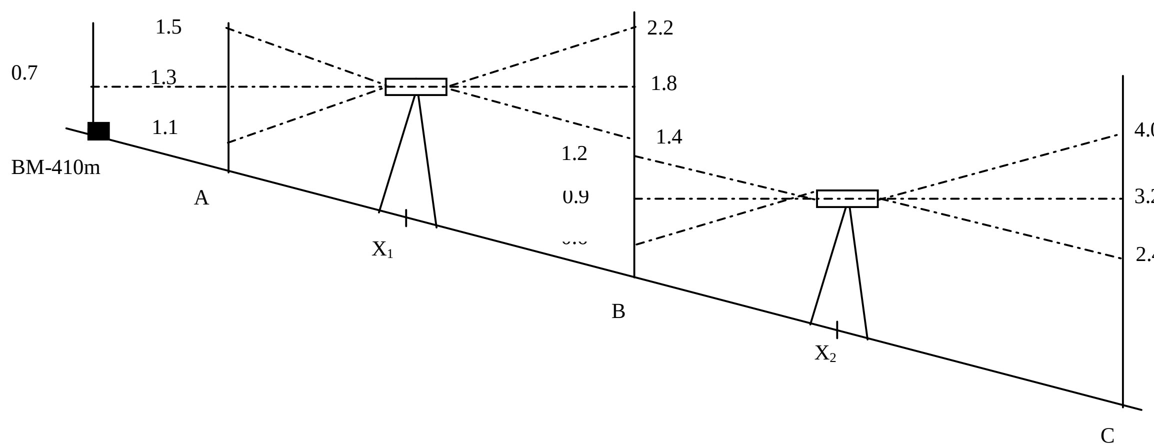
HI between A & B = Distance between X_1 to A + Distance between X_1 to B

HI between A & B = 160 – 80 = 240m.

Slope between A & B = (VI/HI) x 100

Slope between A & B = (0.8/240) x 100 = 0.33 %

Example 3: Calculate slope between staff stations A & C. Readings at the staff stations are taken from two locations of dumpy level. Locations of dumpy level stations X_1, X_2 and staff stations A, B & C are in straight line. From dumpy location X_1, first middle reading is taken on BM then MR, UR & LR taken on staff stations A & B. Now the dumpy level shifted to other location X_2 then MR, UR & LR taken on staff station B & C. Readings taken from dumpy station X_1 and X_2 are as mentioned in figure below.



Dumpy Location	Station	BS	IS	FS	HI	RL	Bearing	UR	LR	Distance from X_1
X_1	BM	0.7			410.7	410				
	A		1.3		410.7	409.4		1.5	1.1	40
	B			1.8	410.7	408.9		2.2	1.4	80
X_2	B	0.9			409.8	408.9		1.2	0.6	60
	C			3.2	409.8	406.6		4.0	2.4	160

VI between A & C = RL of A – RL of C

VI between A & C = 409.4 – 406.6 = 2.8 m.

HI between A & C = Distance between X_1 to A + Distance between X_1 to B + Distance between X_2 to B + Distance between X_2 to C

HI between A & C = 40 + 80 + 60 + 160 = 340 m.

Slope between A & C = (VI/HI) x 100

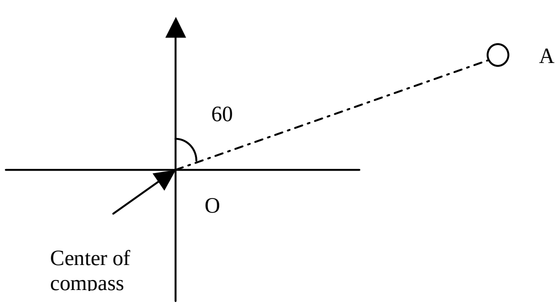
Slope between A & C = (2.8/340) x 100 = 0.82 %

Longitudinal section of a drain: Draw the longitudinal section of a drain. Readings are taken at the center of the drain bed at an interval of 10 m. The readings are as follows:

Chainage	R.L.
0	300
10	301
20	301.5
30	302
40	303
50	305.5
60	304.5
70	305
80	306
90	307
100	310

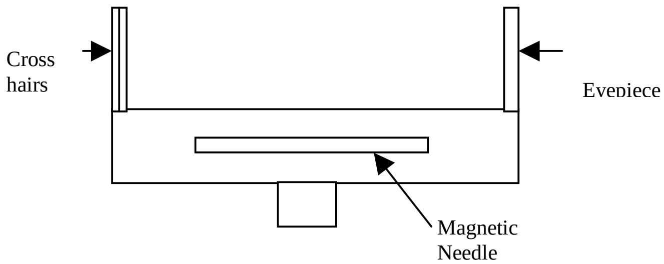
Compass Surveying

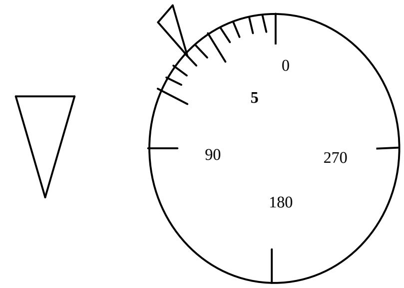
The basic requirements for drawing a map of an area are the bearings and also the distances of the survey stations from the reference points. Measuring tape or steel chain is mainly used for measuring the horizontal distances, while Prismatic Compass is generally used for measuring the horizontal angle, which is measured with respect to the North. The horizontal angle thus measured is called the "bearing" of that line.



Example: As per figure above, the bearing of the line OA is 60^0.

Part of Prismatic Compass:

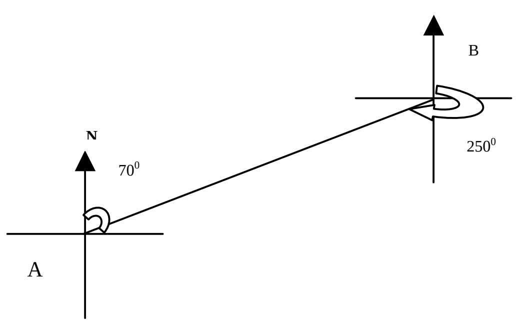


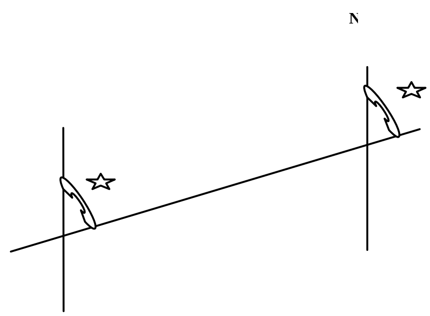


- The brass needle.
- The magnetic needle.
- The cross hairs.
- The prismatic eyepiece.
- Tripod stand.
- Zero to three hundred and sixty degree marks.
- Least count of the compass is 30 minutes (one degree is equal to 60 minutes).
- Magnetic needle always shows the North-South direction.

Key points related to the Compass

Back bearing and fore bearing:





- If bearing of a line AB is 70^0 then bearing of the line BA will be $70^0+180^0=250^0$, the fore bearing of the line AB is 70^0 and back bearing of the line AB is 250^0.
- If bearing of a line AB is 250^0 then bearing of the line BA will be $250^0-180^0=70^0$, here fore bearing of the line AB is 250^0 and back bearing of the line AB is 70^0.
- According to the principles of Geometry, if a straight line crosses the two parallel lines then their parallel angles must be equal. Therefore, the difference of fore bearing and back bearing always remains 180^0. If the fore bearing of a line is less than 180^0 then for finding out the back bearing of that line add 180^0

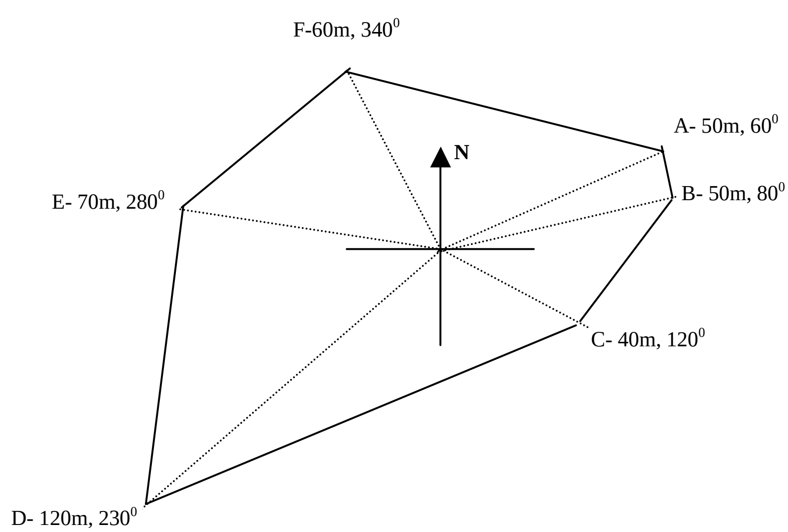
in the fore bearing and if the fore bearing of a line is more than 180^0 then for finding out back bearing of that line subtract 180^0 from the fore bearing.

Example1: Location of a Dumpy level is at X_1 and readings are taken from dumpy station to staff stations A, B, C, D, E and F. These are the readings taken for drawing a contour line. Draw the contour map.

Station	**UR**	**LR**	**Fore bearing**
A	3.7	3.2	60^0
B	2.5	2.0	80^0
C	3.1	2.7	120^0
D	3.3	2.1	230^0
E	3.0	2.3	280^0
F	1.1	0.5	340^0

First of all, find out the horizontal distance between dumpy station X_1 and the staff station A, B, C, D, E & F by using following formula: (UR-LR) x 100.

Station	**Horizontal distance (m)**	**Fore Bearing**
X_1A	50	60^0
X_1B	50	80^0
X_1C	40	120^0
X_1D	120	230^0
X_1E	70	280^0
X_1F	60	340^0



- First of all select a scale for drawing the map; scale of the map should be finalized considering the size of the paper and actual distances on ground. Example, Scale: 1CM=10M.
- Draw an arrow mark for showing the North direction on the drawing-paper.

- Mark a cross symbol on the drawing paper, which will represent the location of surveying instrument station X_1. Find out the direction of staff stations A, B, C, D and E with respect to the location of surveying instrument X_1 by marking with their respective bearings. Draw dotted straight lines in these marked directions.
- Find out the location of the staff stations A, B, C, D and E by marking their respective distances on the straight lines considering the scale of the map.

Example 2: The Dumpy level is at location X_1; following readings are taken on staff stations A, B, & C.

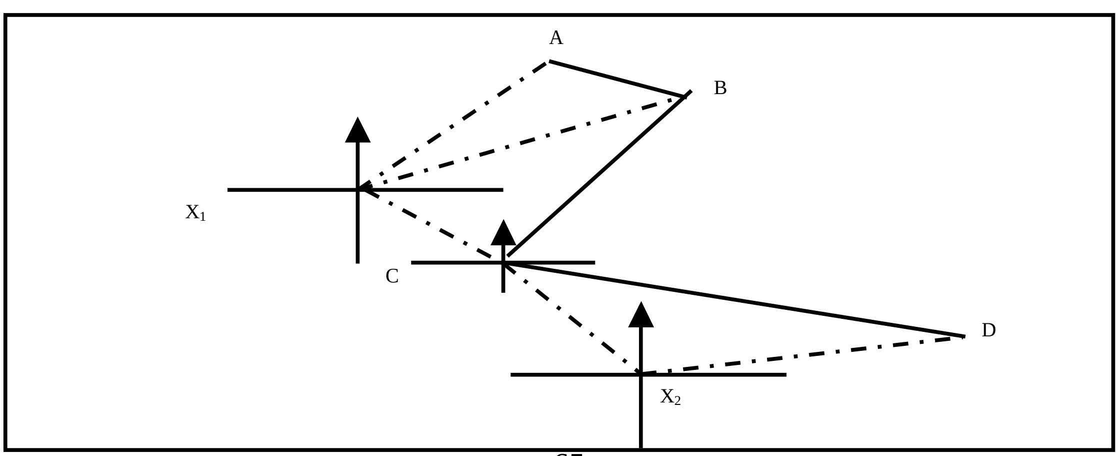
Station	UR	LR	Fore bearing
A	1.7	1.1	30^0
B	1.9	1.3	60^0
C	2.6	2.3	140^0

Now the dumpy level is shifted to other location X_2, and readings are taken on the staff station C, & staff station D. These are the readings of a contour line. Draw the contour map.

Station	UR	LR	Fore bearing
C	2.6	2.2	340^0
D	2.1	1.8	70^0

Find out the horizontal distance between the dumpy station X_1, X_2 and staff stations A, B, C & D by using following formula: (UR-LR) x 100.

Station	Horizontal distance (m)	Fore Bearing
X_1A	60	30^0
X_1B	60	60^0
X_1C	30	140^0
X_2C	40	340^0
X_2D	30	70^0



- First of all select the scale of the map considering the size of the drawing-paper and actual distances at the field. Example, Scale: 1CM=10M.
- Draw an arrow mark showing the North direction on the drawing-paper.
- Mark a cross symbol on the drawing-paper, the center of the cross is the location of the instrument station X_1. Find out the direction of the staff stations A, B and C with respect to the dumpy station. Draw dotted straight lines in these directions.
- Find out position of the staff stations A, B and C by marking their respective distances with respect to the scale of the map.
- Now the dumpy level is shifted to some unknown location. Unknown location of dumpy level X_2 has to be found out on the drawing-paper. The bearing of line X_2C is 340^0 then the bearing of CX_2 will be $340^0-180^0=160^0$. Mark a cross on the location of staff station C and draw the dumpy level position X_2 on the drawing-paper using the same method as described above.
- Draw a cross mark on the location of dumpy level X_2, and mark the position of the staff station D with reference to the dumpy level station X_2.
- Draw a smooth line joining all the marked locations of the station A, B, C & D, this is the contour map of the survey area.

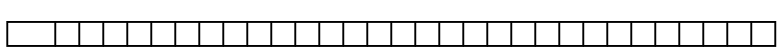
Minor Surveying Instruments

Chain and tape

Chain and tapes are used for measuring horizontal distances in the field. Measuring tapes can be of steel, coated linen, or synthetic material. They are available in different sizes of 20m, 30m, and 50 m.

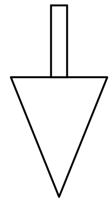
Measuring rods

A measuring rod is a straight wooden or steel stick with its length varying from 2m to 5m. The rod is usually marked in the same way as the measuring tape, and indicates measurement scale in centimeters, decimeters, and meters.



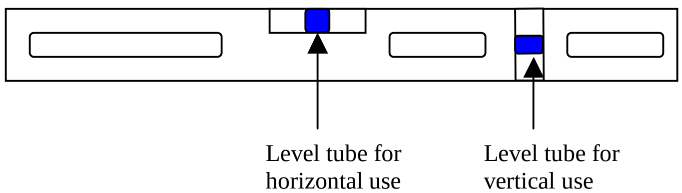
Plum bob

It is used for checking verticality of objects.



Carpenter level

It is used for checking the horizontality and verticality of the objects. Within a carpenter level there are one or more curved glass tubes, called as level tubes.

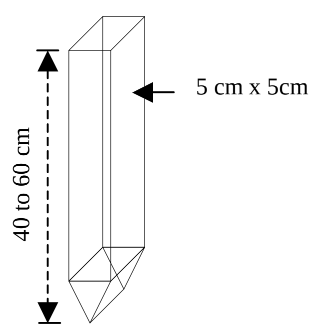


Ranging poles

Ranging poles are straight, round stalks, about 3 to 4 cm thick, and about 2m long. They are made either of wood or of metal. They are used for marking the survey station and also for setting out straight lines on the field.

Pegs

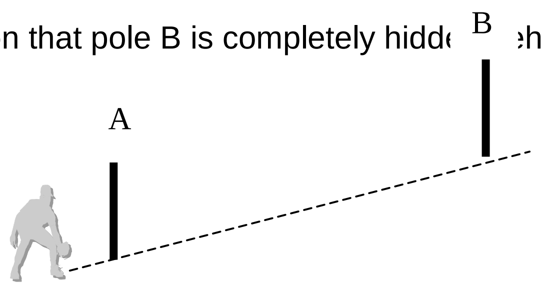
Pegs are used when certain points on the field require permanent markings. Pegs are generally made of wood and steel.



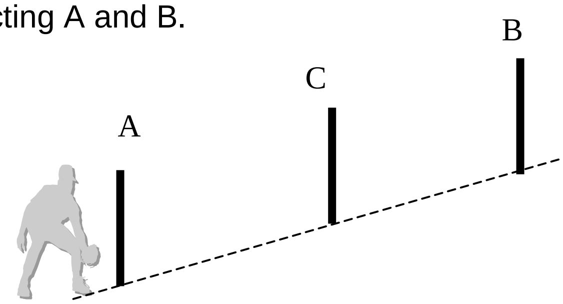
Setting out straight-line with the help of ranging pole:

The correct way to hold a ranging pole is to keep it loosely hanging between the thumb and the index finger, with its lower end kept 10 cms above the soil level. Whenever the observer indicates that the ranging pole is in right position, the assistant releases the pole. The sharp bottom point of the ranging pole leaves the mark on the soil exactly where the pole needs to be placed. Once in place, it should be checked if the ranging pole is vertical. This may be done either with the plumb bob or the carpenter level.

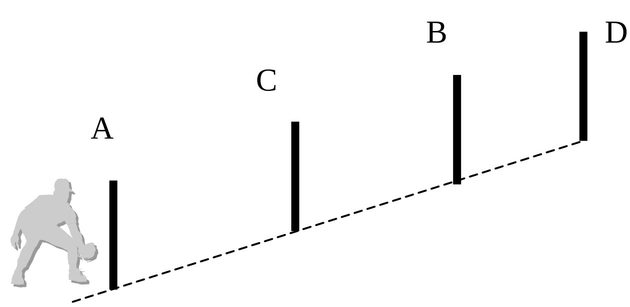
Step I: As shown in fig., pole B is clearly visible to the observer standing close to pole A. The observer stands 1 or 2 m behind pole A, closes one eye, and places himself in such a position that pole B is completely hidden behind pole A.



Step II: The observer remains in the same position and any pole placed by the assistant in between A and B, which is hidden behind pole A, would be on the straight line connecting A and B.

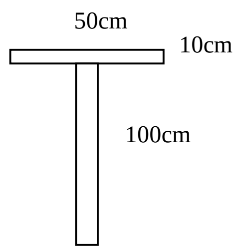


Step III: The observer remains in the same position and any pole D placed behind B, which is hidden behind pole A, B and C, would be on the extension of the straight line.



Boning Rod

The boning rods are T- shaped and made of wood. Their height is normally 110cm and the cross lath is 50 x 10cm.

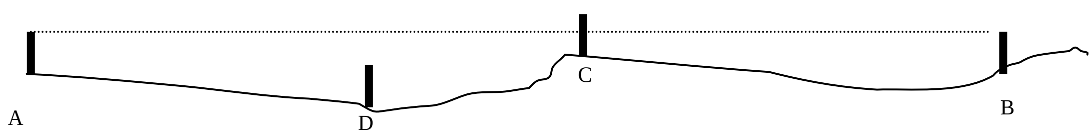


Boning rods are used to set out horizontal lines or lines with a constant slope. The elevation of two points on the line must be known.

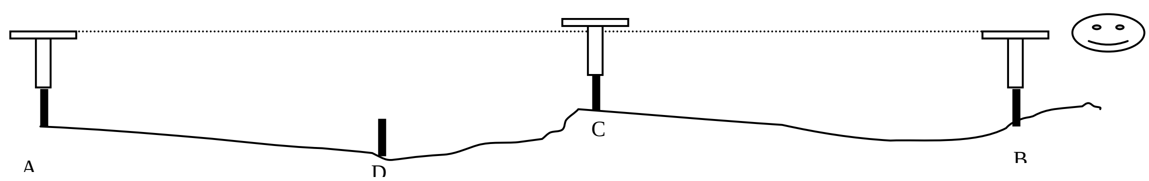
Setting out horizontal line with Boning rods:

Suppose a horizontal line has to be set out between the benchmark A and B. Bench mark A and B have the same elevation. The procedure is:

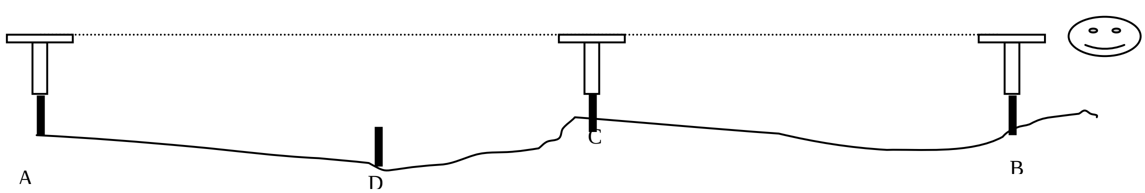
Step I: Set out straight line between A and B and place a peg at regular interval.



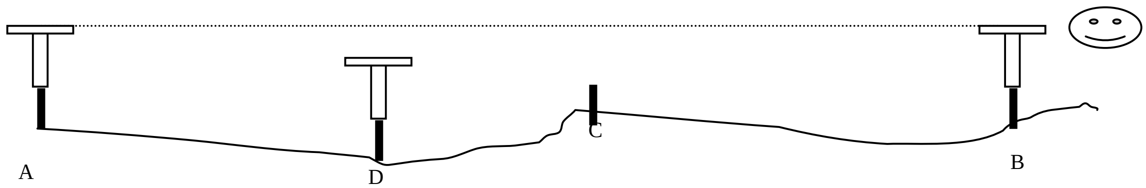
Step II: Place boning rod on the tops of the two benchmarks A and B and also on the top of peg C. The observer looking just over the top of the boning rod A tries to bring the tops of the boning rod ABC in the line. As can be seen from fig., the tops of the boning rods are not in line.



Step III: Hammer peg C further into the soil. It may be necessary to excavate some of the soil-surrounding peg C in order to be able to lower peg C sufficiently. The top of the peg C is at the correct elevation when, looking over the top of boning rod A, the tops of the boning rods A, C and B are in line.

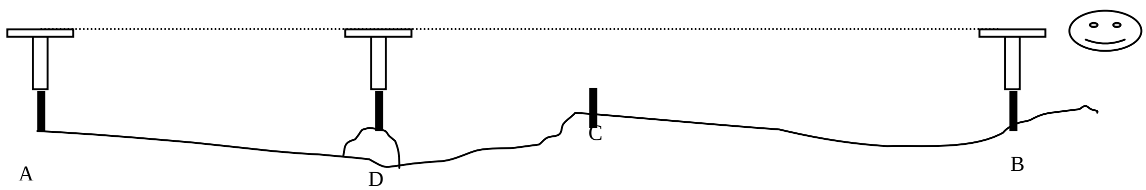


Step IV: Place a boning rod on peg D. When looking over the tops of the

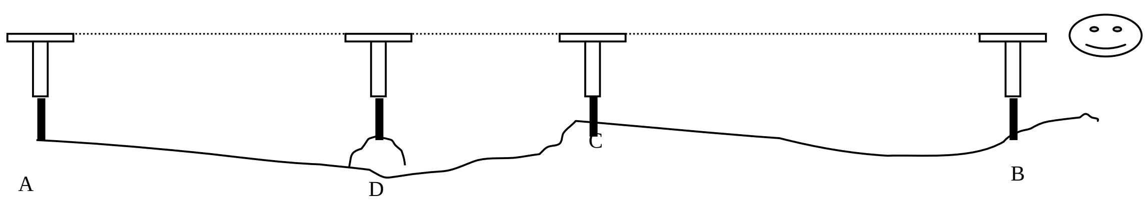


boning rods A and B, it is not possible to see the top of the boning rod on peg D, as peg D is too low.

Step V: Replace peg D by a longer peg or pull out and add some soil in the immediate surroundings of D and hammer peg D again into the soil.



Step VI: The two benchmark A and B and the peg C and D all have the same elevation. Line ACDB is in horizontal plane.

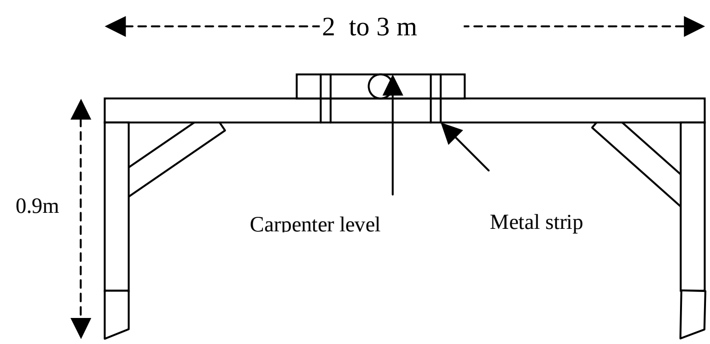


Setting out slopes by Boning rod

The use of boning rods when setting out a slope is the same as described in the setting of horizontal line. Only in this case, the benchmarks A and B do not have the same elevation. Benchmark A is either higher or lower than B.

The N- Frame level

This instrument, used to set out contour lines or slopes, consists of a wooden frame (a main lath, 2 legs and 2 cross poles) as shown in fig. On the main lath, a carpenter level is firmly fixed.



Testing the N-Frame level

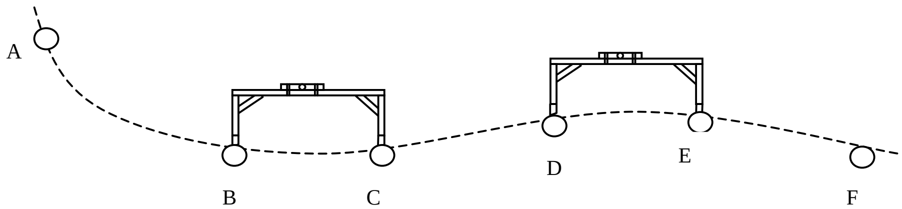
Before fixing the carpenter level to the frame, the instrument must be tested. The frame is placed on two points, which have the same elevation. If the bubble of the level tube is not exactly in between the marks, the carpenter level must be adjusted.

Setting out contour line by N-Frame level

Starting from peg A, a contour line has to be set,

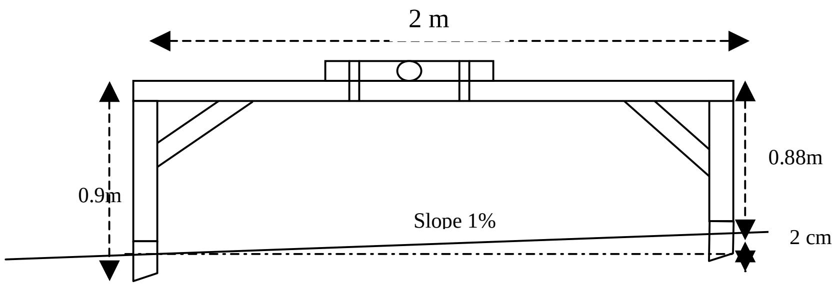
Step I: One leg of the instrument is placed closed to peg A, By turning the frame around this leg, a position of the frame is found such that the second leg is on the ground and the bubble of the carpenter level lies between the marks. This means that the spot thus found by the second leg of the frame is at the same elevation as that of the starting point. Both points belong to the same contour.

Step II: The frame is moved towards D to the newly placed peg and the procedure is repeated until the end of the field is reached.

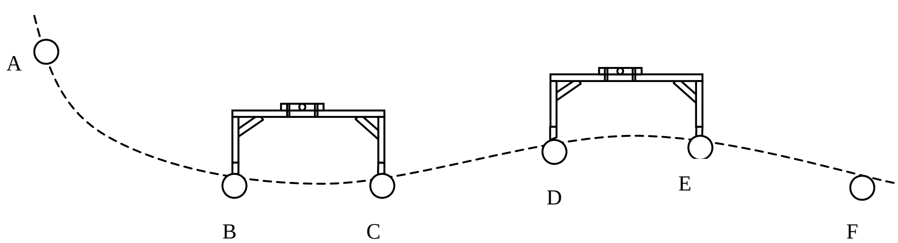


Setting out slopes by N- Frame

Suppose that the slope of a graded bund to be set out on the field is 1%. In order to use the N- frame to set out slopes, it requires a modification; one leg has to be shortened. In this case, one leg has to be shortened by 2 cm, as the length of the main lath is 2 m and the required slope is 1%. This may be done by using the formula: VI = (S x HI)/100.

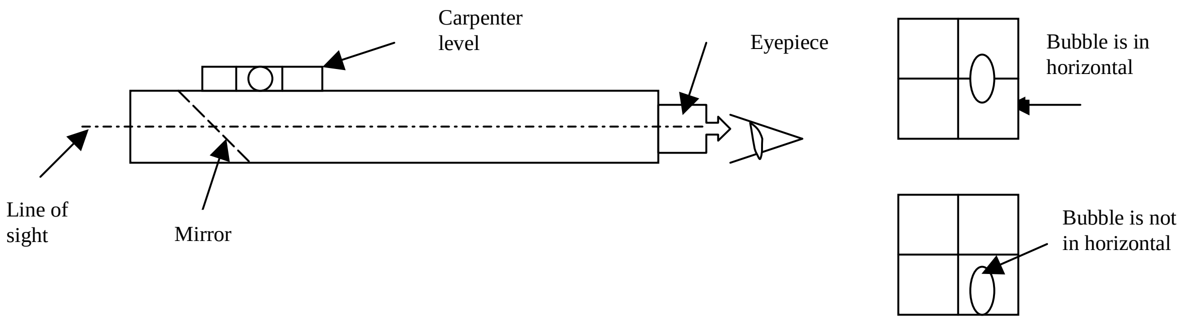


The shortest leg of the N-frame is placed close to the starting point. By turning the frame around this leg, a position is found such that the second leg is on the ground and the bubble of the carpenter level is in between the marks. The spot thus found is 2 cm lower than the starting point. The frame is moved so that the short peg leg gets placed near the peg B. The procedure is repeated until the end of the ground is reached. The succession of pegs thus placed form a line with a slope of 1%.



The Hand Level

The Hand Level consists of a 10-12 cm long tube with an eyepiece at one end and two cross hair lines at the other end. A small carpenter level is also attached to the tube. When the operator looks through the eyepiece, the mirror inside the tube reflects (on the right hand side) the position of the bubble of the carpenter level. The instrument is made in such a way that when the bubble is in sight on the horizontal hairline, the instrument is horizontal and the line of sight is horizontal. For greater stability a forked bush pole can support the instrument, with the metal plate attached at the bottom. This ensures that the instrument is always at the same height above the ground level. Setting out contour and slope is similar to the Dumpy Level.

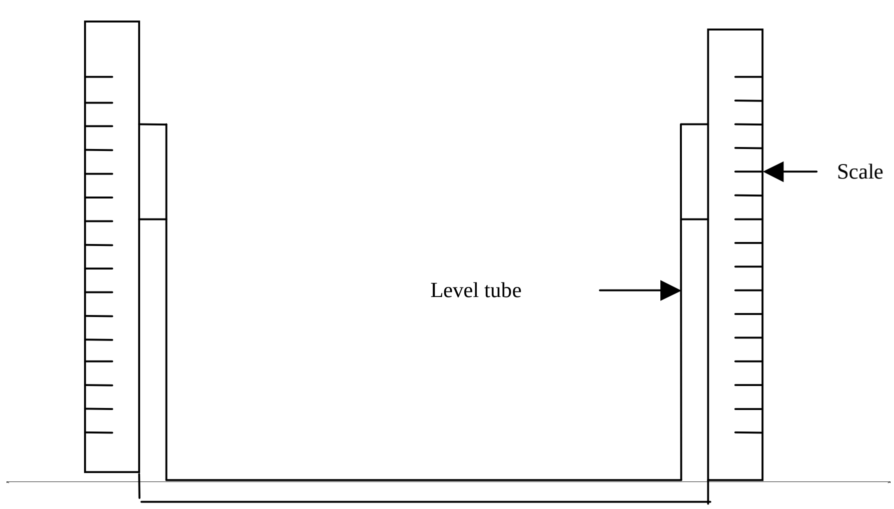


Pipe Level

Since, the village team normally carries out the watershed survey, so this is a simple leveling instrument, which can be easily learned by the village team. It can be used for drawing contour lines, slope measurements & undertaking leveling works. In a watershed it is mainly used for drawing contour line for the implementation of contour trench and contour bunds. It works on the principle of water that water always rests in a horizontal plane.

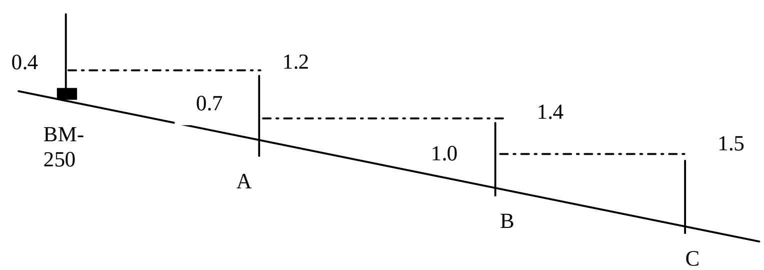
Parts of Pipe Level:

- Two scales about 1.5 m long and graduated at an interval of 1 cm. Made up of bamboo sticks.
- Five to ten meter long transparent rubber tube.
- Colored water and a container.



R.L. calculation by using pipe level:

- Fill the water in a bucket and put it on higher elevation and mix any dark color in it.
- Put one end of pipe in bucket and from other end suck the water by mouth. Suck out water in a continuous flow for at least one minute.
- Fix the pipe on the scales by using a transparent tape.
- One scale is put on the BM and other on the station A. Read both the scales at the level of water. Readings at BM and station A is 0.4m and 1.2m.
- Now shift the scale of BM to station B with scale of station A remaining at previous position. Now readings at station A and station B are 0.7 m and 1.4m.
- Now shift the scale of A to station C with scale of station B kept at the previous position. Now readings at station B and station C is 1.0 m and 1.5 m.
- Now fill up all the readings in a field book.

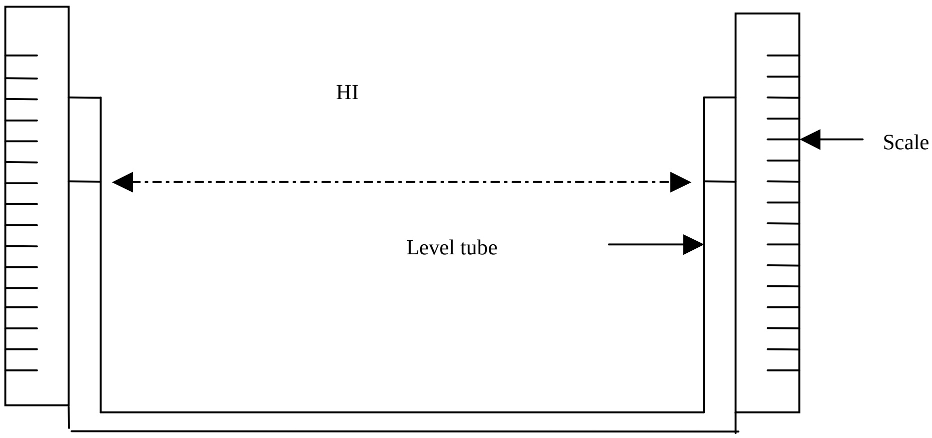


Station	Reading	Rise	Fall	RL
BM	0.4			250
A	1.2		0.8	249.2
A	0.7			
B	1.4		0.7	248.5
B	1.0			
C	1.5		0.5	248

- Fill up the column of station and reading in the field book in the same sequence as the readings taken on it.
- Make the couple in the column of station and reading in the field book.
- Put the known RL of BM in the column of RL.

- Deduct second reading from the first reading in each couple. If the answer is positive than put in the Rise column and in case of negative answer put it in a fall column.
- For the RL calculations, cumulative add or deduct the rise and fall. Add in case of rise and deduct in case of fall.

Slope measurement through Pipe Level:



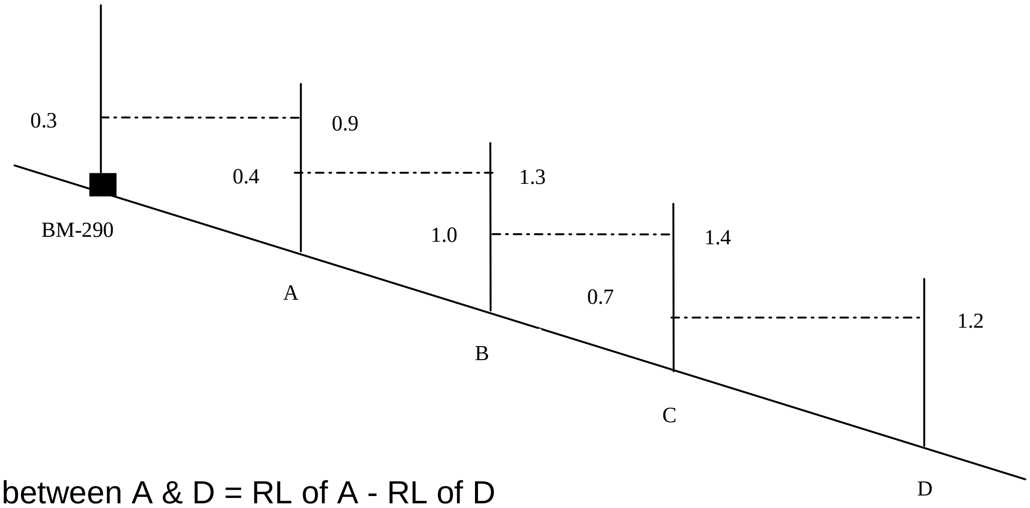
- We know slope (S) = (VI/HI) x 100

  Here, VI= Vertical interval between any two point.

  HI= Horizontal interval between any two point.
- Distance measured from mark of water of one scale to other scale is HI.
- VI is the difference of RL between two points.

Example: Calculate the slope between A & D. the readings are as follows:

Station	**Reading**	**Rise**	**Fall**	**RL**
BM	0.3			290
A	0.9		0.6	289.4
A	0.4			
B	1.3		0.9	288.5
B	1.0			
C	1.4		0.4	288.1
C	0.7			
D	1.2		0.5	287.6



VI between A & D = RL of A - RL of D

VI between A & D = 289.4-287.6 = 1.8m.

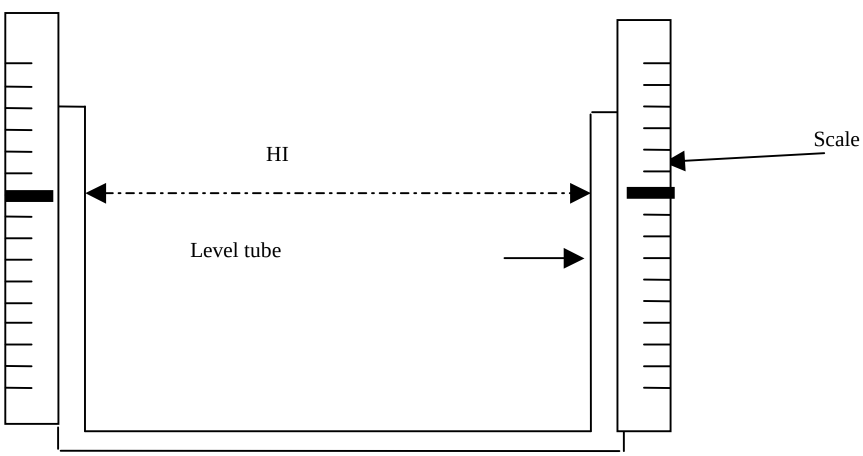
HI between A & D = Distance AB+ Distance BC+ Distance CD

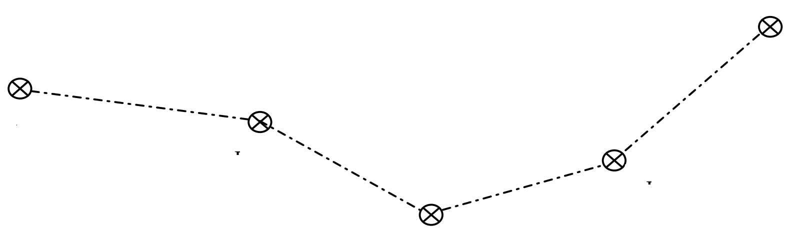
HI between A & D = 4+5+6 = 15m.

Slope (S) = (VI/HI) x 100

Slope (S) = (1.8/15) x100 = 12%

Contouring by pipe level:

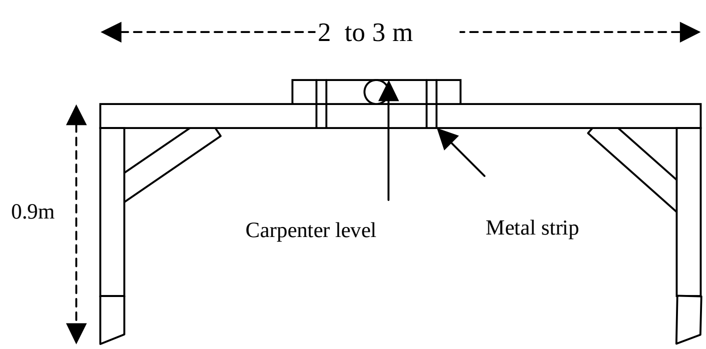




- Fill up the color water into the pipe and fix the pipe with both the scales by a transparent tape.
- Now put both the scales closely on a plain surface and mark the stable water level on the scale by a marker pen. Pipe level set is ready for contouring.
- Start the contouring from the station A, which is a benchmark point for contouring.
- Put one scale at station A and the other one near to next point B. Now surveyor at the station nearer to B is to watch the mark. If water level is below the mark then he has to put the scale in lower elevation and if water level is above mark then he has to put the scale in higher elevation side. As soon as water level and mark point reached at same level that is the contour point B. Mark point B by wet lime.
- Now surveyor at A has to shift with scale at nearer to station C and other surveyor at station B has to remain at the same position. Repeat the above said procedure As soon as water level and mark point reach the same level, that is the contour point B. Mark point B by wet lime.
- Repeat the above procedures for marking the contour point D, E & F. Join all the point by wet lime that is the contour line.

The N- Frame Level

This instrument, used to set out contour lines or slopes, consists of a wooden frame (a main lath, 2 legs and 2 cross poles) as shown in fig. On the main lath, a carpenter level is firmly fixed.



Testing the N-Frame level:

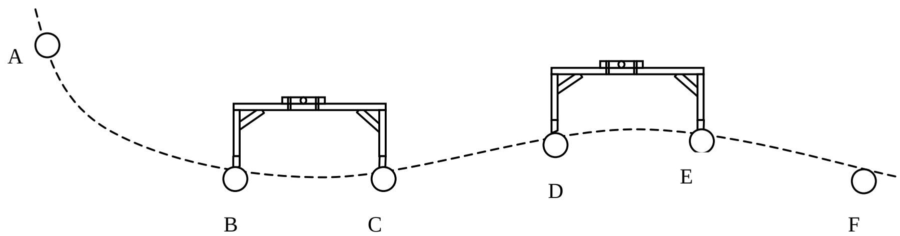
Before fixing the carpenter level to the frame, the instrument must me tested. The frame is placed on two points having the same elevation. If the bubble of the level tube is not exactly in between the marks, the carpenter level must be adjusted.

Setting out contour line by N-Frame level:

Starting from peg A, a contour lime has to be set,

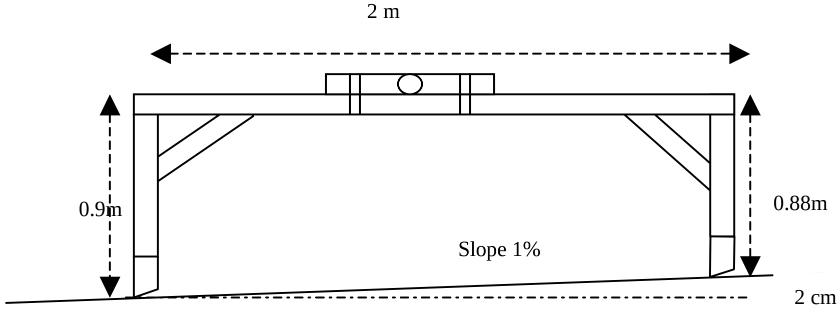
Step I: One leg of the instrument is placed closed to peg A, By turning the frame around this leg, a position of the frame is found such that the second leg is on the ground and the bubble of the carpenter level lies between the marks. This means that the spot thus found by the second leg of the frame is at the same elevation as the starting point. Both points belong to the same contour.

Step II: The frame is moved to the newly place peg and the procedure is repeated until the end of the field is reached.

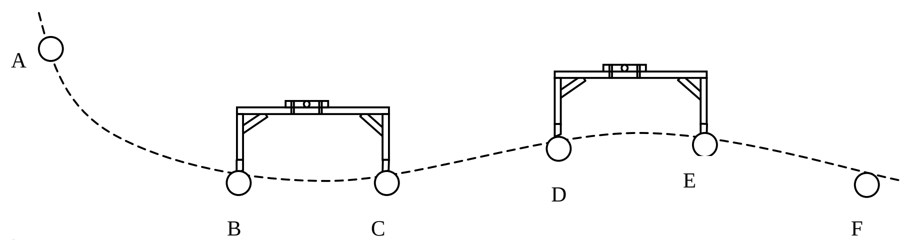


Setting out slopes by N- Frame:

Suppose that the slope of a graded bund to be setout on the field is 1%. Then, in order to use the N- frame to set out slopes, it shall require a modification. One leg has to be shortened. In this case, one leg has to be shortened by 2 cm, as the length of the main lath is 2 m and the required slope is 1%by using the formula: VI = (S x HI)/100.



The shorter leg of the N-frame is placed close to the starting point. By turning the frame around this leg, a position is found such that the second leg is on the ground and the bubble of the carpenter level is in between the marks. The spot thus found is 2 cm lower than the starting point. The frame is moved and the shorter leg is placed near the peg B. The procedure is repeated until the end of the ground is reached. The succession of pegs thus placed form a line having a slope of 1%.



A- Frame:

Fig. 9.5 An A-Frame. The A-frame is so called because of its shape. A weight is suspended with the help of a string/rope from the top of the A-frame. First the A-frame is place on level ground (this is checked by a spirit level) and the position of the string/rope carrying the weight against the horizontal bar of the A-frame is noted. Now when the A frame is taken to the field, one of the legs of the 'A' is fixed and the other is moved until the string again is at the mark. This implies that the second leg is at the same level as the first, i.e., lies on the same contour as the first one. If we repeat the same process starting from the second point we will have found a third point on the contour. We can continue this to trace the contour line fully. (Adapted from Mahanot and Singh)

Chapter VII: Soil and water Conservation Treatments

Ridge area treatment forest regeneration and plantation

On slopes higher than 25% in the ridge area, it is advisable to undertake vegetative interventions only. Where the ridge has an existing forest with some vitality, the main thrust should be towards protection and regeneration. In other situations, plantation may need to be undertaken. In this module we highlight the role of shrubs in dryland afforestation and also provide a short list of those suitable tree, grass and shrub species, which could be usefully integrated into such an afforestation programme.

Ridge area treatment contour trenching

Contour trenching is a simple, and a low-cost method of checking the velocity of runoff in the ridge area of any watershed. A contour trench is a trench dug along a contour line. A contour line is a line, which joins together points of the same elevation. Digging a trench along such a line increases the chances of containing runoff for a longer period of time within the trench. It is also true that if trenches were not to follow a contour, such digging could actually increase the possibility of soil erosion because there would be a rise in the velocity of runoff following an increase in the slope of the land.

Objectives:

- Slowing down the velocity of runoff
- Checking soil erosion, and
- Improving local soil moisture profile

Contour trenches are constructed in the ridge area of a watershed. Rainwater, which falls in this area, flows unchecked carrying with it eroded soil into the flatter portion of the watershed referred to as the "valley". This eroded soil gets deposited as silt in the reservoirs and ponds, thereby reducing their life. Thus, any water harvesting work undertaken in the valley will become meaningless unless appropriate measures such as contour trenching are undertaken to control runoff and soil erosion on the ridge. Contour trenches serve to collect the rainwater that falls in the ridge area. This way the soil moisture profile in the area adjacent to the trench gets improved. Along with the water, the eroded fertile topsoil also gets deposited in the trench. It is, therefore, necessary to combine trench construction with plantation.

Location:

- If the slope of the ridge area is 25% or more, the best form of treatment is the planting of grasses, shrubs and trees. This is because for contour trenches to be effective on such high slopes, they will have to be constructed at very close intervals, which could end up causing more soil erosion due to excessive digging.
- On the other hand, if the slopes are less than 10%, even then contour trenches are not considered to be the best measure. This is because in such a situation, in comparison to contour trenches, contour bunds are a more effective means of checking runoff and soil erosion. In a contour bund, water not only stops in the excavated portion but also against the bund. Therefore, wherever possible, contour bunds must be constructed in place of contour trenches. However, on very high slopes, it is not possible to make contour bunds since there is a great danger of the bunds breaking.
- Thus, given the above considerations, contour trenches are the most appropriate where the slope of the ridge area lies between 10-25%.
- It is an ideal treatment for the non-agricultural land.
- If the depth of soil is less than 20cm, avoid the CCT; CCT should also be avoided in black cotton soil areas.

The Distance Between Trenches:

The distance between the two successive trenches depends on the volume and the velocity of runoff they are expected to handle. This in turn depends on:

- The quantum of rainfall: The greater the rainfall, the lesser the distance
- The permeability of the soil: The more permeable the soil, the greater shall be the distance
- The slope of the land: The greater the slope, the lesser the distance

That is, as the volume and velocity of runoff increase due to any reasons given above, the trenches should become more closely spaced. In several watershed programmes, however, a specific procedure has been adopted for fixing the intervals between trenches:

"The vertical interval between contour trenches is fixed at 1m".

Thus, with a constant vertical interval of 1m, the contour trenches would be spaced at a horizontal interval of 20m on a 5% slope and 10m on a 10% slope. However, one must not follow this rule blindly without taking into account the catchment area that each contour trench has to handle. For example, on high slopes one may end up making too many trenches even though there is very little water, which each trench needs to handle. And on low slopes, very few trenches are made which however are unable to intercept most of the runoff, since each trench is expected to do much more than its fair share of work. In practice, thus, one must fix the maximum and minimum horizontal interval between the two successive contour trenches in a way, which is depicted as follows:

- On high slopes, the trenches should be close to each other but never closer than 10 m.
- On low slopes, the trenches should be far from each other but never farther than 30 m.

Thumb rule: for the vertical interval between two rows.

V.I.= Slope (%)/C, where value of C = 12 for the medium rainfall.

It is commonly expressed in term of vertical interval (VI), which is defined as the difference in elevation between the two similar points on two consecutive bunds. The basic principle involved in fixing the spacing between the two bunds is to keep the velocity of runoff below the critical value, which creates scour.

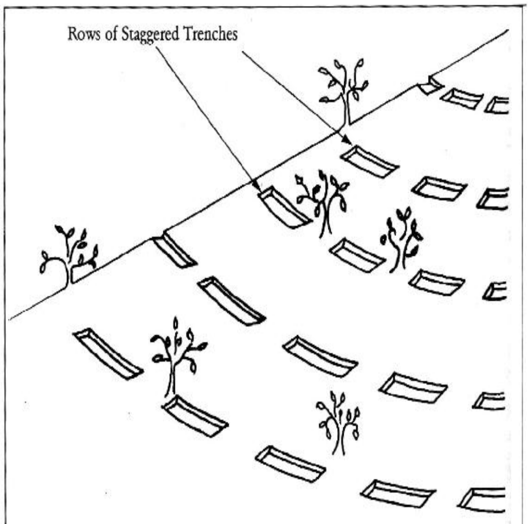
Vertical interval is usually expressed as:

$VI = 0.305 \times [(S/a) + b]$

Where VI = Vertical Interval in meter, S = Slope in percent, a and b = constants specific to particular region. For soil with good infiltration rates values of a and b are respectively taken as 3 and 2 whereas for soils of low infiltration rates the corresponding value are 4 and 2, respectively.

Staggered vs. Continuous Trenching:

Over time, experience of watershed programmes 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.



Contour trenches should always be staggered. In this way mistakes made in contouring are avoided. To ensure that water does not escape from the undug gaps, another line of contour trenches is dug on the next contour below covering these gaps

Therefore, instead of making trenches continuously, they should be made in a staggered and discontinuous manner. Dig a trench 4 m long on a contour line. Give a gap of 4 m. Dig another 4 m trench along the contour. The trenches are further dig in the similar fashion along this particular contour. Then, come to the next contour line. Begin digging in a stretch, which covers the gap left in the higher contour line. The gaps in this contour line should fall below the trenches in the higher contour line. In this way, we maximize the amount of harvested runoff by the trenches. In other words, chains of staggered trenches should be made along successive contour lines so that water left by one line of trenches is captured by the immediately lower line. And so on . . .

In areas where there is an abundance of trees and vegetation, gaps in excavation are in any case essential to allow space for the roots of the trees to spread. Also, where there are hard rocks underneath the soil, trenches must be staggered.

Design: Size of trench depends on the depth of soil and also on some other factors of watershed. Based on the above parameters different sizes of trenches have been planned. The sizes of trenches are as follows:

Sr. No.	Width	Depth
1	0.50 m	0.50 m
2	0.45 m	0.45 m
3	0.60 m	0.45 m
4	0.60 m	0.30 m
5	0.30 m	0.30 m

In general, the most popular size has been used in the many watersheds is as follows:

- **Depth:** 50 cm
- **Width:** 50 cm
- **Berm:** The mud excavated is piled up 20 cm away, downstream of the trench. This gap between the trench and mud is called the berm. This distance is essential so that this mud does not fill up the trench again.
- **Plantation:** If grass has to be planted along the trenches, then the excavated mud should be piled up in a 10cm. high rectangular layer. If trees have to be planted, they should be planted either in the space after the trench or on either side of the trench.

Contour Trenches: Step-by-Step:

- Measure the slope in one section of the ridge area. Ensure that it is between 10 - 25%;
- Draw a straight line with wet lime between the highest and the lowest points along the slope;
- Decide the interval between successive lines of trenches;
- On the straight line, marks points at the decided interval;
- Starting from each mark, demarcate the contour line;
- Dig staggered trenches along these contour lines;
- Depending on the specific conditions (such as thick vegetation, rocks etc),

- leave gaps in the excavation from place to place;
- Make sure that the water left out of one line of trenches is stopped by the line of trenches below;
- Undertake plantation as seems appropriate;

Contour Trenches: Don’ts

- Do not make trenches on slopes higher than 25%. Instead adopt vegetative measures
- Do not make trenches on slopes less than 10%. Instead construct contour bunds
- Do not excavate trenches where there is already dense vegetation
- Do not plant inside the trench
- Do not excavate if roots of a tree are encountered
- Do not excavate trenches across large streams or drainage lines

Ridge area treatment earthen contour bunding

Contour bunding is a simple and low-cost method of checking the velocity of runoff in the ridge area of any watershed. A contour bund is a bund constructed along a contour line. A contour line is a line, which joins together points of the same elevation. Making a bund along such a line increases the chances of containing runoff for a longer period of time within the bund.

Objectives:

- Slowing down the velocity of runoff
- Checking soil erosion
- Improving local soil moisture profile

Contour bunds are constructed on the ridge area of a watershed. Rainwater, which falls in this area, flows unchecked carrying with it eroded soil into the flatter portion of the watershed - the "valley". This silt gets deposited into the reservoirs and ponds, thereby reducing their life. Thus, any water harvesting work undertaken in the valley, will become meaningless unless appropriate measures such as contour trenching and bunding are undertaken to control runoff and soil erosion on "the ridge. Like contour trenches, blinds also collect the rainwater that falls in the ridge area. This way the soil moisture profile in the area adjacent to the blind is improved. Along with the water, eroded fertile topsoil also gets deposited in the blind. It is, therefore, important to combine contour blinding with appropriate vegetative measures.

Location:

- If the slope of the ridge area is 25% or more, the best form of treatment is the planting of grasses, shrubs and trees. This is because for contour trenches or bunds to be effective on such high slopes, they will have to be constructed at very close intervals. This could end up causing more soil erosion, as excessive excavation would loosen the topsoil. On high slopes, it is not possible to make contour bunds since there is a great danger of the blinds breaking due to overtopping.

- If the slopes are between 25% and 10%, even then the contour bunds are not the best measure because of reasons already mentioned under high slopes. In such situations, contour trenches are more effective means of checking runoff and soil erosion.
- Thus, under the above considerations, contour bunds are the most appropriate means where the slope of the ridge area is below 10%.
- Normally farm bunding should be on contour line but it is done and governed by the previous experiences of the farmers.

The Distance Between Contour Bunds:

The distance between two successive bunds depends on the volume and the velocity of runoff they are expected to handle this in turn depends on:

- The quantum of rainfall: the greater the rainfall, the lesser the distance
- The permeability of the soil: the more permeable the soil, the greater the distance
- The slope of the land: the greater the slope, the lesser the distance

That is, as the volume and velocity of runoff increase due to any reason given above, the bunds should become more closely spaced. In several watershed programmes, however, we have found that the vertical interval between bunds is fixed and the horizontal interval gets determined by the slope. Thus, for example, with a constant vertical interval of 1m, the contour bunds would be spaced at a horizontal interval of 10m on a 10% slope and 100m on a 1% slope. However, one must not follow this rule blindly without taking into account the catchment area that each contour bund has to handle. For example, on relatively higher slopes one may end up making too many bunds even though there is very little water, which each bund needs to handle. And on low slopes, too few bunds are made which are unable to intercept most of the runoff, since each bund is expected to do much more than its fair share of work. In practice, one must fix the maximum and minimum horizontal interval between two successive contour bunds as follows

Thumb rule:

- On high slopes, the bunds should be close to each other but never less than 30 m.
- On low slopes, the bunds should be far from each other but never more than 60 m.

It is commonly expressed in term of vertical interval (VI), which is defined as the difference in elevation between two similar points on two consecutive bunds. The basic principle involved in fixing the spacing between two bunds is to keep the velocity of runoff below the critical value, which creates scour.

Vertical interval is usually expressed as:

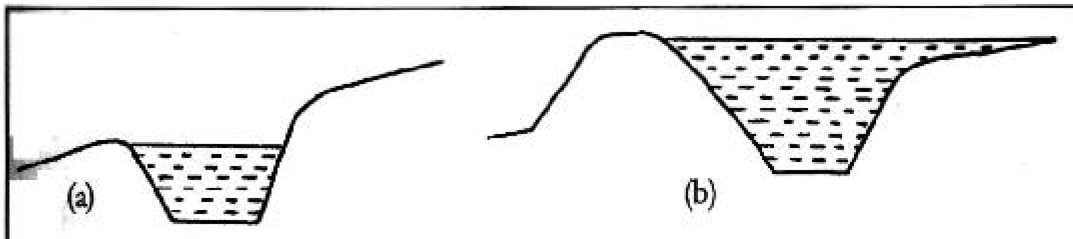
$VI = 0.305 \times [(S/a) + b]$

Where VI = Vertical Interval in meter, S = Slope in percent, a and b = constants specific to particular region. For soil with good infiltration rates values of a and b are respectively taken as 3 and 2 whereas for soils of low infiltration rates the corresponding value are 4 and 2, respectively.

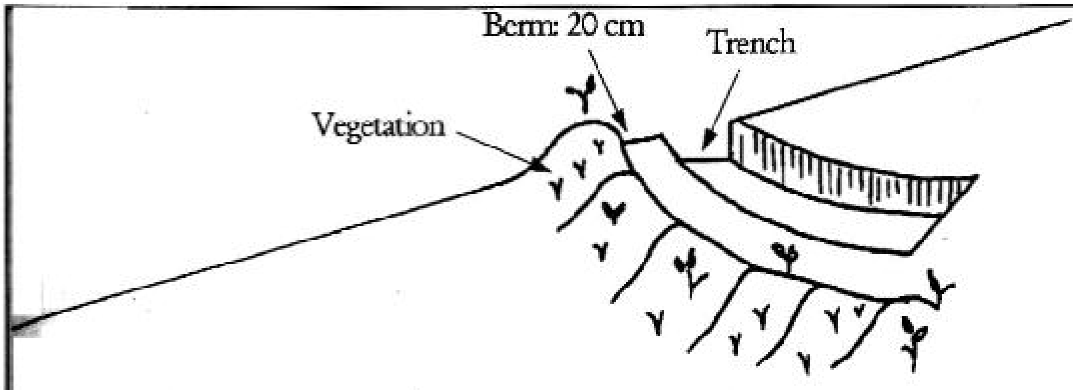
Plan the bunding with the group of farmers and channelize the excess water in to nearby natural drain. Bunding on black cotton soil should be planned carefully and plan the excess water to drain safely into the near by natural drain. The position and the number of outlets are very important.

Contour Bunds vs. Contour Trenches:

Of these two engineering methods of treatment of the ridge area, bunds are superior to trenches in one respect – a rupees spent on contour bunds would create greater storage than a rupee spent on contour trenches. In a contour bund, water not only stops in the excavated portion but also against the bund. Therefore, wherever possible, contour bunds must be constructed in place of contour trenches.



In comparison to contour trenches, contour bunds stop a greater volume of water: (a) in a contour trench, water collects only in the trench whereas, (b) in a contour bund, water collects both in the trench as well as against the bund



If grass is to be planted near the trench this should be done on a bed 10 cm. high, prepared with the excavated earth. If trees are to be planted this should be done on the berm or on either side of the trench

However, bunds are inferior to trenches with respect to the safety and maintenance operations. Bunds always face the danger of being breached by overtopping. Also, bunds can get eroded by rain and may be frequently trampled upon by animals. So, they require more maintenance operations. The danger of overtopping makes bunds inadvisable in the regions with high slopes, where an intense burst of rainfall can cause high volume runoffs, and can overtop bunds. Where there are series of bunds on high slopes, the breach in one bund can cause several bunds below to be breached. Under such considerations contour trenches are superior to contour bunds.

Design:

Situation 1: In Permeable Soils

- **Height:** 60 cm
- **Settlement Allowance:** 20-25%
- **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%

- **Top Width:** 20-30 cm
- **Upstream Slope:** 1:1
- **Downstream Slope:** 1.5:1. In gravelly soils, both upstream and downstream slopes can be kept at 0.75: 1
- **Waste Weir (Exit):** On relatively flat permeable ridge area, an exit need not be given. However, in sloping lands, there is every danger of the bund breaking without an exit. Rapidly flowing water may overtop the bund or slowly erode it. Therefore, provision of an exit becomes imperative. For purpose of water storage, the exit should be placed slightly above ground level. The water will stop at the bund for a short time and then flow out of the exit. In such cases, however, it is extremely important to strengthen those sections of the bund, which are adjacent to the exit.
- **How Should the Soil be excavated for Construction of Bunds?** Soil should never be excavated continuously because this will cause the formation of channels, which will erode soil and carry out water. Instead, several discontinuous trenches should be dug in which soil and water can collect. The width of these trenches should be 1 m. Where excavation has been discontinued a small tooth should be constructed at 90 degrees from the bund. This tooth should be about 2 m. long and should have a maximum height of 30 cm. If stones are available, this tooth should be made entirely of stones. Otherwise, do not forget to provide a stone exit in teeth made of mud. In this way, there will a series of trenches and teeth, which will act as repositories of water and prevent soil erosion.
    - If the slopes are low to moderate, the excavation should be done on the upstream side of the bund. If they are high and the soil depth exceeds 0.5 m., the bund can be constructed with mud excavated from the downstream side of the bund. The difference is that while excavation upstream would increase the slope of the land near the bund, excavation downstream would not.
    - There should be a distance of at least 30 cm between the edge of the excavated portion and the beginning of the bund. This gap between the bund and mud is called the berm. This prevents mud

from sliding back into the excavated portion.

- **Bund Protection with Plantation**: Wherever possible, contour bunds must be protected against erosion by planting grass on the bunds. Grass species such as Cenchrus celiaris, Stylosanthes hamata, Deenanath (Pennisetum purpureum) etc. could be used for bund protection.

Situation 2: In Impermeable Soils

- **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 water logging 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 water logging, a surplus weir 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.
- **Berm:** There should be a distance of at least 30 cm between the edge of the excavated portion and the beginning of the bund. This gap between the bund and mud is called the berm. This prevents mud from sliding back into the excavated portion.
- **Settlement Allowance:** The fine particles of clay have a natural tendency to settle. 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.
- **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 stabilize the bunds.
- **Upstream Slope:** 1.5:1
- **Downstream Slope:** 2: 1

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.
- **Bund Protection with Plantation:** Wherever possible, contour bunds must be protected against erosion by planting grass on the bunds. Grass species such as Cenchrus celiaris, Stylosanthes hamata, Deenanath (Pennisetum purpureum) etc. could be used for bund protection.
- **Waste Weir (Exit):** In black soils, if the slope permits, a channel should be dug upstream of the bund for the exit of water. As opposed to permeable soils, this excavation should be done continuously. The water flowing out of each section should be given a channel, which uses the natural slope to conduct water into the main drainage line. Grasses 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.
- Remember: How fast rain water flows in the field shall depend on:
  - The slope of the land, and
  - The permeability of the soil

  That is, in highly sloping land and impermeable soil, water will flow more rapidly. In order to ensure safety and utility of the bund:
    - Increase the downstream slope of the bund
    - Decrease the distance between bunds
    - Provide an exit in the bunds

Contour Bunds: Step-by-Step

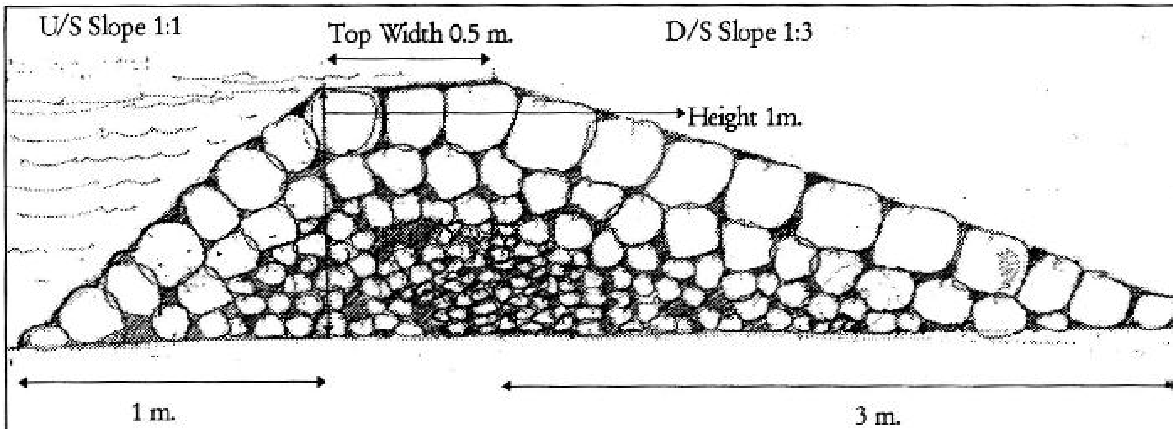
- Measure the slope in one section of the ridge area. Ensure that it is less than 10%;
- Draw a straight line with wet lime between the highest and the lowest points along the slope;
- Decide the interval between successive lines of bunds;
- On the straight line, marks points at the decided interval;
- Starting from each mark, demarcate the contour line;
- Make bunds along these contour lines;
- Depending on the specific conditions (such as thick vegetation, rocks etc.), leave gaps in the excavation from place to place;
- Undertake plantation for bund protection as appropriate.

Contour Bunds: Do's and Don'ts:

- Always provide a berm of 30 cm.
- Always provide a settlement allowance.
- Exit must be provided in sloping land and in impermeable soils.
- In impermeable soils increase the cross section area of bunds.
- On high slopes do not make bunds closer than 30 m.
- On low slopes do not make bunds farther than 60 m.
- Do not make bunds on slopes higher than 10%. For slopes between 10% and 25%, contour trenches are more appropriate. For slopes above 25%, adopt vegetative measures
- Do not construct bunds where there is already a dense vegetation
- Do not excavate if roots of a tree are encountered
- Do not excavate soil continuously in permeable soils.

Drainage line treatment boulder checks

Boulder checks are loose rock dams made on small drainage lines, which have a catchment area of around 10 to 20 ha. As per rainfall parameters the permissible catchment area of the drain for the construction of loose boulder gully plug varies.



Typical cross section of a boulder check. In the construction of a boulder check, bigger boulders are placed outside and smaller ones inside. On the outside, the biggest boulders are placed on the downstream side.

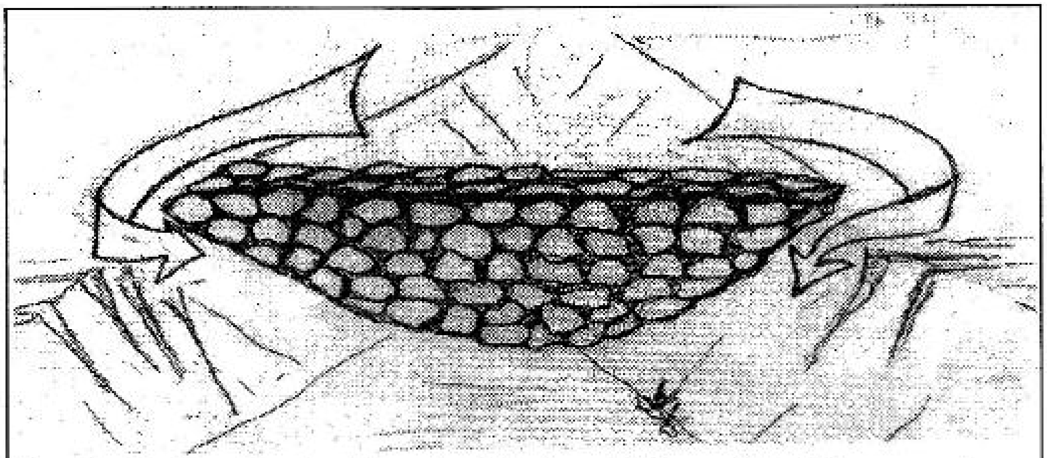
Objectives:

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

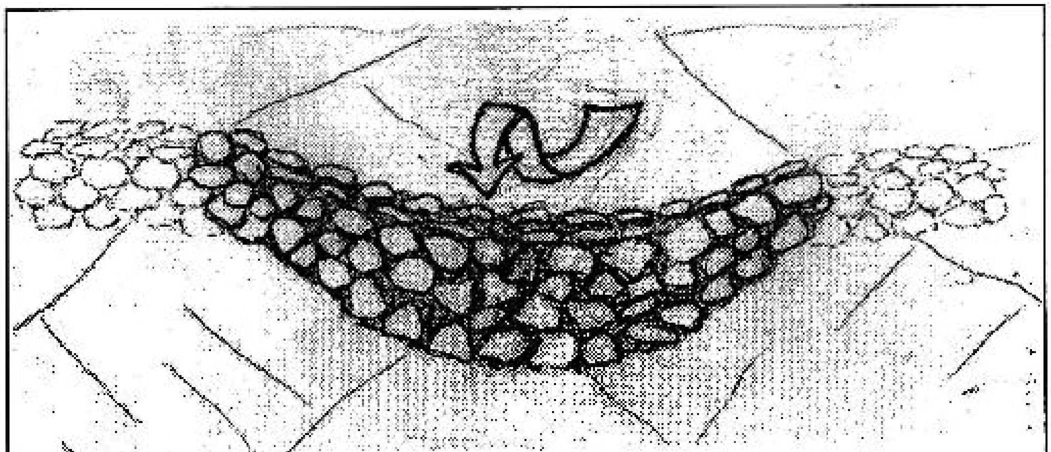
- Reduction in soil erosion;
- Trapping silt, which reduces the rate of siltation in water harvesting structures in the lower, reaches of the watershed.
- Creating a hydraulic head locally which enhances infiltration of surface runoff into the groundwater system; and
- Increasing the duration of flow 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:

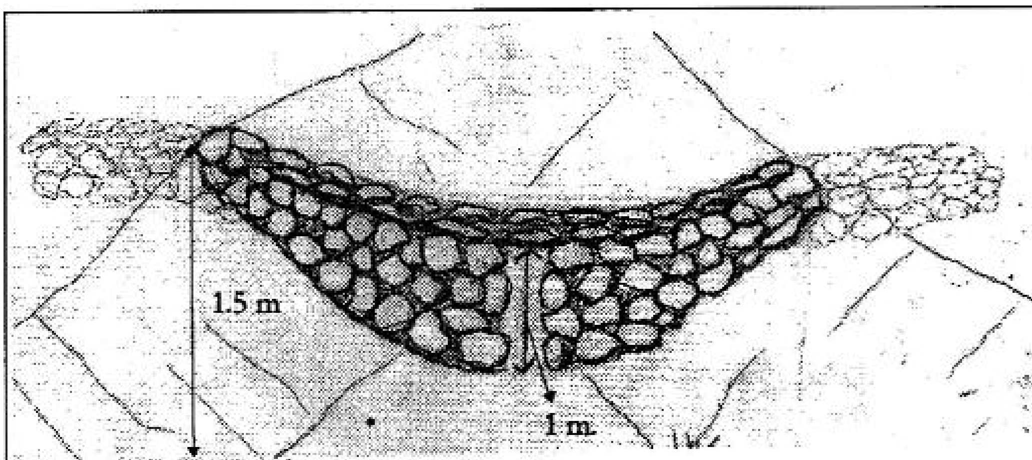
Boulder checks should be made as a series on a drainage line, with each structure dividing the overall catchments of the drainage line into smaller sections.



If no dip is given in a boulder check in the middle, and its sides are not embedded in the embankments, water will tend to cut through the embankments on either side, thus eroding them



With a dip in the middle and sides embedded on either embankment, water flows over the dip safely without endangering the bund



In order to create this dip, the height in the middle is kept less than that on the sides.

- The independent catchment of each boulder check should not be more than 1 to2ha.
- 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 boulder checks can be constructed in sections where the local bed slope is less than 20%.
- Boulder checks should be made where boulders are available in large quantities in the requisite size.
- A boulder check should be made where the embankments are well defined and stable, and 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 including 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.
- Even though storage is not a primary consideration in the case of 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 greater would be the storage per unit height of the structure.

Layout:

On each drainage line there will be a series of boulder checks. The minimum vertical interval between two successive checks on a drainage line should be equal to the height of the structure, so that the water temporarily stored in one check will reach the toe of the another 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 20 m on a 5% slope and 10 m on a 10% slope. In general the relationship can be expressed as follows:

$$HI = VI / S,$$

where HI = horizontal interval; VI = vertical interval and S = slope (%)

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 checks needs to handle. In practice, one must fix the maximum and minimum horizontal interval between two successive boulder checks:

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

Planning

Identify the drainage line to be treated by the checks. Start from the top. Fix the location of the topmost boulder check. Walk 5 m downstream. This gives the downstream bottom edge of the first boulder check. We have decided that the minimum horizontal distance between 2 boulder checks has to be 10 m. Measure the slope of the naala bed over the 10 m stretch, beginning with the bottom edge of the first boulder check.

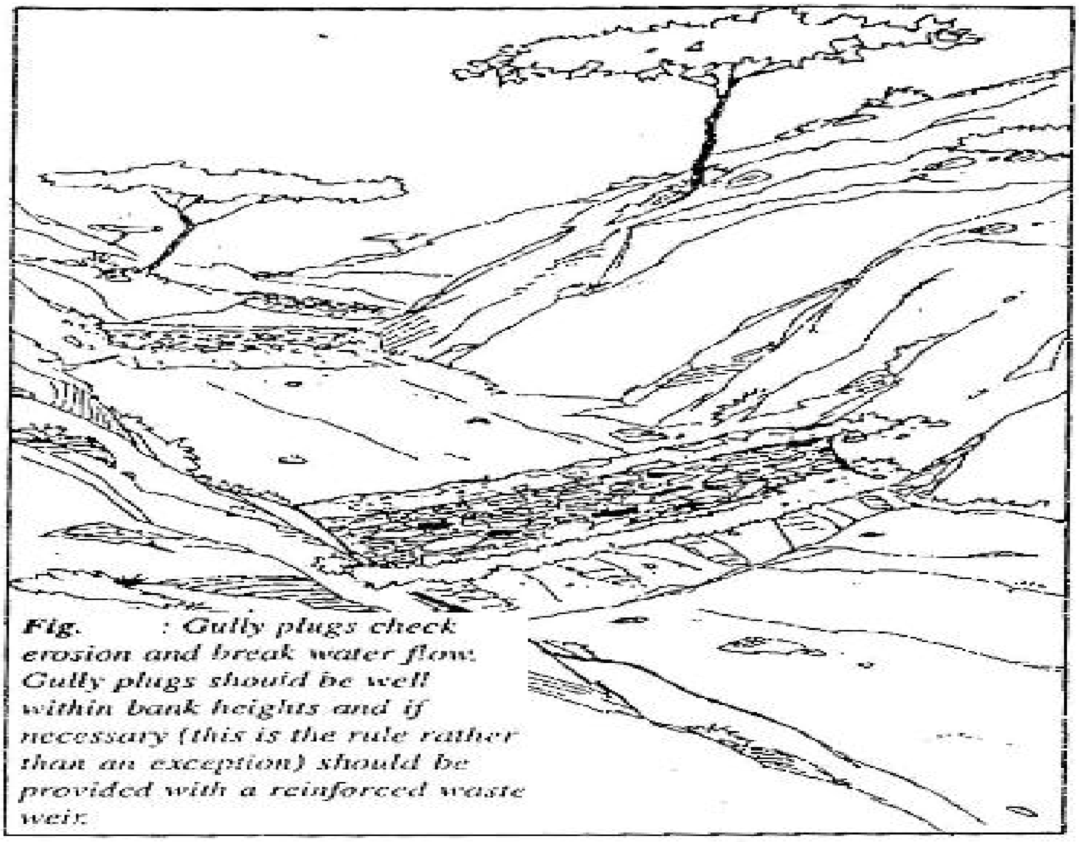


Fig. : Gully plugs check erosion and break water flow. Gully plugs should be well within bank heights and if necessary (this is the rule rather than an exception) should be provided with a reinforced waste weir.

If the slope is 10% or more, keep the horizontal distance between two boulder checks as 10 m. In case the slope is less than 10%, then increase the distance between the boulder checks, depending on the flatness of the slope. Thus, for instance, if the slope is 5%, the distance should be 20 m; if slope is 2%, the distance should be 50 m. Even if the slope is less than 2%, do not increase the distance beyond 50 m, which is the maximum distance we have fixed. Thus, along the length of the drain, the location of the checks is marked.

Design:

Through years of experience in watershed development, the maximum height generally accepted for boulder checks is 1 m. The design height of 1 m means that the top of the check in the middle of the stream is 1 m above ground level. The top width of the boulder check is usually taken as 0.4 m. As the material used in the check has a high angle of repose, the upstream slope of the check should be fixed at 1:1 in general, to be varied only in exceptional cases where the structure has to handle very high volume of runoff and of high velocity. The downstream slope of the boulder check can vary from 2:1 to 4:1 depending on the volume and velocity of runoff. The higher the volume and velocity of runoff, the flatter the slope. Since the boulder check is composed of a highly porous material it is not expected to hold water for a long period. Hence, unlike in earthen structures, the downstream slope of the structure is not made to handle seepage problem. The downstream slope is given for two reasons:

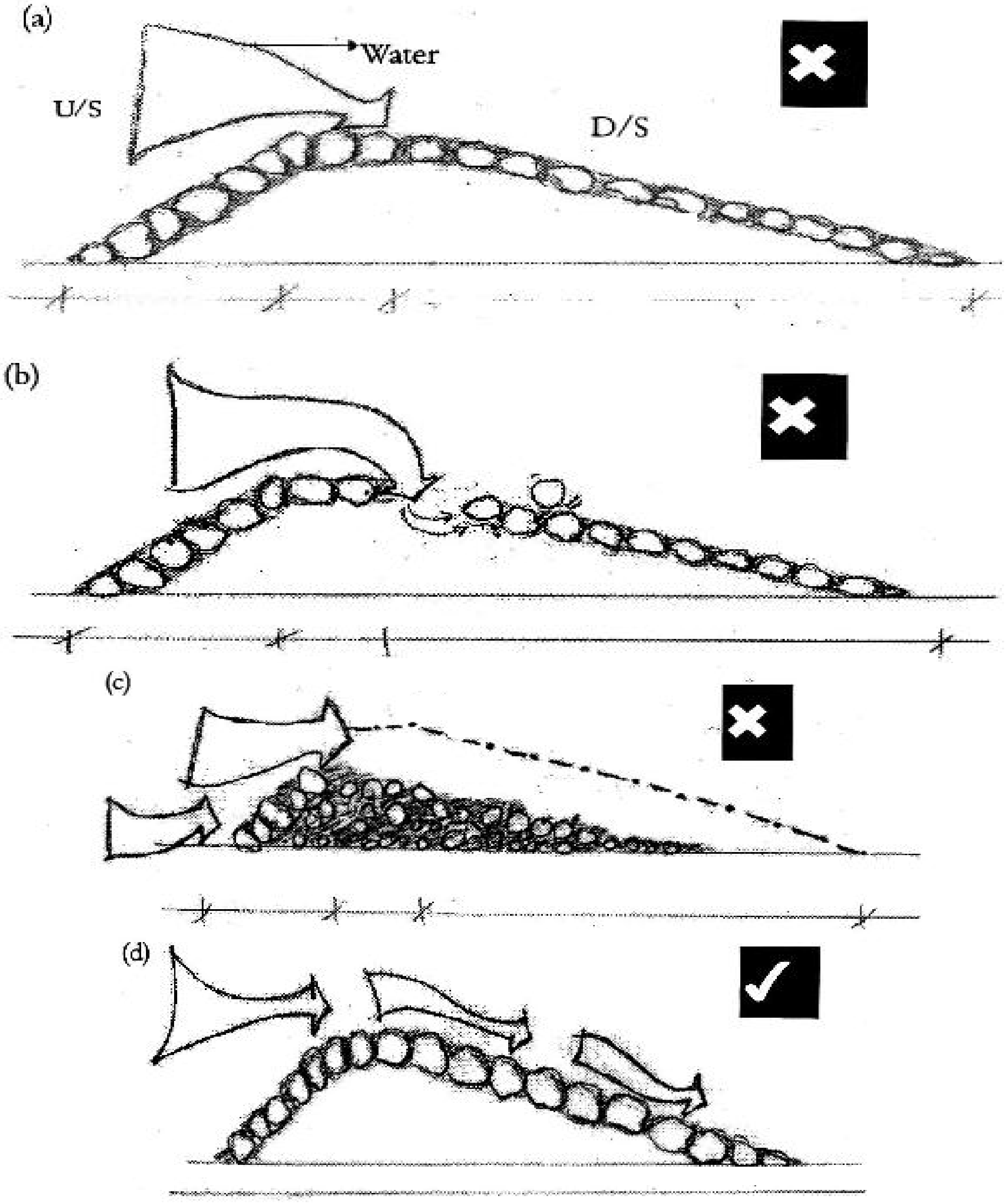
- o absorb the impact of water which enters the structure at a high velocity; and, also
- To drain out water from the structure at a non-scouring velocity.

If the top of the check is level, water will flow over the check uniformly at all points. It is advisable, however, to direct the maximum overflows through the middle of the structure so that the water does not erode the embankments. Therefore, there should be a dip in the middle of the structure and the top level of the structure should be higher towards the embankments on either side. The cross section area of the dip depends on the depth of peak channel flow: the higher the depth, the more is the cross-section area. But the height of the boulder check on either side should not exceed the height of the embankment or 1.5 m whichever is lower. The check should be embedded 0.5 m into both the embankments. This is to prevent erosion of the embankment where the check joins it. If the bed of the drainage line has only boulders, the boulder check can be constructed without any foundation digging. If there is mud or sand in the bed, this must be excavated up to a maximum depth of 0.30 m to secure an adequate foundation for the boulder check.

Construction:

Draw a line running through the center of the proposed site for the boulder check till it reaches those points on either side, which are 1.5 m above the bed of the naala. Naturally, if the embankments are less than 1.5 m high, this line will only reach till the top of the embankment. From this central line, mark 20 cm on the upstream and downstream sides and draw parallel lines from one embankment to the other embankment. These lines mark the boundaries of the crest.

Suppose the required slope is 1: 1 upstream and 3:1 downstream. Then from the center of the upstream crest line a point is marked at a distance of 1 m, along the perpendicular to this line. From the center of the downstream crest line also mark a point at a distance of 3 m, again along the



If small boulders are placed on the outer, particularly downstream face of the boulder check, water will exert pressure on the outer face (a); dislodge the small boulders there (b) and wash down the check (c). Thus large boulders must be placed on the outer face, particularly on the downstream side (d) perpendicular to this line. These points mark the upstream and downstream ends of the boulder check respectively. Draw lines connecting each of these points to the end of the crest lines on both sides.

The trench in a boulder check is not usually dug in the bed of the naala. But if there is a sand or mud at the base of the check, a foundation should be dug up to a depth of 0.25 m. Generally, digging the trench is only required for embedding the check into the embankment. Along the centerline after it enters the embankments, dig a trench, which are half meter wide and half meter deep. The trench must extend half a meter beyond the point where the crest of the check meets the embankment on both sides. Now the filling begins. The check should be raised in horizontal layers. The largest of the boulders must be placed on the outer sides especially on the downstream face. The trenches cut into the embankments on either side of the check must also be filled with boulders. As successive layers are laid out, care must be taken that the downstream and upstream slopes are maintained as per design. When one reaches the crest of the check one must ensure that the top layer slopes down away from the embankments dipping towards the center of the check, thus providing a channel for the safe exit of excess runoff.

Materials:

- The larger boulders must be placed on the downstream face of the check. The outermost edge of the downstream side must be dug up to a depth of 0.25 m and the largest boulders available must be placed at the lowermost edge of the check on the downstream and anchored to the ground.
- Smaller stones can be used to fill up the interiors of the check.
- The use of boulders with a diameter of less than 15 cm (or weight less than 1 kg) must be avoided.
- The use of angular stones provides greater stability to the check than the use of rounded boulders.
- Shale, limestone, mudstone or any loosely cemented rock must not be used, because they disintegrate when in contact with water.

Costing:

First, arrive at the volume of each structure. Volume= Length of the Check x Average Cross Section Area. Since the cross section of the boulder check approximates the shape of a trapezium, the formula for cross section area becomes

$$A = 0.5h(a + b),$$

where A= cross section area, h= height of the structure, a=top width, and b = base width.

For the average cross section, measurements will have to be taken at 3 to 5 points along the length of the check. This volume is multiplied by the rate for the collection and arrangement of boulders (as per the rate schedule). Multiplying the rate per volume of work by the average cross section area would give the rate per running length of the structure.

Rate/Volume x Area = Rate/Running meter

The cost of a 12 m long typical boulder check with 1 m height, 1:1 upstream and 3:1 downstream slopes and 0.3 m top width works out to Rs. 1500 at 2006-07 prices.

Dos and Don'ts:

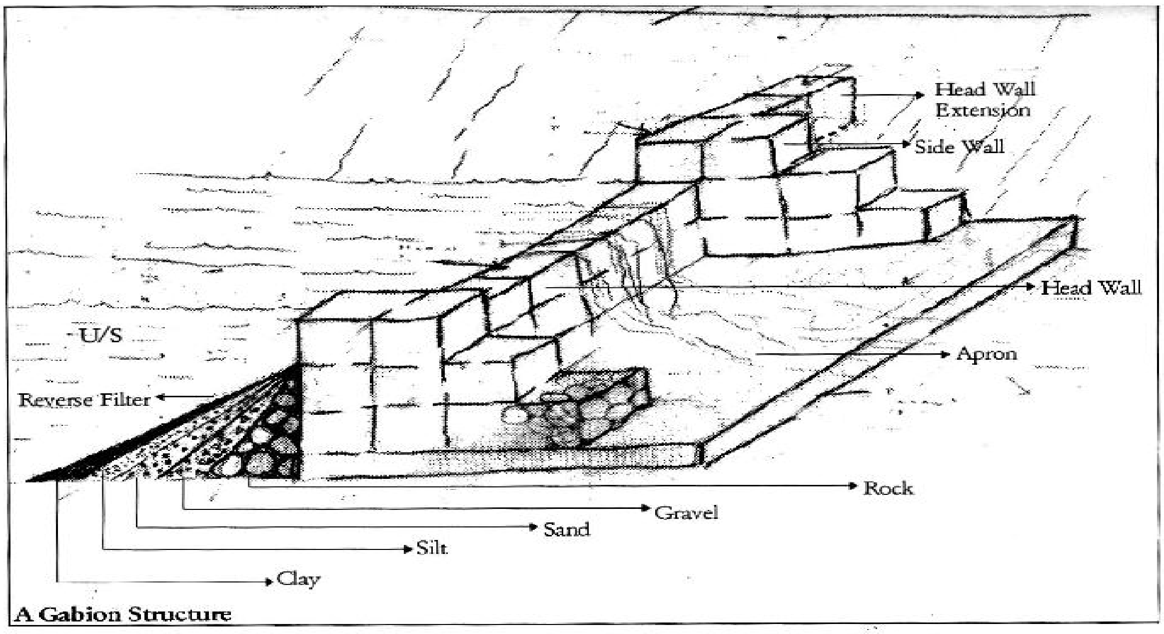
- Locate the check only where the height of the stream embankment is greater than or equal to the sum of the peak depth of flow in the drainage line and design height of the structure.
- The top of the check should be lowest in the middle of the stream and highest at either embankment.
- The height of the check in the middle of the stream should be 1 m above ground level.
- Upstream slope of the check should be 1:1 while the downstream slope can vary from 2:1 to 4:1.
- The bed of the stream at the base of the check should be cleared of mud/sand up to 0.25 m depth.
- The top of the check should extend into either embankment by cutting a trench

and filling it with boulders.

- Larger boulders should be placed on the outer portion of the check.
- The use of angular boulders is preferred.
- No checks should be placed at such locations where the bed slope is above 20%
- No checks should be constructed where boulders are not adequately available within a radius of 50 m.
- Do not use boulders dug up or picked up from the neighbourhood if such use would increase soil erosion in the area from where the boulders are picked up.
- Do not use boulders of diameter less than 0.15 m at any point, which comes into contact with flowing water.

Drainage line treatment Gabian structure

Gabian structures are rock and wire dams constructed across the drainage lines with a catchment area of 30-150 ha. They are also constructed to reinforce highly erodable stream embankments. In this module, we will first describe Gabians across drainage lines in great detail. In the end, we provide a short note on Gabians built along embankments.



Gabian Structure Across Drainage Line:

Objectives:

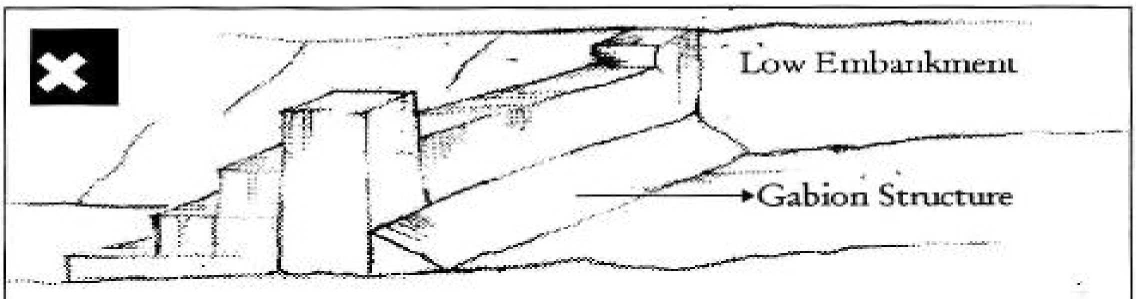
The main aim of constructing gabian structures is to reduce the velocity of water flowing through the drainage line. By reducing the velocity of runoff, gabian structures help in

- Reduction in soil erosion;
- Trapping silt, which reduces the rate of siltation in water harvesting structures in the lower reaches of the watershed.
- Creating a hydraulic head locally which enhances infiltration of surface runoff into the groundwater system; and
- 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.

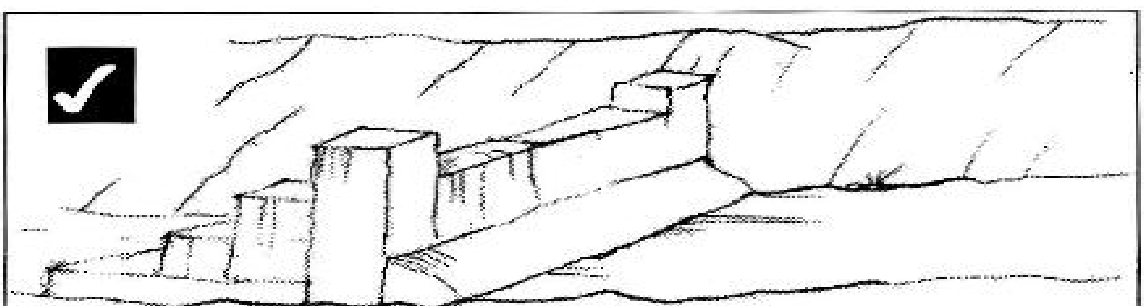
Location:

The minimum independent catchment area for a gabian structure is 5 ha. For a catchment area smaller than this even a loose boulder check may suffice. The precise location of a gabian structure depends on the following factors:

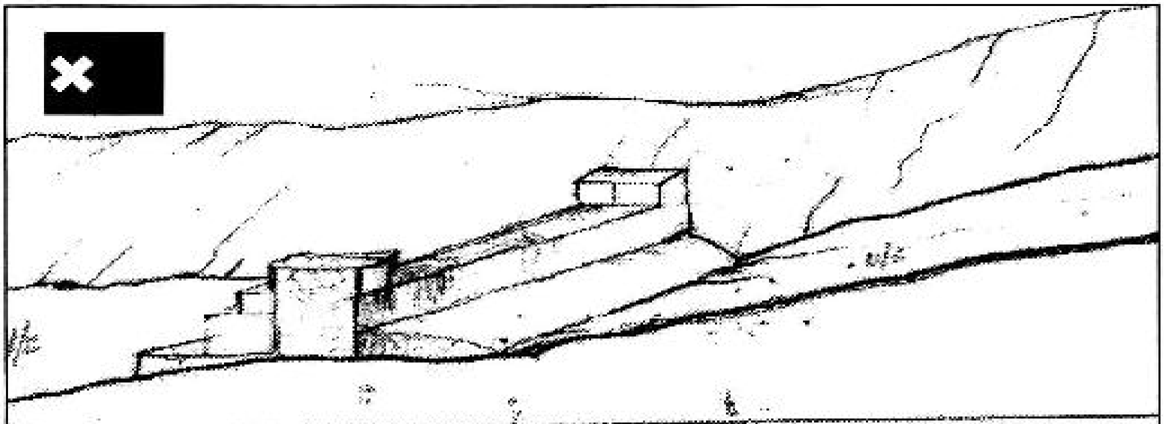
- Stability of the embankments is the primary consideration. The less stable and more erodable the material on the embankments is the weaker the structure is likely to be. In such a situation, making the structure stronger would render it too expensive.
- The elevation of side embankments from the bed of the stream at the least must equal the sum of the depth of peak flow in the stream and the designed height of the structure. For example, if the height of the embankments is 6 m and the depth of peak flow is 4 m, then the height of the gabian must not exceed 2 m to prevent the water from jumping over the sides. Hence, observation of the peak flows is imperative before a gabian structure is planned.



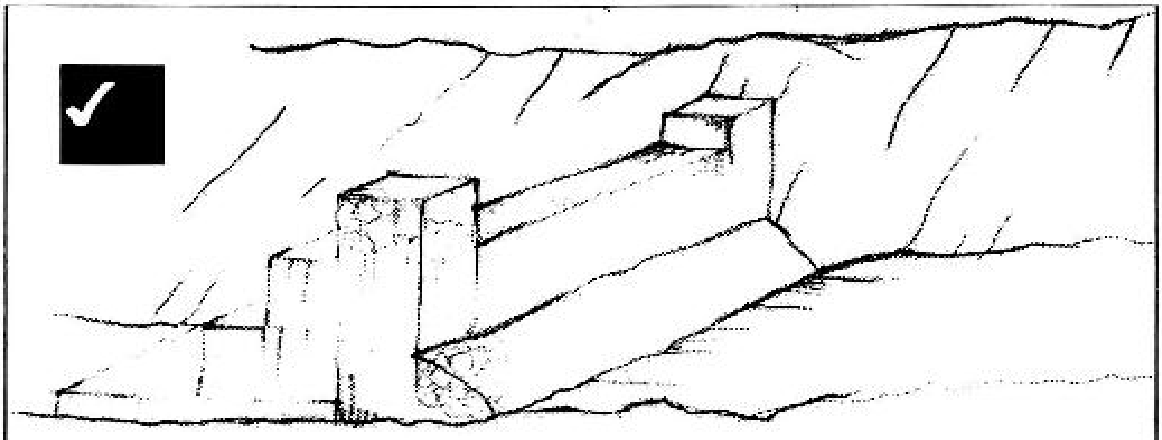
The height of the embankments of the drainage line must be greater than or equal to the sum of the depth of peak flow and the height of the structure. It is not advisable to locate structures where the embankments are low



Choose a site where the embankments of the drainage line are high



If the bed slope of the drainage line upstream of the proposed site for construction of gabion structure is steep very little runoff will be conserved. In addition,there is a danger to the safety of the structure



Gabions should be constructed where the bed slope of the drainage line is flat. Other factors remaining the same, this leads to a greater volume of runoff conserved

- For maximizing storage in the structure, the bed slope of the upstream portion should be low. The flatter the upstream slope, the greater will be the temporary storage per unit height of the structure.
- The material composing the bed of the drainage line upstream of the structure should not be completely impermeable, because what we are looking for is temporary storage followed by groundwater recharge.

Design:

There are two ways of reinforcing a loose boulder structure with wire mesh:

- To make the structure as per the dimensions of the design and wrap it with wire mesh on all sides except the bottom. This wrap is partially anchored under the bottom.
- To cage the boulders in rectangular boxes. The structure would be made up of several such boxes tied together. In such a structure the wire mesh not only provides a covering shell, it also gives horizontal and vertical reinforcements within the structure.

The second method is far superior to the first in terms of strength and is economical in the use of boulders, although more wire mesh is used in the latter than in the first method. In this module, we will concentrate on the second method.

The rectangular box type gabian structure has the following sections:

- **Foundation:** The foundation should be dug up to a depth of 0.6 m across the bed of the drainage line for the entire length and width of the Headwall of the structure. Where the streambed has a thick layer of sand or silt the foundation will have to be dug deeper till a more stable layer is encountered. This foundation should be filled with boulders and the wire mesh should be anchored under the boulders.
- **Headwall:** The headwall is built across the width of the stream from embankment to embankment. In most cases the top of the structure across the entire stream can be level. The entire length of the headwall serves a spillway for the stream. Where it is required that most of the flows be directed towards the center of the stream, that part of the headwall is lowered forming a weir. For a height of up to 2 m the width of the headwall can be restricted to 1 m. For heights beyond 2 m, it is advisable to design it as a step-like structure, where the downstream face is constructed as a series of steps. For every 2 m fall a step should be provided of 1 m width.
- **Sidewalls:** Sidewalls are built to protect the embankments downstream from erosion by the stream spilling over the Headwall. On either end of the headwall, where the natural embankments begin, a block of the Sidewall is laid. The height of the sidewall measured from the top of the headwall is determined by the depth of peak flow in the stream. From here the Sidewall

descends in a series of steps along the embankments to the bed of the stream.

- **Headwall Extension or Wing Walls:** The headwall is extended into both the embankments in order to anchor the structure and secure it against sagging on account of the pressure of water. From the same height as the top of the sidewall, the headwall extends into the embankments.
- **Apron:** During peak discharge, the stream spills over the headwall and falls on the streambed with considerable force and emerges with a strong up thrust a few meters downstream. This can cause severe erosion. Hence, some way has to be found to neutralize the force of falling water. In the gabian structure, a stone apron is usually provided as an energy-dissipating device. The naala bed downstream of the structure is dug up to a depth of 0.6 m for a distance of 3 to 6 m from the Headwall. This is filled with boulders and enclosed in a wire mesh, which is anchored under the boulders. The length of the apron depends upon the radius of the arc made by the water spilling over the headwall. This in turn is determined by the depth of peak flow in the naala. Therefore, the higher the depth of flow, the longer the apron should be.

Materials:

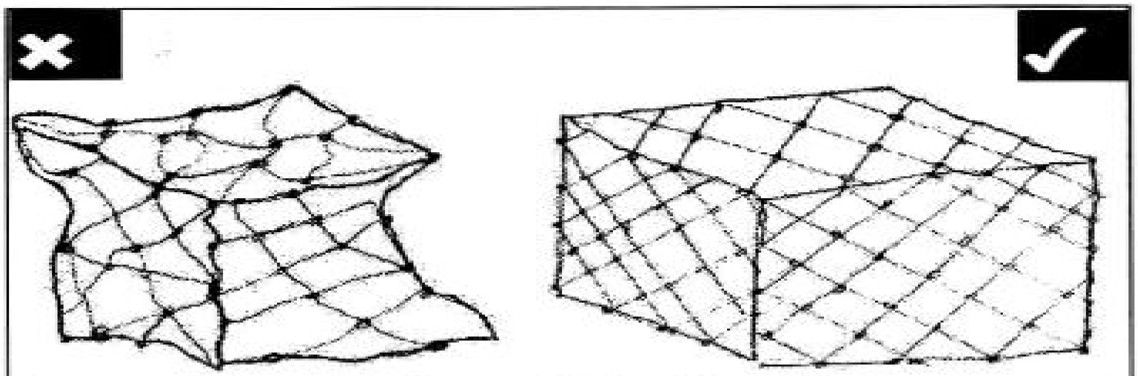
Wire Mesh: Good quality galvanized wire of gauge 12-14 (chain link) must be used for constructing the gabian structures. Readymade mesh with a single twist is commercially available. In these meshes the gap should not be more than 7.5 cm x 7.5 cm. Alternatively the wire can be manually woven into a mesh. In this case even a double twist can be provided at each joint and the minimum gap can be increased to 10 cm x 10 cm.

Boulders: The minimum size of the boulders is dictated by the gap size in the wire mesh. The boulders should be hard and should not deteriorate under water. Angular boulders are to be preferred to round boulders. Arrange smaller sized boulders in such a way that they fill the gap left by larger sized boulders. Besides rendering the structure less permeable, this minimizes the damage to the structure on account of settling and sagging. There are two types of pressures operating on a gabian structure: I) static pressure of standing water; and the ii) pressure of moving water. If small boulders are used in the structure, they would get shifted and dislocated on account of these pressures and the structure would tend to sag.

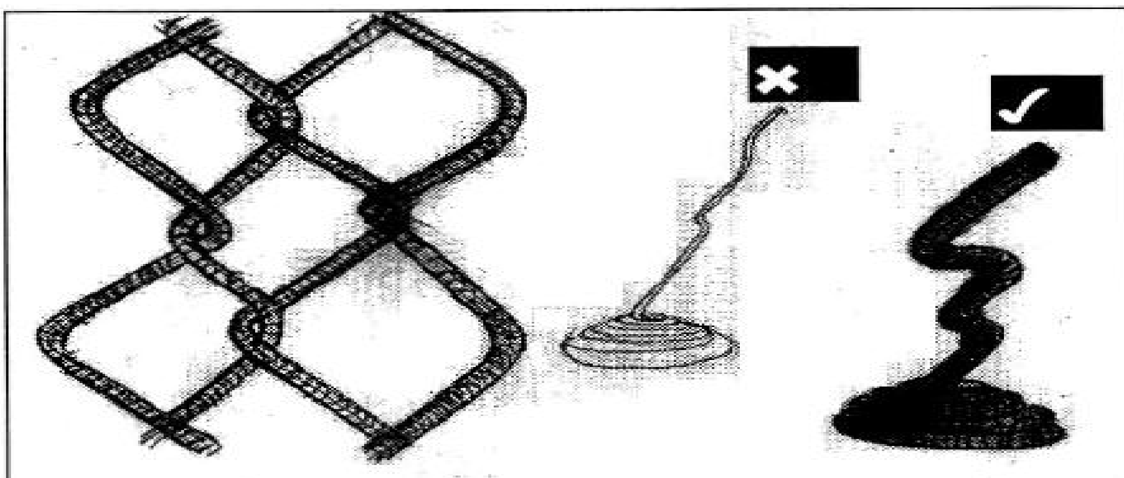
The same problem will occur if the wire mesh is not drawn tight over the boulders or if the embankments are not stable or if the height of the structure for a specific top width exceeds the limit up to which it can withstand water pressure.

Construction:

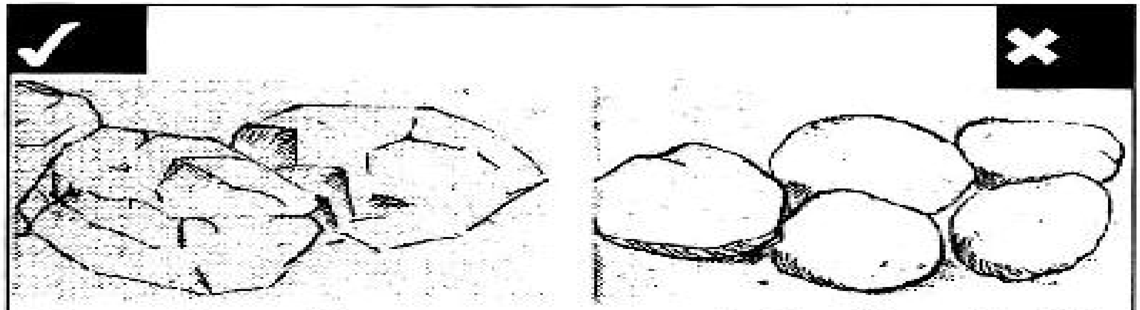
First of all boulders must be collected on the location site. If the structure is going to use woven wire mesh on the site then the weaving of the mesh in sections of 1 to 2 m lengths and 1 m width must commence. For the Headwall, a 1 m wide and 0.6 m deep trench should be dug across the streambed from embankment to embankment. Foundation of similar depth should also be dug for the area demarcated for the apron and the sidewalls. For the headwall extension the embankments are cut to the appropriate depth.



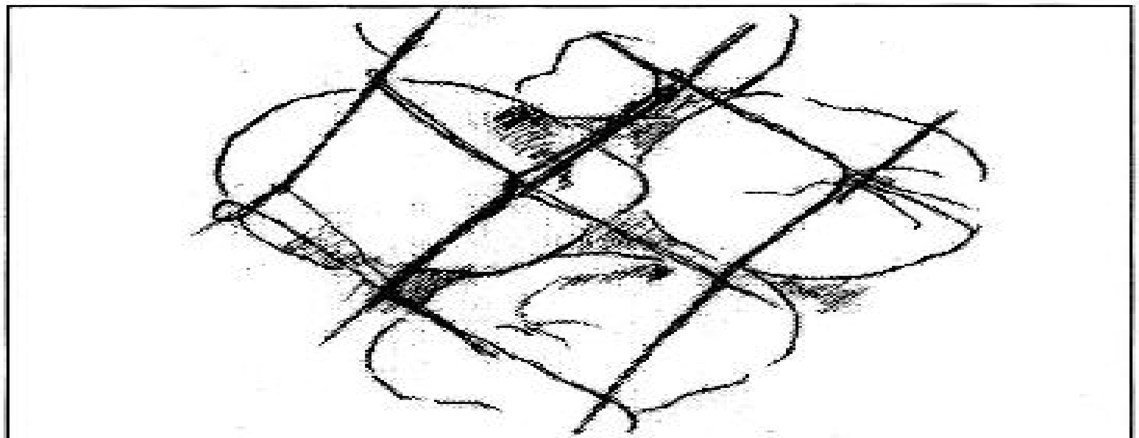
Boxes made out of wire mesh should not have any slack. The wire should be tight and taut



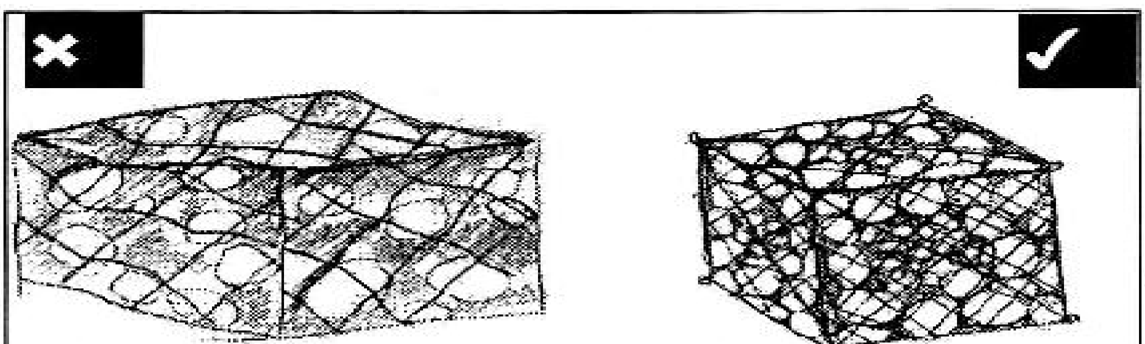
The design of the wire mesh. Ensure that the wire used to tie up the boxes should be of the same guage as the wire used to make the boxes



For making gabion structures, angular boulders should be used instead of rounded ones



The size of the smallest boulder should be more than the gaps in the wire mesh

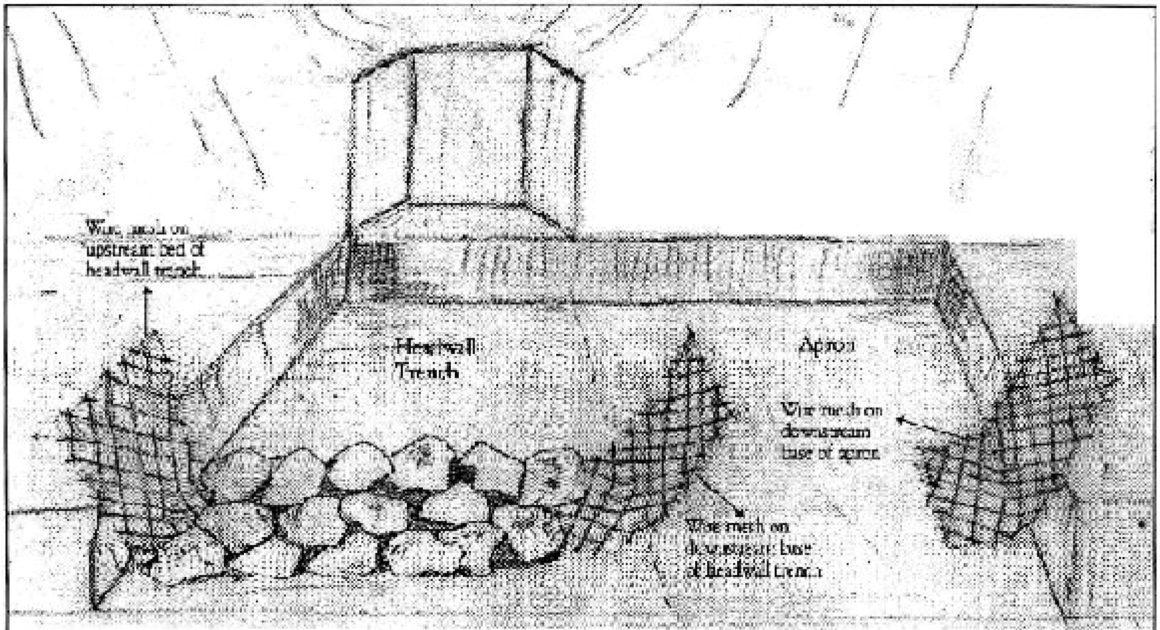


Boulders should not be stacked loosely in the wirse mesh boxes. The packing should be compact and tight

Before the foundation trench is filled, lengths of wire mesh are placed vertically at three places:

- The upstream edge of the foundation;
- Where the headwall ends and the apron begins; and
- Against the downstream edge of the apron.

At all the three places the wire mesh runs along the entire length of the structure. Everywhere, 0.15 m of the wire mesh is folded along the bed of the trench so that the mesh can be embedded under the boulders. After that the trench is filled with boulders up to ground level. Then the wire mesh is laid over the entire surface and tied to that mesh, which has been embedded under the boulders. The headwall as well as the sidewalls should be constructed as boxes of 1 to 2 m length and 1 m height.



Wire mesh is initially placed vertically and anchored below the boulders at three spots: the upstream base of the headwall trench of the gabion structure; the downstream base of the headwall trench and the downstream base of the apron

First the four vertical faces of these boxes are erected with wire mesh, which is tied to the wire mesh in the section below as well as the section alongside. Then the boxes are filled with boulders and covered at the top with the wire mesh. This wire mesh is tied to each of the vertical faces on all four sides. Such boxes are filled up in succession till the structure is complete.

The main structural danger facing the gabian structure arises because of sagging and settling of boulders when they are not placed compactly within the box. Hence, care must be taken that the boulders are placed compactly against each other so that they do not slide or move under the impact of water. Smaller boulders must be placed in the interior part of these boxes while the larger ones must be placed on the outside. Even the smallest boulder should be bigger than the gap in the wire mesh. The wire mesh must be stretched out so that there is no bulging or sagging.

The wire used for tying the wire mesh sections must be of the same strength as the wire used in the wire mesh. It could either be of the same gauge or of a thinner gauge plied and twisted together.

To increase the impermeability of the structure, a reverse filter should be constructed on its upstream face. This device is made by placing layers of small boulders, gravel, sand and mud against the structure. However, the order of placement of these materials is exactly the opposite of the arrangement in a normal filter. The boulders are placed adjacent to the structure, with gravel, sand and mud being placed successively away from it. The reason for the reverse order is that it is desired that the finest material should come in contact with the water first. Following the normal filter scheme would have allowed water to pass unchecked through the boulders and coarser material on the outer surface. One can even try to place used cement or fertilizer bags filled with fine sand against the structure in several layers.

Costing:

The cost of a typical gabian structure, 2 m high, 1 m top width and, say, with a length of 17 m on a large stream with a catchment of 50 hectares works out to Rs.75000 at 2006-07 prices.

Dos and Don'ts:

- Do not build a gabian structure where the embankment is highly erodable or is of insufficient height.
- Do not build a gabian structure at a point on the naala below, where the naala drops sharply.
- Locate the gabian structure where the naala width is relatively low.
- Locate the structure where the bed slope of the naala upstream of the structure is low.
- Care must be taken that the boulders are placed compactly against each other so that they do not slide or move under the impact of water.
- Smaller boulders must be placed in the interior part of these boxes while the larger ones must be placed on the outside.
- Even the smallest boulder should be bigger than the gap in the wire mesh.
- The wire mesh must be stretched out so that there is no bulging or sagging.
- The wire used for tying the wire mesh sections must be of the same strength

as the wire used in the wire mesh. It could either be of the same gauge or of a thinner gauge plied and twisted together.

- For height above 2 m, the headwall must be made as a series of steps sloping on the down streamside to impart stability to the structure.

Gabian Structure Along Embankments:

These structures are built to cushion the impact of water, preventing it from eroding the banks. On very high slopes as in the Himalayas, such structures are built along the contour lines to prevent landslides.

These should be located in those stretches where embankments are prone to severe erosion by the stream. Normally this happens where the stream turns sharply and its flows are directed towards the embankments.

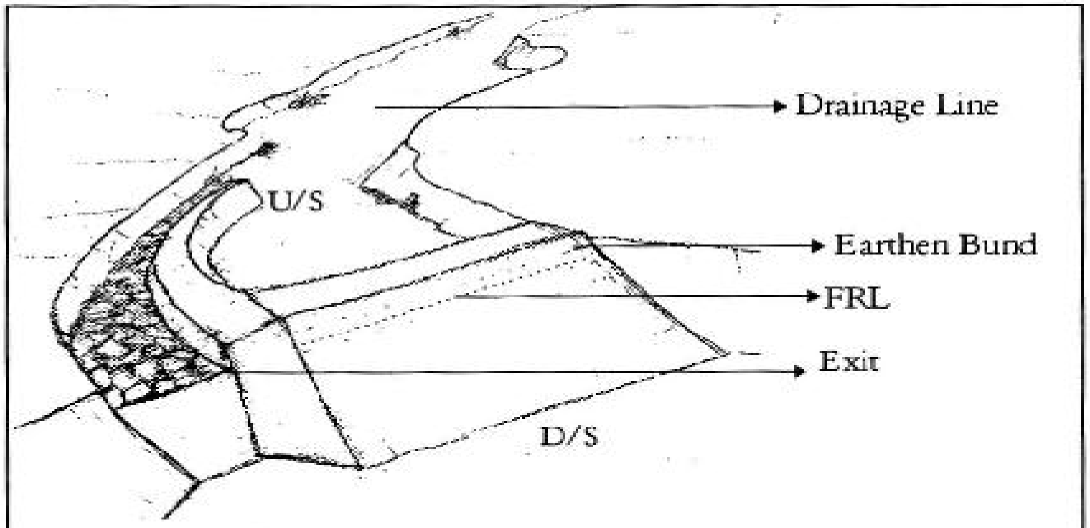
The length of the embankment to be strengthened has to be determined. Along this length the rectangular boxes have to be placed as a straight wall with a vertical face. The wall width could be a standard 1m while the length and height both are dependent on the local conditions. The height of this wall should be at least 1 m above the peak flood levels of the stream. The upstream end of the gabian wall should be well embedded into the embankment so that the stream is not able to cut a path behind the structure. Care must be taken that the gap between the structure and the embankment is filled with rammed earth while raising the rectangular structure.

Drainage line treatment: Earthen water harvesting structure

Types of Earthen water harvesting structure:

Earthen water harvesting structures can be of two kinds depending on the primary purpose for which they are built:

1. Percolation structure
2. Irrigation structure



An overview of an earthen structure

Objectives of Percolation Structures:

Percolation structure is an earthen dam constructed to impound water flowing in a small drain or a medium drain for the primary purpose of increasing the rate of groundwater recharge. A percolation structure augments flows in the groundwater system by controlling the volume and velocity of surface water flow, thereby allowing water a greater time for percolation into the aquifer. This replenishment of groundwater benefits the irrigation wells situated downstream in the catchment. Enhanced groundwater recharge helps lengthen the life of the seasonal streams through regenerative base flows after the end of the rainy season. Depending on the capacity of the structure and duration of water storage, the pond can have secondary benefits (such as pisciculture) that are vital for the livelihood security of marginal farmers and landless labourers.

Objectives of Irrigation Structures:

Irrigation structures that harvest surface runoff from a farm or a group of farms, forming small catchments of about 2-30 hectares, for the primary purpose of providing protective irrigation. Undulating topography forming a series of natural watersheds drained by small, well-defined drainage lines and with fallow land alongside is ideal for irrigation structure construction.

- Most parts of India typically receive rainfall between June and September, very intensely within a few hours and a few days. The number of rainy days does not average more than 40 - 50. Moreover, rains are extremely erratic, often characterized by the late onset and early withdrawal. Prolonged dry spells during the rainy season, resulting in agricultural droughts, are also frequent. Hence, the kharif crop needs to be drought-proofed through 'protective' irrigation, applied to overcome accumulated soil moisture deficits within the rainy season. Irrigation structures built to collect the runoff from small catchments provide this vital requirement. Such structures are very important in areas which are poor in groundwater resources and which do not have access to canal irrigation.
- In addition to providing irrigation, irrigation structures allow greater time for water to percolate into the aquifer. This replenishment of groundwater benefits the irrigation wells situated downstream in the catchment. Enhanced groundwater recharge helps lengthen the life of the seasonal streams through regenerative base flows after the end of the rainy season.
- Depending on the capacity of the structure and the duration of water storage, the structure can have secondary benefits (such as pisciculture) that are vital for the livelihood security of marginal farmers and landless labourers.
- Further, where soil depth and water holding capacity is sufficient a rabi crop such as gram or linseed can be sown in the bed of the pond after the water has been extracted for Irrigation.

Location:

The location of earthen structures is determined on the basis of the following considerations:

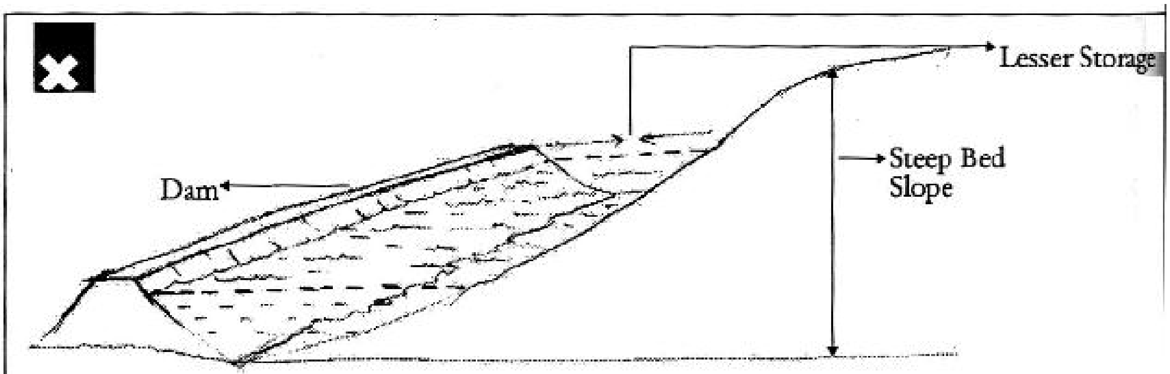
Effective Storage: The site for a earthen structure should be selected at a point where the total runoff is adequate to fill the structure to its full capacity, i.e., the total runoff should be at least greater than or equal to the 'effective' storage of the structure.

Effective storage = Storage capacity + Volume of water percolating from it during one season + Evaporation + Water used for protective irrigation.

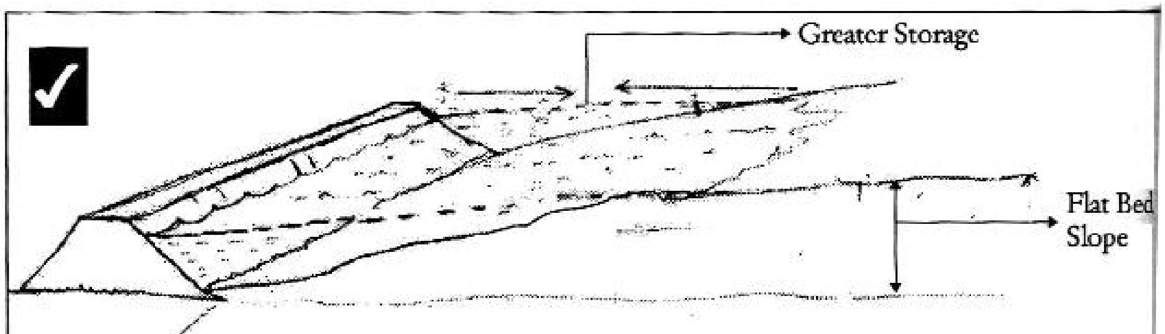
Hence, an estimation of runoff from the catchment and the effective storage of the structure are essential to decide its location. On the other hand, it must also be ensured that the total runoff is not too large in relation to the effective storage of the structure, i.e., the structure should be able to hold most of the water flowing into it. A common mistake is to locate earthen structures in such a place where the catchment area of the stream is very large so that the inflow of water is much higher than structure capacity. Such a structure would necessarily have to let most of its inflow out through a waste weir, which literally means that we end up leaving the entire naala. Therefore given the cost constraints no structure should be constructed where its effective storage is less than 50% of total runoff. Thus matching runoff and storage entails a knowledge about the topography of the catchment, the geology of the bed of the structure and the net irrigation requirement for drought-proofing the kharif crop.

Embankments: At the point of location, the drainage line must have well defined embankments to, which the structures can be anchored. Since the structure is embedded into them, these embankments should be strong and not made of loose material like sand.

a. Slope of the Upstream Naala Bed: The bed slope should be relatively low (not more than 5%) upstream of the site selected for the earthen structure, in order to maximize storage capacity.

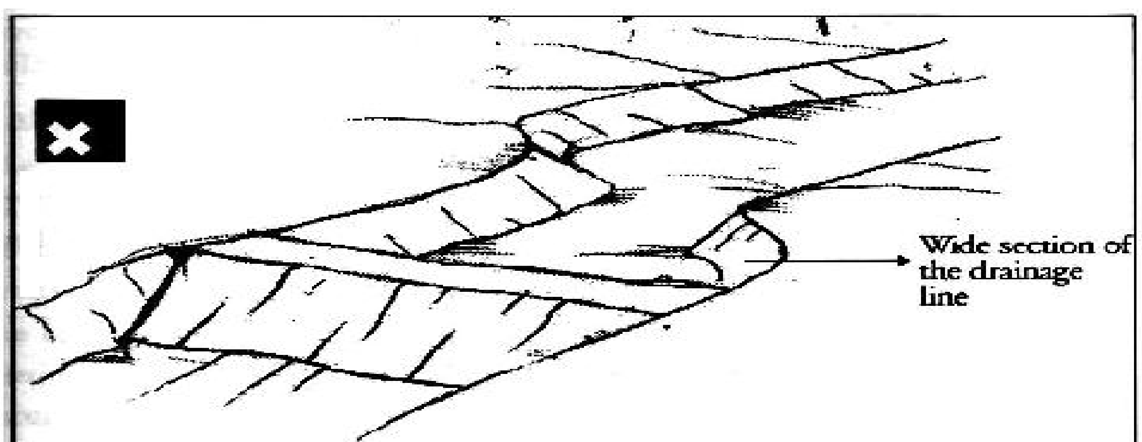


Structures should not be built where the slope of the drainage line is high. This results in lesser volume of storage (other factors remaining constant) and may breach the structure.

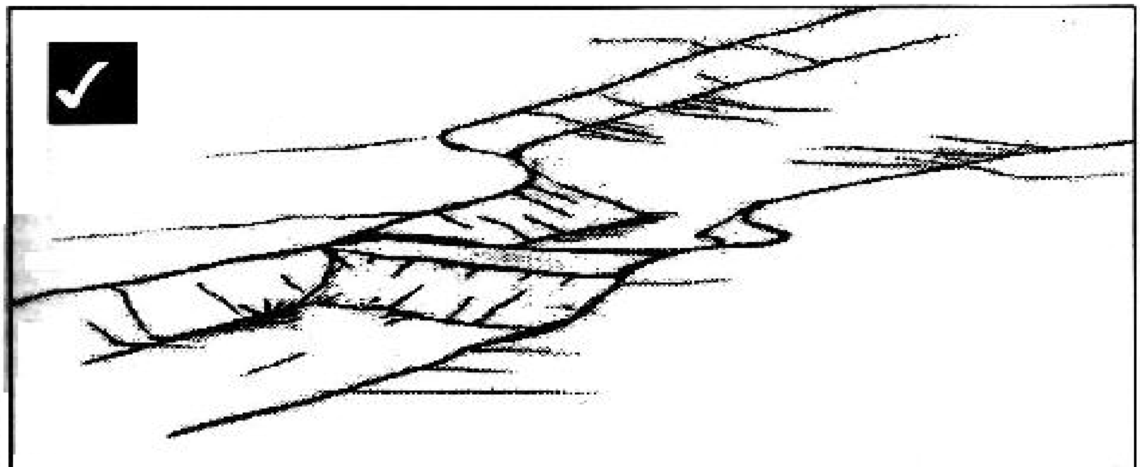


Sites where the slopes are gentle should be chosen instead

b. Width of the Naala: At the site the embankment should be narrow and vertical. But as we move upstream, the naala should ideally widen so as to contain maximum storage within its banks.



All other factors being the same, it is not cost effective to build an earthen bund where the drainage line is wide.



Instead choose a site where the drainage line is narrow and upstream of which the drainage line is wide

Geology: Since the primary objective of structure is irrigation, the geology of the structure must be favorable for water storage, i.e., percolation losses must be minimal up to reasonable depths. In cases where percolation losses are high and the storage structure makes sense only as a groundwater recharge structure, it is advisable to dig intake wells on the downstream to collect the percolating water. If the percolation losses are high but the strata, which can be tapped by dug wells, yield very little water, the site should be abandoned since a structure here will neither store surface runoff nor recharge wells. In the case of the percolation structure, however, the primary consideration is groundwater recharge. Therefore, we would ideally like the bed of the structure to be made up of relatively pervious material. In both cases, the geology of the waste weir site should preferably be a hard rock so that it does not erode very easily.

Availability of Materials: Even if all other factors are favorable and if the requisite materials are not easily available, one may be compelled to abandon the site.

Design:

The design of an embankment type structure refers to its full reservoir level, freeboard, settlement allowance, upstream and downstream slopes of the bund, dimensions of the cut-off trench, waste weir and toe drain and the embankment protection which is required to be provided.

Full Reservoir Level (FRL):

The FRL indicates the maximum capacity of any storage structure. As explained earlier, the FRL is determined bearing in mind the total runoff in relation to the effective storage potential of the site, which in turn depends on the shape of the side embankments, the upstream bed slope and geology of the drainage line and the width of flow. It is also important to assess the irrigation required from the farm pond for drought proofing the kharif crop. The pond capacity is determined on the basis of the net irrigation requirement of the pond and evaporation and percolation losses.

Pond capacity = Irrigation requirement + Evaporation + Percolation.

These losses together are normally estimated at 10% of the total storage. For instance, if the net irrigation requirement from the pond is 1000 cu.mt. and the percolation and evaporation losses from this storage during the monsoon are estimated at 100 cu.mt., the total pond capacity should be 1100 cu.mt.

In order to fix the FRL, we begin with a possible FRL and then using leveling instruments, we draw contour lines in the catchment of the pond. The submergence permissible in any such structure would depend upon the nature of the catchment especially with regards to whether it is inhabited, forested or whether it includes fertile agricultural land. The permission of those whose lands may be submerged would also need to be obtained prior to fixing the FRL. Ideally, they should be actively involved in the planning and design of such structures from the beginning to the end. In case they suffer a loss due to the structure, they must be adequately compensated possibly through sharing with them the benefits obtained from the structure.

The Free Board and the Top Bund Level (TBL):

If water flows over the top of the bund in an earthen structure, the bund will break. Hence, unlike in masonry or boulder structures, the excess water cannot be directed over the top of an earthen structure. Therefore, the top bund level (TBL) in all earthen structures has to be kept higher than the FRL. The difference between the TBL and the FRL is called the 'freeboard'. In other words, freeboard is the difference in elevation between the top of the structure and the base of the waste weir. It has been found through the years of experience that for earthen structures with height less than 5 m, a freeboard of 1 m would be adequate. Keeping a higher freeboard makes the structure safer but it also reduces storage or makes the structure more expensive. One more thumb rule for deciding the free board is at 15% of maximum height of the structure, but free board should be of a minimum height of 1 m. Thus, while one must make full allowance for peak runoff as evident from long-term rainfall data, one must not give unnecessary freeboard beyond the level warranted by peak runoff.

Top Width:

Thumb rule for the calculation of top width of earthen structure is as follows:

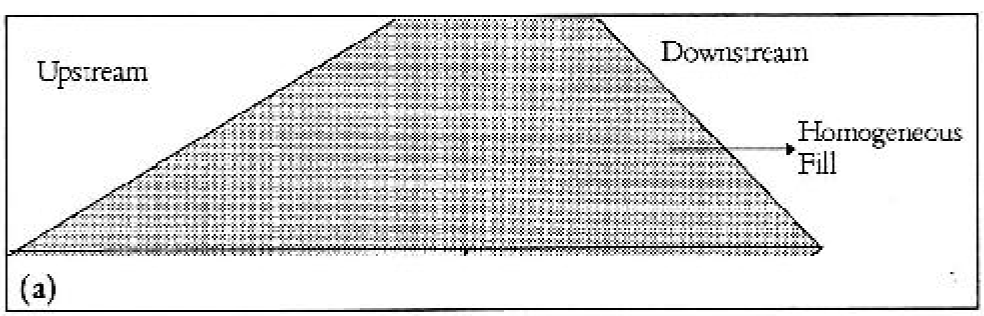
Top width of structure = 1.5 + (Maximum height of dam/5)

But in some special case this formula can be avoided for the calculation of top width. Example, if the road is planned over the dam then the minimum road width should be provided on the top of the structure.

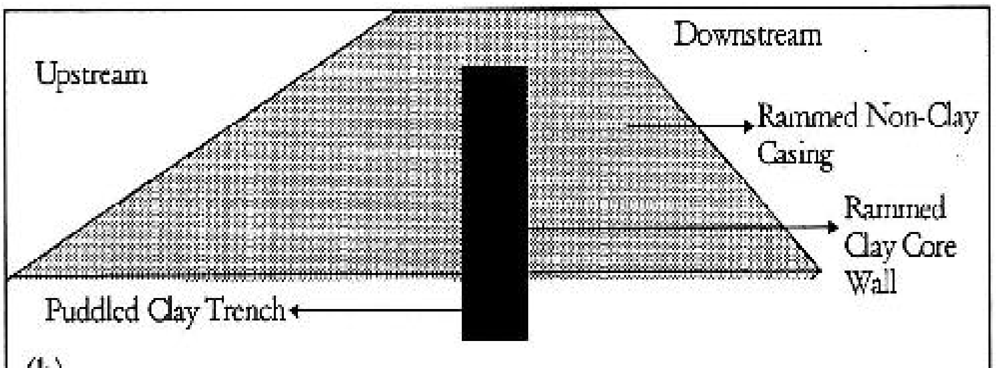
Type of earthen structures:

Depending on the construction materials used, three types of structures can be constructed:

Structure made of Homogenous Material: In places with an impervious foundation where availability of clay is virtually nil, structures can be made from a relatively more pervious material either by increasing the area of cross section, ramming the material to a greater extent or by providing a narrow clay blanket on the upstream side in order to control seepage.

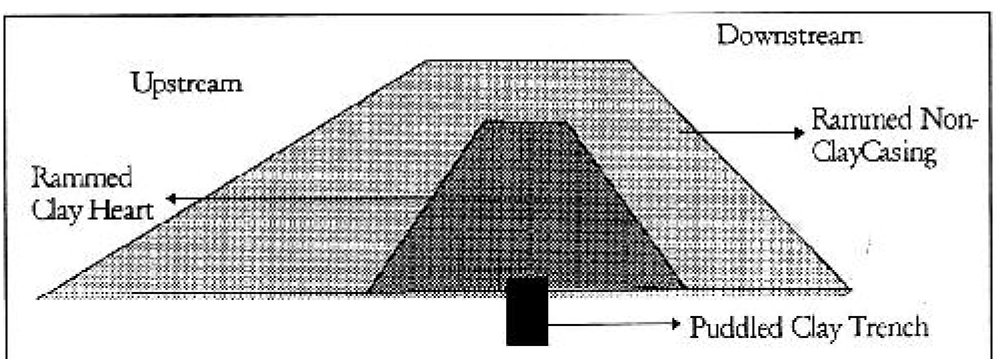


Core Wall Type: Where both the pervious and the impervious materials are available, the structure wall can be partitioned between these according to their relative abundance. Where the availability of impervious clayey soil is limited, one can choose to economize on clay by puddling. In the core wall type structure, there is a narrow, impermeable wall, extending from embankment to embankment and made of puddled clay that forms the core of the structure. To support and protect this, the outer flanks of the structure are made of dry or wet rammed coarser soils, which are arranged by grade. The finest particles being placed inside, graduating to the coarsest material outside. The final shelter is provided by pitching, which involves giving a layer of boulders on the upstream face of the structure.



(b)

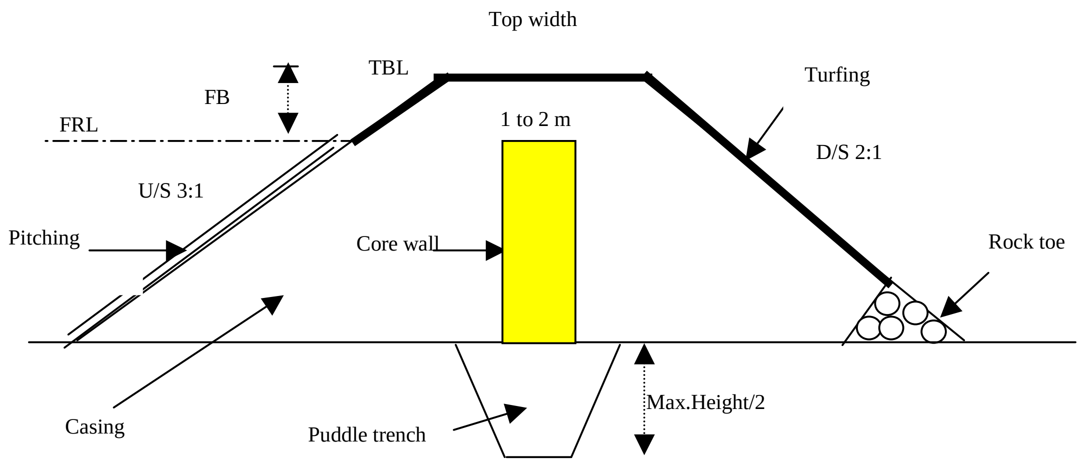
Heart type: Where clay is available easily and in large quantities, it is possible to construct the heart of the bund with wetted and rammed clay, and providing a casing of coarser soils to protect it. In situations where pure clay is not available, it is still possible to make a farm pond using finer and clayey soils for the heart of the structure and graduating to coarser soils in the casing.



(c)

The 3 possible ways of making earthen bunds. (a) a bund made of homogeneous material. (b) a bund with a core wall made of rammed clay (c) a bund with a rammed clay heart

Upstream and Downstream Slopes of Earthen structure:



X Section

The upstream slope of the structure is subject to erosion by intense rainfall and the sloughing action of receding water. The downstream slope of the bund is subject to erosion by intense rainfall and the scouring action of flowing water. In order to protect the bund from such erosive action, the slopes of the structure must be very carefully determined. The precise upstream and downstream slopes of the structure depend on the angle of repose and erodability of the materials used in the outermost faces. Through experience it has been found that for a stable earthen structure, the upstream slope should range from 2:1 to 4:1. The downstream slope should range from 2:1 to 3:1. In general 2:1 slope is provided on the upstream and downstream of the structure.

Settlement Allowance:

The soil used on the embankment of a structure is usually compacted to a certain degree. Even so, a certain allowance has to be made for consolidation of the fill and foundation materials due to the weight of the dam and the increased moisture caused by water storage. This settlement allowance depends on the type of fill material and the method and speed of construction. The design height of the dam will therefore be lower than the height immediately after construction. This means that the structure during the construction phase should be raised 10 to 25% in excess of the design height. An understanding of this is important because large settlement on structures could lead to overtopping of the structure. It must also be remembered that the structure settles the maximum in the portion where its height is also the maximum, i.e., over the deepest portion of the naala. Thus the structure must be convex shaped with the middle portion being higher than the sides.

Cut-off Trench:

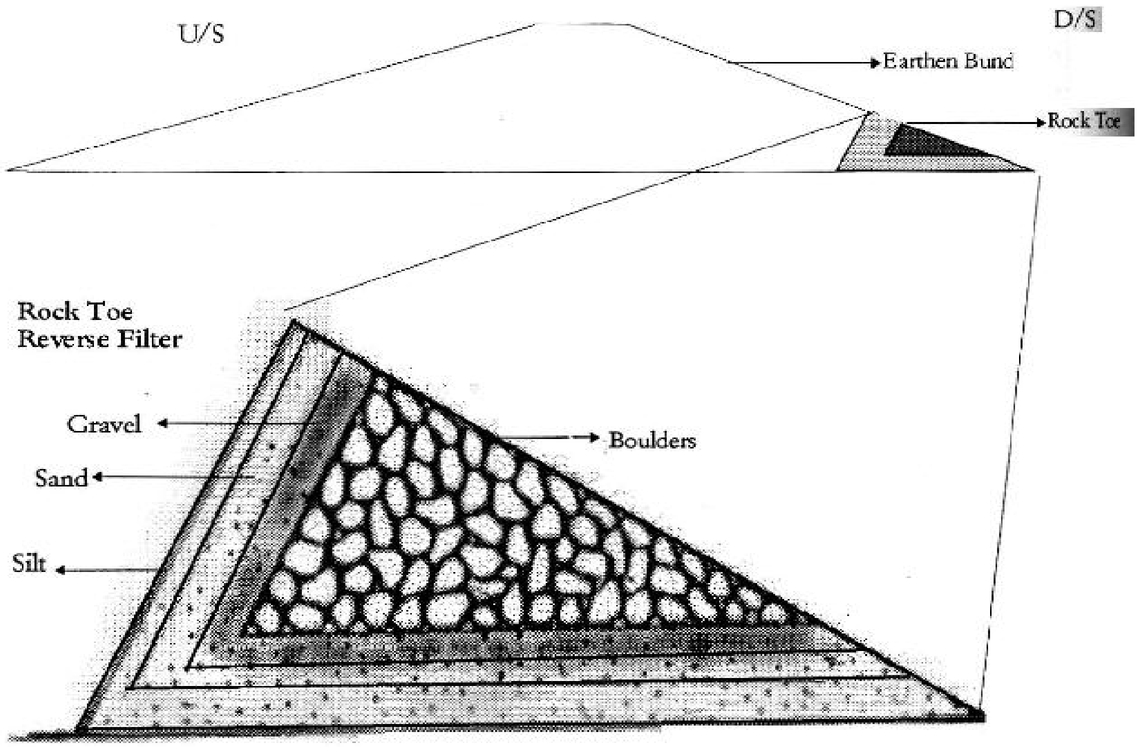
The purpose of the cut-off trench is to control excessive seepage below the structure. It is dug across the bed of the naala parallel to the central line of the structure and is filled with clayey soils, which are compacted either by puddling or ramming. In farm ponds, the depth of the cut-off trench is usually fixed as one-fourth of the height of the structure or till an impervious strata is reached, whichever comes earlier.

Pitching for Embankment Protection:

To protect the surface of the structure from erosion by rain and the sloughing action of receding water in the reservoir, pitching is done by giving a final layer of boulders on the slopes of the structure. The extent of pitching depends on the angle of repose of the material used on the upstream face of the embankment. Where boulders are not easily available, the freeboard zone on the upstream face and all of the downstream face can be protected by planting grass. The roots form a protective web that binds the soil together, and the grass blades cushion the force of raindrops making them less destructive.

Toe Drain or Rock Toe:

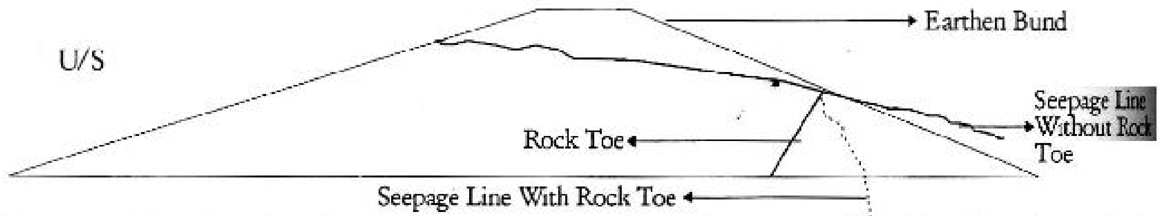
Even in a relatively impervious structure, some amount of water stored in a reservoir percolates from the upstream side to the downstream through the body of the structure, thus forming a seepage line. If this line emerges above the base of downstream face, it would slowly cut into the downstream side and gradually erode it. This would pose a serious threat to the stability of the structure. In order to drag the seepage line downward so that the water is drained within the base of the structure, a toe drain or rock toe is provided. This toe drain is a reverse filter with each subsequent layer increasingly coarser than the previous layer. The filter material must be more pervious than the structure material so that the seeping water can be quickly removed.



A Rock Toe is a reverse filter provided at the downstream base of an earthen bund. A multi-layered filter is provided in which each subsequent layer becomes coarser than the rest

Causes of Failure of Earthen structures

- **Seepage Line:** In any earthen structure, some water always seeps through the structure. The line along which the water seeps is called the seepage line. In relatively pervious and homogenous structures, the seepage line frequently crosses through the bund and appears on the downstream slope. Water which percolates either through the structure or under its foundations carries with it particles of soil thereby forming tunnels/ runs which once formed quickly enlarge, becoming cavities into which the structure sinks, enabling the water to top it and carry it away by erosion. The cause of this failure is a high percolation velocity greater than or exceeding the tolerance limit of the soil. Such a failure can be caused because of a lack of an effective stop wall to obstruct the path of percolation. It could also be caused by cracking of the soil, burrowing of animals and the decaying roots of trees.



In any earthen dam there is always some seepage along the seepage line. A rock toe is made to drag down the seepage line in order to prevent it from cutting the width of the bund.

Slope of Seepage Line in Different Materials

Material	Slope of Seepage Line (%)
Clay	25-30
Good compacted soils	25
Clayey Loams	20
Fine Silt	17
Loam	13
Fine Sand	12
Coarse Sand	10

The seepage line is defined as the line marking the boundary between the saturated (wet earth) and unsaturated (damp or dry earth) zones inside an earthen structure. Studies have shown that the slope marked out by the seepage line is different in different materials.

Even in a relatively impervious structure, some amount of water stored in a reservoir percolates from the upstream side to the downstream through the body of the structure, thus forming a seepage line. If this line emerges above the base of downstream face, it would slowly cut into the downstream side and gradually erode it. This would pose a serious threat to the stability of the structure. In order to drag the seepage line downward so that the water is drained within the base of the structure, a toe drain or rock toe is provided. This toe drain is a reverse filter with each subsequent layer increasingly coarser than the previous layer. The filter material must be more pervious than the structure material so that the seeping water can be rapidly removed.

- **Sloughing:** Sloughing of the side slopes of an earthen structure is said to take place when the water face of the structure is cut into and eaten away by the action of waves or receding water. As the water recedes it carries off some soil particles, leaving behind large pore spaces. On drying, these spaces collapse, leading to further erosion. This leads to the slope becoming so steep that slipping of the upper layers occurs and the top width of the structure is gradually eaten through so that the overtopping and failure ensue. To protect structures against this action, pitching or riveting is undertaken on the water face of the structure. Use of vegetative measures can also prove effective.

- **Scouring:** Rainwater falling on the bund acquires scouring velocity as it flows on the downstream face of the embankment. It, therefore, cuts channels on the downstream side and weakens the structure. Pitching and vegetative measures on the downstream side help keep the velocity of flow within the non-scouring limit.
- **Overtopping:** All causes of earthen structure failure ultimately lead to overtopping. Water washing over the top of the structure gradually erodes the top and downstream slopes, thereby cutting a channel through the structure to a depth below the Full Reservoir Level (FRL), which speedily results in a breach. To prevent this, the top of a structure is raised to a certain height called the 'freeboard' above the FRL.

Waste Weir:

Water in excess of the 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 as per the Rational formula:

$$Q=CIA/360,$$

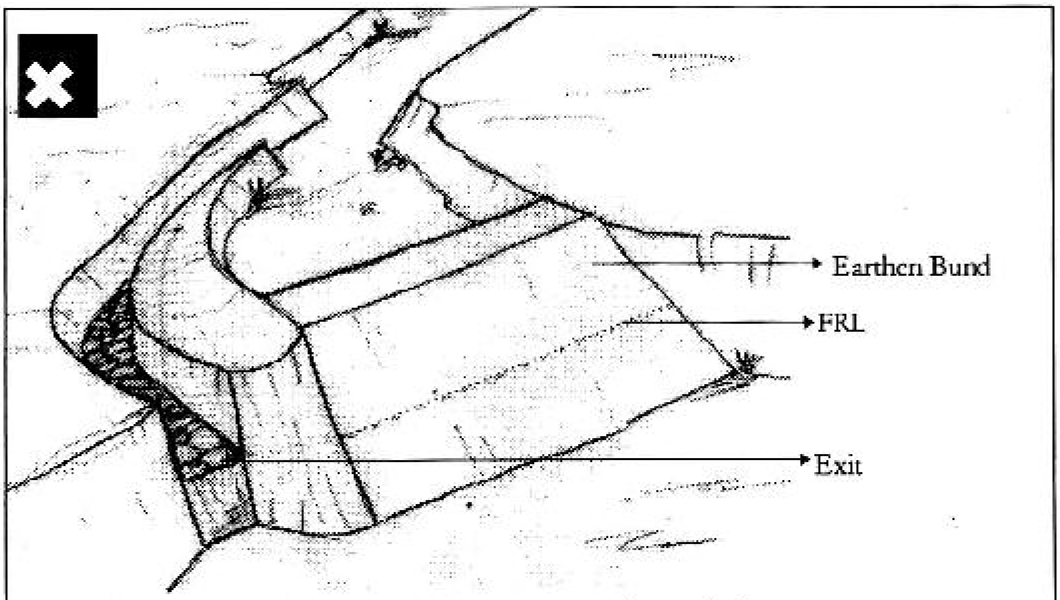
where Q=Peak runoff (cubic meter per seconds); C=runoff coefficient;

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

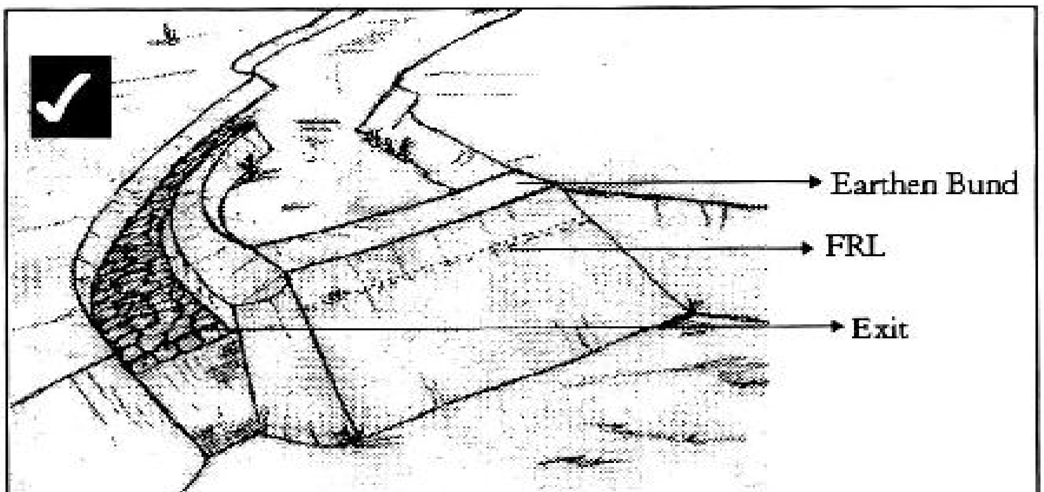
Wherever possible, it is better to have a broader waste weir for a given volume of excess runoff rather than a deeper one so as to maximize the storage capacity. The discharge capacity of the waste weir is given by the crested weir formula,

$$Q= 1.75LH^{3/2},$$

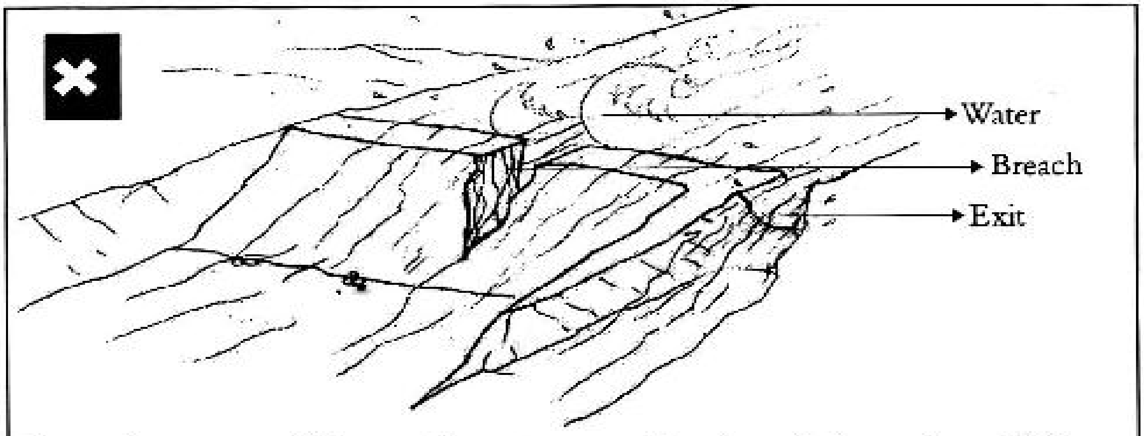
where, Q=discharge (cubic meter per second), L=weir width (m) and H=depth of flow (m).



For a given volume of water which is to pass through the exit, a narrow and deep exit leads to a lower storage . . .



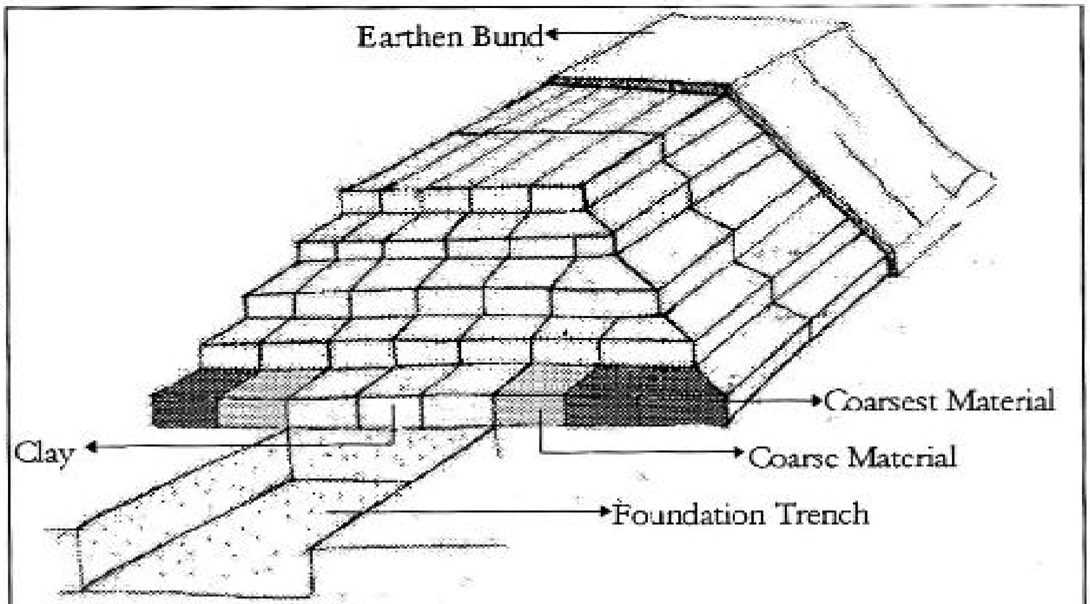
. . . the exit should, therefore, be made wide and shallow to give maximum storage



If an adequate exit is not given to an earthen bund, the water will flow over the top, causing a breach and eventual collapse

Construction:

- Fix the FRL for the structure following the procedure outlined in the Design section.
- Draw a line along the center of the proposed structure from embankment to embankment and determine the height of the bund (including freeboard) at different locations along this line. Wherever the ground level is lower, extra work will be needed to raise the structure to the required height. Settlement allowance must be added to this height at each point. On the basis of the slope parameters decided, indicate distances on the upstream and downstream side at each location and draw lines through these points. Care must be taken to provide the required top width. For instance, if the structure height is 3 m, crest width 2 m and upstream and downstream slopes 2.5:1 and 2:1 respectively, the upstream edge of the structure must be marked at (3 x 2.5) + 1 = 8.5m distance and the downstream edge at (3 x 2) + 1 = 7 m distance.
- Dig trial pits at 3 - 4 locations at the base of the proposed structure. The percolation rate in these pits would help determine the depth of the cut-off trench along the base of the structure.
- Dig a 1 m wide trench of required depth along the centerline of the proposed bund. On both the sides the trench must at least extend, till the point where the top of the bund meets the embankment.



An earthen bund "peeled off". Built layer by layer, the materials get progressively coarser as we move from the inside to the outside

- In a core wall type of structure, the clay is soaked, kneaded and rammed to make a thin impermeable wall. The cut-off trench is filled with puddled clay till the ground level is reached. This is a labor-intensive method but it maximizes impermeability of clay. Where there is an easy availability of clay, a heart type of structure may be made. A thicker wall of clay can be raised by laying, wetting and ramming. After the cut off trench has been filled, the structure comes up in horizontal layers. All sections of the structure must be raised together. In a core wall type, the puddle core wall and the shell must be simultaneously raised. In the heart type, both the hearting and the casing must be done together. The layers should be 6 to 8 inches on either side, which are layed, wetted and rammed. While laying it should be kept in mind that the finer soils should be laid inside, i.e., closer to the clay core, and the coarser soils should graduate outwards. The height of the core wall/hearting must be 0.5 - 0.75 m less than the top bund level. As layer after layer gets compacted, the width of the casing is reduced to create the slopes of the upstream and downstream sides of the structure till the desired height is arrived at.

Dos And Don'ts:

- The effective storage capacity of the structure should not be either too large or too small in relation to total runoff.
- The upstream bed of the structure site should not have a high slope.
- At the point of location of the structure, the drainage line must have well defined embankments in which the structure can be anchored.
- The permission of those whose lands may be getting submerged would also need to be obtained prior to fixing the FRL. Effort must also be made to actively involve them in the planning and design of such structures from the beginning to end.
- Adequate freeboard must be provided to the structures on the basis of the peak runoff rates computed from long-term rainfall data.
- The waste weir must be designed so as to drain out the peak runoff safely when the water is at FRL in the structure.
- In order to protect the safely from such erosive action of water, the upstream and downstream slopes of the safely must be very carefully determined on the basis of the angle of repose and erodability of the materials used. Do not use highly erodable material like clay on the outer faces.
- Adequate settlement allowance must be provided for consolidation of the fill and foundation materials due to the weight of the structure, rainfall and the increased moisture caused by water storage.
- Cut-off trenches to control excessive seepage below the structure must be filled with clayey soils compacted either by puddling or ramming.
- Toe drains must be provided to drag the seepage line downwards so that the water is drained within the base of the structure.

Costing:

Cost of a earthen structure with structure length of 30 m, height 3 m, upstream slope of 3:1 and downstream slope of 2.5:1 and a total storage capacity of 0.75 ha-m works out to Rs. 100000 at 2006-07 prices. A typical cost sheet is appended below:

Dugout type Farm Pond

It is a water harvesting structure suitable for the plane area. Main purpose of the structure is to ensure protective irrigation for the kharif crop. Topography of Bengal, Orissa, Chattisgarh & Bihar is suitable for construction of these types of structures.

Site selection criteria: Following are the criteria for the site selection of a dugout pond:

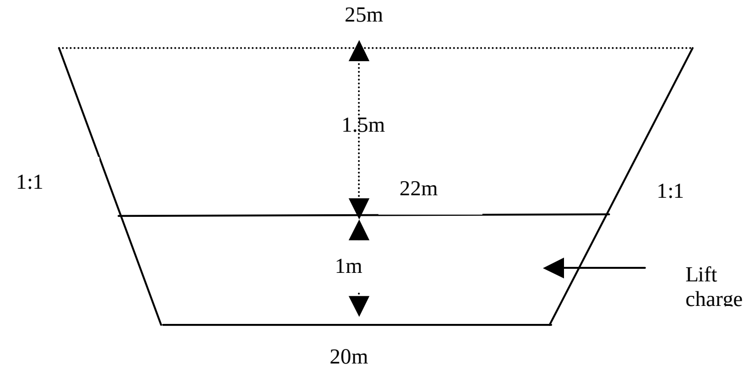
- Location of the structure should be near to farmland so that it can be used for protective irrigation and benefited in the well recharging.
- Catchment area of the pond should be within 2 - 20 hectares.
- Soil strata up to 3 m depths should not be in the form of disintegrated rock or hard rock.
- If any well is there, then the farm pond should be on the upstream side of the well.
- Soil of the dugout should be impermeable so that water can be stored for a longer period.
- One thousand cubic meter (20 m x 20 m x 2.5 m) storage capacity of farm pond required for the protective irrigation of one hectare of the land. Five percent land is required for serving the said requirement. Beneficiaries should be selected as per the requirement of the land for the construction of farm pond.
- At least three to four hectares catchment area is required for storing 1000 cubic meter water in a farm pond.

We can construct two types of farm ponds:

1. **Dugout type:** Where the slope of the field is relatively low and there are no well-defined drainage channels, the pond will have to be created by excavation. The storage capacity will be confined to this excavated portion. Because of the low slope, there will be little storage above the ground level. Such ponds are best located in the lowermost portion of the field. The runoff has to be directed into the pond through bunds or channels.

Trapezium type dugout pond:

Size of the tank depends on the requirement of water for protective irrigation. Depth of dug out pond depends on the soil strata. Side slope of

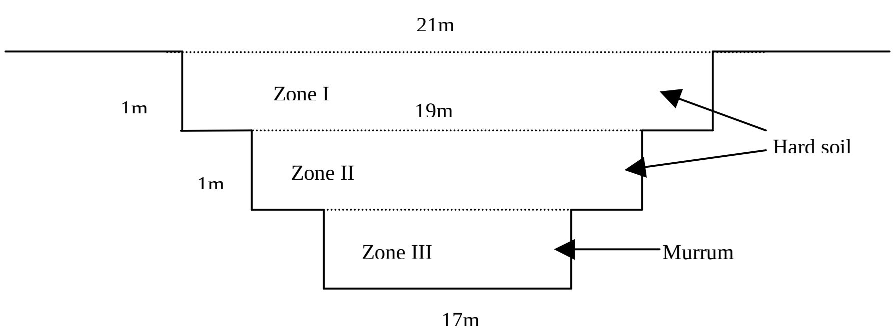


X-Section of dugout pond

the dug out pond depends on the angle of repose, generally 1:1 side slope is provided in cutting section.

Stepped dugout pond:

It is preferred in that location where community may use the pond for their daily work.



X-section of dugout

2. Dugout cum Embankment type: Where there is no well-defined channel and the slope of the farm is medium, farm pond should be of the dugout cum embankment variety. Here, the mud excavated should be used to form an embankment all around the pond except at the inlet. At the full reservoir level, the water level will be higher than the ground level and the embankment will serve as a retaining wall. Therefore, even while the dugout portion will be a significant part of the total storage volume, there will be some storage above the dugout portion retained by the embankments.

The main difference between the embankment and dugout types of farm ponds is that the dugout variety can be made in virtually any topographic situation without reference to the drainage line. As for the design, the freeboard in a dugout pond refers to the difference between the base of the waste weir and the top of the dugout portion of the structure. The freeboard is given mainly to prevent water from flowing into nearby fields during flash floods. Since the main storage is not through the bund, most of the discussion regarding bund parameters becomes redundant. But a certain degree of care has to be exercised in order to protect the pond from erosion by the intense rainfall and the sloughing action of the receding water. Here, the same considerations apply as in determining the slope of the dugout area. If the pond face is made of a material, which has a low angle of repose, it should be cut at an appropriate angle to form a series of steps. The resultant reduction in the pond capacity is to be balanced against the considerations of stability. Pitching should also be done where required. Where percolation losses are high, it may be advisable to allow a layer of transported soil to get deposited on the pond bed during the initial year. By acting as a clay blanket, this layer would reduce percolation losses. In subsequent years, a silt trap can be made in the inlet channel. The inlet channel should be lined with boulders to make it safe against erosion. Before the channel reaches the pond, a silt trap should be placed either by digging a trench or through constructing a boulder check.

A farm pond of 1000 cu.mt., with a catchment of 0.6 ha, can protect 1 ha of standing paddy crop. The cost of construction of such a farm pond would work out to about Rs. 10,000 to 15,000 per hectare. Where the percolation losses of this on-farm reservoir (OFR) could be controlled by the puddling of the reservoir bed, the returns for the investment are likely to be high. In low lying land which gets considerable natural recharge from the water table, the OFR of even smaller size can protect paddy against the agricultural droughts. Even in other types of land situations, the total storage during the season can be substantially raised above the static storage capacity of the OFR, if the conserved water is used strategically. Appropriately located farm ponds would allow for a second crop as well. The moisture stored in the soil profile in a lowland area after the harvest of rice or soyabean is nearly the same as that of the upland region during the rainy season. Hence, suitable upland crops can be grown in this portion as the second crop. Utilisation of soil moisture by these crops proves difficult on account of the drying up of the topsoil layers, which results in the poor germination percentage. The residual storage available in the OFR can be used to ensure better establishment of an upland crop in the post rainy season, which could then utilise the available soil moisture for its growth.

Crop systems combining the farm pond concept with the paddy and soyabean cultivation in 1 hectare plots can also be tried out on vertisols and inceptisol. This system has the following components:

- Small dugout farm ponds are created using 10% of the area, with enough catchment to generate runoff to fill the pond during the main rainy spells. The excavated material is used for improving the drainage characteristics and moisture retention in the catchment of the OFR.
- Rice is grown in the lower portion of the field in about 30% of the area, during the rainy season. The runoff collected in the OFR stabilizes the yield of rice to such a level that the production from this portion is equal to or more than the output from the whole farm before the OFR was established.
- High value legumes such as soyabean and pigeon pea are grown in the catchment of the OFR, in about 60% of the area. The drainage from this area fills the OFR.
- During the post-rainy season, suitable dryland crops are grown in as big an area as is feasible using the water saved in the OFR. In ascending order of water availability, the post-rainy crop could be gram, wheat, sunflower or vegetables.
- Fish fingerlings could be grown in the OFR during the months of July to October.

- Results of an evaluation of the yield performance of crops with OFR on vertisol fields are depicted in the table below. It can be seen that construction of farm ponds can have a significant impact on yield stabilisation.

Precautions:

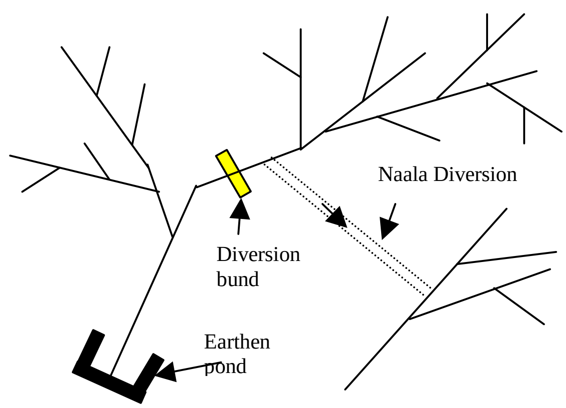
- Catchment area should be treated for the soil conservation interventions otherwise pond will silt up.
- It should be constructed on small drain or the first order drain
- If the dug out pond is used for meeting daily water requirements then stepped type dugout should be preferred.
- Prefer those beneficiaries who have no source of irrigation.
- Select the deep pond instead of a shallow pond
- Exit of a dug out pond should be at the ground level and side of the embankment should be protected with stone pitching.
- Dugout soil should be stacked in form of embankment with a one-meter burm.

Naala Diversions and Naala Training

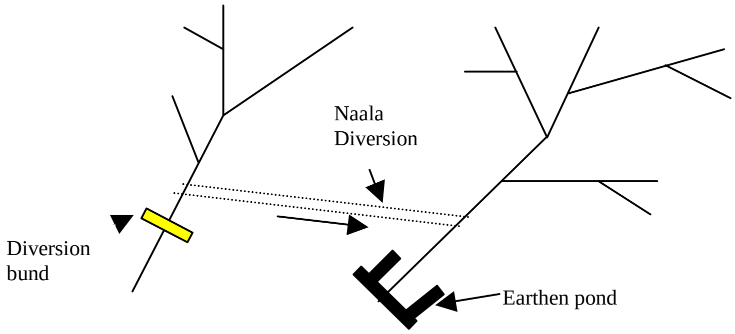
Naala diversion:

While planning for water harvesting structures naala diversion is sometimes necessary. Following are the situations where the naala has to be diverted from its natural path:

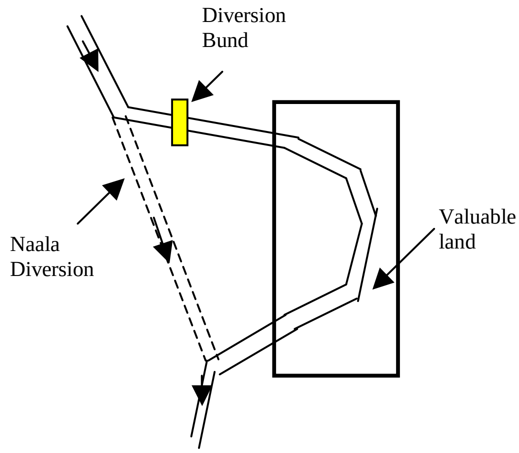
- When a site fulfills all the points of an ideal site selection criteria but is problematic only with regards to the excess catchment; and when there is not enough space for providing an exit: - In that situation, part of naala (as per requirement) can be diverted through an artificial channel to the nearby drain. Caution should be taken while planning for diversion so that the artificial channel should not erode any valuable land. If the cost of structure and cost of diversion is justified in terms of the cost benefit ratio then this type of plan may be thought for implementation.



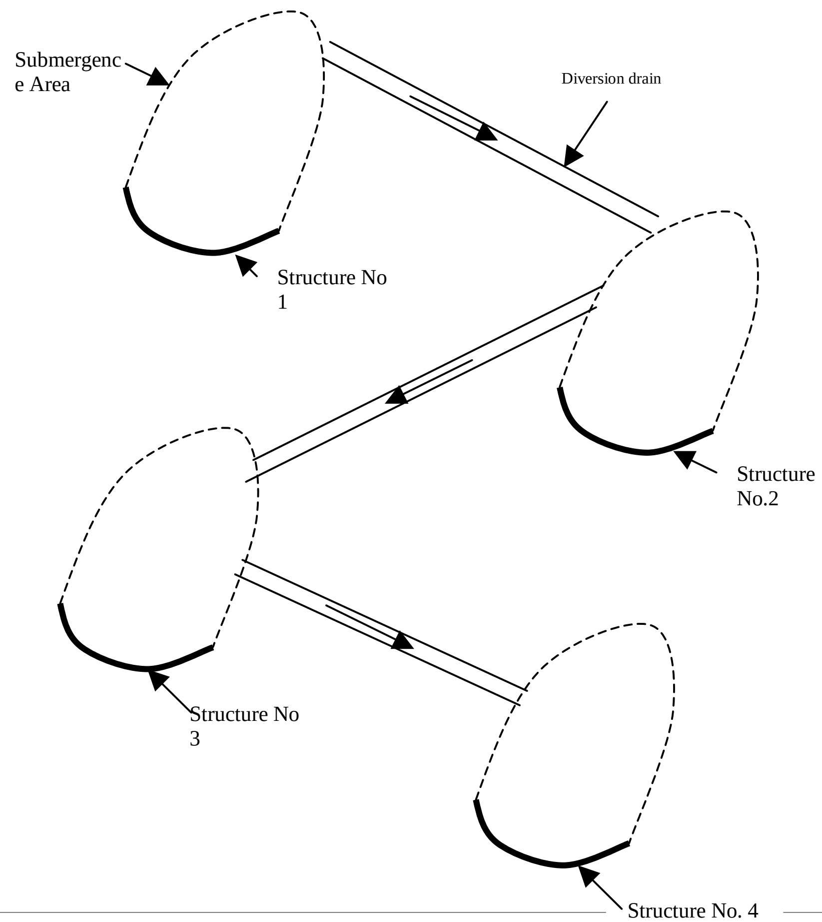
- When a site fulfills all the points of ideal site selection criteria, with an exception that the catchment is not enough for planned storage capacity of water harvesting structure: - In that situation, nearby naala (as per requirement) can be diverted through an artificial channel into the main naala. Caution should be taken while planning for diversion so that the artificial channel should not erode any valuable land. If the cost of the structure and cost of the diversion justified in term of cost benefit ratio then this type of plan may be thought for implementation



- When a valuable land is eroded by naala: - In that situation, naala can be diverted through artificial channel to near by drain. Caution should be taken while planning for diversion that the artificial channel does not erode any valuable land. If it is justified in terms of the cost benefit ratio than this type of plan may be considered for implementation



- Number of water harvesting structure, which can be connected through an artificial channel. It is required for the paddy-cultivated area. It is very important that the level of exit should be decided on the basis of our plan of connections. Example: Structure Nos 1, 2, 3 & 4 are planned for interlinking. We would like, that the over flow of structure No 1, should be diverted in structure No 2 and of No 2 to No 3 and No 3 to No 4 structure. In such a case elevation of the exit of structure Nos 1, 2, 3 & 4 should be in decreasing order. While planning caution should also be taken against any erosion of the valuable land by the artificial channel. If the costs of the structure and cost of the diversion are justified in terms of the cost benefit ratio than this type of plan may be considered for implementation.



Training a Naala:

Erosion of naala depends upon the soil strata, if the hard strata is present in the bed of naala, then the naala erodes the embankment and shape of naala in this case will be U shape. If the hard strata is present the sides of the embankment of naala, then the naala erodes the naala bed and shape of naala in this case will be V shape.

Main problem of a U shape naala is that at the turn, the embankment on one side gets continuously eroded while on the other side silt heaps on depositing every year. In this way a naala changes its course every year. The purpose of training a naala is to protect the curve from the loosening of a portion of an embankment, and prevent the erosion of the loosened embankment. At times, naala has to be diverted through straight channels.

Following structures can do training of a naala:

Gabian spur- It is a structure constructed in the curved portion of naala. It is located in angular shape. Materials used for gabian spur are G.I. wire mesh and boulder.

Gabian retaining wall- It is a wall constructed parallel to the embankment for the protection of loose side embankment.

Renovation of old earthen water harvesting structure

Water harvesting through constructing earthen structure is a traditional system in India. The earthen structures, which are lying unutilized due to some reason, may also be renovated. Following are the situation when an earthen water harvesting structure may be renovated:

Tank silt up: In such a situation where the storage capacity of a pond is reduced due to siltation, a tank can be proposed for the desiltation process, desilted soil may be used for increasing the height of pond so that the storage capacity of a pond can be increased. The main question is that how much quantity of silt should be proposed for desiltation. The quantity of desiltation will depend on following factors:

- Catchment area of pond.
- Annual rainfall data of the area (last 25 year period).
- Present storage capacity of pond.
- Soil type, land use pattern & average slope of catchment area.

We can find out the quantity of water which will reach at pond during the rainy season by using this formula: Q = C x I x A

Example: The present storage capacity of earthen pond is 10,000 cubic meters. Total 15,000 cubic meters (excluding all types of losses) water reaches the pond. In such a situation, we can propose a maximum (15,000-10,000) of 5,000 cubic meters of soil under the desiltation of the said pond. It is very necessary to make a plan for the dumping of excavated silt. The deposited silt in old tank is more fertile as compared to the other soils, so it can be very useful for those farms where the fertility of soil is low. This soil can also be further used for increasing the height or strengthening the bund.

For proposing such a desiltation process, a technical drawing of the pond showing the area of the land subject to submergence the demarcation of desiltation area thereon, and the reduced level of the proposed desiltation area with respect to benchmark established near by site needs to be prepared and presented.

Part of embankment is completely damaged: For repair of such type of bund we have to collect the following information:

- The age of the structure.
- The possible reasons for damage:
    1. Compaction of bund is not up to the mark.
    2. Provided U/S and D/S slope is not up to the required standard.
    3. Absence of core wall/ Hearting.
    4. Insufficient freeboard.
    5. Size of exit is not sufficient with respect to catchment area of the pond.
    6. Any interruption in the exit like a big boulder or a tree etc.

All the above information can be collected through technical surveys, interactions with the community and communication with the implementation agency. After getting information about the damage, we have to plan not only about the repair of bund but also to work on the reason of the damage. This is necessary otherwise this repair will get damaged in the following year.

Example: A bund was damaged after the construction of a pond within a year. After collecting the information about the pond we know that the size of the exit is insufficient as per the design requirement. In that case we have to propose the repair of the bund along with the widening and deepening of the exit.

Seepage from the earthen pond: Generally some seepage at the bottom of pond is visible anywhere but if the seepage is from the D/S slope in large quantity then it becomes very dangerous for the pond. Seepage reduces the storage time in a pond. For controlling the seepage we have to collect the information regarding the core wall or hearting, cutoff trench & the soil used for casing. Then we have to decide on the basis of collected information what measures should be proposed for controlling seepage.

Bund of the pond is weak: Collect the information regarding the catchment area, and the storage capacity. Then design the top width, height, and the U/S & D/S slope. After design, we have to estimate the quantity of the material required for the strengthening of the bund.

Engineering measures for erosion control in agricultural land

Contour cultivation:

Cultivation operations are done across the slope by keeping them on contour or nearly so. The contour furrows so created would form a multitude of mini barriers across the flow path of the runoff, which improves vastly the detention of storage in situ. This will in turn increase the opportunity time and hence the infiltration of rainwater into the soil profile whereby the quantity and velocity of runoff and hence its erosive potential gets greatly reduced. Further when cultivation is done on the contour instead of up and down cultivation, much less power is required to be exerted by men, animals, and machines.

Slope groups %	Ratio of soil loss from contour cultivation/ up and down cultivation
< 1%	0.6
2 to 7%	0.5
7 to 12%	0.6
18 to 24%	0.9

On-farm interventions farm bunding:

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. Contour 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. Due to these difficulties, what is normally practiced in the name of farm bunding is bunding along the field boundaries. In this module we will outline a practical middle path between the extremes of contour bunding and bunding on field boundaries, so that the benefits of bunding are made available to farmers without creating any problems.

Objectives

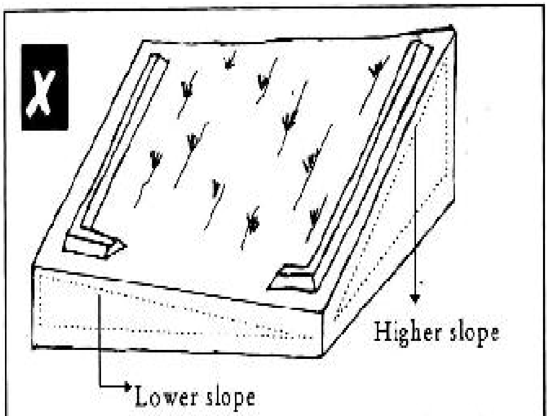
Control of Soil Erosion: In our country, rain falls in a few hours on a few days in a few months. After falling on the ground, rainwater runs off, from the field to the stream and from the stream into big rivers, carrying with it the precious topsoil. Due to this action of rainwater, rills are formed in fields, which soon become small drains. It must be remembered that every year in our country 5330 million tonnes of top soil and 5 - 8 million tonnes of nutrients are lost due to soil erosion. We should also keep in mind that it takes over ten thousand years to form a 2.5 cm thick layer of fertile soil. It is estimated that if these soil losses are prevented, then the agricultural productivity can rise by 30 - 40%. Bunds, by dividing the field into several units, 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 the level of 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 stabilizes the soil moisture profile. What exactly is meant by "improvement"? The definition changes with changing local conditions:

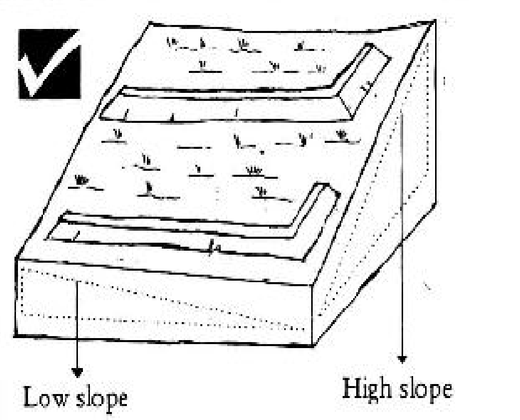
- In permeable soils (sandy or alluvial), the main aim of bunding is to stop runoff.
- In impermeable soils (black or clayey), the purpose of bunding is to make arrangements for the safe exit of water out of the field. On the one hand, we aim to reduce the velocity of run-off. But since the soil is impermeable, 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:

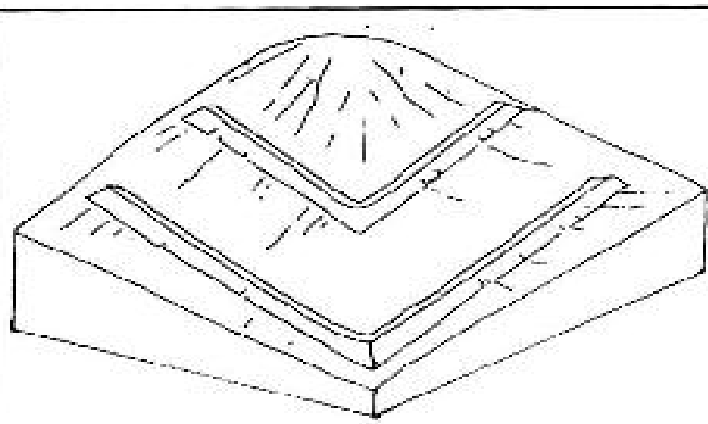
A plan for farm bunding can never be made for one field alone. Because, in any field, water flows in from the fields above it and flows out to the fields below it. Thus, it is important to plan for the entire stretch between the up lying fields to the drainage line as a single unit. Therefore, it is crucial to involve all farmers of the village in the planning process. They must be informed about the proposed plan and its objectives. Only with their complete participation should the plan for bunding be finalized.



If the field slopes towards one corner then the bund should be constructed parallel to the field boundary. But not parallel to that field boundary which is in the direction of the higher slope

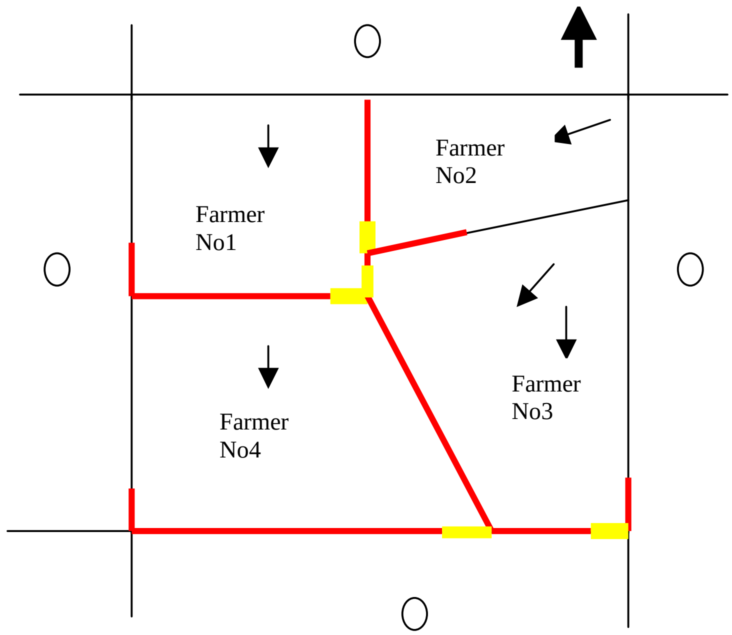


. . . the bund should be made parallel to the boundary which is on the lower slope. When the bund reaches the lower part of the field, it should be turned up for some distance



If the field has a two-way slope then one bund should be made across one slope. Then another bund should be made aross the other slope. The two bunds should be joined together in the middle.

Even so, it may happen that farmers in the up lying 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. But the problem becomes insurmountable if the farmers below



do not agree. This is because water, which is discharged from the fields above, can completely destroy the crops in the fields below. Thus, consent of farmers of the low laying fields where bunding is to begin, is a must.

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 be stopped more frequently.

It is commonly expressed in term of vertical interval (VI), which is defined as the difference in elevation between two similar points on two consecutive bunds. The basic principle involved in fixing the spacing between two bunds is to keep the velocity of runoff below the critical value, which creates scour.

Vertical interval is usually expressed as:

VI = 0.305 x [(S/a) + b]

Where VI = Vertical Interval in meter, S = Slope in percent, a and b = constants specific to particular region. For soil with good infiltration rates values of a and b are respectively taken as 3 and 2 whereas for soils of low infiltration rates the corresponding values are 4 and 2, respectively. Spacing between the two bunds should be finalized after consulting the farmer, as far as possible the above suggested spacing should be tried. Divide the group of farmers according to slope and plan the bunding with the group. Bund should be planned perpendicular to the slope. Avoid the land demarcation bund, which are parallel to slope and also on ridgeline. Plan the bunding with the group of farmers and channelize the excess water in to nearby natural drain. Bunding on black cotton soil should be planned carefully and plan to drain the excess water safely in to the nearby natural drain. Position and no of outlets is very important. Fix the location and number of outlet to discuss with group of farmers.

Design:

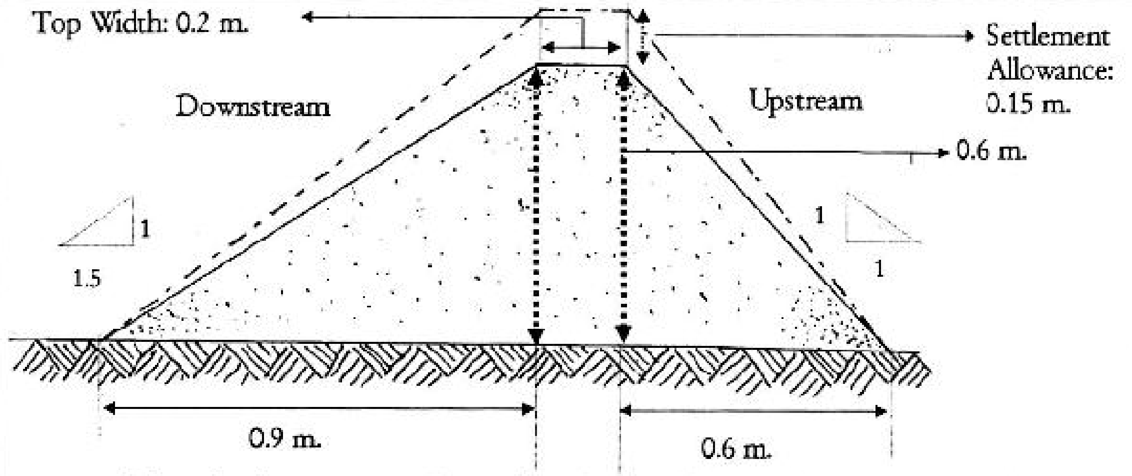
Situation 1: In Permeable Soils

Bund height:

The governing factors are:

- Depth of water to be impounded.
- Design depth of flow over the outlet.
- Freeboard.
- Vertical interval (the more the vertical interval, more the depth of water impounded)
- Dependence on landowners for the maintenance also necessitates slightly greater height than the minimum worked out.
- Depth of water standing against the bunds largely depends upon the rainfall factors and the rate of infiltration of soils (lower the rate more the depth of water impounded).

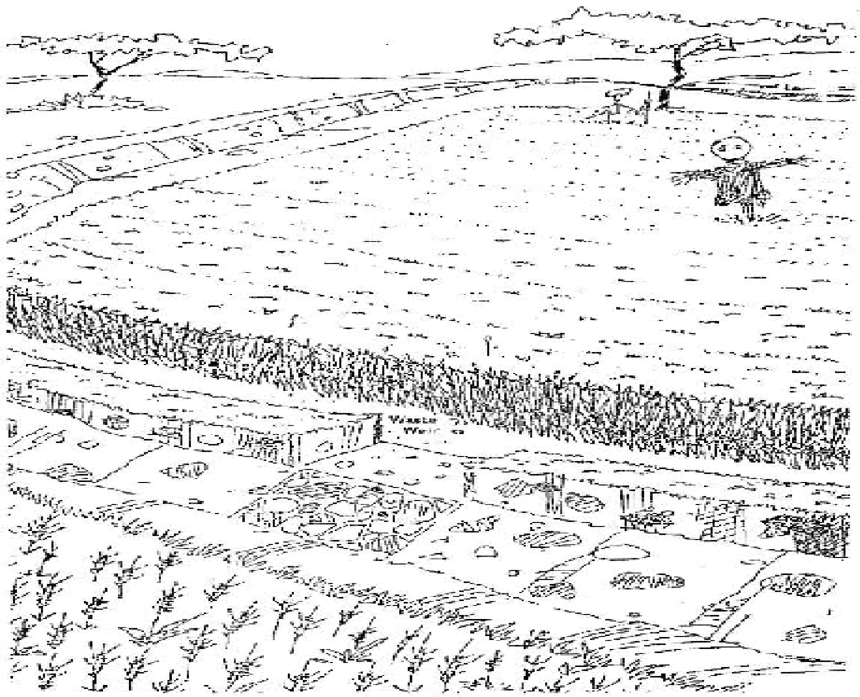
Height of bunds with 30 cm of impounding: This is the usually practice in many states. The depth of impounding is designed as 30 cm; 30 cm being provided as depth of flow over the outlet and 20 cm is provided as freeboard. This makes the overall height of 80 cm. With top width of 0.50 m and bottom width of 2 m, side slope works out 1:1, the cross section then works out to be 1 sq m.

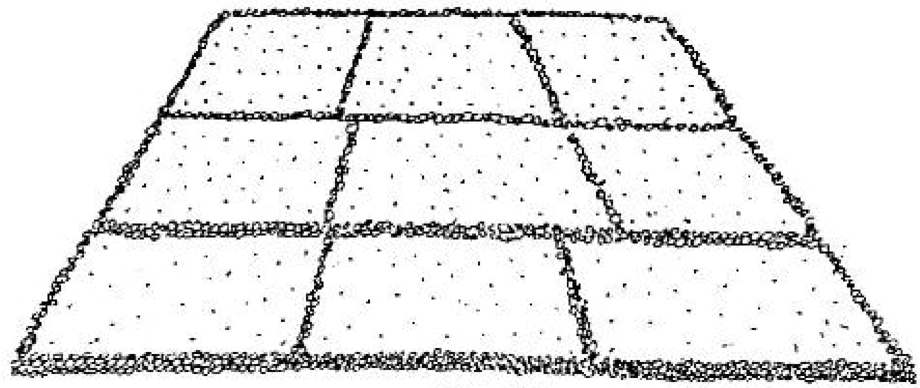


In permeable soils, the upstream slope of bunds should be in the ratio 1:1, and the downstream slopes in the ratio 1.5:1

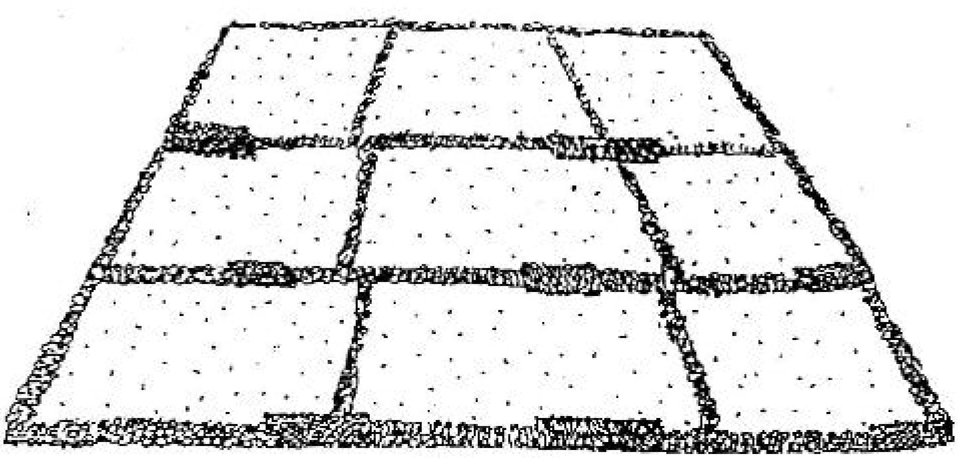
In general the size of the bund is as follows:

- **Height:** 60 cm
- **Settlement Allowance:** 20 - 25%
- **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%
- **Top Width:** 20 - 30 cm
- **Upstream Slope:** 1:1
- **Downstream Slope:** 1.5: 1. In gravelly soils, both upstream and downstream slopes can be kept at 1: 0.75
- **Surplus Weir (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. Rapidly flowing water may overtop the bund or slowly erode it. Therefore, provision of an 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





Low rainfall area



Medium rainfall area

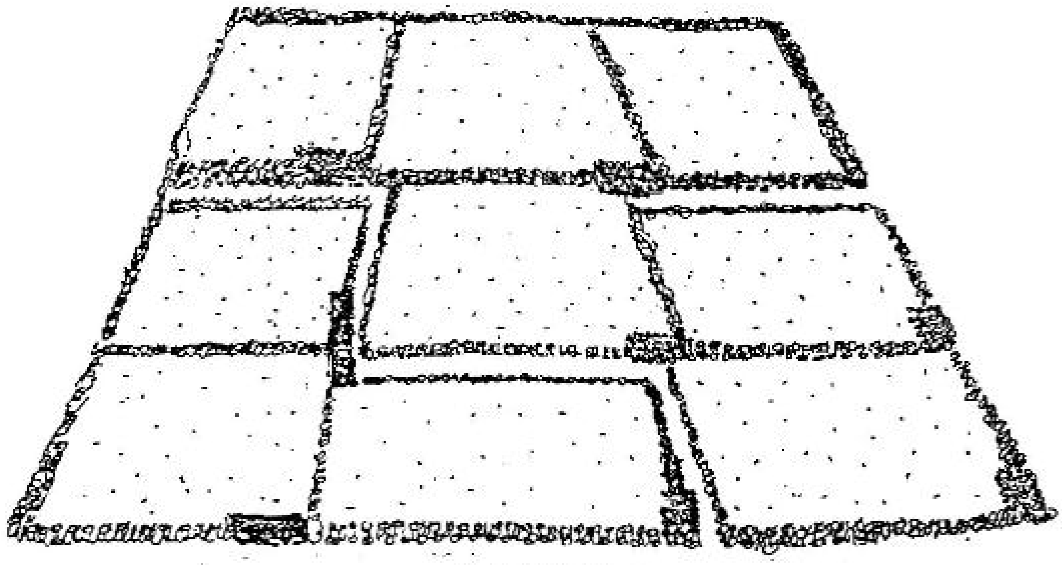
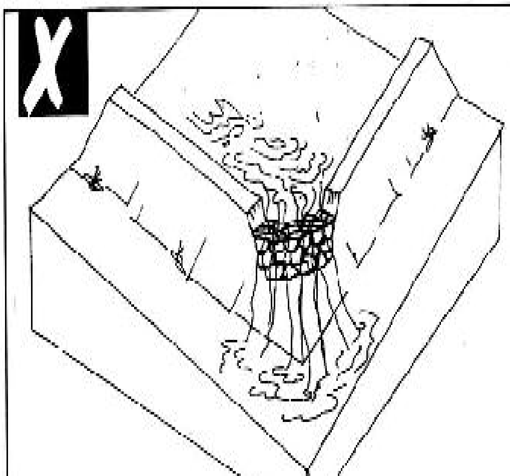
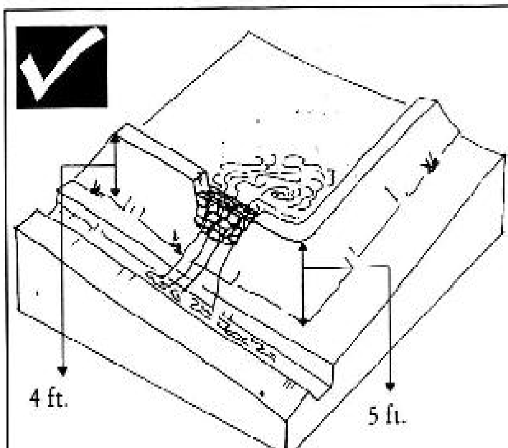


Fig. 9.7: How boundary bunds and drainage treatments would vary with different rainfall types. The top field layout illustrates a system which would be sufficient for a low rainfall area. All that has been done is to bund the fields with stone bunds. The middle layout illustrates requirements for a medium rainfall area. The stone bunds would have to be provided with well designed spillways or waste weirs at field outlet points. The bottom layout illustrates a high rainfall situation in which, additionally, waterways would have to provided to carry away the excess spill during rainy spells. (Adapted from MANAGE Manual)

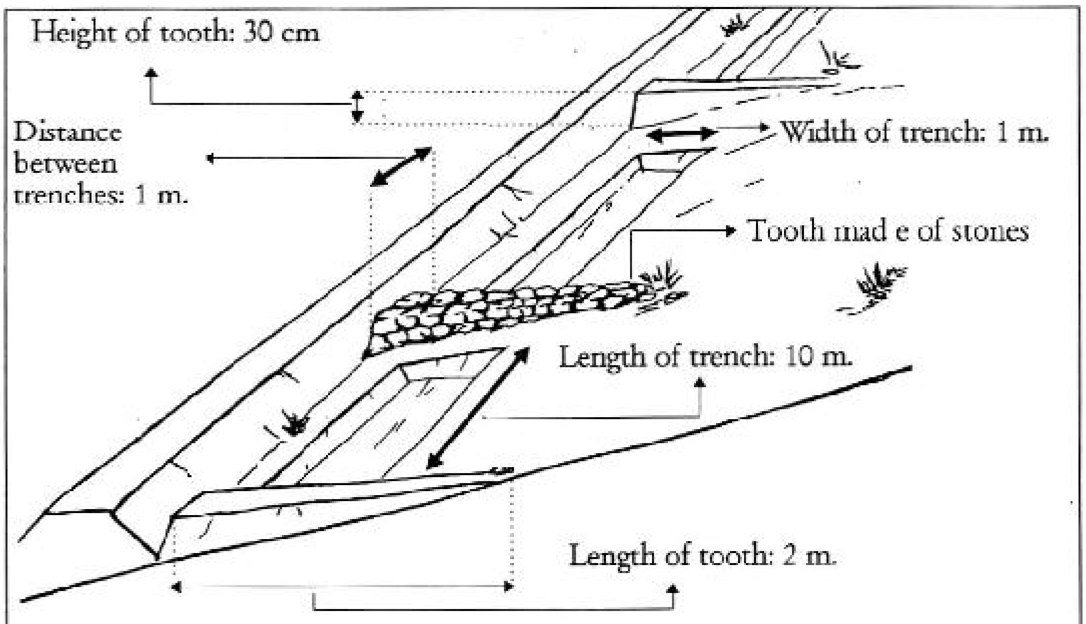


From the point of view of security of the bund, it is best to make the exit at the lowest point of the bund. But in that case no water will stay in the bund

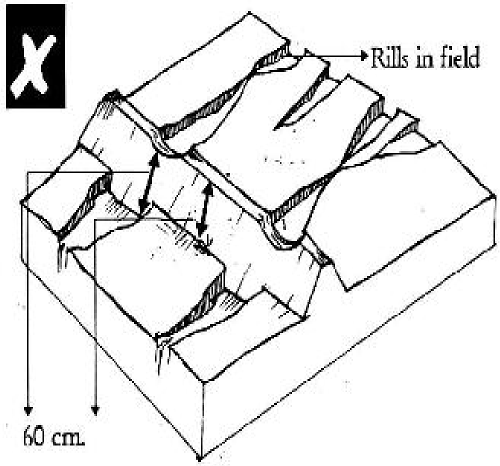


. . . therefore an exit should be made a little above the lowest point. At the same time the lowest point should be strengthened because there the pressure of water will be maximum should, therefore, be made a little above the lowest point of the bund. The water will stop at the bund for a short time and then flow out of the exit. In such cases, however, it is extremely important to strengthen those sections of the bund, which lie below the exit, since water will collect in these sections and create pressure on the bund.

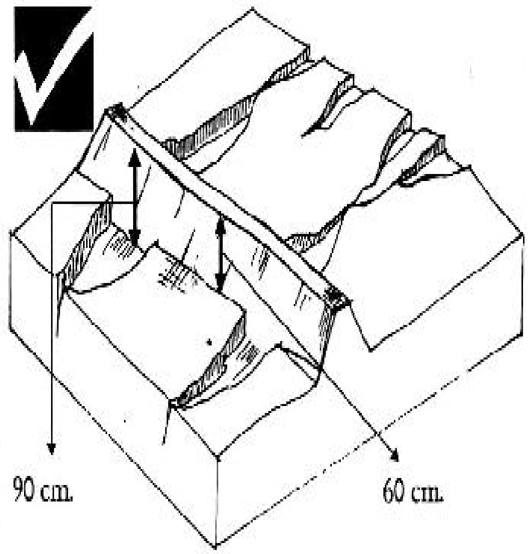
- **How Should the Soil be excavated for Construction of Bunds?** Soil should never be excavated continuously because this will cause the formation of channels, which will erode soil and cause the water runoff. Instead, several discontinuous trenches should be dug in which both the soil and the water can collect. The width of these trenches should be 1 m. Where excavation is discontinued, a small tooth should be constructed at 90 degrees from the bund.



Excavation for construction of farm bunds should never be continuous. After digging a trench 10 m. long, a section of 1 m. length should be left undug. Here *teeth* should be made, originating from the bund. Water will collect in this chain of trenches and teeth and soil erosion will also be reduced.



If there are rills in the field and the section of the bund crossing them has the same height as the rest of the bund, then this section will remain lower than the rest of the bund because here the ground level itself is lower. Water will top over this section and the bund will be breached



. . . therefore the section of the bund crossing over the rill must always be higher than the rest of the bund.

This tooth should be about 2 m. long and should have a maximum height of 30 cm. If stones are available, this tooth should be made entirely of stones. Otherwise, do not forget to provide a stone exit in the teeth made of mud. In this way, there will a series of trenches and teeth, which will act as repositories of water and prevent soil erosion. Farmers, according to their choice, can dig these trenches in two ways:

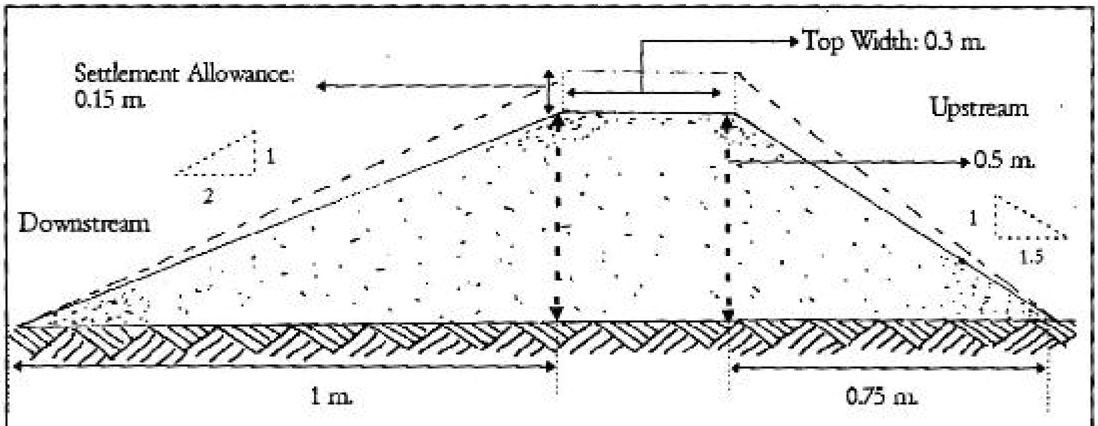
1) Deep and narrow, or,
2) Shallow and wide.

In shallow and wide trenches, crops like paddy can be grown. On the other hand, in a deep and narrow trench, less agricultural land is covered by bunding. The decision will ultimately depend on the farmer. However, no matter how the trench is dug, it will fill up with soil in a few years. Plants or crops (such as tuar, arandi, should be sown on bunds. The roots of these plants will stabilise the bund and arrest soil erosion. These plants also serve as an additional source of income.

- If the slopes are low to moderate, the excavation should be done on the upstream side of the bund. If they are high and the soil depth exceeds 0.5 m., the bund can be constructed with mud excavated from the downstream side of the bund.
- **Alignment of Bunds Under Different Conditions:** The alignment of bunds requires several improvisations on the spot, depending on local conditions:

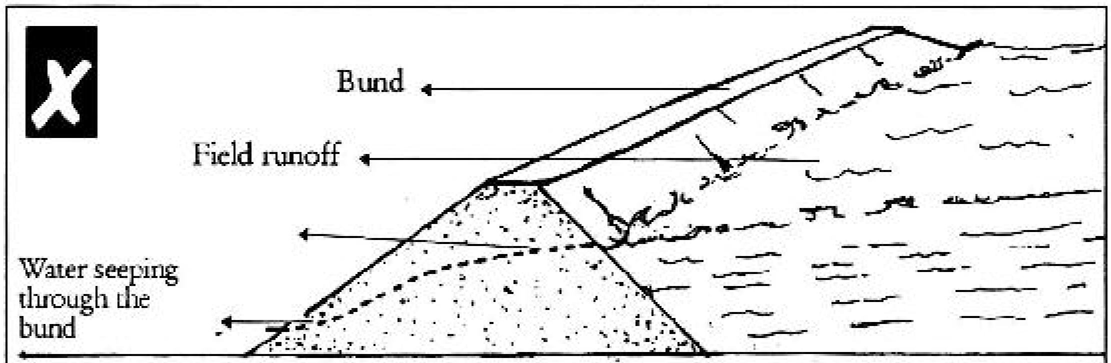
Situation 2: In Impermeable Soils

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

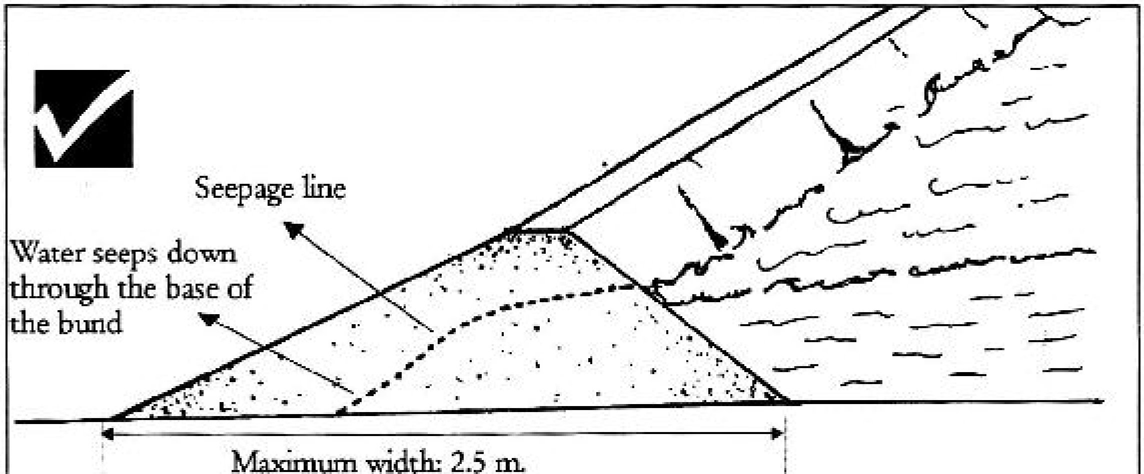


In impermeable soils, the upstream slope should be in the ratio 1.5:1 and the downstream slope in the ratio 2:1

- **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 water logging 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 water logging, a surplus weir 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 anyone bund.



If in impermeable soils, the bund cannot be given a grade and its base is also narrow then the field runoff will seep through the drain, endangering the safety of the bund



. . . in such cases, the downstream slope needs to be reduced so that the base can be widened. Water will then be unable to seep through the bund

- **Settlement Allowance:** The fine particles of clay have a natural tendency to settle. 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.
- **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 stabilize the bunds.
- **Upstream Slope:** 1.5:1
- **Downstream Slope:** 2: 1

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.

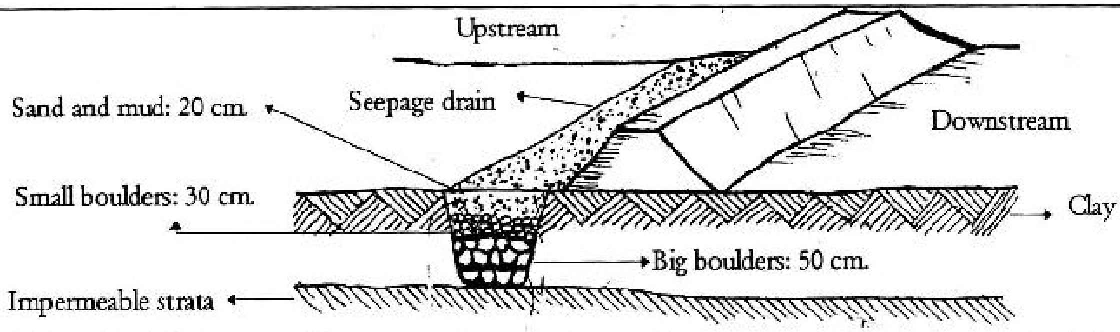
To prevent this, the downstream slope of the bund must be lower than its upstream slope. Its base width can be kept at 2.5 m. This will prevent the seepage of water through the bund since it will be difficult for the water to seep through a broad bund. Another way is to give a gentle grade to the bund. The water will flow along the bund and out of the exit.

- **Waste Weir (Exit):** In black soils, if the slope permits, a channel should be dug upstream of the bund for the exit of water. As opposed to permeable soils, this excavation should be done continuously. 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.
- **Where the clayey soil is underlain by murram up to a depth of 1m:** Here surplus water can be evacuated by yet another technique. Instead of providing for a drainage line outside the field, arrangements can be made for the water to percolate down below the field. Upstream of the bund and parallel to it, dig a trench 1 ft. wide. The digging should be done until the murram layer is encountered. Fill up this trench as follows (reverse filter):

1. From the bottom, up to a height of 50 cm; fill up boulders.
2. Above this layer of boulders, up to a height of 30 cm., pile up smaller boulders.
3. Above this, pile up coarse soil and gravel
4. Top it with coarse sand

This trench will act in two ways:

- The water that collects upstream of the bund will percolate below the ground through this trench
- The permeable strata within the trench will absorb the moisture in the clayey soil around it, thus reducing the amount of water standing in the field.



Where there is impermeable strata underneath clayey soils, a seepage drain can be constructed upstream of the bund for the percolation of water.

Remember: How fast rainwater flows in the field depends on:

- The slope of the land
- The permeability of the soil

That is, in highly sloping land and impermeable soil, water will flow more rapidly.

In order to ensure safety and utility of the bund:

- Increase the downstream slope of the bund
- Decrease the distance between bunds
- Provide an exit in the bunds
- Give a gentle grade to the bunds too

Chapter VIII: Estimating and costing of watershed Interventions

Watershed action plan is incomplete until the costing of each activity is completed. For costing of any structure we have to calculate the quantity and information regarding the current rates. Cost is calculated by following formula:

Cost = Quantity x Rate

We can divide the soil and water conservation interventions in four categories:

	One construction material	**More than one construction material**
One X-Section	**Group-1** CCT, staggered contour trench, Contour bund, Farm bund	**Group-2** CCT, staggered contour trench, Contour bund, Farm bund, Dugout pond, Dyke
More than one X-Section	**Group-3** Boulder gully plug, Earthen gully plug	**Group-4** Earthen naala bund, Masonry Check dam, Gabian

Some mathematical formula regarding costing:

Area calculation-

- Area of square = Length x Breadth
- Area of Rectangle = Length x Breadth
- Area of Triangle =(Height x Base)/2
- Area of Trapezium = 1/2 x (top width + bottom width) x Height

Volume calculation-

- Volume of cube = Length x Breadth x Height
- Volume of Rectangular block = Length x Breadth x Height
- Volume of Triangular block =Length x (Height x Base)/2
- Volume of Trapezium block = 1/2 x (top width + bottom width) x Height x Length

Pythagoras Theorem: Hypotenuse $=[(\text{Base})^2 + (\text{Height})^2]^{1/2}$

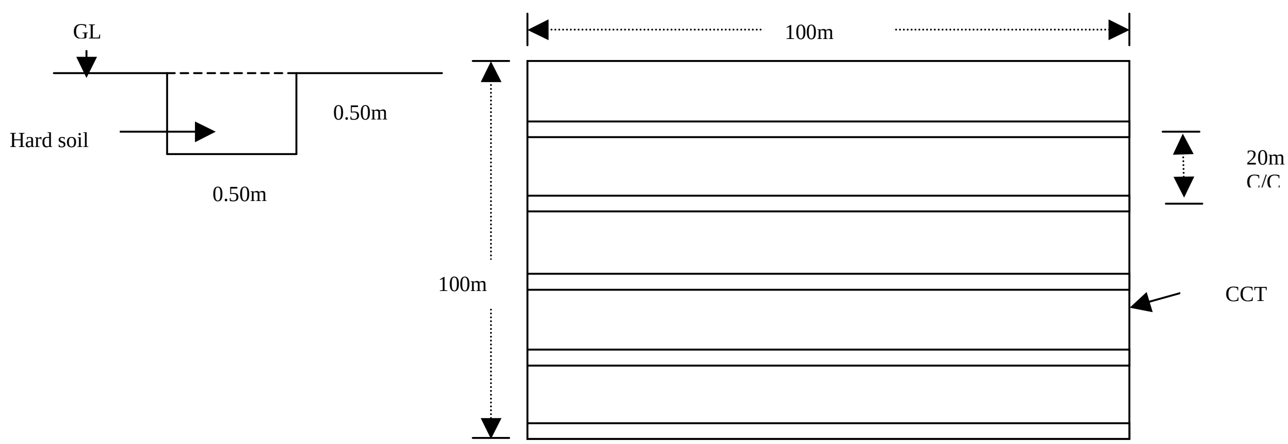
Unit conversion-

- 1 Meter = 100 Centimeter
- 1 Kilometer = 1000 Meter
- 1 Hectare = 10,000 Square meter
- 1 Feet = 30.28 Centimeter
- 1 Brass = 2.83 Cubic meter
- 1 Brass = 100 Cubic feet

Estimate & costing of Continuous Contour Trench:

(Rates used in the examples are the CSR –2003 Rural Engineering Services)

Example 1: Continuous contour trench proposed in 22 hectares land at Mandla in M.P. Distance between two contour trench rows is 20 m and width and depth of CCT is 0.5 m. The soil type is hard soil. Find the cost of said CCT.



Plan of CCT

Solution: First, we calculate the cost of one hectare CCT.

Length of plot = 100m

Width of plot = 100m

No of rows = Width of plat/spacing = 100/20 = 5 nos.

Length of one row of CCT = 100 m

Total length of CCT in one hectare = Length of one row x no of rows = 100 x 5 = 500 m

Quantity of excavation for CCT in one hectare = Length x Width x Depth

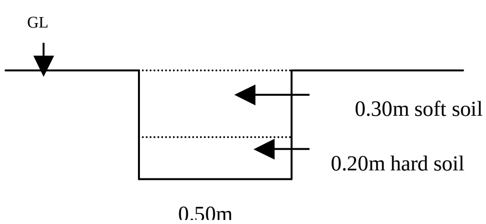
= 500 x 0.5 x 0.5 = 125 cubic meter

Cost of CCT in one hectare = Quantity of excavation in hard soil x Rate

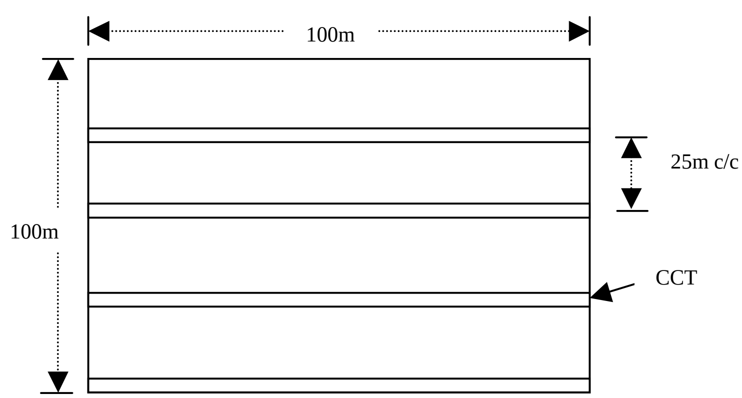
= 125 x 23.20 = Rs. 2900 per hectare

Cost of CCT in 22 hectare = 22 x 2900 = Rs.69, 800

Example 2: Continuous contour trench proposed in 40 hectares land at Angul in Orrissa. Distance between two contour trench rows is 25 m and width and depth of CCT is 0.5 m. The soil type is soft soil & hard soil. The X- section of CCT is as below. Find the cost of said CCT.



Cross section of CCT



Plan of CCT

Solution: First, we calculate the cost of one hectare CCT.

Length of plot = 100 m

Width of plot = 100 m

No of rows = Width of plot/spacing = 100/25 = 4 nos.

Length of one row of CCT = 100 m

Total length of CCT in one hectare = Length of one row x no of rows = 100 x 4 = 400 m

Quantity of excavation for one hectare CCT in soft soil = Length x Width x Depth

= 400 x 0.5 x 0.3 = 60 cubic meter

Cost of one hectare CCT in soft soil = Quantity of excavation in soft soil x Rate

= 60 x 17.90 = Rs. 1074 per hectare

Quantity of excavation for one hectare CCT in hard soil = Length x Width x Depth

= 400 x 0.5 x 0.2 = 40 cubic meter

Cost of one hectare CCT in hard soil = Quantity of excavation in hard soil x Rate

= 40 x 23.20 = Rs. 928 per hectare

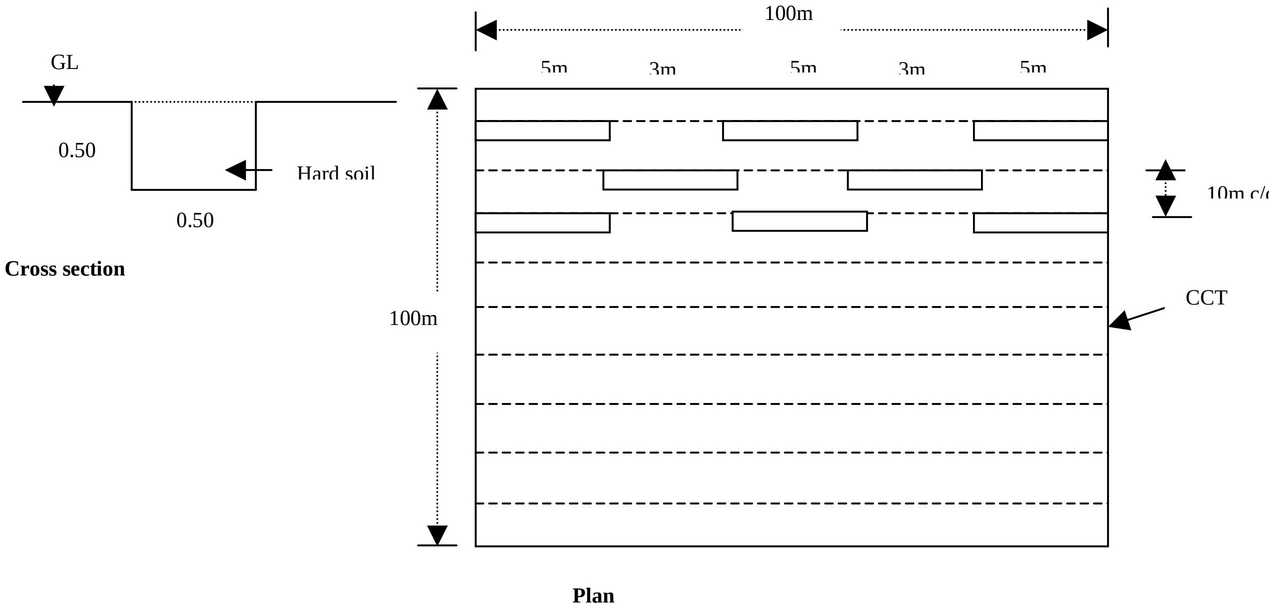
Cost of one hectare CCT = 1074 + 928 = Rs.2002 per hectare

Cost of CCT in 40 hectare = 40 x 2002 = Rs.80, 080

Estimate & costing of Staggered Contour Trench- Examples:

(Rates used in the examples are the CSR –2003 Rural Engineering Services)

Example 1: Staggered contour trench proposed in 35 hectares land at Bhilwara in Rajasthan. Distance between two contour trench rows is 10 m and between two trenches are 3 m. Width and depth of staggered trench is 0.5 m. The soil type is hard soil. Find the cost of Staggered contour trench.



Solution: First, we calculate the cost of one hectare staggered trench.

Length of plot = 100 m

Width of plot = 100 m

No of rows = Width of plat/spacing = 100/10 = 10 nos.

Length of one row = 100 m

No of trench in one row = Length of one row/ (spacing between two trench + length of one trench)

= 100/ (5+3) = 12 trench

Total trench in one hectare = no of trench in one row x no of rows = 12 x 10 = 120 no

Quantity of excavation for one trench = Length x Width x Depth

= 5 x 0.5 x 0.5 = 1.25 cubic meter

Quantity of excavation for staggered trench in one hectare =

Quantity of excavation for one trench x no of trench

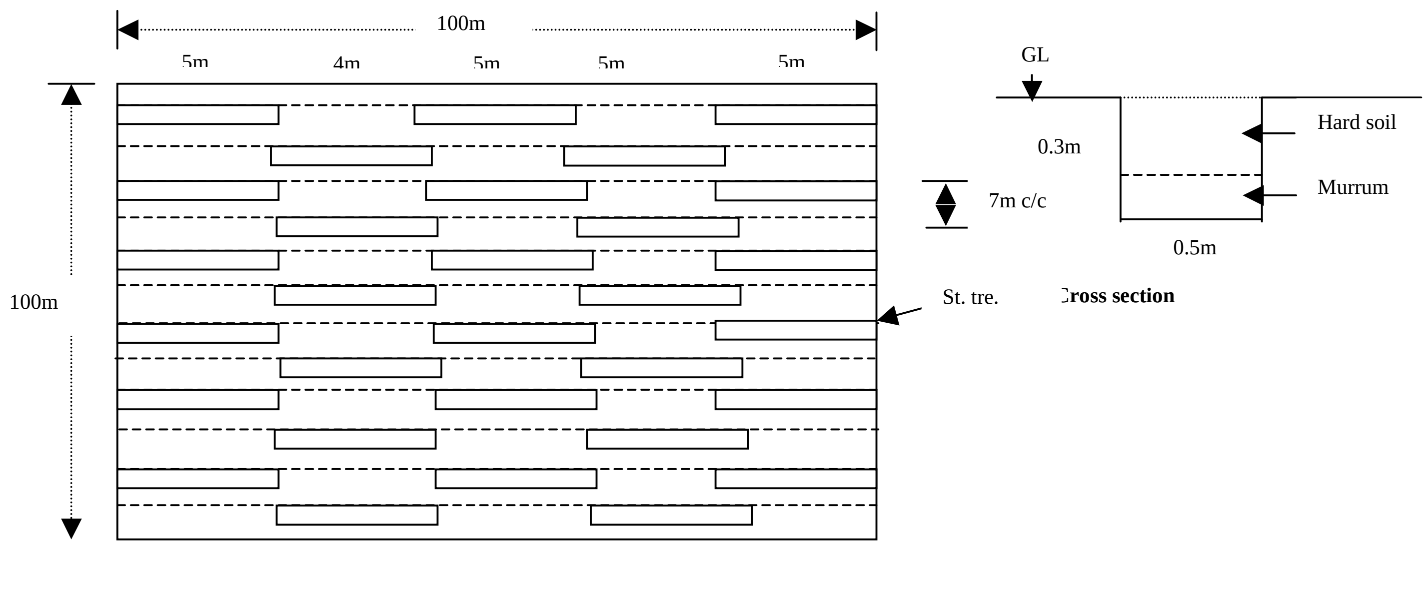
= 120 x 1.25 = 150 cubic meter

Cost of staggered trench in one hectare = Quantity of excavation in hard soil x Rate

= 150 x 23.20 = Rs. 3480 per hectare

Cost of staggered trench in 35 hectare = 35 x 3480 = Rs.1, 21,800

Example 2: Staggered contour trench proposed in 20 hectares land at Madanapalle in A.P. Distance between two contour trench rows is 7 m and between two trenches is 4 m. Width and depth of staggered trench is 0.5 m. The soil type is hard soil & hard murram. Find the cost of Staggered contour trench.



Plan

Cross section

Solution: First, we calculate the cost of one hectare staggered trench.

Length of plot = 100 m

Width of plot = 100 m

No of rows = Width of plot/spacing = 100/7 = 14 nos.

Length of one row = 100 m

No of trench in one row = Length of one row/ (spacing between two trench + length of one trench)

= 100/ (5 + 4) = 11 trench

Total trench in one hectare = no of trench in one row x no of rows = 11 x 14 = 154 no

Quantity of excavation for one trench in hard soil = Length x Width x Depth

= 5 x 0.5 x 0.3 = 0.75 cubic meter

Quantity of excavation for staggered trench in hard soil in one hectare =

Quantity of excavation for one trench x no of trench

= 154 x 0.75 = 115.5 cubic meter

Cost of staggered trench in hard soil in one hectare = Quantity of excavation in hard soil x Rate

= 115.50 x 23.20 = Rs. 2680 per hectare

Quantity of excavation for one trench in hard murram = Length x Width x Depth

= 5 x 0.5 x0.2 = 0.50 cubic meter

Quantity of excavation for staggered trench in hard murram in one hectare =

Quantity of excavation for one trench x no of trench

= 154 x 0.50 = 77 cubic meter

Cost of staggered trench in hard murram in one hectare = Quantity of excavation in hard murram x Rate

= 77 x 30.70 = Rs. 2364 per hectare

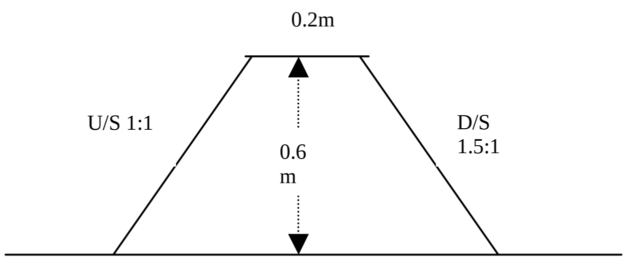
Cost of staggered trench in one hectare = 2680 + 2364 = Rs. 5044

Cost of staggered trench in 20 hectare = 20 x 5044 = Rs.1, 00,800

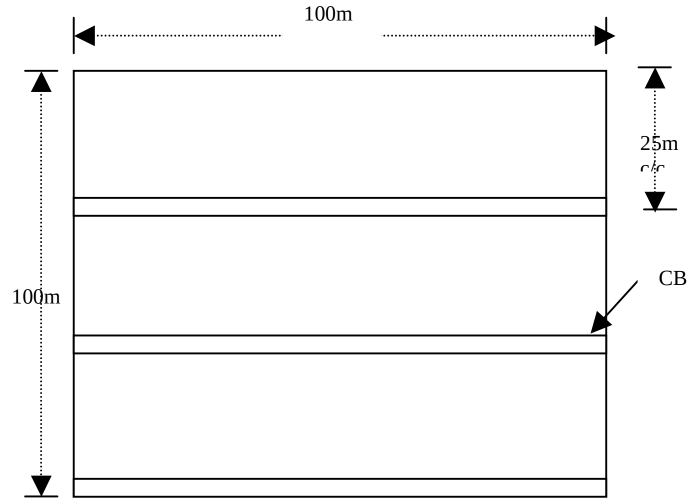
Estimate & costing of Contour Bund – Examples:

(Rates used in the examples are the CSR –2003 Rural Engineering Services)

Example 1: Contour bund proposed in 22 hectares land at Chintamani in Karnataka. Distance between two Contour bund rows is 33 m. Cross section of the contour bund is shown in fig. The soil type is hard soil. Find the cost of said Contour bund.



X-section of contour bund



Plan of Contour bund

Solution: First, we calculate the cost of one hectare Contour bund.

Length of plot = 100 m

Width of plot = 100 m

No of rows = Width of plat/spacing = 100/33 = 3 nos.

Length of one row of Contour bund = 100m

Total length of Contour bund in one hectare = Length of one row x no of rows = 100 x 3 = 300 m

Quantity of excavation for Contour bund in one hectare = 0.5 x Length x (Top Width + Bottom Width) x Depth

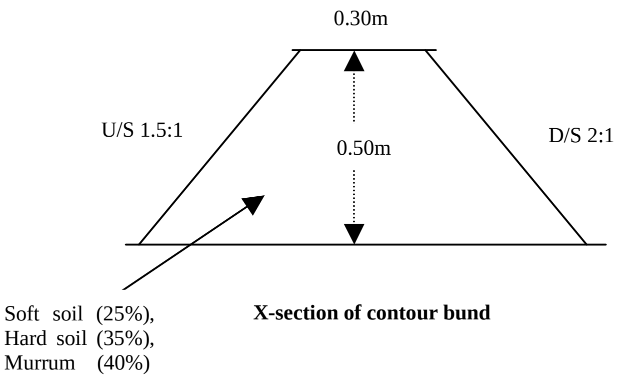
= 0.50 x 300 x (0.2 + 1.70) x 0.6 = 171 cubic meter

Cost of Contour bund in one hectare = Quantity of excavation in hard soil x Rate

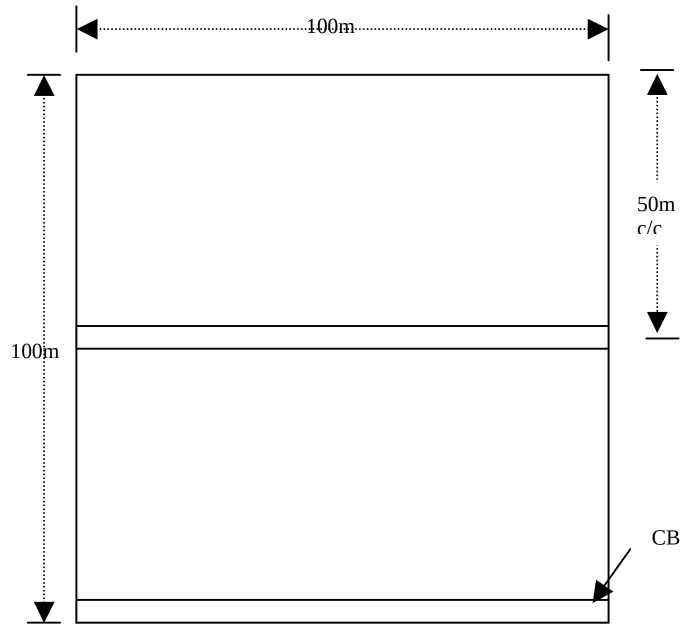
= 117.50 x 28.30 = Rs. 4839 per hectare

Cost of Contour bund in 15 hectare = 15 x 4839 = Rs.72, 585

Example 2: Contour bund proposed in 65 hectares land at Anand in Gujarat Distance between two Contour bund rows is 50 m. The soil type is soft soil, hard soil & murrum. The X- section of Contour bund is as below. Find the cost of said Contour bund.



X-section of contour bund



Plan of Contour bund

Solution: First, we calculate the cost of one hectare Contour bund.

Length of plot = 100 m

Width of plot = 100 m

No of rows = Width of plot/spacing = 100/50 = 2 nos.

Length of one row of Contour bund = 100 m

Total length of Contour bund in one hectare = Length of one row x no of rows

= 100 x 2 = 200 m

Quantity of excavation for one hectare Contour bund = 0.5 x Length x (Top Width +Bottom Width) x Depth

= 0.5 x 200 x (0.3 +2.05) x 0.5 = 117.50 cubic meter

Quantity of excavation for one Hectare Contour bund in soft soil (25%)

= 117.50 x 25/100 = 29.38 cubic meter

Quantity of excavation for one hectare Contour bund in hard soil (35%)

= 117.50 x 35/100 = 41.13 cubic meter

Quantity of excavation for one hectare Contour bund in murrum (40%)

= 117.50 x 40/100 = 47 cubic meter

Cost of one hectare Contour bund in soft soil = Quantity of excavation in soft soil x Rate

= 29.38 x 23 = Rs. 676

Cost of one Hectare Contour bund in hard soil = Quantity of excavation in hard soil x Rate

= 41.13 x 28.30 = Rs. 1164

Cost of one hectare Contour bund in murrum = Quantity of excavation in hard murram x Rate

= 47 x 31.90 = Rs. 1499

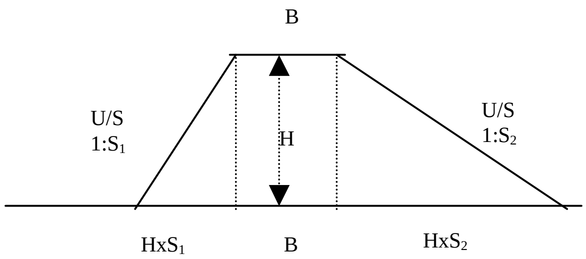
Cost of one hectare Contour bund = 676 + 1164 + 1499 = Rs.3334 per hectare

Cost of Contour bund in 50 hectare = 65 x 3334 = Rs.2, 17,035

Estimate & costing of Boulder Check – Examples:

(Rates used in the examples are the CSR –2003 Rural Engineering Services)

Example 1: Total 210-boulder checks in Dahod watershed in Gujarat. Cross section of the boulder check is shown in fig. Find the cost of said boulder check.



X-section of contour bund

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

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

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

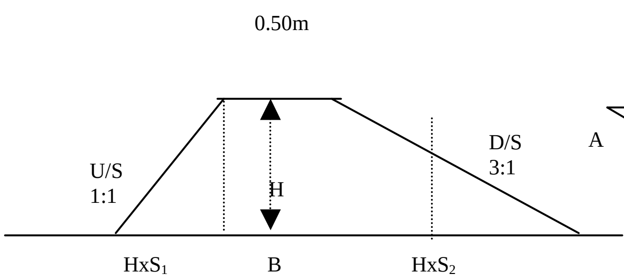
$= [\{2B + H \times (S_1 + S_2)\} /2] \times H$

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

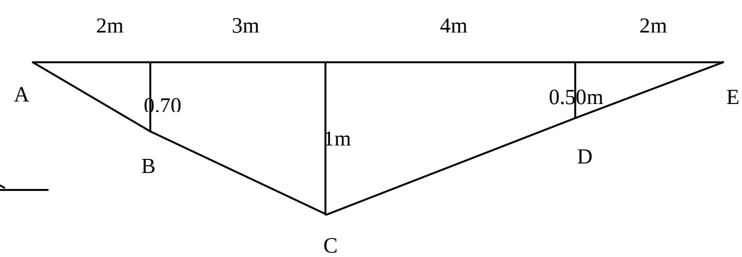
$= [B + \{(H \times (S_1 + S_2)) /2\}] \times H$

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

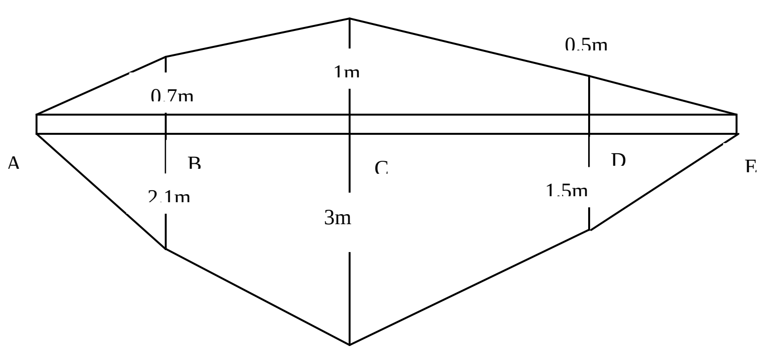
$\mathbf{= B \times H + H^2 \times (S_1 + S_2) /2}$



X-section of boulder check



L-section of boulder check



Plan of boulder check

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

X- sectional area of boulder check **=** B x H + H^2 x (S_1 + S_2) /2

As per drawing we knows,

B = 0.5 m, S_1 = 1, S_2 = 3

X- sectional area of boulder check **=** 0.5 x H + H^2 x (1 + 3) /2

= 0.5 x H + H^2 x 2

1	2	3	4	5	6	7
Point	**Chainage**	**Height**	**X-sectional area**	**Average X-sectional area**	**Distance between two points**	**Volume**
A	0	0	0	-	-	-
B	2	0.7	1.33	0.67	2	1.33
C	5	1	2.5	1.92	3	5.76
D	9	0.5	0.75	1.63	4	6.52
E	11	0	0	0.37	2	0.76
Total						**14.35**

Process of tabular calculation:

- Fill up the name of station in column no 1.
- Cumulative add distances in column no 2.
- Fill up the height (refer L- section) in column no 3
- Fill the value of height (H) in above formula and fill up the answer in column no 4
- Average of X-sectional area and fill it in column no 5.
- Fill up the distance between two points in column no 6.
- Multiply column no 5 & 6 and write the answer in column no 7.

For keying of boulder check- 15% extra boulder required.

Volume of boulder required for keying = 14.35 x (15/100)

= 2.15 cubic meter

Total Volume of boulder required for boulder check = 14.35 + 2.15 = 16.50 cubic meter

Cost of one boulder check = Volume x rate

= 16.50 x 39.20 = Rs. 647

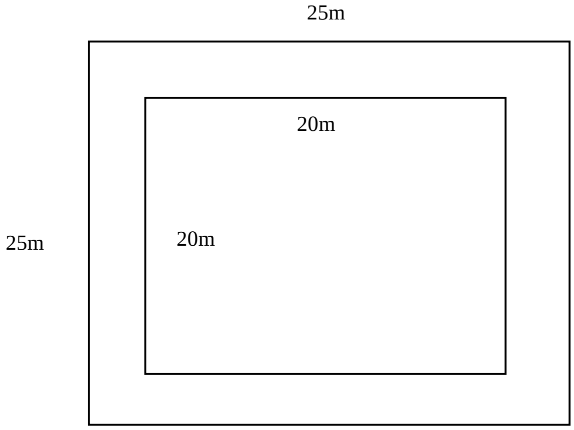
Cost of 210 boulder checks = 210 x 647

= Rs. 1,35,870

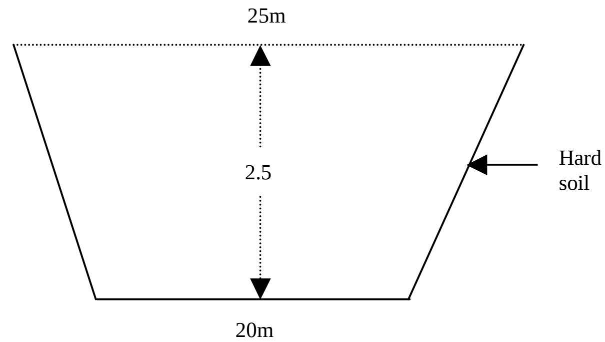
Estimate & costing of Dugout pond – Examples:

(Rates used in the examples are the CSR –2003 Rural Engineering Services)

Example 1: Total 5 dugout ponds are proposed in Udaipur watershed in Rajasthan. Cross section of the dugout pond is shown in fig. Find the cost of said dugout pond.



Plan of Dugout



X-Section of dugout pond

Top area = Length x Width

= 25 x 25

= 625 Square meter

Bottom area = Length x Width

= 20 x 20

= 400 Square meter

Volume of dugout pond = Depth x (Top area + Bottom area)/2

= 2.5 x (625 + 400)/2

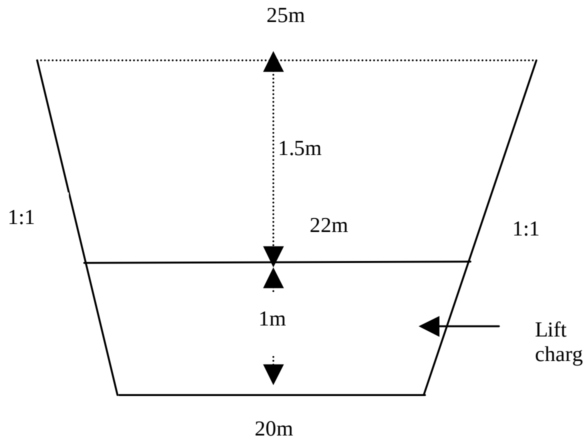
= 1281.25 Cubic meter

Cost of excavation in hard soil = volume x rate

= 1281.25 x 23.20

= Rs 29, 725

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



X-Section of dugout pond

Volume of lift charge soil = Depth x (Top area + Bottom area)/2

Top area = Length x Width

= 22 x 22

= 484 Square meter

Bottom area = Length x Width

= 20 x 20

= 400 Square meter

Volume of lift charge soil = Depth x (Top area + Bottom area)/2

= 1 x (484 + 400)/2

= 442 Cubic meter

Cost of Lift charge = volume x rate

= 442 x 3.20

= Rs 1, 414

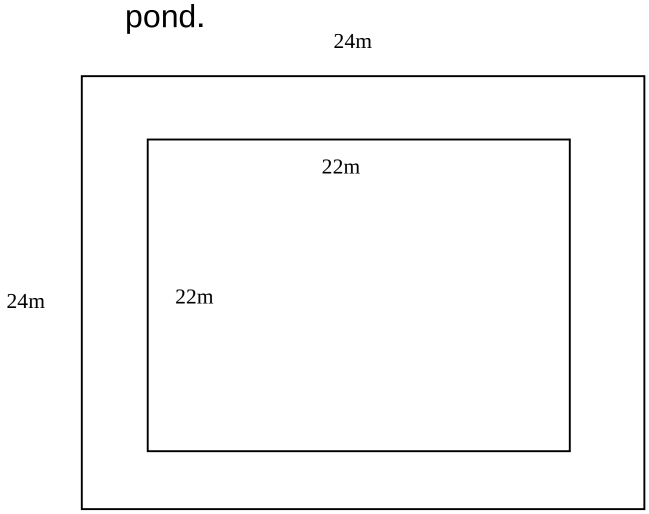
Total cost of dugout pond = 29, 725+ 1, 414

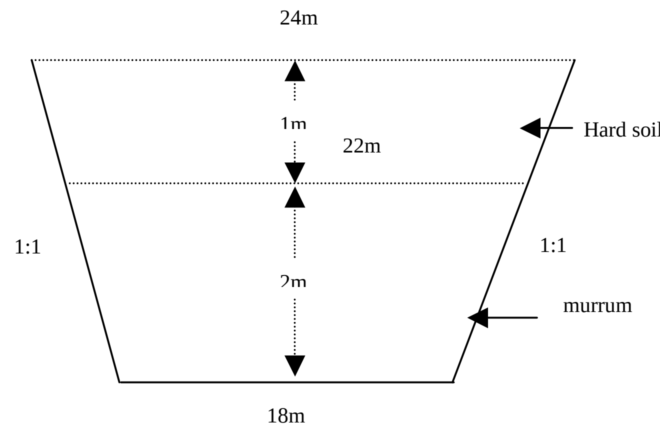
= Rs.31, 139

Total cost of 5 dugout pond = 31, 139 x 5

= Rs.1, 55, 695

Example 2: Total 3-dugout ponds are proposed in Angul watershed in Orrissa. Cross section of the dugout pond is shown in fig. Find the cost of said dugout pond.





X-Section of dugout pond

Plan of Dugout pond

Volume of dugout pond in hard soil = Depth x (Top area + Bottom area)/2

Top area = Length x Width

= 24 x 24

= 576 Square meter

Bottom area = Length x Width

= 22 x 22

= 484 Square meter

Volume of dugout pond = 1 x (576 + 484)/2

= 530 Cubic meter

Cost of excavation in hard soil = volume x rate

= 530 x 23.20

= Rs 12, 296

Volume of dugout pond in hard murrum = Depth x (Top area + Bottom area)/2

Top area = Length x Width

= 22 x 22

= 484 Square meter

Bottom area = Length x Width

= 18 x 18

= 324 Square meter

Volume of dugout pond = 2 x (484 + 324)/2

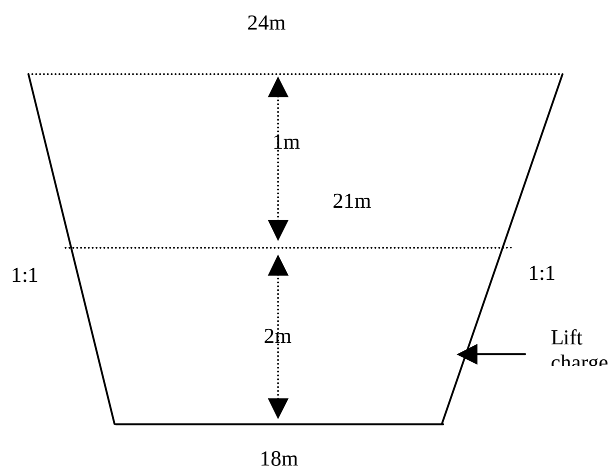
= 808 Cubic meter

Cost of excavation in hard murrum = volume x rate

= 808 x 30.70

= Rs 24, 806

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



X-Section of dugout pond

Volume of lift charge soil = Depth x (Top area + Bottom area)/2

Top area = Length x Width

= 21 x 21

= 441 Square meter

Bottom area = Length x Width

= 18 x 18

= 324 Square meter

Volume of lift charge soil = Depth x (Top area + Bottom area)/2

= 1.5 x (441 + 324)/2

= 573.75 Cubic meter

Cost of Lift charge = volume x rate

= 573.75 x 3.20

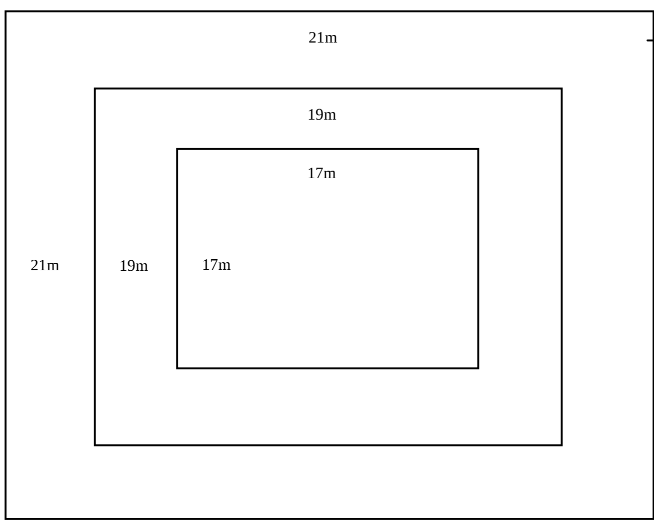
= Rs 1, 836

Total cost of dugout pond = 11, 229 + 24, 806 + 1, 836

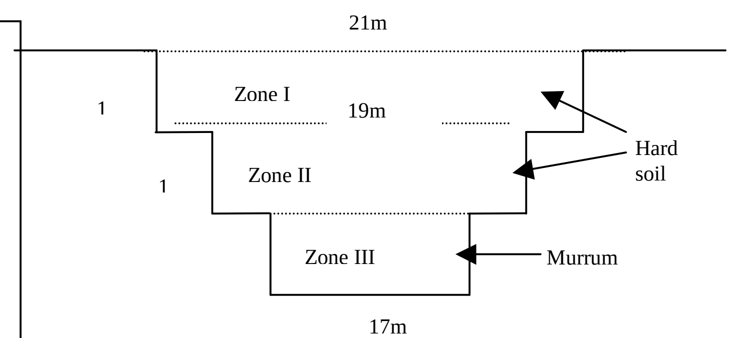
= Rs.37, 871

Total cost of 3 dugout pond = 37, 871 x 3 = Rs.1, 13, 913

Example 3: Total 7 dugout ponds are proposed in Reeva watershed in M.P. Cross section of the dugout pond is shown in fig. Find the cost of said dugout pond.



Plan of dugout pond



X-section of dugout

Volume of dugout pond in zone 1 = Length x Width x Depth

= 21 x 21 x 1

= 441 Cubic meter

Volume of dugout pond in zone 2 = Length x Width x Depth

= 19 x 19 x 1

= 361 Cubic meter

Volume of dugout in hard soil = 441 + 361

= 802 cubic meter

Volume of dugout pond in zone 3 = Length x Width x Depth

= 17 x 17 x 1

= 289 Cubic meter

Volume of dugout in hard murrum = 289 Cubic meter

Cost of excavation in hard soil = volume x rate

= 802 x 23.20

= Rs 18, 606

Cost of excavation in hard murrum = volume x rate

= 289 x 30.70

= Rs 8, 872

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

Volume of lift charge soil:

Volume of lift charge soil in zone 2 = Length x Width x Depth

= 19 x 19 x 0.5

= 180.50 cubic meter

Volume of lift charge soil in zone 3 = Length x Width x Depth

= 17 x 17 x 1

= 289 cubic meter

Total volume of lift charge soil = 180.50 + 289 = 469.50 cubic meter

Cost of Lift charge = volume x rate

= 469.50 x 3.20

= Rs 1, 502

Total cost of dugout pond = 18, 606 + 8, 872 + 1, 502

= Rs.28, 980

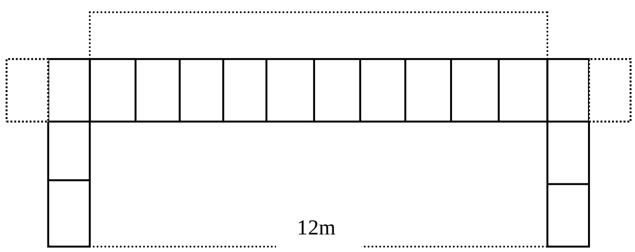
Total cost of 3 dugout pond = 28, 980 x 7

= Rs.2, 02, 860

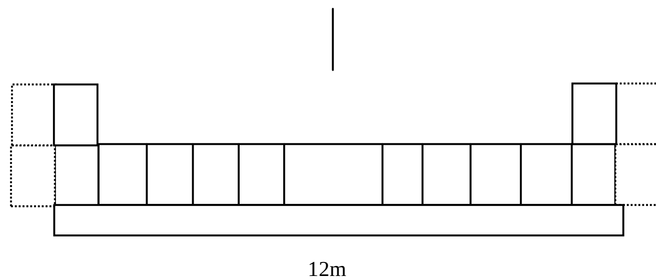
Estimate & costing of Gabian – Examples:

(Rates used in the examples are the CSR –2003 Rural Engineering Services)

Example 1: One gabian is proposed in Neemach watershed in M.P. Length of gabian is 12 m and height of main wall is 1 m. Cross section of the gabian is shown in fig. Find the cost of said gabian.



Plan of Gabian



L-section of Gabian

Quantity of foundation excavation in hard soil = Length x Width x Depth

= 12 x 3 x 0.60

= 21.60 Cubic meter

Quantity of excavation for head wall extension = 2 x Length x Width x Depth

= 2 x 1 x 1 x 2

= 4 Cubic meter

Quantity of boulder filling for apron = Length x Width x Depth

= 12 x 3 x 0.6

= 21.60 cubic meter

Quantity of G.I. wire mesh for apron = Length x Width

= 12 x 3

= 36 square meter

Quantity of G.I. wire mesh for keying of apron = Length x Width

= (12 + 12 + 3 + 3) x 1

= 30 square meter

Total quantity of G.I. wire mesh for apron = 36 + 30 = 66 square meter

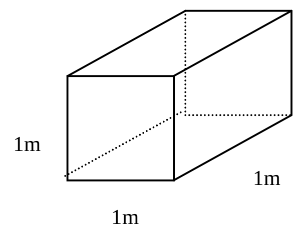
Gabian is constructed in the form of one cubic meter box

So the boulder required for one box = 1 cubic meter

And the G.I. wire mesh required for one box = 5 square meter

No of box in main wall = no of box in X- section x length of main wall

= 1 x 10 = 10 box



No of box in side wall = no of box in X- section x 2

= 4 x 2 = 8 box

No of box in main wall extension = no of box in L- section

= 4 box

Total box in main wall, side wall & main wall extension = 10 + 8 + 4 = 22 box

Total boulder required for main wall, side wall & main wall extension = no of box x 1

= 22 x 1

= 22 cubic meter

Total G.I. wire mesh required for main wall, sidewall & main wall extension

= No of box x 5

= 22 x 5

=110 square meter

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

= 12 x 1 x 1 x 0.5

= 6 cubic meter

Abstract Sheet:

Sr.no.	**Description**	**Quantity**	**Rate**	**Amount**
1	Excavation of foundation in hard soil	21.60	23.20	501
2	Excavation for main wall extension in hard soil	4	23.20	93
3	Boulder filling in apron	21.60	39.20	847
4	G.I. wire mesh for apron and its keying	66	60	3960

5	Boulder required for main wall, side wall & main wall extension	22	39.20	862
6	G.I. wire mesh required for main wall, side wall & main wall extension	110	60	6600
7	Reverse filter	6	136	816
	Total cost			**13, 679**

Example 2: One gabian is proposed in Rampura watershed in M.P. Length of gabian is 9 m and height of main wall is 2 m. Cross section of the gabian is shown in fig. Find the cost of said gabian.

Quantity of foundation excavation in hard murrum = Length x Width x Depth

= 9 x 6 x 0.60

= 32.40 Cubic meter

Quantity of excavation for head wall extension = 2 x Length x Width x Depth

= 2 x 1 x 1 x 3

= 6 Cubic meter

Quantity of boulder filling for apron = Length x Width x Depth

= 9 x 6 x 0.6

= 32.40 cubic meter

Quantity of G.I. wire mesh for apron = Length x Width

= 9 x 6

= 54 square meter

Quantity of G.I. wire mesh for keying of apron = Length x Width

= (9 + 9 + 6 + 6) x 1

= 30 square meter

Total quantity of G.I. wire mesh for apron = 54 + 30 = 84 square meter

Gabian is constructed in the form of one cubic meter box

So the boulder required for one box = 1 cubic meter

And the G.I. wire mesh required for one box = 5 square meter

No of box in main wall = no of box in X- section x length of main wall

= 3 x 7 = 21 box

No of box in side wall = no of box in X- section x 2

= 9 x 2 = 18 box

No of box in main wall extension = no of box in L- section

= 6 box

Total box in main wall, side wall & main wall extension = 21 + 18 + 6 = 45 box

Total boulder required for main wall, side wall & main wall extension = no of box x 1

= 45 x 1

= 45 cubic meter

Total G.I. wire mesh required for main wall, sidewall & main wall extension

= No of box x 5

= 45 x 5

=225 square meter

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

= 9 x 2 x 2 x 0.5

= 18 cubic meter

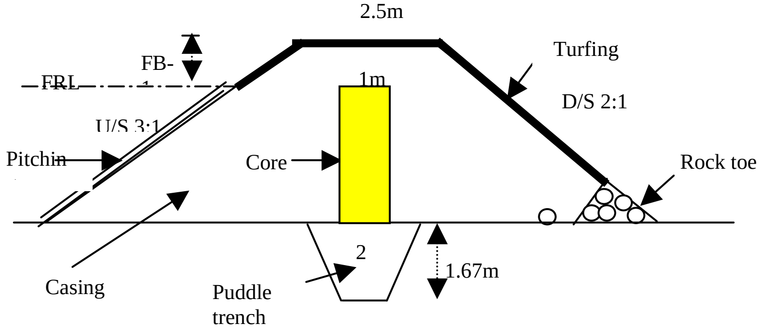
Abstract Sheet:

Sr.no.	**Description**	**Quantity**	**Rate**	**Amount**
1	Excavation of foundation in hard murrum	32.40	30.70	995
2	Excavation for main wall extension in hard murrum	6	30.70	184
3	Boulder filling in apron	32.40	39.20	1270
4	G.I. wire mesh for apron and its keying	84	60	5040
5	Boulder required for main wall, side wall & main wall extension	45	39.20	1764
6	G.I. wire mesh required for main wall, side wall & main wall extension	225	60	13500
7	Reverse filter	18	136	2448
	Total cost			**25,201**

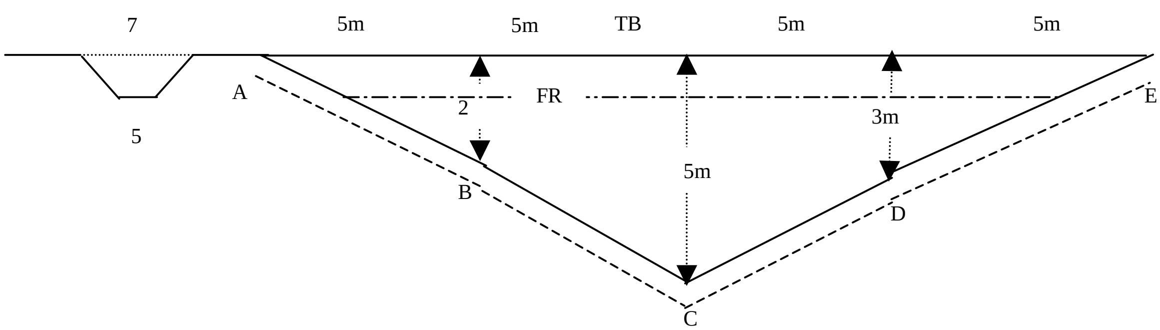
Estimate & costing of Naala bund - Examples

(Rates used in the examples are the CSR –2003 Rural Engineering Services)

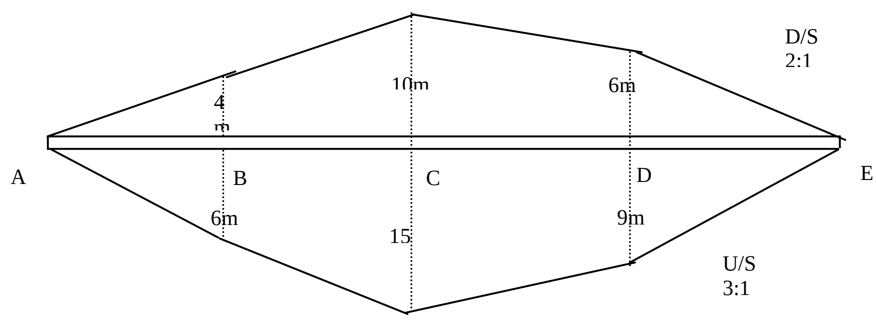
Example 1: One Naala bund is proposed in Agar watershed in M.P. Length of naala bund is 20 m and maximum height of bund is 5 m. Cross section of the naala bund is shown in fig. Find the cost of said naala bund.



X- Section



L-section



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

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

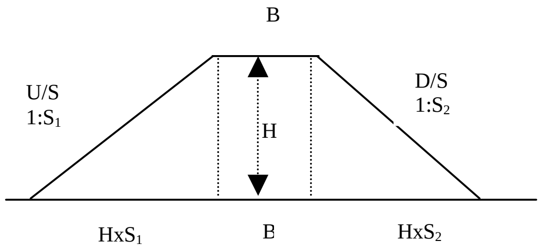
$= [(2B + H \times S_1 + H \times S_2) /2] \times H$

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

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

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

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



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

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

X- sectional area of naala bund **=** $B \times H + H^2 \times (S_1 + S_2) /2$

As per drawing we knows,

B = 2.5 m, S_1= 3, S_2 = 2

X- sectional area of naala bund **=** $2.5 \times H + H^2 \times (3 + 2) /2$

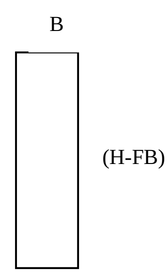
$= 2.5 \times H + H^2 \times 2.5$

Volume of overall bund:

1	2	3	4	5	6	7
Point	**Chainage**	**Height**	**X-sectional area**	**Average X-sectional area**	**Distance between two points**	**Volume**
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 m^3**

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.

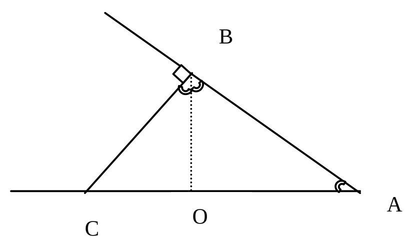
X-sectional area = W x (H – free board)

= 2.5 x (H - 1)

1	2	3	4	5	6	7
Point	**Chainage**	**Height**	**X-sectional area**	**Average X-sectional area**	**Distance between two points**	**Volume**
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 m^3**

Volume of core wall = 35 cubic meter.

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

X-sectional area of rock toe = 1/2 x Base x height

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

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

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

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

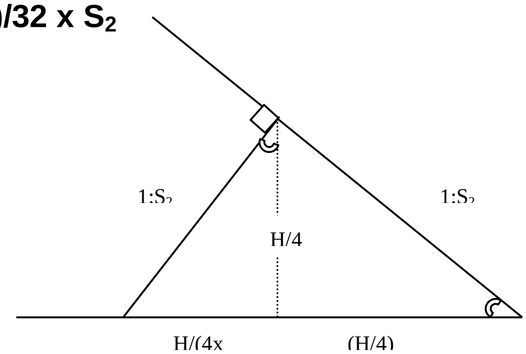
$\mathbf{= H^2 \times (1 + S_2^2)/32 \times S_2}$

We know that, $S_2 = 2$ m

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

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

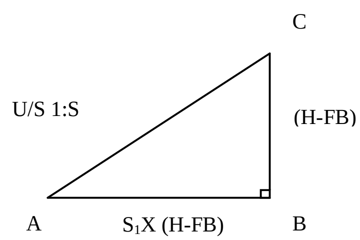
$= H^2 \times 5 /64$



1	2	3	4	5	6	7
Point	**Chainage**	**Height**	**X-sectional area**	**Average X-sectional area**	**Distance between two points**	**Volume**
A	0	0	0	-	-	-
B	5	2	0.31	0.15	5	0.75
C	10	5	1.95	1.13	5	5.65
D	15	3	0.70	1.33	5	6.65
E	20	0	0	0.35	5	1.75
Total						**14.80 m^3**

Volume of rock toe = 14.80 cubic meter.

Area of pitching:



In triangle ABC, Pythagoras Theorem

$AC^2 = AB^2 + BC^2$

$AC^2 = \{S1 \times (H - \text{freeboard})\}^2 + (H - \text{freeboard})^2$

$AC^2 = (H - \text{freeboard})^2 \times (S_1^2 + 1)$

$AC = (H - \text{freeboard}) \times (S_1^2 + 1)^{1/2}$

X- sectional width (AC) = $(H - \text{freeboard}) \times (S_1^2 + 1)^{1/2}$

We know that, $S_1 = 3$, freeboard = 1 m

X- sectional width (AC) = $(H - \text{freeboard}) \times (S_1^2 + 1)^{1/2}$

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

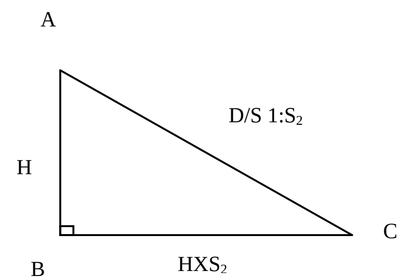
$= (H - 1) \times 3.16$

1	2	3	4	5	6	7
Point	**Chainage**	**Height**	**X-sectional area**	**Average X-sectional area**	**Distance between two points**	**Volume**
A	0	0	0	-	-	-
B	5	2	6.32	3.16	5	15.80
C	10	5	15.80	11.06	5	55.30
D	15	3	9.48	12.64	5	63.20
E	20	0	0	4.74	5	23.70
Total						**158m²**

Area of pitching = 14.80 square meter.

Area of grass turfing:

Turfing is done on slope portion AB & CD but for calculation purposes we have taken it on portion CE.



In triangle ABC, Paythagoras principle

$AC^2 = AB^2 + BC^2$

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

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

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

X- sectional width (AC) = $H \times (S_2^2 + 1)^{1/2}$

We know that, $S_2 = 2$,

X- sectional width (AC) = $H \times (S_2^2 + 1)^{1/2}$

$= (H - 1)\,(2^2 + 1)^{1/2}$

$= (H - 1) \times 2.24$

1	2	3	4	5	6	7
Point	**Chainage**	**Height**	**X-sectional area**	**Average X-sectional area**	**Distance between two points**	**Volume**
A	0	0	0	-	-	-
B	5	2	4.48	2.24	5	11.20
C	10	5	11.2	7.84	5	39.20
D	15	3	6.72	8.96	5	44.80
E	20	0	0	3.36	5	16.80
Total						**112m^2**

Area of grass turfing on slope = 112 square meter.

Area of grass turfing on top width = length x width

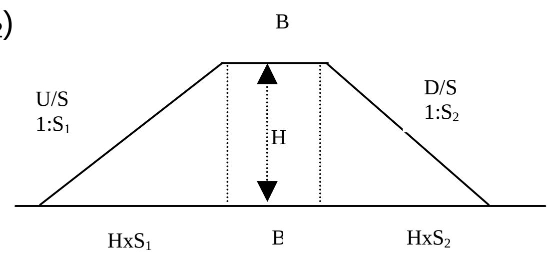
= 20 x 2.5 = 50 square meter

Total area of grass turfing = 112 + 50 = 162 square meter

Area of stripping:

X- sectional width (AC) = (H x S_1)+ B + (H x S_2)

= B + H x (S_1 + S_2)



We know that, B = 2.5 m, S_1= 3, S_1 = 2

X- sectional width (AC) = B + H x (S_1 + S_2)

= 2.5 + H x (3 +2)

= 2.5 + H x 5

1	2	3	4	5	6	7
Point	**Chainage**	**Height**	**X-sectional area**	**Average X-sectional area**	**Distance between two points**	**Volume**
A	0	0	2.5	-	-	-
B	5	2	15	8.75	5	43.75
C	10	5	27.50	21.25	5	106.25
D	15	3	17.50	22.50	5	112.50
E	20	0	2.50	10	5	50
Total						**312.25 m^2**

Area of striping = 312.25 square meter.

Volume of puddle trench:

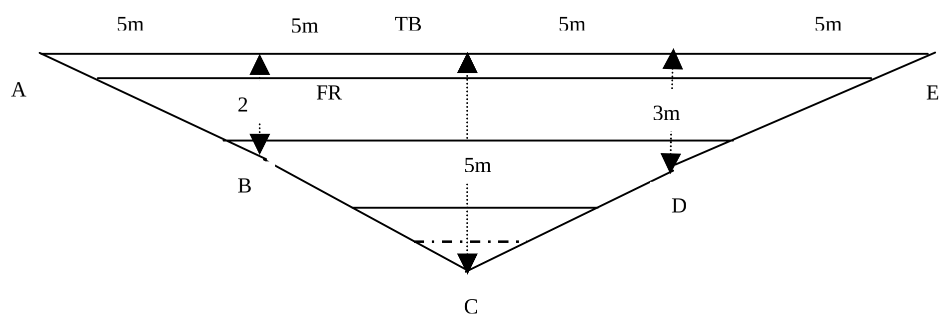
Volume of puddle trench= length x depth x (top width + bottom width)/2

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

= 50.10 cubic meter

Lift charge:

From the L- section we have to calculate the length of each lift in the center of strip.



L-section

Volume of first lift = length x depth x (top width + bottom width)/2

= 9 x 1.50 x (12.5 +20)/2

= 219.38 cubic meter

Volume of second lift = length x depth x (top width + bottom width)/2

= 15 x 1.50 x (5 + 12.50)/2

= 196.88 cubic meter

Volume of third lift = length x depth x (top width + bottom width)/2

= 18 x 0.50 x (2.5 + 5)/2

= 33.75 cubic meter

Volume of exit (length of exit is 10 m)

Volume of exit = length x depth x (top width + bottom width)/2

= 10 x 1 x (7 + 5)/2

= 60 cubic meter

Abstract Sheet:

Sr. No.	**Description**	**Quantity**	**Rate**	**Amount**
1	Excavation of puddle trench in hard soil	50.10	23.20	1162
2	Filling of puddle trench with good clay	50.10	104	5210
3	Casing construction in hard soil	550.20	28.30	15571
4	Construction of core wall	35	104	3640
5	Construction of rock toe	14.80	124.65	1845
6	Construction of pitching	158	122.90	19418
7	Construction of grass turfing	162	8	1296
8	Construction of stripping	312.25	2.30	718
9	Excavation of exit in hard murrum	60	30.70	1842
10	First lift	219.38	3.20	702
11	Second lift	196.88	6.40	1260
12	Third lift	33.75	9.60	324
	Total cost Rs.			**51, 988**

Chapter X: Maintenance of Measurement Book and monitoring system of SWC interventions

Measurement Book

Objective:

- For a transparent mechanism in the implementation of all watershed interventions through maintaining the measurement of work done at the different stages of each activity.
- Valuation of all watershed interventions through ensuring the measurement of each activity at the completion of work. After the completion of final measurement, value of that intervention can be calculated at any time by multiplying the quantity with the rate.
- For monitoring the work done at the different stages of each watershed, interventions like maintaining progressive measurement book should be done at the time of completion of different stages of each activity.
- Payment at the completion of different stages can be justified through showing the output of the work done against the payment made.
- It is an important document to justify the work at the time of evaluation and audit and during other visits that it is completed as per the estimate.

Managerial Aspects:

- Measurement book is an important document as maintained above so this must be kept in a booklet form.
- Measurement book should be printed in duplicate page no (Example: Page number in measurement book should be printed like 1, 1, 2, 2, 3, 3…). Color of both the pages should be different so that it is easy to identify the original and duplicate page no. Duplicate page of measurement book is attached with the payment bill and other one is to be kept in the measurement book itself.
- As mentioned above that it is a valuable document for the audit verification and evaluation, therefore the pages of measurement book should not be

damaged. If it is necessary to do that in unavoidable condition then those pages should be cancelled by marking cross on the page and highlight those pages as cancelled.

- Traditional system of measurement in the field in foot and inch: In this system quantity calculation is very difficult, and therefore the measurement book should be entered in SI units only (meter-centimeter).
- As per above the statement measurement book is an important document for audit verification, over writing in the measurement book is not allowed. If there is need of any correction it is necessary to mark the line as a wrong entry, then enter fresh entry and it should be counter signed by the recording person.
- At the completion of each activity, measurement should be recorded in measurement book as a final measurement of the work. Each item of the watershed activity is included in the final measurement
- It is necessary to maintain the measurement book at the completion of different stages or before each payment of any watershed intervention. This measurement is called a progressive measurement, as it shows the progress of the work at different stages and is also useful in monitoring the work at different stages.
- After recording the measurement book, calculation for the payment should be done on separate sheet for the finalization of bill for the payment.
- State Government CSR rates should be used for the implementation of any physical interventions and it should be finalized in the team meetings

Administrative Aspects:

- There is no need to maintain wage muster when payments are made as per measurement basis. In this condition it requires other type of format for the payment as mentioned below. Wage muster is a document, which is used for maintaining the attendance of labour on the daily wage basis.
- If the work is carried out by measurement basis, the information like how many man days generated in the physical intervention etc. can be found

out by the total amount paid on labour as per measurement basis, divided by the minimum wage rate of the state.

- Activities implemented on daily wage basis should be crosschecked at the time of each payment with the help of the measurement book. Actual expenditure on labour and consumption of construction material should be according to the labour component and the material components calculated on measurement book. If there is any difference it should be within permissible limit of +/-10%. If the difference is more than permissible limit then write a note on the reasons for that variation.
- For activities done on the measurement basis by a group, the payment should be worked out by dividing the total amount as per the measurement book by the total number of labour units (In group work on measurement basis, one work day should be entered as one unit and not as a the attendance of that day). For calculation of labour units, a separate register of attendance for labor unit along with group output is to be maintained for the payment of individual labor.

Social Aspects:

- Due to payment on measurement basis, there is a tendency to exclude those persons whose outcomes of the day is less than the average out put for the day. To maintain the equity, Group for the implementation of physical intervention, should be formed in such a way, which includes all the types of persons like old age person, women, youth, widows etc. Hence efforts should be done to include the vulnerable in the mix group work or any other daily wage work.
- There might be conflict on daily wage versus measurement basis. Issues of wisdom of Village Institutions and equity may be hampered.

Suggestive list of activities, which categorize as measurement/ daily basis:

(Note: This is a general suggestive list, team can exclude or include activities relevant to their team and the team can also change the activity from measurement basis to daily wage basis or vice versa as per their experience.)

S.N.	Work category	Measurement basis	Daily basis
1.	Soil & water conservation	CCT/SCT/Ditch	Earthen WHS/WRS
		Farm bunding	Masonry Structures
		Contour bunding	Gabian Structure
		Gully plug (Bori Bund)	Well Deepening
		Gully Plug (Earthen)	Roof water harvesting
		Gully Plug (Stone)	Farm pond
2.	Biological measures	Watering	Intercultural
		Pitting	Grass seed sowing
		Plantation	Seed ball broad casting
		Supervision	
		Ring making	
		Ploughing	
		Nursery raising	
3.	Fencing	Stone wall	
		Vegetative boundary	
		CPT	
4.	Other activities	Biogas	
		Smokeless Chulha	

*Biogas and Smokeless Chulha would be categorized as complete one item rate.

Format of Measurement Book

Name of village: ----------------Name of work: --------------------- Name of activity:-------------

Period of work: -----------------Date of measurement: -------------- Daily wage rate:-----

S.N.	Particular	No	Length	Width	Height	Quantity	Unit

Procedure of recording measurement book:

Measurement book is recorded at different stages:

- **Progressive measurement:** It is maintained at the completion of different stages of watershed activity or before each running payment of the watershed activity. The main objective of maintaining the progressive measurement is for monitoring the progress of work and the output of work against the payment made. It is necessary to maintain the progressive measurement book in both the cases whether the work is being implemented on measurement basis or on daily wage basis.
- **Final measurement:** It is a complete measurement of any physical intervention, which is recorded at the time of completion of any physical intervention. The main objective of maintaining the final measurement is to keep all the measurement at one place. With the help of final measurement actual work done can be compared with the estimate.

Examples: These are the examples through which the procedures of recording measurement can be understood:

Example I: Masonry check dam is constructed in Pratapgarh. Estimated cost of the structure is 2.5 lakh rupee and actual expenditure on that structure is 2.35 lakh. Work was done on daily wage basis. What is the procedure of recording the progressive measurement book and final measurement book?

Solution: -

Progressive measurement: It is maintained at the completion of different stages.

Stage I:

Name of village: Silatonk **Name of work:** Stone masonry check dam

Name of activity: WHS **Period of work:** 1/03/06 to 7/03/06

Date of measurement: 8/03/06 **Daily wage rate:** 73 Rupees

S. N.	Particular	No	Length (m)	Width (m)	Height (m)	Quantity	Unit
1	Excavation of foundation in hard murrum						
	a) For head wall	01	12	3.2	1.2	46.08	Cu.mt.
	b) For side wall	02	3	1.2	0.80	5.76	Cu.mt.
	c) For wing wall	02	1	1.2	0.80	1.92	Cu.mt.
	Total					**53.76**	**Cu.mt.**

Calculation for the monitoring of payment at the completion of stage I:

Sr.no.	Particular	No. of man days	Rate	Amount	Remark
1.	Excavation of the foundation in hard murrum				
a).	Amount as per daily wage				
	Unskilled labour	24	73	1752	
	Skilled labour	0	0	0	
	Actual total amount to be paid as per daily wage			**1752**	
b).	Amount as per measurement book				
	Unskilled labour	26.88	73	1962	
	Skilled labour	0	0	0	
	Total amount as per measurement book			1962	
c).	Difference of MB and daily wage payment bill			10.70%	Difference is around 10% hence O K
Note: No of man days as per daily wage is calculated from the wage muster or attendance register. And No of man days as per measurement book is calculated on the basis of average daily output (As per table attached, task work- Excavation in hard murrum)					

Stage II:

Name of village: Silatonk

Name of work: Stone masonry check dam

Name of activity: WHS

Period of work: 8/03/06 to 12/03/06

Date of measurement: 13/03/06

Daily wage rate: 73 Rupees

S. N.	Particular	No	Length (m)	Width (m)	Height (m)	Quantity	Unit
1	Plain Cement Concrete in 4:1:8 in foundation						
	a) Of head wall	01	12	3.2	0.15	5.76	Cu.mt.
	b) Of side wall	02	3	1.2	0.10	0.72	Cu.mt.
	c) Of wing wall	02	1	1.2	0.10	0.24	Cu.mt.
	Total					**6.72**	**Cu.mt.**

Calculation for the monitoring of payment at the completion of stage II:

Sr. No.	Particular	No. of man days	Rate	Amount	Remark
1.	Plain Cement Concrete in 4:1:8 in foundation				
a).	Amount as per daily wage				
	Unskilled labour	26	73	1898	
	Skilled labour	3	120	360	
	Actual total amount to be paid as per daily wage			**2258**	
b).	Amount as per measurement book				
	Unskilled labour	23	73	1679	
	Skilled labour	2	120	240	
	Total amount as per measurement book			1919	
c).	Difference of MB and daily wage payment bill			17.66%	

*Difference is more than 10% hence efficiency of the labour is to be enhanced

Note: Number of man days as per daily wage is calculated from wage muster or attendance register. And number of man days as per measurement book is calculated on the basis of rate analysis.

Stage III:

Name of village: Silatonk **Name of work:** Stone masonry check dam

Name of activity: WHS **Period of work:** 13/03/06 to 25/03/06

Date of measurement: 26/03/06 **Daily wage rate:** 73 Rupees

S. N.	**Particular**	**No**	**Length (m)**	**Width (m)**	**Height (m)**	**Quantity**	**Unit**
1	Random rubble masonry in 1:6 cement mortar in foundation.						
	a) Of head wall	01	12	2.2	1.05	27.72	Cu.mt.
	b) Of side wall	02	3	0.8	0.70	3.36	Cu.mt.
	c) Of wing wall	02	1	0.8	0.70	1.12	Cu.mt.
	Total					**32.2**	**Cu.mt.**

Calculation for the monitoring of payment at the completion of stage III:

Sr.No.	**Particular**	**No. of man days**	**Rate**	**Amount**	**Remark**
1.	Random rubble masonry in 1:6 cement mortar in foundation.				
a).	Amount as per daily wage				
	Unskilled labour	76	73	5548	
	Skilled labour	53	120	6360	
	Actual total amount to be paid as per daily wage			**11908**	
b).	Amount as per measurement				

	book				
	Unskilled labour	83.75	73	6114	
	Skilled labour	51.50	120	6180	
	Total amount as per measurement book			12294	
c).	Difference of MB and daily wage payment bill			3 %	There is hardly any difference hence OK
Note: No of man days as per daily wage is calculated from wage muster or attendance register. And No of man days as per measurement book is calculated on the basis of rate analysis (As per table attached, Rate analysis RRM in1: 6 CM)					

Stage IV:

Name of village: Silatonk **Name of work:** Stone masonry check dam

Name of activity: WHS **Period of work:** 26/03/06 to 7/04/06

Date of measurement: 8/04/06 **Daily wage rate:** 73 Rupees

S. N.	**Particular**	**No**	**Length (m)**	**Width (m)**	**Height (m)**	**Quantity**	**Unit**
1	Random rubble masonry in 1:6 cement mortar in superstructure.						
	a) Of head wall	01	12	1.5	2	36	Cu.mt.
	b) Of side wall	02	3	0.6	2.5	9	Cu.mt.
	c) Of wing wall	02	1	0.6	2	2.4	Cu.mt.
	Total					**47.4**	**Cu.mt.**

Calculation for the monitoring of payment at the completion of stage IV:

Sr.No.	Particular	No. of man days	Rate	Amount	Remark
1.	Random rubble masonry in 1:6 cement mortar in superstructure				
a).	Amount as per daily wage				
	Unskilled labour	115	73	8395	
	Skilled labour	79	120	9480	
	Actual total amount to be paid as per daily wage			**17875**	
b).	Amount as per measurement book				
	Unskilled labour	123.25	73	8997	
	Skilled labour	75.85	120	9102	
	Total amount as per measurement book			18099	
c).	Difference of MB and daily wage payment bill			1.25 %	There is hardly any difference hence OK
Note: No of man days as per daily wage is calculated from wage muster or attendance register. And No of man days as per measurement book is calculated on the basis of rate analysis (As per table attached, Rate analysis RRM in 1: 6 cement mortar)					

* If the work is carried out on daily wage basis, Wage muster and wage payment muster has to be maintained.

Final measurement:

Name of village: Silatonk

Name of work: Stone masonry check dam

Name of activity: WHS

Period of work: 01/03/06 to 7/04/06

Date of measurement: 10/04/06

Daily wage rate: 73 Rupees

S.N.	Particular	No	Length (m)	Width (m)	Height (m)	Quantity	Unit
01	Excavation of foundation in hard murrum						
	a) For head wall	01	12	3.2	1.2	46.08	Cu.mt.
	b) For side wall	02	3	1.2	0.80	5.76	Cu.mt.
	c) For wing wall	02	1	1.2	0.80	1.92	Cu.mt.
	Total					**53.76**	**Cu.mt.**
02	Plain Cement Concrete in 4:1:8 in foundation						
	a) Of head wall	01	12	3.2	0.15	5.76	Cu.mt.
	b) Of side wall	02	3	1.2	0.10	0.72	Cu.mt.
	c) Of wing wall	02	1	1.2	0.10	0.24	Cu.mt.
	Total					**6.72**	**Cu.mt.**
03	Random rubble masonry in 1:6 CM in foundation.						
	a) Of head wall	01	12	2.2	1.05	27.72	Cu.mt.
	b) Of side wall	02	3	0.8	0.70	3.36	Cu.mt.
	c) Of wing wall	02	1	0.8	0.70	1.12	Cu.mt.
	Total					**32.2**	**Cu.mt.**
04	Random rubble masonry in 1:6 cement mortar in superstructure.						
	a) Of head wall	01	12	1.5	2	36	Cu.mt.
	b) Of side wall	02	3	0.6	2.5	9	Cu.mt.
	c) Of wing wall	02	1	0.6	2	2.4	Cu.mt.
	Total					**47.4**	**Cu.mt.**

(Note: The main purpose of recording final measurement book is to collect all the measurement at one place, which are recorded in progressive measurement book. This final measurement book shows the implemented tasks against the estimate. If the overall difference is more than +/-10% then write a note on the reasons for that difference. This note will be very useful at the time of audit, evaluation etc.)

Example II: Continuous contour trench was constructed in Bhilwara project area. Total length of the CCT is 1200 running meter, width of trench 0.50 m, depth of trench 0.50 m. and soil strata hard murrum. The payment of the work was made on measurement basis. The rate is decided for the excavation in hard murrum is 36.50 rupees/cu.mt. What is the procedure for entering the measurements in measurement book?

Solution: As mentioned in the example the work was done on measurement basis. If the payment was made at the end of completion of 1200 m trench then there is no need to record the progressive measurement book, therefore final measurement book is recorded and according to the measurement, payment was made to the laborers.

That type of work is normally did by the group work. To distribute the payment among the group individual, it is necessary to keep the attendance (in this case attendance does not show if the person has worked for 8 hours at the site, so we are using the term labour unit for the calculation of payment) of the group persons with the daily output in a separate register. Please note that the attendance of group person should not be recorded in the attendance register or wage muster which is only used for work on daily wage basis.

Final measurement:

Name of village: Mota ka Kheda **Name of work:** CCT on common

Name of activity: WHS **Period of work:** 26/03/06 to 7/04/06

Date of measurement: 8/04/06 **Daily wage rate:** 73 Rupees

S. N.	Particular	No	Length (m)	Width (m)	Height (m)	Quantity	Unit
01	Construction of Continuous contour trench on common land in hard murrum.	1	1200	0.50	0.50	300	Cu.mt.
	Total					**300**	**Cu.mt.**

Calculation for the monitoring of payment at the completion of stage IV:

Sr.No.	Particular	Quantity	Unit	Rate (Rs/Unit)	Amount (Rs)	Remark
1.	Construction of Continuous contour trench on common land in hard murrum.					
a).	Amount as per measurement basis	300	cu.mt.	36.5	10950	
	Actual total amount to be paid as per measurement basis				**10950**	

Note: Rates, for the calculation of payment, should be used from Current Schedule of Rates of State Government. Payment to labour is done on" **Payment register for measurement basis"** instead of wage payment muster. The format of "Payment Register for measurement basis" is given below.

* There is no need to maintain the wage muster, in case of work done on measurement basis.

Payment Register Format, if the work is done on Measurement Basis**:**

S. N	Name	Description of work done	Quantity	Unit	Rate (Rs/Unit)	Total Amount (Rs)	Signature of recipient

Labor cost in the watershed interventions:

Watershed interventions are mainly divided into two sections:

- **Earthen structures:** If the work is carried out by labour only the proportion of wage and non-wage cost in the earthen structures is varies from 90:10 to 70:30. If the earthwork is carried out through machines likes Tractor, Dozer, Excavator, Roller etc the proportion of wage and non-wage cost can reach up to 25:75, which will depend on the use of machinery in the earthwork.
- **Cement structures:** Normally proportion of wage and non-wage cost in the cement structures is 30:70. This proportion is fluctuates with the fluctuation in the rate of construction material like Cement, Steel, and transportation cost etc.

Labour cost in the each activity of watershed intervention depends on the following factors:

- Size of structure i.e. length, width & height of the structure
- Soil strata i.e. soft soil, hard soil, murrum, hard murrum, disintegrated rock & hard rock.
- Lead and lift of construction material.
- Minimum wage of the state.

Task work or out turn work:

The capacity of doing work by a labor in the form of work per day is known as task work. The task varies according to the nature, size and location of work. The factor affecting the task work are given below:

- Output of different workers varies considerably according to their skills.

- Output of an individual worker also varies considerably depending on the variations in the weather and his domestic life.
- Efficient site organization and management increases the labour output, whereas faulty or slack organization decreases it.

- Higher wages, incentive payments, and other amenities such as clean and healthy camps, and lesser working hours improve the output.
- Peculiarity of job and site condition may also have some effect on the output.

The following table gives the approximate quantity of work per day of labor: This table will help in both the case whether the work is implemented on daily wage basis or measurement basis for monitoring the work.

(This table has been prepared on the basis of some standard civil engineering books. The outturn is decided on the basis of some experiments, which are carried out by the scientists. These may vary from state to state; you should cross check these task work with the State Government CSR. If you find any change, please make the correction in this table.)

S N	Particulars of work	Quantity	Labours
1.	**Earth excavation**		
	a. Alluvial soil	3 cu.mt.	1-manday
	b. Loose murrum	2.5 cu.mt.	1-manday
	c. Hard murrum	2 cu.mt.	1-manday
	d. Hard stony	1 cu.mt.	1-manday
	e. Hard rock	0.5 cu.mt.	1-manday
2	Collection of stones and construction of bund		
	a. Collection of stones of 15-20 cm diameter from 1 hectare land for bund	2 cu.mt.	1-manday
	b. Construction of bund	3 cu.mt.	1-manday
3	Planting of cuttings on excavated earth	150 no.	1-manday
4	Carrying of saplings in poly packs up to a distance of 200m and planting the same in excavated earth	50 no.	1-manday

Monitoring system for implementing physical works

Objective:

- To understand, check and verify input and outputs with the result regarding all project measures.
- To steer the quality of work.
- To resolve problems, and conflicts if any.

Components:

- Desk appraisal of physical and financial and all other relevant records.
- Physical verification of work implemented and ongoing.
- On field discussion with different stakeholders involved in project implementation.
- Feed back and decision oriented discussion with local institution about the quantity and quality of work.

Desk monitoring:

- Check all the figures mentioned in the report reflected in the field and the office record.
- All the record maintained as per the standard format.
- The amount spent in each payment matches with concerned measurement book.
- The VWC meeting register has necessary resolution to make payment to labor.
- Some measurements are randomly selected from the MB for site verification.
- MB is also looked from the designed cross section and the dimension point of view.

Field monitoring:

- The monitoring is participatory in nature and aim for building capacity of the villagers to monitor their own progress in watershed development.

- The samples selected in desk monitoring are identified and verified for its correct measurement, strata and according the rate per cu.mt. While walking through the work, select any random pit or work and identify in MB and check for measurement.
- The quality of the work with respect to appropriateness, location marking, dimensions, shape and alignment etc. is checked and discussed with VWC
- It is also important to verify whether the work is done according to the estimated and sanctioned plan. The deviations are discussed and suggested to minimize the same in future.
- If necessary the meeting of all the labours working is called and the various points of monitoring are discussed with them. Problems being faced by the labours are discussed and sorted out in these meetings.
- The team discusses the ongoing work with the owner of land and suggests, agrees and on spot sanctions some modifications if required to suit his needs.
- If there are any serious issues, which need to discuss with all villagers, a Gramsabha is called. The issue may be like less shramdaan, slow speed of work etc.

Cost estimation & design:

- If the cost of any physical interventions is more than 50 thousand, then the selected site should fulfill the ideal site selection criteria and the sanction committee should approve it.
- If the cost of any physical interventions is more than 50 thousand, then it should be designed as per the standard design format.
- If the cost of any physical interventions is more than 50 thousand, then it is mandatory to prepare the estimate and drawing of physical interventions.
- Government department's Current Schedule Rate should be used for the preparation of estimate.
- There should be a sanction committee for the approval of the estimates.
- If the cost of any physical interventions is more than 50 thousand, then all the basic information (demarcation of location on toposheet, catchment area,

storage capacity, submergence drawing, photograph, etc.) regarding the structure should be documented.

- If the cost of any physical intervention is more than 2 lakh than it should be justified in terms of cost benefit ratio.
- One key person should be responsible for site selection, design & estimation of physical interventions.

Implementation / execution of work:

- Sanction committee should initiate work after the approval of the estimates.
- Simplify the estimate and the drawing and share it with the community.
- Village level supervisors should be trained for the implementation of physical interventions.
- It is mandatory to maintain the measurement book of all physical interventions before each payment. Measurement should be recorded in metric system (meter-centimeter).
- Daily activity register, stock register, attendance register, piece rate measurement of each group should be maintained for the physical intervention if the cost is more than 50 thousand.
- After the completion of any physical intervention (cost more than 50 thousand), calculate the actual cost of structure as per the measurement book and the actual rates.
- Piece rate basis should be preferred for the implementation of physical interventions. It is useful in maintenance of measurement book.
- Field visit of key persons at different stages is essential for the monitoring of technical parameters of the physical intervention if the cost of intervention is more than 50 thousand.
- Analyze the actual quantity and cost with the estimated quantity and cost at the time of completion of different stages of physical intervention. It is essential if the cost of physical intervention is more than 1 lakh. If the variation is more than 10%, maintain the reasons for that variation.

- Comparative statement of an estimated and actual work should be maintained for the physical intervention if the cost of intervention is more than 1 lakh.

Framework for monitoring the impact of watershed management