Agricultural TVET College

Small Scale Irrigation Development

Level III

MODEL TTLM

Learning Guide #14

Unit of Competence: Construct Water Harvesting Structures

Module Title: Constructing Water Harvesting Structures

LG Code: AGR SSI3 M14 LO1-LO3

TTLM Code: AGR SSI3 TTLM14 1218V$_1$

Nominal Duration: 80 Hours

Instruction Sheet	Learning Guide #14

This learning guide is developed to provide you the necessary information regarding the following content coverage and topics:–

- Plan water harvesting structures
- Design water harvesting structures
- Construct water harvesting structures

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to –

- ✓ Plan water harvesting structures
- ✓ Identify proper site for water harvesting
- ✓ Chose appropriate water harvesting technique based on applicability & adaptability
- ✓ Identify type of construction materials and equipment considering criteria: such as availability, cost and applicability
- ✓ Interpret lay out drawings and construction specifications using chosen surveying techniques in to physical marks on project site.
- ✓ Selected appropriate shade & lining materials to reduce evaporation & seepage loss respectively

Learning Activities

1. **Read the specific objectives of this Learning Guide.**
2. **Read the information written in the "Information Sheet"**
3. **Accomplish the "Self-check".**
4. **If you earned a satisfactory evaluation proceed to the next "Information Sheet". However, if your rating is unsatisfactory, see your facilitator for further instructions or go back to Learning Activity.**
5. **Submit your accomplished Self-check. This will form part of your training portfolio.**
6. **Read and Practice "Operation Sheets".**
7. **If you think you are ready proceed to "Job Sheet".**

8. **Request you facilitator to observe your demonstration of the exercises and give you feedback.**

INFORMATION SHEET#1	Plan water harvesting structures

1.1. Introduction:

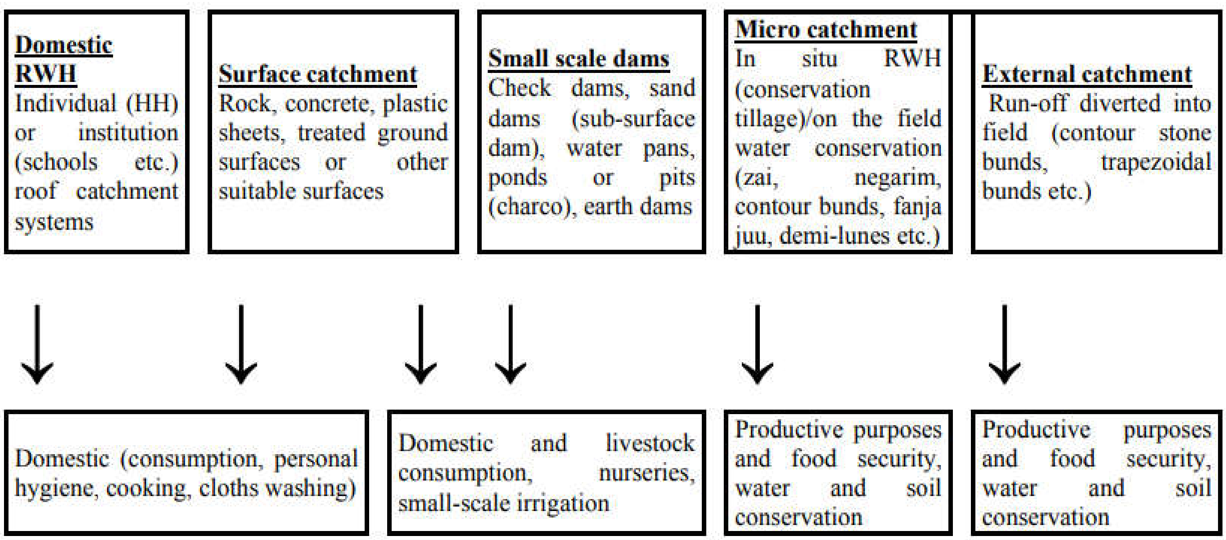
Definition:

Water harvesting in its broadest sense can be defined as the "collection of runoff for its productive use". Runoff may be harvested from roofs and ground surfaces as well as from intermittent or ephemeral watercourses.

Water harvesting techniques, which harvest runoff from roofs or ground surfaces fall under the term ‘Rainwater Harvesting’ while all systems which collect discharges from watercourses are grouped under the term ‘Floodwater Harvesting’.

Overview of RWH concepts

It has been chosen to summarize the concepts of rainwater harvesting as seen below:



In-situ RWH is also called water conservation and is basically a prevention of net runoff from a given cropped area by holding rain water and prolonging the time for infiltration. In-situ RWH is achieved mainly by conservation tillage and has is merged with micro catchment.

Construction of structures with storage capacity normally above 100.000 m^3 could be categorized as rainwater harvesting.

Main reasons and scenarios to utilize of RWH

Water shortage or inferior water quality is still a severe problem for millions of people in Africa (as well as elsewhere) and a hindrance for economical development.

Even in places with less serious water shortages, demand for additional water is dominant. Since the use of rainwater harvesting in general is widely under-utilized, there is even more reason to focus and expand the use in a more structured manner.

So the overall objective and reason to utilize concepts and techniques of rainwater harvesting is to optimize the use of the available rainfall on any given location.

1.2. Identifying potential areas

To assess the potential of water harvesting, the following factors must be determined;

- ☞ The average annual rainfall
- ☞ Catchment area
- ☞ Percentage of rainwater use at the maximal point of volumetric reliability compared to the storage capacity curve, and percentage of total roof area in each demand.

1.2.1: Theoretical Potential of Rainwater Harvesting

Theoretical potential refers to the maximal amount of total collectable rainwater in a DRWH system. All rainwater cannot be harvested, only the precipitation that can be collected on a roof or catchment can be harvested. Hence, the climatic and catchment characteristic aspects of the factors that influence DRWH are considered without the economic and ecological aspects.

1.2.2 Available Potential of Domestic Rainwater Harvesting

Not all harvested rainwater can be used because of storage capacity limitations, rainwater demand, and rainwater collection efficiency. Inadequate storage volume also allows water to be wasted. Rainwater that is collected in a storage tank for consumption under optimal efficiency of rainwater use conditions is referred to as the rain water harvesting available potential. The curve, Rv (volumetric reliability = the ratio of actual rainwater supply to demand) compared to the storage capacity of selected typical catchments, are used to determine the optimal efficiency of rainwater use.

1.2.3 Environmental Bearable Potential of Rainwater Harvesting

Both the theoretical and available potential of a RWH system is mainly to be considered at a catchment area scale. Harvested rainwater is owned and used by landowners. However, when direct rainwater harvesting systems are installed at practical scale, surface runoff reduces downstream, which affects the ecological system and water downstream of the systems.

Therefore, the impact of water harvesting on water resource systems requires broader considerations. The environmental bearable potential of rain water harvesting combines the total roof area percentage with available potential rain water harvesting.

1.3. Identifying & maintaining water contributors

The run-off or stream-flow is the water which is gathered into *rivulets, brooks and rivers*. The volume and variation of run-off are influenced chiefly by the *rainfall and its catchment contributor factors. Some of these catchment and flow contributor factors are;*

- The *size, shape, cover and general topography of the catchment area*
- The nature and condition of the catchment

Basin – wise water resource development

The total land area that contributes water to a river is called a watershed, also called differently as the catchment, river basin, drainage basin, or simply a basin. The image of a basin is shown in Figure 1.

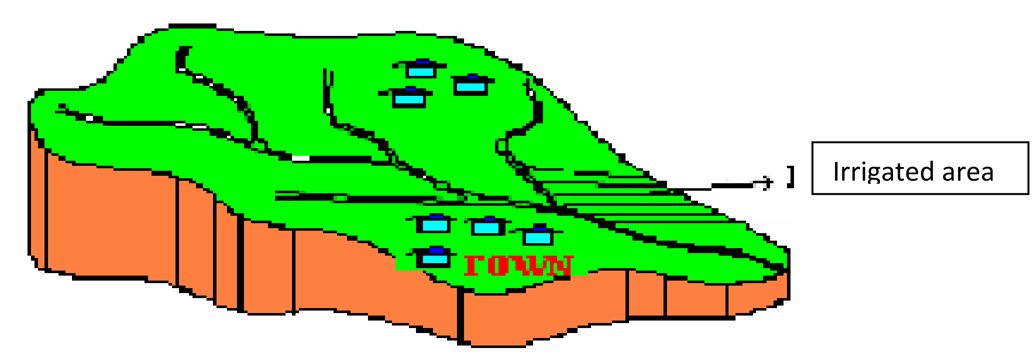


Fig.1. Typical watershed

A watershed may also be defined as a geographic area that drains to a common point, which makes it an attractive planning unit for technical efforts to conserve soil and maximize the utilization of surface and subsurface water for crop production. Thus, it is generally considered that water resources development and management schemes should be planned for a hydrological unit such as a drainage basin as a whole or for a sub-basin, multi-spectrally, taking into account surface and ground water for sustainable use incorporating quantity and quality aspects as well as environmental considerations.

Let us look into the concept of watershed or basin-wise project development in some detail. The objective is to meet the demands of water within the Basin with the available water therein, which could be surface water, in the form of rivers, lakes, etc. or as groundwater. The source for all these water bodies is the rain occurring over the Watershed or perhaps the snowmelt of the glacier within it, and that varies both ***temporally*** and ***spatially***.

Further due to the land surface variations the rain falling over land surface tries to follow the steepest gradient as overland flow and meets the rivers or drains into lakes and ponds. The time for the overland flows to reach the rivers may be fast or slow depending on the obstructions and detentions it meet on the way. Part of the water from either overland flow or from the rivers and lakes penetrates into the ground and recharge the ground water. Ground water is thus available almost throughout the watershed, in the underground aquifers. The variation of the water table is also fairly even, with some rise during rainfall and a gradual fall at other times. The water in the rivers is mostly available during the rains. When the rain stops, part of the ground water comes out to recharge the rivers and that results in the dry season flows in rivers.

Waterways are defined as creeks, rivers, and other natural low areas that convey storm water. Types of streams include:

Ephemeral - streams that derive flow only from surface runoff and flow briefly in direct response to precipitation.

Intermittent – streams that does not flow continuously, but may flow during the wet season or when the water table is high

Perennial – streams that flow continuously throughout the year because flow is maintained by a combination of groundwater discharge (e.g., springs) and surface runoff.

Floodplains are areas bordering a waterway where rain events cause storm water to overflow from the channel. During such events, sediment is deposited during the natural process of flooding. The waterway and floodplain are collectively referred to as the riparian zone, which contains fertile soils capable of supporting a great diversity of vegetation and wildlife unique from drier uplands.

1.4. Assessing Soil moisture status & level of ground water

Water is one of the most important ingredients in any soil. Soil formation would not be possible without water.

Evaluating soil moisture is one of an irrigator's most important management tools. Determining the status of the soil moisture reservoir guides the decision of not only how much to irrigate, but also when to irrigate. The "appearance and feel" method of monitoring soil moisture using a soil probe is still a valid procedure no matter how sophisticated the irrigation scheduling system. A measurement of soil moisture is essential to update knowledge of the need for and timing of irrigation.

Water content is given on a volumetric or mass (gravimetric) units. We have different possibilities for determining of soil moisture as follows:

a. Gravimetric method

The gravimetric method is the oldest and the most widely used method for determining soil moisture. The method is easy– soil sample is weighed before and after drying (oven temperature 105°C), and calculating its original moisture content. It is required for calibrating the equipment used in the others methods.

In soil-moisture sampling, it is essential that all sampling operations the transfer of samples to moisture cans and the weighing of the moist samples be done as rapidly as possible to prevent undue moisture losses. Augers or core samplers are used for soil-moisture sampling.

Fig. 2 Soil sample before drying Fig. 3 Augers Fig. 4 Soil samplers

b. **Electrical resistance**

This device operates on the principle that resistance to the passage of an electrical current between two electrodes buried in the soil will depend upon the moisture content of the soil. A meter at the surface measures changes in electrical resistance. The resistance is read on the meter and is converted to moisture- content values by means of a calibration chart. The accuracy of soil-moisture blocks is at best 1 percent by weight. The device responds with equal rapidity to changes in soil moisture. *It is generally considered most dependable in the low-moisture-content range, below filed capacity*. But salt concentration in soil moisture will materially affect results obtained by use of soil-moisture blocks. Blocks require relatively little effort to install and can be speedily read.

Fig. 5: Electrical-resistance device

c. Tensiometric

A tensiometer consists of a porous point or cup connected through a tube to a pressure-measuring device. The system is filled with water and the water in the point or cup comes into equilibrium with the moisture in the surrounding soil. The tension is changed with different amounts of water – greater tension is with dry soil and less tension is with wetter soil.

The tensiometer is most useful for measuring moisture content of tensions below approximately 0.9 atmospheres. Such tensions will, on the average, correspond to a range in moisture content from slightly below filed capacity to saturation. At the higher tensions found in drier soils, tensiometers become inoperative because air enters the system through the porous point.

Tensiometers are affected by temperature. The temperature gradients between the tensiometer and the soil may cause variations in the tension readings. The salt concentration seems to affect tensiometric methods less than electrical methods.

Fig. 6: Tensiometer

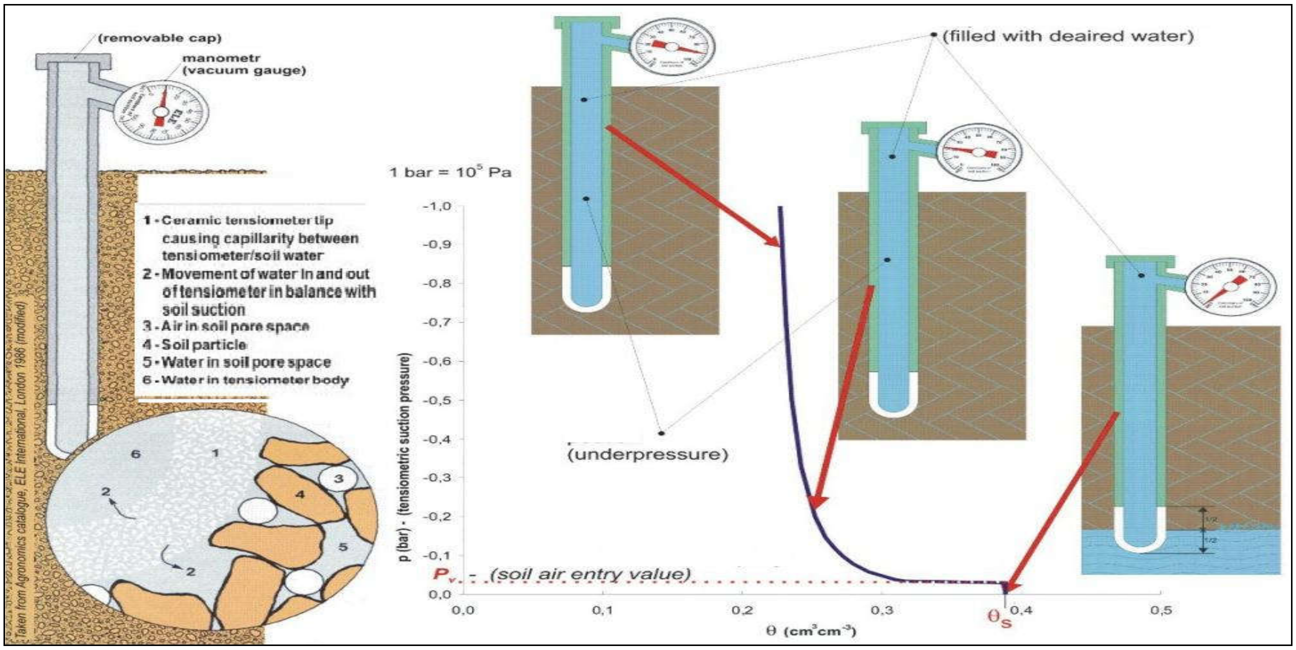


Fig 7: Principe of tensiometric

d. Time Domain Reflectometry (TDR)

TDR measures the apparent dielectric constant of the soil surrounding a waveguide, at microwave frequencies of MHz to GHz. The propagation velocity of an electromagnetic wave along a transmission line of L embedded in the soil is determined from the time response of the system to a pulse generated by the TDR cable tester. TDR method has a lot of advantages: superior accuracy to within 1 or 2 percent by v o l u m e , minimal calibration requirements, excellent spatial and temporal resolution, simple to obtain continuous soil water measurements through automation and multiplexing. TDR method has the problem with highly saline conditions and the soil-specific calibration required for soils with high clay or organic matter contents.

Fig.8: Time domain reflectometry

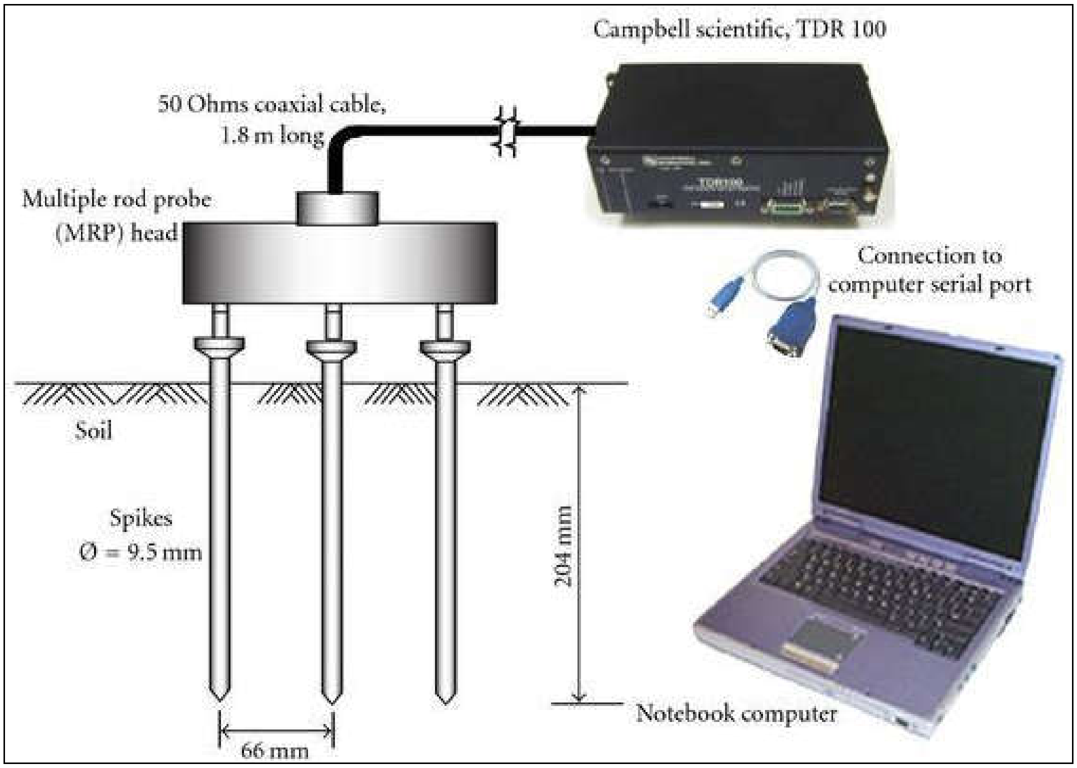


Fig.9: Schema of a typical TDR system.

e. Radioactive

This method is based on the principle of measuring the slowing of neutrons emitted into the soil from a fast-neutron source. The energy loss is much greater in neutron collisions with atoms of low atomic weight and is proportional to the number of such atoms present in the soil. The effect of such collisions is change the speed of neutrons. Hydrogen, which is the principal element of low atomic weight found in the soil, is largely contained in the molecules of the water in the soil.

The radioactive method indicates the amount of water per unit volume of soil. Most investigators have reported accuracy within 1 to 2 percent by volume. However, to obtain this accuracy, it is recommended that the probe be calibrated in the type of soil to be tested. Salt concentration in the soil moisture and temperature do not materially affect the data obtained by the radioactive method.

The radioactive method is time consuming. The equipment is heavy and delicate and equipment failures are likely.

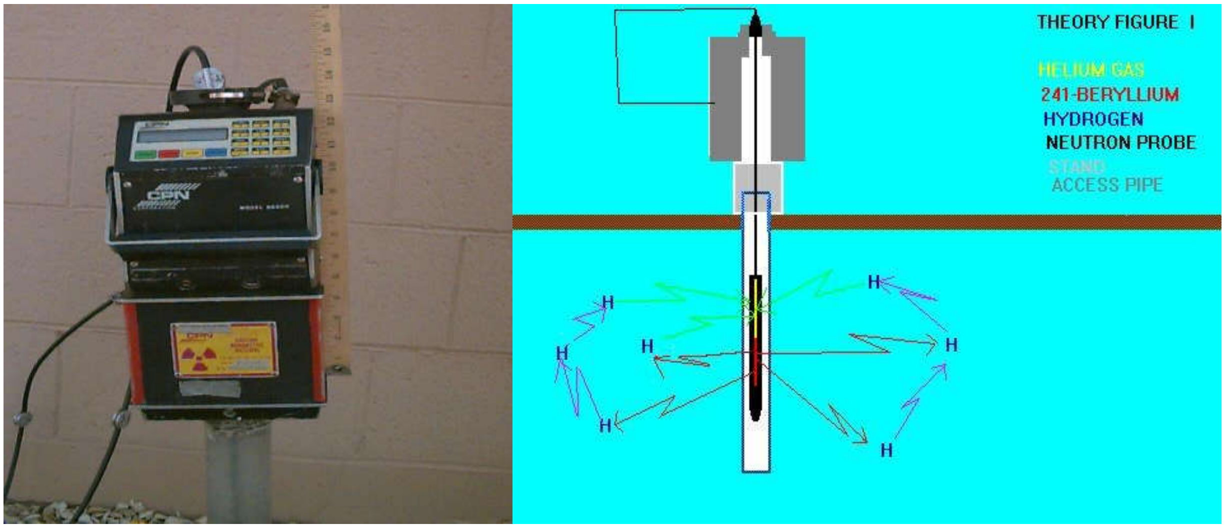


Fig. 10: a) Device for radioactive b) Principle of radioactive method

Sampling and Evaluation Procedures

A soil probe, soil auger, or spade can be used to extract a soil sample. Evaluate the soil moisture at one foot intervals from the surface to the bottom of the active root zone. The active root zone for most irrigated crops is approximately 3 feet deep. When checking for water penetration or soil moisture for dry land crops, probe to the depth of 4 to 5 feet.

The number and location of sampling sites depends on both the uniformity of the soils in the field and the irrigation procedures. Check problem areas in the field in addition to the starting and stopping areas of your particular irrigation system. Sample a minimum of four sites in different parts of the field.

Procedure for evaluating soil moisture using photo guides and descriptions:

- ☞ Determine texture of soil.
- ☞ Squeeze small handful of soil firmly.
- ☞ Observe the condition of the ball and your hand.
- ☞ Attempt to form a ribbon of the soil between your thumb and forefinger.
- ☞ Observe what happens.
- ☞ Compare your observations with the photos and descriptions in the guides.

Level of ground water

Routine water-level monitoring will provide data about natural variations in the groundwater elevation. Owners of water wells should periodically measure the water-table elevation in their wells. Water-table measurements will help you determine that the well has the capacity to provide a sufficient quantity of water. A dramatic change in the water-table elevation will signal a problem with the well supply. You can use manual or automatic water-level measurement techniques to gauge the groundwater elevation on a routine basis.

Water-level measurements can be taken in various ways (Figure 11.):

- The **wetted tape method** (Figure 11. A): A steel tape (calibrated in millimeters), with a weight attached to it, is lowered into the pipe or borehole to below the water level. The lowered length of tape from the reference point is noted. The tape is then pulled up and the length of its wetted part is measured. (This is facilitated if the lower part of the tape is chalked.) When the wetted length is subtracted from the total lowered length, this gives the depth to the water level below the reference point;

- With a **mechanical sounder** (Figure 11. B): This consists of a small steel or copper tube (10 to 20 mm in diameter and 50 to 70 mm long), which is closed at its upper end and connected to a calibrated steel tape. When lowered into the pipe, it produces a characteristic plopping sound upon hitting the water. The depth to the water level can be read directly from the steel tape;

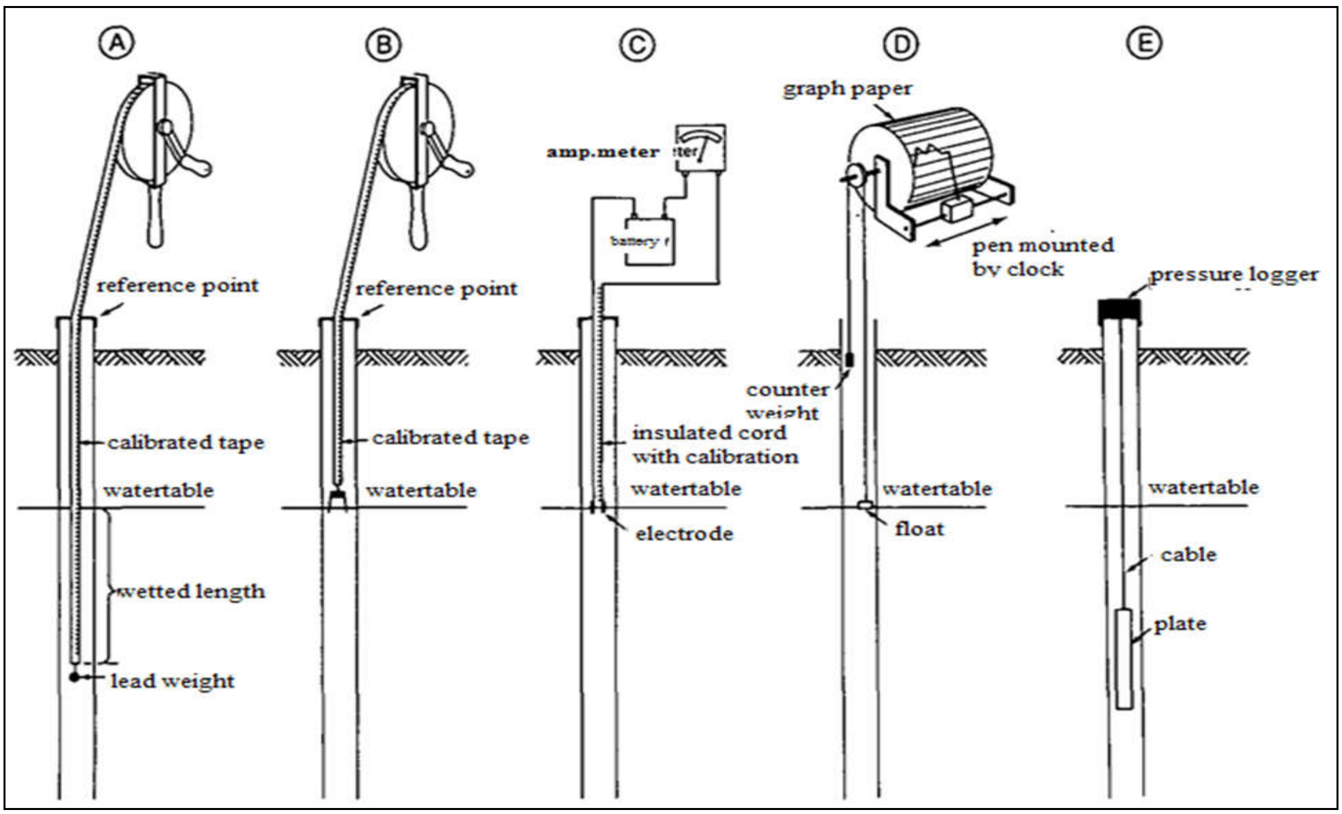


Figure 11: Various ways of measuring depth to water level in wells or piezometers

- With an **electric water-level indicator** (Figure 11.C): This consists of a double electric wire with electrodes at their lower ends. The upper ends of the wire are connected to a battery and an indicator device (lamp, mA meter, and sounder). When the wire is lowered into the pipe and the electrodes touch the water, the electrical circuit closes, which is shown by the indicator. If the wire is attached to a calibrated steel tape, the depth to the water level can be read directly;
- With a **floating level indicator or recorder** (Figure 11.D): This consists of a float (60 to 150mm in diameter) and a counterweight attached to an indicator or recorder. Recorders can generally be set for different lengths of observation period. They require relatively large pipes. The water levels are either drawn on a rotating drum or punched in a paper tape;
- With a **pressure logger or electronic water-level logger** (Figure 11. E): This measures and records the water pressure at one-hour intervals over a year. The pressure recordings are controlled by a microcomputer and stored in an internal, removable memory block. At the end of the observation period or when the memory block has reached capacity, it is removed and replaced. The recorded data are read by a personal computer. Depending on the additional software chosen, the results can be presented raw or in a calculated form. Pressure loggers have a small diameter (20 to 30 mm) and are thus well suited for measurements in small-diameter pipes;

- The water levels of open water surfaces are usually read from a staff gauge or a water-level indicator installed at the edge of the water surface. A pressure logger is most convenient for this purpose, because no special structures are required; the cylinder need only be anchored in the river bed.

Each time a water-level measurement is made, the data should be recorded in a notebook. Even better is to enter the data in a computerized database system. Recorded for each observation are: date of observation, observed depth of the water level below the reference point, calculated depth below ground surface (for free water tables only), and calculated water-level elevation (with respect to a general datum plane, e.g. mean sea level) an example is shown in Figure 20.

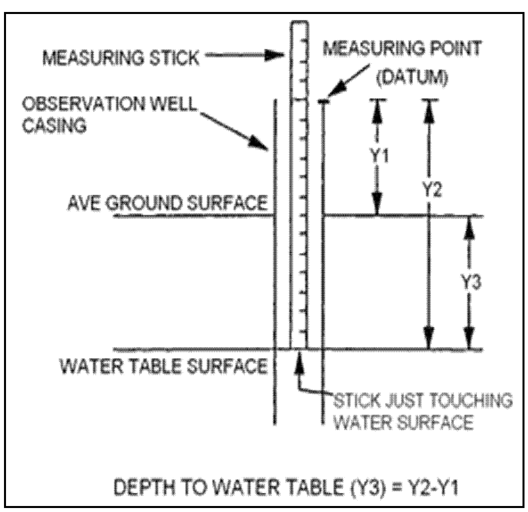


Figure 12: Calculation of the depth to water table from the ground surface.

1.5. Identifying best practices to recharge underground water table

Water is indispensable to all life on earth. However, fresh water is constantly formed newly through a phenomenon known as hydrological cycle. Ground water recharge is the process by which water percolates down the soil and reaches the water table, either by natural or artificial methods.

Ground water recharge may be explained as the process whereby the amount of water present in or flowing through the interstices of the sub-soil increases by natural or artificial means. The amount of water that may be extracted from an aquifer without causing depletion is primarily dependent upon the ground water recharge. Rainfall is the principal source for replenishment of moisture in the soil water system and recharge of ground water. Other sources include recharge from rivers, streams, irrigation water etc. Moisture movement in the unsaturated zone is controlled by suction pressure, moisture content and hydraulic conductivity relationships. The amount of moisture that will eventually reach the water table is defined as natural ground water recharge, which depends on the rate and duration of rainfall, the subsequent conditions at the upper boundary, the antecedent soil moisture conditions, the water table depth and the soil type.

Methods of Artificial Recharge

Artificial recharge methods can be classified into two broad groups; *(1) direct methods, and (2) indirect methods.*

1. Direct Methods

(a) Surface Spreading Techniques

The most widely practiced methods of artificial recharge of groundwater employ different techniques of increasing the contact area and resident time of surface-water with the soil so that maximum quantity of water can infiltrate and augment the groundwater storage. Areas with gently sloping land without gullies or ridges are most suited for surface-water spreading techniques.

Flooding: The technique of flooding is very useful in selected areas where a favorable hydro-geological situation exists for recharging the unconfined aquifer by spreading the surplus surface-water from canals / streams over large area for sufficiently long period so that it recharges the groundwater body. This technique can be used for gently sloping land with slope around 1 to 3 percentage points without gullies and ridges.

Ditches and Furrows: In areas with irregular topography, shallow, flat-bottomed and closely spaced ditches and furrows provide maximum water contact area for recharging water from the source stream or canal. This technique requires less soil preparation than the recharge basin technique and is less sensitive to silting.

Recharge Basins: *Artificial* recharge basins are either excavated or enclosed by dykes or levees. They are commonly built parallel to ephemeral or intermittent stream-channels. The water contact area in this method is quite high which typically ranges from 75 to 90 percentage points of the total recharge area. In this method, efficient use of space is made and the shape of basins can be adjusted to suite the terrain condition and the available space.

Run-off Conservation Structures

In areas receiving low to moderate rainfall, mostly during a single monsoon season, and not having access to water transferred from other areas, the entire effort of water conservation is required to be related to the available ‟ insitu‟ precipitation.

Gully plugs are the smallest run-off conservation structures built across small gullies and streams rushing down the hill slopes carrying drainage of tiny catchments during rainy season. Usually, the barrier is constructed by using local stones, earth and weathered rock, brushwood, and other such local materials. Sloping lands with surface gradients up to 8 percentage points having adequate soil cover can be leveled through ***bench terracing*** for bringing under cultivation. It helps in soil conservation and holding run-off water on terraced area for longer duration giving rise to increased infiltration recharge.

Contour barriers involve a watershed management practice so as to build up soil moisture storages. This technique is generally adopted in areas receiving low rainfall. In this method, the monsoon run-off is impounded by putting barriers on the sloping ground all along contours of equal elevation. Contour barriers are taken up on lands with moderate slopes without involving terracing.

In areas where uncultivated land is available in and around the stream-channel section, and sufficiently high hydraulic conductivity exists for sub-surface percolation, small tanks are created by making stop dams of low elevation across the stream. The tanks can also be located adjacent to the stream by excavation and connecting them to the stream through delivery canals. These tanks are called "***percolation tanks***" and are thus artificially created surface-water bodies submerging a highly permeable land area so that the surface run-off is made to percolate and recharge the groundwater storage. It should be located downstream of a run-off zone, preferably towards the edge of a piedmont zone or in the upper part of a transition zone (land slope between 3 to 5 percentage points). There should be adequate area suitable for irrigation near a percolation tank.

Stream-channel Modification: *The* natural drainage channel can be modified with a view to increase the infiltration by detaining stream flow and increasing the stream-bed area in contact with water. This method can be employed in areas having influent streams (stream-bed above water table) which are mostly located in piedmont regions and areas with deep water table (semi-arid, arid region and valley fill deposits). Stream- channel modification methods are generally applied in alluvial areas.

Surface Irrigation: *Surface* irrigation aims at increasing agricultural production by providing dependable watering of crops during gaps in monsoon and during non-monsoon period. Wherever adequate drainage is assured, if additional source water becomes available, surface irrigation should be given first priority as it gives a dual benefit of augmenting groundwater resources.

Roof Top Rain Water Harvesting: *Rooftop* rainwater harvesting can conserve rainwater for either direct consumption or for recharge of groundwater. This approach requires connecting the outlet pipe from a guttered rooftop to divert rainwater to either existing wells or other recharge structures or to storage tanks. Drainpipes, roof surfaces and storage tanks should be constructed of chemically inert materials such as plastic, aluminium, galvanized iron or fiberglass, in order to avoid contaminating the rainwater.

Advantage of collecting and storing rainwater in urban area is the reduction of demand on water supply systems as well as reducing the amount of storm-water run-off and consequent urban flooding. The urban housing complexes or institutional buildings have large roof area and can be utilizing for harvesting rooftop rain water to recharge aquifer in urban areas.

(b) Sub-Surface Techniques

When impervious layers overlie deeper aquifers, the infiltration from surface cannot recharge the sub -surface aquifer under natural conditions. The techniques adopted to recharge the confined aquifers directly from surface-water source are grouped under sub-surface recharge techniques.

Injection Wells: *Injection* wells are structures similar to a tube well but with the purpose of augmenting the groundwater storage of a *confined aquifer* by "pumping in" treated surface-water under pressure. The aquifer to be replenished is generally one that is already over exploited by tube well pumping and the declining trend of water levels in the aquifer has set in. Artificial recharge of aquifers by injection wells is also done in coastal regions to arrest the ingress of seawater and to combat the problems of land subsidence in areas where confined aquifers are heavenly pumped. Due to higher well losses caused by clogging, the injection wells display lower efficiency (40 to 60 percentage points) as compared to a pumping well of similar design in the same situation. The source water and the water in the aquifer should be compatible to avoid any precipitation, causing clogging of well. Injection-cum-pumping wells are more efficient because the well can be cleaned during pumping operation.

Gravity-Head Recharge Wells: *In* addition to specially designed injection wells, ordinary bore wells and dug wells used for pumping may also be alternatively used as recharge wells, whenever source water becomes available. In certain situations, such wells may also be constructed for effecting recharge by gravity inflow. In areas where water levels are currently declining due to over-development, using available structures for inducing recharge may be the immediately available economic option.

Connector Wells: Connector wells are special type of recharge wells where, due to difference in potentiometer head in different aquifers, water can be made to flow from one aquifer to other without any pumping. The aquifer horizons having higher heads start recharging aquifer having lower heads.

Recharge pits: Recharge pits are structures that overcome the difficulty of artificial recharge of phreatic aquifer from surface -water sources. Recharge pits are excavated of variable dimensions that are sufficiently deep to penetrate less permeable strata. A ***canal trench*** is a special case of recharge pit dug across a canal bed. An ideal site for canal trench is influent stretch of a stream that shows up as dry patch. One variation of recharge pit is a ***contour trench*** extending over long distances across the slope and following topographical contour. This measure is more suitable in piedmont regions and in areas with higher surface gradients. As in case of other water spreading methods, the source water used should be as silt free as possible.

Recharge Shafts: In case, poorly permeable strata overlie the water table aquifer located deep below land surface, a shaft is used for causing artificial recharge. A recharge shaft is similar to a recharge pit but much smaller in cross-section.

2. Indirect Methods

(a) Induced Recharge

It is an indirect method of artificial recharge involving pumping from aquifer hydraulically connected with surface -water, to induce recharge to the groundwater reservoir. In hard rock areas, the abandoned channels often provide good sites for induced recharge. The greatest advantage of this method is that under favourable hydro-geological situations, the quality of surface-water generally improves due to its path through the aquifer materials before it is discharged from the pumping well.

Pumping Wells: Induced recharge system is installed near perennial streams that are hydraulically connected to an aquifer through the permeable rock material of the stream-channel. The outer edge of a bend in the stream is favourable for location of well site.

Collector Wells: For obtaining very large water supplies from river-bed, lake-bed deposits or waterlogged areas, collector wells are constructed. The large discharges and lower lift heads make these wells economical even if initial capital cost is higher as compared to tube well. In areas where the phreatic aquifer adjacent to the river is of limited thickness, horizontal wells may be more appropriate than vertical wells. Collector well with horizontal laterals and infiltration galleries can get more induced recharge from the stream.

Infiltration Gallery: Infiltration galleries are other structures used for tapping groundwater reservoir below river-bed strata. The gallery is a horizontal perforated or porous structure (pipe) with open joints, surrounded by a gravel filter envelope laid in permeable saturated strata having shallow water table and a perennial source of recharge. The galleries are usually laid at depths between 3 to 6 meters to collect water under gravity flow. The galleries can also be constructed across the river-bed if the river-bed is not too wide. The collector well is more sophisticated and expensive but has higher capacities than the infiltration gallery. Hence, choice should be made by the required yield followed by economic aspects.

(b) Aquifer Modification

These techniques modify the aquifer characteristics to increase its capacity to store and transmit water. With such modifications, the aquifer, at least locally, becomes capable of receiving more natural as well as artificial recharge. Hence, in a sense these techniques are artificial yield augmentation measures rather than artificial recharge measures.

Bore Blasting: These techniques are suited to hard crystalline and consolidated strata. Through hydro-geological investigation, suitable sites are fixed where the aquifer displays limited yield that dwindles or dries in winter or summer months. All the blast holes reach the depth of the aquifer required to be benefited, whether unconfined or confined. All the charges of row or circle are exploded at a time.

Hydro-Fracturing: In many cases, blasting has given indifferent results. Hydro-fracturing is a recent technique that is used to improve secondary porosity in hard rock strata. Hydro-fracturing is a process whereby hydraulic pressure is applied to an isolated zone of bore wells to initiate and propagate fractures and extend existing fractures. The water under high- pressure break up the fissures cleans away clogging and leads to a better contact with adjacent water bearing strata. The yield of the bore well is improved. In hydro fracturing, *vertical fractures* are initiated which inter-connects aquifers at different levels in addition to extension of existing fractures. This leads to better conditions for artificial recharge. The technique may be applied at bore well sites located in hard crystalline rock or other massive consolidated strata including metamorphic and sedimentary formations. Generally, a bore well giving low or poor yield is treated, but the technique can also benefit other wells.

(c) Groundwater Conservation Structures

The water artificially recharged into an aquifer is immediately governed by natural groundwater flow regime. It is necessary to adopt groundwater conservation measures so that the recharged water remains available when needed.

Groundwater Dams / Underground Barriers: A groundwater dam is a sub-surface barrier across stream that retards the natural groundwater flow of the system and stores water below ground surface to meet the demands during the period of greatest need. The main purpose of groundwater dam is to arrest the flow of groundwater out of the sub-basin and increase the storage within the aquifer. The sub-surface barriers need not be only across the canal bed. In some micro watersheds, sub-surface dykes can be put to conserve the groundwater flow in larger area in a valley. Sites have to be located in areas where there is a great scarcity of water during the summer months or there is a need for additional water for irrigation. Technical possibilities of constructing the dyke and achieving large storage reservoirs with suitable recharge conditions and low seepage losses are the main criteria for sub-surface dyke. It directly benefits up-gradient area and hence care should be taken that a large number of users are not located immediately downstream.

Fracture-Sealing Cementation Technique: In many hard rock areas, the groundwater circulation to deeper levels is governed by shear, fault or fracture plane indicated by lineaments. The boreholes located on such zones prove productive but due to dissipation of the limited storage along preferred flow planes, in case of adverse topographical situation, these become dry by the end of winter or summer. Fracture-sealing cementation is a suitable water conservation measure in such situations. This measure can also be used to prevent ingress of saline or polluted water from a known source. The groundwater flow system at the site should be adequately known to establish the outflow direction and the preferred fracture planes along which the flow occurs under the influence of the natural hydraulic gradient.

Self check #1	**Knowledge questions**

Name: _________________________ Date: _______________

Directions: Answer the following questions in the space provided

1. Describe the two different groups of artificial recharge methods (***10 points***)
   i. ____
   ____
   ____
   ii. ____
   ____
   ____
2. Write the basic determinant factors in assessing the potential of water harvesting ***(5points)***

____
____
____
____
____
____
____

Note: satisfactory Rating-8 and above pts. ***Unsatisfactory Rating-below 8 pts***

You can ask your teacher for the copy of the correct answers

INFORMATION SHEET#2	Designing water harvesting structures

2.1. Delineating and characterizing catchment area

A catchment or watershed, defined as a land area from which all rainfall would drain by gravity into a common outlet point. In hydrology, the boundary of a catchment is called the hydrological divide. This is the place in a landscape where rainfall will be partitioned into different catchments depending on which side of the divide the rain falls. The size of a catchment is a dynamic phenomenon that is determined by the position of the outlet point. If the outlet point is moved further downstream, the catchment size increases. When this point is finally located at the entrance to the ocean or inland water body, the catchment above that point is regarded as a drainage basin. Catchments and drainage basins do not normally follow village, district, regional or country borders. A basin is normally divided into several catchments that are in turn divided into several sub-catchments (Figure 13).

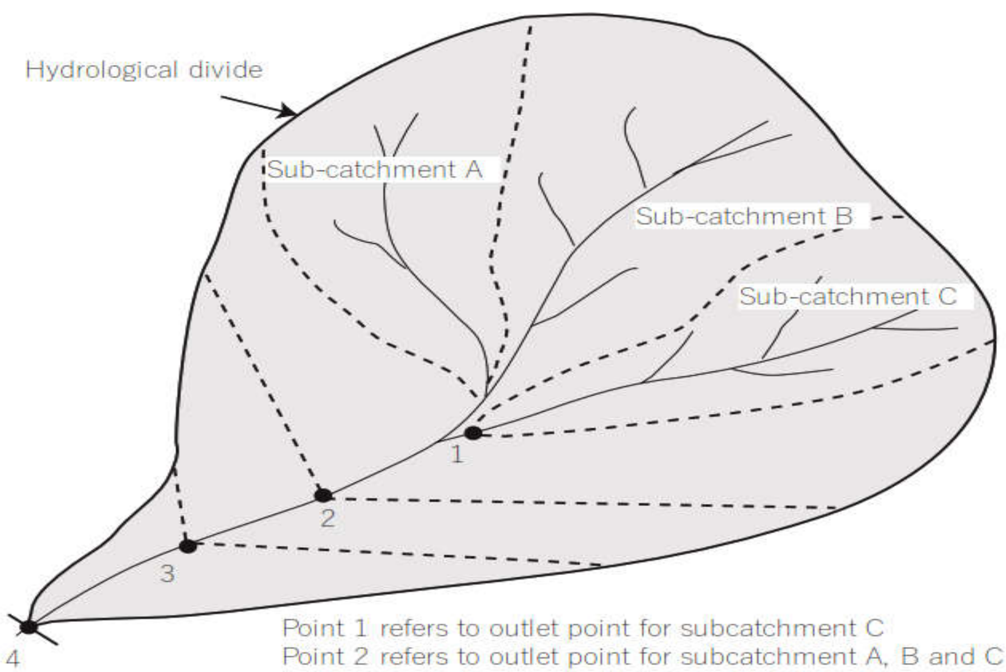


Figure 13. An example of a river basin showing associated catchments

Delineation of watersheds is of fundamental importance because the characteristics of the drainage basin control the paths and rates of movement of water to the outlet and the magnitude and timing of outputs via all modes: stream-flow, ground-water outflow, and evapotra nspiration. In most regions, at least a large proportion of the water passing through

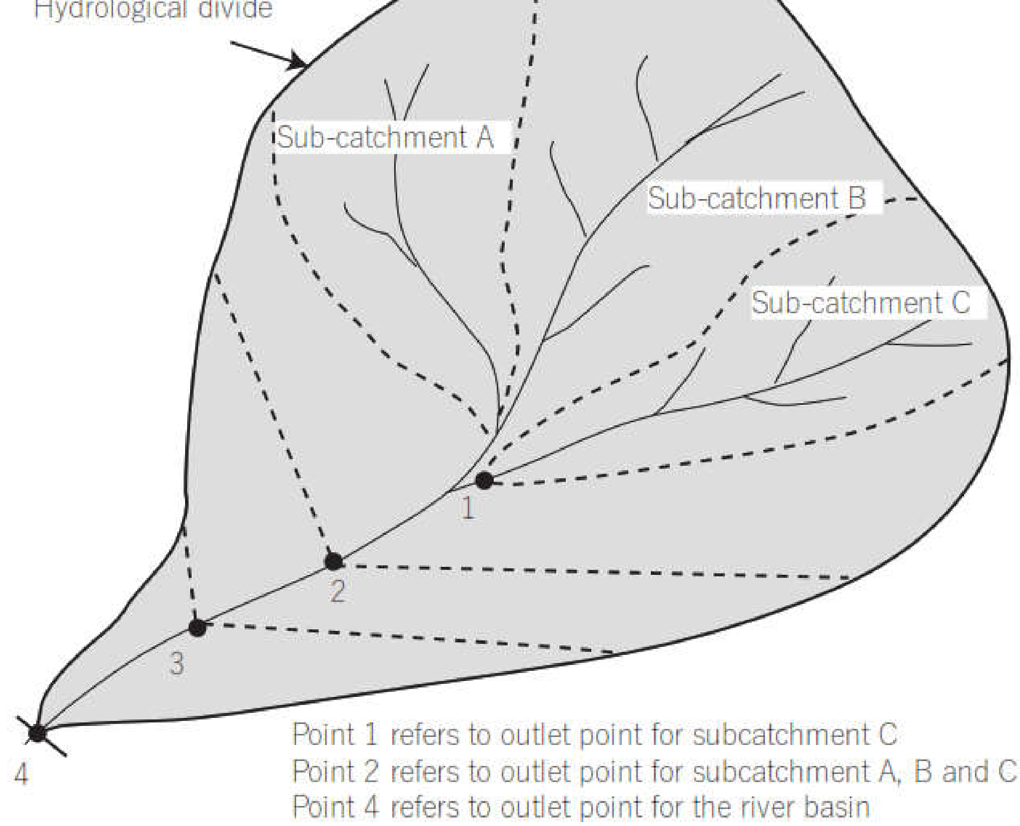


Figure 2.2 ***An example of a river basin showing associated catchments.***

Fig.14. Example of watershed delineation (manually).

The location of the stream cross section that defines the watershed is determined by the purpose of analysis. Hydrologists are most often interested in delineating watersheds above stream gauging stations or above points at which some water resource activity takes place in order to determine the region contributing stream flow.

Watershed Delineation

The conventional manual method of watershed delineation requires a topographic Map (or stereoscopically viewed aerial photographs). To trace the divide, start at the location of chosen stream cross-section. Then draw the line away from the left or right bank, maintaining it always at right angles to the contour lines. Continue the line until its trend is generally opposite to the direction in which it began and is generally above the headwaters of the stream network. Then return to starting point and trace the divide from the other bank, eventually connecting with the first line.

Frequently visual inspection of the contour pattern is required as the divide is traced out to ensure that an imaginary drop of water falling stream ward of the divide would, if the ground surface were imagined to be impermeable, flow down slope and eventually enter the stream network upstream of the starting point. A divide can never cross stream. The lowest point in a drainage basin is always the basin outlet-that is starting point for the delineation. The highest point is usually, but not necessarily, on the divide.

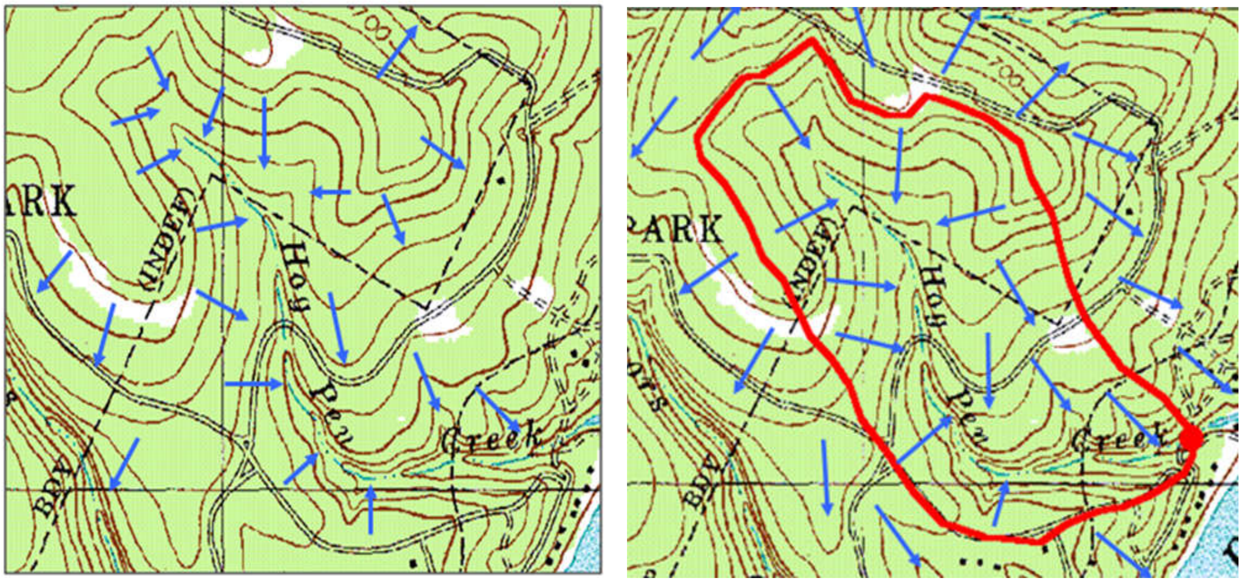


Fig.15. Example of manual watershed delineation.

The automated approach to watershed delineation allows the concomitant on watershed characteristics that could previously be obtained only by very tedious manual methods. The automated watershed delineation can be done with the aid of GIS and digital elevation model (DEM) & other GIS layer such as top map as an input.

Catchment/watershed characteristics

A catchment is characterized by its various features. Some of these features are explained below.

Watershed Geomorphology

Watershed geomorphology refers to the physical characteristics of the watershed. Certain physical properties of watersheds significantly affect the characteristics of runoff and as such are of great interest in hydrologic analyses.

The principal watershed characteristics are:

Area of the watershed: The area of watershed is also known as the drainage area and it is the most important watershed characteristic for hydrologic analysis. It reflects the volume of water that can be generated from a rainfall. Thus the drainage area is required as input to models ranging from simple linear prediction equations to complex computer models.

Length of watershed: Conceptually this is the distance traveled by the surface drainage and sometimes more appropriately labeled as hydrologic length. This length is usually used in computing a time parameter, which is a measure of the travel time of water through a watershed. The watershed length is therefore measured along the principal flow path from the watershed outlet to the basin boundary. Since the channel does not extend up to the basin boundary, it is necessary to extend a line from the end of the channel to the basin boundary. The measurement follows a path where the greatest volume of water would generally travel.

Slope of watershed: Watershed slope affects the momentum of runoff. Both watershed and channel slope may be of interest. Watershed slope reflects the rate of change of elevation with respect to distance along the principal flow path. It is usually calculated as the elevation difference between the endpoints of the main flow path divided by the length. The elevation difference may not necessarily be the maximum elevation difference within the watershed since the point of highest elevation may occur along a side boundary of the watershed rather than at the end of the principal flow path.

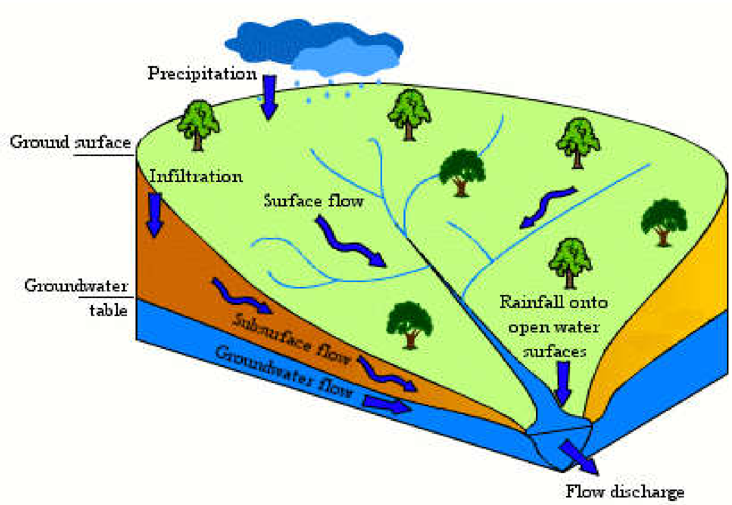


Fig. 16. Watershed boundary and flow components

ShapeofWatershed

Watersheds have an infinite variety of shapes, and the shape supposedly reflects the way that runoff will “bunch up” at the outlet. A circular watershed would result in runoff from various parts of the watershed reaching the outlet at the same time. An elliptical watershed having the outlet at one end of the major axis and having the same area as the circular watershed would cause the runoff to be spread out over time, thus producing a smaller flood peak than that of the circular watershed.

A number of watershed parameters have been developed to reflect basin shape. Following are few typical parameters:

1. **Length to the centroid of area (L_{ca}):**

   The distance measured along the main channel from the basin outlet to the point on the main channel opposite the center of area (centroid).

2. **Shape Factor (L_l)**

$$L_l = (LL_{ca})^{\alpha}$$

Where L is the length of the watershed ($\alpha = 0.3$ for length measurements in miles)

3. Circularity ratio (Fc):

$$F_c = P/(4\pi A)^{0.5}$$

Where P and A are the perimeter an area of the watershed, respectively

4. Circularity ratio (R_c):

$$R_c = A/A_o$$

Where A_0 is the area of a circle having a perimeter equal to the perimeter of the basin

5. Elongation Ratio (R_e):

$$R_e = 2/L_m(A/\pi)^{0.5}$$

Where, L_m is the maximum length of the basin parallel to the principal drainage lines.

Generally, the shape factor (L_l) is the best descriptor of peak discharge. It is negatively correlated with peak discharge (i.e. as the L_l decreases, peak discharge increases).

Landuse andsoilcharacteristics ofwat

Land use and soil characteristics affect both the volume and timing of runoff. During a rainstorm, flow from an impervious, steeply sloped, and smooth, surface make a little retardation and no loss to the flow. In comparison, flow along a pervious grassy hill of the same size will produce retardation and significant loss to the flow due to infiltration. Surface roughness, soil characteristics such as texture, soil structure, soil moisture and hydrologic soil groups also affect the runoff in various ways.

Slope: The channel slope is determined as the elevation difference between the endpoints of the main channel divided by the channel length. In addition, the term drainage density is often used. Drainage density is the ratio of the total length of streams within a watershed to the area of the watershed. Thus drainage density has the units of the reciprocal of length. A watershed with a high drainage density is characterized by quick response.

ChannelGeomorphology

In addition to the drainage area and the watershed length, the channel length is used frequently in hydrologic computation. The runoff produced by a watershed is also highly dependent on the channel characteristics. Two computational schemes are used to compute the channel length:

1. The distance measured along the main channel from the watershed outlet to the end of the channel as indicated on the figure below, which is denoted as L_c. This is different to watershed length, which extends to the boundary. However, there is some subjectivity in the estimation of channel length as it depends on the scale of the topographic map.
2. The distance measured along the main channel between two points located 10 and 85% of the distance along the channel from the outlet, which is denoted at $L_{10\text{-}85}$.

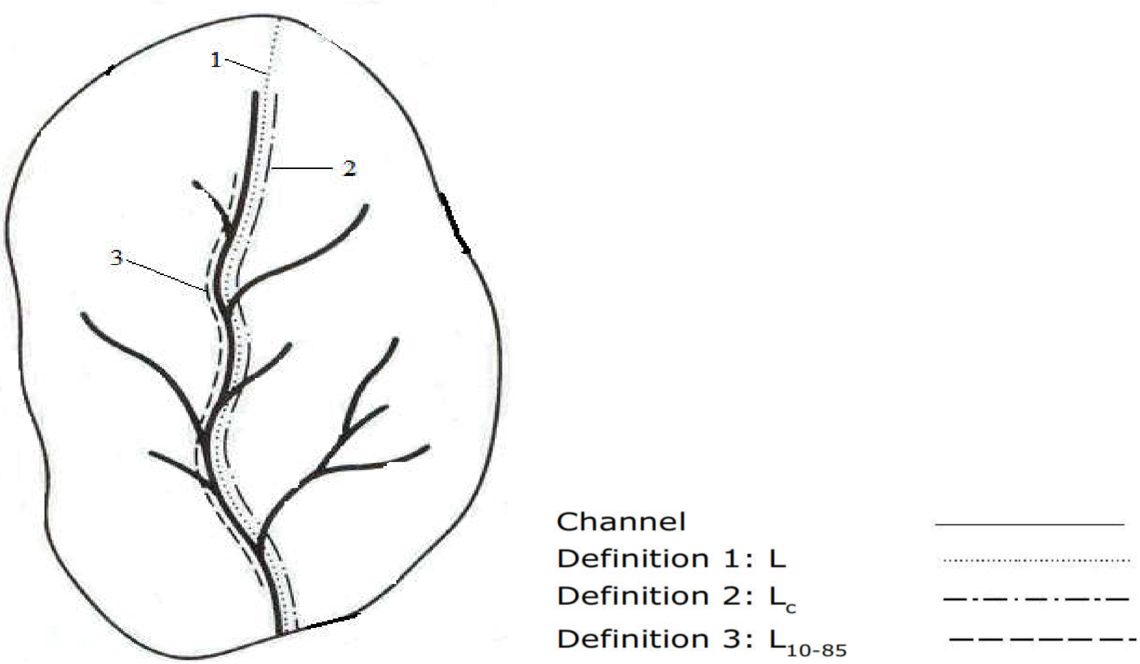


Fig.17. Channel length definition

The channel slope can be described one of the following computation schemes.

1. The most common is the difference of elevation between the points defining the upper and lower ends of the channel divided by the length of the channel between the same to points.
2. The 10-85 slope can also be used:

$$S_{10-85} = \frac{\Delta E_{10-85}}{L_{10-85}}$$

For cases where the channel slope is not uniform, a weighted slope may provide an index that better reflects the effect of slope on the hydrologic response of the watershed.

Drainage Density

The drainage density, D is the ratio of the total length of streams within a watershed to the total area of the watershed; thus D has units of the reciprocal of length (1/L). A high value of the drainage density would indicate a relatively high density of streams and thus a rapid storm response. A value typically ranges from 1.5 to 6 mi/mi^2

$$D = Lc/A$$

2.2. Identifying and characterizing seasonal water ways for flood water level

River as a watercourse concept of natural drainage network consisting of a main water course and its tributaries and of river basin as a geographically defined area that is drained by a drainage network are certainly quite insightful and have been understood for long time.

A. Stream corridors

The stream channel: contains flowing water for at least a portion of the year.

The floodplain: the floodplain, the land adjacent to stream channel, receives floodwaters and concomitant sediment when the stream channel overflows. The nature and size of floodplain vary both along river systems and between river systems. Depending on the surrounding topography, the floodplain may include land on one or both sides of the channel, and the area may vary considerably along a river.

The transitional upland fringe: the upland area on one or both sides of the floodplain that delineates the floodplain from the surrounding landscape.

Fig. 18: The Major Cross-Sectional Components of the Stream Corridor

B. Stream Channel

Flowing water and the sediment it carries form, maintain and modify the stream channel. Although the form of a stream channels can vary greatly, from meandering gentle streams to fast flowing rivers, it tends to take on a rounded u-shape. When scientists study a stream cross-section, they invariably examine two key attributes of the *stream flow system* -and *channel size*. Stream flow is the volume and velocity of water entering the channel.

Precipitation takes after falling to the earth affect the *quantity, quality and timing of the stream flow*. The two basic flow pathways are *storm flow* and *base flow*. *Storm flow* is precipitation that reaches the channel very soon after precipitation via overland or underground routes. *Base flow* is precipitation that percolates to the ground water and moves slowly through the substrate before reaching the channel. *Base flow* provides stream flow during periods of little or no precipitation. The measure of stream flow used by those studying *river systems* is known as *the discharge rate*. Discharge rates depend both on the average velocity at which the water is moving downstream and the size of the channel through which the water is flowing.

Channel size is determined by stream flow and sediment load. Sediment load refers both to the amount of sediment the stream is transporting and depositing and to its characteristics. A stream balance equation formally describes the dynamic relationship between channel size and sediment load and stream flow. This equation states that the channel is in equilibrium when the sediment load is balanced with stream flow.

Stream managers categorize streams based on the balance and timing of the storm flow and base flow components. **There are three main categories:**

- **Ephemeral streams** flow only during or immediately after periods of precipitation. They generally flow less than 30 days per year.
- **Intermittent streams** flow only during certain times of the year. Seasonal flow in an intermittent stream usually lasts longer than 30 days per year.
- **Perennial streams** flow continuously during both wet and dry times. Base flow is dependably generated from the movement of ground water into the channel.

Discharge Regime: Discharge is the term used to describe the volume of water moving down the channel per unit time.

Discharge is calculated as: $Q=AV$, where Q = Discharge

A = Area through which the water is flowing and V = Average velocity in the downstream direction Stream flow is one of the variables that determine the size and shape of the channel.

There are three types of characteristic discharge.

1. *Channel-forming (or dominant) discharge.* To envision the concept of channel-forming discharge, imagine placing a water hose discharging at constant rate in a freshly tilled garden. Eventually, a small channel will form and reach equilibrium geometry. At a larger scale, consider a newly constructed floodwater-retarding reservoir that slowly releases stored floodwater at a constant flow rate. This flow becomes the new channel forming discharge and will alter channel morphology until the channel reaches equilibrium. An estimate of channel forming discharge for a particular stream reach can, with some qualifications, be related to depth, width, and shape of channel.

2. *Effective discharge.* The effective discharge is the calculated measure of channel forming discharge. Computation of effective discharge requires long-term water and sediment measurements, either for the stream in question or for one very similar. Since this type of data is often not available for stream restoration sites, modeled or computed data are sometimes substituted. Effective discharge can be computed for either stable or evolving channels.

3. *Bankfull discharge.* This discharge occurs when water just begins to leave the channel and spread onto the floodplain. Bankfull discharge is equivalent to channel-forming (conceptual) and effective (calculated) discharge for alluvial streams at equilibrium.

C. Structural Changes in the Stream Corridor

The physical structure of the channel and floodplain changes as a river travels from its headwaters to its outlet. Channel width and depth increase downstream as the drainage area and discharge increase. A simplified longitudinal model captures these observed changes by disaggregating the river into three zones (Fig. 19):

- ***Headwaters zone***: generally has the steepest slope. As the water moves over these slopes, sediment erodes and is carried downstream.
- ***Transfer zone*****:** receives sediment from upstream, the gradient decreases. The river widens as smaller streams merge and
- ***Depositional zone****:* the gradient flattens from a build-up of sediment over time. The river widens further and meanders toward its mouth.

These same three zones are also evident on a much smaller scale within the watersheds of contributing streams. The size and structure of watersheds vary significantly due to geologic, morphologic, vegetative, soil and climatic differences. Differences in topographic and geologic structure also influence watershed drainage patterns.

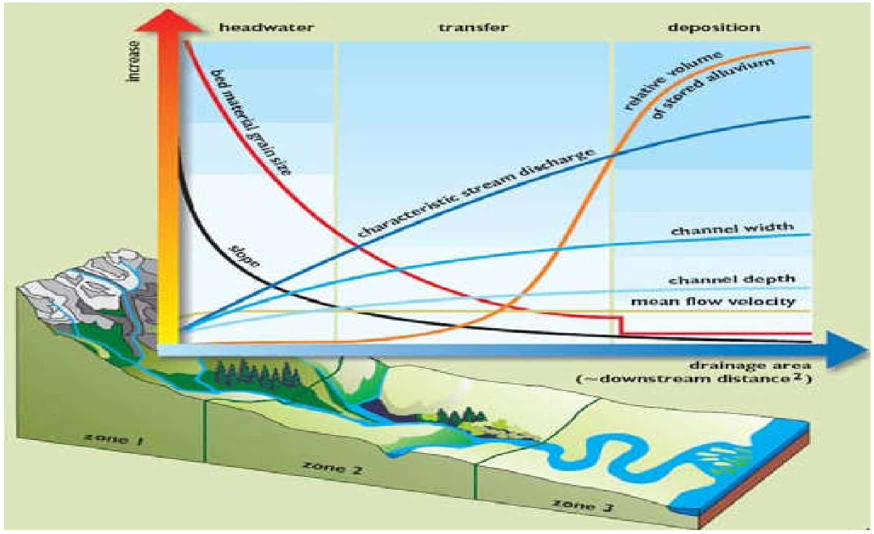


Fig. 19: Typical changes in the stream channel characteristics along its length.

D. Stream Order Models

As water moves along pathways of least resistance in the watershed, it forms streams that join larger and yet larger streams. The resulting river is branched like a tree; the particular form of the branching depends on the watershed through which the water flows. A method of classifying the hierarchy of natural channels according to their position in the drainage system, referred to as *stream order, permits comparison of the behaviour of a river with others similarly situated*. In the most commonly cited and used system (Strahler, 1957), small headwater streams are designated *Order I*. Streams formed by the confluence of two Order I streams are referred to as *Order II*, and so on, with larger numbers indicating larger rivers with multiple tributary streams (Fig.27). *Stream order* correlates generally with *gradient, drainage area, channel width, and discharge*; but because of multiple intervening factors, the *statistical variance* of the correlations is large.

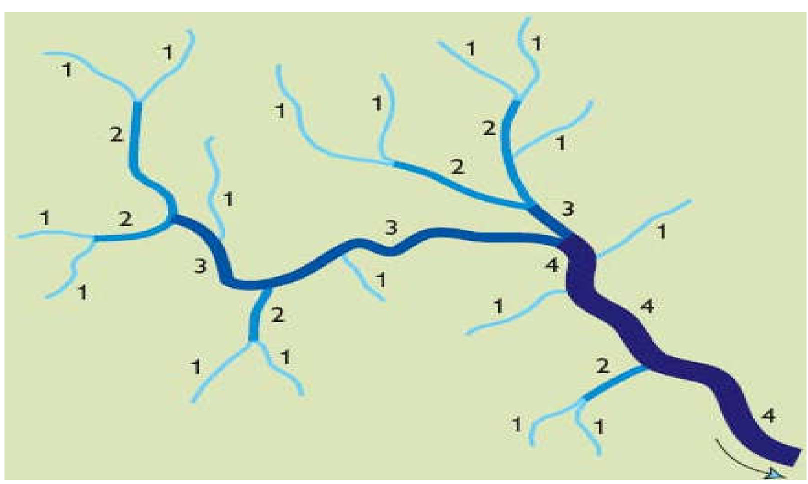


Fig. 20: Stream ordering in a drainage network

Analysis of hydrological data for irrigation

The feasibility of using rivers for irrigation can be determined by a statistical analysis of long- term river flows. For most major rivers, these data are available from the departments or organizations responsible for hydrological data. For most small rivers, flow measurements are not easily available. It is thus difficult to determine the water flow during the growing seasons. Nevertheless, a clear indication is needed, especially during the latter part of the dry season when minimum river flow normally coincides with maximum evapotranspiration. There are ways of obtaining some idea about the flow regime, such as by talking to local (preferably elder) people, visiting the area during the dry season, analyzing satellite imagery data (remote sensing) and by carrying out flow measurements with current meters or isotope and salt dilution methods. Whether data are available or not, one has to come up with a safe water yield, which in turn determines the possible irrigation area.

Once this is known, one should apply for an appropriate water right or water abstraction permit from the relevant authority in the country. It is equally important to have knowledge of high floods in order to properly design diversion structures and flood protection works near the river. Again, it is useful to talk to the local people, who can often indicate flood marks, for example on trees. Many rivers carry large amounts of sediments especially during the rainy season. This has to be verified and, if so, the designs of the headwork have to cater for sediment flushing arrangements to avoid it entering the canal system. The stability of especially meandering rivers has to be considered in order to avoid placing headwork in unstable parts of the river.

2.3. Identifying proper site for water harvesting

Proper site is a suitable location which can deliver the required quantity and quality of water to harvest the desired amount of water in the water harvesting structure to satisfy the water requirement of crops.

Parameters for Identification of Suitable Rain and Floodwater Harvesting Areas

The most important parameters to be considered in identifying areas suitable for rain and floodwater harvesting are as follows:

a) **Rainfall**: The knowledge of rainfall characteristics (intensity and distribution) for a given area is one of the pre-requisites for designing a water harvesting system. The availability of rainfall data series in space and time and rainfall distributions is important for rainfall-runoff process and also for determination of available soil moisture. A threshold rainfall events is used in many rainfall- e.g. of 5 mm/event runoff models as a start value for runoff to occur. The intensity of rainfall is a good indicator of which rainfall is likely to produce runoff.

Useful rainfall factors for the design of a rain or floodwater harvesting system include: (1) Number of days in which the rain exceeds the threshold rainfall of the catchment, on a weekly or monthly basis. (2) Probability and occurrence (in years) for the mean monthly rainfall. (3) Probability and reoccurrence for the minimum and maximum monthly rainfall. (4) Frequency distribution of storms of different specific intensities.

b) Land use or vegetation cover: Vegetation is another important parameter that affects the surface runoff. It is known that from an increase in the vegetation density results in a corresponding increase in interception losses, retention and infiltration rates which consequently decrease the volume of runoff. Vegetation density can be characterized by the size of the area covered under vegetation. There is a high degree of congruence between density of vegetation and suitability of the soil to be used for cropping.

c) Topography and terrain profile: The land forms along with slope gradient and relief intensity are other parameters to determine the type of water harvesting. The terrain analysis can be used for determination of the length of slope, a parameter regarded of very high importance for the suitability of an area for macro-catchment water harvesting. With a given inclination, the runoff volume increases with the length of slope. The slope length can be used to determine the suitability for macro- or micro- or mixed water harvesting systems decision making.

d) Soil type & soil depth: The suitability of a certain area either as catchment or as cropping area in water harvesting depend strongly on its soils characteristics viz. (1) surface structure; which influence the rainfall-runoff process, (2) the infiltration and percolation rate; which determine water movement into the soil and within the soil matrix, and (3) the soil depth incl. soil texture; which determines the quantity of water which can be stored in the soil.

e) Hydrology and water resources: The hydrological processes relevant to water harvesting practices are those involved in the production, flow and storage of runoff from rainfall within a particular project area. The rain falling on a particular catchment area can be effective (as direct runoff) or ineffective (as evaporation, deep percolation). The quantity of rainfall which produces runoff is a good indicator of the suitability of the area for water harvesting.

f) Socio-economic and infrastructure conditions: The socio-economic conditions of a region being considered for any water harvesting scheme are very important for planning, designing and implementation. The chances for success are much greater if resource users and community groups are involved from early planning stage onwards. The farming systems of the community, the financial capabilities of the average farmer, the cultural behavior together with religious belief of the people, attitude of farmers towards the introduction of new farming methods, the farmers knowledge about irrigated agriculture, land tenure and property rights and the role of women and minorities in the communities are crucial issues.

g) Environmental and ecological impacts: Dry area ecosystems are generally fragile and have a limited capacity to adjust to change. If the use of natural resources (land and water), is suddenly changed by water harvesting, the environmental consequences are often far greater than foreseen. Consideration should be given to the possible effect on natural wetlands as on other water users, both in terms of water quality and quantity. New water harvesting systems may intercept runoff at the upstream part of the catchment, thus depriving potential downstream users of their share of the resources. Water harvesting technology should be seen as one component of a regional water management improvement project. Components of such integrated plans should be the improvement of agronomic practices, including the use of good plant material, plant protection measures and soil fertility management (Oweis et al. 1999).

The site which is used for water harvesting must be satisfying the following points. These are:

- The area must collect sufficient runoff water.
- The runoff water collected from the area should be easily diverted to the storage tank.
- The area should be located sufficiently away from pollution sources.
- The area must generate as little sediment as possible.
- For the construction of water harvesting tank availability of suitable materials is crucial.
- The site should not be exposed to land erosion, near gullies or not on tops of swampy ground
- Storage tank must be set on good foundation or soil for the constructions of foundation firm soil need less depth and sandy or loose soil requires deep foundation.

2.4. Choosing appropriate water harvesting technique

Application areas

Rainwater harvesting systems can be installed in both new and existing buildings/landscape and harvested rainwater used for different applications that do not require drinking water quality such as toilet flushing, garden watering, irrigation, cleaning and laundry washing. Harvested rainwater is also used in many parts of the world as a drinking water source. As rainwater is very soft there is also less consumption of washing and cleaning powder. With rainwater harvesting, the savings in potable water could amount up to 50% of the total household consumption.

Criteria for selection of rainwater harvesting technologies

Several factors should be considered when selecting rainwater harvesting systems for domestic use:

- type and size of catchment area

- local rainfall data and weather patterns
- family size
- length of the drought period
- alternative water sources
- cost of the rainwater harvesting system.

To choose roof water harvesting technique

- Availability of roof catchment
- Availability of skilled technician
- Availability of command area close to the building
- Availability of finance
- Applicability and adaptability of the technology
- Climatic condition of the area
- Type of crop to be grown

To choose flood water harvesting technique

- Availability of appropriate catchment based on soil, slope, land cover, size, etc
- Availability of trained manpower who can design, construct and maintain different types of water harvesting techniques
- Availability of command area
- Applicability and adaptability of the technology
- Climatic condition of the area
- Type of crop to be grown

When rainwater harvesting is mainly considered for irrigation, several factors should be taken into consideration. These include:

- rainfall amounts, intensities, and evapotranspiration rates,
- soil infiltration rate, water holding capacity, fertility and depth of soil
- crop characteristics such as water requirement and length of growing period
- hydrogeology of the site
- socio-economic factors such as population density, labor, costs of materials and
- Regulations governing water resources use.

2.5. Selecting design principles for the chosen water harvesting techniques

Designing a rainwater harvesting system

The main consideration in designing a rainwater harvesting system is to size the volume of the storage tank correctly. The tank should give adequate storage capacity at minimum construction costs.

Five steps to be followed in designing a RWH system:

Step 1 Determine the total amount of required and available rainwater
Step 2 Design your catchment area
Step 3 Design your delivery system
Step 4 Determine the necessary size of your storage reservoir
Step 5 Select suitable design of storage reservoir
These steps are described below.

Step 1: Total amount of required and available rainwater

Estimating domestic water demand

The first step in designing a rainwater harvesting system is to consider the annual household water demand. To estimate water demand the following equation can be used:

Demand = Water Use × Household Members × Length of dry period

Calculating potential rainwater supply by estimating run-off

The amount of available rainwater depends on the amount of rainfall, the area of the catchment, and its run-off coefficient. For a roof or sloping catchment it is the horizontal plan area which should be measured (figure 28).

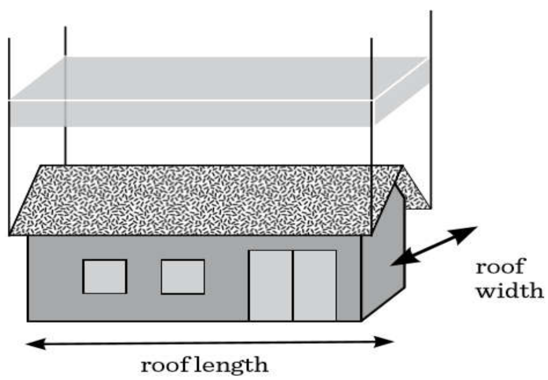


Figure 21: Horizontal plan area of the roof for calculating the catchment surface

The run-off coefficient (RC) takes into account any losses due to evaporation, leakage, overflow and transportation. For a well- constructed roof catchment system it is 0.9. An impermeable roof will yield a high run-off. An estimate of the approximate, mean annual run-off from a given catchment can be obtained using the following equation:

$S = R \times A \times C_r$
Supply = Rainfall × Area × Run-off coefficient (RC)

Where:
S = Mean annual rainwater supply (m^3)

R = Mean annual rainfall (m)
A = Catchment area (m^2)
C_r = Run-off coefficient

In the next example the mean annual rainfall is 500 mm/year (= 0.5 m/year) and the catchment area 3 m × 4 m = 12 m^2: S = 0.5 m/year × 12 m^2 × 0.9 = 5.4 m^3 / year = 15 liters/ day

Step 2: Designing your catchment area

Roofs provide an ideal catchment surface for harvesting rainwater, provided they are clean. The roof surface may consist of many different materials. Galvanized corrugated iron sheets, corrugated plastic and tiles all make good roof catchment surfaces. Flat cement roofs can also be used. Traditional roofing materials such as grass or palm thatch may also be used.

The roof size of a house or building determines the catchment area and run-off of rainwater. The collection of water is usually represented by a run-off coefficient (RC). The run-off coefficient for any catchment is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface.

Table 2: Run-off coefficients for traditional roofing materials and other various catchments

Type	Run-off coefficient
Galvanized iron sheets	>0.9
Tiles (glazed)	0.6-0.9
Aluminium sheets	0.8-0.9
Flat cement roof	0.6-0.7
Organic (e.g. thatched)	0.2
Rock/stone floor	0.7-0.8
Agricultural field	0.15-0.3
Soil compacted	0.4-0.55
Grass covering (sparse)	0.08-0.15
Grass covering (dense)	0.06-0.15

Since roofs are designed to shed water, they have a high run-off coefficient and thus allow for quick run-off of rainwater. The roof material does not only determine the run-off coefficient, it also influences the water quality of the harvested rainwater. Painted roofs can be used for rainwater collection but it is important that the paint be non-toxic and not cause water pollution.

Step 3: Designing your delivery system

The collected water from a roof needs to be transported to the storage reservoir or tank through a system of gutters and pipes, the so-called delivery system or guttering. Several other types of delivery systems exist but gutters are by far the most common. Commonly used materials for gutters and downpipes are galvanized metal and plastic (PVC) pipes, which are readily available in local shops. There is a wide variety of guttering available from prefabricated plastics to simple gutters made on-site from sheet metal.

Gutters are readily available in different shapes (Figure 22); they can be rounded, square, V-shaped, and have open or closed ends with attached downpipe connectors. They can be made in small workshops in sections that are later joined together or they can even be made on-site by plumbers.

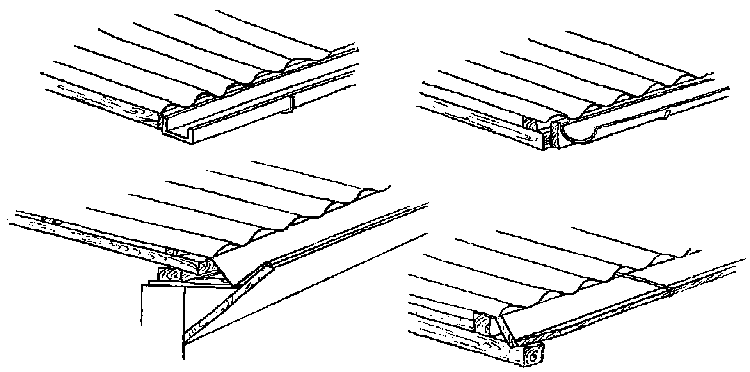


Figure 22: Different types of gutters: square, rounded, V-shaped

Gutters must be properly sized and correctly connected around the whole roof area. When high intensity rainfall occurs, gutters need to be fitted with so-called splash guards to prevent overshooting water losses.

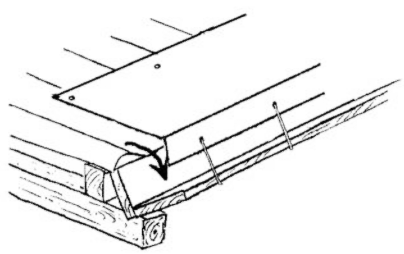


Figure 23: Splash guards

During intensive rainfall, large quantities of run-off can be lost due to gutter overflow and spillage if gutters are too small. To avoid over- flow during heavy rains, it makes sense to create a greater gutter capacity. A useful rule of thumb is to make sure that there is at least 1 cm^2 of gutter cross-section for every 1 m^2 of roof surface.

The following tables give some examples of guttering systems. The guttering requirement for a typical household roof of 60 m^2 is shown in table 1. Typical gutter widths for such roofs are presented in table 2.

Table 1: Examples for guttering systems

Section	Roof size	Slope	Cross sectional area	Gutter sizes
Square	40-100 m^2	0.3-0.5%	70 cm^2	7 × 10 cm
Rounded	40-60 m^2	0.3-0.5%	63 cm^2	125 mm bore **[?]**
45° V-shaped	Not specified	1.0%	113 cm^2	15 cm on each side

Table 2: Gutter sizes quoted in literature

	Square 0.5% slope	**Square 1.0% slope**	**Rounded 1.0% slope**	**45° V-shape 1.0% slope**
Gutter width (at top)	71 mm	63 mm	96 mm	124 mm
Cross sectional area	47 cm^2	39 cm^2	36 cm^2	38 cm^2

Step 4: Sizing your storage reservoir

There are several methods for sizing storage reservoirs. These methods vary in complexity and sophistication.

1 Demand side approach (dry season demand versus supply)

2 Supply side approach (graphical methods)

The first method is the simplest method and most widely used. The second method uses statistical indicators of the average rainfall for a given place.

Method 1: Demand side approach (dry season demand versus supply)

This is the simplest method to calculate the storage requirement based on the required water volume (consumption rates) and occupancy of the building. This approach is only relevant in areas with a distinct dry season. The tank is designed to meet the necessary water demand throughout the dry season. To obtain required storage volume the following equations can be used:

Demand = Water Use × Household Members × Length of dry period

Required storage capacity = demand × dry period

As an example we can use the following typical data. Assuming that:
Water use (consumption per capita per day) = 20 liters
Number of people in the household = 5
Dry period (longest average dry period) = 4 months (120 days)

Minimum storage capacity = T
Then: the water demand = 20 l × 5 persons × 365 days/year = 36,500 liters/year or about 3,000 l/month. For a dry period of four months, the required minimum storage capacity (T) is thus 12,000 liters (T = 4 ×3,000); this calculation is however a rough estimate.

Method 2: Supply side approach (graphical methods)

Another method to estimate the most appropriate storage tank capacity for maximizing supply is to represent roof run-off and daily consumption graphically. This method will give a reasonable estimation of the storage requirements. Daily or weekly rainfall data is required for a more accurate assessment.

This method will give an estimation of the storage requirements. There are three basic steps to be followed:

1 Plot a bar graph for mean monthly roof run-off for a specific house or building in a specific location. Add a line for the demand per month.
2 Plot a cumulative roof run-off graph, by summing the monthly run- off totals.
3 Add a dotted line showing cumulative water use (water withdrawn or water demand).

Step 5: Selection of a suitable storage reservoir design

Suitable design of storage reservoirs depends on local conditions, available materials and budget, etc. In the following sections, the materials, construction and costs of storage reservoirs are described in detail. This information is needed to select the most suitable design and realize the construction of the RWH system.
A per capita water consumption of (x) liters per day for the domestic drinking and cooking purposes is found optimum. Adding 20% towards additional water requirement for visitors, festivals and wastage, a per capita water requirement of 1.2(x) liters per day shall be considered for selecting the size of water storage tank (UNICEF-AFPRO, 1997).

2.6. Preparing design drawings for different structures & lay outs

Working Drawings
Three different types of drawings are needed to show the builder exactly how the building should look, on the inside and the outside. These include the elevations and sections, as well as the plans. Here we describe the different types of plans which have to be made: the foundation plan, floor plan, and roof plan.

FOUNDATION PLAN: A foundation plan, along with its sections, shows the builder how deep the foundations should be laid and gives all the dimensions for the foundation and the footings. Sometimes the corners of the rising walls are indicated on the footings.

FLOOR PLAN: This plan should show the builder the size of the building and the verandahs, the thickness of the walls, and where to place the doors and windows. It also shows which way the doors are meant to open.

ROOF PLAN: Roof plans are made to show the builder what shape the roof should be and how it is to be built. The roof plan should contain such information as the angle of the roof, the shape, and the materials to be used.

The drawing here illustrates the types of plans and what it is they show to the builder.

Elevations and cross sections are of course essential parts of the working drawings. These are examined in detail after some further examples of plans in the next pages.

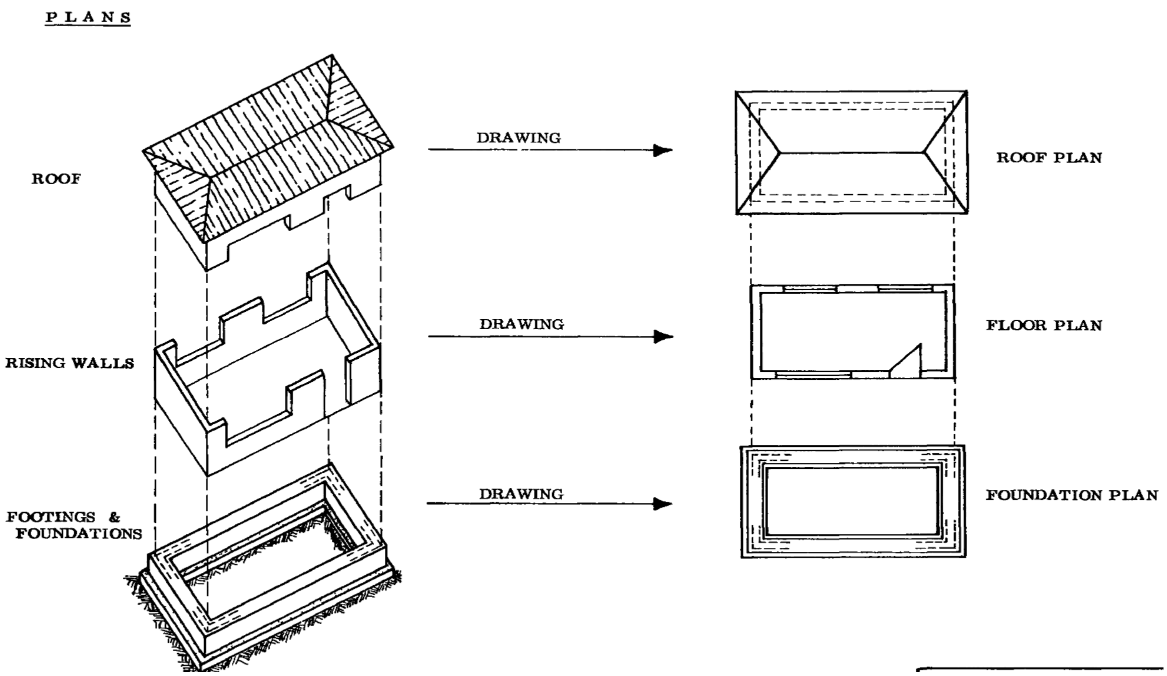


Figure 24: plan

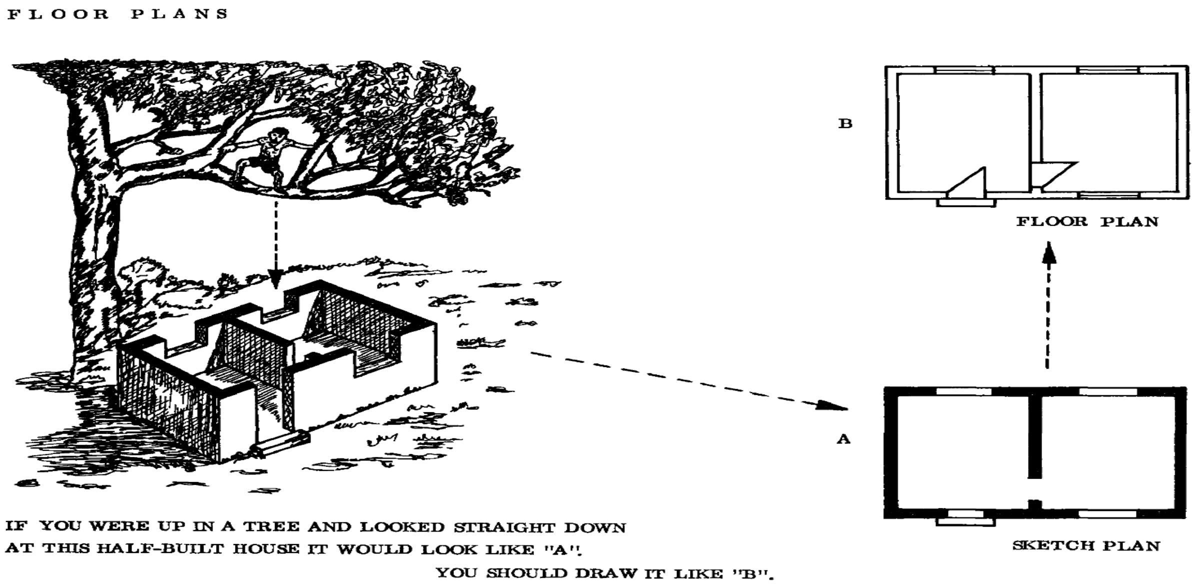


Figure 25: floor plan

Elevations

A special type of drawing is used to show what a building will look like from the outside. These drawings are called "elevations" and they show what you would see if you looked straight on at the side of the house. Of course a house has more than one side, and so there are always a number of elevations. There are as many elevations as there are sides of the house. Houses usually have four sides and so there are usually four elevations.

It is not always necessary to draw all the possible elevations of a building, especially if some of the sides look very similar to each other.

The drawing here shows the front elevation of a small house. You should notice that the sides of the house are not drawn. This is because if you stand directly in front of the house you cannot see the sides. The front elevation shows the sizes and positions of the doors and windows as well as the height and length of the house itself.

The building shown on the next page faces south. The front elevation is therefore called the "south elevation". The other three elevations are the east elevation, the north elevation, and the west elevation.

In general only main features are shown on the elevations. Small details of the doors, windows, etc. are given in the detail drawings.

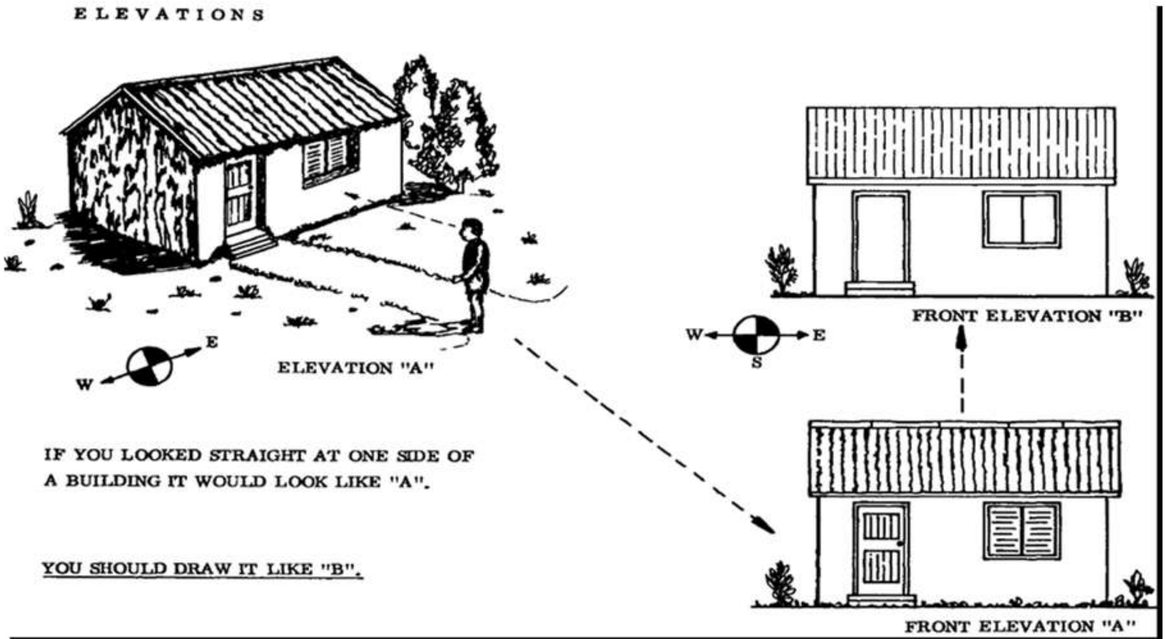


Figure 26: elevation

Sections

Suppose you were able to cut right through a building and then take away one part. What you would see would look something like the diagram on the next page (1). If you now look at the building straight on, you will see a "cross section" of the building (2). The cross section shows the insides of the roof and the room as well as the footings and foundations.

Sections are useful because they give a lot of information about the building which is not found in the elevations and the plans. For example, on a section you can see the height of a room inside the building, the thickness of the ceiling, and the floor and roof construction. You can also see the thickness and width of the foundation, which is not given in the plans and elevations.

Choosing Sections: You will usually find it necessary to take at least two sections through the building. You can take any section through any part of the building, but of course the best sections are the ones which are the hardest to draw! When you take a section through a building, you have to mark on the plan exactly where you have "cut" and the direction from which you look at the section.

On the right page you can see the conventional way of doing this. The place where the building is cut is marked by a broken line which has arrows at its ends to show which way the section faces. All sections should be marked on the plan, and you should label each end of the line with a letter. On the plan here, the section has the letter "A" at each end. When this cross section is drawn, it is labelled as "cross section A-A". The next section would be "cross section B—B" etc.

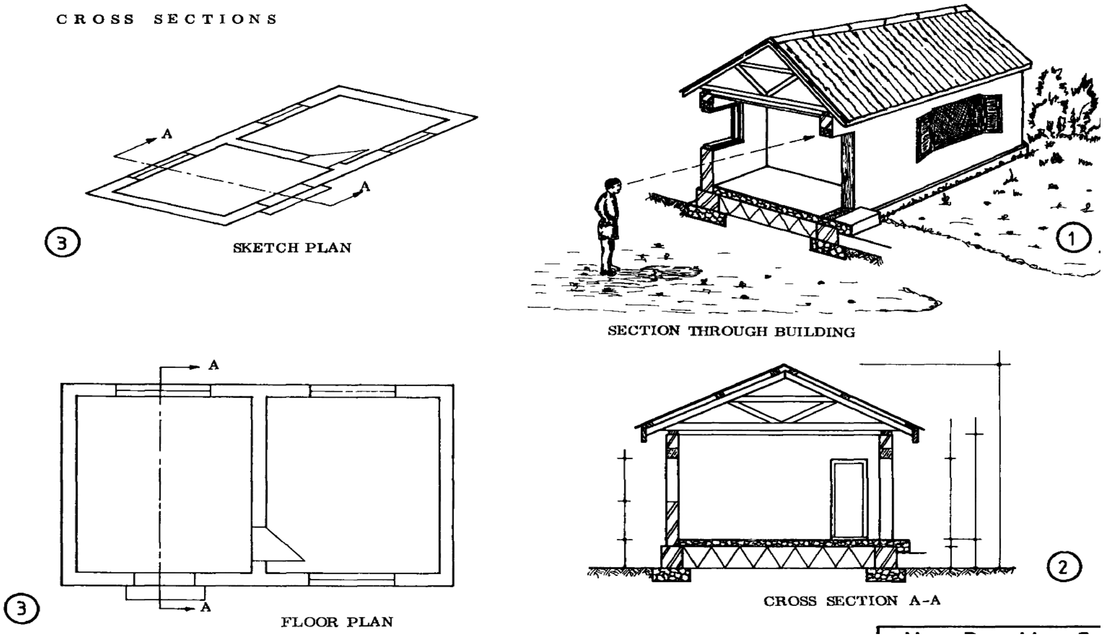


Figure 27: cross section

Plan and cross sectional views WH storage structures

Carrying out layout of different water harvesting structures

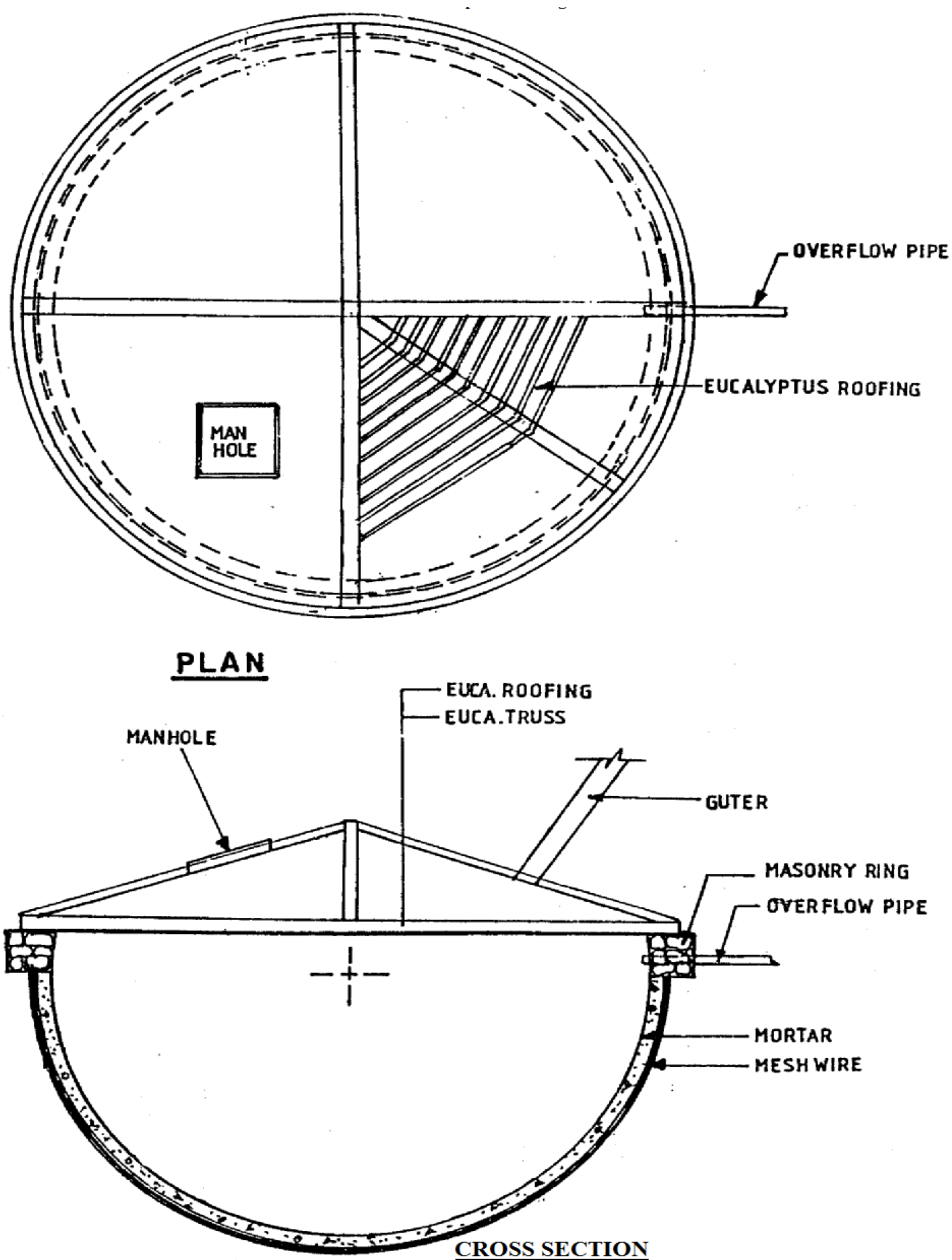


Figure 35: Plan and Cross Sectional View of Hemispherical Storage Tank

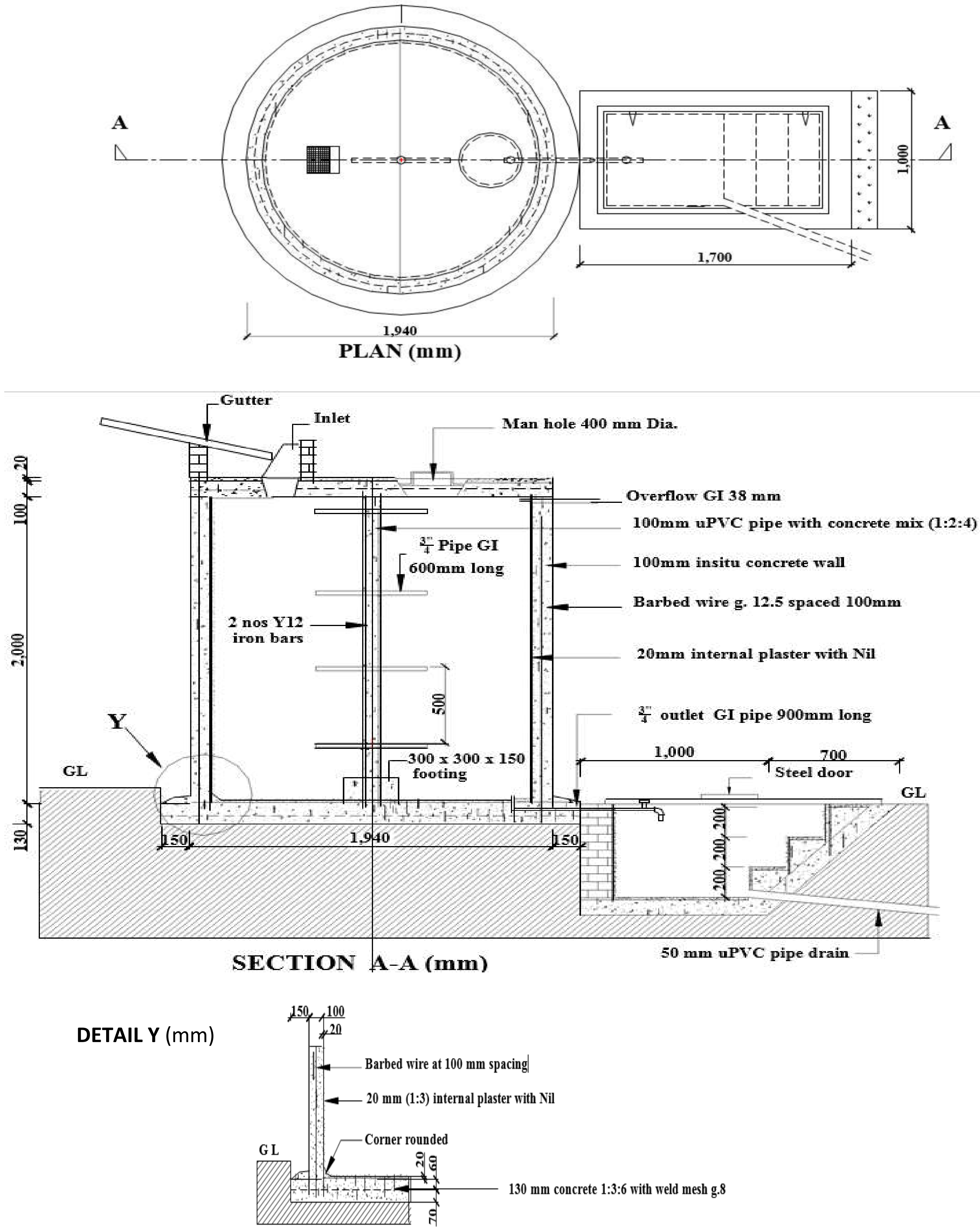


Figure 36: Standard design for a 5 m^3 tank built of concrete in situ

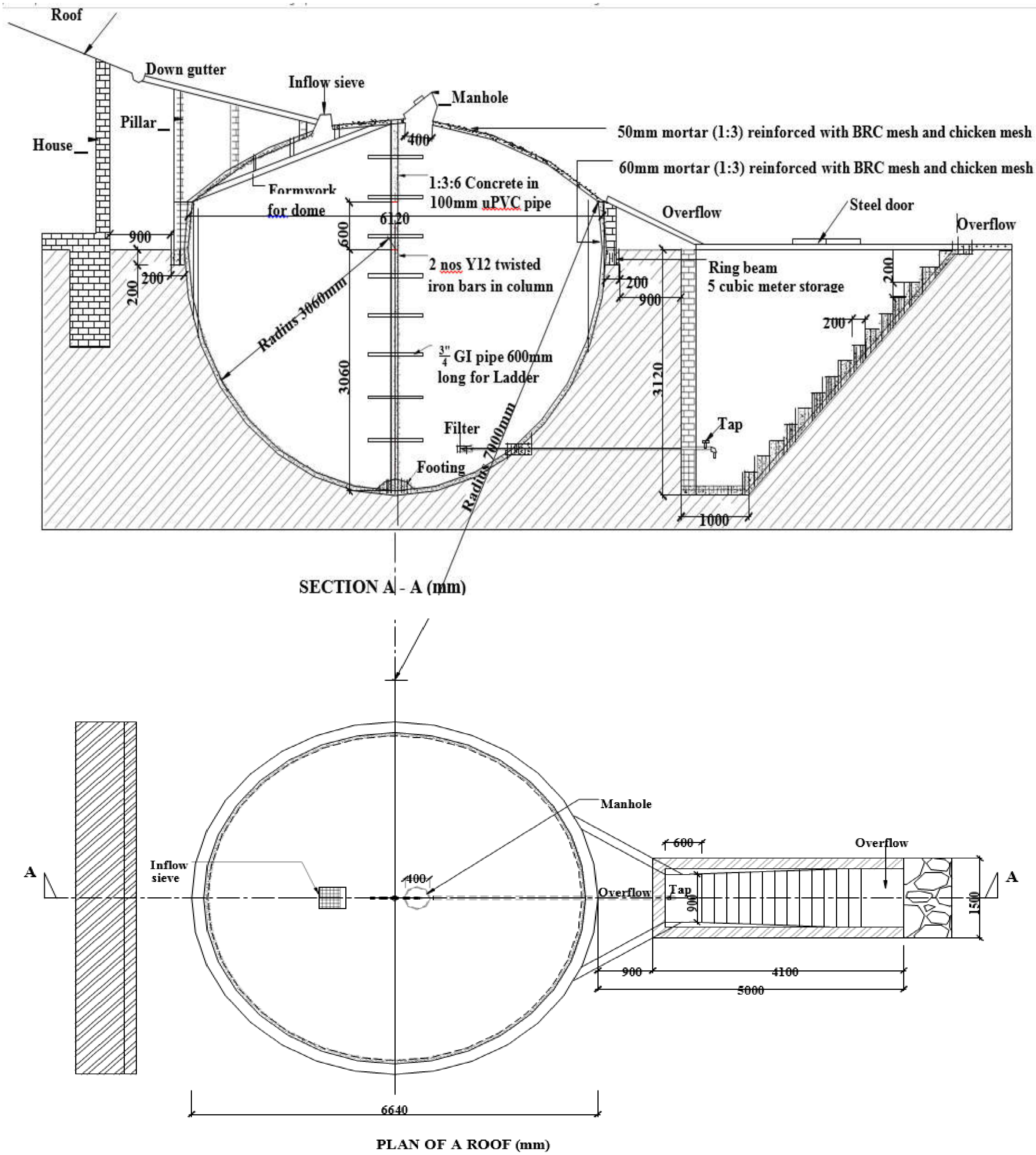


Figure 28: Standard design of a 90 m^3 hemispherical storage tank

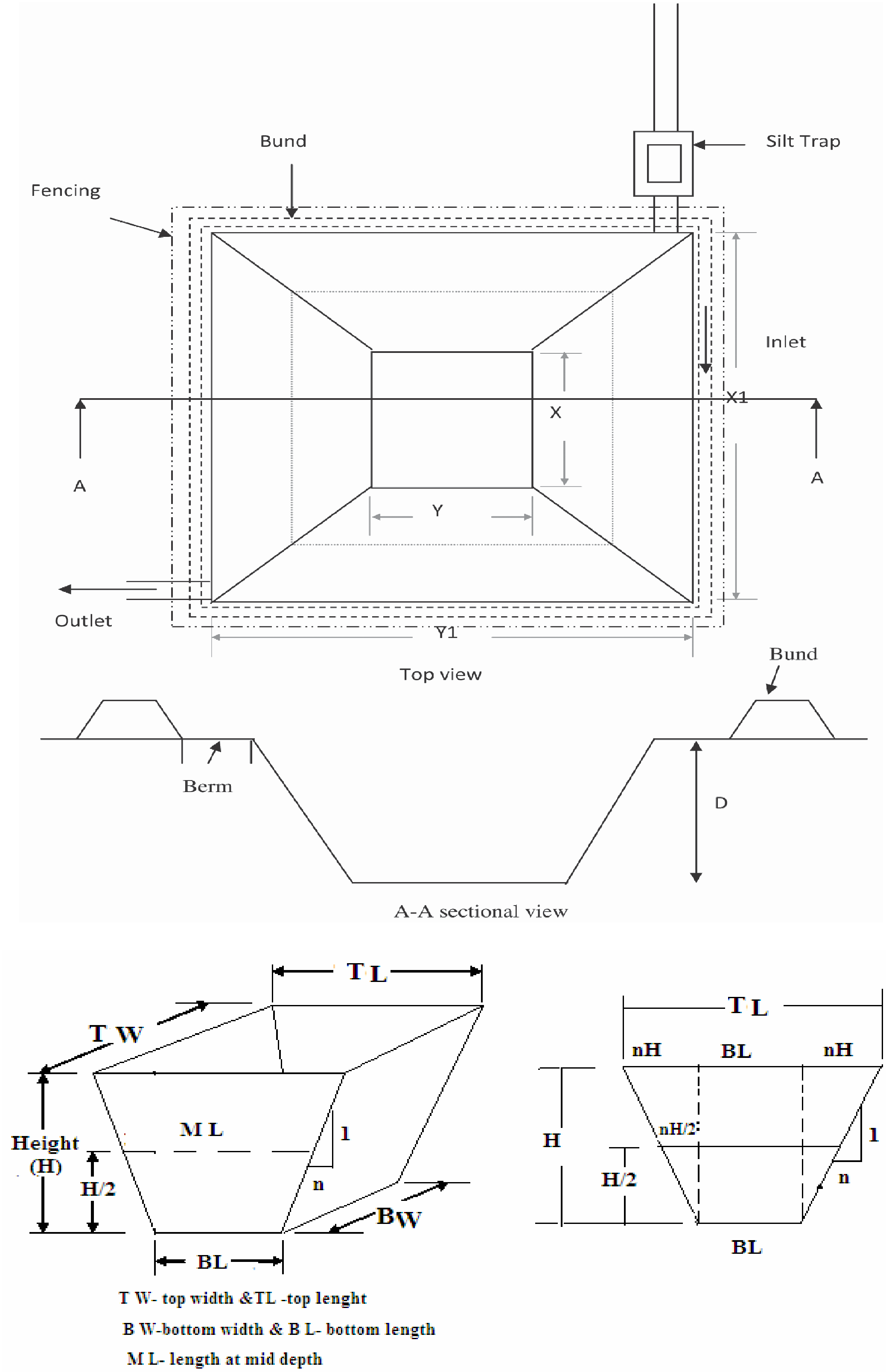


Figure 29: Layout of the dugout farm pond

2.7. Designing silt trap

Sediment pond is used to settle sediment or silt carried in the runoff. It should be located 3m away from the storage facility.
The size of sediment pond should be determined accurately, to the silt characteristics, flow discharges and size of the catchment. Most widely used silt trap is rectangular in shape.

For simple storage up to $60m^3$ capacity the following dimensions are used.

- Max depth 100 cm
- Max length 250 cm
- Max width 100 cm
- Partition is made at a length of 150 cm from the inlet.

It should be constructed with locally available materials.

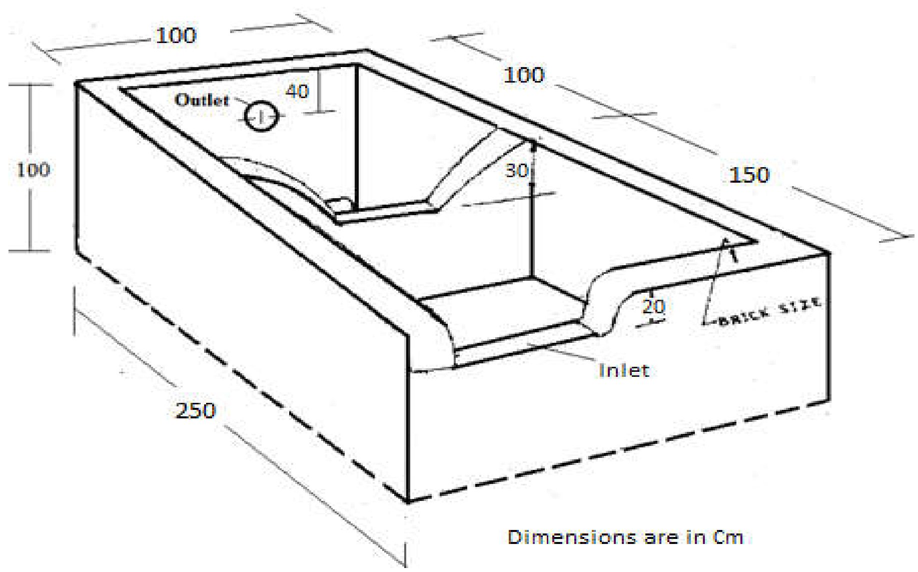


Fig30. Silt trap

- The channel from catchment should be connected to the inlet of the sediment pond at a depth of 20 cm and width 40cm.
- The partition at 150 cm should have a trapezoidal or rectangular spillway at 30 cm depth and 50 cm length.
- The outlet to the storage need to be made with 10 to 20 cm diameter pipe (concrete or pvc) at depth of 50 cm. If pipes are not available in the area the runoff from the silt trap can diverted to the storage tank through lined open channel.
- To reduce the sediment/silt load as much as possible excavate a primary silt trap along the flow way before the sediment pond. Filter mesh should be fixed in the inlet part of the flow pipe.

Self-check-2	Written test

Name: __________________________ Date: ________________

Directions: Answer the following questions.

1. What is catchment area? (1pts)
2. Describe characteristics of watershed or catchment? (5pts)
3. Explain steps to be followed in designing a RWH system. (4pts)
4. Write important parameters used to identify suitable site for rain water harvesting? (5pts)
5. Describe the purpose of selecting site for water harvesting structure? (5pt)
6. Differentiate rain water harvesting from flood water harvesting techniques? (5pt)

Note: Satisfactory rating – 20 points and above Unsatisfactory - below 20 points

You can ask you teacher for the copy of the correct answers.

INFORMATION SHEET#3	Constructing water harvesting structures

3.1 Identifying type of construction materials and equipment

Common types of Construction materials for water harvesting structures are:-

- Soil of different types- sandy soil, clay, silt clay
- Stone - basaltic, sand stone
- Sand - of different size
- Iron bars- deformed reinforcement iron bars of different diameter (6 mm, 8mm, 10mm, 12mm, 14mm etc…)
- Nails /pegs – of different sizes
- Corrugated iron sheets- of different thickness (G28, G32, G35)
- Clay tiles
- Hollow concrete blocks
- Cement
- Gravel – of different sizes
- Stirrups
- Black wire 1.5 mm diameter
- Timber(formwork)
- Woods
- Water
- Steel pipes
- PVC pipes
- Sheet metals of different thickness (1 mm,2mm, 3 mm, 4 mm, etc..)

Types of construction equipment

The following are the lists of construction equipments used during the construction of water harvesting structure. These are:

Surveying equipments

Surveying sets, range pole, line level, string, tape meter and peg etc

Excavation equipment

Excavator machine, tractor, bulldozer, hoe, shovel, spade etc

Mason's equipments

Mixer, hawk, trawl, batching box and plumb bob

Carpentry equipments

Hammer, saw, sprit level etc

3.2 Determining man power requirements

Typical productivity guidelines need to reflect what each worker can achieve in a day by working approximately 8 hrs. These are called task rates. Examples are as follows:

Activity	Task Rate
Vegetation clearing	150 – 300 m^2/md
Excavation, soft soil	3 – 4 m^3/md
Wheelbarrow hauling:	
0 – 40 m	10.5 m^3/md
40 – 60 m	8.0 m^3/md
60 – 80 m	6.5 m^3/md
80 – 100 m	5.5 m^3/md

Deciding Task Rates

The task rates mentioned so far in this book are guidelines only. A reasonable task rate for each activity must be decided on site bearing in mind such factors as:

- the **difficulty of the work** e.g. soil hardness/wetness, bush thickness, throwing distances;
- the **condition of the tools**;
- the **temperature/weather conditions**;
- the **fitness/health of the laborer's** and **their experience** of work.

To decide a task rate for an activity follow this procedure:

Step 1 Set aside one day for a trial on the activity. Organise the labourers on a day-work basis on this activity.

Step 2 Supervise the labourers closely, making sure that they all work hard for an eight-hour period.

Step 3 Stop works after eight hours and measure the quantity of work completed. Divide the quantity by the number of labourers on the activity. This gives an average task rate for the activity.

$$\textbf{Task rate} = \frac{\text{Total work completed in 8 hours}}{\text{Number of labourers on activity}}$$

Repeat this exercise frequently and adjust the task rate so that all labourers work on site for at least six hours a day.

Typical Task Rates

TASK RATES/PRODUCTIVITY NORMS			
ACTIVITY		**TASK RATE**	**REMARKS**
Clearing of garbage		daily paid	
Tree & stump removal		daily paid	Roughly 1 wd for every 20 cm Ø of tree
Grubbing Light ground cover up to 5 cm thick		150-300m^2/wd	Considering grubbing the entire clearing area
Boulder removal		daily paid	From experience
Slotting (for road base)		2 – 4 slots/wd	Check according to the volume of earthwork
Excavation only	Soft/loose soil	3 – 4 m^3/wd	Maximum throwing distance of 4.0 m
	Hard soil	2 – 3 m^3/wd	
	Very hard soil	1 – 1.5 m^3/wd	
Excavate laying of pipe refill		2 – 3 m/wd	Depends on the hardness of the soil and the underground infrastructure
Excavation & loading	Soft/loose soil	3 – 3.5 m^3/wd	
	Hard soil	1.75 – 2.5 m^3/wd	
	Very hard soil	1 – 1.5 m^3/wd	
Sloping	Soft/loose soil	3 – 4 m^3/wd	Sloping includes shaping the slope to the right gradient, e.g. for drains
	Hard soil	2 – 3 m^3/wd	
	Very hard soil	1 – 1.5 m^3/wd	
Formation of camber (for roads)	First spreading	90 m^2/wd	Spread material from ditching or from imported material
Gravel excavation including loading	Normal weathered material	1.5 –2.5 m^3/wd	
	Very hard material with boulders	1 – 1.5 m^3/wd	
Gravel spreading	0.20 m thick	50 – 70 m^2/wd	
Stone collection and loading		2.5 – 3 m^3/wd	
Sand collection and loading		3 – 4 m^3/wd	
Stone masonry		2 – 2.5 m^3/wd	This includes hand laying of the stones only. Mixing of mortar and preparation of stones is not included
Bricklaying for walls		8 – 10 m^2/wd	This includes hand laying of the bricks only. Mixing of mortar and preparation of bricks is not included

wd = worker day

3.3 Determining all service and running cost for the project life time

In order to analyze the life cycle costs of a Constructing water harvesting structures, it is necessary to estimate the operation and maintenance costs over time after the startup of the facility. The stream of operating costs over the life of the facility depends upon subsequent maintenance policies and facility use. In particular, the magnitude of routine maintenance costs will be reduced if the facility undergoes periodic repairs and rehabilitation at periodic intervals.

Since the tradeoff between the capital cost and the operating cost is an essential part of the economic evaluation of a facility, the operating cost is viewed not as a separate entity, but as a part of the larger parcel of life cycle cost at the planning and design stage. The techniques of estimating life cycle costs are similar to those used for estimating capital costs, including empirical cost functions and the unit cost method of estimating the labor, material and equipment costs. However, it is the interaction of the operating and capital costs which deserve special attention.

3.4 Preparing bill of quantity

Bill Of Quantity form: It is the format which is used in a bill of quantity to list (include) a short description of the specification along with its measuring unit, quantity and unit prices to determine the total cost for each trade of item.

Project: XY					
Item	Description	Unit	Quantity	Unit price	Amount

There are four clearly defined steps in preparation of Bill of Quantities:

1) Taking off
2) Squaring
3) Abstracting
4) Writing the final Bill of Quantity

1) Taking off:

This is the process of preparing /defining a detailed list of all labor and materials necessary for the work and entering the items on properly dimensioned paper. The standard form used for entering the dimensions taken or scaled from drawings to determine the accurate quantity in each trade of work, except reinforcement steel, is called take off sheet or dimension paper.

1	2	3	4	1	2	3	4
			Page___				Page __

The dimension paper used for taking off is usually double – ruled as shown below (A4 size).

- ***Column 1*** is used for stating the number of times an item occurs and is called the timising column.
- ***Column 2*** is called dimension column as it is used to enter the dimensions of the items of wo rks. The dimensions are entered in the order indicated below: Length, Width, Height or thickness.
- ***Column 3*** is called squaring column. The stated dimensions in column 2 are multiplied to determine the quantity of the work either in ml, m^2, m^3 or in Pcs. or No.
- ***Column 4*** is called description column and description of the work item is briefly stated

A separate sheet (Bar Schedule) is used to prepare reinforcement quantities as shown below.

No.	Location	Shape	Dia. (mm)	Length (m)	Number of-		Total length (m)	Dia. 6	Dia.8	Dia. 10	Dia.12	Dia.14	Dia.16	Dia.20
					Bar in member	Member (Pcs)								
				Total Length (m)										
				Unit Weight (Kg/m)				0.22	0.39	0.61	0.88	1.20	1.57	2.467
				Total Weight (Kg)										

The following tasks are part of the taking off (used to facilitate defining the quantities):
Describing the item, bracketing (relating the description to the quantity), timising, dotting on (adding to the timising factor), the ampersand (ditto), waste calculations, deduction of items, correction of dimensions (nullifying).

2) Squaring:

The dimensions entered in Column 2 are squared or cubed as the case may be, multiplied by the timising factor, and the result entered in Column 3. This task is called squaring. All squared dimensions should be carefully checked by another person before abstracting, and if correct the item should be ticked with red.

3) Abstracting

The squared dimensions are transferred to abstract sheets and all similar dimensions are collected in the same category to obtain the total quantity of each item.

4) Writing the Final Bill

After the abstract sheets have been completed and checked, the final bill of quantity is written. The dimensions are copied from the abstracts, and as each item is transferred it should be ticked by a vertical line from the abstract sheets. The description of each item in the final BoQ should be short, precise and descriptive as per the specification.

To measure production or set tasks on labor-based works, you must estimate the quantity of work to be done. Data for estimating the quantity of work can be collected using:

- design drawings;
- simple surveying tools such as boning rods, profile boards, line level, special templates, etc.;
- tape measure.

Once data has been collected in the field, from the drawing and the Bill of Quantities (if available), the detailed quantities of work for each activity need to be calculated.

Example for Rooftop Rain Water Harvesting Structure Cost Estimation

Cost Estimation of Rooftop rain water harvesting structure involves the cost of conveyance of the materials, material cost and labor cost. However, the overall cost of the structure depends on the orientation of the building and lead (distance).

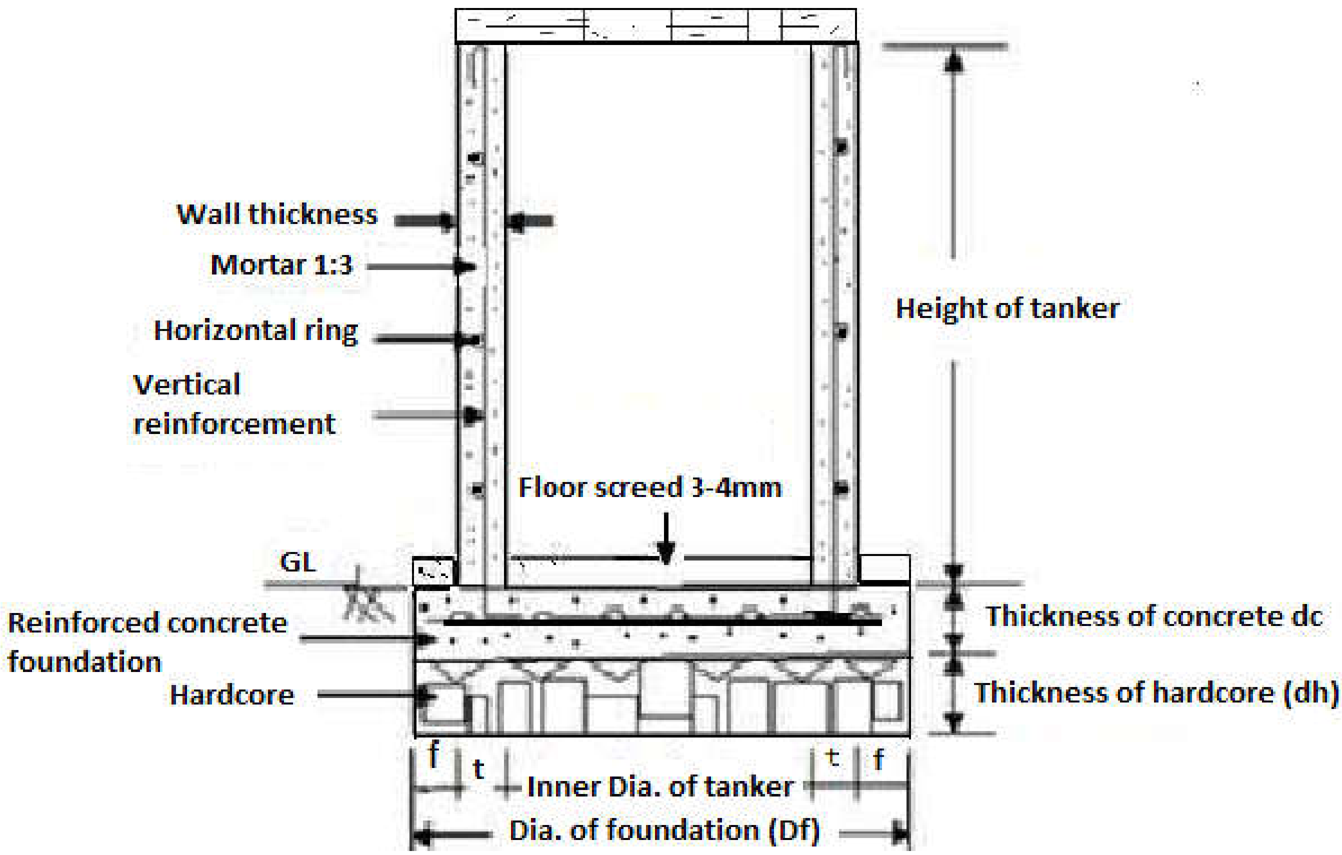


Fig31. Sectional view of Ferro cement tank

1. Design specification or Details of construction

For water tank let the height of the tanker be h

$\mathbf{V_t = \pi r^2}\ h$ where: r= radius of tanker

h= height of the tanker

V_t = volume of the tanker

So that,

$$\mathbf{r} = \sqrt{V_t / \Pi h}$$

To estimate the radius of excavation we have to consider the following

- Thickness of internal and external paltering
- thickness of wall filled with concrete
- 10-15cm edge of the foundation (footing)

Diameter of foundation (D= 2R) = inner diameter of the taker+ 2(f +t)

Radius of excavation (R) = inner radius of tanker (r) + thickness of wall (t) + footing (f)

Volume of excavation=base area x depth of foundation.

$\mathbf{V_{ex} = \pi R^2 D}$

Volume estimation for foundation

$\mathbf{V_{hard\ core} = \pi R^2 d_h}$ Where d_h = depth of hard core

$\mathbf{V_{concrete} = \pi R^2 d_c}$ Where d_c == depth of concrete

For shrinkage and wastage (quality control) add 50% of the volume.

$V_t = \mathbf{1.5 V_{concrete}}$

Since volume of concrete with a ratio of 1:2:3.Out of the total volume 1/6 or 16.6% is cement, 2/6 or 33.3% is sand and 3/6 or 50% is gravel and the respective volume of cement, sand and gravel is: -

$V_{cement} = 1/6 * V_t$

$Vs = 2/6 * V_t$

$Vg = 3/6 * V_t$

$\mathbf{V_{mortar} = R^2 d_f}$, where d_f is depth of floor

The volume mortar with the ratio of 1:3 and taking shrinkage and wastage percent 35% will give us:

$\mathbf{V_{mortar}} = \mathbf{R^2 d_f} * 1.25$

$\mathbf{V_{cement}} = 1/4 * \mathbf{V_{mortar}}$

$\mathbf{V_{sand}} = 3/4 * \mathbf{V_{mortar}}$

<u>Estimation of reinforcement required for the foundation and the super structure.</u>

Length of Ferro required for foundation

To estimate the number of bar that lie horizontally for foundation:

$$\text{No. of bars used for foundation.} = \frac{C}{\text{Spacing b/n bars}}$$

In order to estimate the number of circumference which lies on the foundation parts are:

$$\text{No. of circumference} = \frac{\text{radius}}{\text{Spacing b/n circumference}}$$

Length of Ferro or bar required for super structure

Total length of vertical bar for the wall = height of tanker + depth of foundation + 0.1m bend length. The number of vertical bars required to reinforce the wall =circumference/spacing b/n bars

Total number of rings required = $\frac{\text{height of tanker}}{\text{Spacing b/n rings}}$

The total length of rings = circumference of the ring X number of rings

Total length of bar for super structure is the sum of vertical bars and the total length of ring. Therefore, the total length of bar required to construct the storage is the sum of total length of the bar for foundation and super structure.

Estimation of materials for super structure (wall)

$V_{mortar} = 2\pi r \times t \times h$

Where r=inner radius, m; t= thickness of the wall, m and h= height of tanker, m.

Then determine the element of mortar

$V_{cement} = 1/4 * V_{mortar}$

$V_{sand} = 3/4 * V_{mortar}$

Table shows the details of cost estimation made for 5000 liters capacity of storage tank.

Item	**Unit**	**Quantity**	**Unit cost Birr***	**Total cost Birr**
MATERIALS				
Cement	Bag			
Sand	M^3			
Stone and hard core	M^3			
Gravel	M^3			
Chicken mesh wire	M^2			
Corrugated iron sheet	Pcs.			
Purlin	Pcs.			
Truss	Pcs.			
Nail	Kg			
Wire (6mm∅)	Kg			
Galvanized pipe (3/4'')	M			
Tap (3/4'')	Pcs.			
Nipple (3/4'')	Pcs.			
Gate valve (3/4'')	Pcs.			
Steel (8mm∅)or bars**	bars			
Total cost for materials				
LABOUR				
Mason	Man day			
Daily labourers	Man day			
Total cost for labours				
Contingency (10%)				
Grand total cost				

*** Assumed unit cost price.**
** 1 bar length is 12 meter.

3.5 Conducting land leveling activities

Land leveling is the process of modifying the surface relief by smoothening it. It is the process of flattening or modifying existing (natural) slopes or undulations and thereby creating a level surface. Normally land leveling requires excavation and movement of earth from higher elevations to lower elevations. Land grading is modifying the slope of land to a planned grade (slope) and specifications for Constructing water harvesting structures. The operations are usually accomplished using special equipments to eliminate the minor irregularities but not to change the general topography of the land surface. Most land leveling activities is accomplished with tractor drawn loading - type scraper and grader equipment.

Purpose of Leveling and Grading of Land

The art of determining relative altitudes of points on the surface of the earth or beneath the surface of the earth is called leveling. For the execution of **constructing water harvesting structures** it is necessary to determine the elevation of different points along the alignments of the proposed elevations. Leveling is employed to provide an accurate network of heights, covering the entire area of a project. Land grading involves reshaping the ground surface to planned grades as determined by an engineering survey, evaluation, and layout. Land grading provides more suitable topography for **Constructing water harvesting structures** and other land uses and helps to control surface runoff, soil erosion and sedimentation from the ungraded land during and after construction. Land grading is applicable to sites with uneven or steep topography or easily erodible soils, because it stabilizes slopes and decreases runoff velocity.

Methods of Leveling and Grading

Leveling may be categorized into two types.

- ✓ Simple leveling
- ✓ Differential leveling

Simple Leveling

Land leveling can be accomplished with the aid of leveling instruments (Theodolite, line level, etc) and farm implements (shovel, rakes, spades, rope, hoe, etc)

Water Level

This instrument is used for setting out levels on the site as well as to transfer and control levels over large distances. It consists of a transparent plastic tube filled with water (Fig. 42 Left). The level of the water at one end of the tube (a) will be at exactly the same height as the level at the other end (b), provided that there is no air bubble in the tube and it is not buckled.

The water level enables us to level over large distances with a high degree of accuracy.

If there is no transparent plastic tube available and some rubber hose can be found, the Rural Builder can ach end take two glass bottles knock out the bottoms and fit the bottle necks to each end of the hose. This apparatus is then filled with water until the water is seen in the bottles. Levels can be read as easily with this device as with any other water level (Fig.42 Right).

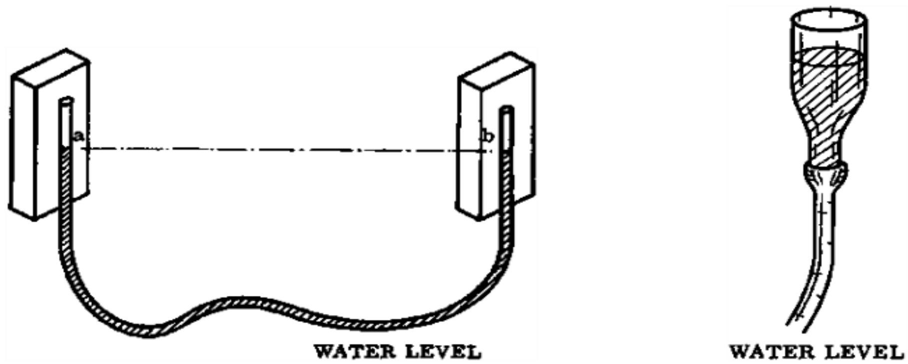


Fig. 32 Water Level

Boning Rods

Boning rods are T-shaped wooden tools, usually 120 cm high and 20 cm wide at the top. They are used in sets of three to help the Rural Builder to level between two given points (Fig.43).

Points a and b are marked with the water level and any point in between them can be obtained by using the third boning rod and sighting along the rods (Fig. 43).

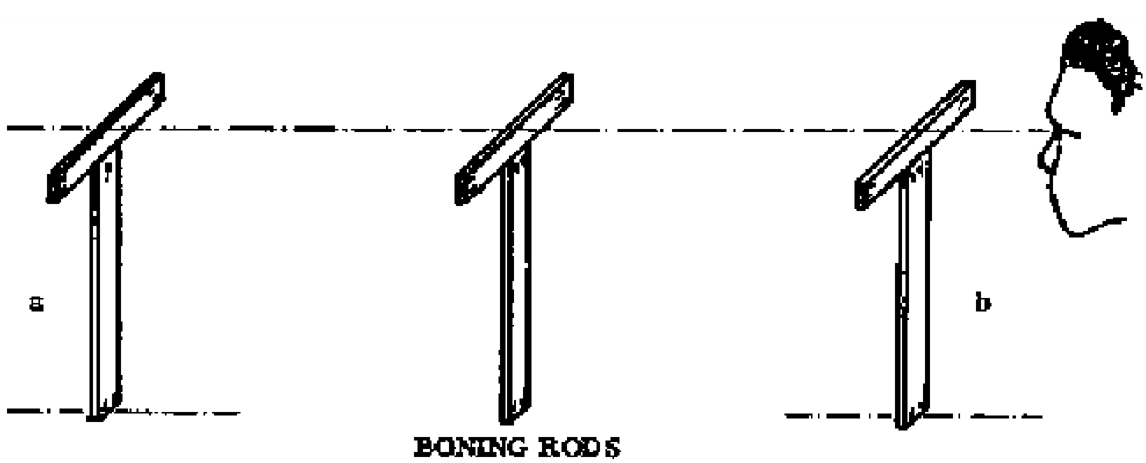


Fig. 33 boning rod

Line level

1. The line level is a simple surveying instrument which can be used to lay out contours and gradients, and also to measure the slope of land. It is simple to operate and is easier to transport than other similar surveying tools such as the A- frame. It is especially quick and very accurate when used properly. However a line level does require three people to operate it.

2. A line level consists of two poles, between which a length of string is suspended. A spirit level is hung on the string. The level is the type used by builders, but has small hooks at either end.

3. The poles should be of even height (about 1.5 m) and the string (about 2 mm in diameter) and precisely 8 meters in length. A notch is made in each pole at exactly the same height (say 1.4 m above ground level) and the ends of the string tied around these notches.

4. The center of the string (4 m from each end) is marked and the level itself is suspended there.

Laying out a contour

5. The poles are held apart by operators with the string extended and the spirit level positioned exactly in the middle of the string. When the bubble in the level is between the two marks this means that the poles are positioned on level points on the land - in other words on the contour. The poles must be held vertically.

6. To lay out a contour across a slope, the teams begin at the edge of the field. The operator holding the pole at the field's edge (operator A) remains stationary while the operator holding the other pole (operator B) moves up and down the slope until the third operator is satisfied that the bubble is centered. Points A and B are then marked (with stones or pegs). Operator A then moves to B and operator B moves onwards and the process is repeated. This continues until the contour line reaches the far end of the field.

7. Care should be taken that small obstacles, such as minor high spots, or rills, are avoided by skipping forward a pace or two. This avoids sharp irregularities in the contour.

8. When the contour has been laid out, the curves can be smoothed by eye according to the guidelines given for stone or earth bunds.

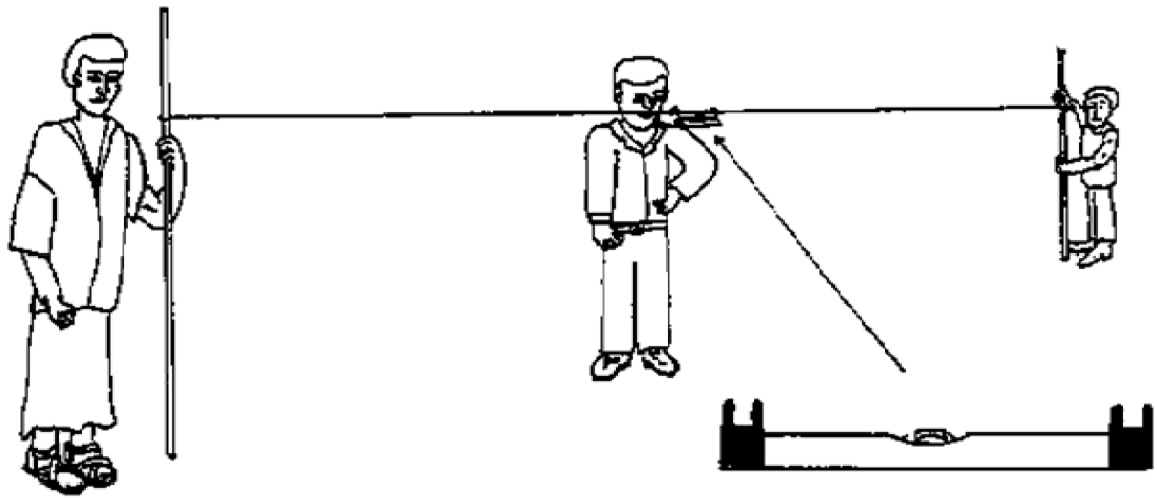


Figure 34. Use of the line level

Laying out a graded contour

9. A graded contour deviates slightly from the true contour and is normally used to align a channel, such as a diversion ditch, or to stake out a graded earth bund.

10. In order to lay out a graded contour, further notches must be made on one of the poles. These notches are made below the original notch at intervals of 2 cm.

11. The usual gradient for a structure such as a diversion ditch is 0.25%. The string of the near side operator (A) should be affixed to the second notch down his pole (2 cm below the original) and the far operator (B) retains his string at the original notch. When the bubble in the level is between the two marks, this now implies that A is 2 cm above B, which is equivalent to a 0.25% slope over the distance of 8 meters. For a slope of 0.5%, Operator A fixes his string to the third notch down his pole (4 cm below the top notch) and, when Operator B finds a position where the level reads dead center, he is at a ground level 4 cm below that of Operator A. Over a distance of 8 meters the slope is then 0.5%.

12. The operation now proceeds as before, operator A moving forward to the spot occupied by B, and B moving onwards - slightly down slope. Once again minor irregularities should be avoided and the curve smoothed.

13. If a diversion ditch must follow a precise field boundary it can be excavated so that the bottom of the ditch is given a suitable gradient. Surveying will therefore take place during excavation.

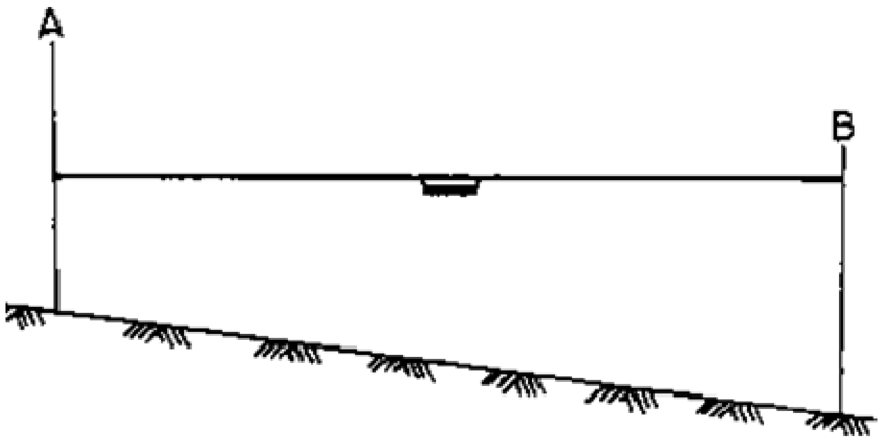


Figure 35. Measuring the slope with a line level

Measuring the slope of the land

14. It is simple to use the line level to measure the slope of the land. Operator A stands exactly upslope of Operator B and adjusts the string to the notch which gives a level reading. For example if this notch is the 3rd (i.e. 4 cm below the top notch) the gradient is 0.5%, if the notch is the eleventh (i.e. 20 cm below the top notch) the gradient is 2.5%, etc.

16. Always check the spirit level - by placing it on a horizontal surface and noting the position of the bubble which should be between the two marks.

17. Check the center point of the string each day and its length also,

18. Remember that when laying out a gradient that operator (A) is upslope.

19. Make sure poles are held vertically.

20. Avoid placing the poles in depressions or on top of minor high spots in the field.

Using Theodolite

The operation of leveling for determining the difference in elevation, if not too great, between two points visible from a single position of the level is known as simple leveling. Suppose A and C are the two points whose difference in elevation, is required to be measured with a leveling instrument set up at B. To eliminate the effect of the earth's curvature and instrumental errors, it is advisable that the level is set up at equal distance from points A and C but not necessarily on the line joining them. (Fig….)

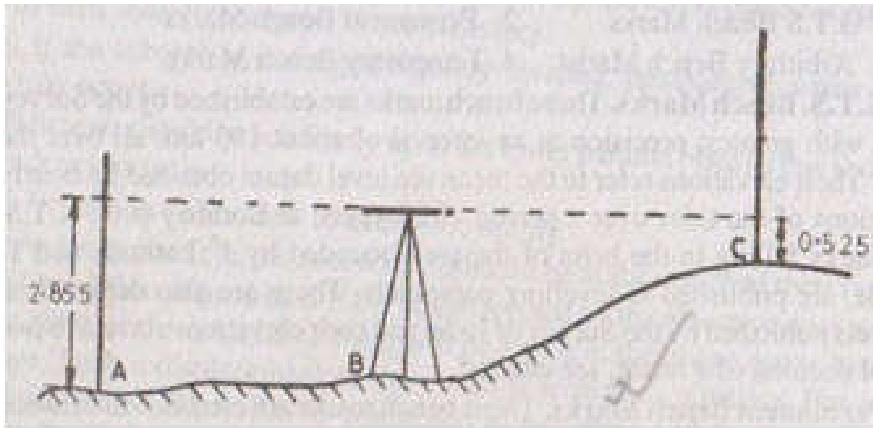


Fig 36 Simple Leveling (Source: Venkatramaiah, 1996)

Following steps should be used

- The telescope of the instrument should be leveled using standard procedure.
- The telescope is focused on the leveling staff held vertically on A.
- Readings of the central horizontal hair of the diaphragm where it appears to intersect the staff is taken ensuring that the bubble of the level is central.
- The staff is shifted to C.
- The telescope is directed towards C and again focused.
- Initial leveling should be such that even after rotating the telescope, the telescope remains horizontal.
- Reading of the central horizontal line is then taken.

Illustration I

Let the respective readings on staff A and staff C be 2.855 and 0.525m respectively. The difference of level between A and C: 2.855 – 0.525 = 2.330 m

If Reduced Level (R.L.) of A = 500.000 m, R.L of B may be calculated as:

R.L of point A = 500.000m

R.L. of the line of sight = 500.000 + 2.855 = 502.855 m

R.L. of the point C = 502.855 – 0.525 = 502.330 m

Illustration II

If one of the points is on the floor and the other is on the ceilings such as in tunnels or buildings, the staff at the elevated point, may be held vertically inverted (Fig.24.2).

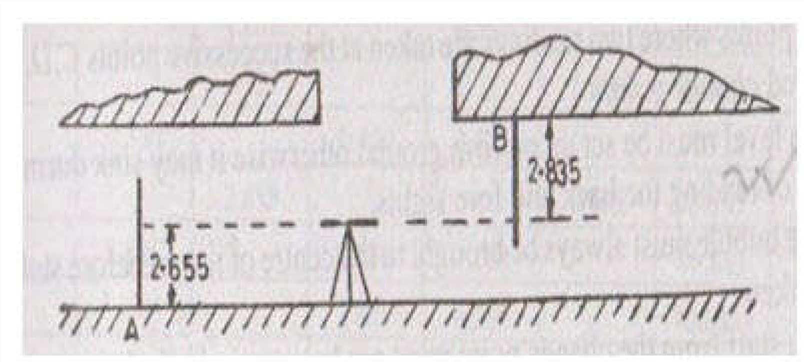


Fig. 37 Simple Leveling with Inverted Staff. (Source: Venkatramaiah, 1996)

If the elevation of A = 200.000 m

Back sight reading on A = 2.655 m

Fore sight reading on B = 2.835 m

R.L. of the line of sight = 200.000 + 2.655 = 202.655 m

So, R.L. of the point B = 202.655 + 2.835 = 205.490 m

Differential Leveling

The method of leveling for determining the difference in elevation between two points either too far apart or obstructed by an intervening ground, is known as differential leveling. In this method, the level is set up at a number of points and the difference in elevation of successive points, is determined as in the case of a leveling.

3.6 Interpreting lay out drawings and construction specifications

To do this, you will have to locate the element of construction you are reviewing to implement a portion of your work. If you are laying out the location of the structure, you will first look at the site plan for location of existing buildings, structures, or property lines so you have a reference point to begin measuring to your building footprint. Some plans simply give a coordinate grid position using Northing and easting, and you will need a "total station" surveyor's transit to locate these points. Here is what you'll need to do to lay out a WH structures from the plans:

- Lay out your building on the site by either the above referenced plan or the measurements given on the site plan. Measure to locations, preferably corners, on one side of the building, and check for any "checkpoints" to verify the accuracy of your layout. If you cannot absolutely establish an exact building line, you may have to suppose the location is correct and continue. This is widely accepted in cases where the site is very large, allowing for tolerance, but on a crowded lot or site, the location must be exact.
- Establish the elevation you will work from. This may be a height relative to a nearby roadway, or an elevation determined from sea level. Your site plan should have a bench mark (a bench mark refers to some item, such as a manhole lid or survey waypoint with a known elevation) elevation or a "height above existing grade" as a starting point.
- Use your plan to measure the location of each corner of the building, including offsets. Remember what exact element of construction you are using for your layout.

3.7 Selecting appropriate shade & lining materials

Definition

Shading materials: It is a kind of material constructed on the roof of water harvesting structure to prevent the loss of water via evaporation and protect the entrance of un wanted materials as well as people and animals.

Lining materials: it is a kind of material constructed on the floor and wall of the water harvesting structure to prevent the loss of harvested water via seepage and depercolation.

Types of shading and lining materials

Shading materials

- **Thatch, plastic , reinforced concrete and GI sheet**

Lining materials

- Red clay
- Termite mound.
- Cement mortar
- Concrete
- Stone or brick with cement mortar
- Polyphone sheet (plastic lining) - the thickness should not be less than 0.5 mm.

Uses of shading and lining materials

The main advantage of using shades and lining materials for water harvesting structures is

- ✓ To reduce evaporation and seepage loss respectively.

Seepage losses

- Appropriate and low cost lining materials should be used in order to reduce the water losses through seepage.
- The following materials are mostly used for lining water tanks.

Evaporation losses

- Reducing evaporation is an important way to increase the supply of water.
- Therefore, the following measures should be taken:
    - The storage tank should be covered with appropriate roofing materials that inhibit vaporization.
    - Surface area of the storage tank should be minimizing to reduce the cost of tank roofing.

Self-check-3	**Written test**

Name: ___________________________ Date: ________________

Directions: Answer the following questions.

1. List down all the necessary construction materials required for water harvesting structures? (3 pt)
2. Mention all the required construction equipments for water harvesting structures? (3 pt)
3. what is land leveling means and explain the purpose of leveling and grading of land?(5pt)
4. write the purpose of preparing of bill of quantity to construct water harvesting structures?(5pt)
5. Define shading and lining materials? (3 pt)
6. Mention the typical examples of shading and lining materials? (3 pt)
7. Describe the uses of shading and lining materials? (3pt)

Note: Satisfactory rating – 20 points and above Unsatisfactory - below 20 points

You can ask you teacher for the copy of the correct answers.

Operation Sheet	Construct water harvesting structures

Objective: To understand how to construct different water harvesting structures.

Materials, Tools and equipments used are:-

Planimeter, Tape meter, line level, theodolite, chaining pins, ranging pole, staff, clinometers, Global positioning system, compass, Auger, core sampler, spatula, oven, pressure apparatus, sensitive balance, sieve, soil grinder, hydro meter, shaker and measuring cylinder, thermometer, stop watch, flasks, shovel, rakes, spades, rope, plumb bob, hoe, mixer, tracing paper, pencil, graph paper, fixer, topographic map, drawing compass set.

Procedures

The following procedures should be taken into account to construct different water harvesting structures:

- ✓ Identify potential areas
- ✓ Identify proper site
- ✓ Identify availability of construction materials in that area
- ✓ Assess soil moisture statues of the area
- ✓ Delineate the catchment area
- ✓ Choose appropriate water harvesting techniques
- ✓ Conduct land leveling activities
- ✓ Select the design principles for the chosen technique of water harvesting
- ✓ Prepare design drawing for the selected technique
- ✓ Prepare bill of quantities
- ✓ Finally lay out the selected area and implement the selected technique of water harvesting structure.

LAP Test/ Job Sheet	Practical Demonstration

Name: ______________________________ Date: ________________

Time started: ________________________ Time finished: ________________

Instructions:

1. You are required to perform the following activity:

- Request your teacher to arrange materials, tools and equipments used in constructing water harvesting structure, in order to handle materials and equipment.
- Request your teacher for evaluation and feedback.

REFERENCE

- Assessment of Best Practices and Experience in Water Harvesting; Rainwater Harvesting Handbook; African Development Bank
- Chao-Hsien Liaw * and Yu-Chuan Chiang (2014): Framework for Assessing the Rainwater Harvesting Potential of Residential Buildings at a National Level as an Alternative Water Resource for Domestic Water Supply in Taiwan
- John Ndiritu, Adesola Ilemobade, and Paulo Kagoda (2018): Guidelines for rainwater harvesting system design and assessment for the city of Johannesburg, South Africa
- Manual for Rooftop Rainwater Harvesting Systems in the Republic of Yemen, (Sharafaddin , Prof. Dr. Taha Taher and Prof. Dr. Abdulla Noaman - Faculaty of Eng. Sana'a University)