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Lesson 1 Introduction to Rainwater Harvesting

1.1 Definition and Scope of Rainwater Harvesting

The present trend of agriculture is passing through a transition phase. Pressure on the most vital natural resources like land and water is increasing due to rise in population, increasing demand on food grains and urbanization. More and more marginal lands are being utilized today across the globe for crop production consequent upon the rising demand on the food grains by the growing population. Major chunk of this land is located in the arid or semi-arid regions where, the rainfall occurs irregularly and in small quantity. Much of this scarce rainwater is soon lost as surface runoff resulting in frequent agricultural droughts. Consequently, the very existence of human beings and livestock population is threatened and in some pockets the situation is observed to be seriously critical. While irrigation is assumed to be the most obvious response to drought, it has proved to be costly and can only benefit a fortunate few. Therefore, an increasing interest on a low cost alternative to conventional irrigation methods is observed in rainfed areas and this is generally referred to as ‘rainwater harvesting’.

In spite of remarkable achievements in the field of science and technology, nature remains to be a mystery for human beings. Sophisticated technologies have enabled us to derive fresh water from sea water through desalinization and avert drought situations by artificial raining through cloud seeding in some parts of the developed countries. Amidst such developments, the shortage of water even for drinking purpose has stood up as a threat across the world, especially in under developed and developing countries like India.

The never ending exchange of water from the atmosphere to the oceans and back again is known as the hydrologic cycle. This cycle is the source of all forms of precipitation and thus, all water. Precipitation stored in streams, lakes and soil evaporates while the water stored in plants transpires to form clouds that store water in the atmosphere. Making the most efficient use of the scarce and precious resource has become very much imperative. It includes using appliances and plumbing fixtures to conserve rainwater without wasting and taking advantage of alternative water sources such as grey water reuse and rainwater harvesting.

Definitions

Water harvesting, in broad sense, can be defined as the 'collection of runoff for productive uses'. It also can be defined in various ways such as the process of collecting natural precipitation from catchments for beneficial use or the process of concentrating precipitation through runoff and storing it for beneficial use.

Rainwater harvesting is the process of direct collection of rainwater and the generated surface runoff out of it. The conservation of rainwater refers to storing of the collected rainwater for direct use or for recharging the ground water. Runoff may be harvested from rooftops and land surfaces as well as from intermittent or ephemeral watercourses. Thus rainwater harvesting and conservation aims at optimum utilization of the natural resource i.e. rainwater, which is the first form of water obtained from the hydrologic cycle. Hence, it is known as the primary source of water. On the other hand, the rivers, lakes and underground reservoirs are the secondary sources of water. In present times, in absence of rainwater harvesting and conservation, we depend entirely on such secondary sources of water and in the process it is forgotten that rain is the ultimate source that feeds to these secondary sources. The value of this important primary source of water must not be lost. Rainwater harvesting and conservation mean to understand the value of rain and to make the optimum use of rainwater at the place where it falls.

Water harvesting techniques, which are used to harvest runoff from rooftops or land surfaces, fall under the term rainwater harvesting**.** All other systems which collect discharges from watercourses are grouped under the term floodwater harvesting.

1.2 History of Rainwater Harvesting

Various forms of water harvesting (WH) have been used traditionally through centuries. Some of them, as practiced across the Middle East in ancient agriculture, were based on techniques such as diversion of '*wadi*' flow (spate flow from normally dry watercourses) onto agricultural fields. WH systems dating back 4000 years or more have been discovered in the Negev Desert of Israel. These schemes involved the clearing of hillsides from vegetation to increase runoff, which was then directed to fields in the plains.

Floodwater farming was in practice in the desert areas of Arizona and northwest New Mexico for last 1000 years. The Hopi Indians on the Colorado Plateau were carrying out crop production in the fields situated at the mouth of ephemeral streams. These fields, where the streams fan out, are called "*Akchin*". Micro-catchment techniques used in southern Tunisia for growing trees were discovered in the nineteenth century by some travelers. In "*Khadin*" system of India, floodwater was impounded at the upstream of earthen bund sand crops were grown at the points of infiltration under residual soil moisture.

The importance of traditional, small scale systems of WH in Sub-Saharan Africa has just begun to gather recognition. Simple stone lines are used, for example, in some West African countries, notably Burkina Faso, and earth bunding systems are found in Eastern Sudan and the Central Rangelands of Somalia for water harvesting.

1.3 Need and Importance of Rainwater Harvesting

The need of rain water harvesting and conservation can be understood by the fact that the wettest place on the earth i.e. Cherrapunjee in Meghalaya state of India, which receives 12063.3 mm of average annual rainfall (1973 – 2002), suffers from acute shortage of drinking water. The reason attributed to inadequate provision of rainwater harvesting leading to quick draining of runoff down the slope along the hilly tracts. The annual rainfall over India is estimated to be 1170 mm, which is much higher than the global average of 800 mm. Moreover, 80 per cent of it occurs in about 70 rainy days during monsoon months (June – September). It makes clear that the sub-continent receives highly intensive and erratic rains in short periods. Practically, it is not possible to arrest all the rains coming in a short duration even through some gigantic structures and thus, it leads to draining out of the runoff at a faster rate leaving little scope for recharging of ground water. Consequently, most part of the country is facing shortage of water even for domestic uses. In regions where crops are entirely rainfed, a reduction of 50% in the seasonal rainfall, for example, may result in a total crop failure. If, however, the available rain can be concentrated on a smaller area, reasonable yields will still be received. Of course in a year of severe drought there may be no runoff to collect, but an efficient water harvesting system will improve plant growth in the majority of years.

Again, the arrival as well as departure of the south-west monsoon in the country is quite uncertain. The timing of onset of monsoon rain, for example in eastern region of India, fluctuates from the last week of May to second week of July leaving the field preparations for *kharif* crops in a state of quandary. Further, reports reveal that at least two critical dry spells are expected to occur during the rainy season and these two events are coincidental to important field operations and crop growth stages. A dry spell during *kharif* season if continues for at least 10 days or more is said to be a critical dry spell. When this dry spell occurs during *beusan* or transplanting stage of rice, the operation is either delayed or deferred in rainfed agriculture. Both the operations are very much essential for a better harvest from rice. In case the operation is delayed, the crop production reduces drastically and when it is deferred, the crop fails. Further, when the critical dry spell coincides with the critical growth stage of the crops, which extends from flowering to grain formation in most of the crops, the crop yield is severely reduced. In order to safeguard the rainfed crops from such drought like situations, rainwater harvesting is imperative.

Apart from the risks of dry spells in *kharif* season, it is observed that growing of a second crop in rainfed areas following withdrawal of monsoon is a chance factor. It is because of quick depletion of soil moisture from the seeding zone due to cessation of monsoon rain. Studies reveal that successful germination of the seeds of many of the oilseed and pulse crops in winter is very much essential for getting a good yield. Adequate soil moisture in the seeding zone of the crops is required to be maintained at the time of sowing of the crops. Water balance study in the crop root-zone of rainfed areas in eastern India reveals that the soil moisture in the seeding zone remains deficient for germination in more than 60% of the years. A provision of pre-sowing irrigation would be of immense help for this purpose. Thus, lack of a source of irrigation is a major constraint for growing a second crop in rainfed areas. Further, the provision of gravity fed irrigation for these areas is an uphill task in the part of the government. It implies that the rainfed areas will remain mono-cropped along with a chance factor of good harvest in rainy season unless and otherwise the rainfall excess during the late season stage of the *kharif* crop is harvested. In order to make the second green revolution in the rainfed areas of eastern India successful, a second crop needs to be grown with the provision of supplemental irrigation from the conserved rainwater.

1.3.1 Benefits of Water Harvesting System

A water harvesting system offers the following benefits:

- In arid and semi-arid regions, water harvesting is a guarantee of optimum crop production against vagaries of monsoon provided other production factors with respect to soil and crop are favourable. This is especially important when no other source of water is available for irrigation.
- Water harvesting system can provide water to take care of the irregularities of rainfall and supplement the soil moisture deficiency for increasing and stabilizing crop production. As the cropping risk is reduced, application of organic or inorganic fertilizers becomes economically viable resulting in increase of the potential yields.
- Water harvesting can meet water needs for domestic uses and livestock consumption where public supplies are not available.
- The extent of arid areas suffering from desertification increases due to want of water harvesting. The provision of water harvesting in those areas helps increase vegetative cover and consequently environmental degradation is checked. It has been also found effective in recharging the groundwater aquifers.
- Generally, water harvesting is a low-external-input technology and not difficult to implement. With few exceptions, it does not require use of pumps or input of energy to convey or apply harvested water.

The implementation of water harvesting may however have a number of detrimental effects as follows:

- Increase soil erosion when slopes are cleared to promote runoff
- Loss of habitat of flora and fauna due to clearance of slope
- Loss of habitat of flora and fauna in depressions (temporary wetlands)
- Conflicts among people living upstream and downstream of watershed for the use of harvested water
- Conflicts between farmers and herders in dry environment when the harvested water is used for livestock.

1.4 Components of Rainwater Harvesting

Water harvesting is the process of collecting and storing water from an area that has been treated to increase runoff generation from precipitation. Regardless of the purpose and type, all water harvesting systems have the following components (Fig. 1.1).

Catchment Area: Catchment area, watershed and drainage basin are the synonymous terminologies used in rainwater harvesting. It is the geographical area that contributes runoff, resulting from precipitation, which passes through a single point into a water harvesting unit, a large stream, a river, lake or an ocean. Therefore, it is also called as the runoff area. The catchment may be only a few hectares for small ponds or hundreds of square kilometers for large streams, rivers. After all, each catchment area is an independent hydrologic unit and any change made in its land use affects the runoff yield of the catchment.

Storage Facility: Water harvesting systems are not only for storing water to meet the crop water requirement but also for meeting the demand of households and livestock consumption. The storage facility refers to the structure where harvested runoff is held until it is used by crops, animals or people. Water may be stored on the ground for example in ponds and reservoirs, in the soil profile as moisture or recharged into the underground aquifers.

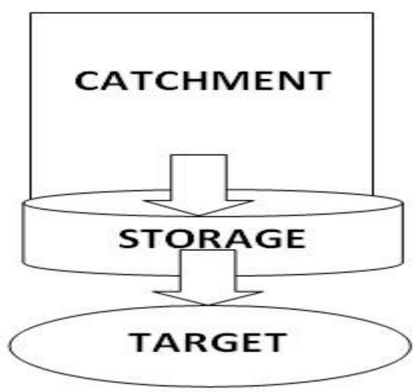

Fig. 1.1. Major components of typical water harvesting system.

(Source: Owesis *et al.*, 2012)

Target: The target groups of a water harvesting system may be the plants, animals or human beings. They are the end users of the system. While in agriculture, the target group is comprised of plants and animals, it is the people and their needs in domestic use. Complex or large scale water harvesting systems usually have additional components for conveying and diverting runoff water to the target and/or storage facility.

Lesson 3 Identification of Areas Suitable for Water Harvesting

3.1 Introduction

Rainwater harvesting is the collection of surface runoff mainly for agricultural and domestic purposes. The identification of potential sites for rainwater harvesting (RWH) is an important step towards maximizing water availability and land productivity in rain fed areas. The traditional fragmented approach of identification of potential sites for RWH is no longer viable and a more holistic approach to water management is essential. Development of methodology for identifying potential sites for RWH is an important step towards identifying areas suitable for certain techniques of water harvesting.

3.2 Parameters for Identifying Suitable Areas

Parameters to be considered for identifying areas suitable for water harvesting include:

- Climatic parameters of the region, especially rainfall
- Hydrology and alternative water resources
- Topography of the region
- Type of vegetation and agricultural production/forestry activities
- Soil types of the region including soil depth and fertility status
- Socio-economic conditions of the community
- National laws and regulations
- Infrastructural facilities available or planned for the area

3.2.1Rainfall Characteristics

The availability of rainfall data collected over years is crucial for the determination of the rainfall-runoff potential of a region. This is particularly true in arid and semi arid regions, where rainfall varies considerably from year to year. However average rainfall can still be used in areas with insufficient rainfall data. Future changes in rainfall pattern expected due to global climate change are also to be taken into consideration.

Rainfall can be measured on site using non recording / recording rainfall gauges to record single rainfall events or the daily total rainfall in the project area. However such data should be used with caution especially when extrapolating the findings to adjacent areas. The elevation of rain gauges from the ground level also affects the amount of rainfall measured. To avoid such discrepancies, the rain gauges should be placed at the same height throughout the project area.

Threshold rain is the depth of rainfall that must fall before runoff starts. It is used in some rainfall-runoff models as an initial value of runoff. Sufficient allowance must be given for the variation of the rainfall in time and space. Apart from the threshold rain that varies with rainfall intensity, the soil type, degree of slope, vegetation cover and antecedent soil moisture condition are other important parameters to be taken into consideration for accurate rainfall measurement.

The intensity of the rainfall is a good indicator of whether a particular rainfall event is likely to produce runoff or not. Of course, determination of the threshold intensity of rainfall that triggers runoff is more difficult to be determined than ascertaining the threshold rainfall depth. Rainfall intensity should also be determined as it is required for rainfall - runoff models. Recording rain gauges can be used for its determination. Rainfall duration can also be determined reliably using a recording rain gauge. This is also an important factor as it is often related to peak discharge in simulation models.

Once these data have been acquired, the most important rainfall parameters to be determined are:

- The relationship between the storm intensity and its duration; and
- The number of storms per year, including their mean standard deviation and probability distribution.

These parameters will then be used to calculate the volume of water available for cropping, possibly by generating synthetic rainfall events for deterministic calculation of runoff quantities. The temperature regime, air humidity and wind conditions during the cropping period are the other climatic factors which have to be taken into consideration when selecting a certain area for water harvesting.

3.2.2 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 catchment area. The intricacies of this phenomenon cannot be explained in detail here, but an overview is presented. Rainfall received in a particular catchment area can be divided into two major components such as the effective rainfall (direct runoff) for water harvesting and the losses. The sources of the losses are:

- Evaporation from the ground
- Water infiltration in the catchment
- Depression storage in the catchment
- Water intercepted by leaves of the plants

In arid and semi-arid areas, extreme fluctuations in both annual rainfall and its distribution during rainy season are considered as the major constraints to agricultural production. In most cases rainfall shows no regular pattern; the wet periods are often followed by marked dry periods. Modeling the rainfall - runoff process in hydrological analysis of an area is very complicated and the model designer must choose the most appropriate model from the existing models or develop one to suit the area under consideration. The lack of meteorological data, suitable topographic maps etc. often creates complications limiting strongly the usefulness of models.

The availability of sufficient runoff from the target area that can be stored to meet the water requirement of the selected crops during the dry periods in between two rainfall events is a good indication of the suitability of the area for water harvesting.

Another factor to be taken into consideration is the availability of other water sources e.g. shallow ground water in *wadi* beds and renewable ground water from deeper aquifers. These water sources can either substitute runoff water during drought periods or extend the cropping period beyond the rainy season.

3.2.3 Vegetation and Land Use

Vegetation strongly affects the surface runoff. An increase in the vegetative density results in a corresponding increase in losses due to interception, retention, and infiltration, which consequently decreases the volume of runoff. The density of vegetation on a given area can be determined in a variety of ways, but remote sensing is the most advanced and accurate method for large project areas subject to availability of funds. Reflectance of the soil and the vegetation is the indicator of the density of the vegetation in remote sensing.

Land use pattern affects the suitability of land for water harvesting in various ways. Introducing micro-catchment harvesting in areas already under cropping is much easier than transferring farmers into potentially suitable areas. On the other hand, farming activities in catchment areas such as primary and secondary tillage operations reduce the runoff yield significantly due to increase in the infiltration rates. On the contrary, overgrazing removes the vegetation cover which results in higher runoff volumes from the catchment. However, overgrazing entails in most cases a higher soil erosion risk with negative impacts on the water harvesting potential of the region.

3.2.4 Topography, Soil Type and Soil Depth

The suitability of an area for water harvesting depends strongly on its topography and soil characteristics, namely:

- The slope of a terrain which is a decisive factor for any type of water harvesting
- Surface structure which influences the rainfall runoff process
- Infiltration and percolation rates, which determine the movement of water into the soil and within the soil matrix
- Soil depth which together with the soil texture determines the quantity of water that can be stored in the soil.

The topography has a strong impact on infiltration volume and runoff yield. Micro-catchment systems are more appropriate for gentle slopes, whereas macro-catchment techniques can only be established in terrains having significant slope. Further information is given in Chapter 3.

The infiltration rate is the amount of water entering the soil, through its surface, over a given time. Infiltrometers and/or rainfall simulators can be used to determine the infiltration behavior of any soil. The main soil parameters affecting infiltration rate are the texture, structure, and depth of the soil. Vegetation and soil fauna also influence the infiltration rate. Dense vegetation absorbs the kinetic energy of the falling raindrops and thus, reduces the splash erosion and helps increasing the water retention followed by increasing the infiltration rate. A well developed root system after natural decay leaves tubular structures in the soil profile that helps increasing the infiltration rate. On the contrary, a bare soil is dislodged quickly due to its exposure to the direct hit of raindrops and thus, the existing soil pores in the surface are sealed resulting in decrease of infiltration rate.

Initial infiltration rates are higher in dry soils. As the rainfall continues, the infiltration rate declines gradually when the soil pores near the surface are filled up with water resulting in lowering down the hydraulic gradient, the driving force for the infiltration process. In clay-rich soils, the cracks that frequently occur in dry condition get closed as the soil becomes wet.

3.2.5 Socio-economic Condition and Infrastructure

The socioeconomic condition of the stakeholders opting for water harvesting scheme is very much important. Many projects have been abandoned soon after their implementation as a result of the negligence of this very important aspect during planning stage. Key considerations of this aspect include the farming systems of the community under consideration, the financial resources of the average farmer in the area, cultural behaviors and religious beliefs of the people, the attitude of the farmers towards the introduction of new farming methods, the farmers' knowledge about irrigated agriculture, land property rights, and the role of men and women in the community. The mobility of the populace may also influence the planning decisions.

As in any development project, the existing infrastructures or that will be developed in the future in the same area have to be taken into account when planning a water harvesting scheme.

3.3 Methods of Data Acquisition

3.3.1 Overview

The basic data required for any water harvesting project are presented in Table 3.1. The choice of method used to acquire these data depends not only on technical and financial considerations, but also to some extent constrained by national security and political issues.

3.3.2 Ground Truthing

Field visits to the area where a water harvesting project is to be executed are always necessary. For reliable results, specialists well versed in hydrology, prevailing vegetative condition of the region, and possibly the agricultural practices of the stake holders will be required. Ideally the local experts should be involved with the process. Some parameters may not be directly ascertained from maps, aerial photographs, or even satellite images and so, an inventory of the terrain should be prepared during field visits. Maps and ground truthing are adequate sources of information when the project is to be executed in a small area. However, it is time-consuming and expensive when planned for larger areas or in regional scale.

Table 3.1. Methods for Determining Parameters Relevant To Water Harvesting

Parameter	**Used or needed for**	**Method**
Crop water requirements	Maximum dry period, evapotranspiration values of crop	Analysis of meteorological data, plant growth, water stress relations
Water storage capacity of soil	Soil cover, natural vegetation and land use	Assessment of satellite images by computer assisted classification based on ground truth
Accessibility	Distance between water harvesting site and villages	Taken directly from topographic map or by digitizing settlement areas
Type of water harvesting system (micro/macro-catchment)	Terrain slope	Comprehensive distance model
Water availability	Rainfall - runoff relationship	Hydrological analysis/procedures and/or measurements
Sociological, economic, and political considerations	Beneficiaries preferences, resources support, participation, sustainability	Observations, interviews, outcome from nearby water harvesting projects.

3.3.3 Aerial Photography

Aerial surveying is a proven technology for extensive data acquisition. Vertical surveys with stereoscopic overlap can be made using large cameras. It depends on the regional or national availability of survey planes, and is cost effective only for large-scale projects. It may be appropriate for water harvesting schemes in regional scale.

3.3.4 Satellite and Remote-Sensing Technology

Satellite and remote-sensing technologies coupled with geographical information systems are the most powerful and reasonably cost-efficient tools used in assessing the potential for water harvesting.

The term remote-sensing is used to describe all the procedures employed in recording information from high altitudes above the Earth's surface. This can be done from an airplane or satellite. Remote sensing technology can not only be used for gathering preliminary information, but also to monitor and update data continuously at regular intervals.

Various types of information available from a variety of remote sensing platforms are presented in Table 3.2. The principal steps in using remotely sensed data to identify areas suited to water harvesting include:

- Definition of data required e.g. land use, geology, pedology, hydrology, etc.
- Data collection using remote sensing and other techniques
- Data analysis e.g. measurement, classification and estimation analysis
- Verification of the results obtained through analysis
- Presenting the results in a suitable format, such as maps, computer data files, written reports with diagrams, tables, maps etc.

Water, forest, pasture and other features reflect light from the sun differently and yield characteristic patterns in the relation between wavelengths and amount on reflected energy. These patterns can be recognized in the data registered by the satellite. Image classification is based on the assumption that the areas with similar characteristic spectra have similar characteristics on the ground. There are two approaches to classification of the data that are distinguished primarily by their initial assumption. In supervised classification, the ground truth data from direct in-field observations are used to identify the initial parameters used in the classification.

Table 3.2. Information for water harvesting planning from remote sensing systems

Parameter	**Satellite type**	**Type of information**	**How to obtain**
Topography	Aerial photo. LIDAR<IFSAR	Raster data (DEM)	Internet sites, local mapping agencies
Inclination/slope	Aerial photo, LIDAR, IFSAR	Raster data (percent degree)	Derive from DEM
Elevation	Aerial photo, LIDAR, IFSAR	Raster data (meters above mean sea level)	Derive from DEM
Surface roughness	Microwave	Root mean square average	Microwave remote sensing
Soil type	Landsat TM, SPOT, ASTER, others	Polygons of soil mapping units	Interpretation and ground truthing
Soil depth	Ground penetrating radar	Raster (cm)	
Soil moisture	Radar remote sensing	Raster (percent)	
Land cover/land use	Landsat TM, SPOT, ASTER others	Polygons (classes)	Visual interpretation, image classification and ground truthing
Type of vegetation	SPOT, ASTER	Polygons (type)	Visual interpretation, image classification and ground truthing
Infrastructure	Aerial photo, Landsat-TM, SPOT, ASTER, others	Vector data (points, lines and polygons)	Visual interpretation and ground truthing (local mapping agencies)
Water bodies	Aerial photo, Landsat, TM, SPOT, ASTER, others	Polygons	Visual interpretation and image classification

In remote sensing cartography, the acquired information is first classified in problem oriented categories, and is then mapped in accordance with standard cartographical rules. As compared to approaches using aerial photography and ground truth, less effort is required to process the remotely sensed data because certain stages of the analysis can be assessed on the monitor to elaborate the statistical evaluations. Since the data gained through this system is in digital form, it can be translated to adjacent scenes with the consideration of the existing illumination differences without the need to carry out field investigations. Since the remotely sensed data are in digital form, it can be further processed and even linked to other compatible data sets.

3.4 Tools

3.4.1 Maps

Maps may be the only means of acquiring data in some countries from Google earth images. Two types of maps such as topographic and thematic have been used commonly in gathering land related information.

Topographic Maps

A topographic map represents the features of an area in an analogue form. This type of map can be found in many regions of the world. They can be digitized and incorporated into a GIS database.

Thematic Maps

Thematic maps represent specific types of information e.g. soils, rainfall or temperature isohyets, vegetation types, etc. These maps present source information in classes. It should be noted that a degree of inaccuracy exists in the way the classes are defined. For instance, a continuous phenomenon such as soil or vegetation type is mapped as homogenous map units with sharp boundaries, whereas the actual circumstances on the ground vary within each map unit; this may affect the project results significantly.

3.4.2 Aerial Photographs

There are archives of black and white aerial photographs in many parts of the world, but their usefulness depends on the age and scale of the images and the specific purpose for which they were taken. Color infrared photographs can be used to differentiate vegetation types.

3.4.3 Geographic Information System

A GIS is a computer based system used to capture, store, edit, manage, and display geographically referenced information, including spatial and descriptive data. Spatial data deal with the location and shape of various features and the relationship among them. Such features as topography, water resources, soil types, land use, infrastructure and administrative boundaries can also be combined in a GIS.

Descriptive data describe the characteristics of these features. Thus a GIS serves as a tool for representing the real world. GIS can be used to help policy makers in identifying and prioritizing appropriate rainwater harvesting interventions

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Water Harvesting

28.1 Importance of Water Harvesting

Rainwater harvesting, in its broadest sense, is a technology used for collecting and storing rainwater for human use from rooftops, land surfaces or rock catchments using simple techniques such as jars and pots as well as engineered techniques. Rainwater harvesting has been practiced for more than 4,000 years, owing to the temporal and spatial variability of rainfall. It is an important water source in many areas with significant rainfall but lacking any kind of conventional, centralised supply system. It is also a good option in areas where good quality fresh surface water or ground water is lacking. Water harvesting enables efficient collection and storage of rainwater, makes it accessible and substitute for poor quality water. There are a number of ways by which water harvesting can benefit a community.

- Improvement in the quality of ground water,
- Rise in the water levels in wells and bore wells that are drying up,
- Mitigation of the effects of drought and attainment of drought proofing,
- An ideal solution in areas having inadequate water resources,
- Reduction in the soil erosion as the surface runoff is reduced,
- Decrease in the choking of storm water drains and flooding of roads and
- Saving of energy to lift ground water.

28.2 Types of Water Harvesting

Rainwater Harvesting: Rainwater harvesting is defined as the method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions. Three types of water harvesting are covered by rainwater harvesting.

- Water collected from roof tops, courtyards and similar compacted or treated surfaces is used for domestic purpose or garden crops.
- Micro-catchment water harvesting is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration basin. The basin is planted with a tree, a bush or with annual crops.
- Macro-catchment water harvesting, also called harvesting from external catchments is the case where runoff from hill-slope catchments is conveyed to the cropping area located at foothill on flat terrain.

Flood Water Harvesting: Flood water harvesting can be defined as the collection and storage of creek flow for irrigation use. Flood water harvesting, also known as 'large catchment water harvesting' or 'Spate Irrigation', may be classified into following two forms:

- In case of 'flood water harvesting within stream bed', the water flow is dammed and as a result, inundates the valley bottom of the flood plain. The water is forced to infiltrate and the wetted area can be used for agriculture or pasture improvement.
- In case of 'flood water diversion', the wadi water is forced to leave its natural course and conveyed to nearby cropping fields.

Groundwater Harvesting: Groundwater harvesting is a rather new term and employed to cover traditional as well as unconventional ways of ground water extraction. Qanat systems, underground dams and special types of wells are a few examples of the groundwater harvesting techniques. Groundwater dams like 'Subsurface Dams' and 'Sand Storage Dams' are other fine examples of groundwater harvesting. They obstruct the flow of ephemeral streams in a river bed; the water is stored in the sediment below ground surface and can be used for aquifer recharge.

28.3 Water Harvesting Technique

This includes runoff harvesting, flood water harvesting and groundwater harvesting.

28.3.1 Runoff Harvesting

Runoff harvesting for short and long term is done by constructing structures as given below.

28.3.1.1 Short Term Runoff Harvesting Techniques

Contour Bunds: This method involves the construction of bunds on the contour of the catchment area (Fig. 28.1). These bunds hold the flowing surface runoff in the area located between two adjacent bunds. The height of contour bund generally ranges from 0.30 to 1.0 m and length from 10 to a few 100 meters. The side slope of the bund should be as per the requirement. The height of the bund determines the storage capacity of its upstream area.

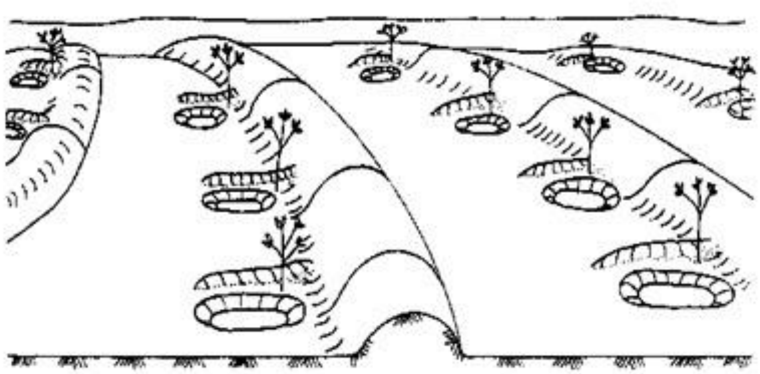

Fig. 28.1. Contour Bunds. (Source: Barron and Salas, 2009)

Semicircular Hoop: This type of structure consists of an earthen impartment constructed in the shape of a semicircle (Fig. 28.2). The tips of the semicircular hoop are furnished on the contour. The water contributed from the area is collected within the hoop to a maximum depth equal to the height of the embankment. Excess water is discharged from the point around the tips to the next lower hoop. The rows of semicircular hoops are arranged in a staggered form so that the over flowing water from the upper row can be easily interrupted by the lower row. The height of hoop is kept from 0.1 to 0.5 m and radius varies from 5 to 30 m. Such type of structure is mostly used for irrigation of grasses, fodder, shrubs, trees etc.

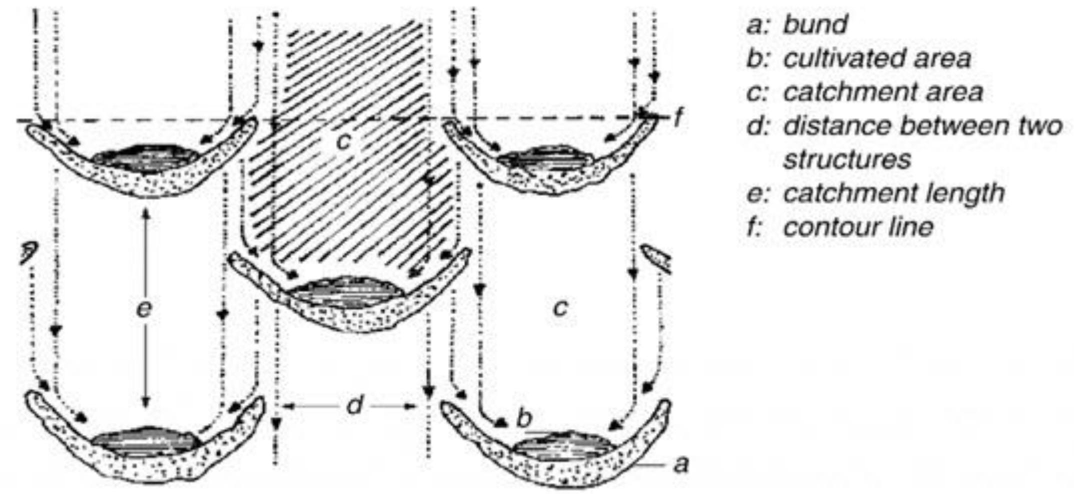

Fig. 28.2. Layout of Semi-Circular Hoop. (Source: Barron and Salas 2009)

Trapezoidal Bunds: Such bunds also consist of an earthen embankment, constructed in the shape of trapezoids. The tips of the bund wings are placed on the contour. The runoff water yielded from the watershed is collected into the covered area. The excess water overflows around the tips. In this system of water harvesting the rows of bunds are also arranged in staggered form to intercept the overflow of water from the adjacent upstream areas. The layout of the trapezoidal bunds is the same as the semicircular hoops, but they unusually cover a larger area (Fig. 28.3). Trapezoidal bund technique is suitable for the areas where the rainfall intensity is too high and causes large surface flow to damage the contour bunds. This technique of water harvesting is widely used for irrigating crops, grasses, shrubs, trees etc.

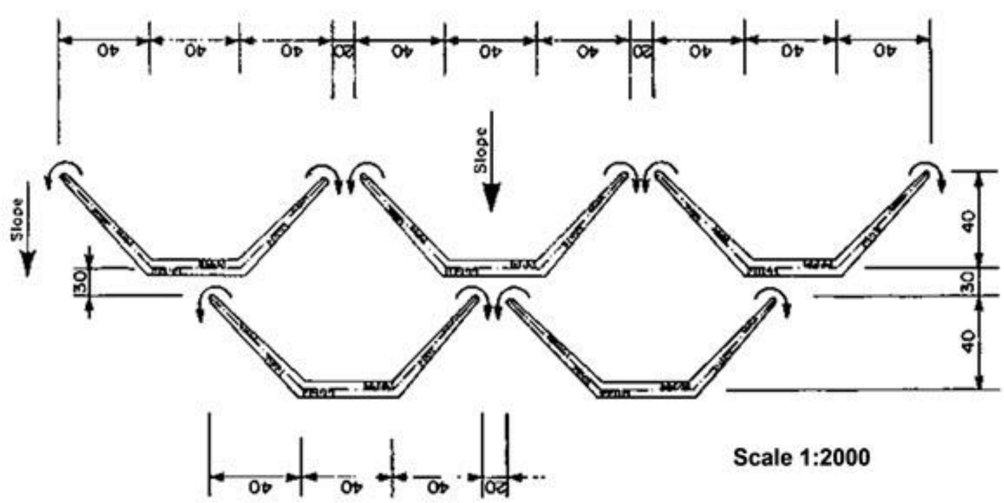

Fig. 28.3. Layout of Trapezoidal Bund. (Source: Barron and Salas, 2009)

Graded Bunds: Graded bunds also referred as off contour bunds. They consist of earthen or stone embankments and are constructed on a land with a slope range of 0.5 to 2%. The design and construction of graded bunds are different from the contour bunds. They are used as an option where rainfall intensity and soils are such that the runoff water discharged from the field can be easily intercepted. The excess intercepted or harvested water is diverted to the next field though a channel ranges. The height of the graded bund ranges from 0.3 to 0.6 m. The downstream bunds consist of wings to intercept the overflowing water from the upstream bunds. Due to this, the configuration of the graded bund looks like an open ended trapezoidal bund. That is why sometimes it is also known as modified trapezoidal bund. This type of bunds for water harvesting is generally used for irrigating the crops.

Rock Catchment: The rock catchments are the exposed rock surfaces, used for collecting the runoff water in a part as depressed area. The water harvesting under this method can be explained as: when rainfall occurs on the exposed rock surface, runoff takes place very rapidly because there is very little loss. The runoff so formed is drained towards the lowest point called storage tank and the harvested water is stored there. The area of rock catchment may vary from a 100 m^2 to few 1000 m^2; accordingly the dimensions of the storage tank should also be designed. The water collected in the tank can be used for domestic use or irrigation purposes.

Ground Catchment: In this method, a large area of ground is used as catchment for runoff yield. The runoff is diverted into a storage tank where it is stored. The ground is cleared from vegetation and compacted very well. The channels are as well compacted to reduce the seepage or percolation loss and sometimes they are also covered with gravel. Ground catchments are also called roaded catchments. This process is also called runoff inducement. Ground catchments have also been traditionally used since last 4000 years in the Negev (a desert in southern Israel) where annul crops and some drought tolerant species like pistachio dependent on such harvested water are grown.

28.3.1.2 Long Term Runoff Harvesting Techniques

The long term runoff harvesting is done for building a large water storage for the purpose of irrigation, fish farming, electricity generation etc. It is done by constructing reservoirs and big ponds in the area. The design criteria of these constructions are given below.

- Watershed should contribute a sufficient amount of runoff.
- There should be suitable collection site, where water can be safely stored.
- Appropriate techniques should be used for minimizing various types of water losses such as seepage and evaporation during storage and its subsequent use in the watershed.
- There should also be some suitable methods for efficient utilization of the harvested water for maximizing crop yield per unit volume of available water.

The most common long term runoff harvesting structures are:

- Dugout Ponds
- Embankment Type Reservoirs

Dugout Ponds: The dugout ponds are constructed by excavating the soil from the ground surface. These ponds may be fed by ground water or surface runoff or by both. Construction of these ponds is limited to those areas which have land slope less than 4% and where water table lies within 1.5-2 meters depth from the ground surface (Fig. 28.4). Dugout ponds involve more construction cost, therefore these are generally recommended when embankment type ponds are not economically feasible. The dugout ponds can also be recommended where maximum utilization of the harvested runoff water is possible for increasing the production of some important crops. This type of ponds require brick lining with cement plastering to ensure maximum storage by reducing the seepage loss.

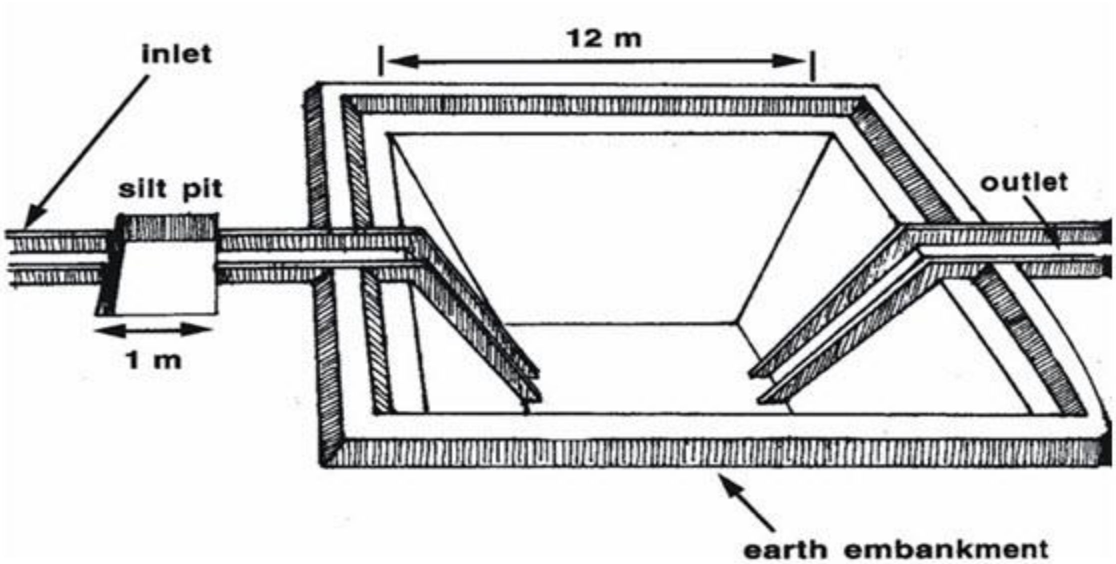

Fig. 28.4. Illustration of Dugout Pond. (Source: Barron and Salas, 2009)

Embankment Type Reservoir: These types of reservoirs are constructed by forming a dam or embankment on the valley or depression of the catchment area. The runoff water is collected into this reservoir and is used as per requirement. The storage capacity of the reservoir is determined on the basis of water requirement for various demands and available surface runoff from the catchment. In a situation when heavy uses of water are expected, then the storage capacity of the reservoir must be kept sufficient so that it can fulfill the demand for more than one year.

Embankment type reservoirs are again classified as given below according to the purpose for which they are meant.

Irrigation Dam: The irrigation dams are mainly meant to store the surface water for irrigating the crops. The capacity is decided based on the amount of input water available and output water desired. These dams have the provisions of gated pipe spillway for taking out the water from the reservoir. Spillway is located at the bottom of the dam leaving some minimum dead storage below it.

Silt Detention Dam: The basic purpose of silt detention dam is to detain the silt load coming along with the runoff water from the catchment area and simultaneously to harvest water. The silt laden water is stored in the depressed part of the catchment where the silt deposition takes place and comparatively silt free water is diverted for use. Such dams are located at the lower reaches of the catchment where water enters the valley and finally released into the streams. In this type of dam, provision of outlet is made for taking out the water for irrigation purposes. For better result a series of such dams can be constructed along the slope of the catchment.

High Level Pond: Such dams are located at the head of the valley to form the shape of a water tank or pond. The stored water in the pond is used to irrigate the area lying downstream. Usually, for better result a series of ponds can be constructed in such a way that the command area of the tank located upstream forms the catchment area for the downstream tank. Thus all but the uppermost tanks are facilitated with the collection of runoff and excess irrigation water from the adjacent higher catchment area.

Farm Pond: Farm ponds are constructed for multi-purpose objectives, such as for irrigation, live-stock, water supply to the cattle feed, fish production etc. The pond should have adequate capacity to meet all the requirements. The location of farm pond should be such that all requirements are easily and conveniently met.

Water Harvesting Pond: The farm ponds can be considered as water harvesting ponds. They may be dugout or embankment type. Their capacity depends upon the size of catchment area. Runoff yield from the catchment is diverted into these ponds, where it is properly stored. Measures against seepage and evaporation losses from these ponds should also be.

Percolation Dam: These dams are generally constructed at the valley head, without the provision of checking the percolation loss. Thus, a large portion of the runoff is stored in the soil. The growing crops on downstream side of the dam, receive the percolated water for their growth.

28.3.2 Flood Water Harvesting

To harvest flood water, wide valleys are reshaped and formed into a series of broad level terraces and the flood water is allowed to enter into them. The flood water is spread on these terraces where some amount of it is absorbed by the soil which is used later on by the crops grown in the area. Therefore, it is often referred to as "Water Spreading" and sometimes "Spate Irrigation". The main characteristics of water spreading are:

- Turbulent channel flow is harvested either (a) by diversion or (b) by spreading within the channel bed/valley floor.
- Runoff is stored in soil profile.
- It has usually a long catchment (may be several km)
- The ratio between catchment to cultivated area lies above 10:1.
- It has provision for overflow of excess water.

The typical examples of flood water harvesting through water spreading are given below.

Permeable Rock Dams (for Crops)

These are long low rock dams across valleys slowing and spreading floodwater as well as healing gullies (Fig. 28.5). These are suitable for a situation where gently sloping valleys are likely to transform into gullies and better water spreading is required.

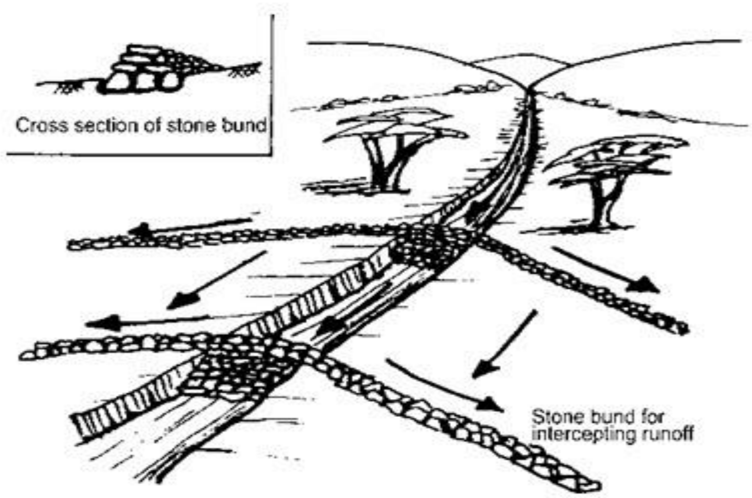

Fig. 28.5. Permeable Rock Dams. (Source: Barron and Salas, 2009)

Water Spreading Bunds (for Crops and Rangeland): In this method, runoff water is diverted to the area covered by graded bund by constructing diversion structures such as diversion drains. They lead to the basin through channels, where crops are irrigated by flooding. Earthen bunds are set at a gradient, with a "dogleg" shape and helps in spreading diverted floodwater (Fig. 28.6). These are constructed in arid areas where water is diverted from watercourse onto crop or fodder block.

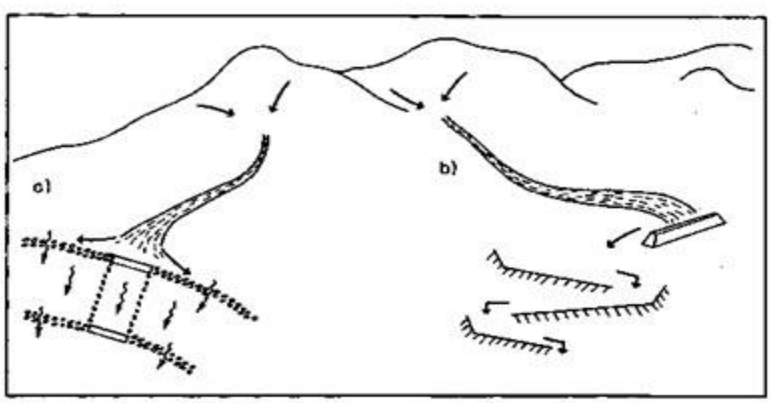

Fig. 28.6. Floodwater farming systems: (a) spreading within channel bed; (b) diversion system. (Source: Barron and Salas, 2009)

Flood Control Reservoir: The reservoirs constructed at suitable sites for controlling the flood are known as flood control reservoirs. They are well equipped with self-operating mechanical outlets for letting out the harvested water into the stream or canal below the reservoir as per requirement.

28.3.3 Groundwater Harvesting

Qanat System: A qanat consists of a long tunnel or conduit leading from a well dug at a reliable source of groundwater (the mother well). Often, the mother well is dug at the base of a hill or in the foothills of a mountain range. The tunnel leading from the mother well slopes gradually downward to communities in the valley below. Access shafts are dug intermittently along the horizontal conduit to allow for construction and maintenance of the qanat (Fig. 28.7). The Qanat system was used widely across Persia and the Middle East for many reasons. First, the system requires no energy, relies on the force of gravity alone. Second, the system can carry water across long distances through subterranean chambers avoiding leakage, evaporation, or pollution. And lastly, the discharge is fixed by nature, producing only the amount of water that is distributed naturally from a spring or mountain, ensuring that the water table is not depleted. More importantly, it allows access to a reliable and plentiful source of water to those living in otherwise marginal landscapes (Fig. 28.8).

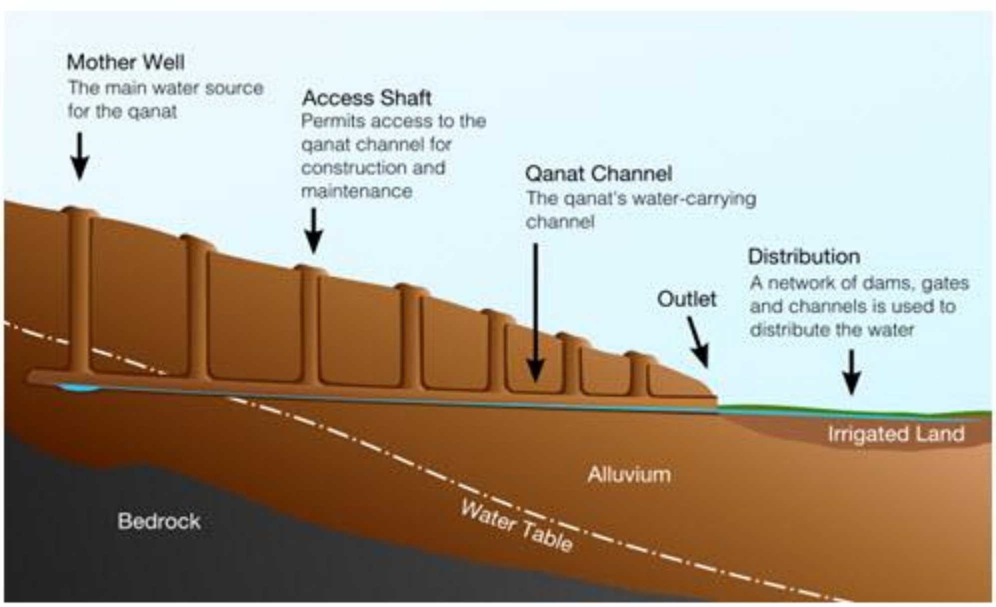

Fig. 28.7. Cross Section Showing Qanats. (Source: Barron and Salas, 2009)

Fig. 28.8. Ariel view of Qanats. (Source: www.visualphotos.com)

28.4 Runoff vs. Flood Water Harvesting

- 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 flood water harvesting.
- Runoff harvesting increases water availability for on-site vegetation while flood waters harvesting provide a valuable source of water to local and downstream water users and play an important role in replenishing floodplains, rivers, wetlands and groundwater.
- Runoff harvesting reduces water flow velocity, as well as erosion rate and controls siltation problem while in flood water harvesting**,** floodwater enters into the fields through the inundation canals, carrying not only rich silt but also fish which can swim through the canals into the lakes and tanks to feed on the larva of mosquitoes

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Other Water Harvesting Structures

32.1 Negarim Micro-catchments

Negarim micro-catchments are diamond shaped basins surrounded by small earth bunds with an infiltration pit in the lowest corner of each. Runoff is collected from within the basin and stored in the infiltration pit. Micro-catchments are mainly used for growing trees or bushes. This technique is appropriate for small scale tree planting in areas with moisture deficit problems. Besides harvesting water for the trees and plants, it simultaneously conserves soil. Negarim micro-catchments are neat and precise, and relatively easy to construct.

Fig. 32.1. Negarims under construction. (Source: Critchley, 1992)

32.1.1 Background

The word 'Negarim' is derived from the Hebrew word for runoff i.e. 'Neger'. Negarim micro-catchments are the most well known form of all water harvesting systems. Although the first reports of such micro-catchments are from southern Tunisia, the technique has been developed in the Negev desert of Israel.

32.1.2 Technical Details

a. Suitability

Negarim micro-catchments are mainly used for growing tree in arid and semi-arid areas. Here the annual rainfall may be as low as 300-700 mm. The soil should be at least 1.5 m, but preferably 2 m, deep in order to ensure adequate root development and storage of the water harvested. Recommended land slope for such micro-catchments varies from 1 to 5%. The topography of the land need not be necessarily leveled and in case of uneven, a block of micro-catchments should be subdivided.

b. Overall Configuration

Each micro-catchment consists of a catchment area and an infiltration pit (cultivated area). The shape of each unit is normally square, but the appearance from above is of a network of diamond shapes with infiltration pits in the lowest corners (Figure 32.2).

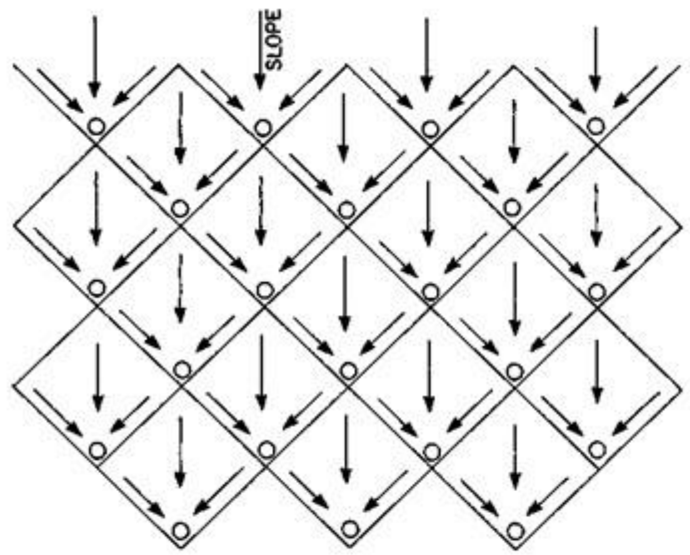

Fig. 32.2. Negarim micro-catchments-field layout.
(Source: http://www.fao.org/docrep/u3160e/u3160e07.htm#TopOfPage)

c. Limitations

Negarim micro-catchments are well suited for hand construction as they cannot easily be mechanized. Once the trees are planted, it is not possible to operate and cultivate with machines between the tree lines.

d. Micro-catchment Size

The area of each unit is either determined on the basis of a calculation of the plant (tree) water requirement or, more usually, an estimate of this. Size of micro-catchments (per unit) normally range between 10 and 100 m^2 depending on the species of tree to be planted but larger sizes are also feasible, particularly when more than one tree will be grown within one unit.

e. Design of Bunds

The bund height is primarily dependent on the prevailing ground slope and the selected size of the micro-catchment. It is recommended to construct bunds with a height of at least 25 cm in order to avoid the risk of over-topping and subsequent damage. Where the ground slope exceeds 2%, the bund height near the infiltration pit must be increased. The top of the bund should be at least 25 cm wide and side slopes should be at least in the range of 1:1 in order to reduce soil erosion during rainstorms. Whenever possible, the bunds should be provided with a grass cover since this is the best protection against erosion.

f. Size of Infiltration Pit

The depth of the infiltration pit should not be more than 40 cm in order to avoid water losses through deep percolation and to reduce the workload for excavation. Excavated soil from the pit should be used for construction of the bunds.

g. Quantity of Earthwork

Quantity of earthwork per unit includes only the infiltration pit and two adjacent sides of the catchment, while the other two bunds of the square are included in the micro-catchment above. Additional earthwork is necessary if it is required to have a diversion ditch above.

32.1.3 Maintenance

Maintenance will be required for repair of damages to bunds, which may occur if storms are heavy soon after construction and the bunds are not fully consolidated. The site should be inspected after each significant rainfall.

32.1.4 Husbandry

Tree seedlings of at least 30 cm height should be planted immediately after the first rain of the season as shown in Fig.32.3. It is recommended that two seedlings are planted in each micro-catchment: one in the bottom of the pit (which would survive even in a dry year) and the other on a step at the back of the pit. If both plants survive, the weaker can be removed after the beginning of the second season. For some species, seeds can be planted directly. This eliminates the cost of raising nursery.

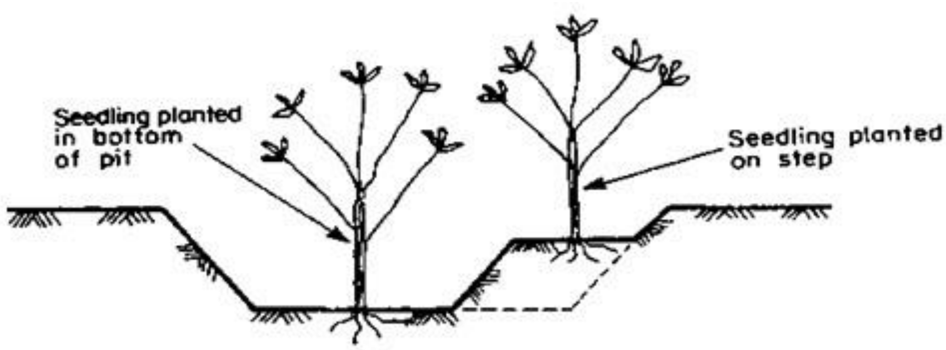

Fig. 32.3. Planting site for seedling.
(Source: http://www.fao.org/docrep/u3160e/u3160e07.htm)

Manure or compost should be applied to the planting pit to improve fertility and water-holding capacity. If grasses and herbs are allowed to develop in the catchment area, the runoff will be reduced to some extent; however, the fodder obtained gives a rapid return to the investment in construction. Regular weeding is necessary in the vicinity of the planting pit.

32.1.5 Socio-economic Considerations

Negarim micro-catchments have been developed in Israel for the production of fruit trees, but even there the returns on investment are not always positive. It is not a cheap technique, bearing in mind that on an average one labour per day is required to build two units, and costs per unit rise considerably as the micro-catchment size increases. It is essential that the costs are balanced against the potential benefits. In the case of multipurpose trees in arid/semi-arid areas, the main benefit will be the soil conservation effect and grass for fodder for several years until the trees become productive. Negarim micro-catchments are suitable for village afforestation blocks and around homesteads where a few open-ended 'V' shaped micro-catchments provide shade or support amenity trees.

32.2 Contour Bunds for Trees

32.2.1 Background

Contour bunds for trees are simplified forms of micro-catchments as shown in Fig 32.4. Construction can be mechanized and the technique is therefore suitable for implementation on a larger scale. As its name indicates, the bunds follow the contour, at close spacing, and by provision of small earth ties the system is divided into individual micro-catchments. Whether mechanized or not, this system is more economical than Negarim micro-catchment, particularly for large scale implementation on level land - since less earth has to be moved. Another

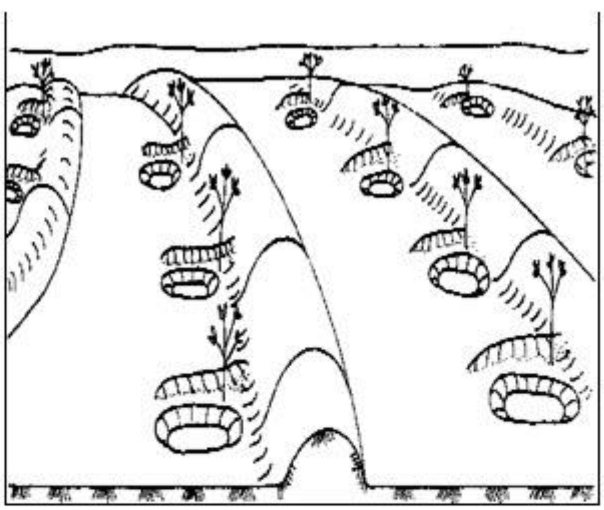

Fig. 32.4. Contour bunds for trees.
(Source: http://www.fao.org/docrep/u3160e/u3160e07.htm)

advantage of contour bunds is their suitability to the cultivation of crops or fodder between the bunds. Like other forms of micro-catchment water harvesting techniques, the yield of runoff is high, and when designed correctly, there is no loss of runoff out of the system. However, contour bunding for tree planting is not yet as common as Negarim micro-catchments.

32.2.2 Technical Details

a. Suitability

Contour bunds for tree planting are recommended for semi-arid and arid areas receiving rainfall up to 200 and 750 mm, respectively. The soils must be at least 1.5 m and preferably 2 m deep to ensure adequate root development and water storage. The prevailing land slope may range between flat to 5%. Above all, the topography of the land should be leveled without rills or gullies.

b. Limitations

Contour bunds are not suitable for undulating or eroded lands as overtopping of excess water with subsequent breakage may occur at low spots.

c. Overall Configuration

The overall layout of contour bunds consists of a series of parallel, or nearly parallel, earth bunds approximately on the contour at a spacing of 5 to 10 m. The bunds are constructed with soil excavated from an adjacent parallel furrow on their upstream side. Small earth ties perpendicular to the bund on the upstream side subdivide the system into micro-catchments. Infiltration pits are excavated in the junction between ties and bunds. A diversion ditch protects the system wherever necessary.

d. Unit Micro-catchment Size

The size of micro-catchment per tree is estimated in the same way as for Negarim micro-catchments. However, the system is more flexible, because the micro-catchment size can be easily altered by adding or removing cross-ties within the fixed spacing of the bunds. Common sizes of micro-catchments are around 10-50 m^2 for each tree.

e. Bund and Infiltration Pit Design

Bund heights may vary within the range of 20 - 40 cm depending on the prevailing slope. As bunds are often made by machine, the actual shape of the bund depends on the type of machine; whether for example a disc plough or a motor grader is used. It is recommended that the bund should not be less than 25 cm in height. Base width must be at least 75 cm. The configuration of the furrow upstream of the bund depends on the method of construction.

Bunds should be spaced at either 5 m or 10 m apart. Cross-ties should be at least 2 m long at spacing of 2 to 10 m. The exact size of each micro-catchment is defined based on the spacing between bunds and cross ties. It is recommended to provide 10 m spacing between the bunds on slopes of up to 0.5% and 5 m on steeper slopes. A common size of micro-catchment for multipurpose trees is 25 m^2.

It corresponds to 10 m bund spacing with ties at 2.5 m spacing or 5 m bund-spacing with ties at 5 m spacing. Excavated soil from the infiltration pit is used to form the ties. The pit is excavated in the junction of the bund and the cross-tie. A pit size of dimension 80 cm x 80 cm and 40 cm deep is adequate.

32.2.3 Maintenance

Like Negarim micro-catchments, maintenance, in most cases, is limited to repair of damage to bunds early in the initial season. It is essential that any breaches, which are unlikely unless the scheme crosses existing rills, are repaired immediately followed by compaction. Damage is frequently caused if animals invade the plots. Grass should be allowed to develop on the bunds, thus assisting consolidation with their roots.

32.2.4 Husbandry

The majority of the husbandry factors noted under Negarim micro-catchments also apply to this system: there are, however, certain differences. Tree seedlings, of at least 30 cm height, should be planted immediately after the first runoff has been harvested. The seedlings are planted in the space between the infiltration pit and the cross-tie. It is advisable to plant an extra seedling in the bottom of the pit for the eventuality of a very dry year. Manure or compost can be added to the planting pit to improve fertility and water holding capacity.

32.2.5 Socio-economic Factors

Contour bunds for trees are mainly made by machine. The cost of bund construction is relatively low and implementation is faster, especially, where the plots are large and level and the kind of mechanization is well adapted. However, as with all mechanization in areas with limited resources, there is a question mark about future sustainability. Experience has shown that very often the machines come abruptly to a halt when the project itself ends.

32.3 Semi-circular Bunds

32.3.1 Background

Semi-circular bunds refer to earthen embankments in the shape of a semi-circle with the tips of the bunds on the contour. Semi-circular bunds, of varying dimensions, are used mainly for rangeland rehabilitation or fodder production. This technique is also useful for growing trees and shrubs and, in some cases, has been used for growing crops. Depending on the location, and the chosen catchment- cultivated area ratio, it may be a short slope or long slope catchment technique. The examples described here are short slope catchment systems.

Semi-circular bunds are recommended as a quick and easy method of improving rangelands in semi-arid areas. These are more efficient in terms of impounded area to bund volume than other equivalent structures such as trapezoidal bunds etc.

32.3.2 Technical Details

a. Suitability

Semi-circular bunds for rangeland improvement and fodder production are suitable for arid and semi-arid areas receiving up to 200 and 750 mm of rainfall per annum, respectively. The soils should not be too shallow or saline. The land slope should not be greater than 2%. In case of modified bund designs, the land slope can be up to 5%. A level topography is required for semi-circular bunds especially for the type of design ‘a’ shown in Fig. 32.5. The main limitation of semi-circular bunds is that the construction cannot easily be mechanized.

b. Overall Configuration

The two designs of semi-circular bunds discussed here, design ‘a’ and ‘b’ shown in Fig. 32.5; differ in the size of structure and in field layout. Design ‘a’ has bunds with radii of 6 m, and design "b" with radii of 20 m. In both the designs, the semi-circular bunds are constructed in staggered lines with runoff producing catchments between structures.

Design ‘a’ is a short slope catchment technique, and is not designed to use runoff from outside the treated area or to accommodate overflow. Design "b" is also a short slope catchment system, but can accommodate limited runoff from an external source. Overflow occurs around the tips of the bund which are set on the contour.

c. Catchment

Catchment to cultivated area ratio (C: CA ratio) of up to 3:1 are generally recommended for water harvesting systems used for rangeland improvement and fodder production. The reasons for applying low ratios are that already adapted rangeland and fodder plants in semi-arid and arid areas need only a small amount of extra moisture to respond significantly with higher yields. Larger ratios would require bigger and more expensive structures with a higher risk of breaching. Design ‘a’ as described here has low C: CA ratio of only 1.4:1 and does not require any provision for overflow. Design ‘b’ has a higher C: CA ratio of 3:1 and therefore provision for overflow around the tips of the bunds is recommended, though occurrence of overflow is usually rare. A larger C: CA ratio for design ‘b’ is possible but it should not exceed 5:1.

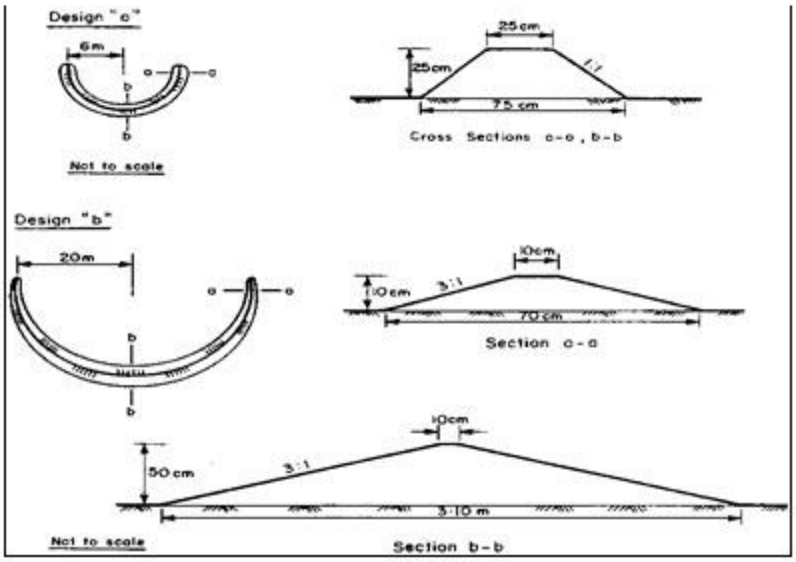

Fig. 32.5. Semi-circular bund dimensions.
(Source: http://www.fao.org/docrep/u3160e/u3160e07.htm)

d. Design Variations

Semi-circular bunds can be constructed in a variety of sizes with a range of both radii and bund dimensions. Small radii are common when semi-circular bunds are used for tree growing and production of crops. A recommended radius for these smaller structures is 2 to 3 m with bunds of about 25 cm in height.

32.3.3 Maintenance

Like other earthen structures, the most critical period for semi-circular bunds is when rainstorms occur just after construction because, the bunds are not fully consolidated at this time. In case of any damage, it is recommended for an immediate repair of the structure followed by provision of a diversion ditch if not already constructed. Semi-circular bunds which are used for fodder production normally need repairs of initial breaches only. This is because in the course of time, a dense network of the perennial grasses will protect the bunds against erosion and damage. The situation is different if animals have access into the bunded area and are allowed to graze. In this case, regular inspections and repair of bund damages will be necessary.

32.3.4 Husbandry

It may be possible to allow the already existing vegetation to develop provided it consists of desirable species or perennial rootstocks. In most cases, however, it will be more appropriate to re-seed with seed from outside. Local collection of perennial grass seed from useful species may also be suitable provided the seed is taken from virgin land. Together with grass, trees and shrub seedlings may be planted within the bunds.

32.3.5 Socio-economic Factors

Water harvesting for rangeland improvement and fodder production will mainly be applied in areas where the majority of the inhabitants are agro-pastoralists. In these areas, the concept of improving rangeland on community basis is usually alien. Therefore, it may be difficult to motivate the population to involve and invest voluntarily for implementing and maintaining such a water harvesting system.

Even when this is possible, it is equally important to introduce an appropriate and acceptable rangeland management programme to avoid overgrazing and further degradation of the land. Controlled grazing is also essential to maintain good quality rangeland, and the bunded area must be rested periodically for it to regenerate, so that natural reseeding can take place.

32.4 Contour Ridges for Crops

32.4.1 Background

Contour ridges, sometimes called contour furrows or micro-watersheds, are used for crop production. Thus, it is also known as a micro-catchment technique. Ridges follow the contour at a spacing of usually 1 to 2 m. Runoff is collected from the uncultivated strip between ridges and stored in a furrow just at the upstream of the ridges. Crops are planted on both sides of the furrow. The system is simple to construct either by hand or machine, and can be even less labour intensive than the conventional tilling of a plot.

The yield of runoff from the very short catchment lengths is extremely efficient. When these ridges are designed and constructed correctly, the loss of runoff water out of the system could be prevented completely. Uniform crop growth is another advantage of the system due to the fact that each plant has approximately the same contributing catchment area. However, the contour ridges for crops are not yet a widespread technique.

32.4.2 Technical Details

a. Suitability

Contour ridges for crop production may be recommended for those areas where, the mean annual rainfall is between 350 and 750 mm, soil is suitable for crop production, land slope ranges between flat and 5% and the land topography is leveled. Moreover, it is difficult to construct ridges by hand in areas with heavy and compacted soil. Also areas with rills and undulations are not suitable for contour ridges.

b. Limitations

Contour ridges are limited to areas with relatively high rainfall, as the amount of harvested runoff is comparatively small due to the small catchment area.

c. Overall Configuration

The overall layout consists of parallel or nearly parallel contour ridges approximately on the contour at a spacing of 1 to 2 m (Fig. 32.6). When the furrow is excavated, the dugout soil is placed downstream of the furrow to form a ridge. The furrow collects runoff from the catchment strip between ridges. Small earth-ties in the furrows are provided at frequent intervals to ensure an even storage of runoff. A diversion ditch may be necessary to protect the system against runoff from above.

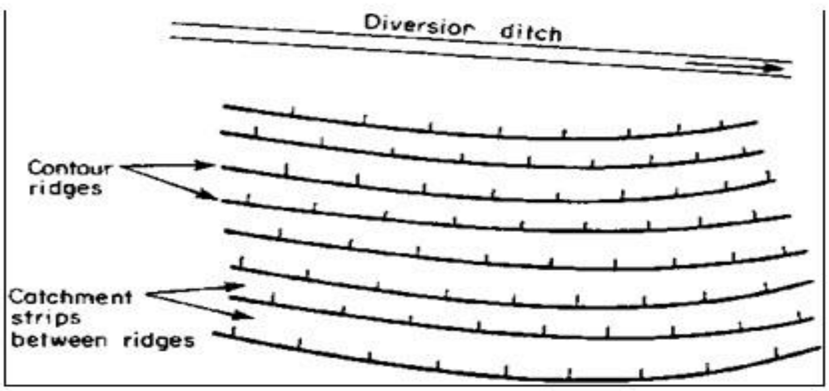

Fig. 32.6.Contour ridges: field layout.
(Source: http://www.fao.org/docrep/u3160e/u3160e07.htm)

d. Catchment: Cultivated Area Ratio

It is a common practice to assume a 50 cm strip with the furrow at its center. Crops are planted within this zone, and use the runoff concentrated in the furrow. Thus, for a typical distance of 1.5 m between ridges, the C: CA ratio is 2:1; that is a catchment strip of 1.0 m and a cultivated strip of half a meter. A distance of 2 m between ridges would give a 3:1 ratio. The C: CA ratio can be adjusted by increasing or decreasing the distance between the ridges.

The calculation of the catchment: cultivated area ratio follows the design model of Chapter 4. In practice, a spacing of 1.5 - 2.0 m between ridges (C: CA ratios of 2:1 and 3:1 respectively) is generally recommended for annual crops in semi-arid areas.

e. Ridge Design

Ridges need only be as high as necessary to prevent overtopping by runoff. As the runoff is harvested only from a small strip between the ridges, a height of 15 -20 cm is sufficient (Fig. 32.7). If bunds are spaced at more than 2 m, the ridge height must be increased.

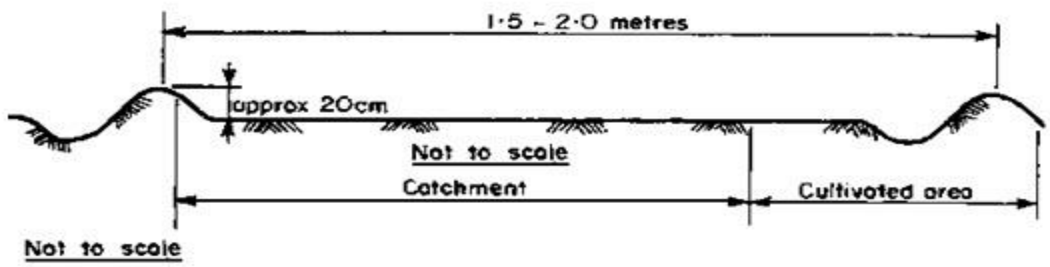

Fig. 32.7.Contour ridge dimensions.
(Source: http://www.fao.org/docrep/u3160e/u3160e07.htm)

f. Earthwork and Labour

Quantities of earthwork for different contour ridge spacing and ridge heights are presented in Table 32.1. It should be noted that the construction of the ridges includes land preparation and so, further cultivation is not required. Where a diversion ditch is necessary, an additional 62.5 m^3 of earthwork for each 100 m of length of ditch has to be added.

Table 32.1. Quantities of Earthwork for Contour Ridges
(Source: http://www.fao.org/docrep/u3160e/u3160e07.htm)

Ridge spacing (m)	**Ridge & Tie height (cm)**	**Earthworks per ha (m^3)**
1.5	15	270
1.5	20	480
2.0	20	360

32.4.3 Maintenance

If contour ridges are correctly laid out, it is unlikely that there will be any overtopping and breaching. Nevertheless if breaches do occur, the ridges or ties must be repaired immediately. The uncultivated catchment area between the ridges should be kept free of vegetation to ensure that the optimum amount of runoff flows into the furrows.

At the end of each season the original height of the ridges need to be restored. After two or three seasons, depending on the fertility status of the soils, it may be necessary to move the ridges down the slope by approximately one metre or more, which is likely to result in a fresh supply of nutrients to the plants.

32.4.4 Husbandry

The main crop (usually a cereal) is seeded at the upstream face of the ridge between the top of the ridge and the furrow as shown in Fig. 32.8. In this area, the plants have a greater depth of top soil. An intercrop, usually a legume, may be planted in front of the furrow. In this practice, it is recommended to reduce the plant population of the cereal crop to approximately 65% of the standard for conventional rainfed cultivation. Thus, the moisture available for less number of plants is more during the years of low rainfall. Weeding must be carried out regularly around the plants and within the catchment strip.

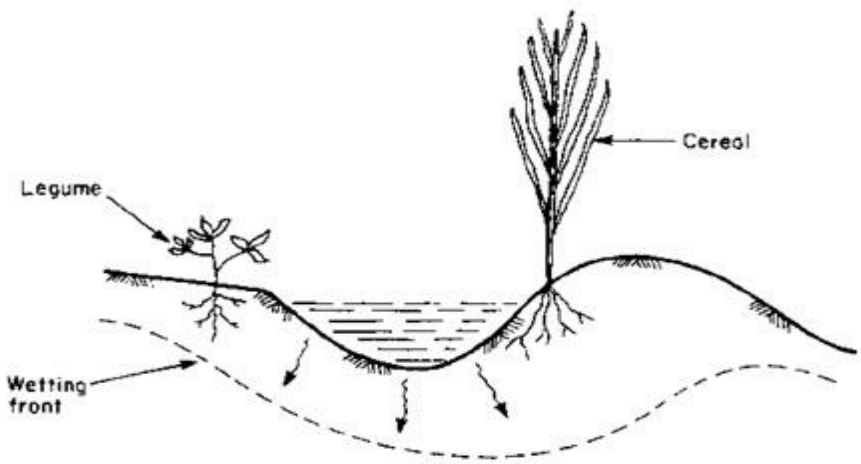

Fig. 32.8.Planting configuration in contour ridges.
(Source: http://www.fao.org/docrep/u3160e/u3160e07.htm)

32.4.5 Socio-economic Factors

Since the contour ridge technique implies a new tillage and planting method compared to conventional cultivation, farmers may be initially reluctant to accept this technique. Demonstration and motivation are therefore very much important. On the other hand, it is one of the simplest and cheapest methods of water harvesting. It can be implemented by the farmer using a hoe, at no or little extra cost. Alternatively it can be mechanized and a variety of implements can be used. When used by a farmer on his own land, the system does not create any conflicts of interest between the executants and the beneficiary.

32.5 Trapezoidal Bunds

32.5.1 Background

Trapezoidal bunds are used to enclose larger areas up to 1 ha and to impound larger amount of runoff which is harvested from an external or long slope catchment. The name is derived from the layout of the structure which is of trapezoidal shape. It consists of a base bund connected to two side bunds or wing walls which extend upstream at an angle of usually 135^0.

Crops are planted within the enclosed area. Overflow discharges around the tips of the wing walls. The concept is similar to the semi-circular bund technique. However, in this case three sides of a plot are enclosed by bunds while the fourth (upstream) side is left open to allow runoff to enter the field. Simple design and construction; and requirement of minimum maintenance are the main advantages of this technique.

32.5.2 Technical Details

a. Suitability

The trapezoidal bunds are also used for growing crops, trees and grass. Their most common application is for crop production in arid to semi-arid areas with soil of good constructional properties and annual rainfall of 250 - 500 mm. A soil of good constructional property has significant clay content and is non-cracking in nature. The topography of the area within the bunds should be made flat and the allowed land slope is from 0.25% - 1.5%, but most suitable when it is below 0.5%.

b. Limitations

This technique is limited to low ground slopes. Construction of trapezoidal bunds on slopes steeper than 1.5% is technically feasible, but involves large quantities of earthwork.

c. Overall Configuration

Each unit of trapezoidal bund consists of a base bund connected to two wing walls which extend upstream at an angle of 135^0. The size of the enclosed area depends on the slope and can vary from 0.1 to 1 ha. Trapezoidal bunds may be constructed as single units or in sets. When several trapezoidal bunds are built in a set, they are arranged in a staggered configuration; units in lower lines intersect overflow from the bunds above. A common distance between the ends of adjacent bunds within the same row is 20 m and a spacing of 30 cm is maintained between the tips of the lower row and the base bunds of the upper row (Fig. 32.9). Of course, the spacing may vary based on the requirement of the site conditions. However, the staggered configuration, as shown in Fig. 32.9, should always be followed. It is not recommended to build more than two rows of trapezoidal bunds since the third or fourth row receives significantly less runoff.

d. Catchment: Cultivated Area (C: CA) Ratio

In this case it is important to determine the necessary catchment size for a required cultivated area. It is sometimes more appropriate to approach the problem the other way round, and determine the area and number of bunds which can be cultivated from an existing catchment.

e. Bund Design

The configuration of the bunds is dependent upon the land slope, and is determined by the designed maximum flood water depth of 40 cm at the base bund. Consequently, as the gradient becomes steeper the wing walls extend to a relatively less distance towards upstream. The greater the slope above 0.5%, the less efficient the model becomes because of increasing earthwork requirements per cultivated area.

32.5.3 Maintenance

Any breach in the bund must be repaired immediately and the earth should be compacted thoroughly. Breaches are often caused by poor construction or because of the production of damaging runoff from the catchment area or both. It are advisable to construct a diversion ditch to protect the repaired bund.

Holes burrowed by rodents can be another cause of breaching. These should be filled in whenever spotted. Allowing natural vegetation to grow on the bunds leads to improved consolidation by the plant roots. Repairs to the wing tips will frequently be needed when overflow occurs. These should be built up immediately and extra stone pitching if required should be provided.

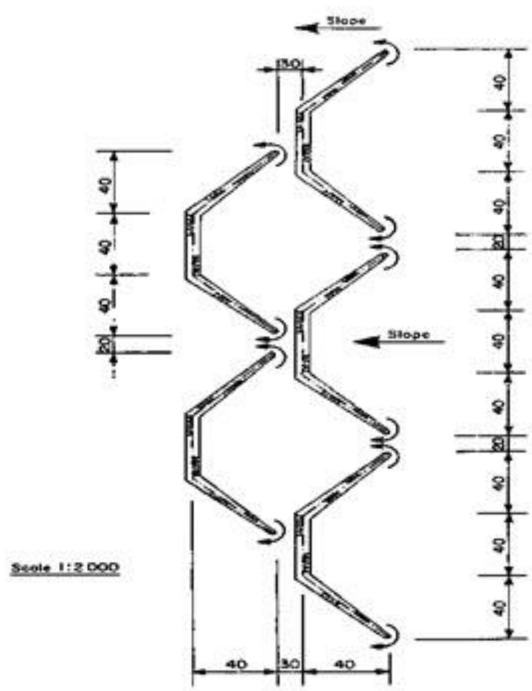

Fig. 32.9. Trapezoidal bunds field layout.

(Source: http://www.fao.org/docrep/u3160e/u3160e07.htm)

32.5.4 Husbandry

Trapezoidal bunds are normally used for production of annual crops in dry areas. The most common crops are cereals, and of these sorghum and pearl millet are by far the most usual ones. Sorghum is particularly appropriate for such systems because it is tolerant to both drought and waterlogging. In case of trapezoidal bund, the water tends to be unevenly distributed because of the slope, and ponding often occurs near the base bund. Likewise the upper part of the catchment may be relatively dry. Sorghum can tolerate both these situations.

Planting is carried out in the normal way after land preparation in the area within the bund. It is generally suggested to plough parallel to the base bund, so that the small furrows formed by ploughing will accumulate some water locally. In the driest areas planting is sometimes delayed until a runoff event has saturated the soil within the bund, and germination of the seeds or establishment of the tender crop is guaranteed. It is also possible to make use of off-season showers by planting a quick maturing legume, such as cowpea or tepary beans **(***Phaseolus acutifolius***).** Another useful technique is to plant cucurbits like gourds or watermelons on the bottom of bund if water ponds deeply.

32.5.5 Socio-economic Factors

It is difficult to generalize about the socio-economic factors concerning trapezoidal bunds, as different variations are found in different circumstances.

As mentioned previously, there are examples of similar structures being used traditionally in Sudan, Africa, where they are often made manually without assistance from any agency and evidently perform well. On the other hand trapezoidal or similar bunds have been constructed in other places using labours under projects food for work or by using heavy machinery. When this has been done without any significant beneficiary commitment, the bunds have been quickly abandoned. The amount of earth moving necessary for trapezoidal bunds indicates that their construction usually requires organized labour or machinery and is beyond the scope of the individual farmer. However, where adequate motivation exists, there is considerable scope for the technique which has a traditional basis and does not require new farming skills.

32.6 Contour Stone Bunds

32.6.1 Background

Contour stone bunds are used to slow down and filter runoff, thereby increasing infiltration and siltation. The water and sediment harvested lead directly to improved crop performance. This technique is well suited to small scale application on farmer's field and, under an adequate supply of stones, can be implemented quickly and cheaply.

Making bunds or merely lines of stones laid in layers is a traditional practice in parts of West Africa, notably in Burkina Faso. Improved construction and alignment along the contour makes the technique considerably more effective. The great advantage of the systems made of stone is that there is no need for spillways, where potentially damaging flows are concentrated. The filtering effect of the semi-permeable barrier along its full length gives a better spread of runoff than earth bunds are able to do. Furthermore, stone bunds require much less maintenance.
Stone bunding techniques for water harvesting (as opposed to stone bunding for hillside terracing, a much more widespread technique) is very much developed in Yatenga Province of Burkina Faso. It has proved to be an effective technique based on its wide spread adaptation and easy in construction.

32.6.2 Technical Details

a. Suitability

Stone bunds for crop production recommended for arid and semi-arid areas receiving mean annual rainfall of 200 – 750 mm. The soil should be fit for crop production with even topography and land slope, preferably, less than 2%.Availability of stones in the nearby locality is a major criterion for stone bunds.

b. Overall Configuration

Stone bunds follow the contour, or the approximate contour, across fields or grazing land. The spacing between bunds ranges normally between 15 and 30 m depending largely on the amount of stone and labour available (Fig. 32.10). There is no need for diversion ditches or provision of spillways.

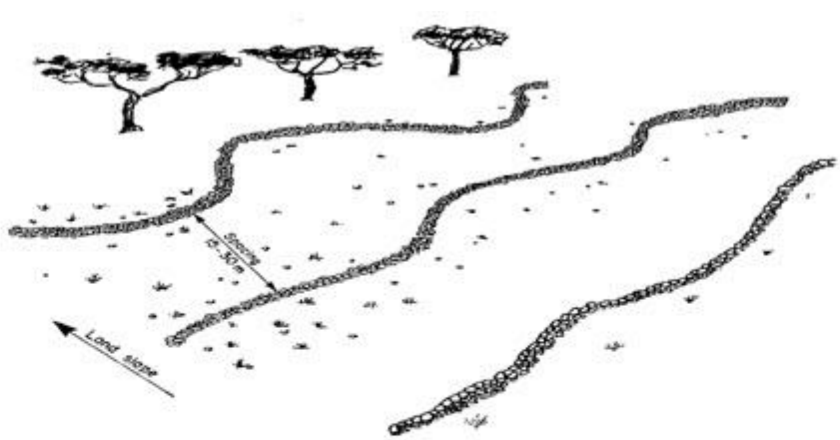

Fig. 32.10.Contour stone bund field layout.

(Source: http://www.fao.org/docrep/u3160e/u3160e07.htm)

c. Catchment: Cultivated Area Ratio

Contour stone bund is a long slope technique relying on an external catchment. Theoretical catchment: cultivated area (C: CA) ratios can be calculated using the formula given in the preceding chapter. Initially it is advisable to be conservative in estimation of areas which can be cultivated from any catchment. The area can be extended either down the slope or upstream in subsequent cropping seasons, if appropriate.

d. Bund Design

Although simple stone lines can be partially effective, an initial minimum bund height of 25 cm is recommended, with a base width of 35 - 40 cm. The bund should be set into a shallow trench, of 5 - 10 cm depth, which helps to prevent undermining by runoff. It is important to note that a mixture of large and small stones is a better for stone bunds. A common error is to use only large stones, which allow runoff to flow freely through the gaps in-between. The bund should be constructed according to the "reverse filter" principle which states that the smaller stones are to be placed upstream of the larger ones to facilitate rapid siltation. Bund spacing of 20 m for slopes less than 1%, and 15 m for slopes between 1 - 2%, respectively, are recommended.

e. Design Variations

Where there is not enough stone readily available, stone lines can be used to form the framework of a system. Grass, or other vegetative material, is then planted immediately behind the lines and forms, over a period of time, a living barrier which has a similar effect to a stone bund. Alternatively, earthen contour bunds can be constructed, with stone spillways set into them.

32.6.3 Maintenance

During heavy runoff events, the stone bunds may be overtopped resulting in dislodgement of some stones. It should be replaced immediately. A more common requirement is to plug any small gaps with small stones or gravel where runoff forms a tunnel through.

Eventually stone bunds silt-up, and their water harvesting efficiency declines. It normally takes three seasons or more to happen, and occurs more rapidly where bunds are wider apart, and on steeper slopes. Bunds should be built up in these circumstances with less tightly packed stones, to reduce siltation, while maintaining the effect of slowing runoff. Alternatively grasses can be planted alongside the bund. The grass supplements the stone bund and effectively increases its height.

32.6.4 Husbandry

Stone bunds in West Africa are often used for rehabilitation of infertile and degraded land. In this context it is recommended that the bunds be supported by a further technique of planting pits. These pits, which are usually about 0.9 m apart, are up to 0.15 m deep and 0.30 m in diameter. Manure is placed in the pits to improve plant growth. The pits also concentrate local runoff which is especially useful at the germination and establishment phase.

As in the case of all cropping systems under water harvesting, an improved standard of general husbandry is important to make use of the extra water harvested. Manuring is very important in fertility management. Apart from it, early weeding is also essential in areas of stone bunding as late weeding is often a constraint to production.

32.6.5 Socio-economic Factors

On-farm stone bunding for crop production is quickly appreciated and adopted by farmers. The techniques involved, including simple surveying, can be easily learned. The amount of labour required is reasonable, and where groups are organized to work in turn on individual member's farms, fields can be transformed in a single day. The benefits of stone bunding are often clearly seen already in the first season and this helps to make the system popular.

Nevertheless, there are some problems encountered in this system. Relatively rich farmers can make use of wage labour to treat their fields, and poor farmers may lag behind. Differing availabilities of stones can lead to inequalities between neighboring areas. Everyone may not be benefitted in the same way.

32.7 Permeable Rock Dam

32.7.1 Background

Permeable rock dams are long, low structures across valley floors which have the simultaneous effect of controlling gulley erosion while causing deposition of silt, and spreading and retaining runoff for improved plant growth (Fig. 32. 11). This is a floodwater harvesting technique.

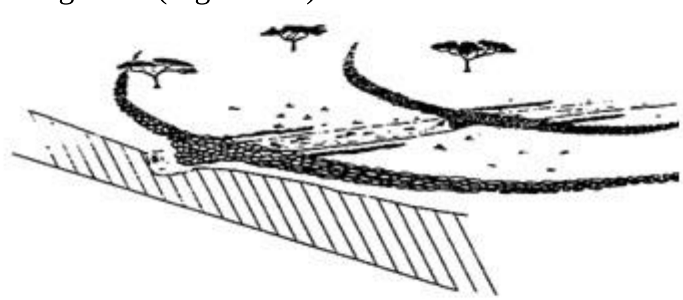

Fig. 32.11.Permeable rock dams. (Source: Critchley et al., 1992)

Permeable rock dams are usually constructed across relatively wide and shallow valleys. Some dams may require central spillways, especially where the water course is incised, but the majority of permeable rock dams will consist of long, low rock walls with level crests along the full length. This causes runoff to spread laterally from the stream course, and, if the dam is overtopped, results in water being distributed evenly along the length of the crest. Wing walls or spreading bunds on the dam should follow the contours away from the centerline of the valley or gully. In addition, contour stone bunds are sometimes used in association with rock dams, especially when the dams are widely spaced. Stone bunds are placed to prevent the overflow from the dam creating a gully downstream of the structure, which could erode back to, and undercut, the dam wall. In general, poor construction of dams at the head of gullies leads to their failure.

Each dam is usually between 50 and 300 m in length. The dam wall is usually 1 m in height within a gully, and between 80 and 150 cm in height elsewhere. The dam wall is also flatter (2:1) on the downstream side than on the upstream side (1:2), to give better stability to the structure when it is full. A shallow trench for the foundation improves stability and reduces the risk of undermining. Large stones are used on the outer wall and smaller stones internally.

32.7.2 Technical Details

a. Dam Design

The main part of the dam wall is usually about 70 cm high although some are as low as 50 cm. However, the central portion of the dam including the spillway (if required) may reach a maximum height of 2 m above the gully floor. The dam wall or spreader can extend up to 1000 m across the widest valley beds, but the lengths normally range from 50 to 300 m. The amount of stone used in the largest structures can be up to 2000 tonnes.

The dam wall is made of loose stone, carefully positioned, with larger boulders forming the framework and smaller stones packed in the middle like a sandwich. The side slopes are usually 3:1 or 2:1 (horizontal: vertical) on the downstream side, and 1:1 or 1:2 on the upstream side. With flatter side slopes, the structure is more stable, but more expensive.

For all soil types it is recommended to set the dam wall in an excavated trench of about 10 cm depth to prevent undermining by runoff waters. In erodible soils, it is advisable to place a layer of gravel, or at least smaller stones, in the trench.

b. Earthwork and Labour

The quantity of stone and the labour requirement for collection, transportation and construction depends on a number of factors and vary widely. The figures were calculated for a rock dam with an average cross section of 0.98 m^2 (70 cm high, base width of 280 cm) and a length of 100 m. The vertical interval between dams is assumed to be 0.7 m, which defines the necessary spacing between adjacent dams.

Transport of stones from the collection site to the fields in the valley is the normal method. Considerable labour may be required to collect, and sometimes break, stone. Labour requirements, based on field estimates, are in the range of 0.5 m^3 of stone per person per day excluding transport

32.7.3 Maintenance

The design given above, with its low side slopes and wide base should not require any significant maintenance work provided the described construction method is carefully observed. It will tolerate some overtopping in heavy floods. Nevertheless there may be some stones washed off, which will require replacing, or tunneling of water beneath the bund which will need packing with small stones. No structure in any water harvesting system is entirely maintenance free and all damage, even small, should be repaired as soon as possible to prevent rapid deterioration.

32.7.4 Husbandry

Permeable rock dams improve conditions for plant growth by spreading water, where moisture availability is a limiting factor. In addition, sediment, which will build up behind the bund over the seasons, is rich in nutrients, and this will further improve the crop growth.

This technique is used exclusively for annual crops. In the sandy soils, which do not retain moisture for long, the most common crops are millet and groundnuts. As the soils become heavier, the crops change to sorghum and maize. Where soils are heavy and impermeable, waterlogging would affect most crops, and therefore rice is grown in these zones. Within one series of permeable rock dams, several species of crops may be grown, reflecting the variations in soil and drainage conditions.

32.7.5 Socio-economic Factors

The implementation of permeable rock dams raises several important socio-economic issues. Many of these are rather specific to this technique. This is because permeable rock dams are characterized by:

- Large quantities of stone needed
- Outside assistance often necessary for transport of stone
- Limited number of direct beneficiaries
- Construction is often determined by the people rather than the technicians

As the structures cannot be made by individual farmers, it is necessary for others to cooperate in construction. It would be ideal if a village committee can be formed to co-ordinate efforts and discuss the situation of priority sites and beneficiaries. It is unrealistic to expect implementation of such a programme without outside help for transport of stones, which should be provided free of charge to the beneficiaries. Long-term sustainability and replicability of the form of development would best be promoted if beneficiaries could establish revolving funds for the hire or purchase of transport.

32.7.6 Effectiveness of the Technology

Permeable rock dams provide a more effective and popular technique for controlling gully erosion than gabions. Permeable rock dams, in addition to the effective control of gullies, have resulted in considerable increase in crop yield behind the dams. Gullies are rehabilitated by the deposition of silt behind the dams, increasing the depth and quality of the soil immediately behind the dam as a result of the deposition of fertile silt. They have also improved the amount of moisture available for crops. Yields of sorghum from land restored with permeable rock dams range up to 1.9 t/ha compared with a yield of 1 t/ha from equivalent untreated land. Other crops planted behind permeable rock dams include rice (on heavy soils), pearl millet and peanuts.

a. Suitability

This technology is appropriate for regions with less than 700 mm annual rainfall, where gullies are being formed in productive land. It is particularly suited to valley floors with slopes of less than 2%, and where a local supply of stones and the means to transport them is available.

b. Environmental Benefits

The control of gulley formation and the encouragement of silt deposition can have positive effects on a river course and water quality.

c. Advantages

Advantages to be obtained from employing this technology include:

- Increased crop production and erosion control as a result of the harvesting and spreading of floodwater
- Improved land management as a result of the silting up of gullies with fertile deposits
- Enhanced groundwater recharge
- Reduced runoff velocities and erosive potentials.

d. Disadvantages

The disadvantages of using this technology include:

- High transportation costs
- Need for large quantities of stone
- Site specificity.

32.8 Water Spreading Bunds

32.8.1 Background

Water spreading bunds are often applied in situations where trapezoidal bunds are not suitable, usually where runoff discharges are high and would damage trapezoidal bunds or where the crops to be grown are susceptible to the temporary waterlogging, which is a characteristic of trapezoidal bunds. The major characteristic of water spreading bunds is that, as their name implies, they are intended to spread water, and not to impound it (Fig. 32.12).

Fig. 32.12. Flow diversion system with water spreading bunds.
(Source: http://www.fao.org/docrep/u3160e/u3160e07.htm)

They are usually used to spread floodwater which has either been diverted from a watercourse or has naturally spilled onto the floodplain. The bunds, which are usually made of earth, slow down the flow of floodwater and spread it over the land to be cultivated, thus allowing it to infiltrate.

35.8.2 Technical Details

a. Suitability

Water spreading bunds are recommended for normally hyper arid or arid areas only receiving mean annual rainfall of 100 – 350 mm. The soil type should be of alluvial fan or floodplain with deep fertile soils. Most suitable slope for water spreading bunds is 1% or less.

b. Topography

The technique of flood water farming using water spreading bunds is very site-specific. The land must be sited close to a ephemeral stream or river or another watercourse, usually on a floodplain with alluvial soils and low slopes. This technique is most appropriate for arid areas where floodwater is the only realistic choice for crop or fodder production.

c. Catchment: Cultivated Area Ratio

The precise calculation of a catchment: cultivated area ratio is not practicable or necessary in the design of most water spreading bunds. The reasons are that the floodwater to be spread is not impounded. Major portion of flood water continues to flow through the system, and furthermore often only part of the stream flow is diverted to the productive area. Thus the quantity of water actually utilized cannot be easily predicted from the catchment size.

d. Bund Design

The land slope has a greater bearing on the design of the bund. Accordingly, its design for slope less than 0.5% and 0.5 to 1% is discussed here.

i) Slopes of less than 0.5%

Where slopes are less than 0.5%, straight bunds are used to spread water. Both ends are left open to allow floodwater to pass around the bunds, which are positioned at 50 m apart. Bunds should overlap in such a manner that the overflow around one should be intercepted by that below it. The uniform cross section of the bunds is recommended to be 60 cm high, 4.1 m base width, and a top width of 50 cm (Fig. 32. 13). This gives stable side slopes of 3:1. A maximum bund length of 100 m is recommended.

ii) Slopes of 0.5% to 1.0%

In this slope range, graded bunds can be used. Bunds, of constant cross-section, are graded along a ground slope of 0.25%. Each successive bund in the series down the slope is graded from different ends. A short wing wall is constructed at 135° to the upper end of each bund to allow interception of the flow around the bund above. This has the effect of further checking the flow. The spacing between bunds depends on the slope of the land. The bund cross section is the same as that recommended for contour bunds on lower slopes. The maximum length of a base bund is recommended to be 100 m.

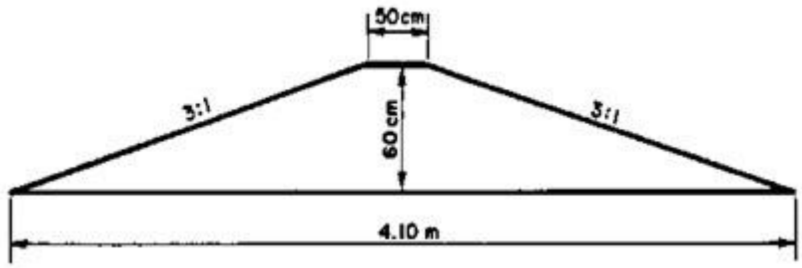

Fig. 32.13.Bund dimensions.
(Source: http://www.fao.org/docrep/u3160e/u3160e07.htm)

32.8.3 Maintenance

As is the case in all water harvesting systems based on earth bunds, breaches are possible in the early stages of the first season, before consolidation has taken place. Thus, there must be planning for repair work whenever necessary and careful inspection after all runoff events. In subsequent seasons the risk of breaching is diminished, when the bunds have consolidated and been allowed to develop vegetation. The vegetation on bunds helps bind the soil together, and reduces direct rainfall damage to the structures. Nevertheless with systems which depend on floodwater, damaging floods will inevitably occur from time to time, and repairs may be needed at any stage.

32.8.4 Husbandry

Water spreading bunds are traditionally used for annual crops, and particularly cereals. Sorghum and millet are the most common. One particular feature of this system, when used in arid areas with erratic rainfall, is that sowing of the crop should be undertaken in response to flooding. The direct contribution by rainfall to growth is often very little. Seeds should be sown into residual moisture after a flood, which gives assurance of germination and early establishment. Further floods will bring the crop to maturity. However if the crop fails from lack of subsequent flooding or if it is buried by silt or sand, as sometimes happens, the cultivator should be prepared to replant. An opportunistic attitude is required. Because water spreading usually takes place on alluvial soils, soil fertility is rarely a constraint to crop production. Weed growth however tends to be more vigorous due to the favourable growing conditions, and thus early weeding is particularly important.

32.8.5 Socio-economic Factors

As the implementation of water spreading systems is a relatively large-scale exercise, consideration has to be given to community organization. One particular problem is that the site of the activity may be distant from the widely scattered homes of the beneficiaries.

A detailed comparison of earthwork and stonework required for various water harvesting systems is presented in Table 32.2.

Table 32.2. Earthwork/stonework for various water harvesting systems (Source: http://www.fao.org/docrep/u3160e/u3160e07.htm)

→ System Name↓	Earthwork (m^3/ha treated)						Stonework (m^3/ha treated)	
	Negarim micro-catchments (trees)	Contour bunds (trees)	Semi circular bunds (grass)	Contour ridges (crops)	Trapezoidal bunds (crops)	Water spreading bunds (crops)	Contour stone bunds (crops)	Permeable rock dams (crops)
Slope %	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(8)**	**(6)**	**(7)**
0.5	500	240	105	480	370	305	40	70
1.0	500	360	105	480	670	455	40	140
1.5	500	360	105	480	970	N/R*	40	208
2.0	500	360	210	480	N/R*	N/R*	55	280
5.0	835	360	210	480	N/R*	N/R*	55	N/R*

* Not recommended

Water Quality of Harvested Water and Environmental Considerations

29.1 Introduction

Water is never found in pure state in nature. Essentially, all water contains substances derived from the natural environment and human activities. These constituents determine water quality. Water quality is a prime factr in determining the suitability of water supplied to satisfy the requirements of different uses. The quality of water in the ponds, lakes or reservoirs is influenced by the quality of runoff water entering into the pond, properties of the soil in the catchment and at the pond site; and any contaminants added to it due to human and animal activities.

Storing water in tanks, reservoirs poses quality and hygienic problems, especially in warmer climates. Thus water quality considerations differ between micro- and macro-catchment systems, and between systems with and without interim storage.

The implementation of water harvesting systems has numerous impacts on the environment e.g. on aquatic life and also on the spread of water related diseases

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29.2 Water Harvested for Human Consumption

Water for drinking purposes and other domestic uses must meet certain qualitative standards. World Health Organization (WHO) has prepared guidelines in 2004 for the provision of safe drinking water, including quality standards and information on the roles and responsibilities of various stakeholders involved in providing drinking water. However, the practical application of these requirements varies from place to place depending on the living standard of the community and type of water source.

The main water quality indicators of drinking water are characterized by their physical, chemical and biological parameters. The list of the main indicators/parameters includes:

- Alkalinity
- Colour of water
- pH
- Taste and odour
- Dissolved salts (sodium, chloride, potassium, calcium, manganese, magnesium)
- microorganisms such as *fecal coliform* bacteria (*Escherichiacoli), Cryptosporidium*, and *Giardia lamblia*
- Dissolved metals and metalloids (lead, mercury, arsenic)
- Dissolved organics such as dissolved organic matter dissolved organic carbon etc.
- Heavy metals

Thus, the basic requirements for safe drinking water can be outlined as:

- Free from disease causing organisms

- Free from compounds that have an adverse effect on human health
- Fairly clear(low turbidity and little colour)
- Without offensive taste or smell

29.3 Water Harvested for Crop Production

The quality of water used for irrigation is an important factor in productivity and sustainability of crop production. In evaluation of irrigation water, emphasis is laid down upon the physical and chemical characteristics of water and only rarely on any other factor considered important. In most of the locations where water harvesting for agriculture is practiced, the physical properties of water are much more important than chemical properties. In this context, attention is focused on the quantities of solids, nutrients and in rare cases the pollutants transported by the particles and the points of their deposition. Water infiltration is hampered when the sediment is rich in clay and/or contains relatively high sodium or low calcium content. If too little water infiltrates into the soil that means when more water evaporates, the crop may suffer from moisture stress and likely to wilt when the situation lingers.

Some of the chemicals used to treat the catchment and their final products may be harmful for the crops and affect plant growth. Also runoff water runs over salt bearing rocks carries dissolved salt that reduces crop growth. The parameters that influence the irrigation water quality are given in Table 29.1.

Table 29.1. Irrigation Water Quality Parameters
(Source: http://www.fao.org/docrep/003/t0234e/T0234E01.htm#ch1)

Water parameter	Symbol	Unit	Usual range in Irrigation Water
(i) Electrical Conductivity (ii)Total Dissolved Solids	EC_w TDS	dS/m mg/*l*	0 – 3 0 – 2000
Calcium	Ca^{++}	meq/*l*	0 – 20
Magnesium	Mg^{++}	meq/*l*	0 – 05
Sodium	Na^{+}	meq/*l*	0 – 40

Carbonate	CO_3^{--}	meq/*l*	0 – 0.1
Bicarbonate	HCO_3^-	meq/*l*	0 – 10
Chloride	Cl^-	meq/*l*	0 – 30
Sulphate	SO_4^{--}	meq/*l*	0 – 20
Nutrients			
Nitrate-Nitrogen	NO_3-N	mg/*l*	0 – 10
Ammonium-Nitrogen	NH_4-N	mg/*l*	0 – 05
Phosphate-Phosphorus	PO_4-P	mg/*l*	0 – 02
Potassium	K^+	mg/*l*	0 – 02
Miscellaneous			
Boron	B	mg/*l*	0 – 02
Acid/Base	pH		6 – 8.5
Sodium Adsorption Ratio	SAR	$(meq/l)^{0.5}$	0 – 15

29.4 Water Quality Considerations Related to Water Harvesting Systems

Various water harvesting systems for storing surface runoff and flood water are designed to meet the irrigation requirement of crops. Such systems may collect water from micro-catchments, long slopes and floods during rainy season.

29.4.1 Runoff Water from On-Farm Micro-Catchment Systems

Runoff water from the catchment is used directly without interim storage, to irrigate crops. The nutrients present in such runoff water are beneficial, but the other substances present in the sediments may be harmful as they reduce the physical quality of the water. When the catchment areas are treated with chemicals like herbicides and pesticides or even with chemical fertilizers before rainfall events, the harvested water is likely to get contaminated and pose a threat to the crops.

29.4.2 Long-slope Water Harvesting

Runoff water from long slopes is used to provide additional water to trees, bushes and annual crops on the cropped area. In most cases, the water is conserved directly in the soil profile although it is sometimes stored in cisterns, ponds or reservoirs. This water may also be used for livestock requirement and other domestic purposes. The catchments are either left in a natural state or cleared of vegetation and stones. In latter case, there is a high risk of soil erosion and hence the probability of sediment transport to stream channels and into the storage bodies is more. For small storage facilities, it may be possible to construct a sediment trap upstream of the reservoir. Most of the suspended sediments settle at the bottom of the trap and the clear surface water is directed towards the main storage facility. Part of the runoff water from the sediment trap may be lost due to evaporation but, in return entry of clean water increases the life of the storage structure. The best strategy for dealing with sediments is to prevent water and wind erosion. Provision of fencing or hedges around the ponds or reservoirs keeps animals and people away from direct contact of water. Sometimes direct drinking of water by animals from surface ponds contaminates the water.

29.4.3 Flood Water Harvesting

Flood water harvesting is commonly used to supply water to trees, bushes and annual crops. In a number of cases the water is stored in ponds and reservoirs. The water moves soil particles, which may carry nutrients as well as chemical pollutants. Sedimentation of distribution basins, canals and storage bodies is the consequent common problem because of large scale transportation of sediments with floodwater.

Deposition of sediments also changes the geometry of the section of ephemeral river beds. It reduces the channel cross section and also changes the hydraulic gradient. The effect is likely to spread along the upstream as well as the downstream of the section resulting in overflow at various sections along the bank during high flows. Banks may be eroded and the river bed may even change its course. During floods, large amount of sediment may be deposited on the floodplain, which may be beneficial in the long term but not desirable as far as the short term benefits are concerned. The more obvious problem produced by sediments is the loss of storage capacity of reservoirs. It is not uncommon for storage facilities to be completely filled with sediment within a few years of construction.

One efficient means to trap sediments is by constructing rock dikes across valleys to capture surface water. The sediments will settle and create a flat surface for growing crops, particularly trees with deep roots to reach the water stored in the trapped sediments. Stored water needs to be protected not only from evaporation and seepage loss but also from contamination. Contamination occurs mainly from human or other animal contact. Similarly stored water needs to be protected from disease vectors such as mosquitoes, files and mollusks.

29.5 Impacts on Downstream Ecosystems and Biodiversity

Usually aquatic flora and fauna develop in concert with existing water regimes. Implementing a water harvesting system alters the flow regime, which may cause some species to become stressed and die out. Other species that prefer the new flow regime will then colonize the riverbed and flood plain. These changes may be considered either desirable or undesirable based on their impact on the ecosystem. In most locations not only the aquatic species are adapted to the flow regime, but also the lifestyle of other species including humans is observed to be gradually fitting into the changing flow regime. In recent years it has been realized that many of the changes produced by significant modification flow regimes are undesirable. Downstream degradation of the aquatic flora and fauna produced by cutting off all flows will eventually be drastic and irreversible. Policies are being formulated to reduce the changes in the flow regimes such that the general environment downstream will not be drastically modified.

In most of the situations, the aquatic environments are not sufficiently understood for developing appropriate guidelines. Post-development flows are being set at about 25% of the pre-development situation with similar variability, but this is an arbitrary figure which has no scientific basis. Presumably it will be adequate to support some species, while others will disappear. Environmental flows, the flows needed to sustain the naturally occurring species, are difficult to define and are currently the subject of scientific and political debates. For many streams, maintenance of the flows necessary to support the natural systems means virtually no development. In other regimes particularly in semi-arid and arid regions, very little is known about possible effects of developing the very limited water resources. These effects may not be immediately apparent, but in the long run they will be noticed, and by then it would probably be impossible to reverse the effects even if there is a desire to do so.

However, water harvesting projects can also contribute to higher levels of biodiversity through demarcation of small areas at various locations (each of about 100 m^2) for the development and multiplication of natural flora by erecting fence around, prohibiting animal grazing and supplying harvested water.

29.5.1 Water-borne Diseases

Any form of water resources development through water harvesting intervention causes changes in natural conditions. Many of these changes offer opportunities for multiplication of disease vectors with devastating effects.

In regions where malaria, dengue fever or similar insect-transmitted diseases are endemic, storage of water on the surface needs to be accompanied by precautionary measures to prevent the water becoming a breeding site for these disease vectors. Where *schistosomiasis* is prevalent, measures must be taken to control the snail that is the intermediate host of the parasite.

It is important that planners, decision-makers and financiers take health issues into consideration when planning for any water resource development project. This will often require changes to the scheme and may raise the cost of the project. But with innovative ideas, the changes and the extra costs should not be very large. Examples are to be taken from other irrigation projects in regions where river blindness and *schistosomiasis* are endemic.

29.5.2Thermal Stratification

Thermal stratification refers to temperature differences in the water at various depths particularly in ponds or large lakes of depth greater than 2 m. Energy from solar radiation heats the surface layers and the heat is transferred to the lower layers by mixing with water and wind effects. However, warm water is lighter than cool water and wind induced circulation cannot mix them with deeper layers of cool water. This causes thermal stratification. The layer relatively warm surface water is known as the epilimnion, and the bottom layer of cooler water is known as the hypolimnion. The temperature changes rapidly with increasing depth in the transition zone between the epilimnion and hypolinion and this transition zone is known as the thermocline (Fig. 29.1).

Thermal stratification influences the photosynthetic activity of plant species in the ponds and consequently the dissolved oxygen in the water. It also influences the chemical stratification in water bodies. For pisciculture purposes the water depth in the ponds is kept around 2 m and in such cases the changes due to thermal stratification are undesirable. It is necessary to understand the water quality aspects in ponds in relation to the use of the water.

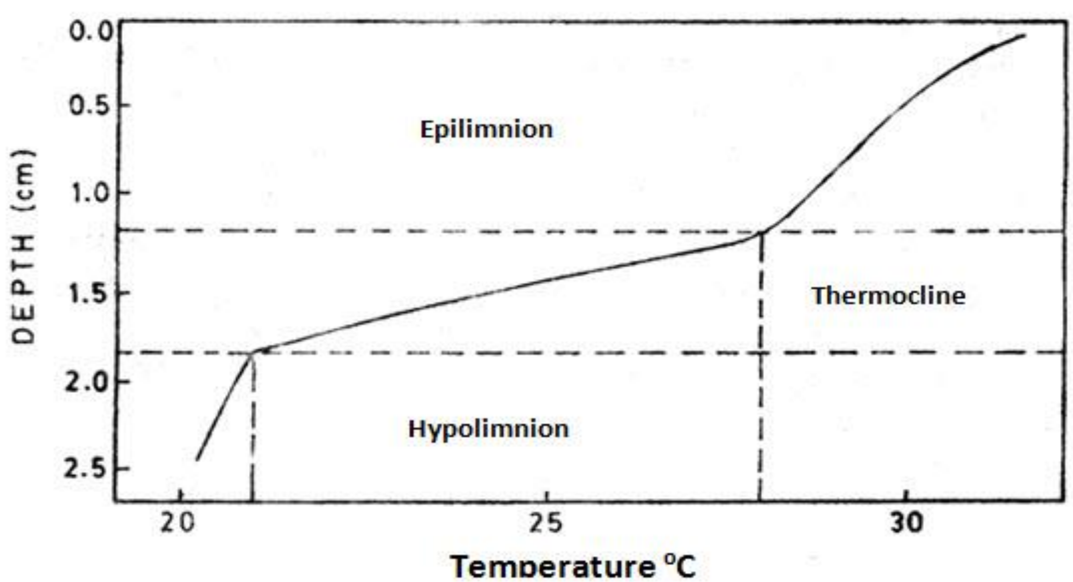


Fig. 29.1.Thermal stratification in pond.
(Source: http://www.fao.org/docrep/field/003/ac174e/AC174E02.gif)

Reservoir/Dam and Farm Ponds

4.1 Definition

A dam may be defined as an obstruction or a barrier built across a stream or a river. At the upstream of this barrier, water gets collectedforming a pool of water. The side on which water gets collected is called the upstream side, and the other side of the barrier is called the downstream side. The lake of water which is formed upstream is often called a reservoir, or a dam reservoir, or a river reservoir, or a storage reservoir.

The water collected in this reservoir can be supplied for irrigating the farm lands through a system of canal network, or may be supplied for drinking purposes. The lake so formed can be used for recreation uses also. The energy of this collected water can be used to turn the blades of a turbine to generate electrical power. And in times of floods, the dams can serve as protections for the towns and cities farther down the river.

Apart from these numerous advantages and uses (such as navigation, irrigation, electricity, flood control, etc.) of a dam, it sometimes helps us in planning war strategy and helps us in controlling the advanceme0nt of enemies and their forces. Dams have been frequently opened in times of war. The Dutch breached their dikes during second world war to bedevil the invading Germans, Chinese used to marauders, partly destroyed the famous Dnieprostroi Dam in the Ukraine to keep its power plant from failing into the hands of Hitler's men.

4.2 Classification of Dams

Dams can be classified depending upon the materials used for construction, use and design as follows

:

4.2.1 Classification According to the Material used for Dam Construction

The dams classified according to the material used for construction are of seven types. Three of them are of ancient origin and four have come into general use only in the last century. The dams of ancient origin are:

- Earth dam
- Rock-fill dam
- Solid masonry gravity dams

The dams introduced in the last century are:

- Hollow masonry gravity dams
- Steel dam
- Timber dams
- R.C.C Arch dam

(1) Earth Dam: Earth dams are made of soil that is pounded down solidly. They are built in areas where the foundation is not strong enough to bear the weight of concrete dam, and where earth is more easily available as a building material compared to concrete or stone or rock (Fig. 1).

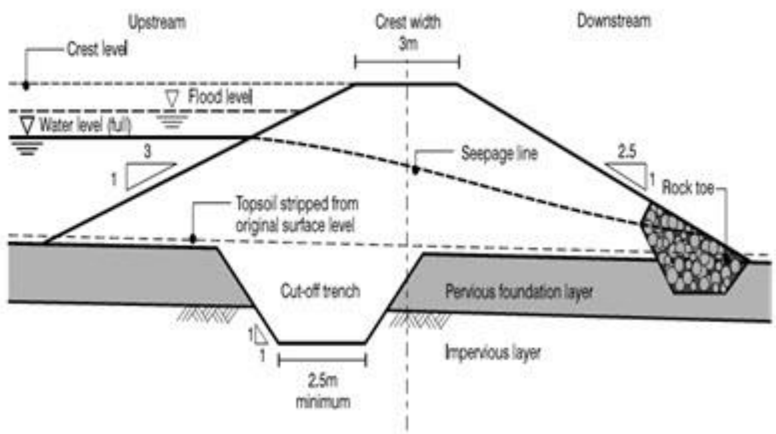


Fig. 4.1. Cross sectional view of earth dam. (Source: Nelson, 1985)

(2) Rock-fill dam: Rock-fill dams are formed of loose rocks and boulders piled in the river bed (Fig. 2). A slab of reinforced concrete is often laid across the upstream face of a rock-fill dam to make it water-tight.

(3) Solid masonry gravity dam: These dams are big in size and quite expensive to be built but are more durable and solid than earth and rock-fill dams. They can be constructed on any dam site, where there is a natural foundation strong enough to bear the heavy weight of the dam (Fig. 3).

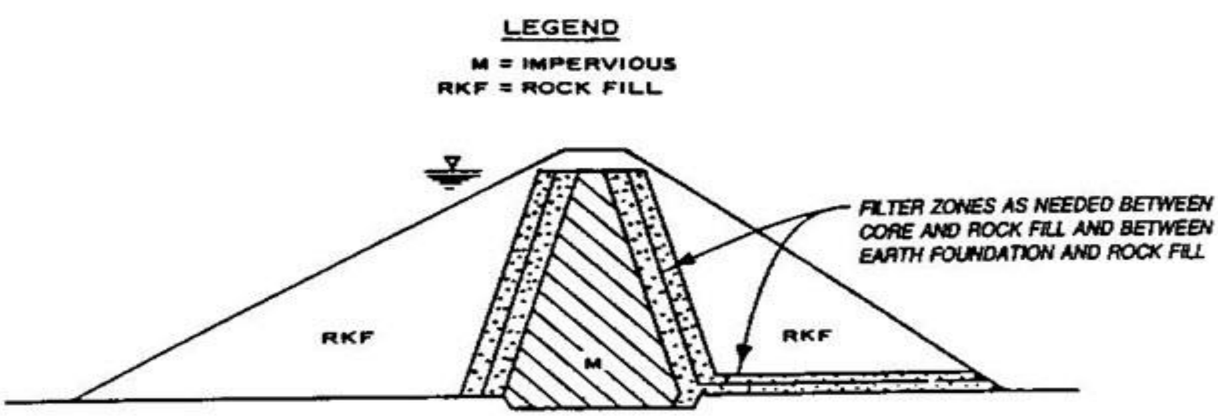


Fig. 4.2. Cross sectional view of rock fill dam.

(Source: http://www.enggpedia.com/civil-engineering)

Fig. 4.3. Photograph of a Solid masonry gravity dam.
(Source: http://en.wikipedia.org/wiki/File:Grand_Coulee_Dam_spillway.jpg)

(4) Hollow Masonry Gravity Dam: It is essentially designed on the same principle of solid masonry gravity dams. But the difference is that it contains less concrete or masonry to the tune of 35 to 40%. Generally, the weight of water is carried by a deck of R.C.C. or by arches that share the weight burden. It is difficult to construct this type of dams and is adopted only if highly skilled labour is available. Otherwise the labour cost becomes too high to construct such complex structure.

(5) Steel Dam: Today, steel dams are used as temporary coffer dams required for the construction of permanent dams. Such coffer dams made of steel are usually reinforced with timber or earth-fill (Fig. 5).

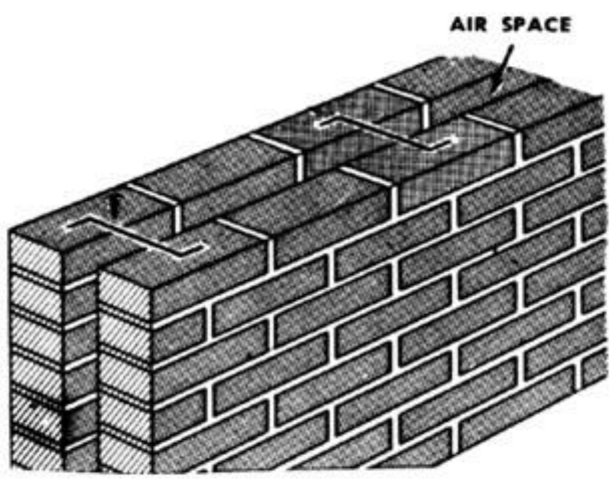


Fig. 4.4. Hollow masonry gravity dam.

(Source: http://encyclopedia2.thefreedictionary.com)

Fig. 4.5. Photograph of a steel dam.
(Source: http://roadtrekin.blogspot.in/)

(6) Timber Dam: These dams are short lived because rotting sets in a few years time. In spite of regular maintenance, the life of a timber dam is not more than 30 to 40 years. However, these are useful for low level needs in agricultural sector (Fig. 6). For example, a cattle-raiser may need a pool for the purpose of drinking and bathing of his livestock and other related needs.

(7) Arch Dam: Arch dams are very complex and complicated. They make use of horizontal arch action in place of weight to hold back the water (Fig. 7). They are best suited at sites where the dam must be extremely high and narrow.

Fig. 4.6. View of a timber dam.

Fig. 4.7. View of an Arch dam.

(Sources: http://civilsolution.wordpress.com/ , http://www.stucky.ch/)

4.2.2 Classification of Dams According to their Use

Based on the use, the dams are divided into three types such as storage dams, diversion dams and detention dams.

(i) Storage Dam: These dams are constructed to store water during the periods of surplus supply and the stored water is used later during the periods of deficient supply (Fig. 8). In countries like India,where the rainfall pattern is very erratic, huge amount of rainfall received during monsoon months flows down wastefully and later on when the crops suffer from drought due to dry spells. The water stored by these dams during rainy season is used for irrigation to the crop fields during dry spells as well as in post-monsoon period. The other uses of these water sources may be for town water supply, pisciculture, navigation, recreation, electricity generation etc.

(ii) Diversion Dam: These are small dams used to raise the water level in the rivers in order to feed off-taking canals or some other conveyance systems. A diversion dam is generally called as a weir or a barrage based on its design specifications (Fig. 9). It is a very useful component in irrigation projects.

(iii) Detention Dam: Flood in rivers during rainy season is a common phenomenon in India. It happens so due to sudden in-rush of runoff from the upper reaches of the river. Detention dams are constructed at various locations of head water tributaries to retard the flood runoff and detain the flood water temporarily (Fig. 10). Thus, the adverse effects of sudden flood are minimized. Sometimes the detention dams are used to trap sediments and so also called debris dam.

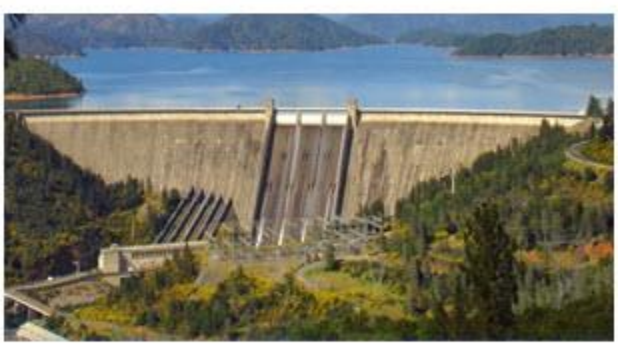


Fig. 4.8. View of a Storage dam.

Fig. 4.9. View of a Diversion dam.

Fig. 4.10. View of a Detention dam.
(Sources: http://www.azwater.gov, http://www.internationalrivers.org/)

4.2.3 Classification of Dams According to Hydraulic Design

Based on the hydraulic design, the dams are divided into three types such as overflow dams, non-overflow dams, rigid dams and non-rigid dams.

(i) Overflow Dam: An overflow dam is designed topass the surplus water over its crest. So, these dams are also called spillways. While choosing the materials for construction of these dams,care should be taken to see that they are non-erodible under such discharges.

(ii) Non-Overflow Dam: These dams are not designed to be over-topped. This type of design gives us wider choice of materials including that of earth-fill and rock-fill dams.
Many a time, the overflow and the non-overflow dams are combined together to form a composite single structure.

(iii) Rigid Dam: Rigid dams are those which are constructed of rigid materials like masonry, concrete, steel, timber, etc.

(iv) Non-Rigid Dam: The non-rigid dams are constructed of earth and rock-fill. Discussion on earth and rock-fill dams has been made in section ---.

4.3 Selection Criteria of a Dam

Whenever we decide to construct a dam at a particular place, the first baffling problem before us is to choose the right type of dam. Suitability and economic viability of the dam are the most vital points to be considered. The most economical one among the list of technically feasible dams should be the first choice of the planners while selecting a dam. Various designs and their estimates of the dams are to be prepared before recommending a particular type of dam. Various factors which must be thoroughly considered before selecting a dam are described below:

4.3.1 Topography

The land configuration otherwise known as the topographyof the location, where the dam is to be constructed, is considered to be the foremost criterion for deciding the type of dam. For example:

1. A narrow U-shaped valley obviously allows a narrow stream of water flowing between high rocky walls at its both sides. A concrete overflow dam is usually recommended for this condition.
2. A low rolling plain landscape would naturally suggest an earth-fill dam with a separate spillway.
3. Availability of spillway site is also very much important while selecting a particular type of dam.
4. A narrow V-shaped valley indicates the choice of an arch dam. The ratio of the top width and the height of the valley, where the dam is to be constructed, should be preferably less than or equal to 1:4. In this condition, it may not be possible to have the spillway as an integral part of the dam. Rather it is suggested to have a separate site for the spillway.

4.3.2 Geology and Foundation Conditions

The natural foundation, on which the dams are to be constructed, should carry the weight of the dam. The dam site must be thoroughly surveyed by geologists, so as to detect the thickness of the foundation strata, presence of faults, fissured materials, and their permeability, slope and slip etc.

Various kinds of foundations generally encountered are discussed below:

1. **Solid Rock Foundation:** Solid rock foundations such as granite, gneiss etc. have a strong bearing power. They offer high resistance to erosion and percolation.Almost every kind of dam can be built on such foundations. Sometimes, seams and fractures are present in these rocks and they must be grouted and sealed properly.
2. **Gravel Foundation:** Course sands and gravels are suitable for earth and rock-fill dams as they are unable to bear the weight of high concrete gravity dams. Low concrete gravity dams up to a height of 15 m may be suggested on such foundations.These foundations have high permeability and, thereforesubjected to water percolation at high rates. Suitable cut-offs must be provided to avoid the danger of undermining.
3. **Silt and Fine Sand Foundation:** Silt and fine sand foundation is suitable for earth dams or very low gravity dams(up to height of 8 m). A rock-fill dam on such a foundation is not suitable. Seepage through such foundation may be excessive. Settlement may also be a problem. Such foundations are vulnerable to erosion at the downstream toe and so

necessary protection against such erosion must be ensured.The dams on such foundation must be properly designed to avoid such dangers.

4. **Clay Foundation:** Unconsolidated and high moisture clays are likely to cause enormous settlement of the dam. Concrete gravity dams or rock-fill dams are not suitable in such foundations. Earthen damsafter special treatment may be recommended for such foundations.
5. **Non-uniform Foundation:** At certain places a uniform foundation of the types described above may not be available. In such cases, a non-uniform foundation of rock and soft material is to be used for construction of the dam. Such unsatisfactory conditions are to be dealt with by special designs. However, every problem is an individual problem and a solution has to be found by experienced engineers. For example- the Jawahar Sagar dam in Rajasthan offers such problem. A bed of clay,if encountered,between the base of the dam and solid rock foundation, it is not economically feasible to remove it. In such condition, the problem is sorted out through anchoring of the base of the dam to the foundations below by means of pre-stressed cables.

4.3.3 Availability of Materials

In order to achieve economy in dam construction, the materials required for it must be available locally or at short distances from the construction site. Sometimes, good soil is easily available, which naturally calls for an earthen dam. If sand, cement and stone etc. are easily available, one should naturally think of a concrete gravity dam. If the material has to be transported from far off distances, then a hollow concrete dam(Buttress) is a better choice.

4.3.4 Spillway Size and Location

Spillway, as discussed earlier, disposes the surplus river discharge. The capacity of the spillway depends on the magnitudes of the floods to be by-passed. The spillway will, therefore, become much more important on streams with large flood potential. On such rivers, the spillway becomes a primary structure and the type of dam becomes a secondary consideration.

The cost of construction of a separate spillway may be enormous or sometimes a suitable separate site for the spillway may not be available. In such cases, it is desirable to combine the spillway and the dam as one structure leading to adoption of a concrete overflow dam.

At certain places, where the excavated material from a separate spillway channel can be utilized in dam embankment, an earth-fill dam may prove to be advantageous. Small spillway requirement often favours the selections of earth-fill or rock-fill dams even in narrow dam sites.

The practice of building a concrete spillway on earth and rock embankments is being discouraged these days, because of their conservative design assumptions and the vigil and watch required during their operations.

4.3.5 Earthquake Zone

If the dam is to be situated in an earthquake zone, its design must include the earthquake forces. Its safety should be ensured against the increased stress induced by an earthquake of worst intensity. The type of structures best suited to resist earthquake shocks without danger are earthen dams and concrete gravity dams.

4.3.6 Height of the Dam

Earthen dams are usually not provided with heights more than 30 m or so. Hence, for greater heights, gravity dams are generally preferred.

4.3.7 Other Considerations

Various other factors such as the life of the dam, the width of the roadway to be provided over the dam, problem of skilled labour, legal and aesthetic points must also be considered before a final decision on dam. However, the overall cost of construction and maintenance; and the funds available will finally decide the choice of a particular kind of dam at a particular site.

4.4 Introduction and Classification Farm Ponds

4.4.1 Introduction

Farm ponds are the most commonly used sources of ex-situ water harvesting structures. In addition to receiving direct rainfall, provision is also made to allow the runoff, generated from the upper reaches, to enter into it.It has wide adaptability in farmers' fields and is used as a handy source of water supply to crop fields. Such ponds are in use since time immemorial not only as assured sources of water supply to crops but also for pisciculture, livestock consumption and meetingthe demands from other sectors etc. However, these ponds have wide variations in shape and size as per the method of construction and their suitability to different topographic conditions. Most of the ponds, initially, constructed in fields are of regular shape. As time progresses,these ponds lose their regular shape and become irregular due to poor repair and maintenance.

4.4.2 General Classification of Pond

Based on the method of construction, location and purpose of use, the farm ponds are divided into several types. A general classification of farm ponds is discussed below:

1. Dugout pond
2. Surface pond
3. Spring or creek fed pond
4. Off-stream storage pond
5. Seepage pond
6. Pump-fed pond and
7. Embankment pond

(i) Dugout Pond

Dugout ponds also called excavated ponds as they are constructed by digging the soil. Ideal location for this pond is flat topography. The excavated soil is used in construction of embankments around the ponds. These ponds collect in-situ rainwater, surface runoff from the adjacent catchments and groundwater. The harvested water is lifted by means of indigenous lifting devices and pumps forvarious purposes such as irrigation, domestic water supply, livestock consumption etc. Excavated ponds are usually generally designed with a regular shape. The conventional shapes of the ponds may be square, rectangular or circular. Out of the three shapes, the circular pond has the highest storage capacity and the least perimeter for a given surface area and side slope. A comparison has been shown in Table 2.1.

Table 2.1. Perimeter and storage capacity of different shaped farm ponds

Shape of pond	**Side slope**	**Perimeter (m)**	**Storage capacity (m^3)**
Circular	1:5:1	105	1499
Square	1:5:1	120	1464
Rectangular	1:5:1	122	1458

N.B.: Each pond has equal surface area of 900 m^2 and equal depth of 2 m.

However, it is difficult to construct circular shaped ponds. Therefore, the square and rectangular shaped ponds are widely adopted. For the same sizeof pond, the total dike length is more in case of rectangular shape than a square one. The perimeter of the pond increases as the shape gets more and more elongated resulting in increase of the construction cost. The dimensions and perimeter ofdifferentfarm ponds having same size of 400 m^2 are presented in Table 2.2.

Table 2.2. Dimensions of farm ponds of size 400 m^2 and of different shapes

Pond shape	**Length: width**	**Width (m)**	**Length (m)**	**Perimeter (m)**
Square	1:1	20.00	20.00	80.00
Rectangular	2.1	14.14	28.28	84.85
	3:1	11.55	34.64	92.37
	4:1	10.00	40.00	100.00

Square ponds are preferred when the pond size is small, less than or equal to 400 m^2, because of low construction cost. For ponds larger than 400m^2 size, the rectangular ponds are recommended.

(ii) Surface Pond

Surface ponds, also called as excavated-cum-embankment type ponds, are the most common types of farm ponds. They are partly excavated in ground where there is some depression and the excavated soil is used for the construction of the embankments. The dugout soil is utilized for the construction of the embankments of the ponds so that the pond can store maximum amount of water. These ponds are mostly fed by surface runoff although they catch in-situ rainfall and so, at times called as watershed ponds. Normally they get no supply during the dry season. Water from these ponds flows out by gravity till the water level in the pond reaches the ground level and then the rest amount of stored water is pumped out. Selection of site of these ponds is therefore very important.

(iii) Spring or Creek Fed Ponds

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

(iv) Off-Stream Storage Ponds

Such ponds are constructed by the side of the streams which flow only seasonally. They are so called since they are used to store the diverted seasonal water of the stream. These ponds also called barrage ponds as they are fed directly by the water running straight out from the water body to the ponds or diversion ponds as the water entering a channel is fed indirectly to the ponds in a controlled manner.

(v) Seepage Ponds

These ponds are supplied with water from the water table by seepage. The water level in the pond will vary according to the level of water table in the adjacent aquifer.

(vi) Pump-Fed Ponds

These ponds are normally at higher level than the water level in adjacent water sources such as a well, spring, lake or irrigation canal and are supplied water from these sources by pumping.

(vii) Levee Pond

These types of ponds are formed by embankments and are usually of a regular shape (rectangular) and are of uniform depth. They are fed with water from wells, storage reservoirs, streams or estuaries. They are mostly used in aquaculture.

4.4.3 Lined and Unlined Ponds

The ponds discussed above may be of lined or unlined types. Unlined ponds have no linings and are otherwise called earthen ponds. They have high seepage losses and hence their storage capacity decreases with time after cessation of rainfall. The rate of seepage losses gradually decreases with deposition of silt in the bottom and sides of the ponds. On the contrary, a lining material is provided either on the sides or bottom or both of the ponds to check the seepage losses in case of lined ponds. Consequently, these ponds have low or even no seepage loss and high storage capacity compared to the unlined ones. The lined ponds are named depending on the types of lining material. Some of the commonly used lined materials are polyethylene, bitumen, clay, brick and cement-concrete etc.

Some more types of ponds based on the purpose of use are walled ponds, drainable ponds, un-drainable ponds, pump drained ponds, cut and fill ponds etc.

Depending on the way the ponds fit in with the features of the local landscape, they have been conveniently grouped into three basic types such as sunken pond, barrage pond and diversion pond.

Sunken Ponds

A sunken pond is leveled with the ground surface and completely dug out. If it is required to have a sunken pond of 4 ft. deep, it needs to be dug 4 ft. down.

Following features are associated with sunken ponds:

- The floor of the pond is generally below the level of the surrounding.
- The pond is directly fed by groundwater, rainfall and/or surface runoff. It can also be fed by pumping.
- It is not drainable or partially drainable.
- These are sometimes constructed in the bottom of the valley by building a dam across the downstream end or in a series down the valley.

Barrage Ponds

Barrage ponds are made by building a wall across a small stream and the ponds are, therefore, like small conservation dams. Water for these ponds comes from a springor seepage area. It is very important that ponds of this type should not be constructed in places where there will be a very large flood of water down the stream in the rainy season.Sometimes barrage ponds are made below large conservation dams making use of seepage water. Barrage ponds have the following features:

- It is drainable through the river bed.
- It may have diversion canal or without. If large floods are present, the excess water is normally diverted around one side of the pond through a diversion canal. The pond water

level then is controlled through water intake. Water enters directly to the pond from a spring, reservoir, lake etc. through a point called as inlet and flows out at another point called as outlet.

- To protect the pond dike from floods, a spillway is built.

Diversion Ponds

Diversion ponds are constructed by bringing water from another source to the pond.The features of the diversion pond are:

- The diversion ponds are fed directly by gravity or by pumping through a diversion canal from a spring, lake or reservoir. The water flow is controlled through a water intake. There is an inlet and outlet for each pond.
- They can be constructed either in sloping ground as a cut and fill pond or in a flat ground as a four dike embankment pond sometimes called as paddy pond.
- It is usually drainable through a drainage canal.

It is important to note that the choice of a particular type of pond largely depends on the kind of water supply available and on the existing topography of the site selected. For an example, if the valley bottom is 50 to 100 m wide, barrage ponds might be appropriate and when the valley bottom is more than 100m wide, diversion ponds may be built. However, when there are choices of several types of ponds, one should give highest priority to diversion ponds fed by gravity and lowest priority to barrage ponds in flooding areas requiring large diversion canals.

Shallow and Deep Ponds

Depending on the depth of water, the pond may be classified as shallow or deep pond. Except in some barrage ponds built on streams with steep longitudinal slope, fish ponds are generally shallow. Their maximum water depth is limited to 1.5 m. The depth of the pond should be at least 0.5 m to limit the growth of aquatic plants. The water depth in small ponds in many of the rural areas varies from 0.5 to 1 m. It is to be noted that the deeper ponds are much more expensive to excavate because of increasing exposed area and volume of earth works. Furthermore, the lifting of the excavated earth materials becomes difficult and requires more labour works and hence, wages. However it has some advantages too. In dry regions with more evaporation losses, deeper ponds are useful to reduce the evaporation loss and enable the pond users to have enough storage for pisciculture, domestic and agricultural uses. Even in the cold regions, where it may be necessary to provide the fish with a refuge in deep ponds, warmer water is useful during the cold weather

Farm Ponds

Farm ponds have a significantly role in rainfed farming system where annual rainfall is more than 500 mm. It helps in mitigating the ill effect of rainfall variability as it stores water from rainfall excess and provides for utilization during prolonged dry spells by means of supplemental/protective irrigation. It also helps in pre-sowing irrigation of *rabi* crop. In high rainfall semi-arid regions of India, farm pond can be used for multiple uses such as protective/supplemental irrigation, fish culture, duck farming integrated with poultry.

27.1 Types of Farm Ponds

Broadly farm ponds can be categorized into two type i.e. embankment type and excavated or dugout type.

27.2 Embankment Type

These type farm ponds are constructed across the stream or water course and consist of an earthen dam. Dimension of embankment are determined based on the required storage. These ponds are suitable for areas having gentle to moderately steep slope and also where stream valleys are sufficiently depressed to permit a maximum storage volume with least earth work. Given the Indian farming system, this type of pond is constructed largely at common land resources as it requires substantial land under submergence.

27.2.1 Capacity of the Ponds

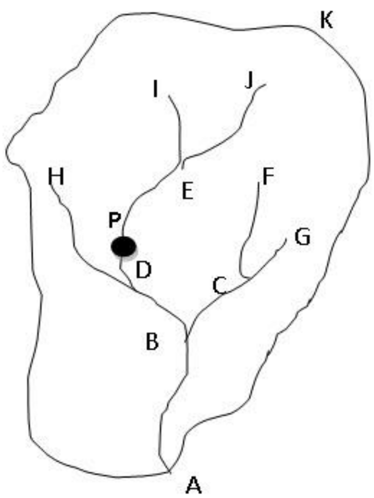
The capacity of the pond is calculated using trapezoidal or Simpson's rule. In trapezoidal rule, the volume of storage (δV) between two successive contours is given as: $\delta V = \frac{h}{2}(A_u + A_l)$, in which his contour interval and and are area bounded by upper and lower contour respectively.

In Simpson rule which is more accurate than trapezoidal method, the volume is estimated as:

$$V = \frac{h}{3}\begin{bmatrix} Twice\ the\ area\ of\ Odd\ contours + \\ 4\ times\ the\ area\ of\ even\ contours + \\ Area\ of\ the\ first\ and\ last\ contours \end{bmatrix} \qquad (27.1)$$

The design aspect of earthen embankment has been discussed in lessons 23 and 24. Like any hydraulic structures, the embankment design also includes hydrologic design, hydraulic design

Example 27.1: Design of Embankment Type Farm Pond



Let's assume to construct an embankment type pond in the watershed shown in Fig. 27.1 at location P. The detailed contours are presented in fig. 27.2. The embankment proposed to have maximum water level at 216 m. The dotted line represents the natural stream IE and JEP of this figure. Pond receives runoff during monsoon rain only. The catchment area is 65 ha. Following data are available.

1. Average annual monsoon rainfall: 750 mm
2. The site condition is such that the 20% of average annual monsoon rainfall is received by the pond as runoff.
3. Rainfall intensity for 25 years return period is 90 mm/hr and daily rainfall is 300 mm.
4. The average sedimentation @ 40t/ha/annum during first 5 years followed by 20, 10, 5 and 2 t/ha/annum in every succeeding 5 years.
5. The soil contains silt and clay with low compressibility.
6. Channel length is 1.2 km, and slope is 2%.

Fig. 27.1. Watershed Map.

and structural design.

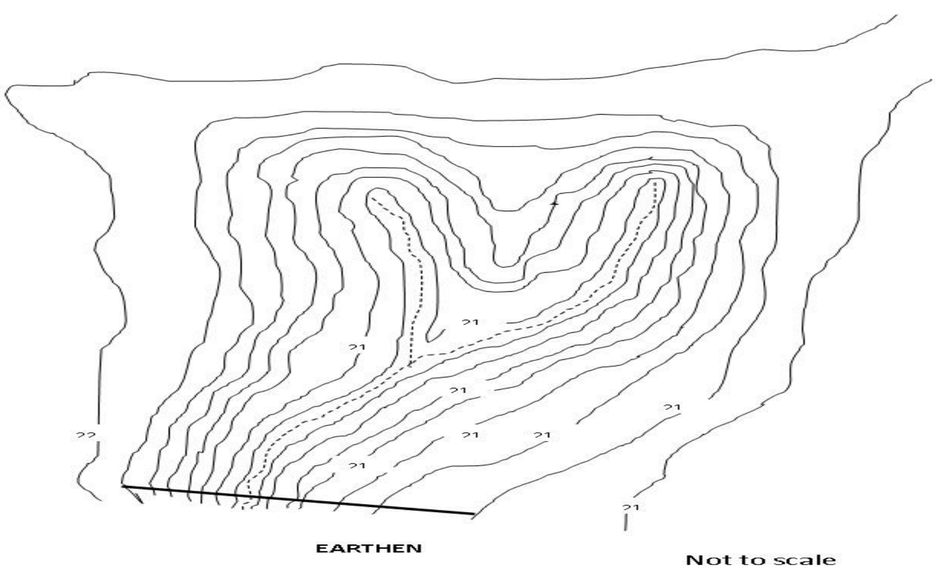


Fig. 27.2. Contour map of the area.

The storage capacity at different heights of the embankment is presented in Table 27.1.

Table 27.1Storage capacity at different height of embankment

Contour level	Contour Interval	Maximum Water Depth	Area Bounded by (Ha)		Incremental Volume, Using Trapezoidal Method (ha-m)	Cumulative volume (ha-m)
			Upper contour, A_u	Lower Contour, A_l		
211	1	0	0.4	0	0.20	0.20
212	1	1	1.5	0.4	0.95	1.15
213	1	2	2.6	1.5	2.05	3.20
214	1	3	3.7	2.6	3.15	6.35
215	1	4	4.3	3.7	4.00	10.35
216	1	5	5.6	4.3	4.95	15.30
217	1	6	6.5	5.6	6.05	21.35

Like drop structures, here also the pond is designed under heading of hydrologic design, hydraulic design and structural design.

A. Hydrologic design

(i) Water Yield Estimation

Average annual monsoon rainfall =750 mm. Expected runoff volume or water yield from 65 ha catchment considering 20% of the rainfall as the runoff

$$= \frac{65 \times 750 \times 20}{1000 \times 100} = 9.75 \text{ ha-m}$$

(ii) Estimation of Peak Discharge

Rational formula, $Q = \frac{CIA}{360}$

Time of concentration to determine, I

$$Tc = 0.01947K^{0.77}\ ;\ K = \sqrt{\frac{L^3}{H}} = \sqrt{\frac{1200^3}{24}} = 8485$$

And Tc = $0.01947(8485)^{0.77}$ = 20.62 min say 21 min.

From chart (relation of one hour rainfall intensity to intensities at other duration), I for 21 minutes = 160mm/hr

Thus the peak discharge (assuming runoff coefficient, C, as 0.3)

$$Q = \frac{0.2\times160\times65}{360} = 5.77\text{cumec.}$$

(B) Hydraulic Design

(i) Storage Capacity

Total storage capacity = live storage+dead storage

Live storage: 9.75 ha-m as determined from hydrologic design

Dead storage:

First 5 years @40 t/ha/annum = 200 t/ha

5-10 years @ 20 t/ha/annum = 100 t/ha

10-15 years @10 t/ha/annum = 50 t/ha

15-20 years @5 t/ha/annum = 25 t/ha

20-25 years @ 210 t/ha/annum = 1050 t/ha

Total = 385 t/ha

Total sediment yield during 25 years from 65 ha catchment

= 25 X 385 = 9625 ton

Assuming the bulk density of the sediment as 1.5 g/cc,

1 ha-m of sediment = 15000 tonnes

Thus dead storage = 9625/15000 = 0.64 ha-m.

Thus total storage capacity required = 9.75+0.64 = 10.39 ha-m.

From storage capacity table, the dead storage of 0.64 corresponds to 212 m contour level which will the top level of dead storage. The total capacity of 10.91 ha-m corresponds to 215.2 m contour. Thus the net height of the embankment at maximum water level will be 215.2 - 211 = 4.2 m. in which maximum water depth would be 3.2 meter.

(iii) Height of the Embankment

Height of water upto full level = 215.2 – 211.0 = 4.2 m

Height of free board (15%) = 15% of 4.2 m = 0.63 m.

Wave height for a fetch of 1.5 km,

$$h_w = 0.014(D_m)^{0.5}$$ = 0.542m

Since free board is more than wave height, free board will be considered.

Height of embankment will be 4.2+0.63 = 4.83. Add 5% settlement allowance thus height will be 4.83+5% = 5.07 m.

Location of principal spillway = at maximum water level = 215.2 m level.

Location of emergency spillway = 211 + 5.07 = 216.07 m level.

Thus the temporary storage between emergency spillway level and principal storage level will be 16.5 ha-m (at 216.07 m level) – 10.91(at 215.2 m level) = 5.59 ha-m

(ii) Design of Principal Spillway

24-hour maximum rainfall at 5 percent probability level is 300 mm with 30% resulted into runoff. Thus expected storm runoff = $\frac{65\times300\times30}{1000\times100}$ = 5.85 ha-m. This principal spillway are mostly in the form of drop inlet spillway. Thus standard RCC pipes are selected from the manufacturer and laid at proper grade such that the condition of pipe running full could be obtained.

Designing drop inlet spillway (principal spillway)

The design discharge for drop inlet spillway is determined by the following relationship (Singh et al. 1990). Procedure is already discussed in case of drop inlet spillway design earlier. However, for the sake of completion of design it is also given here.

$$\frac{V_s}{V_r} = 1 - 2\frac{Q_o}{Q_i} + 1.8\frac{Q_o^2}{Q_i} - 0.8\frac{Q_o^3}{Q_i}$$

Where, V_s = volume of temporary storage (ha-m)

V_r = volume of runoff (ha-m)

Q_o = Required principal wpillway discharge (cumec) and

Q_i = Peak flow from design storm (cumec)

The above polynomial equation are solved for different $\frac{V_s}{V_r}$ and $\frac{Q_o}{Q_i}$ and given in Table 27.2 for quick solution. For intermittent values of $\frac{V_s}{V_r}$ and $\frac{Q_o}{Q_i}$, do the interpolation.

The above polynomial equation are solved for different ; $\frac{V_s}{V_r}$ and $\frac{Q_o}{Q_i}$ given in Table 27.2 for quick solution. For intermittent values of ; $\frac{V_s}{V_r}$ and $\frac{Q_o}{Q_i}$, do the interpolation.

Table 27.2. Estimating principal spillway discharge allowing for temporary storage (for watershed of less than 100 ha)

; $\frac{V_s}{V_r}$	$\frac{Q_o}{Q_i}$,									
	0.00	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**
0.0	1.00	0.99	0.98	0.96	0.95	0.94	0.92	0.91	0.90	0.88
0.1	0.87	0.85	0.84	0.82	0.81	0.79	0.78	0.76	0.74	0.73
0.2	0.72	0.70	0.68	0.67	0.65	0.64	0.62	0.61	0.60	0.58
0.3	0.57	0.55	0.54	052	0.51	0.50	0.49	0.47	0.46	0.45
0.4	0.44	0.43	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.35
0.5	0.34	0.33	0.32	0.31	0.30	0.29	0.28	0.27	0.27	026
0.6	0.25	0.24	0.23	0.23	0.22	0.21	0.20	0.20	0.19	0.18

0.7	0.18	0.17	0.16	0.15	0.15	0.14	0.14	0.13	0.12	0.12
0.8	0.11	0.11	0.10	0.09	0.09	0.08	0.08	0.07	0.07	0.06
0.9	0.05	0.05	0.04	0.04	0.04	0.03	0.02	0.02	0.01	0.01

(Source: Singh et al. 1990)

Here V_s = 5.59 ha-m, V_r = 5.85 ha-m; Q_i = 6 cumec.

Thus ; $\frac{V_s}{V_r}$ = 0.96, for this ratio, $\frac{Q_o}{Q_i}$ = 0.02 (from above table)

And so Q_o = 0.02 X 6 = 0.12 cumec

Thus select the suitable RCC pipe which is capable to handle 120lps discharge.

(iii) Design of Emergency Spillway

Expected peak discharge = 6.0 cumec

Discharge through principal spillway = 0.12cumec

So, design discharge for emergency spillway = 6.0 – 0.12 = 5.88cumec.

So at the level 216.07 m, chute spillway should be constructed for the capacity of 5.88cumec (see design of chute spillway).

(c)Structural Design

Top width = H/5+1.5 = 5.07/5+1.5 = 2.01 m say 2 m.

U/s and D/s slope = 3:1 and 2.5:1

Provide berm of 2.0 meter at the level of 215.2 m i.e. at the level of principal spillway to install pipe inlet.

27.3 Excavated or Dugout Ponds

These types of farm ponds are small dug out structures with well-defined shape and size. These structures have provision for inlet and outlet. Farm ponds are constructed at lower portion of the farm and generally stored water is used for irrigation. In some places farm ponds are used for recharging groundwater. However, for recharging groundwater, high capacity structures located in the highly permeable soil are more suitable. These structures are also called percolation tank (Reddy et al. 2012).

Dugout ponds are constructed by excavating the soil from the ground and the excavated soil is used to make embankment around the pond. The pond could either be fed by surface runoff or groundwater wherever aquifers are available. The depth and size of pond depend upon the volume of water to be stored. This type of pond is more featured in individual farm. Dug-out ponds can be grouped into the following four categories:

1. Excavated or dug out ponds
2. Surface ponds
3. Spring or creek fed ponds and
4. Off stream storage ponds

27.3.1 Excavated or Dugout Ponds

Excavated pond site should be chosen based on general slope of the field. Various locations of dug-pond are illustrated in Fig. 27.1 based on the prevailing land slope. If slope is towards left bottom corner of the field, a form pond must be constructed in the left corner of the plot and similarly for slope towards right bottom corner. If the slope is towards the bottom of the field, pond can be constructed at either side corner with proper field channel at the bottom of the field connecting to the inlet of the structure. If the farm area has multiple slopes in different direction, pond should be located in a portion of the area where maximum water can be drained into the structure.

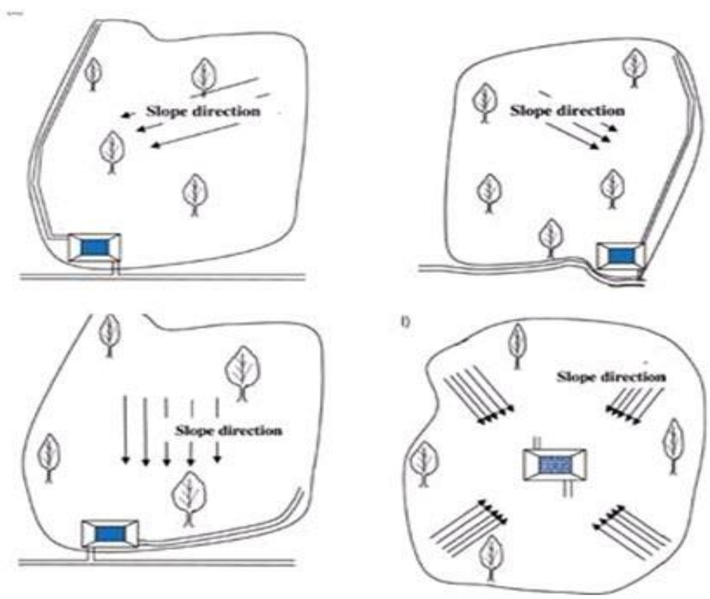


Fig. 27.1. Planning and selection of site for dugout farm pond.
(Source: Reddy et al. 2012)

27.3.2 Surface Pond

When the surface runoff from a farm area is collected into a local depression or the lowest portion of the farm such that the excavation is minimum, this type of pond is called surface pond (Fig. 27.2). Surface pond is possible in the farm area with undulating topography. This type of pond does not require a formal inlet provision but it should have formal outlet provision.

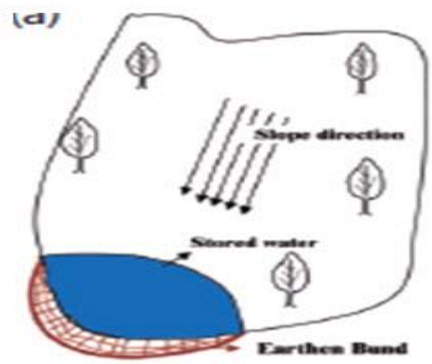


Fig. 27.4. Planning and selection of site for surface pond. (Source: Reddy et al., 2012)

27.3.3 Spring or Creek Fed Ponds

This type of pond is generally constructed at the foothills of the hilly catchments. After the soil saturation occurred due to excess rainfall, the subsurface flow of the catchment oozes up to the surface at the foothills as base flow (Fig. 27.3).

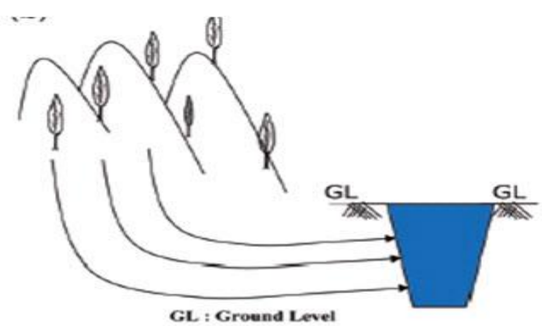


Fig. 27.5. Planning and selection of site for spring or creek fed pond. (Source: Reddy et al. 2012)

27.3.4 Off Stream Storage Ponds

This type of pond should be adopted where construction of embankment across the natural channel is not feasible or economically viable. Off-stream storage ponds collect water from the stream using diversion (Fig. 27.4). In hilly catchment where, storage volume upstream of embankment of dam is not sufficient and unable to sustain the high flow velocity, these types of structure can be adopted.

27.4 Site Selection for Dugout Type Farm Pond

The site selection for a single or multiple pond system requires careful planning considering

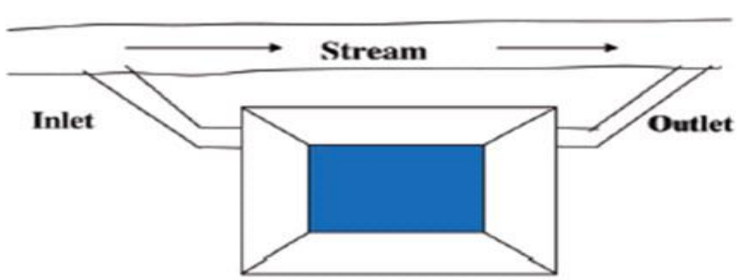


Fig. 27.6. Planning and selection of site for off-stream storage ponds. (Source: Reddy et al. 2012)

several variables. These include local soil condition, topography, drainage capacity, infiltration and rainfall pattern and its distribution. A suitable pond site should be selected to ensure long-term success. Generally such area should be selected where a limited amount of excavation is required to contain, or hold back, a large volume of water. However, the specific selection criteria for different type of ponds are explained in detail by Reddy et al.(2012).

Soil type

Soil type is also playing a major role in deciding the site for farm ponds. The soils having stones and boulders should be avoided for digging farm ponds particularly when pond is to be remained unlined. The soil profile must be investigated and location with good soil depth, free of stones, low Ph, EC and ground water level can be selected for farm ponds.

Topography

The proposed pond construction should be based on the topographic features of the site such that higher excavation to storage ratio could be achieved to attain the economy. Depending upon the capacity of the farm pond, contour survey should be conducted. However for smaller catchment (less than 5 ha), a reconnaissance survey is sufficient. Fig. 27.5 presents a sample contour map and respective location of ponds (Reddy et al. 2012).

Farm Ponds

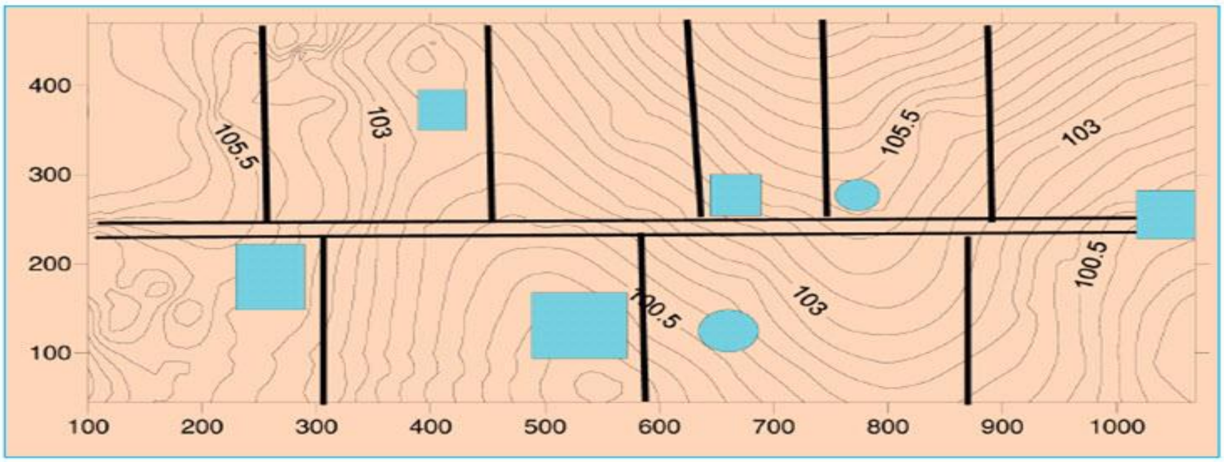


Fig. 27.7. Contour map to select site for farm ponds.

(Source: Reddy et al.2012)

27.5 Design Approach for Dugout Farm Ponds

Rainfall is the most important hydrological parameters for design of farm ponds. The design approach includes determination of design rainfall, probability analysis, surface runoff or water yield, rainfall-runoff relationship of the catchment, shape of the pond and utilization.

Design rainfall

The design rainfall refers to the quantum of rain required during the cropping season in catchment area to provide sufficient runoff to meet the crop water requirement. The design rainfall is very delicate preposition: if actual rainfall is less than design rainfall in cropping season, moisture stress will occur but when actual rainfall is more than design rainfall, surplus runoff may cause damage to the structure. Thus proper probability analysis of the historical rainfall event of the area should be carried out.

Probability analysis

Long term rainfall data, as long as possible but not less than 20 years, is required for carrying out probability analysis. Plotting position method is used for carrying probability analysis. Steps for probability analysis are given below:

1. Arrange the annual/season rainfall data in descending order and rank them such that maximum value gets rank 1 and minimum value with maximum rank (rank should be given in perfect digits such 1,2,3,… etc).
2. If two or more rainfall events are equal, then assign same rank to all such events.

3. Calculate the probability according to any plotting position methods such as Weibul.
4. Plot the probability vs rainfall on normal probability paper.
5. Determine the rainfall for 67 % and 75 % from the plotting curves.

Table 27.3 presents average seasonal rainfall and their expected design rainfall at different probabilities.

Table 27.3. Average seasonal rainfall and design rainfall at 67 and 75% probabilities for different locations of India

S. No	Centres	Average seasonal rainfall, mm	Probabilities	
			67%	75%
Low rainfall area: (average annual rainfall : 0-500mm)				
1	Anantapur	353.6	263	224.8
2	Hisar	345.4	299.1	238.2
Medium rainfall area ((average annual rainfall : 500-1000mm)				
1	Akola	671.7	598.8	534.3
2	Anand	815.5	643.1	549.5
3	Bangaluru	523.5	408.7	388.3
4	Bijapur	403.9	336.6	293.3
5	Faizabad	791.6	667.1	597.7
6	Kanpur	714.5	639.4	611.1
7	Kovilpatti	145.8	109.8	86.2
8	Ludhiana	593.1	409.5	349.0
9	Parbhani	834.1	618.0	545.0
10	Rakhdiansar	878.4	786.4	753.0

11	Solapur	533.0	451.8	408.5
12	Udaipur	604.5	381.0	350.0
High rainfall areas (average annual rainfall : >1000 mm)				
1	Bhubaneshwar	1116.1	1042.1	959.2
2	Dapoli	3259.5	2962.4	2894.3
3	Jabalpur	1174.5	1050.0	793.8
4	Jorhat	1173.3	1065.4	1034.0
5	Mohanpur	1050.2	881.4	865.0
6	Palampur	1521.3	1310.7	1222.5
7	Ranchi	1260.7	1040.7	990.0
8	Ranichauri	771.8	698.3	673.1
9	Raipur	951.1	795.4	734.9
10	Samastipur	993.6	830.0	798.0

(Source Reddy et al., 2012)

Using the design rainfall from Table 27.1, runoff volume for the selected catchment area can be determined using curve number method, which is described earlier.

The further details on dugout farm pond design and construction are provided in the next lesson.

Keywords: Farm pond, design rainfall, probability analysis

Exercise: Prepare detailed drawing of the embankment using the parameters obtained from solved designed example in this chapter.

1. Estimate the capacity of farm pond for the following information:

Sr No.	Contour Value	Area Enclosed (m^2)
1	150	200
2	151	250

3	152	300
4	153	307
5	154	405

Designing Dugout Farm Ponds

The design of farm ponds includes determination of capacity, its location, utilization plan and shape and size.

28.1.1 Catchment and Cultivable Area Ratio

This ratio is particularly important to determine the optimal size of pond based on the available catchment and the utilization of stored water in the cultivable area. The ratio between catchment (A_{ca}) and cultivable area (A_{cu}) also influenced by runoff coefficient and runoff efficiency factor. This ratio indicates the amount of cultivated area in the total catchment area. This ratio is given as (Critchley et al., 1991):

$$\frac{CWR-DR}{DR \times RC \times RE} = \frac{A_{ca}}{A_{ca}} \qquad (28.1)$$

Where CWR is the crop water requirement, DR is the design rainfall, RC is the runoff coefficient, RE is runoff efficiency factor, A_{ca} is the catchment area and Acu is the cultivable area.

Crop water requirement depend upon the type of crop and location specific climate and can be calculated from standard equations and models.

Runoff coefficient is the runoff to rainfall ratio. It is amount of surface flowover the ground. The coefficient is governed by slope, soil type, vegetation, AMC, and rainfall characteristics (intensity, frequency and duration). Typically this coefficient ranges between 10 to 50%. Larger catchment has lower runoff coefficient than smaller catchment (1-5 ha). The runoff coefficients are site specific and should be determined locally.

Efficiency factors address the issue of uneven distribution of the runoff water within the field. The uneven distribution occurs due to differential infiltration and percolation and surface depression. When the cultivated area is leveled and smooth, the efficiency is higher. Generally micro- catchment systems have higher efficiency. The efficiency can be determined using the

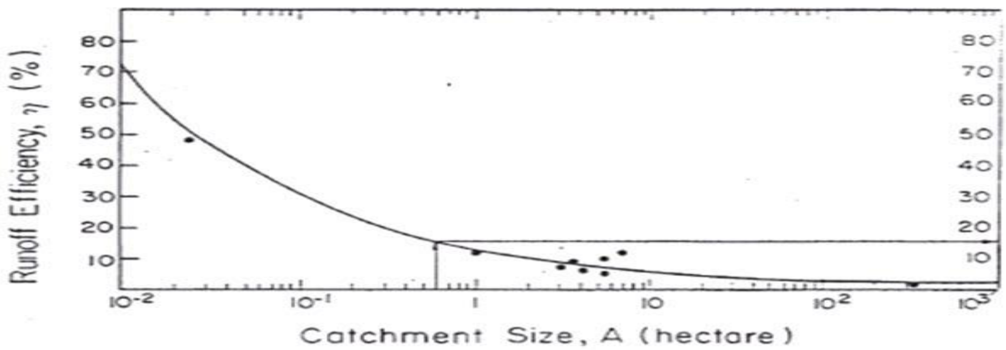


Fig. 28.1. Relationship between runoff efficiency and catchment area. (Source: Ben Asher, 1998)

graphical relationship between runoff efficiency and catchment area (Fig. 28.1).
The basic principle of design is to produce a satisfactory functional structure at a minimum cost. To minimize the cost, the pond should be designed for its maximum utilization considering the three strategies for irrigation particularly in rainfed agriculture (Reddy et al., 2012).

1. Meeting the crop water requirement of growing season.
2. Meeting water requirement of critical irrigation (CRI) during the critical stages of crop growth.
3. Meeting water requirement in cropping system approach e.g. irrigation during critical stages of *kharif* crop plus water requirement of *Rabi* crop such as vegetables.

The graph provided in Fig. 22a and 2b can be used to determine the expected runoff volume to determine the net capacity of the of the proposed farm pond. This graph is however developed for seasonal rainfall of 375 mm at 75 % probability and 425 mm at 67 % probability. Similar graphs can be generated for different rainfall as well. Depending on the efficiency factor, runoff coefficient and catchment area, runoff volume is estimated and accordingly shape, size and dimension of the ponds are designed.

28.1.2 Shape of the Pond

Generally, the farm ponds are excavated in the shape of rectangular, square or inverted cone with circular cross section. Though, inverted cone and other curved shape ponds are difficult to construct but many times it provides higher ratio of volume to wetted surface that increases the net storage after moderating for seepage loss.

28.1.3 Dimension of Ponds

The optimum dimension of farm ponds should be based on the hydrological consideration and catchment area. The farm pond with respect to small catchment may not have sufficient runoff to be filled and risk of being dried during dry spell. Similarly pond with large catchment would require large water control structure and would be difficult to manage. Generally the area under dug out farm pond should not be more than 10% of the farm catchment.

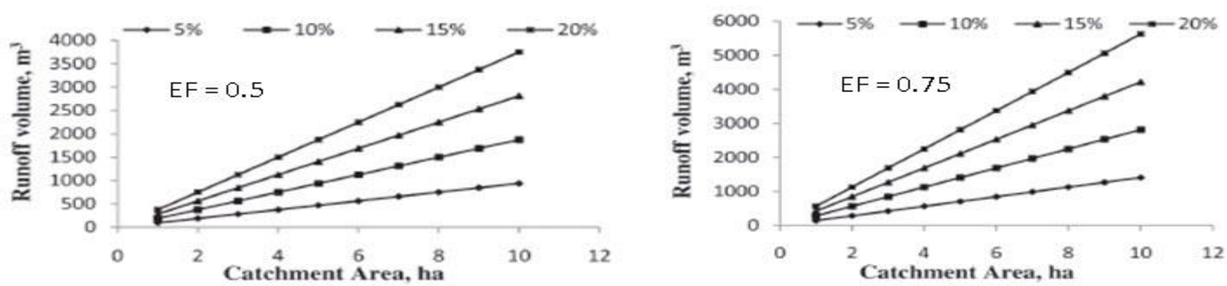


Fig. 28.2a. Expected runoff volume at design seasonal rainfall of 375mm (75 % probability) for different runoff coefficient, efficiency factor (EF) and catchment area. (Source: Reddy et al., 2012)

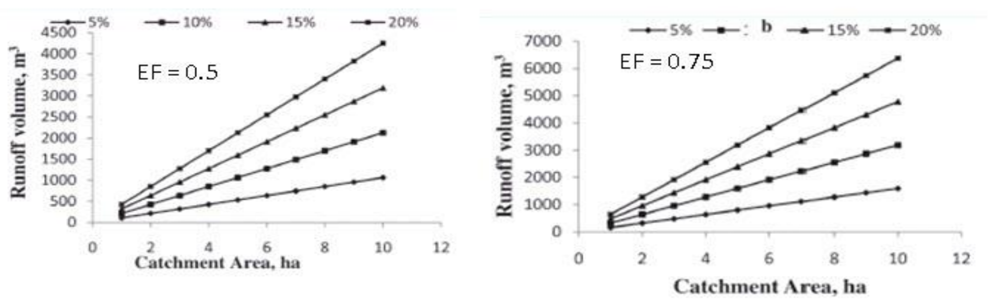


Fig. 28.2b. Expected runoff volume at design seasonal rainfall of 425mm (67 % probability) for different runoff coefficient, efficiency factor (EF) and catchment area. (Source: Reddy et al., 2012)

28.1.4 Depth and Side Slope

The depth of the farm pond is decided by considering soil depth, soil type and equipment used in excavation. Though, the evaporation loss component can be minimized by increasing the depth but, from practical point of view the ideal depth is limited to 3 to 3.5 meter. Any depth beyond 4.0 meter will be uneconomical if human labour is employed in excavation.

Based on experience, it is observed that the side slope of the pond should not be steeper than the natural angle of repose of the excavated material. Table 28.1 presents the recommended side slope of farm pond for different soil as suggested by Critchley et al. (2011). Another factor while considering the side slope is duration of standing of water in the farm pond. For higher duration, flatter side slope is recommended to avoid the slippage due to saturation particularly for unlined pond.

Table 28.1. Recommended side slope

Soil type	Slope (horizontal:vertical)
Clay	1:1 to 2:1
Clay loam	1.5:1 to 2:1
Sandy loam	2:1 to 2.5:1
Sandy	3:1

(Source: Critchley et al. 2011)

The volume of the farm pond can be determined using eq. (28.2) as follows:

$$V = \frac{A+4B+C}{6} \times D \qquad (28.2)$$

Where, is volume of exacavation (m^3); is the area of excavation at ground surface (m^2), is the area of exacavation at mid-depth point (D/2) (m^2); C is the area at the bottom of the pond (m^2) and D is the design depth (m).

28.1.5 Rectangular/Square Section Farm Pond

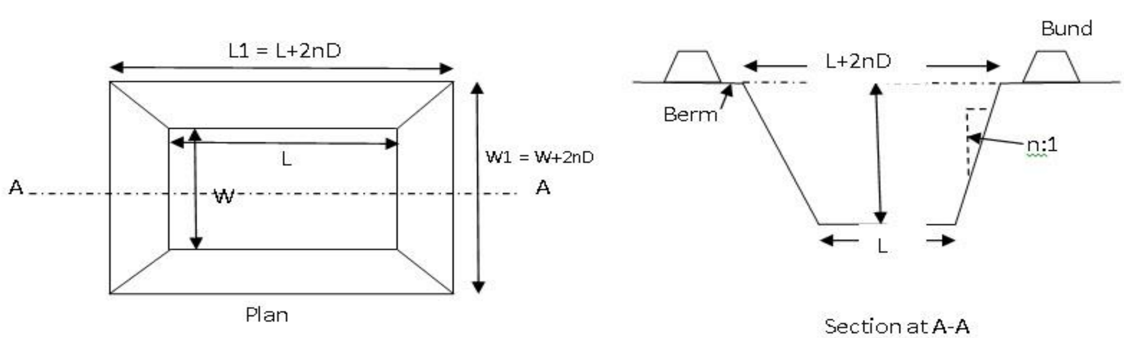


Fig. 28.3. Cross-section of dugout farm pond.

Using eq.28.2, the bottom dimension for rectangular pond is derived as

$$L = \left(^{0.5}/_{C}\right) \times \left(\sqrt{n^2D^2(1+C)^2 - 4C\left\{(4/3)n^2D^2 - {}^{V}/_{D}\right\}} - nD(1+C) \right) \qquad (28.3)$$

Where, $C = {}^{L}/_{W}$, the ratio between length and width at the bottom. For square section, C will be equal to 1, Eq (28.3) would be simplified as

$$L = W = \sqrt{n^2D^2 - 4\left\{\left({}^{4}/_{3}\right)n^2D^2 - {}^{V}/_{D}\right\}} - nD \qquad (28.4)$$

Example 28.1: A dugout farm pond of capacity 500 m^3 is to be constructed in clay loam soil. The soil profile is such that the depth is limited to 3 m and site permits length width ratio as 1. Determine the dimension of the dugout farm ponds.

Solution:

V = 500 m^3, Side slope for clay loam (n) = 2:1 (Table 28.1), D = 3 m

UseEq (28.4)to determine bottom length and width as

$$L = W = \sqrt{2^2 3^2 - 4\left\{\left({}^{4}/_{3}\right)2^2 3^2 - {}^{500}/_{3}\right\}} - 2 \times 3$$

$$L = W = \sqrt{36 - 4\{1.33 \times 36 - 166.67\}} - 6 = 16.6 \text{ m say } 17\text{m}$$

The dimension of top width would be equal to base width plus nD i.e. 17+23 = 23 m.

Similarly from Eq. (28.2), the dimension for inverted cone can be derived as

$$d_1 = \sqrt{\left\{\left({}^{4V}/_{\pi D}\right) - \left({}^{1}/_{3}\right)n^2D^2\right\}} - nD \qquad (28.5)$$

Where, is the diameter at the bottom of the pond and top diameter, can be computed as

$$d_2 = (d_1 + 2nD) \qquad (28.6)$$

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Example 28.2: From above exercise, design an inverted cone type farm pond.

Solution:

Use Eq. (28.5)to determine the diameter of bottom, d_1 as

$$d_1 = \sqrt{\left\{\left(4 \times 500/_{\pi \times 3}\right) - \left(1/_3\right) 2^2 3^2\right\}} - 2 \times 3$$

$$d_1 = \sqrt{\{(212.31) - 12\}} - 6 = 8.15\text{m, say } 8.5 \text{ m.}$$

Using Eq. (28.6), the top diameter will be 14.5 m.

28.2 Economical Cross Section of Farm Ponds

Water lost from dugout ponds are mainly due to evaporation and seepage. The evaporation loss could be minimized by minimizing the surface area and volume ratio, whereas seepage losses could be minimized by reducing the ratio of wetted area and volume. Theoretically the volume of stored water per unit wetted area increases with the increase in depth of the water in ponds but at the same time increases the cost of pond lining. Thus optimization of various pond dimensions must be done for seepage reduction and cost of pond lining.

28.2.1 Optimization of Various Pond Dimensions

Mishra and Sharma (1994) suggested a design methodology to optimize the different pond dimensions based on designed storage volume and prevailing soil type. The optimization include following computational steps.

(a) Average cross-sectional area (

$$A_{av} = \frac{LW + (L + 2nD)(W + 2nD)}{2} \qquad (28.7)$$

(b) Wetted area

$$A_w = LW + 2D\sqrt{1 + n^2}\,(L + 2nD + W) \qquad (28.8)$$

(c) Storage volume, V

$$V = \frac{LW + (L+2nD)(W+2nD)}{2} \times D \qquad (28.9)$$

Where, L and W are the two sides of the pond bottom, D is depth of the pond and n is the side slope (horizontal: vertical::n:1)

Now expressing C=L/W i.e. W=CL, Eqs. 28.7, 28.8 and 28.9 transform as

$$A_{av} = \frac{CL^2 + (L+2nD)(CL+2nD)}{2} \qquad (28.10)$$

$$A_w = CL^2 + 2D\sqrt{1+n^2}\,(L + 2nD + CL) \qquad (28.11)$$

$$V = \frac{CL^2 + (L+2nD)(CL+2nD)}{2} \times D \qquad (28.12)$$

Now converting Eq.(28.12) to quadratic form and solving for L,

$$L = \frac{-Dn(1+C) + \sqrt{[Dn(1+C)^2 - 4C(2D^2n^2 - V/_D]}}{2C} \qquad (28.13)$$

The above Eqs28.10 to 28.13 become simple for a pond with square bottom, i.e. C=1 means L=W

$$A_{av} = \frac{L^2 + (L+2nD)^2}{2} \qquad (28.14)$$

$$A_w = L^2 + 4D\sqrt{1+n^2}\,(L + nD) \qquad (28.15)$$

$$V = \frac{L^2 + (L+2nD)^2}{2} \times D \qquad (28.16)$$

Theoretically, for a particular storage volume, the surface area of the pond is the lowest when the depth is increased to a point where the bottom surface area becomes zero. For this conditions,

$$D = \sqrt[3]{V/2n^2} \qquad (28.17)$$

$$A_{av} = V/D = 2D^2n^2 \qquad (28.18)$$

$$A_w = 4D^2n\sqrt{1+n^2} \qquad (28.19)$$

Example 28.3:
A dugout farm pond of capacity 500 m^3 is to be constructed in clay loam soil. Determine the optimal dimension of a farm pond.

Solution:

V = 500 m^3, n = 2

Using(28.17), the optimal depth, D will be

$$D = \sqrt[3]{500/8} = 3.96 \text{ m say, } 4 \text{ m}$$

$$A_{av} = 2 \times 4^2 \times 2^2 = 128 \text{ m}^2$$

$$A_w = 4 \times 4^2 \times 2\sqrt{1+2^2} = 286.22 \text{ m}^2$$

Compare this result with the exercise 28.1. In earlier exercise, the average cross sectional area was computed as 409 m^2 for 3 m depth whereas in this case the average cross sectional area is only 128 m^2 for 4 m depth. Just by increasing depth by one meter (if site conditions allow), one can significantly reduce evaporation loss (because surface area reduced) and seepage loss (because wetted area reduced). Moreover, the cost of lining could be minimized significantly by just increasing the depth by 1 m.

28.2.1.1 Inlet and Outlet Channel

The inlet channel to the farm pond are constructed in such a way that, all the surface runoff from the catchment area to concentrate at the channel and drain into the pond. The inlet is designed as chute spillway for conveying the runoff in to the pond. While laying the inlet channel, the safe velocity of the water must be ensured to avoid channel erosion. Grasses can be grown in the channel for further protection.

Stone pitching is widely adopted to reduce the erosion from the inlet channel. The entry section is designed as a rectangular broad crested weir to allow 0.3 to 0.5 m depth of flow over 1 to 1.5 m width (Fig. 28.3).

Fig. 28.3. A view of inlet channel and stone pitching.

(Source: Reddy et al. 2012)

28.2.1.2 Outlet/Waste Weir

The out let or waste weir is designed to remove the surplus runoff over and above the designed capacity of the pond. The outlet is generally located at the lower end of the pond. It should be thickly vegetated with grass to reduce the erosion. The flow through outlet should be maintained at non-erosive velocity to minimize the outlet erosion. The outlet is kept at slightly lower elevation (up to 30 cm) as compare to the inlet elevation to avoid the back water. The discharge capacity of the outlet can be assumed to be half as that of the inlet capacity as peak rate of runoff

28.2.1.3 Lining of Farm Pond

The various losses including seepage, percolation and evaporation account for as high as 60% of the gross storage. Seepage and percolation losses can be controlled using pond lining techniques. The seepage losse under different soil class is presented in Table 28.2.

Table 28.2. Seepage losses in different soil class.

Sl. No	Type of soil	Water loss through seepage (cumec/million m^2 of wetted surface)	Drop in depth per day (cm)
1	Heavy clay loam	1.21	10.36
2	Medium clay loam	1.96	16.84
3	Sandy clay loam	2.86	24.61
4	Sandy loam	5.12	44.03
5	Loose sandy soil	6.03	51.80
6	Porous gravelly soil	10.54	90.65

(Source: Agritech.tnau.ac.in)

Several lining techniques are available that uses the material like bricks and stone with cement and mortar. Various other techniques are also used for seepage control. Some of these are Asphalic material, paddy husk with cow dung, cement with soil mixture, fly ash mixture and bentonite treatment of pond surface. Performance of these methods varies but none of them can control seepage losses completely. The LDPE (low density poly-ethylene) film lined pond with brick overlaying as anchorage and safety from external damage to the plastic sheet can last up to 15 to 20 years and is considered as one of the permanent solution.

The advantages of LDPE film lined ponds are listed as

1. Reduction in water losses through seepage and percolation to the extent of 95%
2. Availability of water for a longer period can be ensured.
3. This type of lining provides scope to construct farm pond in porous soil as well where water retention is low

Method for LDPE lining of farm pond

For farm pond lining, the quality and strength of LDPE film depends on the capacity of pond and depth. For higher capacity say 200-1000 m^3 with 3 to 3.5 m depth, minimum 500 micron thickness and 300-350 gsm (gram/m^2) film is required. However, for smaller pond (capacity less than 200 m^3 and depth is limited to 2.0 m) adopted in the prevailing conditions of hill and mountain agro-ecosystem of Himalayan region, 200-250 micron with 200 gsm LDPE film is sufficient for lining. The plastic film other than LDPE namely HDPE (High density polyethylene) and geo-membrane (reinforced HDPE) are also used for pond lining. The HDPE and geo-membrane film are used for lining bigger ponds where capacity is more than 1000m^3. The properties of different polyethylene (PE) films are presented in Table 28.3.

Table 28.3. Properties of different PF films

Property	Test method (ASTM coded)	Unit	Values		
			LDPE film 500µ	HDPE film 500µ	Geo-membrane 500µ
Material density	1505	g/cc	0.92	0.94	0.94
Breaking strength	6093, 638 type IV	N/mm	12	14	28
Puncture resistance	4833	N	120	176	491
Tear resistance	1004	N	50	73	120
Bursting strength	751	Kg/cm^2	4	4.3	8.5
Hydro static registance	751	Kg/cm^2	2	3	6
Impact failure load		Gram force, Gf	555	585	>2000

(Source: Reddy et al., 2012)