

WATER HARVESTING TECHNIQUES, DESIGN OF SMALL DAMS AND HYDRAULIC COMPLEMENTS

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1.0 INTRODUCTION

The rainfall distribution in India is highly variable, the extremes varying from less than 100 mm rain annually received in the western most part of the country and around 12,000 mm in the eastern most part. Spatially, about 30% area of the country receives less than 750 mm rainfall, 42% picks up between 750 and 1250 mm and 20% experiences rainfall between 1250 and 2000 mm on an average annual basis. In terms of temporal distribution, the total rainfall occurs in less than 150 hours and half of it descends in not more than 20 to 30 hours of heavy spells. Hence, runoff is a prominent feature of the hydrologic cycle. The monsoonal runoff if flows uncontrolled causes soil erosion but if used judiciously can be a boon for improving crop production in the rainfed areas. It is noteworthy that the rainfed areas which constitute about 63% (89 million ha) of cultivated land in India account for only 45% of the total food production. Since irrigation consumes over 80% of the available water and conventional irrigation of all the rainfed lands is not feasible, there is a tremendous scope for improving their productivity through rain water harvesting. It is estimated that even after achieving full irrigation potential of 140 million ha, nearly 40% of the total cultivated area of India will still remain rainfed. Moreover, construction of major irrigation projects has limited scope due to topographical, social, financial and environmental constraints. Rainwater harvesting technology is highly location specific depending on climatological, physiographical and socio-economic factors.

2.0 WATER HARVESTING

Water harvesting is the collection, storage and recycling of rain water (surface/sub-surface) for irrigation and other uses. India is characterized with wide variations in physiographic, climatic, soil, environmental and socio-economic conditions. Therefore, water harvesting technology is highly location specific. The various water harvesting practices in vogue may be broadly grouped as follows:

- *In situ* retention of rainfall on the land itself by agronomic/mechanical measures.
- Harvesting surface runoff from the land surface and its storage for later use.
- Diversion of perennial surface/sub-surface water source (springs and streams) into the storage structures.
- Roof top water harvesting

The *in situ* water harvesting practices include bunding and terracing, vegetative barriers, contour bunding, contour ditching, leveling, contour farming, cover crops and mulching, conservation tillage and deep ploughing etc.

The surface runoff water harvesting can be achieved through dugout ponds, *Tankas*, *Khadins*, *Ahars/Havelis*, diversion bunds, roof top rainwater cisterns etc.

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2.1 Indigenous Practices

Stream flow runoff harvesting is practiced through nala bunding, check dams, stop dams, *Bandharas* (weirs), percolation tanks/ponds, *Nadi* etc. Sub-surface dams/ barriers, diaphragm dams, *bandharas* are used for sub-surface flow harvesting.

People through the ages across various agro-ecological regions have come up with indigenous and unique water harvesting structures and systems displaying their innovative technical skills as follows:

North West Himalayas: Water is diverted from a source to the agricultural fields through small channels known as *kuhls* or *guhls*. *Khaals* and *Chaals* were traditionally made at hill top saddles for harvesting rainwater from adjoining slopes for drinking needs of livestock and water recharge. Aesthetically constructed *Naulas*, which harvest the natural sub-surface flow were common in hilly areas for drinking water purposes

North East Himalayas: Bamboo pipeline is commonly used for water conveyance. In Meghalaya, a beautiful bamboo drip irrigation system is in vogue for ages. ‘*Zabo*’ system of farming through rainwater harvesting is practiced in Nagaland. Roof top water harvesting for drinking water needs is quite common in Mizoram.

Arid and Semi-arid areas: In Rajasthan, people have used the scarce and little rainfall through rainwater harvesting structures such as *Tankas* (dugout and lined circular holes, 3-4 m dia.), *Nadi* (small excavated or embanked village ponds), *Khadins* (crops grown on harvested water by constructing earthen bunds) etc.

Western and Central India: In Bihar and U.P., *Khadins* are widely practiced, where runoff water is collected behind an earthen bund usually 3m in height. *Haveli* System of cultivation is a traditional water harvesting practice in black soils of Bundelkhand region where rainwater is impounded in banded fields during monsoon and rabi crop is taken on residual soil moisture.

Tamil Nadu: In Tamil Nadu, a big stream is often diverted to feed a chain of 25 to 30 tanks in a sequence for irrigation of crops.

Arid Kutch: In Kutch, the Maldhari nomads collect sweet water for drinking from well in tanks called *Virda*.

2.2 Water Harvesting Potential

The estimated potential volume of rainwater storage through small scale water harvesting structures in different rainfall zones of India is shown in Table1. A total storage of about 24 m ha-m can be created through such structures.

Table.1 Estimated rainwater harvesting storage potential in different rainfall zones

Rainfall zone (mm)	Geographical area (million hectare)	Rainfall for effective surface storage (%)	Harvestable runoff in water harvesting structure (M ham)
100-500	52.07	5	0.78
500-750	40.26	6	1.51
750-1000	65.86	7	4.03
1000-2500	137.24	6	14.61
>2500	32.57	4	3.26
Total			23.99

3.0 WATER HARVESTING STRUCTURES

The water harvesting structures of various types are known by different names in the country such as farm ponds, small earthen dams, irrigation tanks, *bundhis*, percolation tanks, stop dams etc. The most common water harvesting structures are of two types: a) embankment type ponds for hilly and rugged terrain, and b) excavated or dugout type farm ponds for flat topography.

3.1 Earth Fill Dams

Earth fill dams are constructed at suitable sites to harvest and store surface runoff for irrigation, floods moderation, sediment control etc. It is an earthen embankment constructed across a water course with adequate spillway for disposal of excess storm flow. Conveyance and application system forms part of the dam.

3.1.1 Types of earth fill dams

The commonly used rolled-filled type earth dams in which major portion is constructed in successive compacted earth layers are of three types as given below:

- a) *Homogeneous*: It is constructed with relatively homogeneous soil material and is either keyed into an impervious foundation stratum (Fig 1a) or is constructed with an upstream blanket of an impervious material (Fig. 1b). This type is adopted in low dams where sufficient volumes of satisfactory fill materials are available.

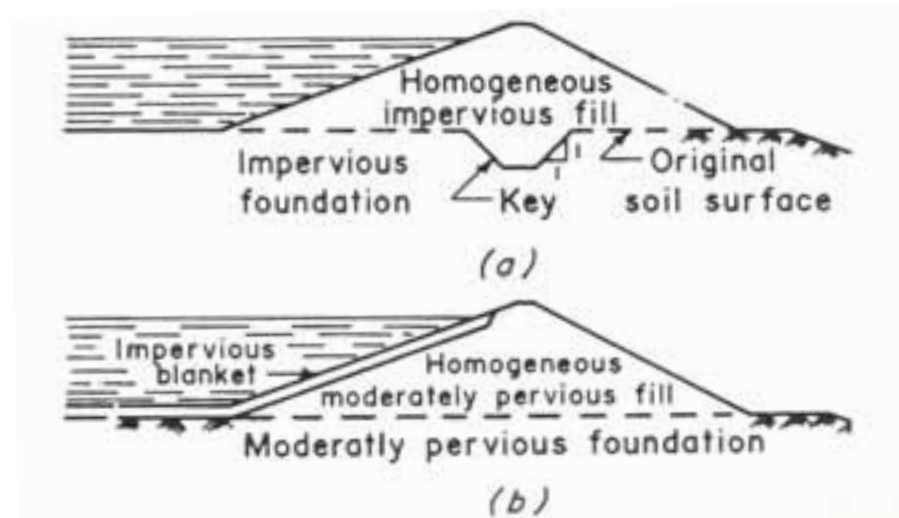


Fig. 1 a&b: Different types of embankments

- b) *Diaphragm*: In this type, the bulk of the embankment is constructed with pervious material (sand, gravel or rock) and a thin diaphragm of impermeable material like plastic, butyl, concrete, steel or wood to act as a barrier against seepage through the fill is provided. Depending on the length of wall, it could be "full diaphragm" or "partial diaphragm" type (1c and 1d).

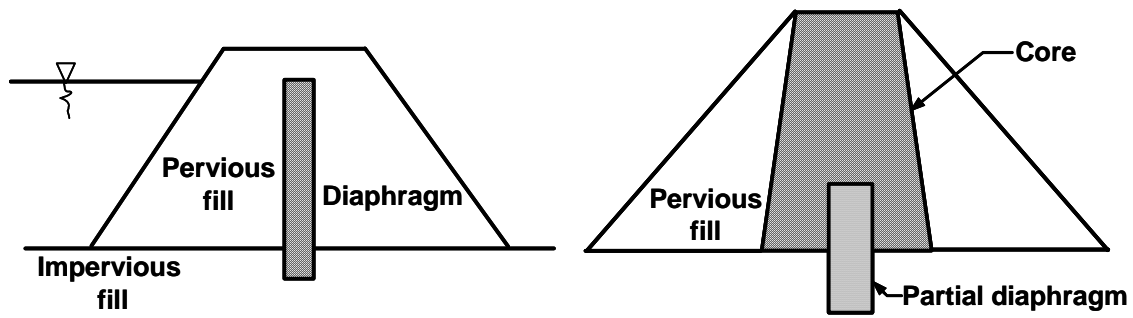


Fig. 1c: Full diaphragm

Fig. 1d: Partial diaphragm

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

3.1.2 Site selection and investigations

The selection of a suitable site for dam construction is very important and this should be finalized after preliminary investigations of few possible sites in the area. In order to be cost effective, the dam should be located where maximum storage volume is obtained through minimum volume of earthfill. The sites where the stream/or river valley is narrow, with steep side slopes, stable earth formation, consolidated stream bed and nearly impervious material are suitable for dam construction. Such sites also minimize the pond area. However, all geological conditions must be investigated and examined. The site features, prove to be useful and handy. For example, a snake type of channel suggests presence of desirable hard and soft horizons in the geological formation. The stream portion which shows moistness or wetness during dry season is expected to have impervious layer at a shallow depth to minimize percolation losses. The other important consideration is that the command area should be as close as possible to the dam/pond site and suitable for irrigated agriculture.

Once the location of the dam is selected from the reconnaissance and preliminary investigations, a detailed engineering survey is taken up so that the design of dam, spillway and other components of the system are planned. The surveys include, topographic (contour) survey of the catchment, reservoir area, dam site, spillway site and the command area. The detailed contour maps including longitudinal and cross sections at 1m or less interval are prepared and plotted on the map.

The various design components of the earth fill dam include (a) foundation including key trench or cut-off, (b) height of dam, (c) side slopes, (d) top width, (e) free board, (f) toe drains or filter, and (g) corewall.

3.1.3 Criteria for design

The basic principle of design is to produce a satisfactory functional structure at a minimum cost. To minimize the cost, the dam should be designed for maximum utilization of the most economical materials available. The operational/maintenance cost also needs due consideration.

To ensure safety and stability of the dam during all phases of construction and operation the following criteria must be met:

- 1) The embankment should be safe against overtopping during occurrence of the inflow design flood by the provision of sufficient spillway and outlet works capacity.
- 2) The slopes of the embankment must be stable during construction and also under conditions of reservoir operation including rapid draw down of the reservoir.
- 3) Seepage flow through the embankment, foundation and abutments must be controlled so that no internal erosion and sloughing takes place.
- 4) The embankment must be safe against overtopping by wave action against erosion and the crest and downstream slopes must be protected against erosion due to wind and rain.

If these criteria are satisfied, the dam will be safe provided proper construction methods are adopted. The design procedures may, however, vary depending upon the purpose of design, size and importance of the structure, and the complexity of the problem.

3.1.4 Design steps

After computation of water yield and peak rate of runoff for the given location, the following design steps are adopted:

Height of dam: The height of dam should be selected in such a way that the cost of dam per unit of storage is minimum. The pond depth-capacity curve and the pond area-capacity curve are used to determine the most suitable height for a given storage volume. The height of small earthen dams should not normally exceed 16 m.

Free board: It is the added height of the dam provided as a safety factor to prevent waves and runoff from storms greater than the design frequency from overtopping the embankment. It is the vertical distance between the elevation of the highest flood level and top level of the dam after all settlement has taken place. It depends upon the height as well as length of the dam. Normally, 10-15 percent is added as free board to the highest flood level of the dam. Minimum free board of 50 cm is provided for length of pond upto 400 m, 75 cm for length between 400 to 800 m and 100 cm for length more than 800 m.

Wave heights for determining free board can also be computed using Hawksley's formula:

$$h_w = 0.014 (D_m)^{0.5} \quad (1)$$

where, h_w is wave height, m, and D_m is fetch or exposure, m.

Settlement allowance: Settlement includes the consolidation of the fill materials and the foundation materials due to the weight of the dam and the increased moisture caused by the storage of water. It depends upon the type of fill material and the method and speed of construction. It varies from 10% of design height for hand compacted (normally constructed) fill to 5% for machine compacted (rolled at optimum moisture) fill.

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

$$W = \frac{H}{5} + 1.5 \quad (2)$$

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

Embankment side slopes: Embankment slopes are required for stability of the embankment on stable foundations. Pervious foundations may require the addition of upstream blankets for stability against seepage forces. Weak foundations may require the addition of stabilizing fills at either or both toes of the dam.

The side slopes depend primarily on the stability of the material in the embankment. The greater the stability of the material, the steeper will be the side slopes or *vice versa*. The recommended side slopes for earthen embankments are presented in Table 2.

Table 2. Recommended side slopes for earthen dams

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

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

Storage capacity: For small embankments, the capacity can be roughly calculated as:

$$\text{Storage capacity (ha-m)} = 0.4 DA$$

where, D is maximum depth of water (m), and A is area of water spread at waste weir (ha).

Storage capacity for large embankments is estimated from the submergence area as discussed in section 3.1.2.

Total storage capacity of a dam is computed as a sum of live and dead storages with a provision of free board and flood flow storage. Live storage depends upon the expected water yield from the watershed. Dead storage is meant for storing sediment reaching the dam/reservoir.

Filters and toe drains: When the water is impounded behind the dam, water seeps through the dam body. The head of water decreases towards downstream till it meets the base at some point. Thus, the saturation line is the line between saturated and unsaturated zones in the earth dams (Fig. 2a). The phreatic line (upper zone of saturation) must remain within the base width of the embankment. In case the saturation line merges out on the downstream face of the dam, there is danger of piping leading to failure of the dam. By providing a horizontal filter of gravel or coarse sand of sufficient thickness placed on the downstream base of the dam, the phreatic surface is lowered (Fig. 2b). In case of bigger dams, specially designed toe filters and drains shall have to be provided.

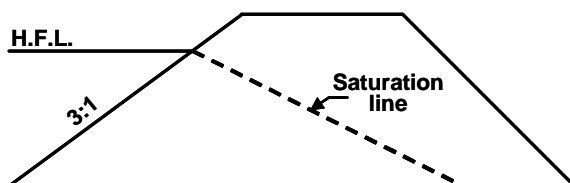


Fig. 2a: Saturation line in an embankment

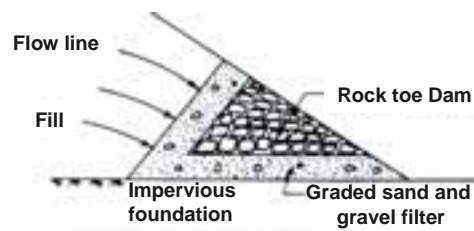


Fig. 2b: Filter at the toe of the dam

Foundation key/Cut off: The purpose of the key is to join the impervious stratum in the foundation with the base of the dam. The most common type of key is constructed of compacted or puddled clay material. A trench, also called key trench, is cut parallel to the central line of the dam to a depth that extends well into the impervious layer. The trench should have a bottom width of not less than 1.5 metres but adequate to allow the use of mechanical equipment if necessary to obtain proper compaction. For effective control of seepage, the cut-off trenches in between upstream and downstream toe lines of the embankment, especially on the stream bed portion should be filled with puddled clay and placed along with the central key trench.

3.1.5 Causes of failure of earth dams

The most common causes of failure of earthen dams are:

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

3.1.6 Design examples

Example 1: The area within the contour lines at the site of a reservoir and face of proposed dam are as follows:

Contour, m	Area, sq.m	Contour, m	Area, sq.m
450	270	460	414500
452	10440	462	460800
454	75600	464	586800
456	144000	466	639900
458	270000		

Assuming 450 as the bottom level of reservoir and 466 as the highest water level, find the volume of water in the reservoir in cubic meters.

Solution: The computations for capacity are given in Table 2:

Table 2: Computation for the volume of water at different contours of reservoir

Contour, m (1)	Area, sq.m. (2)	Average area, sq.m. (3)	Contour interval, m (4)	Volume of water, cu.m. (4) x (3)
450	270	-	-	-
452	10440	5355	2	10710
454	75600	43020	2	86040
456	144000	109300	2	218600
458	270000	207000	2	414000
460	414500	342250	2	684500
462	460800	437650	2	875300
464	586800	523800	2	1047600
466	639900	613350	2	1226700
Total =				4564450

The capacity of the reservoir is approximately 45,64,450 cum or 456 ha-m.

Example 2: Design an earthen embankment with the following data:

- RL of bed surface = 100.0 m.
- RL of Highest Flood Level (HFL) = 106.25 m.
- Slope of saturation line = 4:1
- Assume a fetch of 1 km.

Solution:

Height of water upto HFL = 106.25 - 100.0 = 6.25 m.

Wave height for a fetch of 1 km,

$$h = 0.014 (1000)^{1/2} = 0.443 \text{ m.}$$

$$\text{Free board (15\%)} = 6.25 \times \frac{15}{100} = 0.93 \text{ m}$$

Since, free board is more than height of waves, 1.0 m value is adopted.

Hence, height of dam = 6.25 + 1.0 = 7.25 m

Assuming 5% settlement allowance,

$$\text{Total height} = 7.25 + 7.25 \times \frac{5}{100} = 7.65 \text{ m.}$$

$$\begin{aligned} \text{Top width of the dam} &= \frac{H}{5} + 1.5 = \frac{7.65}{5} + 1.5 \\ &= 3.03 \text{ m or } 3.0 \text{ m.} \end{aligned}$$

Assuming upstream and downstream slopes of 3:1 and 2:1, respectively, the length available for saturation line is $6.25 \times 4 = 25.0$ m. With these specifications, the horizontal projection on the bottom of dam works out to be 22.5 and, therefore, the seepage line will intersect the downstream face and make the section unstable (Fig.3). Hence, the section needs to be modified.

Assuming a slope of 2.5:1 and providing a berm of 3.0 m (Fig.4), the section is safe. For further safety, a toe drain or a filter may be provided.

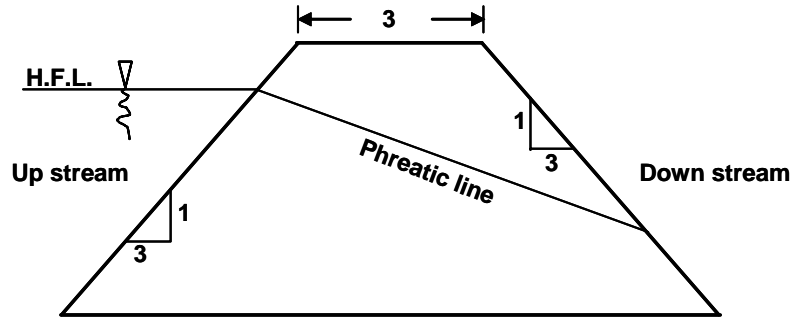


Fig. 3: Section of embankment showing phreatic line meeting down downstream face causing instability

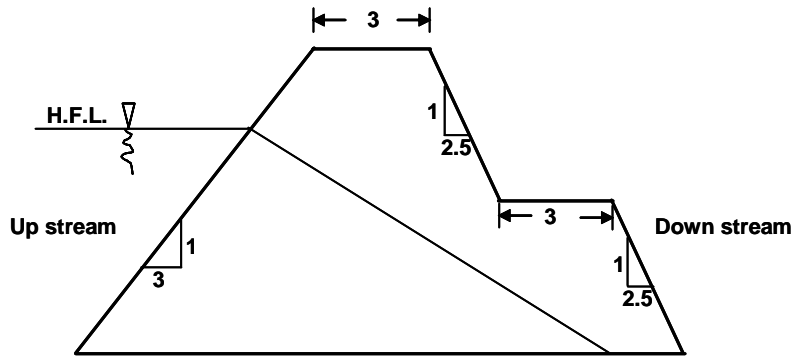


Fig.4: Safe modified embankment section with phreatic line

Example 3: An earthen embankment with a top width of 2.0 m is proposed for construction across a valley whose fill heights at every 10.0 m are presented in Fig 5. The section has side slopes of 2:1. A core trench having 0.75 m depth, bottom width of 1.75m and side slopes of 1:1 is also provided. Calculate the earth work needed for the embankment.

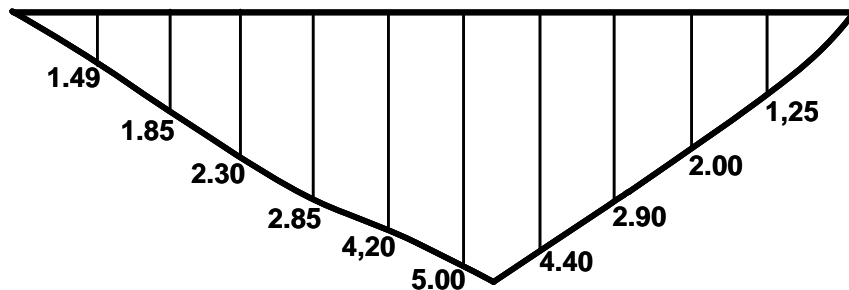


Fig. 5: Fill height across the valley

Solution:

The area of cross section at every 10 m interval may be computed by the formula

$$A = BD + nD^2$$

where, B is top width (2.0 m), D is depth of section and n is side slope (2).

$$\begin{aligned} A &= 2 D + 2 D^2 \\ &= 2 (D + D^2) \end{aligned}$$

The computations for area of cross section are shown in Table 3a.

Table 3a: Computations for area of cross section

D	D ²	(D+D ²)	Area of cross section 2(D+ D ²)
1.45	2.1025	3.5525	7.105
1.85	3.4225	5.2725	10.545
2.30	5.2900	7.5900	15.180
2.85	8.1225	10.9725	21.945
4.20	17.6400	21.9400	43.680
5.00	25.0000	30.0000	60.000
4.40	19.3600	23.7600	47.520
2.90	8.4100	11.3100	22.620
2.00	4.0000	6.0000	12.000
1.25	1.5625	2.8125	5.527

The computations of earth work for the dam are shown in Table 3b. The volume of earth work required to fill the core trench should also be estimated and added to it to compute the total earthwork.

X - sectional area of core trench

$$\begin{aligned} &= \frac{3.25 + 1.75}{2} \times 0.75 \\ &= 1.875 \text{ m}^2 \end{aligned}$$

Length of dam = 110.0 m

Volume of back fill = 1.875 x 110 = 206.25 m³

Total earth work = 2462 + 206.25
= 2668.25 m³

Table 3b: Computations for earth work in the dam

Station	Ground elevation, m	Fill height, m	End area, m ²	Sum of areas, m ²	Distance, m	Double volume, m ³	Volume, m ³
0+00	35.00	0.00	0.000	7.105	10	71.05	35.50
0+10	33.55	1.45	7.105	17.65	10	176.50	88.25
0+20	33.15	1.85	10.545	25.725	10	257.25	128.62
0+30	32.77	2.30	15.180	37.120	10	371.20	185.60
0+40	32.15	2.85	21.940	65.620	10	656.20	328.10
0+50	30.80	4.2	43.680	103.000	10	1036.80	518.40
0+60	30.00	5.0	60.000	107.520	10	1075.20	537.60
0+70	30.60	4.4	47.520	70.140	10	701.40	350.70
0+80	32.10	2.9	22.620	34.620	10	346.20	173.10
0+90	33.00	2.0	12.000	17.620	10	176.20	88.10
1+00	33.75	1.25	5.620	5.620	10	56.20	28.10
1+10	35.00	0.00	0.000	-	-	-	-
Total=							2462.09

3.2 Dugout Ponds

A dugout pond is formed by excavating a pit and forming an embankment around the pit by excavated earth. Generally, in flat areas a site which already has a natural depression is chosen for the pond. Since their capacity is obtained almost entirely by excavation, it limits their practical size and use for locations having smaller water supply requirements.

Dugout ponds could be either fed by surface runoff or ground water aquifer. A dugout pond fed by ground water can be located where shallow sub-surface flow exists or shallow water table exists. A dugout pond can also be constructed in a wide natural drainage way or on side of a drainage to divert runoff into the pond. Surface water ponds are most common farm ponds. Since dugout ponds can be constructed by exposing a minimum water surface area in proportion to volume, they are advantageous in areas with high evaporation losses and scarce water supply.

3.2.1 Site Selection

The site should have enough catchment to provide runoff sufficient to fill the pond. The lowest point of a natural depression is considered as a good location. To be cost effective, a pond should be located where the largest volume can be obtained with least earthwork. Location should also have a favourable outlet condition for excess runoff disposal from the pond. The sub-soil should allow minimum seepage as far as possible. In case, the seepage rates at the site are excessive, good fill material or lining material should be available in the vicinity. Sites with large exposed surface area should be avoided due to excessive evaporation losses and growth of unwanted weeds.

3.2.2 Design Procedure

The design of a dugout pond envisages the determination of specifications for the following:

(a) Storage capacity, (b) Shape, (c) Dimensions (depth, top & bottom widths and side slopes), (d) Inlet and (e) Outlet.

(a) Storage capacity: The capacity of the pond depends on (i) purpose of pond, (ii) annual water yield, (iii) storage losses, and (iv) siltation rates.

The capacity of the pond depends upon the catchment size and factors affecting its water yield. The following information on water yield obtained at some representative research stations may be useful.

Research Station	Soil Type	Runoff per cent
Central Soil & Water Conservation Research & Training Institute, Research Centre, Bellary	Deep black soil	10
Agricultural Research Station, Hagari.	Deep black soil	20
ICRISAT, Hyderabad	Medium deep black soil	10
Dryland Main Centre, Sholapur	Medium deep black soil	15 to 20
Dryland Main Centre, Anantapur	Red soils	> 20
Dryland Main Centre, Bangalore	Red soils	24 to 30
ICRISAT, Hyderabad	Red soils	20

Thus, on a conservative estimate, a dependable minimum value of 10% of the annual rainfall can be expected to go as runoff in case of black soils and 20% in case of red soils.

The pond should be of sufficient capacity to meet the desired purpose. Generally, one or two supplemental irrigations (5 cm each) are planned for a small area from such ponds. The water requirement for livestock can be determined from Table 4.

Table 4: Average daily water requirement of animals and human beings

Kind of animal/human being	Water required in lit day ⁻¹
Cow	10-12
Buffalo	10-12
Camel	15-20
Sheep	4.0
Goat	3.0
Human beings	45.0 (includes water required for bathing, drinking, cooking etc.)

Barring summer months, the evaporation rate is fairly constant during the period of storage in the semi-arid regions. However, the seepage rate varies widely due to the variations in the sub-soil strata. To avoid much loss of water from storage, it is desirable to use the water at the earliest.

A suitable provision should be made for the loss in storage capacity due to silting which is generally kept as 5-10 per cent.

(b) Shape: Excavated farm ponds may normally be of three shapes, viz; (i) square, (ii) rectangular, and (iii) circular. However, as curved shape offers difficulties in construction, either square or rectangular ponds are suggested. Sectional plan and elevation of a typical square dugout pond is shown in Fig. 6.

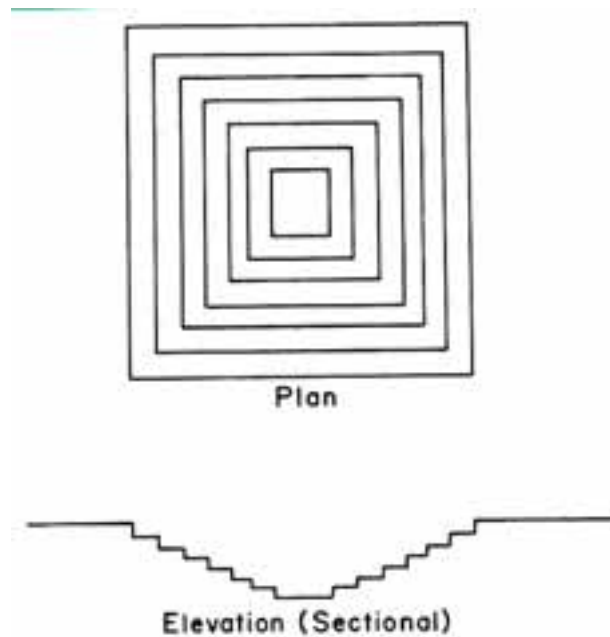


Fig. 6 Farm pond for runoff harvesting and recycling

The volume of the pond is calculated by using the prismoidal formula as follows:

$$V = \frac{d}{6} (A_0 + 4A_1 + A_2) \quad (3)$$

where,

V = Volume of pond (m^3),

d = Depth of pond (m),

A_0 = Area of the pond at the bottom (m^2),

A_2 = Area of the pond at the top (m^2), and

A_1 = Area of the pond at $d/2$ depth below the top of pond (m^2).

(c) Dimensions

- (i) *Depth*: For the same volume of water stored, deeper the pond, lesser is the area occupied by the pond and also lesser are evaporation losses. However, with increased depth, the seepage losses also increase and hence the storage losses may even out. When the construction is done with human labour, any increase in depth beyond 3.5 to 4.0 m becomes uneconomical. It also becomes uneconomical and difficult for lifting devices operated with human and animal power. Hence, a depth of 3 to 4 m may be suitable in general for the ponds.
- (ii) *Side slopes*: The side slopes are decided by the angle of repose of the sub-soil. The constant action of standing water may require relatively flatter side slopes to avoid slippage due to saturation. Generally, side slopes of 1:1 or flatter are adopted.
- (iii) *Bottom area*: When the volume of the pond is known and the depth and side slopes are fixed, the side of the bottom square can be obtained from the following formula:

$$b = \frac{\sqrt{3V - d^3 z^2}}{3d} - d.z \tag{4}$$

where, b = Side of bottom square, m,
V = Volume of pond, m³,
d = Depth of pond, m, and
z = Side slope ratio (horizontal : vertical).

Bottom area (A₀) can be obtained by squaring the value obtained as above.

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

$$B = b + 2 d.z. \tag{5}$$

where, B is length of side of farm pond at the top in metres. Top area (A₂) can be obtained by squaring the value of 'B'

(d) Inlet: The inlet is designed as chute spillway for conducting the runoff into the pond in a controlled manner. The entry section can be designed as a rectangular broad crested weir. Since the velocity of runoff is accelerated along the side slope of the pond, the width is contracted at 1 m below the top level of pond and continued at the same width thereafter.

(e) Outlet: It is economical and advantageous to go in for an inlet-cum-outlet structure wherever possible. When it becomes necessary to separate the two, the outlet is constructed as a rectangular or square channel. This outlet position will be a little lower (15 to 20 cm) than the elevation of the inlet to avoid backing up of the water. The discharge capacity of the outlet can be assumed to be half as that of the inlet capacity as peak rate of runoff.

3.2.3 Construction procedure

The proposal pond site is cleared of all vegetation. The outside limits of the proposed excavation and spoil placement areas are marked with stakes and indicated with the depth of cut. Spread the excavated material not more than one meter high and grade the surface to uniform slope away from the pond. In ponds which are dug using manual labour alone, the excavation is done in the form of steps with successive steps conforming to designed side slope of the pond (2 horizontal to 1 vertical etc.). After reaching the designed depth, the steps are scrapped to form a uniform side slope. The inlet portion is made of masonry chute/ramp/drystone ramp with

cement pointing. This will help in conveying the runoff safely to the bottom of the pond without affecting its slope. In case the sub-soil is found to be made of impervious material, viz; murrum, a small silt collecting tank (silt trap) is provided in the upstream side of the pond to trap the silt. In case the sub-soil is not so impervious, it is preferable to allow silt in pond to get deposited in the bed/sides (by not constructing silt trap), so that with time, the bed and sides of the pond get sealed naturally thus reducing seepage losses.

A good cover of sod forming grasses is established on the side slopes of the pond above the normal water level, the berms, the waste banks and the spillway for protection against erosion.

3.2.4 Design example: A dugout pond is to be constructed in a semi-arid area having red soils. It is proposed to provide one supplemental irrigation of 7.5 cm depth (including losses) to an area of 2.0 ha. Design the pond lined with stone slabs and estimate the cost.

Solution:

Water requirement for one irrigation of 7.5 cm to 2.0 ha area,

$$= 2.0 \times 7.5$$

$$= 15.0 \text{ ha-cm}$$

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

$$\text{Losses} = 15 \times 0.20$$

$$= 3 \text{ ha-cm}$$

$$\text{Designed capacity of the pond} = 15.0 + 3.0$$

$$= 18.0 \text{ ha-cm}$$

$$= 1800 \text{ cu-m}$$

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

Depth of pond = 4.5 m (assumed)
 Side slopes = 1:1
 Shape = Rectangular

Assuming bottom width & length = 12 m x 25 m

Top length = $25 + (4.5 \times 1) 2 = 34 \text{ m}$
 Top width = $12 + (4.5 \times 1) 2 = 21 \text{ m}$
 Area at top (A_2) = $34 \times 21 = 714 \text{ m}^2$
 Mid-length = $25 + (2.25 \times 1) 2 = 29.5 \text{ m}$
 Mid-width = $12 + (2.25 \times 1) 2 = 16.5 \text{ m}$
 Mid-area (A_1) = $29.5 \times 16.5 = 486.75 \text{ m}^2$
 Area at bottom (A_0) = $12 \times 25 = 300 \text{ m}^2$

Volume (V) using Equation (3)

$$= \frac{(714 + 4 \times 486.75 + 300)}{6} \times 4.5$$

$$= 2220.75 \text{ cu-m}$$

$$= 2220 \text{ ha-cm}$$

Since, it is higher than the design capacity, change the dimensions.

Now, assuming bottom dimensions = 12 m x 20 m (length changed from 25 to 20 m, keeping width as same).

$$\begin{aligned} \text{Top length} &= 20 + (4.5 \times 1)2 = 29 \text{ m} \\ A_2 &= 29 \times 21 = 609 \text{ m}^2 \\ \text{Mid-length} &= 20 + (2.24 \times 1)2 = 24.5 \text{ m} \\ A_1 &= 24.5 \times 16.5 = 404.25 \text{ m}^2 \\ A_o &= 12 \times 20 = 240 \text{ m}^2 \end{aligned}$$

$$\begin{aligned} V &= \frac{609 + 4 \times 404.25 + 240}{6} \times 4.5 \\ &= 1849.5 \text{ cu-m} \end{aligned}$$

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

Design dimensions (L x W) are:

$$\begin{aligned} \text{Bottom} &= 20 \text{ m} \times 12 \text{ m} \\ \text{Top} &= 29 \text{ m} \times 21 \text{ m} \\ \text{Depth} &= 4.5 \text{ m} \\ \text{Side slopes} &= 1:1 \end{aligned}$$

Surface Area for Lining: The surface area of lining can be estimated as below:

From Fig.7, length of each sloping side wall = $\sqrt{(4.5)^2 + (4.5)^2} = 6.36 \text{ m}$

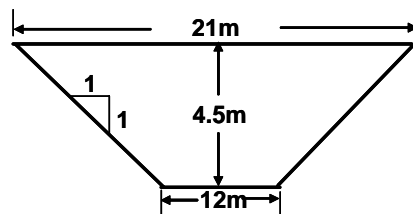
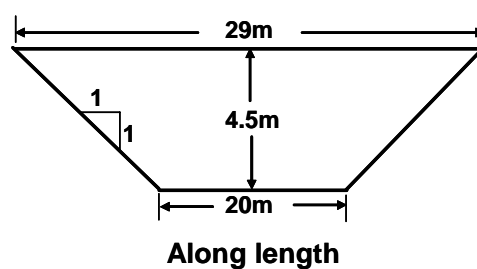


Fig. 7 Cross-section of the farm pond

Surface area of one sloping side wall

$$= \frac{(\text{length at top} + \text{length at bottom})}{2} \times \text{length along sloping sides wall}$$

Distance between the two (i.e. top & bottom) = 6.36 m

Surface area of two sloping side walls & along the length of the pond

$$\begin{aligned} &= \frac{(29 + 20)}{2} \times 6.36 \times 2 \\ &= 311.64 \text{ m}^2 \end{aligned}$$

Surface area of the two sloping side walls along the width of the pond

$$\begin{aligned} &= \frac{(21+12)}{2} \times 6.36 \times 2 \\ &= 209.88 \text{ m}^2 \end{aligned}$$

Bottom area for lining = $20 \times 12 = 240 \text{ m}^2$

Total surface area for lining = $311.64 + 209.88 + 240$
 $= 761.52 \text{ m}^2$
say 762 m^2

Estimate:

(i) Earth work quantity = 1850 cu-m

Taking average rate of excavation from 0 to 4.5 m depth and its placement on the sides including site clearance as Rs. 16 per cubic meter,

Cost of earth work = $1850 \times 16 = \text{Rs. } 29600$

(ii) Lining

Taking rate of 70 to 100 mm thick stone slabs and laying (rough dressed) including cement pointing

= Rs. 60 per Sqm

Cost of lining with stone slab including jointing & pointing

= $762 \times 60 = \text{Rs. } 45720$

Total cost of pond = $29600 + 45720 = \text{Rs. } 75320$.

4.0 GROUND WATER RECHARGE

Presently, around half of the irrigation demands in India are met from groundwater resources. In Tamil Nadu, well irrigation accounts for over 60% of the net irrigated area. The increased dependence on groundwater is causing greater concern due to deficient natural groundwater recharge. In a number of states groundwater is being over-exploited resulting in excessive decline in water table. The component of rainfall contribution as infiltration to groundwater varies from 3 to 25 per cent in different hydrogeological situations and this needs to be supplemented by artificial recharging.

4.1 Factors Affecting Ground Water Recharge

The following factors affect the ground water recharge in a given location:

- i. Availability, source and quality of water.
- ii. Nature of surface soil. The greatest volumes and rates of recharge are possible in thick formations of pervious sands and gravels or porous rocks.
- iii. Depth to aquifer.
- iv. Geologic structure and capacity of the ground-water reservoir.
 - v. The presence of aquicludes which are impermeable or slowly permeable formations overlying an aquifer and prevent or reduce natural recharge.
- vi. Movement of ground water.
- vii. Location of withdrawal area.
- viii. Pattern of pumping draft.

The component of rainfall contribution as infiltration to ground water varies from 3 to 25 percent in different hydrogeological situations as given in Table 5.

Table 5: Rainfall Infiltration Factor in Different Hydrogeological Situations

Hydrogeological Situation	Rainfall infiltration factor (% of normal rainfall)
Alluvial areas	
a. Sandy areas	20 to 25
b. Areas with higher clay content	10 to 20
Semi consolidated sandstones	
Friable and highly porous	10 to 15
Hard rock areas	
a. Granitic terrain	
i. Weathered and fractured	10 to 15
ii. Un-weathered	5 to 10
b. Basaltic terrain	
i) Vesicular and jointed basalt	10 to 15
ii) Weathered basalt	4 to 10
c. Phyllites, limestones, sandstones, quartzites, shales, etc.	3 to 10

4.2 Data Collection

For planning and development of ground water through natural or artificial recharge, the following investigations are necessary in a given location:

- i) Study and analysis of meteorological factors like precipitation, evaporation, etc.
- ii) Rainfall-runoff relationships to explore the possibility of artificial recharge or contributions of rainfall for recharge.
- iii) Ground water fluctuations during the year.
- iv) Inventory of existing wells and their draft.
- v) Aquifer tests to determine their characteristics as discussed in the previous section.
- vi) Collection and analysis of water samples for their suitability.
- vii) Estimation of seepage and recharge contributions from canals, ponds and agricultural lands.

Attempts are first made to collect these data from various government and non-government agencies such as State Ground Water Board, State Water Resources Directorate, Minor Irrigation and Tubewell Department, Central Ground Water Board etc. Some of the data such as draft can be collected through sample survey in a watershed by interviewing the farmers and observing and recording the information at site. For other data, laboratory and field tests such as pumping tests are required. Ground water fluctuations in different periods of the year can be monitored by installing observation wells (unconfined aquifer) or piezometers (confined aquifers). The diameter of observation wells varies from 2.5 to 5 cm and extend to a depth great enough to reach the minimum expected position of the water table. In the absence of observation wells, the data collected from the existing open dug wells can be utilized.

Ground water recharge is greatly influenced by season of the year, intensity and duration of precipitation, topography, vegetative cover, soils, landuse, evapotranspiration, availability of storage etc. The geological conditions which are favourable for natural or artificial recharge may be listed as:

- i) Formations of sand, gravel or highly fractured rocks either underground or exposed over a larger area.
- ii) The presence of fractured or faulted zones.
- iii) Karst or sinkhole topography
- iv) The absence of barriers to the horizontal or vertical movement of ground water
- v) Feasible locations for the installation of recharge wells, dams, diversions or other recharge structures.

4.3 Artificial Recharge

Artificial recharge is becoming increasingly important due to over exploitation of underground resources for various purposes resulting in decline of water table in many parts of the country. Artificial recharge is defined as the process of replenishing underground formations by augmenting the surface water storage.

The objectives of artificial recharge may be listed as:

- To reduce, stop or even reverse the declining level of ground water
- To protect underground fresh water in coastal aquifers against salt water intrusion from the ocean,

- To store surface water, including flood water to prevent flooding in the down stream reaches,
- To improve water quality by removing suspended solids by filtration through ground, and
- To store water to reduce cost of pumping and piping.

The methods for artificial recharge can be broadly classified into three categories, viz; direct surface, direct-sub surface and indirect methods.

4.3.1 Direct surface methods

They are the simplest and most widely used methods in which water from the land surface moves to the aquifer by percolation through the soil. These methods include flooding, ditch and furrow, basins, stream channel modification and over irrigation.

Flooding: Flooding method is applicable on lands having mild slope of 1 to 3 percent and is relatively cheaper in construction and maintenance.

Ditch and Furrow: In ditch and furrow system, the water to be recharged is passed through closely spaced, shallow, flat-bottomed ditches or furrows.

Basins: Use of basins is the most common method of recharge as they allow efficient use of space and are easy to maintain. They are either excavated or are enclosed by dikes or levees and may be constructed individually or in series. Basins have several advantages which include efficient land use, less chances of clogging, and proper handling of stream or storm water.

Stream channel modification: Stream channel modification involves construction of check dams across stream flood plains both above and below the dams. These structures, though temporary, are quite effective in enhancing recharge and are relatively inexpensive.

Over irrigation: Over-irrigation during non-growing seasons also helps in recharging the ground water. Methods of irrigation include overland flow, ditch and furrow systems, flooding and spray systems.

4.3.2 Direct sub-surface methods

In direct sub-surface methods, the water is conveyed and recharged directly into an aquifer. These methods are necessitated where water table is overlain by low permeability or semi-permeable layer thereby preventing direct surface recharge. These methods include injection of water into natural openings in the aquifer, pits or shafts and wells. The water being recharged should be of good quality as it is being directly recharged into the aquifer.

Natural openings: Natural openings caused by fracturing or solution in cavernous limestones or other soluble rocks can serve as recharging zones. Depending upon the source of water and size, configuration, and location of the openings; maintenance, protection and improvement may be necessary.

Pits and shafts: Pits and shafts are constructed where a semipervious layer exists at or near the land surface. The pits have variable dimensions and their depth depends upon the thickness of the confining layer. They are costlier than surface methods and require high maintenance. Shafts are deeper than pits and are of smaller diameter. They are either constructed by hand or are drilled or bored. They can be filled with coarse material or simply lined. Shaft walls or fill materials are susceptible to clogging by suspended solids or biological activity and are, hence, difficult to maintain.

Recharge wells: Recharge wells, also known as injection wells, are used for deep aquifers separated from the surface by materials of low permeability. Wells can be used to recharge one or more aquifers simultaneously depending upon location of impervious layers. If the injection wells are installed in unconsolidated material, the upper section of the well is cased and the screen is placed directly in the aquifer or surrounded by an artificial gravel pack. The design depends upon the recharge purpose, the amount of water to be injected and the acceptance rate of the aquifer. The clogging by suspended material and biologic activity can be periodically corrected by pumping and surging, adding oxidizing agents and using specific chemical treatments.

4.3.3 Induced recharge

The induced recharge is accomplished by withdrawing groundwater at a location adjacent to a river or lake so that lowering of the ground water level will induce water to enter the ground from the surface source. On the basis of this definition, wells located directly adjacent to and fed largely by surface water serve as means of artificial recharge. The amount of water induced into the aquifer depends on the rate of pumping, permeability, type of well, distance from surface stream and natural ground water movement. Water induced for recharge is free from organic matter and pathogenic bacteria and, hence, is of better quality.

4.4 Estimation of Ground Water Recharge

A typical curve of recharge rate *versus* time is shown in Fig. 8. The initial decrease is attributed to dispersion and swelling of soil particles after wetting, the subsequent increase accompanies elimination of entrapped air by solution in passing water and the final gradual decrease results from microbial growth clogging the soil pores. The groundwater recharge can be estimated by employing various methods which include empirical methods, analysis of base flow hydrograph, hydrologic budgeting, tracer techniques, ground water level fluctuation method and mathematical models. The “Groundwater Estimation Committee” of Government of India in 1984 recommended that the groundwater recharge should be estimated based on the ground water fluctuation method. Some of the important methods used for estimation of recharge are discussed below:

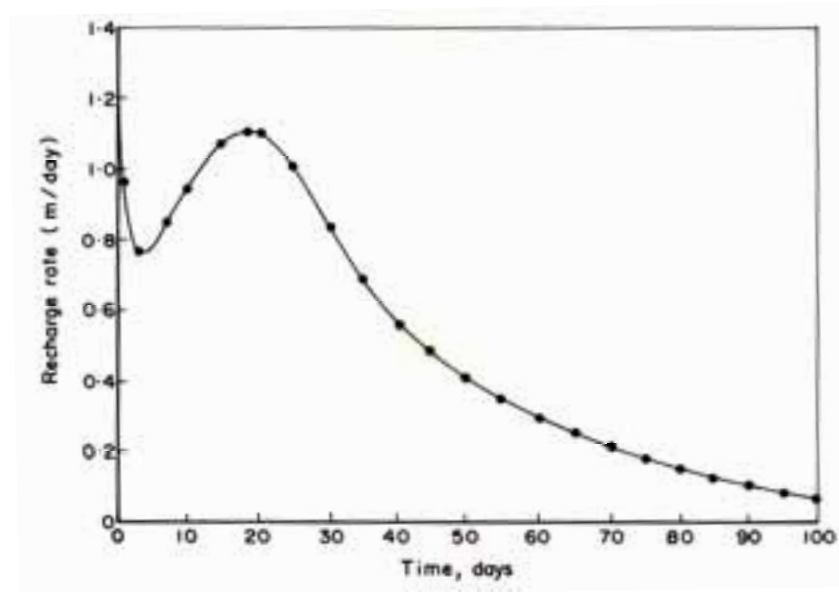


Fig. 8: Typical time variation of recharge rate for water spreading on undisturbed soil

4.4.1 Groundwater level fluctuation method

In this method, the data on seasonal variations of groundwater level, rainfall, applied irrigation water etc. is used. This method is generally not applicable to confined aquifers. It covers recharge only at the soil surface. When the recharge is seasonal, the groundwater level may fluctuate in a sine curve pattern with varying amplitudes. By plotting the annual rise corresponding to annual rainfall, an average relationship is derived which gives a limiting value of rainfall (threshold value) below which there is no recharge. This amount of rainfall is completely lost in evapotranspiration and surface runoff. The recharge in any particular year is the difference between the observed annual rainfall and the total losses. There are several variations of this method which have been utilised by different workers. The rise and fall of water table over an area is a measure of change in groundwater storage or recharge and is computed as:

$$R = h \cdot S_y \cdot A \quad (5)$$

where,

R = Groundwater recharge, ha-m.

h = Change in water level due to recharge

S_y = Specific yield of the formation in the zone of fluctuation,
dimensionless.

A = Surface area of the aquifer, ha

The recharge is estimated based on pre-recharge and post-recharge water table fluctuations. The monitoring of water level network stations needs to be adequate in space and time to smoothen inconsistencies in observations which may arise due to varied hydrological situations and other local factors.

Example:

The mean seasonal (i) pre-recharge (i.e. pre-monsoon) and (ii) post-recharge (i.e. post-monsoon) water table contour map obtained from the data network of observation wells in a watershed of Maharashtra area with weathered basaltic region after treatment measures was prepared. The following information is derived from this map:

- | | |
|---|-----------|
| (i) Average water level elevation during pre-recharge period | = 259.0 m |
| (ii) Average water level elevation during post-recharge period | = 260.8 m |
| (iii) Average surface area of aquifer for the above water level elevation (i.e. influence zone) | = 150 ha |

Find the average groundwater recharge during the period.

Solution:

- | | |
|---|----------------------------------|
| Average change in water level elevation over the aquifer area (Δh) | = 260.8-259.0
= 1.8 m |
| Taking average specific yield (S_y) for basaltic zone (based on literature) | = 3 percent |
| Groundwater recharge during the period | = 1.8 x 0.03 x 150
= 8.1 ha-m |

This means a net gain of 8.1 ha-m of water.

4.4.2 Tracer techniques

Fluorescent dye tracers find a prominent place in recent methodologies to study the movement of ground water. Possible use of isotope techniques in estimating the quantum of recharge from ponds have been attempted. Infected tritium and Co^{60} methods were found to suit the need of quantifying recharge from ponds. Delineating the zone of influence of a percolation tank situated in granite terrain was attempted by using Rhodamine B fluorescent dye as a tracer and it was found that the tracer moved down the gradient from the tank to a distance of 1050 m within 14 days. In another study, recharge measurements was attempted in the state of Andhra Pradesh, on the bed of a percolation tank having sandy loam soil and granitic basement using the tritium injection technique.

4.4.3 Indirect methods

Some indirect methods of estimating groundwater recharge are as under:

- a) Prepare well hydrographs and compare for changes, if any, to determine recharge. It will be good to have some control wells also nearby (beyond the zone of influence) for comparison.
- b) Trend line can be fitted to well hydrographs to quantify increasing and decreasing trends. Increasing trend shows positive groundwater recharge.
- c) Use of secondary data such as increased number of wells, number of irrigations, number of pumping hours and changes in cropped area, i.e. command area and type of crops are also groundwater recharge indicators.

These data may alternatively provide a qualitative estimate of recharge in the absence of other data and/or provide supporting evidence.

4.5 Soil Conservation Measures for Groundwater Recharge

All soil and water conservation measures help in augmenting the groundwater recharge by inducing the infiltration rate and increasing the opportunity time. These measures include contour bunds, graded bunds, bench terraces, trenches, *nalla* bunds, check dams/gully plugs, and other agronomical and biological practices.

Increased groundwater availability due to execution of soil conservation measures, under many watershed development projects taken up in the country, was evident from increased number of wells, increase in well irrigated area and rise in water table in watersheds. The number of dug wells after implementation of the programmes, on an average, increased by over 50% to 125% in the watersheds. There is also considerable improvement in the groundwater due to better recharge in most of the watersheds. In general, the increase in water table was of the order of 1.0 to 2.0 m. In a study conducted to observe the effect of contour bunding on groundwater recharge near Periakulam in Theni District of Tamil Nadu, an increase of 14.5% was observed in the water yield of wells after bunding.

Percolation tanks are the most commonly used measures for artificial recharge into high permeability unconfined aquifers. Percolation ponds are small storage structures constructed across natural streams and *nallas* to collect, spread and impound surface runoff to facilitate infiltration and percolation of water into the sub-soil. In a study to determine the recharge from percolation tanks in basaltic formations in central Maharashtra, it was found that the area of influence of tanks on an average was 1.7 sq. km and the rise of water table was found to be about 2-5 m. The recharge rate varied from 3.2 ha-m to 11.3 ha-m with an average of 7.9 ha-m which is about 60% of the tank capacity. The results of studies conducted in the percolation ponds of

Coimbatore district of Tamil Nadu showed that the zone of influence extends to 130 ha and spreads over 575 m on the upstream side and 1235 m on the downstream side of the pond.

A study conducted in the priority watersheds of Lower Bhavani catchment of Mettupalayam taluk of Coimbatore district showed that there was increase in the ground water recharge due to construction of percolation tanks varying from 16% to as high as 188%. The number of open wells increased from 8 to 50% after the construction of tanks. The increase in the irrigated area ranged from 21 to 170 percent which is a clear indication of the increased groundwater availability.

The soil conservation measures (rock fill dams, *Nalla* bunds, arch weirs) in a watershed (area – 1120 ha; rainfall – 654 mm) at Chinnatekur in Kurnool district of Andhra Pradesh increased ground water levels varying from 0.5 to 1 m. Consequently, the command area of 47 open wells in the watershed increased by 173% as compared to pre-treatment period. The number of open wells also increased from 47 during the pre project period (1984) to 120 during 1992-93.

Due to over exploitation of groundwater in Kutchh district of Gujarat since 1982, the water table has gone down drastically in many areas resulting in drying up of many open wells and sea water intrusion into the coastal aquifers. The total area affected by sea water intrusion has been estimated as 15,500 ha in 244 villages. Shree Vivekananda Research and Training Institute constructed water harvesting systems since 1987 with the assistance of voluntary organisations and the State Government. In all, 58 check dams, 48 percolation tanks, 2 sub-surface dams, 39 recharge wells and 42 storage tanks were constructed. Total capacity of the recharge structures was $1.44 \times 10^6 \text{ m}^3$, which could accommodate two to three floods in a normal rainfall year, thus increasing its recharge capacity to about $3 \times 10^6 \text{ m}^3$ in a year of good rainfall. The area likely to be benefited is of the order of 3301 ha in 20 villages. The rise in water table over a period of 6 years was of the order of 6 m and maximum decline in salts was of the order of 920 ppm. This water harvesting project has given encouraging results and proved the effectiveness of recharge wells and sub-surface dams as recharge structures. The cost of harvested water worked out to be Rs.7.33/m³.

Table 6 shows the impact of soil and water conservation measures adopted on watershed basis on ground water recharge in different agro-climatic regions of India. As evident, a rise in water table height varying from 0.2 to 2.0 m has been noticed as an impact of conservation measures under different situations. It resulted in significant increase in number of wells in the command area, their yields and irrigated area.

Table 6. Effect of watershed management interventions on ground water recharge in different regions of India

Watershed	Surface storage capacity created, ha-m	Observed rise in ground water table, m*
Bazar-Ganiyar (Haryana)	79.0	2.0
Behdala (H.P.)	18.0	1.0
Bunga (Haryana)	60.0	1.8
Chhajawa (Rajasthan)	20.0	2.0
Chinnatekur (A.P.)	5.6	0.8
GR Halli (Karnataka)	6.8	1.5
Joladarasi (Karnataka)	4.0	0.2
Siha (Haryana)	42.2	2.0

*Difference between pre-project and post-project water table.

5.0 SUMMARY

The monsoon runoff if flows uncontrolled causes soil erosion but if used judiciously can be a boon for improving crop production in the rainfed areas. Since conventional irrigation of all rainfed lands in India (89 million ha) is not feasible, there is tremendous scope for improving their productivity through rain water harvesting. Water harvesting being location specific, different water harvesting practices have been evolved by local communities which may broadly be grouped as i) *in-situ* retention of rainfall on the land itself by agronomic/mechanical measures, ii) harvesting surface runoff and its storage, iii) diversion of perennial surface/sub-surface water into the storage structure, and iv) roof-top water harvesting.

The most common water harvesting structures are of two types: a) embankment type ponds for hilly and rugged area, and b) excavated or dugout type farm ponds for flat topography. Earthfill dams consist of an earthen embankment constructed across a water course with adequate spillway for disposal of excess runoff. Depending upon the construction, the earthfill dam may be of three types: a) homogenous, b) diaphragm, and c) zoned embankment. In order to be cost effective, the dam should be located where maximum storage volume is obtained through minimum volume of earth fill. After computation of water yield and peak rate of runoff for the given location, the design parameters to be determined for the dam are: a) height of dam, b) free board, c) settlement allowance, d) top width of embankment, e) embankment side slopes, f) storage capacity, g) filters and toe drains, and h) foundation key/cut-off.

Dugout pond is formed by excavating a pit and forming an embankment around the pit by excavated soil. The design of a dugout pond envisages determination of specifications for: a) storage capacity, b) shape, c) dimensions (depth, top & bottom widths and side slopes), d) inlet, and e) outlet.

The increased dependence on groundwater and its consequent over-exploitation is causing great concern due to ever-declining water table. The component of rainfall contribution as infiltration to groundwater varies from 3-25 per cent in different hydrogeological situations and thus needs to be supplemented by artificial recharging. Factors affecting groundwater recharge are: a) availability, source and quality of water, b) nature of surface soil, c) depth of aquifer, d) geologic structure and capacity of groundwater reservoir, e) presence of aquicludes, e) movement of groundwater, f) location of withdrawal area, and g) pattern of pumping draft. For planning and development of groundwater through natural or artificial recharge, necessary investigations should be carried out. Artificial recharge is defined as the process of replenishing underground formations by augmenting the surface water storage. The direct surface methods of artificial recharge include flooding, ditch and furrow, basins, stream channel modification and over irrigation whereas the direct sub-surface methods include injection of water into natural openings in the aquifer, pits or shafts and wells. The induced recharge is accomplished by withdrawing groundwater at a location adjacent to a river or lake so that lowering of the groundwater level will induce water to enter the ground from the surface source. For estimation of groundwater recharge, ground water level fluctuation, tracer techniques or indirect methods may be employed. All soil and water conservation measures help in augmenting the groundwater recharge by inducing the infiltration rate and increasing the opportunity time. These measures include contour bunds, graded bunds, bench terraces, trenches, percolation ponds, *nalla* bunds, check dams/gully plugs, and other agronomical and biological practices.

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