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Artificial recharge to groundwater

National foreword

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Artificial recharge to groundwater

Recharge artificielle des eaux souterraines

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Foreword

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The committee responsible for this document is ISO/TC 113, *Ground water*.

Introduction

Excessive extraction/use of ground water for various applications has resulted in marked lowering of ground water levels. Ground water levels are depleting very fast in various areas threatening ground water sustainability and causing adverse environmental impacts. Artificial recharge to ground water provides augmentation of ground water resources using surplus surface water available. Artificial recharge techniques can be applied to address the following issues:

a) enhance the sustainability of ground water resources in an area where over-development has depleted the aquifer;

b) conservation and storage of surplus water for future requirements;

c) improve the quality of existing ground water through dilution.

The following are basic requirements for recharging the ground water reservoir:

a) availability of surplus water of suitable quality in space and time;

b) suitable hydrogeological environment;

c) identification of sites for augmenting groundwater;

d) cost effective and appropriate artificial recharge techniques and structures.

Availability of source water of suitable quality is one of the prime requisites for ground water recharge. This can be assessed by analysing the water resources available as runoff and rainfall. The physical, chemical, and biological quality of the recharge water is important in planning and selection of recharge method. Age of water used for recharge is also considered important in certain cases.

The hydrogeological situation in each area needs to be appraised with a view to assess the recharge capabilities of the underlying geological formations. Detailed knowledge of geological and hydrological features of the area is necessary for proper selection of site and type of recharge structure. In particular, the input on geological boundaries, hydraulic boundaries, inflow and outflow of waters, storage capacity, porosity, hydraulic conductivity, transmissivity, natural discharge of springs, water resources available for recharge, natural recharge, water balance, lithology, depth of the aquifer, and tectonic boundaries features such as lineaments, shear zones, etc. are required for effective and efficient artificial recharge to ground water.

The aquifers best suited for artificial recharge are those that can hold large quantities of water and do not release them too quickly. The evaluation of the storage potential of sub-surface reservoirs (aquifers) is invariably based on the knowledge of dimensional data of permeable material in floodplain (alluvial), reservoir rock which includes their thickness and lateral extent. The availability of sub-surface storage space and its replenishment capacity further govern the extent of ground water recharge.

Artificial recharge techniques envisage integrating the surface water resources to ground water repositories resulting in changes in the ground water regime, like

a) rise in water level,

b) increment in the total volume of the ground water reservoir,

c) availability for extended period, and

d) quality of ground water.

The upper part of the unsaturated zone is not considered for recharging since it can cause adverse environmental impacts like water logging, soil salinity, dampness, etc.

Artificial recharge projects are site-specific and replication of the techniques even in similar areas is to be based on the local hydrogeological and hydrological environments. Artificial recharge to ground water is generally supported by the remote sensing studies, hydro-meteorological studies, hydrogeological studies, hydrological studies, soil infiltration testing, geophysical studies, hydro-chemical studies, etc. The studies bring out the potential of unsaturated zone in terms of total volume, which can be recharged.

Artificial recharge of ground water is normally undertaken in the following:

a) areas where ground water levels are continuously declining;

b) areas where substantial volume of aquifer has already been de-saturated;

c) areas where availability of ground water is inadequate in lean months;

d) areas where studies indicate scope for improvement of quality of ground water or areas where salinity ingress into fresh water aquifers has already taken place or is likely to happen in the near future.

Artificial recharge to groundwater

1 Scope

This Technical Report provides details of methods aimed at augmentation of ground water resources by modifying the natural movement of surface water as a general guide. This Technical Report does not cover the process of deciding and planning artificial recharge within an overall water resource management scheme.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 772, *Hydrometry — Vocabulary and symbols*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 772 apply.

4 Artificial recharge techniques

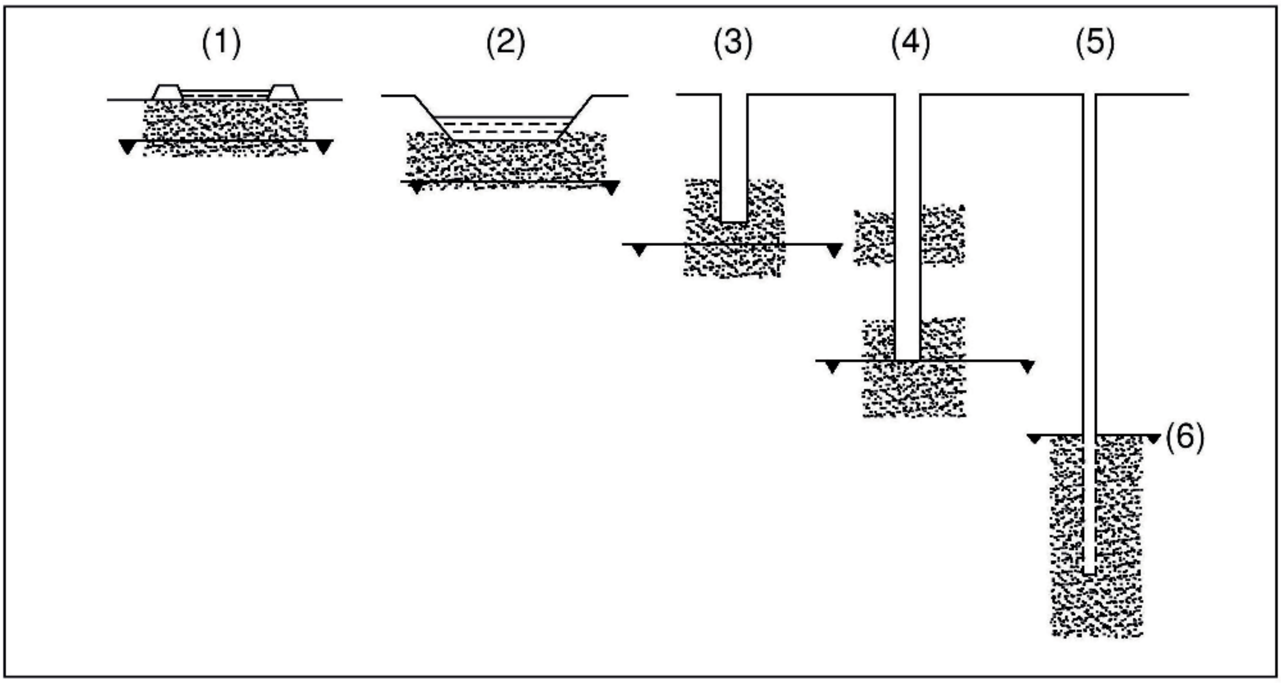
A wide spectrum of techniques are used to recharge ground water reservoirs. Artificial recharge techniques are broadly categorized as

a) surface spreading techniques,

b) sub-surface techniques, and

c) combination of surface and sub-surface techniques.

Aquifer disposition plays a decisive role in choosing the appropriate technique of artificial recharge of ground water as illustrated in Figure 1.



Key

1 and 2	surface spreading techniques
3, 4, and 5	sub-surface techniques
6	indication of water table/piezometeric head

NOTE Local regulations might exclude certain artificial recharge options, such as aquifer to aquifer interconnection, as shown in item 4.

Figure 1 — Recharge techniques for increasingly deep permeable materials.

4.1 Surface spreading techniques

These are aimed at increasing the contact area and residence time of surface water over the soil to enhance the infiltration and to augment the ground water storage in phreatic aquifers. The important considerations in the selection of sites for artificial recharge through surface spreading techniques include the following:

a) the aquifer being recharged should be unconfined, permeable, and sufficiently thick to provide storage space;

b) the surface soil should be permeable and have high infiltration rate;

c) vadose zone should be permeable and free from clay lenses;

d) ground water levels in the phreatic zone should be deep so as to accommodate the recharged water without water logging;

e) the aquifer material should have moderate hydraulic conductivity so that the recharged water is retained for sufficiently long periods in the aquifer and can be used when needed as natural repositories.

The most common surface spreading techniques used for artificial recharge to ground water are flooding, ditch and furrow, recharge basins, runoff conservation structures, and stream modifications.

4.1.1 Flooding

This technique is ideal for lands adjoining rivers or irrigation canals in which water levels remain deep even after monsoons and where sufficient non-committed surface water supplies are available. The schematics of a typical flooding system are shown in Figure 2. To ensure proper contact time and water spread, embankments are provided on two sides to guide the unutilized surface water to a return canal to carry the excess water to the stream or canal.

Flooding method helps reduce the evaporation losses from the surface water system, is the least expensive of all artificial recharge methods available, and has very low maintenance costs.

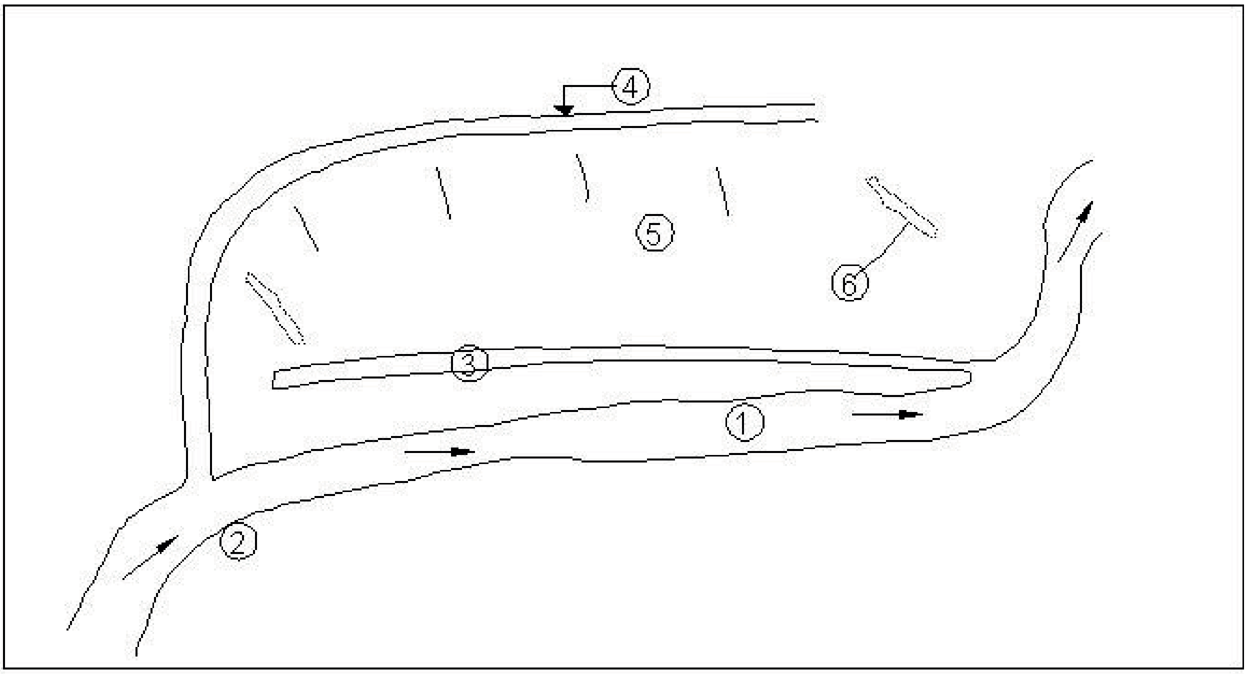
4.1.2 Ditch and furrows method

This method involves construction of shallow, flat-bottomed, and closely spaced ditches or furrows to provide maximum water contact area for recharge from source stream or canal. The ditches should have adequate slope to maintain flow velocity and minimum deposition of sediments. The widths of the ditches are typically in the range of 0,30 m to 1,80 m. A collecting channel to convey the excess water back to the source stream or canal should also be provided. Figure 3 shows a typical plan of a series of furrows originating from a supply ditch and trending down the topographic slope toward the stream. Though this technique involves less soil preparation when compared to recharge basins and is less sensitive to silting, the water contact area seldom exceeds 10 % of the total recharge area. Three common patterns *viz.* lateral ditch pattern, dendritic pattern, and contour pattern are detailed as follows and shown in Figure 4:

a) *Lateral ditch pattern*: the water from the stream is diverted to the feeder canal/ditch from which smaller ditches are taken out at right angles. The rate of flow of water from the feeder canal to these ditches is controlled by gate valves. The furrow depth is determined in accordance with the topography and to ensure that maximum wetted surface is available along with maintenance of uniform velocity. The excess water is routed to the main stream through a return canal along with the residual silt.

b) *Dendritic pattern*: water from the stream can be diverted from the main canal into a series of smaller ditches spread in a dendritic pattern. The bifurcation of ditches continues until practically all the water is infiltrated into the ground.

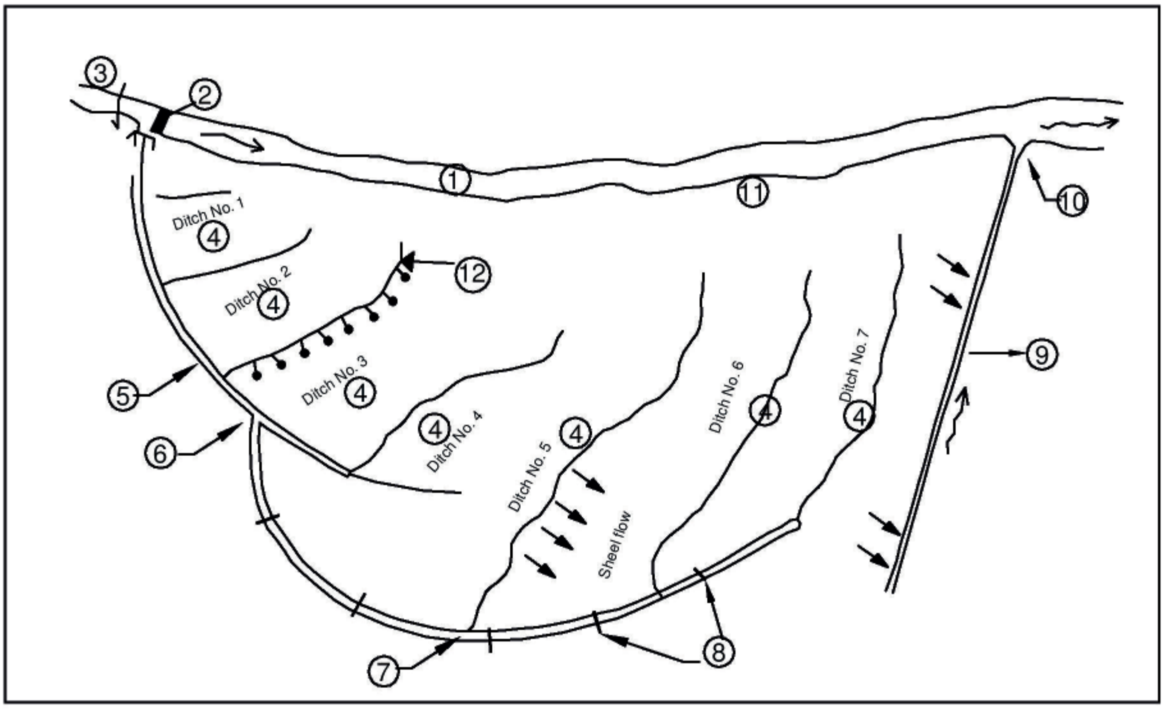
c) *Contour pattern*: ditches are excavated following the ground surface contour of the area. When a ditch comes close to the stream, a switch back is made to meander back and forth to traverse the spread repeatedly. At the lowest point downstream, the ditch joins the main stream, returning the excess water to it.



Key

1	stream
2	direction of flow
3	return flow
4	delivery canal
5	sheet flow
6	embankment

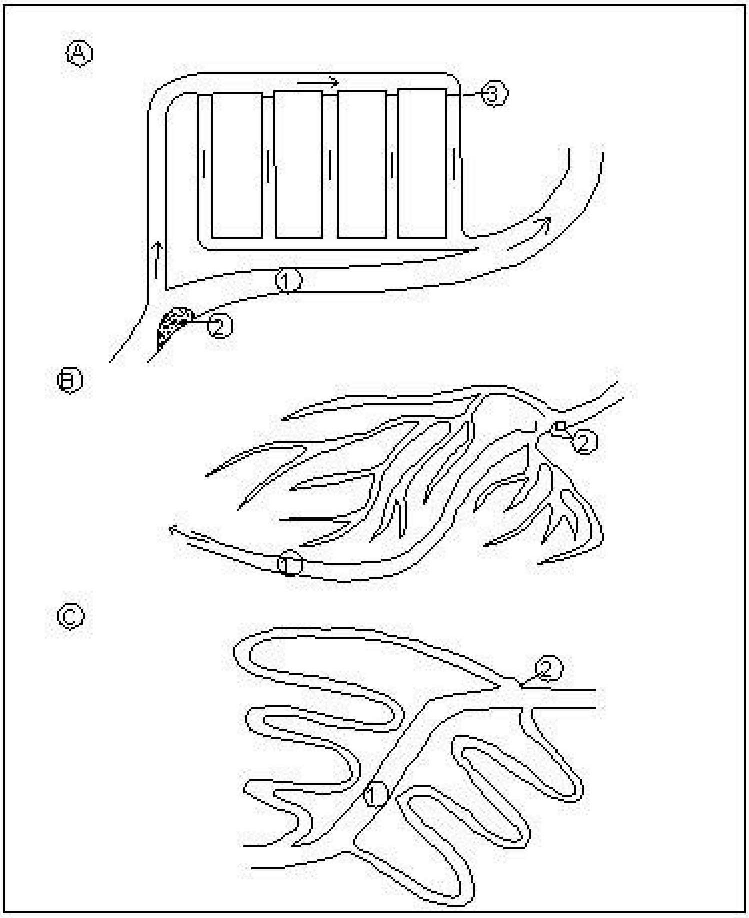
Figure 2 — Schematics of a typical flood recharge system



Key

1	stream
2	diversion structure
3	gate and measuring device
4	various recharge ditches
5	supply ditch
6	alternate diversion
7	supply ditch
8	wire bound check dam
9	collecting ditch
10	measuring device
11	prevailing ground slope
12	ditch

Figure 3 — Schematics of a typical ditch and furrows recharge system



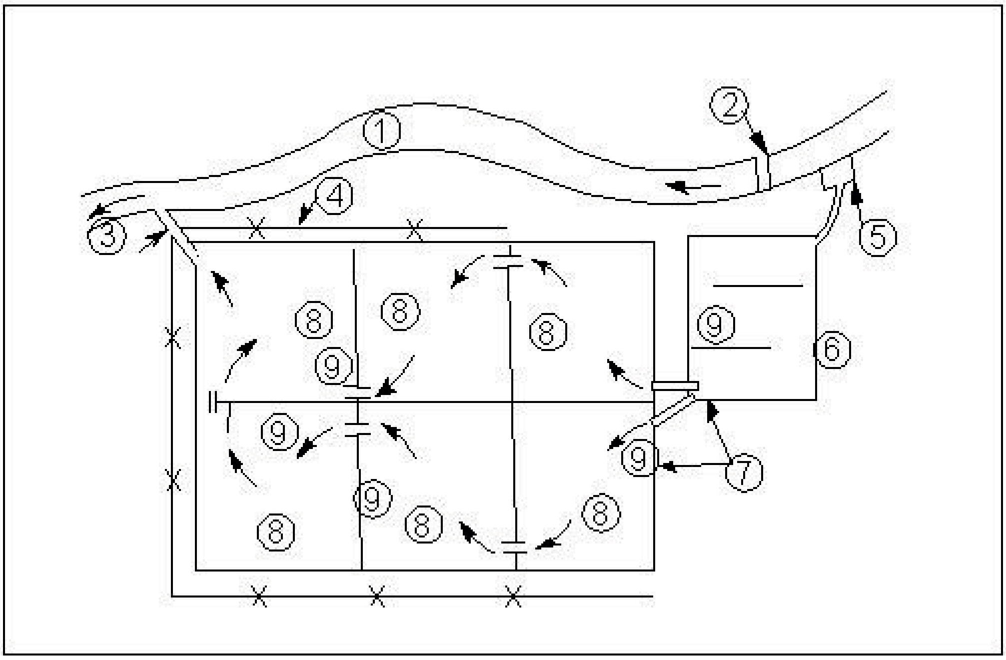
Key

1 stream
2 diversion structure
3 control ditch
A lateral ditch pattern
B dendritic ditch pattern
C contour ditch pattern

Figure 4 — Common patterns of ditch and furrow recharge systems

4.1.3 Recharge basins

Artificially recharged basins are commonly constructed parallel to ephemeral or intermittent stream channels and are either excavated or are enclosed by dykes and levees. They can also be constructed parallel to canals or surface water sources. In alluvial areas, multiple recharge basins can be constructed parallel to the streams (see Figure 5), with a view to increase the water contact time, reduce suspended material as water flows from one basin to another, and to facilitate periodic maintenance such as scraping of silt, etc. to restore the infiltration rates by bypassing the basin under restoration.



Key

1	stream
2	diversion structure
3	cut fall
4	fence as required
5	intake structure
6	sediment retention basin
7	main entrance road on levees as required
8	recharge basin
9	interbasin control structure

Figure 5 — Schematics of a typical recharge basin

In addition to the general design guidelines mentioned, other factors to be considered while constructing recharge basins include the following:

a) area selected for recharge should have gentle ground slope;

b) the entry and exit points for water should be diagonally opposite to facilitate adequate water circulation in individual basins;

c) water released into the basins should be as sediment-free as possible;

d) rate of inflow into the basin should be slightly more than the infiltration capacity of all the basins.

The water contact area in recharge basin is normally high and may range from 75 % to 90 % of the total recharge area. It is also possible to make efficient use of space by making basins of different shapes to suit the terrain conditions and available space.

4.1.4 Runoff conservation structures

These are normally multi-purpose measures, mutually complementary, and conducive to soil and water conservation, afforestation, and increased agricultural productivity. They are suitable in areas receiving low to moderate rainfall mostly during a single monsoon season and having little or no scope for transfer of water from other areas. Different measures applicable to runoff zone, recharge zone, and discharge zone are available. The structures commonly used are bench terracing, contour bunds, contour trenches, gully plugs, check dams, and percolation tank.

4.1.4.1 Bench terracing

Bench terracing involves levelling of sloping lands with surface gradients up to 8 %and having adequate soil cover for bringing them under irrigation. It helps in soil conservation and holding runoff water on the terraced area for longer durations, leading to increased infiltration and ground water recharge.

For implementing terracing, a map of the watershed should be prepared by level surveying and suitable benchmarks fixed. A contour map of 0,3 m contour interval is then prepared. Depending on the land slope, the width of individual terrace should be determined, which, in no case, should be less than 12 m. The upland slope between two terraces should not be more than 1:10 and the terraces should be levelled. The vertical elevation difference and width of terraces are controlled by the land slope. The soil and weathered rock thickness, elevation difference, and the distance between the bunds of two terraces for different slope categories are furnished in Table 1.

In cases where there is a possibility of diverting surface runoff from local drainage for irrigation, as in case of paddy cultivation in high rainfall areas, outlet channels of adequate dimensions are to be provided. The dimensions of the outlet channels depend on the watershed area as shown in Table 2. The terraces should also be provided with bunds of adequate dimensions depending on the type of soils as shown in Table3.

Table 1 — Soil thickness, vertical difference and distance between bunds of two terraces for different slopes

Land slope %	**Thickness of soil and weathered rock** m	**Vertical separation** m	**Distance between bunds of two terraces** m
1	0,30	0,30	30
2	0,375	0,45	22
3	0,450	0,60	20
4	0,525	0,75	18,75
5	0,600	0,90	18
6	0,750	1,05	17,5
7	0,750	1,20	17
8	0,750	1,20	15
Source: Manual on Artificial Recharge of Ground Water, Central Ground Water Board, India, 2007.[1]			

Table 2 — Dimensions of output channels for different watershed areas

Area of watershed ha	**Channel dimensions** (m)		
	Base width	**Top width**	**Depth**
<4	0,30	0,90	0,60
4 to 6	0,60	1,20	0,60
6 to 8	0,90	1,50	0,60
8 to 10	1,20	1,80	0,60
10 to 12	1,50	2,10	0,60
Source: Manual on Artificial Recharge of Ground Water, Central Ground Water Board, India, 2007.[1]			

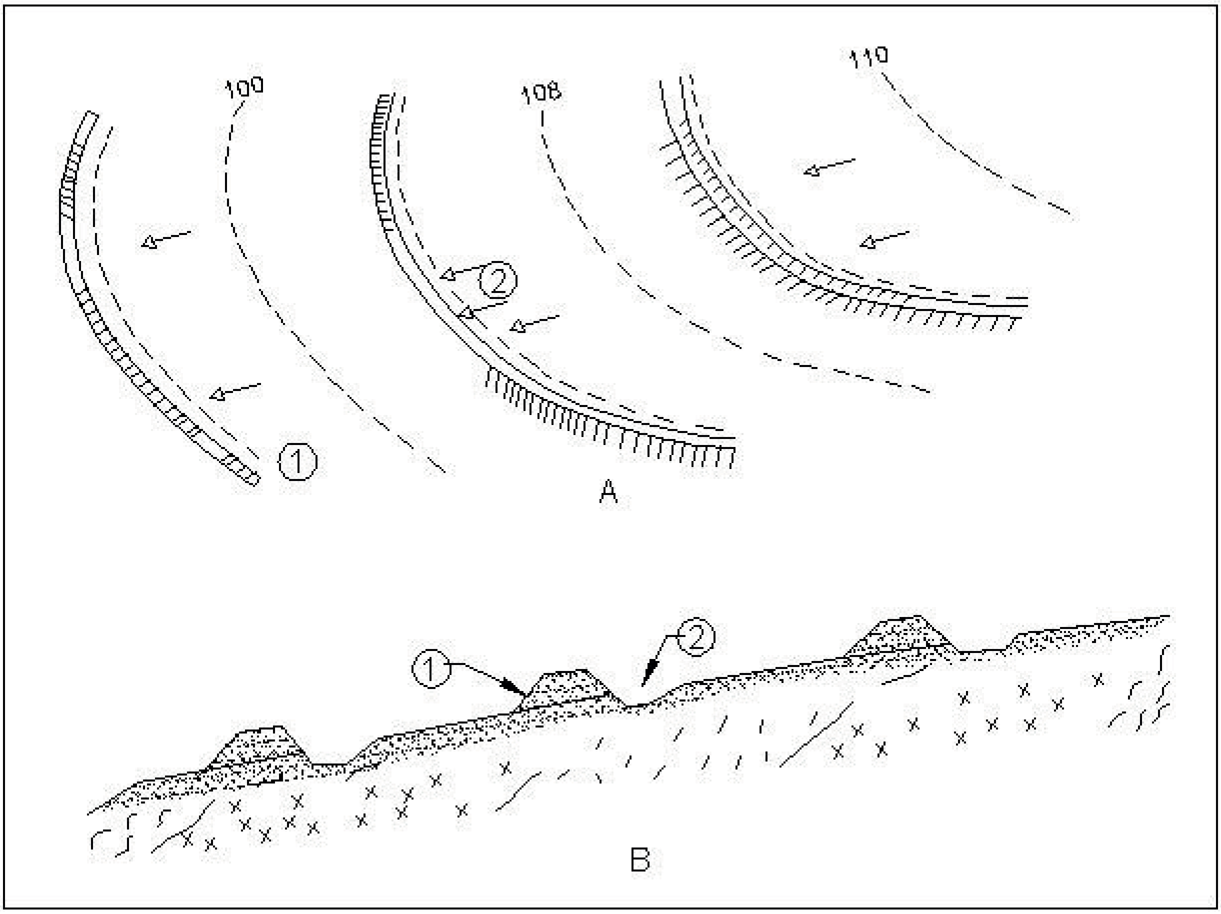
Table 3 — Dimensions of terraces in different soil types

Soil thickness cm	**Base width** m	**Top width** m	**Height** m	**Side slope**
7,50 to 22,50	1,50	0,30	0,60	1:1
22,50 to 45,00	1,80	0,45	0,65	1:1
45,00 to 90,00	2,25	0,45	0,75	1:1
>90,00	2,50	0,50	0,80	1:1
Source: Manual on Artificial Recharge of Ground Water, Central Ground Water Board, India, 2007.[1]				

In areas where paddy is cultivated, water outlets of adequate dimensions are to be provided to drain out excess accumulated water and to maintain water circulation. The width of the outlets may vary from 0,60 m for watersheds up to 2 ha to 3,0 m for watersheds of up to 8 ha generally for rainfall intensity between 7,5 cm and 10 cm. All the outlets should be connected to natural drainage channels.

4.1.4.2 Contour Bunds

Contour bunding is a watershed management practice which is aimed at building up soil moisture storage involving construction of small embankments or bunds across the slope of the land. They derive their names from the construction of bunds along contours of equal land elevation. This technique is generally adopted in low rainfall areas (normally less than 800 mm per annum) where gently sloping agricultural lands with very long slope lengths are available and the soils are permeable. They are not recommended for soils with poor internal drainage e.g. clayey soils. Schematic of a typical system of contour bunds is shown in Figure 6.



Key

1 bund
2 trench
A plan view
B section view

Figure 6 — Schematics of a contour bund

Contour bund is a construction of narrow-based trapezoidal embankments (bunds) along contours to impound water behind them, which infiltrates into the soil and ultimately augment ground water recharge.

Field activities required prior to contour bund include levelling of land by removing local ridges and depressions, preparation of map of the area through level surveying and fixing of bench marks. Elevation contours, preferably of 0,3 m interval are then drawn, leaving out areas not requiring bunding such as habitations, drainage, etc. The alignment of bunds should then be marked on the map.

The important design aspects of contour bunds are

a) spacing,

b) cross section, and

c) deviation freedom to go higher or lower than the contour bund elevation for better alignment on undulating land.

4.1.4.2.1 Spacing of bunds

Spacing of contour bund is commonly expressed in terms of vertical interval (V.I), which is defined as the difference in elevation between two similar points on two consecutive bunds. The main criterion for spacing of bunds is to intercept the water before it attains the erosive velocity. Spacing depends on slope, soil, rainfall, cropping pattern and conservation practices.[1]

Spacing of contour bunds is normally calculated using Formula (1):

$$\text{Vertical Interval}\left(\text{V.I}\right) = 0{,}305\left(\text{XS} + \text{Y}\right) \tag{1}$$

where

X is the rainfall factor;

S is the land slope (%);

Y is the factor based on soil infiltration and crop cover during the erosive period of rains.

The rainfall factor “X” is taken as 0,80 for scanty rainfall regions with annual rainfall below 625 mm, as 0,60 for moderate rainfall regions with annual rainfall in the range of 625 mm to 875 mm and as 0,40 for areas receiving annual rainfall in excess of 875 mm. The factor “Y” is taken as 1,0 for soils having poor infiltration with low crop cover during erosive rains and as 2,0 for soils of medium to good infiltration and good crop cover during erosive rains. When only one of these factors is favourable, the value of Y is taken as 1,50. Vertical spacing can be increased by 10 % or 15 cm to provide better location and alignment or to avoid obstacles.

The horizontal interval between two bunds is calculated using Formula (2):

$$\text{Horizontal Interval}\left(\text{H.I}\right) = \text{V.I} \times 100/\text{Slope} \tag{2}$$

4.1.4.2.2 Cross section of contour bund

A trapezoidal cross section is usually adopted for the bund. The design of the cross section involves determination of height, top width, side slopes, and bottom width of the bund.

The height of the bund depends on the slope of the land, spacing of the bunds, and the rainfall excess expected in 24 h period for 10 year frequency in the area. Once the height is determined, other dimensions can be worked out depending on the nature of the soil.

Height of the bund can be determined by the following methods:

a) Arbitrary Design: The depth of impounding is designed as 30 cm. 30 cm is provided as depth flow over the crest of the outlet weir and 20 cm is provided as free board. The overall height of the bund in this case will be 80 cm. With top width of 0,50 m and base width of 2 m, the side slope will be 1:1 and the cross section, 1 m^2.

b) The height of bund to impound runoff from 24 h rain storm for a given frequency can be calculated by Formula (3):[1]

$$H = \frac{\sqrt{Re \times V.I}}{50} \quad (3)$$

where

H is the depth of impounding behind the bund (m);

Re is the 24 h rainfall excess (m);

VI is the vertical interval (m).

To the height so computed, 20 % extra height or a minimum of 0,15 m is added for free board and another 15 % to 20 % extra height is added to compensate for the settlement due to consolidation.

Top width of the bund is normally kept as 0,3 m to 0,6 m to facilitate planting of grasses. Side slopes of the bund are dependent on the angle of repose of the soil in the area and commonly range from 1:1 for clayey soils to 2:1 for sandy soils. Base width of the bund depends on the hydraulic gradient of the water in the bund material due to the impounding water. A general value of hydraulic gradient adopted is 4:1. The base should be sufficiently wide so that the seepage line should not appear above the toe on the downstream side of the bund.

Size of the bund is expressed in terms of its cross-sectional area. The cross sectional area of bunds depends on the soil type and rainfall and may vary from 0,50 m^2 to 1,0 m^2 in different regions. Recommended contour bund specifications for different soil depths are shown in Table 4.

Table 4 — Recommended contour bund specifications for different soil depths

Soil type	**Soil depth** m	**Top width** m	**Bottom width** m	**Height** m	**Side slope**	**Area of Cross section** m^2
Very shallow soils	<7,5	0,45	1,95	0,75	1:1	0,09
Shallow soils	7,50 to 23,0	0,45	2,55	0,83	1,25:1	1,21
Medium soils	23,0 to 45,0	0,53	3,00	0,83	1,50:1	1,48
Deep soils	45,0 to 80,0	0,60	4,20	0,90	2:1	2,22
Source: Manual on Artificial Recharge of Ground Water, Central Ground Water Board, India, 2007.[1]						

The length of bunds per hectare of land is denoted by the bunding intensity, which can be computed using Formula (4):

$$\text{Bunding Intensity} = \frac{100\ S}{V.I} \quad (4)$$

where

Bunding Intensity is the length of bunds per hectare of land (m^{-1});

S is the land slope (%);

V.I is the vertical interval (m).

The earthwork for contour bund includes the main contour bund and side and lateral bunds. The area of cross-section of side and lateral bunds is taken equal to the main contour bund. The product of cross sectional area of the bund and the bund intensity gives the quantity of earthwork required for bunding/hectare of land.

Deviation Freedom: Strict adherence to contours while constructing bunds is a necessary prerequisite for ensuring maximum conservation of moisture and soil. However, to avoid excessive curvature of bunds, which makes agricultural operations difficult, the following deviations are permitted:

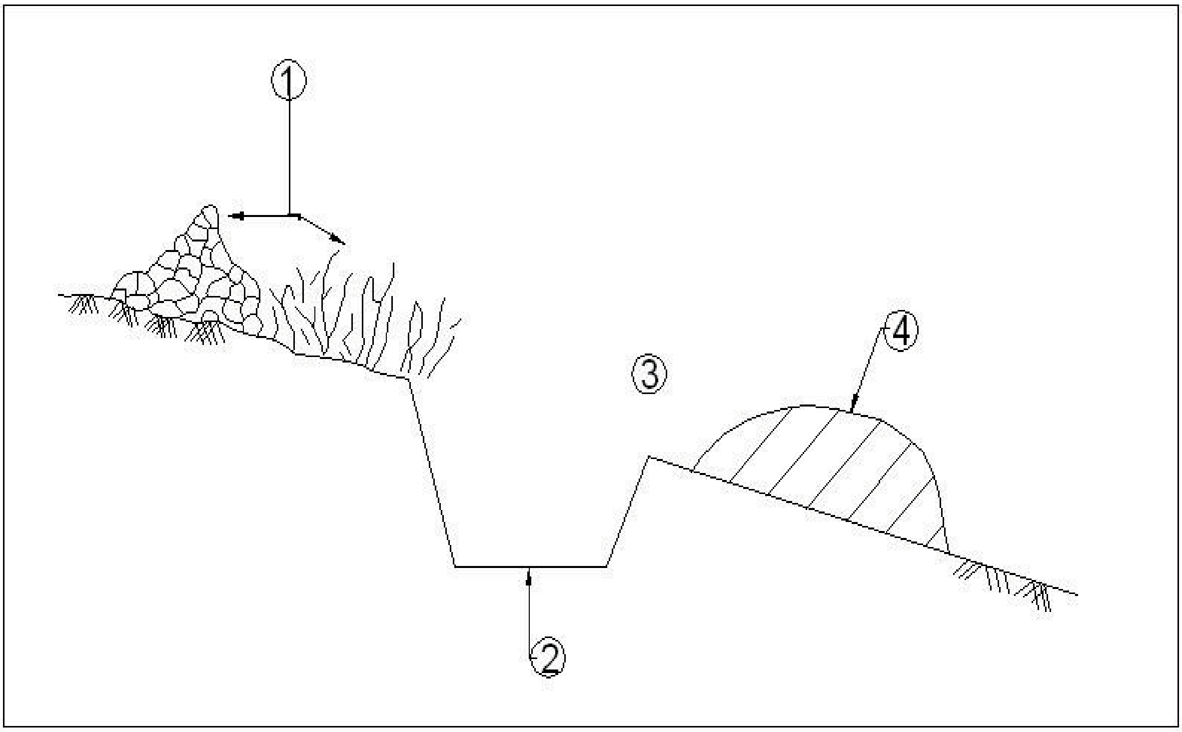
a) maximum of 15 cm while cutting across a narrow ridge;

b) maximum of 30 cm while crossing a gully or depression;

c) maximum of 1,5 m while crossing a sharp, narrow depression not exceeding 5 m in width.

4.1.4.3 Contour Trenches

Contour trenches are rainwater conservation structures which can be constructed on hill slopes, as well as on degraded and barren waste lands in both high and low rainfall areas. Cross section of a typical contour trench is shown in Figure 7.



Key

1 stone or vegetative barrier

2 trench

3 berm

4 spoil bank

Figure 7 — Schematics of a contour trench

The trenches break the slope at intervals and reduce the velocity of surface runoff. The water retained in the trench will help in conserving the soil moisture and ground water recharge.

The size of the contour trench depends on the soil depth and normally 1 000 cm^2 to 2 500 cm^2 cross sections are adopted. The size and number of trenches are worked out on the basis of the rainfall proposed to be retained in the trenches. The trenches may be continuous or interrupted and should be constructed along the contours. Continuous trenches are used for moisture conservation in low rainfall area whereas intermittent trenches are preferred in high rainfall area.

The horizontal and vertical intervals between the trenches depend on rainfall, slope, and soil depth. In steeply sloping areas, the horizontal distance between the two trenches will be less compared to gently sloping areas. In areas where soil cover is thin, depth of trenching is restricted and more trenches at closer intervals need to be constructed. In general, the horizontal interval may vary from 10 m in steep slopes to about 25 m in gentle slopes.

4.1.4.4 Gully plug and check dam

These structures are constructed across gullies or streams to check the flow of surface water in the stream channel and to retain water for longer durations in the pervious soil or rock surface. As compared to gully plugs, which are normally constructed across first order streams, check dams are constructed across bigger streams and in areas having gentler slopes. These can be temporary structures such as brush wood dams, loose/dry stone masonry check dams, Gabion check dams, and woven wire dams constructed with locally available material or permanent structures constructed using stones, brick, and cement. Competent civil and agro-engineering techniques are to be used in the design, layout, and construction of permanent check dams to ensure proper storage and adequate outflow of surplus water to avoid scours on the downstream side for long-term stability of the dam.

The site for check dam should have permeable soils or weathered material underneath to facilitate recharge of stored water within a short span of time. The water stored in these structures is mostly confined to the stream course and height is normally less than 3 m. These are designed based on stream width and excess water is allowed to flow over the wall. In order to avoid scouring from excess runoff, water cushions are provided on the downstream side. To harness maximum runoff in the stream, a series of such check dams can be constructed to have recharge on a regional scale. The design particulars of a cement plug are shown in Figure 8.

The following parameters should be kept in mind while selecting sites for check dams.

a) Total basin area of the stream should normally be between 40 ha and 100 ha. Local situations can, however, be a guiding factor in this regard.

b) Rainfall in the basin should be preferably less than 1 000 mm/annum.

c) Stream bed should be 5 m to 15 m wide and at least 1 m deep.

d) Soil downstream of the bund should not be prone to water logging and should have a pH value between 6,5 and 8.

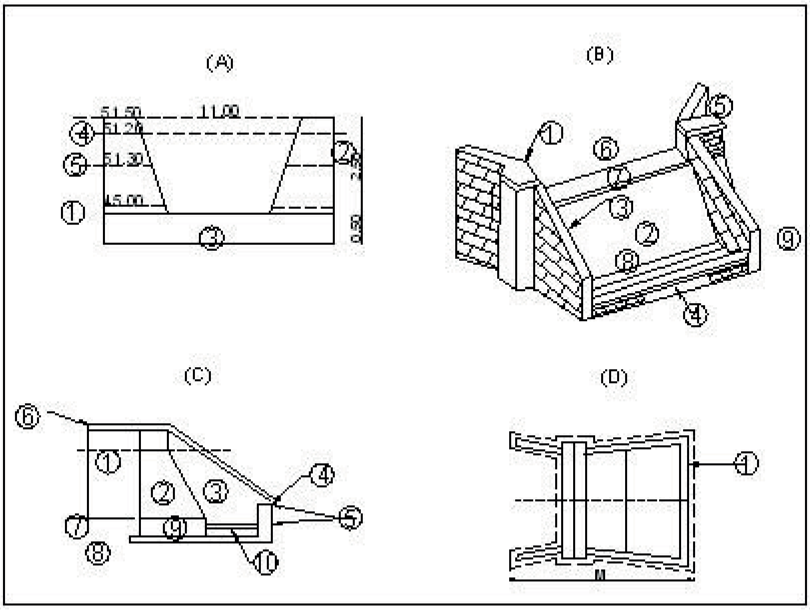
e) Area downstream of the Check dam should have irrigable land under well irrigation.

f) Check dams should preferably be located in areas where contour or graded bunding of lands have been carried out.

g) Rock strata exposed in the impounded area should be adequately permeable to cause ground water recharge.

Check dams are normally 10 m to 15 m long, 1 m to 3 m wide and 2 m to 3 m high, generally constructed in a trapezoidal form. Detailed studies are to be made in the watershed prior to construction of the check dam to assess the current erosion condition, land use, and water balance. The community in the watershed should also be involved in the planning and selection of the type and location of the structure.

For construction of the check dam, a trench, about 0,6 m wide in hard rock and l,2 m wide in soft impervious rock is dug for the foundation of core wall. A core brick cement wall, 0,6 m wide and raised at least 2,5 m above the stream bed is erected and the remaining portion of trench back filled on upstream side by impervious clay. The core wall is buttressed on both sides by a bund made up of local clays and stone pitching is done on the upstream face. If the bedrock is highly fractured, cement grouting is done to make the foundation leakage free.



Key

(A) Vertical section of stream
1 stream bed
2 depth
3 excavation
4 highest flood level
5 full supply level

(B) Horizontal section of bund
1 wing wall
2 main wall
3 side wall
4 head
5 key wall
6 outlet
7 top
8 water cushion
9 toe wall

(C) Vertical section of bund
1 wind wall
2 main wall
3 side wall
4 header wall
5 apron
6 copping in 1:2:4
7 stream bed
8 projection
9 foundation wall
10 water cushion

(D) Plan
1 crip length

Figure 8 — Design of a check dam

4.1.4.5 Percolation tank

A percolation tank is an artificially created surface water body submerging a highly permeable land area so that the surface runoff is made to percolate and recharge the ground water storage. They differ from bunds in having larger reservoir areas. They are not provided with sluices or outlets for discharging water from the tank for irrigation or other purposes. However, they may be provided with arrangements for spilling away the surplus water that might enter the tank, so as to avoid over-topping of the tank bund.

A basin may have more than one percolation tank if surplus runoff is available and the site characteristics are also favourable for artificial recharge through such structures. In such situations, each tank intercepts a share of the yield of the whole basin above it, which can be classified as

a) "free basin", which is the basin area that only drains into the tank under consideration, and

b) "combined basin", which is the area of the whole basin above the tank.

The difference between the combined basin and free basin gives the area of the basin intercepted by the tanks located upstream of any tank. The whole basin of the highest tank on each drainage shall be its free basin. Moreover, each tank will receive the whole runoff from its free basin, but from the remainder of its basin, it will receive only the balance runoff that remains after the upper tanks have been filled.

4.1.4.5.1 Site selection criteria

The important site selection criteria for percolation tank include the following.

a) The strata in the area of submergence of the tank should have high permeability. The soils in the basin area of the tank should be sandy to avoid silting up of the tank bed.

b) The availability of non-committed surplus runoff should be sufficient to ensure filling of the tank every year.

c) As the yield of basins in low rainfall areas generally varies between 0,4 million m^3/km^2 to 0,6 million m^3/km^2, the basin area can be up to 5,0 km^2 for small tanks and between 5,0 km^2 and 8,0 km^2 for larger tanks.

d) Size of a percolation tank should be governed by the percolation capacity of the strata, as well as basin yield. In order to avoid loss of water through evaporation, larger capacity tanks should be constructed only if percolation capacity is proven to be good. If percolation rates are low to moderate, tanks of smaller capacity may be constructed. Percolation tanks are normally designed for storage capacities of less than 1 million m^3.

e) The depth of water impounded in the tank provides the recharge head and hence, it is necessary to design the tank to provide a minimum height of impounded water column of 3 m to 6 m and rarely 6 m above the bed level. This would imply construction of tanks of large capacity in areas with steep gradient.

f) The purpose of construction of percolation tanks is to ensure recharge of maximum possible surface water runoff to the aquifer in as short a period as possible without much evaporation losses. Normally, a percolation tank should not retain water beyond February.

g) The percolation tank should be located downstream of runoff zone, preferably toward the edge of piedmont zone or in the upper part of the transition zone. Land slope between 3 % and 5 % is ideal for construction of percolation tanks.

h) There should be adequate area suitable for irrigation and sufficient number of ground water abstraction structures within the command of the percolation tank to fully utilize the additional recharge. The area benefited should have a productive phreatic aquifer with lateral continuity up to the percolation tank. The depth to water level in the area should remain more than 3 m below ground level during post-monsoon period.

4.1.4.5.2 Investigations required

An area, preferably the entire watershed, needing additional ground water recharge is identified on the basis of declining ground water level trends increase in the demand of ground water and water scarcity during lean period, etc. Areas having scarcity of water despite incidences of flood may also be considered for artificial recharge through percolation tanks.

A base map, 1:25 000 or detailed scale showing geological, physiographical, hydrogeological, and hydrological details along with land use, cropping pattern, etc. is a pre-requisite for the scientific planning. Topographic maps, aerial photographs, and satellite imagery of the area may be consulted to gather preliminary information about the area under study. The nature of basin with regards to the general slope, land use, forest cover, cropping pattern, soils, geology, etc. should be understood to assess their influence on runoff.

The rainfall data of rain gauge stations located in the watershed or in its immediate vicinity is to be collected during the preliminary investigations. The intensity and pattern of rainfall, number of rainy days, and duration of dry spells during the monsoon are to be analyzed. The dependability of normal monsoon rainfall and the departure of actual rainfall from normal rainfall are also worked out along with other weather parameters.

Percolation tanks are to be normally constructed on second or third order streams, as the basin area of such streams would be of optimum size. The location of tank and its submergence area should be in non-cultivable land and in natural depressions requiring lesser land acquisition. There should be cultivable land downstream of the tank in its command with a number of wells to ensure maximum benefit by such efforts. Steps should be taken to prevent severe soil erosion through appropriate soil conservation measures in the basin. This will keep the tank free from siltation which otherwise reduces the percolation efficiency and life of the structure.

Micro-level geological/hydrogeological map is required in the area of submergence, at the tank site, and also downstream of the site to find out the permeability of vadose zone and aquifer underneath. The potential of additional storage and capacity of aquifer to transmit the ground water in adjoining areas is also assessed based on aquifer geometry. Infiltration rates of soils in identified area of submergence are determined through infiltration tests. Aquifer parameters of water-bearing formations in the zone of influence are also determined to assess the recharge potential and number of ground water structures in the area.

Periodic water level measurements and ground water sampling for water quality are required before and after the construction of percolation tanks. Detailed geological investigations are carried out to study the nature and depth of formation at the bund (dam) site for deciding the appropriate depth of cut off trench (COT). It helps in reducing the visible seepage and also ensures safety and long life of the structure. The depth of foundation and its treatment should be considered on the basis of nature of formation while designing and constructing the dam wall and waste weir.

4.1.4.5.3 Engineering aspects

A percolation tank is commonly an earthen structure with a masonry spill way. It is designed for maximum capacity utilization, long life span, cost-effectiveness, and optimum recharge to ground water. Storage capacity, waste weir, drainage arrangements, and COT are the important features of percolation tank that need proper design. The overall design of the percolation tank is similar to that of a small earthen dam constructed for irrigation.

Detailed topographical survey to demarcate the area of submergence in natural depression and alignment of dam line in the valley is to be taken up prior to construction of the structure. A number of sections along and across the drainage are prepared and the best suitable site is identified. The land availability and possibility of land acquisition is explored during the survey. The spillway site is demarcated and is designed in such a way that it allows the flow of surplus water based on single day maximum rainfall after the tank is filled to its maximum capacity. The depth of foundation for masonry work of waste weir, etc. is decided depending on the nature of formation. COT is provided to minimize the seepage losses across the streambed. The depth of COT is generally 2 m to 6 m below ground level depending upon the subsurface strata. In order to avoid erosion of bund due to ripple action, stone pitching is provided in the upstream direction up to high flood level (HFL). The sources for availability of constructional material, especially clay and porous soil for earthwork and stone rubble for pitching, are to be identified.

4.1.4.5.4 Design of Storage Capacity

The storage capacity of a percolation tank may be defined as the volume of water stored in the tank up to the full tank level (FTL). The storage capacity can be computed by using the contour plan of the water-spread locale of the tank. The total capacity of the tank will be the sum of the capacities between successive contours. The smaller the contour interval, the more accurate the capacity computation will be. The summation of all the volumes between successive contours will be required for computing the storage capacity of the tank. When contour plan is not available and only the area of the tank at FTL is known, then the effective volume of the tank may be roughly computed as the area multiplied by one-third of the depth from FTL to the deep bed of the tank.

The tank is designed to ensure maximum utilization of its capacity. A structure of optimum capacity is the most cost effective. An under-utilized structure leads to unproductive expenditure incurred on extra earthwork. The design of storage capacity of a tank depends mainly upon the proper estimation of basin yield which is calculated based on field observations and/or using empirical relationships or norms applicable in the area. The rainfall data of around 50 years, collected from the nearest rain gauge station, may be used for design purposes.

An important consideration is the fact that water stored in a percolation tank starts percolating immediately and the terminal storage in the tank is not the cumulative storage from different spells of rain. The concept of storage capacity of percolation ponds thus, differs significantly from that of an irrigation tank.

The basin yield and basin configuration drawn from topographic surveys at site determine the height of the percolation tank. The top of dam wall is normally kept 2 m to 3 m wide. Upstream and downstream slopes of the dam wall are normally taken as 2,5:1 and 2:1 respectively, as recommended in design manuals for minor irrigation tanks.

4.2 Subsurface techniques

Subsurface techniques aim at recharging deeper aquifers that are overlain by impermeable layers, preventing the infiltration from surface sources to recharge them under natural conditions.

The following are the most common methods used for recharging such deeper aquifers:

a) injection wells or recharge wells;

b) gravity head recharge wells;

c) recharge pits;

d) recharge shafts.

4.2.1 Injection well or recharge well

Injection wells or recharge wells are structures similar to bore/tube wells but constructed for augmenting the ground water storage in deeper aquifers through supply of water either under gravity or under pressure. The aquifer to be replenished is generally one with considerable desaturation due to overexploitation of ground water. Artificial recharge of aquifers by injection wells can also be done in coastal regions to arrest the ingress of seawater and to combat problems of land subsidence in areas where confined aquifers are heavily pumped.

In alluvial areas, injection wells recharging a single aquifer or multiple aquifers can be constructed in a manner similar to normal gravel packed pumping wells. However, in case of recharge wells, cement sealing of the upper section of the wells is done to prevent the injection pressure from causing leakage of water through the annular space of the borehole and the well assembly. Schematics of a demonstrative injection well in alluvial terrain are shown in Figure 9**.** In hard rock areas, injection wells might not require casing pipes and screens and an injection pipe with an opening against the fractures to be recharged may be sufficient. However, properly designed injection wells with slotted pipes against the zones to be recharged might be required for recharging multiple aquifer zones separated by impervious rocks.

The effectiveness of recharge through injection wells is limited by the physical characteristics of the aquifers. Attempts to augment recharge might prove to be counter-productive in cases where the aquifer material gets eroded due to the speed of ground water flow, especially in unconsolidated or semi-consolidated aquifers. Failure of confining layers might also occur if excessive pressure is applied while injecting water. These might result in clogging and/or even collapse of the bore/tube well.

4.2.1.1 Site selection and design criteria

a) A proper understanding of the aquifer geometry is the most important factor in successful implementation of recharge schemes through injection or recharge wells. Detailed studies of the vertical and lateral extents of the aquifer and its characteristics are necessary prerequisites for such schemes. Grain size distribution of granular aquifers is another important parameter in the case of sedimentary aquifers.

b) Recharge through injection well increases the chances of clogging of well screens and aquifer material, resulting in decreased injection rates. Clogging can be caused by suspended particles and air bubbles in the source water, formation of chemical precipitates in the well, source water or mineral assemblages in the aquifer material, proliferation of bacteria in and around the injection well, and swelling and dispersion of clay in the aquifer being recharged.

c) Clogging can be minimized by proper treatment and removal of suspended material from source water, chemical stabilization, and bacterial control. Using non-corrosive materials for pipelines and well casings can minimize clogging by corrosion products. Chlorination of source water prevents development of bacterial growth and it can be used if permitted by the Environmental Authority. Acid treatment helps in removing calcium carbonate precipitates from the gravel packs and aquifers. Periodic development of wells through surging, swabbing, and pumping can considerably improve the efficiency and life of injection wells.

d) As clogging increases, the well losses considerably, the efficiency of injection wells should be taken as 40 % to 60 % as compared to pumping wells of similar design in the same situation.

e) Adequate care should be taken to ensure that the water being used for recharge is not contaminated. It should be compatible with the formation water and mineral assemblages to avoid any precipitation and resultant clogging. Source may conform to the prescribed standards of potable water quality as practiced in several countries. The relative temperatures of source and formation waters also affect the recharge rate.

f) The following considerations are important in the design of an injection well.

    1) The permissible pressure head of hydraulic injection in terms of water column may be worked out as 1,2 times the depth to the top of the confined aquifer, which represent the hydro-fracturing pressure of the confining layer. However, this pressure is likely to be much higher in consolidated strata. Injection of water at pressures exceeding this limit can result in the rupture of the confining layer.

    2) The rate of recharge likely to be accepted by the aquifer may be worked out on the basis of observed discharge-drawdown relation of the existing pumping wells tapping the same aquifer. If the aquifer parameters are known, the recharge rates may be worked out from theoretical considerations using appropriate formulae. However, it is always desirable to determine the actual intake rates through injection/recharge tests in the wells.

    3) The diameter of the conductor and casing pipes and the bore/tube well are to be worked out from the rate of recharge estimated. Usually, pipes with nominal diameters of 100 mm, 150 mm, 200 mm, and 250 mm can handle flows up to 50 m^3/h, 150 m^3/h, 250 m^3/h, and 400 m^3/h, respectively.

    4) For optimum benefits, it is advisable to have injection pumping wells to be used both for ground water recharge and extraction under favourable conditions. In such case, the well assembly should be designed to accommodate higher flows while pumping.

    5) The inner diameter of the housing pipe has to be two nominal diameters higher than the pump bowl size and the length of the housing pipe should be adequate to accommodate seasonal and long-term fluctuations, interference effects of surrounding wells in addition to expected drawdown, and desired pump submergence.

    6) The casing material used for the well should be similar to the one used for production wells and should have adequate tensile strength and collapsing pressure. In case chemical treatment

is anticipated during development, the casing pipe and screens should be made of corrosion-resistant material.

7) The recharge well should be designed to fully penetrate the aquifer to avoid additional head losses due to partial penetration. In hard rocks, the top casing should be adequate to cover the unconfined zone and to protect ingress of potential contaminated water to the upper aquifer.

8) Artificial gravel packs should be provided around screens in case of screened wells in unconsolidated and semi-consolidated formations. The gravel pack should be so designed to arrest the inflow of aquifer particles into the well.

9) It is advisable to achieve exit velocity comparable to entrance velocity recommended (0,03 m/s) for pumping wells to reduce incrustation and corrosion by providing appropriate open area for passage of water into the aquifer. The desired open area can be achieved for a given thickness of aquifer by adjusting well casing diameter and per cent open area of the screen using the relation.

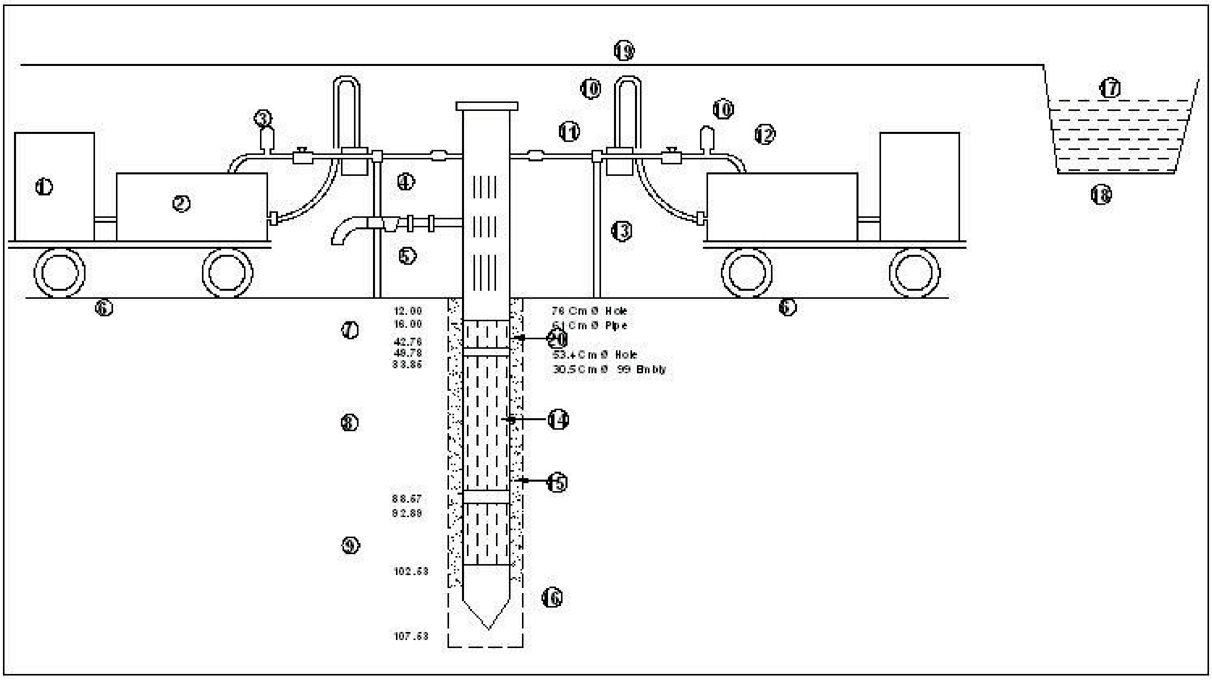
Total area of the screen × Per cent open area = Volume × Entrance Velocity

10) Injection wells may be designed to recharge single or multiple aquifers.

11) For pressure injection, conductor pipes of suitable diameter should be used to reach the aquifer with an inflatable packer to be placed around the pipe just above the screen. In a dual injection well, the inflatable packer is a must.

g) Injection of water into the well should be started at rates below the pre-estimated injection rate, which is then progressively increased, taking care to ensure that the pressure build-up remains below the permissible limit. Once the maximum permissible injection rate is attained, the well should be regularly monitored for injection rate, injection head, and quality of water.

h) The specific injection capacity of the well, computed as the ratio of the quantum of water applied to the head build-up in the well is determined on commissioning a recharge well. The specific injection capacity of the well reduces with time due to clogging. When the injection rate falls below accepted economic limits, the well is required to be redeveloped.



Key

1	prime mover
2	pump
3	valve
4	water meter
5	bypass valve
6	ground level
7	aquifer zone
8	aquifer zone
9	aquifer zone
10	pressure gauge
11	pressure hose
12	air vessel
13	support
14	30,5 cm pipe diameter, 3,2 mm slot open area
15	32 mm × 96 mm pea gravel
16	bail plug
17	canal
18	end view
19	canal bank
20	cement seal

Figure 9 — Schematics of a demonstrative injection well

4.2.2 Gravity head recharge wells

In addition to specially designed injection wells, existing dug wells and tube/bore wells may also be alternatively used as recharge wells, as and when source water becomes available. In areas where considerable de-saturation of aquifers have already taken place due to over-exploitation of ground water resources resulting in the drying up of dug wells and lowering of piezometric heads in bore/tube wells, existing ground water abstraction structures provide a cost-effective mechanism for artificial recharge of the phreatic or deeper aquifer zones, as the case may be. Schematics of a system for artificial recharge through dug wells are shown in Figure 10.

4.2.2.1 Site characteristics and design guidelines

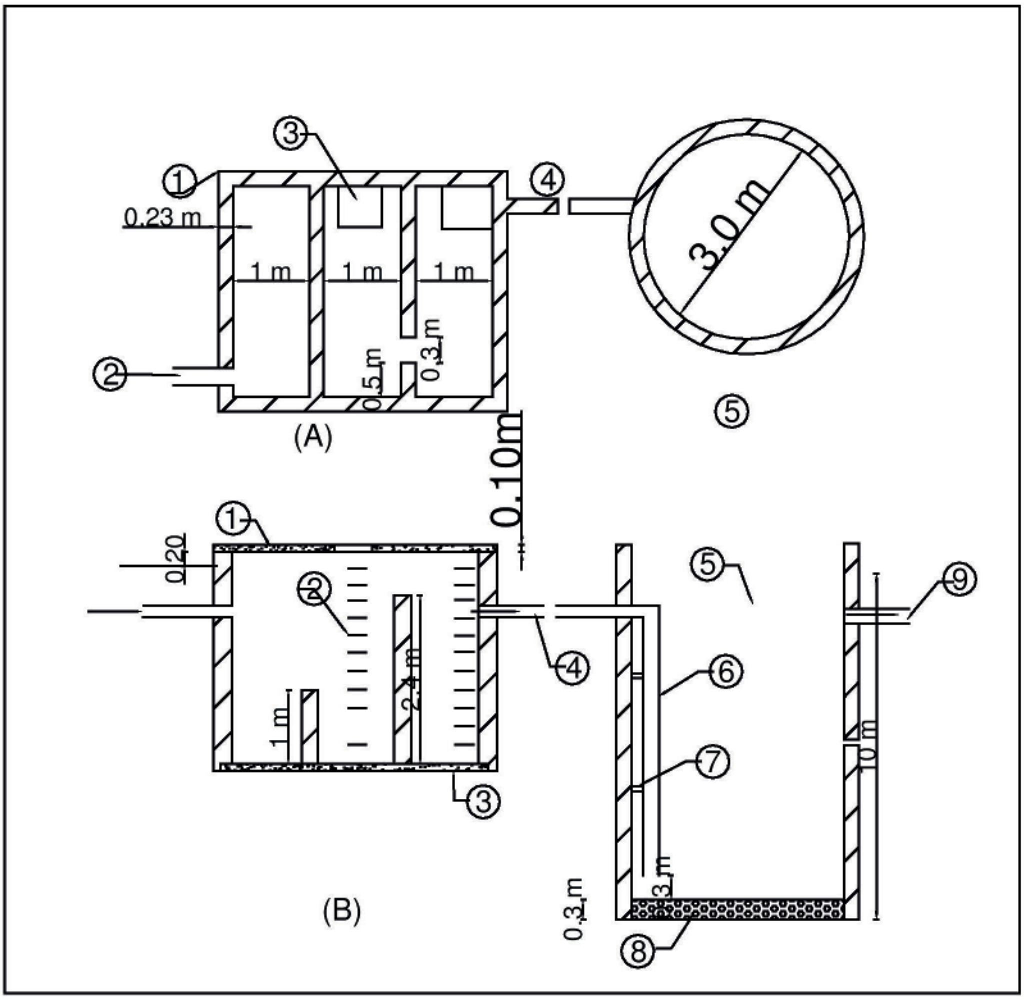
a) In areas where excess surface water is available during rainy season and the phreatic aquifers remain unsaturated, surface water can be pumped into the dug wells for augmentation of ground water resources.

b) Wells with higher yields before getting dried up due to the de-saturation of aquifers should be selected for recharge as they prove to be more suitable for ground water recharge when compared to low-yielding wells.

c) The recharge head available in gravity head recharge wells is the elevation difference between the surface water level in the feeder reservoir/tank and the elevation of water table or piezometric head. The recharge rates in such cases are likely to be much less when compared to pressure injection and will also keep on reducing with build-up of the water table in the aquifer.

d) Pumping of wells during periods of non-availability of recharge water helps in removing the silt that may enter the well during recharge. However, more rigorous development might be essential in the case of deep bore/tube wells.

e) Care should be taken to ensure that the source water is adequately filtered and disinfected when existing wells are being used for recharge. The recharge water should be guided through a pipe to the bottom of well, below the water level to avoid scouring of bottom and entrapment of air bubbles in the aquifer.



Key

(A) Plan view
1 desilting chamber
2 inlet
3 opening and gate
4 outlet pipe to wall
5 open wall
(B) Section view
1 RCC slab
2 steps
3 hole filled with coarse sand
4 outlet of filter
5 open well
6 inlet pipe inside well
7 clamp for support
8 bottom filled with boulder
9 outlet for excess water

Figure 10 — Artificial recharge through an open well

4.2.3 Recharge pits

Recharge pits are normally excavated pits, which are sufficiently deep to penetrate the low-permeability layers overlying the unconfined aquifers (see Figure 11). They are similar to recharge basins in principle, with the only difference being that they are deeper and have restricted bottom area. In many such structures, most of the infiltration occurs laterally through the walls of the pit as in most layered sedimentary or alluvial material, the lateral hydraulic conductivity is considerably higher than the vertical hydraulic conductivity. Abandoned gravel quarry pits or brick kiln quarry pits in alluvial areas and abandoned quarries in basaltic areas can also be used as recharge pits wherever they are underlain by permeable horizons. Trench is a special case of recharge pit dug across a streambed. Ideal sites for such trenches are influent stretches of streams.

4.2.3.1 Site Characteristics and Design Guidelines

a) The recharging capacity of the pit increase with its area of cross section. Hence, it is always advisable to construct as large a pit as possible.

b) The permeability of the underlying strata should be ascertained through infiltration tests before taking up construction of recharge pits.

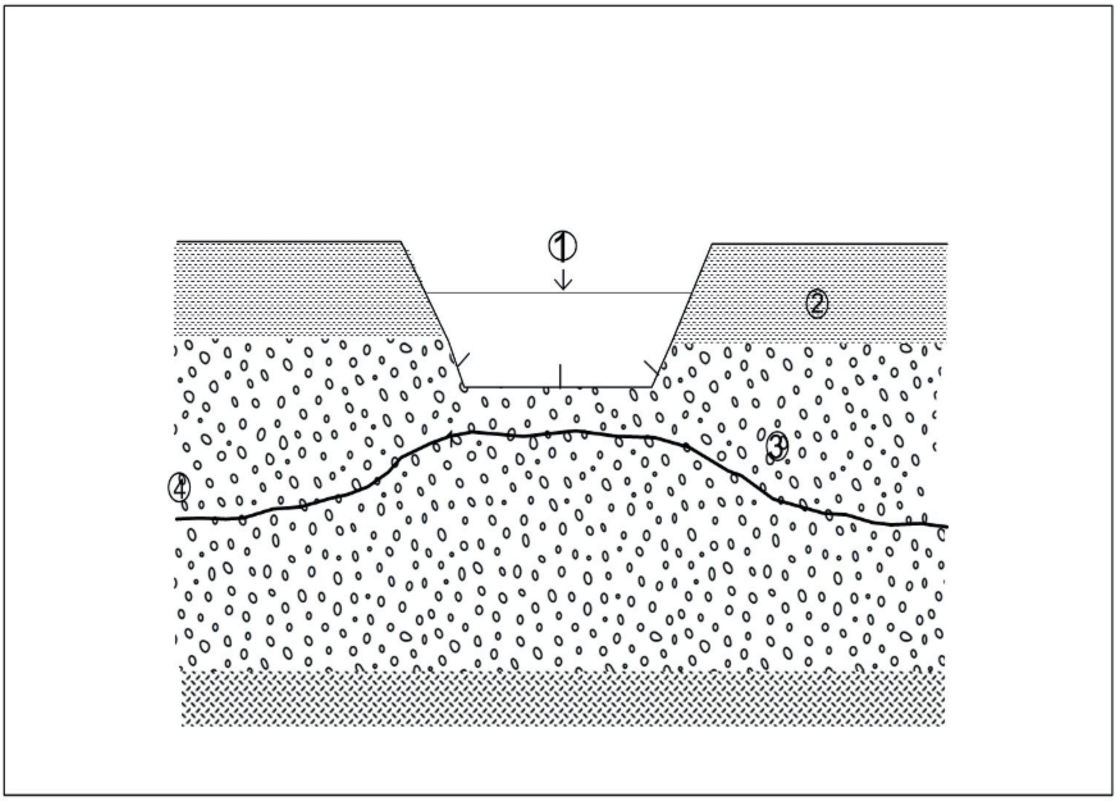
c) The side slopes of recharge pits should be 2:1 as steep slopes reduce clogging and sedimentation on the walls of the pit.

d) Recharge pits may be used as ponds for storage and infiltration of water or they may be back-filled with gravel sand filter material over a layer of cobbles/boulders at the bottom. Even when the pits are to be used as ponds, it is desirable to provide a thin layer of sand at the bottom to prevent the silt from clogging permeable strata.

e) As in the case of water spreading techniques, the source water being used for recharge should be as silt-free as possible.

f) The bottom area of the open pits and the top sand layer of filter-packed pits can require periodic cleaning to ensure proper recharge. Recharge pits located in flood-prone areas and on streambeds are likely to be effective for short duration only due to heavy silting. Similar pits by the sides of streambeds are likely to be effective for longer periods.

g) In hard rock areas, streambed sections crossing weathered or fractured rocks or sections along prominent lineaments or intersection of lineaments form ideal locations for recharge pits.



Key

1 excavated pit filled with water
2 low permeable strata
3 permeable strata
4 water table

Figure 11 — Schematics of a recharge pit

4.2.4 Recharge shaft

Recharge Shafts are similar to recharge pits but are constructed to augment recharge into phreatic aquifers where water levels are much deeper and the aquifer zones are overlain by strata having low permeability (see Figure 11). Further, they are much smaller in cross section when compared to recharge pits. Detailed design particulars of the recharge shaft are shown in Figure 12.

4.2.4.1 Design guidelines

a) Recharge shafts can be dug manually in non-caving strata. For construction of deeper shafts, drilling by direct rotary or reverse circulation may be required.

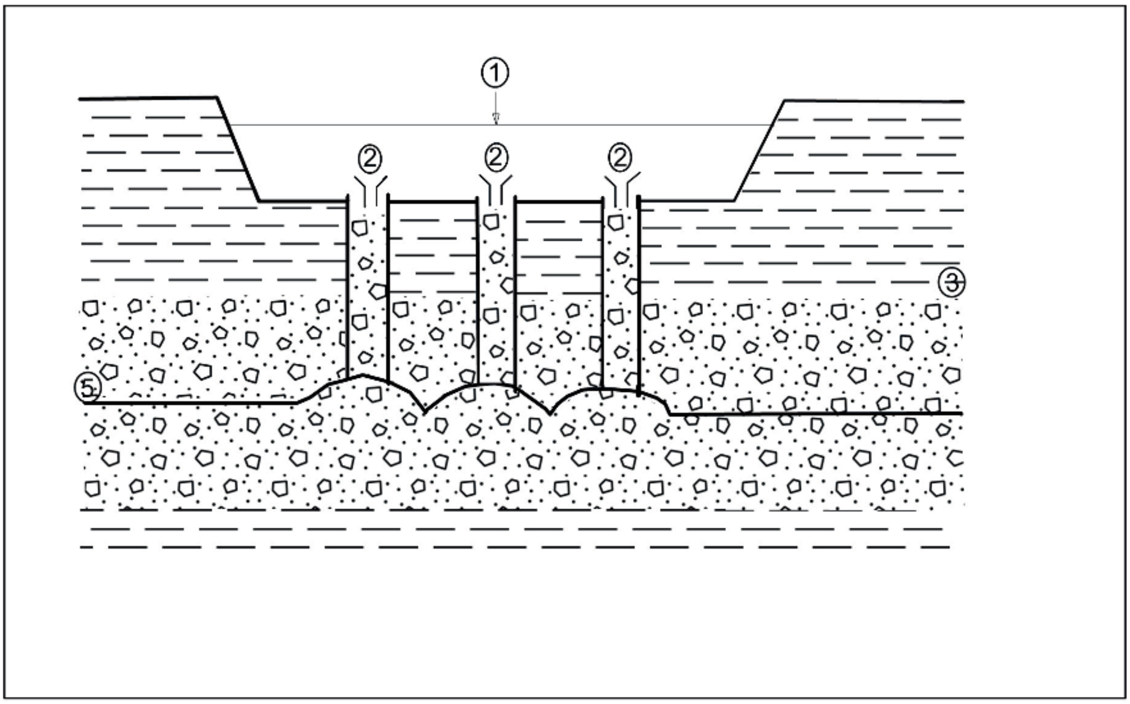
b) The shafts may be about 2 m in diameter at the bottom, if manually dug. In case of drilled shafts, the diameter may not exceed 1 m.

c) The shaft should reach the permeable strata by penetrating the overlying low permeable layer, but need not necessarily touch the water table.

d) Unlined shafts may be back-filled with an inverse filter, comprising boulders/cobbles at the bottom, followed by gravel and sand. The upper sand layer may be replaced periodically. Shafts getting clogged due to biotic growth are difficult to be revitalized and might have to be abandoned.

e) Deeper shafts constructed in caving strata might require lining or casing. In such cases, the shafts need not be completely back-filled and a reverse gravel-sand filter, a few meters thick, at the bottom of the shaft will suffice. In such cases, the water from the source may be fed through a conductor pipe reaching down to the filter pack.

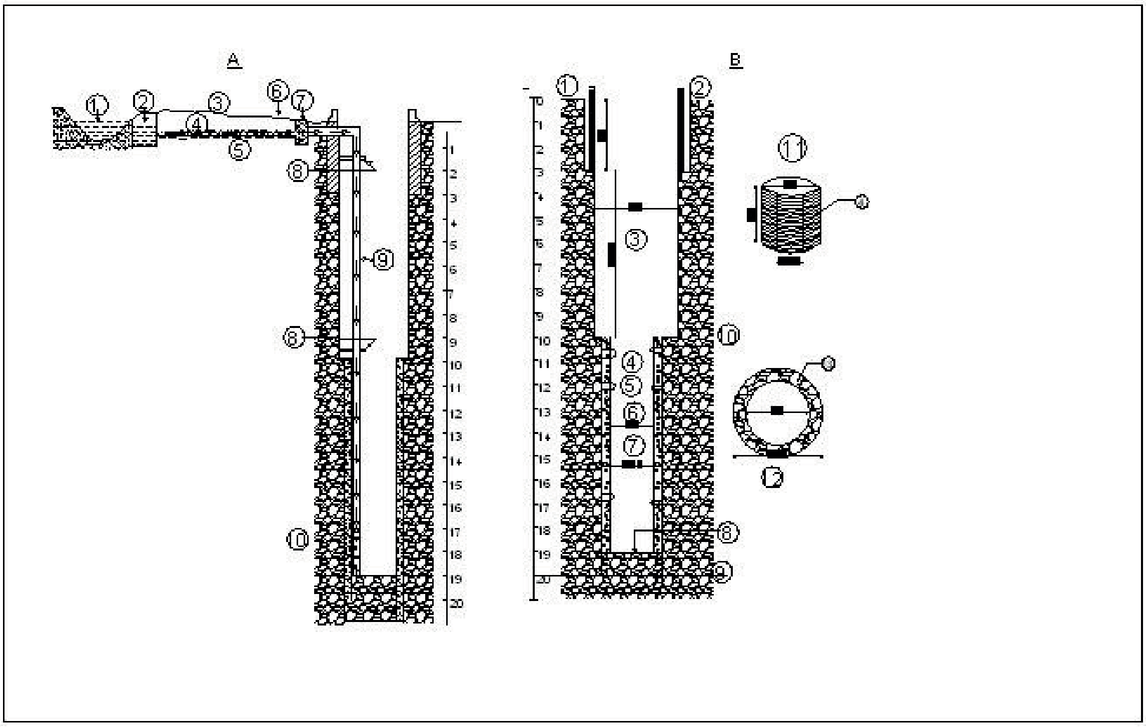
f) The source water should be made as silt-free as possible before letting into the shaft by providing suitable filters.



Key

1	water filled canal or pond
2	recharge shafts
3	low permeable strata
4	permeable strata
5	water table

Figure 12 — Schematics of recharge shafts



Key

(A) Schematic presentation
1 river level
2 infiltration pit
3 ground surface
4 open channel
5 space for sand settlement
6 water flow measurement
7 drum
8 clamp to support pipe
9 pipe
10 perforated pipe

(B) Detail design
1 ground surface
2 lining
3 unlined part
4 wire mesh
5 clamping of pipe
6 inner diameter
7 outer diameter
8 stone pitching
9 water table
10 support to mesh
11 steel cage to wrap wire mesh
12 section along 7(outer diameter)
13 gravel fillings

Figure 13 — Design particulars of a recharge shaft

4.3 Combination of surface and sub-surface techniques

Various combinations of surface and sub-surface recharge methods may be used in conjunction under favourable hydrogeological conditions for optimum recharge of ground water reservoirs. The selection of methods to be combined in such cases is site-specific. Commonly adopted combination methods include recharge basins with shafts, percolation ponds with recharge pits or shafts, and induced recharge with wells tapping multiple aquifers permitting water to flow from upper to lower aquifer zones through the annular space between the walls and casing (connector wells), etc.

5 Environmental impact assessment

Artificial recharge structures are constructed mostly with the objective of augmenting ground water resources and/or to improve its quality. Assessment of environmental impacts of the artificial recharge schemes implemented is essential to assess the efficacy of structures constructed for artificial recharge and helps in identification of cost-effective recharge mechanisms for optimal recharge into the ground water system. It also helps to make necessary modifications in site selection, design, and construction of structures in future.

Impact assessment might require monitoring of the recharge structure, ground water regime, changes in pattern of water supply, cropping pattern, crop productivity, and/or water quality. In recent years, tracers such as Tritium, Rhodamine B, fluorescent dyes, and environmental isotopes are also being used for demarcating the area benefited by artificial recharge structures.

The methodology of impact assessment is highly site-specific and can vary considerably depending upon various factors, such as hydrogeological set-up and ground water utilization pattern. General guidelines for impact assessment of artificial recharge structures are discussed briefly in the following subclauses.

5.1 Monitoring of recharge structures

Surface structures such as percolation ponds, check dams, and cement plugs need to be monitored at regular intervals to assess the actual storage created in the structures, period of impounding, capacity utilization of the structure, rate of percolation, and siltation problems, if any. Quantification of storage in the structures might require setting up of monitoring devices within the structures. Devices such as gauges for area-capacity analysis are commonly used in surface recharge structures. Daily monitoring records are preferred for realistic assessment of storage created by multiple fillings of the structures. Evaporation and seepage losses from the structures are also to be accounted properly to evaluate the recharge efficiency of the structures.

In case of subsurface structures, the intake water supplied to the structures is measured by suitable measuring devices. Appropriate measuring devices, such as flow meters and “V” notches can be used for measurement. Daily records of such measurements help quantify the amount of water utilized for recharge purpose.

5.2 Water level monitoring

The objective of water level monitoring is to study the effect of artificial recharge on the natural ground water system. The monitoring system should be designed judiciously to monitor impact of individual structures, which can further be extended to monitor the impact of groups of such structures in the area where artificial recharge is being done. Monitoring of water levels during the planning stage of artificial recharge projects helps in assessment of the ground water conditions of the area and helps in identification of the most suitable method for ground water augmentation. A properly designed observation well network is used for understanding the ground water flow pattern and the spatial and temporal changes in water level/piezometric head in the area.

During stage of planning and feasibility study, network of observation well is generally of low well density and spreads over a large area with an aim to demarcate the areal extent of the aquifer to be recharged and to know the hydraulic characteristics, as well as ground water flow system. After identification of the feasible artificial recharge structures, the observation well network is optimized.

For effective monitoring of the changes in the water levels due to artificial recharge, the network should have observation wells closely spaced near the recharge structure, then at a sufficient distance from the recharge structure to gauge the composite effects. Observation wells should also be established near the limits of hydrological boundaries. If the aquifer being recharged is overlain by confining/semi-confining layers, piezometers should be installed to monitor the water levels of overlying and underlying aquifers separately to study the effects in both the aquifers. In cases where surface water bodies are hydraulically connected with the aquifers being recharged, it is advisable to monitor the water level profiles of both surface water and ground water.

Demarcation of the zone of influence of the artificial recharge structure is one of the main objectives in monitoring the context of artificial recharge projects. The following observations are generally associated with the area benefited by an artificial recharge structure:

a) well hydrographs in the area benefited will have a flat apex during the period till there is water in the recharge structure (tank, pit, etc.);

b) wells located outside the zone of influence normally show an angular apex during the period of recharge, whereas those situated within the zone of influence have a flatter apex;

c) the recession limbs of well hydrographs close to a recharge structure normally have gentle gradients as compared to those located far off;

d) crops in the zone of influence are normally healthier when compared to those outside the benefited area. Furthermore, crops with high water requirements are more likely to be grown in the zone of influence;

e) well yields in the zone of influence will normally be higher when compared to those outside it. Wells in benefited zone might have more sustainability in lean period than those located outside.

The behaviour of water table/piezometric head profile prepared from the data collected from the observation well network over a period of time can clearly establish the efficacy of the artificial recharge scheme. Answers to questions related to the extent of the area benefited and the quantification of ground water augmentation could also be worked out from such data. The study of fluctuation over time for both surface and ground water levels in the same area can also indicate whether the ground water augmentation is taking place as envisaged or not. In case any deviation is observed, the reasons for the same could be identified and necessary remedial measures taken up. If a groundwater flow model is available or can be devised, then the details of a water level monitoring network can be simulated and tested for efficiency in design.

5.3 Water quality monitoring

A proper evaluation of potential water quality and aquifer quality problems associated with artificial recharge is a key component of a ground water recharge scheme. Development of reliable pre-operational and post-operational monitoring programs is an integral part of a successful ground water recharge scheme.

A reliable water quality monitoring system for an artificial recharge scheme will involve

a) evaluation of existing water quality data,

b) pre-operational monitoring,

c) operational monitoring, and

d) post-operational monitoring based on expected response triggered by artificial recharge.

5.3.1 Evaluation of existing water quality data

The first step that should be followed in evaluating the potential water quality problems associated with a proposed ground water recharge project is to obtain detailed information on the chemical characteristics of the proposed recharge waters. Additionally, the chemistry of the aquifer matrix is an important component to evaluate any possible reactions among the minerals in the aquifer matrix, the original water in the aquifer, and the chemistry of the water to be recharged. A critical examination of the existing data on the waters that would be recharged to the aquifer should be made to first determine their reliability and representativeness. In case the available data are not considered to be reliable, collection and analysis of source water samples may be done afresh.

5.3.2 Pre-operational monitoring

The augmentation of recharge by surface waters and their associated contaminants can greatly increase the potential for ground water quality problems due to the increased hydraulic and contaminant loading.

The characterization of ground water quality is often not adequately done to properly evaluate potential ground water and aquifer quality problems associated with a ground water recharge project. It is important to properly assess how the variable parameters in sampling, such as borehole volume purged and rate of purging before sampling influences the composition of the samples. Chemical parameters of particular importance in reliably assessing ground water quality samples are the redox and pH conditions since precipitation of iron also depends strongly on pH within the aquifer and the presence of suspended solids in the samples. Because of the chemistry of ferrous and ferric iron, small changes in the redox (oxidation reduction) characteristics of the sample as a result of the introduction of oxygen into the sample during sampling can drastically change the chemical characteristics of the samples. Hence, it is important to maintain the oxygen concentrations in a sample collected from an aquifer the same as that of the aquifer. Failure to do so could readily change the distribution between dissolved and particulate forms of many trace contaminants of water quality concern. Consideration of mixing of recharge water with ambient groundwater under recharge conditions should be made and consideration of mixing of all subsequent groundwater sources (groundwater flow system) under abstraction conditions may be made, as well, in order to fully understand any potential geochemical issues.

The presence of suspended solids in a water sample from an aquifer is a clear indication that the sampling well has been improperly constructed and developed and/or the sampling procedure used, especially the purging, has been improperly done. Aquifers typically do not contain large amounts of suspended material. Aquifer samples that contain suspended material are unreliable to properly characterize chemical characteristics of the ground waters within the aquifer at the point and time of sampling.

It is also important that the sampling program for the ground water is properly developed to reflect the site specific hydrogeology of various principal components of the aquifer. Failure to do so could readily lead to erroneous conclusions concerning the chemical characteristics of the aquifer waters and the chemical reactions that can take place within the aquifer upon introduction of recharge waters to it. Depending on the situation, at least one year and often, several years of data might be needed to reliably characterize the aquatic system of interest. The best way to determine the length of time necessary in pre-operational monitoring, as well as the frequency of monitoring a particular system, is to examine the ability to predict the chemical characteristics of the system prior to collecting the next set of samples. Once it becomes clear that the characteristics of a particular recharge water source and aquifer are predictable with a high degree of certainty based on past monitoring results, it should then be possible to reduce the frequency and duration of pre-operational monitoring. If, however, it is not possible to make these predictions reliably because of the high variability in the systems, proceeding with the operation of the proposed recharge project could be met with significant problems in detecting incipient water quality problems before they adversely impact large parts of the aquifer.

5.3.3 Operational monitoring

With the initiation of the recharge activities, a significant increase in the frequency of sampling, especially near the point of recharge, should occur. Actually, the operational sampling program should be initiated several months before actual recharge starts in order to evaluate the ability to conduct the monitoring program with the facilities and personnel available. If the pre-operational monitoring program has been passive, then it should, at the time of initiation of recharge, become an active program, where the data are examined in detail as soon as it is available, for the purpose of determining its reliability and any potential problems that are developing with the recharge project. In addition to chemical and microbiological measurements in the recharge waters as well as within the aquifer, detailed monitoring of the hydraulic characteristics of the injection/infiltration system should be conducted to determine the changes in the hydraulic characteristics of the recharge system and the aquifer in the vicinity of the recharge. In addition to monitoring the chemical contaminants in the recharge waters as well as aquifer, consideration should be given to the contaminant transformation products that might be formed in the recharge water. An area of particular concern in the recharge waters is whether there is sufficient BOD in these waters to exhaust the dissolved oxygen in the aquifer waters for those aquifer systems that are oxic prior to initiation of recharge. Bore hole dissolved oxygen measurements should be made at frequent intervals at various distances from the point of recharge in order to detect incipient dissolved oxygen depletion that could lead to its exhaustion from the recharge waters. Since, in general, except for nitrate-related issues, anoxic conditions in aquifers tend to lead to poor water quality, care should be taken to prevent the recharge waters from becoming anoxic within the aquifer. Failure to do so could readily result in iron, manganese, other heavy metals, arsenic, and hydrogen sulfide problems. If problems of this type start to develop, it may be necessary to add dissolved oxygen either directly or through the introduction of hydrogen peroxide, in the recharge waters in order to prevent problems of this type from occurring.

Once the operational monitoring program data have become stabilized, i.e. are predictable based on past monitoring results, then frequency of operational and post-operational monitoring can be decreased. This will likely take several years of operation, however, for fairly constant composition recharge waters and fairly homogeneous aquifer system with respect to its hydrogeologic and chemical characteristics.

The type of water quality monitoring programme depends on the specific problem being studied, such as changes in ground water quality, effect of soil salination, prevention of any contamination, etc. The samples to be collected will also depend on the purpose and are generally categorized into indicative, basic, and comprehensive. Indicative samples are collected at one month to four months intervals and are used to ascertain the presence of recharged water in the aquifer. Basic samples are taken at monthly intervals for wells already influenced by recharge to determine the effect of recharge on ground water quality and the purification provided by flow through the soil and aquifer system. Comprehensive samples are taken at intervals of six months to one year for observation wells and production wells to determine water quality with respect to specific standards for intended water use.

5.3.4 Post-operational monitoring

When groundwater recharge is terminated, it is important that the monitoring of the aquifer be continued until the waters in the aquifer stabilize in composition. This will normally take several years of monthly monitoring. This monitoring should continue for quarterly intervals for several years.

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