6 Artificial recharge

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6 Artificial recharge

6.1 Introduction

One of the growing concerns facing scientists and engineers in development and management of groundwater resources, is to manage this depleting resource efficiently. The key to a successful groundwater management policy is a thorough understanding of groundwater recharge and discharge processes. Under suitable conditions it is possible to supplement the natural recharge of an aquifer and so add to its safe yield. This is called artificial recharge. Strictly speaking artificial recharge is the process by which the groundwater reservoir is augmented at a rate exceeding natural replenishment. Any man-made scheme or facility with the objective of adding water to an aquifer may be considered to be an artificial recharge system.

Sustainability of sources has become one of the major issues of the rural drinking water supply sector. In this endeavour, the role of the government sector is being shifted from actual implementing authority to that of a facilitator. Since rainwater harvesting and artificial recharge can play a major role in achieving sustainability of drinking water sources, local communities need to be encouraged to take them up on a large scale. Chapter 7 refers to various kinds of rainwater harvesting structures through the ages which have proved to be very useful to society in many different parts of the world. Inputs are needed from governments and NGOs to establish the conditions for communities to take the necessary action.

In the context of small-scale artificial recharge projects, community participation is essential in at least the following areas:

At the planning stage:
During this time, the basic parameters are explained to male and female community representatives, so that they understand the options available and can weigh the advantages and disadvantages of each option. They must also decide between individual household facilities and community facilities. For further details see chapters 1 and 2.

At the implementation stage:
Community women and men can take charge of the material transportation to the site, and to the extent possible be involved in construction training, actual execution and quality control. This will ensure the use of knowledge of both groups, enhancement of local skills with equal chances for both in case of a gender equity approach, and a shared sense of ownership.

Operation and maintenance:
Routine operation and maintenance must be planned for and carried out by men and women in the communities themselves. Weighing and comparing the different tasks helps to achieve equity and to decide whether and where compensation may be needed. An equitable balance in work and benefits is one of the conditions for sustainable systems.

Sharing of "new" water resources:
This is crucial, since it is an area that has the potential for serious conflict. Understanding and agreeing on norms for abstraction and discipline by each and every member of the community of users is absolutely essential. This is possible only if the community is involved in developing the local rules and control mechanisms and accounting for their application.

Evaluation and modification of design:
When all different groups in the community (or in large communities their representatives) have been involved in the above stages, this last step should be smooth and spontaneous. Once the systems are in place, each group should be given the opportunity to reflect critically and improve upon the design so that learning and development continue. Involving both women and men from the various socio-economic sections in the evaluation and making sure (e.g. by using gender and class sensitive participatory tools and techniques) that all can share their views equally taps a wide range of knowledge and experiences.

6.2 Methods of artificial recharge

There are many reasons why water is deliberately placed into storage in groundwater reservoirs. A large number of artificial recharge schemes are designed to conserve water for future use. Other projects recharge water for objectives like control of saltwater intrusion, filtration of water, control of subsidence, disposal of wastes and secondary recovery of crude oil from oil fields.

Artificial recharge methods can be classified in two broad groups: (a) direct methods and (b) indirect methods.

Direct methods are subdivided into surface spreading techniques and sub-surface techniques. The most widely practised methods employ different techniques for increasing the contact area and residence time of surface water in the soil, so that a maximum amount of water can infiltrate and augment the groundwater storage. In *surface spreading* techniques, the various methods available are flooding, ditch and furrow surface irrigation, stream modification and finally, the most accepted one and suitable for small community water supplies, run-off conservation structures or rainwater harvesting.

In *subsurface techniques* injection wells and gravity head recharge wells are more common.

Indirect methods of artificial recharge adopt the technique of induced recharge by means of pumping wells, collector wells and infiltration galleries, aquifer modifications and groundwater conservation structures. They require highly skilled manpower and other resources. The different methods of artificial recharge are presented in tabular form in figure 6.1.

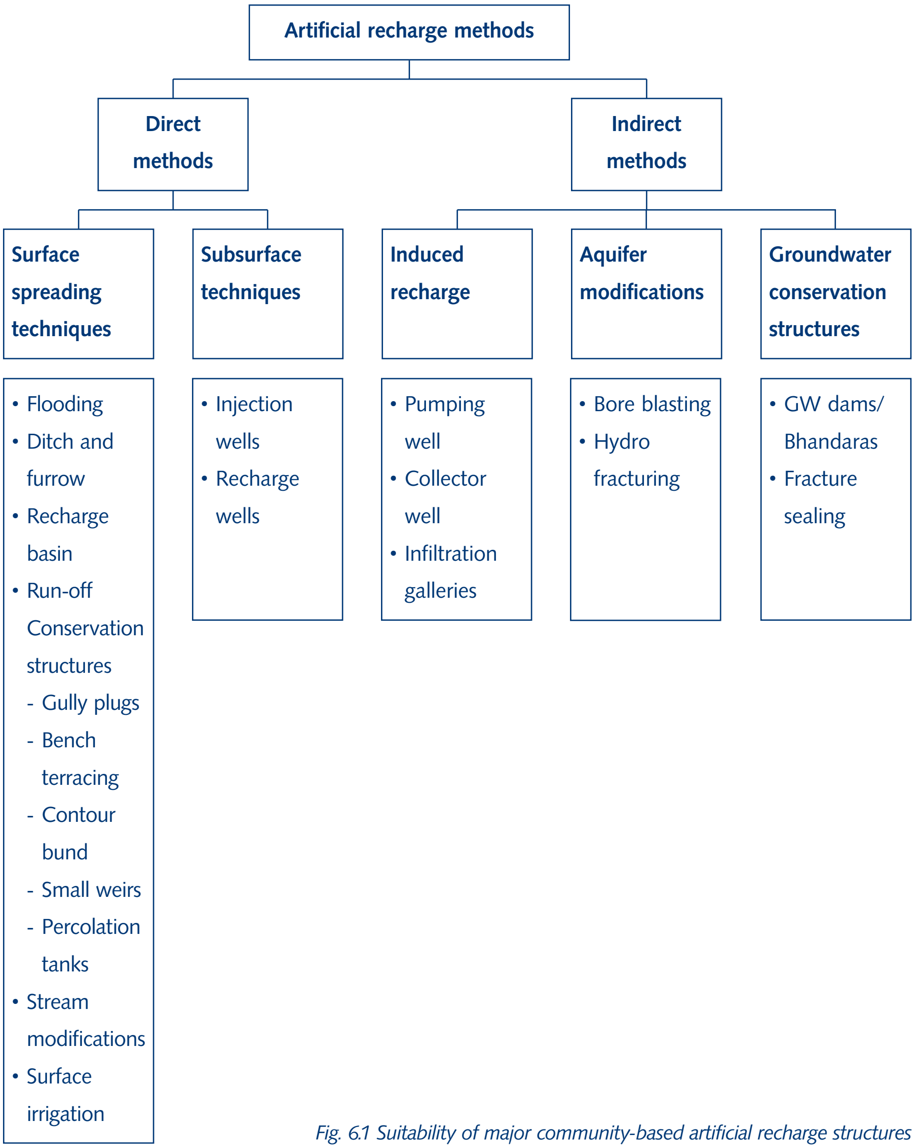

Fig. 6.1 Suitability of major community-based artificial recharge structures

In principle, the choice of an artificial recharge method is controlled by factors such as hydrogeology, socio-economic aspects, sources of water, etc. However, based on operation and maintenance needs and management aspects in the Indian context, the major methods can be grouped as in Table 6.1 below.

Table 6.1 Overview of different artificial recharge methods and their indicative capital cost, construction features and O&M aspects (based on Indian experiences)

Artificial Recharge Methods	Indicative cost in India (US $ Oct. 2001 level)	Complexity in construction		Operation and maintenance	Remarks
		Technology	Labour involvement		
Percolation tanks	200 per '000 m^3	Complex technology requires technical expertise	Through local contractor	Community based	Zone of influence downstream extends up to 1 km
Recharge shaft (depth 10-15m ø 2-3 m)	1250-1750	Simple technology with technical guidance	Local labour	Community based	Requires yearly desilting
Recharge pit (2mx2mx3m)	100	Simple technology	Local labour	Community based	--do--
Check dams	200 per '000 m^3	Complex technology requires technical expertise	Through local contractor	Community based with little training	
Recharge trench	100-200	Simple technology		Community based	
Recharge through handpump	100-175	Simple technology with technical guidance	Through local contractor	Community based with little training	
Recharge through dug well		Simple technology with technical guidance	Through local contractor	Community based	

6.3 Direct methods

Surface spreading techniques

The following considerations become important before undertaking artificial recharge through surface spreading techniques:

- The aquifer to be recharged should be unconfined and sufficiently thick to provide storage space.
- The surface soil should be sufficiently permeable to maintain a high infiltration rate.
- The vadose zone should be permeable and free from clay lenses that may cause perched water conditions.
- Groundwater levels in the phreatic aquifer should be deep enough to accommodate the water table rise, avoiding possible water logging conditions.
- The aquifer material should have moderate hydraulic conductivity so that the recharged water is retained for a sufficiently long period in the aquifer and can be used at the time of need. Very high permeability results in the loss of recharged water due to subsurface outflow, whereas very low permeability will limit the desired recharge rate.
- Topography plays an important role in controlling the recharge rate. Areas with gently sloping land without gullies or ridges are most suited for surface water spreading techniques.

Five different surface spreading techniques are described below.

Flooding

Flooding techniques are very useful in selected areas where the hydrogeology favours recharging the unconfined aquifer by spreading surplus surface water from canals or streams over large areas for a sufficient length of time to recharge the groundwater body. Figure 6.2 shows the method by which the surplus canal/stream water is diverted through a delivery canal and released as sheet flows over the permeable soil of the area. To ensure proper contact time and water spread, embankments are made on two sides of the area. They guide the unused surface water to a return canal which feeds the excess water back to the original canal downstream.

This technique helps in reducing evaporation losses from the surface water system. The water conserved in the groundwater storage can be pumped for augmenting canal supplies during summer or to provide irrigation water to adjacent areas. It is the least costly of all water spreading methods and maintenance costs are also low.

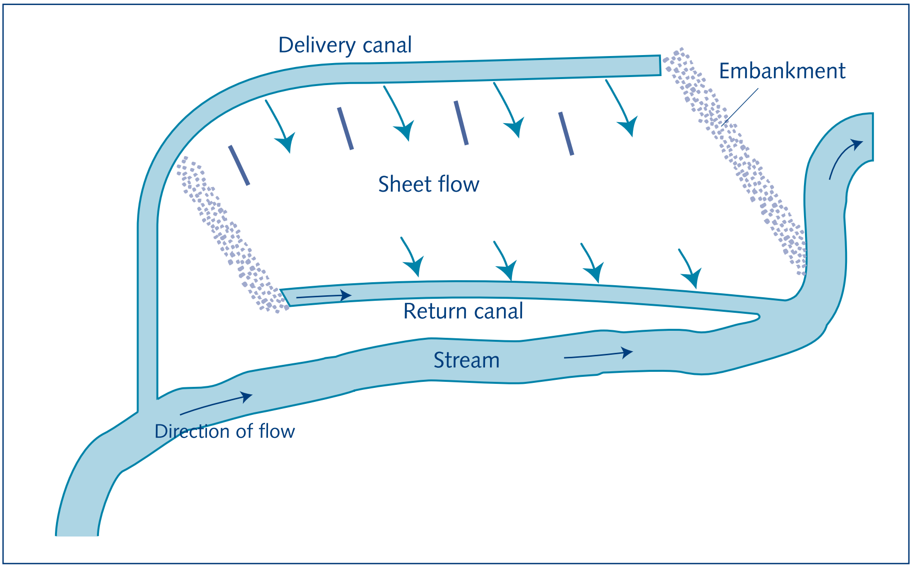

Fig. 6.2. Flooding technique

Ditch and furrow method

In areas with irregular topography, shallow, flat-bottomed and closely spaced ditches or furrows provide maximum water contact area for recharge water from the source stream or canal. This technique requires less soil preparation than recharge basins and is less sensitive to silting. Figure 6.3 shows a typical plan for a series of ditches originating from a supply ditch and trending down the topographic slope towards the stream. Generally three patterns of ditch and furrow systems are adopted (Fig. 6.5, 6.6 and 6.7).

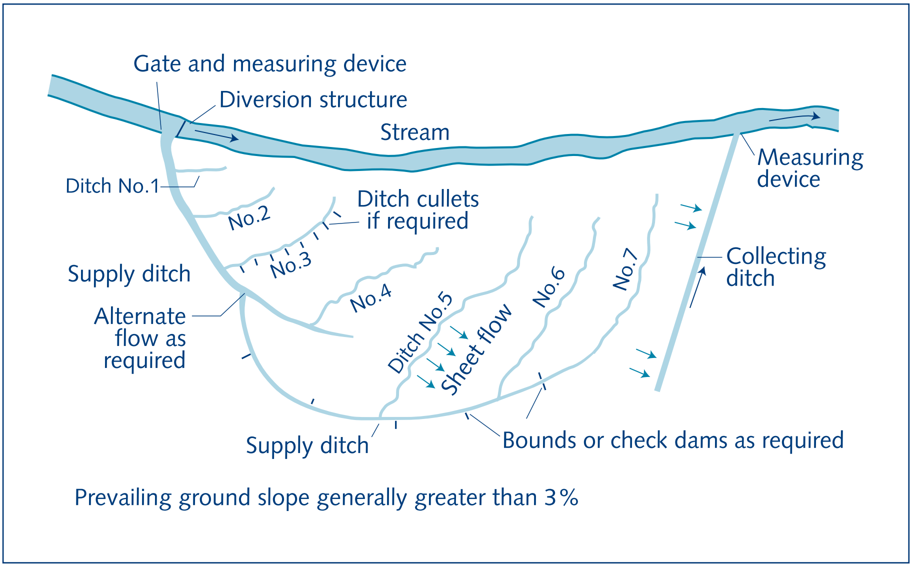

Fig. 6.3. Ditch and furrow method

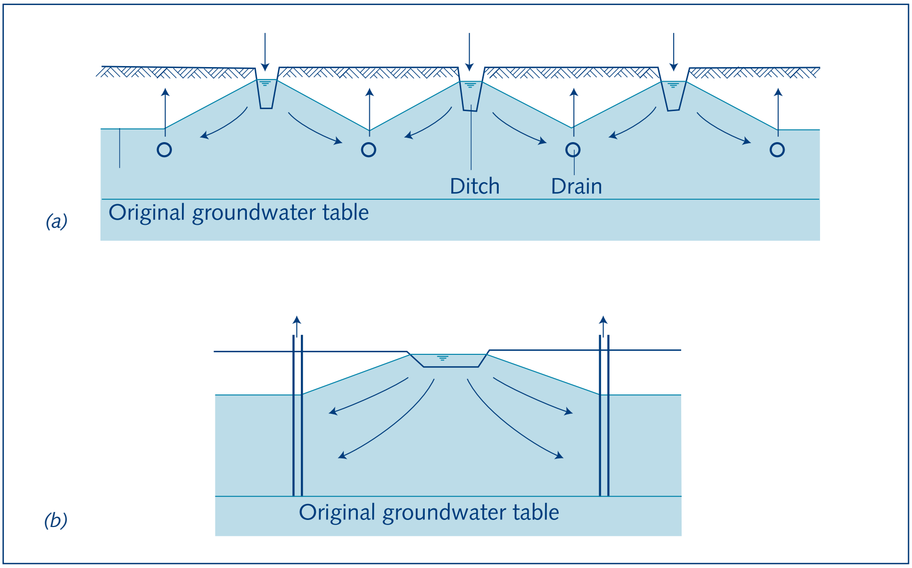

Fig. 6.4. Direct recharge in shallow (a) and deep aquifer (b) with drains and boreholes as recovery method

Direct artificial recharge in shallow aquifers with a high infiltration rate can be accomplished with ditches. In that case drains or galleries are used for groundwater recovery (Fig. 6.4.a). In deeper aquifers the groundwater recovery is via wells or boreholes (Fig. 6.4.b). If the infiltration rate is low, then the infiltration area must be enlarged by larger ditches and shorter ditch intervals.

a. Lateral ditch pattern

The stream water is diverted to the feeder canal/ditch, from which smaller ditches are made at right angles. The rate of flow from the feeder canal to these ditches is controlled by gate valves. The furrow depth is fixed by the topography and also to achieve maximum wetted surface and uniform velocity. The excess water is routed to the main stream through a return canal, along with residual silt.

b. Dendritic (tree-like) pattern

The water can be diverted from the main canal to a series of smaller ditches spread in a dendritic pattern. The branching continues until practically all the water is infiltrated in the ground.

c. Contour pattern

Ditches are excavated following the ground surface contour of the area. When the ditch comes close to the stream a switchback is made and the ditch is made to meander back and forth to traverse the spread area repeatedly. At the lowest point downstream the ditch joins the main stream, thus returning the excess water to it.

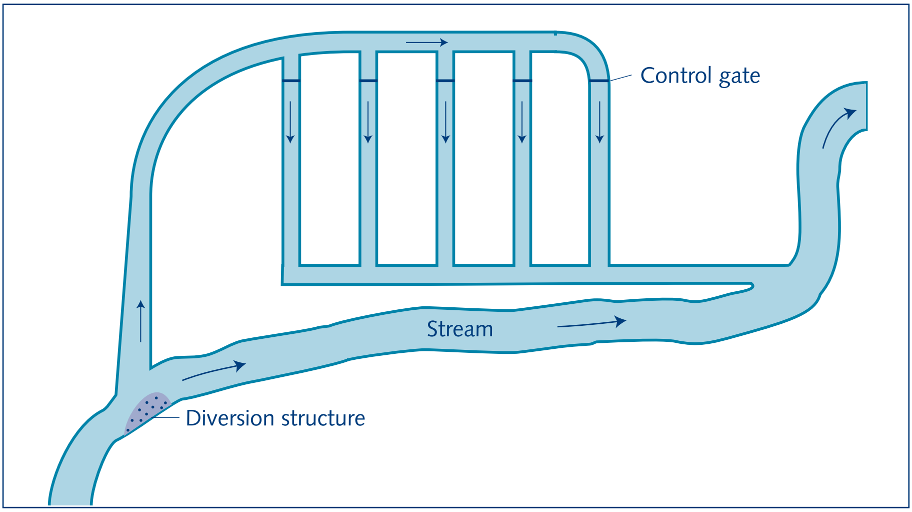

Fig. 6.5. Lateral ditch pattern

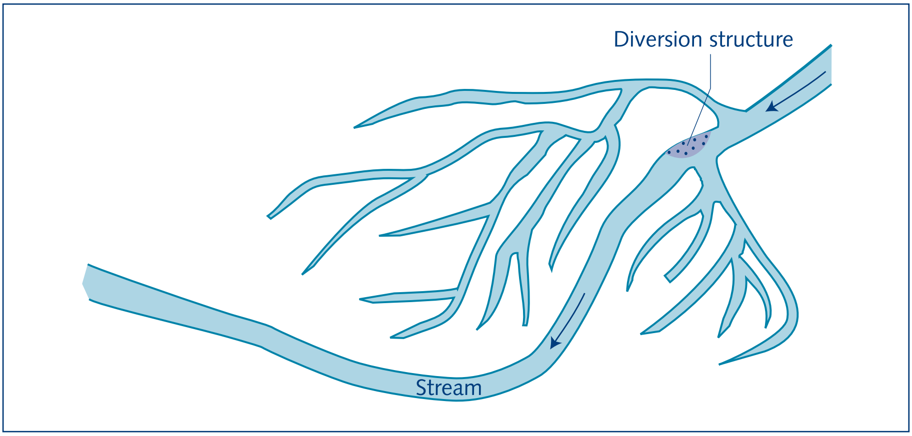

Fig. 6.6. Dendritic ditch pattern

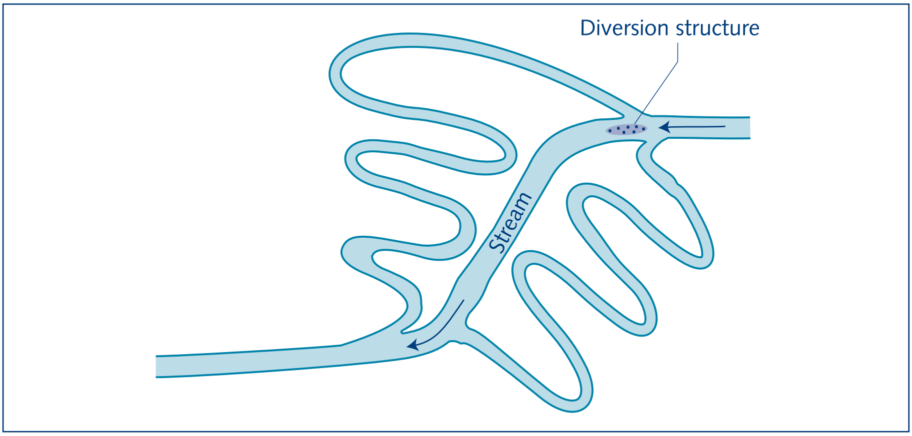

Fig. 6.7. Contour ditch pattern

Recharge basin

Artificial recharge basins are either excavated or are enclosed by dykes. They are commonly built parallel to ephemeral or intermittent stream channels (Fig. 6.8). They can also be constructed at other locations where a canal or any other water source provides the water.

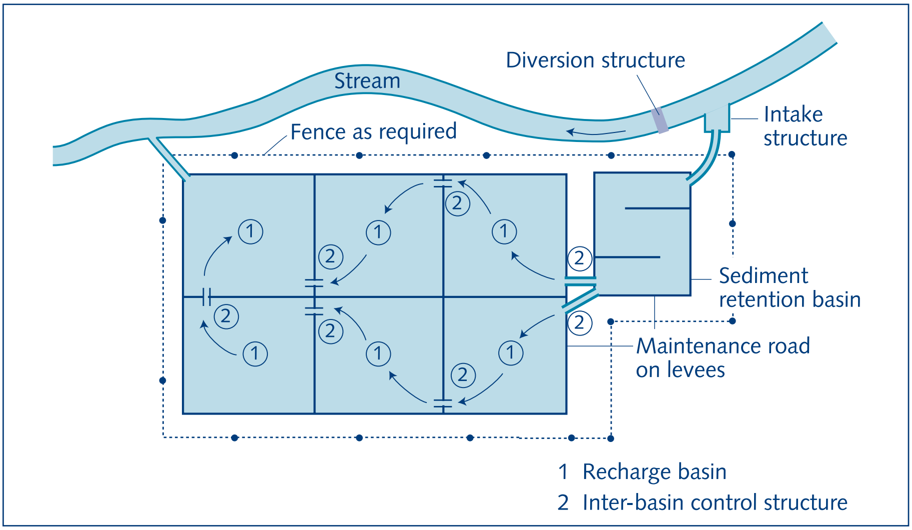

Fig. 6.8. Recharge basin

In alluvial areas multiple recharge basins are generally constructed parallel to the stream. The advantages of multiple basins are:

- water contact time is longer for the stored water;
- suspended material in the source water is reduced as water flows from upstream basins to those below;
- periodic maintenance such as scraping etc. to restore infiltration rates can be done by bypassing the basin concerned.

Run-off conservation structures

Rainfall is a major source of water but it is not evenly distributed throughout the year. During the monsoon period, surplus water is wasted in the form of surface run-off. Water resources planning should address this phenomenon by making efforts to harvest rainwater, especially during rainy seasons.

The main aim of the rainwater harvesting is to conserve the generated surface run-off by collecting it in reservoirs, both surface and sub-surface. The objectives of the rainwater conservation in groundwater reservoirs are:

- Increase the availability of groundwater
- Enhance sustainable yield of aquifers

- Improve quality of groundwater through dilution
- Arrest declining trends of water levels
- Prevent depletion of groundwater reservoirs in areas of over exploitation
- Decrease menace of floods on local and regional areas
- Reduce pressure on storm drains in urban areas
- Enhance the quality of the environment

Rainwater harvesting methods have to be site-specific. The choice and effectiveness of any particular method is governed by local geology, hydrogeology, terrain conditions, total rainfall and its intensity, etc. The rainwater harvesting process includes collection of rainwater, conveyance to a suitable place and then storage in a surface and/or sub-surface groundwater reservoir. The methods listed below are in vogue for conservation of rainwater.

Hilly and open fields

- Basins/percolation tanks
- Check dams
- Ditch and furrows
- Recharge pits and shafts
- Injection tube wells and dug wells
- Sub-surface dams

Urban Areas

- Injection wells/dug wells
- Recharge trenches with injection wells
- Recharge shafts

In areas receiving low to moderate rainfall mostly during a single monsoon season and not having access to water transferred from other areas, water conservation is necessarily linked to "in situ" precipitation. Multi-purpose measures are desirable, that are mutually complimentary and conducive to soil and water conservation, afforestation and increased agricultural productivity. Different measures are applicable in run-off zones, recharge zones and storage zones of a watershed. The structures widely used are (i) gully plug; (ii) bench terracing; (iii) contour bund; (iv) small weirs; and (v) percolation tank.

Gully plug. Gully plugs are the smallest run-off conservation structures built across small gullies and streams rushing down the hill slopes and carrying run-off from tiny catchments during rainy seasons. Usually the bund is constructed by using local stones, earth and weathered rock, brushwood, and other such local materials. Sand bags or brickwork may also be used to strengthen the bund.

Bench terracing. Sloping lands with surface gradients up to 8% and with adequate soil cover can be levelled by bench terracing to bring them under cultivation. Bench terracing helps in soil conservation and in holding run-off water on the terraced areas for longer, resulting in increased infiltration recharge. A map of the watershed should be prepared by level surveying and suitable benchmarks fixed. A 0.3m contour map is the most suitable. Depending on the land slope, the width of individual terraces should be fixed. It should never be less than 12m. The upland slope between two terraces should not be more than 1:10 and the terraces should be levelled.

Contour bunding. Contour bunding is a watershed management practice to build up soil moisture storage. This technique is adopted generally in low rainfall areas. The monsoon run-off is impounded by putting bunds on the sloping ground all along a contour (Fig. 6.9). The flowing water is intercepted before it attains erosive velocity by keeping suitable spacing between two bunds. The spacing depends on the slope of the area and the permeability of the soil. Lower soil permeability means closer spacing of bunds.

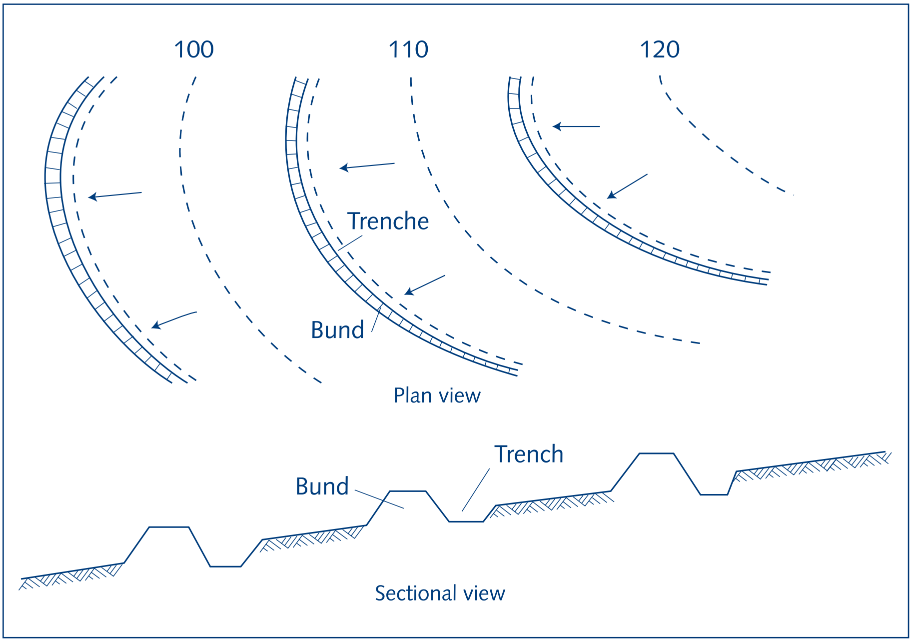

Fig. 6.9. Schematic diagram of contour bunding

Small weirs. A series of small weirs are made across selected stream or irrigation canal sections, so that the stream flow is hindered and water is retained on pervious soil/ rock surfaces for longer. As compared to gully plugs, weirs are constructed across bigger irrigation canals or second order streams with gentler slopes. The reservoir behind the weir acts like a mini percolation tank.

Percolation tanks. Percolation tanks are artificially created surface water bodies submerging a highly permeable land area so that surface run-off is made to percolate and recharge the groundwater storage (Fig. 6.10).

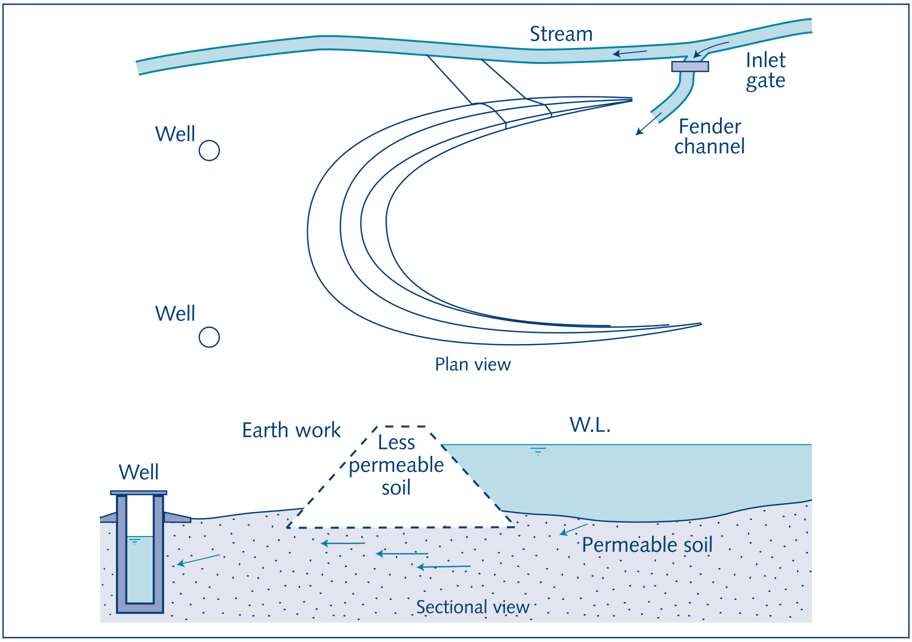

Fig. 6.10. Schematic diagram of percolation tank

For a proper functioning of the percolation tank the hydrogeological characteristics of the site are of utmost importance. The rocks or soil to be submerged should have high permeability, and weathering of the rocks should be laterally extensive and not just localised. Rainfall patterns should ensure that the percolation tank gets filled every year. The soils in the catchment area should preferably be light and sandy to avoid silting up of the tank bed. The canal or stream chosen to create a percolation tank should have an adequate catchment area. The influent run-off volume during a rainy season should range between 300,000 and 800,000 m^3. The size of a percolation tank is governed by the percolating capacity of the strata in the tank bed rather than yield of the catchment. Normally percolation tanks are designed for storage capacity of 200,000- 600,000 m^3. The depth of impounded water provides the recharge head. Hence, the tank design should result in a minimum height of pounded water of 3 to 4.5 m, but not more than 6 m.

Stream channel modification

A natural drainage channel can be modified so as to increase infiltration by detaining stream flow and increasing the stream bed area in contact with water. The channel is so modified that the flow gets spread over a wider area, increasing contact with the percolating river bed. The method includes (i) widening, levelling, scarifying or ditching the stream channel; (ii) L-shaped finger levees or hook levees constructed by bulldozer at the end of the high flow season; and (iii) low head check dams that allow flood flows to pass over safely.

Stream channel modification methods are generally applied in alluvial areas. However, they can be effectively used also in hard-rock areas where thin river alluvium overlies a good phreatic aquifer or the rocks are extensively weathered or highly fractured in and around the stream channel offering scope for artificial recharge.

Surface irrigation

As well as the five surface spreading techniques described in previous sections, recharge of aquifers occurs in a less controlled way through excessive surface irrigation.

Under well-managed modern irrigation practices, a measured amount of irrigation is practised to avoid excess seepage losses (unintended recharge). However, often in irrigation practices the farmers tend to use excessive amounts of water by flooding the fields whenever water is available. The large number of unlined irrigation canals also contribute significantly to the groundwater recharge. Irrigation of land with poor drainage facilities may lead to the development of water logging and salinisation of large areas.

Surface irrigation systems have thus caused an unintended recharge in many areas and groundwater capacity has increased. However, the use of motorised pump sets for lifting groundwater for irrigation has caused substantial drops in groundwater levels. This has resulted in wells/boreholes drying up, leaving the rural poor in particularl with serious drinking water supply problems.

Sub-surface techniques

Recharge pits

Phreatic aquifers are not always hydraulically connected to surface water. On a regional scale impermeable layers or lenses form a barrier between the surface water and the water table, making water spread methods less effective. For effective recharge of the shallow aquifer, the less permeable horizons have to be penetrated to make the aquifer directly accessible. Recharge pits are one option. They are excavations of variable dimensions that are sufficiently deep to penetrate less permeable strata (Fig. 6.11). Recharge pits differ from gravity head recharge wells as the latter do not necessarily reach the unconfined aquifer and the recharging water has to infiltrate through the vadose zone.

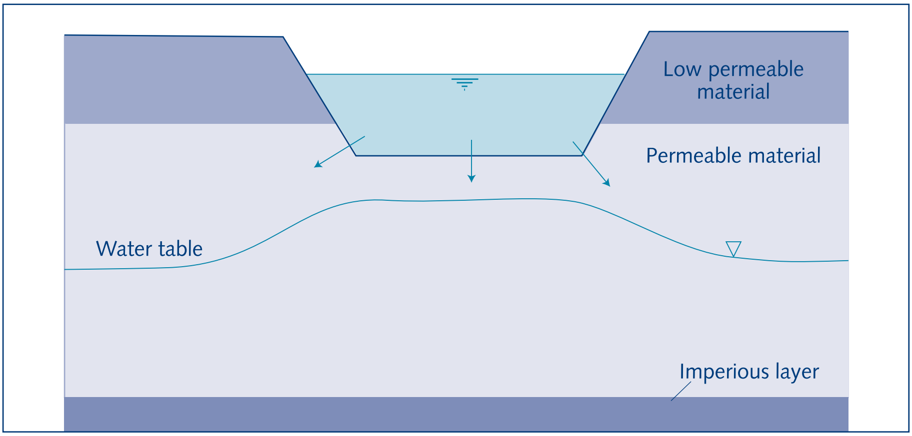

Fig. 6.11. Recharge pit

The larger the cross-sectional area of the pit bottom, the more effective it will be. The actual area required depends on the design recharge volume and the permeability of the underlying strata. Therefore the permeability has to be determined.

The steep side slopes and low permeability of these strata mean that sedimentation occurs only on the bottom and that clogging of side walls is limited. The side-wall slope should be about 2:1. The bottom area of open pits may require periodic manual cleaning. If the recharge pits have a filter pack, then the upper layer of the filter pack also requires periodic cleaning or replacement.

Recharge shafts

In cases where an aquifer is located deep below the ground surface and overlain by poorly permeable strata, a shaft is used for artificial recharge. A recharge shaft is similar to a recharge pit but much smaller in cross section (Fig. 6.12).

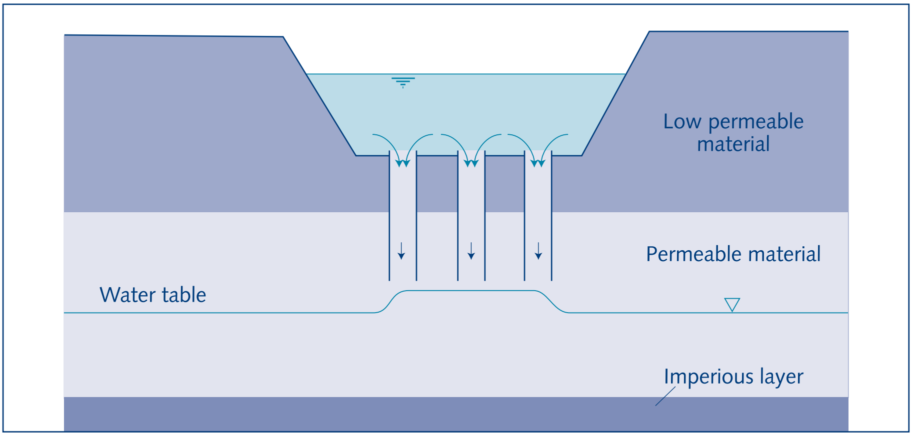

Fig. 6.12. Recharge shafts

A recharge shaft may be dug manually if the strata is non-caving. In good hard clays it is possible to dig deep shafts down to 25 to 30 m depth without lining. For still deeper shafts, bailing, or drilling by reverse circulation or the direct rotary method may be required. When manually dug, the shafts need to be about 2 m in diameter at the bottom. In case of drilled holes the diameter may not exceed beyond 0.8–1 m. The shaft should end in more permeable strata below the confining layer. It may not touch the water table. Unlined shafts should be backfilled, initially by boulder cobbles and then the top few metres by a gravel and sand filter. If the filter material gets choked after some time because of suspended solids in the raw water settled on the upper layers, it should be dug out or bailed out and a fresh filter provided. Siltation and clogging of deeper infilling is difficult to remove. Biotic growth may also clog the infilling. Choked-up shafts are difficult to clean and have to be abandoned. Deeper shafts dug out in caving strata need lining or casing. It is not necessary to backfill lined shafts completely. A few metres thick gravel or coarse sand filter can be placed at the bottom. In case of clogging, the filter material can be removed by bailing and replaced with clean filter material. In lined shafts, the recharge water may be fed through a smaller conductor pipe reaching up to the filter pack.

6.4 Water harvesting technology options

There are many ways of harvesting rainwater. Chapter 7 goes into detail about the most popular rainwater harvesting methods. Here, we discuss three water harvesting systems that can be adopted with the involvement of the local people and achieve maximum value for the resources they demand. They are rooftop harvesting, surface run-off and underground harvesting. It is important to realise that each of these systems has its own characteristics, limitations and advantages.

Rooftop rainwater harvesting

In rooftop rainwater harvesting, the rainwater is collected from roofs of buildings and stored in a groundwater reservoir for beneficial use in future. Advantages:

- Provides water supply self sufficiency
- Reduces the cost of pumping
- Reduces soil erosion in urban areas
- Inexpensive and simple and can be adopted by individuals
- Utilises the rainfall run-off, which usually goes to sewers or storm drains
- Improves the quality of existing groundwater through dilution
- Rainwater may be harvested at place of need and may be utilised at time of need
- In saline or coastal areas it provides good quality (fresh) water and may help in maintaining a balance between the fresh-saline water aquifers
- On islands, due to limited fresh water aquifers, it is a preferred source of water for domestic use
- In deserts it provides an opportunity to store water

Design of recharge techniques

1. Abandoned dug well (Fig. 6.13)

A dry/unused dug well can be used as a recharge structure. The recharge water is guided through a pipe to the bottom of the well or at least below the standing water level, to avoid scouring the bottom and trapping air bubbles in the aquifer. Before using the dug well as recharge structure, its bottom should be cleaned and all the fine deposits should be removed. Recharge water should be silt free. The well should be cleaned regularly. Periodic chlorination should be used to control bacteriological contamination. This technique is suitable for large buildings, having a roof area of more than 1000 m^2.

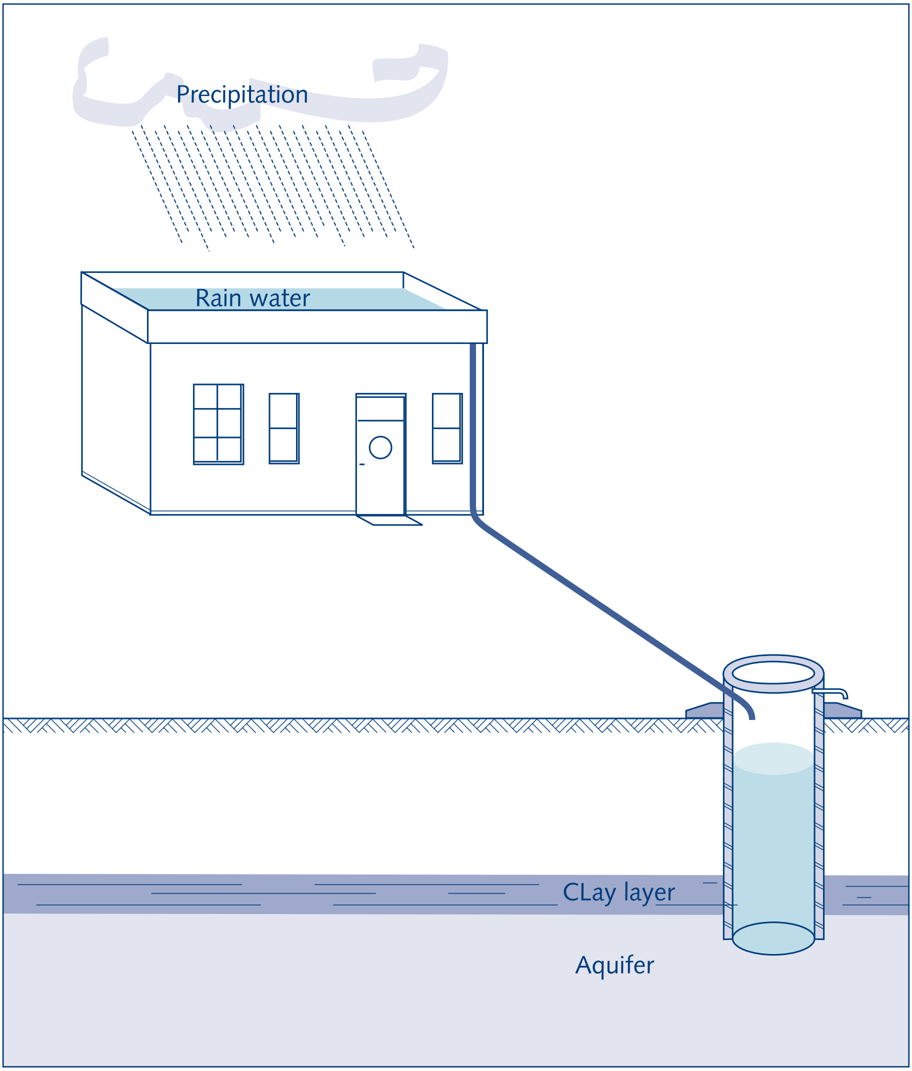

Fig. 6.13. Recharge through abandoned dug well

2. Abandoned borehole (Fig. 6.14)

An abandoned borehole can be used for recharge. The structures are suitable for small buildings having a roof area up to 150 m^2. Water is diverted from the rooftop to the borehole through a 50-100 mm diameter pipe. Recharge water should be silt free.

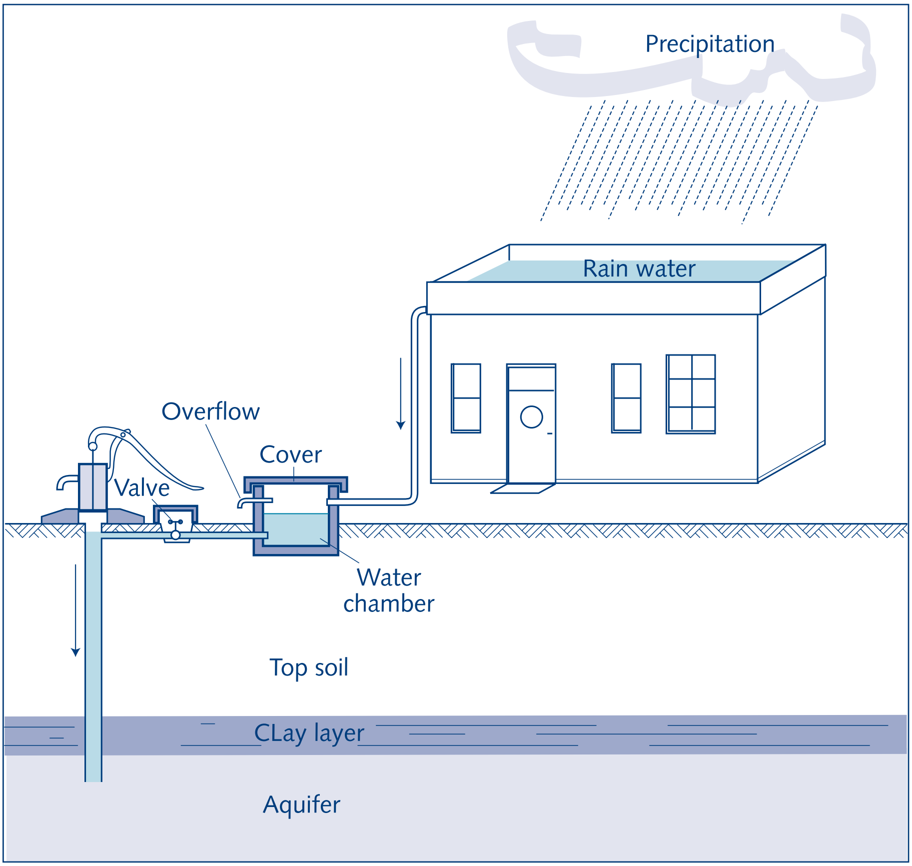

Fig. 6.14. Recharge through abandoned borehole

3. Recharge pit (Fig. 6.11)

Recharge pits are constructed for recharging a shallow aquifer. They are generally 1-2 m wide and 2-3 m deep. After excavation, the pits are refilled with pebbles and boulders. Water to be recharged, should be silt free. Cleaning of the pit should be done periodically. It is suitable for small buildings having a roof top area up to 100 m^2. Recharge pits may have any shape, i.e. circular, square or rectangular. If the pit is trapezoidal, the side slopes should be steep enough to avoid silt deposition.

4. Recharge trench (Fig. 6.15)

Recharge trenches are constructed if permeable strata of adequate thickness are available at shallow depth. The shallow trench is filled with pebbles and boulders.

Trenches are constructed across the land slope. The trench may be 0.5-1 m wide, 1-1.5 m deep and 10-20 m long depending upon the availability of land and roof top area. It is suitable for buildings having a roof area of 200 to 300 m^2. Cleaning of the trench should be done periodically.

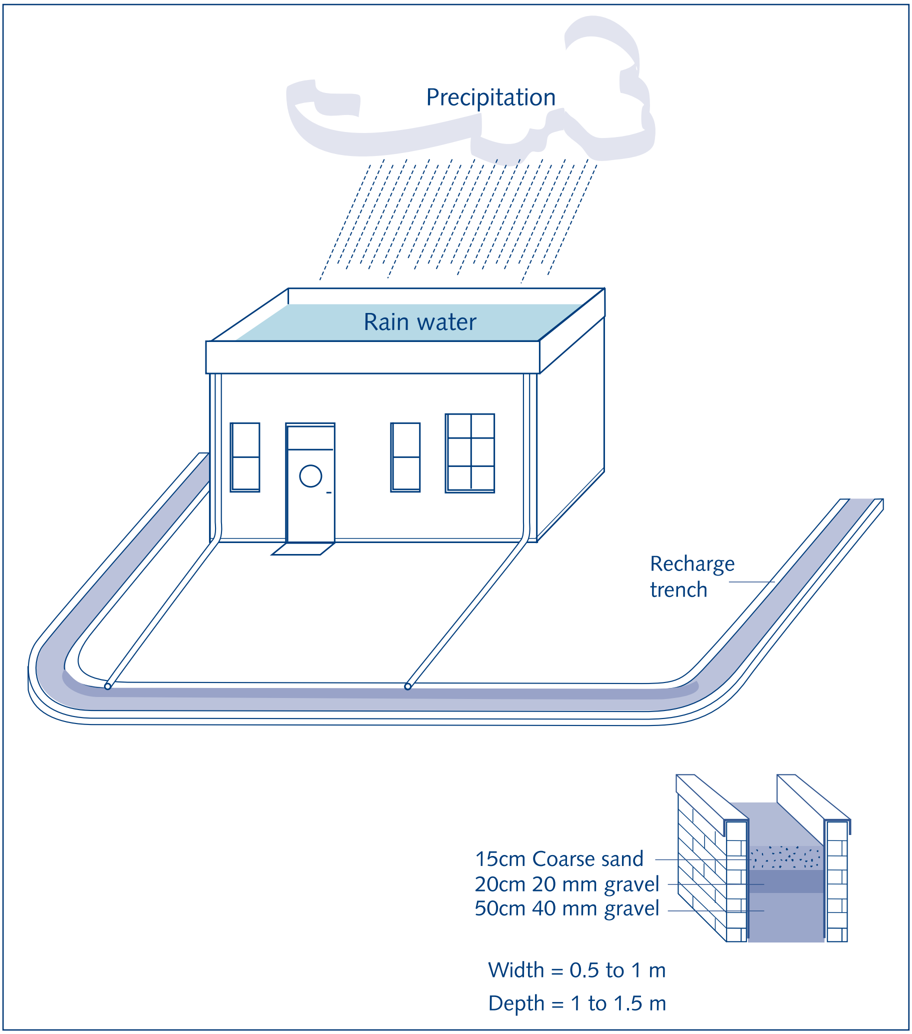

Fig. 6.15. Recharge through trench

5. Gravity head recharge well or borehole (Fig. 6.16)

Boreholes and wells can be used as recharge structures. This technique is suitable where land availability is limited and the aquifer is deep and overlain by impermeable strata (e.g. clay). The rooftop rainwater flows to the well and recharges under gravity. Recharge water should be silt free. The technique is most suitable for areas where the groundwater level is deep. The number of recharging structures for the limited area around the buildings is determined by the rooftop surface area and aquifer characteristics.

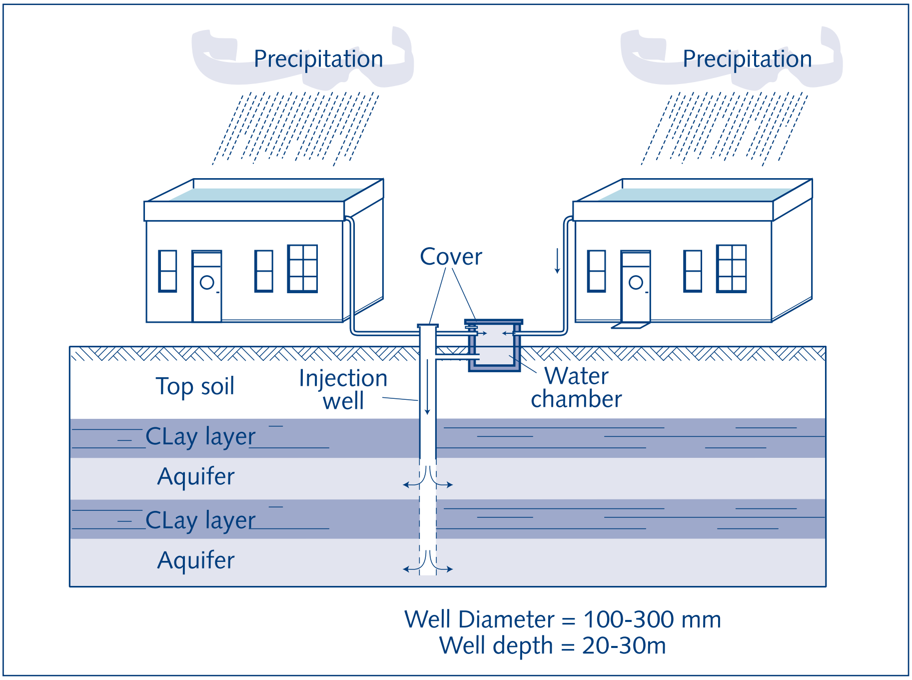

Fig. 6.16. Gravity head recharge well or borehole

6. Recharge shaft (Fig. 6.12)

A recharge shaft may be dug or drilled. Diameters of recharge shafts vary from 0.5-3 m depending upon the availability of water to be recharged. They are constructed where the shallow aquifer is located below strata with low permeability. They should end in more permeable strata (e.g. sand). Depths of recharge shafts vary from 10-15 m below ground level. The recharge shaft is backfilled with boulders, gravels and coarse sand. It should be cleaned periodically by scraping the top layer of sand and refilling it.

Surface catchment systems

Surface catchment water harvesting systems are large-scale communal schemes that collect and store water running off a specific part of the local landscape. This entails either a rocky outcrop or an area of compacted or clay-rich soil. The former is coupled with a rock masonry dam and the latter with a semi-circular clay earth dam.

Masonry check dam

A masonry rock catchment dam may consist of a single straight wall or a number of sections of differing heights or lengths, depending on the shape of the site and the desired size of the reservoir. Wall dimensions range from 2-6 m in height and 10-60 m in length.

Dams are constructed on rocky outcrops, either in rock-top slope areas or lowlands where individual inselbergs or depressions in the river surface are found. The site for the dam and the bottom of the reservoir should be free from rock fissures or fractures that might drain the water away from the site. Aerial photographs and a field survey could assist in the detection of fractures and in the selection of possible sites.

The foundations must be on almost flat, unweathered rock surfaces or rock surfaces sloping slightly backwards to other reservoirs. This ensures the dam's stability and simplifies the design (reduced need for reinforcement). The reservoir should preferably be deep, minimising reservoir surface area so that evaporation losses are minimised. The dam should not exceed a maximum height of 5 m for the simple masonry wall design.

Small dam systems

Small earth dam

The small earth dams discussed in this section are semi-circular or curved banks of earth, generally not more than 3 m in height and 60 m in length. They are built mainly by manual labour, animal traction and light machines (Fig. 6.17). They can be maintained by the user community. Larger constructions are beyond the community-based approach described in this document.

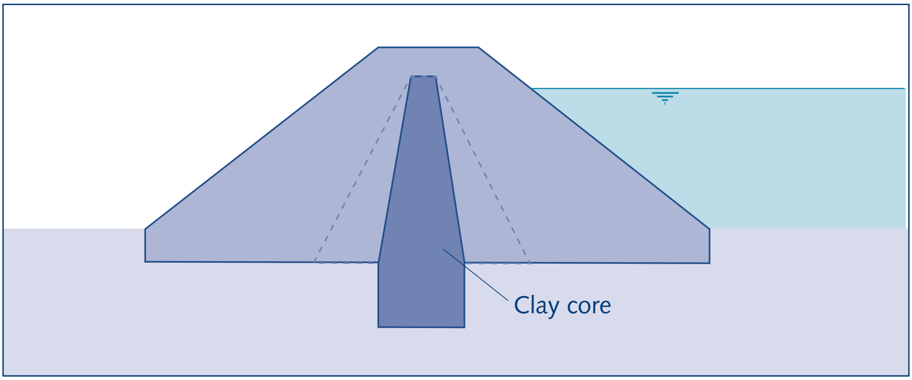

Fig. 6.17. Cross-section of a small earth dam with an impermeable clay core

General design features

In designing simple manually-constructed earth dams, the following design features must be taken into account:

- Ensure a sound foundation that avoids seepage under the dam.
- The dam dimensions must be large enough to ensure stability.
- An outlet pipe system and water tap point (or a transmission pipe to water points closer to the users) should be constructed to abstract water downstream of the dam.
- Two stone spillways are constructed to avoid water overtopping and eroding the dam walls.
- The upstream wall is fully covered with stones to protect it from wave and run-off damage.

- Clay should be used as the primary construction material to achieve an impervious dam and avoiding seepage. Care should be taken in selecting and compacting the clay.
- The dam should be fenced off, for example with live thorn fencing or cut thorn bush to keep livestock from walking along the dam's sides and damaging the structure.

Sand dams

A sand dam is a concrete or masonry barrier constructed in an ephemeral river. Upstream of the sand dam the reservoir fills with sediments carried by the river water during high discharge periods. These sediments may be loose rock, stones, and coarse and finer sand. The river water carries away the fine sand and fine suspended solids. Therefore the risks of siltation are small. The filling-up process of the sand dam may take several years, depending on the sediment transport in the river. If mainly finer sediments are present in the river then the sand dam is best built in stages. This is to avoid smaller particles being retained, limiting the permeability of the sand dam body. In the wet season the high velocity flood waters prevent the silt and mud carried by the river from settling on the sand dam body.

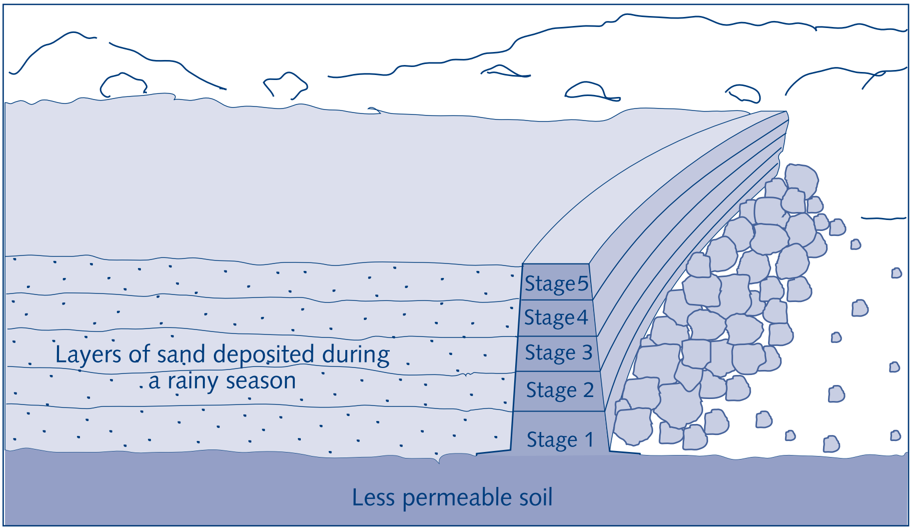

Fig. 6.18. Sand dam (Adapted from Nissen-Petersen, E., 1986)

The water is stored in the pores of the accumulated coarse material in the reservoir of the sand dam. Provided that the bed and walls of the reservoir are impermeable, the water may be stored for long periods. The fact that the water is stored in a sand bed greatly reduces the evaporation losses of the water. Therefore, sand dams are particularly suitable in arid and semi-arid areas with high evaporation rates.

The building can be done in stages, starting with a dam height of some 1.5 m. Annually, depending on the filling rate of the reservoir, the height of the dam can be increased by 0.5-1.0 m. For low dams, a development in stages is not needed.

To retain the stored water in the sand dam selecting the right location is important. The geology in which the dam is to be constructed must be as impermeable as possible to avoid seepage. Weathered and fissured rocks, and sand or coarse medium soils are unsuitable sites. The right foundation is also a key factor for the stability and performance of the sand dam.

Anchoring the dam to the banks of the river needs special attention. Particularly when the soils are soft, floods tend to go around the dam, eroding the land and possibly changing the river course away from the dam and destroying the land. Constructing long wings of sufficient height and growing plants will reduce this risk. The inclusion of a spillway in the centre of the dam will also help to reduce erosion.

Protective measures should also be taken against erosion at the downstream side where the water passes over the dam. A hard surface of rocks, boulders, etc. will prevent the erosion substantially.

Water is withdrawn from the sand dam by a drain pipe (a perforated pipe surrounded by a gravel pack) or from a well dug into the sand bed in or next to the dam. Usually the water can be used without further treatment as the coarse material of the sand dam acts as a filter.

Sub-surface barrier

Sub-surface barriers are used to retain seasonal sub-surface flows and facilitate the abstraction of water through wells or boreholes. To achieve this, an impermeable barrier – either of clay or masonry – is constructed across the river bed from the surface down to an impermeable layer below.

General design features for a sub-surface clay dam (Fig. 6.19)

- The construction of a clay dam should commence immediately after the main rainy season and should be completed before the next rainy season.
- Clay is the primary construction material. Careful selection and compacting of the clay ensures an impervious dam and avoids seepage through fissures and cracks.
- The foundation must be sound and watertight. This avoids seepage under the dam that can lead to loss of stored water.
- The dam must be sufficiently extended into the banks to avoid seepage around the sides of the dam.
- The dam must be two metres wide all the way down to the foundation.

- The top of the dam needs to be protected against erosion from stream forces.
- Rocks should be piled against the banks, both upstream and downstream to protect them from erosion.
- The dam should be located where the river bed is narrower and the sand layer becomes thinner.

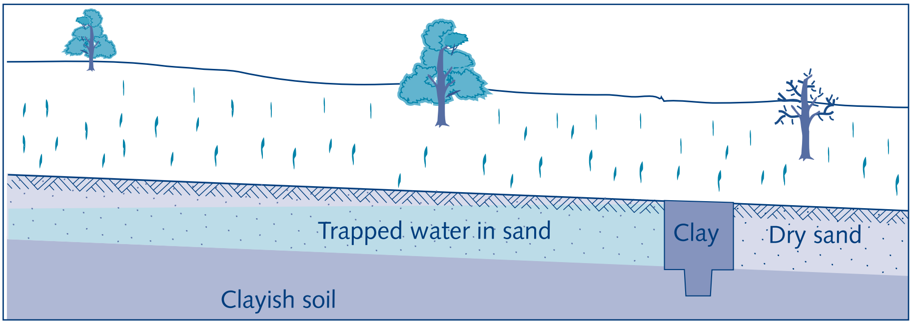

Fig. 6.19. Sub-surface clay dam (Adapted from Nissen-Petersen, E., 1986)

General design features for a sub-surface masonry dam (Fig. 6.20)

- The construction of a masonry dam should commence immediately after the main rainy season and must be completed before the next main rainy season starts.
- The dam should be 50 cm wide.
- The height of the dam depends on the depth of the bedrock layer.
- The dam should be located where impermeable bedrock is less than 5 m below the river bed.
- A sound, watertight foundation must be constructed to avoid seepage under the dam.
- A spill-over apron must be constructed to protect the downstream side of the dam from erosion caused by flowing water.
- The dam should be extended with two wing walls into the river bank to prevent seepage between the river banks and the dam.
- The top of the dam and side walls must be protected against erosion from flowing water.

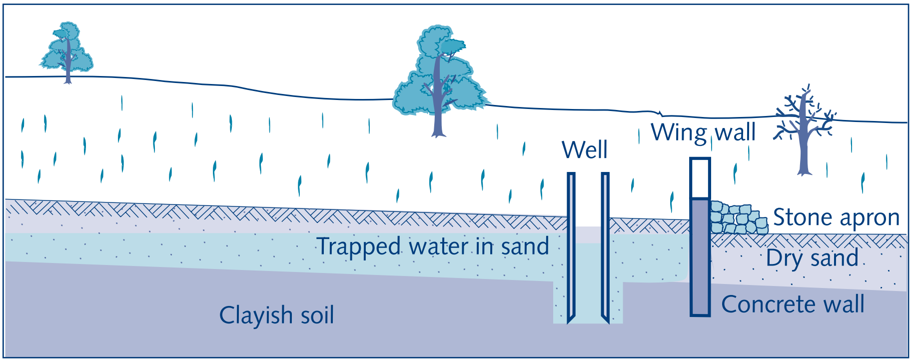

Fig. 6.20 Sub-surface masonry dam (Adapted from Nissen-Petersen, E., 1986)

Percolation tank

Introduction

Percolation tanks (Fig. 6.10) are being recognised as a sound technology not only for rainwater harvesting but also for augmenting groundwater recharge in hard-rock terrain. Hard-rock areas with limited to moderate water holding and water yielding capacities often lead to water scarcity due to inadequate recharge, indiscriminate withdrawal and mismanagement. In this context, percolation tanks are increasingly adopted as a tool for ensuring sustainable development of groundwater. The percolation tank is more or less similar to check dams or small weirs with a fairly large storage reservoir. The tank can be located either across small streams by creating low elevation check dams or in uncultivated land adjoining streams, by constructing a delivery canal connecting the tanks and the stream. Percolation tanks are artificially created surface water bodies that are submerging a land area with adequate permeability to facilitate sufficient percolation of impounded surface run-off to recharge the groundwater.

Design aspects

The design of percolation tanks involves detailed consideration of the following aspects:

- The catchment yield needs to be calculated for long-term average annual rainfall.
- The design of the dam is based on:
  - the topographical setting of the impounded area to calculate the height and length of the dam wall, its gradient, width and the depth of the foundation, taking into account the nature of the underlying formation;
  - details of the cut-off trench, to reduce seepage losses;
  - height of stone pitching on the upstream slope to avoid erosion due to ripple action;
  - suitable turfing on the downstream slope to avoid erosion from rain;
  - upstream and downstream slopes to be moderate so that shear stress is not induced in the foundation beyond a permissible limit;
  - stability of the dam.
- Percolation tanks are normally earth dams with masonry structures only for the spillway. Construction materials consist of a mixture of soil, silt, loam, clay, sand, gravel, suitably mixed and laid in layers and properly compacted to achieve stability and water tightness. The dam is designed not to be over-topped, by providing adequate length of waste weir and freeboard.
- A waste weir is provided to discharge water when the dam overflows. Once the discharge is known the length of the waste weir is decided depending on the volume of maximum permissible flood discharge and permissible flood depth from the waste weir.
- Measures already indicated for the protection of catchment areas of rock dams hold good in the case of percolation tanks also.

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Web sites

There are no specific artificial recharge websites, but there are several interesting experiences documented and disseminated via internet. Use any search engines and general or more specific key words to find valuable information on the net.