Ground Water Recharge Techniques & Designs

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INTRODUCTION

Ground water is a major source of water supply for dinking, industrial and agricultural purposes. Ground water is being largely used for agricultural purposes in the country. It is being over exploited in many areas in the country and its quality is also deteriorating. Many approaches to bring water withdrawals into balance are being adopted. The recharging of ground water is aimed at increasing the availability as well as improving the quality of ground water. Methods available are water spreading, recharge through pits and wells and recharge from water bodies.

Resource management is the coupled approach of limiting the development and use of a resource in order to conserve it. Groundwater management has a somewhat broader scope, in that artificial recharge can be used to expand the amount of available water. The use of artificial recharge to enhance the availability and quality of groundwater has had increasing attention in recent years. In many countries in the world, artificial recharge schemes are being considered and in some areas artificial recharge has been common practice for many years. Furthermore, the technical solutions for implementing and managing artificial recharge schemes have been evaluated, considering traditional methods, modern techniques and instrumentation.

CONCEPT OF ARTIFICIAL RECHARGE

Recharging practices began in 19th century in Europe, Sweden, Germany and Netherlands. The California in United States has large number of artificial recharge projects. Traditional water harvesting in India dates back to Indus Valley Civilization and Mughal Period.

The artificial recharge is the augmentation of underground aquifers by some methods of construction by artificially changing the natural conditions. The concepts of artificial recharge include augmentation of natural ground water, coordinated operation of surface and ground water reservoirs, arresting of declining ground water tables and sea water intrusion, preventing land subsidence and providing storage for treated waste water. Artificial recharge projects are designed to serve one or more of the following purposes:

1. Maintain or augment the natural groundwater as an economic resource.
2. Coordinate operation of surface and groundwater reservoirs.
3. Combat adverse conditions such as progressive lowering of groundwater levels, unfavorable salt balance, and saline water intrusion.

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4. Provide subsurface storage for local or imported surface waters.
5. Reduce or stop significant land use subsidence.
6. Provide a localized subsurface distribution system for established wells.
7. Provide treatment and storage for reclaimed wastewater for subsequent reuse.
8. Conserve or extract energy in the form of hot or cold water.

Therefore, in most situations, artificial recharge projects not only serve as water-conservation mechanisms but also assist in overcoming problems associated with overdrafts. To place water underground for further use requires that adequate amounts of water be obtained for this purpose. In some localities storm runoff is collected in ditches & basins for recharge. Elsewhere recharge water is imported into a region by pipelines or canals from a distant surface water source. A third possibility involves utilization of treated wastewater, which has yet to gain ground in our country.

INITIATIVES OF RECENT YEARS

The Central Ground Water Board (CGWB) has carried out several demonstrative artificial recharge projects including two pilot projects with the assistance of UNDP each in the States of Gujarat and Haryana through which area specific methods and techniques of recharging ground water have been developed. Based on these experiences, the CGWB has prepared and circulated guidelines and manual to the States and UTs to help them prepare ground water recharging schemes.

The CGWB in 1996 prepared a Conceptual Plan to Recharge Ground Water by utilizing surplus monsoon run-off. The availability of non-committed surplus monsoon run-off in 20 river basins of the country was assessed as 87.19 million hectare meters. The position of available run-off and surplus water is outlined as below:-

Average Monsoon Runoff in 20 Major River Basins	15 lakh MCM
Committed use through existing surface water storages	3.7 lakh MCM
Surplus available water for recharge	8.7 lakh MCM (estimated)
Feasible ground water storage potential	2.14 lakh MCM

Source: *National Perspective Plan for Recharge to Ground Water by Utilizing Surplus Monsoon Runoff; Central Ground Water Board, Ministry of Water Resources, Govt. of India, 1996.*

It has been worked out that it is feasible to store 21.42 m.ha. meter of surface water in unsaturated zones above the regional ground water table(s). This however needs further reassessment.

Primarily the in-situ utilization of available surplus monsoon river flows distributed throughout the basins in various States has been visualized. This can be achieved through construction of suitable recharge structures starting from 1st order streams originating in hilly regions and spreading to different nallas and tributaries meeting the main rivers. The low cost structures such as gully plugs, nallah bunds, weirs, percolation tanks, check dams, sub-surface dykes and recharge shafts and wells have been proposed. The construction of recharge structures over main channels of river is also envisaged.

State Govts. have also taken quantum leap and under watershed management, the artificial recharge and rain water harvesting forms an integral component. The programmes initiated by the Ministry of Rural Development for the implementation by the States provides adequate scope of funds and implementation under this.

ARTIFICIAL RECHARGE TECHNIQUES AND DESIGNS

In order to use underground reservoir to store a significant volume of water – possibly of the same order of magnitude as the annual runoff –with the intent to use it at later stage, it is necessary to ascertain the potential storage capacity of the ground water reservoir as well as its suitability for being recharged by the surface water and for easily returning the stored water when needed. The ground water reservoir should present sufficient free space between ground surface and water table to accommodate and retain the water to be recharge for the period during which water is not needed.

This condition requires accurate and detailed hydrogeological investigations including geological mapping, geophysics and reconnaissance drilling, in order to determine the configuration and the storage capacity of the underground reservoir. Artificial recharge of aquifers can be achieved using three different methods, namely Surface Spreading, Watershed Management (Water Harvesting) and Recharge Wells.

A wide spectrum of techniques are in vogue to recharge ground water reservoir. Similar to the variations in hydrogeological framework, the artificial recharge techniques too vary widely. The designs of artificial recharge structures as discussed in the following paragraphs are site specific considering the relevant parameters. The direct technique of recharge is preferred over indirect methods. Based on the experiments and R&D studies in the country on artificial recharge following techniques have been developed for augmenting the ground water in the country.

a. Direct surface techniques
- Flooding
- Basins or percolation tanks
- Stream augmentation
- Ditch and furrow system
- Over irrigation

b. Direct sub surface techniques
- Injection wells or recharge wells
- Recharge pits and shafts
- Dug well recharge
- Bore hole flooding
- Natural openings, cavity fillings.

c. Combination surface – sub-surface techniques

- Basin or percolation tanks with pit shaft or wells.

d. Indirect Techniques

- Induced recharge from surface water source.
- Aquifer modification.

Depending upon geomorphologic and physiographic conditions as well as conditions suitable for recharge, availability of source water the approach for water harvesting and artificial recharge can be used suiting to the environment. The suitability of an aquifer for recharging has been estimated from the following parameters;

- Surface material which has to be highly permeable so as to allow water to percolate easily.
- The unsaturated zone should present a high vertical permeability, and vertical flow of water should not be restrained by less permeable clayey layers.
- Depth to water level should not be less than 7 to 10m.
- Aquifer transmissivity should be high enough to allow water to move rapidly from the mound created under the recharge basin.

An adequate transmissivity for recharge is also a good indicator of the aquifer capacity to produce high well discharge and therefore easily to return the water stored.

1.0 NATURAL AND INDUCED RECHARGE OF THE AQUIFER

Should a significant natural recharge of the aquifer occur from the surface runoff and the deep percolation of rainfall, and should the average annual amount of recharge be of the same order of magnitude as the water demand, there would not be the need for any additional human interventions. On the contrary, any tentative modification of the natural course of surface water may significantly alter the groundwater renewable resources.

Induced natural recharge occurs when intensive exploitation of groundwater close to river results in an important depression of ground water level and in a water-inflow from the river. This phenomenon is well known in areas where river flows all the year: but it may also occur in semi-arid climates where a depression of the piezometric level of an aquifer underlying a temporary river creates the empty space in the aquifer which facilitates its recharge during floods.

Wide spectrums of techniques are in vogues which are being implemented to recharge the ground water reservoir. Similar to the variations in hydrogeological framework, the artificial recharge techniques feasible too, would vary accordingly. The artificial recharge techniques / structures, in varied hydrogeological situation, are described as follows:

1.1 Flood Plain Recharge

Along the major rivers which have well developed flood plains feasible for recharge to ground water. The quantum of unused flood water which is available in rivers is enormous in respect to the space available in the flood plain aquifers. Therefore, ground water conditions may be suggestive of the making recharge only if additional space is created in the aquifers of flood plain by over developing the ground water from Battery of Tube wells. This water can be usefully supplied to the areas of water scarcity. In such an area a ground water storage and recovery can be implemented which is also know as Aquifer Storage Recovery (ASR) method.

1.2 Basin Spreading Recharge

Water commonly is recharged by surface spreading through basins or by induced recharge from adjacent streams and lakes or through injection wells. Water may be recharged by releasing it into basins formed by excavation or by the construction of containment dikes or small dams. Horizontal dimensions of such basins vary from a few meters to several hundred meters. The most common system consists of individual basins fed by pumped water from nearby surface water sources. Silt-free water avoids the problem of sealing basins during flooding. Even so, most basins require periodic scraping of the bottom surface when dry to preserve a percolation surface. Basins, because of their general feasibility and ease of maintenance, are the most favored method of artificial recharge from the surface.

Ditches or furrows, which are shallow, flat-bottomed, and closely spaced to obtain maximum water contact area, are another alternative. Gradients of major feeder ditches should be sufficient to carry suspended material through the system since deposition of fine-grained material clogs soil surface openings. Water spreading in a natural stream channel may use any of the methods described whatever method of surface application is adopted, the primary purpose is to extend the time and the area over which water is recharged. A typical design of Basin recharge methods is given in **Fig. 1.**

1.3 Stream Channel Recharge

Water spreading in a natural stream channel involves operations that will increase the time and area over which water is recharged from a naturally losing channel; this involves both upstream management of stream flow and channel modifications to enhance infiltration. Improvements of stream channels may include widening, leveling, scarifying, ditching to increase infiltration. In areas where streams zigzag through wide valleys occupying only a small part of the valley, the natural drainage channel can be modified with a view to increase the infiltration by detaining stream flow and increasing the streambed area in contact with water **(Fig.2)**.

The channel is so modified that the flow gets spread over a wider area, resulting in increased contact with the streambed. The methods commonly used include:

a) widening, leveling, scarifying or construction of ditches in the stream channel

b) construction of L – shaped finger levees or hook levees in the river bed at the end of high stream flow season

c) Low head check dams which allow flood waters to pass over them safely.

In addition, low check dams and dikes can be constructed across a stream where a wide bottom occurs; this acts as weirs and distribute the water into shallow ponds occupying the entire streambed. Steel weirs, earth dams, concrete dams, or inflatable rubber dams are used. Sometimes the dams are designed with a sacrificial section that washes out during high flows and is replaced when danger is over. When channels have small slopes and water depth, water is spread over the entire width of the channel or flood plain by placing T- or L- shaped earthen levees, generally less than 1 m high, in the channel. Bulldozers are used for pushing up the levees, using natural stream bed sand. If the levees are washed out by high flows, they are restoring again when the flood danger is over.

Stream channel modification can be employed in areas having influent streams that are mostly located in piedmont regions and areas with deep water table such as arid and semi arid regions and in valley fill deposits. The structures constructed for stream channel modification are generally temporary, are designed to augment ground water recharge seasonally and are likely to be destroyed by floods. These methods are commonly applied in alluvial areas, but can also be gainfully used in hard rock areas where thin river alluvium overlies good phreatic aquifers or the rocks are extensively weathered or fractured in and around the stream channel. Artificial recharge through stream channel modifications could be made more effective if surface storage dams exist upstream of the recharge sites as they facilitate controlled release of water.

1.4 Induced Recharge

Induced recharge involves pumping water from an aquifer, which is hydraulically connected with surface water to induce recharge to the ground water reservoir. Once hydraulic connection gets established by the interception of the cone of depression and the river recharge boundary, the surface water sources starts providing part of the pumping yield. Induced recharge, under favorable hydrogeological conditions, can be used for improving the quality of surface water resources due to its passage through the aquifer material. Collector wells and infiltration galleries, used for obtaining very large water supplies from riverbeds, lakebeds and waterlogged areas also function on the principle of induced recharge. The schematic diagram of Induced recharge is given in **Fig. 3**.

Check dams constructed in the river channel upstream of the channel bifurcation help in high infiltration to the channel when wells located in the channels are pumped with high discharge for prolonged periods. Factor important for induced recharge are as follows:

i) Quality of source water, hydraulic characteristics and thickness of aquifer material, distance of the pumping wells from the river and their pumping rates are the important factors controlling the design of schemes for induced recharge.

ii) For implementation of successful induced recharge schemes from stream channels, pumping wells should be selected at sites where water in the streams has sufficient velocity to prevent silt deposition.

iii) Dredging of channel bottom in the vicinity of the existing pumping wells may have to be carried our periodically to remove organic matter and impervious fine material from the beds of the channel.

iv) For wells constructed in unconfined alluvial strata for induced recharge, the lower one-third of the wells may be screened to have optimum drawdowns. In highly fractured consolidated rocks, dug wells penetrating the entire thickness of the aquifer should be constructed with lining above the water table zone and the curbing height well above the High Flow Level (HFL) of the stream.

2.0 Ridges

The ridges generate sufficient quantity of rainfall runoff during monsoon which can be harvested and recharge to ground water through appropriate methods as described below.

2.1 Hill Toe Trenches

Hill Toe trenches are rainwater harvesting structures, which are constructed at the bottom of hill slopes as well as on degraded and barren but sloping waste lands in both high- and low- rainfall areas. Cross section of a typical contour trench is shown in **Fig.4**. The trenches break the slope at intervals and reduce the velocity of surface runoff. The water retained in the trench help in conserving the soil moisture and ground water recharge.

The size of the hill toe trench depends on the soil depth and normally 1 to 2 m wide and 1.5 to 2 m deep trenches 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.

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.

2.2 Gabion Structures

This is a kind of barrier commonly constructed across small stream to conserve stream flows with practically no submergence beyond stream course. The boulders locally available are stored in a steel wire **(Fig. 5).** This is put up across the stream to make a small dam by anchoring it to the streamside. The height of such structures is around 0.5 m and is normally used in the streams with width of about 10 to 15 m. The excess water overflows this structure leaving some storage water to serve as source of recharge. The silt content of stream water is deposited in the interstices of the boulders in due course to make it more impermeable.

2.3 Check Dams/Gully/Nala Plug

Check Dams are constructed across small streams having gentle slope and are feasible both in hard rock as well as alluvial formation **(Fig. 6).** The site selected for check dam should have sufficient thickness of permeable bed or weathered formation to facilitate recharge of stored water within short span of time. The water stored in these structures is mostly confined to stream course and the height is normally around 2 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 run off, water cushions are provided at down streamside. To harness the maximum run off in the stream, series of such check dams can be constructed to have recharge on a regional scale.

A series of small bunds or weirs are made across selected nala sections such that the flow of surface water in the stream channel is impeded and water is retained on pervious soil/ rock surface for longer period Nala-Bunds are constructed across bigger nalas or second order streams in areas having gentler slopes. A nala bund acts like a mini percolation tank with water storage confined to stream course.

Site Characteristic And Design Guidelines

For selecting a site for Check Dams/ Nala Bunds the following aspects may be observed:

- The total catchment of the nala should normally be between 40 to 100 Hectares though the local situations can be guiding factor for this.
- The rain fall in the catchment should be less than 1000 mm/annum.
- The width of nala bed should be at least 5 meters and not exceed 15 meters and the depth of bed should not be less than 1 meter.
- The lands downstream of Check Dam/ Bund should have land under well irrigation.

The rock strata exposed in the ponded area should be adequately permeable to cause ground water recharge through ponded water.

2.4 Abandoned Queries

In many parts of the country as a result of mining activity, queries have been excavated and now after the completion or abandoning of such activities, abandoned queries in form of large cavity and depressions have been created. In mining areas for excavation of sand and rock material heavy pumping of ground water has been made. The unused abandoned queries can be utilized for recharge to ground water after making certain modifications. The depressions will be used as storage spaces where rain water will be stored. Revival and channelization of drainage around such abandoned queries by construction of embankments & modifications in surface drainage towards these depressions will provide surface storage of rain water during monsoon period.

Where the rocks are already weathered, fractured and jointed most of the water will automatically gets recharged to ground water. At places were fractured, weathered and jointed rocks are not present recharge shafts will be constructed to the depth of existent fractures in sub surface which will facilitate the augmentation of ground water aquifers.

3.0 Alluvial Plains

Alluvial plains are mainly consisting of sand clay and their intermixture. The method of recharge in these areas depends upon the depth of unconfined aquifers as well as utilizing the existing abandoned ground water abstraction structures. Different type of recharge methods that can be adopted for alluvium area are elucidated below.

3.1 Dug Well

There are thousands of dug wells which have either gone dry or the water levels have declined considerably. These dug wells can be used as structures to recharge ground water. The storm water, tank water, canal water, etc. can be diverted into these structures to directly recharge the dried aquifer. By doing so the soil moisture losses during the normal process of recharge, are reduced. The recharge water is guided through a pipe to the bottom of well, below the water level to avoid scoring of bottom and entrapment of air bubbles in the aquifer. The quality of source water including the silt content should be such that the quality of ground water reservoir is not deteriorated. In rural areas the rain water runoff can be channelized and recharged to dug wells through a filter.

3.3 Abandoned Hand Pump & tube wells

Due to depletion in ground water levels several tube wells and hand pumps gets defunct. These abandoned Hand pumps and tube wells can be used as recharge wells after proper cleaning/development and constructing a recharge pit with de-silting chamber along with them. These wells have proper connectivity with ground water aquifers which got de-saturated with depletion of ground water levels. Therefore an effective recharge through these wells takes place

3.4 Recharge Shaft

Recharge shaft is an artificial recharge structure which penetrates the overlying impervious horizon and provides affective access to surface water for recharging the phreatic aquifer. These structures are ideally suited for areas with deep water levels. In areas where low permeable sandy horizon is within shallow depths, a trench can be excavated to 3 m depth and back-filled with boulder and gravel. The trench can be provided with injection well to effectively recharge the deeper aquifers **(Fig.7).** The following are site characteristics and design guidelines:

To be dug manually if the strata is of non-caving nature. If the strata are caving, proper permeable lining should be provided. The diameter of shaft should normally be more than 2 m to accommodate more water and to avoid eddies in the well.

In the areas where source water is having silt, the shaft should be filled with boulder, gravel and sand from bottom to have inverted filter. The uppermost sandy layer has to be removed and cleaned periodically.

When water is put into the recharge shaft directly through pipes, air bubbles are also sucked into the shaft through the pipe which can choke the aquifer. The injection pipe should therefore, be lowered below the water level, to avoid this.

3.5 Percolation Tank

Percolation tank is an artificially created surface water body, submerging in its reservoir highly permeable land areas, so that the surface run off is made to percolate and recharge the ground water storage **(Fig 8).** In areas where land is available in and around the stream channel section, a small tank is created by means of earthen dams across the stream. The tank can also be located adjacent to the stream. The percolation tank should have adequate catchment area. The hydrogeological condition of site for percolation tank is of utmost importance. The rocks coming under submergence area should have high permeability. The degree and extent of weathering of rocks should be uniform and not just localized.

The percolation tank should be located down stream of run off zone, preferably towards the edge of piedmont zone or in the upper part of transition zone (Land slope between 3 to 5%). The aquifer zone getting recharged should extend down stream into the benefited area where adequate number of ground water structures should be available to fully utilize the additional recharge.

The purpose of percolation tank is to conserve the surface run off and diverts the maximum possible surface water to the ground water storage. Thus the water accumulated in the tank after monsoon should percolate at the earliest, without much evaporation losses. Normally a percolation tank should not retain water beyond February.

The size of a percolation tank should be governed by the percolation capacity of the strata in the tank bed rather than yield of the catchment. For, in case the percolation rate is not adequate, the impounded water is locked up and wasted more through evaporation losses, thus depriving the down stream area of the valuable resource.

3.6 Recharge Trench with injection well

The aquifer to be replenished is generally one which is already over exploited by tube well pumpage and the declining trend of water levels in the aquifer has set in. Because of the confining layers of low permeability the aquifer cannot get natural replenishment from the surface and needs direct injection through recharge wells **(Fig 9).**

In alluvial areas injection well recharging a single aquifer or multiple aquifers can be constructed in a fashion similar to normal gravel packed pumping well. The only difference is that cement sealing of the upper section of the well is done in order to prevent the injection pressures from forcing leakage of water through the annular space of borehole and well assembly. An injection pipe with opening against the aquifer to be recharged may be sufficient. However, in case of number of permeable horizons separated by impervious rocks, a properly designed injection well may be constructed with slotted pipe against the aquifer to be recharged. In practice the injection rates are limited by the physical characteristics of the aquifer. In the vicinity of well, the speed of ground water flow may increase to the point that the aquifer is eroded, especially if it is made up of unconsolidated or semi-consolidated rocks. In confined aquifer confining layers may fail if too great pressure is created under them. If this occurs, the aquifer will become clogged in the vicinity of the borehole and/or may collapse.

4.0 Urban Areas

Water supply in urban areas is mostly from surface sources like natural or impounded reservoirs as well as from ground water sources. As the population density is more sources are planned and constructed to take care of the water requirements of the population throughout the year. Ground water is in use in areas where the surface water supplies are either not reaching or are not adequate. Land use for constructed areas is more in comparison to open and barren land usage in urban areas. Therefore small but effective recharge structures are required which occupy smaller space and provide optimal recharge to ground water. Roof top Rain Water harvesting is one of such technique that can be adopted for urban areas.

The concept of rainwater harvesting involves 'tapping the rainwater where it falls'. A major portion of rainwater that falls on the earth's surface runs off into streams and rivers and finally into the sea. An average of 8-12 percent of the total rainfall recharge only is considered to recharge the aquifers. The technique of rainwater harvesting involves collecting the rain from localized catchment surfaces such as roofs, plain / sloping surfaces etc., either for direct use or to recharge the ground water resources.

4.1 Roof Top rain Water Harvesting

In Urban areas, the roof top rain water can be conserved and used for recharge of ground water. This approach requires connecting the outlet of storm water drains and pipes from roof top to divert the water to existing wells/ tube wells/ bore well or specially designed recharge wells. The urban housing complexes or institutional buildings have large roof area and can be utilized for harvesting roof top rain water **(Fig.10)**

To design the recharge structure, peak intensity of rainfall and its duration has to be taken into account to assess the total volume of water which shall be available during this period. This is most important as 80% of rainfall occurs in 3 to 5 rainstorms (Table – 1) gives the peak flow for varying catchment area and intensity by which volume can also be calculated.

Table 1: Peak flow for various catchment areas and peak intensity rainfall

Catchment Area (in Sq m)	Rainfall Intensity in (mm/hr)			
	50	100	150	200

	Peak flow (in lps)			
20	**0.28**	**0.56**	**0.83**	**1.11**
30	**0.42**	**0.83**	**1.25**	**1.67**
40	**0.56**	**1.11**	**1.67**	**2.22**
50	**0.69**	**1.39**	**2.08**	**2.78**
60	**0.83**	**1.67**	**2.5**	**3.33**
70	**0.97**	**1.94**	**2.92**	**3.89**
80	**1.11**	**2.22**	**3.33**	**4.44**
100	**1.39**	**2.78**	**4.17**	**5.55**
200	**2.78**	**5.56**	**8.33**	**11.11**
500	**6.95**	**13.89**	**20.83**	**27.78**
1000	**13.92**	**27.78**	**41.67**	**55.55**

The total volume of runoff likely to be generated during peak intensity can be estimated by multiplying the value of peak flow given in the above table with the run off coefficient as given table 2 below.

Table 2: Runoff coefficient for different catchment areas

Type of catchment Area	Runoff Coefficient
Roof top	0.8
Paved Area	0.65 to 0.75
Grassland or open unpaved land	0.1

4.2 Park Type Structures

In urban agglomerate of residential colonies and institutional areas parks are very common feature and can be fruitfully utilized for recharge to ground water. Rainwater from the catchment of park as well as surrounding area is diverted towards the park which is excavated in a basin type depression to accommodate the rainwater from the elevated surrounding area. The water is recharged through recharge shaft/ recharge wells or recharge pit depending upon the hydrogeological conditions and depth of unconfined aquifer. The structure is used as rain water harvesting and recharge structure during monsoon and same is used as play ground in other seasons. Depth of excavation of park is such that the slope is in the ratio of 8:1 in the collector basin and 4:1 in the recharge basin as indicated in **Fig. 11.**

4.3 Storm water harvesting

During rainy season, storm water drains exclusively containing rain water flow up to brim. To harness the available runoff, trenches with recharge tube wells are constructed inside the drain bed itself at a spacing of 100 to 300 m depending the availability of runoff. Depending upon the ratio of depth: slope of the drain walls, a small baffle wall of 0.6 to 1.0 m height is constructed to retain the water. Maintain the catchments neat and clean, no mixing of sewerage and other water should be allowed and open spaces around the storm water drains should be prevented from dumping of unwanted items and scrap material. Open storm water drains are covered with perforated detachable RCC slabs to maintain these drains and prevent pollution and contamination. **Fig. 12** gives the design of such recharge structures.

4.4 Recharge from Mega Urban Structures:

In urban areas mega structures like flyover, Airports, Stadium etc. covers huge area with concrete and prevents natural recharge to take place. Such giant civil structures generates large amount of surface runoff during the rains because of their runoff coefficient range varying from 0.6 to 0.8. In order to provide a conduit to rain water to reach to aquifer certain recharge structures should be constructed in the vicinity of these mega civil structures.

From the road surface lot of runoff goes waste through storm water drains. To harness available runoff, either trenches or shafts with recharge wells are constructed in series along the road side at a spacing of 100 to 300 m depending upon the availability of runoff. In Delhi 45 Flyovers and 26 Subways projects have been executed or being executed. These flyovers will generate enormous amount of surface runoff. The available runoff from the flyovers can be harvested by making shaft or trenches with recharge wells along the storm water drains.

Trenches with length up to 20 m can be constructed with two or more than two recharge tube wells. Generally these trenches are recommended tapping runoff generated from whole campus/catchment of areas ranging from 10000 Sq.mt to 40000 Sq.mts **(Fig 13 & 14).** As the runoff from the whole catchment consists of lot of silt, the same can be removed by constructing a de-siltation chamber as shown in the **Fig. 15**. Walls of recharge structures are not recommended to be plastered from both the sides. Brick wall of the trench shall be constructed in trapezium manner to have better stability (0.46 m-0.34 m-0.23 m thick brick wall). The main advantage of recharge trenches is that they can recharge runoff generated from large areas.

If the trenches need to be constructed above 10 m length, supporting beams may be provided or if possible divide the trench into chambers of 2 or 3 to provide the requisite strength to the walls of the trench. BIS code on sub-surface reservoirs may be consulted while constructing the recharge trenches. If the trenches are constructed in storm water drains where the polluted water is expected during the lean period or non-monsoon months, a bye pass arrangement may be made so that no polluted water enters into the recharge trenches.

5.0 Ponds, Lakes and Water Bodies

The protection, management, and restoration of water bodies is of crucial importance as they are also one of the contributors to the fresh water resource as a means to recharge the groundwater, and for the improvement of the urban environment. Amongst the numerous water bodies, most of the water bodies are deteriorated and silted or filled with garbage or waste material. Following recharge techniques are indicated for enhancing the recharge from such water bodies.

5.1 Village Tank with Shaft

The existing village tanks which are normally silted and damaged can be modified to serve as recharge structure in case these are suitably located to serve as percolation tanks. In general, no "Cut Off Trench" (COT) and Waste Weir is provided for village tanks. Desilting, coupled with providing proper waste weir and COT on the upstream side, the village tanks can be converted into recharge structure. Several such tanks are available which can be modified for enhancing ground water recharge. Studies, however, are needed to ascertain whether the village tanks are suitably located to serve as recharge structures. Some of the tanks in Maharashtra and Karnataka have been converted into percolation tanks.

5.2 Water Bodies through Recharge Shaft

These ponds, lakes and water bodies are required to be reclaimed and restored for storing the rain water during monsoon and augmenting the same to ground water storages by constructing recharge shafts adjacent to them. The recharge shafts should be constructed in a way that only excess water is being recharged to ground water and minimum water level is maintained in water bodies for their sustenance and environment. Before adopting such water bodies for recharge to ground water there is urgent need to restore these water bodies by construction of proper bunds, cleaning of water bodies and excavation and silt removal from the bottom of the ponds **(Fig.16).**

6.0 Ground Water Dams or Sub Surface Dykes

These are basically ground water conservation structures and are effective to provide sustainability to ground water structures by arresting sub surface flow. A ground water dam is a sub surface barrier across stream which retards the natural ground water flow of the system and stores water below ground surface to meet the demands during the period of need **(Fig.17)** The main purpose of ground water dam is to arrest the flow of ground water out of the sub-basin and increase the storage within the aquifer. By doing so the water levels in upstream of ground water dam rises and saturating the otherwise dry part of aquifer.

The underground dam has following advantages: -

- Since the water is stored within the aquifer, submergence of land can be avoided and land above reservoir can be utilized even after the construction of the dam.
- No evaporation loss from the reservoir takes place.
- No siltation in the reservoir takes place.
- The potential disaster like collapse of dams can be avoided.

7.0 Sewerage & Waste Water Recharge

Treated wastewater reuse is conventionally carried out through direct application and/or mixed with fresh surface water wastewater in irrigation. Another way of reusing wastewater is through Artificial Recharge (AR) of the aquifer system with partially treated wastewater. Where soil and groundwater conditions are favorable, a high degree of upgrading can be achieved by allowing waste water after necessary treatment to infiltrate into the soil and move down to the groundwater. The unsaturated zone then acts as a natural filter and can remove essentially all suspended solids, biodegradable materials, bacteria, viruses and other microorganisms. Significant reductions in nitrogen, phosphorus, and heavy metals concentrations can also be achieved. This gives an advantage of AR with wastewater over the direct application method. This process is known as **Soil-Aquifer Treatment (SAT)**. Another advantage of AR over application of wastewater, is the fact that water recovered from an AR system is not only clear and odour-free but also comes from a well, drain or via natural drainage to a stream or low area, rather than from a sewer or sewage treatment plant.

Proposed application of this technology is presently confined only to providing water for irrigation purposes at reclaimed areas. The selection of possible locations for AR/WW was controlled by a set of hydrogeological, planning, and environmental considerations. On top of these considerations is the availability and effectiveness of treatment plants.

Hydrogeological considerations: Based on other recharge experiments (i.e. fresh water recharge) in many of the western countries, the following intrinsic characteristics of the aquifer were recommended to ensure successful basin recharge operations. These recommendations were slightly modified to form the required hydrogeological criteria for the selection of possible application locations.

A minimum of 18m depth to the groundwater was required to allow for geo-purification processes (i.e. filtration, adsorption, etc.) before the infiltrating water reaches the groundwater. This depth also allows for groundwater mounding during the recharge process without affecting the infiltration process. The unsaturated zone must realize an infiltration rate not less than 0.25 m/day.

High values of saturated zone transmissivity and porosity are recommended to prevent water mounding below the basin bottom that can cause a decrease in infiltration rate and recharge capacity (effective porosity > 0.1, and transmissivity > 500 m^3/day). Aquifer characteristics down stream the recharging sites must have good hydrogeological conditions to allow water recovery at the desired rates.

Planning considerations: Water resources plans in urban, rural and industrial areas are considering Waste water & sewerage water reuse as a source for irrigation water. Accordingly, replacement of river water by recharged sewage water for irrigating existing or planned reclamation lands is a main criterion for the selection of possible sites for Artificial recharge through waster water.

Environmental and health safety considerations: Detailed environmental impact assessments will be carried out for each of the individual sites before the application that will include mitigation and monitoring plans. However, for the purpose of the general selection of sites, two factors were taken into considerations. Firstly, the site should not be within or upstream of a groundwater-drinking community, and secondly, no recharge should be considered where groundwater is flowing into the River.

a. Artificial recharge through Waste water can be an added dimension for the reuse policies. The technique has far superior advantages over the direct application of treated wastewater. However, restrictions and precautions should be imposed to prevent a damaging impact on the groundwater.
b. The framework included possible locations, amounts of available wastewater for these locations, general environment and health safety considerations, recharge method, and range of applications. Artificial recharge through waster water application, according to the proposed framework, should be restricted to basin recharge which to be used for irrigation purposes in the reclaimed areas.
c. Due to the presence of thick clay cap and the dependence on groundwater for drinking hydro geologically unsuitable areas and regions should be excluded from the Artificial recharge through waster water plans.
d. Columns experiments to be conducted to study the processes that take place during the infiltration of treated wastewater through the unsaturated zone and to estimate the attenuation capacity of the soil at the location selected for the experimental scale basin recharge.

CONVERGENCE WITH NREGS & WATERSHED DEVELOPMENT PROGRAMME

Under the scheme of NREGS & Watershed Development Programme, water harvesting & ground water recharge works are in operation in various states. There is considerable scope to take up recharging of aquifer in coordination with NREGS & Watershed Development Programmes to avoid duplication of endeavour particularly at micro-catchment levels.

Ministry of Rural Development (MORD) has worked out convergence modalities on water conservation measures such as check dam construction under NREGA and running maintenance under watershed programme/ RRR of water bodies; creation of ponds under NREGA and linking under RKVY programme of Ministry of Agriculture (MOA), etc..

There is need for undertaking major initiative in launching nation-wide programme of recharging ground water in water stressed areas with the assistance of partners. The artificial recharge activities in most cases cannot be taken up by individuals. It would require group action by farmer's and by Government with financial assistance by Government and financial institutions and through public-private participation and donors.

Table 3: Scope for country-wide aquifer recharge works

Sl. No.	Works
1	In 20 Major River Basins
2	In select 100 Tributary River basins
3	In 1st & 2nd order stream basins on watershed basis (each watershed 1000 Km2)
4	Spreading basin installations in Bhabar belt in front of Sub-Himalayas (Assam-Kashmir) over select 600 Km length of permeable boulder-gravel area
5	Desilting of existing ponds
6	Converting ponds into Percolation ponds in Hard rock areas driven with shafts/ wells
7	Locating & constructing new recharge percolation ponds in Hard Rock areas
8	Recharge trenches of 3 to 5 Km length around circular hillocks back- filled with gravels & sands (trench 2m x 3m x 2.5m) over cumulative estimated length of 5,000 Km) at 1000 sites in 10 hard rock states
9	Recharge trenches along Aravalli Hill range over select stretches in Rajasthan & Haryana States
10	Recharging wells (Dugwells/ borewells) driven through specially designed pits/trenches in groundwater over exploited/critical blocks covering Alluvial Aquifers
11	Recharging deep confined Aquifers (Rajasthan, Gujarat Tamil Nadu, Punjab, Haryana, Delhi, West UP & Andhra Pradesh, Madhya Pradesh) through wells
12.	Recharging Urban Aquifers (through infiltration basins) using storm water recharge basin method in 100 major Urban areas (cities) 10 infiltration basins in each urban centre.
13	Recharge basins for combating sea water Intrusion along (i) east coast over cumulative length of 200 Km (ii) West Coast over 50 Km length
14	Recharging through Dune Sands -Costal beach dune sands (200 Km length) - Desert area dune sands (over 200 Km2 area)
15	Recharging of spring sources of Himalayan belt (in 5 hill states) using watershed management approach. Catchment protection - 1000 Spring sources
16	Park-type Urban Recharge Installations
17	Demonstrative recharge well installations 2 Nos. each in Schools/ colleges/ Universities/ Govt. Deptts. Institutional units.
18	Recharge pits/ trenches in low ground area along Railway tracks over selected stretches: 5000 Km length
19	Circular recharge pits around big trees (2m dia. & 2m depth filled with gravel & sand)

The implementation of a Country-wide Recharge Programme would need inter-agency cooperation for joint programming, planning and implementation. A number of organizations and NGOs are working for recharging of ground water. There is however need to strengthen their capacity to enable them participate in implementation of programme. A scope for Country-wide Recharge Plan highlighting the types of structures feasible is indicated in the Table, for its consideration by policy planning & implementing agencies.

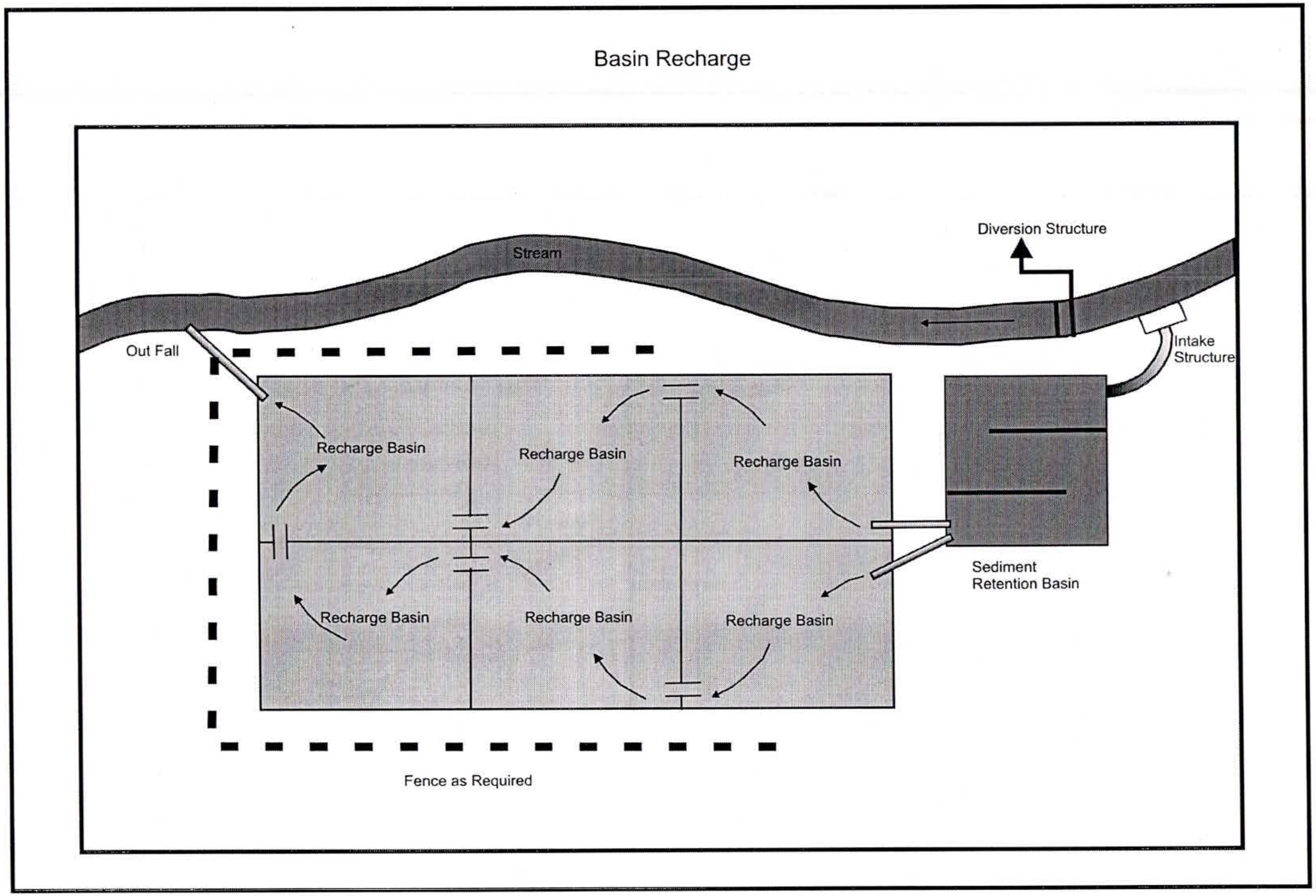


Figure 1: Schematic diagram for basin recharge structure

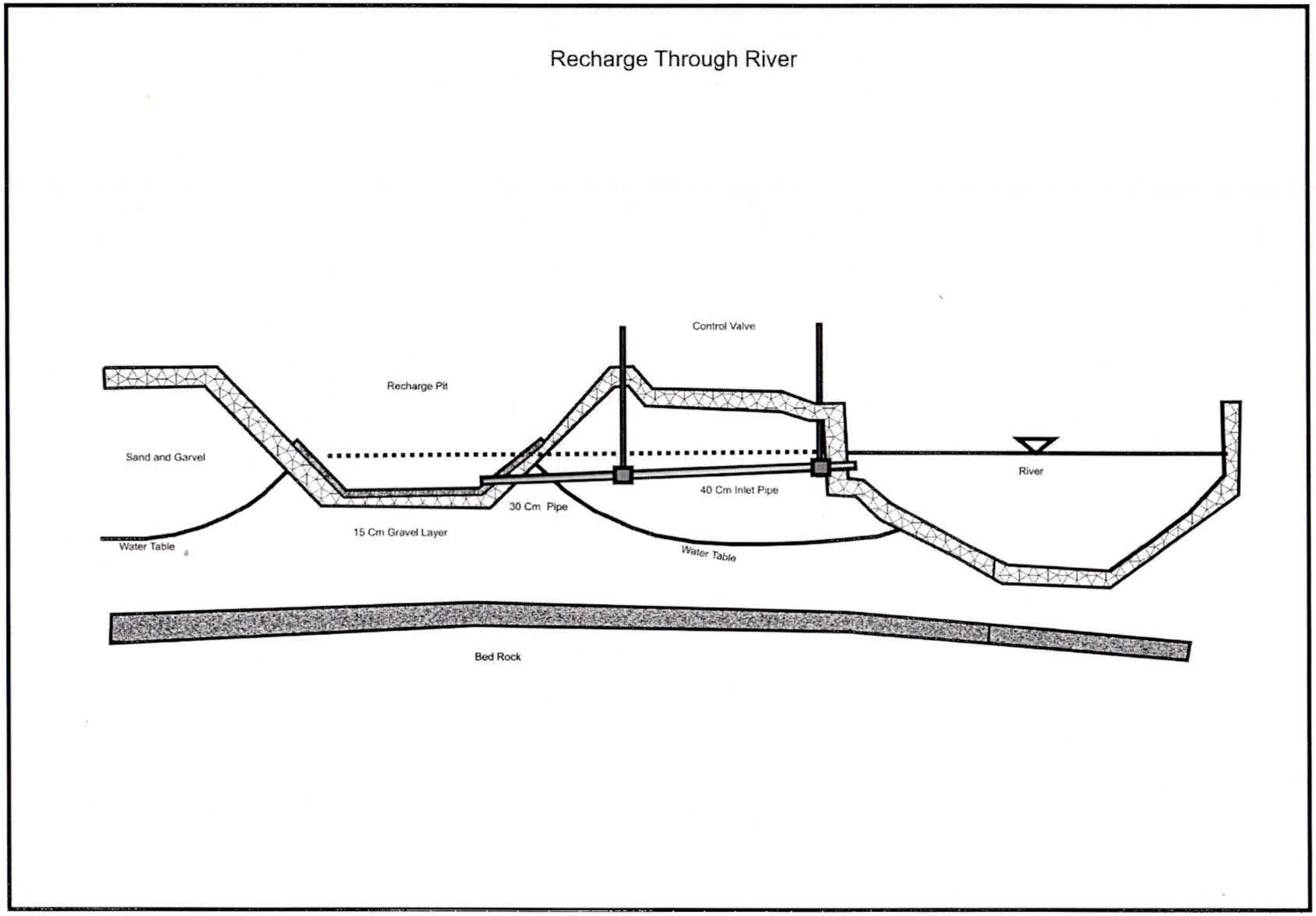


Figure 2: River recharge structure

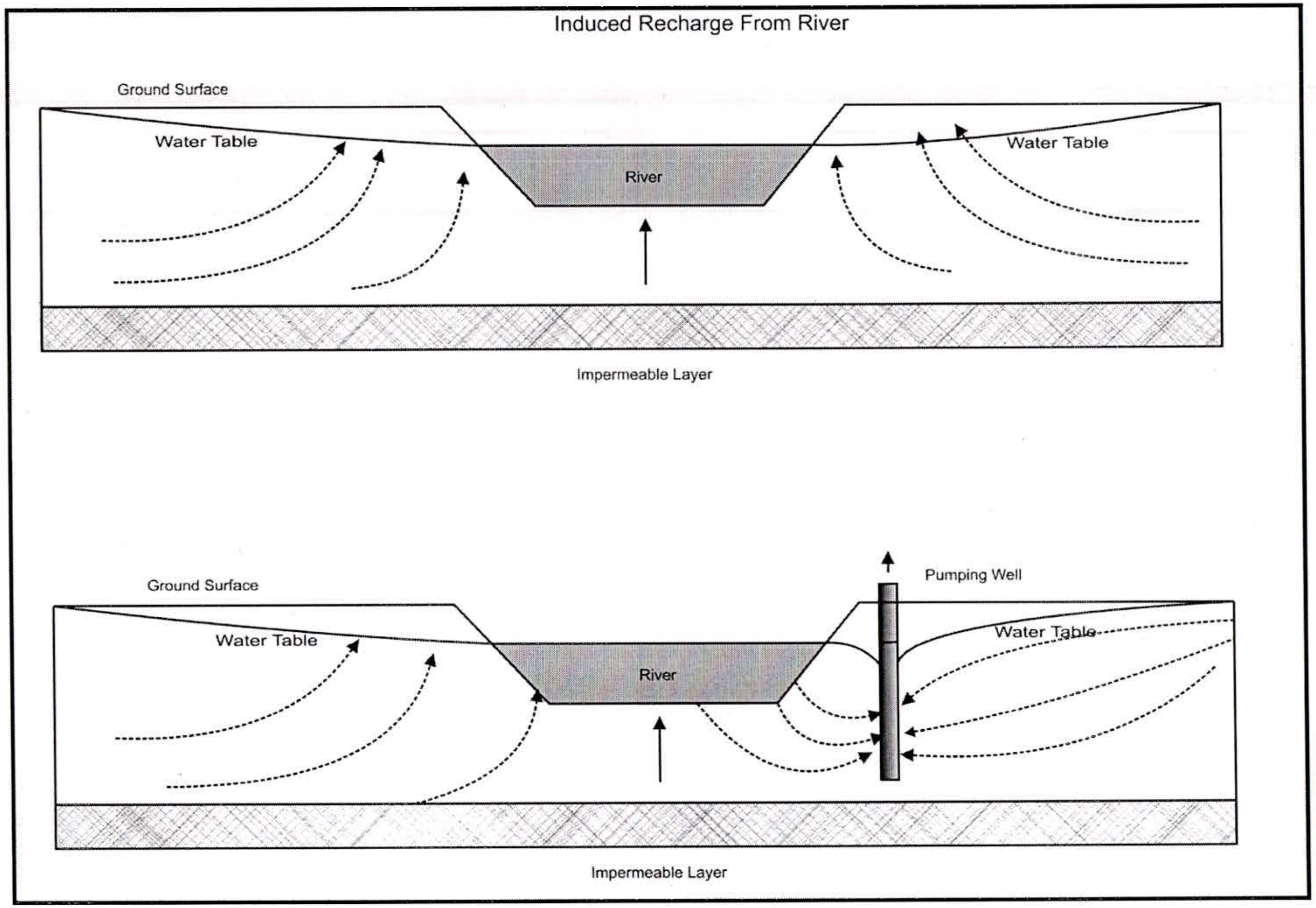


Figure 3: Induced river recharge

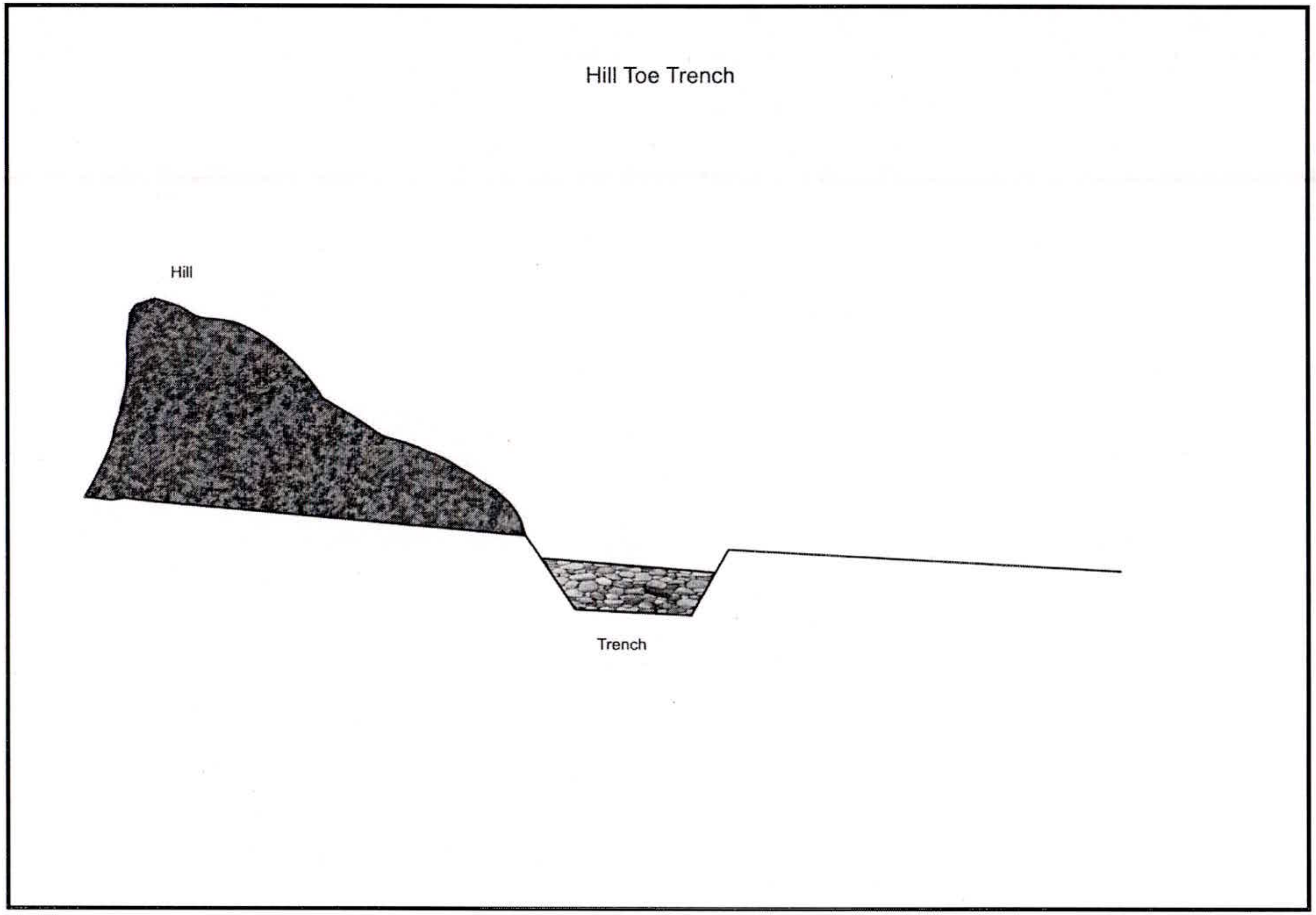


Figure 4: Hill toe trench

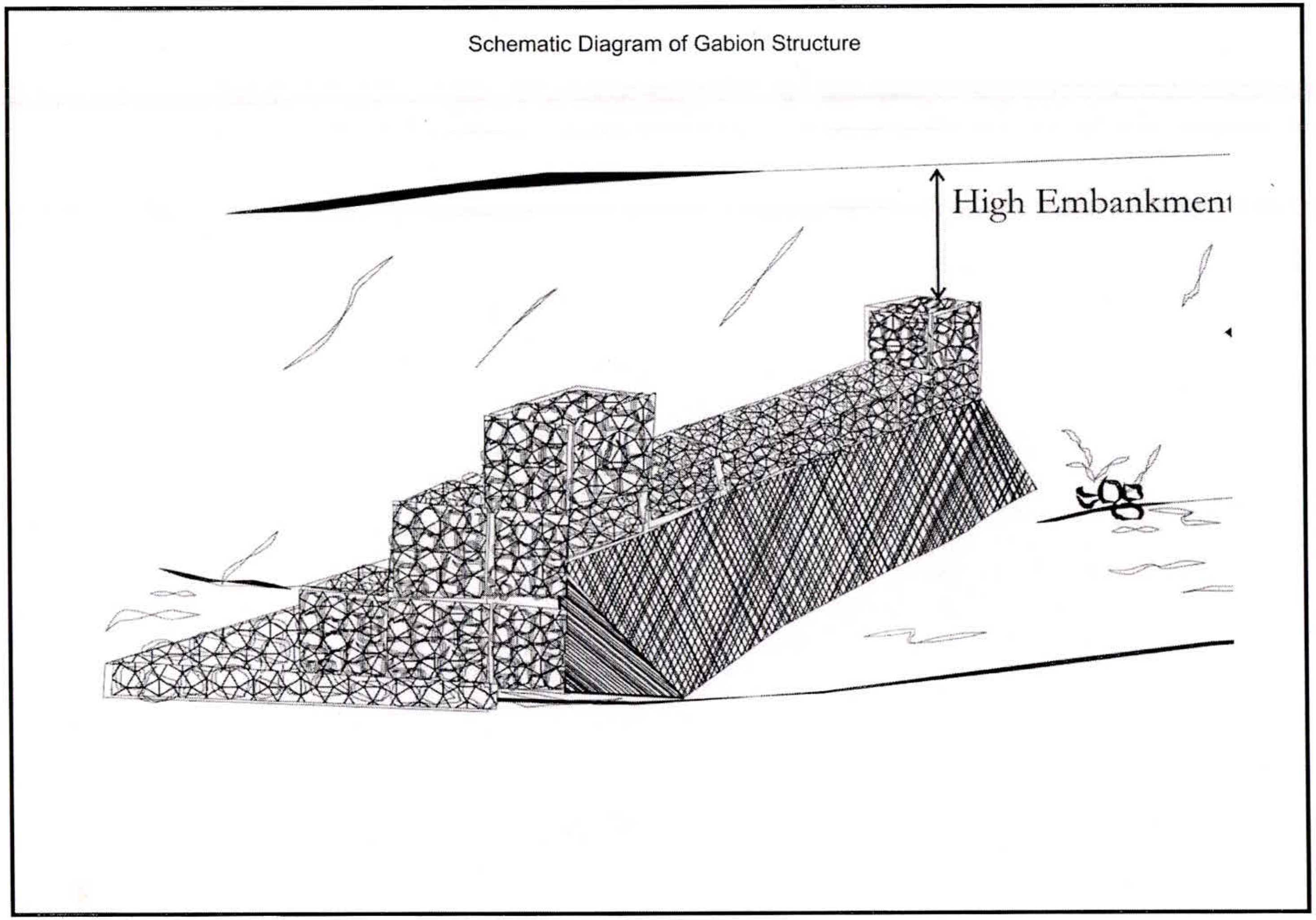


Figure 5: Gabion structure

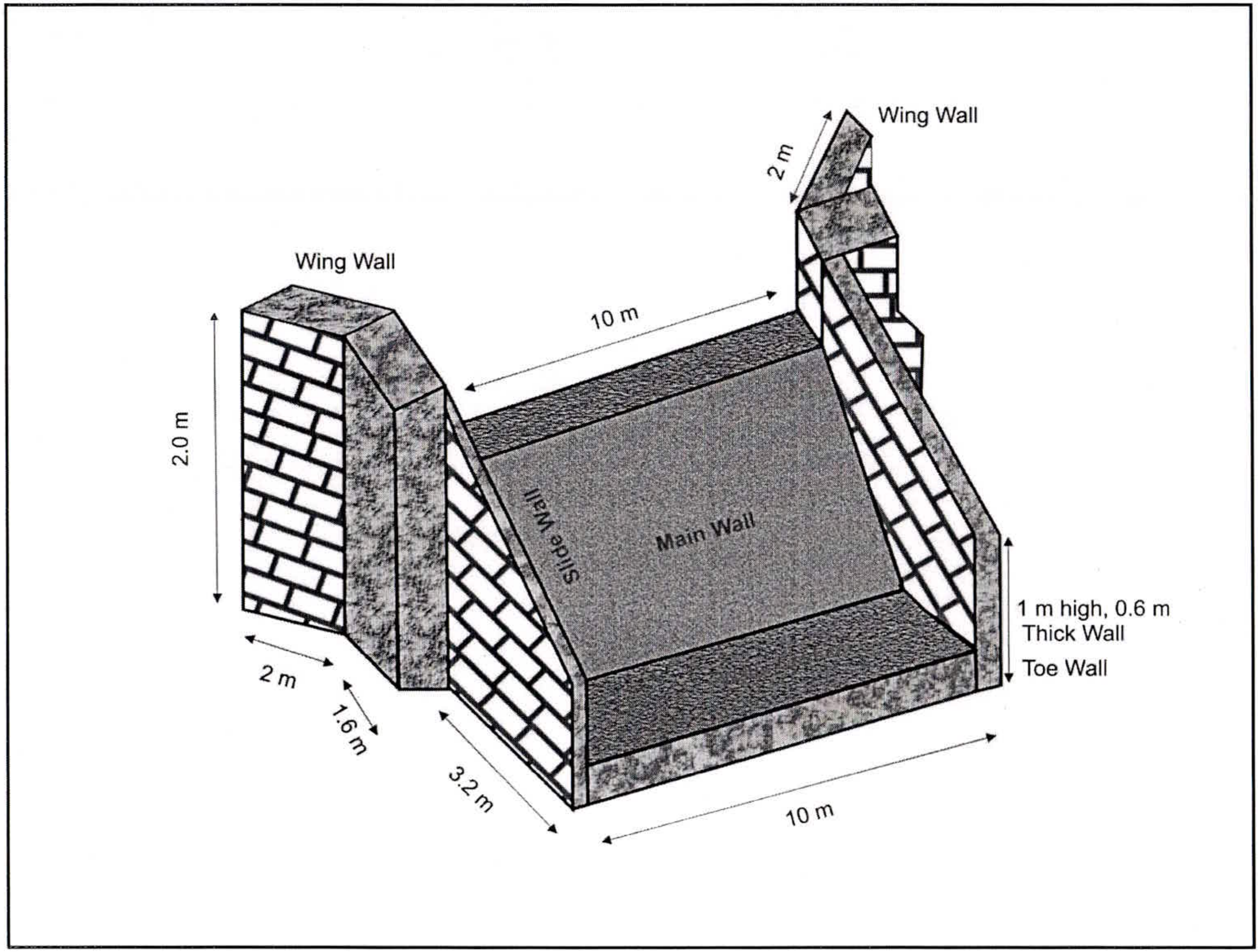


Figure 6: Horizontal section of check dam

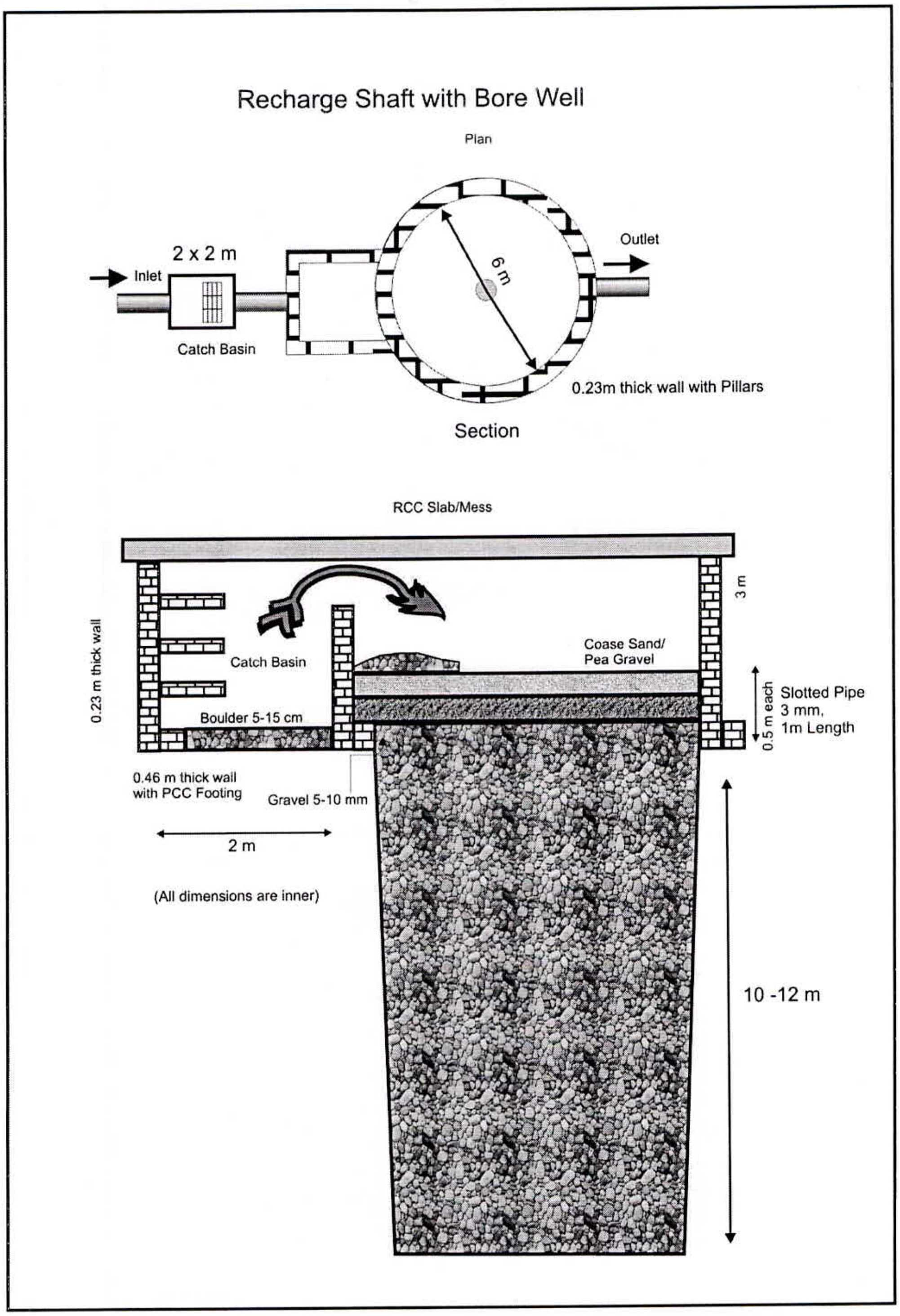


Figure 7: Recharge shaft

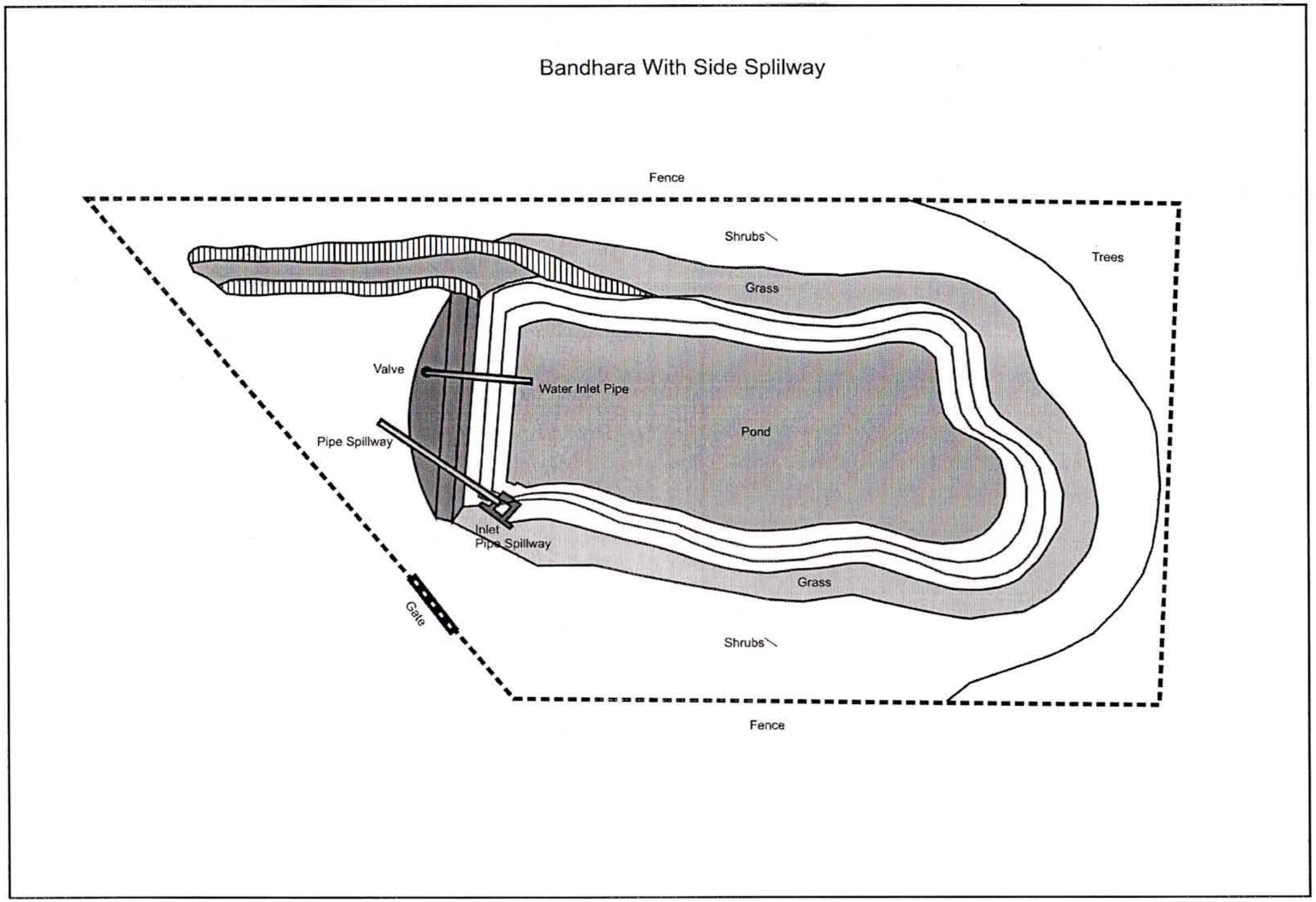


Figure 8: Percolation tank

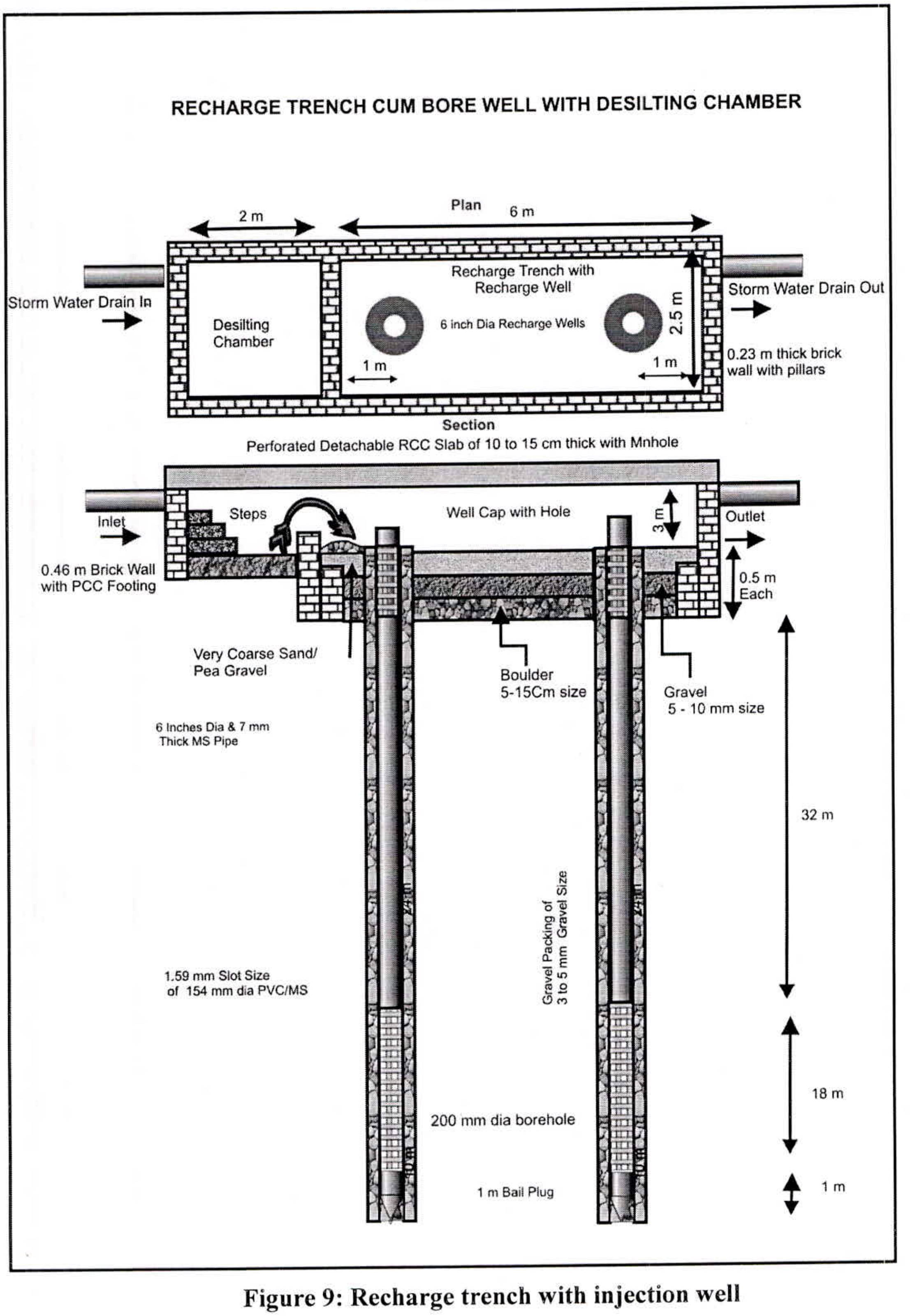


Figure 9: Recharge trench with injection well

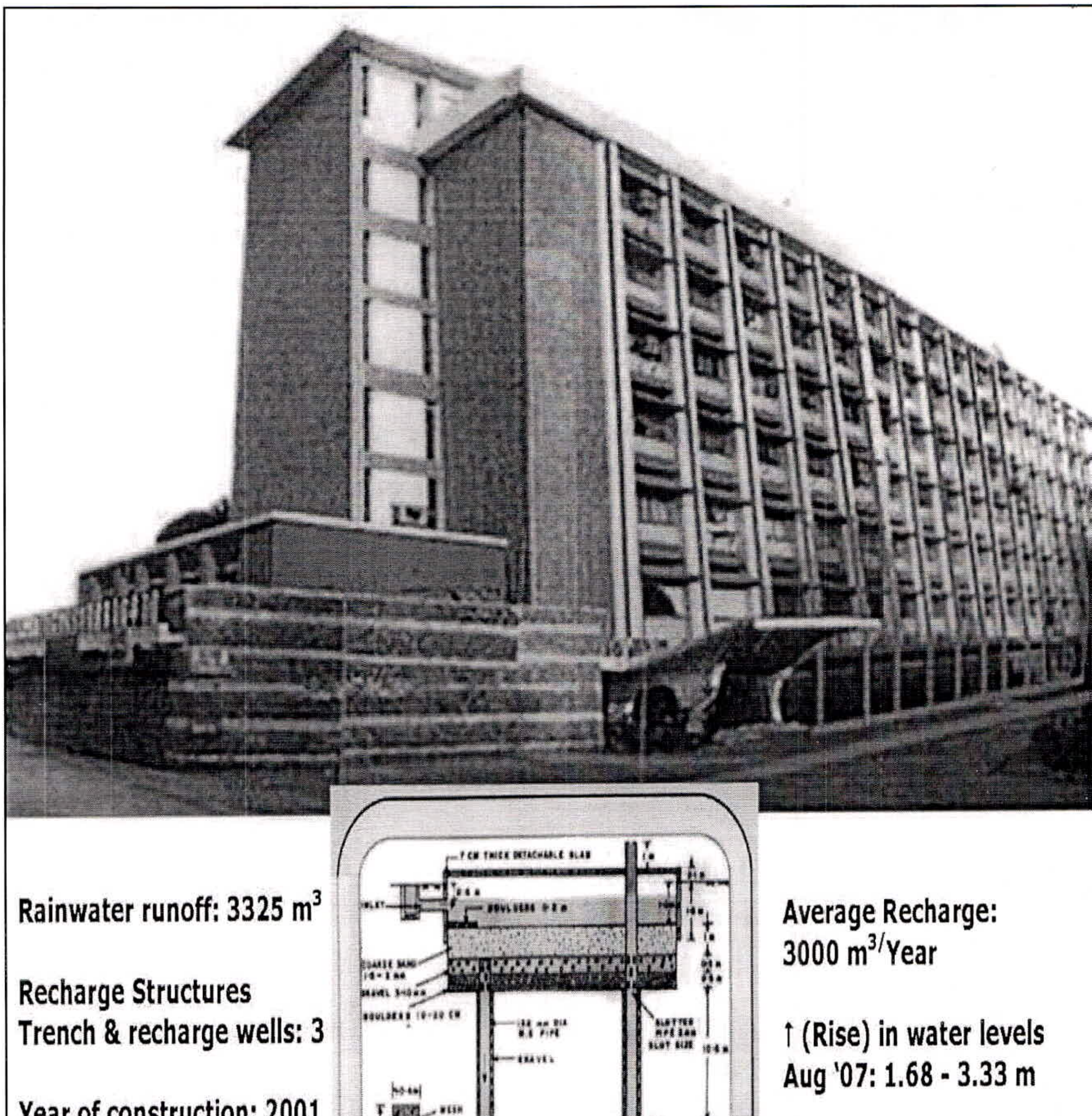
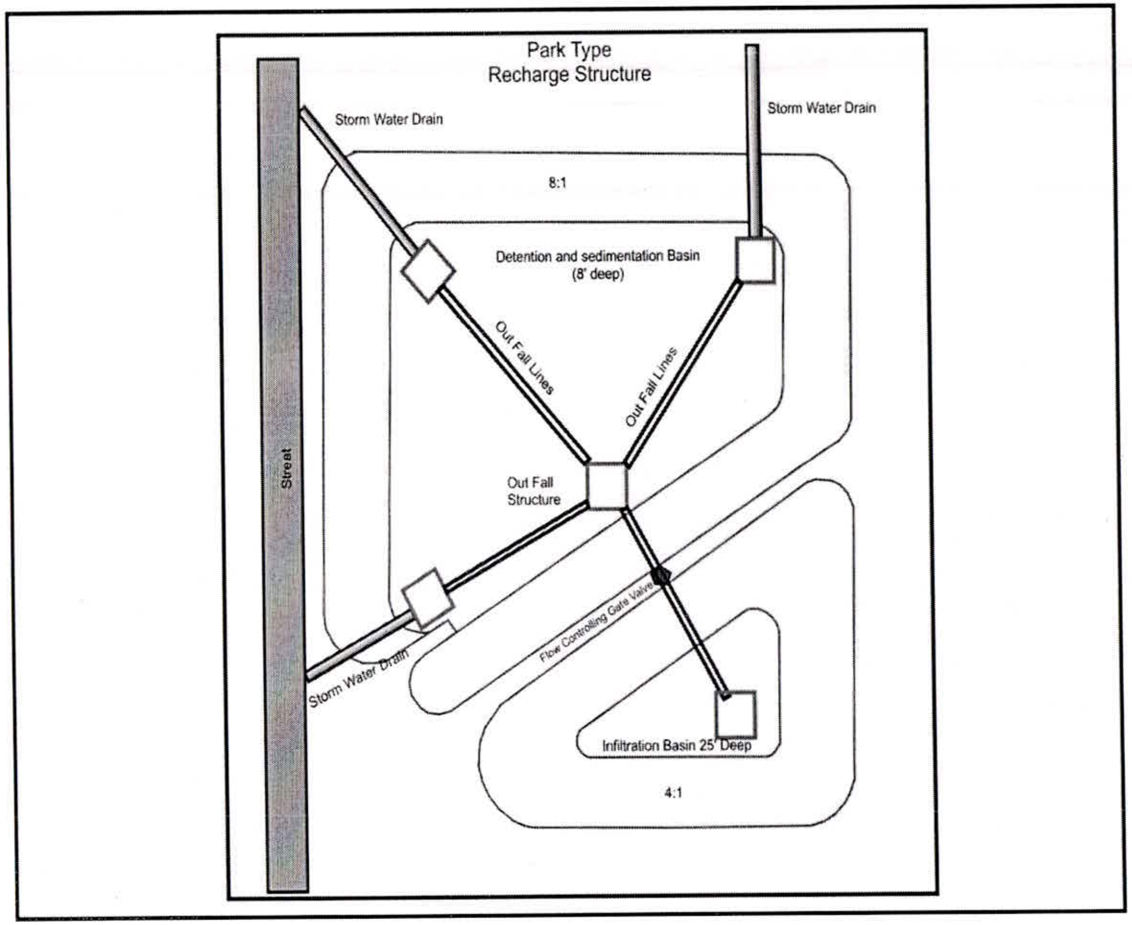


Figure 10: Roof top rain water harvesting & artificial recharge to ground water



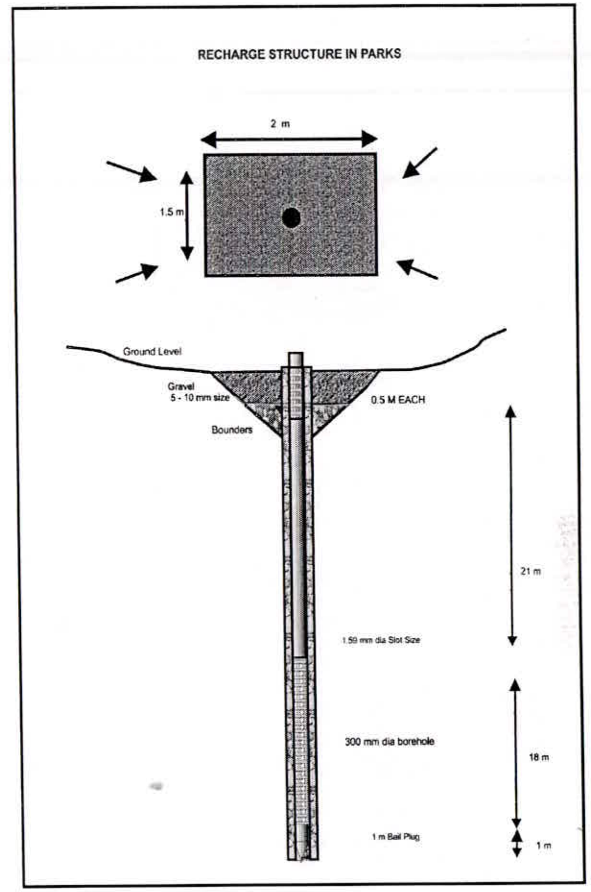


Figure 11: Park type recharge structure with recharge well/shaft

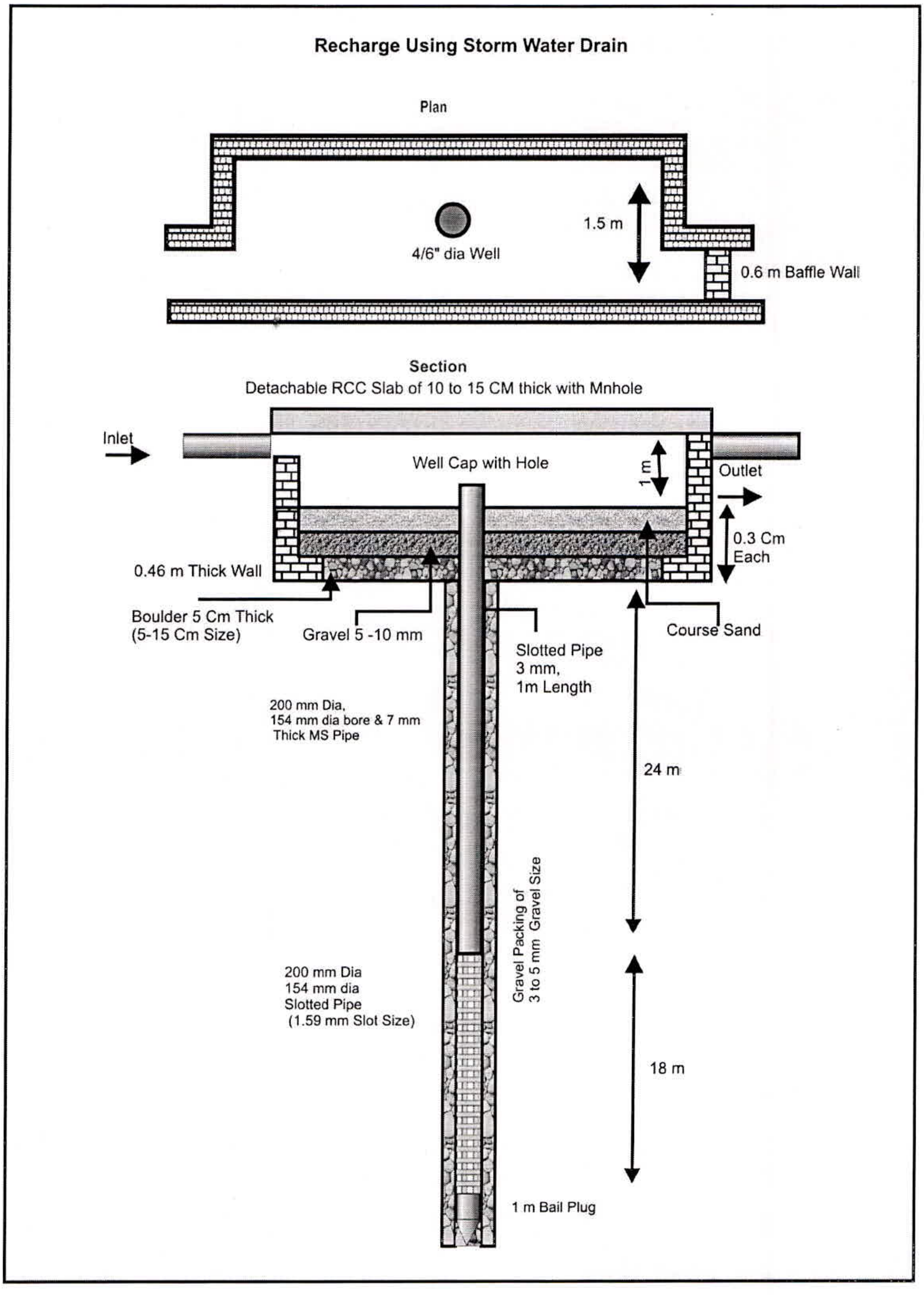
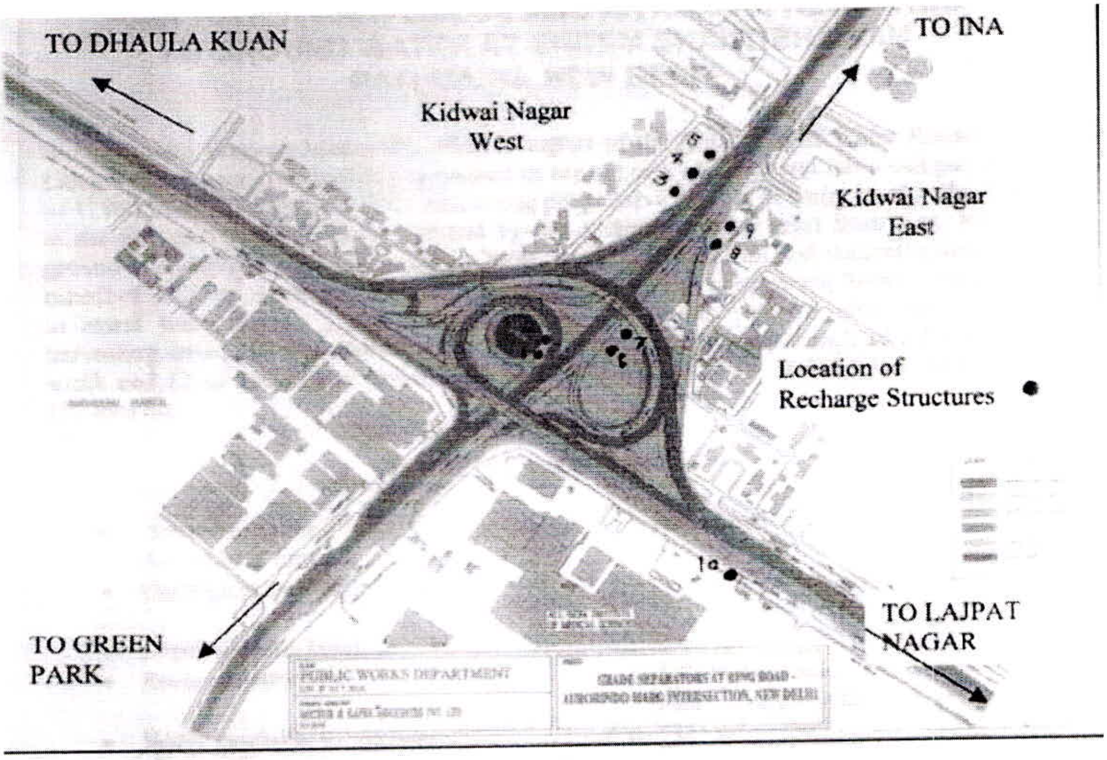
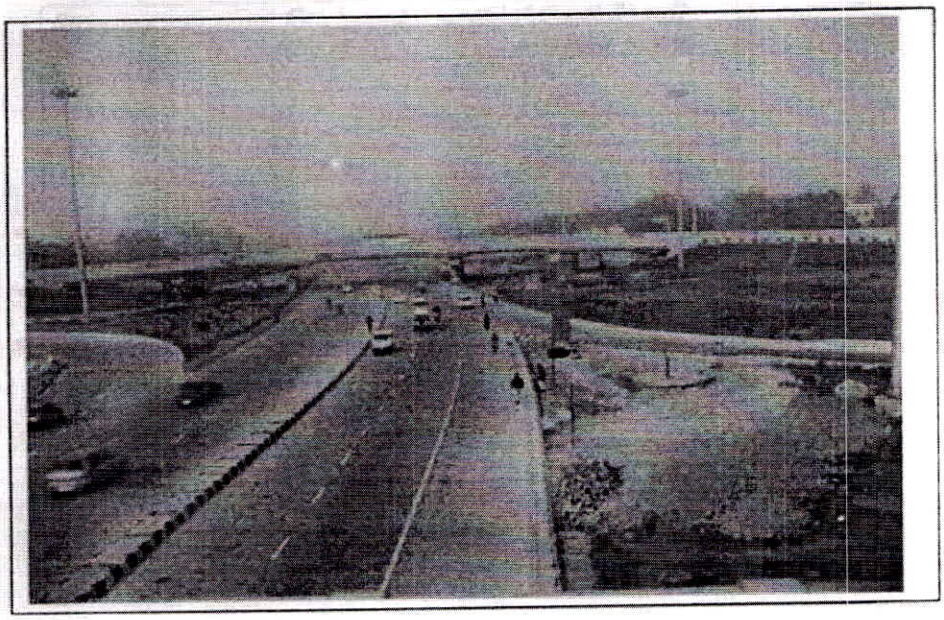


Figure 12: Strom water drain recharge structure





Artificial Recharge Structure at AIIMS Fly-over

Figure 13: Rain water harvesting & artificial recharge at AIIMS Flyover New Delhi

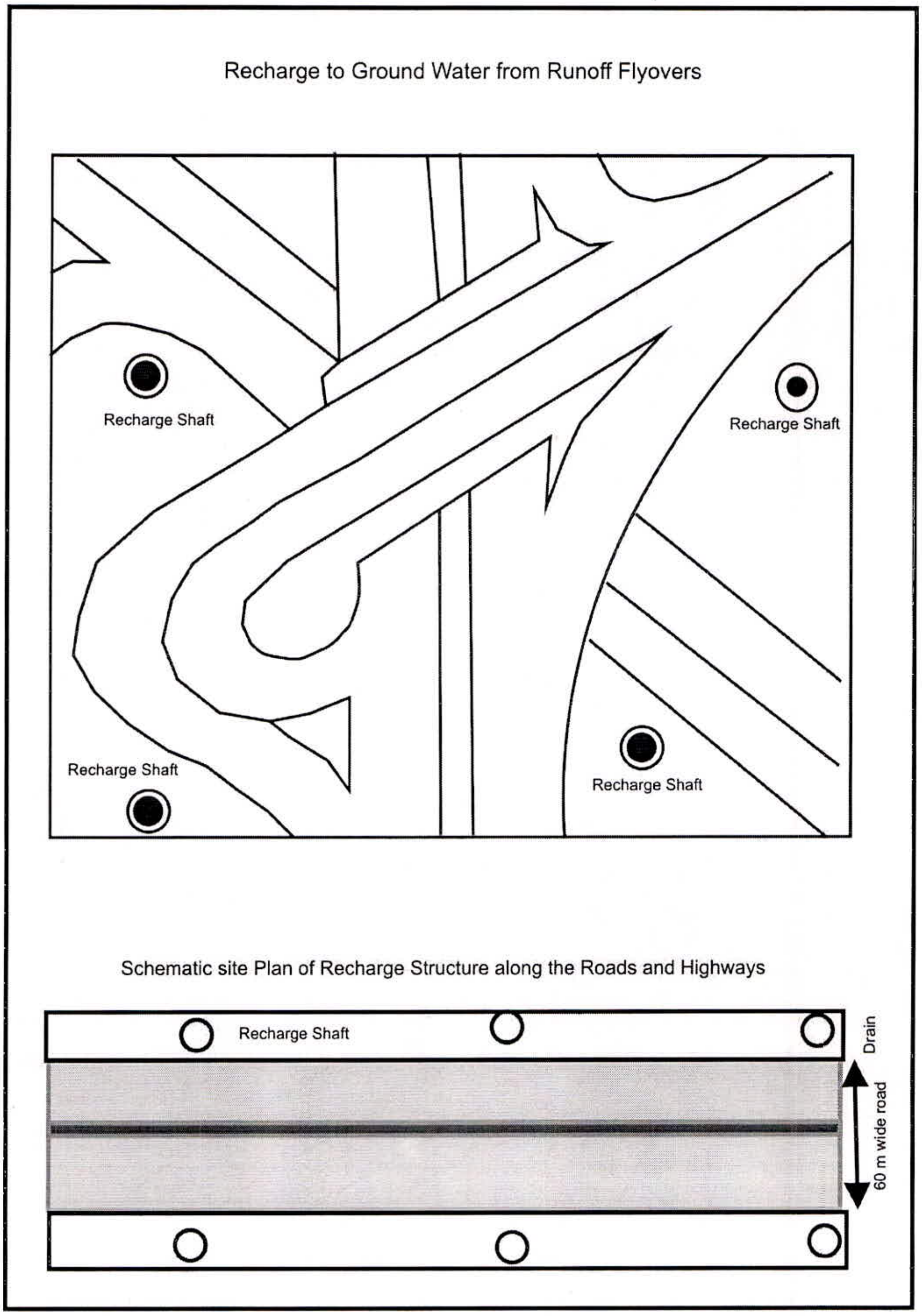


Figure 14: Rain water harvesting & artificial recharge at Flyovers

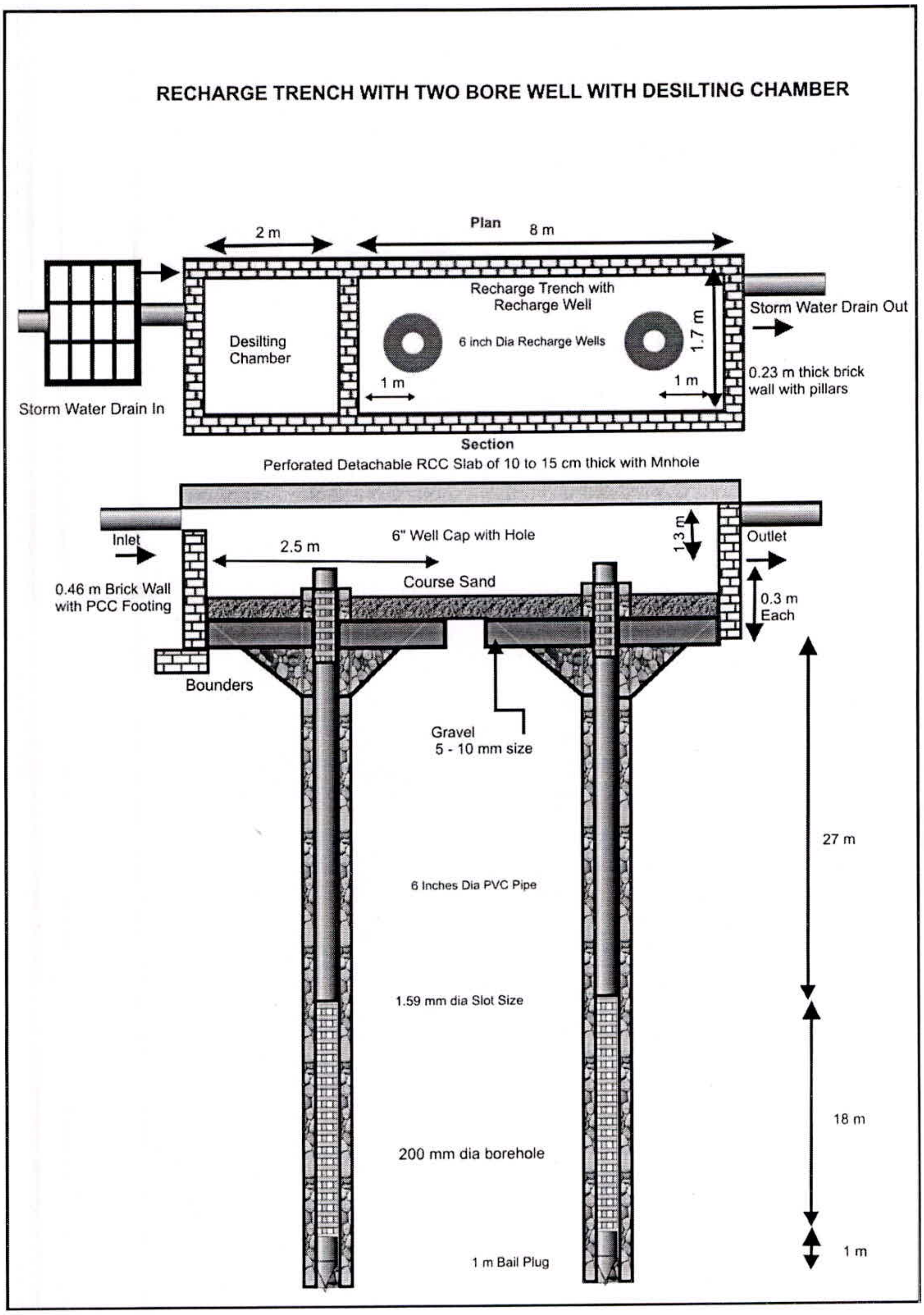


Figure 15: Recharge structure for Flyovers, & other urban mega structures

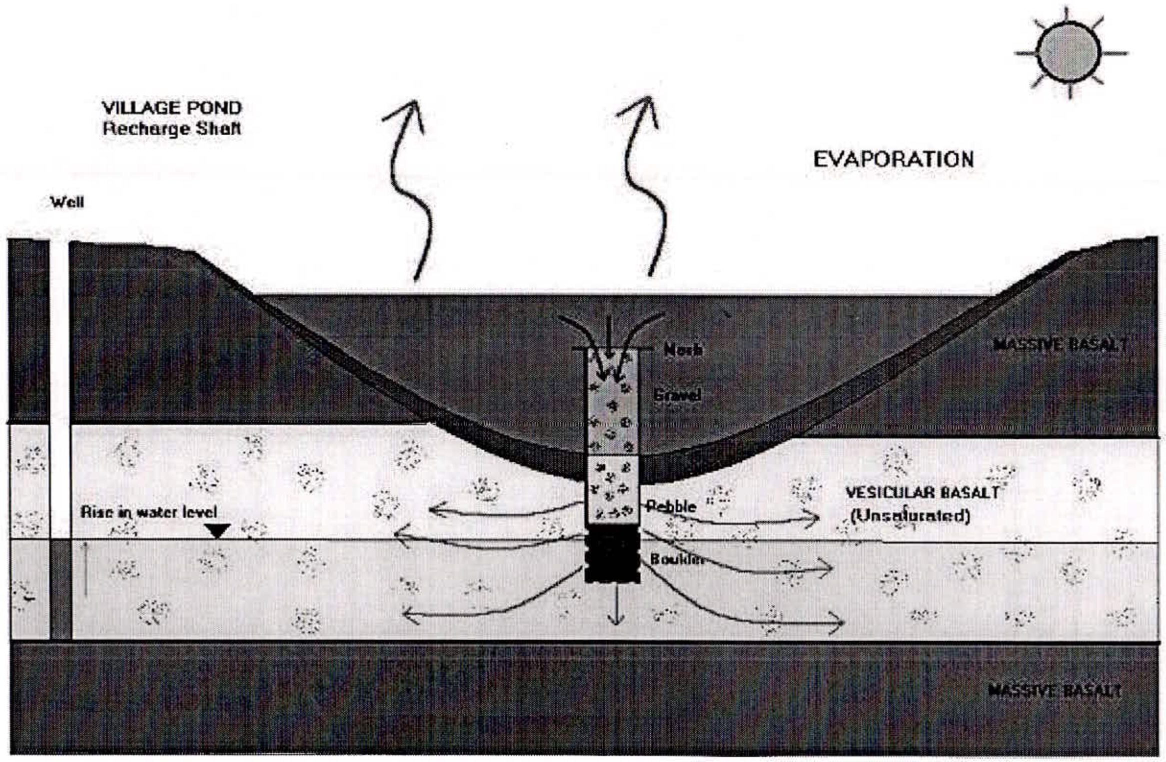


Figure 16: Pond / water body recharge through recharge shaft

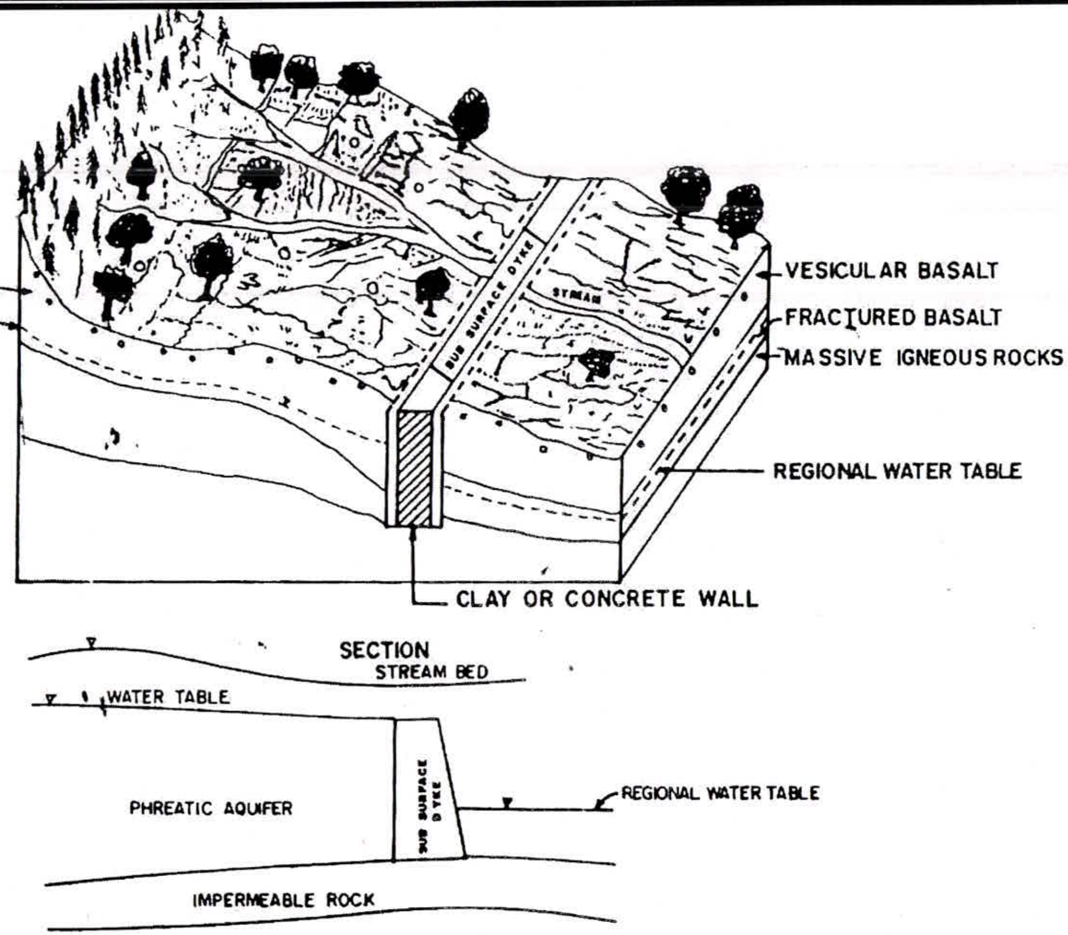


Figure 17: Sub-surface dyke