Indian Standard

ARTIFICIAL RECHARGE TO GROUND WATER — GUIDELINES

1 SCOPE

These guidelines provide details of methods aimed at augmentation of ground water resources by modifying the natural movement of surface water.

2 BASIC REQUIREMENTS FOR ARTIFICIAL RECHARGE PROJECTS

The basic requirements for recharging the ground water reservoir are:

a) Availability of non-committed surplus monsoon runoff of suitable quality in space and time.
b) Identification of suitable hydrogeological environment and sites for augmenting groundwater through cost effective artificial recharge techniques.

2.1 Source Water Availability

Availability of source water of suitable quality, one of the prime requisites for ground water recharge is basically assessed in terms of non-committed surplus monsoon runoff, which, as per the water resource development scenario, is unutilized. This can be assessed by analyzing the monsoon rainfall pattern, its frequency, number of rainy days, maximum rainfall in a day and its variation in space and time. The variations in rainfall pattern in space and time, and its relevance in relation to the scope for artificial recharge to sub-surface reservoirs should be considered for assessing the surplus surface water availability. The physical, chemical, and biological quality of the recharge water also affects the planning and selection of recharge method.

2.2 Hydrogeological Aspects

Detailed knowledge of geological and hydrological features of the area is necessary for proper selection of site and type of recharge structure. In particular, the features, parameters and data to be considered are: geological boundaries; hydraulic boundaries; inflow and outflow of waters; storage capacity; porosity; hydraulic conductivity; transmissivity; natural discharge of springs; water resources available for recharge; natural recharge; water balance; lithology; depth of the aquifer; and tectonic boundaries, features, such as lineaments, shear zones etc. The aquifers best suited for artificial recharge are those that can hold large quantities of water and do not release them too quickly. The evaluation of the storage potential of sub-surface reservoirs is invariably based on the knowledge of dimensional data of reservoir rock, which includes their thickness and lateral extent. The availability of sub-surface storage space and its replenishment capacity further govern the extent of recharge. The hydrogeological situation in each area needs to be appraised with a view to assess the recharge capabilities of the underlying geological formations. The thickness of unsaturated rock formations, occurring beyond three meters below ground level should be considered to assess the requirement of water to build up the subsurface storage by saturating the entire thickness of the vadose zone up to 3 m below ground level.

The upper 3 m of the unsaturated zone is not considered for recharging, since it may cause adverse environmental impacts like water logging, soil salinity, dampness etc. The post-monsoon depth to water level represents a situation of minimum thickness of vadose zone available for recharge which can be considered *vis-a-vis* surplus monsoon runoff in the area.

Artificial recharge techniques envisage integrating the surface water resources to ground water reservoirs. Artificial recharge causes: (a) Rise in water level, and (b) increment in the total volume of the ground water reservoir.

3 PLANNING OF ARTIFICIAL RECHARGE PROJECTS

3.1 Identification of Area

Artificial recharge projects are site-specific and even the replication of the techniques in similar areas are to be based on the local hydrogeological and hydrological environments. The first step in planning the project is to demarcate the area for implementation of recharge schemes. The project can be implemented systematically by adopting a hydrologic unit like watershed or micro-watershed for implementation. However, localized schemes may also be taken up to augment ground water resources. Artificial recharge of ground water is normally undertaken in the following areas:

a) Areas where ground water levels are continuously declining,
b) Areas where substantial volume of aquifer has already been desaturated,
c) Areas where availability of ground water is inadequate in lean months, and
d) Areas where studies indicate scope for improvement of quality of ground water or areas where salinity ingress into fresh water aquifers has already taken place or is likely to happen in the near future.

3.2 Technical Inputs

For proper planning of artificial recharge schemes the studies given in **3.2.1** to **3.2.6** are needed.

3.2.1 *Remote Sensing Studies*

Remote sensing data provides quick and useful baseline information on various parameters controlling the occurrence and movement of ground water such as geology, structural features, geomorphology, soils, land use, land cover, lineaments etc. A systematic study of these factors leads to better delineation of areas suitable for artificial recharge, which is then followed up in the field through detailed hydrogeological and geophysical investigations. Observations from satellite data must be complemented by field checks, existing geologic maps and topographic sheets.

3.2.2 *Hydrometeorological Studies*

These are undertaken to decipher the rainfall pattern, evaporation losses and climatological features. The data on rainfall intensity, number of rain-days, etc. helps in deciding the capacity and design of the artificial recharge structures. These studies can also bring out the extent of evaporation losses in post-monsoon period which would be helpful in designing the storage of particular capacity with a view to have minimum evaporation losses. In semi-arid regions, evaporation losses are significant after January and hence the stored water should percolate to ground water reservoir by this period.

3.2.3 *Hydrological Studies*

Hydrological studies are undertaken to work out non-committed surplus monsoon runoff which can be harnessed as source water for artificial recharge. Hydrological investigations should be carried out in the Watershed/Sub-basin/basin where the artificial recharge schemes are envisaged.

Four types of source water may be available for artificial recharge, namely:

a) *In-situ* precipitation on the watershed,
b) Surface (canal) supplies from large reservoirs located within basin,
c) Surface supplies through inter-basin water transfer, and
d) Treated municipal and industrial waste water.

'*In-situ*' precipitation, available almost at every location, may or may not be adequate to cause artificial recharge. However, the non-committed unutilized runoff can be stored/transmitted through recharge structures at appropriate locations. In case other sources are available in any of the situations, the following information will be required:

a) Quantity of water that may be diverted for artificial recharge,
b) Time for which the source water will be available, and
c) Conveyance system required for bringing the water to the recharge site.

3.2.4 *Soil Infiltration Studies*

In case of artificial recharge through water spreading methods, soil and land use conditions, which control the rate of infiltration and downward percolation of the water, assume special importance. Infiltration can be defined as the process of water entering into a soil through the soil surface. Although a distinction is made between infiltration and percolation (the movement of water within the soil), the two phenomena are closely related since infiltration cannot continue unimpeded unless percolation removes infiltrated water from the surface soil.

3.2.4.1 *Infiltration capacity*

The maximum rate at which water can enter soil at a particular point under a given set of conditions is called the infiltration capacity. The actual rate of infiltration equals the infiltration capacity only when the supply rate (rainfall intensity less rate of retention) is greater than or equal to the infiltration rate.

3.2.4.2 *Factors affecting infiltration capacity*

Infiltration capacity depends on many factors, such as type of soil, moisture content, organic matter, vegetative cover, season, air entrapment, formation of surface seals or crusts etc. Of the soil characteristics affecting infiltration, non-capillary porosity is perhaps the most important. Porosity determines storage capacity and also affects the resistance to flow. Infiltration tends to increase with porosity. Vegetal cover increases infiltration, as compared to barren soil, because of the following:

a) It retards surface flow giving the water additional time to enter the soil,
b) The root system makes the soils more pervious, and

c) The foliage shields the soil from raindrop impact and reduces rain packing of surface soil.

As water infiltrates the soil under natural conditions, the displacement of air is not complete even after many hours. Air spaces in the soil and intermediate zones interfere with infiltration as the air is not pushed out by the infiltrating water but is gradually absorbed by water. Due to this phenomenon, infiltration rate may start rising towards a new high after a few days of continuous application of water. Surface conditions have a marked effect on the infiltration process and the formation of surface seals or crusts which form under the influence of external forces such as raindrop impact and compaction, reduces the rate of infiltration.

3.2.4.3 *Infiltration process*

Infiltration of water through surface takes place generally over small periods of time. The process of redistribution of the soil water however, goes on for most of the time. Infiltration is critically inter-linked with the phenomena of water evolution in the vadose zone, which includes wetting front propagation.

3.2.4.4 *Infiltration rate*

Infiltration rate of soils is determined by infiltration tests. Cylinder or flood Infiltrometers are common instruments, which measure infiltration as the rate of water leaving the device. Maps showing infiltration rates of soils are either available or can be prepared based on the results of infiltration tests. These help in designing suitable artificial recharge structures and assessing the extent of recharge from these structures.

3.2.5 *Hydrogeological Studies*

A correct understanding of hydrogeology of an area is of prime importance in successful implementation of any artificial recharge scheme. A desirable first step is to synthesize all the available data on hydrogeology from different agencies. Regional geological maps indicate the location of different geological strata, their geological age sequence, boundaries/contacts of individual formations and the structural expressions like strike, dip, faults, folds, fractures, intrusive bodies etc. These maps also indicate the correlation of topography and drainage to geological contacts.

Maps providing information on regional hydrogeological rock units, their ground water potential and general pattern of ground water flow and chemical quality of water in different aquifers are necessary. Satellite Imagery provides useful data on geomorphic units and lineaments, which govern the occurrence and movement of ground water. A detailed hydrogeological study, besides the regional picture of hydrogeological set up available from previous studies is imperative to know precisely the promising hydrogeological units for recharge and correctly decide on the location and type of structures to be constructed in the field.

3.2.5.1 *Detailed hydrogeological mapping*

The purpose of hydrogeological mapping is to prepare the following maps, which facilitate the analysis of the ground water regime and its suitability to artificial recharge schemes:

a) Map showing hydrogeological units demarcated on the basis of their water bearing capabilities, both at shallow and deep levels;
b) Map showing ground water contours to determine the form of the water table and the hydraulic connection of ground water with rivers, canals etc;
c) Map showing the ground water table, usually compiled for the periods of the maximum, minimum and mean annual position of water levels;
d) Maps showing amplitudes of ground water level fluctuations and the maximum position of the water table;
e) Maps showing piezometric heads of aquifers and their variations with time;
f) Maps showing ground water potential of different hydrogeological units and the level of ground water development; and
g) Maps showing chemical quality of ground water in different aquifers.

The usage of the above interpretative maps is additive, that is their conjunctive usage provide greater knowledge and understanding of an area than when a map is used in isolation.

The maps mentioned above should be utilized for determining: (a) whether there are any gaps in the data on sub-surface geology or if the available lithological logs of the boreholes in the area are sufficient to arrive at a correct picture of aquifer geometry of the area, (b) whether the available data on aquifer parameters is sufficient in case the area shows promise for artificial recharge techniques for deeper aquifers through suitable recharge techniques, and (c) whether the available ground water structures can serve the purpose of monitoring the effects of an artificial recharge project.

3.2.5.2 *Aquifer geometry*

The data on the sub-surface hydrogeological units and their thickness and depth of occurrence are required to bring out the disposition and hydraulic properties of unconfined, semi-confined and confined aquifers in the area. For surface water spreading techniques, the area of interest is generally restricted to shallow depths. The main stress is on knowing whether the surface rock types are sufficiently permeable or not to maintain high rate of infiltration during artificial recharge.

3.2.6 *Geophysical Studies*

The main purpose of applying geophysical methods for the selection of appropriate sites for artificial recharge studies is to assess the unknown sub-surface hydrogeological conditions economically, adequately and unambiguously. They are usually employed to narrow down the target zone, pinpoint the probable site for artificial recharge structure and its proper design. The applications of geophysical techniques is also useful for bringing out a comparative picture of the sub-surface litho-environment and correlate them with the hydrogeological setting. Besides defining the sub-surface structure and lithology, geophysical studies can also help in studies for identifying the brackish/ fresh ground water interface, contaminated zones (saline) and area prone to seawater intrusion.

3.2.6.1 *Resistivity and seismic methods*

Resistivity and seismic geophysical methods, which are commonly used, can determine the following parameters:

a) Stratification of aquifer system and spatial variability of hydraulic conductivity of the characteristic zone suitable for artificial recharge,
b) Negative or non-productive zones of low hydraulic conductivity in unsaturated and saturated zones,
c) Vertical hydraulic conductivity discontinuities such as dykes and fault zones,
d) Moisture movement and infiltration capacity of the unsaturated zone,
e) Direction of ground water flow under natural/ artificial recharge processes, and
f) Salinity ingress, trend and short duration/ seasonal depth-salinity changes in the aquifers due to varied abstraction or recharge.

3.2.7 *Hydrochemical Studies*

The physical, chemical, and biological quality of the recharge water also affects the planning and selection of recharge method. The physical quality of recharge water refers to the type and amount of suspended solids, the temperature, and the amount of entrapped air. The chemical quality refers to type and concentration of dissolved solids and gases. The biological quality refers to type and concentration of living organisms. Under certain conditions, any or all of these characteristics can diminish recharges rates.

A detailed study of the quality of source water is vitally important wherever direct recharge techniques are contemplated. In cases where *in situ* precipitation or water supplied from canals are used for recharge, no constraints on account of water quality may arise. However, in cases where waters in the lower reaches of rivers or recycled municipal/industrial waste waters are proposed to be used, the quality of water requires to be precisely analyzed and monitored to determine the type and extent of treatment required.

Problems of quality of water arising as a result of recharge to ground water are mainly related to the quality of raw water that is available for recharge and which generally require some sort of treatment before being used in recharge installations. They are also related to the changes in the soil structure and biological phenomena which take place when infiltration begins. It is also necessary to study the chemical compatibility of source water to ground water. The chemical and bacteriological analysis of source water besides that of ground water is therefore essential.

3.2.8 *Clogging of the Soil by Suspended Matter*

A major requirement for water that is to be used in recharge projects is that it should be silt-free. Silt may be defined as the content of undissolved solid matter, usually measured in mg/l, which settles in stagnant water with velocities not exceeding 0.1 m/h. To obtain still clearer water with only 10 mg/l to 20 mg/l suspended solids, further addition of flocculants and frequent agitation of the water should be resorted to.

Near the surface, the interstices of the soil may be filled up and a layer of mud may be deposited on the surface. On the other hand, suspended particles may penetrate deeper into the soil and accumulate there.

The following methods may be used to minimize the clogging effect by suspended matter:

a) Periodical removal of the mud-cake and scraping of the surface layer,
b) Installation of a filter on the surface, the permeability of which is lower than that of the natural strata (the filter should be removed and renewed periodically),
c) Addition of organic matter or chemicals to the uppermost layer,
d) Cultivation of certain plant-covers, notably certain kinds of grass, and
e) Providing inverted filter consisting of fine sand, coarse sand and gravel at the bottom of the infiltration pits/trenches.

Clogging by biological activity depends on the mineralogical and organic composition of the water, and the type, grain size and permeability of the basin floor. The only feasible method of treatment developed so far is to dry the ground in the basin thoroughly.

3.3 Assessment of Sub-surface Potential for Ground Water Recharge

Based on the hydrogeological and geophysical studies, the thickness of the potential unsaturated zone for recharge should be worked out to assess the potential for artificial recharge in terms of volume of water which can be accommodated in this zone *vis-a-vis* source water availability. The studies should bring out the potential of unsaturated zone in terms of total volume, which can be recharged.

4 ARTIFICIAL RECHARGE TECHNIQUES

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

4.1 Direct Methods

4.1.1 *Surface Spreading Techniques*

a) Runoff Conservation Structure:
   1) Bench terracing
   2) Contour Bunds
   3) Gully Plugs, Nala Bunds, Check Dams
   4) Percolation Ponds
b) Flooding;
c) Ditch and Furrows;
d) Recharge Basins; and
e) Stream Modification/Augmentation.

4.1.2 *Sub-surface Techniques*

a) Injection wells (Recharge wells),
b) Gravity head recharge wells (Dug well/Bore well/Tube well recharge), and
c) Recharge pits and shafts.

4.1.3 *Combination Techniques*

These include combination of surface and sub-surface techniques.

4.2 Indirect Methods

a) Induced recharge from surface water sources, and
b) Aquifer modification:
   1) Bore Blasting, and
   2) Hydro-fracturing.

4.3 Ground Water Conservation Techniques

In addition to the techniques mentioned under **4.1** and **4.2**, ground water conservation structures like sub-surface dykes (*Bandharas*) and fracture sealing cementation techniques are also used to arrest sub-surface flows.

5 ARTIFICIAL RECHARGE TECHNIQUES AND DESIGNS

5.1 Surface Spreading Techniques

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

a) The area should have gently sloping land without gullies or ridges,
b) The aquifer being recharged should be unconfined, permeable and sufficiently thick to provide storage space,
c) The surface soil should be permeable and have high infiltration rate,
d) Vadose zone should be permeable and free from clay lenses,
e) Ground water levels in the phreatic zone should be deep enough to accommodate the recharged water so that there is no water logging, and
f) The aquifer material should have moderate hydraulic conductivity so that the recharged water is retained for sufficiently long periods in the aquifer and can be used when needed.

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

5.1.1 *Runoff Conservation Structures*

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

5.1.1.1 *Bench terracing*

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

For implementing terracing, a map of the watershed should be prepared by level surveying and suitable benchmarks fixed. A contour map of 0.3 m contour interval is then prepared. Depending on the land slope, the width of individual terrace should be prepared, which, in no case, should be less than 12 m. The upland slope between two terraces should not be more than 1 : 10 and the terraces should be levelled. The vertical elevation difference and width of terraces are controlled by the land slope.

5.1.1.2 *Contour bunds*

Contour bunding, which is a watershed management practice aimed at building up soil moisture storage involve construction of small embankments or bunds across the slope of the land. They derive their names owing to the construction of bunds along contours of equal land elevation. This technique is generally adopted in low rainfall areas (normally less than 800 mm) where gently sloping agricultural lands with very long slope lengths are available and the soils are permeable. They are not recommended for soils with poor internal drainage, for example, clayey soils. Schematics of a typical system of contour bunds is shown in Fig. 1.

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

5.1.1.3 *Contour trenches*

Contour trenches are rainwater harvesting structures, which can be excavated on hill slopes as well as on degraded and barren waste lands in both high- and low-rainfall areas. Cross section of a typical contour trench is shown in Fig. 2. The trenches break the slope at

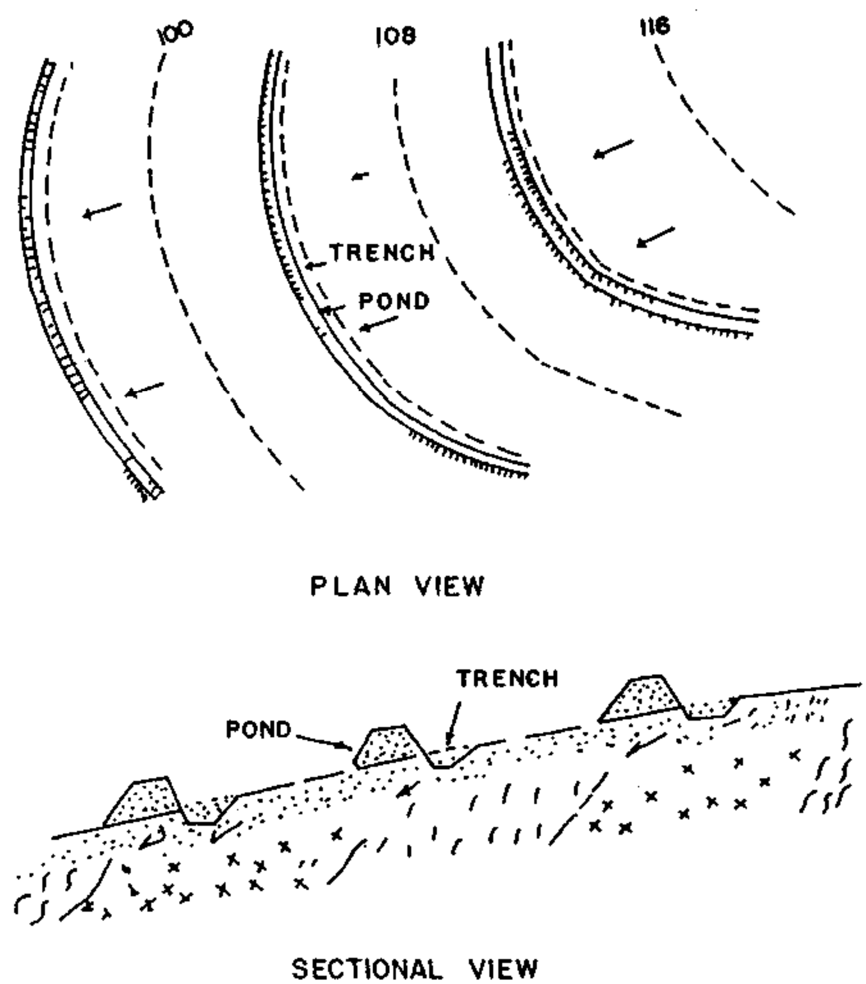

Fig.1 Schematics of Contour Bunds

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

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

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

5.1.1.4 *Gully plugs, nala bunds and check dams*

These structures are constructed across gullies, nalas or streams for impeding the flow of surface water in the stream channel and water is retained for a longer duration in the pervious soil or rock surface. As compared to gully plugs, which are normally constructed across first order streams, nala bunds and check dams are constructed across bigger streams, in areas having gentler slopes. These may be temporary structures such as brush wood dams, loose/dry stone masonry check dams constructed with locally available material or permanent structures constructed using stones, brick and cement. Competent civil and agro-engineering techniques are to be used in the design, layout and construction of permanent check dams to ensure proper storage and adequate outflow of surplus water to avoid scours on the downstream side for long term stability of the dam. Gabion structure is also a kind of check dam constructed across small streams to conserve stream flows using locally available stones and a steel wire mesh, with practically no submergence beyond the stream course.

The site selected for check dam should have sufficient thickness of permeable soils or weathered material to facilitate recharge of stored water within a short span of time. The water stored in these structures is mostly confined to the stream course and the height is normally less than 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 runoff, water cushions are provided on the downstream side. To harness the maximum runoff in the stream a series of such check dams can be constructed to have recharge on a regional scale.

A series of small bunds or weirs may be constructed 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 a longer duration. A nala bund acts like a mini percolation pond. The design aspects of a typical check dam/ cement plug are given in Fig. 3.

The site characteristics and design guidelines to be followed are as given below.

The following parameters should be kept in mind while selecting sites for check dams/nala bunds:

a) The total catchment area of the stream should normally be between 40 to 100 ha. Local situations can, however, be a guiding factor in this regard.

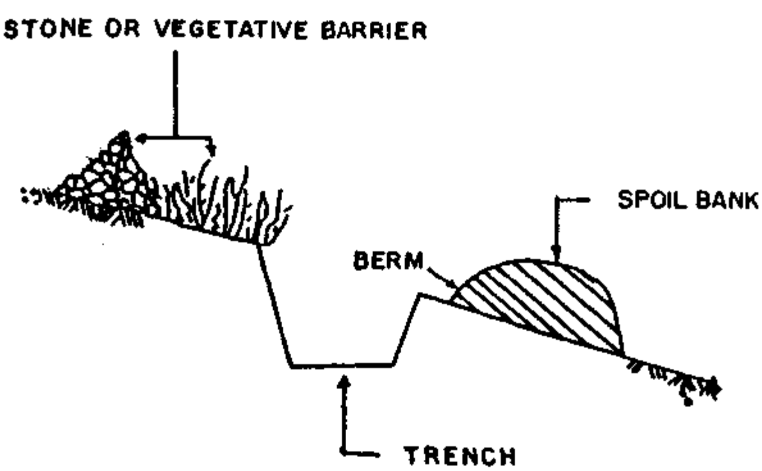

FIG. 2 SCHEMATICS OF A CONTOUR TRENCH

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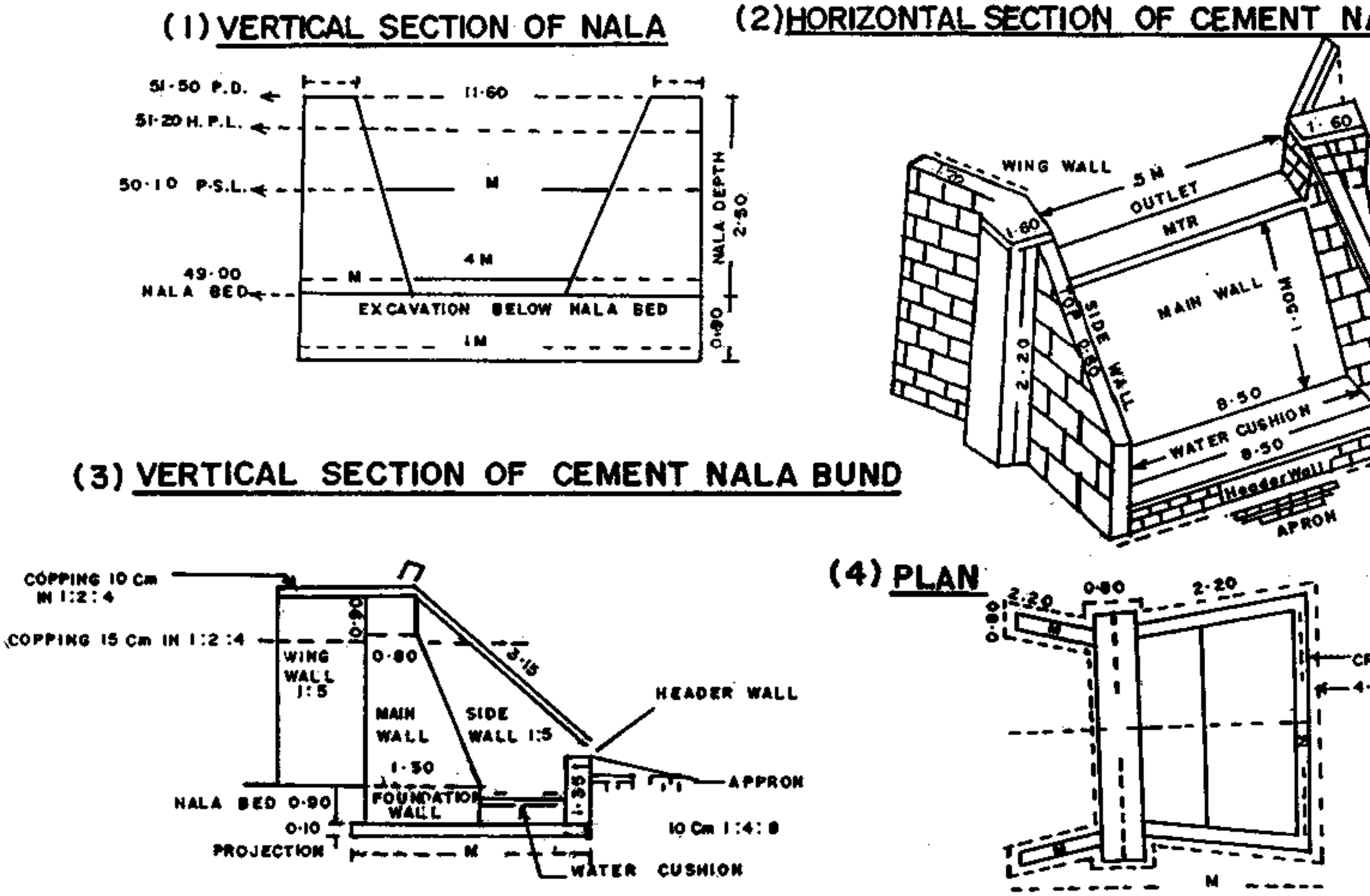


FIG. 3 DESIGN ASPECTS OF CHECK DAM/CEMENT PLUG

b) The rainfall in the catchment should be preferably less than 1 000 mm/annum.
c) The stream bed should be 5 to 15 m wide and at least 1 m deep.
d) The soil downstream of the bund should not be prone to water logging and should have a pH value between 6.5 to 8.
e) The area downstream of the Check Dam/bund should have irrigable land under well irrigation.
f) The Check dams/Nala bunds should preferably be located in areas where contour or graded bunding of lands have been carried out.
g) The rock strata exposed in the ponded area should be adequately permeable to cause ground water recharge.

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

For construction of the check dam, a trench, 0.6 m wide in hard rock and 1.2 m wide in soft impervious rock is dug for the foundation of core wall. A core brick cement wall, 0.6 m wide and raised at least 2.5 m above nala bed is erected and the remaining portion of trench is backfilled on upstream side by impervious clay. The core wall is buttressed on both sides by a bund made up of local clays and stone pitching is done on the upstream face. If the bedrock is highly fractured, cement grouting is done to make the foundation leakage free.

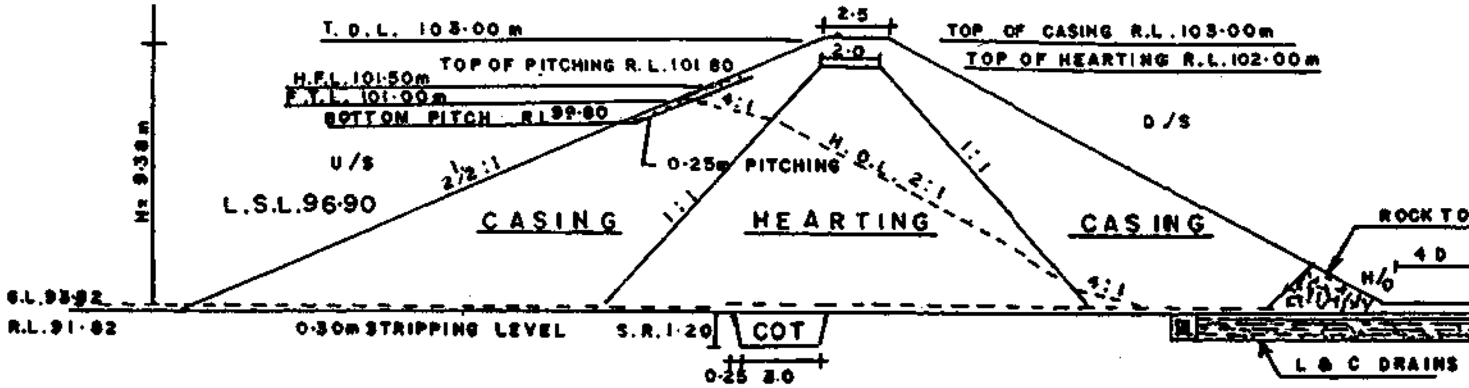
5.1.1.5 *Percolation ponds/tanks*

Percolation ponds/tanks are among the most prevalent runoff harvesting structures in both alluvial and hard rock formations. A percolation tank can be defined as an artificially created surface water body submerging a highly permeable land area so that the surface runoff is made to percolate and recharge the ground water storage. They differ from nala bunds in having larger reservoir areas and from irrigation tanks in that unlike the latter, they are not provided with sluices or outlets for discharging water from the tank for irrigation or other purposes. They may, however, be provided with arrangements for spilling away the surplus water that may enter the tank so as to avoid over-topping of the tank bund.

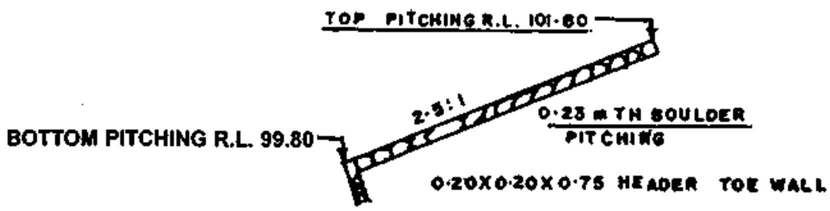
The efficacy and feasibility of percolation tanks is more in hard rock formations where the rocks are highly weathered and fractured. A typical design of percolation pond is given in Fig. 4. Percolation tanks are also feasible in mountain fronts occupied by talus scree deposits. Percolation ponds with wells and shafts are also constructed to recharge deep aquifers where shallow or superficial formations are highly impermeable or clayey.

The site characteristics and design guidelines to be followed are as given below:

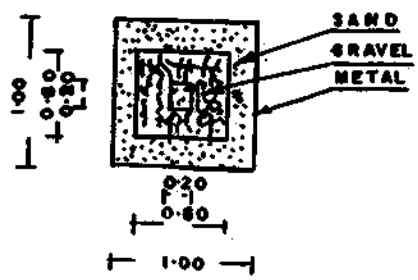
a) The hydrogeology of the area should be such that the litho-units occurring in the area of submergence of the tank should have high permeability. The soils in the catchment area of the tank should be sandy, to avoid silting up of the tank bed.
b) Detailed analysis of rainfall pattern, number of rainy days, dry spells, evaporation rate and detailed hydrogeological studies should be done to demarcate sites suitable for percolation tanks.
c) In areas of semi-arid climate, the storage capacity of percolation tank should be so designed that the water percolates to ground water reservoir by the end of January as the evaporation losses would be high.
d) Percolation tanks should be normally constructed on second or third order streams since the catchment and submergence areas would be smaller.
e) The submergence area should be in uncultivated land as far as possible.
f) The percolation tank should be located downstream of runoff zone, preferably toward the edge of piedmont zone or in the upper part of the transition zone. Land slope between 3 percent and 5 percent is ideal for construction of percolation tanks.
g) Percolation tanks should preferably be located on highly fractured/weathered rock for speedy recharge. In case of alluvium, bouldery/gravelly formations are ideal locations for percolation ponds.
h) The depth of water impounded in the tank provides the recharge head and hence it is necessary to design the tank to provide a minimum height of ponded water column of 3 to 4.5 m and rarely 6 m above the bed level. This would imply construction of tanks of large capacity in areas with steep gradient.
j) The area benefited should have adequate number of wells and cultivable land to utilize the recharged water.



CROSS SECTION OF DAM



DETAILS OF STONE PITCHING



DETAILS OF L & C DRAINS

Fig. 4 Typical Design of Percolation Tank

k) Detailed hydrological studies for runoff assessment should be done and design capacity should normally not exceed 50 percent of total quantum of rainfall in the catchment.

m) Waste weir or spillway should be suitably designed to allow flow of surplus water based on single day maximum rainfall after the tank is filled to its maximum capacity.

n) Cut-off trenches must be provided to minimize seepage losses below the nala bed.

p) Stone pitching should be provided upstream of the bund up to High Flood Level (HFL) to avoid erosion of embankment due to ripple action.

q) Monitoring mechanism consisting of observation wells and staff gauges should be provided both in benefited area and catchment to assess the impact and benefits of percolation tanks.

5.1.2 *Flooding*

This technique is ideal for lands adjoining rivers or irrigation canals in which water levels remain deep even after monsoons and where sufficient non-committed surface water supplies are available. The schematics of a typical flooding system are shown in Fig. 5. To ensure proper contact time and water spread, embankments are provided on tow sides to guide the unutilized surface water to a return canal to carry the excess water to the stream or canal.

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

5.1.3 *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 from source stream or canal. The ditches should have adequate slope to maintain flow velocity and minimum deposition of sediments. The width of the ditches are typically in the range of 0.30 to 1.80 m. A collecting channel to convey the excess water back to the source stream or canal should also be provided. Fig. 6 shows a typical plan of a series of furrows originating from a supply ditch and trending down the topographic slope towards the stream. Though this technique involves less soil preparation when compared to recharge basins and is less sensitive to silting, the water contact area seldom exceeds 10 percent of the total recharge area.

Three patterns of ditch and furrow system are generally adopted:

a) *Lateral ditch pattern* — The water from the stream is diverted to the feeder canal/ditch from which smaller ditches are taken out at right angles. The rate of flow of water from the feeder canal to these ditches is controlled by gate valves. The furrow depth is determined in accordance with the topography

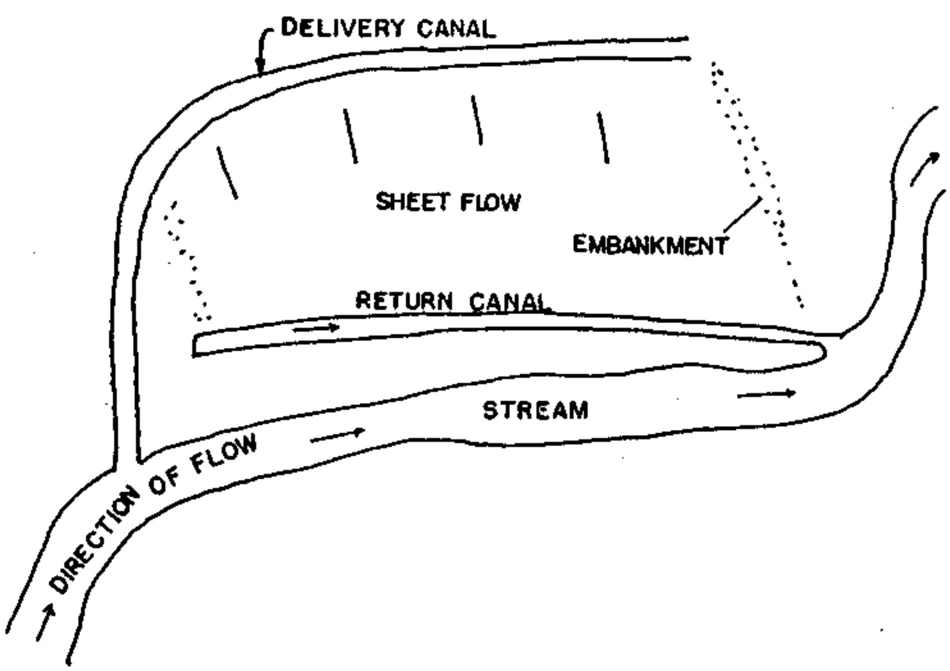


FIG. 5 SCHEMATICS OF A TYPICAL FLOOD RECHARGE SYSTEM

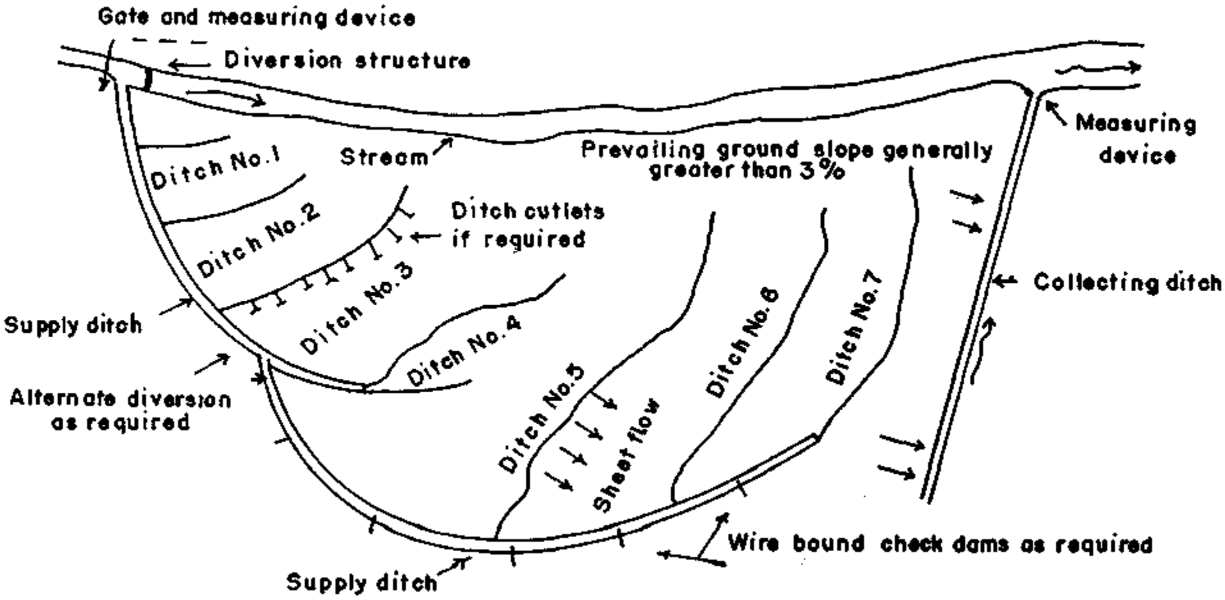


FIG. 6 DITCH AND FURROW METHOD

and to ensure that maximum wetted surface is available along with maintenance of uniform velocity. The excess water is routed to the main stream through a return canal along with the residual silt.

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

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

5.1.4 *Recharge Basins*

Artificial recharge basins are commonly constructed parallel to ephemeral or intermittent stream channels and are either excavated or are enclosed by dykes and levees. They can also be constructed parallel to canals or surface water sources. In alluvial areas, multiple recharge basins can be constructed parallel to the streams (*see* Fig. 7), with a view to:

a) increase the water contact time;
b) reduce suspended material as water flows from one basin to another; and
c) facilitate periodic maintenance such as scraping of silt etc. to restore the infiltration rates by bypassing the basin under restoration.

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

5.1.5 *Modification of Existing Tanks as Recharge Structures*

The existing tanks, which are normally silted and damaged, can be modified to serve as recharge structures. Unlike in the case of properly designed percolation tanks, cut-off trenches, or waste weirs are not provided for village tanks. Desilting of village tanks together with proper provision of waste weirs and cut-off trenches on the upstream side can facilitate their use as recharge structures. As such tanks are available in plenty, they could be converted into cost-effective structures for augmenting ground water recharge with minor modifications.

5.1.6 *Inter Watershed Transfer*

Percolation tanks in a watershed may not have enough catchment recharge. In such situations streams from nearby watershed can be diverted at some additional cost and the tank made more efficient.

5.1.7 *Stream Channel Modification/Augmentation*

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

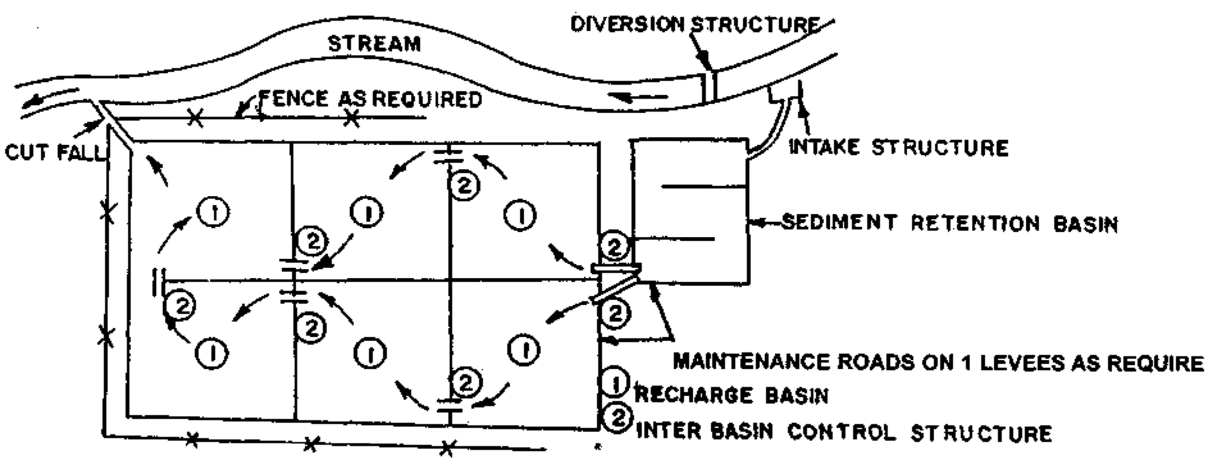


FIG. 7 SCHEMATICS OF A TYPICAL RECHARGE BASIN

increase the infiltration by detaining stream flow and increasing the stream bed area in contact with water. For this, the channel is so modified that the flow gets spread over a wider area, resulting in increased contact with the stream bed. The methods commonly used include the following:

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

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.

5.2 Sub-surface Techniques

Favourable hydrogeological set up for subsurface techniques is shown in Fig. 8A and Fig. 8B.

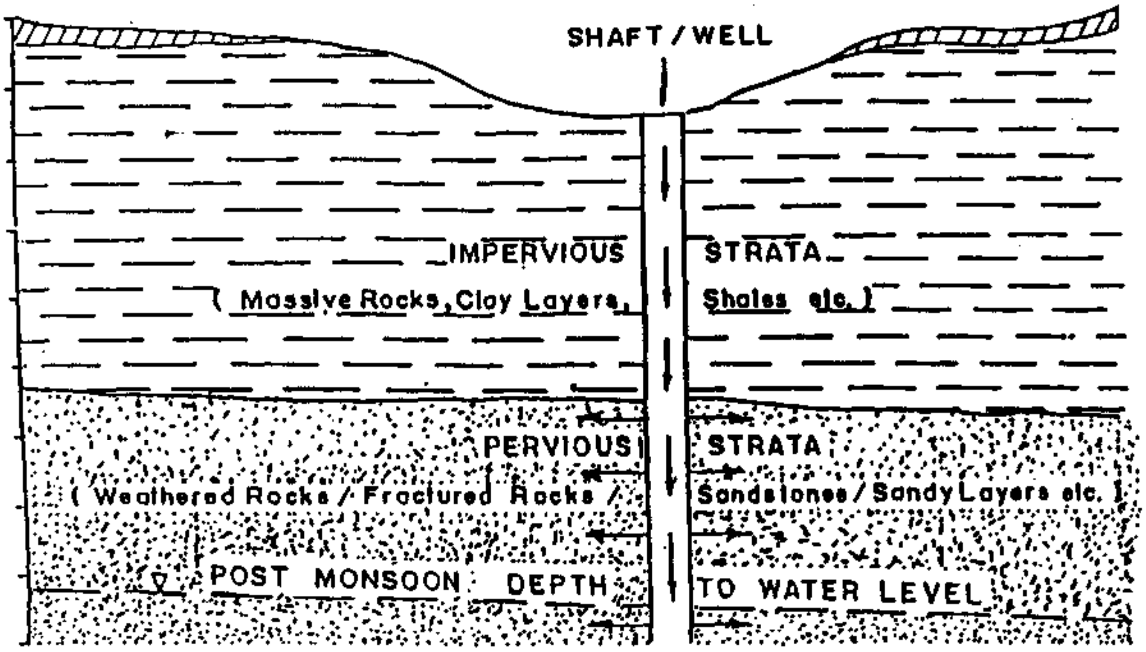
5.2.1 *Injection Wells or Recharge Wells*

Injection wells or recharge wells are structures similar to bore/tube wells but constructed for augmenting the ground water storage in deeper aquifers through supply of water under pressure (*see* Fig. 9). Injection wells are advantageous when land is scarce. The aquifer to be replenished is generally one with considerable desaturation due to overexploitation of ground water. Artificial recharge of aquifers by injection wells can also be done in coastal regions to arrest the ingress of seawater and to combat problems of land subsidence in areas where confined aquifers are heavily pumped.

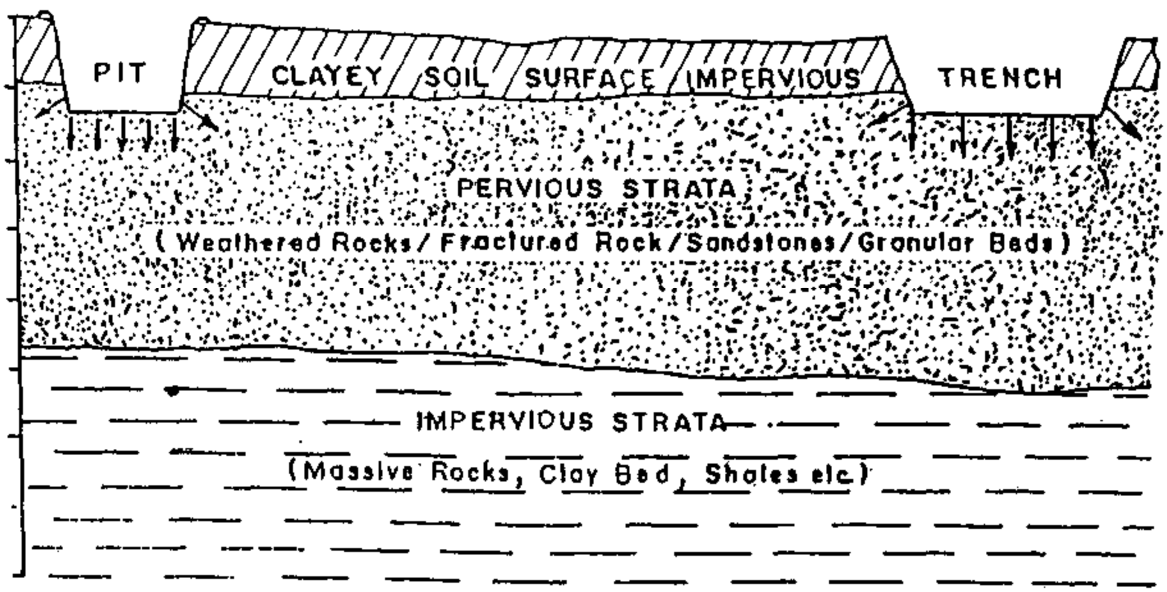
In alluvial areas, injection wells recharging a single aquifer or multiple aquifers can be constructed in a manner similar to normal gravel packed pumping wells. However, in case of recharge wells, cement sealing of the upper section of the wells is done to prevent the injection pressure from causing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

Hydraulically, the effectiveness of induction of water in injection wells is determined by the following:

a) Pumping rate,
b) Permeability of aquifer,
c) Distance from stream,
d) Natural ground water gradient, and
e) Type of well.



8A Use of Shaft/Well for Artificial Recharge for Shallow Depth and Borewell/Tubewells for Deeper Depth of Target Strata



8B Use of Pit/Trench for Artificial Recharge in Impervious Top Layer Setup

FIG. 8 FAVOURABLE HYDROGEOLOGICAL SETUP FOR SUB-SURFACE TECHNIQUES

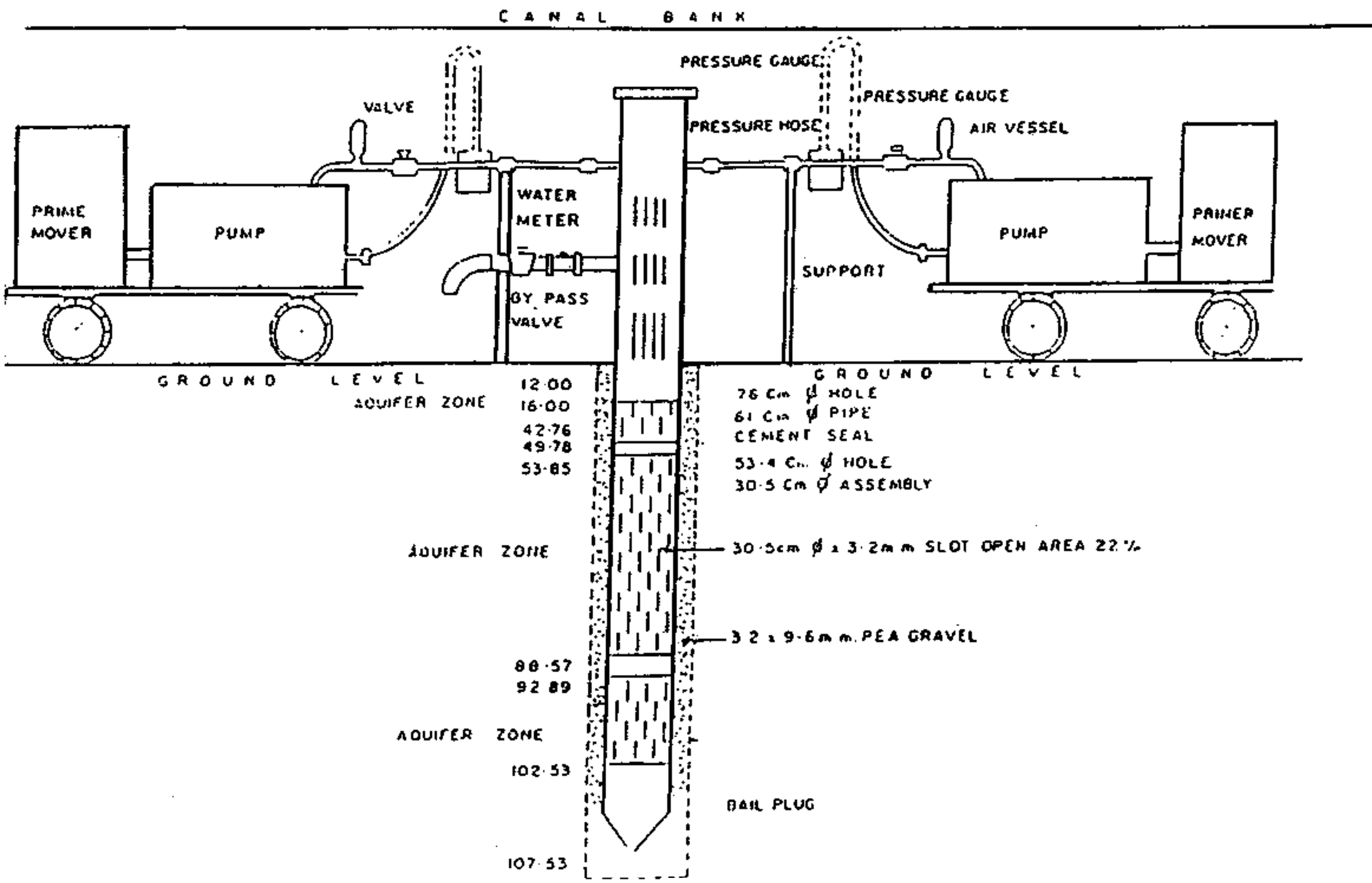


FIG. 9 ARTIFICIAL RECHARGE THROUGH INJECTION WELL

The effectiveness of recharge through injection wells is limited by the physical characteristics of the aquifers. The attempt to augment recharge may prove to be counter-productive in cases where the aquifer material gets eroded due to the speed of ground water flow, especially in unconsolidated or semi-consolidated aquifers. Failure of confining layers may also occur if excessive pressure is applied while injecting water. These may result in clogging and/or even collapse of the bore/tube well. As a means of artificial recharge, injection wells are costlier and require specialized techniques of well construction supported by operation and maintenance to protect them from clogging.

5.2.2 *Gravity Head Recharge Wells (Dug Well/Bore Well/Tube Well Recharge)*

Existing dug wells and tube/bore wells in alluvial/hard rock areas may also be alternatively used as recharge wells, as and when source water becomes available. In areas where considerable desaturation of aquifers have already taken place due to over-exploitation of ground water resources resulting in the drying up of dug wells and lowering of piezometric heads in bore/tube wells, existing ground water abstraction structures provide a cost-effective mechanism for artificial recharge of the phreatic or deeper aquifer zones as the case may be (*see* Fig. 10 and Fig. 11). Storm water, tank water, canal water etc. can be diverted into these structures to directly recharge the dried aquifer. In doing so, the soil moisture losses during the normal process of artificial recharge are reduced. The recharge water is guided through a pipe to the bottom of the well below the water level to avoid scouring 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.

5.2.3 *Recharge Pits*

Recharge pits are normally excavated pits, which are sufficiently deep to penetrate the low-permeability layers overlying the unconfined aquifers (*see* Fig. 12). They are similar to recharge basins in principle, with the only difference of being deeper and having restricted bottom area. In many such structures, most of the infiltration occurs laterally through the walls of the pit as in most layered sedimentary or alluvial material, the lateral hydraulic conductivity is considerably higher than the vertical hydraulic conductivity. Abandoned gravel quarry pits or brick kiln quarry pits in alluvial areas and abandoned quarries in hardrock areas can also be used as recharge pits wherever they are underlain by permeable horizons. Nala trench is a special case of recharge pit dug across a stream bed. Ideal sites for such trenches are influent stretches of streams. Contour trenches, described earlier, also belong to this category.

5.2.3.1 *Site characteristics and design guidelines*

a) The recharging capacity of the pits increase with their area of cross-section. Hence, it is always advisable to construct as large a pit as possible.
b) The permeability of the underlying strata should be ascertained through infiltration tests before taking up construction of recharge pits.
c) The side slopes of recharge pits should be 2 : 1 as steep slopes reduce clogging and sedimentation on the walls of the pit.
d) Recharge pits may be used as ponds for storage and infiltration of water, or they may be backfilled with gravel sand filter material over a layer of cobbles/boulders at the bottom. Even when the pits are to be used as ponds, it is desirable to provide a thin layer of sand at the bottom to prevent the silt from clogging permeable strata.
e) As in the case of water spreading techniques, the source water being used for recharge should be as silt-free as possible.
f) The bottom area of the open pits and the top sand layer of filter-packed pits may require periodic cleaning to ensure proper recharge. Recharge pits located in flood-prone areas and on stream beds are likely to be effective for short duration only due to heavy silting. Similar pits by the sides of stream beds are likely to be effective for longer periods.
g) In hard rock areas, stream bed sections crossing weathered or fractured rocks or sections along prominent lineaments or intersection of lineaments form ideal locations for recharge pits.

5.2.4 *Recharge Shafts*

These are the most efficient and cost-effective structures to recharge the aquifers directly. In areas where source water is available either perennially or for a period of time, for example base flow, springs, canals etc., recharge shafts can be constructed.

Recharge Shafts are similar to recharge pits but are constructed to augment recharge into phreatic aquifers where water levels are much deeper and the aquifer zones are overlain by strata having low permeability (*see* Fig. 13). Further, they are much smaller in cross section when compared to recharge pits. Detailed design guidelines of a recharge shaft are shown in Fig. 14.

5.2.4.1 *Design guidelines*

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

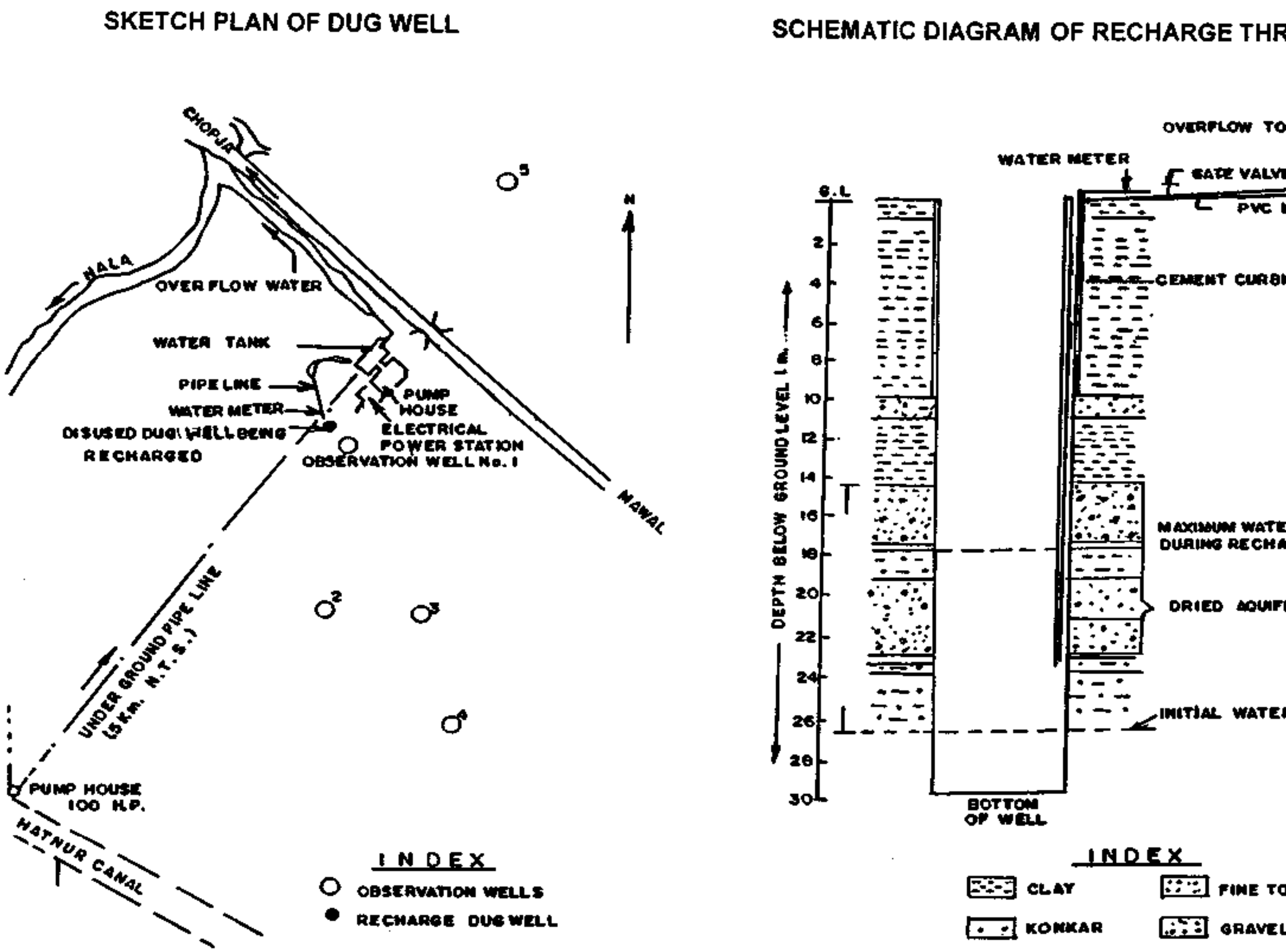


FIG. 10 RECHARGE THROUGH DUG WELL

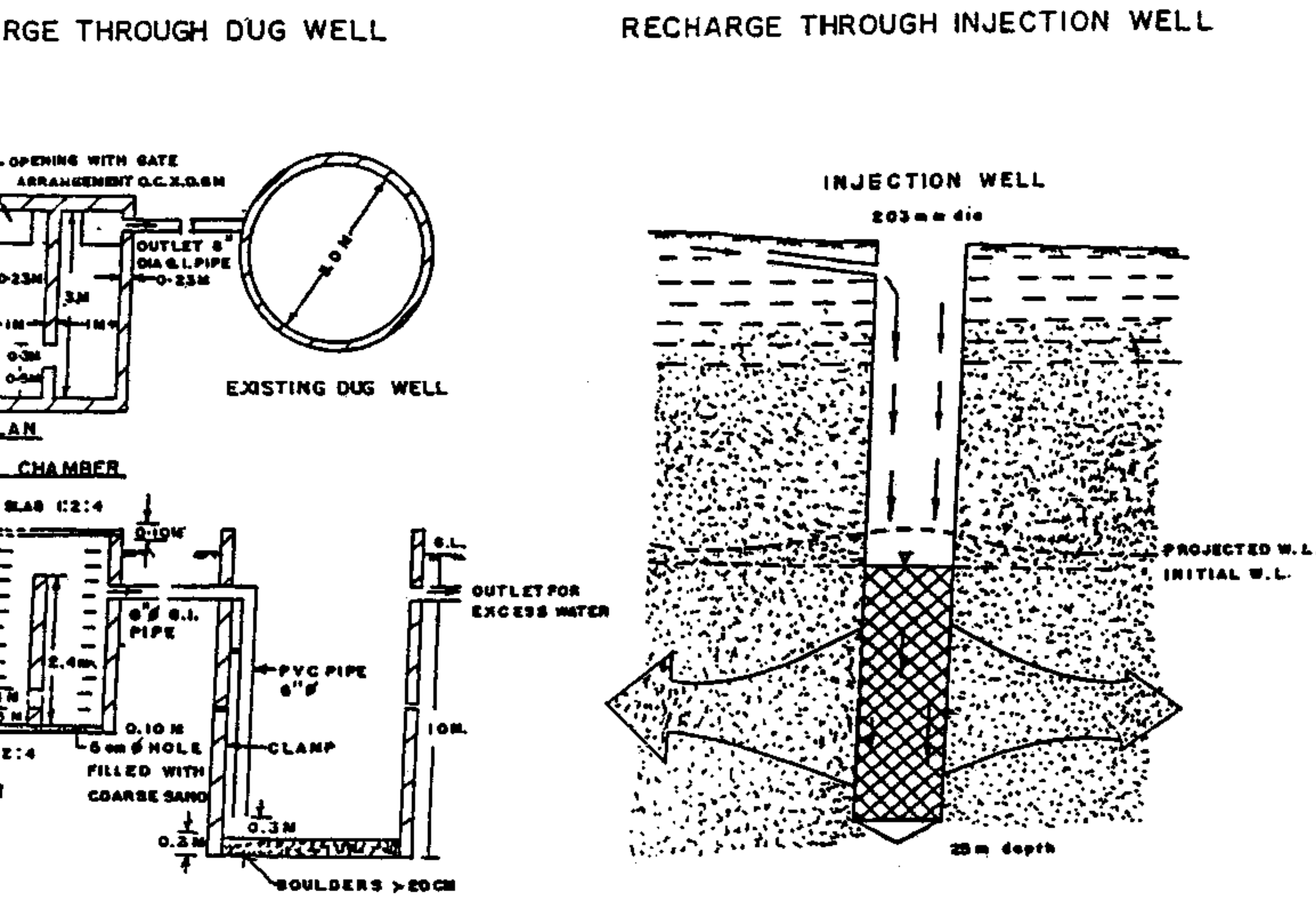


FIG. 11 RECHARGE THROUGH EXISTING GROUND WATER ABSTRACTION STRUCTURES

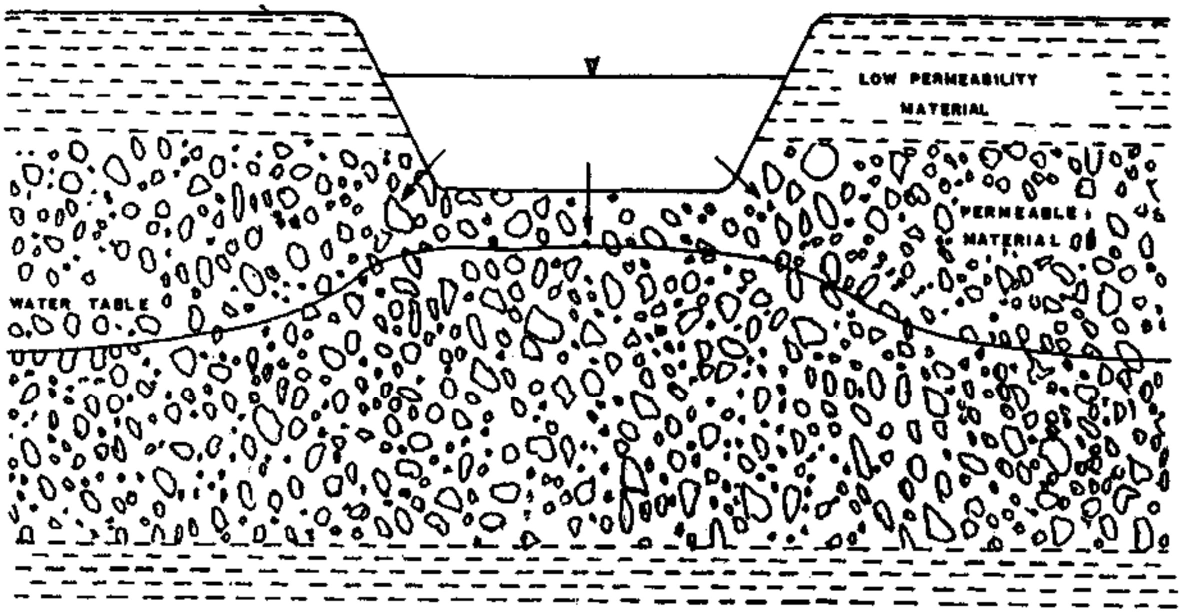


FIG. 12 SCHEMATICS OF A RECHARGE PIT

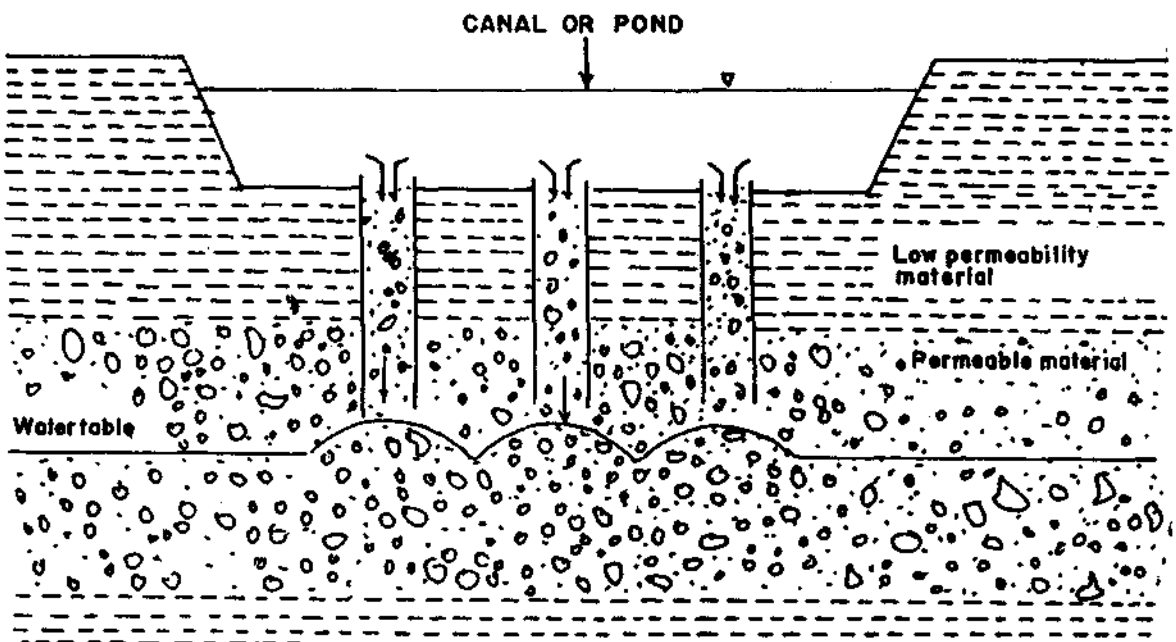


FIG. 13 SCHEMATICS OF RECHARGE SHAFTS

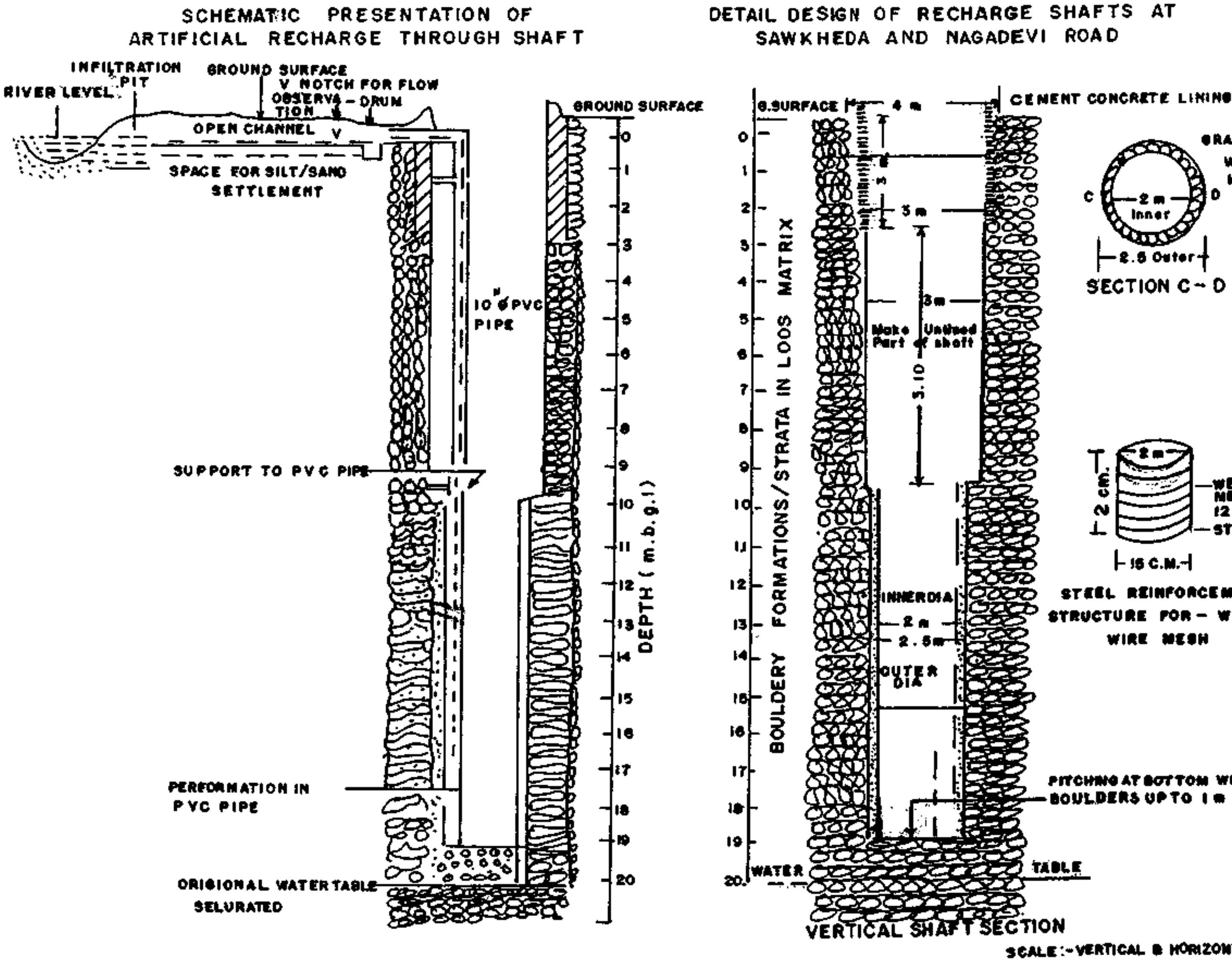


FIG. 14 DESIGN GUIDELINES OF A TYPICAL RECHARGE SHAFT

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

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

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

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

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

5.3 Combination Techniques

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

5.4 Indirect Methods

5.4.1 *Induced Recharge and Required Structures*

Induced recharge is an indirect method of recharge and involves pumping water from an aquifer, which is hydraulically connected with surface water to induce recharge to the ground water reservoir. When the cone of depression intercepts the river recharge boundary, hydraulic connection is established with the surface water source which starts providing part of the pumping yield. In such methods there is actually no artificial build-up of ground water storage but only passage of surface water to the pump through an aquifer. In this sense, it is more a pumpage augmentation rather than artificial recharge measure (*see* Fig. 15). 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 river beds, lake beds and water-logged areas also function on the principle of induced recharge.

In hard rock areas, abandoned buried channels often provide favorable sites for the construction of structures for induced recharge. Check dams constructed in the river channel upstream of the channel bifurcation can help in high infiltration to the channel when wells located in the channel's are pumped with high discharge for prolonged periods (*see* Fig. 16).

5.4.1.1 *Collector wells*

For obtaining large water supplies from river bed/lake bed deposits or water-logged areas, collector wells may be constructed. A Collector well is a large diameter (4 m to 8 m) well from which laterals are driven/drilled near the bottom at one or two levels into permeable strata. The central well is a vertical concrete cassion in precast rings (wall thickness 0.45 m) sunk down to the bottom of the aquifer horizon. The bottom of the cassion is sealed by thick concrete plugs. Slotted steel pipes, 9 mm thick, 150 mm to 500 mm in diameter, having open area above 15 percent and tapered leading are driven laterally through port holes at appropriate places in the cassion. The successive slotted pipes are welded and driven using special hydraulic jacks installed at the bottom of the casing. The number of laterals are usually less than 16, thus permitting a minimum angle of 22° 30′ between two laterals. The maximum length of lateral reported is 132 m and the total length of laterals range from 120 m to 900 m depending upon requirement of yield.

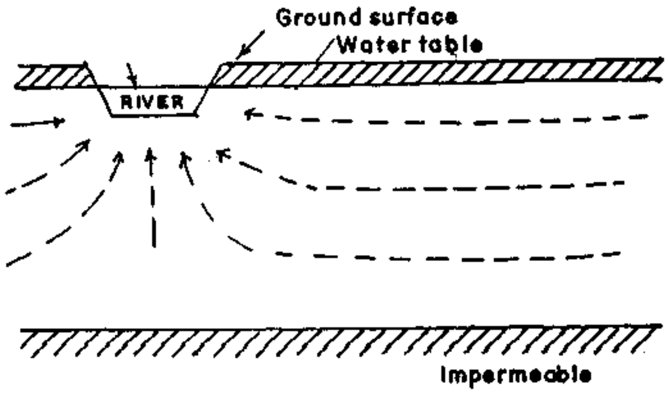
The laterals are developed by flushing and if entrance velocity is kept between 6 mm/sec to 9 mm/sec, these do not get filled by sand. The effective radius of a collector well is 75 to 85 percent of the individual lateral length.

5.4.2 *Aquifer Modification Techniques*

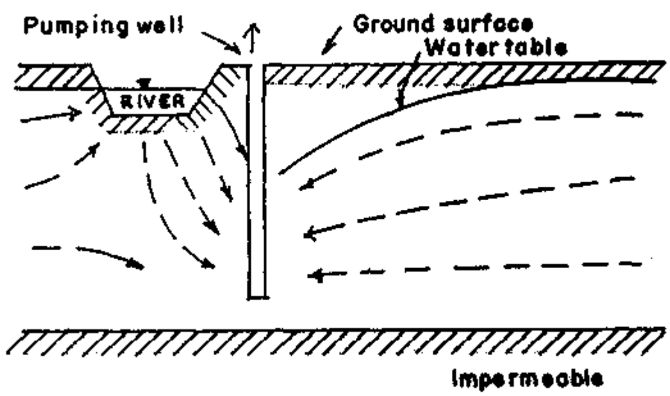
These techniques modify the aquifer characteristics to increase its capacity to store and transmit water through artificial means, thereby increasing its capacity to store and transmit water. The most important techniques under this category are bore blasting techniques and hydrofracturing techniques. Though they are yield augmentation techniques rather than artificial recharge structures, they are also being considered as artificial recharge structures owing to the resultant increase in the storage of ground water in the aquifers.

6 GROUND WATER CONSERVATION TECHNIQUES

Ground water conservation techniques are intended to retain the ground water for longer periods in the basin/watershed by arresting the sub-surface flow. The known techniques of ground water conservation are: (a) Ground water dams/sub-surface dykes/Underground 'Bandharas', and (b) Fracture sealing Cementation techniques.



15A Natural Flow Pattern



15B Flow Pattern with Pumping Well

FIG. 15 INDUCED RECHARGE RESULTING FROM A WELL PUMPING NEAR A RIVER

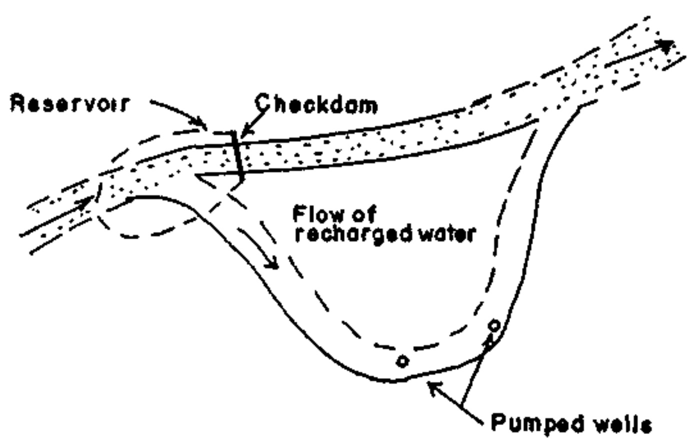


FIG. 16 ARTIFICIAL RECHARGE OF BURRIED CHANNEL

6.1 Sub-surface Dykes/Ground Water Dams/ Underground 'Bandharas'

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

The sub-surface dyke has the following advantages:

a) Since the water is stored within the aquifer, submergence of land can be avoided and the land above the reservoir can be utilized even after construction of the dam;
b) No evaporation losses take place from the reservoir;
c) No siltation of the reservoir takes place; and
d) Potential disasters like collapse of dams can be avoided.

At favourable locations, such dams can also be constructed not only across streams, but in large areas of the valley as well for conserving ground water.

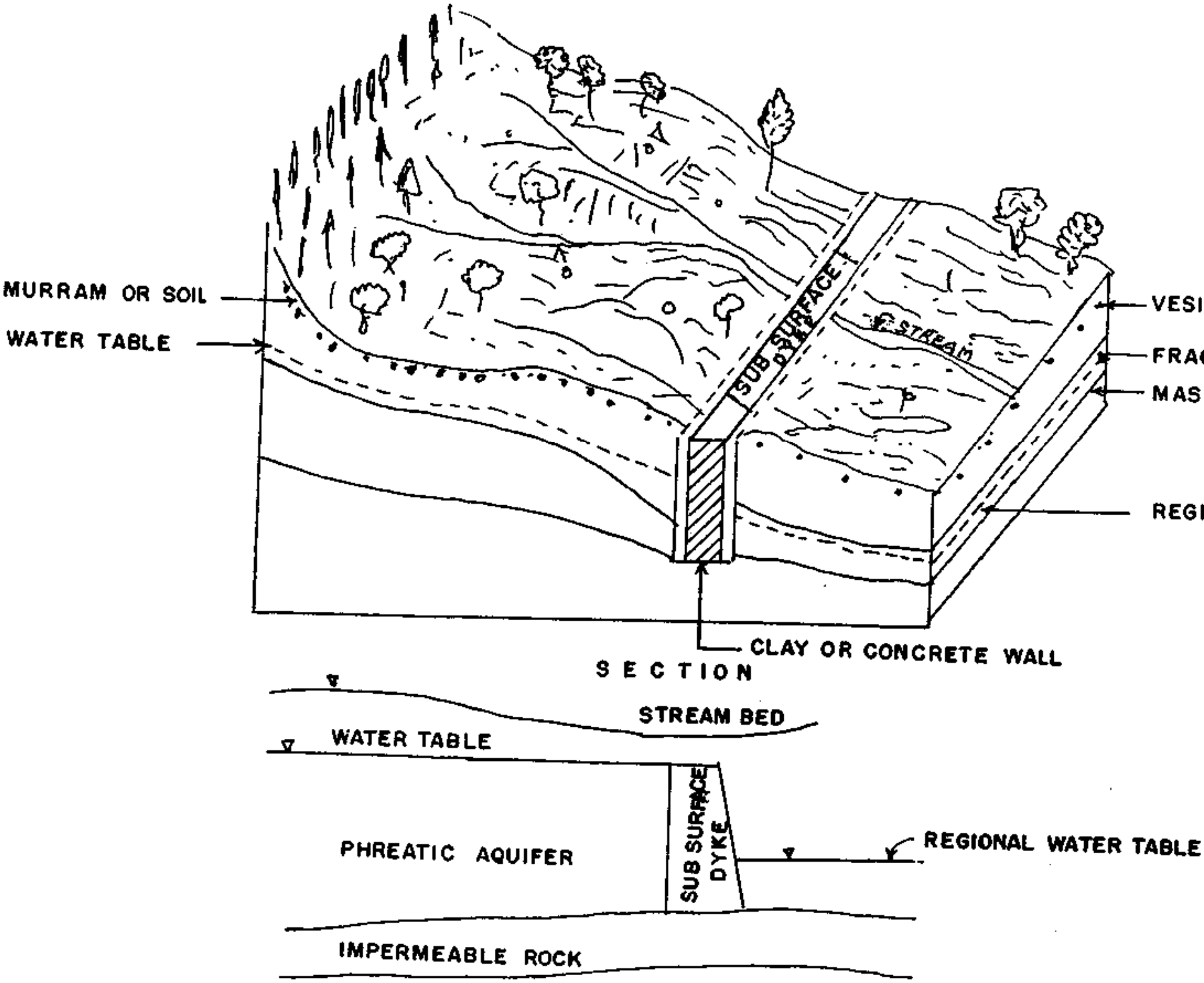


FIG. 17 ARTIFICIAL RECHARGE THROUGH UNDERGROUND BANDHARA

ANNEX A

(Foreword)

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