HARNESSING THE MANAGED AQUIFER RECHARGE POTENTIAL FOR SUSTAINABLE GROUND WATER MANAGEMENT IN INDIA

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ABSTRACT

Total annual utilizable water resource in India is around 1123 BCM constituting only 28% of the precipitation received in the country. This provides a large scope for harvesting the huge quantum of precipitation which otherwise goes waste as runoff and remains unutilized.The sub-surface reservoirs are very attractive and technically feasible alternatives for storing surplus monsoon run off as they can store substantial quantities of water. The sub-surface geological formations may be considered as "warehouse" for storing water that comes from sources located on the land surface. Besides suitable litho logical condition, other considerations for creating sub-surface storages are favourable geological structures and physiographic units, whose dimensions and shape will allow retention of substantial volume of water in porous and permeable formations.

Besides raising ground water levels, recharge of surplus runoff also helps in mitigating flash floods, soil erosion and silting of reservoirs and rivers. The effluence resulting from such sub-surface storage at various surface intersection points in the form of spring line, or stream emergence, would enhance the river flows and improve the presently degraded ecosystem of riverine tracts, particularly in the outfall areas.

It is estimated that annually about 36 BCM of surplus surface run-off can be recharged to augment the ground water. The artificial recharge potential can be effectively and efficiently harnessed by adopting appropriate artificial recharge techniques which is generally referred as managed aquifer recharge. There are various techniques used for artificial recharge to ground water, however the techniques broadly fall under the categories of Surface Spreading Techniques and Sub-surface Techniques. Aquifer disposition plays a decisive role in choosing the appropriate technique of artificial recharge of ground water. The technical expertise and willingness on the part of government agencies and other stake holders has grown many fold in the last couple of decades for construction of artificial recharge structures both in rural and urban areas. There are many success stories reported and being recognised across the country to motivate greater community participation and involvement of stakeholders in the activities of construction, management operation and monitoring of artificial recharge as well as water conservation projects.

The ground water use may be substantially enhanced to support the required agricultural development and to improve the rural livelihoods in the country apart from meeting the urban water supply demand. Aquifer maps should be the foremost bases for identifying the potential recharge zones in overexploited areas. There is a pressing need of adequate scientific understanding for artificial recharge and for formulation of appropriate strategy to utilize geosciences as irreplaceable tools. Design of suitable site-specific recharge structures on unpolluted stream water drains, open areas, parks and playgrounds is the key to raise the ground water table and ensure safe water quality. Capacity building of the Community /Gram Panchayat /Water User Association/ and their involvement in implementation and maintenance is essential in the national programme for managed aquifer recharge. Participatory ground water management is also needed to make the country self reliant in the water and food security front.

WATER RESOURCES SCENARIO IN INDIA

Annual utilizable water resource is about 1123 BCM which constitutes only 28% of the precipitation received in the country. This provides a large scope for harvesting the huge quantum of precipitation which otherwise goes waste as runoff and remains unutilized. The sub-surface reservoirs are very attractive and technically feasible alternatives for storing surplus monsoon run off as they can store substantial quantities of water. The sub-surface geological formations may be considered as "warehouse" for storing water that comes from sources located on the land surface. Besides suitable lithological condition, other considerations for creating sub-surface storages are favourable geological structures and physiographic units, whose dimensions and shape will allow retention of substantial volume of water in porous and permeable formations.

Recharge of surplus runoff not only raise ground water levels, but also helps in mitigating flash floods, soil erosion and silting of reservoirs and rivers. The effluence resulting from such sub-surface storage at various surface intersection points in the form of spring line, or stream emergence, would enhance the river flows and improve the presently degraded ecosystem of riverine tracts, particularly in the outfall areas.

POTENTIAL OF ARTIFICIAL RECHARGE IN INDIA

While implementing pilot/ demonstrative projects since VIII Plan, Central Ground Water Board not only gained the ground experience to implement construction of more than 1700 rainwater harvesting and recharge structures but also prepared a technical report on the potentiality of artificial recharge to ground water in different hydrogeological set-ups as a master plan of the country. While preparing the report, hydrogeological parameters and hydrological database available for each State has been taken into account. The identification of feasible areas for artificial recharge to ground water has been made on the basis of depth and declining trend of ground water levels. The decadal average depth to water level for post monsoon period has been used to estimate the sub-surface storage space for recharge and volume of water needed to saturate the vadose zone to 3 metre below ground level. The quantification of surplus monsoon runoff has been made for the identified areas/sub-basins. The computations for surface water available to harness in each identified area have been made to plan the feasibility of different artificial recharge structures. Based on the hydrogeological situation of each of the states, the feasible numbers of different artificial recharge structures and their cost estimates have been worked out.

A total area of about 4.50 lakh sq.km has been identified in the country which needs artificial recharge to ground water. It is estimated that annually about 36 BCM of surplus surface run-off can be recharged to augment the ground water. In rural areas, techniques of artificial recharge by modification of natural movement of surface water through suitable civil structures like percolation tanks, check dams, *nala* bunds, gully plugs, gabion structures etc. and sub-surface techniques of recharge shaft, well recharge, etc. have been recommended. Provision to conserve ground water flow through ground water dams has also been made in different states. Construction of 2.25 lakh rainwater harvesting structures is envisaged in rural areas. In Jammu & Kashmir, Himachal Pradesh, Uttaranchal, Northeastern States and Sikkim emphasis has been given for spring development. Roof top rainwater harvesting is feasible both by augmenting the ground water storage as well as by storing it in specially built tanks in urban and rural areas. Salient features of the study are given in the table below.

According to the recent assessment report, annual replenishable ground water resources is estimated as 431 BCM with a total ground water draft of 243 BCM .The overall stage of ground water development is 61% in the country. However, there is large variation in the stage of development across the country. Out of 5845 assessment units, 803 are categorized as “overexploited” where the stage of groundwater development exceeds the annual replenishment and significant decline in long-term ground water level trend has been observed in either pre-monsoon or post-monsoon or both. In addition, 169 units/ watersheds are “critical” where groundwater development has reached a high stage of development (> 90% up to 100%) and significant decline is observed in the long term water level trend in both pre-monsoon and post-monsoon periods. There are 522 “semi-critical” units, with stage of ground water development between 70% and 100 % having significant decline in long term water level trend in either pre-monsoon or post-monsoon. Of the remaining, 4280 units are safe and 71 units are saline(CGWB, as on March, 2009).

COMMON ARTIFICIAL RECHARGE TECHNIQUES

The artificial recharge potential for ground water augmentation can be effectively and efficiently harnessed by adopting appropriate artificial recharge techniques which is generally referred as managed aquifer recharge. There are various techniques used for artificial recharge to ground water, however the techniques broadly fall under the following categories;

A) Surface Spreading Techniques – Flooding; Ditch and Furrows; Recharge Basins ; Runoff Conservation Structures; Bench Terracing; Contour Bunds and Contour Trenches; Gully Plugs, *Nala* Bunds, Check Dams ;Percolation Ponds; Stream Modification / Augmentation.

B) Sub-surface Techniques - Injection Wells (Recharge Wells); Gravity Head Recharge Wells; Recharge Pits and Shafts.

Aquifer disposition plays a decisive role in choosing the appropriate technique of artificial recharge of ground water (Todd and Mays, 2005) as illustrated in the **Fig. 1.**

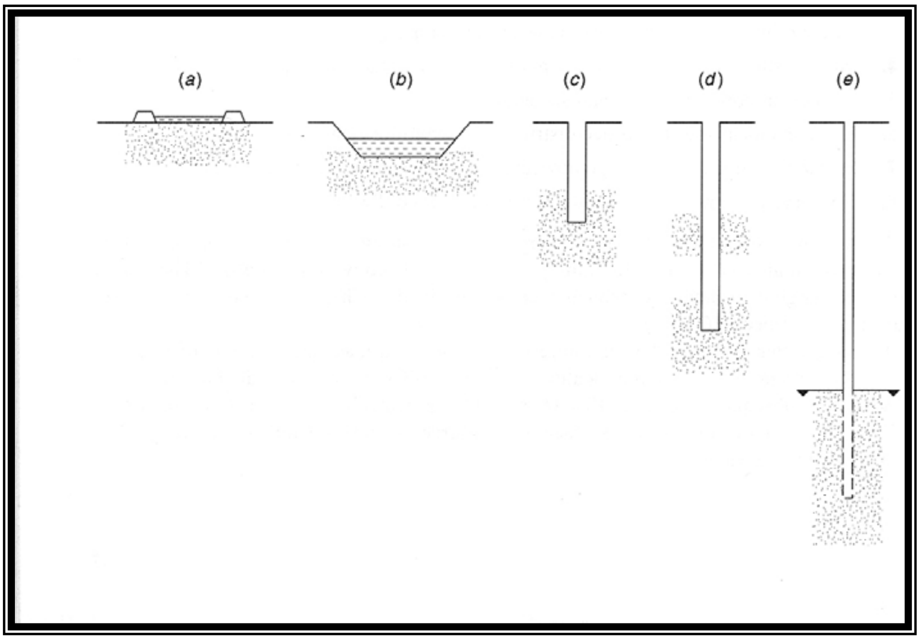

Figure 1- Recharge Systems for Increasingly Deep permeable strata: Surface Spreading (a), Excavated Basin (b), Sub-surface Techniques e.g. Pit/ Trench (c), Shaft or Well (d) and Injection Tube/ Bore Well (e)

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 downward movement of water is governed by a host of factors including vertical permeability of the soil, presence of grass or entrapped air in the soil zone and the presence or absence of limiting layers of low vertical permeability at depth. Changes brought about by physical, chemical and bacteriological influences during the process of infiltration are also important in this regard. The most common surface spreading techniques used for artificial recharge to ground water are flooding, ditch and furrows and recharge basins.

Selection of sites for artificial recharge through surface spreading techniques require some important considerations as follows;

- The area should have gently sloping land without gullies or ridges.
- The aquifer being recharged should be unconfined, permeable and sufficiently thick to provide storage space.
- The surface soil should be permeable and have high infiltration rate.
- Vadose zone should be permeable and free from clay lenses.
- Ground water levels in the phreatic zone should be deep enough to accommodate the recharged water so that there is no water logging.
- 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.

Flooding : This method helps to reduce evaporation losses from the surface water system. It is the least expensive of all artificial recharge methods available and has very low maintenance costs. 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. To ensure proper contact time and water spread, embankments are provided on two sides to guide the unutilized surface water to a return canal to carry the excess water to the stream or canal.

Ditch and Furrows method : This method involves construction of shallow, flat-bottomed and closely spaced ditches or furrows to provide maximum water contact area for recharge from source stream or canal. The ditches should have adequate slope to maintain flow velocity and minimum deposition of sediments. The widths of the ditches are typically in the range of 0.30 to 1.80 m. A collecting channel to convey the excess water back to the source stream or canal should also be provided. 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.

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, with a view to a) increase the water contact time, b) reduce suspended material as water flows from one basin to another and c) to facilitate periodic maintenance such as scraping of silt etc. to restore the infiltration rates by bypassing the basin under restoration.In addition to the general design guidelines mentioned, other factors to be considered while constructing recharge basins include;

- Area selected for recharge should have gentle ground slope.
- Entry and exit points for water should be diagonally opposite to facilitate adequate water circulation in individual basins,
- water released into the basins should be as sediment – free as possible and
- rate of inflow into the basin should be slightly more than the infiltration capacity of all the basins.

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

Bench Terracing : It 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.

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 from the construction of bunds along contours of equal land elevation. This technique is generally adopted in low rainfall areas (normally less than 800 mm) where gently sloping agricultural lands with very long slope lengths are available and the soils are permeable. They are not recommended for soils with poor internal drainage e.g. clayey soils.

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. The important design aspects of contour bunds are i) spacing, ii) cross section and iii) deviation freedom to go higher or lower than the contour bund elevation for better alignment on undulating land.

Contour Trenches : Contour trenches are rainwater harvesting structures, which can be constructed on hill slopes as well as on degraded and barren waste lands in both high- and low- rainfall areas. The trenches break the slope at intervals and reduce the velocity of surface runoff. The water retained in the trench will help in conserving the soil moisture and ground water recharge.

The size of the contour trench depends on the soil depth and normally 1000 to 2500 sq. cm 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.

Gully Plugs, *Nala* Bunds and Check Dams : These structures are constructed across gullies, *nala*s or streams to check the flow of surface water in the stream channel and to retain water for longer durations in the previous soil or rock surface. As compared to gully plugs, which are normally constructed across 1st order streams, *nala* bunds and check dams are constructed across bigger streams and in areas having gentler slopes. These may be temporary structures such as brush wood dams, loose / dry stone masonry check dams, Gabion check dams and woven wire dams constructed with locally available material or permanent structures constructed using stones, brick and cement. Competent civil and agro-engineering techniques are to be used in the design, layout and construction of permanent check dams to ensure proper storage and adequate outflow of surplus water to avoid scours on the downstream side for long-term stability of the dam.

The site 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 maximum runoff in the stream, a series of such check dams can be constructed to have recharge on a regional scale.

Percolation Tanks : Percolation tanks, which are based on principles similar to those of *nala* bunds, are among the most common runoff harvesting structures in India. 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. 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.

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

Detailed hydrogeological mapping is to be carried out in the area of submergence, at the tank site and also downstream of the site to find out the permeability of vadose zone and aquifer. The potential of additional storage and capacity of aquifer to transmit the ground water in adjoining areas is also assessed based on aquifer geometry. Infiltration rates of soils in the probable area of submergence are to be determined through infiltration tests. Aquifer parameters of water-bearing formations in the zone of influence may also be determined to assess the recharge potential and number of feasible ground water structures in the area. Periodic water level measurements along with ground water sampling for water quality may be done before and after the construction of percolation tanks. Geological investigations may be carried out to study the nature and depth of formation at the bund (dam) site for deciding the appropriate depth of cut off trench (COT). This will help in reducing the visible seepage and also ensure safety and long life of the structure. The depth of foundation and its treatment should be considered on the basis of nature of formation while designing and constructing the dam wall and waste weir.

Renovation of Village Tanks as Recharge Structures: The existing village 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. De-silting 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 in rural India, they could be converted into cost-effective structures for augmenting ground water recharge with minor modifications.

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 increase the infiltration by detaining stream flow and increasing the streambed 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 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 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.

SUBSURFACE TECHNIQUES

Subsurface techniques aim at recharging deeper aquifers that are overlain by impermeable layers, preventing the infiltration from surface sources to recharge them under natural conditions. The most common methods used for recharging such deeper aquifers are a) Injection wells or recharge wells, b) Recharge pits and shafts, c) Dug well recharge, d) Borehole flooding and e) Recharge through natural openings and cavities.

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 either under gravity or under pressure. The aquifer to be replenished is generally one with considerable de-saturation 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.

The effectiveness of recharge through injection wells is limited by the physical characteristics of the aquifers. Attempts 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.

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

Recharge Pits: Recharge pits are normally excavated pits, which are sufficiently deep to penetrate the low-permeability layers overlying the unconfined aquifers **(Fig.2)**. They are similar to recharge basins in principle, with the only difference being that they are deeper and have restricted bottom area. In many such structures, most of the infiltration occurs laterally through the walls of the pit as in most layered sedimentary or alluvial material the lateral hydraulic conductivity is considerably higher than the vertical hydraulic conductivity. Abandoned gravel quarry pits or brick kiln quarry pits in alluvial areas and abandoned quarries in basaltic areas can also be used as recharge pits wherever they are underlain by permeable horizons. *Nala* trench is a special case of recharge pit dug across a streambed. Ideal sites for such trenches are influent stretches of streams. Contour trenches, which have been described earlier also belongs to this category.

Recharge Shafts : 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 **(Fig.3)**. Further, they are much smaller in cross section when compared to recharge pits.

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

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

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

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

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

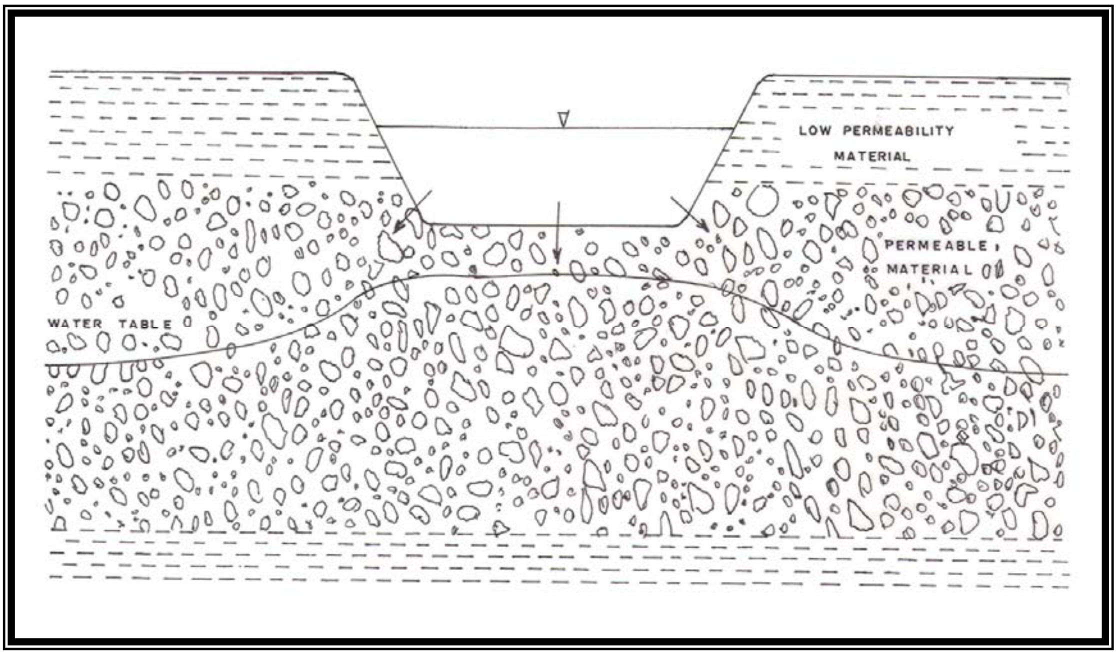

Fig.2- Schematics of a Recharge Pit.

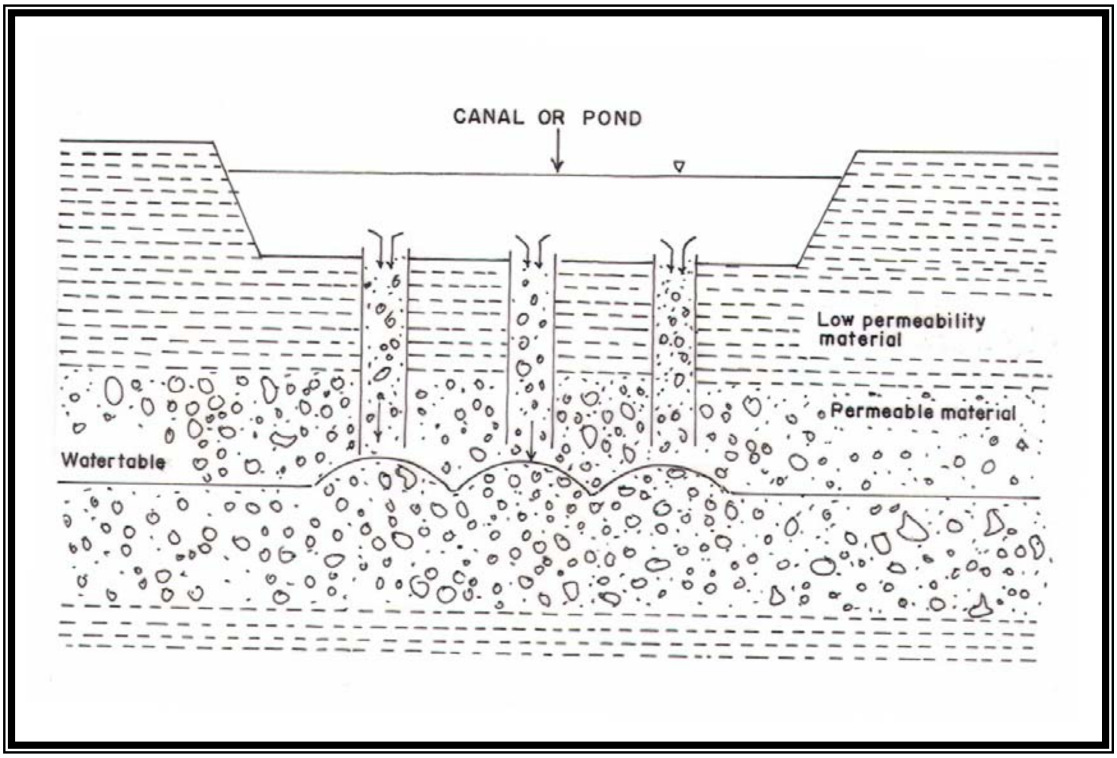

Fig.3- Schematics of Recharge Shafts

COMBINATION METHODS

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 to be combined 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.

SUMMARY AND RECOMMENDATIONS

The ground water use may be further enhanced to support agricultural development and to improve rural livelihoods in the country apart from meeting the urban water supply demand. There is a need of adequate knowledge of rainwater harvesting and formulation of proper strategy.

An appropriate strategy may take into consideration the following:

- ❖ Identification of Aquifers under the stress and the potential recharge zones in respect of overexploited aquifers. Detailed aquifer mapping is required for scientific planning of the ground water augmentation.
- ❖ Design and implement suitable, site-specific roof water and surface water harvesting structures to raise the ground water table. The activities would utilize geology, geophysics and hydrogeology as irreplaceable tools.
- ❖ Introduction of water-harvesting structures on unpolluted stream water drains, open areas, parks and playgrounds.
- ❖ Endeavour to protect aquifer sanctuaries and make them sustainable for future demand.
- ❖ Capacity building of the Community /*Gram Panchayat* /Water User Association/ and its involvement in implementation and maintenance. Participatory approach for monitoring and management of ground water resources is to be promoted in coming years.

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Dr.S.K.Jain obtained M.Tech(Applied Geology) from IIT Roorkee, India in 1983.He was awarded Ph.D. in Geology for Artificial Recharge to Ground Water by the RSTM Nagpur University in 2004.He is working in **Central Ground Water Board** for last 25 years in various positions as Hydrogeologist. His specialization is Artificial Recharge for Ground Water and has contributed immensely in formulation of national master plan for artificial recharge and manual of Artificial Recharge to Ground Water. He was instrumental in formulation of BIS guidelines for Artificial Recharge and Rain Water Harvesting. He is presently nominated as project leader for an ISO Project to develop guidelines of Artificial Recharge in association with members from USA,UK,France,China and Italy. He has successfully implemented Artificial Recharge Projects in over exploited areas of Maharashtra particularly in Jalgaon and Amravati districts.