International Journal of Geology, Earth and Environmental Sciences ISSN: 2277-2081 (Online)
An Online International Journal Available at http://www.cibtech.org/jgee.htm
2013 Vol. 3 (1) January-April pp.165-183/Bhalerao and Kelkar
Review Article

ARTIFICIAL RECHARGE OF GROUNDWATER: A NOVEL TECHNIQUE FOR REPLENISHMENT OF AN AQUIFER WITH WATER FROM THE LAND SURFACE

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ABSTRACT
Ground water, which is the source for more than 85 percent of India's rural domestic water requirements, is depleting fast in many areas due to its large scale withdrawal for various purpose. Ground water plays an important role in sustaining India's economy, environment, and standard of living. It is not only the main source for water supply in urban areas for domestic uses, but also is the largest and most productive source of irrigation water. Indiscriminate ground water development has led to substantial ground water level declines both in hard rocks and alluvial areas threatening sustainability of this resource. There have been continued efforts in India for development of ground water resources to meet the increasing demands of water supply, especially in the last few decades.
The term artificial recharge of groundwater has different connotations for various practitioners. Artificial recharge of ground water is defined as the recharge that occurs when the natural pattern of recharge is deliberately modified to increase recharge. In the broadest sense one can define artificial recharge as "any procedure, which introduces water in a previous stratum". The term artificial recharge refers to transfer of surface water to the aquifer by human interference.
Artificial recharge is a process by which excess surface water is directed into the ground – either by spreading on the surface, by using recharge wells, or by altering natural conditions to increase infiltration – to replenish an aquifer. It refers to the movement of water through man-made systems from the surface of the earth to underground water-bearing strata where it may be stored for future use.
Artificial recharge aims at augmenting the natural replenishment of ground water storage by some method of construction, spreading of water, or by artificially changing natural conditions. It is useful for reducing overdraft, conserving surface run-off, and increasing available ground water supplies. Recharge may be incidental or deliberate, depending on whether or not it is a by-product of normal water utilization.
Natural replenishment of ground water reservoir is a slow process and is often unable to keep pace with the excessive and continued exploitation of ground water resources in various parts of the country. This has resulted in declining ground water levels and depletion of ground water resources in such areas. Artificial recharge efforts are basically aimed at augmentation of the natural movement of surface water into ground water reservoir through suitable civil construction techniques. Such techniques inter relate and integrate the source water to ground water reservoir and are dependent on the hydro - geological situation of the area concerned.
Artificial recharge is becoming increasingly necessary to ensure sustainable ground water supplies to satisfy the needs of a growing population. The important advantages of artificial recharge are subsurface storage space is available free of cost and inundation is avoided, evaporation losses are negligible, biological purity is very high, temperature variations are minimum etc.
Proper planning is essential for the successful outcome of any artificial recharge scheme. Planning of artificial recharge schemes involves the formulation of a suitable plan, under a given set of natural conditions, to augment the natural ground water recharge. An artificial recharge scheme may be aimed at recharge augmentation in a specific area for making up the shortage in ground water recharge compared to the ground water draft either fully or partially.

Techniques used for artificial recharge to ground water body fall under three major categories viz. direct methods which includes surface spreading techniques like flooding, ditch and furrows etc. and sub-surface techniques like recharge wells, recharge pits and shafts etc, indirect methods and combination methods like fracture sealing cementation etc.
The choice of a particular method is governed by local topographical, geological and soil conditions; the quantity and quality of water available for recharge; and the technological-economical viability and social acceptability of such schemes. This paper discusses various issues involved in the artificial recharge of groundwater.

Key Words: *Ground Water, Artificial Recharge, Aquifer, Replenishment And Augmentation Of Ground Water Storage*

INTRODUCTION

Ground water, which is the source for more than 85 percent of India's rural domestic water requirements, is depleting fast in many areas due to its large scale withdrawal for various purpose. Ground water plays an important role in sustaining India's economy, environment, and standard of living. It is not only the main source for water supply in urban areas for domestic uses, but also is the largest and most productive source of irrigation water. Indiscriminate ground water development has led to substantial ground water level declines both in hard rocks and alluvial areas threatening sustainability of this resource. There have been continued efforts in India for development of ground water resources to meet the increasing demands of water supply, especially in the last few decades.
In certain high demand areas, ground water development has already reached a critical stage, resulting in acute scarcity of the resource. Over- development of the ground water resources results in declining ground water levels, shortage in water supply, intrusion of saline water in coastal areas and increased pumping lifts necessitating deepening of ground water structures. Geogenic contamination of ground water due to concentration of Arsenic, Fluoride and Iron in excess of limits prescribed for drinking purposes (BIS, 2004) have also been observed in many parts of the country. To tackle the twin hazards of de-saturation of aquifer zones and consequent deterioration of ground water quality, there is an urgent need to augment the ground water resources through suitable management interventions. Artificial recharge has now been accepted world-wide as a cost-effective method to augment ground water resources in areas where continued overexploitation without due regard to their recharging options has resulted in various undesirable environmental consequences.

Need For Artificial Recharge

The artificial recharge to ground water aims at augmentation of ground water reservoir by modifying the natural movement of surface water utilizing suitable civil construction techniques. Artificial recharge techniques normally needed for the following needs
(i) To enhance the sustainable yield in areas where over-development has depleted the aquifer.
(ii) Conservation and storage of excess surface water for future requirements, since these requirements often changes within a season or a period.
(iii) To improve the quality of existing ground water through dilution.
(iv) To remove bacteriological and other impurities from sewage and waste water so that water is suitable for re-use.
The basic purpose of artificial recharge of ground water is to restore supplies from aquifers depleted due to excessive ground water development.

Why Artificial Recharge?

Average annual water resources in our river basins are estimated as 1,869 billion cubic metres (BCM) of which utilizable resources are of the order of 1,086 BCM. Out of this, 690 BCM is available as surface water and the remaining 396 BCM as ground water. The source of all this water is rain or snow. The huge ground water storage of 396 BCM is the result of rain and snowmelt water percolating through various layers of soil and rocks. However, the amount of percolation varies greatly from region to region and within the same region from place to place depending upon the amount and pattern of rainfall (i.e. number and duration of rainy days, rainfall amount and intensity), characteristics of soils and rocks (i.e. porosity, cracks and loose joints in rocks etc.), the nature of terrain (i.e. hills, plateaus, plains, valleys etc.), and other climatic factors like temperature and humidity. As a result, availability of water from sub-surface storages varies considerably from place to place.

In most low rainfall areas of the country the availability of utilizable surface water is so low that people have to depend largely on ground water for agriculture and domestic use. Excessive ground water pumping in these areas, especially in some of the 91 drought prone districts in 13 states, has resulted in alarming lowering of the ground water levels. The problem has been further compounded due to large-scale urbanization and growth of mega cities, which has drastically reduced open lands for natural recharge. In hard rock areas there are large variations in ground water availability even from village to village.

In order to improve the ground water situation it is necessary to artificially recharge the depleted ground water aquifers. The available techniques are easy, cost-effective and sustainable in the long term. Many of these can be adopted by the individuals and village communities with locally available materials and manpower.

Artificial recharge (sometimes called planned recharge) is a way to store water underground in times of water surplus to meet demand in times of shortage. Some factors to consider for artificial recharge are (O'Hare *et al.,* 1986, Bhattacharya, 2010)

1- Availability of waste water
2- Quantity of source water available
3- Quality of source water available
4- Resultant water quality (after reactions with native water and aquifer materials)
5- Clogging potential
6- Underground storage space available
7- Depth to underground storage space
8- Transmission characteristics of the aquifer
9- Applicable methods (injection or infiltration)
10- Legal / institutional constraints
11- Costs
12- Cultural / social considerations

Advantages and Disadvantages Of Artificial Recharge

Artificial recharge has several potential advantages:

- The use of aquifers for storage and distribution of water and removal of contaminants by natural cleaning processes which occur as polluted rain and surface water infiltrate the soil and percolate down through the various geological formations.
- The technology is appropriate and generally well understood by both the technicians and the general population.
- Very few special tools are needed to dig drainage wells.
- In rock formations with high, structural integrity few additional materials may be required (concrete, softstone or coral rock blocks, metal rods) to construct the wells.
- Groundwater recharge stores water during the wet season for use in the dry season, when demand is highest.
- Aquifer water can be improved by recharging with high quality injected water.
- Recharge can significantly increase the sustainable yield of an aquifer.
- Recharge methods are environmentally attractive, particularly in arid regions.
- Most aquifer recharge systems are easy to operate.

- In many river basins, control of surface water runoff to provide aquifer recharge reduces sedimentation problems.
- Recharge with less-saline surface waters or treated effluents improves the quality of saline aquifers, facilitating the use of the water for agriculture and livestock.
- Negligible losses as compared to losses in surface storages
- No large storage structures needed to store water. Structures required are small and cost-effective
- Enhance the dependable yield of wells and hand pumps
- Reduction in cost of energy for lifting water especially where rise in ground water level is substantial

Artificial Recharge has some disadvantages too:

- In the absence of financial incentives, laws, or other regulations to encourage landowners to maintain drainage wells adequately, the wells may fall into disrepair and ultimately become sources of groundwater contamination.
- There is a potential for contamination of the groundwater from injected surface water runoff, especially from agricultural fields and roads surfaces. In most cases, the surface water runoff is not pre-treated before injection.
- Recharge can degrade the aquifer unless quality control of the injected water is adequate.
- Unless significant volumes can be injected into an aquifer, groundwater recharge may not be economically feasible.
- The hydrogeology of an aquifer should be investigated and understood before any future full-scale recharge project is implemented. In karstic terrain, dye tracer studies can assist in acquiring this knowledge.
- During the construction of water traps, disturbances of soil and vegetation cover may cause environmental damage to the project area.

Identification of Areas for Recharge

The artificial recharge projects are site specific and even the replication of the techniques from 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 of recharge. The Project can be implemented systematically in case a hydrologic unit like watershed is taken for implementation. However, localised schemes are also taken to augment ground water reservoir. The artificial recharge of ground water is normally taken in following areas:

1. Areas where ground water levels are declining on regular basis.
2. Areas where substantial amount of aquifer has already been desaturated.
3. Areas where availability of ground water is inadequate in lean months.
4. Areas where salinity ingress is taking place.

Sources of Water for Recharge

Availability of source water is one of the basic prerequisites for taking up any artificial recharge scheme. The source water available for artificial recharge could be of the following types:

i) *In situ* precipitation in the watershed / area
ii) Nearby stream/ spring / aquifer system
iii) Surface water (canal) supplies from large reservoirs located within the watershed/basin
iv) Surface water supplies through trans-basin water transfer
v) Treated Municipal/industrial wastewaters
vi) Any other specific source(s)

The availability of water for artificial recharge from all these sources may vary considerably from place to place. In any given situation, the following information may be required for a realistic assessment of the source water available for recharge.

i) The quantum of non-committed water available for recharge
ii) Time for which the source water will be available.
iii) Quality of source water and the pre-treatment required.

iv) Conveyance system required to bring the water to the proposed recharge site.

Rainfall and runoff available constitute the major sources of water for artificial recharge of ground water. Rainfall is the primary source of recharge into the ground water reservoir. Other important sources of recharge include seepage from tanks, canals and streams and the return flow from applied irrigation. For proper evaluation of source water availability, a thorough understanding of rainfall and runoff is essential. Collection and analysis of hydrometeorological and hydrological data have an important role to play in the assessment of source water availability for planning and design of artificial recharge schemes. These are elaborated as follows.

a) *Rainfall:* Rainfall in the country is typically monsoonal in nature. 'Monsoon' literally means seasonal wind. It is basically a part of the trade wind system. The southeast trade winds and northeast trade winds converge at the Inter-Tropical Convergence Zone (ITCZ). Due to uneven distribution of land and water masses, it is crooked in shape and keeps shifting seasonally. During its northwards movement, it draws the southeast trades along with it. After crossing the equator, the winds change direction by 90 degrees (due to Coriolis force), taking a southwesterly direction. Hence, these seasonal winds are named Southwest monsoon. It lasts for four months, from June to September. While traversing the vast stretches of water, (Bay of Bengal and Arabian Sea), these winds pick up lot of moisture. On an average, annually, about 1120 mm of rainfall is received in the country. Bulk of this rainfall occurs during Southwest monsoon. These moisture-laden winds normally hits the Kerala coast around May end. As it advances over the peninsula, copious amounts of rainfall occur all along the west coast and the adjoining mountains. After crossing the mountains, the current weakens. At the same time, the Bay of Bengal branch of the monsoon gives rise to heavy rainfall in the Bay islands during the month of May. This branch encounters the hill ranges of Northeast and then takes a westerly course. As a consequence, heavy rains occur in the northeast as also along the foothills of Himalayas. As it advances further, rainfall decreases towards west, almost becoming negligible west of *Aravalli* hill ranges in Rajasthan. This monsoon normally takes a month's time to cover whole of the country (late June or early July). Thus, the entire country is covered by the summer monsoon for two months, July and August, making them the wettest months. The monsoon starts withdrawing gradually by early September and leaves the country by middle of October. The withdrawal of the Southwest monsoon is a result of shifting of ITCZ southwards. In its wake, the Northeast monsoon sets in. This monsoon lasts for nearly three months, from October to December. It is a relatively dry season as compared to its summer cousin. It is largely confined to the southeast and interior southern parts of the country. Rainfall is confined mainly to the month of October and to a lesser extent up to the middle of November.

b) *Runoff:* Precise estimation of runoff is the basic and foremost input requirement for the design of recharge structures of optimum capacity. Unrealistic runoff estimates of catchments yield often leads to the construction of oversized or undersized structures, which, in any case, must be avoided. Runoff is defined as the portion of the precipitation that makes its way towards rivers or oceans as surface or subsurface flow. After the occurrence of infiltration and other loses from the precipitation (rainfall), the excess rainfall flows out through the small natural channels on the land surface to the main drainage channels. Such types of flow are called *surface flows.* A part of the infiltrated rainwater moves parallel to the land surface as subsurface flow, and reappears on the surface at certain other points. Such flows are called *interflows*. Another part of the *infiltrated* water percolates downwards to ground water and moves laterally to emerge in depression and rivers and joins the surface flow. This type of flow is called the *subsurface flow* or *ground water flow*.

c) *Quality of Source Water:* The physical, chemical and biological quality of the recharge water also affects the planning and selection of recharge method. Physical quality of recharge water refers to the type and amount of suspended solids, temperature, and the amount of entrapped air whereas chemical quality refers to type and concentration of dissolved solids and gases. Biological quality refers to type and concentration of living organisms. Under certain conditions, any or all of these characteristics can diminish recharge rates.

c1) Physical Quality: If suspended solids are present in the recharge water, surface application techniques are more efficient than subsurface techniques. Even though suspended particles may cause clogging, the infiltration surfaces are accessible for remedial treatment. Where indirect methods of recharge are used, suspended solids pose virtually no problem. Under such conditions, induced recharge would probably be one of the best methods. Ditch and furrows method is also well suited for large amounts of suspended solid loads because the steady flow of water inhibits settling. Basins should not be indiscriminately subjected to turbid water because surface clogging is almost certain to occur. If basins must be used for recharge with turbid water, they can be used in series, whereby the first basin acts as a clarifier for subsequent basins. This method requires more land, however, and is feasible only where land is readily available. Where suspended solid loads in recharge water are high, subsurface application techniques, including deep pits, shafts, and wells, are prone to failure. Unless pre-treatment measures are provided, subsurface techniques should not be considered when the source water is turbid because clogging of injection wells is particularly troublesome, and well redevelopment is costly.

c2) Chemical Quality: Recharge water should be chemically compatible with the aquifer material through which it flows and the native ground water to avoid chemical reactions that would reduce effective porosity and recharge capacity. Chemical precipitation and unfavourable exchange reactions, as well as the presence of dissolved gases, are causes for concern. Cation exchange reactions involving sodium in recharge water may cause clay particles to swell or disperse, thereby decreasing infiltration rate or aquifer permeability. Dissolved gases may alter aquifer pH or come out of solution, forming gas pockets that occupy pore space and decrease aquifer permeability. Toxic substances in excess of established health standards must not be present in the recharge water unless they can be removed by pre-treatment or chemically decomposed by a suitable land or aquifer treatment system. If artificial recharge is for drinking purpose, then the source water must conform to the drinking water standards in vogue.

c3) Biological Quality: Biological agents such as algae or bacteria may also be present in recharge water. Organic wastes may contain harmful bacteria or promote their growth and decay or organic materials may produce excess nitrate or other by-products. Growth of algae and bacteria during recharge can cause clogging of infiltration surfaces and may lead to the production of gases that further hinder recharge efforts. Although surface spreading removes most bacteria and algae by filtration before the recharge water reaches the aquifer, surface clogging can reduce the infiltration rate considerably. Injection of water containing bacteria and algae through wells is generally not recommended because it causes clogging of well screens or aquifer materials, which is difficult and costly to remedy. The quality of source water is thus vitally important wherever direct recharge techniques are contemplated. In cases where *insitu* 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 analysed and monitored to determine the type and extent of treatment required. In cases where the recharge is contemplated through spreading techniques, raw waste water can be used after primary sedimentation and secondary (biological) treatment to take advantage of filtration and bio-degradation that occurs as the water passes through the upper soil layers and zone of aeration. On the other hand, if the water is to be used for direct recharge, secondary treatment should be followed by chemical clarification (coagulation-flocculation-clarification). The water is then allowed to pass through adequate filter beds. The filtration is followed by tertiary treatment involving air tripping, granular activated carbon treatment, reverse osmosis and disinfection, in that order. The consideration of chemical quality of source water will thus lead to decisions about the extent and type of treatment required, arrangements for treatment plants and the cost of source water. In case it is not possible to ensure the desired quality standard from the treatment, such source(s) may be avoided for recharging the ground water.

Infiltration Capacity of Soil

Infiltration capacity of soil is an important factor that governs the rate of saturation of the vadose zone and thereby the efficacy or otherwise of a recharge scheme. Infiltration capacity of different soil types are done by field-tests by State Agriculture Departments and/ or the Land Use Survey Organizations. This data/ information together with maps showing infiltration rates are usually available in their departmental reports published periodically and 83 are available with the District Agriculture Officer. At the district level, this information is available in the departmental reports of the Central and State Ground Water Boards.

Aquifer Suitability

This depends mainly on storage coefficient, availability of storage space and permeability. Very high permeability results in loss of recharged water due to sub-surface drainage where as low permeability reduces recharge rate. In order to have good recharge rate and to retain the recharged water for sufficient period for its use during lean period, moderate permeability is needed. Older alluvium, buried channels, alluvial fans, dune sands, glacial outwash etc. are the favourable places for recharge. In hard rock areas, fractured, weathered and cavernous rocks are capable of allowing high intake of water. The basaltic rocks i.e. those formed by lava flows, usually have large local pockets, which can take recharge water.

Hydrometeorological Studies

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

Hydrological Studies

Before undertaking any artificial recharge project, it is a basic prerequisite to ascertain the availability of source water for the purpose of recharging the ground water reservoir. For determining the source water availability for artificial recharge, hydrological investigations are required to 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 viz.

(i) Insitu precipitation on the watershed.
(ii) Surface (canal) supplies from large reservoirs located within basin
(iii) Surface supplies through Trans basin water transfer.
(iv) Treated municipal and industrial wastewaters.

'In situ' precipitation will be available almost at every location but may or may not be adequate to cause artificial recharge but the runoff going unutilised outside the watershed/ basin can be stored/ transmitted through simple recharge structures at appropriate locations. In addition none, one or both of the other two sources may be available in any of the situations; the following information will be required:

a) The quantity that may be diverted for artificial recharge.
b) The time for which the source water will be available.
c) The quality of source water and the pre-treatment required.
d) Conveyance system required to bring the water to the recharge site.

Hydrological studies are undertaken to work out surplus monsoon run off which can be harnessed as source water for artificial recharge.

Artificial Recharge Projects

The goal of most artificial recharge projects is to convey water to the saturated zone. Evaluation of the viability of proposed projects and of the effectiveness of existing projects requires an understanding and predictive capability of their hydraulic and chemical effects. It focuses on the potential hydraulic consequences of altering the saturated flow system through artificial recharge, which are largely controlled by the geological and hydrological characteristics of the aquifer system. A combination of field, laboratory, analytical, and simulation methods generally are used to develop an understanding of the hydro-geological system as a basis for predicting potential consequences. Optimization techniques may be coupled with predictive models of ground-water flow and other processes to create an effective tool for planning and management of artificial recharge projects. Pre-project and long-term monitoring of key aspects of a flow system is an essential part of a successful management plan.

Artificial recharge projects are undertaken for many purposes in a variety of aquifer systems. Regardless of the initial distribution and trend of hydraulic heads in these systems, artificial recharge will alter these heads and associated conditions. Characterisation of the geology is important in determining the viability of an artificial recharge project, particularly where significant lateral and (or) vertical ground-water flow is required between recharge and discharge locations.

Hydrological considerations for the saturated-flow component of an artificial recharge project typically include the distribution of head and stress prior to and during project operations, hydraulic properties, the fate of artificially recharged water, and off-site effects. The prediction of saturated flow during artificial recharge projects requires information on the distribution of stress, or recharge and discharge. These stresses can include a variety of natural and artificial processes that can be measured in a variety of ways. The hydraulic properties of an aquifer system, along with the distribution of stress, determine the direction and rate of saturated flow. Given the distribution of head, stress, and hydraulic properties, simulation models can be developed to help address the fate of artificially recharged water and off-site effects. Monitoring and simulation are both used to address off-site effects; however, simulation can also be used to design an efficient monitoring network prior to full-scale implementation.

Successful planning and management of an artificial recharge project often requires consideration of many water management objectives, water routing capabilities, economics, off-site effects, as well as other factors. Optimisation techniques are designed to identify an optimal way to meet an objective given a set of constraints. The linkage of a predictive ground-water flow model with optimisation techniques, or a simulation / optimisation model, allows for simultaneous consideration of the flow system and physical and (or) economic constraints determined by water-resource managers.

Simulation / optimisation models have been applied to ground-water problems for decades and have been used to plan and manage artificial recharge projects. Monitoring of hydraulic conditions prior to and during an artificial recharge project is an essential part of a management plan, and often is an integral part of project operations. Measurement of project performance is clearly one goal of a monitoring programme. A second goal is to provide the information needed for future improvement of predictive modelling capabilities and adjustment of optimisation constraints. Reduced uncertainty in model results translates directly to increased confidence in management decisions based on these models.

Artificial recharge projects can be a valuable component of a groundwater management and conjunctive use strategy, for long-term reliability of groundwater supply, improvement of basin water quality, and for banking of water.

Methods of Artificial Recharge (Mar)

MAR 1 Direct Artificial Recharge

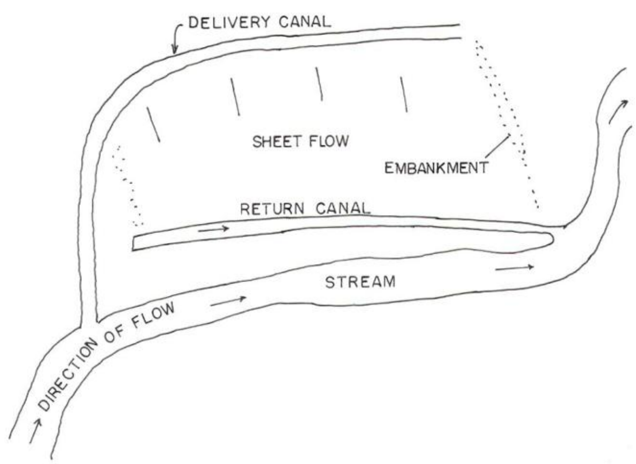
I) *Surface Spreading Techniques:* These are aimed at increasing the contact area and residence time of surface water over the soil to enhance the infiltration and to augment the ground water storage in phreatic aquifers. The downward movement of water is governed by a host of factors including vertical 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. Important considerations in the selection of sites for artificial recharge through surface spreading techniques include

i) The area should have gently sloping land without gullies or ridges.

ii) The aquifer being recharged should be unconfined, permeable and sufficiently thick to provide storage space.
iii) The surface soil should be permeable and have high infiltration rate.
iv) Vadose zone should be permeable and free from clay lenses.
v) Ground water levels in the phreatic zone should be deep enough to accommodate the recharged water so that there is no water logging.
vi) 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 flooding, ditch and furrows and recharge basins.

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



Schematics of a Contour Trench (Source: CGWB, 2007)

B) 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.

C) 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

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

D) 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, *nalah* bunds, check dams and percolation ponds.

d1) 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.

d2) Contour Bunds

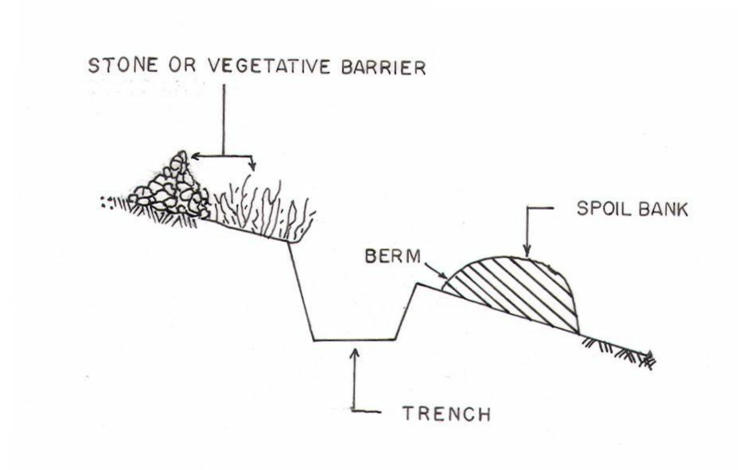
Contour bunding, which is a watershed management practice aimed at building up soil moisture storage involve construction of small embankments or bunds across the slope of the land. They derive their names from the construction of bunds along contours of equal land elevation. This technique is generally 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.

d3) 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 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.

d4) Gully Plugs, Nalah Bunds and Check Dams

These structures are constructed across gullies, *nalah*s or streams to check the flow of surface water in the stream channel and to retain water for longer durations in the pervious soil or rock surface. As compared to gully plugs, which are normally constructed across 1st order streams, *nalah* 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.



Schematics of a Contour Trench (Source: CGWB, 2007)

d5) Percolation Tanks

Percolation tanks, which are based on principles similar to those of *nalah* 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 *nalah* 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.

It is possible to have more than one percolation tank in a catchment if sufficient surplus runoff is available and the site characteristics favour artificial recharge through such structures. In such situations, each tank of the group takes a share in the yield of the whole catchment above it.

E) 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, levelling, 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.

II) ***Sub – surface technique:*** 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 as follows:

A) 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 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. 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.

B) 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.

C) Recharge Pits and Shafts

Recharge pits and shafts are artificial recharge structures commonly used for recharging shallow phreatic aquifers, which are not in hydraulic connection with surface water due to the presence of impermeable layers. They do not necessarily penetrate or reach the unconfined aquifers like gravity head recharge wells and the recharging water has to infiltrate through the vadose zone.

C1) Recharge Pits:

Recharge pits are normally excavated pits, which are sufficiently deep to penetrate the low-permeability layers overlying the unconfined aquifers. 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. *Nalah* 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.

C2) 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. Further, they are much smaller in cross section when compared to recharge pits.

MAR 2 Indirect Recharge Method

I) ***Induced Recharge:*** It is an indirect method of artificial recharge involving pumping from aquifer hydraulically connected with surface-water, to induce recharge to the groundwater reservoir. In hard rock areas, the abandoned channels often provide good sites for induced recharge. The greatest advantage of this method is that under favourable hydro-geological situations, the quality of surface-water generally improves due to its path through the aquifer materials before it is discharged from the pumping well.

A) *Pumping Wells*
Induced recharge system is installed near perennial streams that are hydraulically connected to an aquifer through the permeable rock material of the stream-channel. The outer edge of a bend in the stream is favourable for location of well site. The chemical quality of surface-water source is one of the most important considerations during induced recharge.

B) *Collector Wells*
For obtaining very large water supplies from river-bed, lake-bed deposits or waterlogged areas, collector wells are constructed. The large discharges and lower lift heads make these wells economical even if initial capital cost is higher as compared to tube well. In areas where the phreatic aquifer adjacent to the river is of limited thickness, horizontal wells may be more appropriate than vertical wells. Collector well with horizontal laterals and infiltration galleries can get more induced recharge from the stream.

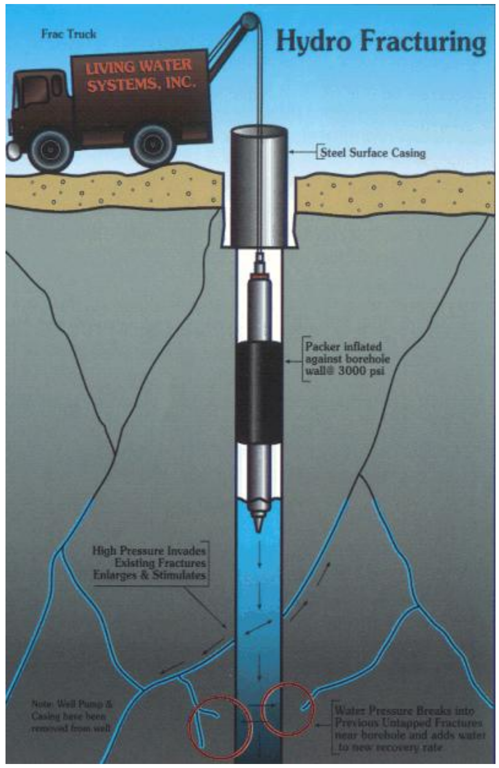
C) *Infiltration Gallery*
Infiltration galleries are other structures used for tapping groundwater reservoir below river-bed strata. The gallery is a horizontal perforated or porous structure (pipe) with open joints, surrounded by a gravel filter envelope laid in permeable saturated strata having shallow water table and a perennial source of recharge. The galleries are usually laid at depths between 3 to 6 metres to collect water under gravity flow. The galleries can also be constructed across the river-bed if the river-bed is not too wide. The collector well is more sophisticated and expensive but has higher capacities than the infiltration gallery. Hence, choice should be made by the required yield followed by economic aspects.

II) ***Aquifer Modification:*** These techniques modify the aquifer characteristics to increase its capacity to store and transmit water. With such modifications, the aquifer, at least locally, becomes capable of receiving more natural as well as artificial recharge. Hence, in a sense these techniques are artificial yield augmentation measures rather than artificial recharge measures.

A) *Bore Blasting*
These techniques are suited to hard crystalline and consolidated strata. Through hydro-geological investigation, suitable sites are fixed where the aquifer displays limited yield that dwindles or dries in winter or summer months. All the blast holes reach the depth of the aquifer required to be benefited, whether unconfined or confined. All the charges of row or circle are exploded at a time.

B) *Hydro-Fracturing*
In many cases, blasting has given indifferent results. Hydro-fracturing is a recent technique that is used to improve secondary porosity in hard rock strata. Hydro-fracturing is a process whereby hydraulic pressure is applied to an isolated zone of bore wells to initiate and propagate fractures and extend existing fractures. The water under high-pressure break up the fissures cleans away clogging and leads to a better contact with adjacent water bearing strata. The yield of the bore well is improved. In hydro fracturing, vertical fractures are initiated which inter-connects aquifers at different levels in addition to extension of existing fractures. This leads to better conditions for artificial recharge. The technique may be applied at bore well sites located in hard crystalline rock or other massive consolidated strata including metamorphic

and sedimentary formations. Generally, a bore well giving low or poor yield is treated, but the technique can also benefit other wells.



(Source: http://www.allaroundthehouse.com/hydro-fracture.gif)

MAR 3 Combination Methods

Groundwater Conservation Structures

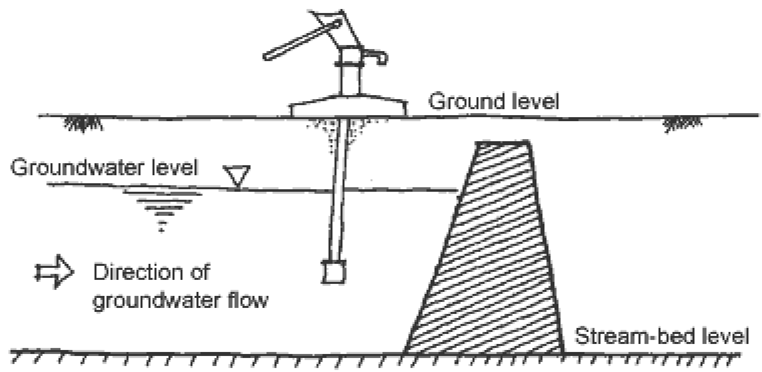
The water artificially recharged into an aquifer is immediately governed by natural groundwater flow regime. It is necessary to adopt groundwater conservation measures so that the recharged water remains available when needed.

A) *Groundwater Dams / Underground Barriers*

A groundwater dam is a sub-surface barrier across stream that retards the natural groundwater flow of the system and stores water below ground surface to meet the demands during the period of greatest need. The main purpose of groundwater dam is to arrest the flow of groundwater out of the sub-basin and increase the storage within the aquifer. The sub-surface barriers need not be only across the canal bed. In some micro watersheds, sub-surface dykes can be put to conserve the groundwater flow in larger area in a valley. Sites have to be located in areas where there is a great scarcity of water during the summer months or there is a need for additional water for irrigation. Technical possibilities of constructing the dyke and achieving large storage reservoirs with suitable recharge conditions and low seepage losses are the main criteria for sub-surface dyke. It directly benefits up-gradient area and hence care should be taken that a large number of users are not located immediately downstream.

B) *Fracture-Sealing Cementation Technique*

In many hard rock areas, the groundwater circulation to deeper levels is governed by shear, fault or fracture plane indicated by lineaments. The boreholes located on such zones prove productive but due to dissipation of the limited storage along preferred flow planes, in case of adverse topographical situation, these become dry by the end of winter or summer. Fracture-sealing cementation is a suitable water conservation measure in such situations. This measure can also be used to prevent ingress of saline or polluted water from a known source. The groundwater flow system at the site should be adequately known to establish the outflow direction and the preferred fracture planes along which the flow occurs under the influence of the natural hydraulic gradient. Under certain hydro-geological conditions, a combination of several surface recharge and sub-surface recharge methods and groundwater conservation techniques, can be used in conjunction for optimal recharge of groundwater.



Source: http://www.rainwaterharvesting.org/methods/modern/gwdia3.gif

Artificial Ground Water Recharge in Maharashtra, India

Technological developments in well construction and pumping methods have resulted in large-scale exploitation of groundwater in India and elsewhere. In many parts of India, due to the vagaries of the monsoon, and, in the arid and semi-arid regions, due to the lack or scarcity of surface-water resources, dependence on groundwater has increased tremendously in recent years. Thus, given the possibility of the available groundwater resources to be over-exploited in these areas, it is essential that proper storage and management of available groundwater resources be instituted.

Replenishment of groundwater by artificial recharge of aquifers in the arid and semi-arid regions of India is essential, as the intensity of normal rainfall is grossly inadequate to produce any moisture surplus under normal infiltration conditions. Although artificial groundwater recharge methods have been extensively used in the developed nations for several decades, their use in developing nations, like India, has occurred only recently. Techniques such as canal barriers, construction of percolation tanks, and of trenches along slopes and around hills, et cetera, have been used for some time, but have typically lacked a scientific basis (e.g., knowledge of the geological, hydrological and morphological features of the areas) for selecting the sites on which the recharge structures are located.

Various techniques for artificial groundwater recharge have been employed in the states of Maharashtra, Gujarat, Tamil Nadu and Kerala. In Maharashtra, studies were carried out on seven percolation tanks in the Sina and the Main River basins. The average recharge volume of these tanks was 50 percentage points of the capacity of the tank, provided the tank bottom was maintained by removing accumulated sediment and debris prior to the annual monsoon. Best results were obtained from systems located in areas of vesicular or fractured basalt. Canal barriers, where the recharge structure was situated within the course of the canal, was found to be most effective and economical as the surface area exposed to evaporation was, on average, 10 percentage points of that of an average-sized percolation tank. Within canal barriers, the rate of infiltration varied from 50 percentage points to 70 percentage points of the capacity of the reservoir. Infiltration was aided by a connector well linking the phreatic, alluvial aquifer at 6 metre depth with the deeper, confined basaltic aquifer at 63 metre depth, allowing the free flow of water by gravity from phreatic aquifer to the confined aquifer at the rate of 0.19 million cubic metres per year. The water level in the phreatic aquifer, which was saturated due to infiltration from the surface reservoir, was 3 metre below ground level, and the piezometric level in confined aquifer was 30 meter below ground level.

Elsewhere in India, watershed management practices adopted in some states to minimize soil loss in erosion gullies also contribute to groundwater recharge. Check dams not only store surface-water during portions of the year, but also encourage infiltration into the surface aquifers, providing a threefold benefit to communities (i.e., prevention of soil loss, provision of water for livestock watering and human use, and groundwater recharge). Such works have been implemented on an extensive scale in Gujarat, Maharashtra, Madhya Pradesh, and Rajasthan since 1960.

Operation and Maintenance

Periodic maintenance of artificial recharge structures is essential because infiltration capacity reduces rapidly as a result of silting, chemical precipitation and accumulation of organic matter. In case of surface spreading structures, annual maintenance consists of scraping the infiltration surfaces to remove accumulated silt and organic matter. In the case of injection wells, periodic maintenance of the system consists of pumping and /or flushing with a mildly acidic solution to remove encrusting chemical precipitates and bacterial growths on the well screens. The intervals between periodic cleanings can be extended by converting injection wells into dual purpose wells. However, in the case of spreading structures constructed with an overflow or outlet
mechanism, annual desilting is a must. Structural maintenance is normally carried out either by government agencies or through initiatives of stakeholders. Success of artificial recharge schemes and related developmental activities primarily depend on the cooperation of the community and hence, should be managed at the local level. From a basin management perspective, the division of a basin into many micro-catchments is, hence, an essential recognition of the community role. The success of implementation and optimal utilisation of the schemes depend on participation and active contribution of the public. Several issues are to be considered in the operation and maintenance of artificial recharge structures. These have been categorised as issues of high concern and moderate concern (ASCE, 2001). Safety, optimisation techniques and programs, value of wet-dry cycles, frequency of pond cleaning and condition of filters attached to the structures fall under issues of high concern, whereas security issues and rising ground water levels are among those of moderate concern in this regard.

Artificial recharge structures such as percolation ponds and check dams are examples of ‘wet/dry cycle’ operation (ASTE, 2001) in which the structures get filled up one or more times during monsoon and remain dry during the summer season. These structures can be maintained by removing the silt deposited at the bottom of the structure periodically. The optimal amount of cleaning would remove the accumulation of surface material that has reduced the recharge capacity of the structure.

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