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REVIEW OF ARTIFICIAL RECHARGE PRACTICES

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ABSTRACT

Development of the groundwater resources in various parts of the world has been increasing in recent years as development of surface water resources approaches its extreme point. The increasing use of groundwater for municipal, industrial and irrigation supply has emphasized the need for increasing the groundwater resources by artificial recharge. For last several years, the practice of artificially recharging the groundwater system has been quite successfully used in many developed countries and also in developing countries like India. Due to over exploitation of groundwater, a declining trend of groundwater regime has been observed in many states of India, like Gujarat, Tamilnadu, Rajasthan etc. A number of methods are practiced to achieve artificial recharge. However the selection of a particular method is governed by local topography, geological and soil conditions, the quantity, quality and availability of water to be recharged. It is, therefore, important to study various aspects of artificial recharging of groundwater for ensuring effective utilisation and controlling the declining trend of groundwater.

This report gives a reviewed summary of various developments in the field of artificial recharge of groundwater at national and international levels. Different methods of recharging have been discussed in detail with reference to their design criteria, application, and economic feasibility. Details of field applications are also provided.

1.0 INTRODUCTION

Artificial recharge is the process by which the groundwater reservoir is augmented at a rate exceeding that under natural conditions of replenishment. Any man-made scheme or facility that adds water to an aquifer may be considered to be an artificial recharge system. A large percentage of artificial recharge projects are designed to conserve water for further use. Other such projects of artificial groundwater have such objectives as control of salt water encroachment, filtration of water, control of subsidence, disposal of wastes and to assist in recovering oil from partially depleted oil fields. With the increase in population, urbanisation and in industrialisation, the water demand is continuously increasing and due to over exploitation of groundwater, in several parts of the country declining trends in the ground water levels have been observed. In such areas, there is need for artificial recharge of ground water by augmenting the natural infiltration of precipitation or surface water into under ground formations by some appropriate methods.

A variety of methods of artificial recharge have been developed including water spreading, recharge through pits, wells, and shafts etc. and pumping to induce recharge from surface water bodies. The choice of a particular method is governed by local topography, geological, and soil conditions, the quantity of water to be recharged, and the quantity and quality of water available for the purpose of recharge, and the techno-economic viability of such schemes. Often, groundwater is the only source of water in arid and semi-arid regions and natural recharge to groundwater by rainfall is not significant, especially in view of the fact that the rainfall is small as compared to evaporation for most of the year, and during the days when the rainfall exceeds evaporation and the storm intensity is sufficient to cause surface runoff, the potential water for recharge moves to locations downstream where it either gets lost by evaporation or joins the sea. The river flow reduces in dry period which can be augmented by artificially storing the increased discharge of rivers during the wet period and using it later during the dry period.

The estimated total replenishable groundwater resources of the country are 45.227 m.ha.m/year, out of which the utilisable groundwater resources for irrigation is of the magnitude of 30.284 m.ha.m/yr. At present the net draft of groundwater is 10.65 m.ha.m/yr leaving a balance of 27.635 m.ha.m/yr available for exploitation.

A report TN-10 on Artificial Recharge of Groundwater has already been prepared in 1984-85 having various aspects of artificial groundwater recharge. The present report includes the further developments in the field of artificial recharge of groundwater.

2.0 REVIEW:

A brief review of various aspects associated with artificial recharge is given in the following sub-sections.

2.1 HISTORY OF DEVELOPMENT

In India, the ground water resources are declining in certain places due to its over exploitation in uncontrolled manner. These places are mainly in the states of Gujarat, Tamil Nadu, Maharashtra, Andhra Pradesh, Punjab, Rajasthan and Haryana. In these states, studies have been taken up by Central/State Government organisations and the brief description of artificial recharge works in these states is given below.

Artificial Recharge in Mehsana Area and Coastal Saurashtra, Gujarat:

A pilot project to study the technical feasibility and economic aspects of artificial recharge to the depleted aquifers in Mehsana area, and for the control of salinity in coastal Saurashtra, Gujarat completed between 1980 and 1984 by the Central Ground Water Board. Artificial recharge works has been carried out in the coastal region of Saurashtra to check the saline water ingress into the aquifers and construction of structures such as check dams, recharge tanks, recharge wells and spreading channels etc. has been completed for the above purpose. A study to assess the impact of storage of surface water on ground water due to downward percolation from storage site in Amrali district was carried out. Artificial Recharge by injection method was made in April 1974, in the city of Ahmedabad.

Rain Water Harvesting and Artificial Recharge to Ground water in Kutch, Gujarat:

In Kutch district, 18 check dams, one percolation tank and two recharge tubewells were constructed in 1989 to store the flood flow, the storage capacity was 44715m and in 1990 two more percolation tanks with recharge tubewells were also constructed to increase the storage capacity to 127020m. This project is situated at Moti Rayan Village of Mandvi Taluk, Kutch District.

Artificial Recharge works in Maharashtra

Ground Water Surveys and Development Agencies (GSDA) has developed unconventional techniques for strengthening of drinking water sources in Maharashtra state. These techniques mainly include fracture - seal- cementation, jacketing to the existing dug wells, bore-blast-technique and hydrofracturing. In order to recharge deeper aquifer borewell injunction technique is also implemented by GSDA.

More than seven thousand percolation tanks have been constructed in Maharashtra state after the severe drought of 19971-72 and to resolve the problem for drinking water in tribal area of Maharashtra State, rock fracturing experiment is conducted to create artificial joints and fractures for storage of ground water for drinking water purposes.

Artificial Recharge Works in Haryana

Artificial Recharge studies were carried out in Ghaggar river basin, Haryana during the period of 1976 to 1978. An experiment on induced recharge was performed at Tatiana site situated on the bank of Ghaggar river in the Kurukshetra district, Haryana State. In this experiment, a test well and 4 observation wells tapping an unconfined aquifer were constructed. The static water level was 6.05 metre b.g.l. Two observation wells were constructed parallel to the river while two observation wells were constructed perpendicular to the river.

An experiment on injection well method were conducted at Dabkheri site in the Narvana branch Canal area, Kurukshetra district, Haryana. In this experiment, two test wells and four observation wells were constructed. From this injection experiment, it was concluded that i) the hydrogeological conditions of the area are suitable for the construction of injection wells, ii) in this aquifer recharge at the rate of 57.7 lps is possible and can be continued for more than 15 days or so and iii) the quality of the canal water particularly with respect to sediment load was quite suitable for injection.

Artificial Recharge Works in M.P.

An experiment of farm rain-water management at Raipur in M.P. has been carried out. This experiment is described in 6.0 (field applications).

Artificial Recharge Works in A.P.

During the last decade percolation tanks and check dams were constructed in drought affected district of Rayala Seema Region of Andhra Pradesh. An experiments on percolation channels was conducted at Mutchukota valley, Anantpur district, A.P. From the experiment it was observed that letting out water into irrigation canals and natural stream courses during non-monsoon period under certain favourable conditions and can aid ground water recharge substantially.

Artificial Recharge Works in Karnataka

Artificial Recharge works have been carried out in Karnataka state to augment the ground water. The various soil and water conservation practices such as graded bunding, contour bunding, bench terracing, level sloping, nala Bunds, farm ponds and check dams, are in vogue since long. As a drought proofing measure, tank irrigation is much in practice in the state. As on 1987, there were 40102 minor irrigation schemes in operation.

Artificial Recharge Works in Kerala

In Kerala states, 3 sub-surface dykes have been constructed, the oldest was constructed in 1963 in the EPM Industrial Estate, Ottapalam. Another sub surface dykes was constructed by CGWB in 1979 in the state seed farm, Ananganadi. The third one sub-

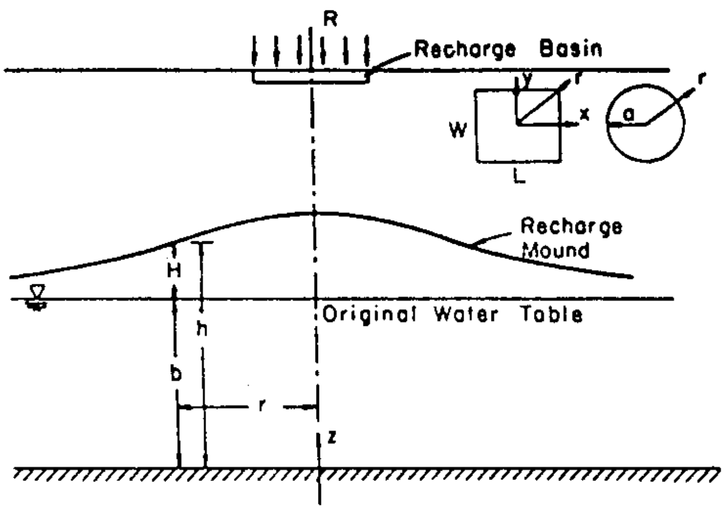

Figure 1. Definition Sketch of Artificial Recharge from Basins.

surface dyke was constructed also by CGWB in 1988 in Kerala Agriculture University. The sub-surface dyke at Ananganadi is not functioning at present due to collapse of the pumping well. The sub-surface dyke at Odakkali is functioning well and the difference in water level in the piezometers between the upstream and downstream sides as on 3-5-91 was ranging between 0.22 and 0.87 metre.

2.2 RECHARGE MOUND

Rao and Sharma (1981a) Developed a generalized analytical solution for the formation of groundwater mound in response to recharge from rectangular areas to finite aquifers has been developed. The solution does not require the use of complicated tables as in the case of infinite aquifers. Finite Fourier transforms are used to solve the linearized differential equation of groundwater flow. The results obtained from the equation are evaluated by comparison with existing numerical and analytical solutions. In stream-aquifer systems, similar to those described here, application of the solution derived in this paper is more realistic than using solutions available for infinite aquifers

Rao and Sharma (1984) Developed an analytical solution for the profile of a groundwater mound due to localized recharge from a strip basin to a finite aquifer with mixed boundaries (impermeable wall and a constant level stream, respectively) using extended finite Fourier transforms. The analytical solution was validated by comparisons with the method of images, and with numerical and experimental results. The existing expression for the inverse of the extended finite Fourier Cosine transform was corrected.

Warner, Molden, chehata and Sunada (1989) Presented seven analytical solutions that describe artificial recharge from basins. Most of these solutions are derived by directly solving the general partial differential equation for groundwater flow. The solutions differ in that they use different boundary conditions, basin shapes, and consider the nonlinearity of the artificial recharge problem differently. Use of each analytical solution is shown in this paper by application to an example problem. A comparative statement of each analytical solution was made to give suggestions on their use, their case of implementation, and their relative agreement. Although no attempt is made to conclude which analytical solution is best for all problems, some general conclusions can be stated on the applicability of the various analytical solutions. Out of the various analytical solutions presented in this paper, Glover's and Hantush's solutions for rectangular recharge basins are highly recommended. Baumann's solution for a circular basin also gave fairly reliable results and is very easy to evaluate numerically (Fig.-1).

zomorodi (1991) Presented a new method to evaluate the response of a water-table to artificial recharge. The solution is formulated in the form of a simple numerical model. The model has several advantages over the traditional methods of mounding prediction. The effect of the unsaturated zone. which modifies the recharge rate as compared with the infiltration rate, is

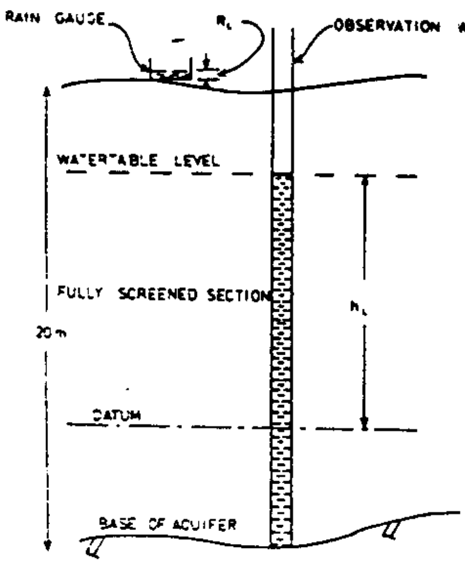

Fig. 2 Measurement of water-table level.

considered. Mounding is calculated for a variable recharge rate induced by a variable infiltration rate. The validity of the model results is illustrated using several sets of field data collected in the Ghazvin plain (Iran. Sample calculations proved that model predicts mounding more accurately than the traditional methods and. therefore, more realistic recommendations for the design and operation of artificial recharge schemes are possible using the model.

2.3 FLOW ANALYSIS

Chowdhury, Shakya and Anjaṇeyulu (1978) Carried out a theoretical analysis of the flow through a recharge well in a leaky aquifer system. The aquifer system consists of a semiconfined extensive aquifer overlain by an unconfined limited aquifer. The ground surface is considered to be water logged. Solution to the basic steady-state differential equation is presented. The solution can be used for predicting the total recharge rate when inflow through the soil surface and through the recharge well takes simultaneously.

Latinopoulos (1981) Presented analytical solutions for the groundwater flow in an unconfined aquifer under seasonal artificial recharge schemes of variable duration. The results can be used for a preliminary assessment of the response of groundwater to artificial recharge. Variations in storage and out flow from the aquifer, apart from the sitting of recharge, are also highly dependent on both the aquifer characteristics and the duration of recharge.

Viswanathan (1984) Developed a model to estimate the water table level as a function of a series of rainfall events, previous day water table levels for the determination of recharge levels of unconfined aquifer.

In this analysis, the model parameters that influence the recharge are not only assumed to be time dependent but also to have varying dependence rates. This model is solved by the use of a recursive least-squares method. The variable-rate parameter variation is incorporated using a random walk model. From the field tests conducted at Tomago Sandbeds, Newcastle, Australia, it was observed that the assumption of variable rates of time dependency of recharge parameters produced better estimates of water-table levels compared to that with constant-recharge parameters. It was observed that considerable recharge due to rainfall occurred on the very same day of rainfall. The increase in water table level was significant for subsequent days of rainfall. The level of recharge very much depends upon the intensity and history of rainfall. Isolated rainfall, even of the order of 25mm day^{-1}, had no significant effect on the water table level (Fig.-2).

Zomorodi (1990) Presented a new methodology for maximization of recharge volume using optimal intermittent operation and a multibasin system. Among the various factors that reduce the rate of recharge in an artificial recharge basin with time ; the setting of the suspended sediments in the recharge water is usually the most important. An equation is developed to represent the change of infiltration rate of turbid water with time and with the concentration of suspended sediments. This equation is further generalized to consider the effect of the basin size on the recharge rate. Optimal scheduling of consecutive recharge and dry periods is determined to result in the maximum recharge rate in the long run. A computer model is developed to provide the optimal design of an intermittent multibasin recharge (IMBR) system. The model is run using a set of real field data, and the results show that when a constant flow rate is available during the recharge season, IMBR would be a more efficient system of artificial recharge than either continuous or intermittent recharge on a single basin.

Sorman and Abdulrazzak (1993) Carried out a study to evaluate the flow process under arid an extremely arid Condition. Groundwater recharge in arid regions is intermittent and usually occurs due to flood flow transmission losses in dry wadi channels. Hydrograph characteristics are the most predominant parameters controlling the magnitude of transmission loss and subsequent groundwater recharge. The hydrograph determines the width of the wetted perimeter, depth, and time of inundation of the Wadi channel. Large variations in the magnitude of channel losses result mainly from the diversity in inflow volumes. The contribution of transmission losses to the groundwater recharge is dependent on runoff volumes and duration, soil moisture content, physical soil profile characteristics and depth to the water table. Runoff volume and duration are the dominant factors influencing the cumulative infiltrated volume and recharge to shallow water tables.
In this paper, several regression equations considering the influence of various hydrographical and channel characteristics are suggested to estimate the transmission losses from a wadi bed and the groundwater recharge.

Hunt (1985) Gives classification for the various streamline patterns that can occur when an abstraction well and recharge well placed along the same streamline in uniform seepage. When the recharge well is upstream from the abstraction well, three flow patterns are possible for the cases in which the abstracted flow rate equals, exceeds, or is less than the recharge flow rate. When the recharge well is downstream from the abstraction well, four different streamline patterns are possible. These classifications make possible the calculation of the steady - state concentration in the abstraction well in terms of the concentrations of the recharge water. The results are illustrated with a numerical example.

Nutbrown (1976) Presents some simple guide lines for assessing the response of groundwater to artificial recharge. Some simple analytic and numerical results are obtained which may be used to assess preliminary estimates of the effects of artificial recharge on the storage and flow in an unconfined aquifer. Particularly, two situations are considered. In the first, a steady-state approach is adopted to describe the longterm effects of recharge and an analytic expression is obtained giving values of the resulting increase in storage. These values compare well with model recharge experiments performed with a detailed description of groundwater flow in the Chalk of the South Downs, U.K. In The second situation, some numerical results are obtained from a transient analysis which describes the seasonal effects of recharge, both on aquifer outflow and storage. These results are relevant to the use of artificial recharge to supplement ground water storage for river regulation and direct supply purposes.

Shamsai and Marino (1992) Presented a numerical investigation of artificial recharge in multilayered, an isotropic unconfined porous media for radial flow configuration. The numerical studies, carried out with a saturated-unsaturated flow model include the simulation of experimental observations previously documented. The numerical analysis considers the effects of the initial depth of saturation, source geometry, anisotropy as well as material property and the ratio of equivalent hydraulic conductivity between layers. Once the geometry of the flow region is fixed, the shape of the flow domain, and the quantity of flow can be determined for any multilayered isotropic-anisotropic system. In multilayered anisotropic system, a higher degree of anisotropy results in a greater inflow and a higher position for the free surfaces, when the degree of anisotropy is greater than one. When the artificial recharge is to be accomplished by an infiltrometer, the Steady-state flow occurs after a substantial amount of time, depending on the hydraulic conductivity and depth to the impervious layer in the system. This study indicates that the ratio of percent increase in flow rates and percent increase in infiltrometer radii approaches unity. In multilayered isotropic system, decreasing the effective hydraulic conductivity of a layer with a thin thickness does not change the value of inflow rate, but increasing the effective hydraulic conductivity of a layer with a major depth in the system, increases the amount of flow rate significantly.

Steenhuis, Jackson, Kung and Brutsaert (1979) Presented two methods for the measurements of groundwater recharge in the region of eastern Long Island. The two methods tested, were, firstly measuring recharge with a direct application of Darcy's law in the Vadose zone and , secondly calculating recharge by closure of the hydraulic budget equation With evaporation computed from micrometeorological data.

The measurements suggest that the general estimate of 50% of annual precipitation is a long-term average at best. The measurements of recharge, which are performed during a three-year period, showed that the vertical flux past the one metre depth was strongly dependent on both the time of the year and the precipitation amount. In late fall. winter and early spring a high percentage of the precipitation became recharge. During the summer months there was a small net upward movement of water past the one metre depth. Precipitation during these months did not contribute to the annual recharge. It may be concluded that in order to estimate recharge, special attention should be given to precipitation during the winter months. A better estimate for annual recharge than the current 50% of annual precipitation might be to take approximately 75-90% of the precipitation from October 15 to may 15.

The above two methods were labour intensive and required experienced technicians. Currently one method can not be recommended above the other. Both methods give a good estimate during the year except for the winter. The closure method using micrometeorological data gives a slightly higher estimate than the direct measurement method based on Darcy's law.

2.4 WATER QUALITY ASPECTS OF ARTIFICIAL GROUNDWATER RECHARGE

LiMa and Spalding (1996) Presented a stable isotope procedure using stable isotopes of deuterium and oxygen-18 of surface and groundwater, together with anion concentrations and hydraulic gradients, to interpret mixing and flow in groundwater impacted by artificial recharge. The surface water fraction (sw-f) was estimated at different locations and depths using measured deuterium/hydrogen (D/H) ratios during the 1992, 1993 and 1994 recharge seasons. Recharged surface water completely displaced the groundwater beneath the recharge basins from the regional water table at 7.60m to 12.16m below the land surface. Mixing occurred beneath the recharge basins in the lower portions of the aquifer at relatively large distance from the recharge basin (>12.16m). Approximately 12m down gradient from the recharge basin. the deeper zone (19.15m depth) of the primary aquifer was displaced completely by recharged surface water within 193, 45, and 55 days in 1992, 1993 and 1994 respectively. A classic asymmetrical distribution of recharged surface water resulted from the recharge induced horizontal and vertical hydraulic gradients. The distribution and break through times of recharged surface water obtained with stable isotopes concurred with those of major anions and bromide in a tracer test conducted during the 1995 recharge season. This stable isotope procedure effectively quantified mixing between surface and groundwater.

Edmund, Darling, Kinniburgh, Kotoub and Mahgoub (1992) Carried out the study, in which various components of the water cycle in and around Abu Delaig a small town in a semi arid region of Sudan, have been investigated with geochemical and isotopic techniques to determine the sources of groundwater recharge. Rain samples contain significant concentrations of dissolved solids for a continental site. The heaviest rains have the lowest chlorinates, and are also the most negative isotopically. Wadi floods generally have lower chloronity than the rain fall indicating the proportionally lower amounts of dust in the more intense rain fall events. Shallow groundwaters at Abu Delaig have relatively evolved compositions (higher mg/ca ratios) compared with rainfall and wadi floods. They also have a distinctive chemistry compared with the deeper groundwaters in the region and recharge from the shallow groundwaters to the deep groundwaters is considered to be insignificant. Groundwaters in the unsaturated zone are saline and have heavy isotopes compared with rainfall, indicating strong evaporation.

It is concluded that the only significant replenishable resources at Abu Delaig are from wadi recharge during floods and that direct regional recharge is insignificant. Fluctuations in the water table, however, lead to dissolve from the lower unsaturated zone contributing to the chemistry of the shallow groudwaters. Elsewhere it is possible that wadi recharge may be a possible route for deeper replenishment, but this needs to be demonstrated by dedicated experiments.

Hoopes and Harleman (1967) Developed some analytical expressions for the temporal and spatial distributions of a dissolved, conservative substance which is injected in to the steady flow between two wells; one well is recharging the dissolved substances in to an infinite, horizontal, confined aquifer at the same rate as the other well is pumping the mixture of fresh water and substance out of the aquifer. These expressions are approximate solutions of the mass conservation equation for the substance, and they are obtained for a substance which is introduced at the recharge well either as a constant concentration of substance or as a constant rate of supply. The resulting solution are shown to be good approximations of the exact solutions through comparison with numerical solutions of the conservation equation and with experimental measurements of the distribution of a dilute salt-water tracer in a sand model. Finally, the analytical results are used to deduce the relative importance of convection, dispersion and diffusion on the substance distribution in the laboratory model and in a field problem.

Bichara (1986) Presented The laboratory experiment in which field conditions have been reproduced in the laboratory in order to investigate the fundamentals governing the mechanism of clogging of recharge wells. Dosing with water of controlled quality and temperature containing different types of added suspended solids of known size, with concentration in the range 0.5-250mg/L, was carried out in 45^0 segmental perspex models simulating confined aquifer conditions. Both filter packed and nonfilter packed wells were tested. It was found that, the lower the concentration of the suspended solids in the recharge water the greater the weight of solids required to clog the well. The filter pack has been clearly established as a major factor in controlling the clogging speed.

Janis, Lindsay, Brent and Marion (1989) Presented the results of human enteric virus movement through soil and ground water aquifers after artificial recharge using waste water. The penetration through the recharge soil of indigenous viruses from treatment plant effluent was found to be much greater than that of a seeded vaccine polio virus. Echovirus type 11th, from waste water was detected at a depth of 9.0M. in groundwater from a bore located 14M. from the recharge basin where as seed polio virus was not isolated beyond a depth of 1.5M. below the recharge basin.

Sami (1992) Carried out a study in which environmental isotope techniques and geochemical data were utilized to gain an understanding of recharge processes and groundwater salinization mechanisms in a semi arid catchments of 665 Km^2 which is underlain by fractured lower Beaufort sand stones and mudstone. Chloride and isotopic relationships suggest that chloride ions in groundwater are of meteoric origin. The recharge and salinization mechanism is, that large storm events periodically dissolve accumulated surficial meteoric salts and, after a period of evaporative enrichment at or near the soil surface, leach them in to the groundwater. Geochemical variations imply that spatial differences exist in recharge volumes, in evaporative enrichment or in the extent of leaching of surficial salts. Meteoric sodium chloride contributes greater than 90% of the dissolved sodium. except at low salinities, where cation exchange processes yield additional sodium inputs in exchange for dissolved calcium and magnesium. At high salinities this process reverses and sodium is adsorbed, releasing calcium and magnesium. This process accounts for up to 40% of the dissolved calcium and magnesium. Contribution from geochemical weathering are relatively uniform inspite of highly variable salinities.

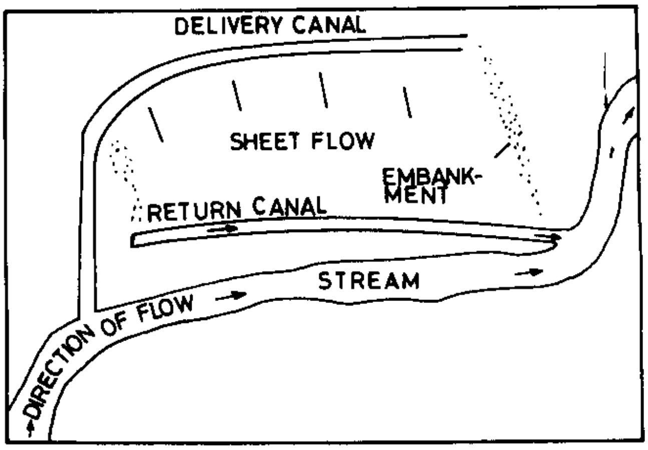

FIG.3 FLOODING TECHNIQUE OF RECHARGE

3.0 ARTIFICIAL RECHARGE METHODS

Artificial recharge methods can be broadly classified into two groups, A) direct methods, B) Indirect methods. The various artificial recharge techniques under these groups are shown in Table 3.1.

TABLE 3.1

ARTIFICIAL RECHARGE METHODS

DIRECT METHODS		INDIRECT METHODS		COMBINATION METHODS
SURFACE SPREADING TECHNIQUES	SUB-SURFACE TECHNIQUES	INDUCED RECHARGE	AQUIFER MODIFICATION	GROUNDWATER CONSERVATION STRUCTURES
1. FLOODING	1. INJECTION WELLS	1. PUMPING WELLS	1. BORE BLASTING	1. GROUND WATER DAMS\UNDER GROUND BANDHARAS
2. DITCH & FURROWS	2. GRAVITY HEAD RECHARGE WELLS	2. COLLECTOR WELLS	2. HYDRO FRACTURING	2. FRACTURE SEALING CEMENTATION TECHNIQUE (F.S.C.)
3. RECHARGE BASIN		3. INFILTRATION GALLERY		
4. RUNOFF CONSERVATION STRUCTURES (I) GULLY PLUGS (II) BENCH TERRACING (III) CONTOUR BUND (IV) NALA BUND (V) PERCOLATON TANK				
5. STREAM MODIFICATION				
6. SURFACE IRRIGATION				

(Source: Manual On Artificial Recharge Of Ground Water)

A) DIRECT METHODS

a) Surface Spreading Techniques

Ground water recharge by surface spreading techniques involves the passage of water from the surface of the soil through the non-saturated zone of the soil and geological strata to the saturated part of the aquifer. The surface spreading techniques can be grouped again under five different methods which are described below:

i) Flooding

This method involves spreading of surplus surface water from canals/streams over large area for sufficiently long period of time so that it recharges the ground water body. This technique is very useful in selected areas where favourable hydrogeological situation exists for recharging the unconfined aquifer. Figure 3 shows the method by which the surplus canal/stream water is diverted through a delivery canal and released as sheet flows over the permeable soil of the area,

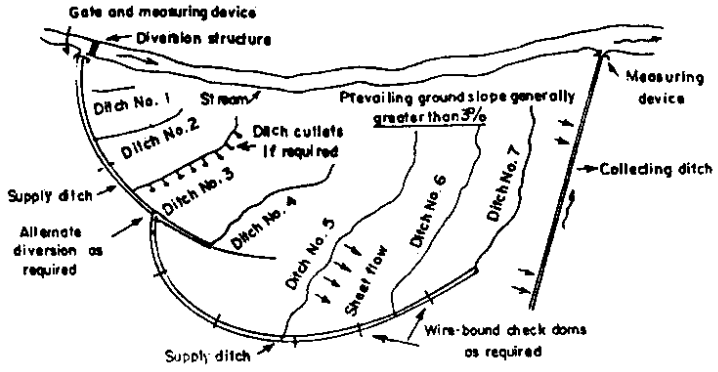

Fig. 4 DITCH AND FURROW METHOD

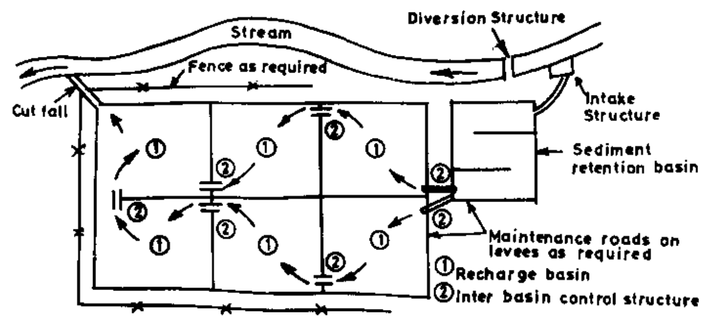

Fig. 5: LAYOUT OF RECHARGE BASINS

where it is required to be recharged.

The water conserved in the ground water storage can be pumped for augmenting the canal supplies during summer. This method is the least costly of all water spreading methods and cost of maintenance is also low.

ii) Ditch and Furrow Method

This method is suitable for irregular terrain as in such areas preparation of basins is not so easy. In areas with irregular topography, shallow, flat bottomed and closely spaced ditches or furrows provide maximum water contact areas for recharge water from surface stream /canal. The silting problem is less critical in this method. Fig. 4 shows a typical plan of ditches originating from a supply ditch. Generally three patterns, namely lateral ditch pattern, dandritie pattern and contour pattern, of ditch and furrow method are adopted.

iii) Recharge Basins

This method involves the spreading of water over the recharge basins. Recharge Basins are either excavated or enclosed by dykes or levees. Basins are commonly prepared parallel to stream channels. They can also be constructed at other locations where other sources provide the source water. In alluvial areas multiple recharge basins are generally constructed parallel to the stream. Fig.5 shows the lay out of recharge basins. The use of multiple basin system is advantageous than single basin system.

The water contact area in this method is quite high, i.e. from 75 to 90% of the total recharge area. In this method efficient use of space is made and the shape of basins can be made suited to the terrain conditions and the available space.

iv) Runoff Conservation Structures

In areas having low to moderate rainfall and not having any other water transferred from other areas, it is necessary to construct runoff conservation structures. A package of multipurpose measures, mutually complimentary and contributed to soil and water conservation, afforestation and increased agricultural productivity is desirable. The widely used structures are i) Gully plug, ii) Bench terracing, iii)Contour Bund, iv) Nala Bund, and v) Percolation Tank.

Gully Plug : Gully plugs are the smallest runoff conservation structures built across small gullies and streams rushing down the hill slopes carrying drainage of tiny catchments during rainy season. These are made by local stones, earth and weathered rock, etc.

Bench Terracing: Bench Terracing are suitable for sloping lands with surface gradient upto 8% and having adequate soil cover. It helps in soil conservation and holding runoff water on terraced area for longer duration giving rise to increased infiltration recharge. The minimum soil thickness required for terracing under

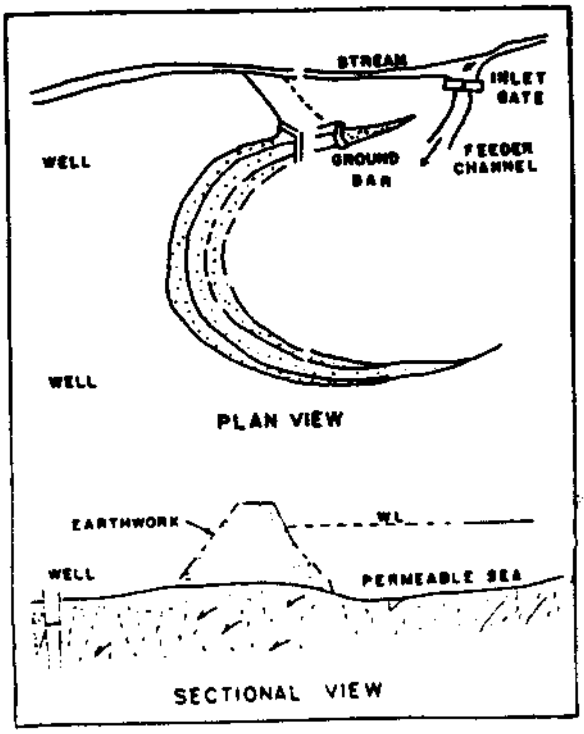

Fig.6 SCHEMATIC DIAGRAM OF PERCOLATION TANK

different land slopes is as under.

Table 3.2 : Land Slope Vs Soil Thickness

Land slope %	Soil and Weathered strata thickness required (m)
1	0.3
2	0.375
3	0.45
4	0.525
5	0.600
6	0.75
7	0.75

(Source: Manual on Artificial Recharge of Ground water)

Contour Bunding: Contour Bunding is a watershed management practice to build up soil moisture storage. This technique is adopted generally in low rainfall areas. In this method runoff is impounded between two contour Bunds of equal elevation made on sloping grounds. The spacing between two contour Bunds depends on the slope of the area and the permeability of the soil. Lesser the permeability of soil, the closer spacing of Bunds is desirable.

Nala Bund: It is a series of small Bunds or weirs made across selected nala sections to retain the flow of surface water in the stream channel on pervious soil surface for longer period of time. As compared to gully plugs, nala Bunds are constructed across bigger nalas in areas having gentler slopes. A nala bund acts like a mini percolation tank.

Percolation Tanks: In areas where uncultivable land of sufficient permeability for sub-surface percolation is available in and around the stream channel section, small tanks are created by making low elevation stop dam across the stream as shown in fig 6. These are similar nala Bunds, but difference is in the larger size of the reservoir area. These can also be located adjacent to the stream by excavation and connecting it to the stream through a delivery canal (Fig.-6). These percolation tanks creates artificially, submergence of surface water bodies in a highly permeable land area so that the surface runoff is made to percolate and recharge the ground water storage.

v) Stream Channel Modification

The natural drainage channels can be modified with a view to increase the infiltration by detaining the stream flow and increasing the stream bed area in contact with water. Usually the streams zigzags through wider valley flat and occupy only a small width. The channel is so modified that the flow gets spread over wider area, increasing contact with percolating river bed. This method includes widening, levelling, scarifying or ditching of

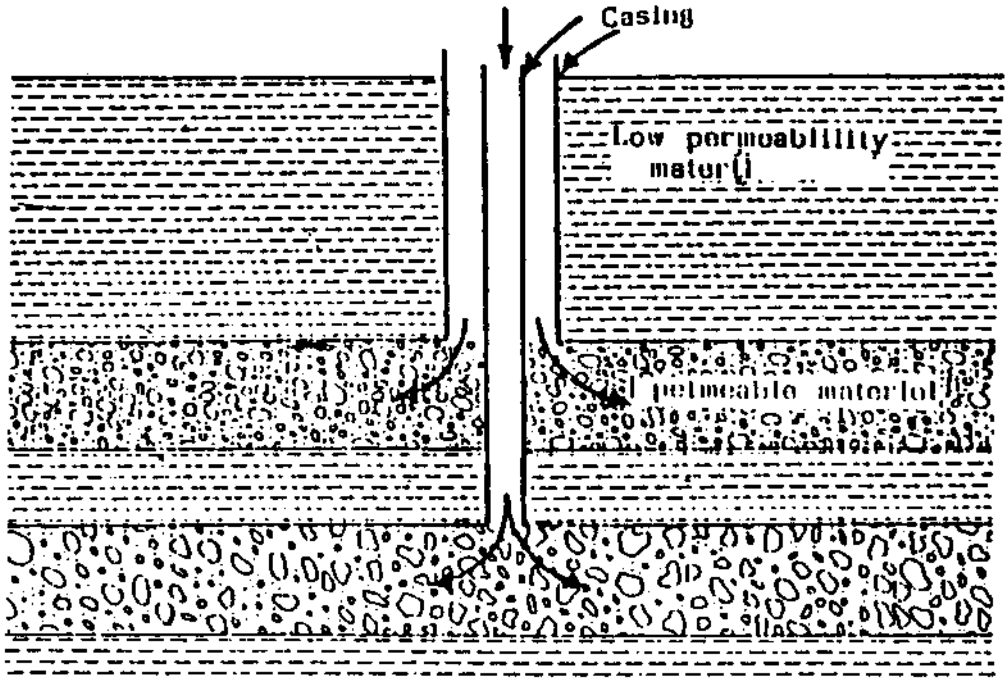

Fig. 7 INJECTION WELL TECHNIQUE

the stream channel, and L-shaped finger levees or hook levees constructed at the end of high stream flow season.

vi) Surface Irrigation

Normally, under well managed modern irrigation practices, a measured dose of irrigation water is provided to the fields to avoid excess seepage losses (unintended recharge). However, under irrigation practices prevalent in this country, the farmers tends to use excessive dose of irrigation by flooding the fields whenever water is available. The large number of unlined main canals and distribution network also contribute significantly to ground water recharge. In many development blocks located in Indo-Genetic alluvial plains, the recharge from surface irrigation forms a much bigger component of ground water budget as compared to recharge from precipitation.

b) Sub-Surface Techniques

When deeper aquifers are overlain by impervious layers, the infiltration from surface can not recharge the sub-surface aquifer under natural conditions. The techniques adopted to recharge the confined aquifers directly from surface water source and grouped under sub-surface recharge techniques. The most widely practiced methods are (i) Injection wells, ii)Gravity head recharge wells, iii) Connector wells, and iv) Recharge Pits and Shafts.

i) Injection Wells

These are structures similar to a tubewell used to augment the groundwater storage of a confined aquifer by 'pumping in' treated surface water under pressure. These are also proved to be advantageous to recharge the depleted aquifer when land is scarce, as in urban areas. Artificial recharge of aquifers by this method is also done in coastal areas to check the intrusion of sea water and to overcome the problem of land subsidence in areas where confined aquifers are heavy pumped. In alluvial areas injection wells recharging a single or multiple aquifers can be constructed similarly as a normal gravel packed pumping wells. Fig.7 shows typical injection well in alluvial areas. In hard rock areas casing and well screen may not be required.

ii) Gravity recharge wells

In addition to specially designed injection wells, ordinary borewells, tubewells and dug wells used for pumping may also be alternately used as recharge wells, whenever source water becomes available. In certain situations such wells may also be constructed for affecting recharge by gravity inflow. In areas of heavy ground water exploitation the dug wells often gets partially or fully dried up. The rock material exposed in the open well is permeable and the unsaturated horizon of phreatic aquifer can be good repository of water if recharged from surface water.

College of Agriculture, Indore has tried to utilise the open wells in Agriculture College Campus for artificial recharge of phreatic aquifer. The excess water from field channels is

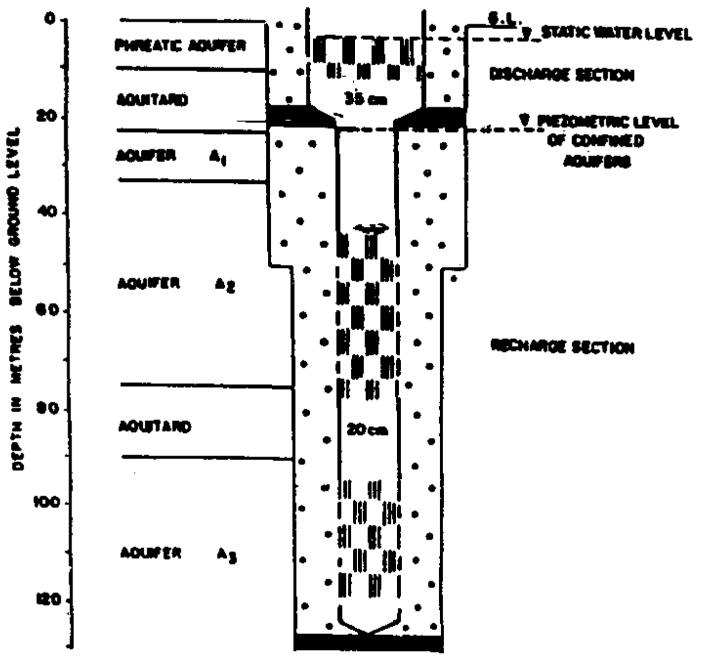

Fig. 8 CONNECTOR WELL AT KAMLIWARA, GUJRAT

diverted to the dug wells. Also, the rain water collected on the roof of the college building was collected and diverted by pipe line to dug well. The effort was made in small way to conserve the surface and rain water and recycle to the phreatic aquifer.

iii) Connector Wells

In recharge areas with multiple aquifer systems, often it is observed that the deeper aquifers have lower piezometric head than the overlying aquifers separated by impermeable confining layers. Connector wells are special types of recharge wells where due to difference in potentiometric head in different aquifers, water can be made to flow from one aquifer to other without any pumping.

For example, in Mehsana district, Gujarat, connector well constructed at site Kamliwara (fig.8) demonstrates the technique. The phreatic aquifer had water table between 2 to 4 metre below ground level. Where as the potentiometric head in deeper confined aquifers ranged between 18 to 35 metre below ground level. The deeper aquifers were recharged from the phreatic aquifer by a connector well.

iv) Recharge Pits and Shafts

Recharge pits are structures which overcome the difficulty of artificial recharge of phreatic aquifer from surface water sources. This method is used where impermeable layer or lenses form a barrier between the surface water and water table. recharge pits are excavated of variable dimensions to penetrate less permeable strata. The recharge pits differ from recharge wells in that they do not necessarily reach the unconfined aquifer and the recharging water has to infiltrate through the vadose zone. In alluvial areas abandoned gravel pits or brick kiln quarry pits, if underlain by permeable strata can serve as recharge pits.

Where the water table aquifer is located deep below land surface, and overlain by poorly permeable strata, a shafts used for causing artificial recharge. It is similar to a recharge pit but much smaller in cross section.

(B) INDIRECT METHODS

These are explained by the following methods.

a) Induced Recharge

It involves pumping from aquifer which hydraulically connected with surface water, to induce recharge to the ground water reservoir. When the cone of depression intercepts river recharge boundary a hydraulic connection gets established with surface source which starts providing part of the pumpage yield. In hard rock areas the abandoned channels often provide good sites for induced recharge. The greatest advantage of this method is that the quality of surface water generally improves due to its path through the aquifer material before it is discharged from the pumping well. This technique was successfully adopted at temple town of Bhadrachallam in A.P. during 1987 to provide safe drinking water to about 2 to 3 lakh pilgrims.

i) Induced Recharge through connector wells and infiltration galleries.

These wells are constructed for obtaining very large water supplies from river bed, lake bed or water logged areas. In areas where the phreatic aquifer adjacent to the river is of limited thickness, horizontal well may be more appropriate than vertical wells. Collector wells with horizontal laterals and infiltration galleries can get more induced recharge from the stream. Hundreds of such wells are operating in Europe and USA with discharges varying from 2000 to 6000 lpm. In India such wells have been installed in Yamuna bed at Delhi and other places in Gujarat, Tamil Nadu and Orissa. These wells become economical with large discharges and lower lift head even if initial capital cost is higher as compared to tubewell. Table 3.3 gives details of collector wells installed in India.

Infiltration galleries are also used for tapping ground water reservoir of river bed strata. The gallery is a horizontal perforated or porous structure (pipe) with open joints, surrounded by a gravel filter envelop laid in permeable saturated strata having shallow water table and a perennial source of recharge.

TABLE 3.3

Details of some radial water collectors installed in India.

Sl. No.	Name of river	Owner of collector well	Length of laterals m	Saturated thickness m	permeability m\day	Width of slots m	Discharge m\day
1.	Mahisagar (Baroda)	Gujarat Refinery	400	12	432	6	45000
2.	Mahisagar (Baroda)	Gujarat Refinery	200-top 200-lower	27	432	6	31500
3.	Mahisagar (Baroda)	Baroda Municipal Corporation	550	17.5	336	6	54000
4.	Tapti (Surat Gujarat)	Baroda Rayons	600	16	384	6	40500
5.	Jammu (Delhi)	Delhi Muni cipal Corp oration	600	16	60	3	18000
6.	Vaigai (Madurai Tamil Nadu)	Tamil Nadu Water Board	600	6	120	3	22700
7.	Nagavalli (Rayagade Orissa)	J.K. Industries	600	6	360	6	22500
8.	Sabarmati (Ahmedabad)	Ahmedabad Municipal Corporation	550	13.5	131	6	36000

For a length of 550m assuming 10 radial directions, the length of lateral will be 55m, which may start buckling during driving. On the other hand if the laterals are driven in two tiers in staggered rows, the force required for driving (a shorter lateral) will be less and also the hydraulic gradient and hence the flow efficiency will improve.

(Source: Manual on Artificial Recharge Of Ground Water)

(b) Aquifer Modification Techniques

These techniques modify the aquifer characteristics to increase its capacity to store and transmit water. With such modifications the aquifer, atleast locally, becomes capable of receiving more natural as well as artificial recharge. The two most popular techniques used to improve yield characteristics of a well are (i) bore blasting, and (ii) hydrofracturing.

(i) Bore Blast Techniques (BBT)

Bore Blast Techniques are adopted to create more storage space for ground water artificially in massive and crystalline hard rocks by fracturing the bed rocks. Hydrological survey is carried out to locate such area where the rock can be blasted to develop cracks below the zone of weathering. Suitable type of

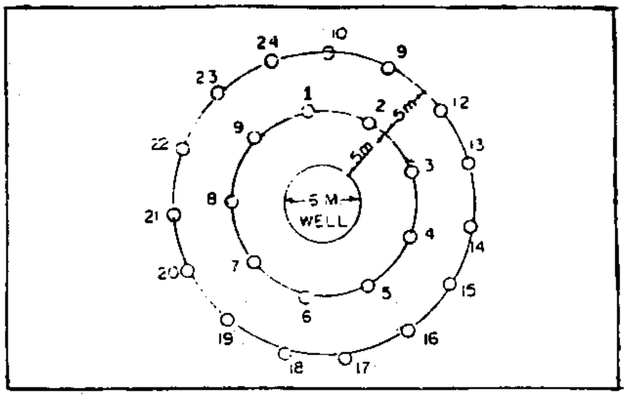

Fig. 9 - Plan showing the bore blast technique

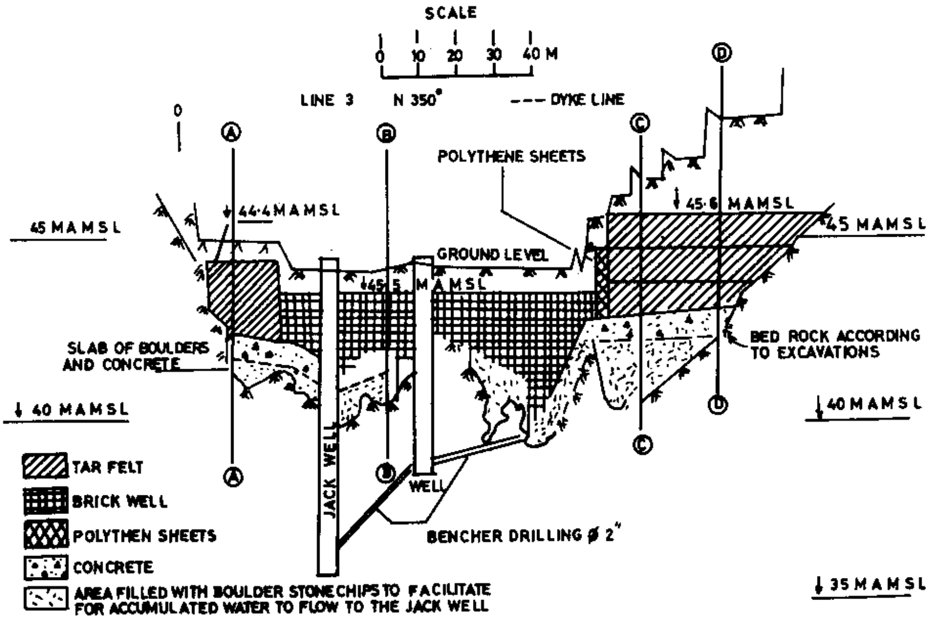

FIG. 10: GROUND WATER DAM ANANGANADI SEED FARM, KERALA

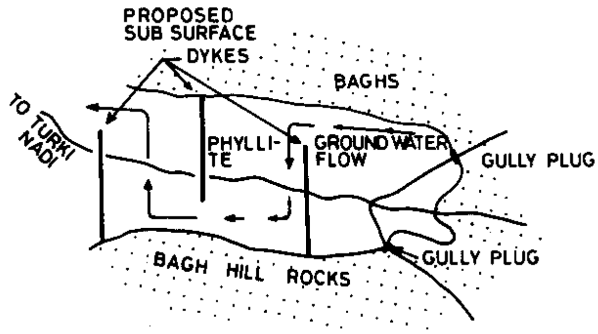

FIG. 11: SUB-SURFACE DYKES AT JAMNI, DISTRICT JHABUA (M.P.)

slurry explosives is lowered in the boreholes and is blasted using detonating cord and electrical detonators. At a time about 5-6 boreholes are blasted. This technique is applied in assured rainfall areas and where landform are mostly hilly.

At sites Ambade & Kurangwadi in Bhar Tehsil, District Pune the village required tanker water supply in summer. Since the application of bore blast techniques around water supply wells in 1989, the wells are able to meet drinking water demand throughout the year. The Groundwater Surveys and Development Agency (GSDA), Maharashtra, call this technique as Jacket well, because a jacket of better aquifer is created around a water supply well. This technique is shown in Figure 9.

(ii) Hydrofracturing

This technique is applied for improvement of poor yielding or unsuccessful borewells. In this technique very high hydraulic pressure is applied to an isolated zone of borewells to initiate and propagate fractures and extend existing fractures. This very high pressure is responsible for opening the closed or sealed fractures and further connecting it to nearby water bodies. In hydrofracturing vertical fractures are initiated which interconnects aquifers at different levels in addition to extension of existing fractures. In this way borewell yield is improved substantially.

3.1 Ground Water Conservation Techniques

After artificially recharging the water, it starts seeping away from recharge site in response to the modified ground gradient and the transmissivity of the aquifer. If the recharged water seeps out of the watershed faster, it may not remain available for exploitation when required, thus defeating the purpose of artificial recharge. Therefore side by side, it is necessary to adopt ground water conservation measures. The known techniques of ground water conservation are (i) ground water dams/ under ground Bandharas (unconfined aquifers) and ii) fracture sealing cementation technique (deeper aquifer).

(i) Groundwater Dams

A groundwater dam is a sub surface barrier across stream which retards the natural ground water flow of the system and stores water below ground surface to meet the demands during the period of greatest need. In Maharashtra the ground water dams are called as underground Bandharas and are widely used as water conservation measures. The CGWB had also constructed ground water dams at Govt. seed farm, Ananganadi in Palghat district (Fig. 10).

In some micro watersheds sub surface dykes can be put to conserve the ground water flow in larger area in a valley. Figure 11 shows a set up of the sub surface dykes at side Jamni, in Jhabua district, M.P.

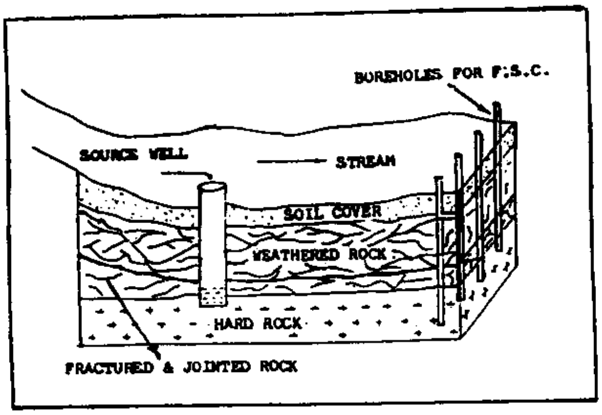

Fig. 12 - Schematic diagram of fracture seal cementation technique

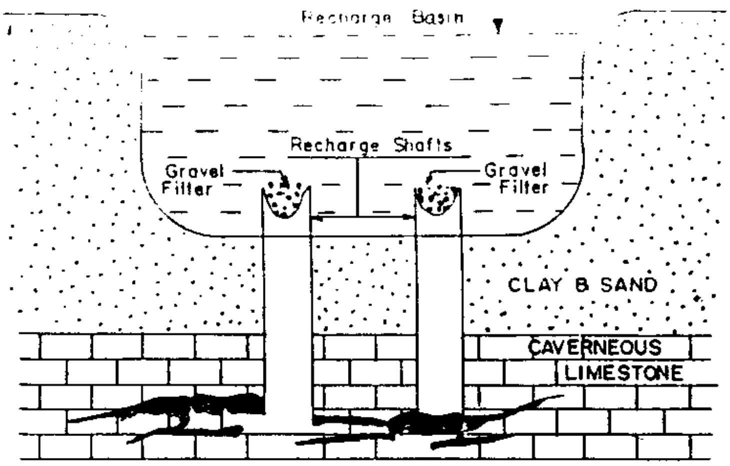

Fig. 13 .RECHARGE BASIN WITH RECHARGE SHAFTS

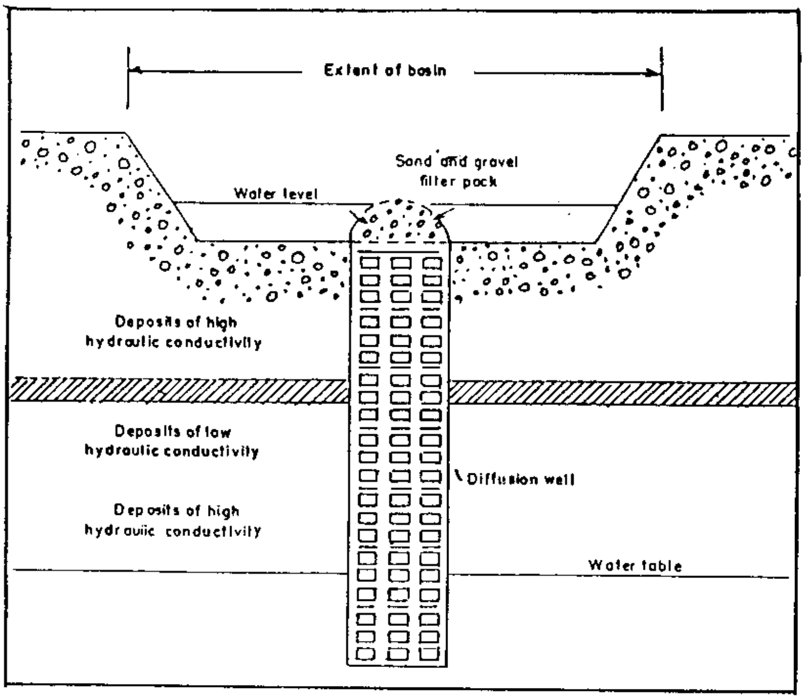

Fig 14 RECHARGE BASIN WITH A DIFFUSION WELL

(ii) Fracture Sealing Cementation Techniques (FSC)

This technique is used to arrest the ground water migration through a net work of shallow depth aquifer from the discharging location. It is suitable in disintegrated rock combined with fractures and granular porosity. After identifying the suitable area on the basis of geohydrological investigations, this technique is adopted. Under this process, normally one or two rows of suitable diameter boreholes are drilled to a depth of a little more than the deepest dugwells in the command area of stream or nala. These rows across the stream are filled with quick setting cement under high pressure for sealing of existing fractures. This technique is useful to create an effect of 'cut-off-walls' or 'underground bandharas'. These measures can also be used to prevent ingress of saline or polluted water from a known source (Fig. 12).

3.2 COMBINATION OF METHODS

Under certain hydrogeological situation a combination of several surface and sub-surface recharge methods and ground water conservation techniques, can be used in conjunction with one another for a optimum recharge of ground water resources. the selection of method for combination is governed by the site specific situation. A few commonly adopted combination techniques are described below.

(i) Recharge Basin with Shafts

At some location of recharge basins the rock exposed on the bottom of the basin are not permeable enough to allow the stored water to infiltrate at a fast rate. In such cases, it is advantageous to construct the recharge shaft at the bottom of the basin. Figure 13 shows the section of a recharge basin with recharge shafts.

Such system of combination of surface and sub surface method may incorporate large diameter pre-cast perforated concrete cylinder installed below a less permeable zone at the base of recharge basin. Such structures are also called Diffusion wells (Fig.-14).

(ii) Induced recharge with connector wells

In areas adjacent to perinnial rivers if multiple aquifer system exists, the deeper aquifer can be pumped heavily to induce recharge from the river. When the deeper aquifer is pumped heavily, the decline in water level creates a piezometric head for flow of water from shallow aquifer to the deeper aquifer. The shallow tier of collector well can recharge the depleted aquifer from the phreatic aquifer which in term is receiving induced recharge from river.

iii) Combination of ground water dam and connector well

An experiment on combination of sub-surface dyke for conserving ground water outflow, with connector wells at the bottom of sub-surface reservoir for recharge of deeper aquifer

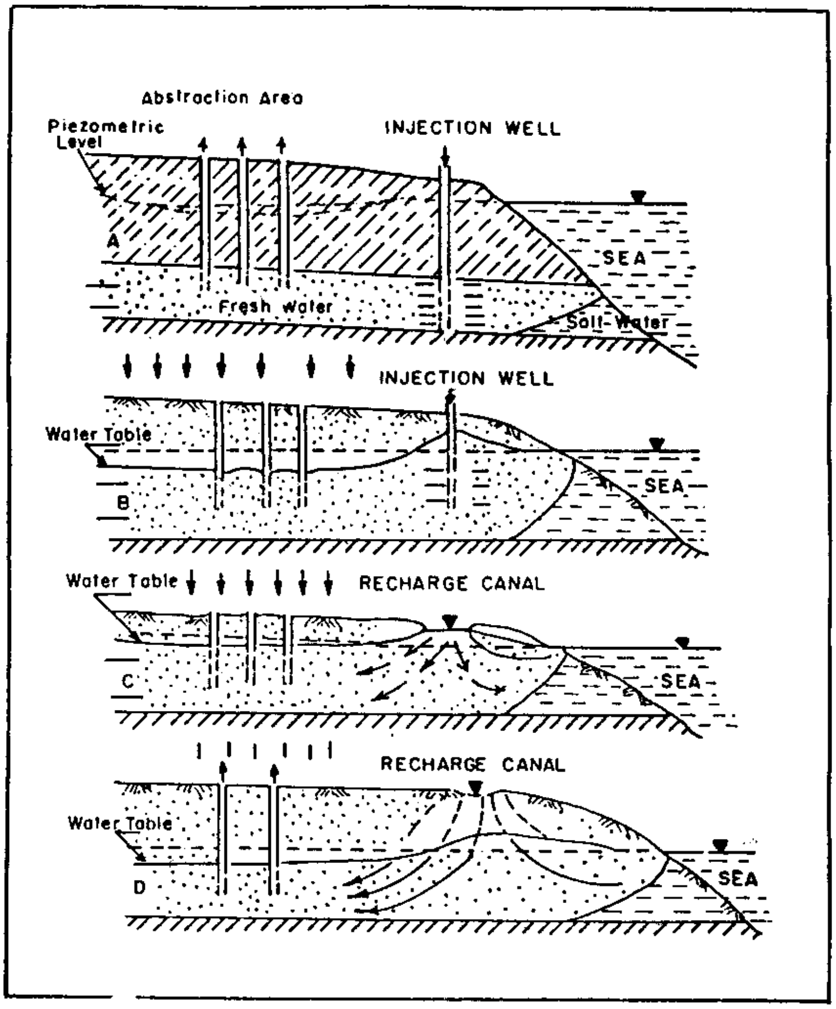

Fig. 15:
METHODS FOR CONTROL OF SEA WATER INTRUSION

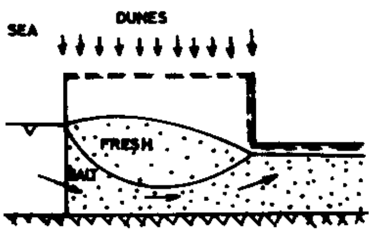

FIG.16a: FRESH WATER LENS IN DUNE AREA

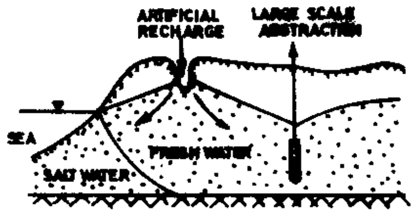

FIG 16b:FRESH WATER BARRIER IN COASTAL AQUIFER

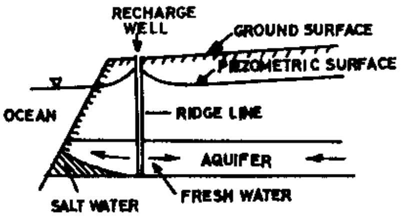

FIG16c:CONTROL OF SEA WATER INTRUSION BY PRESSURE RIDGE PARALLALING THE COAST

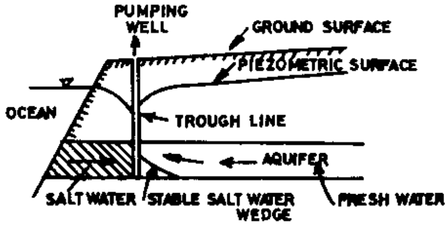

FIG16d:CONTROL OF SEA WATER INTRUSION BY A PUMPING TROUGH PARALALLING THE COAST

is demonstrated at Rayan village in Kutch district, Gujarat. A sub-surface dyke of 55 feet was made across Deerwala chela stream having a width of 233 feet. Four connector wells with slotted well assembly having depth ranging from 90 to 125 feet were constructed from the bottom of the dyke to recharge the deeper aquifer.

(iv) Ground Water Conservation Structures in Combination with bore blasting techniques

In certain adverse situations for augmentation of drinking water supply in Maharashtra a number of ground water conservation structures like underground bundhara and fracture sealing cementation techniques are used in conjunction with jacket wells constructed on upstream side of river.

3.3 ARTIFICIAL RECHARGE METHODS IN COASTAL AREAS

The artificial recharge in coastal aquifers is required for the following purposes: (i) to control the sea water intrusion, (ii) to reduce the rate of decline of ground water levels, and (iii) to reduce or arrest the land subsidence. In addition of the above, the practice of artificial recharge of ground water may also help in, renovating waste waters, reducing flood flows, improvement in ground water quality and conservation of fresh water underground.

i) Methods for Control of Sea Water Intrusion

Sea water intrusion can be controlled by artificially recharging the intruded aquifer by surface spreading methods, and injection well methods. Artificial recharge of ground water produces a hydraulic barrier to the sea water intrusion. Fig. 15(a) shows a case of confined aquifer where the recharge through injection wells keeps on check the advancement of sea water interface towards land. Fig. 15(b) shows a case of phreatic aquifer where the mound developed in water table due to recharge through injection wells control the sea water intrusion and Fig. 15(c&d) shows artificial recharge through recharge canal closed to the shore. The pressure built up due to recharge controls the ingress of sea water.

The other effective methods for controlling intrusion are b) creation of a fresh water ridge above sea level along the coast. c) development of pumping trough adjacent to the coast, and d) construction of artificial sub-surface barrier.

b) Creation of Fresh Water Ridge

In the dune areas, in the coastal track, natural recharge by rainfall builds a fresh water pocket (Fig.16,a). In many cases, this pocket does not reach down to impervious base resulting the flow of sea water below this pocket. This sea water flow could be prevented by increasing the fresh water supply with artificial recharge (Fig.16,b). In an unconfined aquifer surface spreading could create a water table ridge. But in a confined aquifer, a line of recharge wells paralleling the coast could form a ridge in the piezometric surface (Fig. 16,c).

c) Development of Pumping Trough

In the dune areas natural rainfall is lost to the bounding salt water aquifers. Recovery of fresh water in the dunes remains possible by developing a pumping trough. If a line of wells are constructed adjacent to and paralleling the coast, pumping would form a trough in the ground water level and the gradients created would limit sea water intrusion to a stationary wedge in land of the trough as shown in Figure 16 d, for confined aquifer. Owing to its high installation and operational cost, the method has very little application.

d) Construction of Sub Surface Barrier

To break the contact between fresh and salt water, an artificial barrier is constructed so as to close the aquifer near the sea to store the fresh water and to prevent it from being wasted. An impervious sub-surface barrier may be constructed by using clay, silt, cement, sodium silicate etc. The salt water pocket on the inland side may be pumped out after the construction of the barrier. In shallow coastal aquifers, trenches may be excavated and then back filled with controlled compact soils to form a cut-off wall.

(ii) Control of Land Subsidence

The land subsidence in coastal aquifers occurs due to excessive ground water pumpage. Artificial recharge of depleted ground water reservoir, from surplus water, or recycling of waste water after proper treatment, can greatly help in increasing the hydraulic heads of the aquifers and drive water back into the aquitards which can in turn help in restoring the original stability of the land surface. An injection well experiment in Wilmington oil field in Long Beach, California, succeeded in a modest rebound of the coastal aquifers which were showing effect of land subsidence.

4.0 PLANNING AND DESIGN OF ARTIFICIAL RECHARGE PROJECTS

Over development of the ground water resources results in declining ground water levels, Shortage in water supply, and intrusion of saline water in coastal areas. In such areas, there is urgent need for augmenting the ground water resources to control the continuous decline in ground water level. It can be done by planning and executing an artificial recharge project in the region. The planning process includes the selection of suitable recharge site and recharging method.

Various factors that need to be considered for the selection of a recharge site and method are being described as below.

4.1 SELECTION OF RECHARGING SITE

It involves the consideration of the following factors

i) -Availability of land and topography
ii) -Hydrogeological conditions
iii) -Possible sources of water for recharge
iv) -Operation and maintenance problems
v) -economic considerations

i) Availability of land and topography

To achieve the objectives of artificial recharge project, it is imperative that the site selected for recharge satisfies the basic requirements of storage and retrieval. Thus proper scientific investigations should be carried out for the selection of site for artificial recharge of ground water.

Generally, it is considered better to choose flat or gently sloping land for artificial recharge purposes especially if the spreading methods are adopted. Topographical map, low altitude aerial photographs and information collected during the site visits are useful for site selection and its suitability for artificial recharge.

ii) Hydrogeological conditions

The detailed knowledge of geological and hydrological features of the area is necessary for selecting the site and type of recharge. Particularly, the parameters/data to be considered are - geological boundaries, hydraulic boundaries, inflow and outflow of waters, storage capacity, porosity, hydraulic conductivity, transmissivity, natural discharge of springs, natural recharge, etc. Generally, the suspended material in water (Silt, clay, or organic particles etc.) accumulates at the bottom of the basin and thus reduce the infiltration rates even by 50% in some cases. Thus, the hydraulic conductivity of bottom soil largely governs the maximum sustained infiltration rates in infiltration basins. The soils having coarser texture due to higher sand silt fractions have markedly higher infiltration capacity as compared to highly clayey soils which are poorly permeable. The land use and extent of vegetal cover also determines infiltration capacity. Barren lands are poor retainers of water as compared to grass lands and forested tracks. Similarly, the ploughed fields facilitate more infiltration as compared to barren fields not tilled. In general, the organic matter treatment of soils improves its infiltration characteristics but impede deeper percolation. The degree of compaction of soil surface also affects the infiltration rates.

The hydrogeologic conditions of sub-strata control percolation rate, down below once the water has infiltrated from soil surface. The percolation rates will be high in coarse textured and more permeable surface deposits. The higher the specific yield, transmissivity, hydraulic gradient and thickness of sub surface aquifers, the more will be the percolation rates. The percolation rates also affected by presence or absence of impermeable layers or lenses that can impede percolation. Aquifers best suited for artificial recharge are those which absorb large quantities of water and do not release them too quickly, it imply that the vertical conductivity is high, while the horizontal hydraulic conductivity is moderate. Most of the existing recharge areas are located in alluvial plains, as such structures are favourable to groundwater storage both from the point of view of the availability of infiltration waters and transmissivity of the aquifer. Coastal dunes and deltaic areas are often very favourable for artificial recharge schemes. Large sedimentary hydrogeological basins dominantly contain artesian aquifers which can store large volumes of water.

In general, the areas where water table levels were substantially lowered by any reason, are first selected for artificial recharge projects and then the land acquisition process begins which involves land surveys, mapping, negotiations for purchase etc.

iii) Possible sources of water for recharge

For the purpose of artificially recharging the ground water, the basic requirement is to obtain water in adequate amounts and at the proper times. The source of water for recharging purpose may include local surface water, water brought from other regions known as imported water and reclaimed water. Some schemes involve the impoundment of local storm run-off, which is collected in ditches, basins or behind dams, after which it is placed into the ground. Each source of water should be considered in terms of cost of water, location relative to recharge site, quantity and quality. During the planning stage of an artificial recharge project, it is necessary to ensure that the quality of source water should be such that it meets the water quality standards for end use. The quality of source water is important in recharge of confined aquifers. Sampling of the quality of source water should include determination of mineral and inorganic constituents, physical characteristics, organic chemicals and other pollutants and suspended sediment concentrations.

iv) Operation and maintenance problems

The problems which arise as a result of recharge projects, are mainly related to the source water available for recharge and to the changes in the soil structure and the biological phenomena which take place when infiltration begins and to the changes to the environmental conditions. The common problems that arise during the execution of a artificial recharge project are listed below.

a) Silting of Spreading basin

A major requirement for water to be used in recharge projects is that it be silt free. The silt content of river depends upon the type of soil in the area of run-off, the vegetative cover of this area, its topographic slopes and especially intensity of rainfall. It is beneficial to use retention basins to reduce silt load to a level acceptable for spreading operations. Chemical flocculants are some times used to speed up the setting process. The silt load can be removed by scrapping and harrowing the ground surface.

b) Maintenance of recharge rates

Maintenance of recharge rates may involve water treatment, use of retention basins, use of filter beds, periodic drying of basins and then scrapping of basins for silt removal. The recharge rates are assessed by continuously monitoring water inflow. Clogging by biological activity depends upon the mineralogical and organic composition of the water and basin floor and upon the grain size and permeability of the floor. The only feasible method of treatment is thoroughly drying the ground under the basin after short period of operation (about one month).

In case of injection method of recharge, air bubbles which are sucked into the well through the injection pipe produce violent vibration when they finally escape upwards may cause damage to the well. The possibility of air passage must therefore be completely eliminated. To prevent clogging of injection wells the recharge water has to be properly treated. Clogging by corrosion can be reduced by using non-corrosive materials in pipe lines and casing. Chlorination of recharge water can be done to prevent development of bacterial growth. Periodic redevelopment of wells, involving surging, swabbing and pumping can be helpful for efficient running of injection wells.

c) Construction and Maintenance of Diversion Structures

During planning process the problems that are associated with construction and maintenance of diversion structures, used for diverting recharging water from various sources must be considered.

d) Environmental Problems

Due to close vicinity of spreading basins to population centres, various kinds of problems like spread of diseases are created, specially, if recharging water is polluted. The best remedy is to operate parts of spreading basins in sequence, so that water remains in each part for a short period than the larvae-stage of the insects life cycle (mosquitoes and other biological nuisances). The sites are avoided to be located near densely populated and industrial areas.

v) Economic considerations

The economic feasibility of the artificial recharge project is required to be established before taking up the construction and operation of the project. Due to rise in ground water table, as a result of artificial recharge, the immediately benefits that may be realised are - the pumping cost of water gets reduced; the well construction also decreases, in some cases irrigation water requirements of crops get reduced as ground water contribution in the crop root zone increases, and prevention of sea water intrusion in coastal areas etc.

It is utmost important to work out benefit-cost analysis (B-C Analysis) for all major public works before deciding the allocation of funds. This analysis presents the quantifiable efforts, environmental and social aspects of any public projects in money terms. In this analysis, both costs and benefits are expressed in quantitative terms and translated into monetary terms by using market values of the inputs and outputs concerned. After accounting the costs and benefits against their market values and an appropriate criteria is applied to determine the profitability of the project. The commonly used methods are 1) benefit cost ratio (B/C ratio), ii) Net present value (NPV), iii) Internal rate of return (IRR). The check list summarizing the planning phase and format for preparation of an artificial recharge project are given in (Annexure-I & II).

Trilla and Estralrich (1993) Presented a procedure for evaluating the reliability of the aquifer for supplying the actual required seasonal demands and for managing the Potential artificial recharge, and also a stochastic dynamic programming model for planning purposes.

Groundwater is in many cases the only source of drinking water for several Catalan Coastal towns in the north eastern corner of Spain. In practice. the management of these water resources is accomplished with only one objective in mind, to supply an amount of water required in every time period. Other aspects such as maximum net benefits at minimum pumping costs are of minor interest in the planning process. The aquifer of Ridaura river is an example of this situation. The aquifer is considered as an underground reservoir capable of being managed by the same models as the surface reservoirs are, capable of receiving natural and artificial recharge, furthermore, reliability implications derived from the use of the decision policy resulting from the proposed mathematical model will be presented.

4.2 SELECTION OF RECHARGE METHODS

After the selection of a suitable site, an appropriate method of recharging the ground water has to be identified. The broad categories of recharge method as described earlier are

i) Spreading methods
ii) Injection methods
iii) Induced recharge method

Brown and Signor (1972) Presented a review of some of the principles and problems of artificial recharge and summarises the current status of artificial recharge in the Southern High Plains of Texas and New Mexico. Artificial recharge of water to underground storage has become mere important due to increasing need for water and water management agencies are increasingly interested in potential use of artificial recharge. Many problems associated with artificial recharge are presently only in the research stage and, to date, recharge can be successful only under highly restrictive conditions. Thus the practice of artificial recharge to a groundwater system requires a careful examination of the recharge site. Conditions at the site, in conjunction with the quality of water from the recharge source, will indicate the complexity of the design. Experience in using recharge wells on the Southern High Plains of New Mexico and Texas indicates success when using good quality water, and failure when recharge water contains concentrations of particulate matter. Surface spreading is a more suitable method when water has a high sediment content, but may not be feasible in some hydrogeologic situations. Theoretically, well construction is important to the success of injection recharge operations. Results of recharge experiments on the Southern High Plains support these conclusions.

The choice of a particular method is governed by local topography, geological and soil conditions, the quantity of water to be recharged, the quantity and quality of water available for the purpose of recharge and techno-economic viability of such schemes. To select one out of the above categories, a thorough study of surface and sub-surface characteristic of recharge site and quality of recharge water is required to be done. The induced recharge method is least expensive out of these, however, it is possible only if there is a stream or lake in the vicinity of recharge site. Moreover, the bank and bed of the stream or lake should be made of pervious material and also the underground formations between the surface of water and the area where artificial recharging is required.

The choice between spreading and injection method is based on hydrogeologic conditions of soil sub-strata. If there is continuous impervious layers of large areal extent intervening between the ground surface and ground water reservoir, it is always desirable to go far injection method. However, if lenses of less permeable soils are present at shallow depths or a continuous but thin less permeable layer is underlying the surface soils, the use of spreading methods like ditches and furrows are more effective than using injection methods. Spreading methods are generally used when the soil is homogenous throughout the soil strata upto ground water table.

In situations where recharge by injection method is more suitable, the choice is required to be made among various injection methods i.e. recharge pits, shafts and recharge wells. Recharge pits are generally used in conditions where the impervious layer does not extend to far below the ground surface. When the top impervious layer is too thick to be penetrated by a pit, shafts are used for recharging purposes. Recharge wells are used for ground water recharge of deeper aquifers overlain by impervious layers. This method requires clean water for recharging otherwise, the recharge wells may get clogged. Artificial recharge of aquifers by this method is quite common in coastal regions to arrest the ingress of sea water and to combat the problems of land subsidence in areas where confined aquifers are heavy pumped.

In situations where spreading methods are used, the flooding method is preferred where land slopes are gentle (i.e. 1 to 3%) without gullies and ridges, the soil is homogenous and permeable, sufficiently large land area is available and recharge water is relatively cheaper as compared to costs involved in construction of recharge facilities. When a large flexibility in operation and maintenance of recharging facilities is required, the basin method of recharging is adopted as number of basins with necessary control structures provide the desired flexibility of operation. This method is preferably be used where land values are high, and ground has gentle slopes. This method also advantageous for regions where flash flood occur frequently as the basins can store water too. In situations where not much area is available for recharge purposes ditches and furrow methods of water spreading prove more useful. In areas with irregular topography, the basin construction may not be easy so, furrows and ditches method is adopted. Shallow, flat bottomed and closely spaced ditches or furrows provide maximum water contact area for recharge water. This technique requires less soil preparation and is less sensitive to silting than the recharge basins. In regions where streams are subjected to flash floods of short duration, the stream channel modification method is more economical for artificial recharge.

4.3 DESIGN OF ARTIFICIAL RECHARGE SYSTEMS

After selection of an appropriate method for recharge, it is required to find the dimensions, number, and spacing of different recharge units. The design of a particular method of recharge varies depending upon site conditions. The design of recharge method is unique for a particular site condition. The design criteria of different types of recharge systems are described as follows:

4.3.1 Design of Spreading System

In order to maintain mound level below ground surface a certain quantity of water is required to be recharged at a uniform rate. Based on the quantity of water to be recharged, the dimensions number and spacing of recharge units can be

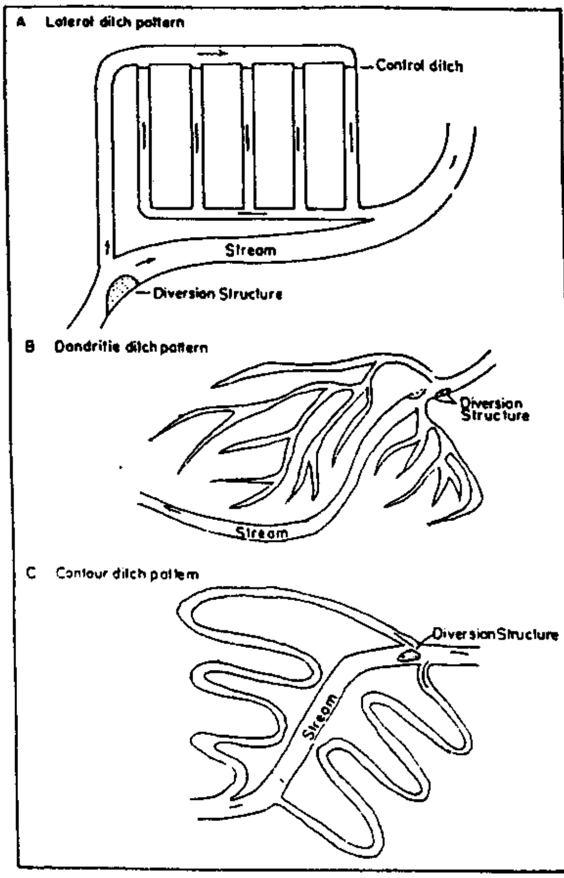

Fig. 17 PATTERNS OF DITCH AND FURROW SYSTEM

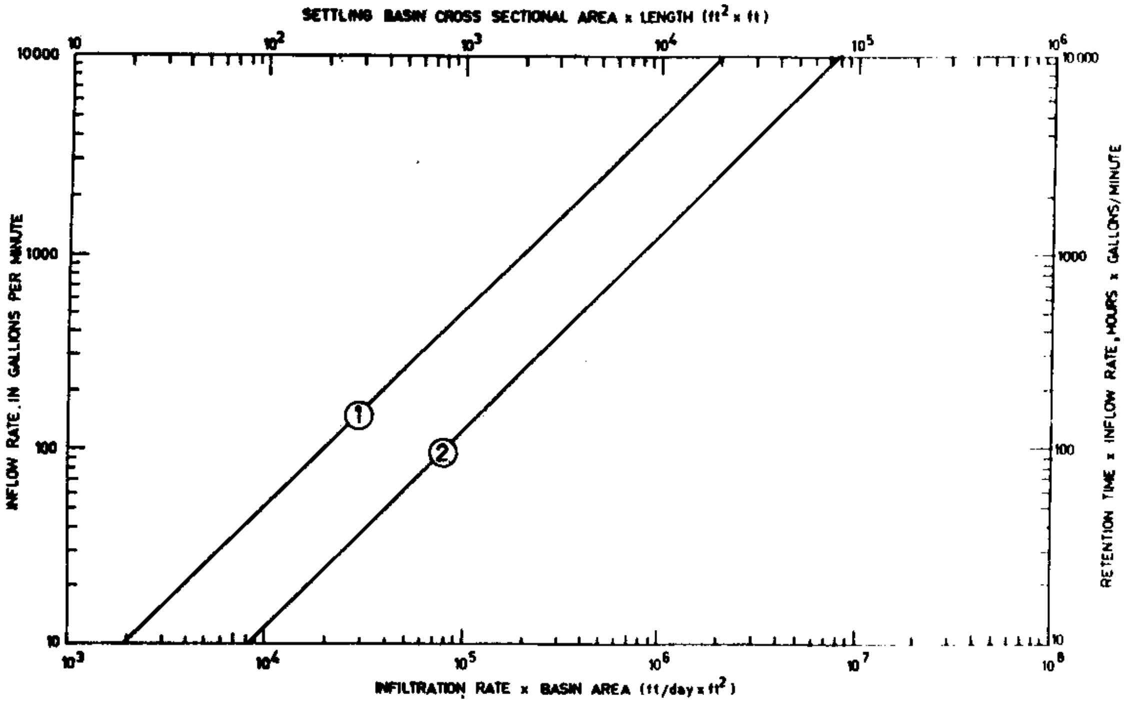

FIG.18: GRAPH FOR DETERMINING THE DIMENSIONS OF SPREADING AND SETTLING BASINS

established for getting a particular recharge rate. To find total quantity of water to be recharged, the surface losses like evaporation and transpiration and leakage from aquifers to underground formations should also be considered.

The flooding method of spreading involves flooding of a large extent of area with a low water depth. The total area to be flooded can be found out by dividing the required recharge rate (volume per unit time) by the average infiltration rate (depth per unit time). The value of design infiltration rate also depends on the operation schedule of flooding area. For example, if the recharge water is available in larger quantity for shorter duration as in case of high flood flow, higher values of infiltration can be taken for finding flooding area. However, if the ground is kept flooded for longer time, an average value of infiltration rate should be used for finding the area to be flooded. The water released from the delivery canal should be from several distribution points so that a thin sheet flow of water moves slowly down the slope without disturbing the soil. The velocity of water flow should be minimum to avoid soil erosion. In general, infiltration rates are highest where soil and vegetation are undisturbed. Thus, as far as possible the native soil should not be disturbed.

The ditch and furrow method of spreading is suitable to irregular terrain where it is difficult to construct basins and a small surface area is required for spreading. Recharging with water having high silt content can also be done by ditches provided these are made in stable soil. The design of ditches involves finding out the dimensions of the ditches with a given spacing and vice-versa. The ditch design is governed by the sub-surface geological conditions. Ditches should have slopes to maintain flow velocity and minimum deposition of sediments. The ditches should be shallow and flat bottomed to maintain maximum water contact area. Width of 0.3 to 1.8 m are typical. A collecting ditch to convey the excess water back to the main stream channel should be provided. Generally, three patterns of ditch and furrow system are adopted as shown in figure-17.

The basin method of spreading is preferred in cases when less pervious soil underlies the more pervious soil strata and overlies the ground water reservoir. In such cases the size of spreading basin is governed by the depth of less pervious layers below ground surface. It has been experienced that if less permeable layer is deep lying, use of large spreading basin is economical. It is advantageous to use multi-basin systems. In the USA, use of multiple recharge basin is in vogue. This is particularly suitable in cases when high silt ladden water is available for recharge purpose. A nomograph for determining the dimensions of spreading and settling basins, which has already been described in a technical note "Artificial recharge of groundwater, is shown in Figure 18. The basin area can be found by this nomograph based on the pumping rate, retention time of water, and infiltration rate. Higher rate of infiltration can be obtained in case of basins as compared to flooding method because water depths in the basins are relatively more. The ground selected for recharge basin should have gentle slope for the economic purpose. The design of individual basins can widely vary to accommodate square, rectangular or polygonal shapes arranged in a single or double row layout. The entry and exit point of water should be diagonally opposite to cause adequate water circulation in individual basin. Water released to basins should have minimum sediment so as to reduce deposition and sealing of the basin bed. The upper one or two basins (sedimentary basins) can be used for removal of silt from the recharging water. The rate of inflow into the basins is so arranged that it is slightly more than the total infiltration capacity of all the basins. The infiltration capacity of basins can be improved by soil treatment, vegetation or special operating procedures like rest period of sufficient duration between flooding periods to allow drying and biodegradation of clogged layers. For the purpose of design, the following estimated rates of infiltration for different soil textures given in Manual on "Artificial recharge of Groundwater", can be used.

Table-4.0: Infiltration Rates for Different Soil Textures

Soil Texture	Infiltration Rate
Coarse sand, fine sand Loamy sand, loamy fine sand coarse sandy loam	High (More than 5 cm/hr)
Sandy loam, fine sandy Loam, loam	Intermediate (1.5 to 5 cm/hr)
Silt loam, Sandy clay loam Clay loam, silty clay loam, silty clay, sandy clay, clay	Low (Less than 1.5 cm/hr)

(Source: Manual on Artificial Recharge of Ground Water)

4.3.2 Design of Injection Systems

Design of injection systems requires knowledge of geohydrological constants such as permeability, transmissivity etc. of the aquifer. These can be determined by carrying out pumping tests. The design procedure to be followed in different injection systems is given in the following paragraphs.

The design of recharge well requires proper understanding of the geometry of the aquifer to know the actual location and extent of additional ground water reservoir created. In this method much weightage is given to exploratory studies and evaluation of site hydrogeology to know the aquifer type, depth, thickness, distribution, hydraulic conductivity, storativity and head distribution of aquifer to be recharged. Grain size distribution of granular aquifers is important design information. If the purpose of injection well is to conserve the surface water underground, the injection well can be so designed that it can act as pumping well also when water is required for use. Injection-cum-pumping wells are more efficient because the well can be cleaned during pumping operation. The recharge well should be designed to fully penetrate the aquifer to avoid additional head losses due to partial penetration. In case of hard rock formations, the top casing should be adequate to cover

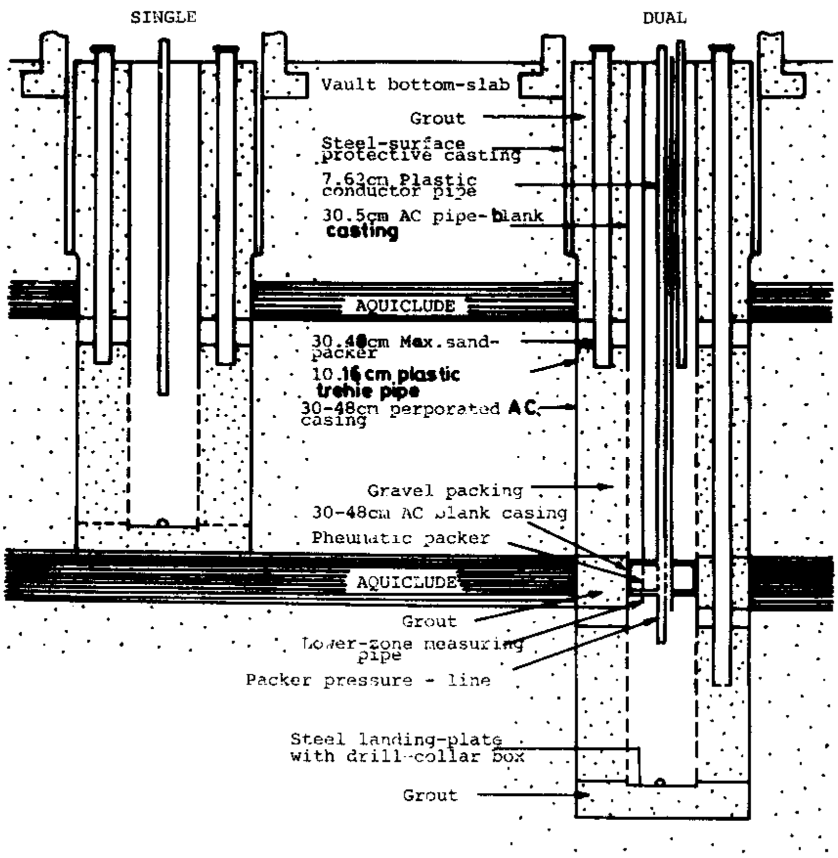

FIG: 10 INJECTION WELL DESIGN

unconfined zone and lower casing pipe may not be required. Two types of injection recharge wells are in use, single aquifer and dual aquifer recharge wells. The single aquifer wells are designed to recharge only one aquifer where as the double aquifer design can handle recharge to two confined aquifers located one below the other. The ideal design drawing of these two types is shown in Figure 19. During injection by recharge well, a cone of recharge will be formed that, theoretically, will be reverse of the cone of the depression for a pumping well. The equation that describes the shape of the recharge cone during the steady state conditions for a well fully penetrating a confined aquifer is :-

$$Q_r = \frac{2\pi kb(h_w - h_o)}{\ln (r_o/r_w)} \qquad (1)$$

In case of fully penetrating well recharging an unconfined aquifer, the equation is -

$$Q_r = \frac{\pi k(h^2_w - h^2_o)}{\ln (r_o/r_w)} \qquad (2)$$

Based on equations 1 and 2, the diameter of recharge well and the injection head to be maintained can be found out for combined and unconfined aquifers respectively. The diameter of injection wells differ from those of production well in that there is no head to accommodate a pump and it is the pump size that usually controls the well diameter in production wells.

A recharge pit is used to penetrate through a less pervious or impervious layer and it may be continued in the pervious formation in order to increase the area of infiltration. Recharge pits are excavated of variable dimensions. A recharge pit having larger length as compared to width may be designed in similar way as the spreading ditches. If the length and breadth of the pit are comparable, the approximate mound shape, pumpage capacity of the area can be used to find the total quantity of water to be recharged in a given time, by which the dimensions of the pit can be find out. Attempts should be made to construct as large pit as feasible, as larger pits have greater effectiveness. The side slopes of wall of a pit should be steep to avoid clogging of sides. It should be 2:1. The larger pits are used like percolation ponds. Even in case the pits are used as ponds, it is advisable to provide a thin layer of filter bed at the bottom to prevent clogging from silting. In case the water table aquifer is located deep below the land surface, a shaft is used for recharge purpose. It may be dug manually. When manually dug, the shaft may be 2 m in dia. at the bottom but in case of drilled holes, the diameter may not exceed beyond 0.8 m to 1 m. The shaft should end in more permeable strata below confining clayey layer. It may not touch water table.

4.3.3 Design of Induced Recharge Systems

The induced recharge systems are generally installed near perennial streams, which are hydraulically connected to an aquifer through the permeable rock material of the stream channel. The pumping wells should be selected at sites where the water in the stream has sufficient velocity to prevent silt deposition in the river bed, as it is the primary cause of decrease in permeability. The outer edge of a bend in the stream is favourable for location of well site. The points to be considered in designing the scheme are quality of river water, the hydraulic characteristics of aquifer material and its thickness and the distance of the pumping well from the river and its pumping rate. The effectiveness of the induction system is determined by i) pumping rate, ii) permeability of aquifer, iii) distance of aquifer from the stream, iv) natural ground water gradient, and v) type of well.

A collector well is a large diameter (4 to 8 m) well from which laterals are driven/drilled near the bottom at one or two levels into permeable strata. The distance of the collectors from the stream is decided based on two considerations. The distance should be such that during the travel of water from stream to the collector well, it gets sufficiently purified and the proportion of the total quantity of water induced through direct infiltration should satisfy collector's capacity. Once the location of collector well with reference to stream is fixed, the dimensions of the collector well can be decided based on quantity of water which is expected to flow towards the collector well.

5.0 OPERATION AND MAINTENANCE OF RECHARGE FACILITIES

In order to maintain, high recharge rates, provide water compatible with the aquifer, maintain or improve ground water quality, it is required to have a proper control on operation and maintenance of recharging facilities. The recharging water can be treated by screening or filtration to remove suspended sediment and floating debris, suspended solids in water used for recharge may consist of bacteria flocs (sewage effluent), organic particles (silt, clay). Upon infiltration, suspended solids are filtered out on the soil surface. In case of spreading methods, the deposition of sediment in the basins can be controlled by various methods such as use of settling basins, filter beds, and periodic drying of basins to allow the scaling skin to curl and crack, and to disrupt growth of algae and scraping of basins. The recharge rate can be monitored by recording amounts of water inflow and outflow from the recharging sites. One observation well at the centre of the recharge area to monitor the maximum mounding effect and another down gradient of the facility to determine impacts on the surrounding water table is at least needed.

Municipal and industrial waste water after initial treatment, can be reclaimed by ground water recharge through direct injection into wells. The process of purifying and reclaiming waste water by allowing it to pass through soil and aquifer is referred as Soil Aquifer Treatment Systems(SAT-System). These SAT systems offer the additional advantage that the soils in the vadose zone act as a natural filter that removes pollutants and other impurities from the waste water by physical, chemical., and biological processes, as it moves down to the ground water. SAT systems should be designed to provide sufficient underground detention time and travel distance for the waste water so that the renovated water will be of the best possible quality. As a general rule, one month under ground detention time and 100 m underground travel distance are considered for most quality improvement in a SAT system.

In case of injection wells, the injection capacity of recharge wells get decreased as the well is clogged, because of the various factors including, suspended particles in the injection water, gas bubbles in the water, proliferation of bacteria in and around the well, formation of chemical precipitates in the injection water and the well, formation of chemical prepicipitates in the soil, swelling and dispersion of clay, and erosion of soil structure and jamming of the aquifer. The clogging of wells and ground water contamination can be prevented by treating recharging water for removal of suspended solids and by chemical stabilization and bacterial control.

Schuh (1988) Developed an in-situ procedure for monitoring changes in impedance of layered pit bottoms of artificial recharge facilities. The method requires only the measurement of the initial hydraulic conductivity, and the hydraulic conductivity during pit operation using a ring infiltrometer and a single tensiometric installation. Hydraulic gradient and impedance ratio criteria measured in a test facility enabled the extent of impedance formation due to clogging to be followed during the application of turbid water. For the top 0-8Cm. layer, impedance changes of 200 to 800 times the initial impedance were measured for two sites, which only one site indicated a ten to twenty fold increase in impedance in the 8-23Cm. layer. No changes in impedance were observed below 23Cm. on this test facility. Physical measurements indicated that deposition of silt predominated at the surface, while some of the clay penetrated to greater depths. Tests including measurements of hydraulic gradient, impedance ratio, and sample cross sections indicated that the proposed method was capable of providing consistent and sensitive interpretations for changes from clogging of the pit bottom in a layered medium. The proposed method also provided site specific flux data for individual locations within the pit. It is concluded that the proposed procedure should provide a useful tool for monitoring hydraulic changes in recharge facilities. It may, in addition, provide a useful research tool for examining changes in the hydraulic environment when combined with other physical, chemical, and biological investigations.

Schuch (1991) Developed a method using surface filter cake to increase recharge with turbid water. During the operation of basin with turbid water, -Infiltration rates quickly decline because of clogging caused by suspended solids in the influent water. Commonly silt particles strain out on the soil surface while clay particles move more deeply in to soil pores during the early hours of basin operation. Eventually, the deposited silt forms a surface filter cake, which removes clay particles and prevent further clogging of the subsoil. Clogging in the surface soil and in the filter cake can result in large enhancement in hydraulic impedance and can decrease infiltration rates to levels that make further operation of the facility impractical.

Some types of organic materials, however, have enhanced recharge. The use of an organic mat surface filter composed of sunflower seed hulls increased infiltration of turbid water through an artificial recharge test basin, compared with previous tests of infiltration through a Clean, sandy basin without an organic mat. During the initial basin operation of an average increase of 81%- in total recharge over previous tests was effected. Surface impedance was larger for the basin without organic mat, while basin with the mat exhibited that impedance increases to greater depths. Experimental results indicated a likely trade-off between short-term recharge enhancement and an eventual larger depths of renovation to offset deeper sediment penetration under the mat. A substantial decrease in hydraulic impedance and a corresponding increase in infiltration rate were measured between 90 to 400 hours from the initiation of the basin test and indicated that despite large sediment influx, soil hydraulic conductivity was larger under the organic mat than for the same basin positions on clean sands using clean water. The large decrease in impedance to flow is attributed to microbial transformation of O_2 to more highly soluble CO_2 which increased water filled large porosity. The result of this was an increase in the hydraulic conductivity of the basin subsoil over that measured on clean basin with clean water before the initiation of the basin operation with turbid water.

Smith, Cook and Walker (1994) Carried out a study to quantify the effect of environmental factors on recharge in the southwestern

Murray Basin, (Australia). In this study, data from-18 sites rain fall, soil texture and, land use, are used and results from a simple water balance model are deduced. Generally, as the texture of the soil became heavier the recharge decreased. Under cropped land as the clay content in the top 2m of the soil profile increased from 0 to 20%, recharge decreased by one order of magnitude. As mean annual rain fall increased the mean annual recharge also increased. Sites with an average clay content of about 10% in the top 2m and a mean annual rain fall of 27omm had an estimated recharge of about half that of sites with a mean annual rain fall of 310-380mm. Data from uncropped pasture land showed similar relationships. However, more pasture sites are required to enable a more detailed examination of the relative effect of the two major land uses.

6.0 FIELD APPLICATIONS/CASE STUDIES

i) Artificial Recharge to Ground Water in Kutch, Gujarat State

In order to arrest the declining trend of water levels, deterioration of ground water quality and to prevent sea water intrusion into coastal aquifers, several remedial measures such as rain water harvesting and construction of recharge tubewells etc. were taken by Shri Vivekanand Research and Training Institute engaged in the rural development works since 1976. Moti Rayan Village of Mandvi taluk, Kutch district is the project area where 18 check dams, one percolation tank and 2 recharge tubewells were constructed in 1989 creating a storage of 44715m^3 The artificial recharge through rainwater harvesting structures (i.e. check dams) constructed has resulted in rise of water levels from 1.2 m to 3.65 m. The improvement in quality by reducing in TDS varied from 10 to 420 ppm. The quantity of water recharged was of the order of 66,469 m^3. During 1990, 2 more percolation tanks with recharge wells were constructed thus increasing the storage capacity to 127,020 m^3. The amount of water infiltrated during the monsoon of 1990 was of the order of 203,967 m^3.

ii) Artificial Recharge measures in Karnataka State

Large areas of Karnataka states are drought prone and the essentially underlain by hard rocks. As a drought proofing measure, tank irrigation is much in vogue in the state. In 1987, there were 40102 minor irrigation schemes in operation, out of which 20,152 are of storage type. The cultivable command area of these scheme is 764,042 ha. It is a common observation that the performance of the wells in the tank periphery is directly related to the quantum of water stored in the tank, indicating that they aid in creating additional storage underground.

iii) Artificial Recharge in Kerala

In Kerala, Agricultural University a sub-surface dykes was constructed by CGWB in 1988. Plastered brick wall of thickness 25 to 60 cm was constructed as a dyke. The length of the dyke is 80 m and the maximum height 8 m. A large diameter (4.2 m) well was constructed on the upstream side of the dyke and seven sets of piezometers were constructed for water level monitoring. The difference in water level in the piezometers between the upstream and downstream sides as on 3.5 .1991 was ranging between 0.22m and 0.87m. During Feb. 1989, this was between 0.2 to 1.01 m. During summer month, the water is used for the purpose of irrigation of different crops and also for the distillation of oil from lemon grass.

iv) Experiment on farm rain water management at Raipur, M.P.

A large volume of rain water goes out as runoff and drainage water every year from farm fields. The experiment consists of 1 ha. field having a Small Farm Reservoir (SFR) to collect excess runoff and drainage water from upper 2/3rd portion of the field representating a microcatchment. The stored water helped in saving paddy from water stress during extended dry spells in 1990-91 and 1991-92. About 90% of stored water in 1990-91 and 47% in 1991-92 was lost from the reservoir but contributed to ground water storage. The stored water was also helpful in growing mustard and gram in post rainy season after harvest of rice etc. Economic returns from the technology are highly attractive. The results suggest that investment made on SFR construction is likely to be returned in 2-3 years and the technology can increase rainfed farm productivity and increase 3-5 times over the existing level in the region. The systems seems appropriate for deep vertisols land (locally called Kankar and Dorsa soils) which cover 45% cropped area in the region.

v) Artificial Recharge by Rock Fracturing in Deccan Trap Area

In tribal area of western Maharashtra, the average rainfall is between 2000 to 3000 mm, but still part of Nasik and Thane districts and Akola taluka of Ahmednagar district, villages are facing problem for drinking water. the area is mostly occupied by Deccan trap rock of igneous origin. The terrain is mostly undulating with steep slopes and valleys which are unfavourable for storage of groundwater. Open wells dug in this area goes dry before March and borewells drilled upto depth of 60 to 100 m are also not found successful which indicates that there is no recharge in the deeper zone.

To resolve this problem rock fracturing experiment is conducted to create artificial joints and fractures for storage of ground water for drinking water purpose. The site was selected at the centre of tribal area of Nasik district near village Saraste, taluka Poind. The fracturing in Deccan trap rock at the depth of 5 to 6 m was made by bore hole blasting in a grid of 10 m x 10 m in 8260 square metre area on 9th June 1983. The regular rainfall was spreaded over the area to affect the natural infiltration in the sub-surface strata. After the monsoon, series of surface and sub-surface observations by geophysical resistivity method were made. As per the anomalies observed by geophysical resistivity a trench well of 20 m x 2m x 6m was excavated in April, 1984 and water was struck at a depth of 4.30 m. The adjoining open well located immediately in the down stream area are dry but in trench well, the netwrok of joints have started contributing ground water. During the excavation of the well 0.40 to 0.80 m of water column was recuperating daily. The trench well water was used by habitat during the summer.

From the above results, it is revealed that rock fracturing is effective in augmenting storage of ground water. Further observation and modification will lead to establish a regular scheme for drinking water in these areas for tribal population.

Hendry (1983) Carried out a study to qualitatively outline the modes of groundwater migration in the unsaturated and saturated zones of a glacial till, using a natural tritium. In this study, a test hole was cored to a depth of 17.4m below ground surface in southern Alberta, Canada, and 55 samples were collected from the cores at 0.3m intervals. The soil water was distilled from each sample and analyzed for natural tritium and the soil samples were analyzed for particle-size distribution. The upper 3m of the stratigraphic section consists of coarse to heavy-textured interbedded lacustrine deposits. These units are underlain by a heavy textured weathered till. The study site is a zone of groundwater recharge with the water table at approximately 9m below ground surface.

Tritium data can be used to show that water, which entered the subsurface environment from ground surface after 1953, has moved to the lacustrine till through intergranular surface and fracture flow and that fractures are transmitting post- 1953 recharge water to depths within the underlying slowly- permeable unsaturated and saturated till. In addition, diffusion of tritium from the fractures in to the adjacent matrix material appears to occur both above and below the water table.

LiMa, Bhar, Richard, Butler, Remson (1987) Presented a simulation model in conjunction with linear and nonlinear programming to examine the effects of various management choices on the optimal allocation of imported water for artificial groundwater recharge in the San Juan valley of central California. The choice between more complex linear and nonlinear objectives is shown to depend on the economic impacts of drawdowns. Suitability of different drawdown reference levels was found to be a function of specific form of the objectives. Sensitivity analysis showed that the imported water could be recharged any where in the central portion of the cone of depression with minimal effect on the value of the objective function. Parametric variation of the total recharge rate illustrated the dependence of the various objective functions on the distribution of drawdown, discharge rate, and hydrogeological properties.

This study has demonstrated that decisions regarding objective functions and their reference levels can be made only after careful consideration of basin characteristics and management goals.

Brothers and Katzer (1990) Presented a method for banking the water through artificial recharging the groundwater system in Las Vegas valley, Clark County, Nevada. In a few years the existing water transmission system from lake mead will be unable to meet the short term summer peak demands, and artificial recharge can be used to alleviate this constraint.

Artificially recharging treated Colorado River water in to the groundwater system is one option available to the Las Vegas

Valley Water District to meet increased summer peak water demands. Also artificial recharge can be used to bank the remaining portion of Nevada's unused Colorado River allocation for future use.

In 1988 the water supply for Las Vegas Valley water district is made up of approximately 75% Colorado River water and 25% groundwater, which is used primarily in the summer to meet peak demands. The District is investigating the feasibility of increasing the importation of the treated Colorado River water in to the Valley during winter months, banking the water by artificially recharging the groundwater system, and subsequently withdrawing this water to meet summer peak demands and future needs. There are two major concerns regarding the feasibility of artificially recharging the treated Colorado River water by deep aquifer injection. The first was the potential for calcite precipitation which, could potentially reduce the aquifer permeability and the second was the long-term effects on well performance and production longevity by injecting through production wells.

Although previous laboratory studies predicted that calcite precipitation would occur but, a small scale artificial recharge pilot study, conducted by the District in 1987, showed insignificant calcite precipitation. A large scale demonstration project, initiated in Feb.1988, injected a total of 1153acre-feet of the treated Colorado River water in to the groundwater system through two existing production wells over a period of two months. Recovery of the native groundwater and Colorado River water mixture began on 21Ist April 1988 and continued throughout the summer. Recharge was accomplished by injection through the existing pump columns with minimal retrofitting of the existing wells and no detrimental effects to the pumps or well production rates have been observed. Water quality analyses and geochemical modeling indicate very little. if any, calcite precipitated during recharge and recovery.

Lee, Williams and Wang (1992) carried out an artificial recharge experiment in the San Jacito basin. During a 3 month recharge' experiment related to conjunctive use of water resources, 1.5*106 T of imported water were percolated through an isolated pond of 128M by 128M in the San Jacito basin. The infiltration rates, which decline with time, averaged 1.9M/day, equivalent to four times the lowest laboratory measured hydraulic conductivity of the fluvial deposits. Ponding altered the unimodel grain-size distribution at the ground surface to types without a dominant mode, but this redistribution did not always lead to reduction in conductivities, which varied over at least three orders of magnitude. Water levels in wells bottomed in the original Vadose zone suggested that an inverted water table descends towards the rising water table. Minor, local perching water occurred at 14M depth, as indicated by the presence of moist ground near one monitoring well and by hydraulic responses during a 20 day intermission in percolation. As it percolated through the sediments 1 the imported northern California water gained Ca but lost Mg, so that the Mg/Ca ratio resembled that of local groundwater. The characteristics of the original source waters appear to be retained by D/H isotope ratios and Cl concentrations, as well as cross-plots of So. vs. Cl and B vs.

Cl. Such unreactive tracers could serve to monitor transport and mixing of the chemically diverse water used in future recharge programs in the San Jacito basin.

Digney and Gillies (1995) Developed a process for direct injection in to confined aquifer for artificial recharge in Saskatchewan. The use of artificial recharge in Saskatchewan and the rest of Canada to improve community and farmstead domestic water supply, has great potential. Approximately 75% of the people in rural Sasketchewan and 26% of all the people in Canada are dependent on groundwater for their domestic water supply. Typically this water is highly mineralized and is often unpalatable due to odour and taste. A source of readily available, high quality water to eliminate expensive chemical treatment of available water and long distance hauling would be of significant value to rural communities. Storage of high quality water in aquifers by injection through wells has been documented and has been shown to depend on the use of a surface water catchment system to provide the high quality water. Development of proper design and operation of recharge procedure is required. For this a computer model of 'the injection process is developed. This model simulates the injection and recovery phases of artificial recharge. Small scale artificial recharge project will provide a valuable commodity to rural water users and will promote sustainable and conjunctive use of surface and groundwater resources.

Fosteer, Bath, Farr and Lewis (1982) Presented the results of a preliminary study of the unsaturated sand-cover, including its physical properties, chemical and isotropic profiles of its pore-water composition in Botswana Kalahari.

The Kalahari is the world's most extensive mantle of sand. A fundamental problem in the evaluation of groundwater resources in this region, is the estimation of the magnitude of any active infiltration, from modern rainfall through the sand-cover to certain deep aquifers. The profiles exhibit evaporative features and suggest that in an area with a mean annual rainfall of 45omm, diffuse recharge should not be presumed to be occurring where the sand-cover is more than ≈ 4m deep.

Bradley and Phadtare (1989) Carry out the study of the effects of paleohydrology on recharge to overexploited semiconfined aquifers in the Mehsana area of Gujarat state, India. During the past few decades, large scale groundwater pumping for irrigation has depleted a series of alluvial aquifers in the Mehsana region. The water levels have been declined more than 25 metre in the overexploited area. A report. UNDP/CGWB (1976) on a regional groundwater investigation by the UNDP and CGWB suggested that artificial recharge in an area called "common recharge zone" might alleviate the diminishing groundwater resources of the overexploited area. To explore this further a pilot project for artificial recharge was carried out in the early 1980's. It was concluded from this study that local vertical downward leakage accounts for 90% or more of natural recharge to the alluvial aquifer zones in the overexploited area and that only minimal contribution could migrate laterally from the common recharge zone. This vertical leakage finding contrasted with the earlier (UNDP/CGWB 1976) report findings that recharge in the "common recharge zone" might move more or less laterally through confined aquifers to the overexploited area. However, consideration of the paleohydrologic depositional environments and related archeological factors indicate that the lenticular nature and variability of the Newer alluvium sediments readily permit vertical leakage. The large groudwater withdrawals have increased downward percolation of recharge through leaky alluvial aquitards.

7.0 CONCLUSION

The main source of groundwater recharge is natural precipitation. In areas of heavy rainfall, the natural ground water recharge can meet the necessary demands of water for different purposes like drinking and irrigation etc., Provided the sub-surface strata is permeable enough to meet percolation of water. But in areas of scarce rainfall, due to high ground water draft, ground water levels are considerably reduced. Thus specifying the need for artificial groundwater recharge. Artificial recharge can be an effective water management technique provided hydrologic conditions of the aquifer system are quantified and an appropriate method of recharge and rational design criteria has been established.

An artificial recharge project is carried out to improve supplies from aquifers lacking adequate natural recharge. This also helps in conserving excess surface water under ground for future use and improve the physical and chemical quality of water. Some other objectives of artificial recharge are control of salt water encroachment, filtration of water, control of land subsidence and disposal of wastes.

Now a days, artificial recharge practices are being used for conserving energy of hot and cold water by storing it underground and extracting it at the time of need. For making the artificial recharge schemes to be successful, it is necessary to know that

i) How much quantity of water may be available for artificial recharge and the time for which the source water will be available?

ii) What is the quality of source water and the pretreatment required?

iii) How much underground storage space is available and at what depth?

iv) How readily will the aquifer accept the recharge water and how readily it can be recovered from the aquifer?

v) How will the quality of water change after recharging?

vi) How quickly will the aquifer plug due to chemical, physical or bacterial action?

vii) Whether conveyance system is required to bring the water to the recharge site or not.

The above factors should be evaluated properly to develop an effective design criteria for recharge scheme. Though, the artificial recharge methodology is comparatively simple, but it will be different in different hydrologic conditions. Hence, the success of an artificial recharge operation depends upon the selection of a suitable method of recharge. In alluvial areas where sub-surface soils are permeable and have gentle slope, spreading method of recharge is useful, while in arid and semi-arid areas where deep confined aquifers have to be recharged, injection method is suitable. In arid and semi-arid regions where surface water is scarce and imported water is also not available, waste water can be used for recharge purposes. The health aspects of artificial recharge with special reference to waste water recharge have to be carefully studied. The monitoring of water levels and water quality is of prime importance in any scheme of artificial recharge of ground water. It is required to demarcate areas where artificial recharge is essentially required and it also helps in identifying the method of artificial recharge.

After establishing a physical situation suitable for requiring artificial recharge measures, field experiments and studies should be taken up at the earliest to verify the feasibility of recharge project. These experiments include, i) hydrogeological mapping, geophysical survey, and exploratory drilling, ii) correct evaluation of aquifer parameters, iii) determination of infiltration coefficient, iv) water quality analyses of source water, v) to evolve proper design of recharge structures, vi) evaluation of availability of source water, vii) carry out the preliminary benefit cost analysis. After verifying the feasibility of artificial recharge schemes, it may be launched for causing artificial recharge in a specific area for partly or fully making up the deficit in ground water budget. usually the area involved is a small watershed covering an urban, rural or industrial centre. Being expensive, the artificial recharge projects should be planned and operated with great care.

PLANNING ARTIFICIAL RECHARGE PROJECT-CHECKLIST

1. Has the need for Artificial recharge been properly established.

2. Have the issues concerning clearance of the scheme by competent authority been cleared on the following points?

a) Economic viability

b) Subside if proposed

c) Sharing of costs

d) Sharing of benefits

e) Acceptance of submergence area

f) Compensation of land required to be paid for procurement

g) Any other issue

3. Meteorological & Hydrological Surveys: Have the following factors been taken into account?

a) Rainfall

b) Evaporation

c) Availability of water

d) Yield of basin and flood for designing spillways

e) Sediment load

4. Field Surveys:

Have the following Surveys been carried out?

a) Regional hydrogeological Survey

b) Detailed site hydrogeological survey

c) Soil Survey

d) Infiltration studies

5. For construction of structures:

A) Have the following investigations been carried out?

a) Foundation conditions of percolation tanks, Bunds, reservoirs, nala Bunds.

b) Subsurface strata conditions for recharge wells, shafts, underground dams (Bandharas).

c) Spill way design

B) Material Surveys:

a) Soils for impervious, semipervious, pervious zones of surface/sub-surface bandharas.

b) Sand/rocks/bricks & tiles/pea gravel (for wells)

c) Cement

d) Steel/steel pipes/slotted pipes/well screens

6. Land Acquisition:

a) Have the land acquisition required for structures, inundation, source water supply channel/pipe line been decided?

b) Has the mode of acquisition of land been discussed?

7. Design:

a) Has the final location of each structure been decided?

b) Has the lay out of structures been marked out?

c) Have the design details of individual structures been finalised?

8. Construction programme schedules:

a) Has the proposed construction programme been prepared and synchronised for timely construction?

b) Have the Agencies undertaking the work been identified?

9. Financial Resources:

a) Have the yearwise requirement of funds been worked out?

b) Has approval of finance department been obtained?

c) Has the expenditure approval been obtained and Budget provision made?

10. B.C.Ratio:

a) Have the cost and benefits been properly worked out?

b) Is the B.C.Ratio reasonable & acceptable?

c) Have all departments concerned agreed to share the allocated cost?

11. Ecological Aspects:

Is the area going to experience any of the following environmental/ecological problem?

a) Inundation of habituated land

b) Creation of water logging

c) Deterioration of quality of groundwater

12. Public participation, cooperation:

a) Have the implications of the scheme been explained and discussed with the local population?

b) Have the aspects of the scheme involving peoples active participation been worked out?

(Source: Manual on Artificial Recharge of Ground Water)

FORMAT FOR PREPARATION OF ARTIFICIAL RECHARGE PROJECT

A) Base information of problem area

1. Location
   - State
   - district
   - Block
   - Lat.& Longitude
   - Areal Extent
   - No. of villages/Towns

2. Population
   - i) Human, Urban & Rural
   - ii) Livestock

3. Landuse
   - i) Culturable & Non-culturable Area
   - ii) Forest

4. Agriculture
   - i) Soil type, thickness and extent
   - ii) Cropping pattern
   - iii) Area under irrigation

5. Climate
   - i) Type of climate
     - a) Humid
     - b) Sub-humid
     - c) Arid
     - d) Semi-arid
   - ii) Rainfall
     - a) Average annual
     - b) Rainfall Distribution
     - c) No. of Rainy days
     - d) Temperature
     - e) Humidity
     - f) P.E.T.
     - G) Wind

6. Topographic Features:
   - i) Elevation range(Maximum, Minimum & General)
   - ii) Landform:
     - a) Hilly Area
     - b) Highly Dissected Plateau
     - c) Moderately Dissected plateau
     - d) Foot Hill Zones
     - e) Peidomont Zone
     - f) Valley Slopes
     - g) Plain Area
     - h) Sand dune Area
     - i) Delta Region
     - j) Coastal Plains
     - k) Karstitic Terrain

7. Surface Water Bodies:
   - i) Rivers/Streams-Perennial, Ephemeral
   - ii) Average Discharge & Duration of flow
   - iii) Canal-Lined, unlined
   - iv) Length and capacity of canal and duration of canal flow
   - v) Number and Area of Natural Lakes &

	Ponds
	vi) Reservoirs, their number and storage capacity a) Major b)Medium & c)Minor
8. Hydrogeology	i) Geological Formations ii) Major Rock Types iii) Structural Features iv) Nature of unsaturated zone a) Moisture Conditions b) Presence/Absence of impervious layers in vadose zone(hardpans) v) Aquifer Systems a) phreatic b) Semi-confined c) Confined vi) Depth of aquifer zones vii) Hydraulic characteristics of aquifers a) Transmissivity b) Storativity/Specific Yield c) Hydraulic conductivity viii) Aquifer boundaries ix) Depth of water level and its seasonal fluctuation x) Groundwater Structures a) Type, Number b) Depth range c) Yield range d) Aquifer tapped xi) Groundwater Resources a) Annual Recharge b) Annual Draft c) Stage of Groundwater Development xii) Groundwater level trends
9) Water requirements	i) Present requirement for different uses (Domestic, Industrial & Irrigation ii) Projected requirement after 10 years, 20 years(Domestic, Industrial & Irrigation)
10) Groundwater	i) Unconfined & confined aquifers a) Potable b) Brakish c) Saline ii) Any special quality problem(Seawater intrusion, pollution & high fluoride etc.)
11) Nature of Problem requiring artificial recharge of groundwater	i) Quantity problem a) Quantification of water shortage for different purposes b) Period of shortage c) Location of deficit areas ii) Quality problem a) Control of sea water intrusion iii) Special problem a) Control of land subsidence b) Waste water reclamation through SAT System

12) Source water Availability for artificial recharge purpose

Source	Location	Quantity	Period of availability	Physical & Chemical quality
i)	Rainfall			
ii)	River			
iii)	Canals			
iv)	Reservoirs			
v)	Municipal Waste Water			

B. Guidelines for Action Plan:

1. Identify the data gaps in base information and carry out necessary investigations using the various investigation techniques.
2. Using base data on topography, rainfall, hydrogeology, aquifer situation and source water availability, identify the suitable method.
3. With reference to the local conditions of the area, further identify the most appropriate techniques of artificial recharge suitable at various sites/locations.
4. Determine the number of each type of artificial recharge structure needed to achieve the quantitative targets.
5. For individual structure at different locations, finalise the design specifications.
6. Finalise the design of the conveyance system required to bring the source water to the recharge site and the treatment required.
7. Plan the required Monitoring System to evaluate the efficacy of recharge scheme.
8. Evaluate the economic feasibility of the artificial recharge project.

(Source: Manual on Artificial Recharge of Ground Water)

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