CENTRAL GROUND WATER BOARD
MINISTRY OF WATER RESOURCES

GUIDE ON ARTIFICIAL RECHARGE TO GROUND WATER

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TO
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1.0 INTRODUCTION

The artificial recharge to ground water aims at augmentation of ground water reservoir by modifying the natural movement of surface water utilizing suitable civil construction techniques. Artificial recharge techniques normally address to following issues -

(i) To enhance the sustainable yield in areas where over-development has depleted the aquifer.

(ii) Conservation and storage of excess surface water for future requirements, since these requirements often changes within a season or a period.

(iii) To improve the quality of existing ground water through dilution.

(iv) To remove bacteriological and other impurities from sewage and waste water so that water is suitable for re-use.

The basic purpose of artificial recharge of ground water is to restore supplies from aquifers depleted due to excessive ground water development.

1.1 Concept of Augmenting Ground Water Reservoir

1.1.1 Ground Water or Sub-Surface Reservoirs

The sub-surface reservoirs are very attractive and technically feasible alternatives for storing surplus monsoon run off. The sub-surface reservoirs can store substantial quantity of water. The sub-surface geological formations may be considered as "warehouse" for storing water that come from sources located on the land surface. Besides suitable lithological condition, other considerations for creating sub-surface storages are favourable geological structures and physiographic units, whose dimensions and shape will allow retention of substantial volume of water in porous and permeable formations.

The sub-surface reservoirs, located in suitable hydrogeological situations, are environment friendly and economically viable proposition. The sub-surface storages have advantages of being free from the adverse effects like inundation of large surface area, loss of cultivable land, displacement of local population, substantial evaporation losses and sensitivity to earthquakes. No gigantic structures are needed to store water. The underground storage of water would also have beneficial influence on the existing ground water regime. The deeper water levels in many parts of the country, either of natural occurrence or due to excessive ground water development, may be substantially raised, resulting in reduction in lifting costs and energy saving. The quality of natural ground water would substantially improve in brackish and saline areas. The conduit function of aquifers thereby reducing the cost intensive surface water conveyance system. The effluence resulting from such sub-surface storage at various surface intersection points in the form of spring line, or stream emergence, would enhance the river flows and improve the presently degraded ecosystem of riverine tracts, particularly in the outfall areas. The structures required for recharging ground water reservoirs are of small dimensions and cost effective, such as check dams, percolation tanks, surface spreading basins, pits, sub-surface dykes etc.

1.1.2 Basic Requirement for Artificial Recharge Projects

The basic requirements for recharging the ground water reservoir are:

a) Availability of non-committed surplus monsoon run off in space and time.

b) Identification of suitable hydrogeological environment and sites for creating sub-surface reservoir through cost effective artificial recharge techniques.

1.1.3 Source Water Availability

The availability of source water, one of the prime requisites for ground water recharge, is basically assessed in terms of non committed surplus monsoon run off, which as per present water resource development scenario is going unutilised. This component can be assessed by analysing the monsoon rainfall pattern, its frequency, number of rainy days, maximum rainfall in a day and its variation in space and time. The variations in rainfall pattern in space and time, and its relevance in relation to the scope for artificial recharge to sub-surface reservoirs can be considered for assessing the surplus surface water availability.

1.1.4 Hydrogeological Aspects

Detailed knowledge of geological and hydrological features of the area is necessary for adequately selecting the site and the type of recharge structure. In particular, the features, parameters and data to be considered are: geological boundaries; hydraulic boundaries; inflow and outflow of waters; storage capacity; porosity; hydraulic conductivity; transmissivity; natural discharge of springs; water resources available for recharge; natural recharge; water balance; lithology; depth of the aquifer; and tectonic boundaries. The aquifers best suited for artificial recharge are those aquifers which absorb large quantities of water and do not release them too quickly. Theoretically this will imply that the vertical hydraulic conductivity is high, while the horizontal hydraulic conductivity is moderate. These two conditions are not often encountered in nature.

The evaluation of the storage potential of sub-surface reservoirs is invariably based on the knowledge of dimensional data of reservoir rock, which includes their thickness and lateral extent. The availability of sub-surface storage space and its replenishment capacity further govern the extent of recharge. The hydrogeological situation in each area needs to be appraised with a view to assess the recharge capabilities of the underlying hydrogeological formations. The unsaturated thickness of rock formations, occurring beyond three meters below ground level should be considered to assess the requirement of water to build up the sub-surface storage by saturating the entire thickness of the vadose up to 3 m. below ground level.

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

The artificial recharge techniques inter relate land integrate the source water to ground water reservoir. Two effects are generated by artificial recharge in ground water reservoir namely - (a) Rise in water level and (b) increment in the total volume of the ground water reservoir.

2.0 PLANNING OF ARTIFICIAL RECHARGE PROJECTS

2.1 Identification Area

The artificial recharge projects are site specific and even the replication of the techniques from similar areas are to be based on the local hydrogeological and hydrological environments. The first step in planning the project is to demarcate the area of recharge. The Project can be implemented systematically in case a hydrologic unit like watershed is taken for implementation. However, localised schemes are also taken to augment ground water reservoir. The artificial recharge of ground water is normally taken in following areas:

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

2.2 Scientific Inputs

In order to plan the artificial recharge schemes following studies are needed

2.2.1 Hydrometeorological Studies

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

2.2.2 Hydrological Studies

Before undertaking any artificial recharge project, it is a basic prerequisite to ascertain the availability of source water for the purpose of recharging the ground water reservoir. For determining the source water availability for artificial recharge, hydrological investigations are required to be carried out in the Watershed/Sub-basin/basin where the artificial recharge schemes are envisaged. Four types of source water may be available for artificial recharge viz.

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

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

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

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

2.2.3 Soil Infiltration Studies

In case of artificial recharge through water spreading methods, soil and Land use conditions which control the rate of infiltration and downward percolation of the water applied on the surface of the soil assume special importance. Infiltration in its most narrow and precise sense can be defined as "The process water entering into a soil through the soil surface". Although a distinction is made between infiltration and percolation (the movement of water within the soil) the two phenomena are closely related since infiltration cannot continue unimpeded unless percolation removes infiltrated water from the surface soil. The soil is permeated by noncapillary channel through which gravity water flows downward towards the ground water, following the path of least resistance. Capillary forces continuously divert gravity water into pore spaces, so that the quantity of gravity water passing successively lower horizons is steadily diminished. This leads to increasing resistance to gravity flow in the surface layer and a decreasing rate of infiltration as a storm progresses. The rate of infiltration in the early phases of a storm is less if the capillary pores are filed from a previous storm.

There is maximum rate at which water can enter soil at a particular point under a given set of conditions, this rate is called the infiltration capacity. The actual infiltration rate equals the infiltration capacity only when the supply rate rainfall intensity less rate of retention) equals or exceeds.

Infiltration capacity depends on many factors such as soil type, moisture content, organic matter, vegetative cover, season, air entrapment, formation of surface seals or crusts etc. Of the soil characteristics affecting infiltration, non-capillary porosity is perhaps the most important. Porosity determines storage capacity and also effects resistance to flow. Thus infiltration tends to increase with porosity. Vegetal cover increases infiltration as compared with barren soil because (i) it retards surface flow giving the water additional time to enter the soil (ii) the root system make the soil more pervious and (iii) the foliage shields the soil from raindrop impact and reduces rain packing of surface soil. As water infiltrates soil under natural conditions the displacement of air is not complete even after many hours. Air spaces in the soil and intermediate zones interfere with infiltration as air is not pushed out by the infiltrating water but is gradually absorbed by water. Due to this phenomena infiltration rate may start rising towards a new high after a few days of continuous application of water. Surface conditions have a marked effect on the infiltration process and the formation of surface seals or crusts which forms under the influence of external forces such as rain drop impact and mechanical compaction or through staking reduces the rate of infiltration.

Infiltration of water through surface takes place generally over small periods of time and it is the process of redistribution of the soil water that goes on for most of the time and therefore predominates. When rainfall ceases the water wetted during the infiltration process starts to drain with the soil being wetted lower down the profile. The soil water conditions during the distribution periods are therefore those that primarily influence plant growth and agricultural husbandry and that also provide the buffer action in hydrologic cycle that the soil water zones has on the transport of water from the soil surface to the ground water aquifer. As such, infiltration is critically inter-linked with the phenomena of water evolution in the vadose zone which includes wetting front propagation.

In order to know infiltration rates of soils infiltration tests are carried out. Cylinder or flood infiltro-meters are common type of instruments which measure the infiltration as the rate of water leaving the device. Map showing infiltration rates of soils are prepared. These help to design suitable artificial recharge structures and to assess the extent of recharge from these structures.

2.2.4 Hydrogeological Studies

A correct understanding of hydrogeology of an area is of prime importance in successful implementation of any Artificial Recharge scheme. A desirable first step is to synthesize all the available data on hydrogeology from different agencies. The regional geological maps indicate the location of different geological strata, their geological age sequence, boundaries/contacts of individual formations and the structural expressions like Strike, Dip, Faults, Folds, Flexures, Intrusive bodies etc. These maps also bring out correlation of topography and drainage to geological contacts.

The Map providing information on regional hydrogeological rock units, their ground water potential and general pattern of ground water flow and chemical quality of water in different aquifers are necessary.

Satellite Imagery maps provides useful data on geomorphic units and lineaments which govern the occurrence and movement of ground water.

A detailed hydrogeological study besides the regional picture of hydrogeological set up available from previous studies is therefore imperative to know precisely the promising hydrogeological units for recharge and correctly decide on the location and type of structures to be constructed in field.

The hydrogeological investigations required before implementation of an artificial recharge scheme are given below.

(i) Detailed Hydrogeological Mapping

The purpose of hydrogeological mapping is to present the following maps which facilitate in the analysis of the ground water regime and its suitability to artificial recharge schemes.

a) Map showing hydrogeological units demarcated on the basis of their water bearing capabilities, both at shallow and deeper levels.
b) Map showing ground water contours to determine the form of the water table and the hydraulic connection of ground water with rivers, canals etc.
c) Map showing the depths to the water table are usually compiled for the periods of the maximum, minimum and mean annual position of water table.
d) Maps that show amplitudes of ground water level fluctuations and the maximum position of the water table of considerable importance for artificial recharge studies.
e) Maps showing piezometric head in deeper aquifers and their variations with time.

f) Maps showing ground water potential of different hydrogeological units and the level of ground water development.
g) Maps showing chemical quality of ground water in different aquifers.

The usefulness of all the above interpretative maps is additive, i.e. their conjunctive usage allow greater knowledge and understanding of an area than when a map is used separately.

At this level of hydrogeological mapping of the area few questions should be answered,

1. Whether there is any gap in data on sub-surface geology of the available lithological logs of the boreholes in the area are sufficient to arrive at a correct picture of aquifer geometry of the area.

2. Whether the available data on aquifer parameters is sufficient in case the area shows promise for artificial recharge techniques for deeper aquifers through Injection well etc.

3. Can the available ground water structure serve the purpose of monitoring the effects of artificial recharge Project

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

2.2.5 Geophysical Studies

a) The main purpose of applying geophysical methods for the selection of appropriate site for artificial recharge studies is mostly to help and assess the unknown sub-surface hydrogeological conditions economically, adequately and unambiguously. Generally the prime task is to compliment the exploratory programme. Mostly it is employed to narrow down the target zone, pinpoint the probable site for artificial recharge structure and its proper design.

b) Nevertheless, the application of geophysical methods is to bring out a comparative picture of the sub-surface litho environment, surface manifestation of such structures, and correlate them with the hydrogeological setting.

c) Besides defining the sub-surface structure and lithology, it can identify the brackish/fresh ground water interface, contaminated zone (saline) and the area prone to seawater intrusion.

Using certain common geophysical methods, it is possible to model the

i) Stratification of aquifer system and spatial variability of hydraulic conductivity of the characteristic zone, suitable for artificial recharge.

ii) Negative or non-productive zones of low hydraulic conductivity in unsaturated and saturated zones.

iii) Vertical hydraulic conductivity discontinuities, such as dyke and fault zone.

iv) Moisture movement and infiltration capacity of the unsaturated zone.

v) Direction of ground water flow under natural/artificial recharge processes.

vi) Salinity ingress, trend and short duration depth salinity changes in the aquifers due to varied abstraction or recharge.

The application of proper techniques, plan of survey and suitable instruments will definitely yield better understandable results, but, of indirect nature.

2.2.6 Chemical Quality of Source Water

Problem which arise as a result of recharge to ground water are mainly related to the quality of raw waters that are available for recharge and which are generally require some sort of treatment before being used is recharge installations. They are also related to the changes in the soil structure and the biological phenomena which take place when infiltration begins, to the changes brought to the environmental conditions. The chemical and bacteriological analysis of source water besides that of ground water is therefore essential.

2.2.7 Suspended matter may clog the soil in two different ways

Suspended Solids and Clogging Problem: A major requirement for waters that are to be used in recharge projects is that they be silt-free. Silt may be defined as the content of undissolved solid matter, usually measured in mg/l, which settles in stagnant water with velocities which do not exceed 0.1 m/hr. To obtain still clearer water, with only 10 - 12 mg/l suspended solids, further additions of flocculants and, frequently, agitation of the water must be resorted to.

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

Methods to minimize the clogging effect by suspended matter can be classified into broad groups:

a) Periodical removing of the mud-cake and dicing or scraping of the surface layer.

b) Installation of a filter on the surface, the permeability of which is lower than that of the natural strata (the filter must, of course, be removed and renewed periodically)

c) Addition of organic matter or chemicals to the uppermost layer.

d) Cultivation of certain plant-covers, notably certain kinds of grass.

Providing inverted filter consisting of fine sand coarse sand and gravel at the bottom of infiltration pits/trenches are very effective.

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 developed so far consists in thoroughly drying the ground under the basin.

2.3 Assessment Of Sub-Surface Potential For Ground Water Recharge

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

3.0 ARTIFICIAL RECHARGE TECHNIQUES AND DESIGNS

A wide spectrum of techniques are in vogue to recharge ground water reservoir. Similar to the variations in hydrogeological framework, the artificial recharge techniques too vary widely. The artificial recharge techniques can be broadly categorised as follows:-

a. Direct surface techniques

- Flooding
- Basins or percolation tanks
- Stream augmentation
- Ditch and furrow system
- Over irrigation

b. Direct sub surface techniques

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

c. Combination surface – sub-surface techniques

- Basin or percolation tanks with pit shaft or wells.

d. Indirect Techniques

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

Besides above, the ground water conservation structures like ground water dams, sub-surface dykes or locally termed as Bandharas, are quite prevalent to arrest sub-surface flows. Similarly in hard rock areas rock fracturing techniques including sectional blasting of boreholes with suitable techniques has been applied to inter-connect the fractures and increase recharge. Cement sealing of fractures, through specially constructed bore well has been utilised in Maharashtra to conserve sub-surface flow and augment bore well yield. (A schematic diagram of these is given in Fig. 1).

3.1 Artificial Recharge Structures

3.1.1 Ditch and Furrow Method:

In areas with irregular topography, shallow, flat bottomed and closely spaced ditches or furrows provide maximum water contact area for recharge water from source stream or canal. This technique requires less soil preparation than the recharge basins and is less sensitive to silting. Fig. 2 shows a typical plan or series of ditches originating from a supply ditch and trending down the topographic slope towards the stream. Generally three patterns of ditch and furrow system are adopted.

3.1.1.1 Lateral Ditch Pattern

The water from stream is diverted to the feeder canal/ditch from which smaller ditches are made at right angles. The rate of flow of water from the feeder canal to these ditches is controlled by gate valves. The furrow depth is kept according to the topography and also with the aim that maximum wetted surface is available along with maintenance of uniform velocity. The excess water is routed to the main stream through a return canal along with residual silt.

3.1.1.2 Dendritic Pattern

The water from stream can be diverted from the main canal to a series of smaller ditches spread in a dendritic pattern. The bifurcation of ditches continues until practically all the water is infiltrated in the ground.

3.1.1.3 Contour Pattern

The ditches are excavated following the ground surface contour of the area. When the ditch comes closer to the stream a switch back is made and thus the ditch is made to meander back and forth to traverse the spread are repeatedly. At the lowest point down stream, the ditch joins the main stream, thus returning the excess water to it.

3.1.1.4 Site Characteristics and Design Guidelines

a. Although this method is adaptable to irregular terrain, the water contact area seldom exceeds 10 percent of the total recharge area.
b. Ditches should have slope to maintain flow velocity and minimum deposition of sediments.
c. Ditches should be shallow, flat-bottomed, and closely spaced to obtain. Maximum water contact area. Width of 0.3 to 1.8 m. are typical
d. A collecting ditch to convey the excess water back to the main stream channel should be provided.

3.1.2 Percolation Tanks (PT) / Spreading Basin

These are the most prevalent structures in India as a measure to recharge the ground water reservoir both in alluvial as well as hard rock formations. The efficacy and feasibility of these structures is more in hard rock formation where the rocks are highly fractured and weathered. In the States of Maharashtra, Andhra Pradesh, Madhya Pradesh, Karnataka and Gujarat, the percolation tanks have been constructed in plenty in basaltic lava flows and crystalline rocks. A typical design of PT is given in Fig. 3 The percolation tanks are however also feasible in mountain fronts occupied by talus scree deposits. These are found to be very effective in Satpura Mountain front area in Maharashtra. The percolation tanks can also be constructed in the Bhabar zone. Percolation tanks with wells and shafts Percolation tanks are also constructed to recharge deeper aquifers where shallow or superficial formations are highly impermeable or clayey with certain modification. Recharge wells with filter are constructed in the Percolation Tanks and the stored water is Moti Ranjan and Bhujpur, Mandvi Kutch district, Gujarat.

3.1.2.1 Important Aspects of Percolation Tanks:

a. A detailed analysis of rainfall pattern, number of rainy days, dry spells, and evaporation rate and detailed hydrogeological studies to demarcate suitable percolation tank sites.

b. In Peninsular India with semi arid climate, the storage capacity of percolation tank be designed such that the water percolates to ground water reservoir by January since the evaporation losses would be high subsequently.

c. Percolation tanks be normally constructed on second to third order stream since the catchment so also the submergence area would be smaller.

d. The submergence area should be in uncultivable land as far as possible.

e. Percolation tank be located on highly fractured and weathered rock for speedy recharge. In case of alluvium, the bouldary formations are ideal for locating Percolation Tanks.

f. The aquifer to be recharge should have sufficient thickness of permeable vadose zone to accommodate recharge.

g. The benefitted area should have sufficient number of wells and cultivable land to develop the recharge water.

h. Detailed hydrological studies for run off assessment be done and design capacity should not normally be more than 50% of total quantum of rainfall in catchment.

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

j. Cut off trench be provided to minimise seepage losses both below and above nalla bed.

k. To avoid erosion of embankment due to ripple action stone pitching be provided upstream upto HFL.

l. Monitoring mechanism in benefitted as well as catchment area using observation well and staff gauges be provided to assess the impact and benefits of percolation tank.

3.1.3 Check Dams Cement Plug nala bunds

Check dams are constructed across small streams having gentle slope and are feasible both in hard rock as well as alluvial formation. The site selected for check dam should have sufficient thickness of permeable bed or weathered formation to facilitate recharge of stored water within short span of time. The water stored in these structures is mostly confined to stream course and the height is normally less than 2 m. These are designed based on stream width and excess water is allowed to flow over the wall. In order to avoid scouring from excess run off, water cushions are provided at down streamside. To harness the maximum run off in the stream, series of such check dams can be constructed to have recharge on regional scale.

A series of small bunds or weirs are made across selected nala sections such that the flow of surface water in the stream channel is impeded and water is retained on pervious soil/tock surface for longer body. Nala bunds are constructed across bigger nalas of second order streams in areas having gentler slopes. A nala bund acts like a mini percolation tank. The design aspects of check dam/Cement plug are given in Fig. 4.

Site Characteristic and Design Guidelines : For selecting a site for Check Dams/Nala bunds the following conditions may be observed.

1. The total catchment of the nala should normally be between 40 to 100 Hectares. though the local situations can be guiding factor in this.

2. The rainfall in the catchment should be less than 1000 mm/annum.

3. The width of nala bed should be atleast 5 metres and not exceed 15 metres and the depth of bed should not be less than 1 metre.

4. The soil down stream of the bund should not be prone to water logging and should have pH between 6.5 to 8.

5. The lands downstream of Check Dam/bund should have irrigable land under well irrigation.

6. The Nala bunds should be preferable located in area where contour or graded bunding or lands have been carried out.

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

8. Nala bund is generally a small earthen dam, with a cut off core wall of brick work, though cement bunds/plugs are now prevalent.

9. For the foundation for core wall a trench is dug 0.6 m wide in hard rock or 1.2 metres in soft rock of impervious nature. A core brick cement wall is erected 0.6 m wide to stand atleast 2.5 metres above nala bed and the remaining portion of trench is back filled on upstream side by impervious clay. The core wall is buttressed on both sides by a bund made up of local clays and on the upstream face, stone pitching is done.

10. Normally the final dimensions of the Nala bund are; length 10 to 15 metres, height 2 to 3 metres and width 1 to 3 metres, generally constructed in a trapezoidal form. If the bedrock is highly fractured, cement grouting is done to make the foundation leakage free.

The check dams are also popular and feasible in Bhabar, Kandi and talus scree areas of Uttar Pradesh, Punjab, and Maharashtra and have substantial impact on augmentation of ground water.

3.1.4. Gabion Structure

This is a kind of check dam being commonly constructed across small stream to conserve stream flows with practically no submergence beyond stream course. The boulders locally available are stored in a steel wire. This is put up across the stream's mesh to make it as a small dam by anchoring it to the streamside (fig 5). The height of such structures is around 0.5 m and is normally used in the streams with width of about 10 to 15 m. The cost of such structures is around Rs.10 to 15000/-. The excess water overflows this structure storing some water to serve as source of recharge. The silt content of stream water in due course is deposited in the interstices of the boulders to make it more impermeable. These structures are common in the State of Maharashtra, Madhya Pradesh, Andhra Pradesh etc.

3.1.5. Modification of Village tanks as recharge structure

The existing village tanks which are normally silted and damaged can be modified to serve as recharge structure. In general no “Cut Off Trench” (COT) and Waste Weir is provided for village tanks. Desilting, coupled with providing proper waste weir and C.O.T. on the upstream side, the village tanks can be converted into recharge structure. Several such tanks are available which can be modified for enhancing ground water recharge. Some of the tanks in Maharashtra and Karnataka have been converted.

3.1.6. Inter Watershed Transfer

The percolation tanks in a watershed may not have enough catchment discharge though a high capacity tank is possible as per site conditions. In such situations stream from nearby watershed can be diverted with some additional cost and the tank can be made more efficient. Such an effort was made in Satpura Mountain front area at Nagadevi Jalgaon district, Maharashtra. The existing capacity of the tank of 350 TMC was never utilised after its construction. This could however be filled by stream diversion from adjacent watershed.

3.1.7 Dug Well Recharge

In alluvial as well as hard rock areas, there are thousands of dug wells which have either gone dry or the water levels have declined considerably. These dug wells can be used as structures to recharge (Fig 6 & 7). The ground water reservoir, storm water, tank water, canal water etc. can be diverted into these structures to directly recharge the dried aquifer. By doing so the soil moisture losses during the normal process of artificial recharge, are reduced. The recharge water is guided through a pipe to the bottom of well, below the water level to avoid scoring of bottom and entrapment of air bubbles in the aquifer. The quality of source water including the silt content should be such that the quality of ground water reservoir is not deteriorated. Schematic diagrams of dug well recharge are given in figures 6 &7.

3.1.8 Recharge Shaft

These are the most efficient and cost effective structures to recharge the aquifer directly. In the areas where source of water is available either for some time or perennially e.g. base flow, springs etc. the recharge shaft can be constructed (Fig 8). Following are site characteristics and design guidelines: -

(i) To be dug manually of the strata is non-caving nature.

(ii) If the strata is caving, proper permeable lining in the form of open work, boulder lining are should be provided.

(iii) The diameter of shaft should normally be more than 2 m to accommodate more water and to avoid eddies in the well.

(iv) In the areas where source water is having silt, the shaft should be filled with boulder, good and sand from bottom to have inverted filler. The upper most sandy layer has to be removed and cleaned periodically. A filter be provided before the source water enters the shaft.

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

The main advantages of this technique are as follows: -

* It does not require acquisition of large piece of land like percolation tanks.

* There are practically no losses of water in the form of soil moisture and evaporation, which normally occur when the source water has to traverse the vadose zone

* Disused or even operational dugwells can be converted into recharge shafts, which does not involve additional investment for recharge structure.

* Technology and design of the recharge shaft is simple and can be applied even where baseflow is available for a limited period.

* The recharge is fast and immediately delivers the benefit. In highly permeable formation, the recharge shaft are comparable to percolation tanks with no submergence and hence no land compensation to local farmers.

The recharge shafts can be constructed in two different ways viz. Vertical and lateral. The details of each is given in the following paragraphs.

3.1.8.1 Vertical Recharge Shaft - The vertical recharge shaft can be further improvised with injection well at the bottom of the shaft.

(a) ***Without Injection well***

- Ideally suited for deep water levels (up to 15 metres b.g.l.)
- Presence of clay is encountered within 15 m.
- Effective in the areas of less vertical natural recharge
- Copious water available can be effectively recharged.
- Effective with silt water also (using inverted filter consisting of layers of sand, gravel and boulder)
- Depth and diameter depends upon the depth of aquifer and volume of water to be recharged.
- The rate of recharge depends on the aquifer material and silt content in the water.
- The rate of recharge with inverted filter ranges from 7 - 14 lps for 2 - 3 meter diameter.

This type of shaft has been constructed at the following places.

- Brahm Sarovar, Kurukshetra district, Haryana - Silt free water
- Dhuri drain, Sangrur district, Punjab - surface run off with heavy silt
- Dhuri link drain, Sangrur district, Punjab - surface run off with heavy silt
- President Estate, New Delhi - Roof Top and Surface Run Off
- Nurmahal Block, Jalandhar district, Punjab
- Kirmich and Samastipur, Kurukshetra distrtict - surface water from depression

(b) *With Injection Well*

In this technique at the bottom of recharge shaft a injection well of 100 - 150 mm diameter is constructed piercing through the layers of impermeable horizon to the potential aquifers to be reached about 3 to 5 meter below the water level. (Fig.-9)

- Ideally suitable for very deep water levels (more than 15 meters)
- Aquifer is over lain by impervious thick clay beds
- Injection well can be with or without assembly
- The injection well with assembly should have screen in the potential aquifer at least 3 – 5 meter below the water level.
- The injection well without assembly is filled with gravel to provide hydraulic continuity so that water is directly recharged into the aquifer
- The injection well without assembly is very cost effective.
- Depending upon volume of water to be injected, number of injection wells, can be increased to enhance the recharge rate.
- The efficiency is very high and rate of recharge goes even up to 15 lps at certain places.

These structures have been constructed at following places.

♦ Injection Well Without Assembly
  - Dhuri drain, Sangrur district, Punjab
  - Issru, Khanna block, Ludhiana district, Punjab
  - Lodi Garden, New Delhi
  - Dhaneta, Samana Block, Patiala district, Punjab

♦ Injection Well With Assembly
  - Dhuri drain, Sangrur district, Punjab
  - Dhuri Link drain, Sangrur district, Punjab
  - Kalasinghian, Jalandhar district, Punjab

3.1.8.2 Lateral Recharge Shaft

- Ideally suited for areas where permeable sandy horizon is within 3 meter below ground level and continues upto the water level - under unconfined conditions (Fig. 9)
- Copious water available can be easily recharged due to large storage and recharge potential.
- Silt water can be easily recharged
- 2 to 3 meter wide and 2 to 3 meter deep trench is excavated, length of which depends on the volume of water to be handled.
- With and without injection well (Details of structures already described in Section 3.1.8.1)

This structure has been constructed at following places.

- Dhuri drain, Sangrur district, Punjab - 300 meters (with 6 injection wells)
- Dhuri Link drain, Sangrur district, Punjab - 250 meter (with 3 injection wells)
- Garhi Kangran, Baghpat district, U. P. - 15 meter (with 2 injection wells)
- Shram Shakti Bhawan, New Delhi - 15 meter (3 lateral shafts with 2 injection well in each)
- Dhanetha, Samana block, Patiala district, Punjab - 4 lateral shaft with injection wells
- D. C. Office complex, Faridabad, Haryana - with injection wells
- Lodhi Garden, New Delhi - with injection wells

3.1.9. Artificial Recharge Through Injection Wells

Injection wells are structures similar to a tube well but with the purpose of augmenting the groundwater storage of a confined aquifer by pumping in treated surface water under pressure (Figure 10). The injection wells are advantageous when land is scarce.

This techniques 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 on the festival of Shriramanawami. The ground water aquifer had meager reserve and had to be necessarily replenished through induced recharge from Godavari River. The surface water could not be directly pumped to the distribution system due to turbidity and bacteriological contaminations. A water supply scheme was successfully executed by construction of 30 filter point wells of 90 cm dia which yielded about 60 cubic metre/ha of potable water, mainly the induced recharge from river with phreatic alluvial aquifer acting as filtering medium. Hydraulically the effectiveness of induction of water in injection well is determined by: -

(a) Pumping Rate
(b) Permeability of aquifer
(c) Distance from stream
(d) Natural ground water gradient
(e) Type of well

In alluvial areas injection well recharging a single aquifer or multiple aquifers can be constructed to normal gravel packed pumping well. An injection pipe with opening against the aquifer to be recharged may be sufficient. However, in case of number of permeable zones separated by impervious rocks, a properly designed injection well with inlet pipe against each aquifer to be recharged need to be constructed. The injection wells as a means of artificial recharge are comparatively costlier and require specialised techniques of tubewell constructed supported by operation and maintenance to protect the recharge well from clogging.

3.1.10 Induced Recharge:

It is an indirect method of artificial recharge involving pumping from aquifer 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 such methods there is actually no artificial build up of ground water storage but only passage of surface water to the pump through an aquifer. In this sense, it is more a pumpage augmentation rather than artificial recharge measure. (Fig. 11).

In hardrock areas the abandoned channels often provide good sites for induced recharge. Check weir in stream channel, at location up stream of the channel bifurcation, can help in high infiltration from surface reservoir to the abandoned channel when heavy pumping is carried out in wells located in the burried channel.

The greatest advantage of this method is that under favourable hydrogeological situations the quality of surface water generally improves due to its path through the aquifer material before it is discharged from the pumping well.

For obtaining very large water supplies from river bed lake bed deposits or water-logged areas, collector wells are constructed. In India such wells have been installed in Yamuna Bed at Delhi and other places in Gujarat, Tamil Nadu and Orissa. The large discharges and lower lift heads make these wells economical even if initial capital cost is higher as compared to tube well.

In areas where the phreatic aquifer adjacent to the river is of limited thickness, horizontal wells may be more appropriate than vertical wells. Collector well with horizontal laterals and infiltration galleries can get more induced recharge from the stream collector wells constructed in seasonal nala beds these can be effective as induced recharge structures for short periods only.

Site Characteristics and Design Guidelines: 1. 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 central well is a vertical concrete cassion in precast rings, (wall thickness 0.45 m) sunk upto the bottom of aquifer horizon. The bottom of cassion is sealed by thick concrete plugs. Slotted steel pipes, 9 mm thick, 15 to 50 cm in diameter having open area above 15% and a tapered leading are driven laterally through port holes at appropriate places in the cassion. The successive slotted pipes are welded and driven using special hydraulic jacks installed at the bottom of the cassion. The number of laterals is usually less than 16 thus permitting minimum angle of 22 30", between two laterals. The maximum length of lateral reported is 132 m. and the total length of laterals from 120 to 900 m. depending upon requirement of yield.

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

3.1.11 Ground Water Dams Or Sub-Surface Dykes Or Underground Bandharas (UGB):

These are basically ground water conservation structures and are effective to provide sustainability to ground w ater structures by arresting sub surface flow. A ground water dam is a sub-surface barrier across stream which retards the natural ground water flow of the system and stores water below ground surface to meet the demands during the period of need (Fig.12). The main purpose of ground water dam is to arrest the flow of ground water out of the sub-basin and increase the storage within the aquifer. By dowing so the water levels in upstream part of ground water dam rises saturating the otherwise dry part of aquifer.

The underground dam has following advantages: -

* Since the water is stored within the aquifer, submergence of land can be avoided and land above reservoir can be utilised even after the construction of the dam.

* No evaporation loss from the reservoir takes place.

* No siltation in the reservoir takes place.

* The potential disaster like collapse of dams can be avoided

The aquifer to be replenished is generally one which is already over exploited by tube well pumpage and the declining trend of water levels in the aquifer has set in. Because of the confining layers of low permeability the aquifer can not get natural replenishment from the surface and needs direct injection through recharge wells. Artificial recharge of aquifers by injection well is also done in coastal regions to arrest the ingress of sea water and to combat the problems of land subsidence in areas where confined aquifers are heavily pumped.

In alluvial areas injection well recharging a single aquifer or multiple aquifers can be constructed in a fashion similar to normal gravel packed pumping well. The only difference is that cement sealing of the upper section of the well is done in order to prevent the injection pressures from forcing leakage of water through the annular space of bore hole and well assembly. In hard rock areas casing and well screens may not be required. An injection pipe with opening against the aquifer to be recharged may be sufficient. However, in case of number of permeable horizons separated by impervious rocks like vesicular basalts or cavernous limestones, a properly designed injection well may be constructed with slotted pipe against the aquifer to be recharged. In practice the injection rates are limited by the physical characteristics of the aquifer. In the vicinity of well, the speed of groundwater flow may increase to the point that the aquifer is eroded, specially if it is made up of unconsolidated or semi-consolidated rocks. In confined aquifer confining layers may fail if too great pressure is created under them. If this occurs, the aquifer will become clogged in the vicinity of the borehole and/or may collapse.

3.1.12 Roof Top Rain Water Harvesting

In Urban areas, the roof top rainwater can be conserved and used for recharge of ground water. This approach requires connecting the outlet pipe from rooftop to divert the water to either existing wells/ tubewells/borewell or specially designed wells. The urban housing complexes or institutional buildings have large roof area and can be utilising for harvesting roof top rainwater to recharge aquifer in urban areas (Fig 12A). Table shows availability of Rainwater through Roof Top Rainwater Harvesting.

Table - Availability of Rain Water through Roof Top Rain Water Harvesting

Rainfall(mm)	100	200	300	400	500	600	800	1000	1200	1400	1600	1800	2000
Roof top area (sqm)	Harvested water from Roof top (cum)												
20	1.6	3.2	4.8	6.4	8	9.6	12.8	16	19.2	22.4	25.6	28.8	32
30	2.4	4.8	7.2	9.6	12	14.4	19.2	24	28.8	33.6	38.4	43.2	48
40	3.2	6.4	9.6	12.8	16	19.2	25.6	32	38.4	44.8	51.2	57.6	64
50	4	8	12	16	20	24	32	40	48	56	64	72	80
60	4.8	9.6	14.4	19.2	24	28.8	38.4	48	57.6	67.2	76.8	86.4	96
70	5.6	11.2	16.8	22.4	28	33.6	44.8	56	67.2	78.4	89.6	100.8	112
80	6.4	12.8	19.2	25.6	32	38.4	51.2	64	76.8	89.6	102.4	115.2	128
90	7.2	14.4	21.6	28.8	36	43.2	57.6	72	86.4	100.8	115.2	129.6	144
100	8	16	24	32	40	48	64	80	96	112	128	144	160
150	12	24	36	48	60	72	96	120	144	168	192	216	240
200	16	32	48	64	80	96	128	160	192	224	256	288	320
250	20	40	60	80	100	120	160	200	240	280	320	360	400
300	24	48	72	96	120	144	192	240	288	336	384	432	480
400	32	64	96	128	160	192	256	320	384	448	512	576	640
500	40	80	120	160	200	240	320	400	480	560	640	720	800
1000	80	160	240	320	400	480	640	800	960	1120	1280	1440	1600
2000	160	320	480	640	800	960	1280	1600	1920	2240	2560	2880	3200
3000	240	480	720	960	1200	1440	1920	2400	2880	3360	3840	4320	4800

4.0 MONITORING MECHANISM FOR ARTIFICIAL RECHARGE PROJECTS

The monitoring of water levels and water quality is of prime importance in any scheme of artificial recharge of Ground Water. The monitoring data speaks for the efficacy of structures constructed for artificial recharge and greatly helps in taking effective measures for Ground Water Management on scientific lines.

4.1 Water Level Monitoring

During the feasibility study stage the monitoring of surface water and ground water levels greatly help in identifying the method of artificial recharge. Net work of observation wells is used to study the ground water flow pattern and temporal changes in potentiometric head in the aquifer.

The observation well net work during feasibility stage is generally of low well density but spread over a large area with the primary aim of defining the boundary zonation of the aquifer to be recharged and to know the hydraulic characteristics of the natural ground water system. After identification of the feasible groundwater structure the observation well net work is redefined in a smaller area with greater well density. The objective of monitoring system is to study the effect of artificial recharge on the natural ground water system. Depending on the method of artificial recharge and the hydrogeology of the area, the observation well net work has to be designed. The monitoring system of observation well network should be designed specially to monitor impact of individual structures which can further be extended to monitor the impact of group of such structures in the artificial recharge scheme area. The net work should contain observation wells (1) near the center of the recharge facility (2) a sufficient distance from the recharge facility to observe composite effects and (3) near the limit of hydrological boundaries. If the recharged aquifer is overlain by confining/semi-confining layer, piezometers should be installed to monitor the water levels of overlying and underlying aquifers which helps in the study of leakages etc.

Where the surface water bodies are hydraulically connected with the ground water aquifer which is being recharged, it is advisable to monitor the water level profiles of both Surface water and Ground water.

The periodic monitoring of Water Levels can demarcate the zone of benefit. In this method a network of observation wells is established in the area likely to be benefitted and following observations are made: -

1. In the zone benefitted, the water levels be observed to the whether the well hydrographs have a flat apex during the time when there is water in the recharge structure (tank, pit etc.).

2. Wells situated outside the zone of influence normally show an angular apex for

the period when the recharge is taking place, while these situated within the zone of influence have a flatter area.

3. The recession limbs of wells close to a recharge structure normally have a gentle gradient as compared to those located far off.

4. Crops in the zone of influence will be healthy compared to those outside such an area. Further more, in the zone of influence there is a tendency to grow crops with high water requirements.

5. Well yields in the zone of influence should be greater than those outside it. The wells in benefitted zones may have more sustainability in lean period than those outside.

The above criteria can be used to define the zone of influence and thereby, a real and temporal demarcation of the effectiveness of recharge structures. This methodology was adopted in Maharashtra, India (Fig.13).

4.2 Tracer Technique For Demarcating Zone Of Benefit

The tracers are useful in demarcating the area benefitted by artificial recharge, Tritium; Rodhomine B, fluorescent dye and environmental isotopes etc. are quite useful in assessing the extent of recharge and efficiency of recharge structures.

4.3 Water Quality Monitoring

The monitoring of water quality during the implementation of artificial recharge schemes is essential to maintain the quality standards for specified uses of the augmented resource. In case of injection wells the composition of native water in the aquifer and the recharged water is important to prevent clogging of well and aquifer due to excessive precipitation of salts. The data on the chemical quality of native water and the changes which take place during the artificial recharge schemes should be collected by regular sampling from observation well net work. Where treated wastewater is used for recharge a careful monitoring is required to detect and preclude any possibility of contamination through a network of monitoring wells. Thus, the type of water quality monitoring programme depends on the specific problem being studied i.e. changes in ground water quality, effect of soil salination, and prevention of any contamination etc. The samples to be collected will also depend on the purpose and are generally categorised into (1) Indicative (2) Basic and (3) Comprehensive. The indicative samples are collected at 1 to 4 months intervals and used to ascertain the presence of injected effluent. Basic samples are taken at monthly intervals for wells already influenced by recharge to determine the effect of recharge effluent on ground water quality and the purification provided by flow through the soil and aquifer system. Comprehensive samples are taken at intervals of 6 months to 1 year for observation wells and production wells to determine water quality with respect to specific standards for intended water use.

4.4 IMPACT ASSESSMENT

The impact assessment of Artificial Recharge schemes can generally be enumerated as follows: -

a) Conservation and harvesting of surplus monsoon runoff in ground water reservoir which otherwise was going un-utilised outside the watershed/ basin and to sea.
b) Rise in ground water levels due to additional recharge to ground water. In case where continuous decline of ground water level was taking place, a check to this and/or the intensity of decline subsequently reduces. The energy consumption for lifting the water also reduces.
c) The ground water structures in the benefitted zone of artificial structures gains sustainability and the wells provides water in lean month when these were going dry. The domestic wells will become sustainable and many of the areas become tanker free.
d) The cropping pattern in the benefitted zone will undergo marked change due to additionality of ground water and cash crops will start growing. Orchards which went dry earlier due to ground water scarcity may rehabilitated and new plantation be grown.
e) Green vegetation cover may increase in the zone of benefit and also along the structures due to additional availability of soil moisture.
f) The quality of ground water may improve due to dilution.
g) Besides the direct measurable impacts, the artificial recharge schemes will generate indirect benefit in terms of decease in soil erosion, improvement in fauna and flora, influx of migratory birds, etc. Besides, the social and economic status of farmers of benefitted zone will also substantially improve due to increase in crop production.

Remarks: -

Format for preparation of Artificial Recharge Project and Checklist for planning is given in Annexure I and Annexure II. General guidelines for the evaluation of ground water recharge projects with special reference to Basaltic Terrain is given in Annexure III.

5.0 CASE HISTORIES OF ARTIFICIAL RECHARGE IN INDIA

The artificial Recharge for augmentation of ground water reservoir and to provide sustainability to ground water development. The schemes for artificial recharge are being implemented in different hydrogeological situations. The case histories in Indian context are given herein under:

5.1 Artificial Recharge For Ground Water Sustainability In Basaltic Terrain - Maharashtra:

The Central Ground Water Board has conducted specific studies in an over exploited watershed WR-2, Amravati district, Maharashtra. where excessive development of ground water to meet the crop requirements for orange cultivation has depleted the ground water resources. The receding ground water levels in this watershed have resulted in increased lifting costs for ground water withdrawal, deepening of wells, construction of deep bore wells and in many cases reduction in areas as well as production of orange crops. The multidisciplinary approach adopted by Central Ground Water Board to augment sub-surface storage included topographical studies to assess and understand various physiographic parameters important to locate the appropriate recharge structures, Hydrometeorological studies to assess the rainfall pattern for working out design of recharge structures, hydrological studies to assess non committed surplus monsoon run off available for recharge and hydrogeological studies to assess the capability of basaltic aquifers to accommodate the additional recharge for utilisation in lean period. The studies have brought out that the watershed covering 488 sq.km. area has surplus monsoon runoff of about 98.9 Million Cubic Metres (MCM) which can be conserved through simple artificial recharge structures like percolation tanks and check dams (cement plugs). The efficiency of these structures constructed at suitable locations with appropriate design in case of percolation tanks is 91% and for cement plugs 94%.

The total capacity utilisation of percolation tank has been found to be upto 150% due to repetitive fittings and up to 400% in case of cement plugs. The benefitted area in case of percolation tanks with gross storage capacity varying from 71 to 220 Thousand Cubic Metres (TCM) varied from 60 to 120 hectares (ha) during 1997-98 and benefits extended upto 1.5 km. down stream of percolation tanks. In case of cement plugs with storage capacity varying from 2.10 TCM to 7.42 TCM varied from 3 to 15 ha during 1997-98. The existing dug wells in the command areas of these structures were benefited not only in terms of rise in ground water levels compared to pre-project period but the sustainability of ground water pumpage increased during summer period. The Figures 14 and 15 indicate the improvement in ground water levels in the command areas of percolation tank and Check dam. Additional areas were brought under cultivation and areas of orange orchards have increased. The project implemented by CGWB has proved the techno-economic feasibility of the artificial recharge techniques in basaltic terrain with no adverse environmental impact.

5.1.1 Technical Evaluation Studies in Jeur Sub-basin Ahmednagar District, Maharashtra:

Central Ground Water Board in collaboration with Directorate of Irrigation Research and Development, Government of Maharashtra has studied the efficiency of existing percolation tanks in sustaining the yield of dug wells used for agriculture. The evaluation of 12 existing percolation tanks in Jeur Sub-basin, Ahmednagar district, during 1989 brought the following.

- The recharge to ground water or effectiveness of percolation tanks varies from 36 to 76.7% with an average of 49.6%. The location of PT in suitable sites and proper design plays an important role in effectiveness and efficiency of percolation tanks.

- In some of the percolation tanks, visible seepage varies from 20 to 53% of the volume harvested. This is mainly due to faulty designs.

- The percolation tanks located over vesicular and fractured basalts have better efficiency.

- The evaporation losses are generally within 15% of the total storage.

5.2 Mountain Front Recharge Augmentation For Alluvial Aquifers - Maharashtra:

The prominent regional aquifer system for Tapi Alluvial basin paralleling Satpura Mountain front is being extensively developed to meet the water requirement of cash crops like Banana and Sugarcane. This has led to decline of water levels of more than 8-10 metres during last 10-15 years. Large number of wells has either gone dry or their yields have declined. There is thus an urgent need to augment the ground water resources of the Tapi alluvial basin. The Satpura Mountain front offers favourable locale to augment ground water reservoir due to the high infiltration capacity of alluvial fans occurring in this zone. The Central Ground Water Board has undertaken artificial recharge studies in one of the watersheds TE-17 in Jalgaon district wherein extensive ground water irrigation for Banana crop has resulted in depletion of ground water resource. The studies undertaken included assessment of surplus monsoon runoff available in the watershed and delineation of potential talus and scree zone locally known as Bazada which offers favourable location for construction of artificial recharge structures. The studies included assessment of the total thickness of unsaturated granular zone above water table to determine the potential of recharge in this zone. The sub surface storage potential of watershed 5 metres below ground level was assessed as 85 Million Cubic Metres (MCM) compared to surplus monsoon runoff of 29.7 MCM. Artificial recharge techniques like recharge through percolation tanks, recharge through existing dug wells, recharge shafts and through injection tubewells were experimented. Some of the existing artificial recharge structures like village tanks were renovated to convert these into percolation tanks and storage capacity of existing percolation tanks was augmented by stream diversion from adjacent watershed. The percolation tanks in Bazada formation of Satpura foothills were found to be highly efficient with efficiency as high as 97% and capacity utilisation going upto 400%. The zone of benefit extended to 5 km with benefited area up to 400 ha. The recharge through existing disused dug wells utilising surplus water from existing canal irrigation system provided encouraging results and after observing this experiment, the local farmers have resorted to dug well recharge through their own efforts providing sustainability to ground water development. Recharge through injection tubewell though feasible is not very effective and efficient compared to other artificial recharge techniques. The studies undertaken by Central Ground Water Board have clearly indicated that the Satpura Mountain front is quite favourable for implementation of a mega artificial recharge project which can utilize the techniques experimented in watershed TE-17 for augmenting the depleting ground water resources of Tapi Alluvial Tract (Fig. 16).

COST-BENEFIT ANALYSIS OF ARTIFICIAL RECHARGE STRUCTURES CONSTRUCTED UNDER THE PROJECT IN WATERSHED WR-2, DISTRICT AMRAVATI

Sl. No.	Type of Structure	Additional Recharge to ground water due to structure (TCM)	Additional area brought under irrigation (ha)	Incremental income due to assured irrigation (Rs/ha/yr)	Total incremental income due additional irrigation by structure (Rs/yr)	Constructional cost ground water of structure (Rs.)	Life of structure (yrs)	Annual investment for construction (Rs.)	Incremental on annual Expenditure @ 10% (Rs.)	Total annual investment (Rs.)	Cost benefit ratio
(A)	**PERCOLATION TANK**										
1	Benoda	131.6	26.32	10,000	2,63,200	29,216,00	25	1,16,864	11,686	1,28,550	1:2.00
2	Manikpur	117.8	23.56	10,000	2,35,600	30,63,500	25	1,22,540	12,254	1,34,794	1:1.75
3	Bhimdi	49.0	9.80	10,000	98,000	17,13,140	25	68,525	6,852	75,377	1:1.30
	Sub Total	**298.4**	**59.68**	**---**	**3,96,800**	**76,98,240**	**---**	**3,07,929**	**30,792**	**3,38,721**	**1:1.75**
(B)	**CEMENT PLUGS**										
1	Tembur-kheda-I	6.70	1.34	10,000	13,400	1,29,000	12	10,750	1,0075	11,825	1:1.33
2	Tembur-kheda-II	9.30	1.86	10,000	18,600	1,78,000	12	14,833	1,483	15,316	1:1.21
3	Malkhed	9.20	1.84	10,000	18,400	34,600	12	2,883	288	3,171	1:5.80
4	Loni-I	6.10	1.22	10,000	12,200	1,50,800	12	12,556	315	3,465	1:2.37
5	Loni-II	6.10	1.22	10,000	12,200	1,50,800	12	12,556	1,255	13,811	1:0.88
6	Shendur-janaghat-I	6.70	1.34	10,000	13,400	77,800	12	6,483	648	7,131	1:1.88
7	Shendur-janaghat-II	5.00	1.00	10,000	10,000	69,800	12	5,817	582	6,399	1:1.56
8	Aloda	4.00	0.8	10,000	8,000	54,000	12	4,500	450	4,950	1:1.63
9	Benoda	5.70	1.14	10,000	11,400	1,13,000	12	10,416	1,042	11,458	1:1.00
10	Mamda-pur	6.00	1.20	10,000	12,000	1,13,000	12	9,417	942	10,359	1:1.16
	Sub Total	**58.70**	**11.74**	**---**	**1,17,400**	**9,32,000**	**---**	**77,669**	**7,766**	**85,435**	**1:1.88**
GRAND TOTAL (A + B)		**357.10**	**71.42**	**---**	**7,13,200**	**86,30,240**	**---**	**3,85,598**	**38,558**	**4,24,156**	**1:1.68**

5.3 Artificial Recharge Experiment For Injection Well Technique In Ahmedabad - Gujarat

The Physical Research Laboratory, Ahmedabad and Gujarat Water Resources Development Corporation Limited have jointly conducted an experiment on recharging the deeper confined aquifers around Hansol, near Ahmedabad during 1977. The experiment involved transferring of water from shallow aquifer to the deeper confined aquifer using siphon principle. In this experiment, a shallow tube well (dia : 350 mm) of 21.34 m depth was drilled in west bank of Sabarmati river bed and tapping the shallow phreatic aquifer between 6.04 and 21.34 m below river bed level. An injection well (diameter of 600 mm up to 75 m from ground level and followed by 400 mm to the depth of 240 m) to a depth of 238 m was drilled and developed at a distance of 61.3 m from the source well on the same bank of the river. An observation well to the same depth of 238 m was drilled near the injection well to monitor the response of the aquifer during artificial recharge. These deep wells tap the confined aquifers below 74 m depth which are under heavy exploitation for agricultural activities. A schematic diagram showing the arrangement of source well, injection well, connecting siphon pipe and the observation well is shown in Fig. 17).

A trial recharge experiment was conducted for 92 days for understanding the response of the aquifer during the recharge in terms of development of recharge cone and dissipation of recharge mound. A stabilised recharge rate of 590 litres per minute (LPM) was observed from 200th minute of the recharge experiment till the end. During the recharge phase, nearly 7.5 million litres of water was recharged into the confined aquifer.

COMPARATIVE COST OF WATER RECHARGE THROUGH VARIOUS ARTIFICIAL RECHARGE STRUCTURES, JALGAON DISTRICT, MAHARASHTRA.

(A) PERCOLATION TANKS CONSTRUCTED UNDER ARP (CGWB)

Sl. No.	Name (Cost in Rs.)	Constructed Storage capacity (Th m^3)	Year of study	Net Recharge (Th m^3)	Annual Investment (Rs.)	Cost of recharge annually (Paise/M^3)
1	Ichkheda (7,57,564)	45	95-96 96-97 97-98	62.1 149.9 116.1	33,333	54 22 29
2	Haripura (2,03,345)	12	95-96 96-97 97-98	23.2 69.3 38.9	8947	38 13 23
3	Dongaon (6,39,020)	11	97-98	48.3	70,292	146
4	Nagadevi with Nala diversion (4,75,102)	350 (Old PT)	95-96 96-97 97-98	113.6 130.5 139.5	20,904	18 15 16
5	Haripura converted (2,08,865)	22	97-98	77.4	8191	11
6	Baghjhira converted (1,54,654)	6	97-98	32.8	6805	21

(B) PERCOLATION TANKS EXISTING BEFORE ARP

7	Baghjhira	45	95-96 96-97 97-98	51.4 62.9 54.6	OLD	Constructed in year 1986-87
8	Giradgaon	364	96-97 97-98	90.9 111.2	OLD	Constructed in year 1980-81

(C) DIRECT RECHARGE SCHEMES OF CGWB

9	Injection well, Dambhumi a)tubewell (1,50,00) b)Dugwell (25,000)	Recharge Rate (m^3/hrs) 3-5 5	 97-98 97-98	 4.2 5.3	 7500 1667	 179 31
10	Recharge shaft a)Savkheda (1,30,210) b)Nagadevi (31,220)	 70 15	 97-98 97-98	 42.0 14	 6511 2081	 16 15
11	Dugwell Recharge at Giradgaon (10,000)	40	95-96	6.8	667	10

(A) Life of percolation Tanks – 25 years. Except Sr. No. 3 which is 10 years due to siltation problem
(B) Life of Injection well and recharge shaft (Sl. No. 10-a) – 20 years.
(C) Life of Recharge shaft and Dugwell (Sr. No. 9(b), 10(b), 11) – 15 years.

5.4 Artificial Recharge In Mehsana Area And Coastal Saurashtra - Gujarat

The Pilot Project on evaluating the technical feasibility of artificial recharge in augmenting the depleted aquifers in the Mehsana area and for controlling the saline ingression in coastal belt of Gujarat was successfully conducted by the Central Ground Water Board in collaboration with UNDP and State Ground Water Agencies.

After detailed hydrogeological surveys and ground water draft estimation, the alluvial area around Kamliwara in the Central Mehsana was selected for pilot experiments on artificial recharge through pressure injection and surface spreading methods during 1983. The source of water drawn for the artificial recharge through pressure injection test was from the phreatic aquifer below the Sarswati river bed. Since ground water was used for artificial recharge, the injection water was devoid of silts and other impurities and chemically compatible with the water in aquifer getting recharged. The experimental results did not show any adverse effect of clogging. The pressure injection experiment was conducted continuously for about 250 days with an average injection quantity of 225 cubic meters per day. During the recharge cycle, a rise in water level of 5 meters in the injection well (apparent built up of 11 m) and 0.6 to 1.0 m in wells 150 meters away from the injection well were observed. The higher rate of injection continuously for about 250 days was probably sustained because of contemporaneous withdrawal from the aquifer through nearby irrigation wells. (Fig. 18).

In Mehsana area, artificial recharge experiments through spreading method were also conducted using canal water. A spreading channel of 3.3 meters width, 400 m length with 1 in 1 side slope was constructed and in which the canal water was fed for 46 days. The recorded build up in water level of 1.4 to 2 m. was observed up to 15 m from the recharge channel and about 20 cm at distance of 200 m. The recharge rate of 260 cubic meters per day was estimated using an infiltration rate of 17 cm/day. Dissipation in recharge mound (1.42 m) was observed in 15 days.

Another experiment using a recharge pit (1.7 m x 1.7 m x 0.75 m) to study the feasibility of recharging the shallow aquifers was conducted at Dabhu in Central Mehsana area. Canal water was used for the experiment and the pit was covered to prevent dust deposition and evaporation losses. During the recharge phase of 60 days, the recharge was effected at the rate of 17.3 cubic meters per day with an infiltration of 0.5 m/day. A rise of 4.13 m in water level was observed at a distance of 5 meters from the recharge pit. Both these recharge methods were effective in alluvial areas.

Artificial recharge through pressure injection technique was tried on a pilot scale using ground water from phreatic aquifer for a short period in the Mehsana alluvial aquifers. The source well was located in the Saraswati River and the water was carried to injection well at distance of 130 meters by 10 cm pipeline. On-line flow meter and pressure gauge were fitted to monitor the flow rate and cumulative quantity and to record the pressure developed during injection experiment. The injection recharge experiment was conducted with 8 litres per second (LPS) rate for about an hour. The injection rate was increased to 12 LPS and the test was continued for 90 minutes. A drastic reduction in recharge rate (3 LPS) was reported and the cause of reduction was attributed to backpressure due to clogging of injection well. Due to well clogging, the water level could not reach to its initial static level even after 8 days. Though, in this case, the silt-free shallow ground water was used for recharge, the observational results clearly indicate the necessity of understanding probable clogging problems which may arise due many other factors apart from silt entry.

Studies on control of salinity in the coastal Saurashtra using spreading and injection method have indicated that the recharge pit and the injection shaft can effect recharge at the rate of 192 and 2600 cubic meters per day respectively. Canal water was used for recharge studies. Problems in land acquisition in this highly developed area make it difficult to select suitable sites for spreading structures.

A short period pressure injection was conducted by the Gujarat Water Resources Development Corporation in 1974 near Ahmedabad city. Processed water from the city water works was injected for 72 hours in a deep tube well and a pressure varying between 80-100 PSI with a rate of 45 litres per second.

5.5 Artificial Recharge Studies In The Ghaggar River Basin - Haryana:

Central Ground Water Board, with the assistance of UNDP, has undertaken artificial recharge studies involving induced recharge and recharge through injection wells at two sites located in the districts Ambala and Kurukshetra along with Ghaggar river in Haryana. The Dabkheri site in the Narwana Branch area, Kurukshetra district was selected for the artificial recharge studies by the injection well method after detailed hydrogeological surveys. An injection well tapping aquifer at different depth levels was developed with cement sealing from ground level to a depth of 15 m. The injection experiment was carried out using canal water with an injection rate of 43.3 LPS under pressure. It was observed that the injection pressure of 1.6 atmosphere raised to 1.96 atmosphere within 30 minutes of injection and remained constant for about 4 hours. Sudden and violent vibrations in the injection line were reported to have been witnessed and the injection pressure shot up to 2.5 atmosphere and it was reported that it was due to clogging of foot valve with grass etc.

After construction and development of another injection well with improved design, second injection recharge experiment was conducted with a recharge rate of 40 LPS for 389 hours and with 22 LPS for another 24 hours. The experiment demonstrated that the hydrogeological conditions of the area are favourable for artificial recharge through injection method. The canal water quality was found to be suitable for injection.

5.6 Artificial Recharge In Moti Rayan And Bhujpur Area, Mandvi Kutch District

In order to augment the ground water reservoir in Moti Rayan area, 18 Check dams, three percolation ponds, two recharge wells and one sub surface dam with four recharge wells were constructed. During the year 1994, there were 34 rainy days from June 30th to

September 15th. The daily rainfall varied from 1 mm to 175 mm. The number of rainy days in June, July, August and September were 1,8,6 and 9 days respectively. The water harvesting structures received around 2 fillings and total quantity infiltrated amounted to 344.664 m^3. This indicates that even during low rainfall years, ground water can be recharged through water harvesting structures. The Fig. 19 gives the details of ground water harvesting structures in Moti Rayan Area.

5.7 Percolation Ponds In Coimbatore District, Tamil Nadu

The water Technology Centre, Tamil Nadu Agricultural University has studied existing 10 percolation tanks in Coimbatore district of Tamil Nadu State for economic evaluation. Eight percolation tanks in Coimbatore taluk and two in Avinashi taluk of Coimbatore district were selected and studied. The study indicate that the total number of wells benefitting from percolation ponds during 1988-89 was 36 out of the 258 wells (14%). The total area benefitted due to these 36 wells was only about 14.4 ha. The direct benefits due to percolation ponds during 1988-89 is as follows

Pond. No.	Total No. of Wells	No. of wells benefitted	Zone of influence (km)	Additional area benefitted (ham)	Average net income (Rs/ham)
1	14	4	0.7	2.5	2542
2	36	6	0.3	2.4	2736
3	25	3	0.4	1.0	2251
4	32	3	0.4	2.1	2087
5	18	2	0.5	0.6	1865
6	24	4	0.7	1.2	1956
7	31	3	0.3	0.7	2134
8	27	5	0.7	1.5	1543
9	24	2	0.3	0.4	1323
10	27	4	0.2	1.3	1569

The poor performance of these percolation tanks during the study period was attributed to inadequate rainfall and poor location of the percolation ponds. The districtwise distribution of the benefitted wells had indicated that 39 per cent of the wells as an important parameter in determining the benefits due to percolation ponds.

5.8 Artificial Recharge In Urban Areas, Nagpur, Maharashtra

Considering the overall physiographic, hydrogeological, hydrological, demographic and socio-cultural set up of the Nagpur Metropolitan Region, following schemes are feasible for ground water augmentations.

a. Roof top rainwater harvesting.
b. Run off rainwater conservation.

c. Recharge through percolation tanks and check dams.

The first two schemes are feasible for the densely populated pockets of the city area underlain by basaltic terrain, where land availability for construction of surface reservoir is non-existent. The third scheme of construction of percolation tanks and check dam is feasible for the peripheral and outskirts region which are rural areas with plenty of open space available.

5.8.1 Roof top rainwater harvesting for ground water recharge

In Nagpur city roof top rain water experiment was done in Ujjwal Nagar area where the roof top rain water collected from the concrete roof of 100 m3 was diverted into the existing water supply dug well of the house hold. About 80,000 litres was recharged during the monsoon.

5.8.2 Run off rain water harvesting for ground water recharge in city area

The rainfall runoff flowing from the roads and open grounds is substantial during the monsoon. This water often creates the water logging and the drainage system is put under stress in the urban agglomerates. This ultimately flows out of the city unutilised. This water if conserved and utilized properly for recharging the ground water reservoir may bring much needed relief to the water scarcity areas of the city. One such scheme has been prepared by the Central Ground Water Board for Ujjwal Nagar of Nagpur. The design and plan of the scheme is presented in Fig.-20. In this scheme about 15000 sq.m. of catchment is intercepted where run off generated would be diverted in the purpose built recharge well in the public garden. The run off water is filtered silt free by providing a filter pit. The scheme has made impact in the wells near the recharge well and water levels in the wells have risen.

5.9 Artificial Recharge To Ground Water Through Roof Top Rain Water in CSIO, Chandigarh

In order to augment the ground water recharge and also to reduce runoff in urban areas like Chandigarh, roof top rain water harvesting can be adopted to recharge the ground water at very nominal cost which will reduce storm water runoff and increase the life of roads and other structures.

In Chandigarh such experiment is being done at one of the CSIO buildings having roof area of 3550 sq.m. During 1998,2427 Cubic Metres of rainwater was harvested and recharged to ground water through propose built injection tubewells (Fig. 21).

The additional recharge to ground water has resulted in sustainable yield of tubewells already being operated. It is estimated that for effective impact roof area of about 1000 sq.m. is required to harvest rain water. However, this should be done by individual house/flat owner and if done collectively the impact will be very significant.

The studies have shown that the ground water quality has improved

5.10 Artificial Recharge To Ground Water In N.C.T. Delhi

In urban areas, dependence on ground water is high, resulting in depletion of ground water resource. This necessitates replenishment of ground water reservoirs through artificial recharge by rainwater harvesting which involves inducing, collecting, storing and conserving local surface runoff. The CGWB has initiated pilot projects in Jawahar Lal Nehru University (J.N.U.), Sanjay Van for artificial recharge experiments.

In J.N.U. and I.I.T. comprising of 5 micro watersheds, 0.46 Million Cubic Meters (MCM) storm water was going waste which could be stored in purpose-built structures and ultimately recharge the depleted aquifers. Four check dams were constructed on rivulets and sixteen piezometers were established to monitor the impact of artificial recharge on ground water regime. The storage capacity of 49,000 Cubic Meters was created in these dams and 1,25,000 Cubic Meters water had already been recharged to the aquifer. Rise of water level maximum upto 4 m has been observed. Apart from sustainable yield of tubewells and more vegetation cover around the check dams. The efficiency of check dams is around 98% (Fig. 22 and 23).

5.11 Rain Water Harvesting In Chennai City, Tamil Nadu

Chennai being a coastal city, is always under threat of seawater intrusion along the coast, if more fresh water is extracted. Indiscriminate extraction in Minjur - a coastal area along the North Sea coast of Chennai, has been spoiled because of over exploitation. The Metrowater is now taking up serious efforts to disseminate Rain Water Harvesting techniques to the citizens of Chennai. In the process, it has issued notifications to the builders who are constructing complexes with 1+3 floors to implement the Rain Water Harvesting measures. Chennai City receives rainfall ranging from 1100 to 1200 per annum. As per statistics, a house on one ground plot (223 sq.m.) gets about 700 litres of water a day by rainfall. Even in the case of multi-storied flats, where the effective space of per resident may be as small as 50 sq.m. , the rainfall corresponds to an amount of about 100 to 150 litres per day. The examples of the step taken in Chennai city are given in Fig. 24 & 24 A.

5.12 Rain Water Harvesting in the President's Estate, New Delhi

President's Estate having 1.20 sq.km. is located on the Northern flank of Delhi ridge. Excessive ground water development has resulted in ground water decline in the range of 6-13 m. Four metre thick aquifer has become desaturated over an area of 0.7 sq.km. The artificial recharge in the Estate is being done through two dried dug wells, one injection well, one vertical recharge shaft, two recharge trenches with injection wells.

Annually 28,170 cum water collected due to rainfall run off will be recharged to ground water.

5.13 Artificial recharge to ground water from runoff in Kushak Nala, New Delhi

In the Kushak Nala which is having a catchment of 3.5 sq.km., about 0.142 mcm water is going as runoff. This excess water is being recharged to ground through 2 Gabbion bunds and 2 nala bunds. It is anticipated that a net rise of 0.21 m in ground water level will occur in about 3.5 sq.km. area.

5.14 Artificial recharge to ground water in Lodhi Garden, New Delhi

Lodhi Garden spread over an area of 36 ha is normally flooded during rains. About 25,000 cum rain fall runoff is available from gardens and its adjoining areas three lateral shafts and three recharge pits around lake are being constructed as recharge structures. Rise in water level up to 0.35 m in about 40 ha area is expected every year.

5.15 Roof Top Rainwater Harvesting in Shram Shakti Bhavan, New Delhi

Shram Shakti Bhavan is having an area of 11,965 sq.km. Roof top rainwater harvested will recharge about 2900 cum water every year that is going as waste at present. Depth to water level has declined by 2-3m in the area over the years. Artificial recharge to ground water is proposed through recharge trenches with two injection wells in each at selected locations (Fig.- 25). It is expected that 1.62 m rise in ground water will occur in 12,000 sq. m. area.

5.16 Artificial recharge to ground water from Brahm Sarovar, Kurukshetra, Haryana

The Brahm Sarovar is filled by the canal water and sarovar water is being drained out on regular basis. In Kurukshetra town and adjoining areas ground water levels are declining at the rate of 30cm per year due to over development of ground water resource. Presently the stage of ground water development is 186.2%. For recharging the ground water, two injection wells, and two lateral recharge shafts with inverted filter have been constructed (Fig.- 26). The rate of recharge in injection well is upto 10 lps while that of recharge shaft is upto 15 lps.

5.17 Artificial recharge to ground water from stagnant water in depressions, District Kurukshetra, Haryana

The Kirmich and Samaspur villages of Kurukshetra district are surrounded by the accumulated rainwater in depressions round the year. Ground water level is very deep i.e.

more than 11 m and area is experiencing continuous decline of water level at the rate of 30 cm/yr. The presence of clay at shallow depths does not allow surface water to seep naturally into ground water reservoir. To artificially recharge stagnant water in depressions recharge shafts piercing through impermeable clay horizons are being constructed (Fig.- 27). Rise in water level in 500 ha is expected to be around 1.12 m.

5.18 Roof Top Rainwater Harvesting and artificial recharge in Deputy Commissioner Office, Faridabad, Haryana

The heavy withdrawal in the vicinity of Faridabad town has caused decline of water levels, which is around 48 cm/yr. The present stage of ground water development in Faridabad block is 90.4%. In the scheme, rain water collected from rooftop and paved area of Deputy Commissioner's Office will be used for recharging ground water which otherwise goes as runoff. Expected recharge to the ground water is around 2350 cum.

5.19 Artificial recharge to ground water in NSG Campus, Manesar, District Gurgaon, Haryana

Due to heavy withdrawal of ground water in the campus there is steep decline in water level with the rate of about 40 cm per year causing failure of existing tube wells. Gabbion structures are proposed to arrest surface runoff which will seep naturally. Besides this, treated sewage water will also be recharged to ground water through vertical recharge shafts with inverted filter. It is expected that 0.66 mcm water will be recharged.

5.20 Artificial recharge to ground water Golden Temple, Amritsar City, Punjab

The Golden Temple Sarovar is filled with canal water and water is pumped out regularly in the sewage drain. In the town water levels are declining at the rate of 0.50 m/yr. due to heavy pumping of ground water. Sarovar water which is being discharged into sewage drain will be used to recharge ground water (Fig.-28). It is estimated that water available for recharge is 0.448 mcm/year. Expected rise in water level in 500 ha will be 0.45m/year.

5.21 Roof Top Rain Water Harvesting and artificial recharge in Kheti Bhavan, Amritsar, Punjab

The water supply in Amritsar city is based on ground water which has resulted in the water level decline. Around Kheti Bhavan there has been decline of water level at a rate of 0.50 m/year. A substantial rainfall runoff from rooftops of building constructed is not only going waste but also damaging the roads and other structures. The surplus runoff around 304 cum is be utilized for recharging the depleted ground water reservoir.

5.22 Artificial recharge to ground water using canal water from Dhuri Link Drain, Dhuri Block, Sangrur District, Punjab

Dhuri link drain passes through Dhuri block where water levels are continuously declining at a rate of 0.40 m/year. In order to meet the ever increasing demand of ground water for agriculture it is proposed to recharge the ground water in the area by constructing 28 vertical shafts and 250m long lateral shaft. The shafts are filled with inverted filter to arrest the silt. Annually around 2.5 mcm water shall be recharged and it is estimated that around 1.15 m/year rise of water level will take place in 1000 ha.

5.23 Artificial recharge to ground water in Issru, Khanna Block, Ludhiana District, Punjab

In the village Issru the water levels are continuously declining at a rate of 0.30 m/year. The stage of ground water development in the block is 218%. Monsoon runoff accumulated in the pond is being recharged to the ground water through vertical shaft cum injection well. Annual water available for recharge is around 0.01 mcm.

5.24 Artificial recharge to ground water from Bist Doab Canal, Nurmahal Block, District Jalandhar, Punjab

In Nurmahal block water level has declined between 5 to 6 m in last 17 years. The spare water of Phillaur and Sarih distributary during monsoon period will be diverted to two storage tanks and same will be recharged to the ground through 6 vertical shafts. Annual water available for recharge is around 1.62 mcm. Expected rise in water level in 1000 ha will be around every year 0.81 m/year.

5.25 Artificial recharge to ground water in Channian and Kalasinghian, Jalandhar and Kapurthala Districts, Punjab

The village Channian and village Kalasinghian is located in Nakodar block of Jalandhar district and Kapurthala block of Kapurthala district respectively. The water levels are declining at a rate of 0.2 m/year. The spare canal water and surface runoff generated during monsoon, accumulated in the village ponds will be recharged. Annual water available for recharge is estimated to be around 0.28 mcm.

5.26 Artificial recharge to ground water using canal water from Dhuri Drain, Dhuri Block, Sangrur District, Punjab

Copious volume of water is available in drain and it is proposed to use the same for ground water recharge through 298m long lateral shaft, 30 vertical shafts with injection wells as recharge structures (Fig.-29). In order to arrest silt inverted filter is provided. Annual water available for recharge is 4.79 mcm. Rise in water level in 3100 ha is expected to be 0.77 m/year.

5.27 Artificial recharge through excess canal water Dhanetha, Samana Block, Patiala District, Punjab

In Samana block the water levels are continuously declining at a rate of 0.35 m/year from 1973 to 1998 and the stage of ground water development is 88%. It is proposed to utilize spare water of Choe No. 1 of main Bhakra Canal during the period of mid-October to mid-December and mid-February to mid-April when there is no demand of water for irrigation for artificial recharge to ground water. Four Lateral shafts with injection wells and five vertical shafts with injection wells are being constructed for recharge. It is expected that rise in water level in 500 ha will be 2.91m/year.

5.28 Roof top Rain Water Harvesting in Palampur Town, District Kangra, Himachal Pradesh

In Palampur town ground water recharge is getting reduced due to urbanization and channelization of the drainage system. A substantial rainfall runoff from the roof top is not only going waste but also damaging the roads and other structures. The run off from rooftop of IPH building will be collected and recharged to ground water by constructing a recharge well. The water will be recharged into the aquifer existing between 12-30 m depth in the area. It is estimated that 576 cu.m. run off water is available for recharge.

5.29 Artificial Recharge in Naker Khad, Renta-Dhawala Village, Tehsil Dehra, District Kangra, Himachal Pradesh

The holy town of Jawalamukhi is experiencing water shortages during summer months. Presently water supply to the town is by 12 percolation wells. In order to harness the surplus runoff in the Khad artificial recharge scheme is proposed to provide sustainable yield to the existing wells during summer months. It is proposed to construct a check dam of 1.85 m height and about 16 m in length across the Khad. Total runoff available for recharge is 120 mcm.

5.30 Artificial Recharge in Sikheri, Mandsaur Block, Mandsaur District, Madhya Pradesh

In Mandsaur block, depletion of water levels is taking place due to over development of ground water. Water levels have declined in the range of 1.25- 4.60 m in last 20 years. Level of ground water development is about 119%. A percolation tank is proposed to be constructed (Fig- 30).

5.31 Roof Top Rain Water Harvesting, PHED Colony, Narmada Water Supply Project, Musakhedi, Indore, Madhya Pradesh

Malwa region of Madhya Pradesh has been facing acute water scarcity due to excessive ground water pumpage. Rain water from roof top from PHED buildings, situated in the campus of Narmada Water Supply Project colony located at Musakhedi, Indore, Madhya Pradesh is proposed to be harnessed for artificial recharge to ground water. Six buildings having an area of 2710 sq. m. are chosen for rainwater harvesting. Rain water coming from the roof tops is proposed for recharging through a dug cum bore well of 20 m depth. Water available for recharge is 2142 cu.m.

5.32 Artificial recharge to Tumar Water Shed, Mandsaur Block, Mandsaur District, Madhya Pradesh

In the Tumar water shed 85% of the total irrigation is through ground water. The huge withdrawal of ground water has led to decline in the water levels. The ground water development has already reached to 118% during 1998. To augument ground water recharge to restrict further decline of water levels one cement plug at Jhawal (Afzalpur), two check dams at Roopwali and Khera villages, 19 Gabbion structures. Total water available for recharge is 10.90 mcm.

5.33 Artificial recharge to Water Shed TE-11, Jalgaon District, Maharashtra

In the TE-11 watershed water levels are steadily declining at the rate of 1 metre per year. The depth to water levels ranges between 30-40 mbgl. In order to tap the rainwater going waste as runoff two percolation tanks and five recharge shafts are being constructed (Fig-31). It is estimated that 14.51 mcm water is available as surplus run-off. Sub-surface storage potential available is 153 mcm. Average thickness of aquifer that has become desaturated is about 12.00 m. Volume of sub-surface aquifer in which recharge can take place is 3827 mcm.

5.34 Artificial recharge in Chogwan Area, Baghpat District, Uttar Pradesh

The Chogwan area lies between Krishni and Hindon rivers covering parts of Binauli block, Baghpat district, Uttar Pradesh. In this area irrigation is from ground water sources. The over-dependence of ground water has caused decline of water levels in the range of 3 – 5 m over last one decade. The area has number of village ponds which have enough water even during summer season. During rainy season, the water over flows through these tanks. At Garhi Kangran, this excess water is being used for Artificial recharge through lateral shafts with three injection wells (Fig.- 32). It is estimated that 4000 cum water is being recharged annually.

5.35 Artificial recharge to ground water in Jammna, District Hoogli, West Bengal

The stage of ground water development (85%) in Hoogli district is very high. In Pandua block the river Dhusi is one such stream which is connected with river Gangur through a 5 km long channel. Almost entire stretch of the channel has been silted particularly there is no flow except during peak monsoon. Average depth to water level is 16 m.bgl. It is proposed to de-silt the channel to augment ground water recharge.

5.36 Artificial recharge to ground water in Khatura Bangar, North 24 Parganas, West Bengal

The status of development of the ground water (80%) in the district of North 24 parganas is quite high. The district has considerable area of water bodies like tanks, beels, rivers, bangar etc. Most of these water bodies have been silted up. Due to which the reservoir capacity has decreased and recharge through the water bodies have been minimised. It is proposed to enhance the recharge rate by de-silting these water bodies. This will result in rise in the water levels in the area.

5.37 Artificial recharge to ground water in District Purulia, West Bengal

In Purulia district cropping intensity is very high (116%). The Irrigation is from surface and ground water resources. Principal rock types are Archean gneiss having 15 – 20 m weathered mantle. Depth to water level varies from 4.00 to 11.00 m bgl. The water level fluctuation vary from 1 to 5 m. The area has moderate to high slopes and bulk of rainfall is lost due to high run-off. Different types of artificial recharge structures such as sub-surface dykes, Nalla bunds, tank excavation, re-excavation of existing minor irrigation tanks and contour bunding are being constructed. The implementation of these schemes will store the excess monsoon run off on the surface which other than supplying water for irrigation will also recharge the shallow unconfined aquifer to create additional sub-surface storage for further utilisation.

5.38 Artificial recharge to ground water in Mainpura, District Jhunjhunu, Rajasthan

Due to excessive withdrawal of ground water for industrial & irrigation purposes, the area has experienced sharp decline in water level to the tune of 7.1 m in last 13 years and average decline in ground water level is 0.54 m /year. The stage of ground water development is 118.76 % in alluvium & 180.43 % in quartzite. The catchment of Kantli river is 4667.8 Sq. Km and runoff availability is 93 MCM. For utilising the some part of the available runoff for augmentation of ground water resources, one sub surface barrier of 0.8 m. height, 2.75 m depth & 89 m long and three gravity head inverted wells of 1.2 m dia & 10 m. depth are being constructed

5.39 Roof Top Rain Water Harvesting In C.G.W.B. Office Premises, Jaipur

Due to over development of ground water for domestic water supply in Jaipur the ground water levels are continuously declining. Therefore for utilising the roof top rain water for recharge to ground water, the CGWB Office building at Jhalana Dungri at Jaipur is identified for experimental study. The roof top / paved area of the building is 1250 Sq. m. The depth to ground water level is 29.0 m.bgl. The rate of decline is 1.10 m / year. The annual availability of water from roof top / paved area is 544 Cum. For recharging the available runoff an injection tubewell of 250 mm dia. and 50 m depth is being constructed (Fig- 33).

5.40 Artificial Recharge To Ground Water Through Sub-Surface Dyke At Nallan Pillai Patral, Gingee Block, Gingee Taluk, Villupuram District, Tamil Nadu

The project is located in a backward area having concentration of landless labour. Villupuram district is severely affected by drought every year. Due to nature of the terrain and gradient of land, depletion of storage of water occurs at a very rapid rate and the entire zone becomes dry during summer. It is proposed to tap ground water by constructing sub-surface dyke. The length of dyke is expected to be about 100 m whereas depth is around 3.50 – 7.00 m. The construction of dyke will result in better availability of water in the dug wells for a longer period even during summer months.

5.41 Artificial Recharge To Ground Water Through Sub-Surface Dyke, Chirayinkil Block , Trivandrum District, Kerala

The area is located in Vamanpuram basin, which is drained by a small nala in which base flow is available upto mid-February only. Due to drying up of the Nala the area faces acute water shortages during peak summer seasons. The average rainfall is 1963 mm of which about 70% is received during south-western monsoon. In village Ayilam, 75% of rainfall goes waste as run off due to very high gradient. Sub-surface dyke is being constructed to arrest the sub-surface ground water outflow (Fig.-34). The dyke will result in building up of ground water levels that can be harnessed during lean season.

ANNEXURE-1

FORMAT FOR PREPARATION OF ARTIFICIAL RECHARGE PROJECT

Base Information of Problem Area

1.	Location	State District Block Basin/Sub Basin/Watershed Lat. & Longitude Area Extent No. of Villages/Towns
2.	Population	(i) Human - Urban & Rural Livestock
3.	Land use	(i) Cultivable & Non-cultivable Area Forest
4.	Agriculture	(i) Soil Type, thickness and extent (ii) Cropping Pattern (iii) Area under irrigation (a) Surface water (b) Ground water
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 Platea (c) Moderately Dissected Plateau (d) Foot Hill Zone (e) Piedmont 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, Ephemera (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 Lake & 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) Ground Water Structures (a) Type, Number (b) Depth range (c) Yield range (d) Aquifer tapped (xi) Ground Water Resources (a) Annual Recharge (b) Annual Draft (c) Stage of Ground Water Development (xii) Ground Water Level trends.
9.	Water Requirements	(i) Present requirement for different uses (Domestic, Industrial and Irrigation). (ii) Projected requirement after 10 years, 20 years (Domestic, Industrial and Irrigation)
10.	Ground Water	(i) Unconfined & confined aquifers (a) Potable (b) Brackish (c) Saline (ii) Any special quality problem, (Seawater intrusion, pollution, high fluoride etc.).
11.	Nature of problem requiring Artificial Recharge of Ground Water	(i) Quantity Problem (a) Quantification of Water shortage for different purposes.

(b) Period of Shortage
(c) Location of deficit areas.
(ii) Quantity 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 Quality	Physical & Chemical
Rainfall				
River				
Canals				
Reservoirs				
Municipal Waste Water				

13. Sub-surface Potential for Ground Water Recharge.
(i) Thickness of un-saturated zone (below 3 mbgl).
(ii) Total runoff in the catchment
(iii) Committed flow…..
(iv) Surplus available for recharge.

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 land source water availability, identify the methods which may be suitable.

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, finalize the design specifications.

6. Finalize 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 efficiency of Recharge Scheme.

8. Evaluate the economic feasibility of the Artificial Recharge Project.

ANNEXURE – II

PLANNING ARTIFICIAL RECHARGE PROJECT – CHECK LIST

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) Subsidy 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 and rainy days intensity
   b) Evaporation
   c) Availability of surplus 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) Sub-surface strata conditions for Recharge wells, underground dams (Bandharas)
c) Spill way design

B. Material Survey

a) Soils for impervious, semipervious, pervious zones of surface/sub-surface bandharas
b) Sand/rocks/bricks & tiles/Pea (for wells)
c) Cement
d) Steel/Steel pipes/Slotted pipes/well screens

6. Land Acquisition

a) Have the land acquisitions required for structures, inundation, and 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. Ecological Aspects :

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

a) Inundation of habitated land
b) Creation of water logging
c) Deterioration of quality of groundwater

11. 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 people's active participation been worked out?

ANNEXURE - III

GENERAL GUIDELINES FOR THE EVALUATION OF GROUND WATER RECHARGE PROJECTS WITH SPECIAL REFERENCE TO BASALTIC TERRAIN

1. INTRODUCTION

The increasing demand for water in the country has brought forward the realisation that the underground reservoirs formed by the aquifers constitute invaluable water supply sources as well as natural water storage facilities. The planned augmentation of water storage in the ground water reservoirs by suitable recharge techniques is useful for reducing over-draft, conserving surface runoff and increasing available ground water supplies. Recharge may be incidental, when it is a by product of normal land and water utilisation measures and planned when the work is carried out with the sole objective of augmenting ground water storage to improve water availability or water quality, reduce impact of floods or preventing/stopping sea water intrusion.

Ground water recharge techniques have been developed world over through large number of experimental projects implemented with diverse objectives. Whereas the aim of majority of the projects was to augment ground water storage by utilizing surplus rainy season flows or the waste waters; projects for beneficiation of water quality, conserving surface waters for subsequent use and stopping land subsidence were quite common. In India, the applicability of technologies to tropical conditions has been evaluated through a number of studies conducted by Central Ground Water Board and the State Ground Water Organisations.

The experiences so gained form the base of this note to serve as guide for the evaluation of recharge schemes, now being conceived on a large scale in the States, before their sanction and implementation in order to derive the maximum returns on investments. Whereas the main considerations will be the technical criteria, the expected financial benefits can altogether not be lost sight of. It is, therefore, recommended that the rate at which the recharged water could be reclaimed must also be worked out for individual schemes.

A well-planned recharge scheme will generally have three components.

(i) Arrangement for source water.

(ii) Well-designed structures to transfer the source water into the ground water reservoir.

(iii) An Action Plan to use the stored ground water by suitable means.

The techno-economic viability of the project will thus depend on how best the cost on each of the above components is kept at minimum. Whereas the detailed project planning may have many permutations and combinations with each option of the recharge scheme, the following may serve as a general guideline for planning:

(i) Rock formation should be of moderate permeability. Low permeabilities reduce intake rate whereas high permeabilities do not allow retention of recharged water for a longer time to make use of it during dry season.

(ii) Basin development schemes, minor irrigation tanks, afforestation, soil conservation schemes, are important schemes serving many other purposes in addition to augmenting recharge to the ground water reservoirs and hence are preferable.

(iii) Injection wells or connector wells are costly schemes requiring high order of quality control and hence are not economically viable at this stage of time.

(iv) Spreading methods have been found to be most economical structures.

(v) Ground water dams are the most preferred conservation measure as they need very little maintenance. They are safe from natural catastrophe. The evaporation losses are minimum and environmental problems arising out of stagnation are avoided.

(vi) Availability of rainfall water from the roof tops is so high that if properly used for artificial recharge (throughout the country) will not only increase ground water availability by will also help in reducing the problem of disposal of storm runoff in cities and towns.

2. OBJECTIVES

The objectives of recharge schemes are generally the following:

1. To augment the ground water resources.
2. To store the surplus surface water particularly during the flood periods for future uses and reduce the flood peaks.
3. To retard the surface run off resulting in lowering of flood peak, conserving the soil by reducing soil erosion and improving the soil moisture retention for longer period to facilitate crop production and plant growth.
4. To improve the quality of water stored. When the source water passes through the soil profile during the process of recharge, the soil mantle acts as membrane to the travel of pathogen contained in the source water.
5. To conserve the ground water at the point of use. This is particularly suited to hard rock areas.
6. To conserve thermal energy.
7. To prevent saline intrusion in coastal aquifers.

3. CONSIDERATIONS FOR GROUND WATER RECHARGE PROJECTS

(a) General Considerations:

- (i) Water availability.
- (ii) Favourable Topographic, Physiographic and Hydrogeologic set up.
- (iii) Infiltration and percolation characteristics of vadose zone.
- (iv) Hydrologic characteristics of the aquifers such as capacity to store, transmit and yield water.
- (v) Technical feasibility
- (vi) Economic viability.

(b) General Recharge Methods

- (i) Water Spreading

(ii) Water Injection (Recharge Wells)

(iii) Induced Recharge

(c) Characteristics of Basalts

Dark greenish-black, apparently homogeneous looking, basaltic rock of the Deccan occupies the most extensive tract of Western Peninsula covering large part of the States of Gujarat, Maharashtra, Madhya Pradesh and Andhra Pradesh. Deccan basalts popularly known as Deccan Trap consist of vast pile of lava flows lying over one another and include other volcanic products as tuffs, breccias, ash-beds and sedimentary intertrappean deposits formed during the period between two lava flows. The lava flows have generally two distinct horizons - Lower massive and Upper vesicular. The massive part is hard and compact whereas the vesicular part is characterised by vesicles filled with secondary minerals (Amygdules). The massive traps are fractured and jointed at places. The weathering of massive and vesicular basalts form favourable locales of surface and sub-surface water circulation. The cracks in the weathered zone are often filled with kankar. An interesting feature of the different basaltic lava flows is the contrast in their water bearing properties. The massive basalts with their fracture porosities, the vesicular basalts with their minutely interconnected and partly filled vesicles and intertrappean sediments with their primary porosities have all a decisive role to play in determining the recharge capabilities and suitable recharge structures of different regions. However, the recharge capacities of the rock types will be greatly influenced by the overlying thickness, texture and structure of the soils and their location with reference to topographic features.

d) Recharge structures specific to Basaltic Terrain

(i) Nala bunding

(ii) Contour bunding

(iii) Contour trenching

(iv) Check dams

(v) Pits and Shafts

(vi) Percolation Tanks

(vii) Surface channels/Trenches

(viii) Groundwater dams

4. GENERAL SUITABILITY OF RECHARGE METHODS

Lithology	Topography	Type of Structures Feasible.
Alluvial or hard Rock upto 40 m depth.	Plain area or gently Undulating area.	Spreading pond, Groundwater dams, irrigation tanks, check dams, percolation tanks, unlined canal systems.
Hard rock down to 40 m depth	Valley slopes	Contour bunds, trenches
Hard rocks	Plateau Regions	Recharge ponds
Alluvial or Hard rock with confined Aquifer (40m depth)	Plain area or gently undulating area.	Injection wells, connector wells.
-do-	Flood plain deposits	-do-
Hard rock	Foot hill Zones	Farm ponds, recharge trenches.
Hard rocks or Alluvium	Forested area	Ground Water Dams.

5. FORMAT FOR PREPARATION AND CONSIDERATION FOR CLEARANCE OF RECHARGE SCHEMES

(a) Name of Scheme

(b) Introduction — Brief outline of scheme, location of project area, topographic and physiographic features, road and communication and justification for selection of area.

(c) Selection of area — Brief description about justifying selection of Project area. Priority be given to those projects where trend of ground water levels-historical, and stage of development of Ground water resources justify it. Area selection to be based on availability of water for recharging and capability of the ground water reservoir to accommodate the additional recharged water.

(d) Water Availability

(i) Quantification

- (i) Rainfall Data;
- (ii) Rainfall run-off analysis;
- (iii) Surplus availability of Non-committed water preferably unutilised component of surface water;
- (iv) Quantification and its location:-
  This will be interalia include:
  - (a) Rainfall, evaporation and transpiration of naturally grown plants and vegetables.
  - (b) Run-off in streams and rivers.
  - (c) Canal water surpluses.
  - (d) Drainage water from irrigated areas.
  - (e) Lakes, ponds and tanks.
  - (f) Reclaimed municipal waste water.

(ii) Quality of Surplus Water — Recharge water should be clean, free from contamination and should have compatibility with quality of Native ground water in aquifers.

e. Topographical and Physiographic considerations for suitability of Recharge Structures

Broad features for consideration with regard to ground slopes: -

Topographic	Areas	Feasible Methods
Plateau Area	Western Ghats	Pits and shafts
Highly Dissected Plateau slopes (Gradients of 1 in 10 and more)	Narrow areas flanking hill ranges and Ghats	Shafts feasible locally
Moderately dissected Plateaus, foot hills and piedmont regions (Gradients between) 1 in 10 to 1 in 100)	Large Tracts between inter-basin divides, plateaus and valley floors.	Contour and Nala bunds, percolation tanks small recharge basins, ground water dams, etc. (Conservation structures)
Low lying valley areas (Gradients of 1 in 100 to 1 in 500)	Valley floors of rivers Godavari, Bhima, Nira, Krishna and their tributaries.	Water spreading, recharge basins and ground water dams (Conservation structures).

1. **Hydrogeological Considerations**

1. Hydrogeological map of Project site accompanied by cross section.

2. Hydrological Parameters:

(a) Hydraulic conductivity of the aquifer being recharged. The objective of recharging is to spread the water in the larger reservoir than to form a mound at the point of recharge.

(b) Specific yield/storativity of the aquifer to be recharge.

(c) Storage capacity of aquifer considering the space available above water table and keeping in view rootzone of plants and crops to avoid water logging.

3. Ground water flow pattern; for ascertaining the movement of recharged water to the point of use.

Features of low permeability of Basalts, their multi - layer occurrence, fractured nature, presence of vesicular and amygdaloidal character besides attitude and the nature of rock formation need to be considered for formulating recharge scheme.

Broad Features for consideration with regard to Ground Water Hydrology in Basaltic Terrain

The success of a recharge scheme will depend on a combination of various favourable situations. However, the following considerations could act as guiding principles.

Hydrogeologic Region	Weathered, fractured and vesicular basalts will constitute most favourable hydrogeologic set-ups. (These needs to be identified and marked on maps).
Topography of Water-shed Area	Piedmont slopes constitute the best environs followed by valley floors. Highly dissected slopes and plateau tops are less favourable.
Water level fluctuations	Areas with high water level fluctuations, deep water table and steeper hydraulic gradient will induce high recharge rates.
Hydraulic conductivity	Weathered, jointed and vesicular basalts are expected to have high hydraulic conductivity and will constitute favourable environs in comparison with massive basalts which are less susceptible to recharge augmentation.
Thickness of soil cover and	Granular soil cover will have high infiltration rate in

Infiltration rate	comparison to fine clay/matrix. Black cotton soil derived from lava flow covering extensive area is clayey and highly calcareous and would impede recharge.
Aquifer Type	Phreatic aquifers will receive recharged water more easily than confined systems. In the vesicular basalts and jointed basalts, the calcareous material filling the vesicles, cavities and joints can subsequently be dissolved by recharged water. This tends to accelerate the recharge rate.
Hydraulic conductivity of Unsaturated rock in the zone of Aeration	Infiltration and percolation rate of unsaturated zone will contribute to accelerated recharge.
Profile of vertical recharge upto unsaturated zone.	The unsaturated zone should as far as possible be free from thick clay beds.
Rate of Recharge	In favourable conditions vesicular and fractured basalt are expected to attain a recharge @ 10% - 15%, whereas in non-favourable physiographic locales underlain by massive basalt, the rate may be as low as 2 - 3%.
Quantitative assessment of ground water	Pre-Recharge Ground Water Balance of Aquifer system. Post-Recharge Ground Water Balance of Aquifer system.

g. Techno-economic feasibility

(a) Technical option for various types of recharge structures.

- (i) Planning
- (ii) Design
- (iii) Suitable drainage
- (iv) Estimates and costs
  - ■ Earth work
  - ■ Masonry work
- (v) Cost estimates.

h. Financial Analysis

Cost of Projects shall have three components :

(i) Cost of Recharge Scheme

(ii) Cost of supplying the recharged water to beneficiaries.

(iii) Operation and Maintenance.

i. Assessment of benefits

Economics of the investment be given in detail to justify the investment. However, this may not have much relevance when the water is required for drinking purpose since this will be a public responsibility of a welfare State. In case the recharge water is to be used for irrigation the cost benefit ratio be worked out considering pre - and post - development incomes.

A. Net - Pre - Project Income

B. Net - Post - Project Income

Net Incremental Income (B - A) = C

Cost of Investment

(i) Cost of recharge facility

(ii) Cost of reclaimed water

(iii) BC Ratio, FRR and IRR to be evaluated and considered as per Government policy and practices.