ARTIFICIAL RECHARGE – A NEED OF THE HOUR

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OVERVIEW

The earth's population is projected to about 10 billion by the year 2050 (State of World population Report, 1993, U.N. Population Fund). Also, people will continue to migrate from rural areas to cities. Such cities have mega water needs, produce mega sewage flows, and will have mega problems. The problem has been further compounded due to large-scale urbanization and growth of mega cities, which has drastically reduced open lands for natural recharge. Also, more water will be needed for irrigation of crops to provide enough food for the expanding population. Competition for water will become increasingly intense and can lead to unrest and war if not properly resolved.

Increasing water demands require more storage of water in times of water surplus for use in times of water need. Traditionally, this has been achieved by constructing dams. However, dams have finite lives because of eventual structural failure and sediment deposits in the reservoir. Also, good dam sites are becoming increasingly scare, dams are not possible in flat areas, and they lose water by evaporation and can have adverse environmental and socio-economic effects. If water can not be stored above ground by constructing dams, it must be stored below ground, via enhanced or artificial recharge of groundwater.

SOURCES OF WATER

Water is a vital natural resource which forms the basis of all life. It is the most important requirement of plants, animals and mankind. Water also plays key role in the development of earth's surface, moderating climate and diluting pollutants. Water is a key resource in all economic activities ranging from agriculture to industry.

EARTH'S WATER RESOURCES: Fig 1 shows world water balance at glance.

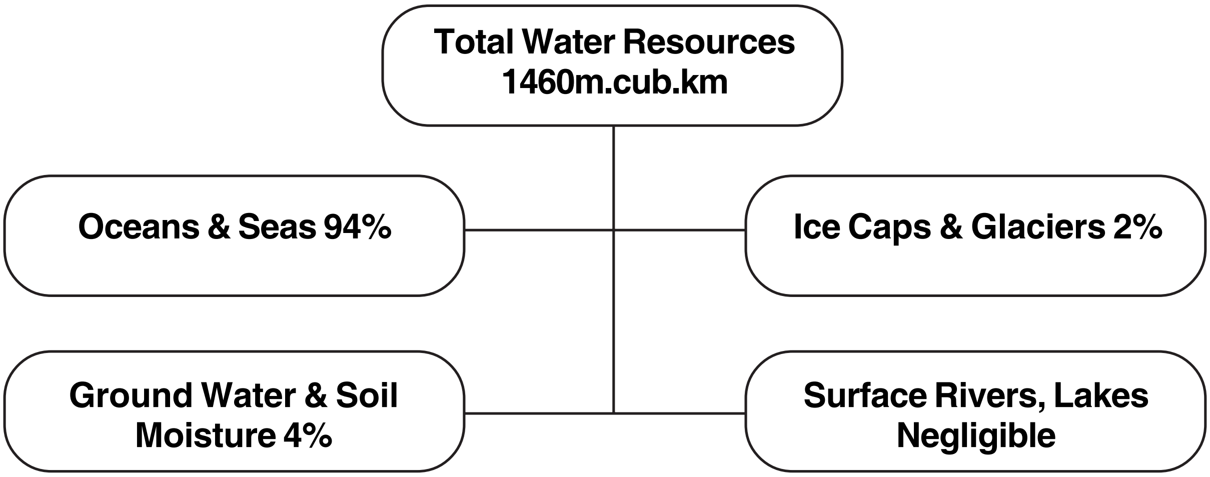

Fig 1 World's Water Balance at a glance

At global scale, about 71% of earth surface is covered with water. Total volume of water in hydrosphere is estimated to be 1.4 billion km^3 of which 97% is ocean water (unsuited for human use due to high salt concentration) and rest 3% is available as fresh water. About 2.997% of it is locked up in ice cups or glaciers or is buried so deep that it costs too much to extract. Only about 0.0035% of earth's total volume of water is easily available to us as soil moisture, exploitable ground water and lakes and streams. Table1 shows the earth' water resources in detail. Fig 2 shows earth's fresh water resources at a glance.

Surface Rivers, Lakes Negligible

Water Resources	**% Total water**
Ocean	97.6
Ice and Snow	2.07
Ground water down to 1 km	0.28
Lakes and reservoirs	0.009
Saline lakes	0.007
Soil moisture	0.005
Biological moisture in plants and animals	0.005
Atmosphere	0.001
Swamps and marshes	0.0001
Rivers and streams	0.0001
Total	**100%**

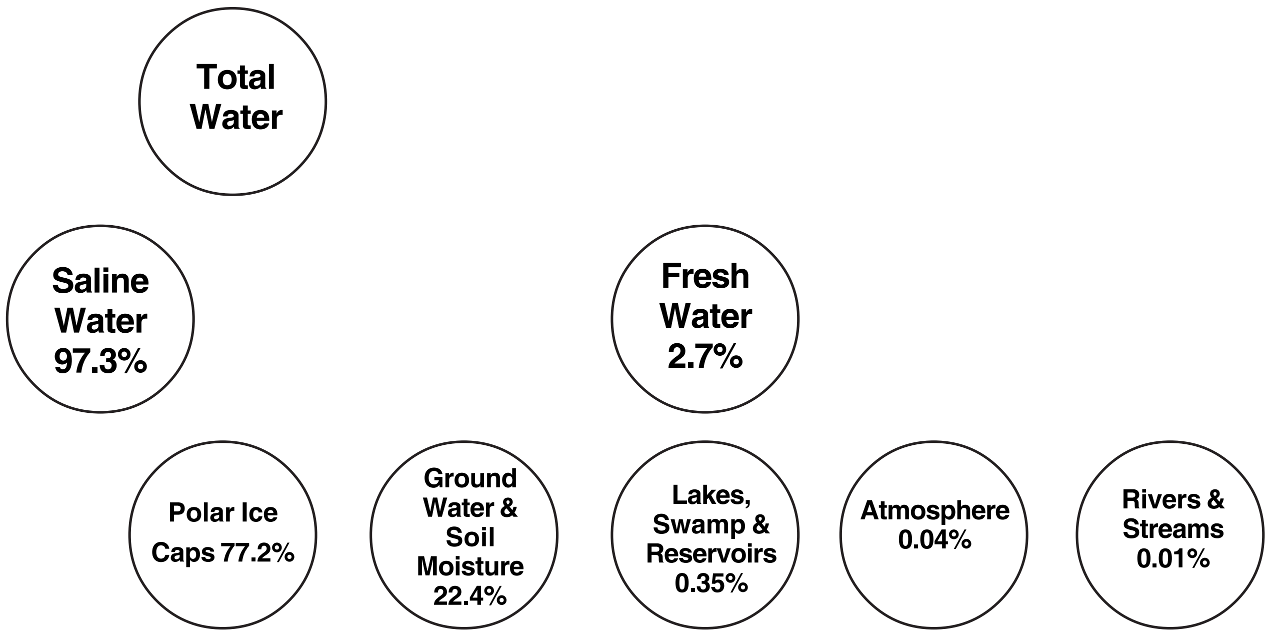

Fig 1 Fresh Water Resources at a glance

INDIA'S WATER RESOURCES

The basic source of water for India is the rainfall over the most part of the country and snowfall in the Northern region. The rainfall varies from place to place and from year to year. India, with a geographical area of nearly 3.3 million square kilometers experiences changes in climate. Normal annual rainfall varies from 100 mm in Western Rajasthan to over 1100 mm at Eastern states. Fig 3 shows the resources of water in India.

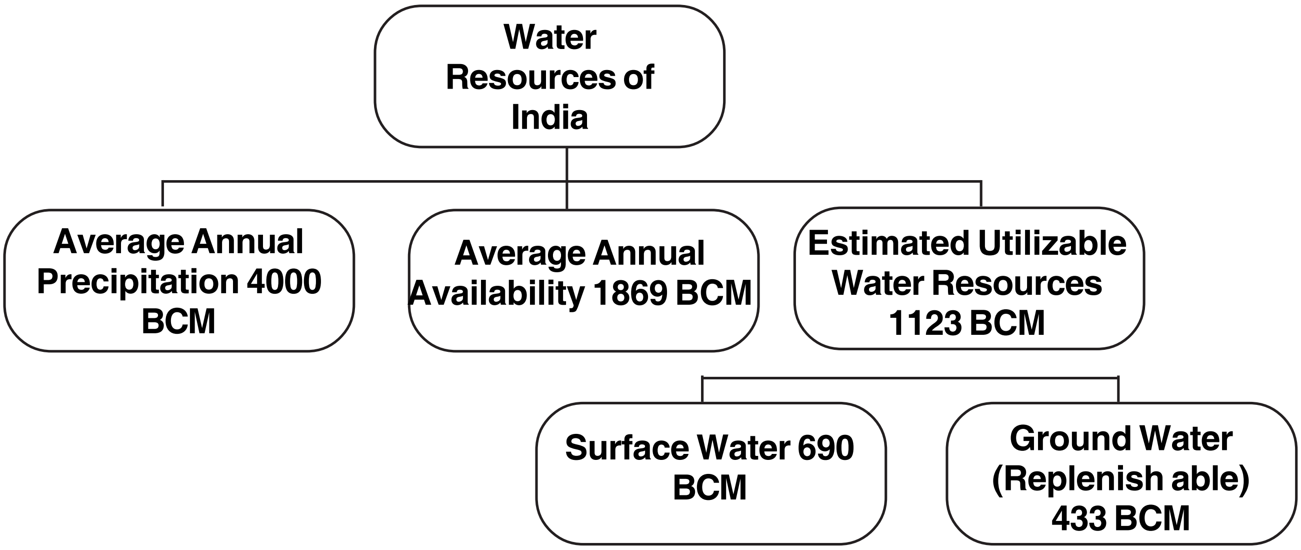

Fig 3 Resources of water in India

Surface water sources in India

Table 2 shows the availability of water in every basin of India.

Table 2 Availability of water basin wise in India

Sr. No.	Name of the River Basin	Average annual availability (Cubic km/Year)
1.	Indus (up to Border)	73.31
2.	a) Ganga	525.02
	b) Brahmaputra ,Barak & Others	585.60
3.	Godavari	110.54
4.	Krishna	78.12
5.	Cauvery	21.36
6.	Pennar	6.32
7.	East Flowing Rivers Between Mahanadi & Pennar	22.52

8.	East Flowing Rivers Between Pennar and Kanyakumari	16.46
9.	Mahanadi	66.88
10.	Brahmani & Baitarni	28.48
11.	Subernarekha	12.37
12.	Sabarmati	3.81
13.	Mahi	11.02
14.	West Flowing Rivers of Kutch, Sabarmati including Luni	15.10
15.	Narmada	45.64
16.	Tapi	14.88
17.	West Flowing Rivers from Tapi to Tadri	87.41
18.	West Flowing Rivers from Tadri to Kanyakumari	113.53
19.	Area of Inland drainage in Rajasthan desert	NEG.
20.	Minor River Basins Draining into Bangladesh & Burma	31.00
	Total	**1869.35**

(Source : Ministy of Water Resources, Government of India)

Ground water sources in India

The ground water resources of the country have been estimated for freshwater based on the guidelines and recommendations of the GEC-97.The total Annual Replenishable ground water resources of the country have been estimated as 433 billion cubic meter (BCM). Keeping 34 BCM for natural discharge, the net annual ground water availability for the entire country is 399 BCM. The Annual ground water draft is 231 BCM out of which 213 BCM is for irrigation use and 18 BCM is for domestic & industrial use.

GUJARAT'S WATER RESOURCES

Water resources in Gujarat state are concentrated primarily in the Southern and Central part of the mainland. Saurashtra and Kutch in the Northen mainland, with exceptionally high irrigation needs, have limited surface and ground water resources.

Surface water sources in Gujarat

Table 3 shows the scenario of surface water in the state.

Table 3 Surface water sources in Gujarat

Name of basins	Narmada, Tapi, Mahi, Sabarmati and others.
Total surface water availability(75% dependability)	18,513 MCM
Contribution from other stateDistribution of resources	18,047 MCM
Gujarat Main	16,225 MCM
Saurashtra	2,082 MCM
Kachchh	206 MCM

(Source CGWB, Ahmedabad, Ministry of Water Resources, GOI)

Ground water sources in Gujarat

Table 4 shows the scenario of ground water in the state.

Table 4 Ground water sources in Gujarat

Dynamic resources	16,060.35 MCM
Utilizable resources for irrigation	12,848.28 MCM
Gross annual ground water draft	9,708.86 MCM
Stage of ground water development	75.57%
Number of Over Exploited Talukas	31
Number of Dark Talukas	8
Number of Grey Blocks	42
Total static resources	1,87,057 MCM
For hard rock area	0.02* 10^6 MCM
For alluvial area	2.56* 10^6 MCM

(Source CGWB, Ahmedabad, Ministry of Water Resources, GOI)

INCREASING RESOURCE DEMAND

Since independence, India has witnessed an unprecedented increase in population. From a population of about 343 million in 1947, the population has grown at a rate of 2.04% to 1200 million in 2011. With an increasing number of mouths to feed, there has been an additional pressure on agriculture resulting in an increase in net sown area. High cropping intensity has also resulted in an increased demand fro water resources. Domestic water need in the urban areas has also grown notably with the current urban population is about 31%. By the year 2050, the population is expected to reach around 160 crores, the per capita availability will drastically reduced and our country shall be water stressed in many river basins. In planning critical resources like water we need to plan on safer side. A close watch on an increase in population is essential. The following table 5 shows probable water availability against year.

Table 5 Water Availability

Year	Water availability (Kilo Liter per year per capita)
1000	70,000
1850	10,000
1950	5,177
2000	1,820
2025	1,400 (likely population 130 crores)
2050	1,140 (likely population 160 crores)

(Source: Patel A S (2008) Water Management)

The demand for fresh water has been identified, as the quantity of water required to be supplied for specific use and includes consumptive as well as necessary non-consumptive water requirements for the user sector. The total water withdrawal/utilization for all used in 1990 was about 518 BCM or 609 m^3/capita/year. Estimates for total national level water requirements, through an iterative and building block approach, have been made for the year 2025 and 2050. (Table 1.5) based on a 4.5% growth in expenditure and median variant population projections of the United Nations. The country's total water requirement by the year 2050 will become 1,422 BCM which will be much in excess of the total utilizable average water resources of 1,086 BCM. Table 6 shows the water requirements for different uses by the year 2050.

Table 6 Water requirements for different uses(in BCM)

Category	2025	2050
Irrigation	688	1008
Domestic	52	67
Industries	67	81
Energy	13	40
Inland Navigation	4	7
Flood Control	-	-
Afforestation	67	134
Ecology	10	20
Evaporation	42	65
Total	**942**	**1422**

(Source : National Commission for Integrated Water Resources Development Plan, 1999)

WATER QUALITY MANAGEMENT

Water Quality is a major environmental concern in developing countries. Pollution of waters of rivers, streams and lakes is mainly the fallout of rapid urbanization, industrialization and inadequate storage of flood flows for meeting the needs of water supply and sanitation sectors. The main sources of water pollution are discharge of domestic sewage and industrial effluents, which contain organic pollutants, chemicals and heavy metals, and runoff from land based activities such as agriculture and mining. Further, bathing of animals, washing of clothes and dumping of garbage into the water bodies also contribute to water pollution. All these factors have led to pollution of rivers, lakes, coastal areas and groundwater seriously damaging the eco-systems. The rapid urbanization, industrialization and increasing use of chemical fertilizers and pesticides etc. have made our rivers and water bodies highly polluted. Water quality Assessment Authority (WQAA) has been setup to effectively coordinate and improve the work of water quality monitoring by various organizations.

FRESH WATER MANAGEMENT

The availability of fresh water is going to be the most pressing problem over the coming decades. The stress on water resources is a result of multiple factors namely urban growth, increased industrial activities, intensive farming, and the overuse of fertilizers and other chemicals in agricultural production. Untreated water from urban settlements and industrial activities, and run-off from agricultural land carrying chemicals, is primarily responsible for deterioration of water quality and contamination of lakes, rivers, and groundwater aquifers.

WASTEWATER MANAGEMENT

Rapid industrialization calls for wastewater treatment and its disposal to be so planned and sited so as to protect people, the quality of water (both surface and ground) and environment from adverse impact. The industrial units must set up effluent treatment plants for treating the wastewater to the desired standard before releasing to water bodies. Effective checks and monitoring should be placed in position and deterrent punitive measure be taken against defaulting units. For small units located in various industrial estates, common effluent treatment plants be set up and the industry should share the capital and O & M cost of the plants. Toxic effluents, however, are not segregated in the industries and are often discharged mixed with other effluents.

RECYCLING AND REUSE OF WATER

As the demand in industries is going to increase, the technological development in processing and methods of reusing water are expected to reduce the demand of fresh water. Wastewater is recovered, treated or untreated and then recycled for repetitive use by the same user. The term reuse applies to wastewaters that are discharged and then withdrawn by a user other than the discharger. Reclaimed waters from wastewater after treatment are generally used for agricultural irrigation, cooling water, algal cultivation and pisciculture, apart from other industrial uses.

In most cases industrial water uses are non-consumptive making reuse possible through recycling and conservation measures. Recycling of wastewater also helps in recovery of certain commercially viable by-products. Process industries are major users of water and can recycle or reuse water wastes for lesser duty purpose.

WATER CONSERVATION

In arid and semi-arid areas, the low and erratic rainfall normally occurs with high intensity of short duration resulting in high run-off and poor soil moisture storage. As a result, the loss is about 50 to 60 percent of rainwater. Runoff varies from 10 to 30 percent of the rainfall depending on the amount and intensity of rain, soil characteristics and vegetation cover. This surface runoff if harvested over a large area can yield considerable amount of water for storage and providing life saving irrigation to the crop during the dry spells in the monsoon season and also for growing a second crop in rabi season. The major constraints that still limit the adoption of this technology on a macro scales are, the high initial cost, and non availability of cheap and defective sealants for permeable Alfisols. Additionally, long breaks in the monsoon and low intensity rains limit the runoff flow into the ponds during dry spells when water is needed most. Despite these difficulties, small water storage ponds seem to be the most viable strategy to stabilize productivity of the ecologically disadvantaged dry land regions. The surface runoff from an area can also be increased by reducing the infiltration capacity of the soil through vegetation management, cleaning, sloping surface vegetation and reducing soil permeability by application of chemicals. To maximize profitability from the limited quantity of water stored in small ponds, planning for its judicious use is most crucial. Research conducted at different locations in India established that a supplemental irrigation of 5 to 10 cms at the critical stage of crop growth substantially increased the yields of cotton, wheat, sorghum, tobacco, pearl, millet, etc. vis-à-vis no irrigation.

Therefore one has to conserve the surface runoff by different techniques, for use in fair weather.

These techniques are

(a) Conservation by Surface Storage: Storage of water by construction of various water resources projects has been one of the oldest measures of water conservation. The scope of storage depends on region to region depending on water availability and topographic condition. The environmental impact of such storage also needs to be examined for developing environment friendly strategies.

(b) Conservation of Rainwater : Rainwater has been conserved and used for agriculture in several parts of our country since ancient time. The infrequent rain if harvested over a large area can yield considerable amount of water. The example of such harvesting techniques involves water and moisture control at a very simple level. It often consists of rows of rocks placed along the contour of steps. Contour terraces have been found in use in various parts of the world. Runoff captured by these barriers also allows for retention of soil, thereby serving as erosion control measures on gentle slopes. This technique is especially suitable for areas having rainfall of considerable intensity, spread over large part i.e., in Himalayan area, North-East states, and Andaman and Nicobar Island. In areas where rainfall is scanty and for a short duration, it is worth attempting this technique, which will induce surface runoff, which can be stored.

(c) Groundwater Conservation: Out of total 400 mham precipitation occurs in India, about 45mham percolates as a groundwater flow. It may not be possible to tap the entire groundwater resources. The entire groundwater cannot be harvested. As we have limited groundwater available, it is very important that we use it economically and judiciously and conserve it to maximum possible. Some of the techniques of groundwater management and conservation are as below :

(i) Artificial Recharge: In water scarce areas, where there is a low and erratic rainfall, there is an increased dependence on groundwater. There are various techniques to develop and manage groundwater artificially. In one of the methods, water is spread over ground to increase area and length of time for water to remain in contact with soil, to allow maximum possible quantity of water to enter into the ground. Digging recharge wells, which admit water from the surface to fresh water aquifer, can also do the artificial recharging

(ii) Percolation Tank Method: Percolation tanks are constructed across the watercourse for artificial recharge. The studies conducted indicates that on an average, area of influence of percolation on 1.2 km^2, the average groundwater rise was of the order of 2.5m and the artificial recharge to groundwater from each tanks was 1.5 hectare meter.

(iii) Catchment Area Protection (CAP) : Catchment area protection plans are usually called Watershed Protection or Management Plans. These are adopted as an important measure to conserve and protect the quality and quantity of water in a watershed. It helps in with holding runoff water albeit temporarily by a check bund constructed across the streams on hilly terrain, which will delay the runoff so that greater time is available for water to seep underground. This technique also helps in soil conservation; afforestation in the catchment area is also adopted for water and soil conservation.

ARTIFICIAL RECHARGE

The term artificial recharge refers to transfer of surface water to sub-surface aquifers through human intervention. Augmentation of groundwater resources through artificial recharge can be considered as an activity, which supplements the natural process of recharging the aquifers through percolation of a fraction of the rainfall through the soil to the water table. Artificial recharge thus becomes relevant in a situation witnessed by India, where the rainfall is seasonal and is not spread uniformly over the year and quantum of natural recharge is inadequate to meet the increasing demand on groundwater resources.

NEED OF ARTIFICIAL RECHARGE:

a) To augment the ground water resources.

b) To store the surplus surface water particularly during the flood periods for future uses and reduce the flood peaks.

c) To improve the quality of ground water. 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.

d) To get relief in water logged areas
e) To conserve the ground water at the point of use. This is particularly suited to hard rock areas.
f) To conserve thermal energy.
g) To prevent saline intrusion in coastal aquifers.
h) 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.

ADVANTAGES OF RECHARGING STRUCTURES

a) No large storage structures needed to store water. Structures required are small and cost-effective.
b) Enhance the dependable yield of wells and hand pumps.
c) Negligible losses as compared to losses in surface storages.
d) Improved water quality due to dilution of harmful chemicals/ salts.
e) No adverse effects like inundation of large surface areas and loss of crops.
f) No displacement of local population.
g) Reduction in cost of energy for lifting water especially where rise in ground water level is substantial
h) Utilizes the surplus surface runoff which otherwise drains off.

ARTIFICIAL RECHARGE METHODS

Mainly there are three main categories of artificial recharge as listed below.

* Direct methods
* Indirect methods
* Incidental methods

Direct Methods

Direct methods of recharge can further be subdivided into two main categories as surface methods and sub-surface methods.

Surface Methods

In this method of recharge, water is applied on the permeable ground surface where it infiltrates into the unsaturated zone to reach slowly the underground water table. Surface techniques especially spreading techniques of artificial recharge are most widely used because of their economy and easiness in operation. Various types of spreading techniques are as follows.

* Basins
* Furrows and ditches
* Regulated stream channels
* Flooding

Sub Surface Methods

Sub surface techniques are very much useful when there is a low permeability between the ground surface and the unsaturated upper level of the recharged aquifer. Generally, these techniques are useful when surface methods cannot be satisfied technically and economically. These techniques have following advantages:

* They occupy smaller area
* Utilize better quality recharge water
* They are capable of recharging confined aquifers.
* They can be designed to avoid mixing of recharge and pumped water.

The following are some sub-surface techniques of recharge:

* Recharge through the wells
* Recharge through pits and shafts.
* By constructing sub surface dykes

Indirect Methods

Indirect methods of recharge are meant to include type of recharge that is induced by pumping from an aquifer hydraulically connected to a surface reservoir, a river, a canal or another aquifer. Although these techniques have limited applications if compared to the direct methods, its usefulness in certain localities is beyond comparison. Induced recharge is one of the techniques for indirect methods.

Incidental Methods

Incidental recharge includes non-deliberate replenishment from irrigation system, leaking domestic and industrial systems and disposed industrial and domestic waste waters. In spite of its significant contribution to the groundwater, this last method was the least investigated technique.

The incidental recharge occurs where water enters the ground due to activities whose objective is not artificial recharge (Todd 1985). Examples include water from irrigation, septic tanks, water mains, waste-disposal facilities.

Percolation Pond

A percolation pond is a small water storage structure constructed across a natural stream or water course to harvest the runoff from the catchment and impound for longer time to facilitate percolation of impounded water into the soil substrata both vertically and laterally, thereby recharging ground water storage in the zone of influence of the pond. Such ponds have been reported to be very useful in harvesting the unutilized balance of the surface flow during periods of availability and conserving it the underground reservoirs and thereby ensuring sustained agricultural production under many well commands in the vicinity of the ponds. (National Institute Of Hydrology-Roorkee 1998-99)

Fig 4 Dhahran Percolation Pond

Considerations In Planning And Construction Of Percolation Ponds

Formulation of percolation pond is preceded by extensive hydrological, geohydrological and engineering investigations. Beside these technical aspects, practical aspects also play important role while planning for construction of percolation pond. Some broad guidelines regarding selection of site and investigation for taking are as under

* There should be adequate scope to accommodate, in the aquifer the augmented recharge from the proposed percolation pond. This implies that the ground water in the influence zones is deep enough and should not be less than 3 meters below ground level during post monsoon season.

- There should be substantial number of working wells in the influence zone with the adequate extent of cultivable land to reap the benefits of the pond.
- There should be no springs and seepage zones in the influence zone of the pond.
- The percolation pond should not be located in heavy soils or in impervious strata.
- The topography at the proposed site of the percolation pond should be such that a deep pond is formed.
- The pond site should avoid runoff from easily erodable catchment areas.
- The site should be such that the construction materials are available as near as possible & the labour potential is adequate in the vicinity of the proposed site.
- Proper study of catchment area and rainfall pattern should be made to ensure that the percolation tank get filled every year.
- The size of the percolation pond should be governed by the percolating capacity of the strata in the tank bed rather than yield of catchment.

The traditional practice of collecting rainwater in ponds suffers from following limitations.

- Large open surface is subjected to high rate of evaporation losses.
- Large bed area effecting high seepage losses.

in spite of limitations, the ponds, the bulk water requirement is met from them. Small groundwater mound form under the pond bed, used partially supply through wells dug in the pond bed. This traditionally practiced rainwater-harvesting structure served water supply since ages. During scarcity years, some deepening of ponds is made, but it is being done on a haphazard manner, does not help much.

Check Dams

A check dam is essentially a masonry or concrete overflow type barrier constructed across the stream having well defined banks with flatter bed gradient. The stream generally has a good base flow after the rainstorm.

Mainly check dams are of two types : (i) gated check dam, and (ii) non gated check dam. In gated check dam, the barrier wall has slot openings, which allows storm flood with silt to facilitate easy discharge of flood during initial period of monsoon. After two or three storms, plates are placed in slots. Silt is removed after every four or five years in order to improve the percolation rate through streambed. Now a days fiber reinforced glass plastic gates are used because steel gates are liable to rusting action and cement concrete blocks are too heavy to operate.

In non gated type check dams, simple masonry weir is constructed across the stream. The height of the dam is kept low so that storm flood is contained within the banks. To enhance percolation and to increase reservoir storage, regular desilting of check dam is necessary for this type of structure. The dam storage percolates down to create recharge mound, which is recovered for irrigation use. To take greater advantage of the stream flow, many times a series of check dams are constructed all along its course.

Fig 5 Check Dam

Recharge Wells

In this method water is not pumped into the aquifer but allowed to percolate through a filter bed, which comprises sand and gravel. A recharge well is generally a borehole, 300 mm diameter, which is drilled to the desired depth depending upon the geological conditions, preferably 5 m in the aquifer.

This structure is generally constructed in streambed and on upstream side of possible check dam across the stream. It consists of 8-10 deep bore wells of 300 mm diameter with 200 mm slotted pvc pipe and annular space filled with sand and gravel. Water can be recharged underground through wells where deep confined aquifers or space limitations preclude application of other methods. Considerable care should be taken in operation and construction of recharge wells to minimize the effects of clogging which may take place because of entrapment of finer aquifer particles from filtration of suspended materials in the recharge water, from bacteria and from chemical reaction between recharge and ground water. Generally, gravel packed wells can recharge more efficiently. Recharge water should be clear, should not have high sodium content, and should be chlorinated.

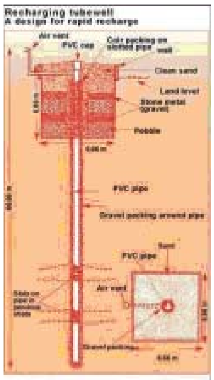

Fig 6 Recharging Tube Well

Construction Of Recharge Wells

The following steps clearly described the methods for construction of recharge wells:

* Excavating the earth

Fig 7 Excavation

* Making a borehole to facilitate ground water recharging

Fig 8 Making Of Borehole

* Providing masonry or rcc walls in the excavated portion and thereafter providing the filter materials.

Fig 9 Providing Masonry Or RCC Walls

* Covering the tank made with a rcc or stone slab provided with a manhole.

Fig 10 Covering Tank

Conversion Of Dried Tube Well Into Recharge Well

* With the following simple steps, one can convert dried tube well into recharge well
* Replace top few meters of the cast iron casing pipe of the dried tube well with a perforated pvc pipe.

Fig 11 replacing ci pipe with perforated pvc pipe

* Wrap the perforations with a screen-made of either coir screen or closely knit nylon mesh.

Fig 12 wrapping of perforations

Aquifer Storage Recovery (A.S.R) Wells

Aquifer storage and recovery (ASR) is a specific type of aquifer recharge practiced with the purpose of both augmenting ground water resources and recovering the water in the future for various uses. Many water suppliers and states are eager to employ asr well technology to meet current and future water demands by storing water during wet periods or periods of low demand, and recovering it during dry periods or times of high demand. ASR projects are increasing in number throughout the world, especially in areas with potential water supply shortages. ASR is an attractive option to conventional surface storage in that land-surface requirements for ASR implementation are very much less than for surface storage. ASR provides a cost-effective solution to many of the world's water management needs, storing water during times of flood or when water quality is good, and recovering it later during emergencies or times of water shortage, or when water quality from the source may be poor. Large water volumes are stored deep underground, reducing or eliminating the need to construct large and expensive surface reservoirs. In many cases, the storage zones are aquifers that have experienced long term declines in water levels due to heavy pumping to meet increasing urban and agricultural water needs. Groundwater levels can then be restored if adequate water is recharged.

ASR Wells are used to achieve two objectives:

* Storing water in the ground; and

* Recovering the stored water either using the same well or by pairing injection wells with recovery wells located on the same well field.

The main driving force behind the current rapid implementation of asr technology around the world is water supply economics. ASR systems can usually meet water management needs at less than half the capital cost of other water supply alternatives. When compared to alternatives requiring construction of water treatment plants and surface reservoirs to meet increasing peak demands, potential cost savings have been known to exceed 90 percent. A second important driving force has been the increased recognition of this technology as being good for the environment, aquatic and terrestrial ecosystems. By reducing or eliminating the need for construction of dams, and by providing reliable water supplies through diversions of flood flows instead of low flows, asr systems are usually considered to be environmentally friendly. Storage zones range in depth from as shallow as about 75 m (200 ft) to as deep as 900 m (2,700 ft). Groundwater levels in the storage zones range from as much as 10 m (30 ft) above land surface to more than 300 m (900 ft) below land surface (bls). Natural water quality in the storage zone ranges from fresh, suitable for drinking without treatment, to brackish, including total dissolved solids (tds) concentrations up to about 5,000 mg/l. Asr was shown to be feasible and highly cost-effective storing drinking water in an aquifer containing seawater. For most of these sites, it is first necessary to properly develop the storage zone around the well, after which it is possible to recover the same volume as that stored. At a few, more challenging sites water quality, hydraulic or geochemical constraints may limit recovery to somewhat less than the volume

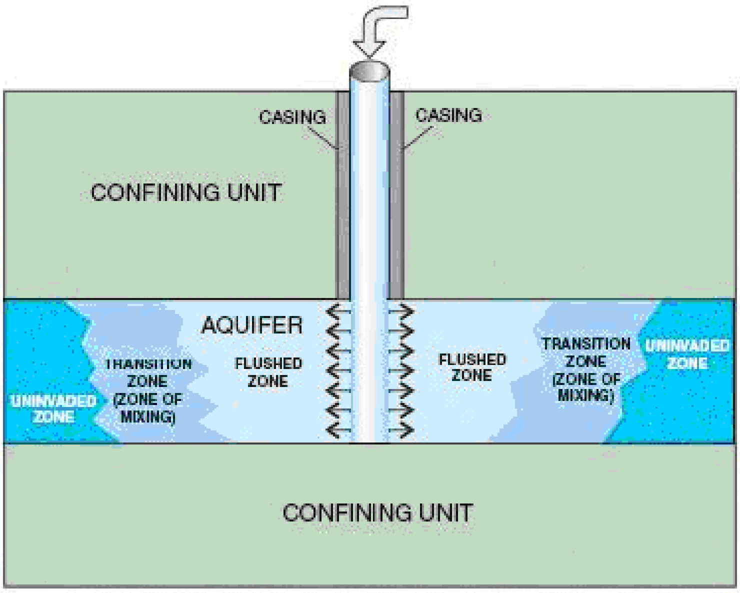

Fig 13 ASR well cross-section; source: u.s. Geological survey.

Well Clogging Mechanism And Their Prevention

According to experience gained all over the world, the main causes for the clogging of injection wells are:

* The presence of air bubbles in the recharge water
* The presence of suspended matter in the recharge water
* The growth of bacteria in the gravel pack and surrounding formation
* Reactions between the recharge water on one hand, on one other hand, the native ground water and aquifer material present in the formation
* Mechanical jamming.

Identification is greatly facilitated by the installation of piezometers, one at the outer circumference of the gravel pack and others at distances of, say, 2 and 5 m from the well centre. At any moment, these piezometers show where clogging has taken place, while the rise of water level with time gives valuable information about the nature of the clogging matter. For this purpose, the changes in water level accompanying variations in capacity and temperature should first be eliminated.

* Presence of air bubble: during injection, air bubbles may be entrained by the free fall of the water when the injection pipe ends some distance above the water level in the well casing and may come out of solution when the water pressure drops below atmospheric. In water at rest, air bubbles with diameters between 0.1 and 10mm rise at velocities of 0.3-0.4 m/s, meaning that injection with higher flow rates carries them downward, through the well screen openings into the gravel pack and surrounding formation. Here,they clog the pores between the individual grains, causing andadditional resistance, which in its turn decrease the injection capacity andtheamount of air supplied. On the other hand, the air bubbles present willdissolve into the water flowing by, together meaning that already after a shorttime an equilibrium situation is brought about and no further increase in injection head occurs.

  Clogging by air bubbles is easily recognized by a sharp increase in the injection head directly after recharge operations starts, reaching its maximum value already after some hours. When the operation is stopped, the water in the well will, moreover, foam due to escaping air bubbles.

* Presence of suspended matter: clogging by suspended matter manifests itself by an increase in the injection head, sc, which, for a particular well and recharges water, grows linearly with time, while it is proportional to the square of the capacity. Another problem is that for waters with a low suspended matter content, drinking water for instance, there is no relation between turbidity and clogging rate, making evaluation of field tests rather difficult.

  During well injection, the physical and chemical environment of the recharge water changes, by which dissolved impurities may be transformed into suspended ones. Small amount of iron and manganese present in any recharge water may fall out by contact flocculation or may be precipitated, together with carbonates, by changes in ph and redox potential, again resulting in clogging by suspended impurities. The removal of clogging by suspended matter can easily be obtained by well cleaning, but it is seldom 100% effective.

* Growth of bacteria: bacteria are also suspended matter, but theircombined volume is extremely small. Clogging caused by bacteria can easilybe removed by burning them away with chlorine. Some operators prefer to do this once or twice a year instead of the

continuous chlorination. Bacterial clogging disappears by it when the well is taken out of service and the food supply stops. The ensuring putrefaction, however, may impart a horrible taste to the water present in the formation.

* Reaction involving the recharge water: for completeness, it may be recalled that reactions between the two types of water can only occur at the start of the injection process, at the interface, between the recharge water and the displaced native groundwater. In fine-grained formations, this mixing zone is narrow and no adverse effects need to be feared. In coarse grained and fissured rock formations, an appreciable amount of mixing may take place, but here the openings are so large that the reduction in permeability by the deposits formed is again small. The most important reaction follows the mixing of anaerobic groundwater containing ferrous iron with aerobic recharge water, producing insoluble ferric oxide hydrates. To be doubly safe, the recharge operations proper could be preceded by an injection of anaerobic water, pushing the zone of possible reactions to such a distance away from the well that the increase, sc, in the injection head is always negligible.

* Mechanical jamming: with a dual-purpose well, the direction of flow reverses periodically, which might lead to a decrease in pore space, lowering the permeability of the formation in the immediate vicinity of the well i.e. Mechanical jamming.

Summing up, it may be said that injection well clogging by air bubbles and bacteria can be prevented, while clogging due to mechanical jamming is rare and its influence on the rise, sc, in the injection head always small. Clogging due to interaction between the recharge water and the aquifer material can only partially be prevented by the addition of chemicals, which may adversely affect the quality of the artificial groundwater recovered. Clogging by suspended matter can e prevented to a large degree by pre-treatment, but this may involved high costs of operation.

Cleaning Of Injection Wells

Even with good quality recharge water, injection wells clog easily and they should therefore always be designed and constructed in such a way that an effective cleaning can be obtained with simple means. In many cases, moreover, this offers a more economic solution than upgrading the pre-treatment to prevent clogging from taking place. The cleaning of injection wells can be effected in three ways:

* At short intervals, varying from about once a day to once a month, by simple back pumping at about the same capacity as the injection rate for a period of about 0.25 h. This procedure can even be executed automatically, obviating the need for labour

* At long intervals, ranging from about 6 months to 5 years, using more intensive hydraulic means such as back pumping at high rates, treating the screen section by section and, in particular, by the creation of flow reversals

* Only when the treatment mentioned above is not adequate, it may be followed by the application of chemicals to liberate, disintegrate, disperse and dissolve clogging matter. This chemical cleaning is dangerous, both for the well and for the operating personnel and should therefore only be practiced as a last resource.

Back Pumping

Stopping the injection and pumping the well creates a flow reversal, which first liberates the clogging material in the gravel pack and at the formation wall, and then pulls this material through the screen openings into the well and out through the pump. When clogging is due to suspended matter in the recharge water, back pumping for 5-15 minutes at about the same capacity as the injection rate removes some 80% of the increase in the injection head, sc. Pumping for longer periods make little sense, while increasing the capacity to 3-5 times the injection rate perhaps removes another 10% of sc. The most attractive combination of pumping rate, pumping period and intervals between pumping varies from one well to another and should be established each time a new by field trials. Pumping should start at a low rate to prevent excessive drawdown and a collapse of the well casing and screen. Otherwise, this cleaning method is simple, hardly affects the total amount of water injected, can be done automatically, but it requires the presence of a pump and possibility of discharging the dirty water. With dual purpose wells, this is seldom a problem, but with single purpose wells, the installation of a submersible pump with discharge piping may be rather expensive. Air lift pumps as shown in figure below may now be more economical proposition with the added advantage of low maintenance costs.

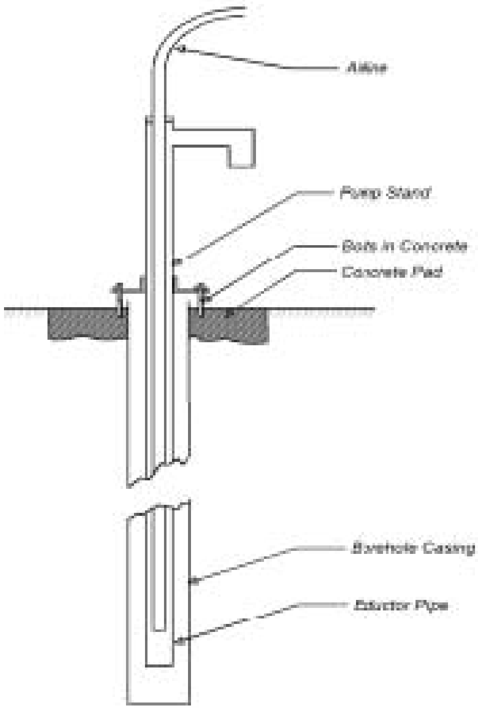

Fig 13 air lift pump

More Intensive Hydraulic Methods

When the cleaning method is not feasible or not effective in the long run, more vigorous means must be applied. Scrubbing with brushes removes deposits on the inside of a well screen and casing. Slots in the well screen may be cleaned with powerful water jets directly horizontally outward. These jets also agitate and clean the inside of the gravel pack, while a submersible pump removes the liberated clogging simultaneously. To clean the outside of the gravel pack and the formation wall, large value of the entrance velocity, vc are necessary, which can be obtained by treating the screen sections by section. Flow reversals can be affected in different ways, but in the case under consideration the use of compressed air is most simple and effective. The operation starts with the air cock open and the three way valve turned so as to deliver air down the air line. The combination of drop pipe and inside airline operates as a regular air lift pump, abstracting water from the well and out through the discharge pipe. After the water bas become clear, free from suspended matter, the supply of air is cut off and the water in the well is allowed to regain its static level. The air cock is now closed and the three way valve is turned so that the air supply is directed down the bye pass to the top of the well. This air forces the water out of the casing and back through the screen openings into the formations, agitating the sand and loosening the clogging. After the water level has been lowered to the bottom of the drop pipe, the air will escape upward through this pipe, without the danger of air clogging the formation. The air cock is now opened, allowing a rapid rise of the water level in the well and inflow of groundwater at high velocities. The inflow is further promoted by directing the air supply down the airline to pump the well. The procedure is repeated several times, until the pumped water has become clear and no more debris can be drawn into the well.

Chemical cleaning

In some cases, the clogging material is so strongly attached to the grains of the gravel pack and surrounding formation, that the shear stresses created by hydraulic cleaning are inadequate to dislodge them. The surging described above must now be preceded by chemical treatment of which the most important are

* Chlorine or chlorine compounds, such as sodium hypochlorite (naocl) or calcium hypochlorite ($ca(ocl)_2$), to burn away deposits of bacterial slimes. Moreover, they kill the bacteria present and when the distance over which this occurs is large, subsequent growth of bacteria is greatly retarded.

* Acids, such as hydrochloric acid(hcl), sulphuric acid (h_2so_4) or sulphamic acid (nh_2so_3h), to dissolve deposits of calcium carbonate, magnesium hydroxide and iron and manganese oxide hydrates, which moreover act as cementing agents forming thick encrustations around the well screen.

* Polyphosphates to disperse deposits of iron and manganese oxide hydrates, silt and clay particles.