

Chapter - 2

Literature Review



2.1 WORLD WATER SCENARIO OF ARTIFICIAL RECHARGE OF GROUND WATER

2.1.1 General

Globally, growing populations will demand more and more water to meet vital domestic needs, irrigation requirement of crops so as to produce enough food as well as industrial requirement. Of necessity, the water demand will be much greater and more intense in the third world countries where close to 90% of the world population is envisaged to live.

Increasing water demands will require more storage of water in times of water surplus for use in times of water need. Traditionally, this has been achieved with dams. However, dams have finite lives because of sediment accumulation in the reservoir and also good dam sites are scarce. Hence, if water can not be stored above ground, it must be stored below ground via artificial ground water recharge. Obviously, the need for artificial recharge of ground water can be expected to increase. It can be achieved with surface infiltration systems and with wells, pits or shafts. Surface infiltration systems require the availability of adequate land with permeable soils; and unconfined aquifers of sufficient transmissivity. Where suitable conditions for surface infiltration systems do not exist, recharge can be accomplished with wells, pits or shafts.

Normally water sources for recharge include any excess surface water from runoff, stream, irrigation canals, etc. Where such waters are scarce, treated sewage flows can be used. Increasing populations produce increasing sewage

flows, and also, the disposal of sewage effluent into rivers or other surface water bodies is becoming problematic because of increasing stringent treatment requirements. Therefore, sewage water may have to be necessarily treated and planned reuse of such water may have to be adopted. Ground water will then play an important role in the treatment and storage of sewage effluent for reuse. Issues which required to be addressed are optimum combination of the treatment of water before recharge and after recovery from the aquifer, sustainability of soil- aquifer treatment (SAT), and health effects of water reuse (Bouwer, 1994) (Ref.7).

Various countries of the world are seized with the problem of artificial recharge of ground water on a sustainable basis, and are engaged in addressing contextual issues.

2.1.2 EURO survey on Artificial Recharge

Connorton and MC Intosh (1994) (Ref.12) presented the report of "EUREAU Survey on Artificial Recharge" conducted on fourteen member countries of EURO, which is the union of national associations of water suppliers from countries within the European Community and the Economic Free Trade Association. The survey was carried out in February and March 1993 with the aim to collect information on present and proposed usage of artificial recharge (AR).

The AR has broad based usage within the overall water resources framework. It is practiced in varying forms and dimensions across the various countries of the world. The range of diversification includes purposes, sources of recharge water, level of pretreatment in relation to quality of recharge water, methods of recharge, local hydrology, etc.

Of the fourteen countries, only ten countries are practicing AR to varying degrees and have firm plans for further development. The results of the survey for each of the ten countries - Belgium, Denmark, France, Germany, Greece, the Netherlands, U.K., Spain, Switzerland and Sweden are presented.

Belgium: One major AR project is in the development stage and several more are being planned to represent a water resource of some 27 Mm³ annually.

Denmark: Four significant AR projects are operating, three for water supply and one for environmental purpose. The source of water in the latter case is sewage effluent; while in others, it is stream, lakewater and lakederived ground water. Pretreatment consists of filtration through sands and gravels within infiltration basins.

France: Four major AR schemes are well established with a combined output greater than 200 Mm³ annually, of which the Croissy scheme is the oldest started in 1959 and is one of the largest AR applications worldwide.

Germany (former FDR): AR accounts for some 10% of the total public water supply with concentration varying from state to state. The highest usage is in north Rhine – Westfolia (20% of state supply) and Saxony (15% of state supply). The areas along the river Ruhr gain more than 80% (290 Mm³ annually) of their drinking water using AR. Pretreatment ranges from pre-sedimentation to multi-barrier treatment.

Greece: Two major AR schemes accounting for 10 Mm³ public water supply annually are operative and further development of some 32 Mm³ annually is being planned.

The Netherlands: Some 15% (170 Mm³) of public water supply annually is attributed to 16 AR schemes operating for the primary purpose of water supply coupled with environmental benefit in most schemes. High levels of pretreatment approaching drinking water standards apply to the majority of the schemes.

U K (England and Wales) : The Lee Valley and Enfield – Haringey schemes of north London are currently the only AR projects under way to provide a strategic drought resource of 60 M m³ annual water supply for the London area having a resource deficit of 10%. Other AR projects are in the planning stage.

Spain : Two AR schemes are currently under way, one in Barbastro province (0.04 Mm³ annually) and the other in Barcelona province (13.5 Mm³ annual). A third AR scheme is being planned in Gerona province in which surface water is to be used for recharging throughout the year using infiltration basins.

Switzerland: The principal population centers of Zurich, Geneva and Basel rely on sophisticated AR schemes sourced from the rivers. In all three schemes, pretreatment is carried out to a very high level; recharge methods include percolation basins, well injection and ditch recharge. The Swiss Water Protection Law of 1971 introduced the concept of ground water protection areas which are being incorporated into these AR schemes.

Sweden : Artificial recharge supports 50% of the total ground water component put into supply by water companies which represents over 20% of the total surface and ground water supplies by water companies (966 Mm³ in 1991). This is provided by over 1800 separate AR facilities distributed widely across the country. Recharge is mostly via infiltration basins using sands and gravels as the principal aquifer.

Summing up, in all ten practicing countries, provision of public water is the dominating purpose for AR. However, environmental benefits are often an important associated spin- off. A third important purpose is to improve or maintain water quality by displacement of poorer quality native ground water associated with industrialized river-side sites such as in France and Switzerland or provide a barrier to saline water intrusion such as in Greece.

In terms of national importance, Sweden, the Netherlands and Germany rely most heavily on AR which accounts for some 20% and 15% of total water resources in these countries. In Germany, the overall proportion is around 10% but many of the AR plants are long established, more particularly in Ruhr valley for nearly a century.

Ground water was and still is the main source for drinking water in Germany. It is therefore no wonder that artificial ground water recharge was introduced in 1975 i.e. just in the early stage of public water supply.

2.1.3 Other work on Artificial Recharge in Europe

Detay (1994) (Ref.15) presented an analysis of the results obtained for ground water resource management using artificial recharge (AR) techniques in the Paris area.

The aquifer comprises permeable alluvial formation of 5 to 15m thickness underlain by permeable fractured formation of chalk stone which becomes impermeable at a depth of 30-40 m. The AR water is drawn from Seine river and it undergoes treatment processes including clarification, settling and sand filtrations. Infiltration capacity ranges from 1 to 3 m/day. Altogether 54 Mm³ water reaches the aquifer every year. The efficiency of AR by surface spreading technique depends to a large extent upon the maintenance of high infiltration rates. There is a likelihood of infiltration getting reduced because of clogging resulting from retention of suspended solids, growth of algae and bacteria, entrained gases released from the water and precipitation of dissolved solids due to chemical reactions. Based on the understanding of the clogging phenomenon and the quality characteristics of the aquifer and the recharge water, ground water management strategies have been developed in terms of drying and cleaning the recharge basin for some time (2-3weeks) and then refilling the

basin. There is significant denitrification during the AR process which is beneficial to the aquifer's water quality. Further modification to the water quantity is sought by adjusting the mixture of waters (rain water, water coming from Seine ground- ground exchanges and AR water). The study highlights the AR to be a very good technique which can be integrated into a national ground water management set-up.

Artificial recharge in the Netherlands is carried out for two notable reasons among others - (i) to expand the capacity of ground water extraction and (ii) to overcome the intrusion of brackish water.

de Jonge (1994) (Ref.14) described the Dune Water works of South Holland which is responsible for the production and distribution of drinking water to over 1.25 million inhabitants. Water is extracted from the dune area situated in Meijndel. Artificial recharge is done by infiltration of pretreated river water by means of recharge basins and deep wells. Since the beginning of 1990, more emphasis has been given to use deep well infiltration to meet the increasing demand of drinking water. It has been possible to maintain deep well infiltration of river water without any significant clogging with the inclusion of pretreatment system comprising coagulation, floatation and rapid sand filtration.

In Sweden, artificial recharge is a well known method to produce potable water which presently accounts for almost 25%. Lekanderet, etc. (1994) (Ref.31) reported about efficient operation of artificial recharge in four water plants, of which two have basin recharge and the other two have induced recharge. In case of basin recharge, the provision of fine - grained filter in the topmost layer of the filter bed helped maintain the normal infiltration. In case of induced recharge, there were problems related to removal of organic matter as well as iron and manganese which are under investigation, taking cognizance of

hydrogeological conditions. Artificial well has been practiced in north London since 1890s which continues to this day, adding more production bore holes.

O'shea (1994) (Ref.37) described a drought management strategy by way of bore hole recharge in Lee valley in north London where lowering of ground water levels occurred extensively because of historic over exploitation of the confined chalk / Basal sands aquifer. During average rainfall years, surplus fully treated water from the existing pumped storage in the Thames and Lee valley reservoirs is used for bore hole recharge. During drought years, when river flows and associated storage levels in the reservoirs become critical, the recharge scheme is switched to abstraction mode and bore holes discharge untreated ground water in to the ancient New River along side where the bore holes are located or directly into the Lee valley reservoirs. This is a unique strategy for drought management. Moreover, it has also enhanced the local environment through retention of the historic amenity of the New River in an operational role.

2.1.4 Artificial Recharge in U. S. A.

In U. S. A., artificial recharge of ground water has received immense research attention with the objective to increase the amount of available ground water in which the treatment and storage of sewage effluent for reuse has a great role to play. Based on the research findings, the Bureau of Reclamation is required to establish demonstration projects for the purpose of meeting the contingency of water supply as also for skill transfer.

Clement (1994) (Ref.10) described Wood River Ground Water Regime Demonstration Projects on ground water recharge in the western states of USA

wherein the effects on ground water quality by dilution from a less contaminated source have been examined.

Ground water in the project area has average levels of 22 mg/l of nitrate-N which is above the maximum contaminant levels of 10 mg/l. In the first two years of operation, 1,726.900 m³ of water, having NO₃-N concentration of approximately 0.5 mg/l, has been introduced in to the basin. As a consequence, the ground water quantity and quality have been directly enhanced. The water samples collected from the monitor wells showed nitrate-N concentrations below 1 mg/l.

The study provides an insight for the management of poor quality ground water.

Shaikh et al.(1994) (Ref.54) reported the results of a pilot recharge test carried out to investigate the feasibility of recharging a ground water basin by surface spreading in the San Gorgonian Pass area in Riverside County, California. The purpose of the pilot test was to investigate the effects of the low permeability zones on vertical movement of water, potential mounding, lateral movement of water at shallow zones and sustained surface spreading rates. These investigations were required as the subsurface material in the test area is composed of alluvial deposits of interlayer with lenses of fine-grained material of relatively low permeability.

The results indicated that the low permeability zones in the sub-surface layers reduced the vertical movement of water but did not completely impede its vertical movements. An average percolation rate of 0.9 m per day and an average vertical movement of 1.2 m per day were observed during the test.

Occurrence of water mounding was indicated in the initial phase which later dropped below 150 m depth about 100 days after beginning of the test.

David and Pyne (1994) (Ref.47) reported the results of ASR Projects. Aquifer storage recovery (ASR) wells are dual purpose wells used for the cyclic storage and recovery of water. Water is charged during times when it is available and is recovered when needed. Twenty ASR systems are storing treated drinking water in fresh, brackish and sea water aquifers in a wide variety of hydro-geologic settings and about 40 additional ASR systems are in various stages of development throughout the United States.

The ASR system provides opportunity to utilize brackish water aquifers having suitable hydro-geologic characteristics for storage of very large volumes of high quality surface water. It is first necessary to create a buffer zone surrounding the stored water in the aquifer. This is usually built up slowly during a sequence of several ASR cycles, each of which stores the same volume and recovers a portion of it until recovery quality reaches acceptable concentration for key constituents such as total dissolved solids, chloride or nitrate. A principal technical challenge is the total suspended solids (TSS) causing well clogging for which cleaning and redevelopment of recharge wells may be necessitated. Reduction of TSS through pretreatment would reduce the redevelopment frequency. The technology holds promise for wide adoption.

Crowder and Willardson (1994) (Ref.13) described artificial recharge and recovery of ground water in aquifers of the western United States, being evaluated in the High Plains States Ground Water Demonstration Program. Declining ground water levels and shifting values of water towards urban, environmental, wild life and other purposes have led irrigators to explore ground water recharge and conjunctive use for sustaining crop production. The

High Plains Program established 13 projects to artificially recharge ground water in the Western and High plains States, using seasonal or annual surplus of water. This water is later used for meeting peak or drought period municipal/agricultural demands. Other objectives of the projects are flood control, wild life habitation promotion, recreation, and demonstration of technology of reuse of treated waste water.

Many opportunities exist for recharge and conjunctive use in both urban and agricultural areas. Federal and State interests in artificial ground water recharge relate to enhancing the efficiency and equity of water use throughout the nation/state, and minimizing public resistance and political costs with respect to disturbance of ecosystem and environment associated with surface water storage and management.

Lytle (1994) (Ref.35) described a five - year research and demonstration project pertaining to recharge through injection of treated surface water into a 1500 ft deep bedrock aquifer of sedimentary formations of the Denver Basin, Colorado.

In Denver area, the peak flows created by snow melt in the rocky mountains occur in the spring season, while the peak municipal demands occur in the summer season. Thus, the peak flows and the peak demands are out of phase and as a consequence, water supply deficit occurs during the peak demands in the summer season.

Storage of excess surface water flows, occurring in the Denver area through snow melt runoff in the rocky mountains, improves conjunctive use of scarce water resources. It makes surface water and ground water facilities more efficient by increasing their usage during summer season having peak municipal

demand. The surface water so stored in the deep aquifers is more productively utilized as there is no evaporative loss. While there has been a decrease in injection well performance related to injecting colder, more viscous water into the underlying warm water reservoir as well as some water quality shifts; but the injection well continues to produce a high quality, potable water supply and the conjunctive use plan is seemingly feasible. Water quality data indicate trends towards aquifer water becoming more similar chemically to the injected water.

Light (1994) (Ref.33) described an effluent reuse program in the metropolitan city of Tucson which saves over 6 Mm³ of potable ground water resource each year. The key element of the reuse program is a recharge and recovery facility which stores effluent in the unconfined aquifer during low demand periods and recovers the stored water when demand is high.

The reuse program comprises three basic components:

Treatment plant that filters and disinfects secondary effluent to reclaimed water standards; underground storage and recovery facility; and pipeline to deliver reclaimed water to customers. Extraction wells are used to recover the reclaimed water.

The recharge area comprises volcanic sandy gravels interbedded with clay, sand to silty sand and loam. The vadose zone is about 35 m thick. The aquifer is confined to semi-unconfined.

For sustaining infiltration rates of the basins algal growth is controlled by regular operation of the basin. A drying period significantly rejuvenates infiltration rates. Additional rejuvenation can be realized through the treatment of the ground. Every two years the basins are ripped to a depth of 0.4 m and

every 5 years, they are ripped to 1m, if needed. Thick vadose zone removes several undesirable constituents (nitrogen, pathogenic organisms, etc.)

Wilson et al. (1994) (Ref.62) discussed the fate of organics in sewage effluent during soil aquifer treatment (SAT) based on field- and laboratory - scale observations at Tuscan, Colorado (U.S.A.). Sewage effluent is a reusable resource in the face of increasing water demands. Its use in ground water recharge is an important means for reuse. Surface spreading of treated sewage effluent results in SAT. During SAT, effluent is renovated by natural processes as it percolates through the soil profile. A principal quality concern when considering SAT in a potable reuse scheme, is disinfection byproducts (DBPs) formed during chlorination of recovered water containing dissolved organic carbon (DOC). The other byproducts are organic halides (TOX). This paper evaluates the fate of DOC and TOX. The vadose zone was found effective in reducing DOC and TOX during SAT. Biodegradation is the dominant process in reducing DOC levels and sorption is the dominant process in reducing TOX levels. The surface accumulation of organic matter sustains the sorptive capacity of the soil, while biodegradation is a renewable process.

These results are encouraging for the potable reuse of effluent through SAT.

Lau (1994) (Ref.29) reported the results of a waste water reuse project carried out along a dry, hot coast on the island of Oahu, Hawaii. It is a site-specific demonstration of artificial recharge of ground water, adopting the principles of waste water irrigation to field plots of 0.2 to 0.4 ha size, growing California grass and sugarcane. The vegetated soil acted as a "living filter" to purify the applied waste water, resulting in a recharged water quality fit for non potable uses. The soil comprised 0.9 to 1.5 m deposits of sugarcane mill wash of silty clay texture with moderate infiltration capacity (0.4 to 1.4 x10⁻³ cm/s).

The underlying fossilized coral reef limestone was heterogeneous, porous (about 0.20) and highly permeable (> 0.4 cm/s).

The irrigation water source was the primary treated effluent from the nearby waste water treatment plant, which was applied to both crops at 508 mm/week for the high rate and 254 mm/week for the lower rate. The effluent was applied to the California grass plots by elevated sprinklers for the first three crops and by border flooding for the fourth and fifth crops. The sugarcane crop was irrigated by flood-drip irrigation. Monitoring was done to assess the quantity and quality consequences of recharge by installing piezometer wells penetrating to 1.5 m or 9.1 m depth in field and near-field sites. The results indicated that the aquifer was abundantly recharged. The recharge freshened ground water chlorides to 245 mg/l, stripped virtually all of the effluent nitrogen, and inactivated effluent bacteria. Toxics (pesticides and heavy-metals) were all below maximum contaminant levels. No adverse environmental effects—surface runoff, insect infestation and ground water contamination—were identified. The biomass produced was in adequate quantity and of usable quality.

The results provide a base for large scale adoption of waste water recharge of ground water to address the concerns related to water supply, waste water management, ground water potential development and agricultural production.

Endicott and Conklin (1994) (Ref.18) advocated micro filtration as a recharge treatment alternative based on research with the ground water in the Central Basin of Los Angeles County and the East Coastal Plami area of Orange County which is vulnerable to sea water intrusion. The Alamitos Barrier has been created which is an engineered fresh water pressure ridge and sea water

trough designed to protect ground water from sea water intrusion through the alluvial - filled Alamitos Gap, located near the Los Angeles - Orange County line. The pressure ridge is created by injection of fresh water into the ground water aquifer via a network of wells located in area that spans the Alamitos Gap. The trough is created by extraction of brackish ground water from wells located on the seaward side of the injection well area. Fresh water for injection at the Alamitos Barrier currently consists of imported water purchased from the Metropolitan Water District. Recent studies indicate that injection should be increased from 4.9×10^6 m³/yr to 12.3×10^6 m³/yr. It is recognized that at some day, the supply could be limited due to competing demand. Therefore, the option is being considered to utilize water reclaimed from a nearby waste water treatment plant. The waste water reclamation process may be either a conventional pretreatment train (lime clarification, recarbonation, filtration) or the recently developed technique of microfiltration followed by a final treatment train (parallel reverse osmosis and granular activated carbon).

Leaf & Leaf (1994) (Ref.30) discussed integrated management of artificial recharge of alluvial ground water in the South Platte River basin below Denver, Colorado. The integrated management involved replacement of water for the depletions to the rivers attributed to the pumping of the well, and also utilization of the recharge to mitigate existing or potential ground water quality problems. Colorado water law recognizes alluvial ground water pumping in the South Platte River Basin as surface water diversions due to the direct hydraulic communication between alluvial ground water and the river system. Due to the ground water hydraulics, alluvial withdrawals cause river depletion spatially and temporally. Over the past decade, the use of artificial recharge is one method used in the lower basin to mitigate the depletion effect from well pumping on the surface stream. The Ground Water Management Sub district of

the Central Colorado Water Conservancy District (Central) initiated alluvial recharge in 1979. Currently, Central operates 12 decreed artificial recharge facilities at five sites and has recharge facilities at five more sites and has recharged total of 62.7 Mm³ into the ground water alluvium. Moreover, the recharge of water into the aquifer which has a lower concentration of NO₃-N in the aquifer, dilutes the concentration of NO₃-N in the ground water and is an effective means of improving ground water quality in the area.

Evidently artificial recharge in the alluvial aquifer of the South Platte Basin below Denver is a cost effective valuable water resources management tool. Artificial recharge is a cost - effective means to provide augmentation water to offset well depletions and mitigate ground water quality problems in the alluvial aquifer.

Hemenway and Paul Grundemann (1994) (Ref.63) documented the testing and operations of aquifer storage and recovery (ASR) technology that uses dual- injection / extraction wells to store treated drinking water in an aquifer during times of availability, with subsequent recovery of stored water to meet seasonal, emergency or long-term demands for Centennial Water and Sanitation District (CWSD) that serves Highlands, Ranch, Colorado. The CWSD, which is located in the southern portion of the Denver Basin along the range of Colorado, uses both groundwater and surface water sources to meet the water demands which have increased over years. There is also a seasonal demand. The test ASR involved three injection/recovery cycles of various durations and storage periods. The longest test involved continuous injection for 47 days at approximately 300 gallons per minute with storage of water for 49 days.

Information obtained during the ASR injection/recovery tests indicated an appreciable amount of head buildup during injection. The head buildup was substantial enough during the Cycle 3 long-term injection period to have propagated a fracture within the water-bearing zones in the vicinity of the well. However, the fracturing may have actually increased the hydraulic capacity of the well, as observed in the Cycle 3 recovery pumping water levels. Also, well loss coefficients during recovery were actually lower than the initial coefficients calculated from the pumping tests conducted before the injection cycles.

In general, particulate concentrations were somewhat higher during the initial portion of the injection periods. This would be expected as the flow in the transmission pipeline is reversed during injection, back flushing particulates from the line. Sand content also was noted to be somewhat higher during recovery than during injection.

The results of the ASR testing indicated that ASR is a viable technology for the CWSD to help meet their projected storage and water demands, and formed the basis for developing operational guidelines for future ASR operations.

Lee and Jones - Lee (1994) (Ref.32) described water quality aspects of recharge water used in ground water recharge projects.

The development of a ground water recharge project should require in-depth assessment of characteristics of the recharge waters and their impact on the quality of the waters recovered from the aquifer and on the longevity of the recharge project. The residual contaminants in domestic and industrial wastewaters and surface water runoff from urban and rural areas that are recharged to ground waters through incidental or enhanced recharge projects

can be adverse to ground water quality and aquifer quality. Attention should also be given to the compatibility so as to protect the quality of the aquifer and the recovered water. Guidance is provided in this paper on the overall approach that should be followed in evaluating water quality issues in ground water recharge projects. Particular attention is given to potential water quality and aquifer quality issues associated with the recharge of surface waters and waste waters that have received limited treatment prior to recharge, where the unsaturated zone of the aquifer is used as an extension of the wastewater treatment system to remove contaminants that could be adverse to recovered water quality, aquifer quality, and the long term longevity of the recharge recovery project. Owing to the accumulated (stored) contaminants, the aquifer waste treatment zone could become a source of contaminants for the aquifer and would require remediation to prevent ground water pollution from current or previous recharge of surface waters that have not been adequately treated prior to recharge.

Sienkiewich (1994) (Ref.56) advocated the need for institutional arrangements for successful conjunctive use of ground water stored in Southern California.

The Metropolitan Water District of Southern California is pursuing regional expansion of conjunctive, use of ground water storage in Southern California. The Metropolitan is attempting to expand conjunctive use of 2800 square miles of local ground water basins with imported water storage. Recharge techniques in use are spreading, deep-well injection and shallow-well injection.

Although conjunctive use is becoming an increasingly important element of Southern California's water supply, development of individual projects is a

challenging endeavor. Satisfactory resolution of institutional basin management issues may dominate technical factors in project realization. Planning projects that are beneficial to all involved parties appears to be the key to success.

A pilot project was developed to test institutional arrangements. Success in the pilot project regarding both technical and institutional arrangements provided justification for planning larger scale storage program.

Schaefer et al. (1994) (Ref.52) presented the report of the Hurton Project of the High Plains States Ground Water Demonstration Program. The project was developed to demonstrate the artificial recharge potential of glacial aquifers in eastern South Dakota. The project concept is to use high flows from the James River during spring runoff as a source of water, treat the water, and inject the water into the Warren aquifer, a buried glacial aquifer. The recharge event will be extensively monitored for water level effects, water quality changes, and interactions occurring in the aquifer.

There is also proposal to conduct a special study of the potential for ground water recharge in the High Plains States (Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming) as well as in other States such as Arizona, California, Idaho, Montana, Nevada, North Dakota, Oregon, Utah, and Washington. The Bureau of Reclamation is required to establish demonstration projects to recharge ground water aquifers in these states so as to demonstrate the significance of artificial recharge as a means of increasing the amount of available ground water.

2.1.5 Artificial Recharge in Brazil

Boochs and Billib (1994) (Ref.6) have developed a management concept for the ground water reservoir in combination with an existing surface water

reservoir. It is based on field experiments and computer simulations carried out at an irrigation area located in a small alluvial ground water bearing basin in the North- East of Brazil.

To enable productive agriculture in arid regions with long dry periods, the storage of water is essential. When using surface reservoir for storage, there are several disadvantages such as high evaporation losses, reservoir siltation, and pollution risks. Groundwater storage may overcome these problems. Ground water basins, when necessary, with artificial underground dams and / or ground water recharge can provide carry over storage for the excess waters of wet periods to be extracted during dry periods.

Artificial underground dams, compared to equivalent surface reservoir volume, have following advantages:

- smaller construction costs
- shorter period of construction with immediate benefits
- smaller evaporation losses
- almost no sedimentation and loss of reservoir capacity
- no inundation of fertile soils through reservoirs
- no environmental hazards such as increase of mosquitoes and water born disease.

Optimization can be achieved by artificial recharge with water from the surface reservoir. To avoid waterlogging and salinization hazards by capillary rise, the ground water should be controlled by pumping.

2.1.6 Artificial Recharge in Australia

Dillon et al. (1994) (Ref.17) reported the results of a pilot study conducted in 1993 at Andrews Farm on the Northern Adelaide Plains.

The Pilot study involved harvesting of water from a suburban 31.6 km² catchment, detaining it in a newly constructed wetland, and injecting it under pressure through a sand filter into a confined calcareous aquifer by an injection well. A total of 6.5 million liters potable water and 19 million liters storm water were injected, and 5.4 million liters of ground water was extracted. The native ground water is saline (3.4 dS/m to 4.5 dS/m).

While injection of storm water reduced ground water salinity, possible entry of pollutants (nutrients, heavy metals, organic chemicals and bacteria) was examined. Faecal coliforms were the only analyzed chemical species in storm water which exceeded the irrigation and livestock guidelines. As a matter of precaution, pretreatment of storm water needs to be done. Moreover, care is required for removal of likely well clogging.

The pilot study shows the possibility of enhancing ground water resources by injection of storm water and treated waste water.

Gergez et al. (1994) (Ref.19) narrated experiences in injecting storm water into aquifers to enhance irrigation water supplies in south Australia. The injection tests are an adjunct of a trial project which is under way to assess the potential of the confined aquifer system to support artificial recharge / reuse. The associated objectives of the trial project are to evaluate well completion techniques, hydraulic properties of the aquifer system, quality and availability of recharge water, likely behavior of pollutants in injected water and overall economics of such schemes.

The results and experiences of the pilot study will help develop standards for injection and reuse schemes in south Australia. Most importantly, it will provide a research backup to a flood mitigation / water treatment complex of

wetlands constructed at Andrew's Farm where the storm water may be used for artificial recharge. This has been necessitated to address a major concern pertaining to acute decline of water table by up to 75 m in the Northern Adelaide Plains.

The results of the study carried thus far suggest that the aquifer system at Andrew's Farm seems capable of accepting, storing and releasing recharged storm water. Since it is confined system, the amount of storage is limited, and the operation has a better chance of success if the water is reused on a regular basis. Some clogging of the well and near aquifer material has been observed but it is believed that major clogging due to aquatic micro fauna can be avoided by appropriate filtering. The use of dual purpose injection / discharge well will also help to control the clogging problem by redeveloping the well at the beginning of each pump out season. Interim cost analysis indicates that the artificial recharge of storm water should be economically viable-as well as environmentally sound.

2.1.7 Artificial Recharge in China

Peimin et al. (1994) (Ref.44) reported the results of a case study on artificial recharge of ground water in the lower reach flood plain of a seasonal Huangshui river in Shandong Peninsula of China. The aquifer, having thickness of about 10-60m, is mainly composed of loose deposits of sand, gravel and clay lens. In general, the aquifer has fairly high transmissivity and storage volume. A series of recharge wells at two depths- 0.5 m (partially penetrating the river bed) and somewhat deeper (fully penetrating the river bed)- were installed in the Huangshui river course. The well water was used for injection, which in one case was natural (clear water) and in another case, it was made artificially muddy. The recharge capacity was higher in deeper than shallower well. In both cases, the recharge capacity was much reduced with the use of muddy water which caused well clogging. The higher recharge capacity in case of deeper well

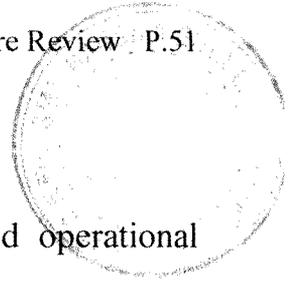
resulted because of more permeable aquifer, while the shallower well encountered less permeable clayey layer. The study showed the feasibility of ground water recharge in case of permeable aquifers. Well clogging could be a limiting factor in artificial ground recharge which may have to be remedied.

The study is intended to build understanding to develop a structural framework for enlarging the scope of river water infiltration into aquifer through artificial well recharge. Presently the river bed of the Huangshui river is not fully composed of permeable sands and gravels. In the lower - middle part of the river course, about 5.8 km long river bed is covered by low-permeable clayey soil with a thickness of 3-17 m infiltration in to the aquifer.

2.1.8 Artificial Recharge in Japan

Abiko and Katsuragi (1994) (Ref.1) described the extent of artificial recharge in Yamagata City which is one of the foremost cities of north east Japan. Ground water is utilized for domestic consumption, irrigation and most importantly for melting of snow which extensively occurs in that region. Under multiple utilization, the ground water has been under stress. To relieve such stress, several schemes (23 nos.) of ground water recharge involving pit method, basin method and well method are under operation. Over a period of three decades since the start of ground water recharge in 1961, 8 Mm³ of ground water has been recharged by well method (4.8 Mm³), basin method (3.0 Mm³) and pit method (0.2 Mm³).

The requirement of ground water for snow melting in the city has become a crucial requirement and more than twenty recharge wells are working for this purpose. Well method is known as snow melting recharging well. Provision has been made for recovering the water used in snow melting and redirecting it into ground through recharge wells.



2.1.9 Artificial Recharge in Oman

Schmid and Riekkel (1994) (Ref.53) described design and operational aspects of recharge dams in the Sultanate of Oman where over extraction of ground water has caused drop of water tables in many areas. The dams provide storage and ground water recharge of storm runoff water.

Most of the recharge projects are concentrated in the coastal plains which have the largest cultivated areas in Oman. The typical layout of recharge dams in Oman is characterized by a long spillway, always integrated in the dam, which is a fill embankment. The spillways are of three types—gabion lined, rock armored and concrete lined. The appropriate type is selected on the basis of hydrological characteristics and economic considerations. Operational assessment remains to be done as recharge events have been few because of low average rainfall.

Al-Harthy (1994) (Ref.2) presented an analysis of recharge benefit of the Al Khawd recharge dam, the first one built in the Sultanate of Oman, which is located in the coastal plain, 5 km from the sea. The analysis is based on the first flood which was impounded in 1987.

The recharge area downstream of the dam site has loose gravels with weakly cemented interbedded layers down to 100 m depth which enable the aquifer to have high transmissivity (7000m^2). In deeper layers, presence of silt and clay is indicated but existence of continuous clayey and silty layers in larger areas is not confirmed.

The dam has been designed for the reservoir storage capacity of 12.5Mm^3 , using the data for the period 1965-1983 during which several major

floods occurred, feeding base flows lasting for years. However, in post-dam period, only low to medium level floods had occurred and therefore, design water storage could not be achieved. Nevertheless, the recharge benefit of the dam to the tune of 1.5 to 2 Mm³/year on an average has been achieved during the observation period from 1987 to 1992.

2.1.10 Artificial Recharge in the Tropics

Chris Barrow (Ref.11) reviewed the role of conventional practices adopted by different names in the tropics for the purpose of water harvesting and ground water recharge. Shallow aquifers are often roughly in balance with recharge more or less equivalent to losses through drainage and withdrawal by deep-rooted plants. However, excessive exploitation of ground water in recent years has led to the fall of the water tables. Natural recharge can not balance the depletion. Therefore, artificial recharge has to be adopted. Where an aquifer is unconfined, simply spreading water on the ground and harvesting runoff with check-dams or earthen ridges may be all that is needed. Confined aquifers must usually be recharged by forcing water down boreholes or into suitable outcrops of the aquifer utilizing seasonal and ephemeral streams and flows.

Wadi farming, flood channel irrigation, check dam irrigation farming, bund irrigation, water spreading and spate irrigation are all terms applied to the same or similar systems of earthen or stone dams and banks designed to spread water over the ground to moisten it or to trap wet silt.

Check dams are simply built barrages which trap water and sometimes water born sediments. Hopefully the plot of soil behind the check dam is moist enough to support crops up to harvest. An example of a traditional check dam farming technique is the Mexican bolsa. Bolsas are earthen walled basins or

bordered gardens which catches the water diverted from seasonal creeks. After the carryout flows from the arroyos have wetted the bolsa and have ceased, the cultivator plants seeds and covers the moist bolsa with a mulch of dry dust or sand to reduce evaporation. As little as the equivalent of 300 mm/rainfall fed in to a bolsa can sustain a crop of wheat, maize, beans, cotton or vegetables.

2.2 ARTIFICIAL RECHARGE IN INDIA

2.2.1 General

India has a long history of constructing check dams across drainage ways, causing impoundment of water in the form of ponds / tanks for domestic use and irrigation. The existence of more than 5 lakh tanks in hard- rock covered areas of peninsular India bears testimony to the concern of the past rulers for harnessing local - level surface runoff for vital domestic and productive utilization. During the British period, the tumult of large dam and reservoir-based irrigation masked the significance of check dam based runoff harvesting. In recent years, there has been a good realization for integrated watershed development in rainfed areas which has been given an operational form by launching it as a central government programme with an adequate budgetary allocation. Runoff harvesting by construction of check dams is an important programme component.

Check dams are constructed across drainage ways to reduce concentrated flows in the channel, causing impoundment of water and also filtering sediments. Further, by reducing volume and velocity of runoff in downstream channel, check dams reduce the potential for erosion to occur.

Check dams constructed for water impoundment with concurrent ground water recharge is accompanied with soil conservation as a spin- off benefit. While sediment trapping is not a primarily intended purpose for check dam

construction, sediment accumulation occurs behind the check dams, and to that extent, the sediment concentration in own slope channel is reduced and in turn, there is reduced sediment loading in the down stream dam reservoir.

For irrigated ecosystem, having surface water supplies from ephemeral surface water sources in semi- arid environment, optimally intensified and productive agriculture can not be achieved unless ground water potential is simultaneously developed for conjunctive use. This is all the more imperative for addressing the problem of domestic water supply as also water equity. As the check dams serve the primary purpose of local -level runoff harvesting and storage, the stored water can be an important source for artificial recharging of ground water and achieving thereby augmentation of ground water potential. There is a need for a systematic planning of artificial recharge of ground water in both rain fed and irrigated ecosystems which has been lacking until recently. A renewed interest in check dam mediated runoff harvesting has started-picking up, and work has been carried out sporadically which is reviewed.

2.2.2 Semi-arid hard rock terrain in western India

Ground water levels have been greatly depressed due to years of over exploitation. As a remedial action, percolation tanks have been constructed in large number for artificial recharge of ground water. Percolation tanks have not been uniformly successful.

Karmarkar et al. (1994) (Ref.26) made geological studies at sites of percolation tanks to understand the basis of success or otherwise of the percolation tanks located on Deccan Trap basalts of Maharashtra in recharging the ground water.

The Deccan Trap basalts are the most important rocks in the geological set up of Maharashtra. From the stand point of jointing, which determines the

percolation behaviour of the basalt rocks, two main types are: (i) compact and jointed basalts without gas cavities and (ii) amygdaloidal basalts without joints and with gas cavities. It is the former type of basalts that can allow percolation and form good aquifers. Even among the jointed basalts, water flow can occur only in those in which joints are open and interconnected. It is, therefore, imperative to establish the suitability of sites for percolation tanks based on geological studies.

Limaye and Limaye (1994) (Ref.34) described the impact of check dams constructed across seasonal small and medium streams on ground water augmentation in semi – arid hard rock terrain in Western India. The run off water from the small catchments is impounded behind the check dams. The runoff storing areas are properly shaped to serve as percolation tanks which have been constructed in thousands to support about 2.5 million dug wells in this region which provide life saving irrigation to food crops. As the water percolating to the hard rock aquifers fully recharge them during the four months of the rainy season, the residence of the phreatic ground water gets expanded in amount and time, enabling enhanced ground water availability for irrigation to cultivated crops. However, there has been over pumpage of ground water because of intensification of irrigation and also reduction in storage and percolation efficiency due to siltation of the percolation tanks, disturbing the ground water balance. The redeeming option is large scale adoption of drip or sprinkler method of irrigation which can substantially economize irrigation water use. Desiltation of percolation tanks is an essential requirement which can be made socially sustainable by giving the right of fish farming in the tank to a fishermen's cooperative society on the condition that it undertakes the responsibility of annual desilting of the tank when it becomes dry in summer. The silt can be productively used by farmers for soil conditioning. Tanks constructed in areas having hard rocks have very low percolation efficiency

because of rocky bed. Such tanks should have sluicing arrangement to discharge water in to the nearby streams where conditions are more favourable for water percolation and ground water recharging.

Athavale et al. (1994) (Ref.4) evaluated the feasibility of artificial recharge through injection bore wells in the Deccan trap basalts through field experiments in Katol area of Nagpur district (Maharashtra).

Ground water occurring in the weathered and jointed section of Deccan trap basalts is the main source of drinking water and supplementary irrigation for villages in an area of about 500,000 km². The natural recharge of ground water does not compensate the extensive ground water extraction through pumping. Artificial recharge through bore well injection seems to be an option. The intake capacity of 9 bore wells was measured by injecting water under gravity, which showed a wide variation from 0.013 to 2.6 liters per minute of well depth. The effect of hydrofracturing was evaluated in some wells which did not produce any significant change in the hydrological properties. Surging was able to restore the intake capacity to a large extent.

Considering the situation of frequent power failures in rural areas, check dam mediated natural head difference and gravity flow for injection of surface water into a well field with one injection and seven observation wells, drilled down to compact rock level (30m), was also evaluated. 3.5 million liters of pretreated surface water was injected at an average rate of 48 liters per minute and about 75% of this quantity was pumped out at an average rate of 103 liters per minute. Potassium iodide tracer was used to determine the velocity of subsurface flow in both injection and recovery phases, which was about 4.5 m / day in the former and 9.0 m / day in the latter.

The study was aimed to develop well injection technology for artificial recharge of ground water to mitigate the problem of drinking water scarcity in water scarce Deccan trap areas, which seems feasible for extensive adoption.

Deshmukh (1994) (Ref.16) presented a case study of artificial recharge in Ralegen Sindi watershed area. It is situated in chronic drought prone region of Ahmednagar district (Maharashtra). The key component is construction of a series of check dams (31 nos.) across the main stream and five small stream tributaries originating in low lying hills bordering the watershed area. The other reinforcing measures include contour bunding in higher level land areas along the hill slopes and contour trenches in hill slopes. These measures conserved soil and almost checked the run off losses, of which a large part infiltrated into the soil, extensively augmenting the ground water.

2.2.3 South India (Andhra Pradesh)

Subrahmanyam and Prakasam (1989) (Ref.59) described the scope of artificial ground water recharge in hard rock areas of Andhra Pradesh Drought prone areas having limited surface water potential, compelling heavy dependence on the ground water resources. The shallow aquifers with limited storage capacity and erratic rainfall makes artificial ground water recharge imperative. Percolation tanks and series of checkdams have been found to substantially augment ground water recharge, besides conserving soil and runoff in the watersheds.

Artificial recharge can be accomplished through various spreading methods, through injection wells or through pits and shafts. Spreading methods include flooding method, natural channel method, etc. The local field conditions including the physiography and hydrogeology of the area have to be carefully considered before selecting a method for artificial recharge.

The usefulness of (i) percolation tanks (ii) recharge from Minor Irrigation tanks converted into percolation tanks (iii) checkdams (iv) percolation canals (v) artificial recharge in the tail end areas of irrigation project commands, etc. for artificial ground water recharge has been discussed. Checkdams are found to serve twin purposes of ground water recharge and soil conservation. In hardrock area with steep slopes, the checkdams are found more appropriate and in areas with gentle slopes, percolation tanks are found cost - effective and performing better than checkdams.

Hanumant Rao (Ref.25) described an innovative farmer's participatory technology, evolved by integrating "four waters" viz. rain water, ground water, surface water and soil moisture in watershed development which was introduced in Andhra Pradesh in all the 7100 watersheds in the state. Capacity building was done to enable farmers in the watershed committees to formulate and execute the works without the help of engineers and contractors. 24 type designs and 10 ready reckoner tables were prepared. It is possible to increase the benefits and times more with the same cost and increase the recharge of the ground water 10 times more.

The following types of structures and activities were involved

1. Mini percolation tanks (M. P. Ts)-30 to 40 per watershed in the first and second order streams. Big percolation tanks in 3rd and 4th order streams, if feasible.
2. Check dams in the 2nd or 3rd order streams with earthen dam at centre and surplus weir on side - (no check dam on the main stream and no cement structure in the stream course). The earthen bund check dams should not be constructed in the main stream where maximum flood discharges will be very high.

3. Sunken pits in gullies in first and second order streams.
4. M. P. Ts at head of gullies and upstream of sunken pits and drainage line treatment.
5. Contour Cut off Tanks strictly along contour, with side slopes for cut section with M. P. Ts at gully junctions.
6. Boundary bunds to be formed with Technology "Boudary Bund". Contour bunds to be formed wherever farmers agree. Contour ploughing in rainfed lands is a must.
7. Diversion drain and sump for recharging open dug wells.
8. Subsurface dam at the downstream of watershed.
9. Rubble stone diversion weir on the mainstream for gravity irrigation.
10. Restoring and desilting very small tanks (kuntas) lying within the watershed.

Incidentally, the geo-hydrological conditions were also favorable for water percolation and ground water recharging. The improved ground water regime enabled extensive extraction of ground water through wells for irrigation to kharif and rabi crops on a sustainable basis. As a consequence, the food grain production increased to 138.6 tons in post- watershed management period from 29.0 tons in the earlier period. Moreover, the hill slopes, which were barren earlier, are thickly vegetated with grasses and trees of high economic value. The entire Ralegan Sindi area has become an oasis in water starved region of Ahmednagar district and serves as an eminent example of community participation in watershed management.

2.2.4 Alluvial tract in north-west India

Gupta (1994) (Ref.24) presented an evaluation of ground water recharge in Haryana. The State of Haryana in North-West India lies in semi-arid zone. It

has a highly productive agriculture because of extensive irrigation through canals and tube wells. While there is sufficient irrigation - induced recharge of ground water into the soils which are mostly sandy loam to sandy but massive extraction of good quality ground water has caused substantial decline of water table. The water table is declining from 0.3 to 1 m per year in 73 blocks out of a total of 103 blocks. Efforts have been made for artificial recharge of ground water by water spreading in abandoned irrigation channels and through injection tube-wells. The rise in ground water level has been achieved to the tune of 1.5 to 2.5 m.

The artificial recharge of ground water through irrigation to kharif crops holds promise for stabilizing ground water level in the State of Haryana. It has also been decided not to line the irrigation channels and water courses.

Singh (1994) (Ref.57) described the need and scope of artificial recharge in Punjab. The State has intensively irrigated agriculture with paddy as the dominant crop during kharif and wheat as the dominant crop during rabi. The net irrigated area has reached 94%, of which 32% from canal and 62% from tubewells. While there is substantial recharge of ground water through inflows from irrigation system as well as through rainfall, but because of massive ground water extraction, there is a declining trend of ground water level. During the rainy season, a large amount of runoff and flood water goes waste. All round efforts are being made to impound that water in water bodies/ basins/ percolation channels for recharging the ground water. 31 low dams on rivulets have been proposed out of which 4 dams with a storage capacity of 15 million m³ have been completed which is expected to reduce the wastage of water, and also enable the recharge of ground water. Under the World Bank loan / assistance programme, the State has proposed to construct cross regulators on rivulets and drains so that water bodies are created at suitable intervals to

recharge and augment the ground water resource. There are many occasions when the irrigation demands mismatch the canal water supplies. On such occasions, canal water can be diverted through escapes into the drains where additional water bodies can be developed for ground water recharge. The trials with such diversions have shown positive impact on the water table rise. The major sources of ground water recharge are paddy fields, vast network of canals, storage bodies and heading up of water in irrigation channels.

Arya and Samra (1995) (Ref.3) made assessment of the community driven integrated watershed management on 155 ha of non- arable and 336 ha of arable land in village Bunga (Haryana). Harvesting, storage and recycling of rain water for supplementary irrigation enabled the villagers to increase the cropping intensity and production in arable land. The yield of wheat increased by 183% and overall production of crops increased by 146%. Increased availability of fodder both from the arable and non-arable lands brought about dramatic changes in the animal husbandry. The quality of livestock improved and milk production increased from 231 thousand liters to 723 thousand litres. There was a discernible improvement in the socio-economic condition of the people. The survey revealed that the watershed management has improved the environmental qualities of the village resource base due to better and diversified natural vegetation cover on the non - arable land and crop production on the arable land in which the harvesting and storage of rain water played a key role.

Grewal et al. (1995) (Ref.22) described the salient features of Sukhomajri watershed management project in hill ecosystem of Punjab in which the participatory approach was adopted. The project included the construction of check dam for harvesting of rain water from the non- arable catchment and utilizing the same for irrigating the farm lands located in the valley. It has also

helped in moderating the flood peaks. The water reservoir was the core piece of the project. The supplementary irrigation to crops produced much higher crop yields. The recharge of ground water led to improved soil moisture regime under which the production of grass and fodder got enhanced leading to the adoption of improved animal husbandry and dairying. The project gave a sound footing to the concept of watershed management with people's participation.

2.3 ARTIFICIAL RECHARGE IN GUJARAT

2.3.1 Artificial recharge works taken up by Gujarat Government

Recognizing the benefits accruing from artificial recharge as extensively documented in India and abroad, the Government of Gujarat took a conscious decision to promote artificial recharge activities such as scarcity Relief Tank and Check Dam.

Under this programme, a total of 3048 relief tank schemes were taken up at a cost of Rs.6592.36 lakh in 18 districts of the State (Kachchh, Banaskanta, Sabarkanta, Surendranagar, Kheda, Mehsana, Ahmedabad, Amreli, Bhavnagar, Jamnagar, Junagadh, Rajkot, Vadodara, Bharuch, Surat, Valsad, panchmahals and Dangs). The check dams numbering 3584 were constructed at a total cost of Rs. 5484.91 lakh in the 18 districts of the state.

The percolation tanks and the check dams have provided widespread benefits all over the State. There has been immense people participation in the programme activities from planning to implementation and thereafter in operation and maintenance. People, in general, have imbibed the perception of owning the hydraulic structures.

2.3.2 Artificial recharge works taken up by NGOs

Parthasarthy & Patel (1997) (Ref.38) compiled the information of the recharge activities of the Swadhyaya Parivar in Saurashtra. Two typical schemes adopted are "Nirmal Neer & "Recharge " wells.

Under Nirmal Scheme, the methods used for increasing infiltration include:

- Constructing a recharge pond/percolation tank by building earthen embankment by " Shram Bhakti " (voluntary labour) and a masonry spillway.
- Constructing a series of barriers on sloping ground/ river or nala bed to create a battery of small recharge ponds.
- Diverting surface water flow to natural depression or limestone quarry pits.
- Constructing small surface weirs of plastic bags filled with fine soil.
- Constructing long earthen bund to prevent sea water intrusion and storage of rain water.
- Constructing series of bumps and depressions along river/ nala beds.
- Constructing farm bunds and farm ponds.

The well recharge scheme involved removal of floating debris and suspended particles from surface water runoff and injecting into open wells or tubewells or hand pumps to recharge confined aquifers for which bores were drilled in river beds.

The two schemes were taken up in six districts (Amreli, Bhavnagar, Jamnagar, Junagadh, Rajkot and Surendranagar). Under 'Nirmal Neer ' scheme,

707 percolation tanks have been constructed creating a water resource potential of 22.856 Mm³.

Under Aghakhan Rural Support Programme (ARSP) India, 67 check dams, percolation tanks and 15 recharge wells have been constructed in Surendranagar and Junagadh districts of Saurashtra region.

Saurashtra Lokmanch, a farmer organization, has taken up activities under Jal Sanchya Abhiyan Programme which include open well recharge, Khet talavadies (farm ponds) and nala plugs.

Shri Vivekanand Research and Training Institute (VRTI), a voluntary organization located near Mandvi Kutchh, has taken up rain water harvesting structure in Kutchh region since 1987. VRTI structures comprised of check dams, percolation tanks, underground check dams and recharge tube wells. The recharge experience in Kutchh area has been reported. In streams with wide sandy beds and high HFL, underground check dams are constructed. Check dams are generally narrow with height of dam check dams are constructed in series at spacing such that upstream check dam is just above water spread of downstream check dam.

Underground check dams are constructed by excavating 15 to 20 m deep trench in entire width of river. The downstream side of the trench is filled with polythene sheet. The trench is filled with pervious sand and recharge wells are constructed along the width of the trench. On top of the underground barrier, a check dam of about 2m height, may be constructed. Structures capture surface flow as well as base flow and under flows of rivers. In Mandvi and Mundra talukas, 58 check dams, 48 percolation tanks, 2 underground check dams, 49 recharge wells and 42 storage tanks have been constructed upto July 1997 with gross storage capacity of 1.44 Mm³. It is benefiting irrigation to 3301 ha.

Premjibhai an Industrialist, acted as a catalyst for constructing check dams in Upleta Taluka. He gives cement free of cost for constructing check dams. He has initiated more than 150 check dams in this region. The check dams are having height ranging from 1m to 2m. Beneficiaries contribute free labour and stones.

Babubhai Parmar conceptualized and implemented an innovative water management system in Bhayavadar village about 25 years ago. Bhayavadar is an arid village and receives about 300 mm to 600 mm of average annual rainfall.

Farm recharge is a concept in which the rain water falling in the pond is inundated in the field itself by closing all the outlets. The water thus inundated is allowed to infiltrate into the ground and also diverted to the well nearby the field through a network of pipes connecting all the depression in the field to the well. Babubhai constructed an open channel all along the bund on the sloping side of the field to collect the run off of his 20 bigha field. The channel has been reconnected 1 to 4 cement pipes of 150 mm diameter which act as sluice to channel. When the pipes are open or unplugged they carry water out of field and when they are plugged, water flows towards well. When sufficient water flows into well the sluice pipes are unplugged to drain excess water from field to adjacent stream.

A structure similar to silt trap is constructed prior to well to control velocity of flow from field and trap the silt particles.

The check dam was also constructed on the adjacent stream to recharge the well in case the rainfall is low. If the rainfall is excess, a sluice pipe to drains water inundated in the check dam into the well.

An overhead tank just above the well is constructed to supply tap water pipe running into the path way for the thirsty bye-passers.

2.3.3 Evaluation Studies

Gujarat has a long history of the usage of earthen tank as a source of water supply for domestic usage and irrigation purposes. Patel, and Sarvaiya, (2002) described the contributions of Jojwa – Wadhwana Earthen Tank, situated in Dhaboi – Sankheda taluka of Vadodara district constructed in 1909-10, as it catered to the need of irrigation and allied requirements.

Wadhwana tank derives its water from Orsang river, caters to the needs of irrigation to a maximum extent of 5127 ha in the year 1997-98 (73% utility). For the last 10 years, inflow of water to tank has reduced due to Water Resources Projects taken on u/s of river. Govt. has planned to obtain the water from Sardar Sarovar Project via its system. For the last two years water is being fed in tank to replenish the shortage. Farmers are being trained for the new challenges. Tank is being renovated and systems of canals are being modernized by providing lining. Results are encouraging. Tank serves as a tool for sustainable development in rural area, equally contributing toward village economy, social development, its micro-climate, and environment.

Patel and Patel (2004) (Ref.41) discussed the impact of check dams on ground water recharge in Bhadar-1 River Basin, and various aspects of the appropriateness of check dams in hard rock areas to emphasize the need to implement the construction of check dams on a large scale in drought prone areas to control scarcity condition.

During the monsoon large runoff with low time of concentration reduces the recharge rate, resulting into lowering of water table and yield of wells leading to water scarcity in the hard rock areas. The hard rock areas, being

impervious and heterogenic in nature with sloping terrain, are dependent upon the recharge of rain water through the weathered layers, joints and fractures in these formations.

There is a need to restrict the flow of run off water in the hard rock areas so that the ground water gets replenished through fractures and joints for further utilization for irrigation and domestic water supply. Unfortunately, till now the entire planning of water resources was based upon construction of major, medium and minor dams in the hard rock regions to conserve water. While the benefit of these water resources are largely enjoyed by the people living in the down stream side of the dam in the command area, the people living in the Catchment areas suffer from lack of adequate water resources.

Check dams have been observed to be an appropriate rural technology for poor rural areas. These are cost effective and environmental friendly without disturbing the social fabric of the area. These structures do not require high level technology, skilled labour and huge financial resources for construction and maintenance hence are accessible to poor farmers. More than 420 Checkdams have been constructed under “Sardar Patel Participatory Water Conservation Programme” in Bhadar-I river basin covering 188 villages.

In an another study, the authors evaluated the impact of check dams on geohydrological conditions in Rajkot district.

Prior to construction of checkdams under various programmes in this district, the geo-hydrological conditions like the depth to water levels, thickness of water column, discharge from the wells, number of running hours per day were far below the average performance prior to the construction of these checkdams. After the construction of these checkdams, attempts have been made to study the changes in these parameters. Talukawise study of declining

parameters has been carried out from this district. It has been observed that the average taluka wise rise in the water level ranges from a meager 1.85 m - 3.45 m in 1999 to 5.05 m – 12.78 m in year 2004. The thickness of water column has been observed to increase from a meager 1.85 m – 3.45 m in year 1999 to 6.7 m to 15.55 m in year 2004. The discharge of wells/tube wells has been observed to increase from a meager 175-215 LPM in 1999 to 375-575 LPM in 2004. The number of running hours has been observed to increase from a meager 200-300 hours/year in 1999 to 375-400 hours/year in 2004.

Further, the construction of check dams has enhanced ground water recharge. Farmers have been benefited by assured water supply that saved kharif crop. These water conservation structures have helped in recharging ground water significantly as a result of which the ground water resources could be utilized effectively for solving the drinking water problem in these areas.

Patel (1999) (Ref.39) carried out exhaustive investigations on the performance of check dams and percolation tanks in Saurashtra region and documented in his Ph.D. thesis the impact on hydrological conditions through the following indicators:

- Height of water mound
- A real extent of water spread
- Recharge and volumetric efficiencies
- Water quality such as T.D.S. and Fluoride
- Management of recharge structure.

The author recorded the height of water mound in ground water aquifer varying from 2.3 m to 8.0 m in various types of geological conditions. There has been an all round improvement in ground water regime including that in ground water quality by way of decrease in T.D.S. and Fluoride due to dilution caused

by recharge. It has, however, been observed that siltation in percolation tanks and check dams decreased storage capacity as well as the recharge rate.

According to Chadha and Bhowmick (2000), (Ref.9) suitable sites for artificial recharge structures are selected depending upon the local topographic, geological and soil conditions. The basic requirement obviously is the maximum percolation rate of the surface water and sustenance of the recharged water in the ground water bodies. In unconsolidated formation, it needs the presence of unsaturated/partially saturated top granular zone suitable for ground water recharging whereas in hard rock terrain the surface water percolation depends on the presence of the weathered /highly fractured rock system with appreciable thickness of unsaturated portion at the top.

Geophysical techniques are highly suitable and effective means of determining the aforesaid characteristic formational features for suitable site locations. Whereas electrical resistivity and electro magnetic methods (EMR) can differentiate saturated and unsaturated parts of the formations, refraction seismic techniques possess high success rate in identifying fractured part of the rock and map depth to compact rock. However in unconsolidated sediments, electrical resistivity method is quite effective in locating permeable granular zone and its lateral extent. The method is also suitable to identify and map interface between fractured and compact rock formations. At shallow depth, EMR technique is very successful in mapping the lateral extent of unconsolidated and consolidated part of the formation. The airborne EM technique can be used to cover larger area to differentiate low and high conductive zones where, under favourable condition, low electrical conductivity indicates zone of high ground water recharge. Combination of different techniques is finally the requirement for selection of suitable sites for construction or artificial recharge structures.

Patel (2002) (Ref.40) critically reviewed the performance of water harvesting and ground water recharge structures constructed in large numbers. The performance indicators used were: (i) maximum rise in water mound and the duration of rise; (ii) radius of influence of percolation tanks; and (iii) recharge rate and the recharge rate equation.

Based on the analysis of the data of four percolation tanks, five check dams and four ASR wells, it was concluded that the maximum height of water mound observed for percolation tank at 200m upstream of bund of the tank was 6.2 m for milliolite lime stone, 2.3 m for weathered basalt and 4.45 m for Gaj limestone. Water mound on downstream at 200 m distance was 8m for milliolite, 3m for weathered basalt rock and 5.1 m for Gaj lime stone. The height of water mound in ASR wells got raised from 6.1 to 8.4 m, the radius of influence varied from 530 to 570 m. The period of development of water mound was 100 to 120 days, and the height of water mound was higher in lime stone when compared to other formations. Recharge structures showed greater effects on the down stream as compared to upstream. The life of percolation tanks and check dams depended on de-silting.

Mahesuria (2002) (Ref.36) advocated for large scale construction of check dams recharging of ground water in Saurashtra region of Gujarat. According to his estimation, about 16,300 Mm³ of runoff is wasted to sea every year which can be stored to recharge ground water that can support 6.50 lakh wells. His contention is that irrigation cost through check dams is more economical (about Rs.20,000/- per ha) against that of about Rs.1.5 lakh/ha under major and medium schemes.

Singi and Asopa (2002) (Ref.55) made an independent evaluation of check dams at the request of Government of Gujarat. Focusing on Saurashtra region, the study estimated that there was a recharge of 138.47 Mm³ of runoff

water during a drought year, and the same have been 307.11 Mm³ in a normal rainfall year through a total of 10257 constructed check dams. The average number of wells were 7, benefiting from each one of the check dams. The average distance of the wells from the check dams was 621 ft. On an average, the net addition to gross income for the check dam respondents relative to the non-check dam respondents was Rs.404 per bigha during the drought year. A more comprehensive cost-benefit analysis indicated that within a period of three years, for an initial investment of an average Rs.1,58,000, a total benefit of Rs.2,51,582 per check dam was obtained.

Other crucial benefits emanating from check dams were reduced severity of drinking water problem both for humans and cattle, increased security of crop production and availability of some green fodder for cattle during summer enhancing milk production.

The study builds a strong case for large scale construction of check dams, which may be around 1,17,500 nos, for the Saurashtra region.

Patel B.B. (2004) (Ref.42) presented a case study of check dams in village and taluka Umralla (Bhavnagar). The case study involved impact evaluation and cost benefit analysis of check dams. The village Umralla is situated on the bank of river Kalubhar. It has a population of 12000 and cultivatable land area of 7900 ha. Some part of the village falls under the command of Rengole Irrigation scheme.

There are series of check dams on Kalubhar river along the river length of 100 km, of which 8 to 10 check dams are in upstream of Umralla village and one check dam on downstream of village. There are two check dams in village Umralla. Benefits occurring from the check dams include increase in irrigation facilities, rise of water tables, increased yield of crops, increased availability of

water for domestic use, and increased number of live stock. Benefit – cost ratio is 3.10 which is considered to be high.

Vhora, P.H. (2002) (Ref.61) stated that in Kutch and Saurashtra region where there is insufficient and erratic rainfall and where there is no more scope for medium and major irrigation projects, it is inevitable and imperative to conserve and store maximum available rain and run off water to recharge ground water table to increase agricultural production.

The author mentions that Gujarat State Land development corporation Limited (GLDL) has constructed earthen water harvesting structures with 0.5-1.5 ha.m storage, 160 stone masonry structures are constructed by the Khopala village people of Bhavnagar and 177 stone and RCC masonry structures are constructed by “Sardar Patel Sahbhagi Jal Sanchay Yojana” in 1999-2000 with a storage capacity of 0.5-1.5 ham. Later levels in wells of Khopala village increased from 1.2 to 1.5 m to 7 to 15 m. Similarly, the water levels in wells of Juthel village of Junagadh district also increased upto 7.5 m and the income of farmers have also increased substantially.

Singh Manmohan (2004) (Ref.57) discussed the impact of check dams on water resource development and conservation. Check dams are small barriers built across the direction of water flow on shallow rivers and streams for the purpose of water harvesting. The small dams retain excess water flow during monsoon rains in a small catchment area behind the structure. The impounded water percolates into the ground. The major environmental benefit is the replenishment of nearby ground water reserves and wells. The water impounded by the dam (surface and subsurface), primarily intended to be use in irrigation during the monsoon and later during the dry season, can also be used for livestock and domestic needs.

Silt accumulation can be reduced to minimum by limiting the undue activity around water bodies, banks stabilized to contribute minimum silt, contour bunding of hilly slope may also help. Even before monsoon, the silt may be manually removed with community participation. The removed silt can be disposed off suitably in land leveling, helping containment of water logging. Weed growth in water bodies must be watched and discouraged. The care should be taken to prevent the deterioration of water quality and minimize the loss of water by evaporation.

Rawal, Abhay (2002) (Ref.49) reported astonishing increase of water levels in the wells in the range of 2 to 17 m due to construction of check dams in Saurashtra.

As per the official report of government of Gujarat, it was found that there was a considerable increase in ground water level due to construction of check dams in Jamnagar, Junagadh, Rajkot, Amreli & Bhavnagar districts of Saurashtra. There was increase of water levels ranging from 2.50 to 17 m despite low rainfall in Saurashtra, which caused increase in the production of cotton, groundnut by 3 to 5 times of the average production.

In Bhavnagar, Amreli, Junagadh and Surendranagar districts, there was only 30 to 87% of average rainfall. Even though there was considerable increase in water levels in these districts, ranging from 5 to 10 m. As per survey report of 34 wells conducted by Central Ground Water Board in different talukas of Jamnagar district, there was increase in water level in 22 wells i.e. in 64.71% area and the result was encouraging. The increase of water levels from 3.70 m to 10.47 m in wells near to check dam and 2 to 6 meters in well away from check dams was observed. There was also increase of groundnut and cotton around 50 kg/bigha to 400kg/bigha.

Out of 1,348 check dams constructed in Rajkot district, in survey of 574 check dams, there was increase of water levels from 4 to 6.50 m in the wells away from the check dam.

In Surendranagar district, 80 check dams were constructed and the rainfall is 300 mm, there was increase in water levels from 3.4 m to 11.0 m.

As per the opinion of hydrologist, geologist, if the pattern of good rainfall is continues for 4 to 5 years and if thousands of check dams are constructed with good planning and sound technology, then there will be considerable increase in ground water level after 5 years. The storage of rain water is the best alternate to avoid acute water shortage in future.

Rawal, Abhay (2002) reported the ground water recharge works done in village Khopada (Taluka Gadha-da,Bhavnagar) under the aegis of Khopada Navnirman Vikas samiti)

The works included construction of 200 check dams, each with storage capacity of 80,000 to 1 lakh cub.ft. totaling to 150 to 200 lakh cub.ft. i.e. 42 lakh liters of water storage. In addition, there were 10 “simtalav’ and 25 ‘khet talavadi’. After first rainfall of 15 to 18 cm, water levels in wells increased by 20 to 50 ft. This made possible to provide protective irrigation to crops that pushed up the production of crops worth Rs.12 crore as against the pre-check dam crop production worth Rs.2 crore. The agricultural land became more productive after the construction of check dams and attained much higher land value.

According to Patel (2007), the root cause of serious water problems in Saurashtra, Kachchh and North Gujarat is improper water management and unreasonable extraction or use of ground water. This has led to salinity ingress in sizeable area. Artificial recharge is seen as the only solution to this grave

manmade problem. Involvement of Government, N.G.O.s & other social and public organizations can solve this problem by doing the works based on the foundation of public awareness. Taking inspiration from Swadhyay and other religious and social organizations, attempt has been done to create public awareness for artificial water conservation, under the aegis of Lok Chetna Maha Bahiyam, sponsored by Rotating Service Trust "Patan city". To solve the problems of water in North Gujarat Region, sincere attempts have been made for educating farmers about water conservation methods, planned development of resources of water and water management.

Kapadia (2004) (Ref.64) estimated ground water recharge due to check dams using Artificial Neural Networks (ANN), which was estimated using ANN which involved only two input data-rainfall in season and number of check dams in Taluka. The ground water level data obtained by ANN method were compared with the water level data recorded by Gujarat Water Resources Development corporation (GWRDC). There was a close correspondence between the ANN estimated data of rise in water level and the data recorded by GWRDC in various talukas of Bhavnagar, Amreli and Junagadh districts. The percent variation ranged from a minimum of 0.2% to a maximum of 17.5 %. The results of the study indicate the usefulness of the ANN system for estimating ground water levels.

United Nations Department of Technical cooperation for Development acting as executing agency for the UNDP carried out artificial recharge studies in Mehsana and Coastal Saurashtra region of Gujarat. The project was operated from 1981 to 1985 with total UNDP aids of US \$477,000. The development objectives of the project were to find ways and means to increase ground water resources so as to sustain accelerated agricultural production in the region.

The study indicated that the depletion of the ground water was related to over exploitation both in the phreatic and confined aquifers. The injection of water from the phreatic aquifer into the confined A2 and A3 aquifers is feasible. The recharge in the confined aquifer is from the overlying phreatic aquifer zone. The artificial recharge is an important element in the water resources management.

According to Athavale (1994), (Ref.5) construction of surface water harvesting structures (SWHS) in the catchment area of major and medium irrigation projects does not have any limiting role in the inflows to the large dams. The smallest dam has a storage capacity of 1.05 billion cubic meters (BCM), while the average storage capacity of the SWHS is 0.08 Mm³. Thus, the storage in the smallest dam is 13125 times the storage in an average SWHS. Pisharoty (1991) (Ref.38)-showed that the Sardar Sarovar dam on the Narmada river, having a storage capacity of 5.8 BCM can store only 14.14% of the total catchment inflows. He stated that the livestorage of the dam can be filled with less than 3 days of peak flows, and concluded that construction of thousands of SWHS in the catchment area may not reduce the inflow to the large dam to any significant extent. On the contrary, the construction of SWHS in the catchment area has a complementary role in reducing the silt load and thereby increasing the life span of a large dam. Summing up, the author stated that a judicious combination of all sizes (small, medium and large) is required and the SWHS have a definite role to play in an integrated river basin management plan.

2.4 INFERENCE REMARKS

The review of literature brings out the significance of artificial recharge as a means of increasing the amount of available ground water in areas where natural recharge cannot replenish depleted aquifers. It also authenticates the relevance of artificial recharge for semi- arid areas where seasonal excesses and

shortages of surface water occur; where suitable aquifers exist with a capacity for inter-season storage; and where surface water is short in supply.

The literature survey, however, also brings to attention several information deficiencies with respect to the artificial recharge which are listed below:

1. There is no information to show that artificial recharge through check dams represents a cost-effective addition to the capabilities of water resource management to meet not only inter-season shortage in a more equitable way but also to provide potable water supplies from untreated sources since the vadose zone serves as an ideal treatment mechanism.
2. There is no articulation of the factual situation with respect to the majority of artificial recharge in the basin which relies on harvesting of largely in appropriated surface water from fields, ditches and creeks. The sharing, whatsoever of the influent runoff that occurs with the major water diverters, is stored more efficiently and utilized more productively without incurring conveyance and evaporation losses, bringing in the wake a net saving of the gross water resource potential of the basin.

Additionally, the artificial recharge induces ground water gradients because of increased ground water elevations, making replenishment to the main river stream, which may be significant during the lean season.

3. There is no explicit attestation of the advantage of reduced sediment loading into the downstream reservoir consequential to

sediment entrapment caused by the construction of check dams, and thereby sustaining the live storage of the downstream reservoir.

The above mentioned deficiencies provided a basis for setting research agenda of the thesis, additionally taking cognizance of socio-ecological imperatives contextual to the study area of Rajkot district as elaborated below:

- (i) The semi- arid Rajkot district of Saurashtra region of Gujarat State is frequented by the phenomena of acute water scarcity, necessitating the supply of water for drinking by railway and tankers. Such a situation invites research attention so that developmental initiatives have backup of knowledge base.
- (ii) As per rainfall studies carried out by Junagadh Agricultural University. Junagadh, the average rainfall is low (567 mm) with high coefficient of variation (32%). Moreover, 80% of the rainfall is received through heavy storms of about 27 days, generating huge localized runoff, whose wastage cannot be afforded in water - scarce Rajkot area. Check dams are the rational means for harnessing that water by way of underground storage of water for its productive utilization.
- (iii) The water resource is a social good as well as economic good, and it has multiple dimensions encompassing social, economical, environmental and engineering parameters. This has been comprehended in the research agenda of the thesis.
- (iv) Deccan trap basalt covering almost 90% of the area in Rajkot district has highly fractured basaltic rocks to a depth of 30-40m which provides the aquifer storage space for artificial recharge of ground water. The ground water is the most critical water resource

as protective irrigation to kharif crops which are crucial for food security. In an endeavor to enhance ground water potential by artificial recharge, 4600 check dams have been constructed, soliciting the participation of people in site selection, design formulation and cost-effective construction as well as in operation and maintenance of check dams, making contribution of money, labour, material, etc. This is unique in respect of level and scale of people's involvement.

- (v) Per capita annual availability of water in Rajkot district is much less compared to the minimum requirement of 1000 m³. Bhadar Irrigation Project, constructed in 1965, envisaged to meet the balance requirement of the villages of both the catchment area (2500 km²) and the command area (17000 ha). However, water is being supplied only to the downstream side villages, disregarding equity consideration for the catchment area villages. The construction of check dams ensures equitable ground water supply.
- (vi) Bhadar irrigation project was designed for sedimentation rate of 3.57 ha.m/100km²/year and actual sedimentation rate observed in the year 1986 was 7.08 ha.m/100km²/year, which has reduced the effective life of project. With the construction of a large number of checkdams, the sedimentation rate has again decreased to 3.717 ha.m /100km²/year which should obviously lengthen the life of the reservoir.
- (vii) In Rajkot district, groundnut and bajra are the principal kharif crops for which protective irrigation is made available largely from wells which is a dependable source. Ground water having a larger duty (245 ha/Mm³) compared to surface water irrigation duty (175 ha/Mm³). However, under the conditions of erratic rainfall and

naturally occurring low ground water recharge, availability of ground water for protective irrigation got reduced resulting in decreased crop production. The construction of check dams has enhanced and stabilized ground water availability as protective irrigation to kharif crops.

- (viii) The construction of 4600 check dams in five years in Rajkot district has caused a substantial enhancement of ground water recharge associated with rise of ground water table as well as quality improvement of ground water.

There is presumption of some negative effects on the major and medium irrigation projects of the check dams because of sharing of the influent runoff. Such presumption does not stand ground on scrutiny of the facts that actual runoff sharing is not substantive; whatsoever is shared, it becomes a fully conserved ground water resource incurring no conveyance and evaporation losses, contrasting to the very large conveyance and evaporation losses that this water would have been subjected to if it would have moved to the reservoir, leaving only a small net amount for consumptive utilization. Contrary to the conjectural presumption of negative impact, there is a positive impact of check dams by way of sediment entrapment that results in reduced sediment loading into the reservoir associated with protection of live storage. Understandably, the manual or mechanical removal of reservoir sediments is a difficult proposition, whereas check dam induced sediment deposits are amenable to easy removal by people participation and can be utilized for soil conditioning.

The comprehension of the above mentioned aspects in the research agenda makes this study more important.