MASTER PLAN FOR ARTIFICIAL RECHARGE TO GROUND WATER IN INDIA

1.0 INTRODUCTION

The rapid expansion in development of ground water resources for varied usage has contributed in expansion of irrigated agriculture, overall economic development and in improving the quality of life in India. Last three decades have seen an exponential growth in number of ground water structures and more than 17 million wells all over the country are providing irrigation water to more than 50% of irrigated area. The substantial proportion of agricultural output is from ground water irrigation due to higher yields in ground water irrigated areas. This resource has become an important source of drinking water and food security for teeming millions of the country. It provides 80 percent of water for domestic use in rural areas and about 50 percent of water for urban and industrial areas. The significant contribution made for Green Revolution and also as primary reliable source of irrigation during drought years has further strengthened the people's faith in utilisation of ground water as dependable source.

The speedy and uncontrolled usage of ground water has also created many problems. The intensive ground water development in many parts of the country has resulted in depletion of ground water levels and availability of the resource. The pristine ground water quality too became its victim. Though, for the country as a whole the availability of ground water resources appears quite comfortable but localised areas have shown the deleterious effects of excessive ground water development. The sustainability of the ground water resources in such areas has assumed criticality and its capability to meet the basic needs for economic development in its present status is being looked as doubtful.

Proliferation in ground water withdrawal has resulted in development related issues. The numbers of critical and over-exploited blocks have increased from 253 to 383 between 1984-85 and 1992-93. Ground water quality in coastal area has also been affected due to excessive ground water development. The development of ground water resource in such areas therefore need to be regulated and augmented through suitable measures to provide sustainability. The National Water Policy 1987 enunciates development and implementation of ground water recharge projects for augmenting the available supplies. It also envisages integrated and coordinated development of surface and ground water. Over-exploitation of ground water needs to be avoided near the coast to prevent ingress of sea water into fresh water aquifers. As such the ground water reservoir needs suitable management efforts for its protection and augmentation.

1.1 CONSTITUTION OF GROUP

Realising the necessity and urgency to provide sustainability to ground water resources in the critical areas of the country, the Chairman, Central Ground Water Board constituted a group to prepare a Master Plan for Artificial Recharge to Ground Water for different States and Union Territories of the country. Harnessing of monsoon runoff through artificial recharge techniques would be one of the thrust areas in coming years in management of ground water resources. The necessity of such a plan, which would serve as a planning and implentation document to the State Government can not therefore be underestimated.

The following members constituted the group :

1. Dr. S.K.Sharma, Member (SAM)
2. Dr. Saleem Romani, Regional Director, NCR, Bhopal
3. Shri Santosh Kumar Sharma, Regional Director, CR, Nagpur
4. Shri M.Mehta, Regional Director, NWHR, Jammu

The group members held meeting to discuss the various issues related to preparation of Master Plan and prepared a format for eliciting desired information from different States. The Regional Directors of CGWB were requested to send the details on the various aspects of artificial recharge. The data made available by the Regional offices were utilised in preparing the Master Plan for Artificial Recharge. S/Shri S. K. Jain and S. Bhattacharya, Scientist 'C' assisted the group in compilation the Master Plan.

2..0 NATIONAL SCENARIO OF GROUND WATER

2.1 HYDROGEOLOGICAL SET UP

India is a vast country with varied hydrogeological situations resulting from diversified geological, climatological and topographic set up. The rock formations, ranging in age from Archaean to Recent, which control occurrence and movement of ground water, widely vary in composition and structure. Physiography varies from rugged mountainous terrains of Himalayas, Eastern and Western Ghats and Deccan Plateau to the flat alluvial plains of the river valleys and coastal tracts, and the Aeolian deserts in western part. Similarly rainfall pattern also shows region wise variations.

The following categories have been evolved to describe the ground water characteristics of various rock types occurring in the country. The proper understanding of the characteristics of rock types help in location and design of artificial recharge structures.

1. Porous rock formations
   - (a) Unconsolidated formations.
   - (b) Semi-consolidated formations
2. Hard rock/ consolidated formations

2.1.1 POROUS ROCK FORMATIONS

2.1.1.1 Unconsolidated Formations: The sediments comprising newer alluvium, older alluvium and coastal alluvium are by and large the important repositories of ground water. These are essentially comprises of clay, sand, gravel and boulders, ferruginous nodules, kankar (calcareous concretions), etc. The beds of sand and gravel and their admixtures form potential aquifers. The aquifer materials vary in particle size, rounding and in their degree of assortion. Consequently, their water yielding capabilities vary considerably. The coastal aquifers show wide variation in the water quality both laterally and vertically.

The piedmont zone of the Himalayas is extending from Jammu and Kashmir in the west to Tripura in the east, offers suitable locations for artificial recharge. The hydrogeological conditions and ground water regime in Indo-Ganga-Brahmaputra basin indicate the existence of large quantities of fresh ground water at least down to 600 m or more below land surface. Bestowed with high rainfall and good recharge conditions, the ground water gets replenished every year in these zones. The alluvial aquifers to the explored depth of 600 m have transmissivity values from 250 to 4000 m^2/day and hydraulic conductivity from 10 to 800 m/day. The well yields range upto 1000 litres per second (lps), but yields of 40-100 lps are common.

2.1.1.2 Semi-consolidated Formations: The semi-consolidated formations are mainly comprises of shales, sandstones and limestones. The sedimentary deposits belonging to Gondwana and Tertiary formations are also included under this category. The sandstones form highly potential aquifers locally, particularly in Peninsular India. Elsewhere they have only moderate potential and at places they yield meagre supplies. These sediments normally occur at narrow valleys or structurally faulted basins. Though these formations have been identified to possess moderate potential, the physiography of the terrain, normally restricts its development. Under favourable situations, these sediments give rise to artesian conditions as in parts of Godavari Valley, Cambay basin and parts of West Coast, Pondicherry and Neyveli in Tamil Nadu. Potential semi-consolidated aquifers particularly those belonging to Gondwanas and Tertiaries have transmissivity values from 100 to 2300 m^2/day and the hydraulic conductivity from 0.5 to 70 m/day. Generally the well yields in productive areas range from 10 to 50 lps. Lathi and Nagaur sandstone in Rajasthan and Tipam sandstone in Tripura state also form productive aquifers.

2.1.2 HARD ROCK FORMATIONS:

2.1.2.1 Consolidated Formations: The consolidated formations occupy almost two thirds of the country. From the hydrogeological point of view, the consolidated rocks are broadly classified into the following three types :

a) Igneous and metamorphic rocks excluding volcanic and carbonate rocks

b) Volcanic rocks

c) Carbonate rocks

These formations, occupying two third of the area of the country, control the ground water availability and scope for augmentation and artificial recharge. The nature, occurrence and movement of ground water in these formations are described as follows:

2.1.2.2 Igneous and Metamorphic Rocks (excluding volcanic and carbonate rocks): The most common rock types are granites, gneisses, charnockites, khondalites, quartzites, schist and associated phyllite, slate, etc. These rocks possess negligible primary porosity but are rendered porous and permeable due to secondary porosity by fracturing and weathering.

Ground water yield and the capability to accept recharge also depends on rock types. Granite and gneiss are better repositories than Charnockite. The ground water studies carried out in the crystalline hard rocks reveal the existence, of lineaments alone of deeply weathered and fractured zones, locally forming potential aquifers. These lineament zones are found to be highly productive for construction of borewells. These in turn offer good scope for recharge through suitable techniques.

In areas underlain by hard crystalline and meta-sedimentaries viz; granite, gneiss, schist, phyllite, quartzite, charnockite, etc., occurrence of ground water in the fracture system has been identified down to a depth of 100 m and even upto 200 m locally. In most of the granite/ gneiss area, the weathered residium serves as an effective ground water repository. It has been observed that the fracture systems are generally hydraulically connected with the overlying weathered saturated residium. The yield potential of the crystalline and meta-sedimentary aquifers show wide variations. Bore wells tapping the fracture systems generally yield from less than 1 lps to 10 lps. The transmissivity values of the fractured rock aquifers vary from 10 to 500 m^2/day and the hydraulic conductivity varies from 0.1 to 10 m/day.

2.1.2.3 Volcanic Rocks: The basaltic lava flows are mostly horizontal to gently dipping. Ground water occurrence in them is controlled by the contrasting water bearing properties of different lava flows. The topography, nature and extent of weathering, jointing and fracture pattern, thickness and depth of occurrence of vesicular basalts are the important factors which play a major role in the occurrence and movement of ground water in these rocks. Basalts or Deccan Traps usually have medium to low permeabilities depending on the presence of primary and secondary porosity. Pumping tests have shown that under favourable conditions, bore wells yield about 3 to 6 lps at moderate drawdowns. Transmissivity values of these aquifers are generally in the range of 25 to 100 m^2/day and the hydraulic conductivity varies from 0.05 to 15 m/day.

2.1.2.4 Carbonate rocks: Carbonate rocks include limestone, marble and dolomite. Among the carbonate rocks, limestones occur extensively. In the carbonate rocks, solution cavities lead to widely contrasting permeability within short distances. Potential limestone aquifers are found to occur in Rajasthan and Peninsular India in which the yields range from 5 to 25 lps. Large springs exist in the Himalayan Region in the limestone formations.

The distribution and potential of the major hydrogeological units are presented in Table-1 and Fig.-1.

Table1: Distribution Of Hydrogeological Units in the Country and their Potential

Geologic Age		Rock Formation	States/Hydrogeological Characters
CONSOLIDATED FORMATIONS:			
Jurassic/ Upper cretaceous to Eocene	Rajmahal Traps, Deccan Traps	Basalts, Dolerites Diorites and other acidic derivaties of Basaltic magma	Occur in West Bengal, Bihar, Madhya Pradesh, Gujarat, Maharashtra, Andhra Pradsh, Karnataka. Hydrogeological characteristics almost same as above. Fractured and Vesicular basaltic layers and inter-trappean sedimentaries are productive. Yield upto 5 lps, Storativity: 1 to 4%. Hydraulic conductivity 5 to 15 m/day. Unconfined shallow aquifers and leaky confined/ confined deeper aquifers.

Pre-Cambrian	Cuddapahs Delhi & Equivalent Systems	Consolidated Sandstones Shales, Conglomerates. Limestones, Dolomites Quartzites, Marbles Intrusive Granites & Malani Volcanics.	Occur in all States. These formations are devoid of primary porosity. Weathering & denudation, structural weak planes and fractures impart porosity and permeability in the rock mass. Solution cavities (caverns) in carbonate rocks at places, give rise to large ground water storage / circulation. The ground water circulation is generally limited within 100 m depth. Storativity value of unconfined aquifer is generally low (0.2% to 3%). Hydraulic conductivity varies widely depending on fracture incidence (2 to 10 m/day). Leaky confined / confined aquifers may be present in layered formations. Granites and granite-gneisses are the most productive aquifers. Yield range 2 to 10 lps and more.
SEMI – CONSOLIDATED FORMATIONS			
Tertiary		Nummulitic Shales and Limestones Carbonaceous Shales Sandstones Shales Conglomerates Ferrugineous Sanstones Calcareous Sandstones Pebble Beds and Boulder-Conglomerate Sands Clays	The Hydrogeological potential of these formations is relevant only in the valley areas. Lower Siwaliks and their equivalents in Himachal Pradesh, Jammu & Kashmir, Assam, Punjab, Haryana, Uttar Pradesh, Sikkim generally do not form potential aquifers. The Upper Siwaliks have moderate ground water potential in suitable topographic locations. Tertiary sandstones of Rajasthan, Gujarat, Kutch, Kerala, Orissa, Tamil Nadu, Andhra Pradesh, West Bengal and North Eastern States have moderate to moderately good yield potential upto 28 lps. Possess moderate primary porosity and hydraulic conductivity.
Upper Carboniferous to Jurassic	Gondwana Jurrasic of Kutch and Rajasthan Baghbeds Lametas and Equivalents	Boulder-Pebble Beds Sandstones Shales Coal Seams Sandstones Calcareous Sandstone Shales Quartzites Limestones.	Occur in Bihar, Maharashtra, Andhra Pradesh, Orissa, Madhya Pradesh, Gujarat, Rajasthan and Tamil Nadu. These formations do not have wide regional distribution, possess moderate primary porosity and hydraulic conductivity. Karstified limestones are good water yielders. Friable sandstones in Barakars and Kamthis (Lower Gondwana) and their equivalent formations possess moderately good potential. Yield upto 14 lps.
UNCONSOLIDATED FORMATIONS:			
Pleistocene to Recent	Fluvio-glacial deposits Glacio-lacustrine deposits.	Mixed Boulders, Cobbles, Sands and Silts. Conglomerates, Sands Gravels, Carbonaceous shales and blue Clays. Boulders, Cobbles, Pebble beds, Gravels, Sands, Silt	The morainic deposits occupy valleys and gorges in interior Himalayas. Karewas (Kashmir Valley) are lacustrine deposits displaying cyclic layers of clayey, silty and coarser deposits with intervening boulder beds. Locally

	Piedmont and Himalayan Foot Hill deposits.	and Clays.	significant hydrogeological potential. The Bhabhar piedmont belt contains many productive boulder – cobble – gravel – sand aquifers. The water table is deep. Forms recharge zone for deeper aquifers of alluvial plains in south. Tarai belt is down-slope continuation of Bhabhar aquifers. The deeper confined aquifers display flowing artesian conditions. Shallow water table yields upto 28 lps.
	Alluvial Plains (Older & Newer Alluvium)	Clays & Silts, Gravels and Sands of different mix. Lenses of Peat & Organic matter, Carbonate and Siliceous Concretions (Kankar).	Occur widespread in the Indo-Ganga-Brahmaputra alluvial plains. Form the most potential ground water reservoirs with a thick sequence of sandy aquifers down to great depths. The unconfined sand aquifers sometimes extend down to moderate depth (125 m). Deeper aquifers are leaky-confined / confined. The older alluvium is relatively compact. The unconfined aquifers generally show high Storativity (5 to 25%) and high Transmissivity (500 to 3,000 m^2 / day). The deeper confined aquifers generally occuring below 200 to 300 m depth have low Storativity (0.005 to 0.005) and Transmissivity (300 to 1000 m^3 / day). Highly productive aquifers yield upto 67 lps and above. The potentials of peninsular river, alluvium are rather moderate with yield upto 14 lps. But the alluvial valley fill deposits of Narmada, Tapi, Purna basins, 100 m thick, sustain yield upt 28 lps. The quality of ground water at deeper level is inferior. Storativity (4×10^{-6} to 1.6×10^{-2}) and Transmissivity 100 to 1,000 m^2 / day). Thick alluvial sequences in deltas of major rivers on the eastern coast and in Gujarat estuarine tracts have & hydrogeological potential limited by salinity hazards.
	Aeolian deposits	Fine to very fine sand and silt.	The aeolian deposits occuring in West Rajasthan, Gujarat, Haryana, Delhi, Punjab have moderate to high yield potentials; are well sorted and permeable; lie in arid region; natural recharge is poor and water table is deep.

2.2 GROUND WATER QUALITY

The ground water in most of the areas in the country is fresh. Brackish ground water occurs in the arid zones of Rajasthan, close to coastal tracts in Saurashtra and Kutch, and in some zones in the east coast and certain parts of Punjab, Haryana, Western Uttar Pradesh, etc., which are under extensive surface water irrigation. The fluoride levels in the ground water are considerably higher than the permissible limit in vast areas of Andhra Pradesh, Haryana and Rajasthan and in some parts of Punjab, Uttar Pradesh, M.P, Karnataka and Tamil Nadu. In the north-eastern regions, ground water with iron content above the desirable limit occurs widely. Pollution due to human and animal wastes and fertilizer application have resulted in high levels of nitrate and potassium in ground water in some parts of the country. Ground water contamination in pockets of industrial zones is observed in localised areas. The over-exploitation of the coastal aquifers in the Saurashtra and Kutch regions of Gujarat has resulted in salinisation of coastal aquifers. The excessive ground water withdrawal near the city of Chennai has led to seawater intrusion into coastal aquifers.The artificial recharge techniques can be utilised in improving the quality of ground water and to maintain the delicate fresh water-salt water interface.

2.3 GROUND WATER RESOURCE POTENTIAL

The total annual replenishable ground water resource is about 43 million-hectare metres (Mham). After making a provision of 7 Mham for domestic, industrial and other uses, the available ground water resource for irrigation is 36 Mham, of which the utilisable quantity is 32.6 Mham.The stage of ground water development for the country as a whole, works out to be 37%. The utilisable irrigation potential has been estimated as 64 million hectares (Mha) based on crop water requirement and availability of cultivable land. Out of this, the potential from natural rainfall recharge is 50.8 Mha and augmentation from irrigation canal systems is 13.2 Mha. The irrigation potential created from ground water in the country till 1993 is estimated as 35.4 Mha. State wise ground water resource potential is given in Table-2.

Inspite of the national scenario on the availability of ground water being favourable, there are pockets in certain areas in the country that face scarcity of water. This is because the ground water development over different parts of the country is not uniform, being quite intensive in some areas resulting in over-exploitation leading to fall in water levels and even salinity ingress in coastal areas. The declining water levels have resulted in failure of wells or deepening of extraction structures leading to additional burden on the farmers.

Table 2: Ground Water Resource of India [As on 01.04.98]

Sl. No.	States & Union Territories	Total Replenishable Ground Water Resource	Provision for Domestic Industrial & Other uses	Available Ground Water Resource for Irrigation in Net terms	Utilizable Ground Water Resource for Irrigation in Net terms	Gross Draft Estimated on Prorata basis	Net Draft	Balance Ground Water Resource for future use in net terms	Level of Ground Water Develop-ment
		MHaM/Yr	MHaM/Yr	MHaM/Yr	MHaM/Yr	MHaM/Yr	MHaM/Yr	MHaM/Yr	[%]
	States								
1	Andhra Pradesh	3.52909	0.52936	2.99973	2.69975	1.11863	0.78304	2.21668	26.10
2	Arunachal Pradesh	0.14385	0.02158	0.12227	0.11005	-	-	0.12227	-
3	Assam	2.24786	0.33718	1.91068	1.71962	0.20356	0.14249	1.76819	7.46
4	Bihar	2.69796	0.4047	2.29327	2.06394	1.17895	0.82527	1.46800	35.99
5	Chattisgarh	1.60705	0.24106	1.36599	1.22939	0.10925	0.07647	1.28952	5.60
6	Goa	0.02182	0.00327	0.01855	0.01669	0.00219	0.00154	0.01701	8.30
7	Gujarat	2.03767	0.30566	1.73199	1.55881	1.21895	0.85327	0.87872	49.27
8	Haryana	1.11794	0.16769	0.95025	0.85523	1.02637	0.71846	0.23179	75.61
9	Himachal Pradesh	0.02926	0.00439	0.02487	0.02238	0.00591	0.00413	0.02073	16.63
10	Jammu & Kashmir	0.44257	0.06640	0.37620	0.33860	0.00586	0.00403	0.37217	1.07
11	Jharkhand	0.66045	0.09907	0.56138	0.50525	0.17352	0.12146	0.43992	21.64
12	Karnataka	1.61750	0.24186	1.37564	1.23665	0.64973	0.45481	0.92083	33.06
13	Kerala	0.79003	0.13135	0.65869	0.59281	0.17887	0.12509	0.53360	18.99
14	Madhya Pradesh	3.48186	0.52228	2.95958	2.66362	1.05494	0.73846	2.22112	24.95
15	Maharashtra	3.78677	1.23973	2.54704	2.29233	1.26243	0.8837	1.66334	34.70
16	Manipur	0.31540	0.04730	0.26810	0.24129	Neg.	Neg.	0.26810	Neg.
17	Meghalaya	0.05397	0.00810	0.04587	0.04128	0.00260	0.00182	0.04405	Neg.
18	Mizoram	Not Assessed							
19	Nagaland	0.07240	0.01090	0.06150	0.05535	Neg.	Neg.	0.06150	Neg.
20	Orissa	2.01287	0.30193	1.71094	1.53984	0.37196	0.26037	1.45057	15.22
21	Punjab	1.81923	0.18192	1.63730	1.47357	2.30028	1.61020	0.02710	98.34
22	Rajasthan	1.26021	0.19977	1.06044	0.95440	1.10350	0.77245	0.28799	72.84
23	Sikkim	Not Assessed							
24	Tamil Nadu	2.64069	0.39610	2.24458	2.02013	2.00569	1.40398	0.84060	62.55
25	Tripura	0.06634	0.00995	0.05639	0.05075	0.02692	0.01885	0.03754	33.43
26	Uttar Pradesh	8.25459	1.23819	7.01640	6.31476	4.25171	2.97619	4.04021	42.42
27	Uttaranchal	0.28411	0.04262	0.24149	0.21734	0.09776	0.06843	0.17306	28.34
28	West Bengal	2.30914	0.34637	1.96277	1.76649	0.9025	0.63175	1.33102	32.19

	Total States	43.30063	7.09873	36.20191	32.58033	19.25207	13.47627	22.72564	37.23
	Union Territories								
1	Andaman & Nicobar	Not Assessed							
2	Chandigarh	0.00297	0.00044	0.00252	0.00227	0.00351	0.00245	0.00007	-
3	Dadar & Nagar Haveli	0.00422	0.00063	0.00359	0.00323	0.00065	0.00046	0.00313	12.81
4	Daman	0.00071	0.00011	0.00060	0.00054	0.00069	0.00048	0.00012	80.00
5	Diu	0.00037	0.00006	0.00031	0.00028	0.00042	0.00029	0.00002	94.84
6	NCT Delhi	0.02916	0.01939	0.00977	0.00879	0.01684	0.01180	-0.00203	120.78
7	Lakshdweep	0.03042	0.00456	0.00195	0.00176	0.00109	0.00076	0.00119	39.12
8	Pondicherry	0.01746	0.00262	0.01484	0.01335	0.01645	0.01152	0.00332	77.63
	Total Uts	0.08530	0.02782	0.03358	0.03022	0.03966	0.02777	0.00581	
	Grand Total	**43.38593**	**7.12655**	**36.25938**	**32.63345**	**19.29173**	**13.50404**	**22.73145**	**37.24**

Out of 4272 blocks in the country (except Andhra Pradesh, Gujarat and Maharashtra where ground water resource assessment has been carried out on the basis of mandals, talukas and watersheds respectively), 231 blocks have been categorised as “Over-exploited” where the stage of ground water development exceeds the annual replenishable limit and 107 blocks are “Dark” where the stage of ground water development is more than 85%. Besides, 6 mandals have been categorised as “Over-exploited” and 24 as “Dark” out of 1104 mandals in Andhra Pradesh. Similarly out of 184 talukas in Gujarat, 12 are “Over-exploited” and 14 are “Dark” and out of 1503 watersheds in Maharashtra, 34 are “Dark”.These areas face ground water scarcity and need further augmentation through suitable artificial recharge techniques.

2.4 GROUND WATER DEVELOPMENT SCENARIO

During the past four decades, there has been a phenomenal increase in the growth of ground water abstraction structures due to implementation of technically viable schemes for development of the resource, backed by liberal funding from institutional finance agencies, improvement in availability of electric power and diesel, good quality seeds, fertilizers, government subsidies, etc. During the period 1951-92, the number of dugwells increased from 3.86 million to 10.12 million, that of shallow tubewells from 3000 to 5.38 million and public bore/ tubewells from negligible to 68,000. The number of electric pump sets has increased from negligible to 9.34 million and the diesel pump sets from 66,000 to about 4.59 million. There has been a steady increase in the area irrigated from ground water from 6.5 Mha in 1951 to 41.99 Mha in 1997. During VIII Plan, 1.71 million dugwells, 1.67 million shallow tubewells and 11,400 deep tubewells are added. Similarly number of electric pump sets and diesel pump sets is expected to rise by 2.02 million and 0.42 million respectively.

Such a magnitude of ground water development with sub optimal planning has resulted in creating deleterious effects in terms of ground water depletion and quality deterioration. The combination of these challenges emerging in different parts of country need a suitable ground water management approach. Augmentation and artificial recharge to ground water reservoir offers a positive approach to overcome the problems of ground water scarcity. The preparation of Master Plan for Artificial Recharge is an effort in this direction.

3.0 CONCEPT OF ARTIFICIAL RECHARGE TO GROUND WATER

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

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

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

To improve the quality of existing ground water through dilution.

The basic purpose of artificial recharge of ground water is to restore supplies from aquifers depleted due to excessive ground water development. Desaturated aquifer offer good scope and locations in which source water if available can be stored using artificial recharge techniques.

3.1 GROUND WATER RESERVOIRS

The rivers and rivulets of the Indian sub continent are mainly monsoon fed with 80 to 90 percent runoff generated during the monsoon. The principle source for ground water recharge is also monsoon precipitation. The country receives more than 75% monsoon rainfall from June to September except in the eastern coast. Annually the rainy days vary from 12 to 100, and actual rainfall time varies from a few hours to over 300 hours. Incidences of upto 60 percent annual rainfall within a few days duration are not uncommon, which cause excessive runoff, taking a heavy toll of life, agriculture and property. Harnessing of excess monsoon runoff to create additional ground water storage will not only increase the availability of water to meet the growing demand but also help in controlling damages from floods.

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

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

The structures required for recharging ground water reservoirs are of small dimensions and cost effective such as check dams, percolation tanks, surface spreading basins, pits, sub-surface dykes, etc. and these can be constructed with local knowhow.

3.2 BASIC REQUIREMENTS

The basic requirements for recharging the ground water reservoir are:

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

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

3.2.1 SOURCE WATER AVAILABILITY

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

3.2.2 HYDROGEOLOGICAL ASPECTS

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

The evaluation of the storage potential of sub-surface reservoirs is invariably based on the knowledge of dimensional data of reservoir rock, which includes their thickness and lateral extent. The availability of sub-surface storage space and its replenishment capacity further govern the extent of recharge. The hydrogeological situation in each area needs to be appraised with a view to assess the recharge capabilities of the underlying hydrogeological formations. The unsaturated thickness of rock formations, occurring beyond three metres below ground level should be considered to assess the requirement of water to build up the sub-surface storage by saturating the entire thickness of the vadose Zone to 3 metre below ground level. The upper 3 m of the unsaturated zone is not considered for recharging, since it may cause adverse environmental impact e.g. water logging, soil salinity, etc. The post-monsoon depth to water level represents a situation of minimum thickness of vadose zone available for recharge which can be considered vis-à-vis surplus monsoon run off in the area.

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

3.3 NATIONAL PERSPECTIVE PLAN

The Central Ground Water Board in 1996 prepared a National Perspective Plan for utilisation of surplus monsoon run off for augmentation of ground water resources. This plan was a broad policy frame of the artificial recharge schemes for implementation in the country. The plan envisaged in situ conservation of surplus monsoon run off through artificial ground water recharge techniques.

The salient features of National Perspective Plan are :

The surplus monsoon run off available for creation of sub surface ground water storage in twenty river basins of the country has been estimated as 87.19 million hectare metres.

Saturating the vadose zone to 3 metres depth below ground level will create sub surface storage potential of 59.06 M.Ham. Of this, the retrievable storage potential works out to be 43.65 M.Ham. The availability of monsoon run off is, however, not uniform in all the basins, resulting in surplus and deficit of monsoon run off vis-à-vis the water required to recharge the vadose zone.Hence, the above potential is further modifed.

On the basis of availability of monsoon run off and storage potential of vadose zone the feasible ground water storage has been estimated as 21.42 M.Ham. of which 16.05 M.Ham. can be utilised. The creation of additional sub surface storage may bring substantial areas under irrigation.

The sub surface storages created would be free from environmental hazards and interstate controversies, since the surface structures created for recharge would be of small dimensions and would be with in the basin/ watershed.

The creation of sub surface storage will help (i) in equitable distribution of water resources, especially in the water scarcity hilly areas, since the augmentation of ground water resources will commence from the first order streams, (ii) in ensuring sustainability of existing ground water abstraction system for major parts of the year due to extended recharge period of 3 to 4 months, thereby mitigating drinking water scarcity in problematic villages and (iii) in mitigating hazards of flash floods, soil erosion, and silting of major reservoirs or river channels, thereby increasing the lift of the reservoirs, as also navigability of the river channels.

4.0 NEED FOR ARTIFICIAL RECHARGE TO GROUND WATER

Artificial Recharge is the process by which the ground water reservoir is augmented at a rate exceeding that under natural conditions of replenishment. Any man made scheme or facility that adds water to an aquifer may be considered to be an artificial recharge system.

Natural replenishment of ground water reservoir is slow and is unable to keep pace with the excessive continued exploitation of ground water resources in various parts of the country. This has resulted in declining ground water levels and depleted ground water resources in some areas of the country. In order to augment the natural supply of ground water, artificial recharge of ground water has become an important and frontal management strategy in the country. The artificial recharge efforts are basically augmentation of natural movement of surface water into ground water reservoir through suitable civil structures. The artificial recharge techniques interrelate and integrate the source water to ground water reservoir and are dependent on the hydrogeological situation of the area.

The rainfall occurrence in India is limited to about three months period ranging from around 10 to 100 days. The natural recharge to ground water reservoir is restricted to this period only. The artificial recharge techniques aim at increasing the recharge period in the post-monsoon season for about 3 more months providing additional recharge. This results in providing sustainability to ground water development during the lean season.

In arid areas of the country rainfall varies between 150 and 600 mm/year with even less than 10 rainy days. Majority of the rain occurs in 3 to 5 major storms lasting only a few hours. The rates of potential evapo-transpiration (PET) are exceptionally high in these areas which range from 300 to 1300 mm. The average annual PET is much higher than the rainfall and at times as high as ten times the rainfall. The entire annual water resource planning has to be done by conserving the rainfall by either storing on surface or in sub-surface reservoir. The climatic features are not favourable for creating surface storage. Artificial recharge techniques have to be adopted which help in diverting most of the surface storage to ground water storage within shortest possible time.

In hilly areas, even though the rainfall is high the scarcity of water is felt in the post-monsoon season. Due to the steep gradients, major quantity of water flows in the low lying areas as surface run-off. Springs which are the major source of water in hilly areas are also depleted during the post monsoon period. There is thus a need to provide sustainability to these springs. In hilly areas, rain water harnessing is needed for providing sustainable yield to springs. This can done by increasing the recharge period during and after rainy season. Small surface storages above the spring level would provide additional recharge and would result in sustainable yield to springs.

Roof top rain water harnessing can also be adopted to meet domestic water requirements. The roof top rain water can be stored in specifically constructed surface or sub-surface tanks. Most of the urban areas face water scarcity. Dependence on ground water has increased many fold and the natural recharge to ground water has decreased, due to urbanization, construction of buildings and paved area. The over-development of ground water is resulting in decline of ground water levels and to counter this artificial recharge has to be adopted. In urban areas water falling on roof tops can be collected and diverted to the open wells/ tubewells/ borewells by providing a filter bed.

There is thus a need to prepare a systematic implention plan for augmenting ground water resources under various hydrogeological situations. The National Perspestive Plan prepared by CGWB provides an overview of the possibilites for storing surplus monsoon run-off in sub-surface reservoirs in major basins of the country. This covered all the areas to saturate vadose zone upto 3 m depth b.g.l. based on available surplus monsoon run-off. However specific emphasis needs to be given in the areas where ground water levels are declining and water scarcity is being felt. Keeping this need in view an attempt has been made, to prepare a master plan for each state where artificial recharge can be taken up in identifed water scarcity areas. In this plan emphasis has been given to the areas with declining and deep ground water levels. The plan also includes roof top rain water harvesting in Urban and rural areas.

5.0 METHODOLOGY FOR PREPARATION OF THE MASTER PLAN

The plan for artificial recharge has been prepared considering the hydrogeological parameters and hydrological data base. The following aspects were considered for preparation of the plan :

Identification and prioritization of need based areas for artificial recharge to ground water.

Estimation of sub surface storage space and quantity of water needed to saturate the unsaturated zone (to 3 mbgl)

Quantification of surface water requirement and surplus annual run off availability as source water for artificial recharge in each sub basin/watershed.

Areas of poor chemical quality of ground water and scope of improvement by suitable recharge measures.

Working out design of suitable recharge structures, their numbers, type, storage capacity and efficiency considering the estimated storage space and available source water for recharge.

Cost estimates of artificial recharge structures required to be constructed in identified areas.

5.1 DATA PREPARATION

Depth to water table map for post monsoon period based on decadal average of depth to ground water levels was prepared with contour intervals of 3 metres. The data of ground water levels was taken from National Hydrograph Network Stations of CGWB. Similarly a long term (decadal) post monsoon water level trend map was prepared. This map brought out the ranges of water level rise and fall on long term basis. These two maps were superimposed to bring out depth to water table variations alongwith the trends of water levels over the last decade.

5.2 IDENTIFICATION OF FEASIBLE AREAS

The area feasible for artificial recharge have been demarcated into four categories as follows in most of the states:

Areas showing water levels between 3 and 6 mbgl and declining trend of more than 10 cm/year.

Area showing water levels between 6-9 mbgl and declining more than 10 cm/year.

Water levels between 6 and 9 mbgl and declining trend of more than 10 cm/year

Water levels more than 9 mbgl.

However, in few states, the categorisation of area was done to suit the local situations depending upon data availability and specific ground conditions. The areas of above categories were demarcated and identified as feasible areas for planning and implementation of artificial recharge to ground water. Based on the severity of decline of ground water levels and ground water scarcity situation, priortisation for implementation of plan was decided. The availability of funds needed for the implementation, surveys, investigations, preparation of design and cost estimates for the structures, capability of the implementing agencies, land acquisition in case of scheme involving submergence etc. are some of the important aspects which need to be considered for implementation of the plan.

5.3 ESTIMATION OF AVAILABLE STORAGE SPACE

The thickness of available unsaturated zone (below 3 mbgl) of the 4 categories described earlier is estimated by considering the different ranges of water level. The different range of DTW at 3 m interval are averaged to arrive at thickness of unsaturated zone. The total volume of unsaturated strata is calculated by considering the above categories and unsaturated thickness of different ranges. This volume was then multiplied by average specific yield on an area specific basis to arrive at volume of water required to saturate the aquifer to 3 mbgl.

5.4 SOURCE WATER REQUIREMENT

After assessing the volume of water required for saturating the Vadose zone, the actual requirement of source water is to be estimated. Based on the experience gained in the pilot/experimental projects implemented in different hydrogeological situations , an average recharge efficiency of 75% of the individual structure is considered. The volume of source water required for artificial recharge was calculated by multiplying a factor of 1.33 (i.e. reciprocal of 0.75). In few cases different values are taken depending upon the regional scenario prevailing thereupon.

5.5 SOURCE WATER AVAILABILITY

The surface water resources available in various basins and sub basins utilised for preparation of plan were based on information mostly provided by State Government. In few cases information from other Government Agencies were considered. The data availablity for source water availability for each sub basin includes committed run off, provision for future planning and surplus water available. The availability of source water per annum was worked out by adding the amount of surface water provided for future planning and surplus available. This availability so worked out is for the entire sub basin and not exclusively for the requirement of the areas identified for artificial recharge. The source water availability for areas identified for artificial recharge was apportioned from total water availability in the basin.

5.6 CAPACITY OF RECHARGE STRUCTURES

The capacity of recharge structurs was worked out based on the findings of various artificial recharge studies under taken in different States and the same was used for planning the recharge structures.

Maximum storage capacity (single filling) and gross capacity due to multiple fillings during rainy season were taken into consideration for designing percolation tanks, cement plugs, check dams and other surface storage structures.

5.7 NUMBER OF RECHARGE STRUCTURES

The numbers of recharge structures required to store and recharge the ground water reservoir have been worked out as follows: -

$$\textbf{No. of Structures} = \frac{\textbf{Total Surface Water Considered}}{\textbf{Average Gross Capacity of Water Spreading Recharge Structures (Considering Multiple Fillings)}}$$

The type and design of different types of structures like percolation tanks, check dams, recharge shafts etc. in a particular block/watershed would be guided by prevailing hydrogeological situation, existing density and number of structures, land availability etc. The planning of type and design of proposed structures should accordingly be decided. The allocation of source water for recharge through specific type of artificial recharge structures should be done considering these aspects.

6.0 DESIGN OF ARTIFICIAL RECHARGE STRUCTURES

A wide spectrum of techniques are in vogue which are being implemented to recharge the ground water reservoir. Similar to the variations in hydrogeological framework, the artificial recharge techniques feasible too, would vary accordingly. The artificial recharge structures, which are feasible in varied hydrogeological situation, are described as follows:

6.1 PERCOLATION TANKS

Percolation tank is an artificially created surface water body, submerging in its reservoir a highly permeable land areas, so that the surface run off is made to percolate and recharge the ground water storage. In areas where land is available in and around the stream channel section, a small tank is created by means of an earthen dams across the stream. The tank can also be located adjacent to the stream The percolation tank should have adequate catchment area.. The hydrogeological condition of site for percolation tank is of utmost importance. The rocks coming under submergence area should have high permeability. The degree and extent of weathering of rocks should be uniform and not just localised.

The percolation tank should be located down stream of run off zone, preferably towards the edge of piedmont zone or in the upper part of transition zone (Land slope between 3 to 5%). The aquifer zone getting recharged should extend down stream into the benefited area where adequate number of ground water structures should be available to fully utilise the additional recharge.

The purpose of percolation tank is to conserve the surface run off and divert the maximum possible surface water to the ground water storage. Thus the water accumulated in the tank after monsoon should percolate at the earliest, without much evaporation losses. Normally a percolation tank should not retain water beyond February.

The size of a percolation tank should be governed by the percolation capacity of the strata in the tank bed rather than yield of the catchment. For, in case the percolation rate is not adequate, the impounded water is locked up and wasted more through evaporation losses, thus depriving the down stream area of the valuable resource.

These are the most prevalent structures in India as a measure to recharge the groundwater reservoir both in alluvial as well as hard rock formations (Photo-1). The efficacy and feasibility of these structures is more in hard rock formation where the rocks are highly fractured and weathered. In the States of Maharashtra, Andhra Pradesh, Madhya Pradesh, Karnataka and Gujarat, the percolation tanks have been constructed in plenty in basaltic lava flows and crystalline rocks. The percolation tanks are, however, also feasible in mountain fronts occupied by talus scree deposits. These are found to be very effective in Satpura Mountain front area in Maharashtra. The percolation tanks can also be constructed in the Bhabar zone. Percolation tanks with wells and shafts can also be constructed in areas where shallow or superficial formations are highly impermeable or clayey.

6.1.1 IMPORTANT ASPECTS OF PERCOLATION TANKS

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

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

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

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

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

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

The benefited area should have sufficient number of wells and cultivable land to develop the recharged water.

Detailed hydrological studies for run off assessment be done and designed capacity should not normally be more than 50 percent of total quantum of rain fall in catchment.

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

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

To avoid erosion of embankment due to ripple action stone pitching be provided upstream upto highest flood level (HFL).

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

6.2 CHECK DAM/ CEMENT PLUG/ NALA BUND

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

A series of small bunds or weirs are made across selected nala sections such that the flow of surface water in the stream channel is impeded and water is retained on pervious soil/ rock surface for longer period Nala-Bunds are constructed across bigger nalas or second order streams in areas having gentler slopes. A nala bund acts like a mini percolation tank with water storage confined to stream course.

6.2.1 SITE CHARACTERISTIC AND DESIGN GUIDELINES

For selecting a site for Check Dams/ Nala Bunds the following aspects may be observed :

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

The rain fall in the catchment should be less than 1000 mm/annum.

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

The lands down stream of Check Dam/ Bund should have land under well irrigation.

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

6.3 GABION STRUCTURE

This is a kind of check dam being commonly constructed across small stream to conserve stream flows with practically no submergence beyond stream course. The boulders locally available are stored in a steel wire (Photo-3). This is put up across the stream to make a small dam by anchoring it to the streamside. The height of such structures is around 0.5 m and is normally used in the streams with width of about 10 to 15 m. The excess water overflows this structure leaving some storage water to serve as source of recharge. The silt content of stream water is deposited in the interstices of the boulders in due course to make it more impermeable. These structures are common in the states of Maharashtra, Madhya Pradesh, Andhra Pradesh, etc.

6.4 MODIFICATION OF VILLAGE TANKS AS RECHARGE STRUCTURE

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

6.5 DUG WELL RECHARGE

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

6.6 RECHARGE SHAFTS

In areas where phreatic aquifer is overlain by poorly permeable strata, the recharge to ground water storage by water spreading method becomes ineffective or have very low efficiency. This situation also occur in ponds/depressions where due to siltation an impermeable layer or lens is formed which affects hydraulic connection of surface water and phreatic aquifers. Recharge shaft is an artificial recharge structure which penetrates the overlying impervious horizon and provides affective access of surface water for recharging the phreatic aquifer. These structures are ideally suited for areas with deep water levels. In areas where low permeable sandy horizon is within shallow depths, a trench can be excavated to 3 m depth and back filled with boulder and gravel. The trench can be provided with injection well to effectively recharge the deeper aquifers.

6.6.1 SITE CHARACTERISTIC AND DESIGN GUIDELINES

The following are site characteristics and design guidelines:

To be dug manually if the strata is of non-caving nature.

If the strata is caving, proper permeable lining should be provided.

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

In the areas where source water is having silt, the shaft should be filled with boulder, gravel and sand from bottom to have inverted filter. The upper most sandy layer has to be removed and cleaned periodically.

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

6.7 INJECTION WELL

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

In alluvial areas injection well recharging a single aquifer or multiple aquifers can be constructed in a fashion similar to normal gravel packed pumping well. (Photo-5).The only difference is that cement sealing of the upper section of the well is done in order to prevent the injection pressures from forcing leakage of water through the annular space of borehole and well assembly. In hard rock areas casing and well screens may not be required. An injection pipe with opening against the aquifer to be recharged may be sufficient. However, in case of number of permeable horizons separated by impervious rocks, a properly designed injection well may be constructed with slotted pipe against the aquifer to be recharged. In practice the injection rates are limited by the physical characteristics of the aquifer. In the vicinity of well, the speed of ground water flow may increase to the point that the aquifer is eroded, specially if it is made up of unconsolidated or semi-consolidated rocks. In confined aquifer confining layers may fail if too great pressure is created under them. If this occurs, the aquifer will become clogged in the vicinity of the borehole and/or may collapse.

6.8 GROUND WATER DAMS OR SUB SURFACE DYKES OR UNDERGROUND BANDHARAS (UGB)

These are basically ground water conservation structures and are effective to provide sustainability to ground water structures by arresting sub surface flow. (Photo-6) A ground water dam is a sub surface barrier across stream which retards the natural ground water flow of the system and stores water below ground surface to meet the demands during the period of need . The main purpose of ground water dam is to arrest the flow of ground water out of the sub-basin and increase the storage within the aquifer. By doing so the water levels in upstream part of ground water dam rises saturating the otherwise dry part of aquifer.

The underground dam has following advantages: -

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

No evaporation loss from the reservoir takes place.

No siltation in the reservoir takes place.

The potential disaster like collapse of dams can be avoided.

6.9 ROOF TOP RAIN WATER HARVESTING

In Urban areas, the roof top rain water can be conserved and used for recharge of ground water (Photo-7). This approach requires connecting the outlet pipes from roof top to divert the water to either existing wells/ tubewells/ borewell or specially designed wells. The urban housing complexes or institutional buildings have large roof area and can be utilised for harvesting roof top rain water.

7.0 MONITORING MECHANISM

The monitoring of water levels and water quality is of prime importance in any scheme of artificial recharge to ground water. The monitoring data speaks for the efficacy of structures constructed for artificial recharge and greatly helps in taking effective measures for ground water management on scientific lines. As such the plan for artificial recharge should have the monitoring mechanism inbuilt with the scheme.

7.1 WATER LEVEL MONITORING

The monitoring of surface water and ground water levels during feasibility studies greatly help in identifying the method of artificial recharge. Network of observation wells is used to study the ground water flow pattern and temporal changes in potentiometric head in the aquifer.

The observation well network during feasibility stage is generally of low density, spread over a large area with the primary aim of defining the boundary zonation of the aquifer to be recharged and to know the hydraulic characteristics of the natural ground water system. After identification of the feasible ground water structures, the observation well network is redefined in a smaller area with greater well density. The objective of monitoring system is to study the effect of artificial recharge on the natural ground water system. Depending on the method of artificial recharge and the hydrogeology of the area, the observation well network has to be designed. The monitoring system of observation well network should be designed specially to monitor impact of individual structures which can further be extended and dovetailed to monitor the impact of group of such structures in the artificial recharge scheme area. The network of observation wells should be (a) adjacent to the recharge facility (b) at a sufficient distance from the recharge facility to observe composite effects and (c) near the limit of hydrological boundaries. If the recharged aquifer is overlain by confining/ semi-confining layer, piezometers should be installed to monitor the water levels of overlying and underlying aquifers which helps in the study of leakages etc. Where the surface water bodies are hydraulically connected with the ground water aquifers which is being recharged, it is advisable to monitor the water level profiles of both surface water and ground water.

The periodic monitoring of water levels can demarcate the zone of benefit. In this method a network of observation wells is established in the area likely to be benefitted to study the following :

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

Wells situated outside the zone of influence normally show an angular apex for the period when the recharge is taking place, while those situated within the zone of influence have a flatter area.

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

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

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

The above criteria can be used to define the zone of influence and thereby, a real and temporal demarcation of the effectiveness of recharge structures.

7.2 TRACER TECHNIQUE FOR DEMARCATING ZONE OF BENEFIT

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

7.3 WATER QUALITY MONITORING

The monitoring of water quality during the implementation of artificial recharge schemes is essential to maintain the quality standards for specified uses of the augmented resource. In case of injection wells the composition of native water in the aquifer and the recharged water is important to prevent clogging of well and aquifer due to excessive precipitation of salts. The data on the chemical quality of native water and the changes which take place during the artificial recharge schemes should be collected by regular sampling from observation well network. Where treated wastewater is used for recharge a careful monitoring is required to detect and preclude any possibility of contamination through a network of monitoring wells. Thus, the type of water quality monitoring programme depends on the specific problem being studied i.e. changes in ground water quality; effect of soil salination, and prevention of any contamination etc. The samples to be collected will also depend on the purpose and are generally categorised into

(1) Indicative

(2) Basic, and

(3) Comprehensive.

The indicative samples are collected at 1 to 4 months intervals and used to ascertain the presence of injected effluent. Basic samples are taken at monthly intervals for wells already influenced by recharge to determine the effect of recharge effluent on ground water quality and the purification provided by flow through the soil and aquifer system. Comprehensive samples are taken at intervals of 6 months to 1 year for observation wells to determine water quality with respect to specific standards for intended water use.

7.4 IMPACT ASSESSMENT

The impact assessment of artificial recharge schemes can generally be enumerated as follows: -

Conservation and harvesting of surplus monsoon run off in ground water reservoir which otherwise was going un-utilised outside the watershed/ basin and to sea.

Rise in ground water levels due to additional recharge to ground water. In case where continuous decline of ground water level was taking place, a check to this and/or the intensity of decline subsequently reduces. The energy consumption for lifting the water also reduces.

The ground water structures in the benefitted zone of artificial structures gains sustainability and the wells provides water in lean month when these were going dry. The domestic wells will become sustainable and many of the areas dependant on water supply through tankers are benefitted.

The cropping pattern in the benefitted zone will undergo marked change due to additionality of ground water and cash crops will start growing. Orchards which went dry earlier due to ground water scarcity may rehabilitate and new plantation may grow.

Green vegetation cover may increase in the zone of benefit and also along the structures due to additional availability of soil moisture.

The quality of ground water may improve due to dilution.

Besides, the direct measurable impacts, the artificial recharge schemes will generate indirect benefit in terms of decrease in soil erosion, improvement in fauna and flora, influx of migratory birds, etc. Besides, the social and economic status of farmers of benefitted zone will also substantially improve due to increase in crop production.

8.0 STATE WISE MASTER PLAN FOR ARTIFICIAL RECHARGE

8.1 ANDHRA PRADESH

Andhra Pradesh, covering an area of 275068 Sq. Km., covers 23 districts and 1123 mandals. The population of the State is 66,508,008 (1991 census). It has semiarid type of climate with a normal rainfall of 896 mm. The distribution of rainfall is highly variable from 1113 mm. in north and north eastern parts to 561 mm in south and south western parts of the state.

Andhra Pradesh State is drained by three major, ten medium and a large number of minor rivers. These river basins represent varied hydrogeological, rainfall and agroclimatic conditions. Because of the bigger size of the major basins they are further subdivided in to sub-basins. The plan for artificial recharge to ground water is prepared after considering various hydrogeological parameters, soils and hydrological database (Fig-2).

8.1.1 SOURCE WATER AVAILABILITY

The three major basins viz Godavari, Krishna and Pennar in Andhra Pradesh cover 72% of the total area. Krishna and Pennar basins have no surplus water for artificial recharge. In addition, the sub basins-Manjira, Middle Godavari. Manner and Lower Godavari of Godavari basin have also no surplus water. Pranhita, Sabari, Sarda, Yeluru, Gundalakamma and Swarnamukhi have surplus surface water. It has been assessed that 1095 MCM source water can be harnessed for recharge through suitable structures.

8.1.2 RECHARGE STRUCTURES AND COST ESTIMATES

From hydrogeological point of view, hard rocks underlie major part of the state. In hard rock areas surface water spread techniques like percolation tanks, cement plugs/bunds check dams, are most appropriate. Accordingly these structures are recommended for artificial recharge to ground water. Other structures like contour trenches, gabion structure, nala bunds etc. are more appropriate for soil and water conservation.

The number of recharge structures feasible in an area depends on the type of recharge structure and its gross storage capacity. The total volume of surface water available for artificial recharge to groundwater is estimated as 1095 MCM. Based on the hydrogeological situation, it has been considered that around 70% of the available water i.e. 760 MCM will be recharged through percolation tanks and the remaining i.e. 335 MCM by check dam. Based on the average storage capacity of the recharge structures 3800 percolation tanks and 11167 check dams are proposed in the areas which need artificial recharge. The exact locations of percolation tanks and check dams may be decided based on field investigation which include soil condition, catchment area, favourable location, hydrogeology etc.

Based on the estimates, the unit cost of construction of percolation tank with 100 thousand cubic metres (TCM) single filling capacity is around Rs. 20 lakhs and for check dam of 10 TCM single filling capacity is Rs 4.2 lakhs.

The total outlay is estimated to be about Rs.1229 crores for the artificial recharge structures in the state. The plan of artificial recharge to ground water by suitable recharge structures using surface water resources is given in Table-3.

Table-3 Feasibilty and Cost Estimates of Recharge Structures

S. No	Name of the Sub Basin	Volume of Surface Water for Artificial Recharge to Ground Water (MCM)	Resource to be harnessed by				Estimated cost of Structures Rs. in (Crores)	
			Percolation Tank		Cement Plug/ Check Dam		Percolation Tanks @ Rs. 20 lakhs	Cement Plugs/ Check Dam @ Rs.4.2 lakhs
			Volume (MCM)	Nos.	Volume (MCM)	Nos.		
1	G-9 Pranhita	468	300	1500	168	5600	300	235
	G-12 Sabari	144	100	500	44	1466	100	61
2	Sarada	42	30	150	12	400	30	17
3	Yeleru	197	150	750	47	1566	150	66
4	Gundlakamme	40	30	150	10	333	30	14
5	Swarnamukhi	204	150	750	54	1800	150	76
	Total	1095	760	3800	335	11167	760	469

Total cost Rs. 1229 crores

8.1.3 AREA BENEFITTED

The watershed development through artificial recharge is taken up basically from ridge to valley. The water that is retained in upper reaches is recharged through percolation tanks, check dams etc and will improve groundwater, reduce velocity of run off water and help in soil conservation. It is estimated that the recharge structures proposed in the plan will benifit around 3400 sq.km. of area. On completion of various artificial recharge structures it is anticipated that an additional area to the extent of 1,56,428 hectares could be brought under irrigation.

8.1.4. ROOFTOP RAIN WATER HARVESTING IN URBAN AREAS

There are 213 urban areas 264 towns and 32 cities. Out of 213 urban areas, 3 cities were declared as Municipal Corporations and 112 towns declared as Municipalities in Andhra Pradesh

The rain water harvested from roof tops in urban areas can be recharged through pipes into recharge pits. The available roof top area in urban area depends on the number of houses and their size. Since the data on size of the houses is not available hence an average roof size of 50sq.m has been considered in the computations.

Normal rainfall of urban area is taken for quantification of the roof top water. Depending upon number of houses, for different cities, their roof top areas, normal rainfall and the volume of water from roof top is assessed. The total roof top water availability works out to be 124.28 MCM for 32 cities.

Pits are dug away from the building foundation where the soil is more porous and permeable. The pits may be back filled with permeable material like pebble, gravel and sand for better percolation. It is estimated that 100 sq. m roof top area would be able to generate 6 cubic metre of water for recharge.

The construction cost per cubic metre volume of recharge water is estimated as Rs. 600/-. For 50 Sq. km roof top area generating 3 cubic metres of water, the cost per recharge structure would be around Rs. 1800/-. There are around 26 lakhs houses in 32 cities of Andhra Pradesh. The approximate cost of constructing recharge pit in a house would not be more than 0.5% of the total cost of the house. The cost of roof top rainwater harvesting would be around Rs. 468 crores for the entire state.

8.1.5 TOTAL COST

Total cost of the artificial recharge structures and rooftop rainwater harvesting would be Rs. 1697 crores for the state of Andhra Pradesh.

8.2 BIHAR AND JHARKHAND

The state of Bihar and Jharkhand cover an area of 1,73,877 sq.km.. As per the 1991 census, the population of Bihar including Jharkhand is 86.4 million. The average annual rainfall is 1231.6 mm. The state comprises of 3 major basins namely Ganga, Subarnarekha and South Koel.

8.2.1 IDENTIFICATION OF AREA

The identification of the area suitable for artificial recharge has been done on the basis of depth of mean post-monsoon water level. The areas where the average water level of last 10 years is more than 7 mbgl in post-monsoon period (November) has been considered suitable for artificial recharge. Suitable areas for artificial recharge were identified in 10 districts viz; Gaya, Jamui, East Singhbhum, West Singhbhum, Rohtas, Godda, Lohardaga, Ranchi, Bokaro and Gumla. Maximum area found feasible for recharge is in Rohtas and Bokaro districts. An area of 4082 sq.km. is found suitable for artificial recharge in the state (Fig-3 & Table – 4).

8.2.2 SUBSURFACE STORAGE AND WATER REQUIREMENT

The storage space for recharge has been assessed for the areas where the mean post monsoon water levels more than 7 meters bgl. The storage space available for artificial recharge is considered as a slice of unsaturated zone occurring 3 m below ground level and the mean post-monsoon depth to water level exceeding 7 m. The difference between 3 mbgl and average post monsoon depth to water level is then multiplied with the area to arrive at the volume of unsaturated zone possible for recharging. The district wise break up of the volume of the aquifer likely to be recharged was worked out for 10 need-based districts and the specific yield of rock formation has been utilised to arrive at the total volume of water required for saturating the phreatic aquifer. The gross volume of surface water required for artificial recharge is estimated on the basis of 75% efficiency of the artificial recharge structures (Table – 4).

8.2.3 SOURCE WATER AVAILABILITY

The basin wise surface water availability with 75% dependability has been taken from IInd Bihar State Irrigation Commission report. The total annual inflow with 75% dependability for the State is 339675.8 MCM. However, for preparation of this plan the overland flows generated within the state are considered. Out of the total resource, contribution from the catchment outside the state is 273323.8 MCM and contribution from the catchment within the state is 66352.00 MCM. The district wise distribution of surplus surface water resource generated within the ten identified districts is given in Table-4.

Table-4: Requirement of Surface Water Resources for Artificial Recharge to Ground Water in the Districts of Bihar & Jharkhand.

S.No.	Name of District	Area identified for Artificial Recharge (sq.km.)	Volume of water Required (MCM)	Surface Water required at 75% efficiency (MCM)	Total surplus runoff available (MCM)
1.	Gaya	294	207.24	275.63	195.67
2.	Jamui	594	101.31	134.74	991.46
3.	Rohtas	750	123.75	164.5	6.49
4.	Godda	250	41.25	54.86	482.63
5.	Lohardaga	200	33.00	43.89	395.64
6.	Ranchi	300	49.50	65.84	1769.85
7.	Bokaro	750	123.75	164.59	70.32
8.	East Singhbhum	344	63.81	84.87	860.48
9.	Gumla	100	16.50	21.94	3551.57
10.	West Singhbhum	500	82.5	109.7	2500.61
	Total	4082	842.61	1120.56	10824.72

8.2.4 RECHARGE STRUCTURES

For consideration of suitability of artificial recharge structures, the states have been divided into two broad groups (i) Hard rock area of south Bihar/Jharkhand (ii) The marginal alluvial area of central Bihar i.e. in Gaya district.

In hard rock areas the suitable artificial recharge structures are:

(i) Percolation Tank

(ii) Nala Bunding

In marginal alluvial areas the suitable artificial recharge structures are:

(i) Contour Bunding'

(ii) Recharge Shaft

(iii) Percolation Tank

Emphasis has been given on the renovation of old contour bunding (Ahar System) which is very common in the area. Such system is existing since long and occasional repairs are undertaken by the local farmers.

The volume of surface water considered for planning the artificial recharge is based on the surplus runoff availability and the space available for recharge. Based on the field situation it has been considered that 50% storage will be through percolation tanks and 50% through Nala bunding in hard rock areas. However, for marginal alluvial areas nala bunds are not suitable therefore 25% resources will be recharged through recharge shafts and percolation tanks respectively and 50% through contour bunding.

The percolation tank single filling capacity is 75 TCM. Considering 200% of multiple filling, the gross storage is 150 TCM. For Nala Bunding of 10 TCM capacity the actual storage will be 25 TCM based on 250% of multiple filling. The nala bunds should be concrete structures in lower order streams. The entire surface water diverted through recharge shaft is likely to be utilised for recharging. Contour Bunding has 50 TCM storage capacity and considering 150% multiple filling the gross storage capacity would be 75 TCM. The contour bunds are of 300 to 400 m length depending upon the local slope and availability of land.

Number of structures have been worked out at district level based on gross storage capacity of individual structure. The district wise number of different type of artificial recharge structures is given in Table-5.

Table-5 : Districtwise Feasibilty of Artificial Recharge Structures

a) Hard Rock Areas

S.No.	Name of District Considered	Volume of Surface Water for Artificial Recharge (MCM)	Artificial Recharge Structures			
			Percolation Tank		Nala Bunding	
			Total Volume of Water (MCM)	No.	Total Volume of Water (MCM)	No.
1.	Jamui	134.74	80.84	539	53.89	2156
2.	Rohtas	6.49	3.89	26	2.6	104
3.	Godda	54.86	32.91	219	21.94	878
4.	Lohardaga	43.89	26.33	175	17.56	702
5.	Ranchi	65.84	39.50	263	26.34	1054
6.	Bokaro	70.32	42.19	281	28.13	1125
7.	East Singhbhum	84.87	50.92	339	33.94	1358
8.	Gumla	21.94	13.16	88	7.78	351
9.	West Singhbhum	109.7	65.82	439	43.88	1755

b) Alluvial Areas

S. No	Name of District Considered	Volume of Surface Water for Artificial Recharge	Percolation Tank		Recharge Shaft		Contour Bunding	
			Total Volume of Water (MCM)	No.	Total Volume of Water (MCM)	No.	Total Volume of Water (MCM)	No.
1.	Gaya	195.67	48.9	326	48.9	1630	58.7 39.13	782 (Renovation) 521 (New)

The proposed plan envisages utilisation of total volume of 788.32 MCM surface water for recharge purpose through different structures as per following break up:

S. No.	Structure	Resource Proposed to be Utilised (MCM)	No. of Structures
1.	Percolation Tank	404.46	2695
2.	Nala Bunding	236.06	9483
3.	Contour Bunding	97.83	1303
4.	Recharge Shaft	48.9	1630

8.2.5 COST ESTIMATES

Based on experiences gained by CGWB, the cost of structures has been work out and given in Table – 6.

Table-6: Unit Cost of Structures

S. No.	Structure	Unit cost (Rs. in Lakhs)
1.	Percolation Tank	15.00
2.	Nala Bunding	1.66
3.	Recharge Shaft	2.00
4.	Contour Bunding	Renovation of old contour bunding Rs. 3.00 lakhs New contour bunding Rs. 5.00 lakhs

The district wise cost estimates for different types of structures are given in Table-7.

Table-7: Estimated Cost of Artificial Recharge Structures

S.No.	District	Percolation Tank (Rs. in Crores)	Nala Bunding (Rs. in Crores)	Recharge Shaft (Rs. in Crores)	Contour Bunding (Rs. in Crores)
1.	Gaya	48.90	-	32.60	1.Renovation of old Rs.23.46 crores 2.New system Rs.26.05 crores
2.	Jamui	80.85	35.79		
3.	Rohtas	3.89	1.73		
4.	Godda	32.85	14.57		
5.	Lohardaga	26.25	11.65		
6.	Ranchi	39.5	17.5		
7.	Bokaro	42.15	18.68		
8.	East Singhbhum	50.85	22.54		
9.	Gumla	13.16	5.83		
10.	West Singhbhum	65.85	29.13		
	TOTAL	404.25	157.42	32.60	49.51

Total Rs. 643.8 crores.

8.2.6 ROOFTOP RAINWATER HARVESTING IN URBAN AREAS

There is a great potential for roof top harvesting in urban areas of the states of Bihar and Jharkhand. All the district headquarters are considered for roof top rainwater harvesting and ground water augmentation. There are 22.28 lakh of houses in 42 districts headquarter as per 1991 census. 25 % of the houses are considered for rain water harvesting. An average roof area of 40 sq. m is taken for working out the total roof top area. 70% of normal monsoon rainfall of respective districts are considered. Accordingly a total 32.22 MCM rainwater will be harvested in the 42 cities of the states. The cost of roof top rainwater harvesting is estimated as 330 crores for 5.50 lakh buildings taking the unit cost as Rs.6000.00.

8.2.7 TOTAL COST

Total cost of the artificial recharge schemes and roof top rain water harvesting is Rs. 974 crores for the States of Bihar and Jharkhand.

8.3 CHHATTISGARH

Chhattisgarh, the newly formed State of India after bifurcation of Madhya Pradesh on 1st November, 2000, covers an area of 135000 Sq. km. The population of the state is 17.65 million (Census 1991) with density of population being 130 per Sq.km. The average annual rainfall of the state is 1356 mm. The state has 3 administratiave divisions, 16 districts, 96 tehsils and 146 development blocks. There are 19720 populated villages and 6 major cities in the state. About 59285.27 Sq.Km. area of the state is covered by forest. The agricultural land and irrigated land in the state is 5.8 million ha and 1.16 million ha respectively. The state comprises of Mahanadi and Godawari basins with small parts of Ganga, Narmada and Swarnarekha basins. These basins can be subdivided into 74 major watersheds 8 watersheds of Son and Narmada falling partly in the adjoining Madhya Pradesh state.

8.3.1 IDENTIFICATION OF AREA

Based on data of National Hydrograph Stations established by CGWB to monitor the fluctuation of groundwater levels in different hydrogeological situations, a trend analysis was carried out for the decade between 1989 and 1998. A total area of 11,706 Sq.km. in Chhattisgarh shows declining trend in ground water levels. 22 major watersheds have been identified in Chhattisgarh in which declining trend of more than 0.1 m/yr was recorded (Fig-4). These watersheds have been identified for construction of suitable artificial recharge structures for augmenting the available ground water resources.

8.3.2 SUB-SURFACE STORAGE SPACE AND WATER REQUIREMENT

To estimate the sub surface storage space available a map was prepared on the basis of average post monsoon depth to water level for period 1989-1998. The decadal post monsoon average depth to water level is predominantly in the range of 3 to 6 m below ground level. Based on this map the volume of unsaturated zone available for recharge (Vadose zone to 3 m below ground level) was calculated for each of the 22 identified watersheds. A total 19280 MCM volume of unsaturated zone was estimated for the Chhattisgarh state, which gives a sub-surface storage potential of 196.8 MCM based on the specific yield of the rock types in the watersheds. The requirement of water to fully saturate the vadose zone upto 3 m below ground level was worked out for each watershed at 75% efficiency considered for recharge structures. The total requirement of water for creating the sub-surface storage works out to 3261.74 MCM for the entire state.

8.3.3 SOURCE WATER AVAILABILITY

The availability of surplus monsoon runoff was estimated for 22 identified watersheds mainly on the basis of NWDA data and State Irrigation Department. The total availability of source water for recharge works out to 5106.46 MCM, which far exceeds the total requirement to create the sub-surface storage. However, for each watershed the requirement vis-a-vis the availability was seen and the least of the two was considered as available source water for harnessing in artificial recharge structures. The total quantum of source water which can be utilized for creation of sub-surface storage works out to 257.93 MCM for all the 22 identified watersheds (Table-8).

8.3.4. RECHARGE STRUCTURES AND COST ESTIMATES

The suitable artificial recharge structures in the state are gully plugs, gabion structures, contour bunds in the upper reaches of the watersheds, percolation tanks, nala bunds in the runoff zones and recharge shafts, gravity head wells in down stream areas. The main artificial recharge structures proposed are given below along with the estimated number of feasible structures and their cost.

a) Percolation Tanks

Percolation tank is the main artificial recharge structure proposed for effective utilisation of the surplus monsoon runoff. In hardrock areas only 50% of the total estimated surplus surface water resources have been considered for storage in the percolation tanks. As per the hydrogeological conditions in Chhattisgarh an average percolation tank has filling capacity of 0.1 MCM. It can actually store 200% of its capacity due to multiple filling during the monsoon. Thus an average gross storage capacity of 0.2 MCM has been considered. The average cost of such structure has been considered as Rs.20 lakh. The number of feasible percolation tank in each identified watershed has been calculated and presented in Table-8. The total percolation tanks feasible in Chhattisgarh are 648 costing Rs.64.8 Crores.

b) Nala Bunds

There is a large scope for constructing Nala bunds/Cement plugs in various second order streams of the state. About 25% of surplus monsoon runoff can be utilized by recharge through these structures. The average capacity of Nala bunds/Cement plugs has been considered as 0.01 MCM. The average cost of each structure has been taken as Rs.1 lakh. It is estimated that 2151 Nala bund/Cement plugs can be constructed in the state at the cost of 21.51 crores (Table-8).

c) Recharge Shafts & Gravity Head Recharge Wells

These structures are feasible in village and urban areas. About 10% of the surplus monsoon runoff can be utilized through these structures. The average recharage capacity through recharge shafts, gravity head recharge through dugwells during an operational period of 60 days in monsoon and post monsoon period is considered as 0.01 MCM. The average cost of structure may be taken as Rs.2.5 lacs. The number of structures and their cost for each identified watershed was calculated and presented in Table-8. For the entire state the feasible structures are 2582 costing Rs.64.55 crores.

d) Gully Plugs, Contour Bunds, Gabion Structures

These structures are mainly soil conservation structures and help in increasing the soil moisture with limited recharge to ground water. It is estimated that 15% of total water available for recharge can be utilized by these structures which have an average storage capacity of 0.005 MCM. The average cost of each structure is taken as Rs.10,000/-. The structures feasible in each identified watershed has been estimated and presented in Table-8. For entire state the feasible structures total up to 7740 costing 7.74 crores.

8.3.5 ROOF TOP RAIN WATER HARVESTING

There are 6 Standard Urban Areas in Chhattisgarh which cover an area of 200.54 Sq.km. with total number of houses around 203230. Due to scarcity of water individual houses in most of the urban areas have gone for construction of borewells/dugwells for sustainable water supply. However, this unplanned withdrawal of ground water has resulted in lowering of water levels and dwindling of yield/drying up of wells. The availability of roof top in urban areas is an attractive solution for collection of rain water during monsoons and recharging it to the ground water reservoir. An attempt has been made to study the feasibility of roof top rain water harvesting in urban areas of the state. Looking to the varied hydrogeological and other situations of space availability etc even if 25% of the houses with an average roof area of 50 Sq,metre are considered, a total roof area of 4.71 Sq.km. is available to collect the rainfall. Considering the average annual normal rainfall in each urban area the total volume of rain water which can be collected on roofs was worked out. Only 90% of this volume of rain water has been considered as available source water for recharging ground water. The total available water from roof top rain water harvesting works out to 3.07 MCM. The average expenditure on providing the necessary arrangements through pipe fittings, filter etc to divert the roof water to the existing groundwater structure (tubewell/dugwell) has been considered as Rs.10,000/- per house. The total cost for roof top rain water harvesting in 50,808 houses of the 6 cities of Chhattisgarh declared as standard Urban Areas works out to 50.8 crores.

8.3.6 COST ESTIMATES AND BENEFITS

The main artificial recharge structures in the 22 identified watersheds are percolation tanks, Nala bund/Cement plugs, Recharge shaft/gravity head recharge wells and water conservation structures like gully plug, contour bund and gabion structures. The total cost of these artificial recharge structures works out to 136.44 crores. For urban areas the roof top rain water harvesting in 6 major cities have been planned with a total cost of Rs.50.8 crores. The total cost estimations of the proposed Master Plan is 274.2 crores.

The benefits from the proposed plan would be in terms of creation of additional irrigation potential in rural areas and supplementing etc. drinking water needs in urban areas.

An additional irrigation potential of 0.038 million ha. would be created. In urban areas the roof top rain water harvesting will cater to the annual drinking water needs of additional 2.1 lakh population.

Table - 8. Feasibility of Different Artificial Recharge Structures and Cost Estimates in Chhatisgarh State

S. No	Basin	Sub - Basin	Name of Watershed and its Code	Volume of Surface Water to be Harnessed (MCM)	RESOURCES HARNESSED BY: Percolation Tanks (Capacity 0.2 MCM)	No.	Nala Bunding/ Cement Plug/ Check Dam (Capacity 0.03 MCM)	No.	Gravity Head / Dug Well/ Tube Well/ Recharge Shaft (Capacity 0.01 MCM)	No.	Gully Plugs/ Gabion Structures (Capacity 0.005 MCM)	No.	ESTIMATED COST (Rs. Lakhs): Percolation Tank @ Rs. 20 lakhs	Nala Bunding etc. @ Rs. 1 lakh	Recharge Shaft @ Rs. 2.5 lakhs	Gully Plugs/ Gabion Structures @ Rs. 1 lakh
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	GANGA	Son	Kunnai SO-9	6.83	3.42	17	1.71	57	0.68	68	1.02	205	340.00	57	170.00	20.50
SUB-TOTAL				6.83	3.42	17	1.71	57	0.68	68	1.02	205	340.00	57	170.00	20.50
2	MAHANADI	Mahanadi	Sandhur MH-1	2.26	1.13	6	0.57	19	0.23	23	0.34	68	120.00	19	57.50	6.80
3			Pairi MH-5	2.66	1.33	7	0.67	22	0.27	27	0.40	80	140.00	22	67.50	8.00
4			Beguni MH-6	3.99	2.00	10	1.00	33	0.40	40	0.60	120	200.00	33	100.00	12.00
SUB-TOTAL				8.91	4.46	23	2.23	74	0.90	90	1.34	268	460.00	74	225.00	26.80
5		Seonath	Tendula SE-2	5.98	2.99	15	1.50	50	0.60	60	0.90	179	300.00	50	150.00	17.90
6			Hamp SE-7	11.97	5.99	30	2.99	100	1.20	120	1.80	359	600.00	100	300.00	35.90
7			Agar SE-8	25.8	12.90	65	6.45	215	2.58	258	3.87	774	1300.00	215	645.00	77.40
8			Arpa SE-9	12.9	6.45	32	3.23	108	1.29	129	1.94	387	640.00	108	322.50	38.70
9			Kuranj SE-10	7.18	3.59	18	1.80	60	0.72	72	1.08	215	360.00	60	180.00	21.50
10			Kharun SE-13	9.58	4.79	24	2.40	80	0.96	96	1.44	287	480.00	80	240.00	28.70
11			Jamuni SE-15	12.24	6.12	31	3.06	102	1.22	122	1.84	367	620.00	102	305.00	36.70
SUB-TOTAL				85.65	42.83	215	21.41	715	8.57	857	12.85	2568	4300.00	715	2142.50	256.80
12		Mand	Sonkanwar MN-5	21.55	10.78	54	5.39	180	2.16	216	3.23	647	1080.00	180	540.00	64.70
13			Kutri MN-2	4.79	2.40	12	1.20	40	0.48	48	0.72	144	240.00	40	120.00	14.40
SUB-TOTAL				26.34	13.17	66	6.59	220	2.63	264	3.95	791	1320.00	220	660.00	79.10
14		Ib	Ib IB-1	4.79	2.40	12	1.20	40	0.48	48	0.72	144	240.00	40	120.00	14.40
15			Kharuna IB-3	17.56	8.78	44	4.39	146	1.76	176	2.63	527	880.00	146	440.00	52.70
SUB-TOTAL				22.35	11.18	56	5.59	186	2.24	224	3.35	671	1120.00	186	560.00	67.10

16		Indravati	Upper Indravati IN-1	18.09	9.05	45	4.52	151	1.81	181	2.71	543	900.00	151	452.50	54.30
17			Dantewara IN-3	13.96	6.98	35	3.49	116	1.40	140	2.09	419	700.00	116	350.00	41.90
18			Narang IN-7	11.97	5.99	30	2.99	100	1.20	120	1.80	359	600.00	100	300.00	35.90
19			Borada IN-8	16.62	8.31	42	4.16	139	1.66	166	2.49	499	840.00	139	415.00	49.90
20			Chargaon IN-12	19.95	9.98	50	4.99	166	2.00	200	2.99	599	1000.00	166	500.00	59.90
21			Kotri IN-13	12.63	6.32	32	3.16	105	1.26	126	1.89	379	640.00	105	315.00	37.90
SUB-TOTAL				93.22	46.61	234	23.31	777	9.33	933	13.98	2798	4680.00	777	2332.50	279.80
22		Sabri	Sabrikolab SA-2	14.63	7.32	37	3.66	122	1.46	146	2.19	439	740.00	122	365.00	43.90
SUB-TOTAL				14.63	7.32	37	3.66	122	1.46	146	27.97	439	740.00	122	365.00	43.90
	TOTAL			257.93	129.0	648	64.5	2151	26	2582	64	7740	12960.00	2151	6455.00	774.00
GRAND TOTAL Rs. 223.4 Crores																

8.4 DELHI (National Capital Territory)

National Capital Territory, Delhi occupies an area of 1485 Sq. Km. Out of this about 145 Sq. km is the ridge area comprising of weathered quartzite rock. The present population of Delhi is about 125 lakhs. Administratively, the state has 6 blocks namely Alipur block, City block, Mehrauli Block, Najafgarh block, Kanjhawala block & Shahdara block. In Alipur block, Kanjhawala block, Najafgarh block & part of Mehrauli block the area is cultivable. Due to increase in population, the water demand is increasing and ground water is also used for irrigating the cultivable land. Therefore due to overexploitation of groundwater resources the ground water levels have been declining especially in southern and south western parts.

8.4.1. IDENTIFCATION OF AREA

Feasible areas for artificial recharge to ground water have been identified on the basis of depth to water level (> 3 m.bgl) areas showing declining trend of water level and having surplus surface water availability. The area identified for artificial recharge to ground water is 692.9 Sq. Km in NCT Delhi (Fig-5).

8.4.2 SOURCE WATER AVAILABILITY

The average annual rain fall of the state is 611.8 mm, of which 533.1 mm occurs during monsoon period (June to September). Considering 30 % runoff coefficient in urban areas 12 % in other areas, the runoff availability for Delhi state is assessed as 162 MCM. The surplus monsoon runoff available from Yamuna is 282 MCM. Thus a total of 444 MCM surplus runoff is available for recharge to ground water. As the recharge areas are at higher elevations, the surplus water of Yamuna river can not be diverted under gravity to these areas. Hence only the available surface runoff from the recharge areas i.e. 70.45 MCM may be utilized for recharge to ground water.

8.4.3. RECHARGE STRUCTURES AND COST ESTIMATES

In southern & western part of Mehrauli block there are lot of quarries & depressions and many bunds have already been constructed. The available runoff about 4.45 MCM accumulates in these quarries, depressions & bunds and recharging the ground water. Thus the available surplus runoff for artificial recharge is only 66 MCM. Therefore there is very little scope for the construction of recharge structures for recharge to ground water due to non-availability of sufficient runoff. In other areas of Delhi state such as JNU, IIT, Sanjay Van, Vasant Kunj, Kushak nala area, Lodi Garden, Nehru Park, Talkatora Garden, Presidents Estate & Shram Shakti Bhawan etc. many artificial recharge structures have been constructed. The expected recharge from these recharge structures is 0.4 MCM. Therefore the net surplus runoff available from recharge areas is 65.6 MCM.

In order to harness the net available runoff, the following artificial recharge structures are given in Table-9 along with cost estimates.

Table-9: Feasible Recharge Structures and Cost-Estimates.

Sl. No	Recharge Scheme Proposed	No. of Structures	Storage / Recharge Capacity (MCM)	Unit Cost Rs.Lakhs	Estimated Cost (Rs. in Crores)	Feasible Area for Recharge
1.	Percolation tanks	23	0.69	3.5	0.81	Village ponds in Najafgarh, Kanjhawala & Alipur blocks
2.	Existing dug wells	23	0.07	0.4	0.09	Existing dug wells in villages
3.	Nala bunds	10	0.30	5.0	0.50	Limited scope, Delhi ridge area is feasible area.
4.	Lateral trench with recharge wells for harvesting runoff from storm water drains	19216	61.49	1.2	230.59	In urban areas
5.	Roof top rain water harvesting in institutional areas	2496	3.05	1.0	24.96	10 % of the roof area, especially institutional areas.
	Total	21768	65.6		256.95	

Total Cost is Rs. 257 Crore

8.5 GOA

Goa state is endowed with rich water resources with an annual rainfall of more than 3000 mm. The state is situated on the West Coast of India. The state is divided into two districts namely north and south Goa districts.

The hydrological and physiographic situations in the state do not permit large-scale surface and ground water storage on the surface and in the aquifers. Due to steep hydraulic gradient the dynamic ground water resources also gets depleted quickly during summer months. Hence, there is need to have water conservation structures to utilize the non-monsoon flow in streams and rivers.

8.5.1. IDENTIFICATION OF AREA

The hydrogeological framework in the state consists of both hard rock and alluvial aquifers. The former constitutes nearly 92% area of the state. The ground water extraction is through dug wells and bore wells. The laterites are the most prominent litho units in the state, which extend up to a depth of 30 m below ground level. The coastal alluvium has good primary porosity whose thickness extends upto a depth of 22 m with area width ranging from 40 m to 1.5 km at places along the coast. It is observed that the average depth to water level during pre and post monsoon periods during 1992 and 1999 in Goa state is more or less same with minor variations. Deeper water levels of more than 9 m bgl are observed during the pre monsoon period in parts of Tiswadi, Ponda, Sanguem and Canacona talukas. These pockets are situated in recharge areas, dissected plateaus and mountain slope. Deeper water levels during post monsoon periods are observed in ghats of Canacona Taluka.

In Goa state, implementation of any type of schemes with an orientation towards artificial recharge to ground water may be difficult because of the complex physiographic set up of the terrain. Deeper ground water levels are characteristic of plateau regions, where the source water is limited for recharge purposes. Such areas are capped with laterites. Ground water in laterites, when fully saturated seeps through the contact zone between the Laterite and the clay zone below and finally emerges into the streams making sub surface storage in the aquifer difficult. Water harnessing schemes are possible which can conserve non-monsoon base flow in the area. The flow in rivers and streams during non-monsoon period can be harnessed through suitable conservation structures.

8.5.2 SOURCE WATER AVAILABILITY

Surface runoff is available around 8811 MCM in Goa State annually and 529 MCM/year during non monsoon. The basin wise average rainfall, runoff and average annual run off is given in Table-10. A part of this run off is being harnessed through major and medium irrigation projects in the state and the rest of the resources join the sea during rainy season.

Table-10: Basin Wise Average Rainfall, Runoff for Goa State

S.No	Basin Name	Basin Area (Sq.Km)	Avg. Annual Rainfall (mm)	Runoff Co-efficient (%)	Avg. Annual Runoff in MCM	Non monsoon Run-off (MCM)
1	Terekhol	59	3314	70	136.87	8.21
2	Chapora	227	3140	70	498.95	29.94
3	Mandovi	1654	3673	70	4252.60	255.16
4	Zuari	937	3323	70	2179.56	130.77
5	Sail	286	2997	70	600.00	36.00
6	Saleni	135	3049	70	288.13	17.29
7	Talpona	240	3049	70	512.23	30.73
8	Guljibag	90	3049	70	192.09	11.53
9	Baga	73	2957	70	151.10	9.07
	Total	3701	3715	70	8811.53	529

Source: CWC, GOA.

8.5.3. RECHARGE STRUCTUTRES AND COST ESTIMATES

For Goa State, considering the physiographic and hydrogeologic set up, “Bandharas” and Kolhapur type weirs are ideal measures. They are suitable where ground water reservoir gets fully recharged during monsoon but suffers rapid depletion due to sub – surface leakage in the form of base flow, springs etc., during post – monsoon.

The construction of Bandharas or similar structures like sub – surface dykes can be taken up during fair weather season. Spacing of these structures depend upon the topography and upon cross – sectional area of streams / valleys. The feasible areas suggested for water conservation is shown in fig – 6. These structures can be taken up leaving the coastal plains of the State where the water table is shallow.

Cost estimate for water conservation structures are as follows:

Water available for conservation : 423 MCM (80% of 529 MCM)

Water, which can be conserved per

sturcture (Bandhara / K.T. Weir) : 0.3 MCM

No. of structures feasible : 1410

Unit cost per structure : Rs. 4.5 lakhs

Total cost : Rs. 6345 lakhs or say Rs. 63 crores.

8.5.4 ROOF TOP RAINWATER HARVESTING IN URBAN AREAS

In the state of Goa roof top rainwater harvesting possibilities are favourable. There are number of small and large private and institutional buildings in the state. The roof top rain water harvesting in around 10,000 buildings would be feasible @ Rs. 10,000/- per building with an average roof area of 60 sq m. The estimated cost for rooftop rain water harvesting in the state would be Rs.10 crores.

8.5.5 TOTAL COST

A total of Rs. 73 crores is estimated for ground water conservation and rain water harvesting in the state of Goa.

8.6 GUJARAT

The State of Gujarat located in western part of India has an area of 1.96,024 Sq.Km. with the longest coastline of 1600 km. There are 18,569 villages and 264 towns with a population of 41,309,582 (1991 census). The droughts are frequent in major part of Gujarat. The rainfall shows steep reduction from 2000 mm in extreme south (Dangs and Valsad districts) to 300 mm in Kachchh district. Gujarat has three distinct physiographic areas namely main land Gujarat, Saurashtra and Kachchh regions. Gujarat is covered by number of large and small river basins having varied nature. These basins represent varied and complex hydrogeological, agro-climatic and hydrological features.

8.6.1. IDENTIFICATION OF AREA

Based on the depth to water level data and long term trend of ground water level four categories were identified. A total of 64264 sq. km area has been identified for artificial recharge in 12 districts of the state (Table – 11). In other 12 districts storage space is available but the avaibility of surplus surface water for recharging to ground water is inadequate. The areas demarcated for artificial recharge are shown in the Fig-7.

8.6.2. SUB-SURFACE STORAGE SPACE AND WATER REQUIREMENT

The thickness of available unsaturated zone (below 3 m bgl) is estimated by considering different ranges of water levels in the identified areas. Average specific yield of formations vary between 2 and 10 per cent in the state. Storage space volume available in aquifers is 28422 MCM in Gujarat region, 1998 MCM in Saurashtra region and 12889 MCM in Kachchh region. Total sub surface storage potential is 61319 MCM in the state.

8.6.3. SOURCE WATER AVAILABILITY

Availability of source water for different basins has been worked out by State Government. Monsoon surface water availability has been computed considering 90% of water availability during monsoon out of annual run off during the year. Inter state allocation of river water as riparian right has not been considered in the calculations. To compute source water available for recharge, cummulative committed storage from the existing and proposed irrigation projects has been deducted from monsoon availability of surface water. The committed storage was computed by combining storage from major, medium and minor irrigation structures (existing, in progress and proposed) in the state after enhancing the same by 1.5 times for more than one filling. The source water availability has been further reduced by 10% for arriving at total source water availability for harvesting. Further, the availability of source water for artificial recharge is computed for the area identified for recharge. The total surplus water available for planning artificial recharge in the state is 1925 MCM/yr. (Table: 11). However, total surplus water proposed to be utilised for artificial recharge in Gujarat is only 1408 MCM/yr. in the areas identified for artificial recharge. In Gujarat region 714 MCM/yr. of water is available, and in Saurashtra region the availability is 694 MCM/yr. Though no surplus water is available in Kachchh region as per the present commitments of the state, the rain water harvesting needs to be practiced and intensified to harvest each drop of rainfall.

8.6.4. RECHARGE STRUCTURES AND COST ESTIMATES

For planning suitable artificial recharge structure, the areas have been grouped into three broad hydrogeological units, i.e., Alluvium, Hard Rock and Semi-consolidated formation. In hard rock areas with moderate relief, weirs/check dams are considered feasible, whereas, in plateau and plain areas occupied by hard rock, percolation tanks are considered appropriate. In semi-consolidated formation weirs/check dams are considered feasible. In the areas occupied by alluvium percolation tanks are considered appropriate. A percolation tank generally has a capacity of 0.09 MCM and receives three fillings in two years, hence, on an average 1.5 times capacity utilisation (0.140 MCM) has been considered on an annual basis. A weir/check dam of 0.017 MCM capacity will actually store 300% of its capacity due to multiple filling. Thus gross storage capacity of weir/check dam has been considered as 0.05 MCM/yr. The surplus water available for artificial recharge is proposed to be utilised by construction of appropriate structures feasible in different terrains. 692 MCM will be stored in percolation tanks and 661 MCM will be recharged through weir/check dams. To achieve this 4942 percolation tanks and 13210 weir/check dams would be required (Table – 11). Based on the experience gained from recharge studies in the past, it is observed that cost of structure depends upon local situation. For the present planning average cost of structure has been adopted from the guidelines laid down by Govt. of Gujarat. A percolation tank for about 0.09 MCM capacity may cost around Rs.10 Lakh. Similarly a weir/check dam may cost around Rs. 5 Lakh for 0.017 MCM/yr. storage. Thus the total cost of project is estimated to be Rs. 1155 crores for constructing percolation tanks (Rs. 494 crores) and weir/check dams (Rs. 661 crores) Table – 11.

8.6.5. ROOF TOP RAIN WATER HARVESTING IN URBAN AREAS

The urban centres in Gujarat State depend heavily on ground water for drinking water supplies. About 70% of drinking water needs are met from ground water sources and as a result are water table in urban centres has started receding at an alarming rate. The ground water reservoir and urgently requires augmentation.

The suitable method for artificial recharge in urban area is to arrest the rainwater from roof tops and store or recharge the same through injection wells/shafts. As per 1991 census 23 urban centres have been identified where the population exceeds 1 Lakh and about 96 Lakh people reside in these urban centres. There are about 18 Lakh households in such centres and considering about 25% houses are suitable for harvesting and considering 40 sq.m. as typical house hold roof top area the total area available for harvesting (90% of total roof top) has been estimated to be 162 Lakh sq m. The source water available for harvesting has been taken as 60% of normal rainfall in the urban centre after making allowance for storm rains etc., Thus the total source water available for harvesting has been estimated as 8.28 MCM/yr. The Average cost of making the roof top harvesting arrangements for storing it at surface and recharging to ground water is @ Rs. 10,000/- per house. Thus cost of roof top harvesting for 4.5 lakh houses of the state is estimated as Rs. 450 crores.

8.6.6. TOTAL COST

The total cost of artficial recharge structures and roof top rain water harvesting is estimated as Rs. 1605 crores for the state of Gujarat.

Table – 11: Artificial Recharge to Ground Water by Suitable Recharge Structures Using Surface Water Resources

S. No	River Basin	Basin No.	Catch ment in Gujarat	Volume of Surface Water for Artificial Recharge (MCM)	Proportionate Surplus Water Available (Non committed	Surface Water Proposed for Artificial Recharge to Ground Water	Sturctures Proposed				Estimated cost of Structures (Rs. in Lakh)		
							Percolation Tanks		Check Dams		Percolati on Tanks	Check Dams	Total
			Sq. km	MCM	MCM/yr	MCM/yr	Volume (MCM)	No.	Volume (MCM)	No.	Rs.	Rs.	Rs.
1	Rel	G-01	238	0	0.0	0.0	0	0	0	0	0	0	0
2	Banas	G-02	4383	4215.3	Nil	0.0	0	0		0	0	0	0
3	Saraswati	G-03	2282	3000.9	222.8	222.8	123	875	45	891	8750	4455	13205
4	Rupen	G-04	2662	707.1	23.6	23.6	21	152	2	47	1520	235	1755
5	Sabarmati	G-05	18495	5310.4	88.5	88.5	80	569	9	177	5690	885	6575
6	Mahi	G-06	8357	381.0	Nil	0.0	0	0	0	0	0	0	0
7	Dhadar	G-07	4201	7263.9	244.1	244.1	220	1569	24	488	15690	2440	18130
8	Narmada	G-08	1564	6016.4	Nil	0.0	0	0	0	0	0	0	0
9	Kim	G-09	1330	0.0	0.0	0.0	0	0	0	0	0	0	0
10	Tapi	G-10	2189	1391.7	Nil	0.0	0	0	0	0	0	0	0
11	Mundhola	G-11	1518	0.0	0.0	0.0	0	0	0	0	0	0	0
12	Purna	G-12	2281	32.0	185.4	32.0	10	69	22	448	690	2240	2930
13	Ambika	G-13	2675	0.0	0.0	0.0	0	0	0	0	0	0	0
14	Auranga	G-14	699	71.1	131.1	71.1	21	152	50	995	1520	4975	6495
15	Par	G-15	907	32.5	330.8	32.5	10	70	23	455	700	2275	2975
16	Kotak	G-16	584	0.0	0.0	0.0	0	0	0	0	0	0	0
17	Damangang	G-17	1000	0.0	0.0	0.0	0	0	0	0	0	0	0
	Total Gujarat Region		55365	28422.4	1231.2	714.6	484	3456	175	3501	34560	17505	52065

	Saurashtra												
1	Shetrunji	S-42	5571	3353.1	193.8	193.8	58	415	136	2714	4150	13570	17720
2	Bhadar	S-64	7076	1769.1				0		0	0	0	
3	South	S-43, S-63	10234	154.3	37.2	37.2	11	80	26	520	800	2600	3400
4	Northwest	S-01, S-15 & S-65, S-68	7794	51.0	32.6	32.6	10	70	23	456	700	2280	2980
5	N&Northeast	0	13259	9792.9	207.8	207.8	62	445	145	2909	4450	14545	18995
6	East	S-31, S-41	5002	4877.1	222.2	222.2	67	476	156	3110	4760	15550	20310
	Total Saurashtra		48936	19997.6	693.6	693.6	208	1486	485	9709	14860	48545	63405
1	Kachchh	K-1, K-97	11663	12888.6									
	Total State	0	115964	61308.7	1924.7	1408.2	692	4942	661	13210	49420	66050	115470

8.7 HARYANA

Haryana state is located in the north western part of India. It has an areal extent of 44212 sq.km. and forms 1.35 % of the geographical area of the country. The state has been divided in four administrative divisions, 17 districts and 55 tehsils. There are 6988 villages and 94 towns in the state. The total population of the state was 164.44 lakhs (1991) Around 97% of the state area is plain and is known as Indo-Gangetic plain. The state forms the part of Ganga & Indus basin. The normal annual rainfall varies from more 1000 mm in the north east to less than 300 mm in the south west. In the south western parts of the state, drought is a common feature.

8.7.1. IDENTIFICATION OF AREA

Based on the post monsoon depth to water level and long term ground water level trends, four categories of areas have been identified and demarcated on the map (Fig-8). These areas have been divided into three sub basins viz., Yamuna, Ghaggar and internal sub – basins. A total of 16120 sq.km area identified in these three sub – basins of the state for artficial recharge

8.7.2. SUB-SURFACE STORAGE SPACE AND WATER REQUIREMENT

The total volume of unsaturated strata is calculated by considering different categories of unsaturated thickness of different range. This volume is multiplied by average specific yield to arrive at the amount of water required which is to be recharged by artificial methods to saturate the aquifer to 3 m bgl (Table 12). Sub surface storage potential of the state is estimated as 16310 MCM in three sub basins. Maximum storage space is available in sub basins of internal drainages.

8.7.3. SOURCE WATER AVAILABILITY

The amount of surface water considered for artificial recharge is 684.50 MCM. The average annual intake capacity of one recharge structure is around 0.0 43 MCM. Therefore total number of structure required to recharge 684.50 MCM will be 15928. The district wise and sub basin wise number of structures are given in Table 13.

8.7.4. RECHARGE STRUCTURE AND COST ESTIMATE

The main recharge structure suitable in the state are recharge shaft, horizontal trench with injection wells percolation tank and cement plug. The average cost of a, recharge structure to recharge 0.043 MCM water will be around Rs. 1.00 lakh. The total cost of 15928 recharge structures required to recharge will be around Rs. 15928 lakh. The districtwise and sub basin wise number of structures feasible and cost estimates are given in Table 13.

8.7.5. AREA BENEFITTED

It is estimated that influence of recharge schemes as proposed will be observed in about 16,000 sq.km. and it will not only check decline in water level but rise of water level upto 0.5 m per year is expected.

In Haryana state almost entire cultivable area in northern and eastern parts is under irrigation by surface or ground water. The area falling in southern and south western parts have less irrigation facility. The additional recharge to ground water will bring about 1,37,000 ha. of additional area under assured irrigation . Taking the average of Rs.10, 000 per hectare as additional benefit due to assured irrigation, the additional annual benefit would be around Rs. 13700 lakhs

8.7.6. ROOF TOP RAIN WATER HARVESTING IN URBAN AREAS

In Haryana State there are 96 urban agglomerations classified as towns. The total area of the towns is 1052 sq.km. and have population of 4,054744 persons as per 1991 census. The total number of houses in urban area are around 6,90,000. If 50 sq.m. is considered to be roof top area of one house , the total roof top area in the State is 34.50 sq.km. The total rain water available from roof top is 15.28 MCM during monsoon period and 3.04 MCM during non-monsoon period. The total availability of water per year is about 18.32 MCM. If 10% of this lost is evaporation etc. 16.49 MCM of water is available for recharge. To harvest the roof top rain water in urban areas it is proposed to construct one recharge structure for a group of four houses. The total number of structures required to harvest roof top rain water will be 1.7 lacs. The average cost for one recharge structure will be about Rs.10,000/-.

Thus the total cost to harvest 16.49 MCM of roof top rain water will be around Rs. 170 Crores.

Artificial Recharge from Sewage Water

Besides rainfall, ample scope exists to recharge treated sewage water, which is disposed away from the town without any purposeful gain. At present, in majority of the towns sewage water is subjected to primary treatment only. In certain towns, the sewage water is subjected to secondary treatment. This secondary treated water can also be used as source for artificial recharge after assessing the suitability of chemical quality. The towns where treated sewage water is available are Panipat, Karnal, Faridabad, Yamunanagar, Gurgaon Sonepat etc. The total capacity of the plants installed for treatment in these towns is 0.325 MCM per day. Therefore, total treated water availability per year is 118.6 MCM. To recharge this water around 300 recharge structures will be required. The total cost of these structures will be 300 lacs at the cost of Rs. 1 lac per structure. Besides this, there are about 48 urban agglomeration which are located in the area suitable for artificial recharge. The total population of these towns is around 13 lacs. The sewage generated from these towns is around 45.5 MCM annually. The sewage in these towns is subjected to primary treatment only, which is not suitable for artificial recharge. If sewage in these towns is given secondary treatment, it may be utilized for artificial recharge in proximity of the towns.

8.7.7. TOTAL COST

The cost of taking up artificial recharge in rural and urban areas is 332 Crores.

TABLE: 12 Requirement and Availability of Surface Water Resources for Artificial Recharge to Ground Water in Major Sub Basins of Haryana

S.No.	Sub Basin/ District YAMUNA	Area Identified for Artificial Recharge (sq.km.)	Sub Surface Storage Potential (MCM)	Surface Water Requirement (MCM)	Proportionate Non committed Water Resources Available as (surplus /kept for future planning) (MCM)
1.	Faridabad	1150	923	1240	28.29
2.	Gurgaon	935	723	967	23.00
3.	Jind	300	105	140	7.38
4.	Panipat	695	242	321	17.10
5.	Kaithal	195	123	163	4.80
6.	Karnal	1230	432	574	30.26
7.	Kurukshetra	305	96	127	7.50
8.	Yamunanagar	65	68	90	1.60
9.	Rohtak	225	54	71	5.54
10.	Sonipat	700	147	195	17.22
	Sub-Total	5800	2914	3876	142.7
	Internal Drainage				
1.	Gurgaon	480	420	559	21.57
2.	Rewari	1205	2205	2933	54.15
3.	Bhiwani	1390	2445	3252	62.46
4.	Rohtak	420	266	354	18.87
5.	Jind	280	158	210	12.58
6.	Hissar	315	242	321	14.16
7.	Mahendragarh	1520	3226	4290	68.31
8.	Kaithal	20	4	5	0.90
	Sub total	5630	8966	11924	253.0
	Ghaggar				
1.	Sirsa	895	970	1290	55.11
2.	Hissar	1210	1202	1599	74.51
3.	Jind	290	124	165	17.86
4.	Kaithal	1295	1030	1370	79.74
5.	Kurukshetra	675	857	1140	41.57
6.	Ambala	195	106	142	12.01
7.	Panchkula	130	139	185	8.01
	Sub total	4690	4430	5892	288.8
	Grand total	16120	16310	21692	684.5

TABLE 13 : Artificial Recharge to Groundwater by Suitable Recharge Structures Using Surface Water

S.No.	Name of Sub basin	Name of Sub Basin / District	Surface Water Considered for A.R. to Ground water(MCM)	Resoures to be harnessed by Recharge Shaft intake capacity(10 LPS for 50 days)(MCM)	No.of Structures	Estimated Cost in Rs. lakhs @ 1.0 lakh per Structure (in lakhs)
	Ganga	Yamuna				
1.		Faridabad	28.29	0.043	658	658
2.		Gurgaon	23.00	“	535	535
3.		Jind	7.38	“	172	172
4.		Panipat	17.10	“	398	398
5.		Kaithal	4.80	“	112	112
6.		Karnal	30.26	“	704	704
7.		Kurukshetra	7.50	“	175	175
8.		Yamunanagar	1.60	“	37	37
9.		Rohtak	5.54	“	129	129
10.		Sonipat	17.22	“	401	401
		Sub total	142.7		3321	3321
	Ganga	Internal				
1.		Gurgaon	21.57	“	502	502
2.		Rewari	54.15	“	1260	1260
3.		Bhiwani	62.46	“	1453	1453
4.		Rohtak	18.87	“	439	439
5.		Jind	12.58	“	293	293
6.		Hissar	14.16	“	330	330
7.		Mahendragarh	68.31	“	1589	1589
8.		Kaithal	0.90	“	21	21
		Sub total	253.0		5887	5887
	Indus	Ghaggar				
1.		Sirsa	55.11	“	1282	1282
2.		Hisar	74.51	“	1733	1733
3.		Jind	17.86	“	416	416
4.		Kaithal	79.74	“	1855	1855
5.		Kurukshetra	41.57	“	967	967
6.		Ambala	12.01	“	280	280
7.		Panchkula	8.01	“	187	187
		Sub total	288.8		6720	6720
		Grand total	684.5		15928	15928

8.8. HIMACHAL PRADESH

Himachal Pradesh is one of the northern most state with an area of 55673 sq. kms.The major river systems of the region are the Chenab, the Ravi, the Beas, the Sutlej, and the Yamuna. The catchments of these rivers are fed by snow and rainfall and are protected by fairly extensive cover of natural vegetation. The rainfall in the state varies from 900 to 2000 mm. In the high altitude areas where rainfall is as low as 200 - 800 mm, snow is the major source of precipitation. Average rainy/snowfall days varies from 50 - 75 / year.

The depth to water level during post monsoon varies from 1.38 to 14.30m bgl in Kangra, 2.12 to 7.64m bgl in Kullu, 2.02 to more than 50m bgl in Una, 0.85 to 20.60 m bgl in Mandi, 2.80 to 22.21m bgl in Solan and 3.35 to 33.70m bgl in Sirmour. However, the depth to water is shallower in low-lying valleys and deeper in high topographic areas in the valley fill areas. Ground Water resource estimation are made only for the valley fill areas. The level of ground water development is 21.78% in the valley areas.

Major source of water supplies in rural and urban settlements are the springs. These are formed mainly either along the faults or other structurally week zones. Discharge of these springs varies from seepages to more than 40 lps. Recently the discharge of the springs has started decreasing during peak summers and most of the minor springs get dried up. There is an urgent need to rehabilitate these sources of water supplies by adopting proper management practice for recharging. In addition to the springs there are a number of thermal springs which are located between the Main Central Thrust and Central Himalayan axis.

8.8.1. SOURCE WATER AVAILABILITY

Water is contributed to the rivers by both rainfall and snowfall received in the catchment during the year. Sufficient water is available in streams & rivers round the year, which can be harnessed by suitable structures.

8.8.2. RECHARGE STRUCTURES AND COST ESTIMATES

Water harvesting structures are to be selected in different areas depending on hydrogeological topographical and climatic conditions. The feasibility of suitable structures to recharge the ground water is discussed as follows:

A. VALLEY AREAS

Valley areas are confined mainly to southern periphery of the State covering an area of 2500 sq km. Water level in these areas generally becomes deeper towards the hills ranging in depth from 30 m to more than 60 meters. Average annual rainfall varies from 90 cm to 145 cm. Followings are the suitable rainwater harvesting and ground water conservation structures.

Check Dam Cum Sub-Surface Dyke

In order to conserve sub-surface flow it is proposed to construct sub-surface dyke by excavating the stream bed, 1 metre wide to a depth of about 10 meters. The average width of dyke across the stream is about 30 m. Height of sub-surface check dam is required to be raised on the stream bed to harness the stream flow and also to arrest the sub-surface flow. It is proposed to construct sub-surface dyke by using polyfibre sheet filled with clay and fine sand, which can be retrieved from the excavated material. Sub-surface dyke of 30 m length, 10 m depth and 1 m width will impound 0.18MCM of flow in one filling. Considering average three fillings per year each structures is expected to harness about 0.54 MCM annually. A total of 1000 check dam cum sub surface dykes would conserve 540 MCM of flow. Total cost of these structures at the rate of about Rs. 10 lakhs per structure will be Rs. 100 crores.

Revival of Ponds

In the valley region, there are around 300 ponds having an average water spread area of 0.05 sq. km. which require revival for rain water harvesting. These ponds needs to be desilted to enhance recharge to ground water. Ponds can also be connected to minor rivulets by raising small check dams and constructing diversion channels. It is suggested that these tanks may be deepened to another 2 m for increasing the storage capacity.

Pond with dimension of 300 m x 200 m x 2 m will harness about 0.12 MCM in single filling, and with multiple filling (average 3 fillings) about 0.36 MCM water can be harnessed. Around 108 MCM of rain water can be harnessed through 300 existing ponds. Considering the average cost of revival of around Rs. 10 lakh per pond, a total amount of Rs. 30 crores is needed for 300 ponds.

B. LOW HILL RANGES OR SIWALIKS

Population concentration is maximum in this part of the state covering about 10000 sq. km. area of Kangra, Bilaspur, Una, Hamirpur, Solan and Sirmour districts. Annual rainfall varies from 90 to 200 cm averaging to 145 cm. Total rainfall available over this area is 11962 MCM (75% of rainfall) for harvesting by constructing check dams and from roof top rainwater. Water from roof top can be collected and taken to nearby dug well or pond or stored in water tanks. Even reinforced cement concrete (RCC) tanks in the courtyard or under the houses can also be used for storages. Both check dams and roof top harvesting structures are suitable in this area.

Check Dams

About 500 check dams can be constructed across the streams considering an average width of 15 m and height 5 m with water spread for over 600 sq m. The estimated cost for each structures will be around Rs. 20 lakh. Thus Rs. 100 crores shall be required to store about 30 MCM of water.

Roof Top Water Harvesting Structures

There are about 1000 houses with an average roof area of about 100 sqm. Considering average rainfall of 145 cm., about 0.145 MCM of rain water can be harvested.

Considering the average cost of Rs. 25,000 for each rooftop rainwater harvesting structures, total cost works out to be Rs. 2.5 crores.

C. HIGH HILL RANGES

Springs are the only source of water supplies in these areas. Drying up or reduction of spring discharge results in acute water problems. Springs can be recharged by construction of check dams or gabion structures across the streams in the recharge zones. There are around 500 springs in the area, which require the revival through artificial recharge techniques. For a spring, on an average 3, check dams each having a width of 15 metres and a height of 1.5 m may be required. Approximate cost for each spring development will be about Rs. 30 lakhs. Thus the total cost for development of 500 springs will be Rs. 150 crores.

Roof Top Rain Water Harvesting (High Hills)

The population in this area is scanty. There will be about 1000 houses with roof area of about 100 sq. metres. This area receives rainfall between 80 cm and 20 cm but snowfall is moderate to heavy. The estimated cost of each rain water harvesting structure will be Rs. 50,000. Thus for 1000 roof top rain water harvesting structure, around Rs. 5 crores shall be required.

8.8.3. TOTAL COST

The total cost of artificial recharge, rain water harvesting and spring development would be around Rs. 465.5 crores as detailed below:

Sub-Surface Dykes	Rs.100.00 crores
Check Dams	Rs.100.00 crores
Revival of Ponds	Rs. 108.00 crores
Revival of Springs	Rs. 150.00 crores
Roof Top Rain Water Harvesting	Rs. 7.50 crores
TOTAL	Rs. 465.50 crores

8.9 JAMMU AND KASHMIR

Jammu and Kashmir has a total geographical area of 2,22,236 km^2, which includes an area of 78,932 km^2 under illegal occupation of Pakistan and 37,555 km^2 area under illegal occupation of China. The Jammu and Kashmir State is divided into two administrative divisions viz. Kashmir Division comprising Kashmir and Ladakh regions, and Jammu division comprising Jammu region. The average annual precipitation is 660 mm. Nearly entire State of Jammu and Kashmir is drained by the rivers of Indus River System and the only exception is the small area in the extreme north-east which is part of Qara Qash River Basin Kandi region of the state has an average annual rainfall of about 1100 mm. It faces acute water scarcity, especially during summer due to very high run-off resulting from high topographic gradient of 1:60 to 1:100. The fragile eco-system of the Kandi region is prone to erosion and as result high rate of siltation takes place in the ponds which necessitates periodic de-silting. The problem of water scarcity is more acute in higher reaches of the Kandi area as the villages are located on high slopes of Siwalik hills and the rivers and streams flow through deep cut valleys.

8.9.1. SOURCE WATER AVAILABILITY

The mean annual surplus run-off in Chenab sub-basin is 27220 MCM while in Tawi sub-basin it is 1953 MCM. Thus, the total surplus run-off available is 29173 MCM.

8.9.2. RECHARGE STRUCTURES AND COST ESTIMATES

The depth to water level during pre-monsoon season in Kandi region is generally very deep (15 to 74 m below ground level). Rainwater harvesting and groundwater conservation structures are required to provide sustainability to existing sources such as springs, ponds wells etc. Considering the topography, precipitation and local aspects (Fig. 9) following structures are proposed:

8.9.2.1 Nala bund/check dams

Nala bund-check dams are the most suitable structure in Kandi area to store and recharge the ground water. The average length of such structure will be about 15m with avarage height of 1.5m above the nala bed. The underlying formations are highly permeable down to water level, there by rate of recharge will be very high. The avarage cost of such structure will be around Rs. 10 lakhs. Each nala bund–check dam will impound 0.0135 MCM of surface flow in single filling. Considering the average of three fillings per year the structure is expected to harvest about 0. 04 MCM annually. Taking into account the topography of the catchment it is proposed to construct 500 such structures to conserve 200 MCM of surface flow. The total cost of these structures at the rate of Rs. 10.0 lakh per structure works out to be Rs. 50 crore.

8.9.2.2 Revival of Kandi Ponds

There are 336 big ponds, covering on an average of 1,50,000 m^2 area, which need to be revived for increasing their efficiency as rainwater harvesting structure. These major ponds in Kandi region should be desilted and deepened for storing the rainwater. The ponds can also be connected with nearby rivulets by constructing small check dams and constructing diversion channels. The deepening of ponds may be done to the extent that the average depth of water in it is about 2 m. Considering an average depth of deepening as 2 m the volume of water that can be harnessed by one pond of the dimension of 300 x 500 m would be 0.30 MCM in one filling. Thus, an additional storage 101 MCM water can be created in 336 Kandi ponds. Considering the cost as Rs. 10 lakh per pond the total cost of deepening 336 ponds and connecting them with the nearby rivulets works out to be Rs. 33.60 crores.

8.9.2.3 Rooftop Rainwater Harvesting – Kandi Villages

Majority of the Kandi Villages have pucca houses with an average of about 100 m^2 roof area. Considering the average monsoon rainfall of 900 mm and evaporation loss of 10% about 81,000 litres of water can still be collected in a year, which is sufficient for the family of five at the norm of 45 litres per capita per day. Water from rooftop collected with the help of galvanised corrugated iron (GCI) sheets and can be taken to the nearby dugwell or village pond or stored in water tanks made from GCI sheets or galvanised plain (GP) sheets. Reinforced cement concrete (RCC) tanks, located in the courtyard or under the house, can also be used. The total number of Kandi villages in Jammu Province is 702, which together have around 3 lakh houses. Considering that 50 % of these have pucca roof area, the total rooftop area is 15 million Sq. m. It is capable of harvesting about 11.9 MCM of rainwater. Considering the average cost of Rs. 10,000 for each rooftop of 100 m^2 roof area in Kandi villages, the total cost of rooftop rainwater harvesting works out to be Rs. 150 crores.

8.9.4. ROOF TOP RAINWATER HARVESTING IN URBAN AREAS

Jammu city, the winter capital of the State, is located in Kandi terrain and faces acute water scarcity, especially during summer. The drinking water supply largely based on ground water is greatly stressed due to steep rise in demand. The city is spread over an area of 170 km^2. The average annual rainfall at Jammu is 1100 mm out of which about 950 mm rainfall is received during monsoon period. Considering an amount of Rs. 5 lakh for 1000 Sq. m roof top area of institutional building an amount of Rs. 12.50 crores would be required for rain water harvesting for 250 institutional buldings of Jammu city.

8.9.3. TOTAL COST

The total cost of artificial recharge to the groundwater in the State of Jammu and Kashmir would be around Rs. 246 crores, with break up as follows:

(i) Nala bund/check dams …… Rs. 50.00 crores
(ii) Revival of Kandi Ponds ……… Rs. 33.60 crores
(iii) Rooftop Harvesting in Villages …. Rs. 150.00 crores
(iv) Rooftop Harvesting in Jammu City … Rs. 12.50 crores

TOTAL COST :- Rs. 246.10 crores.

8.10 KARNATAKA

Karnataka State comprising of 26 districts and 175 talukas covers an area of 1,91,791 sq.km. The total population of the State is 4,49,71,201 (1991 census). The annual rainfall varies from about 2000 to 4000 mm along west coast and the western Ghat Regions to about 600 mm towards northern plains Karnataka State is drained by seven major rivers namely the Godavari, the Krishna, the Cauvery, West Flowing rivers Palar, Ponnaiyar and Pennar. These basins represent varied hydrogeological, rainfall and agroclimatic features.

8.10.1 IDENTIFICATION OF AREA

Based on post monsoon depth to water level and ground water level trends, the feasible areas for artificial recharge have been identified in four categories. Total 36,710 sq. km area has been identified in seven basins of the state (Table – 14) for artificial recharge. Areas identified for artificial recharge are shown in Fig.10.

8.10.2. SUB-SURFACE STORAGE SPACE AND WATER REQUIREMENT

The thickness of available unsaturated zone (below 3 mbgl) has been estimated by considering different ranges of water level to arrive at thickness of effective unsaturated zone, and to finally estimate the total storage potential that can be created under ground by recharging ground water reservoir (Table-14). A total volume of 1,83,789 MCM is estimated as storage potential in the State with maximum in Krishna basin. An amount of 3676 MCM can be stored by taking average specific yield of 0.02.

8.10.3. SOURCE WATER AVAILABILITY

After assessing the actual volume of water required for saturating the Vadose zone, the source water requirement is estimated and based on the field experience it is felt that an average recharge efficiency of 75% can be considered which may be possible to achieve. For working out the availability of source water the volume of non-committed surface water available after utilisation is considered which can be harnessed and utilised for recharging ground water (Table-15). Surface water requirement in the state is estimated as 4901 MCM and non – committed surplus surface water is estimated as 2157 MCM. The basin wise details are given in Table.14

Table–14: Basinwise Sub-Surface Storage Potential in Unsaturated Strata and Surplus Surface Water Available for Artificial Recharge to Ground Water in Karnataka.

S. No.	BASIN	Area (sq.km.)	Area Identified for Artificial Recharge (sq.km.)	Volume of Unsaturated zone (MCM)	Total Storage Potential (MCM) as Volume of Water sp. Yield 0.02	Surface water Requirement (MCM)	Proportionate Non-committed Water Resource Available as Surplus (MCM)
1	2	3	4	5	6	7	8
1	Godavari	4405	1610	4659	93.18	124.24	154.00
2	Krishna	113271	27724	146688	2934.00	3912.00	1726.00
3	Cauvery	34273	5116	22194	443.88	591.84	152.00
4	West Flowing	26214	160	240	4.80	6.40	68.00
5	Palar	2826	460	2088	41.76	55.68	Nil
6	Ponnaiyar	3638	920	5160	103.20	137.60	53.00
7	Pennar	7146	720	2760	55.20	73.60	4.00
TOTAL		191,773	36,710	183,789	3,676.02	4,901.36	2,157.00

8.10.4. RECHARGE STRUCTURES AND COST ESTIMATES

The artificial recharge and ground water conservation structures feasible in the state are Percolation Tanks, Check Dams, Filter bed unit and sub-surface dykes. The basin-wise details of feasible structures are given in Table-15.

Table-15 : Artificial Recharge to Ground Water by Suitable Recharge Structures

S.No	Name of Basin	Surface water for Planning Artificial Recharge to Ground Water (MCM)	Resource to be harnessed							
			Sub-surface Dyke (15% of the Source Identified) MCM	No. of Structures (0.3 MCM per structure)	Desilting/ Construc-tion of Percolation Tanks (50% of theSource identified)MCM	No. of Structures (0.2 MCM per structure)	Check Dam (25% of the source identified) MCM	No. of Structures (0.03 MCM per structure)	Filter bed 10% of the source identified MCM	No. of Structures (0.02 MCM per structure)
1	Godavari	124	19	63	62	310	31	1033	12	600
2	Krishna	1726	260	866	863	4315	431	14366	172	8600
3	Cauvery	152	23	76	76	380	38	1267	15	750
4	West Flowing	6	1	3	3	1.5	15	50	0.5	25
5	Palar	Nil	--	--	--	--	--	--	--	--
6	Pennar	4	0.6	2	2	10	1	33	0.4	20
7	Ponnaiyar	53	9	30	26	130	13	433	5	250
TOTAL		2065	312.6	1040	1032	5160	515.5	17182	204.9	10245

The estimated cost of various recharge structures to be provided in various basins of Karnataka works out to Rs.1233 crores (Table-16).

Table-16: Basin Wise Cost Estimates of Various Artificial Recharge Structures

S.No.	RIVER BASIN	Cost of Atificial Recharge Structures (lakhs of Rs.)			
		Sub Surface Dyke Unit cost @ Rs.4.5 lakhs	Percolation Tank Unit cost @ Rs.18 lakhs	Check Dams Unit cost @ Rs.0.75 lakhs	Filter Bed Unit cost @ Rs.1.25 lakhs
1.	Godavari	283.5	5580	775	750
2.	Krishna	3897	77670	10775	10750
3.	Cauvery	342	6840	950	938
4.	West Flowing	13.5	270	37.5	31
5.	Palar	--	--	--	--
6.	Pennar	9	180	25	25
7.	Ponnaiyar	135	2340	325	312
TOTAL		4680	92880	12887.5	12806
Grand Total		1233 crores			

Under the of the plan for artificial recharge total volume of 1549 MCM is likely to be recharged annually which will create additional irrigation potential of 166000 ha.

8.10.5 ROOF TOP RAIN WATER HARVESTING IN URBAN AREAS

In Karnataka, Bangalore is metropolitan city followed by other municipal corporations like Hubli/Dharwad, Mangalore, Belgaum, Shimoga and Mysore and 286 municipalities in the State. The density of urban population is 28269/sq.km in Karnataka. As per 1991 census there are about 8323916 houses available in the urban areas of Karnataka. The exact size of individual houses is not available; therefore an average roof size of 50 sq.m is adopted for the calculation of the roof area. Rainwater availability in urban areas covered in various districts works out to a total of 50.05 MCM during monsoon and 35.35 MCM during non-monsoon periods. At feasible locations, 90% of the figure for harvesting the rainwater is taken as source for artificial recharge.

The houses having dugwell or borewell etc. i.e. 10% of total houses are targeted for recharging ground water reservoir through roof top rainwater harvesting. The average cost exependiture for providing the necessary arrangements through pipe fittings etc., shall cost around Rs. 6000/house. A total cost has been worked out as 499 crores taking into account one tenth of the total houses in urban areas have well in the premises, which may be fit to harness the rooftop rainwater for artificial recharge purposes.

8.10.6 TOTAL COST

The total cost of the recharge structures in rural and urban areas of the Karnataka is Rs. 1732 crores.

8.11 KERALA

Kerala State occurs as a narrow stretch of land covering an area of 38,863 sq km, and comprises of 14 districts, 61 taluks, 151 community development blocks and 983 panchayats. The total population of the state as per 1991 census is 2,90,98,518, with a density of 749 persons per sq.km. Among the 14 districts, Alleppey has got the highest density of 1408 persons per sq km. Cochin taluk of Ernakulam district ranks first with 3198 persons per sq.km and Devikulam taluk of Idukki district has the lowest density of 129 persons per sq.km. Kerala receives rainfall from both north east and south west monsoons. The maximum precipitation is on the Western Ghats and the lowest in the vicinity of Palghat gap.Kuttiyadi basin in northern Kerala experiences the maximum rainfall of 3934 mm, while Pambar (Amaravathi) basin, which is a rain shadow area, records an annual rainfall of 1367 mm. Kerala State is drained by 41 west flowing rivers and 3 east flowing rivers. The Bharathapugha, Periyar and Pampa are the major rivers. The run off estimated in the state is around 70165 MCM., out of which 42672 MCM is considered to be utilisable resources. The total base flow in lean period in the 30 major rivers is around 6640 MCM.

8.11.1 IDENTIFICATION OF AREA

Analysis of the water level trends depth to water level and physiographic features, has been done to demarcate areas for artificial recharge. The areas identified for artificial recharge structures fall in 15 out of total 44 watersheds, covering an area of 4650 Sq. km.

8.11.2. SUB SURFACE STORAGE SPACE AND WATER CONSERVATION

The thickness of available unsaturated zone (below 3m bgl) of four categories is estimated by considering the different ranges of water level . The different range of water level at 3 m interval are averaged to arrive at thickness of unsaturated zone effectively. The total volume of unsaturated strata is calculated considering the above categories of depth to water level and the volume of space available is estimated. The net amount of water rechargeable by artificial recharge to saturate the aquifer upto 3 m. bgl is then calculated by taking the average specific yield of 0.02 to 0.07.

8.11.3. SOURCE WATER AVAILABILITY

The surface water resources available in various basins were provided by the state government. The data available for each basin includes committed runoff, surplus water available for future planning. The availability of source water was worked out by adding the amount of surface water provided for future planning and surplus available. The availability so worked out is for the entire basin and not for the requirement of the areas identified for artificial recharge. Hence, apportioning of surface water availability was done to account for requirement of identified areas. For planning the artificial recharge structures in each basin of Kerala, the amount of surface water availability and storage volume was matched to arrive at the feasibility of the scheme.

8.11.4. RECHARGE STRUCTURES AND COST ESTIMATES

Hydrologically, the areas have been grouped into hard rock and alluvial areas. Since the coastal alluvial area is having shallow depth to water level of less than 3 m.bgl, only the hard rock area has been considered for artificial recharge. The surface spreading techniques consisting of check dams, gully plugs and nalah bunds are most appropriate. The ground water conservation structure like sub-surface dyke is also appropriate for this state due to its undulating topography.

Other structures like contour trenches, village ponds, recharge wells, percolation tanks etc. may also be taken in select pockets, which would be more appropriate for soil and moisture conservation.

The volume of surface water considered for planning the artificial recharge is 1078 MCM. Based on the field situation it has been considered that 40 % storage would be through check dams, 20 % would be through subsurface dykes, 20% storage by gully plugs and 20% by nalah bunds. Accordingly 40% of it i.e. 431.2 MCM will be stored in check dams, 215.4 MCM will be stored by subsurface dykes, 215.4 MCM will be stored by gully plug and the same amount of 215.4 MCM will be stored by nalah bund. Therefore, 4312 check dams, 7181 subsurface dykes, 10780 gully plugs, 10780 nalah bunds are proposed in the identified areas of Kerala (Table 17).

Table 17. Artificial Recharge To Ground Water By Suitable Principal Recharge Schemes Using Surface Water Resources

Sl No	Name of Basin	Volume of surface water considered for planning artificial recharge to ground water MCM	Check dams (Average gross capacity- 0.1 MCM)		Subsurface dykes (Average gross capacity 0.03 MCM)		Gully plugs (Average gross capacity 0.02 MCM)		Nalah bunding (Average gross capacity 0.02 MCM)	
			MCM	Nos.	MCM	Nos.	MCM	Nos.	MCM	Nos.
1.	Neyyar	115	46	460	23	766	23	1150	23	1150
2.	Karamana	136	54.4	544	27.2	906	27.2	1360	27.2	1360
3.	Vamanapuram	95	38	380	19	633	19	950	19	950
4.	Ittikara	77	30.8	308	15.4	513	15.4	770	15.4	770
5.	Kallada	82	32.8	328	16.4	546	16.4	820	16.4	820
6.	Karuvannur	22	8.8	88	4.4	146	4.4	220	4.4	220
7.	Ponnani	29	11.6	116	5.8	193	5.8	290	5.8	290
8.	Bhavani	74	29.6	296	14.8	493	14.8	740	14.8	740
9.	Kadalundi	134	53.6	536	26.8	893	26.8	1340	26.8	1340
10.	Kabbini	70	28	280	14	466	14	700	14	700
11.	Valapatnam	39	15.6	156	7.8	260	7.8	390	7.8	390
12.	Kuppam	15	6	60	3	100	3	150	3	150
13.	Kariangode	39	15.6	156	7.8	260	7.8	390	7.8	390
14.	Chandragiri	84	33.6	336	16.8	560	16.8	840	16.8	840
15.	Shiriya	67	26.8	268	13.4	446	13.4	670	13.4	670
TOTAL		1078	431.2	4312	215.4	7181	215.4	10780	215.4	10780
Total estimated cost (Crores)				646.8		359.1		107.8		107.8

The check dams should be constructed on second and third order drainage, on favourable hydrogeological and physiographical locations. The gully plugs and nalah bunds can be constructed based on density of structures per sq.km and be planned realistically to make it implementable on practical considerations.

The cost estimate for artificial recharge scheme viz. check dams, Subsurface dykes, gully plugs and nallah bunds are worked out as follows;-

Based on the experiences gained from central sector artificial recharge studies, it is observed that the cost of recharge schemes depends upon the specific local situations. The average cost of construction of check dam (33.3 TCM Single filling storage capacity) is around Rs. 15,000.00. The cost of subsurface dyke (10 TCM single fillings storage capacity) is Rs.5,000.00. The cost of gully plug and nalah bund is Rs. 1,000.00 each. Total cost of these schemes is estimated as Rs. 1221 crores.

8.11.5. AREA BENEFITTED

The impact of artificial recharge to ground water shall be created mainly at the down stream side of the recharge structures. This area will normally be maximum during the end of monsoon and distinct rise in ground water level will be observed as compared to other areas not receiving the artificial recharge. It is estimated that the maximum influence of recharge schemes proposed in the plan will have impact in an area of 1150 sq.km. A rise of 3 to 6 m in water level shall be observed depending on the quantity of recharge and variation in specific yield. This will also result in saving of energy, as the suction lift pump sets would be reduced by 2 to 6 meters.

Though the impact of artificial recharge will be witnessed over 4650-sq. km. the entire area can not be brought under assured irrigation. Hence the calculation of additional area to be brought under assured irrigation from the proposed artificial recharge schemes is done considering the prevailing cropping pattern of the state. Based on this a Delta factor of 0.7m per year is adopted. It is estimated that a total area of about 190000 ha . additional land can be brought under assured irrigation. The scheme wise additional irrigation from check dams, sub surface dykes,gully plugs, and nallah bunds schemes would be 61600 ha., 30770 ha., 30770 ha., and 30770 ha. respectively.

8.11.6. ROOF TOP RAIN WATER AND RUNOFF HARVESTING IN URBAN AREAS

Roof Top Rainwater Harvesting

There are 57 municipal towns and 5 metropolitan cities in Kerala. The list of 62 urban lands and its area alongwith the roof area of various buildings were estimated. The total area of urban land is 1646.53 sq.km and the total available roof area is 248.5 sq.km as on year 1995. The annual rainfall varies from 2267 mm to 3428 mm. Taking average 3000 mm annual rainfall and after accounting for PET, 1.754 m rainfall is available for recharge. An area of 248.5 sq.km roof area would yield 435.869 MCM rain water which can be effectively utilised for recharge by roof top rainwater harvesting structures. The average cost expenditure for providing the necessary arrangements through pipe fitting etc. shall be around Rs. 6000/- per house. Thus a total of Rs. 45 crore is estimated in the State for rooftop rainwater recharge. The houses in topographic highs in midland and highland regions and houses located in brackish water zone in coastal tracts can be taken up on priority.

Runoff Water Harvesting Schemes

The substantial amount of rainwater is wasted as runoff. This runoff water can be utilised with scientific planning. This water if conserved and can be diverted for recharging to the ground water reservoir, by which the water scarcity in the urban area can be solved to an extent. It is estimated that in 40 urban areas of Kerala around 1200 schemes would be needed with an average of 30 schemes per town/city. This will represent about 0.5 sq. km. of urban area per recharge well. The average cost of recharge well, filter pit, pipe line and development of surrounding space will be around Rs 1 lakh. Therefore expenditure Rs.12 crores is estimated.

8.11.7. TOTAL COST

Total cost of the artificial recharge structure, roof top rain water and runoff harvesting in the state of Kerala is Rs. 1278 crores.

8.12 MADHYA PRADESH

Madhya Pradesh State after its reorganisation on 1st November 2000, covers an area of 308000 Sq.Km. It comprises of 9 administrative divisions, 45 districts, 60 tehsils and 313 community development blocks. There are 51806 villages and 19 major cities in the State. The population of State as per census 1991 is 48.57 million with density of population as 158 per Sq.Km. The average rainfall of the State is 1068 mm.

Madhya Pradesh is drained by five major river basins namely Ganga, Narmada, Godavari, Tapi and Mahi. These basins are divided into 11 sub basins and further sub divided into 155 major watersheds out of which 6 watersheds in Son and Narmada sub-basin falls partly in adjoining Chhatisgarh State.

8.12.1. IDENTIFICATION OF AREA

Based on data of National Hydrograph Stations established by CGWB to monitor the fluctuation of groundwater levels in different hydrogeological situations, a trend analysis was carried out for the decade between 1989 and 1998. A total area of 36,335 Sq.km. in Madhya Pradesh shows declining trend in ground water levels. The maximum decline of groundwater level during the decade was 11 m in Ratlam district, followed by 7.5 m in Mandsaur and 6 m in Neemuch district. 69 major watersheds have been identified in Madhya Pradesh in which declining trend of more than 0.1 m/yr was recorded (Fig.12). These watersheds have been identified for construction of suitable artificial recharge structures for augmenting the available ground water resources.

8.12.2. SUB-SURFACE STORAGE SPACE AND WATER REQUIREMENT

To estimate the storage space available in the sub-surface, a map was prepared on the basis of average post monsoon depth to water level for period 1989-1998. The decadal post monsoon average depth to water level is predominantly in the range of 3 to 6 m below ground level. In some pockets of Chambal, Sind, Sone and Tapi basin the depth to water level exceed 9 m below ground level.

Based on this map the volume of unsaturated zone available for recharge (Vadose zone up to 3 m below ground level) was calculated for each of the 62 identified watersheds. A total 107344 MCM volume of unsaturated zone was estimated for the M.P. State, which gives a sub-surface storage potential of 2837.49 MCM based on the specific yield of the rock types in the watersheds. The requirement of water to fully saturate the vadose zone upto 3 m below ground level was worked out for each watershed at 75% efficiency. The total requirement of water for creating the sub-surface storage works out to 3773.86 MCM for the entire State.

8.12.3. SOURCE WATER AVAILABILITY

The availability of surplus monsoon runoff was estimated for 69 identified watersheds mainly on the basis of NWDA and State Irrigation Department data. The total availability of source water for recharge works out to 10787.72 MCM, which far exceeds the total requirement to create the sub-surface storage. However, for each watershed the requirement vis-a-vis the availability was seen and the least of the two was considered as available source water for harnessing in artificial recharge structures. The total quantum of source water, which can be utilized for creation of sub-surface storage, works out to 2319.96 MCM for all the 69 identified watersheds (Table-18).

8.12.4 RECHARGE STRUCTURES AND COST ESTIMATES

The major parts of the area identified for artificial recharge is covered by hard rocks except some parts of Chambal and Narmada basins. The suitable artificial recharge structures are gully plugs, gabion structures, contour bunds in the upper reaches of the watersheds, percolation tanks, nala bunds in the runoff zones and recharge shafts, gravity head wells in down stream areas. The main artificial recharge structures proposed is given below along with the estimated number of feasible structures and their cost.

Percolation tanks

Percolation tank is the main artificial recharge structure proposed for effective utilisation of the surplus monsoon runoff. 50% in hardrock areas and 30% in alluvial areas of the total estimated surplus surface water resources could be stored in the Percolation tanks. Under the Hydrogeological conditions in M.P. an average percolation tank has filling capacity of 0.1 MCM. It can actually store 200% of its capacity due to multiple filling during the monsoon. Thus an average gross storing capacity of 0.2 MCM has been considered. The average cost of such small structure has been considered as Rs.20 lac each. The number of feasible percolation tank in each identified watershed has been calculated and presented in Table-I8. The total percolation tanks feasible in M.P. are 5302 costing Rs.1060.4 Crores.

Nalabunds

As most of the rivers originate in M.P. there is a large scope for constructing Nala bunds/Cement plugs in various second order streams. About 25% in hardrock areas and 30% in alluvial areas of surplus monsoon runoff can be utilized by recharge throught these structures. The average capacity of Nala bunds/Cement plugs has been considered as 0.01 MCM. The average cost of each structure has been taken as Rs.1 lakh. It is estimated that 20198 Nala bund/Cement plugs can be constructed in the State at the cost of 202 crores (Table-I8).

Recharge shafts & Gravity head recharge wells

These structures are feasible in village and urban areas. About 10% of the surplus monsoon runoff can be utilized through these structures. The average recharage capacity through recharge shafts, gravity head recharge through dugwells during an operational period of 60 days in monsoon and post monsoon period is considered as 0.01 MCM. The average cost of structure may be taken as Rs.2.5 lacs. The number of structures and their cost for each identified watershed was calculated and presented in Table-I8. For the entire State the feasible structures are 23,181 costing Rs.579.5 crores.

Gully plugs, Contour bunds, Gabion structures

These structures are mainly soil conservation structures and help in increasing the soil moisture with limited recharge to ground water. It is estimated that 15% of total water available for recharge can be utilized by these structures which have an average storage capacity of 0.005 MCM. The average cost of each structure is taken as Rs.10,000/-. The structures feasible in each identified watershed has been estimated and presented in Table-I8. For entire State the feasible structures total up to 69,598, costing 69.6 crores.

8.12.5 ROOF TOP RAIN WATER HARVESTING IN URBAN AREAS

There are 19 standard Urban Areas in Madhya Pradesh which cover an area of 1321.05 Sq.km. with total number of houses about 976704. Due to scarcity of water individual houses in most of the urban areas have gone for construction of borewells/dugwells for sustainable water supply. However, this unplanned withdrawal of ground water has resulted in lowering of water levels and dwindling of yield/drying up of wells. The availability of roof top in urban areas is an attractive solution for collection of rain water during monsoons and recharging it to the ground water reservoir. An attempt has been made to study the feasibility of roop top rain water harvesting in urban areas of the State. Looking to the varied hydrogeological and other situations of space availability etc even if 25% of the houses with an average roof area of 50 Sq,metre are considered, a total roof area of 12.21 Sq.Km. is available to collect the rainfall. Considering the average annual normal rainfall in each urban area the total volume of rain water which can be collected on Roofs was worked out. Only 90% of this volume of rain water has been considered as available source water for recharging ground water. The total available water from rooftop rainwater harvesting works out to 12.04 MCM. The average expenditure on providing the necessary arrangements through pipe fittings, filter etc to divert the roof water to the existing groundwater structure (tubewell/dugwell) has been considered as Rs.10,000/- per house. The total cost for rooftop rainwater harvesting in the 19 cities of Madhya Pradesh declared as standard Urban Areas works out to 244.09 crores.

8.12.6. TOTAL COST AND BENIFITS

The total cost of artificial recharge structures in urban areas works out to 1909 crores and for roof top rain water harvesting in urban area as Rs.244 crores..

Out of the 1972 MCM of surplus runoff water available for harvesting through percolation tanks, Nala bunds and Recharge shafts only 70% is considered as additional recoverable resources for irrigation. An area of about 0.28 million ha is the additional irrigation potential created. In Rural areas the roof top rain water harvesting will cater to the annual drinking water needs of additional 8.5 lakh population.

Table - 1. EASIBILITY OF DIFFERENT ARTIFICIAL RECHARGE STRUCTURES IN MADHYA PRADESH STATE AND COST ESTIMATES

S.No	BASIN	SUB-BASIN	NAME OF WATERSHED AND ITS CODE	QUANTITY OF AVAILABLE WATER TO BE HARNESSED (MCM)	RESOURCES HARNESSED BY								ESTIMATED COST (RS.LAKHS)			
					PERCOLATION TANKS		NALA BUNDING/ CEMENT PLUG/ CHECK DAM		GRAVITY HEAD/DUG WELL / TUBE WELL/ RECHARGE SHAFT		GULLY PLUGS/ GABBION STRUCTURES		PERCOLATION TANK	NALA BUNDING	RECHARGE SHAFT	RECHARGE GABBION STRUCTURES
					(MCM)	No.	(MCM)	No.	(MCM)	No.	(MCM)	No.	@20 LAKHS	@1 LAKH	@2.5 LAKHS	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	GANGA	Chambal	Upper Chambal CH-1	9.58	4.79	24	2.40	80	0.96	96	1.44	287	480	80	240.00	28.70
2			Middle Chambal CH-2	9.31	4.66	23	2.33	78	0.93	93	1.40	279	460	78	232.50	27.90
3			Maten CH-3	18.35	9.18	46	4.59	153	1.84	184	2.75	551	920	153	460.00	55.10
4			Siwana CH-4	47.88	23.94	120	11.97	399	4.79	479	7.18	1436	2400	399	1197.50	143.60
5			Idar-retam CH-5	25.54	12.77	64	6.39	213	2.55	255	3.83	766	1280	213	637.50	76.70
6			Gambhir CH-8	31.92	15.96	80	7.98	266	3.19	319	4.79	958	1600	266	797.50	95.80
7			Shipra CH-9	14.36	7.18	36	3.59	120	1.44	144	2.15	431	720	120	360.00	43.10
8			Upper Kali sind CH-10	62.44	31.22	156	15.61	520	6.24	624	9.37	1873	3120	520	1560.00	187.30
9			Sind	55.06	27.53	138	13.77	459	5.51	551	8.26	1652	2760	459	1377.50	165.20
10			Lakhunder CH-12	76.61	38.31	192	19.15	638	7.66	766	11.49	2298	3840	638	1915.00	229.80
11			Ahu CH-13	11.44	5.72	29	2.86	95	1.14	114	1.72	343	580	95	285.00	34.30
12			Lower Kali-sind CH-14	30.51	15.26	76	7.63	254	3.05	305	4.58	915	1520	254	762.50	91.50
13			Newaz CH-17	41.5	20.75	104	10.38	346	4.15	415	6.23	1245	2080	346	1037.50	124.50
14			Chapi-ghani CH-18	52.52	26.26	131	13.13	438	5.25	525	7.88	1576	2620	438	1312.50	157.60
15			Upper parvati CH-20	9.58	4.79	24	2.40	80	0.96	96	1.44	287	480	80	240.00	28.70
16			Sarai-sip CH-27	43.09	21.55	108	10.77	359	4.31	431	6.46	1293	2160	359	1077.50	129.30
SUB-TOTAL				539.69	269.85	1351	134.92	4497	53.97	5397	80.95	16191	27020	4497	13492.50	1619.10
17	GANGA	Sind	Upper Sind SI-1	9.58	2.87	14	2.87	96	2.40	240	1.44	287	280	96	600.00	28.70

18			Kunwari SI-4	245	73.50	368	73.50	2450	61.25	613	36.75	7350	7360	2450	1530.00	735.00
19			Naisail SI-6	100.9	30.27	151	30.27	1009	25.23	252	15.14	3027	3020	1009	630.00	302.70
20			Maghiur SI-7	23.94	7.18	36	7.18	239	5.99	599	3.59	718	720	239	1497.50	71.80
21			Pahuj SI-8	27.93	8.38	42	8.38	279	6.98	698	4.19	838	840	279	1745.00	83.80
22			Lower Sind SI-9	76.56	22.97	115	22.97	766	19.14	1914	11.48	2297	2300	766	4785.00	229.70
SUB-TOTAL				483.91	145.17	726	145.17	4839	120.98	4315	72.59	14517	14520	4839	10787.50	1451.70
23	GANGA	Betwa	Upper Betwa BE-1	33.91	16.96	85	8.48	283	3.39	339	5.09	1017	1700	283	847.50	101.70
24			Halali BE-2	28.86	14.43	72	7.22	241	2.89	289	4.33	866	1440	241	722.50	86.60
25			Bah BE-3	10.96	5.48	27	2.74	91	1.10	110	1.64	329	540	91	275.00	32.90
26			Sagar BE-4	12.5	6.25	31	3.13	104	1.25	125	1.88	375	620	104	312.50	37.50
27			Budhana BE-8	11.04	5.52	28	2.76	92	1.10	110	1.66	331	560	92	275.00	33.10
28			Keatan BE-11	11.3	5.65	28	2.83	94	1.13	113	1.70	339	560	94	282.50	33.90
29			Bina BE-12	47.88	23.94	120	11.97	399	4.79	479	7.18	1436	2400	399	1197.50	143.60
30			Upper Dhasan BE-14	6.38	3.19	16	1.60	53	0.64	64	0.96	191	320	53	160.00	19.10
31			Jimpa BE-15	6.38	3.19	16	1.60	53	0.64	64	0.96	191	320	53	160.00	19.10
32			Arjun BE-16	33.12	16.56	83	8.28	276	3.31	331	4.97	994	1660	276	827.50	99.40
33			Ur BE-17	25.54	12.77	64	6.39	213	2.55	255	3.83	766	1280	213	637.50	76.70
SUB-TOTAL				227.87	113.94	570	56.97	1899	22.79	2279	34.18	6836	11400	1899	5697.50	683.60
34	GANGA	Ken	Upper Sonar KE-1	43.09	21.55	108	10.77	359	4.31	431	6.46	1293	2160	359	1077.50	129.30
35			Kopra KE-3	22.88	11.44	57	5.72	191	2.29	229	3.43	686	1140	191	572.50	68.60
36			Bearma KE-11	15.96	7.98	40	3.99	133	1.60	160	2.39	479	800	133	400.00	47.90
37			Upper Ken KE-12	9.71	4.86	24	2.43	81	0.97	97	1.46	291	480	81	242.50	29.20
38			Mirhasan KE-13	77.41	38.71	194	19.35	645	7.74	774	11.61	2322	3880	645	1935.00	232.20
SUB-TOTAL				169.05	84.53	423	42.26	1409	16.91	1691	25.36	5072	8460	1409	4227.50	507.20
39	GANGA	Tons	Upper Tons To-1	52.27	26.14	131	13.07	436	5.23	523	7.84	1568	2620	436	1307.50	156.80
40			Bihar TO-3	34.91	17.46	87	8.73	291	3.49	349	5.24	1047	1740	291	872.50	104.70
41			Lower Tons TO-4	71.82	35.91	180	17.96	599	7.18	718	10.77	2155	3600	599	1795.00	215.50
42			Belan TO-5	9.58	4.79	24	2.40	80	0.96	96	1.44	287	480	80	240.00	28.70
SUB-TOTAL				168.58	84.29	422	42.15	1406	16.86	1686	25.29	5057	8440	1406	4215.00	505.70
43	GANGA	Son	Choti Mahanadi SO-4	9.58	4.79	24	2.40	80	0.96	96	1.44	287	480	80	240.00	28.70
44			Katni SO-5	5.02	2.51	13	1.26	42	0.50	50	0.75	151	260	42	125.00	15.10
45			Mid Son SO-6	4.33	2.17	11	1.08	36	0.43	43	0.65	130	220	36	107.50	13.00
46			Banas SO-7	7.45	3.73	19	1.86	62	0.75	75	1.12	224	380	62	187.50	22.40
47			Lower Rihand SO-16	3.76	1.88	9	0.94	31	0.38	38	0.56	113	180	31	95.00	11.30
48			Mahan SO-17	9.58	4.79	24	2.40	80	0.96	96	1.44	287	480	80	240.00	28.70
SUB-TOTAL				39.72	19.86	117	9.93	331	3.97	397	5.96	1192	2000	331	995.00	119.20
49	NARMADA	Left bank	Banjar NL-2	13.83	6.92	35	3.46	115	1.38	138	2.07	415	700	115	345.00	41.50
50			Sher NL-4	33.5	10.05	50	10.05	335	8.38	838	5.03	1005	1000	335	2095.00	100.50
51			Ajnal NL-12	36.18	18.09	90	9.05	302	3.62	362	5.43	1085	1800	302	905.00	108.50
52			Choti tawa NL-	10.37	5.19	26	2.59	86	1.04	104	1.56	311	520	86	260.00	31.10

			14													
53			Kareri NL-15	39.9	19.95	100	9.98	333	3.99	399	5.99	1197	2000	333	997.50	119.70
54			Kundai NL-18	156.41	78.21	391	39.10	1303	15.64	1564	23.46	4692	7820	1303	3910.00	469.20
55			Deb NL-19	14.36	7.18	36	3.59	120	1.44	144	2.15	431	720	120	360.00	43.10
56			Gomai NL-20	9.58	4.79	24	2.40	80	0.96	96	1.44	287	480	80	240.00	28.70
SUB-TOTAL				314.13	150.37	752	80.21	2674	36.44	3645	47.12	9423	15040	2674	9112.50	942.30
57	NARMADA	Right Bank	Sindhor NR-5	11.17	5.59	28	2.79	93	1.12	112	1.68	335	560	93	280.00	33.50
58			Tandoni NR-6	11.57	5.79	29	2.89	96	1.16	116	1.74	347	580	96	290.00	34.70
59			Uri NR-18	103.74	51.87	259	25.94	865	10.37	1037	15.56	3112	5180	865	2592.50	311.20
60			Hathni NR-19	81.5	40.75	204	20.38	679	8.15	815	12.23	2445	4080	679	2037.50	244.50
61			Orang NR-20	14.36	7.18	36	3.59	120	1.44	144	2.15	431	720	120	360.00	43.10
SUB-TOTAL				222.34	111.17	556	55.59	1853	22.24	2224	33.35	6670	11120	1853	5560.00	667.00
62	GODAVARI	Wardha	Jam WA-2	7.98	3.99	20	2.00	67	0.80	80	1.20	239	400	67	200.00	23.90
63			Kulbhera WA-4	23.94	11.97	60	5.99	200	2.39	239	3.59	718	1200	200	597.50	71.80
64			Hirri WA-8	3.59	1.80	9	0.90	30	0.36	36	0.54	108	180	30	90.00	10.80
65			Bawathani WA-9	20.75	10.38	52	5.19	173	2.08	208	3.11	623	1040	173	520.00	62.30
66			Bagh WA-15	7.98	3.99	20	2.00	67	0.80	80	1.20	239	400	67	200.00	23.90
SUB-TOTAL				64.24	32.12	161	16.06	537	6.43	643	9.64	1927	3220	537	1607.50	192.70
67	TAPI	Tapi	Upper Tapi TA-2	11.17	5.59	28	2.79	93	1.12	112	1.68	335	560	93	280.00	33.50
68			Middle Tapi TA-4	64.9	32.45	162	16.23	541	6.49	649	9.73	1947	3240	541	1622.50	194.70
	SUB-TOTAL			76.07	38.04	190	19.02	634	7.61	761	11.41	2282	3800	634	1902.50	228.20
69	MAHI	Mahi	Pat MA-2	14.36	7.18	36	3.59	120	1.44	144	2.15	431	720	120	360.00	43.10
SUB-TOTAL				14.36	7.18	36	3.59	120	1.44	144	2.15	431	720	120	360.00	43.10
	Total			2319.96	1056.50	5302	605.87	20198	309.62	23181	347.99	69598	105740	20198	57952.00	6959.80
											GRAND TOTAL			**Rs. 1908.5 Crores**		

8.13 MAHARASHTRA

Maharastra State covers an area of 3,07,713 sq.km. and comprises of 33 districts and 303 talukas. There are 322394 inhabited villages. The population of state is 78.748 million as per 1991 census. The state experiences south west monsoon with Rainfall ranging from 6000 mm in western Ghits to less than 500 mm in Madhya Maharashtra. The eastern part of Maharashtra known as Vidharba Region receives Rainfall upto 1500 mm. Maharashtra falls in four major basins namely Godavari (49%), Krishna (22.6%), Tapi-Purna (16.7%) and west flowing small rivers known as coastal tract. These basins represent varied hydrogeology, rainfall and agroclimatic features. Considering the size of basins, Godavari and Krishna basins are further subdivided to smaller sub basins. The plan for artificial recharge is prepared considering the hydrogeological parameters and hydrological data base. The areas feasible for artificial recharge are shown in Fig.13.

8.13.1 IDENTIFICATION OF AREA

The Maharashtra State has been divided into 1506 watersheds. The areas identified for artificial recharge measures is 65267 sq. km which have been compiled into watersheds, talukas and districts. Total 422 watersheds have been identified in the plan for artificial recharge, out of which some of the watersheds are in parts.

8.13.2. SUB-SURFACE STORAGE AND WATER REQUIREMENT

The thickness of available unsaturated zone (below 3 m bgl) is estimated by considering the different ranges of water level. The different range of DTW at 3 m interval are averaged to arrive at thickness of unsaturated zone effectively.

The total volume of unsaturated strata is calculated as 281645 MCM. This volume was then multiplied by average specific yield i.e. 1.5 to 7.0% (0.015 to 0.07) on area specific basis to arrive at 11252 MCM of water required which is to be recharged by artificial recharge.

Based on the experiences gained in the field experiments, an average recharge efficiency of 75% of the individual structure is only possible. Therefore, to arrive at the total volume of actual source water required at the surface, the volume of water required for artificial recharge has been multiplied by 1.33 (i.e. reciprocal of 0.75). 15003 MCM is required as source water to bring depth to water level upto 3 mbgl.

8.13.3. SOURCE WATER AVAILABILITY

The surface water resources available in various basins & sub basins were based on information provided by the state government. The data available for each sub basin included committed runoff, reserved for future planning and surplus water available. The availability of source water was worked out by adding the amount of surface water provided for future planning and surplus available. This availability so worked out is for the entire sub basin and not for the requirement of the areas identified for artificial recharge. Hence, to account for the requirement of identified area, apportioning of surface water availability was done. For planning the artificial recharge structures in each sub basin of Maharashtra, the amount of surface water availability and storage volume was matched to arrive at the feasibility of the scheme. Total 3171 MCM surplus surface water (excluding coastal basins) is available for artificial recharge.

8.13.4. RECHARGE STRUCTURES AND COST ESTIMATES

Hydrogeologically, the areas have been broadly grouped into hard rock and alluvial areas. In hard rock areas i.e. Godavari, Krishna, Coastal basins and part of Tapi-Purna, the surface spreading techniques consisting of percolation tanks and cement plugs/bunds are most appropriate. In alluvial areas i.e. part of Tapi and Purna basins, the percolation tanks in mountain fronts and recharge shaft in alluvial/bazada zone are most appropriate. Accordingly these structures have been recommended for artificial recharge.

Other structures like contour trenches, gabbian structure, nala bunds, village ponds etc. may also be taken up side by side which would be more appropriate for soil and moisture conservation. The under ground bandharas or sub surface dykes are ground water conservation structures and hence be taken up a site specific location to conserve the ground water at appropriate locations.

The amount of surface water considered for planning the artificial recharge is 2318 MCM. Based on the field situation it has been considered that 70% storage would be through percolation tanks and remaining by check dams or recharge shafts. Accordingly 70% of it i.e. 1622 MCM will be stored in percolation tanks, 498 MCM will be stored in Cement plugs/check dams and 198 MCM through recharge shafts. Therefore, 8108 percolation tanks, 16598 cement plugs/check dams and 2300 recharge shafts are proposed in the identified areas of Maharashtra. The percolation tanks should be constructed on second and third order drainage, on favorable hydrogeological and physiographical locations. The cement plugs can be constructed on any order of drainage in hard rock areas. The density of structures per sq.km. is to be planned realistically to make it implementable on practical considerations.

The cost estimate for artificial recharge schemes viz. Percolation tank, cement plug and recharge shaft are worked out based on the experiences gained from central sector artificial recharge studies, it is observed that the cost of recharge schemes depends upon the specific situations. At present the average cost of construction of a PT (100 TCM single filling storage capacity) is around Rs. 20 lakhs. The cost of cement plugs or masonry check dam of 10 TCM single filling capacity is Rs. 2.0 lakh. The average cost of one recharge shaft is Rs. 2.0 lakhs. Therefore, an expenditure of Rs. 2,000 crores is estimated to undertake the construction of proposed recharge structures. The unit cost of storing the water in percolation tanks and cement plugs is worked out as Rs. 11956/- per TCM. The unit cost of recharge from recharge shaft is worked out as Rs. 4166/- per TCM. The plan of artificial recharge is given in Table 19.

8.13.5. AREA BENEFITTED

The impact of artificial recharge to ground water shall be created mainly at the down stream side of recharge structures. This area will normally be maximum during the end of monsoon and a distinct rise in ground water level will be observed as compared to other areas not receiving the additional recharge. It estimated that the maximum influence of recharge schemes proposed in Master Plan would be distinctly observed in around 15600 Sq.Km. area at the monsoon period. A rise of 2 to 5m in water level shall be observed depending upon the quantity of recharge and variation in specific yield. This will also result in saving of energy , as the suction lift of pump sets would be reduced by 2 to 5 m.

The impact of artificial recharge though will be witnessed in around 15600 sq km but the entire area will not be brought under assured irrigation. Therefore the calculation of additional area to be brought under assured irrigation from the proposed recharge schemes has been done. Considering the prevailing cropping pattern the Delta factor of 0.5 m/year is adopted for further calculation.

It is estimated that a total of 3536.00 ha. additional land can be brought under assured irrigation during Rabi & Kharif seasons. The scheme wise additional irrigation from percolation tanks, cement plugs and recharge shafts would be 243300 ha. 74,700 ha and 35,600 ha respectively. This will also provide sustainability to the ground water round the year and dependability on tanker water supply will reduce significantly in proposed areas.

8.13.6 ROOF TOP RAIN WATER AND RUNOFF HARVESTING IN URBAN AREAS

Considering the over all demographic, climatic, hydrogeological, physiographic and socio-economic set up of the urban areas, following recharge techniques are proposed:

1. Roof top rainwater harvesting,
2. Runoff harvesting

These techniques are feasible in densely populated urban pockets where land availability for construction of tanks/reservoirs etc. is almost non-existent. There are 249 urban towns in 30 districts covering about 6214.3 sq.km of the state. The state has three meteropolitan cities namely Mumbai, Pune and Nagpur covering about 15% of urban area of the state. There are 9 municipal corporations and 228 municipalities in the state. The urban population density varies from 751 persons per sq.km in Satara to 16,432 persons per sq.km. in Mumbai. There are 53,25,000 *pucca* houses inuse in the state as per 1991 census. The exact size of individual house is not available, therefore an average roof size is adopted as 50 sq.m. for calculation of roof area. The total urban roof area in Maharashtra works out to be 266.25 sq.km, which is 4.3% of the total urban geographical area. The roof area of 30 district headquarters is 177.25 Sq.km., which is 8.7% of the corresponding geographical area of these districts, headquarter. The roof top area in 3 meteropolitan cities of the state is 10.2% of their geographical areas.

The estimation of water available from roof top harvesting is worked out by multiplying the roof area with normal rainfall data available for monsoon period. The details of district wise roofwater availability worksout to be as 290.8 MCM during monsoon and 12 MCM during non-monsoon period. The above quantity of rainwater is received at rooftop but same is not available down the roof due to various losses in the form of moisture absorption, evaporation losses and leakage etc. Therefore 90% of the above figure is considered available for harvesting the rainwater which will be taken as source for artificial recharge to ground water at feasible locations.

The number of houses in 232 urban areas of the state are around 35,14,500 as per 1991 census. The houses having dug-well or bore-well etc. are targeted for recharging the ground water reservoir through roof top rainwater harvesting. It is observed that on an average only 25% of the houses are having their own well in the premises, which can be utilised for harnessing roof top rain water. The remaining around 8.78 lakhs houses shall be required to be covered under this scheme wherein well for recharge has to be constructed. The average cost expenditure for providing the necessary arrangements through pipe fittings etc. shall cost around Rs. 6000 per house. Thus a total cost of Rs. 527 crores is estimated in the state for roof top rain water recharge.

Runoff Water Harvesting

The rainfall runoff flowing from the roads and open grounds is substantial during rains. This water often creates the water logging and the drainage system is put under stress in the urban agglomerates. This ultimately flows out of the city unutilised. This water if conserved and utilised properly for recharging the ground water reservoir may bring much needed relief to the water scarcity areas of the city. A scheme suitable for artificial recharge in urban area is prepared by C.G.W.B and is successfully implemented and operated at Nagpur Municipal Corporation ground. In this scheme about 15000 sq.m of residential catchment was intercepted and runofff generated was diverted into the specially constructed recharge well in the public garden. The runoff water was filtered silt free by providing a filter pit Number of such locations can be identified within city areas where such structure may be constructed to provide a sustainable ground water based water supply in the city.

It is estimated that in 232 urban areas of Maharashtra around 3500 schemes would be needed with an average of 15 schemes per town/city. This will be around Rs. One lakh. Therefore an expenditure of Rs. 35 crores is estimated. It is estimated that more than 8 lakh additional urban population would get adequate water supply round the year. This will also ensure sustainability of ground water during the peak demand period of summer.

8.13.7. TOTAL COST

The total cost of the recharge structures proposed in rural and urban areas of the Maharashtra in the Plan is Rs. 2562 Crores.

Table-19 Artificial Recharge to Ground Water By Suitable Principal Recharge Using Surface Water Resources.

S. No	Name of the basin	Name of the sub-basin	Volume of surface water considered for planning artificial recharge to groundwater MCM	Resources to be harnessed by						Estimated cost of structures (crores)		
				Percolation tanks (Average Gross Capacity 200 TCM)		Cement Plugs (Average Gross Capacity 30 TCM)		Recharge shaft 30 TCM capacity		Percolation Tanks @Rs.20 lakhs each	Cement Plugs Rs/ 2/- lakhs each	@Rs.2 lakhs each.
				MCM	Nos.	MCM	Nos	MCM	Nos.			
1.	GODAVARI	G-1 Upper Godavari G-2 Pravara G-3 Purna G-4 Manjra	269	188	940	81	2700					
2.		G-7 Penganga	40	28	140	12	400					
3.		G-8 Wardha	203	142	710	61	2033					
4.		G-9 Wainganga	191	134	670	57	1900					
5.		G-10 & G-11 Indravati	8	5	25	3	100					
	Sub Total		711	497	2485	214	7133			497	143	-
6.	KRISHNA	K-154 16 Upper	33	23	115	10	333					
7.		K-17213 Upper Bhima	91	64	320	27	900					
8.		K-19 (Sinna-Bori	368	258	1290	110	3666					
	Sub Total		492	345	1725	147	4899			345	98	-
9	TAPI-PURNA	Hard Rock	305	213	1065	92	3066					
10		Tapi Alluvium	270	189	945	-	-	81	1350			
11		Purna Alluvium	389	272	1360	-	-	117	1950			
	Sub total		964	674	3370	92	3066	198	2300	674	61	46
12	Coastal Basin		151	106	528	45	1500	-	-	106	30	
	Total		2318	1622	8108	498	16598	198	2300	1622	332	46

Total cost Rs. 2000 crores.

8.14 NORTH EASTERN STATES

The north eastern states of India comprises of the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura. The region is mainly a hilly terrain except vast alluvial plains of Brahmaputra and Barak rivers in Assam and small intermontane valleys scattered in other states of the region. Inspite of the world's record of heavy rainfall at Mawsynram near Cherrapunji of Meghalaya, many parts of the region face acute scarcity of drinking water specially during lean period. Table-20 shows the details of the state-wise geographical area, districts, population, nos. of blocks and inhabited villages of the seven states.

Table –20: State-wise Area, Population, Districts, Blocks and Villages

State	Area (Km^2)	Population		No. of districts	No. of blocks	Inhabited villages
		Urban	Rural			
Arunachal Pradesh	83743	864558 (total)		13	56	3649
Assam	78438	2470888	19823674	23	218	24685
Manipur	22327	373215	1038160	6	18	2082
Meghalaya	22429	241333	1094486	7	30	4902
Mizoram	21081	689756 (total)		8	22	699
Nagaland	16579	120234	654696	7	28	1112
Tripura	10486	2053058 (total)		4	10	-
TOTAL	2,55,083	2,94,24,058		68	382	37129

Ground water occurs alluvial terrain under unconfined to semi-confined conditions and the depth to water level rests within 5 meters below ground level. Groundwater occurs in the Bhabar zone of Arunachal Pradesh and Assam under unconfined to semi-confined conditions and depth to water level rests within 15m.

In the southern part of Arunachal Pradesh, in parts of Manipur, Mizoram, Nagaland, Tripura, West Garo Hills semi-consolidated Tipam sandstone of Tertiary age forms potential aquifer. Ground water occurs in this formation under semi-confined to confined conditions and depth to water level ranges from 5 to 10m. The hard rock terrain includes high hill ranges of Arunachal Pradesh, high land plateau of Meghalaya, Karbi-Anglong, N.C. Hills and the inselberg areas of Assam. Quartzite, phyllite, granite gneiss and schists are the rock types. Ground water occurs in the secondary porosity developed by fractures, joints, gneissosity and schistosity under unconfined to semi-confined conditions.

8.14.1. RECHARGE STRUCTURES AND COST ESTIMATES

Physiographically the major parts of North Eastern States are hilly with localised small valleys through which the entire run off passes. As the area is hilly with high slope the major part of the rainfall is lost in surface runoff. Apart from this the small rivers, nallas also act as carriers for base flow, spring water. In spite of good rainfall of more than 2000mm in hilly areas there is acute shortage of water specially during the summer. Further availability of water is restricted in these streams only. Thus the water in the streams should be harvested for irrigation and domestic needs through the following structures:

Considering the physiography, rainfall, and hydrogeology of the area aresa were identified for artificial recharge structures (Fig.14). 2650 check dams, 5100 weirs, and 6100 gabbion structures are recommended as per following statewise breakup (Table.21). The unit cost of Check dams, Weirs and Gabion Structure has been considred as Rs.10 lakh, Rs.2 lakh and Rs.0.2 lakh respectively.

Table – 21. Artficial Recharge Structures and Cost Estimates

State	Check Dams		Weirs		Gabion Structures		Total Cost Rs. (Lakh)
	Total No	Total Cost Rs. (Lakh)	Total No	Total Cost Rs. (Lakh)	Total No	Total Cost Rs. (Lakh)	
Arunachal Pradesh	500	5000	1000	2000	1000	200	7200
Assam	250	2500	500	1000	1000	200	3700
Manipur	300	3000	500	1000	500	100	4100
Meghalaya	300	3000	600	1200	600	120	4320
Mizoram	500	5000	1000	2000	1000	200	7200
Tripura	300	3000	500	1000	1000	200	4200
Nagaland	500	5000	1000	2000	1000	200	7200
TOTAL	2650	26500	5100	10200	6100	1220	37920

8.14.2 ROOF TOP RAIN WATER HARVESTING IN URBAN AREAS

Rainfall of 1500mm per year is very common in the North Eastern States and for hamlet roof of 10 m^2 the rainfall potential will be 15 m^3. Considering the loss due to evaporation,first wash, spillage etc. as 20% the net available rain water works out for 10 m^2 roof top area as 12 m^3.Thus the net roof top harvest storage is sufficient to cater the drinking water requirement of a family of five even if they have roof top area of 10m^2.

In the states there are 2100 schools and 420 Govt. buildings with an average roof area of 100 and 200 sq m respectively where roof top rainwater harvesting can be started as community rain water harvesting system to meet the daily drinking water requirement. Considering an average cost of 1.5 lakh for each building a total cost of Rs. 37.8 crores is required for harvesting 5,33,000 m^3 of water (Table – 22). The average life of the structures constructed scientifically will be around 20 years. The cost of 1 ltr. of water will be 28 paisa. However, the cost will be decreased/compensated by using the local materials. The extra cost for energy for pumping of water will be saved and health hazard due to use of improved water will be avoided.

Table – 22. Estimate for Roof Top Rainwater Harvesting in NER

State	Nos of Buildings		Total area in sq. m	75% of average rainfall (m)	Volume of water harvested	Total cost Rs. (Lakh)
	Govt.	School				
Arunachal Pradesh	80	400	56000	2.25	126000	720
Assam	100	500	70000	1.5	105000	900
Manipur	50	250	35000	1.5	52500	450
Meghalaya	50	250	35000	2.25	78750	450
Mizoram	50	250	35000	2.1	73500	450
Nagaland	50	250	35000	1.5	52500	450
Tripura	40	200	28000	1.6	44800	360
Total	420	2100	294000		533050	3780

8.14.3 DEVELOPMENT OF SPRINGS

The seven North Eastern States experience heavy to very heavy rainfall ranging from annual 2000mm to 3000mm. Emergence of spring is very common but they are far from the settlement. These springs can be developed scientifically for providing safe drinking water to the rural people. Presently rural people are to walk long distance in rugged terrain to fetch drinking water. Moreover, at times the spring water becomes polluted due to bathing and washing of clothes.

It is estimated that in North Eastern States there are about 1400 numbers of springs. Considering an average discharge of 2 lps per spring, the springs can be developed safely at an estimated cost of Rs. 70 crores. By doing so it is estimated that 8.82 MCM will be made available for drinking and other purposes. Generally the life of such structure is 20 years. Its is estimated that it will cost Rs. 4/- per m^3 of water. Thus the extra cost of energy will be saved and solve the health hazard caused by the use of polluted water by the local community. Table-23 gives the details of calculation of total cost for development of 1400 springs of North Eastern States.

Table –23. Estimate For Development of Spring in NE States

State	Area (km^2)	No. of spring	Average discharge (lps)	Annual discharge (m^3)	Unit cost Rs. (lakh)	Total cost Rs. (lakh)
Arunachal Pradesh	83743	300	2 lps	6300	5	1500
Assam	78438	250	2 lps	6300	5	1250
Manipur	22327	150	2 lps	6300	5	750
Meghalaya	22429	200	2 lps	6300	5	1000
Mizoram	21081	200	2 lps	6300	5	1000
Nagaland	16579	200	2 lps	6300	5	1000
Tripura	10486	100	2 lps	6300	5	500
TOTAL		1400				7000

8.14.5. TOTAL COST

Table-24 gives the summarised cost estimate for various types of structures feasible in North Eastern states which works out to Rs.487crore.

Table -24. Cost Estimate for various structures in North Eastern Region

Type of structure	Total No.	Unit cost Rs. (lakh)	Total cost Rs. (lakh)
1. Check Dams	2650	10.0	26500
2. Nala Bund/Weir	5100	02.0	10200
3. Gabion Structure	6100	0.2	1220
4. Roof Top Rainwater Harvesting	2520	1.5	3780
5. Spring Development	1400	05.0	7000

TOTAL = Rs.487 crores.

8.15 ORISSA

The state of Orissa with an areal extent of 1,55,707 sq. km is drained by 11 principal rivers, among which Mahanadi is the largest. These are grouped under eight major river basins within the state. Physiographically the state is divided into five distinct units namely coastal plains, northern uplands, the erosional plains of Mahanadi valley, south western hilly regions and subdued plateaus.

8.15.1 IDENTIFICATION OF AREA

The areas sowing DTW more than 6 m below ground level are taken as first criteria for demarcation of feasible areas for artificial recharge purpose. Areas having depth to water level between 4-6 m bgl with appreciable decline (> 0.1 m/year) are also considered. Total 8095 sq. km area in 16 districts of the state has been identified for artificial recharge (Fig– 15)

8.15.2. SUBSURFACE STORAGE SPACE AND WATER REQUIREMENT

The volume of water to be added for the optimal recharge of the aquifer in these pockets can be calculated by multiplying the volume of aquifer with the specific yield value of that particulars aquifer. The specific yield values of the major types of aquifers are taken from 0.003 to 0.1. Total sub surface storage potential in the vadose zone is estimated as 334 MCM in the state.

Based on the experiences gained in the field experiments and ground conditions, 100% water stored at surface do not reach to the aquifer due to various losses. Therefore, surface water requirement shall be higher than the subsurface storage available. This has been estimated depending upon local situation and type of artificial recharge techniques. Total volume of surface water required is 406.0MCM for the state (Table – 25).

8.15.3 SOURCE WATER AVAILABILITY

A total of 4552 MCM surface water is available in the state against the requirement of 406 MCM for artificial recharge. This is around 9% . Therefore source water availability would not be problem.

Table - 25: Surface Water Availability and Requirement

S. No	District Name	Area suitable for artificial recharge purpose (km^2)		Volume of aquifer to be recharge (MCM)	Specific yield	Sub-storage potential in MCM	Total volume of surface water required for Artificial Recharge (MCM)	Total surface water availability (MCM)
		Total	Breakup					
1	Malkangiri	160	160	480	0.02	9.6	11.46	88.4
2	Koraput	1500	1400 100	4200 500	0.003 0.02	12.6 10.0	32.9	555.0
3	Nowarangpur	180	100 80	77 64	0.003 0.02	0.231 1.28	2.48	66.6
4	Rayagada	1000	500 300 200	1908 900 800	0.003 0.02 0.03	5.724 18.0 24.0	58.7	510.0
5	Gajapati	275	175 70 30	690 225 100	0.003 0.003 0.02	2.07 0.675 2.0	7.1	118.0
6	Phulbani	1700	1200 500	4610 1500	0.003 0.02	13.83 30.00	59.9	1090.0
7	Kalahandi	660	160 500	520 575	0.003 0.03	1.56 17.25	23.02	515
8	Nuapara	80	80	56	0.03	1.68	1.9	62.4
9	Bargarh	240	240	745	0.02	14.9	17.83	187
10	Sundergarh	780	780	2800	0.02	56.0	67.18	615.0
11	Keonjhar	240	100 40 100	430 120 300	0.003 0.02 0.02	1.29 2.4 6.0	11.08	103.0
12	Mayurbhanj	660	440 220	1365 620	0.003 0.05	4.1 31.0	40.05	151.8
13	Kendrapara	140	140	102	0.1	10.2	11.55	109.2
14	Dhenkanal	160	70 60 30	230 130 23	0.03	11.5	13.83	131.2
15	Khurda	160	60 60 40	190 125 57	0.03	11.16	12.6	124.8
16	Puri	160	160	350	0.1	35.0	39.39	124.8
	Total	8095				334.05	406.0	4552.2

8.15.4 RECHARGE STRUCTURES AND COST ESTIMATES

Physiograpahy, hydrogeology and hydrology control the feasibility of structures in a particular area. The recharge structures recommended and their weightage is given in Table-26 depending upon the physiography and hydrogeology.

Table-26 Artificial Recharge Structures and their weightage.

Sl. No	Description of the location	Percolation tank	Sub surface dyke	Nala/ contour bunding	Check dams & weirs	Water spreading and flooding	Induced recharge	Recharge shaft
1.	Hilly areas> 600m elevation Mod-high slope.	15%	15%	70%				
2.	High land areas 9300-600m elevation plateaus & hills	50% (50%)	25%	25% (25%)		(25%)		
3.	Midland areas With rolling Topography (50-300m) elevation	40% (55%)	15%	15% (15%)	15% (15%)	15% (15%)		
4.	In un-consolidated to semi Consolidated Formations.	25% (40%)			30% (30%)	15% (20%)	15% (10%)	15%

Note:-

50% of recharge allocated for percolation tank is planned to be met by modifying storage tank into percolation tank.

Induced recharge and water spreading structures are complementary to check dams and weirs, as they do not have surface water impounding facilities.

The weightage given in brackets are applicable for artificial recharge to improve ground water quality.

Based on Table 25 & 26, the No. of structures to be constructed district wise is worked out taking average gross capacity of one percolation tank as 200 TCM, Nala/contour Bunding/check dam as 150 TCM, check weir is 150TCM, Recharge trench as 60 TCM and subsurface dyke as of 60 TCM in multiple fillings.

The cost budgeted for each structure is calculated and is given in Table 27 along with unit cost of each scheme. The total amount required for the artificial recharge purpose for augmentation of ground water recharge is calculated to be Rs. 414 crores.

Table-27 Cost of Artficial Rechareg Structure

Sl. No.	Structure	Total Number	Average Cost of each.in Rs lakhs	Total cost in Rs. (crores)
1.	Percolation Tank	569	20.0	113.80
2.	Conversion of storage tank to percolation tank	761	10.0	76.10
3.	Sub surface dyke	698	10.0	69.8
4.	Nala/Contour Bunding	809	5.0	40.45
5.	Check dam/weir	679	5.0	33.95
6.	Water spreading/flooding	1981	2.0	39.62
7.	Induced recharge	668	5.0	33.4
8.	Recharge shaft	334	2.0	6.68
	Total			413.76

8.15.5. ROOF TOP RAIN WATER HARVESTING IN URBAN AREAS

In urban areas of the state, it is proposed to have roof top rainwater harvesting in 1 lakh buildings. The cost of these is estimated as Rs. 100 cores @ Rs. 10,000/- each on an average.

8.15.6. TOTAL COST

Total cost of artificial recharge schemes and roof top rain water schemes in the state is estimated as Rs. 514 crores.

8.16 PUNJAB

The state of Punjab forms part of Indus basin. It has further been subdivided into four sub basins viz. Ravi, Beas, Satluj and Ghaggar. The plan for artificial recharge is prepared considering the hydrogeological parameters and hydrological data base.

8.16.1 IDENTIFICATION OF AREA

Based on depth to water level and ground water level trend the areas of four categories are demarcated on map and feasible areas are identified for artificial recharge to ground water (Fig – 16). In the state 22750 sq. km area is identified in four basin and maximum area is found in Satluj basin.

8.16.2. SUBSURFACE STORAGE SPACE AND WATER REQUIREMENT

The thickness of available unsaturated zone (below 3-m bgl) of above four categories is estimated by considering the different ranges of water levels. The different range of depth to water at 3 m interval are averaged to arrive at thickness of effective unsaturated zone. The total volume of unsaturated strata is calculated by considering the above categories and unsaturated thickness of different range. This volume than multiplied by average specific yield of 15% (0.15 as fraction) to arrive at the net amount of water required to be recharged by artificial methods to saturate the aquifer upto 3 m bgl . This is estimated as 18864 MCM

After assessing the actual volume of water required for saturating the vadose zone, the actual requirement of source water is to be estimated. Based on the experience gained in the field experiments, an average recharge efficiency of 75% of the individual structure is only possible. Therefore, to arrive at the total volume of actual source water required at the surface, the volume of water required for artificial recharge is calculated and multiplied by 1.33 (i.e. reciprocal of 0.75) . The sub basin wise requirement of water has been given in Table- 28. Total 25,089 MCM surface water is required in the state for artificial recharge.

Table 28: Requirement And Availability Of Surface Water Resources For Artificial Recharge To Ground Water In Sub-Basins Of Punjab

S.No.	Name basin	Area identified for artificial recharge (Km^2)	Sub- surface storage potential (MCM)	Surface water requirement reciprocal of 75 % efficieccy (MCM)	Proportionate non committed water resources available as surplus/ kept for future planning (MCM)
1	Ravi	1500	1053	1401	228.70
2	Beas	4800	3645	4848.50	448.70
3.	Satluj	16450	12702.50	16893	293.80
4.	Ghaggar	3900	1463	1946	229.70
	Total	22,750	18,863.5	25,088.5	1,200.9

8.16.3 RECHARGE STRUCTURES AND COST ESTIMATES

The amount of surface water considered for the artificial recharge is 1201 MCM/annum. The average intake capacity of the recharge structure is 0.03 MCM/annum. Therefore total number of structures required to recharge 1201 MCM will be 40030. The sub-basin wise, number of structures feasible has been given in Table-29.

TABLE 29 : Artificial Recharge Structure and Cost

S.No.	Name of basin	Amount of surface water considered for A.R. (MCM)	Total cost in Rs. (Lakh)	Total cost in Rs. (Lakh)
1	Ravi	228.7	7623	7623
2	Beas	448.7	14957	14957
3.	Satluj	293.8	9793	9793
4.	Ghaggar	229.7	7657	7657
	Total	1200.9	40030	40030

Based on physiography and hydrogeology the state can broadly be classified into two groups viz. flat alluvial area and hilly consolidated and semi consolidated area. In alluvial area, which cover 90% of the area of the state. The structures feasible for artificial recharge are recharge shafts, lateral trench with injection wells and trenches. The recharge strucutures feasible in hilly area are check dams, gabbion structures and nala bunds. The rain water run off available in the state usually contain silt contents. Therefore, recharge structures using rainfall run off as source must have the provision to make water silt free to avoid clogging of aquifers.

The principal recharge structures feasible in the state are vertical and lateral shaft with injection wells filled with inverted filter. Based on the experience gained from centrally sector artificial recharge studies, it is observed that cost of recharge schemes depend upon the hydrogeological condition. At present average cost of a recharge shaft with inverted filter and pipes etc. cost around Rs. one lac. The total cost of Rs. 40030 recharge structures required to recharge the surplus surface runoff is Rs.400.30 crores. The sub basin wise number of structures feasible and cost has been given in Table – 29.

8.16.4. AREA BENEFITED

The impact of artificial recharge to ground water will be mainly all around the structures due to gradient of water table. The impact will be maximum during post monsoon period and a distinct rise in ground water level will be observed in the recharge area as compared to area not receiving the additional recharge. it is estimated that influence of recharge scheme as proposed in Master Plan will be observed in about 22750 Sq. Km. area and it will help to check in decline in water level. There will be rise in water level locally and mound will be formed around the recharge structures temporarily and ground water will flow in all the directions, which will dissipate after wards. This will result in saving of energy, due to reduction in pumping lift.

8.16.5 RAINWATER HARVESTING IN URBAN AREAS

Considering physiography, climate hydrogeological and socio-economic set up of the urban areas, following techniques are proposed for ground water recharge

1. Roof top rain water harvesting.

2. Artificial recharge from treated sewage water.

Roof Top Rain Water Harvesting

In Punjab state there are 120 urban agglomeration classified as towns, out of these in 64 towns, the water level is declining and as such are considered for artificial recharge.

The total number of houses in these towns are around 6,93,420. If 50 Sq.m is considered to be rooftop area of one house, the total rooftop area is 3,46,71,000 Sq.m. The total rooftop area in urban areas of the state is 3,46,71,000 Sq.m. from which a total 21.282 MCM rooftop rainwater can be available during monsoon and 6.03 MCM during non- monsoon period. The total availability of water per year is about 27.311 MCM, out of this 10% is lost in evaporation etc. and thus 24.58 MCM of water is available for recharge. To recharge 24.58 MCM of water 12800 recharge structures will be required at the cost of 128 crores.

Artificial Recharge From Treated Sewage Water

Besides rainfall, ample scope also exists to recharge treated sewage water, which is disposed away from the towns without any purposeful gain. The treated sewage water can also be used as source for artificial recharge after ascertaining the suitability of chemical quality. In Ludhiana, Jalandhar and Amritsar towns, the sewage treatment plants are under construction and the water of these plants can be used for artificial recharge on their completion.

Benefits Of Recharge In Urban Areas

The per capita consumption of water in urban areas ranges between 80 to 130 lts per capita per day. As per the data available, an average of 105 lts per day per capita is supplied in the urban areas of the Punjab state. The total annual requirement of water for domestic purpose is of the order of 230 MCM. If additional 1201 MCM water is recharged, it will meet the requirement for domestic water supply in urban areas and will provide sustainability of ground water resource which are under highly stressed condition due to over exploitation.

8.16.6 TOTAL COST

The cost of artificial recharge for surplus monsoon runoff of 1201 MCM will be Rs.400.30 crores. The cost to harvest rainwater from roof top of urban areas will be Rs.128 crores. Thus the total cost for implementing artificial recharge schemes in the state will be of the order of Rs. 528.30 crores.

8.17 RAJASTHAN

Rajasthan is the driest and most water deficient state of India with aridity becoming more severe in the areas west of Aravalli ranges, which form the main water divide of the state. The state is divided into 14 river basins, which cover eastern, northern and southern river catchments. Luni is the only river west of Aravalli and in remaining Western Rajasthan the drainage is internal in the desert sand.

8.17.1. IDENTIFICATION OF AREA

The areas feasible for artificial recharge have been demarcated into following three categories:

Areas showing declining trend (more than 0.2m/yr) and water level between 3 and 9 m bgl.

Areas showing declining trend (more than 0.1m/yr) and water level between 9 and 20m bgl

Water level more than 20m bgl

The areas of above three categories cover 39,120 sq. km of the state as shown in Fig-17

8.17.2 SUBSURFACE STORAGE SPACE AND WATER REQUIREMENT

The thickness of available unsaturated zone (below 3 mbgl) of above 3 catagories is estimated by considering the different ranges of water level. The total volume of unsaturated strata is calculated by considering and unsaturated thickness of different ranges. This volume is than multiplied by average specific yield of different aquifers to arrive at the net amount of water required which is to be recharged by artificial recharge to saturate the aquifer upto 3 mbgl. The storage space available in the feasible areas of the state is 32921 MCM.

Assessment of actual volume of water required to saturate the vadose zone has been worked out. An average recharge efficiency of 75% of the individual structure is considered in the computation 86 MCM of surface water is required to saturate the vadose zone of the feasible areas.

8.17.3 SOURCE WATER AVAILABILITY

As per the Tahal-WAPCOS report on Water Resources Planning for State of Rajasthan a total of 14747 m^3/yr of surface water goes unutilized from 14 river basins considering total availability and committed surface water resources. Proportionate surface water availability, in identified area has been worked out and has been considered for planning the artificial recharge structures.

The amount of surface water considered for planning the artificial recharge is 860.9 MCM. Plan proposes that 75% of it i.e. 645 MCM will be stored in percolation tanks, 15% i.e. 129 MCM will be stored in anicuts and the rest 10% i.e. 86.1 MCM through recharge shafts. Therefore, a total of 3228 percolation tanks, 1291 Anicuts and 2871 Recharge Shafts are proposed in the identified areas of Rajasthan for artificial recharge.

8.17.4. RECHARGE STRUCTURES AND COST ESTIMATES

Most of the artificial ground water recharge structures will be located in such areas where the stage of groundwater development is either overexploited or critical caused by excessive development of groundwater resulting in sharp decline in water level. A total number of 3228 percolation tanks, 1291 Anicut and 2871 recharge shafts are proposed (Table-30). Average cost of construction of a percolation tank of 200 TCM single filling storage capacity, Anicut average capacity of 100 TCM and recharge shaft of average capacity of 30 TCM has been considered in the computation. A total of Rs. 739.6 Crores is estimated to undertake the construction of proposed recharge structures. (Table -30).

8.17.5. AREA BENEFITTED

The expected benefits from the construction of artificial recharge structures will be within39120 sq. km. Assured irrigation to be brought by percolation tank shall be in around 96848 ha, by Anicuts 4370 ha and by recharge shafts 15498 ha. Therefore total 116716 ha of additional land could be brought under assured irrigation in the feasible areas by considering delta factor as 0.5.

8.17.6. ROOF TOP RAIN WATER HARVESTING IN URBAN AREAS

There are many urban towns in the state where around 4 lakh houses are proposed to be taken up for roof top rain water harvesting using the existing dug well / bore well / tube wells. An average expenditure of Rs. 10,000/- would cost Rs. 400 crores towards rooftop rainwater harvesting in the state.

8.17.7. TOTAL COST

Total cost of artificial recharge schemes in the state including roof top rainwater harvesting is Rs. 1140 crores.

Table30 :- Artificial Recharge To Ground Water By Suitable Recharge Structures Using Surface Water Resources.

Sl No	Name of Basin	Volume of Surface Water Considered for Planing of Artificial Recharge to Ground Water MCM	Resource To Be Harnessed By						Estimated Cost of Stuctures (Rs. In crores)		
			Percolation tanks (Average capacity 0.2 MCM)		Anicut (Average capacity 0.1 MCM)		Recharge Shaft (Average capacity 0.03 MCM)		Percolation Tank	Anicut	Recharge Shaft
			MCM	No.	MCM	No.	MCM	No.			
1.	SHEKHAWATI	21.600	16.20	81	3.24	32	2.16	72	16.200	0.480	1.872
2	BANGANGA	25.650	19.24	96	3.85	39	2.57	86	19.200	0.585	2.236
3	SABI	21.600	16.20	81	3.24	32	2.16	72	16.200	0.480	1.872
4	BANAS	302.100	226.58	1133	45.32	453	30.21	1007	226.600	6.795	26.182
5	CHAMBAL	310.224	232.67	1163	46.53	465	31.02	1034	232.600	6.975	26.884
6	LUNI	54.000	40.50	203	8.10	81	5.40	180	40.600	1.215	4.680
7	WEST BANAS	45.150	33.86	169	6.77	68	4.52	151	33.800	1.020	3.926
8	SUKLI	13.800	10.35	52	2.07	21	1.38	46	10.400	0.315	1.196
9	OTHER NALA	6.450	4.84	24	0.97	10	0.65	22	4.800	0.150	0.572
10	MAHI	60.288	45.22	226	9.04	90	6.03	201	45.200	1.350	5.226
	TOTAL	860.862	645.65	3228	129.13	1291	86.10	2871	645.600	19.365	74.646

GRAND TOTAL RS. 739.6 Crores.

8.18 SIKKIM

Sikkim State having an area of 7096 sq km., is drained by perennial Tista and Rangit rivers. The major river Tista, originates from Tista-Khangse glacier and passes through the area. Although there is negligible ground water development in the State of Sikkim, still there is scope for artificial recharge to ground water through construction of nala bunds, gabions etc. which may augment the springs.

8.18.1. IDENTIFICATION OF AREA

The proposed structures through rain water harvesting may act both for ground water replenishment and conservation and are generally adopted in this hilly State to provide –

a. assured water supply during non-rainy seasons, and

b. to provide sustainability to springs whose discharge reduces considerably during non rainy season.

c. In order to harness rainfall for the above purpose the following structures are proposed:

The State is dotted with number of springs which are mainly structurally controlled. These springs can be developed for providing water. The spring water can be transported under gravity for drinking water supply and irrigation. In order to provide sustainability some recharge structures at higher elevation can be constructed e.g. gabions, nala bunds, etc.(Fig-18).

8.18.2 RECHARGE STRUCTURES AND COST ESTIMATES

Gabion structure – In 1st or 2nd order streams to control siltation and also to harness surface water in stream beds.

Nala bunds/cement plugs - In 1st or 2nd order streams to control siltation and also to harness surface water in stream beds.

Roof top rain water harvesting– Rain water may be harvested directly through roofs and the accumulated water may be conserved for day to day use. Since the State receives considerable amount of rainfall, such structures may be highly useful especially during the non-rainy months.

A plan for development and augmentation of ground water resources in the State is envisaged and it is contemplated that 2100 springs development, 69,596 roof top rain water harvesting structures, 2500 of cement plugs and nala bunds and 5300 gabion structures may be constructed in the state which would harness 44.08 MCM of water and would require a fund of Rs.172 lakhs for construction purposes (Table-31).

Table – 31. Rainwater Harvesting Structures and Cost

Type of structure	No. of structure	Total cost (Lakh Rs.)	Total volume of water harvested (MCM)	Life of structure (in years)
Spring Development	2100	4200	11.58	20
Gabions	5300	1060	10.6	5
Cement Plug / Nala bund	2500	5000	12.5	20
Roof top rain water harvesting	69596	6960	9.4	20
Total	**75496**	**17220**	**44.08**	

8.19 TAMIL NADU

Tamil Nadu spreads over an area of 130058 sq.km and has been divided into 29 districts, which are further sub-divided into 384 blocks. The State of Tamil Nadu, along with the enclaves constituting the Union Territory of Pondicherry is characterised by diverse climatic, physiographic, and hydrogeologic conditions. The state receives rainfall during south west monsoon (June – October) & northeast monsoon (November – December) and the normal annual rainfall is of the order of 1008.1 mm (1901 – 1950). The contribution from south west monsoon is of the order of 525.1 mm (52%), while the contribution from north east monsoon is of the order of 28% and non monsoon rainfall (January – May) is of the order of 200.5 mm (20%). The ground water development scenario of the state is also very complex. Increasing demand and vagaries of rainfall, coupled with the near-total utilistion of available surface water resources have resulted in increasing dependence on ground water as the major source for domestic, agricultural and industrial sectors. Development of ground water has already reached a critical stagein 102 blocks of the state. over exploitation of ground water in these areas has resulted in declining ground water levels, shortage in water supply, increased pumping lifts and consequent increase in power consumption.

In several areas of the state where rainfall is high, considerable variability of rains in terms of their onset, distribution and amount over space and time result in uncertainty about availability of water for rainfed crops. In hilly terrain, steep slopes result in heavy runoff and low infiltration, resulting in shortage of water duing summer season. In all such areas, there is an urgent need to take steps for augmentation of ground water resources through appropriate techniques to provide assured supply of water for irrigation, industrial and domestic needs.

8.19.1 IDENTIFICATION OF THE AREA

The area characterised by depth to water level more than 3 m during the post monsoon period coupled with declining long term trend (Decade) is considered as area requiring artificial recharge. The scope for artificial recharge denotes the surface water availability & the ability of the aquifer to take in the water.

The area characterising, both declining trend and depth to water level in different categories, for each district has been determined and 17,293 sq. km area have been identified for artificial recharge to ground water in Tamil Nadu (Fig. 19)

8.19.2 SUBSURFACE STORAGE SPACE AND WATER REQUIREMENT

The thickness of unsaturated zone for each category of depth to water level is arrived at by averaging the limits of each zone and subtracting 3 m from the average so that the balance represents the unsaturated zone upto 3 m bgl. In case of the zone characterised by depth to water level more than 9 m, the average of 9 m and 20 m in considered, as most of the places have water level down to 20 m or above and 3 m is subtracted to get the unsaturated thickness upto 3 m bgl. Average specific yield of 1.5% & 10% has been assumed for crystallines & sedimentary formations respectively.

The field experiments have shown that an average recharge efficiency of 75% of each structure is only possible, accordingly, the surface water required for artificial recharge is computed by multiplying the volume of water required for saturating the aquifer upto 3 m bgl by 1.33. Volume of available sub surface storage is of the order of 2704.68 MCM and surface water requirement is of 3597.22 MCM. The source water availability is of the order of 26834.32 MCM and it is noticed that source water availability is adequate to saturate the aquifer upto 3 m bgl in all the districts.

8.19.3 SOURCE WATER AVAILABILITY

The surface water availability has been computed using improved strange curve for each watershed in a project entitled "Identification of Recharge areas Using Remote Sensing and GIS in Tamil Nadu, taken up by the Institute of Remote Sensing, Anna University, Chennai and sponsored by the Dept. of Rural Development, Govt. of Tamil Nadu and Tamil Nadu Water Supply and Drainage Board. The same has been utilised in this report for determining the surface water availability for each district. The map of area identified for artificial recharge has been superimposed over the block map and the blocks covering the critical area either full or in part has been identified and the harnessable surface water for each of the blocks have been summed up to get the surface water availability for each district.

8.19.4 RECHARGE STRUCTURES AND COST ESTIMATES

Tamil Nadu state has varied hydrogeological conditions. However, as an attempt is being made to saturate the shallow aquifer, percolation ponds and check dams will be appropriate structures to plan for artificial recharge to ground water in a regional scale. It has been considered that 70% of available sub surface storage would be recharged through percolation ponds and remaining 30% through check dams.

In Cuddalore district, the terrain is not suitable for check dam and hence only percolation ponds are recommended.

The capacity of percolation ponds is taken as 0.1 mcm (100 TCM) with a recharge efficiency of 75%, while the capacity of check dam is taken as 0.01 mcm (10 TCM) with a recharge efficiency of 75% (Source: Country wide experiments conducted by CGWB). In Tamil Nadu, it is expected that percolation ponds will get 3 fillings while the check dams will have 5 fillings.

The details of computations in respect of number of artificial recharge structures required for Tamil Nadu is given in Table – 32. A perusal of the table shows that 8612 percolation ponds and 18170 check dams will be required to store 3040.37 MCM of water for recharge.

The average cost of percolation pond of above mentioned capacity is Rs. 20 lakhs, while the cost of check dam of above mentioned capacity is Rs. 2 lakhs. The cost estimate has been computed for the artificial recharge schemes and is given in Table.33. A perusal of the table shows that Rs. 1722.4 crores is required for construction of percolation ponds while Rs. 363.4 crores is required for construction of check dams. Thus the plan of artificial recharge will involve a total expenditure of Rs. 2086 crores.

Table 32: Artificial recharge to Ground water by Recharge Structures

S. No	District	Volume of surface water requirement for Artificial Recharge* (MCM)	Artificial Recharge Structures Proposed				Quantum of water proposed to be recharged (MCM)
			Percolation Pond		Check Dam		
			Total volume of water (MCM)	Number of structures	Total volume of water (MCM)	Number of structures	
1	2	3	4	5	6	7	8
1	Tiruvallur	0.00	0.00	0	0.00	0	0.00
2	Chennai	0.00	0.00	0	0.00	0	0.00
3	Kancheepuram	0.00	0.00	0	0.00	0	0.00
4	Vellore	272.35	190.65	635	81.71	1634	272.35
5	Tiruvannamalai	23.68	16.58	55	7.10	142	23.68
6	Dharmapuri	0.00	0.00	0	0.00	0	0.00
7	Erode	185.65	129.96	433	55.70	1114	185.65
8	Nilgiris	0.00	0.00	0	0.00	0	0.00
9	Coimbatore	673.07	471.15	1571	201.92	4038	673.07
10	Namakkal	347.11	242.98	810	104.13	2083	347.11
11	Salem	`40.26	28.18	94	12.08	242	40.26
12	Villupuram	0.00	0.00	0	0.00	0	0.00
13	Cuddalore **	350.10	245.07	817	0.00	0	148.65
14	Nagappattinam	0.00	0.00	0	0.00	0	0.00
15	Tiruvarur	0.00	0.00	0	0.00	0	0.00
16	Thanjavur	0.00	0.00	0	0.00	0	0.00
17	Perambalur	8.24	5.77	19	2.47	49	8.24
18	Tiruchchirappalli	23.68	16.58	55	7.10	142	23.68
19	Karur +	38.30	26.81	89	11.49	230	38.30
20	Dindigul	149.41	104.59	349	44.82	896	149.41
21	Theni	38.41	26.89	90	11.52	230	38.41
22	Virudhnagar	179.37	125.56	419	53.81	1076	179.37
23	Madurai	68.37	47.86	160	20.51	410	68.37
24	Sivagangai	264.08	184.86	616	79.22	1584	264.08
25	Pudukkottai	0.00	0.00	0	0.00	0	0.00
26	Ramanathapuram	0.00	0.00	0	0.00	0	0.00
27	Tuticorinn	107.91	75.54	252	32.37	647	107.91
28	Tirunelveli	171.03	119.72	399	51.31	1026	171.03
29	Kanyakumari ***	656.19	524.95	1749	131.24	2625	300.79
	Total	**3597.22**	**2583.67**	**8612**	**908.52**	**18170**	**3040.37**

* If Surface water requirement is more than the surface water availability, surface water availability has been considered for computation of number of artificial recharge structures.

The area of influence of percolation pond is taken as 1 sq. km, if number of percolation ponds required exceeds the limit of density of 1 per sq. km the number of percolation ponds recommended has been restricted to the density of 1 per sq. km

** In Cuddalore district, the terrain is relatively a flat terrain, with no scope for check dam & hence only percolation ponds are considered.

*** In Kanyakumari district, the density of check dam is exceeding the limit of 5 per sq. km & hence the distribution is taken as 80% for percolation pond & 20% for check dam. In such combination, the number of percolation ponds has been restricted to density of 1 per sq. km

+ Karur District data in respect of harnessable Surface water availability is not readily available as Bharathithasan University, Tiruchchirapalli has carried out the same study for this district. Hence, the requirement has been considered as availability as the requirement is very less.

Table 33: Cost of Artificial Recharge Structures

S.No	District	Artificial Recharge structure		Total cost Rs. (lakhs)
		Percolation pond (@ Rs.20 lakhs)	Check Dam (@ Rs. 2 lakhs)	
1	2	3	4	5
1	Tiruvallur	0	0	0
2	Chennai	0	0	0
3	Kancheepuram	0	0	0
4	Vellore	12700	3268	15968
5	Tiruvannamalai	1100	284	1384
6	Dharmapuri	0	0	0
7	Erode	8660	2228	10888
8	Nilgiris	0	0	0
9	Coimbatore	31420	8076	39496
10	Namakkal	16200	4166	20366
11	Salem	1880	484	2364
12	Villupuram	0	0	0
13	Cuddalore **	16340	0	16340
14	Nagappattinam	0	0	0
15	Tiruvarur	0	0	0
16	Thanjavur	0	0	0
17	Perambalur	380	98	478
18	Tiruchchirappalli	1100	284	1384
19	Karur +	1780	460	2240
20	Dindigul	6980	1794	8772
21	Theni	1800	460	2260
22	Virudhnagar	8380	2152	10532
23	Madurai	3200	820	4020
24	Sivagangai	12320	3068	15388
25	Pudukkottai	0	0	0
26	Ramanathapuram	0	0	0
27	Tuticorinn	5040	1294	6334
28	Tirunelveli	7980	2052	10032
29	Kanyakumari ***	34980	3250	38230
	Total	172240	36340	208580

Say 2086 crores

8.19.5. AREA BENIFITTED

The impact of artificial recharge to ground water shall be created mainly downstream of recharge structures. the impact will be seen immediately after the monsoon and there is likely to be a rise of water level by 2 – 5 m which will result in the saving of energy expenditure due to reduction in suction lift. The impact will be felt over 17000 sq. km.

The amount of water proposed to be recharged is 3040.37 mcm, out of which, it is presumed that 50% will be lost as either base flow or used for the existing cropping pattern where the water supplied may be less than the actual requirement. Considering the average delta of 0.5 m/year, the additional land that can be brought into cultivation is likely to be 304037 ha. The artificial recharge to ground water will not only augment the area under irrigation but also provide sustainable source for irrigation to the existing cropping pattern.

8.19.6. ROOTOP RAIWATER HARVESTING IN URBAN AREAS

The consideration of climatic, demographic, hydrogeological and socio economic conditions of urban areas, Roof Top Rain Water Harvesting (RTRWH) is recommended for urban areas. The urban area is of the order of 6175.59 sq. km and is 4.75% of total area. The urban areas are found in all the districts and the urban population is 19,077,592. The population density varies from 22077 per sq. km (Chennai District) to 498 per sq. km (Nilgiris District). The number of houses in urban area is 4042853. (Source: 1991 Census).

The data regarding number of houses is available but the individual roof size is not available. Hence an average roof size of 50 sq. m has been assumed for roof area for each house. The roof area corresponding to 4042853 houses works out to be 202.14 sq. km.

Rain water available at roof top is estimated from monsoon rainfall for each district. IMD data of Normal Monsoon Rainfall (1901-1950), has been considered. Tamil Nadu is blessed with both south west and north east rainfall and hence rainfall contributed from both the monsoon has been considered for computation. The rainfall received on the rooftop is not available for recharge in toto as a part of the rainfall will be lost as evaporation, leakage etc. Hence 90% of rainfall received is considered available for recharge. It is seen that 170.76 mcm is availabile for recharge.

The number of houses in the urban area is 4042853 as per 1991 census. It is observed that on an average atleast one house in four houses will have ground water abstraction structure and hence in this scheme, it is proposed to link four houses and allow the water to feed the existing well. Further due to flat culture actual roof area shall be 50% of the above houses. Therefore total 5 lakh houses proposed for roof top rain water harvesting. The average cost of providing necessary arrangements through pipe fittings, shall cost around Rs. 6000 per house for around 5 lakh houses. The total cost of this is worked out as Rs. 300 crores.

8.19.7. TOTAL COST

The total cost of recharge structures proposed in rural and urban areas of Tamil Nadu is Rs.2386 crores.

8.20 UTTAR PRADESH AND UTTARANCHAL STATES

The State (including Uttaranchal) is divided into four major physical divisions namely Himalayan zone , sub-Himalayan zone, Alluvial Tract and Southern Rocky Terrain. The state is a part of Ganga basin comprising of Yamuna, Ramganga, Gomti, Ghaghra and Son sub-basins. The alluvial plains and southern Rocky terrain area main water bearing formations with point of view of ground water availability. The plan for artificial recharge is prepared considering the hydrogeological and hydrological data base.

8.20.1 IDENTIFICATION OF AREA

The areas feasible for artificial recharge have been demarcated as 42125 sq. km in alluvial belt and 3055 sq. km in hard rocks of Ganges basin of the state. Fig-20 shows the area identified artificial recharge of ground water in the state.

8.20.2. SUBSURFACE STORAGE SPACE AND WATER REQUIREMENT

To estimate the available storage space, different ranges of depth to water level at 3m. interval are averaged to arrive at thickness of unsaturated zone effectively. The specific yield has been taken as 10 percent in alluvial area and 2 percent in hard rock areas. The total volume of storage space thus arrived to 22413 MCM (2.2 Mham). Total surface water required is worked out as 29709 MCM against the surplus availability of 15239 MCM/year.

8.20.3 RECHARGE STRUCTURES AND COST ESTIMATES

Hydrogeologically the areas of U.P. state have been broadly grouped into (i) Alluvial area and (ii) Hard rock area. In the hard rock areas i.e. southern most part of the state, comprising Bundelkhand and Vindhyan formations, the surface spreading techniques consisting of percolation tanks and cement plugs/bunds are most appropriate. In the alluvial area i.e. Central Ganga plain and marginal plain the recharge shafts are the most appropriate. According to suitability as above the recharge structures have been worked out in the state for artificial recharge. For planning these artificial recharge structures the storage capacity of structures have been considered as below:

PercolationTank- A percolation tank of single filling capacity of 100 Thousand cubic meter (TCM) i.e. 0.1 MCM will have multiple fillings during monsoon hence would result to 200% storage capacity and thus will have gross storage capacity of 200 TCM (i.e. 0.2 MCM).

Cement Plugs/Check Dams- A cement plug of 10 TCM (i.e.0.01 MCM) single filling capacity will actually store 300% due to multifillings. This will have gross storage of 30 TCM (i.e. 0.03 MCM).

Recharge Shaft- A recharge shaft on an average will recharge 1 TCM (i.e.0.001 MCM)/day with about 60 operational days during monsoon and postmonsoon. This will have 60 TCM (i.e. 0.06 MCM) recharging capacity annually.

Table-34 shows sub-surface storage potential in unsaturated strata for artificial recharge to ground water in U.P. In hard rock area of state, the available surface water as monsoon runoff surplus for artificial recharge is 2477 MCM, however requirement is only 1260 MCM. 70% of this is planned for storage in percolation tanks and rest is planned for storage in Cement plug/check dams. Thus for hard rock areas of the state, 4410 percolation tanks and 12600 cement plugs/check dams are required. The construction of percolation tanks is recommended on the second and third order drainage, whereas, the cement plugs may be constructed on any order of drainage, on favourable hydrogeological and physiographical locations. The density of these structures per square kilometer may be based on practical consideration.

In alluvial and marginal alluvial areas of the state the available surface water as monsoon surplus runoff is 12762 MCM, for artificial recharge, for which construction of recharge shafts in planned. The numbers of recharge shafts (lateral and vertical) have been worked out by dividing the available surplus water by average gross capacity of recharge shaft i.e. 0.06 MCM. Thus 2,12,700 recharge shafts (lateral and vertical) have been worked out for alluvial and marginal alluvial area of the state. In urban area the surplus monsoon is recommended to be harnessed from roof top and in rural areas from village tank/ponds etc.

On the basis of unit cost of per structure i.e. Rs. 20 Lakh for percolation tank, Rs. 2 Lakh for cement plug, and Rs. 1.0 Lakh for recharge shaft, the total expenditure of Rs. 3261 Crores is estimated to undertake the construction of proposed recharge structures (Table- 35).

8.20.6 AREA BENEFITTED

Implementation of the proposed plan would arrest the depletion of water level and on other hand would result in creation of additional ground water resources 12431 MCM (1.24 M.Ham.) annually which would create additional irrigation potential. The drinking water scarcity can be effectively mitigated out of this additional storage. The plan would result rise in water level upto 3m. below ground level ultimately resulting less costlier ground water structures, lifting device and saving energy for ground water lift.

The installation of these structures will ensure sustainability of existing ground water abstraction structures throughout the year. It will also help in reducing hazards of soil erosion and silting of river channels hence controlling the flood situation in the state.

Table –34 Sub-Surface Storage Potential for Artificial Recharge

Sl. No	Name of Basin	Area identified for Artificial Recharge (sq.km)	Volume of Unsaturated zone (M/CM)	Average Specific yield	Total storage Potential as Volume of Water (MCM)	Surface Water requirement (reciprocal of 75% (MCM)	Proportionate non-committed water resources available for future planning (MCM)
1.	Alluvial area	42125	214654	0.10	21465	28549	12762
2.	Hard rock area	3055	47355	0.02	947	1260	2477
		45180	262009		22413	2909	15239

8.20.5 HIMALAYAN AND SUB HIMALAYAN REGIONS

In the lower and higher hills of both states, number of springs are drying up. Therefore 500 schemes of spring development are feasible on Himachal Pattern. An expenditure of Rs. 150 crores @ Rs. 30 lakh each is estimated on account of spring development consisting of 3 check dams each. In addtion to these, 500 check dams (15 x 5 m^2) can be constructed in low hill ranges @ Rs. 20 lakh each costing Rs. 100 crores. Sub surface dykes at 500 places in valley areas are feasible to check the sub surface ground water flow @ Rs. 10 lakh each costing Rs. 50 crores. The cost of all these schemes in hilly regions is estimated as Rs. 300 crores.

8.20.6 ROOF TOP RAINWATER HARVESTING IN URBAN AREAS

Uttar Pradesh is most densely populated state and encompauses of number of Urban cities and towns. It is estimated around 10 lakh houses/buildings of the state including Uttaranchal shall be feasible for the rooftop rainwater harvesting @ Rs. 6000/- each. This will cost Rs. 600 crores.

8.20.7 TOTAL COST

Total cost of the recharge structures and rain water harvesting in Uttar Pradesh and Uttaranchal is estimated as Rs. 4161 crores.

Table –35 Artificial Recharges Structure and Cost

Basin	Type of Area	Amount of Surface Water available as Surplus (MCM)	Resource to be harnessed						Estimated Cost (Rupees in Crores)			
			Hard Rock Area				Alluvial area					
			Percolation Tanks (Capacity 200 TCM)		Cement Pluss (Capacity 20 TCM)		Recharge Shaft (Capacity 60 TCM)		Percolation Tanks (@ Rs.20 Lakh)	Cement Plug (@Rs. 2 Lakh)	Recharge Shaft (@ Rs.1.0 Lakh)	Total
			MCM	No	MCM	No	MCM	No				
Ganga Basin in U.P.	Alluvial area	12762	-	-	-	-	12762	2,12,700	-	-	2127	2127
	Hard rock area	1260	882	4410	378	12600	-	-	882	252	-	1134
	Total	14022	882	4410	378	12600	12762	2,12,700	Total Cost (Rupees in crore)			3261 crores

8.21 WEST BENGAL

The State of West Bengal has a total geographic area of 87,853 sq km.,and has a population of 67.98 million as per 1991 census with a population density of 766 per sq km. The average rainfall in the state is about 1750 mm of which 1250 mm occurs during the period from June to September. While the hilly Himalayan region receives the heaviest rainfall ranging from 2500 to 6000 mm, the southern districts in the plains receive on an average rainfall from 1125 to 1875 mm. There are three major river basins in the State, namely, the Ganga, Brahmaputra and Subarnarekha. The Tista, Torsa, Jaldhaka, etc., are the tributaries to the river Brahmaputra. The Mahananda, Mayurakshi, Ajoy, Damodar, Dwarakeswar, Kasai, Jalangi, Churni, etc. are other tributaries to the river Ganga/Bhagirathi–Hugli river.

8.21.1 IDENTIFICATION OF AREA

The area suitable for artificial recharge has been identified where mean post monsoon water level is more than 3 mbgl and having declining trend >10cm/year. An area of 7500 Sq. Km. (2600 sq. km. falling in hard rock area & the rest in alluvial part) is found suitable for artificial recharge in the State where ground water occurs under unconfined condition (Fig.21). Depletion in piezometric surface is also found to occur in the urban area of Calcutta city and Haldia Industrial area.

8.21.2. SUB-SURFACE STORAGE AND WATER REQUIREMENT

The storage space available for artificial recharge is considered as a slice of unsaturated zone between 3 m bgl and mean post-monsoon depth to water level beyond 3 m bgl and the estimated difference between these two is then multiplied by the area identified for recharge to arrive at the volume of unsaturated zone possible for recharging. The specific yield for alluvium areas is taken as 12 - 18% and for hard rock areas as 3%. The sub surface storage potential in 10 districts is estimated as 1998 MCM.

The volume of water required for saturating the unsaturated zone below 3 mbgl has been estimated, considering the volume of the aquifer to be recharged & the specific yield. Considering the 75% average recharge efficiency of the artificial recharge structure, the actual volume of water for saturation has been evaluated & it is imperative that this volume of water will come from surface water only. The gross volume of surface water required, as estimated, for artificial recharge in the state is 2664 MCM which is much less than the total source water available.

8.21.3. RECHARGE STRUCTURES AND COST ESTIMATES

Considering the hydrogeological set up of the State, the following artificial recharge / conservation structures are proposed to be constructed for augmentation & conservation of ground water resources.

1) In hard rock areas, the suitable structures are as follows :

   i) Percolation Tank / Check Dam

   ii) Gabion Structures

   iii) Nala Bund / Cement Plug

iv) Desiltation of village pond

v) Development of existing spring

vi) Roof top harvesting structure

vii) Conservation of ground water by sub-surface dyke

2) In alluvial areas, the suitable stuructures are as follows :

i) Percolation Tank with recharge shaft

ii) Reexcavation of old tanks

iii) Desiltation of village pond with recharge shaft

iv) Roof top harvesting sturcture

v) Injection well

The gross storage capacity & percentage of resources allocated for different artificial recharge structures are presented in Table -36.

Table – 36. Gross storage capacity and percentage of resources allocated for artificial recharge structures

Artificial recharge structure proposed	Storage capacity of individual structures single filling (TCM)	Resource allocated in percentage of gross proposed water requirement
A.Hard rock area Percolation tank / Check dam	100	50% of hard rock area
Development of Spring	30	
NallaBund/Cement Plug	10	30% of hard rock area
Gabion Structure	2	20% of hard rock area
b. Alluvium Area Percolation tank with recharge shaft	100	i) 100% in Bankura, Barddhaman, Birbhum, Medinipur, Malda districts ii) 50% in Hugli, Murshidabad, Nadia & North 24 Parganas districts.
Re-excavation of old tank	100	50% in Hugli, Murhsidabad, Nadia & North 24 Parganas districts.
Desiltation of existing ponds with 10% recharge shaft	Can not be assessed	

The amount of surface water requirement for artificial recharge is 2664.13 MCM which is only 2% of the surface water resources (132905 MCM) estimated in the State. Therefore source water availability would not be a problem to harness 2664.13 MCM as per proposed plan.

Districtwise number of artificial recharge structures have been worked out based on gross storage capacity of individual structure & the allocated resources. The districtwise no. of different type of artificial recharge structures is given in Table-37.

Table – 37. Districtwise number of Artificial Recharge Structure proposed

A. Hard rock Terrain

District	Volume of surface water require-ment for artificial recharge (MCM)	Artificial Recharge Structure							
		Percolation Tank		Gabion structure		Nalla Bund / Cement Plug		Subsurface Dyke	
		Total vol. of water required (MCM)	No. (0.2 MCM gross capacity	Total vol. of water required (MCM)	No. (0.01 MCM gross capacity)	Total vol. Of water required (MCM)	No.	Total volume of water to be arrested (MCM)	No
Purulia	151.80	75.90	380	30.26	3026	45.54	910	0.054	30
Bankura	8.00	4.00	20	1.60	160	2.4	48	0.045	25
Birbhum	16.00	8.00	40	3.20	320	4.8	96	0.027	15
Darjeeling				1.00	100				
Total	**175.80**	**87.90**	**440**	**35.06**	**3606**	**52.74**	**1054**	**0.126**	**70**

B. Alluvial Area

District	Amount of surface water requirement for artificial recharge (MCM)	Artificial Recharge Structure			
		Percolation Tank with recharge shaft		Re excavation of tank	
		Total vol. of water required (MCM)	No.	Total vol. of water required (MCM)	No.
Bankura	304	304	1520	-	-
Burdwan	976	976	4480	-	-
Birbhum	80	80	400	-	-
Medinipur	320	320	1600	-	-
Hugli	69	35	175	3.4	170
Murshidabad	400	200	1000	20.0	1000
Malda	135	135	675	-	-
Nadia	108	54	270	5.4	270
North 24 Parganas	96	48	240	4.8	240
Total	2488.00	2152	10760	33.6	**1680**

In Darjeeling district, springs of varying discharge of 1 lps to 5 lps are found to occur at different altitudes which are in general structurally controlled. The present water requirement of the area is meet up with this spring water only. The spring discharge may be enhanced by proper development of springs by cleaning the spring openings and its channels. By constructing Gabion structure / nala bund in the upper reaches of the spring may also increase the spring discharge. Details of the proposed structures and cost estimates are given in Table- 38. This area is also feasible for roof top harvesting structures.

Table – 38. Artificial Recharge Structures & Cost

Type of Structure	No. of Structure	Total vol. of water to be conserved (MCM)	Total Cost (Lakh Rs.)
Percolation tank with 10% recharge shaft / Check dam	11200	-	1120.0
Cement Plug / Nala bund	1054	52.7	15.0
Gabions	3606	35.1	7.2
Reexcavation of tank with 10% recharge shaft	1680	33.6	168.0
Development of spring	1000	30.0	10.00
Roof top * harvesting structure	1500	0.54	7.5
Desiltation of village pond with 10% recharge shaft	500	-	12.50
Sub-surface dyke	70	-	0.35
Total	**8343**	**289.13**	**1340.55**

***** Proposed for Kolkata and Darjeeling

8.21.4. TOTAL COST

The total cost of the artificial recharge structures is **1340.55** crores in the state.

8.22 ANDAMAN AND NICOBAR ISLANDS

Andaman and Nicobar group of Islands form two districts, the northern the Andaman district and the southern the Nicobar district, separated from each other by the deep sea of 10^o channel. The Andaman group of Islands cover an area of 6340 sq. km. and the Nicobar group 1953 sq. km. Mean annual rainfall of these Islands is over 3000 mm. Perennial streams of the status of major river are absent in the Andaman and Great Nicobar Island. The major Perennial streams like Dhanikhari, Protheropore Nala and Pema Nala in South Andaman are all small streams – the Dhanikhari being the largest.

Though the development of ground water is in low key yet the artificial recharge and conservation structures seem to provide a very good mechanism for augmentation of ground water resources in the Islands. Even endowed with high rainfall, quick evaporation losses and proximity to sea facilitate high evapotranspiration, and huge base flow from the aquifers to the sea. To meet the crisis of ground water, atrificial recharge structures like i) percolation tank, ii) cement plug/ nala bund and subsurface dykes as ground water conservation structure appears to be highly useful in the Islands . Presently in many Islands perennial springs ooze through the fractures and topographic lows which cater to a great extent to the village population. Keeping in view the importance of springs, the development of these springs is needed with proper recharge structures at appropriate locations up stream of spring discharge.

Depending upon high rainfall in rainy months and scarcity of drinking water in the lean periods (Dec/Jan to April), harvesting of rainwater is very old practice of the Islanders. The tribes in the Islands till date collect rainwater in green coconuts. Recently the Island administrations have started designing the roofs of Govt. buildings for harvesting of rain water from the roof top. This practice may be popularised in the entire districts of Andaman and Nicobar so that an appreciable quantity of rain water may be conserved through properly designed roofs and the water may be concerned for day to day use after rainy season.

Considering all the above modes of augmentation of ground water resources, a master plan for artificial recharge to ground water, rain water harvesting and spring development has been prepared (Table-39 and Fig.-22). The plan includes spring development (145 nos.), roof top harvesting (2600 nos.), cement plug (270 nos.), percolation tank (38 nos.) and sub-surface dykes (150 nos.). For construction of all these structures the cost is estimated as Rs.3640 lakhs. Total volume of water may likely to be harvested through these structures would be around 3.05 MCM.

Table - 39 Cost And Number Of Structures proposed in Andaman and Nicobar

Type of structure	No. Of structure	Total cost (Lakh Rs.)	Total volume of water harvested (MCM)
Spring Development	145	290	0.435
Roof top rain water harvesting	2600	1300	0.351
Cement Plug / Nala bund	270	540	16.2
Percolation tank	38	760	0.57
Sub-surface dyke	150	750	1.50
Total	**3203**	**3640**	**3.056**

8.23 CHANDIGARH

Chandigarh U.T. has an area of 114 sq.km. out of which 38 sq.km. is rural and remaining 76 sq.km. is urban. The U.T. of Chandigarh has limited area for agriculture. The main source of irrigation is ground water, which is pumped through 39 deep tube wells, installed by Chandigarh Administration and 90 private shallow tube wells. Around 23% of the area of U.T. is covered under forest (Fig.23).

The monsoon runoff, which goes out as waste from the city area flowing over 40% of the paved area of the territory, can be utilised by roof top harvesting. Chandigarh has a large number of private and public buildings with considerable roof top areas. The water falling on roof top of these buildings which is nearly silt free can be diverted to recharge well/shaft for artificial recharge to the aquifer system. Such utilisation of rainfall runoff will also help in checking the flow of storm water and flooding of areas which will lead to increase the life of man made structures like roads, drains etc. and will also check silting problem caused by heavy flow of rain water during monsoon.

The roof top rain water harvesting and artificial recharge considered for the union Territory of Chandigarh are as follows:

1. Area Identified for artificial recharge		: 32.59 sq.km.
2. Volume of Unsaturated Zone suitable for artificial recharge.		: 257 MCM
3. Average Specific Yield of aquifer		: 10%
4. Total sub surface Storage Potential of aquifer.		: 25.7 MCM
5. Amount of Surface Water considered for artificial recharge annually		: 25.7 MCM
i) Urban		: 23.1 MCM
ii) Rural		: 2.6 MCM
6. Structures suitable for artificial recharge	: i) Recharge Shafts	
	: ii) Lateral trench with injection wells and trenches	
	: iii) Check dams and Gabbion structures	
7. Number of recharge structures feasible		
@ 0.043 MCM per year i) Urban		: 537
ii) Rural		: 60
8. Estimated cost of recharge structures	: i) Urban Rs. 537 Lacs	
@ Rs. 1.0 Lacs per structure	: ii) Rural Rs. 60 Lacs	

Total cost is Rs.597 lacs (Say 6 crores) of UT of Chandigarh.

8.23 DADRA NAGAR AND HAVELI

Union Territory of Dadra Nagar and Haveli as geographical area of 491 sq.km (Fig.24). The Union Territory comprises of 2 parts namely; (i) Dadra which has only 3 villages and (ii) Nagar Haveli having 69 villages. The Eastern part of the UT is hilly with elevation ranging from 40 – 400 m amsl. The western part is plain with elevation upto 40 m amsl. The hilly terrain constitutes 60% of the total area. Annual rainfall varies from 2155 mm to 2400 mm. Total population of UT is around 1,50,000 out of which around 90% is rural. UT is rich in forest wealth having 53% area under forest. The area is drained by Dhamanganga river and its tributaries namely Piparia Nadi, Sakartond Nadi and Dudhni Nadi flowing towards west and Dongarkhadi towards east.

The area is underlain by Deccan Trap (basaltic lava flow) and is intruded by dolerite and trachyte dykes. Small and localised patches of alluvium also occur along river's bank. Thickness of alluvium is within 9 m. Depth to water level is within 9 m bgl during pre-monsoon however, during post-monsoon it is shallow and ranges between 0-3 m followed by 3-6 m bgl. There is insignificant rise (<0.1m) in water level in eastern region and decline (<0.20 m bgl) in western and central part of UT. However, due to shallow depth to ground water (0-3m) and rich forest cover the possibilities for artificial recharge to ground water is limited.

The population of the UT is widely scattered. There is acute shortage of water in summer in hamlets inspite of copious rainfall. Therefore, roof water harvesting is proposed in 1000 households, institutional and other buildings of the UT. The average cost of roof water collection, transmission and recharge is estimated to be around Rs.20,000/- each. This will cost around Rs.2.0 crores. There is also need to conserve surface run off near rural water supply schemes supported by check dams/ cement plugs and sub surface dykes at around 50 locations with unit cost of Rs.2 lakhs each. This will cost Rs.1.0 crore. The total cost of the rain water harvesting and run off conservation in the UT of Dadra and Nagar Haveli is Rs.3.0 crores.

8.24 DAMAN AND DIU

Daman lies on the Gujrat coast while Diu is an island on the southern fringe of Kathiawar Peninsula. Daman is bounded on north and south by the Bhagwan and Kalem rivers respectively, on the east by Gujrat state and on the west by the Arabian sea. Diu lies in the gulf of Cambay near Veraval port and is separated from the southern extremity of the Saurashtra peninsula by a narrow channel running through a swamp. The island is connected to the mainland by a narrow channel on the north. Daman has a mild and humid climate while Diu has sultry climate.

Total area of Daman and Diu is 112 Sq. km, divided into two districts with capital located at Daman. Total population is 1,01,586 with population density of 906 persons/Sq. km. Urban population is 46.8%. The area of Daman is 72 Sq. km and that of Diu is 40 Sq. km. Total area under irrigation is 517 ha and all the villages have been electrified.

There is limited surplus surface water in Daman & Diu resulting in limited scope for artificial recharge. Small water conservation structures eg. nala bunds and check dams at select locations are proposed at 100 places with the unit cost of Rs. 5 lakh each. Rainwater harvesting in household and institutional buildings is feasible in about 2000 buildings at the cost of Rs. 50,000/- each. The total cost of the plan is estimated as Rs. 15 Crores.

8.25 LAKSHADWEEP

Lakshadweep is the tiniest Union Territory of India and lies about 220 to 440 km from coastal city of Cochin in Karela. It is an archipelago consisting of 12 atolls, three reefs and five submerged banks. Of its 36 islands covering an area of 32 sq. km., only 10 are inhabited. They are Andrott, Amini, Agatti, Bitra, Chetlat, Kadmat, Kalperi, Kauaratti (HQ), Kiltan and Minicoy. Total population of Lakshadweep is 51,407 (1991 Census) with population density of 1615 persons per sq.km. Urban population is 56.13%.

The flora of the island includes bananas, colocasia, drumstick, bread-fruit, jackfruit and wild almond. Coconut is the only crop of economic importance. Two different varieties of sea grass are seen adjacent to the beaches. They prevent sea-erosion and movement of the beach sediments.

The UT experiences heavy rainfall but water scarcity is felt in the area. There is limited possibility of artificial recharge keeping in view the physiography, level of ground water development and hydrogeological set-up. However, rain water harvesting on 1000 household and institutional buildings shall be feasible in the area. The cost of each structure including of storage tank/sump is Rs. 1lakh. The total cost of the plan is Rs. 10 Crore for Lakshadweep islands.

8.26 PONDICHERRY

Union Territory of Pondicherry has four districts namely Pondicherry, Karaikal, Mahe and Yanam and its total area is 492 sq. km. Total population of the UT is 8,07,785 (1991 census) and 45% it is engaged in agriculture. Irrigation in Pondicherry is mainly through tanks and tube wells.

Pondicherry has average rainfall of 1205 mm. Geomorphology of the area is characterised by Coastal Plain, Flood Plains and Pediments. Sandstone and Limestone are main geological formations in the area. Depth to water level ranges between 6 to 35 m bgl. Ground water quality is not potable at places.

As per the GIS study conducted in the area for identification of artificial recharge. It is proposed to construct the following schemes in the UT of Pondicherry as given in Table – 40.

Table – 40: Artificial Recharge Structure in UT of Pondicherry

S. No.	Type of structures	No. of structures	Unit cost (Rs. in lakhs)	Total (Rs in lakhs)
1	Percolation pond	5	20	100
2	Check dam	20	2	40
3	Desitting of ponds	40	1	40
4	Recharge pit	14	0.5	7
5.	Nala bund	10	0.5	5
6	Desilting / Recharge well	20	1.5	30
		109		222

Roof top rainwater is proposed to be undertaken in 1000 institutional and private buildings having average roof area of 70 m^2 @ Rs. 10,000/- each. This will cost Rs. 10 crores. Total cost of the recharge schemes proposed in the UT of Pondicherry is 12.2 crores.

9.0 OVER VIEW OF MASTER PLAN FOR ARTIFICIAL RECHARGE TO GROUND WATER

The preparation of master plan for artificial recharge to ground water in different states, prepared by Central Ground Water Board, aims at providing area specific artificial recharge techniques to augment the ground water reservoir based on the twin important requirements of source water availability and capability of ground water reservoir to accommodate it. The specific problems in different areas in the states like excessive ground water development resulting in ground water decline, water scarcity due to inadequate recharge in arid areas, low ground water retention in hilly areas despite substantial rainfall, urban areas with limited ground water recharge avenues and related problems of urban pollution, etc., have been considered while preparing the master plan. To fully utilise the available surplus monsoon runoff in rural areas, emphasis has been given for adoption of artificial recharge techniques based on surface spreading like percolation tanks, nala bunds, , etc., and sub surface techniques of recharge shaft, well recharge, etc. In urban areas, hilly areas and coastal regions priority has to be given to rain water conservation measures through roof top harvesting techniques, etc.

The Master Plan while bringing out the areas suitable for artificial recharge to ground water reservoir, prioritises the areas wherein schemes need to be implemented as a first priority to ameliorate the water scarcity problems. The proposals and schemes recommended are not the ultimate ones but are the first stage of implementation. These need to be further extended in other areas depending on the availability of infrastructure, finances and future problems.

Out of total geographical area of 3614156 sq. km of the country, an area of 448760 sq. km has been identified for artificial recharge. The total quantity of surplus monsoon runoff to be recharged works out to 36155 MCM. The total number of artificial recharge structures proposed are 2.25 lakh in Rural areas at an estimated cost of Rs. 19880 Crores and 37 lakh in urban areas (roof top rainwater harvesting) at estimated cost of Rs. 4585 crores. The master plan envisages the number of artificial recharge and water conservation structures in the country as 39 lakh at an estimated cost of Rs. 24500 crores. This plan can be implemented in a phased manner over a time period of 10 years with an annual outlay of Rs. 2400 crores.This would take care of availabilty of funds for implmentation and would enable the implementing agaencies to review and modify the schemes based on data generated and experience gained in initial phases.An overview of the areas identifed , extent of recharge feasible from proposed programme , number of artificial recharge structures and cost estimate are illustrated in the Tables 41 & 42.

Table 41. Statewise Feasibility and Cost Estimates of Artificial Recharge Structures as Envisaged in the Master Plan

S. No	Name of State	Area Identified for Artificial Recharge (sq. km.)	Quantity of Surface Water to be Recharged in MCM	Type and Number of Artificial Recharge Structures	Total Cost of Plan (Rs. in crores) Rural	Urban	Total
1	2	3	4	5	6	7	8
1	Andhra Pradesh	65333	1095	3800 Percolation Tanks 11167 Check Dams Rain Water Harvesting in Urban Area.	1229	468	1697
2	Bihar & Jharkhand	4082	1120	2695 Percolation Tanks 9483 Nala Bunds 1303 Contour Bunds 1630 Recharge Shafts	644	330	974
3	Chhattisgarh	11706	258	648 Percolation Tank 2151 Nala Bunds / Cement Plug / Check dam 2582 Gravity Head / Recharge shafts 7740 Gully plugs, Gabion structures	223	51	274
4	Delhi	693	444	23 Percolation tanks 23 Existing dug wells 10 Nala Bunds 19216 Lateral trench with recharge wells 2496 Roof top rain water harvesting	232	25	257
5	Goa	3701	529	1410 check dam / KT weirs 10,000 Roof top rain water structure	63	10	73
6	Gujarat	64264	1408	4942 Percolation Tanks with Recharge Tubewell 13210 Check Dams Rainwater Harvesting (4.5 lakh houses)	1155	450	1605
7	Haryana	16120	685	15928 Recharge Shafts and Recharge Trenches Roof Top Rain Water Harvesting (1.7 lakh houses)	159	173	332
8	Himachal Pradesh	--	149	1000 Sub surface dykes 500 Check dams 300 Revival of Ponds 500 Revival of spring 2000 Roof top harvesting structures	458	7.5	465.5
9	Jammu & Kashmir	--	161	500 Sub surface dykes 336 Revival of Kandi Ponds Roof top harvesting (1.5 lakh houses)	234	12.5	246.5

10	Karnataka	36710	2065	1040 Sub Surface Dams 5160 Percolation Tanks/ Desilting of old Tanks 17182 Check Dams 8.3 lakh roof top rain water harvesting with Filter Bed.	1233	499	1732
11	Kerala	4650	1078	4312 check dam 7181 sub surface dykes 10780 gully plugs 10780 nalah Bunds Rooftop rainwater harvesting (0.7 lakh houses) Runoff water harvesting (1200 structures)	1221	57	1278
12	Madhya Pradesh	36335	2320	5302 Percolation Tanks 20198 Nala Bunds/ Cement Plug/ Check Dams 23181 Gravity Head/ Dug wells/ Tubewells/ Recharge Shafts 69598 Gully Plugs, Gabian Structures.	1909	244	2153
13	Maharashtra	65267	2318	8108 Percolation Tanks 16598 Cement Plugs 2300 Recharge Shafts, Urban schemes of Roof Top Rain Water Harvesting (8.78 lakh houses) 3500 Run off Harvesting	2000	562	2562
	North Eastern States						
14	Arunachal Pradesh	--	--	500 Check dams 1000 Weirs 1000 Gabian Structures 480 Roof top harvesting 300 Development of Spring	87	7	94
15	Assam	--	--	250 Check dams 500 Weirs 1000 Gabian Structures 600 Roof top harvesting 250 Development of Spring	49.5	9	58.5
16	Manipur	--	--	300 Check dams 500 Weirs 500 Gabian Structures 300 Roof top harvesting 150 Development of Spring	48.5	4.5	53
17	Meghalaya	--	--	300 Check dams 600 Weirs 600 Gabian Structures 300 Roof top harvesting 200 Development of Spring	53.5	4.5	58

18	Mizoram	--	--	500 Check dams 1000 Weirs 1000 Gabian Structures 300 Roof top harvesting 200 Development of Spring	82. 0	4.5	86.5
19	Nagaland	--	--	500 Check dams 1000 Weirs 1000 Gabian Structures 300 Roof top harvesting 200 Development of Spring	82.0	4.5	86.5
20	Tripura	--	--	300 Check dams 500 Weirs 1000 Gabian Structures 240 Roof top harvesting 100 Development of Spring	47	3.5	5.05
21	Orissa	8095	406	569 Percolation Tanks 761 Converted Percolation Tanks 698 Sub Surface Dykes 809 Nala Contour Bunds 679 Check Dam weir 1981 Water spreading / flooding 668 Induced recharge 334 Recharge shafts Roof top harvesting (1 lakh)	414	100	514
22	Punjab	22750	1200	40030 Recharge shafts and Recharge Trenches 12800 Roof Top Harvesting structures in Urban Areas	400	128	528
23	Rajasthan	39120	861	3228 Percolation Tanks 1291 Anicuts 2871 Recharge shafts Rooftop Rainwater Harvesting structure (4 lakh houses)	740	400	1140
24	Sikkim	--	44	2100 Spring Development 2500 Cement Plugs/ Nala Bunds 5300 Gabian Structures 69596 Roof Water Harvesting	103	70	173
25	Tamil Nadu	17292	3597	8612 Percolation Ponds 18170 Check Dams 5 lakh rain water harvesting structure	2086	300	2386
26	Uttar Pradesh & Uttaranchal	45180	14022	4410 Percolation Tanks 12600 Cement Plugs (Check Dams) 2,12,700 Recharge Shafts Roof top rain water harvesting structures (10 lakh)	3561	600	4161

1	2	3	4	5	6	7	8
27	West Bengal	7500	2664	11200 Percolation Tanks with shaft 3606 Gabian structure 1054 Nala Bund/ Cement Plug 1680 Re-excavation of tanks 500 Desiltation of village pond 1000 Spring Development 70 Sub Surface Dykes. 1500 Roof Top Harvesting for Calcutta & Darjeeling	1333	7.5	1340.5
28	Andaman & Nicobar Islands	--	3	145 Spring Development 270 Cement Plugs 38 Percolation Tanks 150 Sub surface dykes 2600 Roof Top Harvesting	23	13	36
29	Chandigarh	33	26	597 Recharge shafts, recharge trenches, check dams and Gabian structures.	0.6	5.4	6
30	Dadra & Nagar Haveli			50 check dams / cement plugs 58 Sub surface dykes 1000 houses rain water harvesting	2	1	3
31	Daman & Diu			100 Nala bund/check dams 2000 roof top rain water harvesting structures		15	15
32	Lakshadweep			1000 roof top rain water harvesting structures		10	10
33	Pondicherry	--	--	5 Percolation Tanks 14 Recharge pit 20 Check Dams 40 Desilting of ponds 10 Nala bund 20 Desilting/Recharge wells. Rainwater harvesting 10,000 houses	2.2	10	12.2

GRAND TOTAL (Rs. in crores) **19877.8 4635.5 24513.3**

Say Rs. 24500 Crores

Table 42. Financial Outlays for different States and U.T's of India

(in Crores of Rupees)

S.No.	States and U.T's	Rural	Urban	Total
1	ANDHRA PRADESH	1229	468	1697
2	BIHAR AND JHARKHAND	644	330	974
3	CHHATTISGARH	223	51	274
4	DELHI(NCT)	232	25	257
5	GOA	63	10	73
6	GUJRAT	1155	450	1605
7	HARYANA	159	173	332
8	HIMACHAL PRADESH	458	7.5	465.5
9	JAMMU & KASHMIR	234	12.5	246.5
10	KARNATAKA	1233	499	1732
11	KERALA	1221	57	1278
12	MADHYA PRADESH	1909	244	2153
13	MAHARASHTRA	2000	562	2562
	NORTH EASTERN STATE			
14	ARUNACHAL PRADESH	87	7	94
15	ASSAM	49.5	9	58.5
16	MANIPUR	48.5	4.5	53
17	MEGHALAYA	53.5	4.5	58
18	MIZORAM	82	4.5	86.5
19	NAGALAND	82	4.5	86.5
20	TRIPURA	47	3.5	50.5
21	ORISSA	414	100	514
22	PUNJAB	400	128	528
23	RAJASTHAN	740	400	1140
24	SIKKIM	103	70	173
25	TAMIL NADU	2086	300	2386
26	UTTAR PRADESH & UTTARANCHAL	3561	600	4161
27	WEST BENGAL	1333	7.5	1340.5
28	ANDAMAN & NICOBAR	23	13	36
29	CHANDIGARH	0.6	5.4	6
30	DADRA AND NAGAR HAVELI	2	1	3
31	DAMAN & DIU	-	15	15
32	LAKSHADWEEP	-	10	10
33	PONDICHERRY	2.2	10	12.2
	TOTAL	19874.3	4586.4	24460.7