Status and Strategies for Management of Water Resources in India

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1. Introduction

Water resources of the country play major role in agriculture, hydropower generation, livestock production, industrial activities, forestry, fisheries, navigation and recreational activities etc. National Water Policy (2002) stresses the need for multi-sectoral integrated water resources development and management considering drainage basin as a whole or a sub-basin as a hydrological unit taking into account both surface and ground water for sustainable development. All individual developmental projects and proposals should be formulated and considered within the framework of such an overall plan. Appropriate river basin organizations need to be established for the planned development and management of a river basin or sub-basins, wherever necessary Special multi-disciplinary units will be required to prepare comprehensive plan taking into account not only the needs of irrigation but harmonizing various other sectors, so that the available water resources are put to optimum use. As per the National Water Policy in planning and operation of systems, water allocation priorities should be broadly as: (i) drinking water, (ii) irrigation, (iii) hydropower, (iv) ecology, (v) agro-industries and non-agricultural industries and (vi) navigation. India receives annual precipitation of about 4000 km^3, including snowfall. Out of this, monsoon rainfall is of the order of 3000 km^3. The long-term average annual rainfall for the country is 1160 mm, which is the highest anywhere in the world for a country of comparable size (Lal, 2001). The annual rainfall in India however fluctuates widely. The highest rainfall in India of about 11,690 mm is recorded at Mousinram near Cherrapunji in Meghalaya in the northeast[5]. In this region rainfall as much as 1040 mm is recorded in a day. At the other extreme are places like Jaisalmer, in the west, which receives barely 150 mm of rain. Though the average rainfall is adequate, nearly three-quarters of the rain pours down in less than 120 days, from June to September and thus exhibits very high spatial and temporal variability.

India is endowed with a river system comprising of more than 20 major rivers with several tributaries. Many of these rivers are perennial and some of these are seasonal. Apart from the water available in the various rivers of the country, the ground water is also an important source of water for drinking, irrigation and industrial uses etc. It accounts for about 80% of domestic water requirement and more than 45% of the total irrigation in the country. As per the international norms, if per-capita water availability is less than 1700 m^3 per year then the country is categorized as water stressed and if is less than 1000 m^3 per capita per year then the country is classified as water scarce. In India per capita surface water availability in the year 1991 and 2001 were 2309 and 1902 m^3 and these are projected to reduce to 1401 and 1191 m^3 by the years 2025 and 2050 respectively. Hence, there is a need for judicious planning, development and management of the greatest assets of the country viz. water and land resources for raising standards of living of millions of people particularly in rural areas.

2. Status of Surfcae and Ground Water Resources

Although, India occupies only 3.29 million km^2 geographical area, which forms 2.4% of the world's land area, it supports over 15% of the world's population. The population of India as on 1st March 2001 stood at 1,027,015,247 persons. Thus, India supports about $1/6^{th}$ of world population, $1/50^{th}$ of world's land and $1/25^{th}$ of world's water resources[7]. India also has a livestock population of 500 million, which is about 20% of the world's total livestock population. More than half of these are cattle, forming the backbone of Indian agriculture. A brief description of availability of surface and groundwater water resources of India is given as follow.

2.1 Surface Water Resources

In the past, several organizations and individuals have estimated water availability for the nation within the limitations of physiographic conditions and socio-political environment, legal and constitutional constraints and the technology of development available differently. Utilizable water resource is the quantum of withdrawable water from its place of natural occurrence. Recently, the National Commission for Integrated Water Resources Development (NCIWRD, 1999) estimated the basin-wise average annual flow in Indian river systems as 1953 km^3 and the utilizable annual surface water of the country is 690 km^3. The details of available and utilizable surface water resources are given in Table 1.

2.2 Ground Water Resources

The annual potential natural ground water recharge from rainfall in India is about 342.43 km^3, which is 8.56% of total annual rainfall of the country. The annual potential ground water recharge augmentation from canal irrigation system is about 89.46 km^3. Thus, total replenishable groundwater resource of the country is assessed as 431.89 km^3. After allotting 15% of this quantity for drinking, and 6 km^3 for industrial purposes, the remaining can be utilized for irrigation purposes. Thus, the available ground water resource for irrigation is 361 km^3 of which utilizable quantity (90%) is 325 km^3. The basin wise per capita water availability varies between 13,393 m^3 per annum for Brahmaputra-Barak basin to about 300 m^3 per annum for Sabarmati basin. The state-wise estimates of dynamic ground water (fresh) resource made by the Central Ground Water Board (CGWB, 1995) are given in Table 2. The basin-wise ground water potential of the country is given in Table 3 (IWRS, 1998).

Table 1. Basinwise average flow and utilizable water (in km^3/year) (NCIWRD, 1999)

S. No.	River Basin	Average Annual Flow	Utilizable Flow
1	Indus	73.31	46
2	Ganga-Brahmaputra-Meghna Basin		
	2a Ganga	525.02	250
	2b Brahmaputra sub-basin	629.05	24
	2c Meghna (Barak) sub-basin	48.36	
3	Subarnarekha	12.37	6.81
4	Brahmni-Baitarani	28.48	18.3
5	Mahanadi	66.88	49.99
6	Godavari	110.54	76.3
7	Krishna	69.81	58
8	Pennar	6.32	6.86
9	Cauvery	21.36	19
10	Tapi	14.88	14.5
11	Narmada	45.64	34.5
12	Mahi	11.02	3.1
13	Sabarmati	3.81	1.93
14	West flowing rivers of Kachchh and Saurashtra including Luni	15.1	14.98
15	West flowing rivers south of Tapi	200.94	36.21
16	East flowing rivers between Mahanadi and Godavari	17.08	13.11
17	East flowing rivers Between Godavari and Krishna	1.81	
18	East flowing rivers Between Krishna and Pennar	3.63	
19	East flowing rivers Between Pennar and Cauvery	9.98	16.73
20	East flowing rivers south of Cauvery	6.48	
21	Area of North Ladakh not draining into Indus	0	NA
22	Rivers draining into Bangladesh	8.57	NA
23	Rivers draining into Myanmar	22.43	NA
24	Drainage areas of Andman, Nicobar and Lakshadweep Islands	0	NA
	Total (Rounded)	1953	690

Table 2. State-wise dynamic fresh ground water resource of India (in km^3/ year)
(CGWB, 1995)

S. No.	States	Replenish-able Ground Water Resource from Normal Natural Recharge	Replenish-ment due to Recharge Augment-ation from Canal Irrigation	Total Replenish-able Ground Water Resource	Percentage Contribution of Recharge Augment-ation to Total GW Resource
1	Andhra Pradesh	20.03	15.26	35.29	43
2	Arunachal Pradesh	1.44	0.00	1.44	0
3	Assam	24.23	0.49	24.72	2
4	Bihar	28.31	5.21	33.52	16
5	Goa	0.18	0.03	0.21	14
6	Gujarat	16.38	4.00	20.38	20
7	Haryana	4.73	3.80	8.53	45
8	Himachal Pradesh	0.29	0.08	0.37	22
9	Jammu & Kashmir	2.43	2.00	4.43	45
10	Karnataka	14.18	2.01	16.19	12
11	Kerala	6.63	1.27	7.90	16
12	Madhya Pradesh	45.29	5.60	50.89	11
13	Maharashtra	33.40	4.47	37.87	12
14	Manipur	3.15	0.00	3.15	0
15	Meghalaya	0.54	0.00	0.54	0
16	Mizoram	Not Assessed			
17	Nagaland	0.72	0.00	0.72	0
18	Orissa	16.49	3.52	20.01	18
19	Punjab	9.47	9.19	18.66	49
20	Rajasthan	10.98	1.72	12.70	14
21	Sikkim	Not Assessed			
22	Tamil Nadu	18.91	7.48	26.39	28
23	Tripura	0.57	0.10	0.67	15
24	Uttar Pradesh	63.43	20.39	83.82	24
25	West Bengal	20.30	2.79	23.09	12
26	Union Territories	0.35	0.05	0.40	13
	Total	342.43	89.46	431.89	21

3. Water Requirements

Traditionally, India has been an agriculture-based economy. Hence, development of irrigation to increase agricultural production for making the country self-sustained and for poverty alleviation has been of crucial importance for the planners. Accordingly, irrigation sector was assigned a very high priority in the 5-year plans. Giant schemes like the Bhakra Nangal, Hirakud, Damodar Valley, Nagarjunasagar, Rajasthan Canal project etc. were taken up to increase irrigation potential and maximize agricultural production. Long-term planning has to account for the growth of population. According to National Water Policy (2002) the production of food grains has increased from around 50 million tonnes in the fifties to about 203 million tonnes in the year 1999-2000. A number of individuals and agencies have estimated the likely population of India by the year 2025 and 2050. According to the estimates adopted by NCIWRD (1999), by the year 2025, the population is expected to be 1333 million in high growth scenario and 1286 million in low growth scenario. For the year 2050, high rate of population growth is likely to result in about 1581 million people while the low growth projections place the number at nearly 1346 million. Keeping in view the level of consumption, losses in storage and transport, seed requirement, and buffer stock, the projected food-grain and feed demand for 2025 would be 320 million tonnes (high demand scenario) and 308 million tonnes (low demand scenario).

Table 3. Ground water potential in river basins of India (Pro rata basis) (in km^3/year) (IWRS, 1998)

S. No.	Name of the basin	Total replenis-able ground water resources	Provision for domestic, industrial and other uses	Available ground water for irrigation	Net draft	Balance ground water potential	Level of ground water develop ment (%)
1.	Brahmani with Baitarni	4.05	0.61	3.44	0.29	3.16	8.45
2.	Brahmaputra	26.55	3.98	22.56	0.76	21.80	3.37
3.	Chambal Composite	7.19	1.08	6.11	2.45	3.66	40.09
4.	Cauvery	12.30	1.84	10.45	5.78	4.67	55.33
5.	Ganga	170.99	26.03	144.96	48.59	96.37	33.52
6.	Godavari	40.65	9.66	30.99	6.05	24.94	19.53
7.	Indus	26.49	3.05	23.43	18.21	5.22	77.71
8.	Krishna	26.41	5.58	20.83	6.33	14.50	30.39
9.	Kutch & Saurashtra Composite	11.23	1.74	9.49	4.85	4.64	51.14
10.	Madras and South Tamil Nadu	18.22	2.73	15.48	8.93	6.55	57.68
11.	Mahanadi	16.46	2.47	13.99	0.97	13.02	6.95
12.	Meghna	8.52	1.28	7.24	0.29	6.95	3.94
13.	Narmada	10.83	1.65	9.17	1.99	7.18	21.74
14.	Northeast Composite	18.84	2.83	16.02	2.76	13.26	17.20
15.	Pennar	4.93	0.74	4.19	1.53	2.66	36.60
16.	Subarnarekha	1.82	0.27	1.55	0.15	1.40	9.57
17.	Tapi	8.27	2.34	5.93	1.96	3.97	33.05
18.	Western Ghat	17.69	3.19	14.50	3.32	11.18	22.88
	Total	431.43	71.08	360.35	115.21	245.13	31.97

The requirement of food grains for the year 2050 would be 494 million tonnes (high demand scenario) and 420 million tonnes (low demand scenario). Table 4 provides details of the population of India and per capita water availability as well as utilizable surface water for some of the years from 1951 to 2050 (projected). The availability of water in India shows wide spatial and temporal variations. Also, there are very large inter annual variations. Hence, the general situation of availability of per capita availability is much more alarming than what is depicted by the average figures.

3.1 Domestic Use Water Requirement

Community water supply is the most important requirement and it is about 5% of the total water use. About 7 km^3 of surface water and 18 km^3 of ground water are being used for community water supply in urban and rural areas. Along with the increase in population, another important change from the point of view of water supply is higher rate of urbanization. As per the projections, the higher is the economic growth, the higher would be urbanization. It is expected that nearly 61 percent of the population will be living in urban areas by the year 2050 in high growth scenario as against 48% in low growth scenario. Different organizations and individuals have given different norms for water supply in cities and rural areas. The figure adopted by the NCIWRD (1999) was 220 litres per capita per day (lpcd) for class I cities. For the cities other than class I, the norms are 165 for year 2025 and 220 lpcd for the year 2050. For rural areas, 70 lpcd and 150 lpcd have been recommended for the year 2025 and 2050. Based on these norms and projection of population, it is estimated that by the year 2050, water requirements per year for domestic use will be 90 km^3 for low demand scenario and 111 km^3 for high demand scenario. It is expected that about 70% of urban water requirement and 30% percent of rural water requirement will be met by surface water sources and the remaining from ground water.

3.2 Irrigation Water Requirement

Irrigated area in the country was only 22.6 million hectare (M-ha) in 1950-51. Since food production was much below the requirement of the country, due attention was paid for expansion of irrigation. The ultimate irrigation potential of India has been estimated as 140 M-ha. Out of this, 76 M-ha would come from surface water and 64 M-ha from ground water sources. The quantum of water used for irrigation by the last century was of the order of 300 km^3 of surface water and 128 km^3 of ground water, total 428 km^3. The estimates indicate that by the year 2025, water requirement for irrigation would be 561 km^3 for low demand scenario and 611 km^3 for high demand scenario. These requirements are likely to further increase to 628 km^3 for low demand scenario and 807 km^3 for high demand scenario by the year 2050.

Table 4. Per capita per year availability and utilizable surface water in India (in m^3)

S. No.	Year	Population (in million)	Per-capita surface water availability	Per-capita utilizable surface water
1	1951	361	5410	1911
2	1955	395	4944	1746
3	1991	846	2309	816
4	2001	1027	1902	672
5	2025 (Projected)	a. 1286 (Low growth) b. 1333 (High growth)	1519 1465	495
6	2050 (Projected)	a. 1346 (Low growth) b. 1581 (High growth)	1451 1235	421

3.3 Hydroelectric Power Water Requirement

The hydropower potential of India has been estimated at 84,044 MW at 60% load factor. At the time of independence (1947), the installed capacity of hydropower projects was 508 MW. By the end of 1998, the installed hydropower capacity was about 22,000 MW. The status of hydropower development in major basins is highly uneven. According to an estimate, India has plans to develop 60,000 MW, additional hydropower by the twelfth five year plan. It includes 14,393 MW during tenth five year plan (2002-2007); 20,000 MW during eleventh (2007-2012) and 26,000 MW during twelfth (2012-2017) five year plans. A potential of the order of 10,000 MW is available for development of small hydropower projects in the Himalayan and sub-Himalayan regions of the country. Therefore, it is not only desirable but also a pressing need of time to draw a master plan for development of small, medium and large hydro-schemes for power generation.

3.4 Industrial Water Requirement

Rough estimates indicate that the present water use in the industrial sector is of the order of 15 km^3. The water use by thermal and nuclear power plants with installed capacities of 40000 MW and 1500 MW (1990 figures) respectively, is estimated to be about 19 km^3. In view of shortage of water, the industries are expected to switch over to water efficient technologies. If the present rate of water use continues, the water requirement for industries in the year 2050 would be 103 km^3; this is likely to be nearly 81 km^3 if water saving technologies are adopted on a large scale.

3.5 Total Water Requirements

Total annual requirement of water for various sectors has been estimated and its break up is given Table 5.

Table 5. Annual water requirement for different uses (in km^3) (NCIWRD, 1999)

Uses	Year 1997-98	Year 2010			Year 2025			Year 2050		
		Low	High	%	Low	High	%	Low	High	%
Surface Water										
Irrigation	318	330	339	48	325	366	43	375	463	39
Domestic	17	23	24	3	30	36	5	48	65	6
Industries	21	26	26	4	47	47	6	57	57	5
Power	7	14	15	2	25	26	3	50	56	5
Inland Navigation		7	7	1	10	10	1	15	15	1
Environment – Ecology		5	5	1	10	10	1	20	20	2
Evaporation Losses	36	42	42	6	50	50	6	76	76	6
Total	399	447	458	65	497	545	65	641	752	64
Ground Water										
Irrigation	206	213	218	31	236	245	29	253	344	29
Domestic	13	19	19	2	25	26	3	42	46	4
Industries	9	11	11	1	20	20	2	24	24	2
Power	2	4	4	1	6	7	1	13	14	1
Total	230	247	252	35	287	298	35	332	428	36
Grand total	629	694	710	100	784	843	100	973	1180	100
Total Water Use										
Irrigation	524	543	557	78	561	611	72	628	807	68
Domestic	30	42	43	6	55	62	7	90	111	9
Industries	30	37	37	5	67	67	8	81	81	7
Power	9	18	19	3	31	33	4	63	70	6
Inland Navigation	0	7	7	1	10	10	1	15	15	1
Environment – Ecology	0	5	5	1	10	10	1	20	20	2
Evaporation Losses	36	42	42	6	50	50	6	76	76	7
Total	629	694	710	100	784	843	100	973	1180	100

With the increasing population as well as all round development in the country, the utilization of water has also been increasing at a fast pace. In 1951, the actual utilization of surface water was about 20% and 10% in the case of ground water. The utilizable water in river basins is highly uneven. For example in the Brahmaputra basin, which contributes 629 billion m^3 of surface water of the country's total flow, only 24 billion m^3 is utilizable.

4. Stratagies for Management of Surface and Groundwater Resources

In view of the existing status of water resources and increasing demands of water for meeting the requirements of the rapidly growing population of the country as well as the problems that are likely to arise in future, a holistic, well-planned long-term strategy is needed for sustainable water resources management in India. The water resources management practices may be based on increasing the water supply and managing the water demand under the stressed water availability conditions. Data monitoring, processing, storage, retrieval and dissemination constitute the very important aspects of the water resources management. These data may be utilized not only for management but also for the planning and design of the water resources structures. In addition to these, now a days decision support systems are being developed for providing the necessary inputs to the decision makers for water resources management. Also, knowledge sharing, people's participation, mass communication and capacity building are essential for effective water resources management. Some important aspects of such strategies are described as follows.

4.1 Flood Management

Among all natural disasters, floods are the most frequent to be faced in India. Floods in the eastern part of India viz. Orissa, West Bengal, Bihar and Andhra Pradesh in the recent past, are striking examples. As per the information published by different government agencies the tangible and intangible losses due to floods in India are increasing at alarming rate. As reported by Central Water Commission (CWC) under Ministry of Water Resources, Government of India, the annual average area affected by floods is 7.563 million ha. This observation is based on the data for the period 1953 to 2000 published in IWRS (2001), with variability ranging from 1.26 million ha in 1965 to 17.5 million ha in 1978. On an average floods have affected about 33 million persons during 1953 to 2000 and average annual damage due to floods is about 4,600 crores. There is every possibility that this figure may increase due to rapid growth of population and increased encroachments of the flood plains for habitation, cultivation and other activities.

The main causes of floods in India are inadequate capacity within river banks to contain high flows, river bank erosion and silting of river beds. The additional factors are land slides leading to obstruction of flow and change of the river course, retardation of flow due to tidal and back water effects, poor natural drainage in the flood prone area, cyclone and associated heavy rain storms or cloud bursts, snowmelt and glacial outbursts and dam break flows. After the disastrous floods of 1954 a national programme of flood management was launched. The government of India has taken a number of steps for flood management. Some of the important policies on flood management include: policy statement (1954); high level committee on flood (1957); policy statement (1958); ministerial committee on flood control (1964); ministers committee on flood and flood relief (1972); working groups on flood control for five year plans; Rashtriya Barh Ayog (1980); National Water Policy (1987); National Commission for Integrated Water

Resource Development (1996); Regional Task Force (1996); and National Water Policy (2002).

The committees and commissions constituted by the government have given valuable recommendations on different issues of flood management. Various types of structural as well as non-structural measures have been envisaged to reduce the damages in the flood plains. The structural measures are: (i) dams and reservoirs, (ii) detention basins, (iii) embankments, (iv) channel improvement, (v) drainage improvement, (vi) watershed management. The non-structural measures are: (i) flood forecasting, (ii) flood proofing, (iii) disaster mitigation system and preparedness, (iv) flood plain zoning and (v) flood insurance. Construction of embankments, levees, spurs, etc. have been implemented in some of the states. The total length of constructed embankments is 16,800 km and drainage channels are of 32,500 km. A total of 1,040 towns and 4,760 villages are currently protected against flood. Barring occasional breaches in embankments, these have provided reasonable protection to an area of about 15.07 M ha. A large number of reservoirs have been constructed and these reservoirs have resulted in reduction of intensity of floods.

The non-structural measures such as flood forecasting and warning are also being adopted. The flood forecasting and flood warning in India commenced in 1958, for the Yamuna river in Delhi. It has evolved to cover most of the flood prone interstate river basins in India. The Central Water Commission has established a flood forecasting network covering 70 rivers basins covering 18 States/Union Territories. The forecasts are issued at about 173 stations. Out of these 145 stations are for river stage forecasts and 28 for inflow forecasts to the reservoirs. The response of state governments towards enactment of flood plain zoning bill is not encouraging. Though some of the states (e.g. Rajasthan and Manipur) have enacted the flood plain zoning legislation, but the major flood affected states (e.g. Assam, Himachal, Goa and Sikkim) have not considered such legislation. A working group of National Natural Resources Management System (NNRMS, 2002) standing committee on water resources for flood risk zoning of major flood prone rivers considering remote sensing input was constituted by the Ministry of Water Resources in 1999. The working group recommended flood risk zoning using satellite based remote sensing with a view to give thrust towards implementation of flood plain zoning measures.

The flood management measures have to be more focused and targeted towards the decided objectives within a stipulated time frame. For flood plain zoning, methods have to be evolved in consultation of the local bodies so that the legislation on flood plain zoning is adopted. As suggested by the Working Group of tenth five year plan that the possible apprehensions of difficulties in drafting a legislation should not become a bar to the idea of the approach of flood plain zoning itself. Flood forecasting constitutes one of the most important actions of flood disaster preparedness. Technical advancement in a well planned flood forecasting and warning system can help in providing higher lead time for timely action. It is well recognized that long term solution of flood problems lies in creating appropriate flood storage in reservoirs. The total live storage capacity of completed projects in India is about 174 km^3. A large flood storage space in reservoirs is required for a successful flood management programme. Flood management also calls for community participation.

In view of the unprecedented floods in the year 2004 in Assam, Bihar and some other parts of the country and as a follow-up of the announcements made by the Hon'ble Prime Minister during his visits to Bihar and Assam, the Government set up a 21 Member Task Force headed by the Chairman, Central Water Commission to study the flood/erosion problems in Assam and other neighboring states as well as Bihar, West Bengal and Eastern Uttar Pradesh and suggest suitable measures for management of floods and erosion control. The Task Force submitted the report on 31st December, 2004 wherein short and long term measures for flood management and erosion control, requirement of funds, strengthening of institutional set up at centre and states, international dimensions etc. have been indicated. The report of the Task Force has been circulated to the concerned state governments and the recommendations are under consideration of MOWR (Jeyaseelan, 2005).

Further, the farmers, professional bodies, industries and voluntary organizations have to be aware about flood management. People's participation in preparedness, flood fighting and disaster response is required. Media like radio, TV, newspapers can also play an important role in flood management. As India shares river systems with six neighboring countries viz. Nepal, China, Bhutan, Pakistan, Bangladesh and Myanmar; hence, bilateral cooperation for flood management is necessary for India and the concerned country. The government of India has taken some initiatives in this regard; however, more active participation is required.

4.2 Drought Management

The drought prone area assessed in the country is of the order of 51.12 million ha. The planning and management for drought mitigation appear to have a low priority due to associated randomness and uncertainty in defining the start and end of droughts. Further most of the drought planning and management schemes are generally launched after persisting drought conditions. The traditional system of drought monitoring and estimating losses by crop cutting needs replacement with real time remote sensing, GIS, GPS and modeling techniques for ensuring transparency and quick response. Scope of losses may be extended to ground water depletion, damage to perennial trees, plantations, orchards and depletion in fertility of livestock. Food, fodder, agricultural inputs and water banks may be established in vulnerable areas instead of their storage in surplus regions to avoid transport bottlenecks during the drought.

Though the occurrence of drought cannot be prevented, being well prepared for its likely occurrence can lesson its impacts on life and vegetation. Efforts should be directed towards reducing the demand an increasing the availability of water locally. Some of the measures considered are improved land-use practices, conjunctive use of surface and groundwater, watershed management, rainwater/runoff harvesting, efficiency improvement, conservation, recycling water and water allocation strategies among competing demands. Drought contingency planning, including restrictions of water use, rationing programs, special water tariffs and reduction of low-value uses (agriculture) require detailed examination. Thus, most measures focus on management, reallocation and distribution of existing water resources and on establishing priorities accordingly for different uses.

After normal rainfall resumes there is a rapid decrease of government and public interest in drought planning schemes. Most of the time the execution of the drought management scheme is based on the administrative units, while planning of water resources is based on basin scale. Therefore, an integrated basin development approach is required to be developed and implemented for preparing the drought management plan before, during and after the occurrence of the drought. In this regard, there is a need for the development of the decision support systems (DSS) for the monitoring and management of the drought on basin scale utilizing the advanced capabilities of remote sensing, GIS and knowledge based systems. The DSS should also provide support to the decision makers for providing the information at different spatial and temporal scales. It would help them in taking the required management measures in the drought prone areas for different administrative units. In the drought prone areas publication campaign may be launched for water conservation with the help of electronic and print media. Necessary steps may be taken at political, administrative and technical levels to encourage the people participation in the drought management for optimum utilization of the available water supply to meet the demands. Strengthening of R&D and capacity building in terms of emerging information technologies and issues of damages is also called upon to bring in resilience in the drought coping strategies.

4.3 Inter-basin Water Transfer

The vast variation, both in space and time, in the availability of water in different regions of India has created a food-drought-flood syndrome with some areas suffering from flood damages and other areas facing acute water shortage. The States of Karnataka, Tamil Nadu, Rajasthan, Gujarat, Andhra Pradesh and Maharashtra are the worst drought prone States. The States of Uttar Pradesh, Bihar, West Bengal, Orissa and Assam face severe flood problems. Inter-basin transfer of water in India is a long-term option to partly overcome the spatial and temporal imbalance of availability and demand of water resources.

The transfer of water from surplus areas to deficit areas is not a new concept. Many such schemes have been implemented all over the world. In India too, projects like Periyar –Vaigai system, Indira Gandhi canal, and Telugu Ganga stand as classic examples of inter-basin water transfer. In the seventies, the Garland Canal proposal of Capt. Dastur and the Ganga - Cauvery Canal proposal of Rao (1973) were received with considerable attention. A National Perspective Plan (NPP) for water resources development was formulated by the Government of India in 1980s. The distinctive feature of the NPP is that the transfer of water is essentially by gravity and only in small reaches by lift pumping (not exceeding 120 m). This plan comprises of two components: (a) Himalayan Rivers Development, and (b) Peninsular Rivers Development. While the second component will be an inter-state venture, the first will involve neighboring countries too and thus will be an international venture. Thirty such links (16 in peninsular component and 14 in Himalayan component) have been identified. Some of the major benefits expected from inter linking of the rivers as mentioned in WMF, 2003 and IWRS, 1996) are: (i) irrigation potential is to increase from 140 to 175 million ha; (ii) drinking water availability is to increase by about 12 km^3; (iii) peak flood discharge to get reduced by about 30% due construction of reservoirs; (iv) generation of 34,000 MW of electricity; and (v) possibilities of inland navigation to provide cheap transport.

The need for making water available to water short areas by transfer from other areas including transfers from one river basin to another, based on a national perspective, after taking into account the requirements of such areas/basins has also been underlines in the National Water Policy (2002). A Committee of environmentalists, social scientists and other experts under the Chairmanship of Secretary, Ministry of Water Resources has been constituted in December, 2004 with a view to making the process fully consultative. Recently, after arriving at consensus between Uttar Pradesh and Madhya Pradesh a tripartite MoU on Ken-Betwa river link has been signed on 25.8.2005 by the Chief Ministers of Uttar Pradesh and Madhya Pradesh and Union Minister of Water Resources in the presence of Hon'ble Prime Minister. These efforts will now pave way for preparation of DPR for this link. Five identified links have been prioritized and discussions are in progress with the states concerned for building up consensus (Jeyaseelan, 2005).

4.4 Groundwater Management

As a result of increase in water demands for domestic, industrial and agricultural uses, over-exploitation of groundwater has resulted in permanent depletion of ground water reservoirs, lowering of the ground water table in many parts of the country and sea water intrusion in coastal areas. It is a matter of serious concern. Based on the ground water resources estimation carried out for 8,189 assessment units, jointly with the states/union territories, 673 assessment units have been categorized as 'over-exploited' where annual ground water abstraction is more than the annual replenishable resource. Another 425 assessment units have been categorized as 'dark/critical' where the development is between 85 and 100% with declining trend of water levels. Management options to arrest declining ground water levels are two fold viz. regulated withdrawals and augmentation of ground water.

To protect the aquifers from overexploitation, an effective groundwater management policy oriented towards promotion of efficiency, equity, and sustainability is required. Agricultural holdings in India are highly fragmented and the rural population density is large. The exploitation of groundwater resources should be regulated so as not to exceed the recharging possibilities, as well as to ensure social equity. The detrimental environmental consequences of over-exploitation of groundwater need to be effectively prevented by the Central and State Governments. Over exploitation of groundwater should be avoided, especially near the coasts to prevent ingress of seawater into freshwater aquifers (National Water Policy, 2002). Clearly, a joint management approach combining government administration with active people participation is a promising solution Nagaraj et al., 1999).

In critically overexploited areas, bore-well drilling should be regulated till the water table attains the desired elevation. Artificial recharge measures need to be urgently implemented in these areas. Amongst the various recharge techniques, percolation tanks are least expensive in terms of initial construction costs (Oaksford, 1985). Many such tanks already exist but a vast majority of these structures have silted up. In such cases, cleaning of the bed of the tank will make them reusable. Promotion of participatory action in rehabilitating tanks for recharging would go a long way in augmenting groundwater supply. Due to declining water table, the cost of extraction of groundwater has been increasing over time and wells often go dry. This poses serious financial burden on farmers. Hence, special programs need to be designed to support these farmers. Finally, the role of government will have to switch from that of a controller of groundwater development to that of a facilitator of equitable and sustainable development. Shah (2005) mentions that three large-scale responses to groundwater depletion in India have emerged in recent years in an uncoordinated manner, and each presents an element of what might be its coherent strategy of resources governance as follows:

Energy-irrigation nexus: Throughout South Asia, the ‘groundwater boom’ was fired during the 1970’s and 90’s by government support to tubewells and subsidies to electricity supplied by state-owned electricity utilities to farmers. The invidious energy-irrigation nexus that emerged as a result and wrecked the electricity utilities and encouraged waste of groundwater are widely criticized. However, hidden in this nexus is a unique opportunity for groundwater managers to influence the working of the colossal anarchy that is India’s groundwater socio-ecology. Even while subsidizing electricity, many sate governments have begun restricting power supply to agriculture to cut their losses. International Water Management Institute research has shown that with intelligent management of power supply to agriculture, energy-irrigation nexus can be powerful tool for groundwater demand management in livelihood supporting socio-ecologies to create tradable poverty rights in groundwater. Mexico finally had to turn to electricity supply management to enforce its groundwater concessions (Scot et al., 2003).

Inter-basin transfers to recharge unconfined alluvial aquifers: In western India’s unconfined alluvial aquifers, it is being increasingly realized that groundwater depletion can be countered only by importing surface water, Arizona-style. Jiangsu province in eastern China has implemented its own little inter-basin water transfer from Yangzee to counter groundwater depletion in the Northern part. Similarly, one of the major uses Gujarat has found for water of the Sardar Sarovar Project on Narmada river is to recharge the depleted aquifers of North Gujarat, and Kachchh. A key consideration behind India’s proposed mega-scheme to link its northern rivers with peninsular rivers too is to counter groundwater depletion in western and southern India.

Mass-based recharge movement: In many parts of hard-rock India, groundwater depletion has invoked wildfire community-based mass movement for rainwater harvesting and recharge, which interestingly has failed to take off in unconfined alluvial aquifers. It is difficult to assess the social value of this movement partly because ‘formal hydrology’ and ‘popular hydrology’ have failed to find a meeting ground. Scientists want check dams sited near recharge zones; villagers want them close to their wells. Scientists recommend recharge tubewells to counter the silt layer impeding recharge; farmers just direct floodwaters into their wells after filtering. Scientists worry about upstream-downstream externalities; farmers say everyone lives downstream. Scientists say the hard-rock aquifers have too little storage to justify the prolific growth in recharge structures; people say a recharge structure is worthwhile if their wells provide even 1000 m^3 of life-saving irrigation/ha in times of delayed rain. Hydrologists keep writing the obituary of the recharge movement; but the movement has spread from eastern Rajasthan to Gujarat, thence to Madhya Pradesh and Andhra Pradesh. Protagonists think that with better planning of recharge structures and larger coverage, decentralized recharge movement can be a major response to India’s groundwater depletion because it can ensure that water tables in pockets of intensive use rebound close to pre-development levels at the end of the monsoon season every year they have a good monsoon, which is at least twice in 5 years. They surmise that this is not impossible because even today, India’s total groundwater extraction is barely 5% of its annual precipitation.

Shah (2005) mentioned following workable solutions for management of groundwater resources:

i. Banning private wells is futile; crowd them out by improving public water supply.
ii. Regulating final users is impossible; facilitate mediating agencies to emerge, and regulate them.
iii. Pricing agricultural groundwater use is infeasible; instead, use energy pricing and supply to manage agricultural groundwater draft.
iv. No alternative to improved supply side management: better rain-water capture and recharge, imported surface water in lieu of groundwater pumping.
v. Grow the economy, take pressure off land, and formalize the water sector.

The Central Ground Water Authority has been constituted under Section 3(3) of the Environment Protection Act, 1986 to regulate and control the development and management of ground water Resources in the country. For augmentation of ground water resources, Central Ground Water Authority had requested all the Chief Secretaries of states and union territories to include provision of roof top rain water harvesting in building bye laws. In order to increase the recharge to ground water aquifers, Government of India has prepared a Master Plan for Artificial Recharge to Ground Water which envisages recharge of 36,453 MCM of surplus monsoon runoff through construction of 3.925 million artificial recharge and rooftop rain water harvesting structures. During the next 2 years, implementation of the scheme is estimated to cost of Rs.1750 million. Mass awareness campaign to encourage rain water harvesting for ground water recharge has been taken up by involving NGOs, Residents Welfare Associations, industries, big institutions like offices, hospitals, hotels etc. In order to promote rain water harvesting, financial grants/assistance is also being provided by the government (Jeyaseelan, 2005).

4.5 Conjunctive Use of Surface and Groundwater

Large canal infrastructure network for providing irrigation has been the prime goal of the Government of India, since first five-year plan, which continued up to seventh five-year plan. In some of the irrigation project commands such as Sarda Sahayak in U.P., Gandak in Bihar, Chambal in Rajasthan, Nagarjuna Sagar in Andhra Pradesh, Ghatprabha and Malprabha in Karnataka etc., problems of waterlogging are being faced. The main reason for excessive use of surface water as compared to groundwater is its much lower price for irrigation as compared to the cost incurred in using groundwater. Waterlogging problems could be overcome if conjunctive use of surface and groundwater is made. Groundwater utilization for irrigation in waterlogged areas can help to lower the groundwater table and reclaim the affected soil. Over exploitation of groundwater in areas like Mehsana, in Gujarat; parts of Meeurt and Varanasi districts in Uttar Pradesh, Coimbatore in Tamil Nadu and Karnal district in Haryana etc. has resulted in mining of groundwater (Chandra, 2001). Many research workers have focused the causes of waterlogging (Raghuvanshi et al., 1990). Several groundwater flow modeling studies have focused on assessing the waterlogged areas and measures to control problems of waterlogging and salinization (Gates et al., 2002 and Dawoud et al., 2004). It is desirable that the irrigation needs for fulfilling crop water requirements should be satisfied by judicious utilization of available canal water in conjunction with ground water so as to keep the water table within the acceptable range. Thus, the optimal conjunctive use of the region's surface and groundwater resources would help in minimizing the problems of waterlogging and groundwater mining.

4.6 Efficient Irrigation Management

Introduction of irrigation has resulted in substantial increase in crop productivity. However, the productivity level is lower than what has been achieved elsewhere in the world. Conveyance and field application losses vary widely with the type of strata through which canal system passes, material used and quality of works in the canal lining, preparation of the field, type of soil, stream size and method of irrigation. There is no national level assessment of overall irrigation efficiencies obtained from surface and ground water. However, in general, the overall efficiencies obtained are of the order of 35-40 percent in surface water and 65-70 percent in ground water and National Commission on Integrated Water Resources Development Plan has postulated that it is possible to achieve higher efficiencies of the order of 50-60 percent for surface water and 72-75 percent for ground water. All out efforts have to be made to improve the efficiencies of the irrigation systems, which has been rightly identified a one of the thrust areas (Jeyaseelan, 2005).

In order to achieve higher level of efficiency in irrigation, attention will have to be given go the following management problems; (i) excessive loss of irrigation water due to seepage, (ii) inequitable distribution of water between head and tail reaches, (iii) poor maintenance of the canal system, (iv) inadequate drainage and water logging, (v) lack of field channels and poor maintenance where they have been constructed, (vi) improper water management practices (vii) improper cropping calendar and cropping pattern (viii) poor extension services, (ix) lack of land leveling, (x) lack of interaction with the beneficiaries and (xi) stake holder involvement.

It has now been recognized that unless farmers are progressively involved in an organized way in the operation, management and maintenance of irrigation system, the objective of increased utilization and production from irrigation commands cannot be realised and, even if realised, cannot be sustained in the long run. Many shortcomings of present irrigation management could be overcome by effective involvement of farmers. Participatory Irrigation Management (PIM) encourages sense of belonging among farmers. Promotion of PIM, being one of the thrust areas, necessary guidelines has been circulated. The states have to formulate accordingly their policies to transfer the irrigation management of the systems at minor level and below to the farmers. The Ministry of Water Resources circulated a Model Act to all the states in 1998, either to amend the existing Irrigation Act or enact a new legislation to put a proper legal and organisation a framework in place for PIM. Eight states have already enacted/amended legislations in this regard and remaining states are in the process. More emphasis is given to participatory approach in the restructured Command Area Development Water Management (CADWM) Programme, wherein the central assistance under the programme is linked with the formation of Water Users' Associations and beneficiaries contributing a minimum of 10% of cost of certain components.

Out of the irrigation potential of 100 Mha created, only about 85 Mha is reported as utilised, leaving behind a gap of about 15 Mha. Some gap between the two could occur when river inflows and consequent irrigation supplies are inadequate. Delay in construction of distribution networks, diversion of water for domestic/industrial water supply, change in cropping pattern to water intensive crops etc. are some of the reasons for the gap between potential created and utilised. Action for bridging this gap is being taken through Command Area Development (CAD) programme, which was launched in 1974-75 as a centrally sponsored scheme to ensure, inter-alia, timely completion of on-farm development works for speedy utilisation of irrigation potential created. The CAD programme has now been restructured as Command Area Development and Water Management (CADWM) Programme. The programme needs to be further strengthened and rationalized to give focus to those projects, which have large gaps in potential created and utilized even after 5 years of their completion.

The present status of maintenance of irrigation projects in the country is not upto the mark. The financial allocations made for the upkeep of irrigation projects is not adequate and, even whatever provision is made, is not utilised effectively. A major portion of maintenance provisions gets spent on staff salary component, with the result that very little is left for the actual maintenance of the system, which remains unattended and consequently the system deteriorates. Recently, a committee has been set up under Member (WP&P), CWC with members from States for "fixing norms for establishment component for O&M".

4.7 Watershed Management

For an equitable and sustainable management of shared water resources, flexible, holistic approach of Integrated Water Resources Management (IWRM) is required, which can cater to hydrological variations in time and space and changes in socio-economic needs along with societal values. Watershed is the unit of management in IWRM, where surface water and groundwater are inextricably linked and related to land use and management. Watershed management aims to establish a workable and efficient framework for the integrated use, regulation and development of land and water resources in a watershed for socio-economic growth. Local communities play a central role in the planning, implementation and funding of activities within participatory watershed development programs. In these initiatives, people use their traditional knowledge, available resources, imagination and creativity to develop watershed and implement community-centered program. Currently, many programs, campaigns and projects are underway in different parts of India to spread mass awareness and mobilize the general population in managing water resources. Some of these are being implemented by the central/state Governments, while others have been taken up by various Non-Governmental Organizations (NGOs). Coordinated watershed development programs need to be encouraged and awareness about benefits of these programs should be created among the people.

4.8 Water Conservation

Water conservation implies improving the availability of water through augmentation by means of storage of water in surface reservoirs, tanks, soil, and groundwater zone. It emphasizes the need to modify the space and time availability of water to meet the demands. This concept also highlights the need for judicious use of water. There is a great potential for better conservation and management of water resources in its various uses. On the demand side, a variety of economic, administrative and community-based measures can help conserve water. Also, it is necessary to control the growth of population since large population is putting massive stress on all natural resources.

Since agriculture accounts for about 69% of all water withdrawn, the greatest potential for conservation lies in increasing irrigation efficiencies. Just a 10% improvement in irrigation efficiency could conserve enough water to double the amount available for drinking. In India, sprinkler irrigation is being adopted in Haryana, Rajasthan, Uttar Pradesh, Karnataka, Gujarat and Maharashtra. An important supplement to conservation is to minimize the wastage of water. In urban water supply, for example, almost 30% of the water is wasted due to leakages, carelessness, etc. while most metro cities face deficit in supply of water. It is, therefore, imperative to prevent wastage. In industries also, water conservation should be practiced.
Rainwater Harvesting

Rainwater harvesting is the process to capture and store rainfall for its efficient utilization and conservation to control its runoff, evaporation and seepage. Some of the benefits of rainwater harvesting are: (i) it increases water availability, (ii) it checks the declining water table, (iii) it is environmentally friendly, (iv) it improves the quality of groundwater through dilution, mainly of fluoride, nitrate, and salinity, and (v) it prevents soil erosion and flooding, especially in the urban areas. Even in ancient days, people were familiar with the methods of conservation of rainwater and had practiced them with success. Different methods of rainwater harvesting were developed to suit the geographical and meteorological conditions of the region in various parts of the country. Traditional rainwater harvesting, which is still prevalent in rural areas, is done by using surface storage bodies like lakes, ponds, irrigation tanks, temple tanks etc. In urban areas, rainwater will have to be harvested using rooftops and open spaces. Harvesting rainwater not only reduces the possibility of flooding, but also decreases the community's dependence on groundwater for domestic uses. Apart from bridging the demand-supply gap, recharging improves the quality of groundwater, raises the water table in wells/bore-wells and prevents flooding and choking of drains. One can also save energy to pump groundwater as water table rises. These days rainwater harvesting is being taken up on a massive scale in many states in India. Substantial benefits of rainwater harvesting exist in rural and urban areas. There is a need to recharge aquifers and conserve rainwater through water harvesting structures.

4.9 Water Quality Conservation and Environment Restoration

Implementation of water pollution prevention strategies and restoration of ecological systems are integral components of all development plans. To preserve our water and environment, we need to make systematic changes in the way we grow our food, manufacture the goods, and dispose off the waste (Lazaroff, 2000). In India, agriculture is the biggest user and polluter of water. If pollution by agriculture is reduced, it would improve water quality and would also eliminate cost incurred for treatment of diseases. Like all other inputs, there is an optimal quantity of fertilizer for given conditions and excess application does not improve the crop yield. Pricing of fertilizers and pesticides as well as appropriate legislation to regulate their use will also go a long way in stopping indiscriminate use. Industries need to carefully treat their waste discharges. Manufacturers should reduce water pollution by reusing materials and chemicals and switching over to less toxic alternatives. Also, there is a need to encourage reductions or replacement of toxic chemicals, possibly through fiscal measures. Efforts should be made to restore landscapes and ecosystems to more efficiently protect water quality, aquatic and wildlife.

4.10 Recycle and Reuse of Water

Recycling and reuse of water is another way through which we can improve water availability. In the city of Frankfurt, Germany, every drop of water is recycled eight times. In Dalian, China after investigating various potential solutions, such as sea water desalination, water conservation and importation from other regions, to address Dalian's water shortage problems, waste water reuse was designated as the best solution (World

Water and Environment Engineering (WWE), 2005). Use of water of lesser quality, such as reclaimed wastewater, for cooling and fire fighting is an attractive option for large and complex industries to reduce their water costs, increase production and decrease the consumption of energy. This conserves better quality waters for potable uses. Currently, recycling of water is not practiced on a large scale in India and there is considerable scope and incentive to use this alternative. Estimates show that recyclable water is between 103 to 177 km^3/year for low and high population projections (Gupta et al., 2004).

4.11 Vulnerability to Climate Change and Adaptation Strategies

Climate change is a human-induced stress (at least in part) that is generally not yet taken into account. An annual mean global warming of 0.4 to 0.8^0 C has been reported since the late 19^{th} century (IPCC, 1998). In India, the analysis of seasonal and annual air temperatures, using the data for 1881 to 1997 has shown a warming trend of 0.57^0 C per hundred years Pant et al., 1997). Substantial increases in greenhouse gases are likely in the future as a consequence of which global mean surface temperature is expected to increase by between 1.4^0 and 3^0 C for low emission scenarios and between 2.5^0 C and 5.8^0 C for high emission scenarios by 2100 with respect to 1990 (IPCC, 2001). Lal (2001) stated that globally averaged precipitation is projected to increase, but at the regional scale both increases and decreases are projected. Global mean sea level is likely to rise by 0.14 to 0.80 meters from 1990 to 2100.

Under changed climatic scenarios a number of chain events, like melting of glaciers, sea level rise, submergence of islands/coastal areas and deviant rainfall patterns, are likely to occur. Likely impacts would include a greater annual variability in the monsoon's precipitation levels, leading to more intense floods and droughts. Climate change is likely to result in hydrologic conditions and extremes of a nature that will be different than those for which the existing projects were designed. The approaches for effectively dealing with climate change will have to be different than those that have been employed to manage variability in the past. It is also likely that the variability due to climate change may be beyond the range for which current projects have been designed and are being operated. A review of current coping strategies of populations already affected by climate variability is needed. The likely impacts of increased climate variability and climate change on the water resources are required to be assessed. The coping strategies need to be evolved considering major factors viz. social, economic, institutional etc. to reduce vulnerability and enhance adaptation to climate related developments and events. Some part of the country facing the frequent drought are adopting the dry land farming practices to grow the crops which require less amount of water. However, there is a need to take up such studies for assessment of available water resource for different agro-climatic regions of India and various adaptation practices under the changing climatic scenarios.

Some recommendations to cope up with the problems resulting due to climate change in a systematic and a planned manner are: (i) a nation wide climate monitoring programme should be developed; (ii) while formulating new projects that influence climate, it should be ensured that no action is taken which causes irreversible harmful impact on the climate; (iii) improved methods for accounting of climate related uncertainty should be developed and made part of decision making process; (iv) existing systems should be examined to determine how they will perform under the climate situations that are likely to arise; (v) water availability and demands in all regions, particularly in water scarce regions should be reassessed in the new climate scenario; (vi) a re-examination of the water allocation policies and operating rules should be taken up to see how these need to be updated to handle extremes that are likely to arise; and (vii) there should be proper coordination amongst concerned organizations so as to freely share the data, technology and experience for capacity building.

4.12 Environmental Flow Requirement (EFR)

An environmental flow is the water regime provided within a river, wetland or coastal zone to maintain ecosystem and their benefits where there are competing water uses and where flows are regulated. Environmental flows provide critical contributions to river health, economic development and poverty alleviation. They ensure the continued availability of many benefits that healthy river and groundwater systems bring to society. Environmental flows normally include the flow requirements in rivers and estuaries for maintenance of riverine ecology. The total EFR for most of Indian rivers ranges between 20 to 27% of the renewable water resources. But these EFR estimates may be considered as preliminary. These need verification through detailed, basin-specific assessments of the EFR. At the same time, it is important to appreciate that EFR allocations of less then about 20% of the mean annual flow are likely to degrade any river beyond the limits of possible re-habilitation. An additional factor, not yet considered in the assessment, is that a reduction in river flows decreases the ability of a river to cope with pollution loads. These loads are known to be massive in many Indian basins. Unutilizable portion of surface runoff in most Indian basins is adequate to meet the EFR. Only in a few basins, namely Pennar, West flowing rivers in Kutch, Saurastra and Luni, Cauvery and east flowing rivers between Pennar and Kanyakumari, the EFR exceeds the unutilizable runoff. In these basins, a part of the potentially utilizable water resources has to be earmarked for EFR. Sometimes, during the period of water scarcity it may be difficult to meet out the EFR considering the importance of the demands from the other water sectors such as drinking water supply, irrigation, hydropower etc. In such a situation, an optimum allocation policy may be evolved considering the potential demands and available supply. Efforts must be made to restrict the pollution loads to the rivers and other water bodies from the point and non-point sources of pollution in order to minimize the EFR.

4.13 Water Rights, Ownership and Pricing

One of the most important issues to be considered during planning, development and management of surface and groundwater resources is water rights, ownership and pricing aspects. Water Rights refer to a legal system for allocating water from a water source to water users. The nature of water rights could be natural (customary) or legal (positive-granted by law), individual or group rights, positive (having obligation on others to do something) or negative (obligation to refrain from doing something) and riparian rights. As per common law, every riparian owner has a natural right to use the water of a stream which flows past his land with due consideration of other riparian owners.

As regards ground water, it was presumed that right belong to land owner and there is no limitation on how much a particular land owner draws, which has resulted in over-exploitation and permanent depletion of ground water table in many parts of the country. In order to regulate exploitation of ground water, CGWA and CGWB are taking appropriate regulatory, legal and other measures. In case of states, the sovereign powers of the state over natural water resources are covered in the Constitution at Entry 17 in the List II and Entry 56 and 57 of List I of the Seventh Schedule. Since disputes in respect of sharing/distribution of water of inter-state rivers are on the rise, a committee constituted by MOWR has attempted and submitted "Draft National Policy Guidelines for Water Sharing Amongst States" to MOWR in August, 2004, which encompasses developing the waters of inter-state rivers with better agreement between the co-basin States/Union Territories, such that developments are not detrimental to the interests of one or the other and are guided by national perspective (Jeyaseelan, 2005).

A strategy, which needs consideration, is changes in water pricing structures. Mostly water rates are based only on a portion of what it costs to obtain, develop, transport, treat and deliver water to the consumer. The costs are usually paid for in part by subsidies from the state using tax payer's money and therefore are not accurately reflected in an individual's water bill. Prices of water for all uses should be fixed, keeping in mind its economic value, control of wastage, and the ability of users to pay. As water is becoming scarcer, pricing will be an important factor in avoiding wastage and ensuring optimal use.

4.14 Legal Restrictions on Water Use

One of the active strategies could include provisions of legal restrictions on use of water, mainly during the period of scarcity. The National Water Policy (2002) includes policy directions for development and management of water resources. Also, provision of legal restrictions on proper utilization of ground water resources has been advocated at various forums in the country. In fact, the state of Gujarat has already enhanced such legislation and other states may also follow the suit. However, provision of legal restrictions should be carefully thought of and need mobilization of qualified water specialists to explore effective solutions. The legal strategies so adopted should be such which can be implemented with minimum probability of being rendered ineffective by injunctions and law suits.

The rates can be thought to vary with the availability either by an increase in price during period of abundant supply. The policy of peak demand pricing can also be effective in conserving water in which higher rates can be proposed for water use beyond a prescribed limit. Moreover, some economic incentives for using small amount of water can be given to consumers for encouraging water conservation. Studies are required on collection of economic data on other actions to induce conservation since reduction in water use will probably to be attributable to both price increases and other factors. These efforts are needed separately for residential, commercial and industrial sectors.

4.15 Desalination of Water

Since 1970, there has been significant commercial development using various desalination technologies, including distillation, reverse osmosis, and electrolysis. This technology is suitable for use in areas where freshwater is scarce, but saline water is available and energy is cheap. Compared to water recycling technologies, desalination presents fewer health risks. Desalination, as currently practiced, mostly uses fossil fuels. Both distillation and membrane processes are already in use for desalination in China, with multi stage flash having received attention since the 1970s and sea water reverse osmosis being studies since 1965. In 2004, a multi-effect distillation plant was installed in Qingdao city. The system can produce 3000 m^3/d. The power consumption of the plant is 1.6kWh/m^3 of water (World Water and Environment Engineering (WWE), 2005). Africa's largest desalination plant has been launched in Algiers in June, 2005. When it comes to fruition, it will be the Africa's largest sea water desalination plant. The US $225 million project will also be the largest membrane desalination plant in Africa as well as one of the largest desalination plants in the entire world. Construction of this plant for supplying 2,00,000 m^3/d of reverse-osmosis potable water is expected to take 24 months (WWE, 2005). Solar and wind energy are available in abundance in India and may be explored as alternative sources for this purpose in the coastal states. Between the high capital and energy requirements, desalinated water costs several times more than water supplied by conventional means. But the costs are now coming down. Current production cost is about Rs. 50 per m^3 (Times of India newspaper, New Delhi, dated 30 July 2004). Many facilities in coastal region are using reverse osmosis for desalinization. For example, at Kalpakkam reactor, Tamil Nadu, 1.8 million litres water is being produced per day. It is expected that as the costs come down, desalinization would become commercially viable in next 6 to 8 years.

4.16 Data Monitoring and Information System

For planning, design and operation of the water resources projects, temporal and spatial data of various hydrometeorological variables as well as basin characteristics are required. However, in India the network of monitoring the hydrometeorological variables is inadequate. Also the data collection, processing, storage and dissemination are not well organized. In this regard, a comprehensive, reliable and easily accessible Hydrological Information System (HIS) is a pre-requisite. To achieve these objectives, there is a need to strengthen the existing monitoring network of data and develop the HIS by improving the data processing, analysis and dissemination techniques through proper coordination amongst the various agencies.

To improve the existing HIS in India, a giant step has been taken up by implementing the World Bank aided Hydrology Project Phase-I (HP-I). During the HP-I the data monitoring network has been strengthened and HIS has been developed for various river basins of the nine peninsular states of India, viz. Andhra Pradesh, Chhattisgarh, Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Kerala, Orissa and Tamil Nadu. Six central organizations namely Ministry of Water Resources, Central Water Commission, National Institute of Hydrology, Central Ground Water Board, India Meteorological Department, Central Water and Power Research Station also participated in HP-I. The information system will be very much useful for processing, storage and dissemination of the reliable and spatially intensive data on water quantity as well as quality in computerised databases. Special attention has been paid to standardize data observation and validation procedures so that data are of good quality and are compatible across various agencies. Infrastructure and human resources development aspects have been attended for sustainability of the system which should grow with developments in hydrology and allied technologies Chowdhary et al., 2002). Data processing with decentralised hierarchical structure ensures a completely participatory approach. The system will promote greater interaction between different HIS agencies and also ensure uniformity of tools and procedures. Improvements in infrastructure and institutional support are beginning to reflect in terms of availability of organised hydrological databases and timely availability of better quality data to the users. It would only be fitting that the improved system further grows and the experience gained is utilised for similar improvements in all other states of India. Recent techniques, such as remote sensing and Geographic Information System (GIS) coupled with field based monitoring stations may be utilized to monitor the data in real time and update the database.

4.17 Applications of Decision Support System in Water Resources

Recently, new advances in computer technology have enabled widespread improvement in water resources planning and management. One of the new trends in solution of water management problems has been to aggregate several models into integrated software i.e. a knowledge based Decision Support System (DSS) that focuses on the interaction between the use and the data, models, and computers. Rapidly advancing computational ability, development of user-friendly software and operating systems, and increased access to and familiarity with computers among decision makers are the important reasons for this growth in the fields of both research and practice. Automating the process with a DSS could effectively improve the water resources planning and management.

The aim has been to create a system in which the mechanics of linking one component with another are largely transparent to the user. Although time and effort is required in customizing the system for a particular river basin, its use has been designed to be as simple as possible. Communication is by means of a user-friendly interface, which makes extensive use of hypertext for guidance and color graphics in presenting the results. A keyboard is not normally required since all the facilities are accessed by touching the appropriate icon representing the particular component. Moreover, controls for operating a model may be familiar in as much that the icons mimic a video-recorder viz. play, pause and stop. In this way, the person responsible for the project is able to make rational use of the system without an in-depth knowledge of modeling techniques. Under the Ministry of Water Resources, Government of India, World Bank funded

Hydrology Project Phase-II has commenced recently. Besides the nine states and six central agencies who participated in the HP-I, four states namely Himachal Pradesh, Punjab, Goa and Pondicheri as well as two central agencies viz. Central Pollution Control Board and Bhakhra Beas Management Board are also participating in the HP-II. In this project development and applications of DSS for water resources planning is one of the major components and it is expected to bridge some of the gaps between developed advance technologies and their field applications (Kumar, et al, 2005).

4.18 Eco-hydrological Approach to Water Resources Management

All development activities involve both positive and negative environmental impacts. There is need to properly evaluate environmental and social issues for ensuring sustainable development in proper perspective. One must give due attention to the protection, conservation and long-term environmental sustainability of our finite/available freshwater resources. With the environmental clearance having been made mandatory with the promulgation of EIA Notification in 1994, comprehensive environmental impact assessment are carried out and environmental management plans are formulated for the projects before they are taken up. Above Notification was amended during 1997 and the element of public hearing has been introduced in the environmental clearance process. Mandatory public hearing is to be conducted in the project area and its report is to be included in the documents submitted to the Ministry of Environment & Forest for environmental clearance, which is to be considered only if the report of the public hearing is favorable. The National Water Policy (2002) also mentions that in the planning, implementation and operation of a project, preservation of the quality of environment and ecological balance should be duly considered. The adverse impact on environment, if any, should be minimized and should be offset by adequate compensatory measures.

The eco-hydrological approach to water resources management considers the water flow domain and water use domain for categorizing the water as green and blues. Green water concept refers to the water used in growth of economic biomass i.e. rainfed food, timber, fuel-wood, pastures, etc. as well as the ecosystems biomass growth i.e. plants and trees in wetlands, grasslands and forests etc. Blue water concept refers to economic use of water in society i.e. irrigation, industry and domestic uses as well water flow required for ecosystem functions such as aquatic freshwater habitats etc. Considering green and blue water approach indicates that there is plenty of water around and the conventional blue water crisis is misleading. However, almost all water is involved in securing ecosystem service which supports human livelihoods and provides us resilience to cope with shocks. The water crisis is therefore different in character not primarily about direct human use, but just balancing water between humans and nature.

4.19 Virtual Water Transfer

By definition virtual water is the water embedded in a product, i.e. the water consumed during its process of production. Virtual water refers to all sorts of production where water is used, e.g. it is not restricted to grain only. The production includes other inputs or investments like energy, labor, soil, market etc. The concept emerged in the 1990s and receives more and more attention from people concerned with water management and in particular with water related to food production. The water requirements of food are by far the highest. It takes 2 to 4 litres per day to satisfy the drinking water needs of a human being and about 1000 times as much to produce the food[31]. In this way, the concept of virtual water is very important for food production and consumption. The importance of virtual water at global level is likely to increase as projections show that food trade will increase rapidly i.e. doubling for cereals and tripling for meat between 1993 and 2020[32]. Therefore, the transfer of virtual water embedded in the food that is traded is becoming an important component of water management on global and regional level, particularly where water is scarce. India is a vast country with large spatial and temporal variations in availability of water resources. Hence, it is important that virtual water is properly assessed in terms of its value in space and time. It also needs to be analyzed how virtual water is considered at policy level on food trade, water management and agriculture.

4.20 People Participation and Capacity Building

For making the people of various sections of the society aware about the different issues of water resources management, a participatory approach may be adopted. Mass communication programmes may be launched using the modern communication means for educating the people about water conservation and efficient utilization of water. Capacity building should be perceived as the process whereby a community equips itself to become an active and well-informed partner in decision making. The process of capacity building must be aimed at both increasing access to water resources and changing the power relationships between the stakeholders. Capacity building is not only limited to officials and technicians but must also include the general awareness of the local population regarding their responsibilities in sustainable management of the water resources. Policy decisions in any water resources project should be directed to improve knowledge, attitude and practices about the linkages between health and hygiene, provide higher water supply service levels and to improve environment through safe disposal of human waste. Sustainable management of water requires decentralized decisions by giving authority, responsibility and financial support to communities to manage their natural resources and thereby protect the environment.

4.21 Recent Initiatives in Water Resources Planning and Management

As stated by Jeyaseelan (2005) in the National Common Minimum Programme, water sector has been accorded high priority and, keeping in view the present scenario of water resources development and management and available financial resources, thrust areas identified by MOWR/PMO are: improving water use efficiency, appropriate regulation and management of ground water, revival and restoration of existing water bodies, ground water recharge, command area development and participatory irrigation management, flood management and erosion control, dam safety and rehabilitation, protection against coastal erosion, pursue agenda for inter-linking or rivers starting with south bound rivers, early completion of ongoing major irrigation projects, new initiatives with focus on irrigation, setting up of NEWRA for north-east and institutional reforms.

In order to bring more area under irrigated agriculture, Government has taken up a number of initiatives. First among these is to provide Central Loan Assistance (CLA) to the States under Accelerated Irrigation Benefit Programme (AIBP) since 1996-97 to accelerate completion of ongoing irrigation and multipurpose projects, some of which are even continuing from pre-fifth plan period. In all, 184 Major/Medium/ERM irrigation projects have received Central Loan Assistance of Rs.17120.82 crores since its inception till 31.03.2005 and about forty (40) projects/project components have since been completed, adding an additional irrigation potential of about 2.7 Million ha.

A pilot scheme "National Project on Repair, Renovation and Restoration of Water Bodies directly linked to Agriculture" has been launched for Rs. 300 crores on 30th April, 2005 by the Hon'ble Prime Minister to cover one or two districts in each of the states to restore and augment storage capacities of traditional water bodies and to recover the lost irrigation potential of the existing water bodies, which are at present in disuse. This is a state-sector scheme will be funding pattern of Centre: State in the ratio 75:25. Detailed Project Reports submitted by the states for the selected districts were examined and MOWR approved projects in sixteen districts of nine states. Active community participation is envisaged as a necessary input to ensure optimum utilization of assets and facilities proposed to be created under the scheme and to sustain the scheme on long term basis through involvement of Panchayati Raj Institutions and Water Users' Associations (WUAS). Catchment area treatment to a limited extent is part of this scheme. Once the pilot scheme is completed and validated, it will form the basis for launching of the "National Water Resources Development Project" at a much larger scale, which may take 7-10 years for completion.

As another initiative, a major scheme named as Bharat Nirman to bring 10 million hectares (Mha) under assured irrigation in a period of four years through completion of on-going major, medium and ERM projects, revival and renovation of water bodies and ground water development for irrigation is in pipeline. The broad target fixed, beginning from 2005-06 to 2008-09 is 1.90, 2.40, 2.85 and 2.85 Mha respectively (Jeyaseelan, 2005).

5. Concluding Remarks

Water is one of the most essential natural resources for sustaining life and it is likely to become critically scarce in the coming decades, due to continuous increase in its demands, rapid increase in population and expanding economy of the country. The uneven spatial and temporal distribution of the precipitation in India, results in highly uneven distribution of available water resources and leads to floods and drought affecting vast areas of the country. Therefore, in addition to focusing on the agricultural needs of water, equal emphasis is to be laid on management of floods and droughts. Mitigation of floods and special needs of drought prone areas will continue to require due attention in future and development plans will need to address these issues. Suitable models are needed for forecasting the monsoon rainfall accurately, which may be utilized by the decision makers and farmers for adopting appropriate strategies for management of droughts and floods. There is a need for increasing the availability of water and reducing its demands. For increasing the availability of water resources, there is a need for better management of existing storages and creation of additional storages by constructing small, medium and large sized dams considering the economical, environmental and social aspects. The availability of water resources may be further enhanced by watershed management, improving efficiency of irrigation, rejuvenation of dying lakes, ponds and tanks and increasing the artificial means of ground water recharge. In addition to these measures, inter-basin transfer of water provides one of the options for mitigating the problems of the surplus and deficit basins. However, for inter-basin transfer of water the scientific studies need to be carried out for establishing its technical and economic feasibility considering the environmental, social and echo-hydrological aspects.

Integrated and coordinated development of surface water and ground water resources and their conjunctive use should be envisaged right from the project planning stage and should form an integral part of the project implementation. There is a need for judicious management of groundwater resources, which presently require adequate inputs including manpower, financial inputs, technologies etc. Some of the important measures which may be taken up for sustainable development of groundwater resources include improving public water supply, use of energy pricing and supply to manage agricultural groundwater draft, increasing rain-water harvesting and ground water recharge, transfer of surface water in lieu of groundwater pumping, increasing the economic growth and reduction in dependence on agriculture and formalizing the water sector.

There should be a periodic reassessment of the surface and ground water potentials on a scientific basis, taking into consideration the quality of water available and economic viability of its extraction. The available information and data collected so far by different operational and field organizations, scientific groups and engineering community are inadequate for planning, development and management of the vast water resources in the country. The time series data of the hydrological and meteorological variables, the space oriented data and relation oriented data are generated in a fragmented manner for specific locations and extrapolated to larger regions or river basins. Thus, in this regard, a comprehensive, reliable and easily accessible Information System for water resources data is a pre-requisite. The effort made in the World Bank aided Hydrology Project – I, is an important step in this direction. Decision Support Systems are required to be developed for planning and management of the water resources projects. Such systems provide an integrated approach for water resources management considering the various water related disciplines together with socio-economic aspects. These systems may be utilized for studying the different scenarios of water demand for arriving at the optimum allocation of water for various demands under varying water availability conditions.

Climate change is posing a challenge before the water resources engineers. Studies are required to be taken up for assessment of water resources under changing climatic scenarios. For predicting the future climatological variables on micro, meso and macro watershed scales, a comprehensive general circulation model coupled with the physically based hydrological model is required to be developed for India. With the rapid industrialization and increasing use of fertilizers and pesticides, the quality of surface and groundwater resources is deteriorating. The movement of pollutants in the rivers, lakes and ground water aquifers needs to be regulated. In this regard, regular water quality monitoring programme has to be launched for identifying the areas likely to be affected because of the water quality problems. For maintaining the quality of freshwater, water quality management strategies are required to be evolved and implemented. Minimum flow should be maintained in the rivers for meeting the criteria of EFR. The eco-hydrological approach based on the concepts of blue and green waters may be considered as an integral part of the water resources management practices by balancing water between human beings and nature. Also, the concept of virtual water transfer requires to be introduced at policy level for food trade, water management and agriculture. As most of the major rivers covering about 83% of geographical area in India are inter-state in character; hence, there is a need for greater inter-state cooperation for integrated development of water resources. Water resource will have to be planned, developed and managed with an integrated approach keeping national perspective in view, which calls for a more effective and proactive role to be played by the central and state governments. The capacity building and awareness programmes should be organised for the users and public for encouraging their effective participation in water management practices and developing ethical concepts for making efficient use of water resources. Capacity building is also needed for the water resources managers and developers for updating the knowledge and technology in the area of water resources management.

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