Water Resources Management

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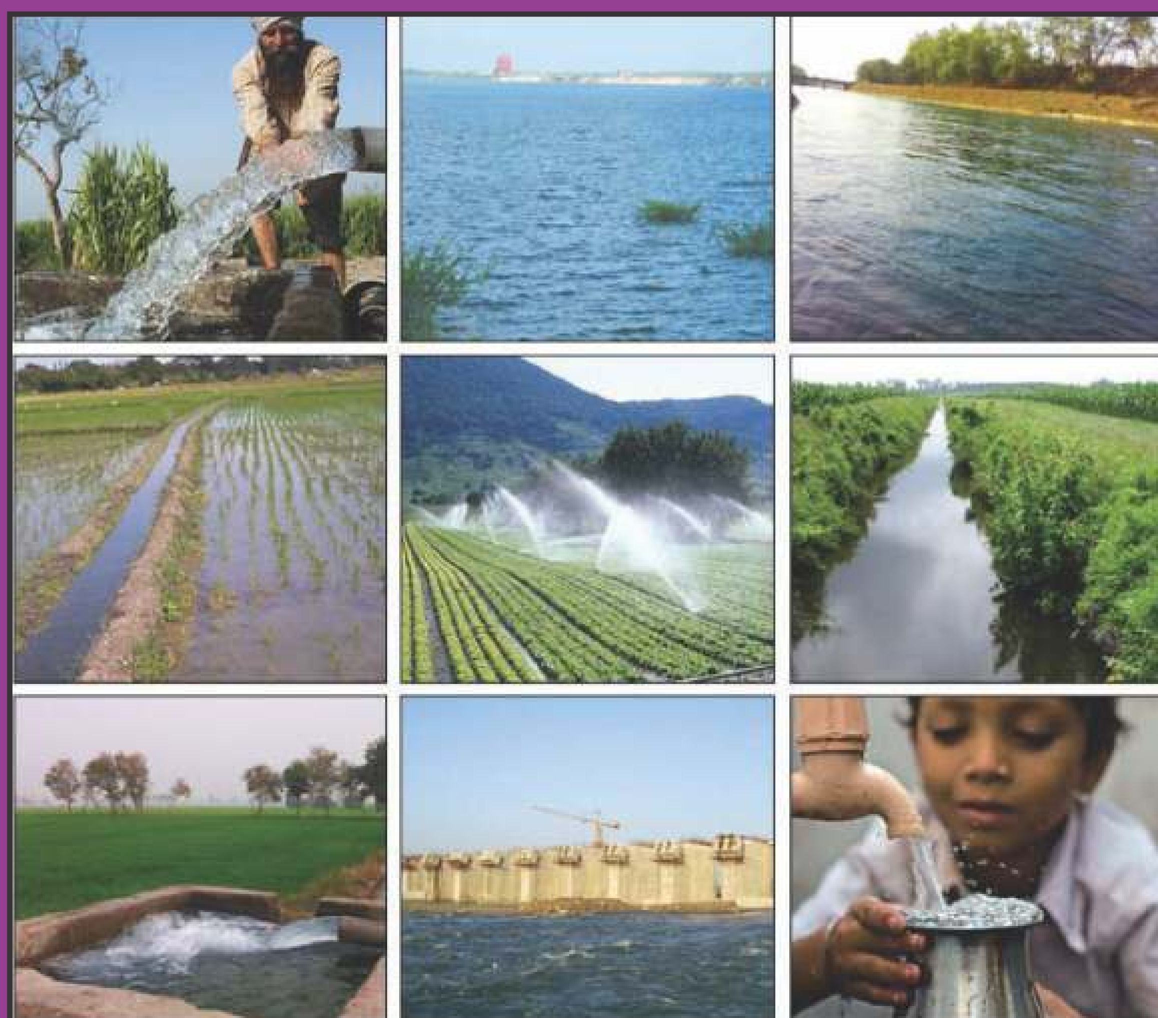

Indian National Academy of Engineering

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INDIAN NATIONAL ACADEMY OF ENGINEERING

RESEARCH REPORT

WATER RESOURCES MANAGEMENT

Indian National Academy of Engineering

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Celebrating Silver Jubilee

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FOREWORD

The Indian National Academy of Engineering is committed to advance the profession and enhance the contributions of the engineers to the service of the society. INAE commissions research studies of high relevance to enable sustained development of the nation. The research study titled *Water Resources Management* addresses important and crucial challenges facing us related to water and technologies.

It is my pleasure and privilege to place this study report before you. The research was conducted by a group of six fellows of the Academy, who are acknowledged experts in the field – Prof. S S Chakraborty as the Group Coordinator, Prof. Subhash Chander, Dr. N K Tyagi, Prof. S Mohan, Dr. R R Sonde and Er. Paritosh Tyagi.

The Academy has shown sustained interest in this important domain of high interest and concern. The Academy organised in February 2008, a seminar on Water Resources Management, at IIT Delhi. The study reported herein is a continuing effort with better perspectives and more intensity in looking at the possibilities and challenges.

The study assesses demand for water from various sectors of the economy, their trends and the potential shift from one sector to another in the light of the changes in the composition of the economy, the food security requirements, implications of changes in the lifestyle, technology (including in agriculture, power generation, etc.) and other significant factors. On the supply side, the major issues are seasonal and geographical variations, the concerns for environmental changes, quality of water and climate change. The report recommends a series of measures to improve water resources management leading to better economy and quality of life.

I earnestly appeal to all the stakeholders to contribute in our endeavor of sustainable development. We should pledge our active support for taking all the steps and necessary actions to enable the nation to have adequate water of right quality for all the stakeholders in our growing economy.

Baldev Raj

Dr. Baldev Raj
President

PREFACE

Rapid economic growth and sustained overall development are underpinned by the availability and judicious stewardship of resources, water being a primary one. India, encompassing vast diversity (geographical, meteorological, and cultural), large population, and facing uncertainties of climate change, will find it extremely delicate to balance the various forces that arise in equitable utilization of this resource. We are facing, by most estimates, water scarcity of such magnitude that our development plans may go awry without focused attention, preparing doable plans of actions and acting on these, concertedly, and truly immediately.

While the government has taken some measures in this regard, the Indian National Academy of Engineering had decided to bring in a focused engineering and technology perspective, but not ignoring the agricultural and sociological aspects, to the issues at hand, and commissioned a Research Study. A group of six Fellows of the Academy was constituted. On behalf of the group, let me assert the pride it felt for having been invested with the responsibility for this essential and challenging task.

The study takes a look at water demand/availability in 2025/2050 in the major sectors, agriculture, industry, energy and domestic consumption, maintaining water quality and making water-energy linkages robust, at the river-basin level. A set of recommendations has also been mooted.

Our recommendations have been communicated to the Academy for consideration and submission to the Government of India for appropriate action. Our efforts would indeed reap rich dividend if these recommendations were acted upon in a time-bound framework by the various stakeholders to ensure efficient and effective management and sustainable use of the resource.

Prof. S S Chakraborty	March 27, 2012
Group Coordinator	New Delhi

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Abbreviations

AIBP	Accelerated Irrigation Benefit Program
BAU	Business As Usual
BCM	Billion cubic meter
BTU	British thermal unit
CV	Coefficient of Variation
CWU	Consumptive Water Use
cm	Centimeters
DD	Degree of Development
EC	End Century
EFR	East flowing rivers
ET	Evapotranspiration
EWS	Early Warning System
GWh/d	Giga watt hour per day
GOI	Govt. of India
GWAR	Ground Water Abstraction Ratio
ha-m	Hectare meter
ha	Hectare
IMT	Irrigation Management Transfer
kcal	Kilo calories
kg	Kilogram
kg/g	Kilogram per Gram of Product
km	Kilometer
km2	Kilometer Square
Km3	Kilometer cube
Kwhr/ha	Kilowatt hour per Hectare
KW/ha	Kilowatt per Hectare
kWh/m3	Kilo watt hour per cubic meter
kWh/ML	Kilo watt hour per million liter
L/Day	Liters per day
LP	Per unit of Land
lpcd	Liter per capita per day
MC	Mid century

MJ/m3	Million joule per cubic meters
MW	Mega watt
Mha	Million hectare
MAD	Management Allowed Deficit
mm	Millimeter
m3/sec	Cubic meters per seconds
NSF	National Sanitation Foundation
PABA	Program for Accelerated Benefits for Agriculture
PET	Potential Evapotranspiration
PIM	Participatory Irrigation Management
RCT	Relative cost
SRI	System of Rice Intensification
UN	United Nations
WRD	Water Resources Development
WP	Water Productivity
WFR	West flowing rivers
ZTL	Zero Tillage

Research Study on Water Resources Management

Executive Summary

Water, a gift of nature, plays a critical role in meeting our needs in diverse fields – providing, inter alia, water for drinking, agricultural and industrial uses (to mention a few) as well as maintaining the eco-system. In recent years, the urge for rapid socio-economic development, all over the world, has necessitated undertaking large water development and management programs, often with (unintended) adverse impacts. India with its long history of water resources development and management and a large irrigation network, has been in the forefront for establishing institutions and policies aimed at facilitating planned development of water resources, including, laying down a well thought out National Water Policy. The evolving water supply and demand scenario was assessed in detail by the National Commission for Integrated Water Resources Development (1999). Currently, the National Water Policy is under review.

Despite the continuing concerns and efforts, the water sector in India appears to be in a bind. Withdrawal of water at four times the rate it was 65 years ago to support a population of 1210 million (in 2010) at an enhanced level of nutrition, public health parameters and living standards, is, to say the least, stressing the water capital. The ecosystem health has also been compromised severely. Realizing the seriousness and the importance of the water issues to our programs for national well being, the Indian National Academy of Engineering decided to undertake a research study to look into a few critical aspects of water supply and demand in various sectors.

The present study analyses, inter-alia, water availability, water quality and water demands in a few sectors alongwith the water-energy linkages, at the river basin level.

Water Availability

Box-I: India's Water Resources (Natural) at a Glance

Total renewable water	*2081BCM*
Surface water (SW)	*2039BCM*
Ground water (GW)	*432BCM*
Overlap between SW and GW	*390 BCM*
Utilizable surface water	*690.3 BCM*
Completed surface storage capacity	*218.9BCM*
Storage capacity under creation	*63.9 BCM*
Storage to be added during 2025-2050	*107.5 BCM*
Net available groundwater	*398.7BCM*

India has a reasonably good endowment of water resources with an average rainfall of 1083 mm equivalent to 3560 billion cubic metre (BCM)/year. However, the available amount is substantially less and is estimated at 1869 BCM in the form of surface water and ground water. Extreme temporal and spatial variations reduce the available amount further and utilisable water, from both surface and ground sources, is assessed at 1123 BCM. In terms of utilizable flow, the Ganga, with 421 BCM of water, is the richest basin followed by the Godavari (117 BCM) and the Krishna (84.4 BCM). There is, of course, very heavy *water crowding* because of high population density in the Ganga basin. In terms of per capita utilizable water availability, the picture looks less rosy as the value is less than 1000m^3/yr for the country as a whole. In some basins, the Katchchh in Gujarat and the Luni in Rajasthan, water availability is less than 400m^3/person. Another factor affecting water security is reservoir storage which is only 200m^3/cap/yr in India, compared to2500m^3 in China, 3400m^{3}in Brazil and 6000 m^3 in the USA. In most of the river basins, the water criticality ratio (amount of water withdrawal as a percentage of utilizable flow) is high – more than 0.8 for the Indus and is close to.0.6 for the Ganga.

The situation in respect of ground water is also precarious. Water withdrawal, as a percentage of average annual recharge in many States including Punjab (145%), Rajasthan (125%), Haryana (109%) Gujarat (75%) and Tamil Nadu (85%), is quite high. At country level, the estimated groundwater development stands at 58 % of annual recharge.

Climate is one of the factors that is expected to disturb the hydrologic cycle. Fortunately for India, the implications of climate change are more on the demand side than on water availability.

In short, the traditional water availability criterion appears to put India in the category of countries with a high degree of impending water scarcity. But should we continue to look at water availability only in terms of blue water?

We must look beyond blue water to improve water availability significantly

Our useable water supply appears to be low because blue water has been the major focus of attention. Easier manageability of blue water as compared to green water might be the reason for such development. However, we must now look beyond blue water for augmenting our water availability. Even at present, the green consumptive use in crop production is more than 60% of the total water consumed. Global estimates show that out of the total 5600 BCM of additional water required by 2050, 4800 BCM would be green water (IWMI, 2005). As current consumptive use from rain in India is only about 355BCM, the prospects for improvement are good.

Further additions to blue water

Grey and black waters should gradually become part of our formal water supply. Urban population is slated to reach around 800 million by2050, producing a huge quantity of wastewater. Further additions are possible from saline groundwater, rainwater harvesting, ground water recharge and inter-basin water transfer. Large distance water transfers, as well as regional links may be taken up after appropriate investigations.

Water Quality

Preserving water quality is critical for sustained economic development and it is NOT a quality vs development issue.

Box-2. Different waters

Green waters
Rainwater stored in the soil that supports terrestrial ecosystem and the rain-fed crops

Blue waters
Renewable surface runoff and groundwater recharge which has been the main focus of water management.

Grey water and black waters
Water generated from domestic activities, other than toilets, is grey water, which can be re-circulated for low end uses. Toilet water is called wastewater or black water which can be used after treatment.

Saline/sodic waters
Normally ground water, which can be used for irrigation with or without treatment within certain limits.

Water has value only if it meets the quality requirement for the required (desired) use. An interesting outcome is that water resources development contributes to industrial and agricultural development, which, in turn, generate wastes that degrade water quality. Degradation of water quality affects health and productivity, thereby impacting development activity adversely. It is disappointing to note that in our quest for development, the water quality issue has been virtually ignored, leading to deterioration of the health of rivers, aquifers and wetlands.

Water Quality Parameters and Standards

The common issues regarding surface and groundwater are salinity, toxicity and presence of pathogens. The specific problems relating to surface water are eutrophication, oxygen depletion and ecological health; whereas groundwater specific issues are presence of fluoride, nitrate and arsenic contamination.

As water quality standards differ with intended use, it is essential that while quantifying the degree of pollution, the standards and guidelines for use are kept in view. River stretches are classified into five categories with specified levels of parameters, as shown in the Table below:

Table 1 : Water quality standards with designated use

Parameter / Designated Best Use	Units	A	B	C	D	E
Dissolved oxygen (DO), Min	**mg/l**	6	5	4	4	-
Biochemical oxygen demand (BOD), Max	**mg/l**	2	3	3	-	-
Total Coliforms organism , MPN, Max	**Per 100 ml**	50	500	5000	-	-
pH value	**-**	6.5-8.5	6.5 - 8.5	6-9	6.5-8.5	6.5-8.5
Free ammonia, Max	**mg/l**	-	-	-	1.2	-
Electrical Conductivity , Max	**µmho/cm**	-	-	-	-	2250
Sodium adsorption Ratio, Max	**-**	-	-	-	-	26
Boron , Max	**mg/l**	-	-	-	-	2

The designated best use 'A' denotes water fit for drinking after disinfection; 'B', for mass bathing; 'C', for drinking after conventional treatment; 'D', for fisheries and wildlife, and 'E', for agriculture, industrial cooling, controlled waste disposal and navigation.

Water Quality Status

- The annual Silt load reaching the North-Indian rivers ranges from 4 to 98 hectare meters per 100 sq km of catchment area. The highest silt load occurs in the Teesta (98.4 ham/100km^2).
- Cases of extreme values are relatively limited in number, But certain reaches of important rivers have become polluted because of discharge of untreated domestic and industrial effluents into the rivers.
- The length of river reaches with BOD higher than 6 mg/l is 2800 km in Maharashtra and 1200 Km in Uttar Pradesh.
- Excessive fluoride in drinking water is a major concern in the States of Haryana, Rajasthan, Gujarat and Andhra Pradesh. The permissible limit is only 1mg/l, whereas its concentration in some locations exceeds 30 mg/l.

Box-3 River reaches with BOD>6 mg/l

The Ganga basin- 1800 km

The Godavari basin- 800 km

The Krishna basin- 700 km

The Narmada basin- 200 km

The Tapi basin - 100 km

- 10 million people (approx.) are affected by Arsenic pollution of drinking water in the Gangetic plains. The problem is more acute in Murshidabad, Nadia, North and South 24 Paraganas, Malda and Bardhaman districts of West Bengal. Recent reports indicate the presence of high arsenic levels even up to Kanpur in Uttar Pradesh.

It is obvious that deterioration in water quality is a matter of serious concern. It should be realized that sustainability of a river basin depends on maintenance of quality, which is linked as much to the management of water quality as to river flow and land use management.

Water Demands

Water has multiple linkages with various development components, viz, human health, food, energy, environment etc. This leads to many cross-domain issues of technical, economic, social, legal, and political nature. Water demand projections from 2025 to 2050 in three important sectors namely, agriculture, health and industry as well as the water - energy nexus, were reviewed and analysed with a view to developing recommendations for infrastructure development and management of water resources for sustained growth and welfare of the society.

Water Demand in Agriculture

The two major ingredients in Agriculture are CO_2 and water. Plants must transpire water in copious amounts to produce food. Water must be made available to plants via a growing medium through the water delivery and application systems. In this production chain, the efficiency norms applicable to manmade industry are difficult to apply, resulting in water demands which are much larger than that in other sectors of the economy. Consequently, **we *eat more water than we drink*** or use for other purposes. The average water foot print of an Indian is 1093 m^3/cap/yr, of which 70 %is contributed by food.

Food Demand Drivers

The primary drivers of water demand are population and its growth rate, nutrition standards, composition of diet and the level of urbanization. Water demands are greatly influenced by: where, when and how food is produced. In the production process, water demands are also influenced substantially by resource-use efficiency which depends on a combination of technological, managerial and policy interventions. The projected values of demand drivers (Table-2), indicate a 31% increase by 2050 with 75% increase in urbanization. The nutrition status (Kcal) goes up by 20%,but direct food grain(FG) consumption decreases by 20% and is substituted by non-food grains (NFG) and animal products (ANP) which increase by about 80%. Unless compensated by increased productivity, the water-foot print of food, which is at present about 800 m^3/cap/yr would increase. The project irrigation efficiencies are low to begin with, but are expected to increase gradually.

Table 2 : Food demand drivers at a glance

Demand Driver	2010	2025	2050
Population, Millions	1210	1333	1581
Urban population, %	29	45	51
Food consumption, Kcal/cap/day	2500	2775	3000
FG:NFG:ANP	60:31:9	57:32:11	48:36:16
Av. grain yield, t/ha	1.95	2.40	3.10
Irrigated grain yield, t/ha	2.93	3.60	4.40
Rain-fed grain yield, t/ha	1.12	1.30	1.80
Surface Irrigation Efficiency,%	35-45	35-50	40-60
Ground water Irrigation Efficiency, %	55-65	65-70	65-75

Food Demand: 2025-2050

Estimated food grain requirements for 2025 and 2050 are 291 and 377 million tons respectively which are lower by 29 and 43 million tons than those projected by NCIWRD (GOI, 1999). But demand for fruits and vegetables would go up from 122 to 322 million tons. This shift in composition of diet, from grain to non-grains and animal products with increase in GDP, follows the global trend.

Water Demand for Food

Basin level water demand projections for Agriculture in this Report are based on **Policy** Dialogue Simulation Model, PODIUMSIM, which is an upgrade of PODIUM. This has four major components: food consumption, food production, water demand and water supply like PODIUM, but with substantial improvements at spatial and temporal scale in individual components (Amarasinghe, 2005). It considers the water supply and demand at river basin level on a monthly basis. Values reported for 2000 and 2025 are from Amarasinghe, 2007; for 2050, there are some deviations.

Consumptive Use (CU)

The basic demand for water in agriculture is reflected in the crop consumptive use which is met entirely by rainfall in rain-fed crops and by rainfall together with irrigation in irrigated crops. The crop CU in India will increase from 362.2 BCM in 2010 to 381.9 BCM in 2025 and 419.8 BCM in 2050. During the next 40 years, the largest increase of 22 BCM in CU will take place in the Ganga basin and the lowest, in the Indus basin. In fact, crop CU in the Indus basin may slightly decline due to inter-sector water transfer. River basins like the Sabarmati, the Mahi and the Tapi will also be reaching their limits of further development.

Irrigation Diversion Requirements

The Irrigation Diversion Requirements may reach 735 BCM by 2050, an increase of 14% over the 2010 value of642 BCM (Table-3). These are lower than 807 BCM, the requirement projected by NCIWRD (1999), but higher than the irrigation requirement of 643 BCM, projected by Amarasinghe, et al, 2007. The difference arises mainly because of changes in composition of diet, crop yields and irrigation efficiencies.

Table 3 : Summary of past and projected irrigation diversion requirements (BCM)

Source	2000	2010	2025	2050
Surface water	343	355	380	407
Groundwater	276	287	310	328
Total	619	642	690	735

Contribution of Surface and Ground Waters in Irrigation Diversions

Across the basins, the share of groundwater in irrigation continues to increase. The total irrigated area in 2050 is placed at 117 Mha, of which 70 Mha would be from ground water.

The Ganga basin would account for nearly 43 % of the total irrigated area in 2050 and Irrigation Diversions in the Indus basin would decrease from 87 BCM to 74 BCM. This decline in irrigation diversions in the Indus basin is more pronounced in surface water (54 BCM to 45 BCM) as compared to ground water.

Groundwater will continue to be the main pillar of the country's food production framework. But in view of the fact that ground water availability ratio (GWAR) in water deficit but food surplus basins, has already crossed 70%, the major thrust in ground water development will have to shift to basins having physical sufficiency of water but facing economic deficiency of water.

A majority of the river basins have low project - irrigation efficiencies but high basin efficiencies indicating appreciable recirculation and implying less scope of water saving at basin level.

Change in Cropping System:

River basins operating above a criticality ratio of 0.6 such as the Indus, the Sabarmati, the Luni, the Pennar and the Krishna will have to redesign their cropping and farming systems so as to reduce water demand in agriculture sector without reducing livelihood support. There would be added emphasis on horticulture and dairying.

Green Water Use:

Consumptive use from rainfall (green water) in rain-fed grain crops in the country is of the order of 355 BCM, but its productivity is low. Supplementary irrigation from on-farm harvested rainwater could improve the productivity by 25 -75 % depending upon the crop and the agro climatic region.

Water Demand for Health and Sanitation:

The National Water Policy accords prime importance to drinking water in the priority for allocation. Supply of safe drinking water is the cherished national goal. Access to safe drinking water, reported to be 96% in urban and 73% in rural areas by 2008, as per a Note submitted to the National Consultation Committee, probably requires reassessment. Urbanization and the level of income have an impact on per capita domestic water requirements which increase with the level of urbanization. The NCIWRD (GOI, 1999) adopted different norms according to the classification of cities, towns and villages (Box 4). Water for domestic use is largely a function of population and is placed at 111 BCM (Box-5) for 2050 (an increase of 135 % over 2010 demand).

Box-4	**Water supply norms, LPCD**		
Class of city	**2010**	**2025**	**2050**
Class I	220	220	220
Class II-IV	150	165	150
Rural Areas	55	75	150

Box-5	**Water demand, BCM**		
	2010	**2025**	**2050**
Low variant	42	55	90
High variant	43	62	111
Share of surface water	55%	57%	60%

The share of surface water in domestic water supply would increase from 55 % in 2010 to 60 % in 2050. The estimated water requirement for bovine population is in the range of 5-6 BCM.

Industrial Water demand

Next only to agriculture, industry is a major user of water. The Ministry of Water Resources, Govt. of India, estimates that industrial water use in India is around 7-8 per cent of the total freshwater withdrawal in the country. Central Pollution Control Board (CPCB) data indicate that Indian industry consumed about 10 BCM water as process water and 30 BCM as cooling water. NCIWRD estimated the water demand for industries at 80 BCM in 2025 and 143 BCM in 2050. This is an increase of 350% during a period of 40 years, as demand for2010 was only 41.4 BCM.

Industrial water use is closely linked to the economy of a country and would rise significantly with increasing GDP.

Major Water using Industries

The dominant Industrial Water users are Thermal Power Plants (with a share of 88%), followed by Engineering (5.05%) and Pulp and Paper industries (2.26%) (Table 4). Most of the industrial water use is non-consumptive in nature and generates a high volume of waste water of the order 83,000 million litres per day. As per global standards of water use, Indian industry is highly water inefficient. For example, a Thermal Power Plant, in India, uses 80 m^3 per MWh compared to the global best of 10 m^3 per MWh. In Textiles, it is 200-250 m^3/ton of cotton cloth against a corresponding global value of 100 m^3/ton, resulting in high effluent discharge.

Table 4 : Water use by major industries in India

Industrial Sector	Water use Million m^3	Water use, %
Thermal power plants	35157	87.87
Engineering	2020	5.05
Pulp and paper	906	2.26
Textiles	830	2.07
Steel	517	1.29
Sugar	195	0.49
Fertiliser	74	0.18

High effluent generation is a critical issue. Every cubic meter of water diverted to industry generates 0.77 m^3 waste water, contributing to pollution in surface and ground water bodies

Low industrial water productivity

As in agriculture, the economic productivity of industrial water use in India is low. The value of industrial goods per m^3 of water use (in terms of USD) is only 7.5 in India compared to 23.4 in Brazil, 30 in Argentina and 95.6 in Korea. Hence, the need for adoption of best management practices cannot be over emphasised.

There is a critical need for technology upgradation in the water sector. Cost effective technologies are available off the shelf with gradually decreasing costs. Indian industry today can substantially reduce its water consumption and wastewater discharge by putting into use efficient updated systems for recycling/reuse of processed water. Suitable policies, framed and implemented by the Government, would promote technology adoption, reduce pollution and result in more efficient water use in industry, saving upto 7 BCM of water.

Energy Water Linkage

Energy and Water are the basic elements of the biosphere which are embedded in all production and consumption systems. There are differing perspectives relating to energy and water linkage, indicating the directions and opportunities for increasing the use efficiency and minimizing the cost and environmental problems. These perspectives could be: use of energy in water infrastructure (pumping water for irrigation, desalinization); water use in energy infrastructure (thermal power generation); and water energy as part of the system.

Agricultural water use and energy consumption

In agriculture, energy is most intensively used in irrigation. As crop production requirements increase over time, so would energy requirement. The estimated energy used in pumping water for irrigation namely, 86 GWh in 2000, would increase to 97 GWh by 2025 and 128 GWh in 2050. Energy to be used in pumping surface water is only marginal, as more than 85 % would be used in groundwater irrigation.

Energy consumption in irrigation is linked to the volume of water to be pumped, which in turn, is influenced by the efficiency of water application. As the efficiency of water application is higher in micro irrigation, as compared to surface water application methods, adoption of Drip and Low Energy Precision Application (LEPA) system, would reduce the energy requirements and hence lessen water and energy foot prints of irrigation.

Energy use in Drinking Water Supply and Sanitation

Increasing urbanization in the country would need increased reliable energy supply. The unit consumption for domestic water supply is estimated at0.371 kWh/m^3 for surface water and 0.482 kWh/ m^3 for groundwater. Energy consumption for rural water supply is expected to be in the range of 5-6 GWh/day. However, demands for urban water are expected to increase rapidly from 6.65 GWh/day in 2000 to 12 GWh/day in 2025 and would be doubling again in 2050 to reach 24GWh/day in 2050.

Box-6 Energy required in different stages of urban water supply, kWh/million litres

Stage	Energy required
Fresh water treatment	26
Water distribution	317
Waste water treatment	661

Water quality plays a major role in deciding energy consumption for domestic use. The cost of water use goes up with the level of treatment required to produce safe drinking water. It costs only 3 kWh/ million litre for chlorination, but the energy used in ultrafiltration is in the range of 68-103 kWh/10^6 litre.

The energy consumption per unit of water supply at distribution stage is 12 times higher than that at the treatment stage. Waste water treatment with 661 kWh/1000 kilolitre of energy consumption, is the most energy consuming process (Box–6) and over a period of next forty years, it will grow 4 times to reach 81 GWh in 2050(Table 5).

Table 5 : Projected energy consumption for sewage treatment

Year	2000	2025	2050
Item			
Urban population (million)	310	560	910
Sewage generated (million m^3/day)	35.6	64.26	127.67
Energy for treatment sewage (GWh/day)	22.6	40.9	81.2

Water Consumption in Power Generation

Power sector is the largest user of water and is the best example of the close energy-water nexus. It requires about 5000 to 18000 m^3 of water to generate a million kWh of power in a coal based plant and about 3000 m^3 in a natural gas plant. Water consumption in power production is estimated to grow from 4.8 BCM to about 17 BCM in 2025 and 68 BCM in 2050.

Briefly, water and energy are the two significant inputs promoting growth and development. The efficient use of one will reduce demand for the other and also decrease the carbon foot print of the nation.

Meeting the Water Challenge (2050)

The projected water demand for 2050, with 10% improvement in irrigation efficiency and 46.5% improvement in crop productivity (over 2000 values), is placed at 735 BCM. In addition, demands from industrial, domestic and other sectors (373 BCM) would raise water demand bar to 1108 BCM against the total utilizable quantity of 1123 BCM. In addition, apart from the ecosystem demands, and the water demand because of appreciation of spiritual, recreational and aesthetic services provided by water with the development of the economy would have to be included.

It is evident that while our water demands would rise significantly, increase in water supply is not keeping pace with the growth in demand. Growth in agriculture, energy, industry and environment sectors would have serious impacts on the water budgets in the river basins. Overcoming such a challenge would require adoption of appropriate demand and supply management techniques in all water dependent sectors.

Demand Management in Agriculture

Demand management can be mediated through biological interventions like introduction of improved germplasm with higher yield potential or higher resistance to biotic and abiotic stress and fortification with nutrients; improved plant nutrient management; and improved water management technology. Seed has been a major factor in agricultural productivity enhancement all over the world. Water and the nutrient input-responsive germplasm were major factors in triggering the Green Revolution in India. Continuing efforts to capitalize on new advances in molecular biology would be a major factor in sustaining and increasing future productivity growth. Packages of practical and cost effective water demand management technologies (zero till, system of rice intensification, laser levelling, micro irrigation, sub surface drainage etc) are available. Some of these technologies providing triple benefits by reducing water use, increasing yield and saving fertilizers are already in use. For example, micro-irrigation is being implemented under AIBP. Taken together, these technologies can meet 50- 60% of the demand supply gap, and improve dependability of the water supply systems.

Reducing Irrigation water through Improvement in efficiency

Irrigation diversion requirement is greatly influenced by the method used for conveying water from the source to the point of use and its application to the crop. Technically, it is possible to improve the conveyance efficiency from the present range of 50 to 60 % to 60-70 % or even higher, at a cost of course. Change in conveyance efficiency does not affect per unit area yields, but alters the water productivity at project level.

Improvement in Water Productivity

Research shows that opportunities for gains from increased irrigation efficiency—reducing "wastage" in agriculture—are less than those imagined (Molden, 1997, 2007). However, the technologies used in minimizing these losses at farm level create better environment in the crop root zone, where action for food production takes place, thereby increasing yield and also economizing use of nutrients. The reduction in beneficial water use in agriculture should be seen in terms of increased productivity, namely more yield or higher returns per unit of water used. Laser levelling, micro Irrigation, and proper scheduling of irrigation to crops, save water and increase yield. The third group of technologies is what was developed to increase the mechanization and reduce the cost of cultivation. It may be noted that, measures like Zero-Till Farming (ZTL), System of Rice Intensification (SRI) not only increase productivity per unit area, but also reduce the cost of cultivation, besides saving water. Reduced labour and fertilizer cost and decrease in green house gas emissions are some other benefits of Zero-Till Farming.

Water smart technologies save some water directly, but more importantly, such interventions increase yield and productivity by creating a favourable environment in the crop root zone where action for food production takes place.

Enhanced green water use for increasing productivity in rain-fed area

Upgrading rain-fed agriculture through watershed management is a proved potent option. It has been established that even in medium to high rainfall zones, crop yields are drastically reduced on account of short term agricultural droughts of 2-3 weeks duration. Supplying irrigation water to increase Consumptive Water Use (CWU) would significantly increase yield in many regions, particularly those having less than 150 mm CWU. With 100 mm of additional CWU, maximum yield can be doubled in districts with less than 150 mm CWU.

Higher productivity translates into reduced blue water use, less irrigation diversions and increased environmental flows. Hence agricultural productivity holds the key to water security for people and environment

Reallocation of water amongst crops

Agriculture not only provides food and nutritional security, but also provides livelihood support to about 60% of the population, of which more than 70% are small and marginal farmers and share croppers. As the productivity of grain crops, both in terms of yield and value of produce per unit water used for grain crops, is low as compared to non-grain crops (fruits and vegetables), it is difficult for such people to live on income from cultivation of grain crops only. Hence, for income generation as well as for meeting the growing demand for fruits and vegetables, reallocation of water amongst grain and non-grain crops needs to be encouraged.

Virtual Water Trade

In several river basins, where productivity of grain or non-grain crops or both are low, water use will shift to the high value product to provide livelihood support and will set in virtual water trade in food commodities from water rich basins. At present, virtual water export is taking place from water deficit basins to water sufficient basins, because of the crop productivity differentials, but it is not sustainable in the long run.

What is economically profitable may not remain hydrologically sustainable in future

Demand management in industry and urban water supply

Technology upgradation is required in wastewater treatment, energy generation and most other water consuming industries e.g. steel, leather, paper and textile etc, because their water foot prints in India are much higher than those the world. Wastewater and power generation are energy guzzlers and, by implication, heavy water users.

Supply Management

Ensuring water security for food, economic development and maintenance of ecosystem in a healthy state on a sustainable basis, would require development of additional water resources.

In agriculture, reclamation and reuse of domestic wastewater, aquifer recharge during monsoon, and creation of new resources by completing ongoing and planned water development projects including National River Linking Project, should be accorded priority. Large scale rehabilitation of irrigation infrastructure could increase the irrigation potential by 5Mha. Completion of Last Mile Irrigation

Infrastructure could bridge the gap between the potential created and the irrigation realised by 9 Mha. Wastewater, after treatment, is going to be a major source of additional water supply. It may be added that its consumptive use in domestic, industry and other sectors is less than 20 %. The estimated diversion for these sectors in 2025 being of the order of 260 BCM, around 200 BCM would be the dependable committed water supply for reuse. As compared to other sectors; agriculture is better suited for use of such waters. Drinking water scarcity in certain locations such as Chennai may justify investment in desalination. Alongwith the National River Linking Project, a priority project, small Regional River linking projects, may also be taken up for detailed studies and necessary follow up action.

Demand management technologies have an edge over supply management techniques. However, taking into account the size of the gap, lag in technology diffusion and the need for dependability most of the time, supply and demand management aspects should go together till India reaches the level of development where returns to management are higher than those to development.

In conclusion, we note that the water challenge is a formidable and critical one which would intensify with time. Though it will impose a financial and economic cost on the economy, it can be tackled by implementing a charter for sustainable management of water resources, through various suitable interventions as under:

A. Supply Management

Creation of Large Storages and Linkages

It is planned to create additional live storage capacity of 170 BCM by 2050. Completion of the storage projects under construction by 2025 would provide live storage of 63 BCM. The balance storage capacity of 107 BCM would be provided by 2050 by implementing various projects under consideration. In addition, the National River Linking Project will provide additional utilizable water of 173 BCM.

Large Scale Rehabilitation of Irrigation Works

Such an intervention would require renovation, desilting and setting up of management infrastructure for irrigation works, creating an additional potential of 5 mha.

Last Mile Irrigation Infrastructure

This will set up the command area management structure and rehabilitate the system to bridge the gap of 9 mha (approx) between the irrigation potential created and that utilized.

Small Scale Irrigation Infrastructure

Minor irrigation infrastructure projects, such as dams built closer to the community for using water during dry spells, will have a potential of irrigating 1.5 mha.

Aquifer Recharge

This would require construction of percolation tanks, check dams, contour bunds etc. to saturate the catchment area and increase abstraction efficiency to 90%, and recharge efficiency to 75%.

Rain Water Harvesting

This involves harvesting rain water in the watersheds and using it for micro-irrigation in rainfed cultivated areas. This will increase the yield of various crops by 25-40% and would be applicable in 20 mha of medium to high rainfall unirrigated farm land.

Use of Waste Water in Irrigation

Recycling and reusing waste water, in lands near urban areas for irrigation and other purposes, need to be ensured, through appropriate regulations, as necessary.

The investment cost on these supply enhancement interventions will be around Rs. 11200 billion at 2012 price-level, upto 2050.This cost also includes the cost of development of hydropower potential of 34000 MW, as a part of the River Linking Project.

B. Demand Management

Technology interventions identified for maximising productivity are listed below:

Laser Levelling

Conventional surface irrigation method in rice-wheat system involves surface application. Use of laser levelling equipment for quicker and better levelling of the fields will contribute to water saving and increase water use efficiencies, besides reducing energy used in pumping water. This intervention can be effectively used in 80 mha of land for field crops.

Zero or Minimum Tilling

This technology involves direct planting of the crops without any or minimum tillage of lands. It not only reduces water use by 20-30%, but also reduces cost of cultivation, increases yield by 10-20% and decreases greenhouse gas emission. This would be applicable in an approximate area of 25 mha for rice, wheat and other grain crops.

Sprinkler or Drip Irrigation

Use of sprinkler or drip irrigation saves 20-40% of water and increases yield by 10-40%; applicable to a large range of crops like wheat, vegetables, plantations, fruits, cotton and sugarcane, covering an area of 40mha.

System of Rice Intensification (SRI)

This envisages transplanting seedlings of lesser age with more spacing and less water application only at saturation size. This will increase the yield by 20-30%, reduce labour and fertilizer cost and decrease greenhouse gas emission; saving of water is about 10-30%.

Land Surface Modification, Bed and Furrow Irrigation and Drainage

Bed and furrow Irrigation permit growing of crops on beds with less water, reducing chances of plant submergence due to excessive rain. This will increase the yield of various crops like wheat, cotton, maize and sugarcane by 5-15%. This intervention can be effectively used for 20 mha farm land.

Biotic and Abiotic Stress Management

The objective is to encourage better management of plant stress by optimum use of pesticides and innovative crop protection technologies. There is no direct saving of water under this intervention but the yield of most crops increases by 10-30%. Applicable to 100 mha farm land.

Improved Germplasm

This would increase yield potential by using higher yielding seed varieties that are best adapted for specific conditions. There is no direct saving of water under this intervention but the yield of most crops increases by 20-30%. Would benefit 100 mha farm land.

Increased Fertilizer Use

This would involve increasing fertilizer use to reduce mineral exhaustion and improve yields in irrigated lands. The yield of all crops will increase by 25-50%. The intervention can be effectively used for 30 mha.

Irrigation Scheduling

The objective is to determine the exact amount of water for application to the field as well as the exact timing for application. The yield of all crops will increase by 5-20%, saving 10-15% of water.

Piped/lined Water Conveyance from Tubewells

This reduces the losses in the conveyance system. Use of piped/lined water conveyance from tubewells saves 20-40% water and increases yield by 10-40%. Applicable for a large range of crops like wheat, vegetables, fruits, cotton and sugarcane covering an area of 20 mha.

Subsurface Drainage

A subsurface drain is a perforated conduit of tile, pipe or tubing, installed below the ground surface to intercept, collect and/or convey drainage water. This intervention is applicable in an area of 10mha in waterlogged and salt affected lands. The yield would increase by 20-30%.

The investment on the above productivity enhancement interventions will be around Rs. 4000 billion if all the measures are simultaneously implemented in areas which are suitable for implementation of these measures. However, when any measure is implemented, it is likely that the scope for implementation of other measures will be reduced to varying extent. Hence, the investment cost for carrying out these measures on all India basis, depending upon location of the area; will be around 50% of the stand alone costs, which amounts to Rs. 2000 billion, up to 2025. The inter se priority for a particular intervention will be area specific and the cost curve (2030 WRG) can be used for determining inter se priority.

C. Water Security for Domestic, Industrial and Other Requirements

The requirement of 261 BCM by 2025 and 373 BCM by 2050 will be met by utilizing perennial ground water resources as well as from the storages created. As the requirements are dependent on concentration of human habitation and industrial activities, perennial sources of surface and ground waters need to be identified. Also, to ensure conservation, demand should be reduced as far as possible, leakages in the supply network should be minimised and recycling of waste water should be ensured for Agricultural/Horticultural uses. In some areas, desalination may be the only way to provide water security for domestic requirements.

D. Sustainability of Ecosystems

The total environmental demands to maintain category 'D' ecosystem is estimated as 353 BCM. Detailed study on the water needs for each river and their tributaries need to be conducted to ensure the specific quantum of flows required. A Scientific Panel consisting of Biologists, Ecologists, Geomorphologists and Hydrologists needs to be constituted to assess the water needs after taking care of the species composition in the riverine Wetlands. The Panel would define the capacity to support and maintain a balanced, integrated, adoptive ecosystem having the full range of elements (genes, species and assemblages) and processes expected in the natural habitat of a region. Till such results become available, provisions as under need be made in various reaches of the rivers for sustainability of the Aquatic Ecosystem.

"Minimum flow in any ten daily period to be not less than observed ten daily flow with 99% exceedance. Where ten daily flow data are not available, this may be taken as 0.5% of 75% dependable annual flow expressed in cubic meters per second".

E. Institutions

AIBP to be renamed as PABA

Availability of new technologies is not sufficient, by itself, to promote development. An effective institutional framework and sustained policy support are also required. The current Accelerated Irrigation Benefit Programme (AIBP) of the Govt. may be renamed as Programme for Accelerated benefits for Agriculture (PABA). The Programme may adopt the technologies discussed earlier for efficient execution on the ground after providing suitable incentives as necessary.

Development of Water Technology Hubs

These hubs will be useful for benchmarking the available technologies to provide a clear picture of the benefits to private entrepreneurs. These will also provide incubation facilities to inexpensive new technologies for attracting private participation.

Engaging Local Users in Water Management

All stakeholders, including members of the public, need to be given full opportunities to share their views and influence the outcome of water projects impacting them. This will ensure efficient, effective, equitable and environmentally sustainable management practices.

Strengthening Technology Diffusion Network

The technology diffusion network needs to be strengthened. To start with, each Krishi Vigyan Kendras should have a water technologist.

The investment on these interventions will be around Rs. 200 billion upto 2025.

F. Policy

Climate Change

This study review impact of climate change on water availability and water demands. Climate change would have a direct impact on water demands and water availability. Mitigation and adaptation to climate change would require speedy action on implementation of supply and demand measures suggested at para A & B.

Private Participation

Private participation in development and management of water resources, specially in large industrial clusters, needs to be encouraged.

G. Investment

The total investment on the measures under para A to F would be around Rs. 13,400 billion (Rs. 6,200 billion up to 2025 and another Rs.7,200 billion upto 2050). This cost also includes the cost of development of hydropower potential of 34,000 MW as a part of the River Linking Project.

CHAPTER 1

Introduction

1.1 Background

Water is a basic need for all living organisms as well as an important environment parameter to sustain life. Precipitation is the prime source for all water. As water occurs in nature and moves, its quantity, quality and energy continuously vary in space and time. Human beings need water of adequate quality and quantity at the right time and at the right place. Our interest in water seeks to promote a life style utilising safe adequate water and to make it a beneficial resource through suitable modifications in the water environment for meeting our food, fibre and energy requirements.

1.2 Water Resources Development in India

India supports more than 1/6th of the world's human and cattle population on 1/50th of global land with a meagre 1/25th of the world's water resources. Hence, judicious planning for its conservation and use is imperative.

Water Resources Development (WRD) in India has its own history. Right from Independence, India has been developing at a very fast pace. Rapid urbanization and infrastructure development have been the key features in the last few decades. At the same time, the steep rise in population led to significant increase in the demand for food, water supply and power. One of the potent solutions to these multi-faceted challenges was the creation of water storage facilities to provide irrigation and power. The impact of such storages on various facets of development has changed the socio-economic profile of the country.

In the early stages of our economic development, it was generally assumed that our water resources were almost inexhaustible. However, the historical situation in which relatively plentiful water resources were used primarily for irrigated agriculture, with relatively small demands from other sectors has changed drastically. Water demands in agriculture as well as in other sectors viz., domestic, industrial, energy, etc. will continue to rise rapidly because of, inter alia, increasing population as well as changes resulting from income growth, spread of urbanisation and fast industrialisation. Water has also to be provided for maintaining eco-systems. Such a scenario of increasing demands from various sectors, requires an integrated water resources development and management approach to meet the evolving challenges in the water sector.

1.3 Food and Nutrition Security

Agriculture sector provides food and nutrition security. It was and will continue to remain a dominant consumer of water. The increasing for food grains in the context of rising population poses a challenge which has to be met. As nearly 65% of the population depend on agriculture, and irrigated agriculture plays a critical role in food production, poverty alleviation and rural development, it has to be at the centre of water resources development. Besides, more than half of the cultivated land continues to be under rain-fed farming. It is estimated that even after development and utilisation of the full irrigation potential, about 60 mha will remain as rain-fed. Agriculture in India, is, complex, diverse, risk-prone and is characterised by low input usage. Variability in rainfall results in wide fluctuation and unstable yields. As the bulk of the rural poor live in the rain-fed regions, the challenge before Indian agriculture is to transform rain-fed farming into more sustainable and productive systems for providing better support to the population dependent upon it.

1.4 Challenges and Prospects

Looking back at our progress in the water sector, after six decades of Independence, one may derive some satisfaction from the path traversed so far. However, it is apparent, increasingly, it appears, at time, that the sector as a whole needs radical change to keep with the times.

Water management is facing severe problems, the magnitude, importance and complexity of which were not envisaged earlier. Globally, water is likely to become a critical resource in the developing countries in the next few decades. Pragmatic and cogent solutions therefore need to be developed and implemented within the shortest possible time frame. New concepts and perceptions are emerging all over the world and the developing countries including India are in the process of imbibing and assimilating new thought processes and fresh knowledge to resolve complex, inter-related issues. The water management scenario is likely to witness far more changes in the next decade or so compared to those in the past 2000 years.

As mentioned earlier, though available water in nature is more or less fixed, water requirement increased substantially in the recent past mainly due to developmental activities, urbanization, industrialization, use of advanced agricultural practices, and population increase. This has not only reduced per capita water availability but has also impacted adversely the quality of water available. The variability of available water has become more severe with the added effects of climate change. Reduced dry-season flows are predicted in India because of the retreat of glaciers and reduction in snow cover in the Himalayas, the major contributor to the flows in the Indus, the Brahmaputra and the Ganga.

Irrigation schemes, mostly designed between 1950 and 1970, have, at times failed to respond to the changing rural realities of the new century. Farmers are hence, either exiting or reducing their reliance on these systems and resorting to individual irrigation investments e.g. on pumps and plastic pipes that draw water from aquifers or surface water bodies, thereby creating unintended complications. Over-extraction of groundwater has reached un-sustainable limits in large areas. At the same time, attempts to reform the irrigation sector through Irrigation Management Transfer (IMT) and Participatory Irrigation Management (PIM) have had mixed results with a few successful cases interspersed with a large number of not so successful ones. All this resulted in poor performance of the sector which, in turn, negatively affected the livelihoods of millions of people.

Notwithstanding the recent focus on the services sector, the Indian economy is primarily agrarian and will probably remain so, at least in the near future. The water consumption pattern for irrigated agriculture, which currently consumes more than 70% of the water resources, needs to be changed through appropriate technology interventions. Available water resources in the basin must be used judiciously for achieving the highest water productivity (WP) levels. Traditional methods of water productivity assessment at field/ farm/ or small regional/ level have limited use in proper understanding and framing of basin level recommendations. Innovative methodology, which can estimate land and WP, at the pixel, the basin and the intermediate levels, needs to be introduced to assess water use, crop dominance, actual ET, yield and crop water productivity, by combining meteorological data, ground survey, and census data with remotely sensed imagery.

We are on an exciting threshold of genetic engineering and technology contributing to food and water security. Using advanced genetics, efforts are on to develop water stress tolerant varieties of plants that would contribute towards addressing problems of water scarcity, increased salinization, increased contamination of groundwater, as well as, solving several other associated problems in waste water management. Molecular mapping and modifications are very effective tools for fostering eco-farming and for enhancing the productivity of rainfed and saline soils. While traditional technologies need to be developed further, latest technologies need to be used for effective use of waste water.

An IT-based Agriculture Monitoring and Early Warning System (EWS) can keep the agriculturist informed about the most opportune time and efficient use of resources for agricultural activities. India now has access to advanced meteorological data acquisition through a bi-lateral agreement with the USA. Mapping, short and medium range weather forecasting, together with GIS-based EWS would further enhance the efficiency of water use.

There is no unique solution or prescription for the whole country in view of the steeply varying hydrologic and agro-climatic conditions, socio-economic set ups, political compulsions etc. Water management strategies and policy initiatives need to reviewed, so as to address various relevant issues fruitful and in a coordinated manner. It is in this background that the Indian National Academy of Engineering (INAE) decided to undertake a Research Study on Water Resources Management.

1.5 Format of the Study

INAE entrusted the "Research study on Water Resources Management (WRM)" to a Study Group consisting of the following Fellows of the Academy:

Prof. S S Chakraborty (Group Co-ordinator), Prof. Subhash Chander, Dr. N K Tyagi, Dr. R R Sonde and Prof. S Mohan, Er. Paritosh Tyagi, FNAE also helped the group, particularly with reference to Water Quality issues.

The Group deliberated on the issues and recommended that, the INAE Study would focus on technological aspects for meeting water challenges rather than on institutional, legal, social or transboundary issues.

Accordingly, the Study, alongwith its findings, is presented in the format as under:

1. Water availability in India: Highlights the spatial and temporal variability of precipitation and flows. Basin wise availability of water potential, utilisable flows available in various basins as a result of storages already created and likely to be constructed, and available dynamic ground water are presented. Water required to provide acceptable eco-services in various basins, as well as recommendations on increasing utilisable water are also given. The Study also reviews the findings on the possible impacts of climate change on water availability and on glaciers.

2. Water demands in Agriculture: coordinates information on water productivity, reviews water demand estimates for food. Projections based on PODIUMSIM are considered sound. Irrigation diversion requirements for 19 basins are noted. The future role of rainfed agriculture in terms of increased green water use for reducing blue water diversion is assessed. Criticality of water stress in the river basins is analysed and strategies to cope with increasing demand at basin and country level recommended.

3. Water demands in other sectors: reviews water demands in domestic, industrial, power, navigation, environment sectors as well as and reservoir evaporation losses in 2050. The assessment that results arrived at currently are of the same order as the projections made by National Commission for Integrated Water Resources Development (NCIWRD). Hence basin wise demands indicated by NCIWRD are accepted.

4. Water Quality: Presents a review of various issues related to water quality and defines the way forward to tackle quality issues. At the end certain principles to address/ mitigate the quality concerns have been formulated.

5. Energy-Water Linkage: Highlights energy-water linkages which perpetuate wasteful use of natural resources. Presents the energy consumption in agriculture, domestic and industrial sectors and defines benchmarks for achieving energy optimisation. Recommendation for economising the water/energy use are made in each case. Water requirements for energy production are also stated.

6. Meeting the water challenges, 2025-2050: Reviews the basin wise demand supply gap in the 2025 and 2050 scenarios and stipulates that agricultural productivity holds the key to water security. Possible interventions to bridge the demand-supply gap are indicated. Basin level water demand balance alongwith suitable strategies and action programmes are presented. Technological interventions and their prioritization for implementation are suggested.

7. Inter-basin Transfer of Water: looks at the genesis and necessity of the National River Linking Programme. A review of the status of the project including monitoring by the Hon'ble Supreme Court of India is presented. It is suggested that comprehensive assessment of the programme is necessary based on the specific criteria indicated in the study

8. Recommendations: A set of recommendations and possible action programs are suggested for consideration.

CHAPTER 2

Water Availability in India

2.1 Introduction

Water sustains life, in the plant and animal kingdoms. Spatial and temporal variations in precipitation account for the uncertainties in water availability for the most part. Water requirements to meet diverse demands have to take into account, inter alia, population and its geographical distribution across the country. Hence decisions relating to water infrastructure and its operation to match the dynamic nature of the demands require information on availability of water in time and space.

Freshwater is available as green water and blue water. Green water is what supplies terrestrial ecosystems and rain-fed crops from the soil moisture zone, and also water that evaporates from plants and water surface into the atmosphere as water vapour. Blue water is directly associated with aquatic ecosystems and flow in surface water bodies and aquifers, and is stored behind dams and in other water harvesting structures or recharged in aquifers.

Human beings withdraw more water than what is strictly needed to satisfy the transpiration needs of plants or for life sustaining and industrial purposes. The unused water, which gets polluted during use, returns to the rivers as return flow from agricultural lands and effluents from industry and urban/rural settlements as grey water. Grey water from upstream of the basin becomes available for reuse in downstream areas. Water needed for irrigation and industrial use competes with water for the environment and may lead to insufficient environmental flows. Non-availability of these flows impacts aquatic biodiversity as well as riparian flood plain and estuarine ecosystems. Sound management of water resources requires that lifting blue water from the rivers is done in a manner as to ensure the maintenance of the aquatic ecosystem.

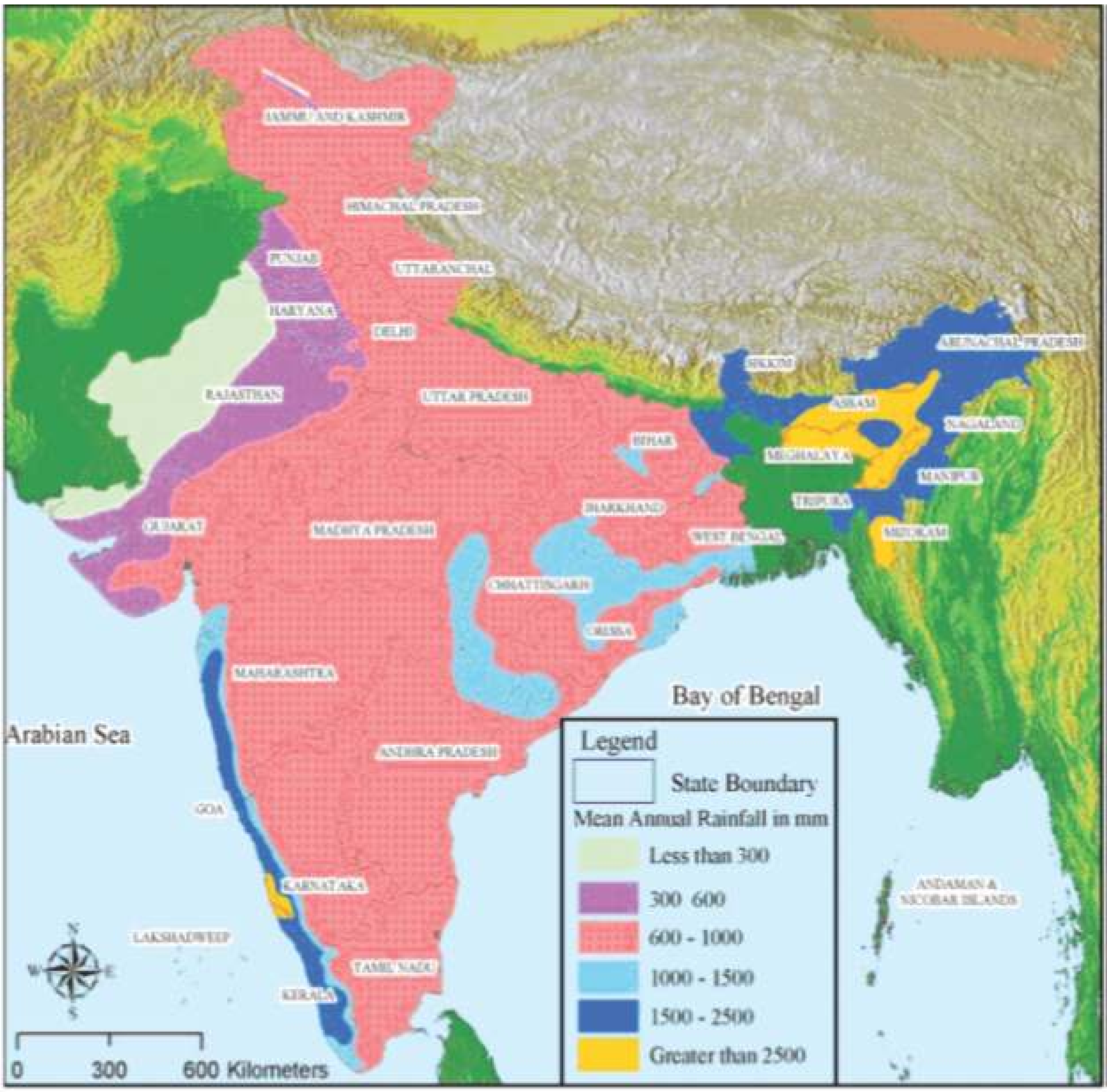
Rainfall and its variability leading to the possibility of generating blue water by water harvesting structures for meeting various demands, as well as planning to explore alternative options and its impact on downstream use need review. Water availability in various river sub-basins and storages provided, to utilize such water in irrigated command areas as well as for other uses is assessed in this chapter.

2.2 Rainfall and its Variability

(A) Spatial Variability

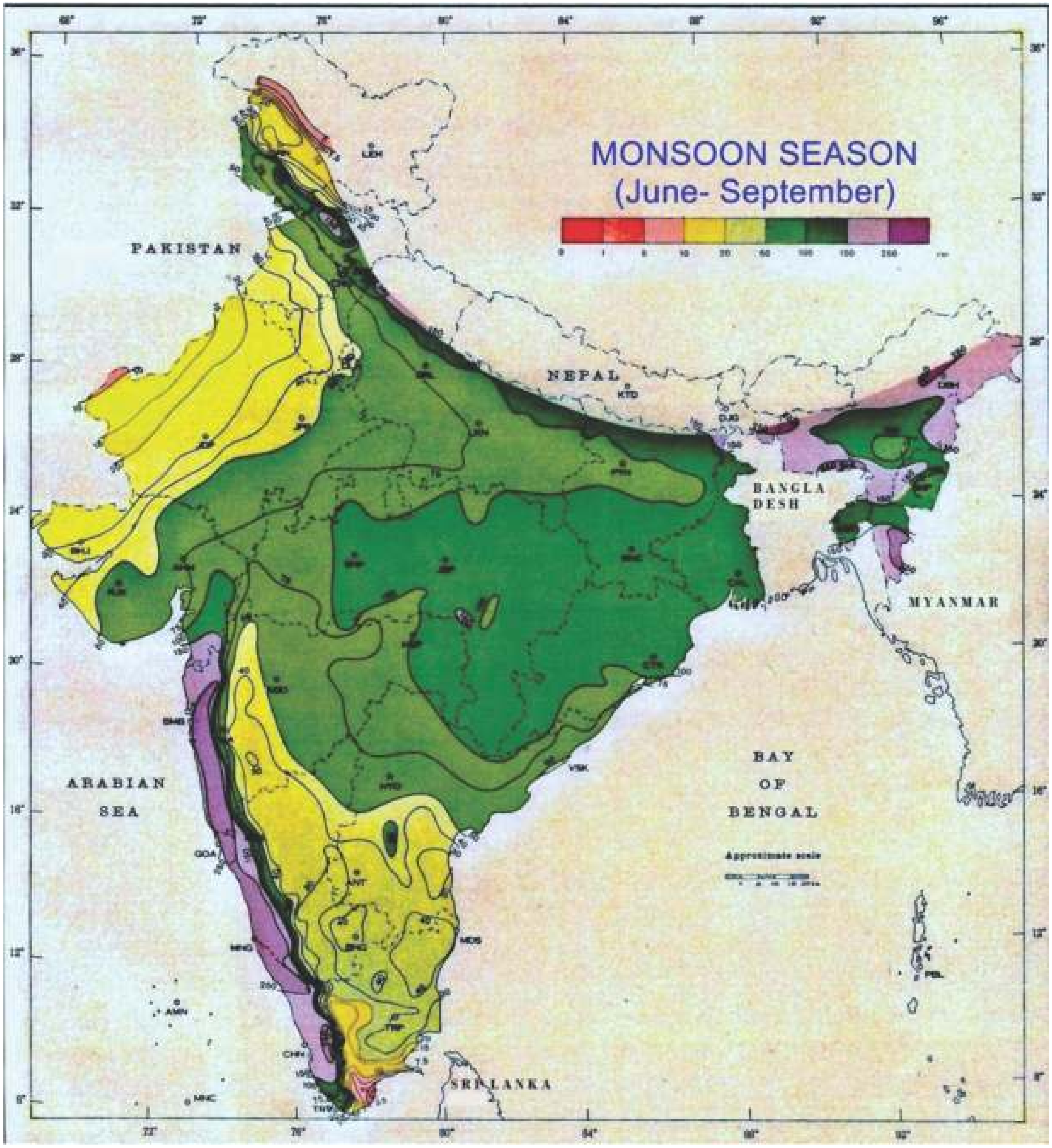
India receives 75% of the annual rainfall during a short span of four monsoon months (June to September). Variability in the onset, withdrawal and quantum of rainfall during this season has profound impacts on its water resources.

There is a large variation in the amounts of rainfall received in different regions of India. The average annual rainfall is less than 31.3 cm over western Rajasthan, while Mausinram in Meghalaya receives as much as 1141 cm. The rainfall pattern vary from humid in the northeast (about 180 days rainfall in a year), to arid in Rajasthan (20 days rainfall in a year). The spatial variability of the annual and monsoon rainfall is shown in Figure-2.1 and 2.2 respectively.



Source: M. Dinesh et al, (2008)

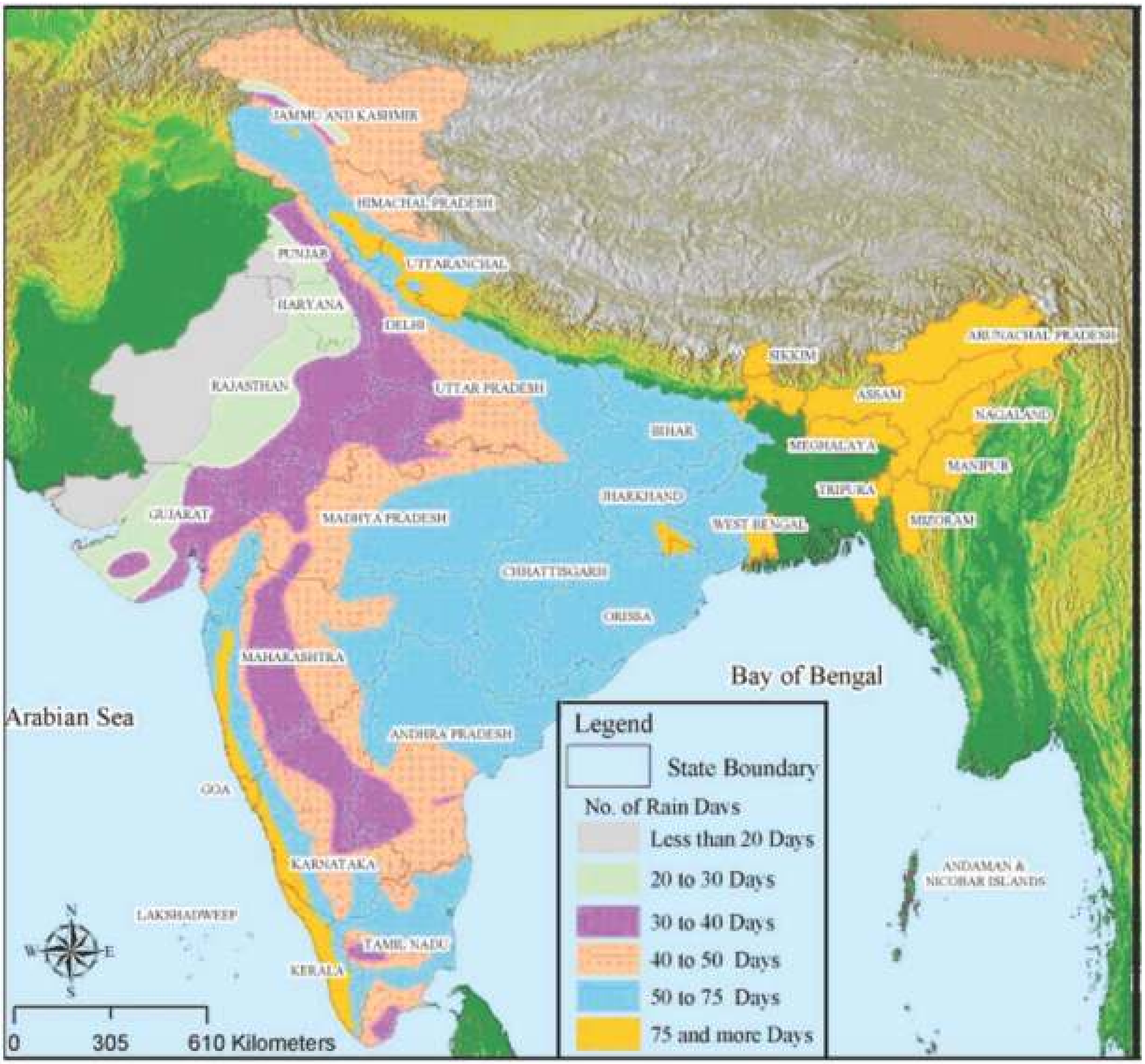
Figure 2.1 : Average Rainfall of India



Source : IMD

Figure 2.2 : Monsoon Rainfall of India

The number of rainy days and their spatial distribution is shown in Figure-2.3.

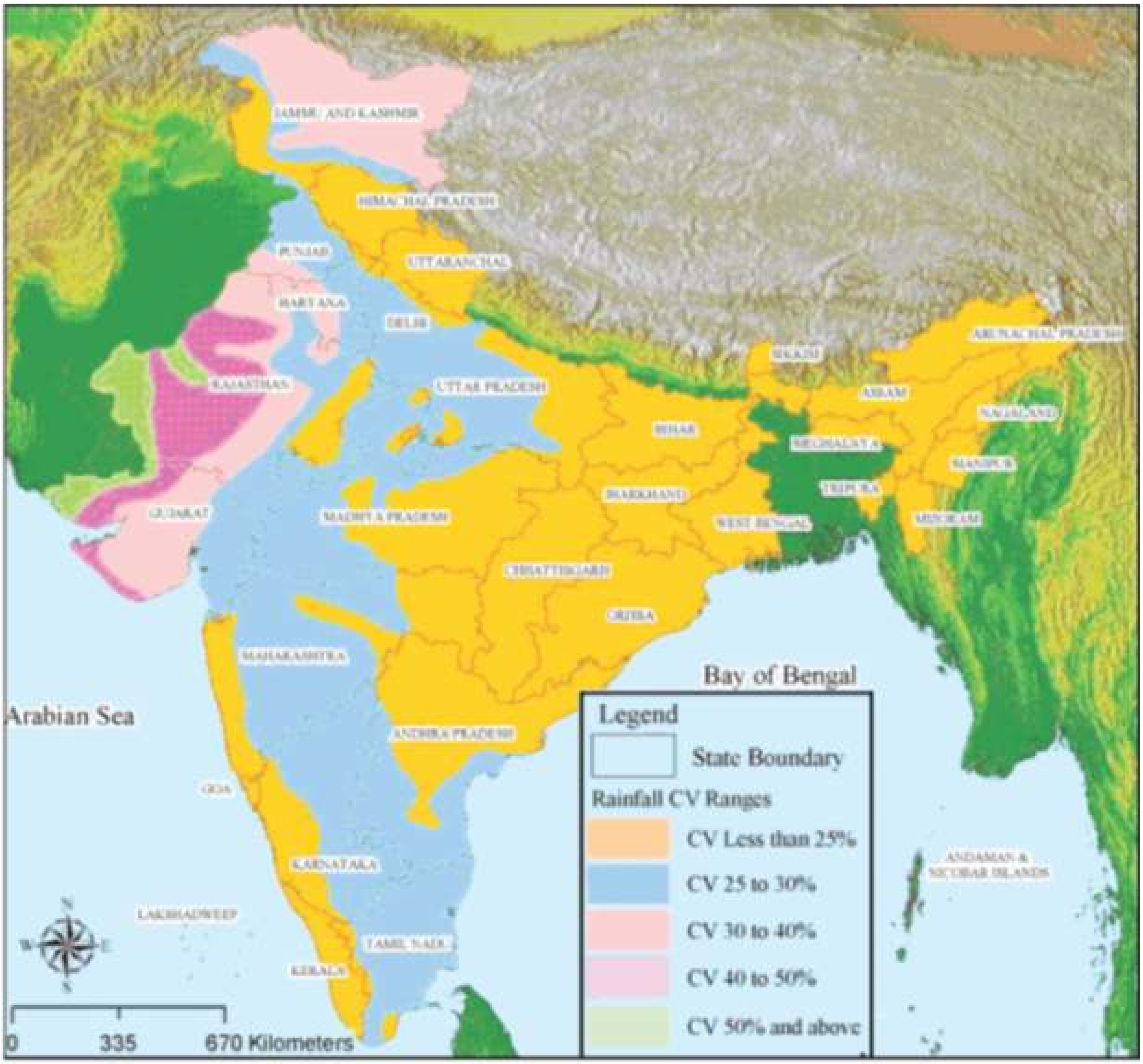


Source : M. Dinesh et al, (2008)

Figure 2.3 : Number of Rainy Days in India

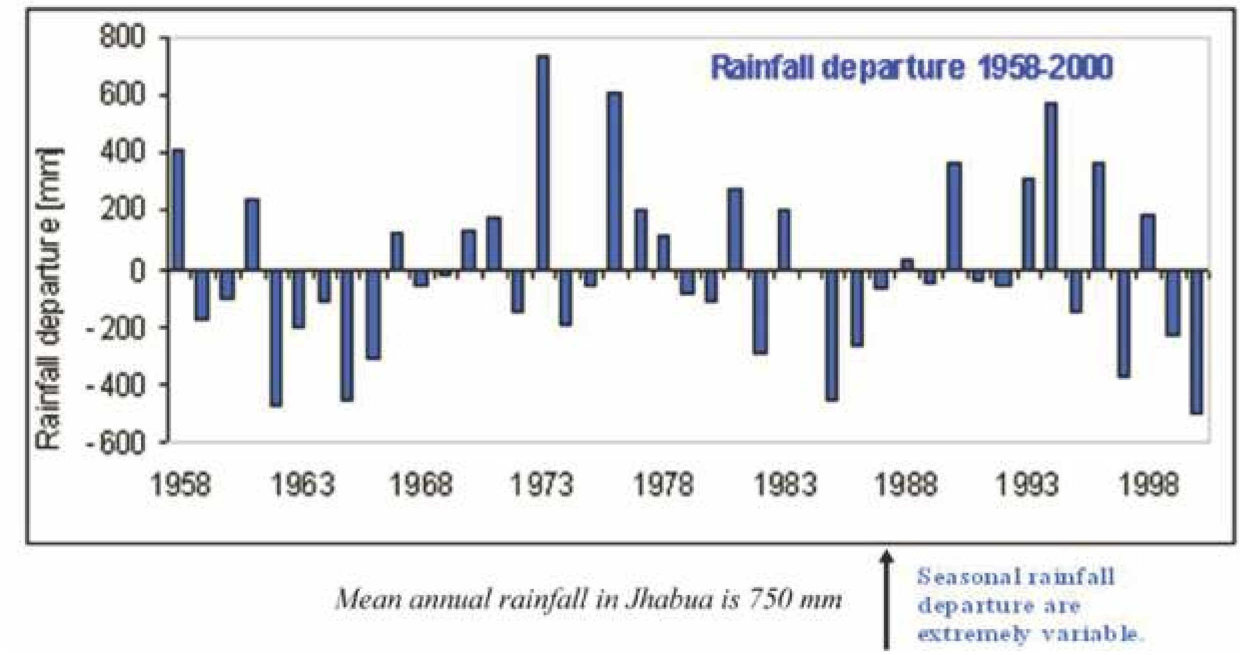
(B) Temporal Variability

The coefficient of variation of rainfall is shown in Figure-2.4(a). It can be seen from Figures 2.1, 2.2 & 2.3 that rainfall is highest in the north east, with more than 4 times the number of rainy days as compared to western India, which experiences not only much less rainfall but also faces increased variability as can be seen from plotting of the coefficient of variation in Figure 2.4(a). Deviation from the mean annual rainfall of 750 mm in Jhabua watershed for the period 1958-2000 is shown in figure 2.4(b). The coefficient of variation for this watershed is greater than 50%. In such cases, Integrated Watershed Management Approach can provide water security in all the years except in extreme drought conditions when the departure from the mean is more than -400mm. The State-wise distribution of rainfall is listed in Table-2.1.



Source: M. Dinesh et al, (2008)

Figure 2.4 (a) : Coefficient of Variation



Source: Integrated watershed management and rain water harvesting Prof. Eldo (Dept of civil engg IIT Mumbai)

Figure 2.4 (b) : Yearly Rainfall Departure from the Mean for Jhabua Rainfall Station

Table 2.1 : Average Annual Rainfall of the States of India

Sl. No.	State	Meteorological Divisions	Average annual rainfall (mm)
1.	Andaman and Nicobar Islands	Andaman and Nicobar Islands	2,967
2.	Arunachal Pradesh	Arunachal Pradesh	2,782
3.	Assam	Assam and Meghalaya	2,818
4.	Meghalaya	Assam and Meghalaya	2,818
5.	Nagaland	Nagaland, Manipur, Mizoram and Tripura	1,881
6.	Manipur	Nagaland, Manipur, Mizoram and Tripura	1,881
7.	Mizoram	Nagaland, Manipur, Mizoram and Tripura	1,881
8.	Tripura	Nagaland, Manipur, Mizoram and Tripura	1,881

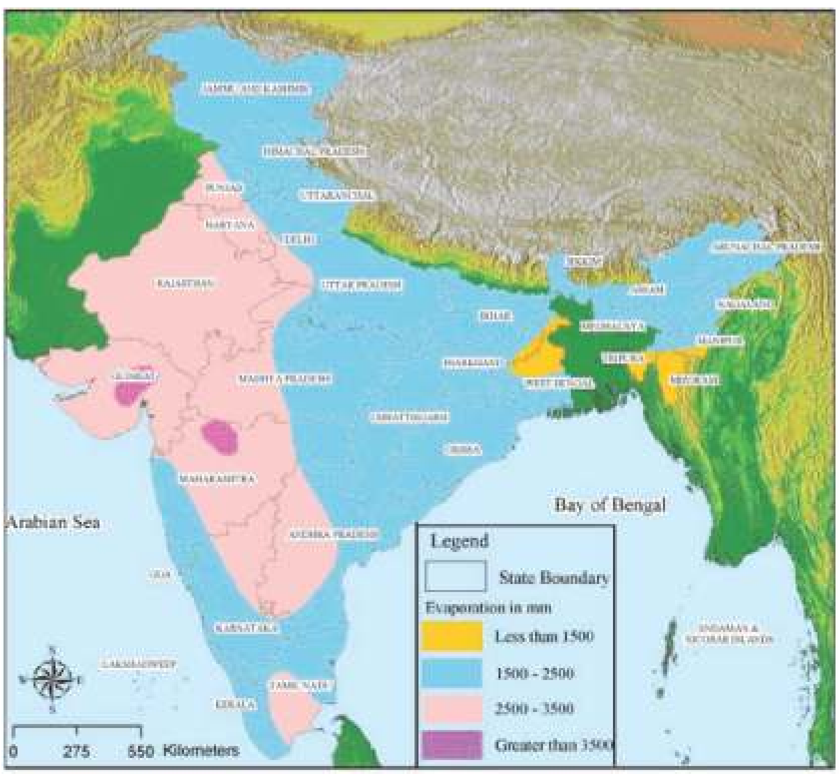
9.	West Bengal	Sub-Himalayan West Bengal and Sikkim	2,739
		Gangetic West Bengal	1,439
10.	Sikkim	Sub-Himalayan West Bengal and Sikkim	2,739
11.	Orissa	Orissa	1,489
12.	Bihar	Bihar Plateau	1,326
		Bihar Plains	1,186
13.	Uttar Pradesh	Uttar Pradesh	1,025
		Plain of West Uttar Pradesh	896
		Hills of West Uttar Pradesh	1,667
14.	Haryana	Haryana, Chandigarh and Delhi	617
15.	Delhi	Haryana, Chandigarh and Delhi	617
16.	Chandigarh	Haryana, Chandigarh and Delhi	617
17.	Punjab	Punjab	649
18.	Himachal Pradesh	Himachal Pradesh	1,251
19.	Jammu and Kashmir	Jammu and Kashmir	1,011
20.	Rajasthan	West Rajasthan	313
		East Rajasthan	675
21.	Madhya Pradesh	Madhya Pradesh	1,017
		East Madhya Pradesh	1,338
22.	Gujarat	Gujarat region	1,107
		Saurashtra and Kachchh	578
23.	Goa	Konkan and Goa	3,005
24.	Maharashtra	Konkan and Goa	3,005
		Madhya Maharashtra	901
		Marathwada	882
		Vidarbha	1,034

25.	Andhra Pradesh	Coastal Andhra Pradesh	1,094
		Telengana	961
		Rayalaseema	680
26.	Tamil Nadu	Tamil Nadu and Pondicherry	998
27.	Pondicherry	Tamil Nadu and Pondicherry	998
28.	Karnataka	Coastal Karnataka	3,456
		North Interior Karnataka	731
		South Interior Karnataka	1,126
29.	Kerala	Kerala	3,055
30.	Lakshadweep	Lakshadweep	1,515

Source: *http://www.rainwaterharvesting.org/urban/rainfall.htm*

2.3 Potential Evaporation and its Variation

The potential evaporation is less than 1500 mm/year in some parts of West Bengal and more than 3500 mm/year in some pockets of Maharashtra and Gujarat. The variation in other parts of India is shown in Figure 2.5.



Source : M. Dinesh et al, (2008)

Figure 2.5 : Evaporation Variation in India

The rainfall and potential evaporation regimes of States having major water harvesting programs are shown in Table-2.2.

Table 2.2 : Rainfall and Potential Evaporation Regimes of States having Water Harvesting Programs

Name of State	% Area with rainfall in the range of						% of area with evaporation in the range of (PE)			
	<300 mm (very low)	300-600 mm (low)	600-1,000 mm (medium)	1,000-1,500 mm (high)	1,500-2,500 mm (very high)	>2,500 mm (extremely high)	<1,500 mm (low)	1,500-2,500 mm (medium)	2,500-3,000 mm (high)	>3,500 mm (very high)
Gujarat	10.88	39.08	47.27	2.77					88.53	11.47
Rajasthan	41.80	32.45	25.75						100.00	
Maharashtra			85.86	6.93	7.21			37.96	56.23	5.81
Madhya Pradesh			95.71	4.29				56.94	42.89	0.17
Andhra Pradesh			97.83	2.17				52.70	47.30	
Karnataka			88.01	3.65	5.67	2.67		62.82	37.18	
Tamil Nadu			96.52	2.98	0.50			64.56	35.44	
Orissa			54.01	45.99				100.00		
Chattisgarh			59.39	40.61				100.00		

Source: M. Dinesh et al, (2008)

Due to extreme spatial and temporal variability of rainfall and evaporation, the flows in the river system of India exhibit a lot of variation in time and space. The surface and ground water availability in various river basins is indicated in the subsequent paragraphs.

2.4 Macro Picture of India's Water Resources

Food and Agriculture Organization in its Aquastat project collected data from India Meteorological department, Central Water Commission and Central Ground Water Board and computed India's Water resources. The Macro-picture of India's Water Resources is shown in Table-2.3.

Table 2.3 : Macro Picture of India's Water Resources

INTERNAL RENEWABLE WATER RESOURCES (IRWR)						
Precipitation (mm/year)	[1]	1 083				
Area of the country (1000 ha)	[2]	328 726				
Precipitation (km^3/year)	[3]	3 560	=([1]/ 1000000) x([2]x10)			
Surface water produced internally	[4]	1 404	(a)			
Groundwater produced internally	[5]	432	(b)			
Overlap between surface water and groundwater	[6]	390	(c)			
Total internal renewable water resources	[7]	1 446	=[4]+[5]-[6]			
EXTERNAL RENEWABLE WATER RESOURCES (ERWR)	**Natural**			**Actual**		
Surface Water						
Surface water entering the country	[8]	635.2	(d)			
Inflow not submitted to treaties				[9]	635.2	
Inflow submitted to treaties						
Inflow secured through treaties				[10]	**0**	
Accounted inflow				[11]	635.2	=[9]+[10]
Flow in border rivers						
Total flow of border rivers		**0**			0	
Accounted flow of border rivers	[12]	**0**		[13]	0	
Border lakes						
Accounted part of border lakes	[14]	**0**		[15]	0	
Surface water: entering and bordering the country	[16]	635.2	=[8]+[12]+[14]	[17]	635.2	=[11]+[13]+[15]
Surface water leaving the country		1 385	(e)			
Outflow not submitted to treaties				1 142		(f)
Outflow submitted to treaties				243.6		(g)
Outflow secured through treaties				[18]	170.3	(h)
Surface water: total external renewable				[19]	464.9	=[17]-[18]

Groundwater						
Groundwater entering the country	[20]	**0**		[21]	0	
Groundwater leaving the country		**0**				
Total						
Total external renewable water resources	[22]	635.2	=[16]+[20]	[23]	464.9	=[19]+[21]
TOTAL RENEWABLE WATER RESOURCES (TRWR)	**Natural**			**Actual**		
Surface water: total renewable	[24]	2 039	=[4]+[16]	[25]	1 869	=[4]+[19]
Groundwater: total renewable	[26]	432	=[5]+[20]	[27]	432	=[5]+[21]
Overlap between surface water and groundwater	[6]	390	(c)	[6]	390	(c)
Water resources: total renewable	[28]	2 081	=[24]+[26]-[6]	[29]	1 911	=[25]+[27]-[6]
Dependency ratio (%)				[30]	30.52	=100*([17]+[21]])/([17]+[21]+[7])

Source : Aquastat, FAO(http://Faostat.fao.org/site/544/default.aspx)

Notes: *(a) Estimated by difference between total discharge of rivers (1869.37) and total inflow to India (635.22).*

(b) Central Water Commission 1988.

(c) Estimated that overlap between surface water and groundwater is about 90%

(d) 210.2 from Nepal; 347.02 from China (181.62 Indus, 165.40 Brahmaputra); 78 from Bhutan (was before 90, but has been re-estimated: see water resources balance sheet Bhutan)

(e 20 to Myanmar; 243.58 (11.1E+232.48W) Indus to Pakistan, 1121.62 to Bangladesh (Brahmaputra 537.24, Ganges 525.02, Meghna 48.36; outside GBM to Chittagong 11)

(f) 1121.62 to Bangladesh; 20 to Myanmar.

(g) 11.1 Eastern Indus tributaries (for India); 232.48 Western Indus tributaries (for Pakistan). 232.48 = 181.62 (China to India) + 50.86 (generated in India)

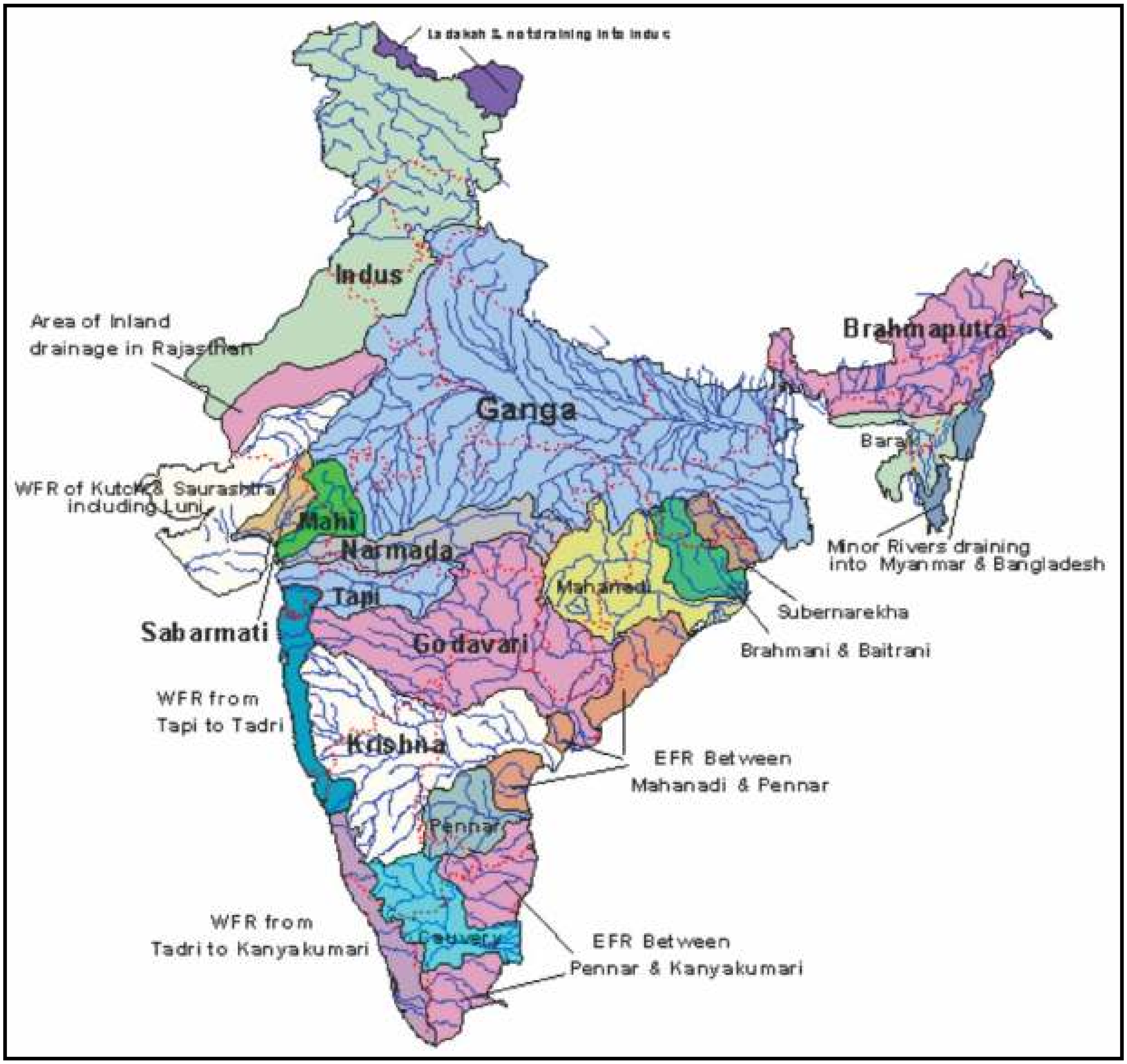
(h) Western Indus tributaries for Pakistan. Total natural to Pakistan 243.58; reserved for India 73.31 (11.1 EI, 62.21 WI). Reserved for Pakistan: 243.58-73.31=170.27

The blue water (both surface and ground water) available to India is around 1911 Km^3 of which around 30% is contributed by neighboring countries. Central Water Commission has placed this figure at 1869.35 km^3 which is of the same order as that assessed by FAO.

2.5 Basin-wise Water Availability

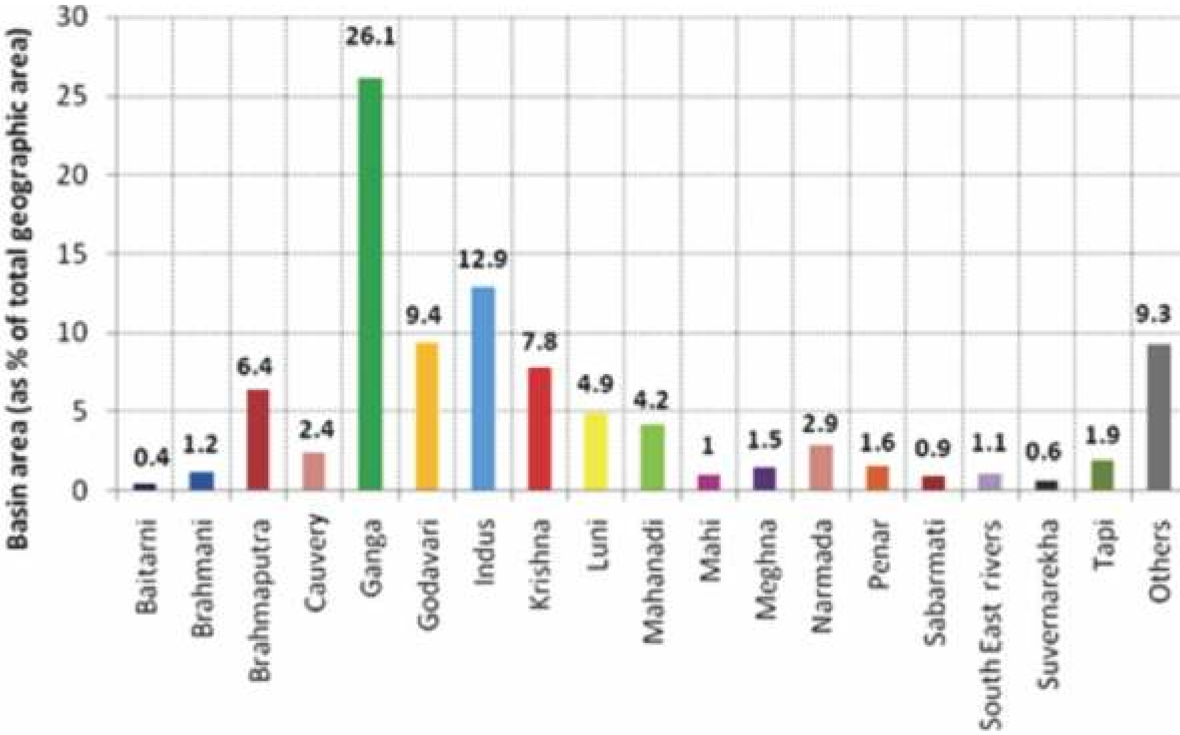
River basin is the natural hydrological unit considered for planning of water resources. Hence, the basin wise water resources are indicated below.

The basin map of India is in Figure 2.6(a) and areas of river basins as percentage of total area is shown are in Figure 2.6(b). The average annual potential and utilizable water in each basin is given in Table 2.4. Fifty nine percent of this potential exists in the Ganga and the Brahmputra Basins.



Source: Central Water Commission, (2008)

Figure 2.6 (a) : Basin Map of India



Source : Gosain et.al. (2011)

Figure 2.6 (b) : Areas of River Basins of India as Percentage of Total Geographic Area

Table 2.4 : Water Resources of Major River Basins of the Country

River Basin	Catchment area (km^2)	Average annual Potential (km^3)	Utilisable surface water resources (km^3)
Indus (up to Border)	321289 (1165500)	73.31	46.00
a) Ganga	861452 (1186000)	525.02	250.00
b) Brahmaputra c) Barak and others	194413 (580000) + 41723	585.60	24.00
Godavari	312812	110.54	76.30
Krishna	258948	78.12	58.00
Cauvery	81155	21.36	19.00
Subernarekha	29196	12.37	6.81
Brahmani & Baitarni	51822	28.48	18.30

Mahanadi	141589	66.88	49.99
Pennar	55213	6.32	6.86
Mahi	34842	11.02	3.10
Sabarmati	21674	3.81	1.93
Narmada	98796	45.64	34.50
Tapi	65145	14.88	14.50
WFR from Tapi to Tadri	55940	87.41	11.94
WFR from Tadri to Kanyakumari	56177	113.53	24.27
EFR between Mahanadi & Pennar	86643	22.52	13.11
EFR between Pennar & Kanyakumari	100139	16.46	16.73
WFR of Kutch & Saurashtra including Luni	321851	15.10	14.98
Area of Inland drainage in Rajasthan	-	Negligible	Not applicable
Minor Rivers draining into Myanmar& Bangladesh	36202	31.00	Not applicable
Total		**1869.35**	**690.31**

Source: Central Water Commission, (2008)

The live storage capacity of reservoirs converts the water available in basins to utilizable water. The utilizable surface flows for each basin as computed by CWC are shown in Table-2.4. The basin-wise figures of water storage development are shown in Table 2.5.

Table 2.5 : Basin-wise Status of Water Storage Development

River Basins	Live Storage Capacities of Projects (km3)					% of grand total of live storage capacities with respect to	
	Completed	Under Construction	Total	Under Considerati on	Grand Total (4) + (5)	Average Annual Potentia l	Utilizable Surface Water Resources
1	2	3	4	5	6	7	8
Indus (up to Border)	16.29	0.28	16.57	2.58	19.14	26.12	41.62
a) Ganga	42.06	18.60	60.66	30.08	90.74	17.28	36.30
b) Brahmaputra, Barak and others	2.33	9.35	11.68	41.26	52.94	9.04	220.60

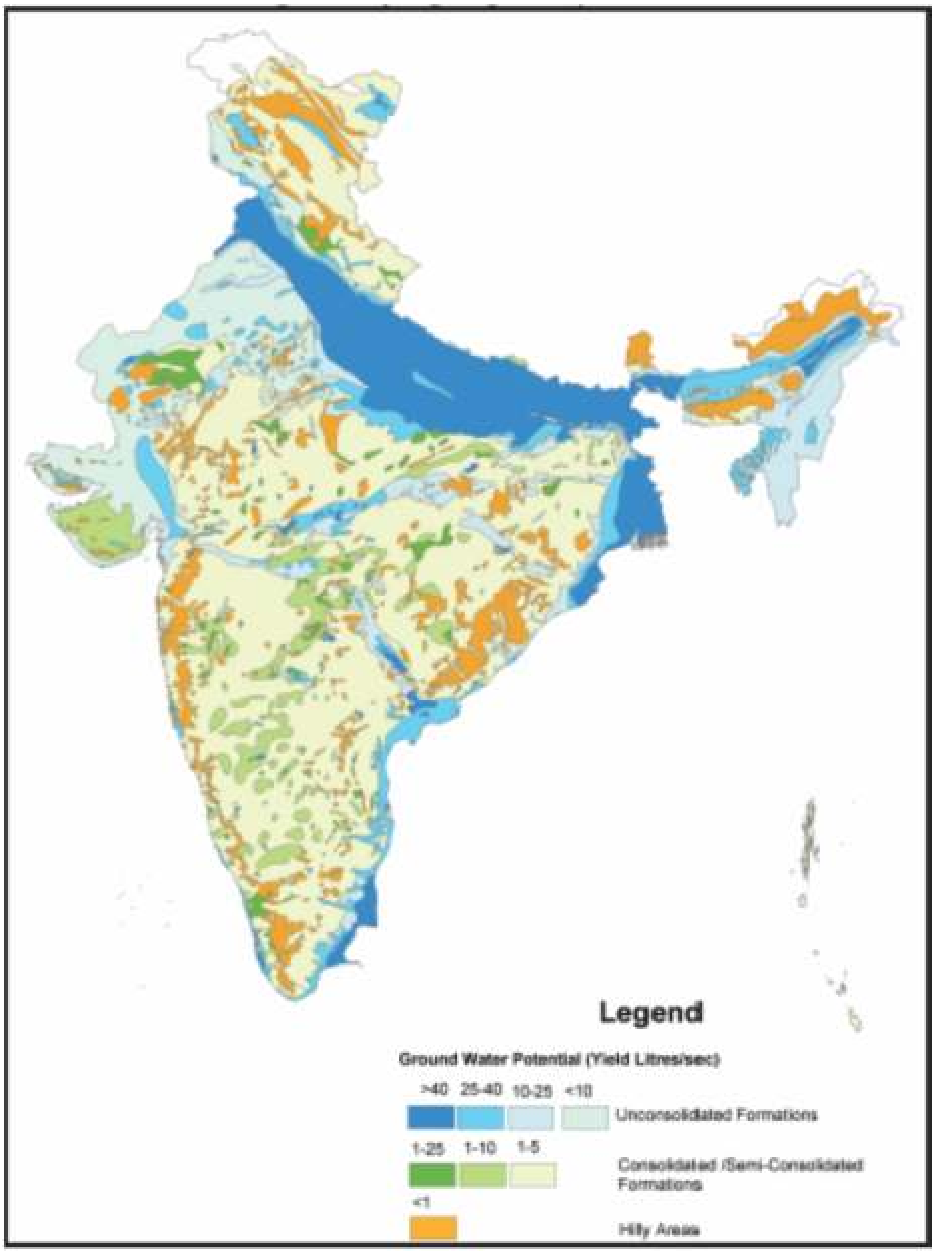
Godavari	25.12	6.21	31.33	5.84	37.17	33.63	48.72
Krishna	41.80	7.74	49.55	1.13	50.68	64.87	87.37
Cauvery	8.60	0.27	8.87	0.26	9.13	42.74	48.05
Subernarekha	0.67	1.65	2.32	1.38	3.70	29.94	54.37
Brahmani & Baitarni	4.65	0.88	5.52	8.72	14.24	50.02	77.84
Mahanadi	12.33	1.87	14.21	10.09	24.30	36.34	48.61
Pennar	2.65	2.17	4.82	0.00	4.82	76.32	70.26
Mahi	4.72	0.26	4.98	0.01	5.00	45.33	161.16
Sabarmati	1.31	0.06	1.37	0.10	1.47	38.51	76.00
Narmada	16.98	6.63	23.60	0.47	24.07	52.74	69.77
Tapi	9.41	0.85	10.26	0.29	10.54	70.86	72.71
WFR from Tapi To Tadri	11.27	3.46	14.73	0.08	14.81	16.95	124.07
WFR from Tadri To Kanyakumari	10.24	1.32	11.55	1.45	13.01	11.46	53.59
EFR between Mahanadi & Pennar	1.60	1.42	3.03	0.95	3.97	17.64	30.30
EFR between Pennar & Kanyakumari	1.84	0.07	1.91	0.00	1.91	11.59	11.40
WFR of Kutch & Saurashtra including Luni	4.73	0.80	5.52	2.85	8.37	55.46	55.90
Area of Inland drainage in Rajasthan	-	-	-	-	-	-	-
Minor Rivers draining into Myanmar & Bangladesh	0.31	-	0.31	-	0.31	1.01	-
Total	**218.90**	**63.90**	**282.80**	**107.54**	**390.34**	**20.86**	**61.93**

Source: Central Water Commission, (2008)

Note: Last column is 100 (Live storage/ Utilizable flows) in that basin. For example, live storage in Indus is 19.14 Km^3. Utilizable flow is 46Km^3. Value in last column is 41.62%.*

2.6 Ground Water Availability in India

India has diversified geology, climatology and topography. The hydro geological map is shown in Figure-2.7. The groundwater potential is limited to Intermountain Valleys in the northern and north eastern Himalayan ranges, the hilly tracts of Rajasthan and the Peninsular regions. The large alluvial tract in the Ganga-Brahmaputra plains, extending over 2,000 km, has extensively thick and hydraulically interconnected, moderate to high yielding aquifers. To the north of this tract, all along the Himalayan foot hills and 'terai' belt down slope, occurs along the linear belt with characteristic 'auto-flowing' conditions. The entire peninsular India is occupied by hard rock formation with rugged topography and fissured nature of rocks. These give rise to discontinuous aquifers with limited moderate yield potentials. In these areas, the aquifer formations are limited to near-surface weathered mantle, abandoned river channels, Coastal and deltaic tracts in the country form narrow linear strip around the peninsula. The eastern coastal, deltaic tracts and estuarial areas of Gujarat are receptacles of thick alluvial sediments. Though highly productive aquifers occur in these tracts, salinity hazard imposes quality constraints for groundwater development. In this terrain, groundwater abstraction requires to be regulated so as not to exceed the annual recharge and also not to disturb the hydro-chemical balance leading to sea water ingress. The state-wise ground water availability is shown in Table-2.6. The total utilizable resource, (surface water + ground water) basin wise is given in Table-2.7.



Source: Central Water Commission, (2008)

Figure 2.7 : Hydrogeological Map of India

Table 2.6 : State-wise Ground Water Resources Availability, Utilization and Stage of Development-India (in Km^3/yr)

Sl No	Sates/Union Territories	Annual Replenishable Ground Water Resource					Natural Discharge during non-monsoon season	Net Annual Ground Water Availability	Annual Ground Water Draft			Projected Demand for Domestic and Industrial uses upto 2025	Ground Water Availability for future Irrigation	Stage of Ground Water Development (%)
		Monsoon Season		Non-Monsoon Season		Total			Irrigation	Domestic and Industrial uses	Total			
		Recharge from Rainfall	Recharge from other sources	Recharge from Rainfall	Recharge from other sources									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	States													
1	Andhra Pradesh	16.04	8.93	4.20	7.33	36.50	3.55	32.96	13.88	1.02	14.90	2.67	17.65	45
2	Arunachal Pradesh	1.57	0.00009	0.98	0.0002	2.55	0.26	2.30	0.0008	0	0.0008	0.009	2.29	0.04
3	Assam	23.65	1.99	1.05	0.54	27.23	2.34	24.89	4.85	0.59	5.44	0.98	19.05	22
4	Bihar	19.45	3.96	3.42	2.36	29.19	1.77	27.42	9.39	1.37	10.77	2.14	15.89	39
5	Chhattisgarh	12.08	0.43	1.30	1.13	14.93	1.25	13.68	2.31	0.48	2.80	0.70	10.67	20
6	Delhi	0.13	0.06	0.02	0.09	0.30	0.02	0.28	0.20	0.28	0.48	0.57	0.00	170
7	Goa	0.22	0.01	0.01	0.04	0.28	0.02	0.27	0.04	0.03	0.07	0.04	0.18	27
8	Gujarat	10.59	2.08	0.00	3.15	15.81	0.79	15.02	10.49	0.99	11.49	1.48	3.05	75
9	Haryana	3.52	2.15	0.92	2.72	9.31	0.68	8.63	9.10	0.35	9.45	0.60	-1.07	109
10	Himachal Pradesh	0.33	0.01	0.08	0.02	0.43	0.04	0.39	0.09	0.02	0.12	0.04	0.25	30
11	Jammu & Kashmir	0.61	0.77	1.00	0.32	2.70	0.27	2.43	0.10	0.24	0.33	0.42	1.92	14
12	Jharkhand	4.26	0.14	1.00	0.18	5.58	0.33	5.25	0.70	0.38	1.09	0.56	3.99	21

Sl No	Sates/Union Territories	Annual Replenishable Ground Water Resource					Natural Discharge during non-monsoon season	Net Annual Ground Water Availability	Annual Ground Water Draft			Projected Demand for Domestic and Industrial uses upto 2025	Ground Water Availability for future Irrigation	Stage of Ground Water Development (%)
		Monsoon Season		Non-Monsoon Season		Total			Irrigation	Domestic and Industrial uses	Total			
		Recharge from Rainfall	Recharge from other sources	Recharge from Rainfall	Recharge from other sources									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
13	Karnataka	8.17	4.01	1.50	2.25	15.93	0.63	15.30	9.75	0.97	10.71	1.41	6.48	70
14	Kerala	3.79	0.01	1.93	1.11	6.84	0.61	6.23	1.82	1.10	2.92	1.40	3.07	47
15	Madhya Pradesh	30.59	0.96	0.05	5.59	37.19	1.86	35.33	16.08	1.04	17.12	1.74	17.51	48
16	Maharashtra	20.15	2.51	1.94	8.36	32.96	1.75	31.21	14.24	0.85	15.09	1.52	16.10	48
17	Manipur	0.20	0.005	0.16	0.01	0.38	0.04	0.34	0.002	0.0005	0.002	0.02	0.31	0.65
18	Meghalaya	0.79	0.03	0.33	0.005	1.15	0.12	1.04	0.00	0.002	0.002	0.10	0.94	0.18
19	Mizoram	0.03	0.00	0.02	0.00	0.04	0.004	0.04	0.00	0.0004	0.0004	0.0008	0.04	0.90
20	Nagaland	0.28	0.00	0.08	0.00	0.36	0.04	0.32	0.00	0.009	0.009	0.03	0.30	3
21	Orissa	12.81	3.55	3.58	3.14	23.09	2.08	21.01	3.01	0.84	3.85	1.22	16.78	18
22	Punjab	5.98	10.91	1.36	5.54	23.78	2.33	21.44	30.34	0.83	31.16	1.00	-9.89	145
23	Rajasthan	8.76	0.62	0.26	1.92	11.56	1.18	10.38	11.60	1.39	12.99	2.72	-3.94	125
24	Sikkim	-	-	-	-	0.08	0.00	0.08	0.00	0.01	0.01	0.02	0.05	16
25	Tamil Nadu	4.91	11.96	4.53	1.67	23.07	2.31	20.76	16.77	0.88	17.65	0.91	3.08	85
26	Tripura	1.10	0.00	0.92	0.17	2.19	0.22	1.97	0.08	0.09	0.17	0.20	1.69	9

Sl No	Sates/Union Territories	Annual Replenishable Ground Water Resource					Natural Discharge during non-monsoon season	Net Annual Ground Water Availability	Annual Ground Water Draft			Projected Demand for Domestic and Industrial uses upto 2025	Ground Water Availability for future Irrigation	Stage of Ground Water Development (%)
		Monsoon Season		Non-Monsoon Season		Total			Irrigation	Domestic and Industrial uses	Total			
		Recharge from Rainfall	Recharge from other sources	Recharge from Rainfall	Recharge from other sources									
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
27	Uttar Pradesh	38.63	11.95	5.64	20.14	76.35	6.17	70.18	45.35	3.42	48.78	5.30	19.52	70
28	Uttaranchal	1.37	0.27	0.12	0.51	2.27	0.17	2.10	1.34	0.05	1.39	0.08	0.68	66
29	West Bengal	17.87	2.19	5.44	4.86	30.36	2.90	27.46	10.84	0.81	11.65	1.24	15.32	42
	Total States	**247.88**	**69.51**	**41.83**	**73.15**	**432.42**	**33.73**	**398.70**	**212.38**	**18.04**	**230.44**	**29.12**	**161.92**	**58**
	Union Territories													
1	Andaman & Nicobar	-	-	-	-	0.330	0.005	0.320	0.000	0.010	0.010	0.008	0.303	4
2	Chandigarh	0.016	0.001	0.005	0.001	0.023	0.002	0.020	0.000	0.000	0.000	0.000	0.020	0
3	Dadara & Nagar Haveli	0.059	0.005			0.063	0.003	0.060	0.001	0.007	0.009	0.008	0.051	14
4	Daman & Diu	0.006	0.002	0.000	0.001	0.009	0.0004	0.008	0.007	0.002	0.009	0.003	-0.002	107
5	Lakshdweep	-	-	-	-	0.012	0.009	0.004	0.000	0.002	0.009	-	-	63
6	Pondicherry	0.057	0.057	0.007	0.029	0.160	0.016	0.144	0.121	0.030	0.151	0.031	-0.008	105
	Total Uts	**0.138**	**0.075**	**0.012**	**0.031**	**0.597**	**0.036**	**0.556**	**0.129**	**0.051**	**0.181**	**0.050**	**0.365**	**33**
	Grand Total	**248.01**	**69.59**	**41.85**	**73.19**	**433.02**	**33.77**	**399.25**	**212.51**	**18.09**	**230.62**	**29.17**	**162.29**	**58**

Source: Central Water Commission, (2008)

Table 2.7 : Water Resources Potential in the River Basins of India

Sl No.	Name of the River Basin	Average Annual Water Potential (BCM)	Estimated Utilizable Surface Water (BCM)	Estimated Replenishable Ground Water Resources (BCM)	Total Utilizable Water (4) + (5) (BCM)
1	**2**	**3**	**4**	**5**	**6**
1	Indus (up to Border)	73.31	46.00	26.49	72.49
2	a) Ganga	525.02	250.00	170.99	420.99
	b) Brahmaputra, Barak and others	585.60	24.00	35.07	59.07
3	Godavari	110.54	76.30	40.65	116.95
4	Krishna	78.12	58.00	26.41	84.41
5	Cauvery	21.36	19.00	12.30	31.30
6	Subernarekha	12.37	6.81	1.82	8.63
7	Brahmani & Baitarni	28.48	18.30	4.05	22.35
8	Mahanadi	66.88	49.99	16.46	66.45
9	Pennar	6.32	6.86	4.93	11.79
10	Mahi	11.02	3.10	4.20	7.30
11	Sabarmati	3.81	1.93	3.00	4.93
12	Narmada	45.64	34.50	10.83	45.33
13	Tapi	14.88	14.50	8.27	22.77
14	West Flowing Rivers from Tapi to Tadri	87.41	11.94	8.70	20.64
15	West Flowing Rivers from Tadri to Kanyakumari	113.53	24.27	9.00	33.27
16	East Flowing Rivers between Mahanadi & Pennar	22.52	13.11	9.00	22.11
17	East Flowing Rivers between Pennar & Kanyakumari	16.46	16.73	9.20	25.93
18	West Flowing Rivers of Kutch & Saurashtra including Luni	15.1	14.98	11.23	26.21
19	Area of Inland drainage in Rajasthan	Neg.	N.A	N.A	N.A
20	Minor Rivers draining into Myanmar & Bangladesh	31.00	N.A	18.80	18.80
Total		**1869.35**	**690.31**	**431.42**	**1121.73**

Source: CWC/CGWB, (2000)
Note: Total may not tally due to rounding off.
N.A.: Not Available

2.7 Spatial Variation of Water Availability in India

The surface water availability in various river basins in India is shown in Table-2.5. Figure 2.8(a) shows the runoff map of India. The average precipitation of the sub-basins were computed by Dr. Sandhya Rao of INRM Consultants using the gridded precipitation data of IMD. The coefficient of runoff was computed using the average flow in each basin as given in Table-2.5. The runoff coefficient is 12% for West Flowing rivers of Kutch and Saurashtra including the Luni, 15.3% for the Pennar and more than 90% for the Barak and the Brahmaputra basins. For most of the basins, the value varies between 25 to 58%. For the Krishna basin, the runoff coefficient is 37%. The basin was divided into 12 subbasins by the Krishna Godavari Commission. Figure 2.8(b) defines the 12 sub basins of the Krishna basin and runoff coefficient which varies around 64% for the Upper Krishna to 11% for the Vedavati is shown in Table 2.8. It may be inferred from the above that river basins of India show not only extreme variability in surface water availability between basins but also in subbasins within the basin. The variation of runoff coefficient with the rainfall for the sub-basin 6 of Krishna basin is shown in Figure 2.8 (c).

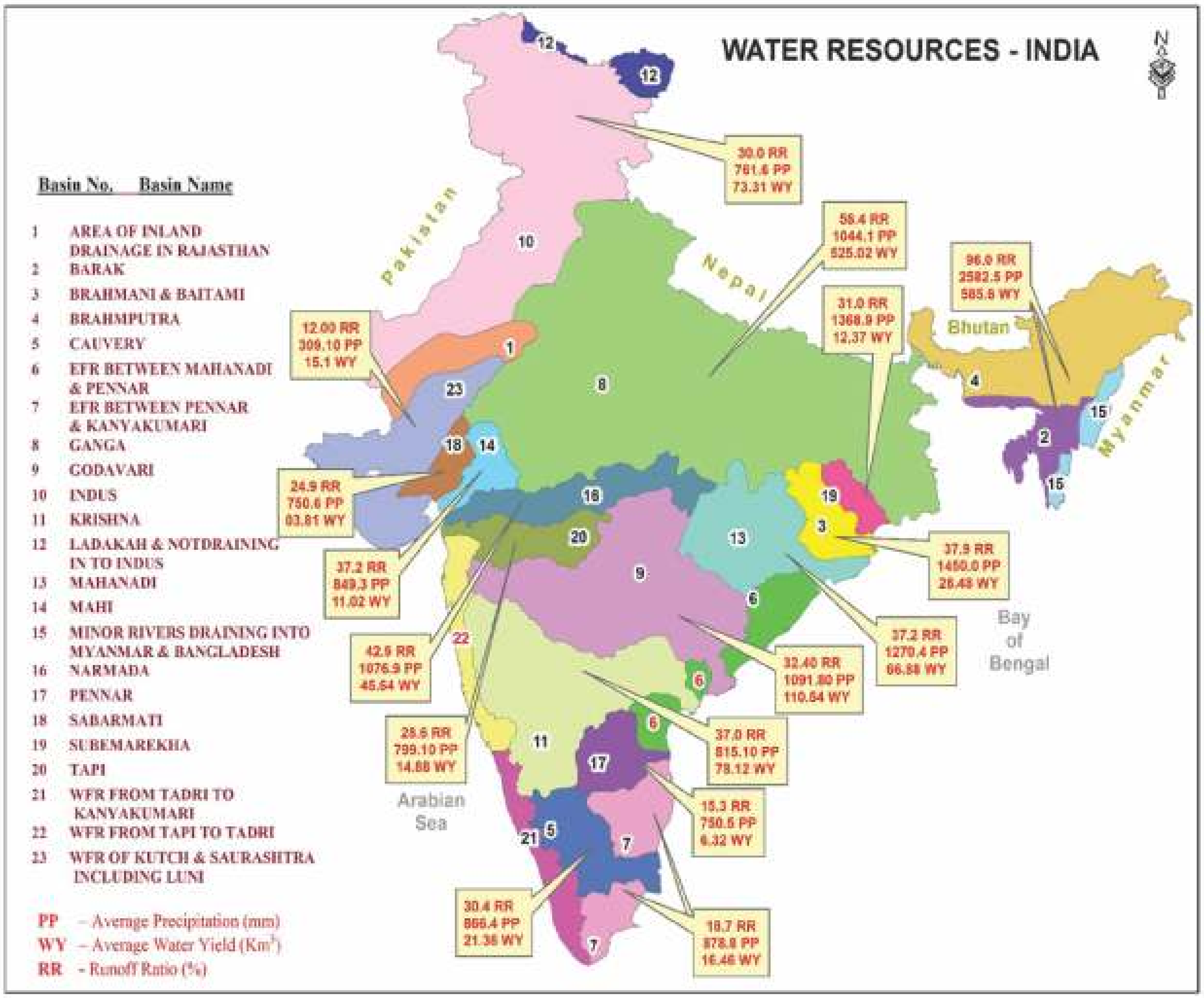
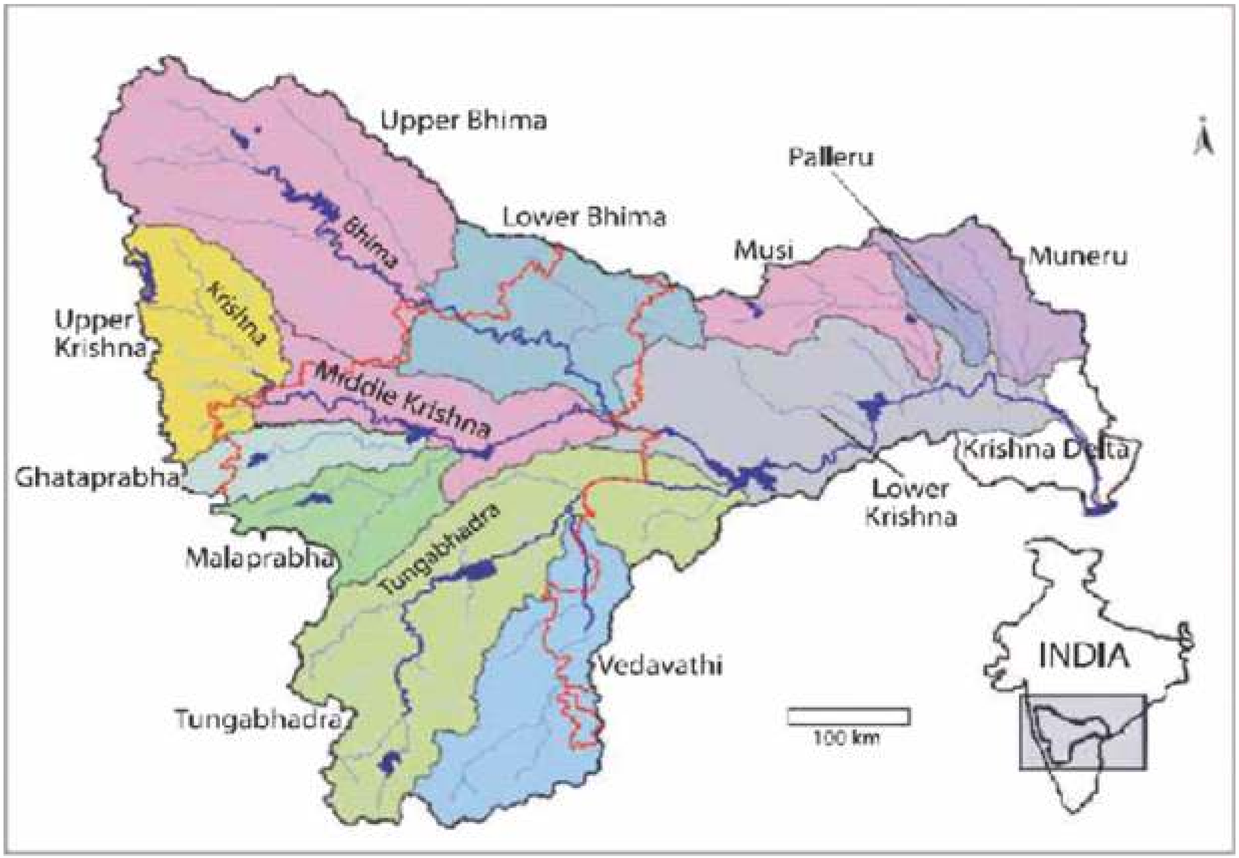


Figure 2.8 (a) : Runoff Map of India



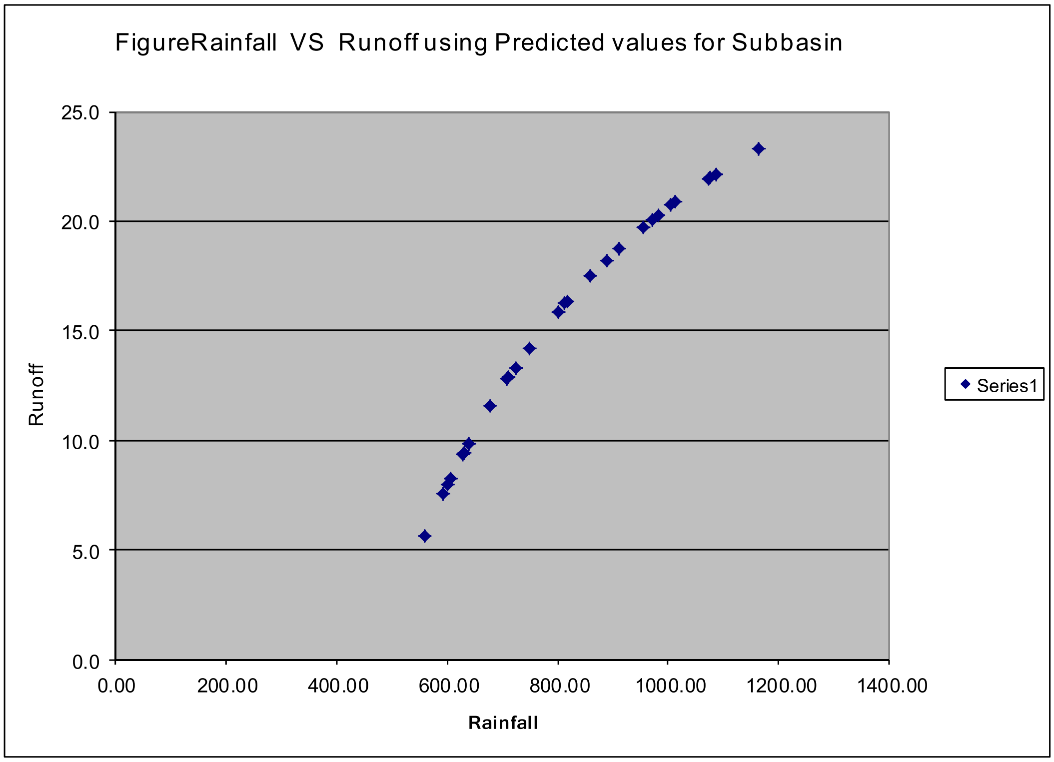
Source: IWMI Research report no 111

Figure 2.8 (b) : Sub-basins of the Krishna Basin

Table 2.8 : Runoff Coefficient in Krishna Sub-Basins

Name of Sub-basin	Sub-Basin	Rainfall (mm)	Area (sq km)	Average Flow (BCM)	Runoff Coeff (%)
Upper Krishna	K-1	1621	17972	18.58	63.8
Middle Krishna	K-2	615	17558	1.53	14.2
Bhataprabha	K-3	1043	8829	4.56	49.5
Malaprabha	K-4	771	11549	2.44	27.4
Upper Bhima	K-5	761	46066	11.07	31.5
Lower Bhima	K-6	730	24548	2.41	13.4
Lower Krishna	K-7	735	34255	4.9	19.5
Tungabhadra	K-8	962	47827	16.23	35.3
Vedavathi	K-9	592	23590	1.53	11
Musi	K-10	774	11212	1.56	18
Palleru	K-11	832	3263	0.79	29.1
Muneru	K-12	984	10409	3	29.3
	Total Basin	**847.24**	**257078**	**68.6**	**31.5**
	Upto Vijayawada				

(Source- Subhash Chander 2010)



Source- Subhash Chander 2009

Figure 2.8 (c) : Rainfall vs % Runoff Using Predicted Values for Sub-Basin 6

2.8 Utilizable Flows in River Basins of India

All natural freshwater, surface water or ground water are not accessible for use. Utilizable Water Resources are calculated taking into factors like the economic and environmental feasibility of storing floodwater behind dams, or extracting groundwater, the physical possibility of catching water which naturally flows out to the sea, and the minimum flow requirements for navigation, environmental services, aquatic life, etc. It includes the seasonal and inter-annual variations, i.e. seasonal flow or flow during wet years. It is the flow that can be regulated.

The average water potential in India is 1869 Km^3. The utilizable surface water flow computed by CWC is 690.31 Km^3. In Table -2.7 the replenishable ground water is added to compute the utilizable flows as 1121.73 Km^3. Garg and Hassan (2007) have shown that CWC has computed the 690.31 Km^3 figure by adding the replenishable ground water to the yield of the constructed storages and the addition in the above table amounts to adding the groundwater again. There is a flaw in the assumption that flows can be utilized only by constructing major and medium irrigation projects. In practice, flow is utilized by diverting low flows by constructing barrages, minor irrigation structures, water harvesting structures and in Integrated Watershed Management Projects by conserving water as soil moisture, recharging aquifers by intercepting runoff from rain for later use to match the demand pattern. For example, an artificial recharge of river water is being done in Madhya Ganga using monsoon flows in unlined canals for use during winter. Hence, the utilizable flows should be pegged at 1869 Km3 minus the flow which is required to maintain the eco-services in the basins including flows which cannot be utilized in coastal region and water released to meet international obligations. Even this quantity can be increased by micromanaging the basins to ensure that evaporation and evapo-transpiration which does not presently add value to the economy is harnessed for beneficial use. A very rough assessment of Utilizable flows in

2025 and 2050 has been made in proportion to the available storage and shown in Table-2.9. It is assumed that all projects which are under construction in column 3 of Table-2.5 will be completed by 2025. The projects in column 5 of Table-2.5 will be completed by 2050.

Table 2.9 : Utilizable Flows in 2025 and 2050

Name of Basin	Live storage capacities of projects completed (1)	Live storage capacities of projects likely to be completed by 2025 (2)	Utilizable flow in 2025 (Utilizable surface water + replenishable G.W.)* (3)	Projects added between 2025 and 2050 (4)	Utilizable flow in 2050 (Utilizable surface water+ replenishable G.W.)* (5)
Indus (up to Border)	16.29	0.28	66.31	2.58	72.49
a) Ganga	42.06	18.6	338.12	30.08	420.99
b) Brahmaputra, Barak and others	2.33	9.35	40.37	41.26	59.07
Godavari	25.12	6.21	104.96	5.84	116.95
Krishna	41.8	7.74	83.11	1.13	84.41
Cauvery	8.6	0.27	30.76	0.26	31.3
Subernarekha	0.67	1.65	6.09	1.38	8.63
Brahmani & Baitarni	4.65	0.88	11.16	8.72	22.35
Mahanadi	12.33	1.87	45.67	10.09	66.45
Pennar	2.65	2.17	11.79	0	11.79
Mahi	4.72	0.26	7.29	0.01	7.3
Sabarmati	1.31	0.06	4.80	0.1	4.93
Narmada	16.98	6.63	44.67	0.47	45.33
Tapi	9.41	0.85	22.38	0.29	22.77
West Flowing Rivers from Tapi to Tadri	11.27	3.46	20.58	0.08	20.64

West Flowing Rivers from Tadri to Kanyakumari	10.24	1.32	30.57	1.45	33.27
East Flowing Rivers between Mahanadi & Pennar	1.6	1.42	18.97	0.95	22.11
East Flowing Rivers between Pennar & Kanyakumari	1.84	0.07	25.93	0	25.93
West Flowing Rivers of Kutch & Saurashtra including Luni	4.73	0.8	21.13	2.85	26.21
Area of Inland drainage in Rajasthan	-	-		-	
Minor Rivers draining into Myanmar	0.31	-		-	
	218.91	**63.89**	**934.64**	**107.54**	**1121.73**

**utilizable flows will be available for 50% of the years and in all those years the flows in the river are more than utilizable flows.*

(1) Col. 2 Table-2.5
(2) Col.3 Table 2.5 (The projects are likely to be completed by 2025)
(3) {Estimated utilizable surface water (Table 2.4)/col. 2 (table2.5)}{col 2 - col 3 (table 2.5)+ projects under consideration(table2.5)}+{Estimated replenishable ground water(table2.7)}*
(4) Col 5 Table 2.5 (projects under consideration are assumed to be completed by 2050)
(5) (Estimated utilizable surface water (Table 2.4)+ estimated replenishable ground water (Table 2.7)

2.8.1 Water Required for Providing Acceptable Eco-services in Various Basins

Environmental flows are defined in the Brisbane Declaration (http://www.riverfoundation.org.au/images/stories.pdfs/bnedeclaration.pdf) as the 'quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihood and well-being that depend on these ecosystems'. It is now widely accepted that a naturally variable regime of flow, rather than just a minimum low flow, is required to sustain freshwater ecosystems (Poff et al., 1997; Bunn & Arthington, 2002; Postel & Richter, 2003; Annear et al., 2004; Biggs, Nikora & Snelder, 2005; Poff, 2010), and this understanding has contributed to the implementation of environmental flow management on thousands of river kilometers worldwide (Postel & Richter, 2003).

IWMI has been engaged in research to estimate the environmental flow requirement in various sub-basins of India. Water required to provide acceptable eco-services depend on the tradeoff between the requirement for ecosystem and other uses. Environmental flows aim to maintain an ecosystem in, or upgrade it to, some prescribed or negotiated condition/ status also referred to as "desired future state", "environmental management class"/ "ecological management category", "level of environmental protection", etc. (e.g., Acreman and Dunbar 2004; DWAF 1997). This report uses the term 'environmental management class' (EMC). The higher the EMC, more water will need to be allocated for ecosystem maintenance or conservation and more flow variability will need to be preserved. Ideally, these classes should be based on empirical relationships between flow and ecological status/ conditions associated with clearly identifiable thresholds. However, so far there is insufficient evidence for such thresholds (e.g., Beecher 1990; Puckridge et al. 1998). These categories are therefore a management concept, which has been developed and used in the world because of a need to take decisions under conditions of limited lucid knowledge. A largely modified ecosystem corresponds to class D of Environment Management Classification (Smakhtin et.al. 2006). In this class, large scale construction of infrastructure such as dams, diversions and transfer to other basins is restricted to ensure that the ecosystem is reversible but with lower than expected species richness and presence of alien species. The water required by various basins for this class is given in Table-2.10.

Table 2.10 : Estimates of Long-Term EWR Volumes (Expressed as % of Natural Mean Annual Runoff - MAR) at River Basin Outlets for Management Class D Using FDC Shifting Method.

Name of Basin	Environmental Flow as % of Natural Mean Annual Runoff
Brahmaputra	34.7
Cauvery	10.6
Ganga	20.0
Godavari	17.4
Krishna	8.4
Mahanadi	9.7
Mahi	2.3
Narmada	7.1
Pennar	7.3
Tapi	9.0
Periyar	12.1
Sabarmati	6.6
Subarnarekha	7.4

Source: Smakhtin et.al. 2006

No estimate is available for other basins/rivers. Therefore, the utilizable flows for west flowing rivers from Tapi to Kanyakumari, east flowing rivers from Mahanadi to Kanyakumari, West Flowing Rivers of

Kutch & Saurashtra including Luni, minor rivers draining into Myanmar and Bangladesh, Indus and Brahmaputra are restricted to the value suggested by CWC in Table 2.7. The Indus and the Brahmputra are included in this group because of international obligations.

It is assumed that the difference between the average flow and the utilizable flow in these rivers will be able to meet the need of ecological flows as well as international obligations in Indus and Brahmaputra. The maximum flows which can be utilized in an average year/ 50% dependable year after deducting 836 Km^3 of environmental flows and non-usable water are 1033 Km^3. A study was carried out to test this methodology on the Krishna basin. 70 Km^3 of surface and ground water has been utilized in the basin in years the flows in the river are more than average flows. The use has reduced the Environmental Management class of the Krishna delta to Class D. Reducing 8.4% of the average flows from the average flow availability of 78.12 Km^3; the utilizable flows are 71.6 Km^3. The non-usable flows and ground water to sea in Krishna delta below Vijayawada are around 2 Km^3 leaving around 69 Km^3 available for utilization. These flows are nearly equal to the maximum flows which are being used from the basin in all years when the available flows in the river are more than the average flows. For other years the utilizable flows will be less than 71 Km^3. The reduction will be nearly equal to average flows minus the available flows, provided there is no carryover storage in Nagarjuna sagar Dam or other upstream dams from the previous year.

2.8.2 Increasing Utilizable Water

Utilizable water can be increased by rain water harvesting, proper management of green water through integrated watershed management, artificial recharging of aquifers (the master plan for artificial recharge to ground water in India which aims at recharging surplus runoff of about 36.4 BCM in an area of about 450,000 Km^2, identified in various parts of the country experiencing a sharp decline of ground water levels), pre-monsoon pumping and additional river bed recharge in monsoon or through seepage from unlined canals and irrigated fields during monsoon as in Madhya Ganga Canal Project. (As per NCIWRD replenishable water resource due to recharge from canal irrigation is 89.46 BCM).

Sharma et. al. (2008) identified about 27.5 Mha of potential rain-fed area, which accounted for most of the rain-fed production and generated sufficient runoff (114 BCM) for harvesting and reutilization. It was possible to raise the rain-fed production by 50% over this entire area through the application of a single supplementary irrigation (28 BCM) and some follow up on the improved practices. Extensive area coverage rather than intensive irrigation need to be followed in regions with higher than 750 mm/ annum rainfall, since there is a larger possibility of alleviating the in-season drought spells and ensuring a second crop with limited water application. This component may be made an integral component of the ongoing and new development schemes in the identified rural districts. The proposed strategy is environmentally benign, equitable, poverty-targeted and financially attractive to realize the untapped potential of rain-fed agriculture in India. Some of the other options to increase total water availability are:

1. Conjunctively using unreliable surface water with more reliable ground water to enhance the total use and dependability of supply.

2. Use of dug out farm ponds which get filled up repeatedly in each rain spell, and the water used in between the spells.

3. Installing low gates in minor tanks which spill frequently.

4. Inducing ground water seepage through seepage tanks in the fractured rocky areas of the peninsula

5. Increase storage through minor and medium projects, and carry over storage in major projects.

6. Increase utilizable water from these storages by using the water during rainless period in the monsoon season as well as creating offline storages wherein the flood waters can be stored for use during the dry season.

7. Increase utilizable water by conjunctively utilizing rain, green water, surface and ground water.

8. Inter basin transfers as per the River Interlinking Project of the GoI taking into consideration following criteria.

Criterion 1

The donor basin should experience high flows when recipient basin experiences drought.

Criterion 2

The scope for future development of the donor basin must not be constrained by the proposed Inter-basin water transfer

Criterion 3

The recipient basin must face a substantial deficit in meeting present or projected future (minimum) water demand after considering all possible alternate water supply sources for meeting the demand. The irrigation demand in the basin should be computed on the basis of crops chosen keeping in mind the irrigated capability of soil and climatic considerations. The demand computation should be based on most efficient water use in these basins.

Criterion 4

A comprehensive environmental impact assessment must ensure sustenance of environmental quality and health in both the donor and the recipient basins.

Criterion 5

A comprehensive socio-economic assessment should indicate that the donor and recipient basins experience minimum disruption.

2030 Water Resources Group has developed a cost curve for India. The cost curve and the likely water availability because of implementation of the various options to create storages/ avoid wasteful evaporation is shown in Figure 2.9.

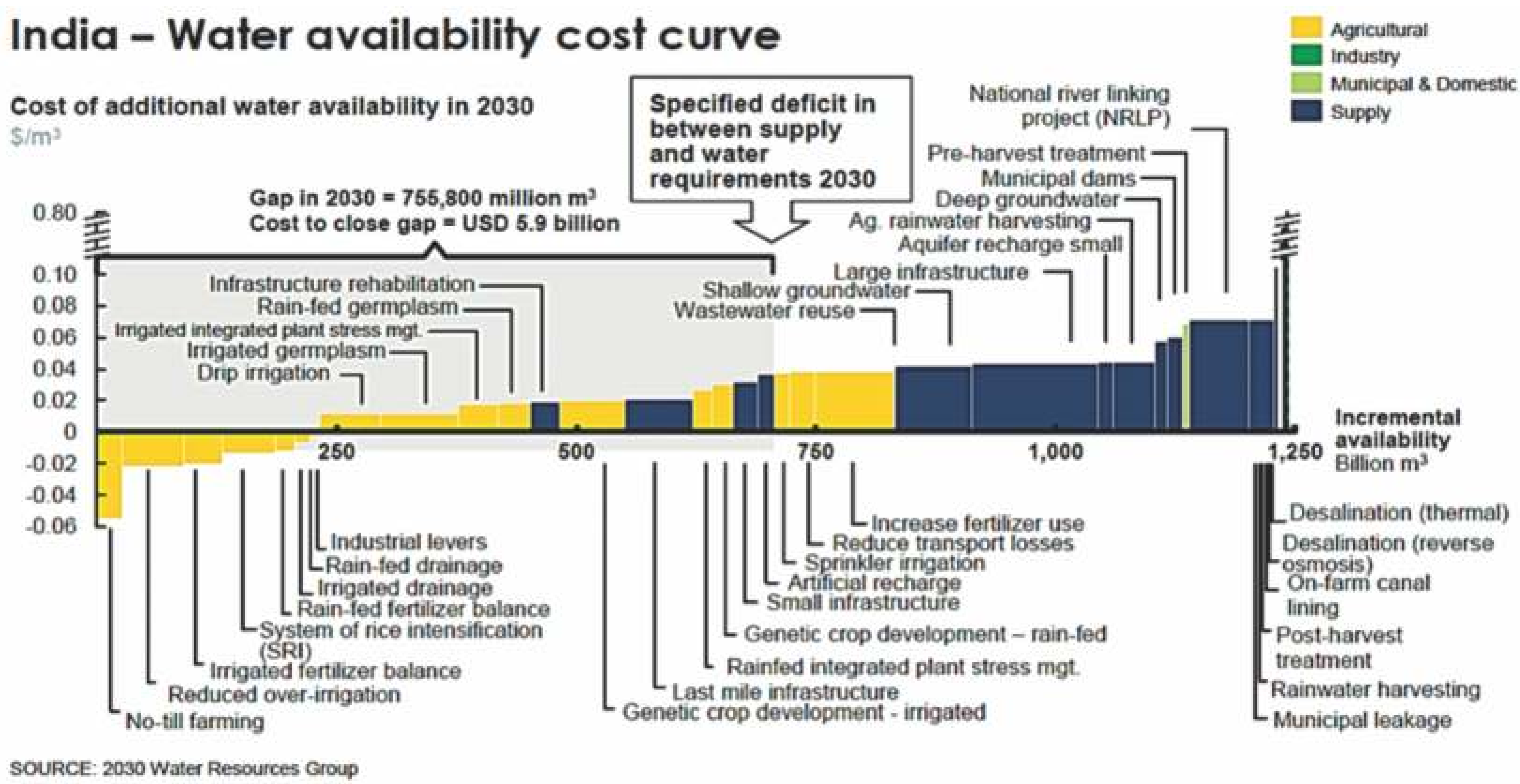


Figure 2.9 : India – Water Availability Cost Curve

The group has computed the standalone capability of the various measures in the cost curve in increasing water availability as well as virtual water savings by avoided irrigation. The estimates are

Water availability, Billion m^3

- 1.Traditional water Supply infrastructure 469 BCM
  - Infrastructure rehabilitation
  - Last mile infrastructure
  - Small infrastructure
  - Artificial recharge
  - Large infrastructure

Virtual Water Savings or avoided irrigation

- 2.Agricultural Efficiency 149 BCM
- 3. Increased yield 580 BCM
- 2 & 3 through
  - Drip irrigation- physical water savings
  - Irrigated germplasm
  - Irrigated integrated plant stress mgt.
  - Rain-fed germplasm
  - Reduced over-irrigation-physical water savings
  - No-till farming
  - Irrigated fertilizer balance
  - System of rice intensification (SRI)
  - Rain-fed fertilizer balance
  - Irrigated drainage
  - Rain-fed drainage

Industrial efficiency 7 BCM

Municipal Efficiency 22 BCM

The choice of the above options will vary from sub-basin to sub-basin and its climate, geology, topography, acceptability of the option to stake holders and impact of choice of the option on downstream water users. It is important that all options describe above are used to reduce wasteful evaporation to suppress the demand in the basins. Systems that combine storage options as well as reduce wasteful evaporation are likely to be more acceptable than those based on a single option.

2.9 Impact of Climate Change

(A) On Water Availability in Various Basins

Climate change challenges the traditional assumption that past hydrological experience provides a good guide to future conditions. The consequences of climate change may alter the reliability of current water management systems and water-related infrastructure. (Climate Change and Water- IPCC Technical

Paper VI) .The quantitative projections of changes in precipitation, river flows and water levels at the river-basin scale are uncertain and need to be determined. Gosain et.al. (2011) used the Simulated climate outputs from PRECIS RCM for the present (1961–1990, BL) near term (2021–2050, MC) and long term (2071–2098, EC) for A1B IPCC SRES socioeconomic scenario to determine the quantitative projections at the river basin scale. This scenario is characterized by a future world of rapid economic growth, global population that peaks in the mid-century (MC) and declines thereafter, and rapid introduction of new and more efficient technologies, with the development balanced across energy sources.

The spatio-temporal water availability in the various river basins for three scenarios namely BL, MC and EC was computed using SWAT distributed hydrological model. The results of the study are analyzed to find the impact of Climate change on blue and green water for the three scenarios. The quantitative projections are tabulated in Tables 2.11, 2.12 and 2.13 and plotted in Figures 2.10, 2.11 and 2.12. The water related infrastructure in place in various basins has not been considered in the simulation exercise. Therefore, the rate of change projections may only be used to forecast the future. The trends indicate that blue water, and green water availability increases with time in all except Brahmaputra, Cauvery and Ganga basins. The green water storage decreases in mid-century scenario and the increases to the baseline scenario by end of the century. The coefficient of variation for blue water, green water and green water storage mostly improves by mid-century and then reduces to base line scenario by the end of century.

Table 2.11 : Change in Precipitation (-ve Value denotes increase from the BL)

Basin	MC	EC
Baitarni	-2.5	-9.9
Brahmani	-8.1	-8.9
Brahmaputra	2.3	-20.7
Cauvery	1.7	-10.2
Ganga	-2.5	-23.0
Godavari	-16.1	-8.0
Indus	-16.6	-9.3
Krishna	-1.5	-10.9
Luni	-13.8	-2.5
Mahanadi	-13.3	-9.0
Mahi	-11.5	-3.9
Meghna	-25.0	-11.6
Narmada	-17.4	-6.8
Pennar	3.5	-6.2
Sabarmati	-13.7	-2.7
Subernrekha	-1.1	-8.3
Tapi	-17.5	-5.7

Source: Gosain et.al. (2011)

Table 2.12 : Change in Water Yield (-ve Value denotes increase from the BL)

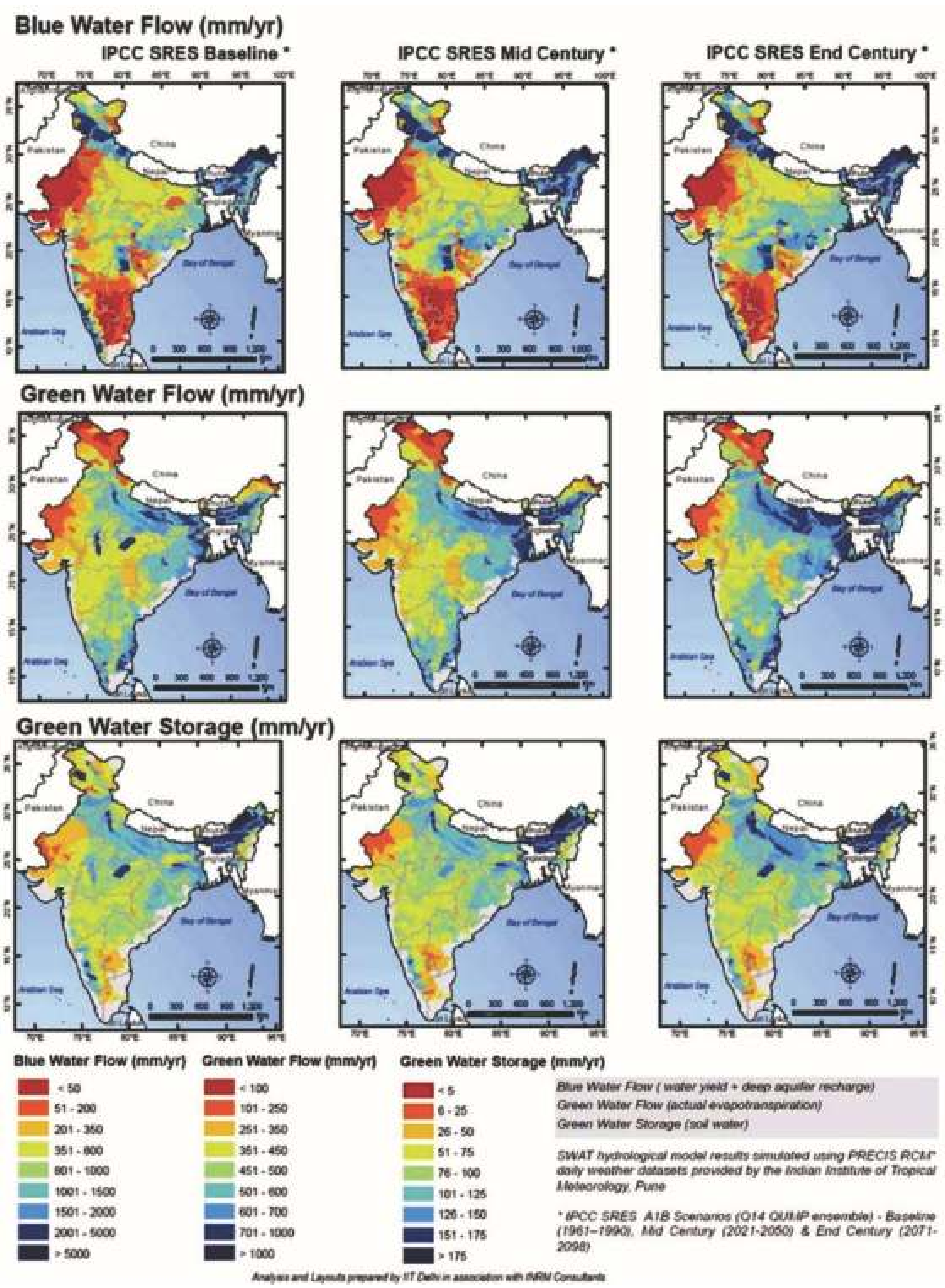
Basin	MC	EC
Baitarni	-2.8	-17.6
Brahmani	-12.6	-24.9
Brahmaputra	3.5	-8.7
Cauvery	3.4	-4.7
Ganga	0.5	-27.0
Godavari	-27.2	-33.6
Indus	-20.0	-17.5
Krishna	-4.3	-4.4
Luni	-51.9	-7.5
Mahanadi	-19.0	-29.3
Mahi	-26.0	-25.0
Meghna	-33.8	-37.8
Narmada	-27.0	-34.5
Pennar	-30.9	-7.4
Sabarmati	-38.6	-29.8
Subernrekha	-1.4	-17.1
Tapi	-32.5	-32.6

Source: Gosain et.al. (2011)

Table 2.13 : Change in Actual ET (-ve Value denotes increase from the BL)

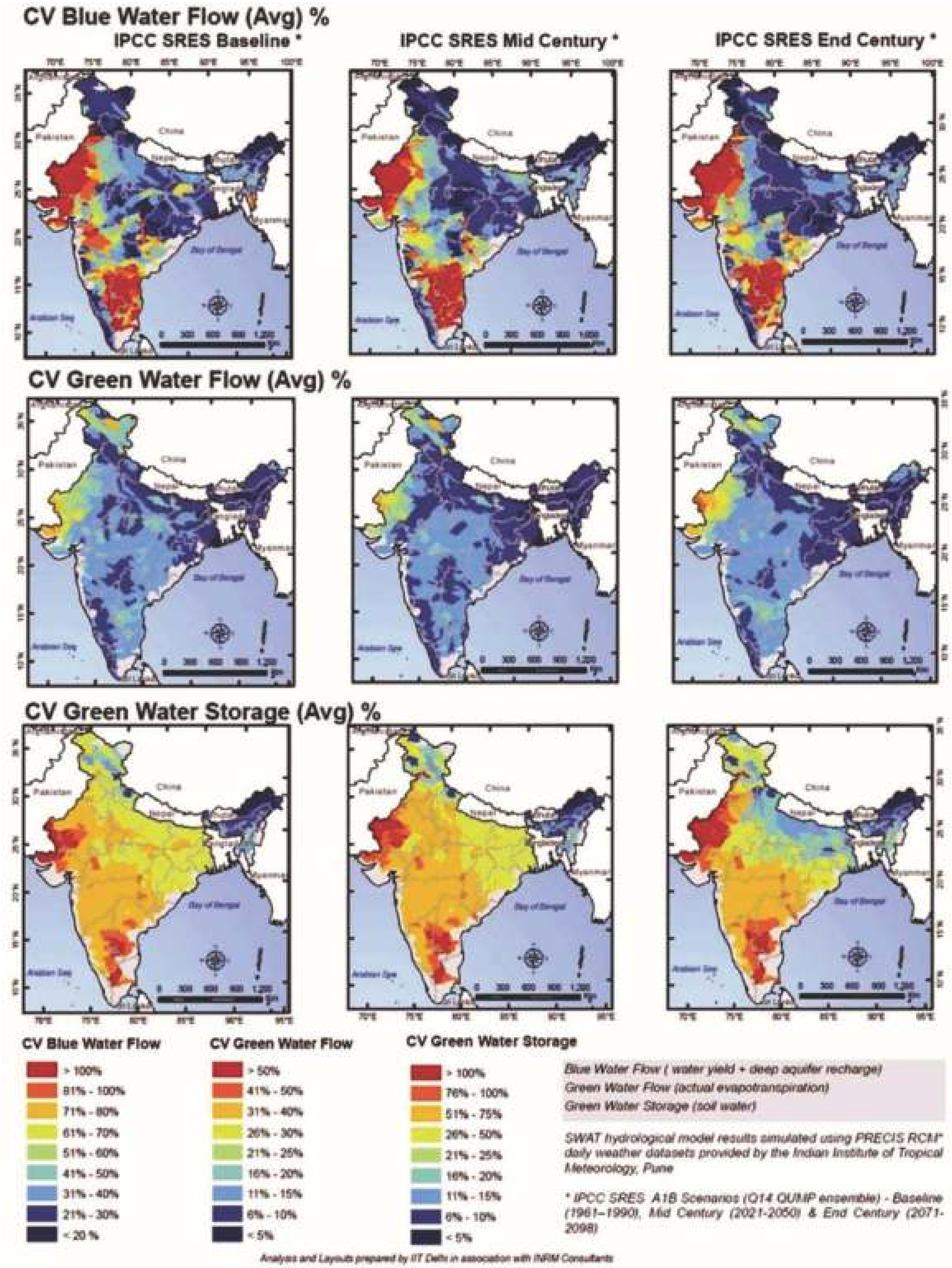
Basin	MC	EC
Baitarni	-1.9	-21.6
Brahmani	-1.2	-35.3
Brahmaputra	-8.1	-7.7
Cauvery	1.1	8.5
Ganga	-7.0	-16.0
Godavari	1.4	-50.0
Indus	-11.9	-23.9
Krishna	0.7	3.8
Luni	-10.5	-59.7
Mahanadi	-2.0	-39.6
Mahi	4.1	-44.3
Meghna	-3.0	-48.4
Narmada	-0.8	-50.1
Pennar	1.9	-12.8
Sabarmati	2.8	-71.1
Subernrekha	-0.6	-22.6
Tapi	0.3	-54.9

Source: Gosain et.al. (2011)



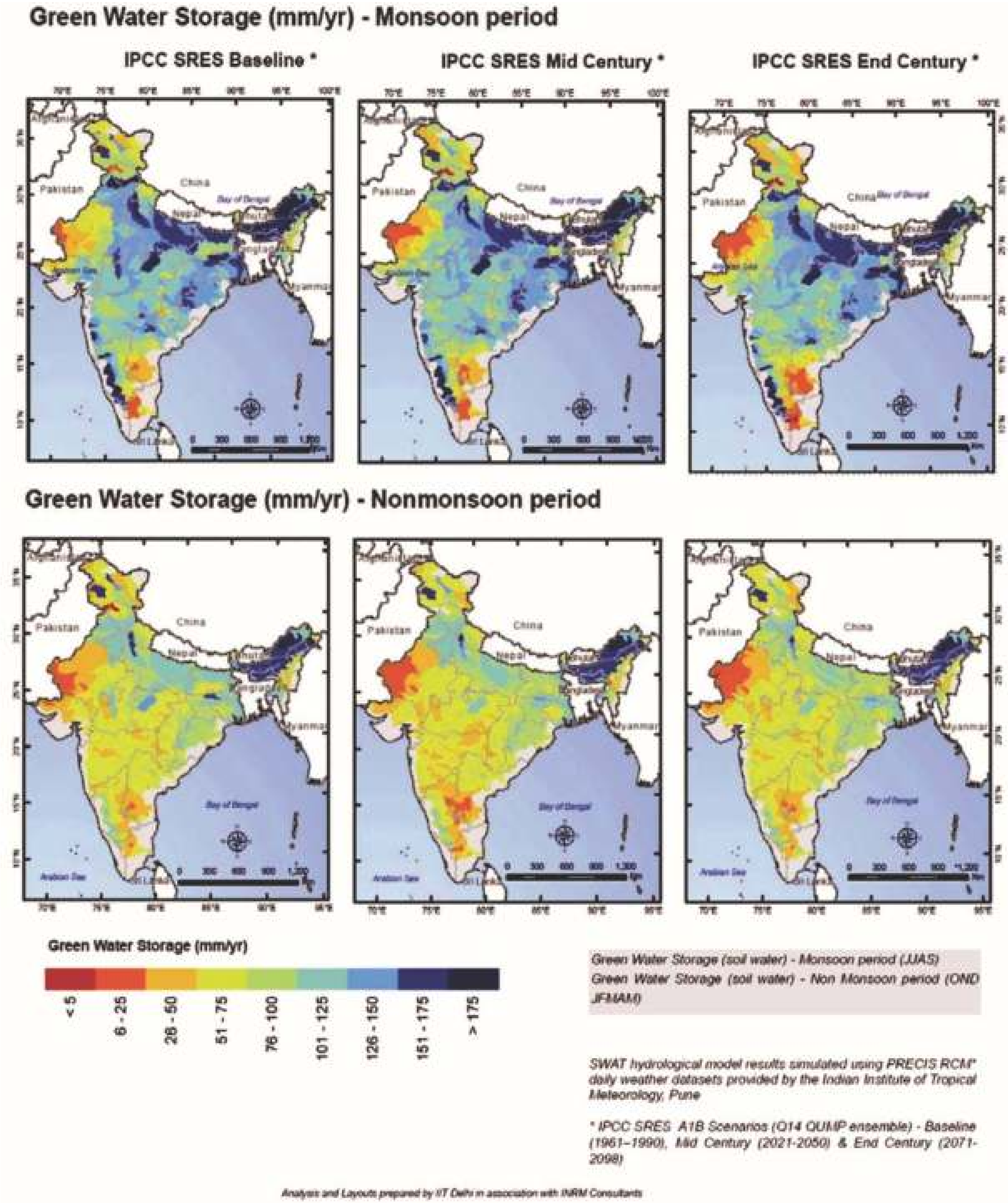
Source: Gosain et.al. (2011)

Figure 2.10 : Annual Average Blue Water Flow, Green Water Flow and Green Water Storage in all 1025 Modeled Sub-Basins in India for IPCC SRES A1B BL, MC and EC Scenarios.



Source: Gosain et.al. (2011)

Figure 2.11 : Coefficient of Variation (CV) of Annual Average Blue Water Flow, Green Water Flow and Green Water Storage in all 1025 Modeled Sub-Basins in India for IPCC SRES A1B BL, MC and EC Scenarios



Source: Gosain et.al. (2011)

Figure 2.12 : Annual Average Green Water Storage in the Monsoon and Non-Monsoon Periods in all 1025 Modeled Sub-Basins in India for IPCC SRES A1B BL, MC and EC Scenarios.

Based on the trends in this study the average flow in various sub-basins in mid-century and end century scenarios is indicated in Table 2.14.

Table 2.14 : Availability of Surface Water in BCM

Basin	Present Estimates (Table-2.7)	Mid Century Flow Estimates	End Century Flow Estimates
Baitarni	5.42	5.57	6.37
Brahmani	23.06	25.97	28.80
Brahmaputra	585.6	565.10	636.55
Cauvery	21.36	20.63	22.36
Ganga	525.02	522.39	666.78
Godavari	110.54	140.61	147.68
Indus	73.31	74.78	86.14
Krishna	78.12	81.48	81.58
Luni	15.1	22.94	16.23
Mahanadi	66.88	79.59	86.48
Mahi	11.02	13.89	13.78
Narmada	45.64	57.96	61.39
Pennar	6.32	4.37	6.79
Sabarmati	3.81	5.28	4.95
Subernrekha	12.37	12.54	14.49
Tapi	14.88	19.72	19.73

Source : Authors own estimates

All basins except Brahmaputra, Ganga, Cauvery and Pennar show improvement in average flows by mid-century. The maximum increase from 15.1 BCM to 22.94 BCM is indicated in Luni. However this increase is not sustained till the end of the century and yield decreases to 16.23 BCM. Brahmaputra, Ganga, Cauvery and Pennar also show increase in water availability by End of the Century in comparison to present availability. This is also true for all other basins.

B. On Glaciers in India

Glaciers 'mother' several rivers and streams with melt runoff. A significant portion of the low flow contribution of Himalayan Rivers during the dry season is from snow and glaciers melt in the Himalayan region. The results of Sagarmatha project conclude that for the Ganga, the response of the river, near the headwaters in Uttarkashi is significantly different from what is seen downstream at Allahabad. At Uttarkashi, flows peak at between +20 percent and +33 percent of baseline within the first two decades and then recede to around –50 percent of baseline by decade 6; further downstream the deglaciation impacts are barely noticeable. Most of the other modeling studies carried out recently support these findings that it is at a seasonal level and in the higher reaches of the streams that Himalayan glacier runoff changes will be felt most signicantly. The probable impact would become progressively greater as one moved upstream in a basin, decreasing the distance to the glacier terminus. The status of glaciers in the Indus, the Ganga and the Brahmaputra and their contribution to flows are given in Tables 2.15, 2.16, and 2.17 respectively.

Table 2.15 : Principal Rivers of the Himalayan Region – Basic Statistics

River			River Basin			
	Mean Discharge (m^3/s)	**Glacial melt in River Flow (%)**	**Area (km^2)**	**Population X1000**	**Population Density (per Km^2)**	**Water Availability (m^3/person/ year)**
Indus	5,533	44.8	1,081,718	178,483	165	978
Ganges	18,691	9.1	1,016,124	407,466	401	1,447
Brahmaputra	19,824	12.3	651,335	118,543	182	5,274

Source: IUCN, IWMI, Ramsar Convention, and WRI (2003) Water Resources Atlas. Available at http://multimedia.wri.org/watersheds_2003/index.html (accessed 12 June 2007)

Note: The hydrological data may differ depending on the location of the gauge stations. The contribution of glacial melt is based on limited data and should be taken as indicative only.

Table 2.16 : Status of the Glacier Inventory of Indus Basin

Basin	No. of glaciers	Glacierised area (Km^2)	Ice volume (km^3)
Jhelum	133	94.0	3.0
Satluj	224	420.0	23.0
Others	3398	33382.0	-
Total	3755	33896.0	26.0

Source: Kaul et al. 1999

Table 2.17 : Status of the Glacier Inventory of Ganga-Brahmaputra Basins

Basin	No. of glaciers	Glacierised area (Km^2)	Ice volume (km^3)
Bhagirathi	238	755.0	67.0
Tista	449	706.0	40.0
Brahmaputra	161	223.0	10.0
Others	640	2378.0	-
Total	1488	4062.0	117.0

Source: Kaul et al. 1999

2.10 CONCLUSION

India receives 1083 mm of average rainfall over a geographical area of 329 million hectares (mha). However, rainfall distribution varies widely across the land, both spatially and temporarily. Some areas in western Rajasthan receive less than 300 mm average annual rainfall, whereas some areas in the Northeast receive more than 2500 mm of Average rainfall. Most of this rainfall occurs in the monsoon months of June, July, August and September and its variability is highest in low rainfall areas of North western India and some pockets in the leeward side of the Western Ghats. The runoff generated in various sub-basins of India varies from 25 to 35 percent of rainfall except in the Luni, the Pennar and the east flowing rivers south of the Pennar. This average value is not a true representation of the variation in runoff even within the basin as can be seen by the average runoff coefficient in the sub-basins of the Krishna basin. These runoff coefficient values also change with the quantum of rainfall experienced in the sub-basins. These values increase with increasing rainfall requiring a different water resources management strategy to optimally use the resource from year to year requiring adaptive management techniques as in managing other natural resources.

Climate Change is not likely to decrease the average water availability in most of the basins. The frequency of extreme events is likely to increase resulting in increased flooding and probably longer droughts. The rainfall in Jhabua in Figure 2.4 (b) gives an idea of the extreme variations which have been experienced in some of the north western Watersheds. Climate Change is also going to result in melting of glaciers. The impact is much more in North western basins such as the Indus as compared to the eastern basins. These impacts are more within the vicinity of glaciered areas and tend to decrease as the contribution of rainfall to the yield increases further downstream of the river. As India is already used to dealing with such extremes, the lessons learnt in last 20 years in tackling these situations in various regions would be the basis for coping with increased variability because of climate change.

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CHAPTER - 3

Water Demands in Agriculture

3.1 Introduction

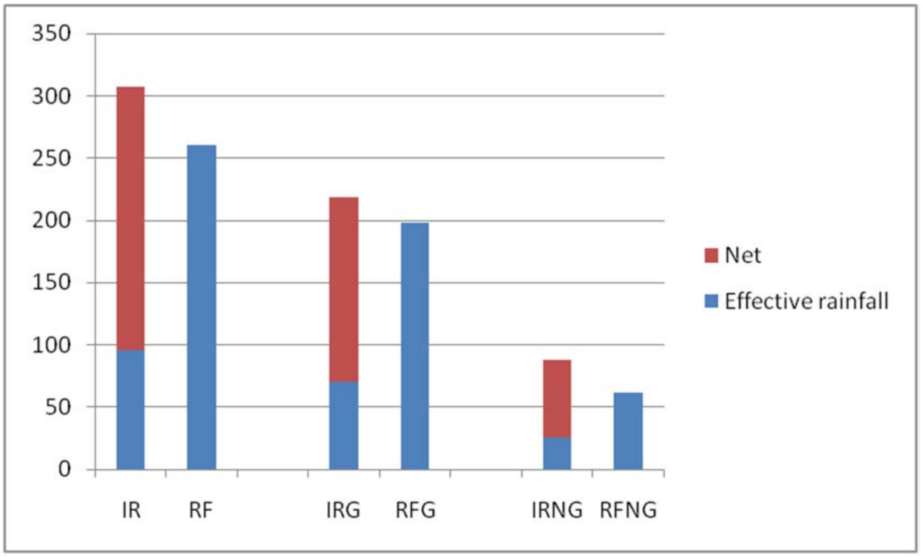
Agriculture will continue to remain the prime mover of the Indian economy at least for a few more decades as it provides not only food and nutrition security, but also livelihood support to a majority of the population.

Agricultural production essentially involves conversion of energy from the sun to chemical energy by plants through photosynthesis in which carbon dioxide (CO_2) and water are the two major ingredients. Plants must transpire water in copious amount and water must be made available to the growing medium through appropriate delivery and application mechanisms. Hence, agriculture is primarily nature's water-based industry, where the efficiency norms, applicable to manmade industry, are difficult to apply. This leads to water demands which are much higher than those in other sectors of the economy. Water demands in the production process are only one part of a multidimensional issue. Overall water demands in agriculture are influenced by a number of factors relating to food production and consumption sectors. Growth in crop yield, cropping intensity and groundwater use, as well as green water use efficiency, (reflected in the contribution to production from rain-fed agriculture as mediated through climate change) are some of the significant elements on the crop-production side. Projected growth of future population and its spatial variations, the rural-urban population mix, levels of income and associated changes in dietary preferences etc. are the key players on the crop-consumption side. How, where, when and how much is to be produced are shaped by public policies and programmes, which finally shape water requirements in agriculture.

The first section in this Chapter deals with crop water requirements, water productivity and production. Water demand projections in Studies by various agencies over a period are reviewed next. This is followed by a critique of the methodologies employed to arrive at water demand so as to help in identifying a suitable demand estimation model. Such a review, leads to the choice of a methodology, named PODIUMSIM (Amarasinghe et al, 2007). In this method, water demands are estimated for the years 2010, 2025, and 2050, along with projected population growth and improvement in crop production technology. The water stress status and its implications on water security for food are analysed. The impact of introduction of water smart technologies on water demand is reviewed and a set of inferences drawn to help in making policy recommendations.

3.2 Crop Production, Productivity and Water Demand

The basic demand for water in agriculture is reflected in crop-consumptive use which is met entirely by rainfall in rain-fed crops and by rainfall plus irrigation in irrigated crops. Irrigation essentially meets the consumptive-use deficit which is not met through effective rainfall. The direct use of rainfall by plants (green water) in forests and grass land, which is seldom taken into account, is huge. But even in non-irrigated cultivated crops, it is in no way less, as the area under rain-fed agriculture is very large. Our terrestrial precipitation is around 4000 BCM, but our planning is centered around 1100 BCM, withdrawn from rivers and aquifers for human livelihoods and socio-economic development.



Source: Amarasinghe et al, 2007a

Figure 3.1 : Consumptive Water Use of Grain and Non-Grain Crops (BCM)

It is interesting to note that 60 - 70% of global food production come from rain fed agriculture. Even in India, more than 45% of food production come from 70% of the area, which is cultivated under rain-fed conditions. The green consumptive water use was estimated at 355 BCM in the year 2000 (Amarasinghe et al, 2007 a). Even for crops grown under irrigated condition, the contribution of green water was 96 BCM (Figure-3.1). Hence the need for integrating use of green and blue water, what Falkenmark and Rockström (2005) call moving past the "tunnel vision" of concentrating on liquid blue water only. The key elements in this approach are: evaporative demand involved in plant production, and the naturally infiltrated rainwater available to meet that demand in a more productive way, through systematic management.

There is an urgent need to convert evaporation to evapotranspiration

3.2.1 Crop Water Requirements

Water requirement for crop production is a function of a large number of factors dealing with climate, agronomic practices and water management. The most important climatic factors are rainfall and evaporative demands. Generally, rainfall received at 75 % probability of exceedence is considered adequate for planning purposes. Seasons are important, for deciding on the crops to be grown. Rainfall availability has to be considered for different growing seasons. What is important not only the total seasonal rainfall, but also its distribution over time affecting effective rainfall and runoff. For crops, even a drought for even two weeks, may be harmful; however, for planning at basin scale, monthly values are considered adequate. In estimating the water requirement, lack of information on location-specific values of crop coefficients for different stages of crop growth is a serious limitation. This is because actual measurements of crop evapotranspiration (ETa) for various crops and regions are few and the locations are not contiguous (Tyagi et al, 2000). Generally the methodology suggested by FAO (Allen et al, 1998) for various climatic situations under conditions of adequate water supply, are used. In India, the annual potential evapotranspiration (PET) ranges from 1,144 mm in the Brahmaputra basin to 1,968 mm in the Mahi basin, the average for the country being 1,777 mm. The monthly 75 percent dependable rainfall ranges from 296 mm in the Indus basin to 1,800 mm in the Meghna basin. Obviously there is a mismatch between rainfall distribution and the PET.

Water demand is also affected by water use technologies and the direct use of local rainfall (green water) or management of evapotranspiration. Though plants make no difference in transpiring water of a given quality from different sources, the technical efficiency of supplied water use differs because of the losses in the supply chain and the impairment in quality. This modifies the land phase of the hydrologic cycle. Though it has not been feasible to reduce crop consumptive use appreciably without sacrificing crop yields, it is possible to mediate irrigation requirements through various agronomic, engineering and administrative measures (Tyagi, 2009). It is important to consider basin level irrigation efficiency to arrive at the total irrigation demand. The basin level efficiency measures the ratio of beneficial water depletion to the total irrigation water depletion at the river basin scale and should not be confused with field/farm/project irrigation efficiency. It is interesting to note that basin scale efficiency for Bhakra sub basin is more than 80% (Molden et al, 2001), while the farm irrigation application efficiency ranges between 50 and 65% for surface irrigation and 65 to 75% for sprinkler irrigation. Because of the varying agro-climatic conditions and management practices, the net irrigation water requirements for the crops of the basins range from a high of 580 mm in the Pennar basin to a low of 95 mm in the Brahmaputra basin.

3.2.2 Climate Change as Driver of Water Demand in Agriculture

Climate change is likely to become a very important driver of water demand in agriculture. The two important parameters of climate change are rise in temperature and the level of carbon dioxide. Plants need carbon dioxide for photosynthesis. Logically high CO_2 should lead to increased photosynthesis, especially in C3 Plants (*C3 plants*, accounting for more than 95% of earth's plant species, use rubisco to make a three-carbon compound as the first stable product of carbon fixation). C3 plants flourish in cool, wet, and cloudy climates, where light levels may be low, because their metabolic pathway is more energy efficient, and if water is plentiful, the stomata can stay open and let in more carbon dioxide. However, water losses through photorespiration are high. Crops like non-glutinous rice, wheat, barley, tapioca and potato fall in this category. But the situation is different in C4 plants *which* possess biochemical and anatomical mechanisms to raise the intercellular carbon dioxide concentration at the site of fixation. This reduces, and sometimes eliminates, carbon losses by photorespiration. C4 plants, which inhabit in hot and dry environments, have very high water-use efficiency. So in C4 plants, there can be twice as much photosynthesis per gram of water as compared to C3 plants. But C4 metabolism is inefficient in shady or cool environments. Less than 1% of earth's plant species can be classified as C4. Crops like maize, sugarcane, and sorghum come under this category. Efforts are on to convert C3 plants to C4 category for increased water use efficiency. C4 plants as such, will not be as responsive to increased CO_2 as C3 plants. Experiments conducted with the hypothesis that carbon dioxide levels will double, show that "carbon dioxide fertilizer" can increase the average yield in C3 plants by 30 percent.

The effect of increased CO_2 may get neutralized by the rise in temperature which will increase evaporation and thereby irrigation demand. The changes in monsoon cycle and drier soil conditions may lead to decreased yields or increased water demands. Hence, the impact on water demand and productivity will vary with geographical location. Agriculture will be adversely affected not only by an increase or decrease in the overall amounts of rainfall, but also by shifts in the timing of the rainfall. Higher temperatures reduce the total duration of a crop cycle, leading to a lower yield per unit area, especially for India's wheat and paddy crops. The effects of climate change on water demands in agriculture are summarized as under in a recent ICAR publication (Agrawal, P.K., Ed.2009):

- Increase in CO_2 to 550 ppm increases yields of rice, wheat, legumes and oilseeds by 10-20%.
- A 1^0C increase in temperature may reduce yields of wheat, soybean, mustard, groundnut, and potato by 3-7%. Much higher losses at higher temperatures.
- Productivity of most crops to decrease only marginally by 2020 but by 10-40% by 2100.
- Possibly some improvement in yields of chickpea, rabi maize, sorghum and millets; and coconut in west coast.

- Less loss in potato, mustard and vegetables in north-western India due to reduced frost damage
- Animal distress due to heat; effects on reproduction and loss of 1.5 million tons of milk by 2020

Reduced wheat yields (a major irrigated crop) due to temperature increase during winter season and loss of 1.5 million ton of milk production are going to be a major adverse effects of climate change.

3.2.3 Crop Water Productivity and Production

Productivity, in general, is a ratio indicating the unit of output per unit of input. The term (crop) water productivity (WP) refers to the physical amount or value of the product over volume or value of water depleted or diverted. Depending on how the terms in the numerator and denominator are expressed, water productivity can be expressed in *general physical or economic terms* (Seckler et al. 1998). The choice of the denominator (depleted or diverted water) may vary with the objectives; however both physical and economic productivities are relevant for us. In all productivity computations, numerator is the crop yield per unit area, whereas the denominator keeps on changing depending upon at what level the value of productivity is assessed. Agriculturists consider water applied to the crop or water evapotranspired by the crop, which yields a high water productivity value, as useful. However, engineers and economists consider water diverted for irrigation at project level which yields low productivity values as wasteful because water diverted at the project is much larger in quantity than the water reaching the field. In rain-fed agriculture, effective rainfall meets the entire evapotranspiration (ET) needs; even in irrigated areas, part of the ET requirements are met by rainfall. Hence, from the resource management aspect, inclusion of water from irrigation as well as rainfall would be a more holistic approach and give a better appreciation of water productivity as can be seen from Table 3.1 (Tyagi, 2009). It may be added that ET/ CWU is a better indicator of water use as it is more stable compared to irrigation requirement and includes the contribution of rainfall in both irrigated and rain-fed agriculture.

Table 3.1 : Water Productivity of Rice and Wheat System in Part of Bhakra Canal Command

Items	Rice	Wheat
Water balance		
Rainfall (cm)	60.6	5.6
Irrigation (cm)	83.4	30.2
Total water Supply (cm)	144	36
ETc	58.7	33.8
Yield (kg/ha)	3830	4460
Physical water productivity (kg/m^3)		
ETc	0.644	1.32
$WP_{IR\ (cm)}$	0.459	1.477
$WP_{TW\ (cm)}$	0.266	1.246
Economic water productivity (Rs./m^3)	0.47	2.5

Source : Tyagi, 2009

Water productivity in both irrigated and rain-fed agriculture exhibits wide variation across the country (Table -3.2). Productivity in Punjab is as high as 1.01 kg/m^3 as against 0.21 kg/m^3 in Orissa. In States like

Madhya Pradesh, where the overall water productivity is low (0.36/m^3), the water productivity under irrigation is lower than rainfed condition. Choices of crop to suit the agro climate and soil and water management are the major determinants for productivity under such situations.

Table 3.2 : Water Productivity of Grains in Irrigated and Rain-Fed Conditions across States of India

ID	State	Total			Irrigation			Rain-fed		
		Yield	CWU	WP	Yield	CWU	WP	Yield	CWU	WP
		ton/ha	mm	kg/m^3	ton/ha	mm	kg/m^3	ton/ha	mm	kg/m^3
	India	1.66	344	0.48	2.59	446	0.58	0.95	265	0.36
1	Uttar Pradesh	2.13	351	0.61	2.61	377	0.69	1.13	296	0.38
2	Maharashtra	0.85	272	0.31	1.25	461	0.27	0.78	238	0.33
3	Andhra Pradesh	1.96	460	0.43	2.86	628	0.45	0.81	243	0.33
4	Madhya Pradesh	0.99	278	0.36	1.39	417	0.33	0.78	207	0.38
5	West Bengal	2.31	447	0.52	2.73	461	0.59	2	436	0.46
6	Orissa	0.93	434	0.21	1.53	535	0.29	0.68	392	0.17
7	Bihar	1.71	373	0.46	2.06	400	0.51	1.19	332	0.36
8	Rajasthan	1	220	0.46	2.12	435	0.49	0.55	134	0.41
9	Punjab	4.07	404	1.01	4.14	411	1.01	1.79	184	0.97
10	Karnataka	1.32	272	0.49	2.51	495	0.51	0.96	204	0.47
11	Chattisgarh	0.94	362	0.26	1.42	513	0.28	0.81	322	0.25
12	Tamil Nadu	2.47	463	0.53	3.38	650	0.52	1.09	178	0.61
13	Haryana	3.13	363	0.86	3.51	395	0.89	0.98	185	0.53
14	Assam	1.45	492	0.29	2.51	522	0.48	1.36	489	0.28
15	Gujarat	1.11	280	0.4	1.81	533	0.34	0.83	178	0.47
16	Jharkhand	1.08	409	0.26	1.66	442	0.38	1.03	406	0.25
17	Uttaranchal	1.75	298	0.59	2.59	408	0.63	1.22	229	0.53
18	Jammu & Kashmir	1.38	271	0.51	1.48	455	0.33	1.32	161	0.82
19	Himachal Pradesh	1.78	245	0.73	2.03	353	0.58	1.73	220	0.79
20	Kerala	2.17	470	0.46	2.45	538	0.45	1.82	381	0.48
21	Others2	1.68	404	0.42	2.43	443	0.55	1.35	386	0.35

Source : Amarasinghe and Sharma, (2009)

Notes:
1. States are ranked ordered in descending order of total CWU
2. Others include Nagaland, Manipur, Meghalaya, Mizoram, Sikkim, Tripura, Arunachal Pradesh and Union Territories (Andaman and Nicobar, Diu, Dadra and Nagar Haveli, Delhi, Goa, Lakshadweep, Pondicherry)

Normally, past trends in productivity are used to forecast future yields. The annual average increase in yields of grain crops between 1965-1985 was at a compound growth rate of 2.32% (GOI, Ministry of Agriculture, 2002). There appears to be a stronger association between irrigation and the average yield after 1985. Improved watershed management is also likely to result in increased crop yields from rain-fed areas.

In India, the net cropping area varied between 141 and 142 million ha during last two decades and is likely to remain at this level in future as well. As area expansion is not a possibility, increases in productivity and irrigation intensity are the only options in future. Productivity shows large spatial variations. Hence, for a large country like India, crop yields have to be estimated for smaller geographical units and then aggregated on a larger scale. The ICID (2005) for its CPSP study adopted this procedure and used the NSSO data for smaller administrative units and averaged them at basin level to take care of the spatial variations in productivity.

3.3 Agriculture Water Demands Projection Review

Since the inception of planned development of water resources in the country, water demand in agriculture has been the primary focus. This is reflected in the sectoral water allocations, which placed water diversions to agriculture between 70-85% during different time periods. The estimation and projection of water demands in the country has been largely confined to irrigation supplies met through diversion of surface and ground waters. The concern for food security through planned development of water resources was reflected in the constitution of the National Commission for Integrated Water Resources Development (NCIWRD), which submitted a number of Reports (GOI, 1999, 2003). These reports became the basis for discussion and further refinements for other studies. The projection horizon of various studies was 2010, 2025, 2030 and 2050 (Table-3.3).

The water demand projections by NCIWRD (GOI, 1999) were based on two different estimates of population - a high variant figure of 1333, and 1581 million and the low variant figures of 1286.30 and 1345.9 million in 2025 and 2050, respectively. The census data of 2010 put India's population at 1201 millions and hence by hindsight, the high variant population estimate seems to be more logical. The food demand was estimated at 308 and 420 million tons for 2025 and 2050 with respective water demands of 611 and 807 BCM. The NCIWRD adopted a higher per capita consumption of food grains under the well-fed scenario and further assumed that a much larger share of nutritional intake would come from food grains.

Table 3.3 : Water Requirement for Irrigation in 2010, 2025, 2050 (BCM)

Variable	Remarks and assumptions	Units	2010	2025	2050
Population	Low growth scenario	Million	1,156.60	1,286.30	1,345.90
	High growth scenario	Million	1,146.00	1,333.00	1,581.00
Urbanization	Low growth scenario	%	32	37	48
	High growth scenario	%	34	45	61
Per capita food demand	@ 4.5% expenditure growth	Kg/Cap/Yr.	194	218	284
Food PLUS demand	Low growth scenario	MT	245	308	420
	High growth scenario	MT	247	320	494
NSA(Net sown area)	Marginal increase	M ha	143	144	145
Variable	**Remarks and assumptions**	**Units**	**2010**	**2025**	**2050**
GIA/GSA	Low growth scenario	%	40	45	52
	High growth scenario	%	41	48	63
Cropping intensity	20% growth assumed over 50 years	%	135	140–142	150–160

% Food crops	Rain-fed areas (no change)	%	66	66	66
	Irrigated areas (no change)	%	70	70	70
Food crop yields	Rain-fed areas (modest increase)	T/ha	1.10	1.25	1.50
	Irrigated areas (modest increase)	T/ha	3.00	3.50	4.00
Food PLUS production	Low growth scenario	MT	246	307	422
	High growth scenario	MT	249	322	494
Irrigation efficiency	Surface water irrigation	%	40	50	60
	Groundwater irrigation	%	70	72	75
GIR (NIR = 0.36)	Surface water irrigation		0.91	0.73	0.61
	Groundwater irrigation		0.52	0.51	0.49
Surface water dependence	Growing dependence on SW assumed	%	47	49–51	54.3
Total water required	Low growth scenario	BCM	543	561	628
	High growth scenario	BCM	557	611	807

Source: Verma and Phansalkar, 2007; as referred from NCIWARD Report
GIA=Gross irrigated area, GSA=Gross sown area, GIA=Gross irrigated area, MT=Million tons, Mha=Million ha

India Water Partnership-IWP (1999), made projections for water (irrigation) demands for food and non-food grain production for 2025 for three different situations: (1) continuation of current trend of 3% growth in per capita income per year with business as usual, (2) using 1987-88 data as base, and bringing the entire population above poverty line, and (3) poverty reduction scenario in which every malnourished person was well fed. The estimates for water demands for these three situations (1, 2 and 3) were put at 731, 806 and 867 BCM, respectively.

Vaidyanathan (2004) used crop consumptive use which includes estimating the changes in crop water demand in agriculture between 1966-1991, based on mean annual rainfall and evaporation. This study did not cover all the States and had obvious limitations inherent in annual values of rainfall, which do not capture temporal variations. This limitation to some extent was overcome in Amarasighe et al (2007a), which considers potential evapotranspiration (PET) at district level, crop coefficients (ratio of actual to potential ET) at different stages of crop growth (initial, development, middle and late) as per FAO guidelines (Allen et al, 1998) and crop calendar to estimate CWU.

Assuming the base year water utilization of 629 BCM (1997-98), for the same scenarios as used by IWP (1999), Water and Security in South Asia (WASSA) (Reddy et al, 2004), put the water demand for 3% growth scenario for 2025 at 730 BCM, which amounted to 67 % of the utilizable water resources for producing 280 million tons of food grains. They assumed an annual growth rate of 1 % in crop yields over the then prevailing average national yield of 2.4 tons/ha under irrigated and 1.0 ton/ha under rain-fed conditions, arriving at an average of 3.4 tons/ha for irrigated and 1.25 tons/ha for rain-fed farming in 2025.These projections are closer to IWP(1999) projections.

In recent years, International Water Management Institute (IWMI) and International Food Policy Research Institute (IFPRI) have undertaken studies on future demand for food and water in India (Seckler et al,1998 and Rosegrant et al,2002) leading to estimates at various periods of time. The study by Amarasinghe et al, (2007a) which is more comprehensive, estimates a food demand of 276 million tons in 2025 and 377 million tons in 2050, assessed the impact of changing consumption patterns on food demand and evaluated various projections. Population in 2025 was taken as 1315 million, [as projected by Dyson and Hachette (2000)] and 1581 million, by 2050 as assumed in NCIWRD report (GOI, 1999).

Table 3.4 : Comparison of Irrigation Demands Projected in Different Studies

Driver	Amarasinghe et al		NCIWRD		Seckler et al	Rosegran et
	2025	2050	2025	2050	2025	2025
Net irrigated area, Mha	74	81	67	93		
From ground water, Mha	43	50	34	42		
Gross irrigated area, Mha	105	117	98	146		
Net water demand , BCM	313	346	359	536	323	332
Irrigation efficiency, %						
Surface water	35-50	40-60	50	60		
Ground water	70	75	72	75		
Total irrigation demand,						
BCM	675	637	611	811	702	741
From ground water, BCM	304	325	245	344		

An overview of these projections (Table-3.4) shows considerable divergence in demands for food and water, arising largely because of the assumptions in arriving at these demands. For example, projections made by NCIWRD were arrived at by assuming the "well-fed scenario" for the entire population with a much higher proportion of nutrient requirements being met from grains. On the other hand, Amarasinghe et al (2007a) worked on the premise that the share of direct grain consumption would decrease more sharply with income level. Levels of income and urbanization, which result in changes in life style, modify diet composition and impact the food consumption pattern. As income and access to different kinds of foods increase, people diversify food consumption. Trends of food consumption from countries at various levels of development (Table-3.5) show that direct per capita grain consumption decreases and calorie intake through non-grain and animal-products increases with increase in income. In India, the contribution of grain crops to calorie-supply declined from 73 % in 1980 to 65 % in 2000 while that of animal products increased from 6% to 8 %. In developed countries, the share of food grains in direct consumption was only 32 % in 2000 and the balance calories were met from non grain (42%) and animal products (26%). The consumption of each commodity depends upon the food conversion factor, defined by the quantity (Kg) required to generate 1000 k calories of energy, which is different for each crop (Annexure 3.2). It should also be noted that production of animal products like milk, meat, chicken etc; requires grain and non-grain crops. The quantum of these commodities used depends on how the animals are raised and the feed given to them. Like the food conversion factor, the feed conversion factor is defined as the ratio of the quantity of crop consumed (kg) to generate 1000 kcal of animal product in the diet. The relevant feed conversion factors (Annexure 3.3) are multiplied by respective kcal supply from animal products to estimate the feed demand.

Table 3.5 : Calorie Intake of Food Categories-Grains (G), Non-Grains (NG) and Animal Products (AP)

Year	Developed countries				Developing countries				India			
	Total	G	N G	AP	Total	G	N G	AP	Total	G	N G	AP
	Kcal	%	%	%	kcal	%	%	%	kcal	%	%	%
1980	3,217	32	40	28	2,308	64	27	9	2,082	71	22	6
1985	3,261	31	40	29	2,444	64	27	9	2,229	69	23	7
1990	3,289	31	40	28	2,520	62	27	10	2,366	69	23	7
1995	3,199	33	40	27	2,602	59	29	12	2,399	67	25	7
2000	3,275	32	42	26	2,654	56	31	13	2,413	63	28	8
2010									2,504	61	31	9

Source : FAO 2005a, FAO, 2010a

The major point of divergence between IWMI and NCIWRD projections is in terms of the projected irrigation demand in the year 2050. The IWMI study foresees reduced irrigation demand in 2050 largely because of its assumption of a sharper decline in contribution to diet from grain crops. Grain crops have much lower water productivity as compared to non-grain crops and hence economic factors will make cultivation of non-grain food crops more profitable under water scarcity conditions. However, we are of the view that through irrigation demands will continue to grow up to 2050 (and beyond), a part of these requirements will be met from reuse of waste water generated by urban population. Moreover, improvement in irrigation efficiency comes at a cost and beyond a certain level, the cost of improvement exceeds that of the benefits to be realized (Tyagi et al, 1993). It may be added that water-scarce countries, like Israel are meeting more than 30% of irrigation requirements from regenerated water and India would not perhaps be an exception.

3.4 Water Demand Projections for Major Basins

Projection for basin-level water demands for agriculture in this Report are based on Policy Dialogue Simulation Model (PODIUMSIM) which is an improved version of PODIUM. PODIUM was developed by International Water Management Institute (IWMI) in the mid 1990s to explore important issues e.g. the quantum of water needed to meet our food requirements, the extent of irrigation efficiency improvement to attain a given level of production with available water supply etc, at the national level. PODIUMSIM has four major components: food consumption, food production, water demand and water supply (like PODIUM), but with substantial improvements at spatial and temporal scales in individual component (Amarasinghe, 2005). It considers the water supply and demand at river basin level on monthly basis.

The country's geographical area is grouped into 19 major river basins (Figure-3.2). The Ganga is the largest basin with a catchment area of 861,404 km^2 and the Sabarmati, the smallest, covering only 21,674 km^2. The Easterly flowing rivers between the Mahanadi and the Pennar have been put in one group EFR1, while these flowing between the Pennar and Kanyakumari are in group EFR2. Similarly the Westerly flowing rivers in Kutch and Saurashtra in Gujarat and the Luni River are put in group WFR1 and those south of the Tapi, are in group WFR2. Data requirement for various components of PODIUMSIM is Annexure 3.1. It may be added that in India, PODIUMSIM was previously used with 1995 as base, subsequently changed to 2000 by Amarasinghe et al (2007). Projections made in this report are rationalized values based on these studies (Amarasinghe et al 2007; ICID 2005 and NCIWRD-GOI, 1999).

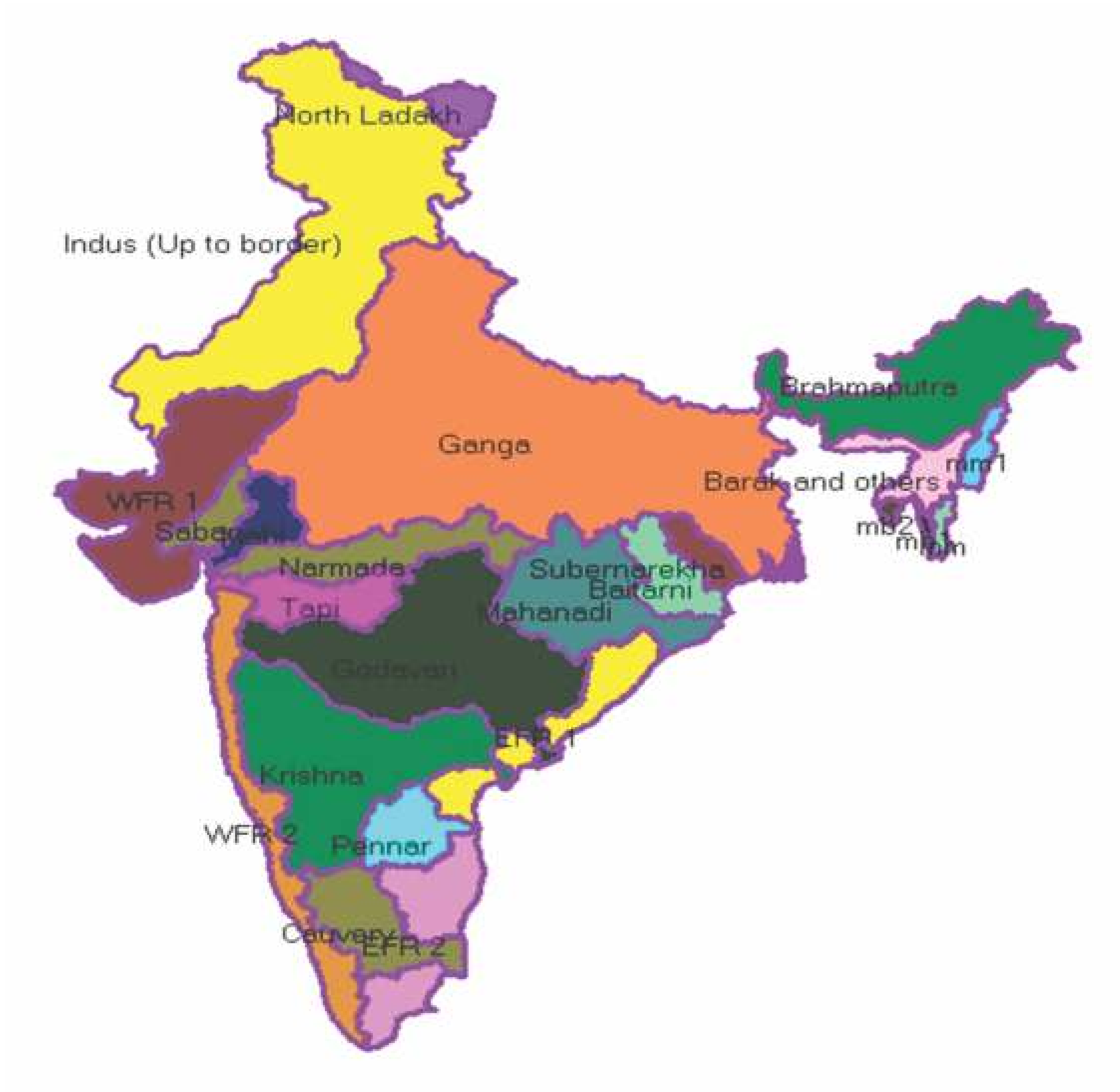


Figure 3.2 : River Basins in India

3.4.1 Estimated Agriculture Water Demands

The model generates a large number of irrigation related data e.g. production of various grain/non-grain crops, production from irrigated/rain-fed areas, consumptive- use and water diversion from surface and ground water sources etc. We have selected the three major outputs for review, namely: consumptive use (Table-3.6) as well as surface and ground water withdrawals for irrigation (Table-3.7).

3.4.1.1 Consumptive Water Use

Consumptive use, at all India level, continues to grow from 362 BCM in 2010 to 382 and 420 BCM in the years 2025 and 2050 respectively. During the next 40 years, the largest increase of 22 BCM will take place in the Ganga basin and the lowest, in the Indus basin. In fact, crop consumptive use may slightly decline because of inter-sector water transfer. River basins like the Sabarmati, the Mahi and the Tapi also will be reaching their limits of development.

Table 3.6 : Basin wise Consumptive Water Use (CWU) during 2010-2050 (BCM)

Basin	2010 CWU	2025 CWU	2050 CWU
Ganga	142.58	148.51	164.75
Indus	41.79	41.41	40.81
Brahmaputra	2.69	2.99	3.64
Subarnarekha	2.89	3.25	3.97
Mahanadi	10.76	11.53	12.97
Godavari	26.28	28.4	32.46
Krishna	28.71	30.48	33.77
Pennar	8.06	8.5	9.34
Cauvery	9.93	10.36	11.13
Tapi	6.06	6.63	7.78
Narmada	7.94	8.55	9.91
Mahi	3.85	4.02	4.32
Sabarmati	2.7	2.89	3.27
WFR1	29.13	31.06	35.44
WFR2	9.71	10.7	12.71
EFR1	9.14	9.7	10.73
EFR2	15.26	15.69	16.5
Brahmini Baitarni	4.71	5.24	6.3
All India	362.19	381.86	419.8

3.4.1.2 Irrigation Diversions

Basin-wise irrigation diversion requirements for the years 2010, 2025 and 2050 are given in Table-3.7. PODIUMSIM projections based on data from Amarasinghe (Personal communication) show a decline in irrigation diversion requirement in 2050, assuming a significant increase in contribution from non-grain food crops and animal products. Non food-grain crops have higher water productivity compared to grain crops. But such saving in water from a shift to non grain crops would, to some extent, get neutralized by higher water consumption in animal products. The feed requirement is projected to increase from 37.5 million tons in 2025 to 111 million tons in 2050, of which 107 million tons is maize, (Amararsinghe 2007a). The other source of reduction in irrigation diversion might be an increase in irrigation project efficiencies. An increase in surface irrigation from 35-50 to 42-60 and ground water irrigation increase from 70 to 75 has been assumed. A dramatic increase of about 15% in surface irrigation, may be difficult to achieve with current investment trend. As regards ground water irrigation, efficiencies of surface application methods, which are currently dominant, may not be higher than 70%. Efficiencies might reach 75 per cent in micro-irrigation, which covers less than 2 million ha at present. Further, the projected increase in population from 1333 million in 2025 to 1581 million in 2050 would add to food demand and hence irrigation demands. The NCIWRD (GOI, 1999) projected irrigation water demands of 611 BCM and 807 BCM in the year 2025 and 2050 (a sharp increase of 200 BCM largely to be met from surface water). The analysis by Verma and Phansalkar (2007), shows that such a scenario may not be feasible as the total water demand may exceed the available utilizable water. We are, therefore, of the opinion that irrigation demands will continue to increase, however, at a lower rate than that in the period between 2025 and 2050. Taking into account the population increase between 2025 and 2050 and assuming an overall increase of 10 % in irrigation efficiency, the likely irrigation diversion requirement in the year 2050 would be of the order of 735 BCM. If efficiency increases by 7.5% only, the demand will go up to 808 BCM, a value closer to the NCIWRD projection of 807 BCM. We are choosing an optimistic scenario of 10% in efficiency over the 2025 value and placing the irrigation demand in 2050 at 735 BCM.

Across the basins, contribution of groundwater continues to increase and the diversions from the surface and the ground water become almost equal implying that the area under groundwater irrigation will go up. The total irrigated area in 2050 is estimated at 117 Mha, of which 70 Mha would be from ground water. The Ganga basin would account for nearly 43% of the total irrigated area in 2050.

Table 3.7 : Past and Projected Basin-wise Irrigation Water Diversion Requirement (BCM) in India

Basin	2000			2010			2025			2050		
	Surface water	Ground water	Total	Surface water	Ground water	Total	Surface water	Ground Water	Total	Surface water	Ground water	Total
Indus	61	41	102	63	42	105	54	33	87	45	29	74
Ganga	135	131	266	134	130	264	136	144	280	109	160	269
Brahmaputra	2	1	3	5	1	6	7	1	8	9	0	9
Barak	2	1	3	2	1	3	3	1	4	3	0	3
Subarnarekha	2	1	3	4	2	6	4	1	5	3	1	4
Brahmani-Baitarani	3	1	4	6	2	8	6	2	8	5	2	7
Mahanadi	16	2	18	18	2	20	27	4	31	25	5	30
Godavari	20	18	38	22	20	42	25	23	48	22	24	47
Krishna	31	18	49	26	15	41	34	22	56	31	23	54
Pennar	3	4	7	4	5	9	3	5	8	2	5	7
Cauvery	14	7	21	15	7	22	17	9	26	13	8	20
Tapi	2	5	7	2	6	8	3	6	9	3	6	9
Narmada	7	6	13	8	7	15	10	8	18	7	10	17
Mahi	2	2	4	3	3	6	2	3	5	2	3	5
Sabarmati	1	5	6	1	5	6	1	7	8	1	8	9
WFR1	5	18	23	4	19	23	4	21	25	4	23	27
WRF2	5	2	7	5	4	9	8	3	11	6	3	9
EFR1	14	4	18	14	4	18	15	4	19	12	5	17
EFR 2	18	11	29	19	12	31	21	13	33	15	11	26
Total	343	278	**621**	355	287	**642**	380	310	**689**	317	326	**643***

** This estimate is considered low and has been rationalized as explained in the text and the value is placed at 735 BCM*

3.5 Impact of Irrigation Drivers on Water Demand Projections

Projections of future water demands are based on the trends in demand drivers. Demands are very sensitive to some of the drivers and the soundness of projections depends on the accuracy of these trends. Water-related major drivers of water demands are: irrigation efficiencies and crop water productivity.

3.5.1 Irrigation Efficiencies

Irrigation project efficiencies are critical for demand generation; however, the estimates are rather rudimentary. The existing efficiencies of surface irrigation projects are reported to be between 30 and 40%, a figure that has not changed since the early 1980s'. During last three decades, large scale modernization of surface irrigation projects was undertaken through Command Area Development Programmes. Further, Government policies have led to micro irrigation in about 0.5 Mha. Laser levelling is another physical intervention that has been introduced on a limited scale in North India. The ongoing interventions like structural changes, improvement in water delivery schedules and formation of Water Users Associations, would certainly result in improved efficiencies and hence a larger irrigated area without increasing demands. Efficiency of a well managed sprinkler and drip system can be as high as 80-95 % (Narayanmoorthy, 2007). Data on estimated net irrigated area of 100 Mha by Thenkabail et al (2006), using remote sense imageries, in contrast with the 61 Mha in official estimates, underlines the necessity of rechecking our efficiency estimates. A 5% increase in irrigation efficiency could bring down the water demand by 24 BCM.

3.5.2 Productivity

Increase in productivity might be achieved through various routes. For example, it might be increased through improvement in irrigation efficiency without an increase in yield per unit area. It could also be changed with shift in per unit area yield without any change in irrigation efficiency through usage of other inputs. Depending upon identification of the scarce resources, one might maximize crop yield per unit of water use (WP) or per unit of land (LP). In practice, an optimized combination of the two approaches is used. The projections are sensitive to changes in productivity. In the business as usual (BAU) scenario, the annual increase in crop yield has been kept at 1%. But the fact remains that there is a significant gap between the realised and the potential yields. Crop yield growth assumptions are quite sensitive to total crop production and the irrigation demand projections. A small change from the assumed rate of yield growth rate in both irrigated and rain-fed area, changes water demand and the change in water demand projection shifts the growth rate.

3.6 Status of Water Availability/Scarcity for Food Production across Basins

With the progress of Water Resources development, water availability moves closer towards its physical limits and gradually becomes more and more scarce, making further development difficult and costly. Under scarcity conditions, satisfying the needs of all sectors–agriculture, public health, industry and ecosystem, becomes a challenging task and requires a higher level of management. Several indices that quantify scarcity and stress have been proposed. Raskin (1997) and Alcamo et al, (2000) used criticality ratio (ratio of water withdrawal to total renewable water-CR) as an index of scarcity status. Higher criticality ratio is an index of more intensive water use and poor quality of water for downstream users. Though this criterion may not be very objective, Alcamo et al, 2000 as quoted by Rosegrant et al (2002), consider a CR equal to or greater than 0.4 as high water stress and a CR of 0.8 as very high water stress.

Amarasinghe et al, (2004) used a set of three different indices to assess the severity of scarcity, namely; degree of development-DD (ratio of primary water supply to potentially useable supply); depleted fraction-DF (ratio of water depleted in process, non-process activities and un-utilizable outflows of return flows to primary water supply; ground water abstraction ratio-GWAR (ratio of ground water withdrawal to ground water availability). The degree to which the food demands were being met from internal source of the basin was indicated by ratio of the value of crop production to value of crop demand showing the extent to which food was surplus or deficient to be met by imports. The Country-wide analysis of water scarcity and food production and deficiency bring out a number of interesting features regarding development and management of water resources in the country with far reaching policy implications.

- The degree of development (DD) in the Indus, the Pennar and the WFR1 was more than 80% (very high stress); in the Mahi, the Sabarmati and the EFR2 between 60-80% (high stress). These basins are physically water stressed and even with improved water use efficiency, demands of the entire sector would not be fully met. The Ganga, the Cauvery, the Krishna, the Subarnarekha and the EFR1 had DD between 40-50% (stress), calling for introduction of efficiency-enhancing measures urgently. Basins like the Brahmaputra, the Meghna, the Mahanadi, the Godavari and the Narmada had less than 30 % DD indicating a reasonable scope for development.
- A majority of river basins except the Brahamputra, the Mahanadi, the Meghna and the group-1 of East Flowing Rivers (EFR1) were losing over 90% of the developed water resources (DF) through crop evapotranspiration. The average DF for the country was 87% indicating little scope for increased recycling. These basins will have to either increase the productivity or develop new water resources to meet future demands.
- Ground Water Abstraction Ratio (GWAR) in the Indus, the Sabarmati, the Mahi, the Pennar and the WFR1 was more than 60%, resulting in sharp and continuous decline in groundwater table indicating the need for increasing recharge and rationalising abstraction. These basins include the States of Punjab and Haryana which supply food grains for the Public Distribution System (PDS).

Based on the computed values of these indices, the Basins were grouped into 5 clusters (Figure-3.3), representing physically water scarce-food deficit, physically water scarce-food surplus, economically water scarce-food deficit, non-water scarce-food sufficient and non water scarce-food surplus (Amarasinghe, 2004).

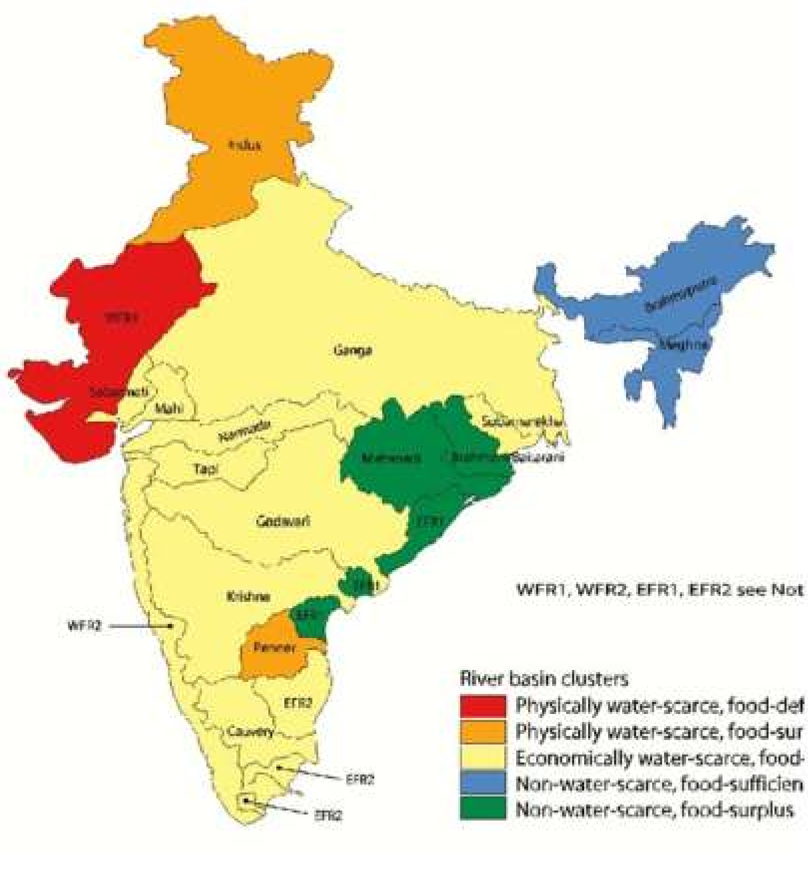


Figure 3.3 : River Basin Clusters According to Water Scarcity and Food Surplus or Deficit

- Basins in Cluster -1 (the Luni and the WFR-1) are both physically water stressed and food deficit. Food dependence on other basins or on import will grow and water is likely to be transferred from food grains to high value crops or to other sectors of economy.

- Cluster- 2 (the Indus and the Pennar) have physical water scarcity because of over-development, making further development unsustainable. Increasing demands from other sectors will reduce the supply which will impact food grain security because these are food grain surplus basins.

- Cluster -3 comprising of 11 basins holds the key to food security in future. States like Uttar Pradesh, Bihar, Bengal and Madhya Pradesh etc., fall in this group. There is ample scope for water development in these basins as well as for improvement in water productivity.

- Cluster-4 (the Brahmaputra and the Meghna) are two exceptions which are non –water scarce and food sufficient. There is a lot of water potential that remains to be developed and needs investment. Availability of additional cultivable land is a constraint.

- Cluster -5 comprises the Easterly Flowing river Mahanadi. Between the Mahanadi and the Pennar, the Brahmani-Baitarni basin has high DF, low DD and relatively low GWAR, but is food surplus. Water scarcity is not a problem and water resources could be tapped further for increasing food production.

The average process depletion (Evapotranspiration from crop land) was close to 70% of the primary withdrawal and 40% of the total withdrawal. But part of the water lost at system level is captured downstream for recirculation and some of it becomes ground water. So basin level efficiencies are higher than irrigation project efficiencies. As mentioned earlier, in Bhakra sub basin of the Indus system, basin efficiency exceeds 80% while project efficiency is in the range of 60%. Process depletion is projected to increase to about 50% in 2025 and 60% in 2050 making river basins physically water scarce.

Majority of the river basins have low project irrigation efficiencies but high basin efficiencies indicating appreciable recirculation and implying less scope of water saving at basin level

3.7 Strategies for Meeting Increased Water Demands

It is clear from the present analysis that our water resources would get stretched to their physical limits in the next few decades. Appreciation for the role of ecosystems and the value of their services will grow and environmental flows will no longer be considered a luxury. Hence the agriculture sector, which is the dominant but low value output producer, will have to resort to some innovative interventions.

3.7.1 Enhanced Green Water Use for Increasing Productivity in Rain-fed Area

In future, it is going to be more difficult to provide additional water supplies through long distance transfers and hence, a significant part of additional food demand will have to be met from rain-fed agriculture, which at present has low productivity. Upgrading rain-fed agriculture through watershed management is a proven potent option. It is an established fact that, even in medium to high rainfall zones, crop yields are drastically reduced on account of short term agricultural droughts of 2-3 weeks duration. There is experimental evidence (Sharma, et al, 2006) showing that supplemental irrigation at critical stages with irrigation amounts ranging from 50-200 mm, (depending upon the crop and the region where it is being grown), will increase the yield by 50-150%. Supplying irrigation water to increase CWU would significantly increase yield in many regions, particularly those having less than 150 mm CWU. With 100 mm of additional CWU, the maximum yield can be doubled in districts with less than 150 mm of CWU. Crop management in terms of agronomic practices like developing and adapting the crop calendar to match with high probability of rainfall occurrence, growing drought tolerant high yielding crop varieties and crop canopy management, would be useful in bridging the yield gaps between the experimental yields and the current farm yields.

In the long term, green water will be even more important for an organised socio-economic development than the blue water that now attracts all the attention of planners and policy makers.- **Falkenmark and Rockström, (2005)**

3.7.2 Improvement in Irrigation Water Use Efficiency

Savings resulting from reduction in seepage from canal water distribution system or deep percolation from excess irrigation at the field level such as rice paddies, which join the fresh groundwater aquifers and can be used again, do not add to any additional water supply at the basin level. But it saves energy which is used in pumping to recover this water. Production of energy itself requires water. On the other hand savings resulting from reduction in non-beneficial water use, such as seepage joining poor quality aquifers, evaporation from water bodies and bare land surface, add to additional useable water supplies at the basin level. Research shows that opportunities for gains from increased irrigation efficiency-reducing "wastage" in agriculture - are much less than is imagined (Molden, 1997, 2007). However, the technologies used in minimizing these so called losses, create better environment in the crop root zone, where action for food production takes place, increasing yield and also economizing the use of nutrients. The reduction in beneficial water use in agriculture should be seen in terms of increased productivity, in the shape of higher yield, or higher returns per unit of water used.

Based on the experience relating to application of individual land and water smart technologies including, laser levelling, micro-irrigation, zero or minimum tillage and system of rice intensification (SRI) in rice, it is evident that integrated use of these technologies, would make irrigated agriculture a resource-efficient production system (Tyagi,2009). A number of studies show the efficiency of the drip system for improving overall productivity and profitability of several widely spaced row crops (Reddy et al 2004). Management-allowed-deficit (MAD), which involves reducing water application at non-critical stages of crop growth or continuously maintaining a deficit moisture regime in the root zone, curtails actual evapotranspiration. Yields obtained are not at the maximum level, but the water so saved allows irrigation of additional areas resulting in higher over all water productivity. Analysis made by Amarasinghe and Sharma (2009) showed that 25 mm of deficit irrigation, if practiced in about 251 district with more than 25% irrigated grain area, will have 10% less grain yield, but can save 14% of the net ET requirement. All the saved net ET can provide 8% additional production. Deficit irrigation of 50 mm can save 27% of net ET and increase production by 17%.

Other possible avenues for increasing water productivity are: improving reliability of water supply, growing crop varieties that consume less water per unit of production or produce more for the same level of consumptive use, and take advantage of the positive interaction of other production inputs such as fertilizer to increase yields. Integrated management of nutrients, particularly, nitrogen, phosphorous and potash (N P K), has tremendous potential of boosting crop yields (Brar and Pasricha, 1998).

Water smart technologies save some water directly, but more than that, such interventions increase yield and productivity by creating a favourable environment in the crop root zone where action for food production takes place.

3.7.3 Reallocation of Water amongst Crops

Agriculture not only provides food and nutritional security, but also provides livelihood support to about 60% of the population, of which more than 70 % are small and marginal farmers and share croppers. Low productivity of grain crops, both in terms of yield and value of produce per unit water used for grain crops, as compared to that of non-grain crops (fruits and vegetables) makes it difficult for such people to sustain themselves on cultivation of grain crops. It is reported by Amarasinghe et al, 2007 that per unit of water consumed, the value of non-grain crops produced in most basins, was 2.7 times that of grain crops at prices prevailing in 2000. Price stability of grain crops is much higher than that of non-grain crops, particularly the fruits and vegetables; however, it may be possible to divert some water, say between 5-10%, to increase the income and livelihood support from agriculture.

3.7.4 Virtual Water Trade

In several river basins with low productivity of grains or non-grains crops or both, water-use will shift to the high value produce to provide livelihood support and will usher in virtual water trade in food products from water-rich basins. At present, virtual water export is taking place from water-deficit basins to water sufficient basins because of the crop productivity differentials, but it is not sustainable in the long run.

What is economically profitable may not remain hydrologically sustainable in future.

3.8 Conclusion

Water demand will continue to increase but at a lower rate of growth because of introduction of water-smart technologies and enhancement in biological yields potential. The increase in irrigation demand is highly sensitive to water productivity and under the present situation, may go up from 642 BCM from 2010 to 735 BCM in 2050.The summary of irrigation water demand projections is given below

Summary of past and projected irrigation water diversion requirements (BCM)				
Source	2000	2010	2025	2050
Surface water	343	353	380	407
Groundwater	276	287	310	328
Total	621	642	690	735

Consumptive use from rainfall (green water) in rain-fed grain crops in the country is of the order of 355 BCM. It is possible to improve the productivity of green water use through supplementary irrigation from farm-harvested rainwater. A100 mm increase in consumptive use in areas with less than150 mm crop consumptive use can double the crop yield and help reduce blue water demands

Groundwater will continue to be mainstay of the country's food production. However, as GWAR, in water deficit but food surplus basins, has already crossed 70%, the major thrust in ground water development be in basins with physical-sufficiency but economic deficiency of water.

River basins operating above a criticality ratio of 0.6 such as the Indus, the Sabarmati, the Luni, the Pennar and the Krishna will have to redesign their cropping and farming pattern so as to reduce water demand in agriculture sector without reducing the livelihood support.

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Annexure 3.1

Types and sources of data used for the water supply and demand analysis

Data	Sources	Reference
Urban and rural population	2011 Census records (2011)	GOI 2010
Crop consumption (calorie supply, food and feed consumption of different crops)	Nutritional intakes and per capita consumption data of the FAOSTAT database of the FAO and the various rounds of National Sample Survey Organization (NSSO) reports	FAO 2010a; 2001, Amarasinghe et al, 2007a
Land use statistics, crop area and crop yield	Crop production data of the FAOSTAT database and the various issues of agricultural statistics at a glance, fertilizer statistics, crop yield estimation surveys of principal crops	FAO 2010a; GOI 2010,
Rainfall, potential evapotranspiration and land use map	International Water Management Institute's Climate and Water Atlas	IWMI 2010
Crop calendar, crop coefficients	AQUASTAT database of the FAO and FAO Irrigation and Drainage Paper No. 56	FAO 2005b; 1998

Annexure 3.2

India's food conversion factors

Food conversion factor	Rice	Wheat	Maize	Other cereals	Pulses	Oil crops	Roots and tubers	Vegetables	Fruits	Sugar
kg/1,000 kcal	0.287	0.322	0.335	0.322	0.288	0.398	0.321	4.184	2.114	0.283

Source : Estimates based on FAOSTAT data of 1999, 2000 and 2001 (FAO 2005a).

Annexure 3.3

Feed conversion ratios and the seed and waste share in the total crop consumption

	Rice	Wheat	Maize	Other Pulses	Oil	Roots Vegetables	Fruits	Sugar crops	Cereals	Tubers
(kg/1,000 kcal)	0.005	0.012	0.074	0.005	0.016	0.008	0.000	0.000	0.000	0.006
Seeds and waste - % of total	6.8	11.7	17.0	9.7	8.2	12.7	19.2	6.7	14.0	00.04

Source : Estimate based on FAOSTAT data of 1999, 2000, and 2001 (FAO 2005a).

Annexure 3.4

Irrigation efficiencies for rice and other food crops

	2000			2025				2050	
Basin	**Surface - Rice**	**Surface - Other crops**	**Groundwater - all crops**	**Surface-Rice**	**Surface - Other crops**	**Groundwater-all crops**	**Surface-Rice**	**Surface-Other crops**	**Groundwater - all crops**
Indus	0.30	0.30	0.65	0.34	0.34	0.70	0.43	0.44	0.75
Ganga	0.30	0.30	0.65	0.34	0.34	0.70	0.43	0.44	0.75
Brahmaputra	0.30	0.30	0.65	0.34	0.34	0.70	0.43	0.44	0.75
Barak	0.30	0.30	0.65	0.34	0.34	0.70	0.43	0.44	0.75
Subarnarekha	0.35	0.35	0.65	0.40	0.39	0.70	0.50	0.52	0.75
Brahmani-Baitarani	0.37	0.37	0.65	0.42	0.42	0.70	0.53	0.55	0.75
Mahanadi	0.39	0.39	0.65	0.45	0.44	0.70	0.56	0.58	0.75
Godavari	0.40	0.50	0.65	0.46	0.56	0.70	0.57	0.60	0.75
Krishna	0.40	0.55	0.65	0.46	0.60	0.70	0.57	0.60	0.75
Pennar	0.40	0.55	0.65	0.46	0.60	0.70	0.57	0.60	0.75
Cauvery	0.40	0.40	0.65	0.46	0.45	0.70	0.57	0.59	0.75
Tapi	0.40	0.40	0.65	0.46	0.45	0.70	0.57	0.59	0.75
Narmada	0.35	0.35	0.65	0.40	0.39	0.70	0.50	0.52	0.75
Mahi	0.35	0.35	0.65	0.40	0.39	0.70	0.50	0.52	0.75
Sabarmati	0.35	0.35	0.65	0.40	0.39	0.70	0.50	0.52	0.75
WFR1	0.35	0.35	0.65	0.40	0.39	0.70	0.50	0.52	0.75
WRF2	0.35	0.35	0.65	0.40	0.39	0.70	0.50	0.52	0.75
EFR1	0.45	0.45	0.65	0.52	0.51	0.70	0.60	0.60	0.75
EFR2	0.35	0.35	0.65	0.40	0.39	0.70	0.50	0.52	0.75

Annexure 3.5

Trends in irrigated and rain fed crop yields 2000 – 2025

Crop yield (tons/ha)	**2000**	**2025**	**2050**
Average grain yield	1.7	2.4	3.1
Irrigated grain yield	2.6	3.6	4.4
Rain-fed grain yield	1	1.3	1.8

Annexure 3.6

Trends in land productivity of important crops (tons/ha)

	Average yield			**Average Irrigated yield**		
	2000	**2025**	**2050**	**2000**	**2025**	**2050**
Total grains	1.66	2.39	3.20	2.59	3.52	4.41
Rice Net	1.97	2.59	3.07	2.52	3.27	3.88
Wheat Net	2.76	4.16	5.38	3.01	4.32	5.54
MaizeNet	1.82	2.96	3.90	2.66	3.29	4.52
Oter cereals Net	0.84	1.11	1.33	1.30	1.68	1.83
Pulses Net	0.55	0.74	0.89	0.72	0.91	1.09
Oilcrops Net	0.78	1.16	1.48	1.05	1.50	1.82
Roots ad tubers Net	4.11	5.75	7.01	0.00	0.00	0.00
vegetables Net	13.17	22.79	32.33	18.57	28.71	39.76
Fruits Net	12.62	16.59	17.63	12.62	16.59	16.63
Sugar cane Net	6.44	7.84	8.93	6.66	8.31	9.08
Cotton Net	0.80	1.12	1.35	2.04	2.02	2.11

Annexure 3.7

Population in different river basins as per 2010 census data (Millions)

Basin	Population		
	Total	Rural	Urban
Indus	58.07	40.83	15.91
Ganga	442.35	300.00	142.00
B.Puttra	42.58	34.64	7.09
S.Rekha	17.22	14.07	3.13
Mahanadi	30.60	24.42	5.85
Godavari	93.13	60.02	32.83
Krishna	85.34	55.96	29.49
Tapi	22.58	13.22	9.34
Narmada	28.96	18.82	9.72
Cauvery	39.09	23.37	15.86
Mahi	9.11	6.23	2.73
Sabarmati	7.93	5.04	2.86
WFR1	78.72	53.56	23.94
WFR	261.3	741.38	20.36
EFR1	23.23	17.66	5.57
EFR	246.8	827.2	919.75
Pennar	16.84	12.08	4.76
Meghna	12.99	9.71	2.59

Annexure 3.8

Production and demand of different crops (Million tons)

Crop	Production			Demand		
	2000	2025	2050	2000	2025	2050
Rice	89	117	143	82	109	117
Wheat	72	108	145	67	91	102
Other cereals	32	49	78	37	73	137
Pulses	13	18	19	14	18	21
Total- Grains	207	292	385	201	291	377
Oil crops	31	73	97	48	103	133
Roots/tubers	7	14	26	7	13	24
Vegetables	74	150	227	75	150	189
Fruits	46	83	106	47	78	123
Sugar	30	46	60	26	42	55
Cotton	2	4	6	2	4	6

Source : 2000 data are from the FAOSTAT database (FAO 2005); the 2025 and 2050 data estimated from the PODIUMSIM (Amarasinghe et al. 2006).

CHAPTER 4

Water Demand in Other Sectors

Domestic (Urban and Rural) Water Requirements

4.1 Introduction

Urbanization affects water demand in various ways and is an important factor for estimating future water demand of the country. A number of studies estimated different rates of urbanization for projection of water demand for India as a whole. For instance, Kumar (1998) assumes that about 32.5% of the population would live in urban area in 2020. Bhalla et al. (1999) used Government of India's estimate of 35% urban population in 2020; Bansil (1999) estimated that about 40% of the India's population would live in urban area in 2020 while the UN projection puts it around 39.2% for the same year. The estimated future urban population in India is shown in Table 4.1.

Table 4.1 : Urban Population in India

Year	Population (million), Based on		Percentage of total population, Based on	
	Past Census	UN Projection	UN Projection	Past Census
2001	286	303	28	30
2011	377	439	32	35
2021	459	575	37	40
2025	*492*	*630*	*40*	*45*
2050	*695*	*970**	*45*	*48*

**Planning Commission now estimates urban population in 2030 at 600 million*

Source: http://censusindia.gov.in/

Demand for water depends on several factors such as population, income level lifestyle and industrialization. As income rises, people tend to use more water. City dwellers consume more water than those living in rural areas. The affluent section of the society consumes more water on per capita basis. Preliminary results of the 2011 census released by the Government of India (http://censusindia.gov.in/) estimate the current population of the country at 1210 million. The medium variant of the UN population projection shows that the population of India would stabilize at a level of about 1718 million by 2065 against earlier estimates which had projected the population to stabilize at about 1580 million by 2050. Thus, the updated estimates show that the population will stabilize at a higher value and at a later date. However in this study the estimates up to 2050 are considered.

4.2 Water Demand Drivers

India's population is increasing but is expected to stabilize around the middle of this century. The BAU scenario assumes that the population will increase at 1.3 percent and 0.52 percent over the periods 2000-2025, and between 2025 and 2050 respectively and would stabilize in the early 2050s. However, several large States will reach this peak in population well before the 2050s and some States will have declining trends in the 2030s and 2040s. Urbanization will continue to increase, and slightly more than half of India's population will live in the urban areas by 2050 (Mahmood and Kundu 2006).

Population growth is one of the key primary drivers of future water demand. Changing regional demographic patterns also influence the composition of regional water demand. This is important for a large country like India with significant spatial variations of water availability, particularly with irrigation as the largest consumptive water use sector in many regions. Irrigation played a significant role in the past in various States, where a major part of the rural population depended on agriculture for their livelihood. However, regional demographic patterns are changing with rapid urbanization.

Mahmood and Kundu (2006) project India's total population at 1.6 billion (approx) by 2050 (stabilizing thereafter) and estimates that about 53% of the population will live in urban areas by 2050. Other Scholars view this as a conservative estimate of urban population growth in India (Alagh, 2008). In either scenario, demographic trends in many States will change significantly by the second quarter of this century. Many States will have more cities with major urban centres, and more urban than rural population.

Table 4.2 presents the population projection of the UN medium variant for a few selected years. Water resources would be one of the infrastructure sector components facing increasing stress on account of the growing population and rising demand for water. The projected population of India for a few years as well as projections of State-wise urban population proportion and the corresponding population (using regional models suggested by United Nations), are given in Tables-4.3 and 4.4, respectively.

Table 4.2 : Projected Population of India for a Few Selected Years – UN Medium Variant

Year	Population as per UN medium variant (million)
2025	1459
2050	1692
2060	1718
2065	1718

Source: http://esa.un.org/unpd/wpp/unpp/panel_population.htm

Table 4.3 : State-wise Projection of Urban Proportion Using UN Method of URGD 2011-2051

State	2001	2011	2021	2031	2041	2051
A.P	0.2730	0.2887	0.3242	0.3793	0.4447	0.5100
Assam	0.1290	0.1536	0.1899	0.2401	0.3012	0.3679
Bihar	0.1335	0.1433	0.1676	0.2093	0.2656	0.3298
Gujrat	0.3739	0.4106	0.4600	0.5184	0.5778	0.6323
Haryana	0.2892	0.3400	0.3996	0.4648	0.5290	0.5887
HP	0.0980	0.1149	0.1422	0.1831	0.2364	0.2981
J&K	0.2481	0.2681	0.3060	0.3620	0.4279	0.4941
Karnataka	0.3399	0.3788	0.4300	0.4904	0.5521	0.6094
Kerala	0.2597	0.2683	0.2985	0.3508	0.4158	0.4824

State	2001	2011	2021	2031	2041	2051
Maharastra	0.4243	0.4680	0.5200	0.5763	0.6305	0.6790
MP	0.2482	0.2743	0.3165	0.3746	0.4408	0.5065
Orissa	0.1500	0.1734	0.2099	0.2616	0.3244	0.3918
Punjab	0.3390	0.3899	0.4486	0.5115	0.5722	0.6275
Rajasthan	0.2339	0.2496	0.2840	0.3378	0.4032	0.4703
TN	0.4404	0.5365	0.6160	0.6754	0.7201	0.7574
UP	0.2101	0.2311	0.2684	0.3232	0.3887	0.4563
WB	0.2797	0.2962	0.3323	0.3878	0.4531	0.5180
India	0.2778	0.3066	0.351	0.4102	0.4757	0.5394

Table 4.4 : State-wise Projection of Urban Population - Average Variant

State	2001	2011	2021	2031	2041	2051
A.P	20805057	23888789	28362794	34020497	39642535	44199180
Assam	3438495	4598140	6193648	8201864	10475838	12658314
Bihar	14677658	18826352	25286340	34153831	45741158	58297655
Gujrat	18918215	23503570	28169912	33239709	37633855	40508620
Haryana	6115134	8194779	10444988	12826918	14970671	16479172
Karnataka	17964055	22260438	27224073	32116304	36432027	39318110
Kerala	8269367	9270861	10850612	13077710	15417211	17243174
Maharastra	41105760	49909254	59453643	68239949	75291667	79296655
MP	20149372	26373730	35216649	45680548	56605075	66904958
Orissa	5520750	7010354	9070377	11643620	14513461	17076307
Punjab	8257701	10378189	12660251	14861480	16561890	17553539
Rajasthan	13216987	16669200	22746067	31781177	42797293	53908014
TN	27483602	36010534	43078275	47924549	50470307	51089618
UP	36701739	49884385	72227870	105634494	150652462	203813586
WB	22425227	26106484	31427656	37908216	44238330	49288704
Total major states	265049120	332885059	422413155	531310866	651443780	767635606
Total India	285745080	361406001	471472932	603090851	744671603	877226827

Many of the States with a declining population before the 2050s are in the south and the east, and also have a high urbanization growth. These States are located in river basins which experience regional water scarcities now and it is expected that the migration from agriculture to employment in the non-agriculture sector will be highest in these States. In fact, Sharma and Bhaduri (2006) have shown that the probability of rural youth moving out of agriculture is high in areas with more acute water scarcities, alongwith high non-agricultural employment opportunities in the neighbourhoods. We assume this changing demographic pattern would continue. Mahmood and Kundu (2006) project the proportion of urban population to India's total population at 34.44% and 38.84% for 2025 and 2050 respectively. Urbanization would be lowest in Assam and the highest in Tamil Nadu. In Assam, urban population would be 19.38% and 23.78% of total population in 2025 and 2050 respectively, whereas in Tamil Nadu, urbanization figures for the same period would be 50.52% and 54.92% respectively. In case of highly populated States, i.e. Uttar Pradesh and Bihar, about 68% and 76% of the population would live in rural areas in 2050. An examination of the demographic trends at the State level suggests that the population of Andhra Pradesh, Kerala, Karnataka, Punjab and Tamil Nadu, will show a declining trend by 2050, and a significant part of the population of these states will live in urban areas. Haryana, Gujarat, Orissa, Maharashtra and West Bengal will have a moderately declining population. In all these States, water demand for the domestic and industrial sectors is likely to increase rapidly, and the water use patterns in the agriculture sector will change. However, Bihar (including Jharkhand), Madhya Pradesh (including Chhattisgarh), Rajasthan and Uttar Pradesh (including Uttaranchal) will not only continue to have increased population, but will continue to have a substantial rural population by 2050. An exhaustive assessment of the water requirement for various uses was made by the National Commission for Integrated Water Resources Development (NCIWRD) using the data available at that time and the projections for the future. Table 4.5 shows the water requirement computed by NCIWRD for different uses for 2025 and 2050.

Table 4.5 : Annual Water Requirement (BCM) for Different Uses

Year	Year 2025			Year 2050		
	Low	High	Percentage	Low	High	Percentage
Irrigation	561	611	72	628	807	68
Domestic	55	62	7	90	111	9
Industries	67	67	8	81	81	7
Power	31	33	4	63	70	6
Inland navigation	10	10	1	15	15	1
Environment – ecology	10	10	1	20	20	2
Evaporation Losses	50	50	6	76	76	7
Total	784	843	100	973	1180	100
Population	1286	1333		1346	1581	

Source : NCIWRD1999

In this context, a quick exercise to update the estimates of future water use was taken up utilizing the revised population data.

4.3 Domestic Water Requirement

With increasing household income and increasing contribution from the service and industrial sectors, water demand in the domestic and industrial sectors would increase substantially. The NCIWRD assumed norms assess rural domestic water demand in 2025 and 2050 at 70 and 150 litre per capita per day (lpcd), respectively, and the urban water demand at 200 and 220 lpcd, respectively. These norms also assume 100 percent coverage for both the rural and the urban sectors.

Table-4.6 shows the domestic water requirement for 2050. The norms for per capita water requirements are similar to those adopted by NCIWRD. Per capita demand for the urban and rural areas has been taken as 220 and 70 litres per capita per day (lpcd) until 2025. The Commission had adopted a figure of 150 lpcd for rural areas for 2050 and beyond, considering the changes in lifestyles which will result in higher per capita water demand. Further, based on the trends and estimates for the future, it is likely that about 60% of the population of India will live in urban areas by 2050. It is noted that this sector will require about 119 BCM of water by 2050.

Table 4.6 : Domestic Water Requirement for the Year 2050

Item	Unit	Year 2025	Year 2050
Population	Million	1333	1692
Percentage urban	Million	0.45	0.6
Percentage rural	Million	0.55	0.4
Norm – urban area	lpcd	220	220
Norm – rural area	lpcd	70	150
Demand – urban	BCM	48.17	81.52
Demand – rural	BCM	18.73	37.05
Total	BCM	66.90	118.58

The Commission reviewed various norms suggested for water requirement for human use and suggested a target of providing 220 litres per capita per day (lpcd) for urban areas and 150 lpcd for rural areas by 2050. On the basis of these targets, it estimated the water requirement for domestic use under high and low population growth scenarios. It further assumed that roughly 55-60% of the water requirement for domestic use will be met from surface water sources. The total bovine water requirement for 2010, 2025 and 2050 was estimated assuming a 0.5% annual growth rate of bovine population and water requirement of 18-30 lpcd (Table 4.7).

Table 4.7 : Estimation of Domestic and Municipal Use and Bovine Requirements in 2010, 2025 and 2050

Population Type	2010	2025	2050
Targets for domestic and municipal use			
(lpcd) Class I cities	220	220	220
Class II-VI cities	150	165	220
Rural areas	55	70	150
Low and high projections (BCM)	42-43	55-62	90-111
% from surface sources (approx.)	55	57	60
Bovine water requirements (BCM)	4.8	5.2	5.9

Source: Adapted from Tables 3.26 and 3.27 (NCIWRD 1999)

Domestic water demand includes the livestock water demand. We assume 25 liters per head of the cattle and buffalo population. The livestock population is projected at the same rate as that of animal products calorie supply. We estimate the livestock water demand to increase from 2.3 BCM in 2000 to 2.8 and 3.2 BCM by 2025 and 2050, respectively.

4.4 Industrial Water Requirement

The service and industrial sectors in India expanded rapidly in the 1990s and contributed to GDP growth more than 5.1% annually between 1991 and 2002. Over this period, per capita GDP increased at 3.9% annually, and is growing at 5.3% annually in this decade. Such growth patterns in the economy will exert a significant pressure for water demand in the domestic and industrial sectors in the future. In fact, according to the current trends of economic growth and urbanization, most of the additional water demand between 2000 and 2050 could well come from the domestic and industrial sectors (Amarasinghe et al page 5). Whether such increasing water demand will be met through groundwater or surface water or a mix of both important for assessing future water needs.

Industrial water use in the country is growing at a fast pace but unfortunately. However, reliable data such use are not easily available and estimates from different sources vary. The Ministry of Water Resources, estimated industrial water use in India at about 40 BCM in 2010. The Central Pollution Control Board assumed that in 2000, Indian industry consumed about 10 BCM of water as process water and 30 BCM as cooling water. The World Bank noted that water demand for industrial uses and energy production will grow at a rate of 4.2% per year, rising from 67 BCM in 1999 to 228 BCM by 2025 (www.cseindia.org).

The National Commission, on its own admission, is tentative about its projections for water use in industries. It notes the dearth of information and analysis on both present water requirement and the future growth of industries in India. In such a scenario, it used data available with the Central Pollution Control Board (CPCB) and Planning Commission's classification of industries into 17 sub-sectors for arriving at its estimates. The estimates for the years 2010, 2025 and 2050 are 37, 67 and 81-103 BCM, respectively. These estimates are based on a 'sliding scale', with the lower estimate of 81 BCM arrived at by assuming significant breakthroughs in the development and adoption of water-saving technologies for industrial production. It is further assumed that 70 % of these requirements will be met from surface water sources.

4.5 Water Requirement for Other Uses

The Commission also estimated water requirements for power generation, development of inland navigation, compensating evaporation losses from reservoirs, floods as well as environment and ecology. These requirements are briefly noticed below:

4.5.1 Power Generation

While recognizing the growing importance of non-thermal sources, particularly hydropower, the Commission contends that, in view of the cost economies in power generation from coal and the high initial investment and long gestation period in the implementation and operation of hydro-schemes, thermal power will continue to be the mainstay of the power sector in the foreseeable future. Based on estimates collected from various sources for thermal power, and by using lump-sum provisions based on 9 % annual growth assumption for hydropower, it used a water requirement norm of 0.001 BCM/100 MW power generation capacity. Based on this ballpark number, and projections about India's growing power generation capacities, the Commission arrived at its final results (Table -4.8). The estimated water requirement for power generation is 69.8 BCM for 2050.

Table 4.8 : Water Requirement for Power Development 2010, 2025 and 2050 (BCM)

Category	Norm for water requirement (0.001 BCM/100 MW)					
	2010		2025		2050	
	Low	High	Low	High	Low	High
Thermal	2.81	3.43	7.85	9.59	28.71	35.07
Hydropower*	15.00	15.00	22.00	22.00	30.00	30.00
Nuclear	0.29	0.36	1.13	1.38	3.68	4.50
Solar/Wind	0.00	0.00	0.01	0.01	0.04	0.04
Gas-based	0.02	0.02	0.06	0.07	0.18	0.22
TOTAL	18.10	18.80	31.10	33.10	62.60	69.80

*Note: * Lump-sum based on 9 % annual growth assumption.*
Source: Adapted from Table 3.28 (NCIWRD 1999);

In our study on energy water linkage presented in chapter 7, based on projections up to 2050, water consumption for power sector is placed at 68.45 BCM. Keeping these results in view, the values suggested by the Commission are retained in this study.

4.5.2 Development of Inland Navigation

NCIWRD estimates that out of 900 billion tonnes km per annum of the total inland cargo, only one billion tonnes km is earnestly being moved by inland waterways. The flow requirements in water channels are expected to be met mostly by seasonal flows in various river systems and canals. However, in the event of damming the entire river flow, some water would be required to be released from upstream reservoirs for keeping the waterways navigable, especially during the lean season. Hence, the Commission projected 7, 10 and 15 BCM surface water requirements for 2010, 2025 and 2050, respectively, for inland navigational purposes.

4.5.3 Environment and Ecology

In the early 1990s, the concept of environmental flows (E-Flows) was not familiar in India. Gradually, the concept of minimum flows was introduced and the initial stipulations were based on directions that, for example, at least 10% of the lean season flow should be set aside for environmental needs. However, this practice is considered to be inadequate these days and there is a demand for higher allocation for environmental needs. NCIWRD had allocated 5 BCM for E-Flows for 2010 and 20 BCM for 2050. The water requirements for the eco-system was discussed under Chapter 2, while analyzing the water availability in different basins.

It is estimated that India's forests can, on a sustained basis, provide only about 0.041 BCM of fuel wood every year compared with the current demand for 0.240 BCM. Further, industrial wood requirements are more than twice the current silvicultural productivity; Also, that while the carrying capacity of forests is only 31 million head of cattle, currently about 90 million graze in forests. However, most of the water requirements for aforestation would be met from precipitation and soil moisture (green water) and that there is no need for any specific earmarking for this purpose.

4.5.4 Compensating Evaporation Losses

The loss due to evaporation from surface water reservoirs would depend on the reservoir geometry (surface area), water available in the reservoir as well as potential evaporation. Evaporation from a water body is generally expressed as a percentage of the reservoir capacity. However, such calculations would require reasonably accurate withdrawal data from all reservoirs. In the absence of such information, the Commission adopted an alternative method based on live storage capacity. It assessed national average values of evaporation losses from reservoirs at 15% of the live storage capacity for major and medium irrigation reservoirs and 25%, for the minor irrigation reservoirs. The Technical Advisory Committee of NWDA prescribed a norm for estimation of evaporation losses at 20% of total withdrawals from the reservoir.

4.6 Total Water Requirement

The total water requirements in the country for sectors, other than irrigation, by 2050, assessed by NCIWRD, is 373 BCM. Assessments made in this Study are only marginally different and hence NCIWRD values have been retained. Basin-wise breakup of the estimates for the years 2050 and 2025, given in Table-4.9, were considered while reviewing the demand-supply gaps at basin level.

Table 4.9 : Basin-wise estimates of demands for 2025 and 2050

Basin	Water use for Irrigation 2050 (BCM) (1)	Water use for all uses 2050 (BCM) (2)	Water use other than Irrigation 2050 (BCM) (3)	Water use other than Irrigation 2025 (BCM) (4)
Indus	57.1	77.12	20.02	14.014
Ganga	353.5	494.08	140.58	98.406
Brahmaputra	31.5	55.83	24.33	17.031
Meghna	10	12.33	2.33	1.631
Subernarekha	6	10.05	4.05	2.835
Brahmini-Baitrani	15	21.12	6.12	4.284
Mahanadi	45.8	60.96	15.16	10.612
Godavari	69.9	98.78	28.88	20.216
Krishna	61.6	91.53	29.93	20.951
Pennar	9.4	13.84	4.44	3.108
Cauvery	23	35.19	12.19	8.533
Tapi	11.1	18.19	7.09	4.963
Narmada	18.9	30.71	11.81	8.267
Mahi	6	10.19	4.19	2.933
Sabamati	5	8.66	3.66	2.562

Basin	Water use for Irrigation 2050 (BCM) (1)	Water use for all uses 2050 (BCM) (2)	Water use other than Irrigation 2050 (BCM) (3)	Water use other than Irrigation 2025 (BCM) (4)
West flowing rivers of Kachchh including Luni	13	28.73	15.73	11.011
West flowing rivers south of Tapi	30.6	51.08	20.48	14.336
East flowing rivers between Mahanadi - Pennar	19.4	27.41	8.01	5.607
East flowing rivers south of Pennar	17.9	30.44	12.54	8.778
Rivers draining into Bangladesh & Myanmar	2.4	3.75	1.35	0.945
	807.1	1180	372.89	261.023

(1) Source – NCIWRD report Annexure 3.2 col.26
(2) Source - NCIWRD report Annexure 3.2 col.32
(3) Col (1)-col (2) water use includes: Domestic +Industrial +(minor quantity for) navigation and Ecology +evaporation of reservoirs
(4) 70% of the column (3)

4.7 Conclusion

This Study has computed the water requirement for various uses, other than irrigation, for the years 2025 and 2050, based on recent census data and future projections. It is observed that total demand for water is likely to exceed the availability much earlier than 2050. However, the situation might be saved if sincere attempts are made to conserve water, particularly the water used for agriculture and municipal purposes.

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CHAPTER 5

Water Quality

5.1 Introduction

The famous quote: “Water water everywhere, but not a drop to drink” from the poem, “The rhyme of the Ancient Mariner” by Samuel Taylor Coleridge highlights effectively the need to adapt water quality for specific uses. Perennial rivers are diverted and dry up, drinking water supply systems are contaminated and rainwater is not stored safely. Hence, we too may not have a drop to drink if corrections are not made in time.

The picture on the right borrowed from Wikipedia shows very clearly how Nature tries to keep water clean but Man is out to pollute water. The victim always is water quality.

5.2 An Overview

There is increasing concern over sustained availability of water. However deliberations to deal with the perceived shortage of water resources focus usually on flow or volume. Attention devoted for ensuring quality of water is seldom commensurate with that given for enhancing quantity.

The shortage of water resources is attributed to increase in demand while the resources are known to be finite. The point that needs to be examined is whether water resources, which remain practically unchanged in volume, continue to be of the same quality. The present scenario of pollution in rivers, lakes and coastal waters is no less serious than the threat of demand outstripping the water resources.

A fresh look at the existing and projected demand is relevant. Increase in demand because of increase in population and emergence of new uses, e.g. air-conditioning, is understandable. But the component of waste included in the demand for domestic and agricultural purposes is not justified. Further, the grounds for not adopting on a large scale the well demonstrated technologies for reducing water consumption or providing for recycling and reuse are not plausible or convincing.

Given the uneven distribution of rainfall and the high water requirement during dry weather, storage is an undeniable need. As it is difficult to find suitable storage space above ground, underground storage will be the answer.

On the legal front also, water has received much less attention than, for example, forests. Treaties, covenants and adjudications regarding water are mostly confined to water flows and control of water pollution. In contrast, forests and wildlife are protected by laws that provide inter alia, for their conservation. A river cannot be conserved if she cannot support aquatic life not only because of pollution that exhausts its dissolved oxygen but also because of complete stoppage of flow by a barrage or a lift irrigation project. Ecological sustainability is the goal of maintaining the quality of water.

The current Institutional set up also complicates the issues regarding water quality. The quantitative and qualitative aspects are separated and dealt with in separate organisations, namely, the Ministry of Water Resources and the Ministry of Environment and Forests, respectively. The establishment of the National Water Quality Assessment Authority is a step in the right direction.

It is interesting to note that while development of water resources contributes to industrial and agricultural progress, this in turn generates wastes that degrade water quality. Degradation of water quality affects health and productivity, as well as all development activities adversely. Hence, preservation of water quality is a critical need for sustaining all development activities, and not an impediment in the development process.

5.3 Perceptions about Water Quality

Turbidity, colour and odour are perceived by our senses. If any one of these is observed, we assume that water is not safe for use. This may well be a fair judgement in most cases. However, we also tend to believe the converse, namely, clear, colourless and odourless water is safe. This is not always correct Fluorides and Arsenic, to name a few, are examples of harmful impurities present in water, which escape detection by our senses.

Reverence for rivers is a tradition in our society and the waters of several rivers, are considered to be holy, particularly the Ganga. The unusual self-purifying and preservation quality of water reinforce reverence and myths are formed and perpetuated. Even the natural purification caused by sunlight and aeration of a flowing body of water are sometimes regarded as a divine phenomenon.

Ideally, environmental concerns should be internalised in all development planning activities and lack of awareness about environmental concerns in development organisations has to be remedial urgently. In this context, two extremely ill-informed views are as under:-

1. Cooling water from thermal power plants actually improves the quality of water in the river. The view is apparently related to the practice of boiling water to make it safe for drinking. There is no realisation that the hot effluent is devoid of oxygen, that it forms the top layer, that fish and other forms of aquatic life are instantly harmed by the lack of oxygen and the thermal shock to which they are sensitive.

2. Water conveyed through a tunnel cannot be further polluted and thus tunnels help in protecting the quality of river water. What is not realised is that sunlight, contact with biota in the bed and aeration due to turbulence in the river are totally lacking in a tunnel and that these factors are most important for self-purification of river water and providing the sparkle of fresh water.

It is clear that the awareness gap about environmental concerns is so large that internalisation may take quite some time to be effective. Hence, while internalisation of environmental concerns should be the aim, external measures are needed in the meantime to ensure that such concerns about water quality are duly taken note of in development projects, plans and policies.

5.4 Major Threats to Water Quality

Nature ensures that clouds carry clean, fresh water from ocean to land where it appears in springs, streams and wells. This arrangement is vitiated by pollutants emitted by industries into air, agro-chemicals applied in the fields and sewage discharging into lakes and rivers. In fact, lakes and rivers with dams and estuaries are in particularly bad condition as regards water quality. Some relevant facts are noted below:-

- Silt load reaching the North-Indian rivers annually ranges from 4 to 98 hectare meters per 100 sq km of catchment area.
- Instead of having a flow that can dilute the treated wastewater ten times, the Yamuna receives partially treated wastewater which is three times the lean flow in the river.
- Detergents from urban dwellings and agro-chemicals from rural fields carry nutrients, which cause eutrophication in many stretches of rivers and lakes and consequent depletion of dissolved oxygen and destruction of inland fisheries.

5.5 Parameters of Water Quality

For any specific use of water, certain parameters of water quality are relevant. Accordingly, water quality is measured with reference to such specific parameters. For example, for drinking water, the taste and impact on health may be the foremost criteria for which dissolved salts and presence of pathogens, respectively, are the relevant concerns. The parameters that take care of these concerns are salinity, which often imparts unacceptable taste as well as presence of coliform organisms, which are indicators of contamination of water by micro-organisms that can cause disease.

Water quality parameters can be grouped according to the specific use of water, e.g. drinking, agriculture, industry, and ecology. A list of significant parameters is in Annexure 5.1. The Table therein shows what the parameter indicates, its significance and the probable area that may be adversely affected by that parameter.

Testing procedures are specific to parameters. Procedures are standardised for universal use. Procedures aim at being simple, low cost, fast, accurate and precise and evolve with time. Electronics has revolutionised measurement of various parameters with the help of sensors, transmitting the measured values through networks and using the data for trend analysis, monitoring of activities and control of processes. Application of biological parameters is improving monitored data to be more relevant and reliable.

Monitoring and surveillance are often used synonymously. But there is a fine difference, viz., monitoring is done by the operator to check that the processes are run properly while surveillance is done externally through indirect parameters that serve as good indicators. For example, analysing a sample of water after treatment at the waterworks serves to monitor, whereas the incidence of water-borne diseases in the town helps in surveillance.

5.6 Water Quality Standards

World Health Organisation has taken a lead in setting standards for water quality. International standards were first issued in 1958 and revised in 1963 and 1971. After a more detailed study, guidelines were issued in 1984, with the suggestion that countries may issue national standards. Guidelines have been revised from time to time, the fourth revised edition was issued in 2002. Guidelines are voluminous and are available on the web-site of World Health Organisation. New parameters and new information on importance of the various parameters became available through continuous efforts.

In India, Drinking Water Standards were recommended by the Indian Council of Medical Research and the Central Public Health & Environmental Engineering Organisation and revised from time to time. An extract showing the current standards published by the Bureau of Indian Standards as IS:10500 is placed in Annexure 5.2.

The Central Pollution Control Board (CPCB) dealt with water quality while prescribing ambient standards for water. In this context, the factor adopted by CPCB is the Designated Best Use. River stretches were accordingly classified into five categories with specified levels of parameters, as shown in Table 5.1 below.

Table 5.1 : Water Quality Standard with Designated Use

Parameter / Designated Best Use	Units	A	B	C	D	E
Dissolved oxygen (DO), Min	mg/l	6	5	4	4	-
Biochemical oxygen demand (BOD), Max	mg/l	2	3	3	-	-
Total Coliforms organism , MPN, Max	Per 100 ml	50	500	5000	-	-
pH value	-	6.5-8.5	6.5 - 8.5	6-9	6.5-8.5	6.5-8.5
Free ammonia, Max	mg/l	-	-	-	1.2	-
Electrical Conductivity , Max	µmho/cm	-	-	-	-	2250
Sodium adsorption Ratio, Max	-	-	-	-	-	26
Boron , Max	mg/l	-	-	-	-	2

The designated best use A denotes water fit for drinking after disinfection; B denotes fit for mass bathing; C denotes fit for drinking after conventional treatment; D denotes fit for fisheries and wildlife, and E denotes fit for agriculture, industrial cooling, controlled waste disposal and navigation.

5.7 Water Quality Index

In view of diverse requirements for water quality for purposes like drinking, agriculture and industries, the issue of creating an index for water quality is highly complex. Many attempts were made with varying success to evolve a Water Quality Index. However, there is general acceptance for the index adopted by the National Sanitation Foundation (NSF), USA.

NSF index for water quality is calculated with the value of 9 parameters selected out of 35. In order of decreasing weightage, the parameters are dissolved oxygen, faecal coliform, pH, temperature change, total phosphates, nitrate, turbidity and total solids.

The value of the Water Quality Index ranges from 0 to 100. Water quality of different sources can be easily compared with the help of this Index. Notwithstanding the general acceptance of the NSF Index, an Index for Water Quality needs to be developed for Indian conditions.

5.8 Causes of Impact on Water Quality

In general, such causes may be either natural or anthropogenic, (without excluding other causes). However, all significant causes can be grouped under these two categories.

Natural causes may inter alia, include the following: -

- matter carried by rainwater, whether from air or from ground
- salts leached out by water while percolating through soil and underground strata
- increase in the concentration of dissolved salts due to evaporation of water
- transfer of soluble matter to water bodies due to floods and volcanic activity

Anthropogenic activities, impacting on water quality have a much larger variety than the natural causes. A few are listed below: -

- discharge of sewage and industrial effluent into water bodies
- placing agro-chemicals and various wastes in a manner that these might be washed into water bodies
- leaching of salts into groundwater from chemical fertilisers, insecticides, industrial sludge and municipal solid wastes
- diversion of water from a river or lake to an extent that such water body becomes incapable of assimilating any unavoidable pollution load.

Erosion of soil may be caused by both natural and anthropogenic causes. Erosion of soil of catchment area of rivers is a major water quality issue. Soil erosion inflicts severe economic losses by way of reduction in reservoir capacity due to sedimentation, flooding because of rise in river bed level, impaired fisheries due to increase in turbidity and decreased agricultural yield because of to loss of fertile top soil. These effects have their own impacts, even if indirect, on water quality. The silt load of some of the rivers is shown below:

River Basin	*Silt load ha-m per 100 sq km per annum*
• Beas	22.17
• Ganga system	4.33
• Teesta	98.40
• Brahmaputra system	7.81
• Chenab	25.20

5.9 Impacts Induced by Water Quality

Various factors including many diseases, associated with water quality have complex adverse impacts.

Diseases, such as cholera, typhoid, dysentery, diarrhoea, hepatitis and poliomyelitis, caused by consumption of water containing the pathogen (micro-organism that causes the disease), are referred to as *water-borne* disease. Diseases caused by the presence of excessive quantities of certain elements or compounds, such as fluorides, nitrates, arsenic, mercury, magnesium or iron in drinking water are referred to as *water-induced* disease. Diseases, e.g. guinea-worm, malaria, filariasis, dengue and encephalitis, caused by the presence of water bodies to support breeding of mosquitoes, are known as *water-based diseases*. Trachoma and Scabies, caused by lack of water for ensuring cleanliness are called *water-related diseases*, a term that can be used for all the diseases, mentioned earlier.

Presence of pharmaceutical compounds in drinking water is a matter of concern. Excrete of human beings, cattle and pets as well as careless disposal of expired drugs/chemicals result in presence of pharmaceuticals in drinking water.

In view of the public apprehension of adverse effects of pharmaceuticals in drinking water, the utilities supplying drinking water have started taking action for removing them. However, a recent WHO study suggests that significant health risks arising from exposure to trace levels of pharmaceuticals in drinking water are extremely unlikely.

Intermittent water supply limits the period in which water may leak out of distribution pipes. It also provides the convenience of turning on the supply to specific sections during selected hours. For these reasons, water supply undertakings resort to intermittent water supply. The chain of practices that follow intermittent water supply have significant effects on water quality. First, people tend to store water for use during non-supply hours. The manner in which water is stored and drawn for use provides ample opportunities for contaminating water. Secondly, high demand during the limited hours of supply, leads to low pressure towards the distant reaches of the system. Such a scenario prompts people to install booster pumps directly on the water supply pipelines to draw water more easily during supply hours and for some more time subsequently. As a result, the water pipes come under suction conditions which admit water accumulated outside the pipe near leaky joints and surface drains. Severe contamination may occur and when water supply is resumed, the contaminated water may reach the consumers at random. This is the reason why any water supply system in the country hardly provides safe drinking water to the consumers. In fact, intermittent water supply system cannot be trusted for water quality.

Intermittent water supply in our country has facilitated scaling-up of a few product lines as under:-

- bottled drinking water
- domestic water purifiers
- tankers for emergency water supply
- booster pumps to draw water from supply mains

The increasing popularity of bottled water may be viewed optimistically as a reflection of the rising awareness of water quality. However, the burden of poor water quality on the society raises issues as under:

- Cost of medical treatment of water-borne and water-related diseases
- Cost of installation of domestic water purifiers
- Loss of man-hours due to sickness
- Loss in agricultural and industrial production
- Disincentive to tourism, particularly for international tourists who are very health-conscious
- Inequitable sharing of the burden imposed on the society as the poor suffers more from bad quality of water

5.10 Proactive Steps

The axiom “Prevention is better than cure” is very much relevant in the water quality domain. Mercury released from one broken fluorescent tube is sufficient to contaminate 30 cubic meters of water. Sewage, carried by flushing the water closet once, may convert a clean well to an unsafe one for drinking. Diversion of flow, may so damage the longitudinal connectivity, as to cause a serious setback to aquatic life. Indeed any number of examples would show that a little care can safeguard water quality and, in effect, protect public health, raise productivity and bring happiness and prosperity to the society.

5.11 Abatement Measures

Treatment of dirty and contaminated water has been in practice long enough to become known to people both in urban and rural areas. The concerns relate to cost of treatment, post-treatment storage in a safe manner and the risk of re-contamination during conveyance to point of use. Solutions have to be found in accordance with specific local conditions.

The range of abatement measures is too wide to be discussed in detail. In general, they form a sequence of physical measures, like screening and sedimentation, followed by biological measures based on bacterial action, the population of which is supported by providing air and sludge according to design. However, the applications as under, which use water and soil in almost natural conditions, may be highlighted for promoting public awareness: -

- rejuvenated wetlands
- overland flow
- root zone treatment
- phytoremediation

5.12 Control of Water Pollution

Water Quality Management envisaged, to a very large extent, water pollution control – one of the prime functions of the Central and State Pollution Control Boards. Steps taken in the discharge of this function include:

- Preparation of an inventory of all industries and outlets discharging effluent or sewage
- An analysis report of the effluent or sewage to be obtained/ prepared by the State Pollution Control Board
- Computing the pollution load with the help of estimated or measured quantity of effluent or sewage
- Analysis of samples taken from the river (upstream and downstream of major drains that meet the river), to ascertain water quality and impact of pollution
- Selection of sites for disposal of municipal solid wastes and other hazardous wastes so that the water bodies are not adversely affected by the disposal of such wastes
- Identification and use of old and abandoned sites, used earlier for disposal of wastes, for taking up remediation measures
- Ascertaining groundwater quality to assess the impact of on-going activities on aquifers that can be harnessed as sources of water supply.

5.13 Water Quality Monitoring

Appearance and odour may, in most cases, be sufficient to detect pollution. However, some pollutants may not be detected merely by eye or nose. For example, fluorides, nitrates and arsenic may go undetected for some years even while water containing these harmful substances is being consumed. Sampling and testing in a laboratory are, therefore, necessary to determine water quality, identify sources of contamination and plan action to safeguard water quality. On the other hand, eutrophication in a water body would indicate that the water body is receiving excessive quantities of nutrients, because of the presence of detergents in sewage or escape of fertilisers from fields.

The Central Water Commission, the Central Ground Water Board as well as the Central and State Pollution Control Boards have been collecting data on water quality for a long time. Occasionally, such data are collated and analysed to frame Actions plans for protecting water quality. A major step in this context was the Ganga Action Plan which was subsequently enlarged as the National River Conservation Plan and the National Lake Conservation Plan to cover other water bodies and basin as the Ganga River Basin Environment Management Plan to cover the entire.

The Central Water Commission has installed 371 water quality monitoring stations to collect samples from various rivers of India. The results show that extreme cases are relatively limited in number. For example, only at 12 stations, mostly in Madhya Pradesh and Rajasthan, the pH of water exceeded 8.5; only at 3 stations, the dissolved solids were so high as to have electrical conductance in excess of 3000 micro-ohm/cm, only at 2 stations, the hardness exceeded 600 mg/l; only at one station, the chlorides exceeded 1000 mg/l, and only at one station, the sulphates exceeded 400 mg/l. However, certain other parameters were found to have relatively higher concentration. These include iron, which was higher than 1 mg/l at 22 stations, nine of which were in Bihar; fluoride, which was higher than 1.5 mg/l at 15 stations; dissolved oxygen, which was lower than 5 mg/l at 17 stations, and bio-chemical oxygen demand, which was higher than 3 mg/l at 36 stations, 15 of which are in the Ganga Basin up to Allahabad. A typical map showing the distribution of stations showing abnormal results for bio-chemical oxygen demand is in Annexure 5.3.

In 2001, the Ministry of Environment and Forests created the Water Quality Assessment Authority, which is chaired by the Secretary to the Government in the Ministry of Environment and Forests and the Secretariat is in the Ministry of Water Resources. At the State level, Water Quality Review Committees have been constituted to identify problem areas and develop action plans. A Uniform Monitoring

Protocol, notified in 2005, was adopted by all Water Quality Monitoring Agencies. The Water Quality Monitoring Committee assists the Water Quality Assessment Authority in co-ordinating all monitoring activities. The Central Pollution Control Board also assisted the Water Quality Assessment Authority in capacity building of State Water Quality Review Committees to prepare water quality management plan for the State.

A summary of the Uniform Monitoring Protocol is enclosed (Annexure 5.4).

A network of ten stations is planned to be established in the Ganga Basin for real time monitoring of ten parameters, viz., pH, turbidity, conductivity, temperature, dissolved oxygen, dissolved ammonia, bio-chemical oxygen demand, chemical oxygen demand, nitrates and chlorides. These will be stand alone and unmanned stations, fitted with communication devices for transmitting data to a central receiving station in the Central Pollution Control Board.

Certain other parameters have significant relevance to water quality. Faecal coliform organisms are good indicators of contamination of water by agents of water-related diseases. Many heavy metals, such as lead, chromium, nickel, cadmium, copper and arsenic and compounds containing fluorides and toxic matter can cause health problems. Phosphates are good indicators of the threat of eutrophication, which can affect aquatic life. Salinity and boron impact on agricultural output. Selenium can affect the health of grazing cattle. Now that on-line monitoring is going to be adopted, diurnal variation of dissolved oxygen should be observed, which can provide very useful information for ecological sustainability. Biodiversity and saprobicity, which respectively represent the number of species and their healthy distribution, are indices that give an objective assessment of water quality. All such additional parameters need to be covered in an appropriate manner.

5.14 Prediction of Water Quality

Many studies and models have been attempted for predicting water quality. However, uncertainties persist in prediction of water quality because of the complex nature of physical, chemical, bio-chemical and biological processes occurring in a water body. Each of these processes has its own characteristic which may be significantly accelerated or interfered with by some other process. Sun light, turbulence, turbidity, temperature and dissolved solids can have significant influence on the biological processes in a water body. However, even under best of circumstances, prediction of water quality is very difficult.

5.15 Way Forward for Improved Water Quality

Action is needed urgently on several fronts for achieving water quality. Natural processes have to be optimally utilised by making maximum use of sunlight, turbulence, temperature, sediments, aeration, algae and aquatic life, etc.

Technical measures would include a variety of practices, e.g. flushing the toilets with treated wastewater, treating domestic sewage by root zone system or phytoremediation, making flow water available for meeting ecological needs and assimilating the inevitable pollution load, adopting clean technology and having a network of reliable laboratories for monitoring water quality. Modern techniques of ionic sensors, remote sensing and bio-monitoring should be brought into practice.

Legal action includes, inter alia, enforcement of environmental laws, in particular, the Water (Prevention and Control of Pollution) Act 1974 as amended from time to time. Urban Local Bodies, which have a major role in health and sanitation issues, should be stopped from discharging untreated/partially treated sewage into water bodies and dumping solid wastes near the river banks.

Financial and economic aspects include rationalisation of current low water tariffs for proper maintenance of water treatment works and the distribution system.

Social awareness has to be promoted and directed towards adoption of proper wastewater treatment measures for significant impact on water quality.

Public participation has to be secured in an appropriate manner for promoting and ensuring water quality. Experience shows that NGOs Student Groups have acted commendably in monitoring water quality. However, it is difficult to employ such groups on a regular, widespread basis. In this context, Community-Based Organisations (CBOs) have an excellent potential for dealing with water quality management.

The way forward would have to be sustained by following certain principles/ guidelines as under:

- Sustainability of a river is linked as much to land use management as to water quality management.
- Water pollution must be controlled by all means - technical, legal and social.
- Effective regulatory control must be ensured on
    - the use of river bed and flood plains for any inappropriate purpose
    - large-scale abstraction of water from any source, and
    - the discharge of any pollutant with reference to the assimilative capacity of the receiving body of water, whether on surface or under ground
- No effluent, domestic or industrial, should be allowed to be drained in a manner that it would reach a river/ lake
- No housing complex, mall, multiplex/hotel or any other large building/ or group of buildings may use drinking water for flushing toilets/ horticulture/ or central air-conditioning plants.
- Monitoring stations and parameters may be expanded and converted into real time monitoring so that decision are taken to prevent or abate pollution well in time.
- Biological parameters may be relied on more than physical and chemical analysis of water samples. For example, the healthy reappearance of Gangetic Dolphin may be taken as an ecological indicator and programme target.
- Co-ordination among Government Agencies, Public-Private Partnership and People's Participation should be encouraged by all means to promote efficient water quality management.
- Ensuring water quality is a problem of default in performance: we need to take determined action urgently.
- Use and application of modern techniques viz ionic sensors, remote sensing and bio-monitoring should be encouraged wherever feasible.

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5. World Health Organisation: Pharmaceuticals in Drinking Water; 2011

Annexure 5.1

Table showing Parameters relevant to Water Quality

Sl No.	Parameter	Indication	Significance	Affected area
1	Dissolved oxygen	Organic pollution lowers dissolved oxygen	Survival of aquatic life; Water Quality Indicator (WQI)	Downstream of towns
2	Faecal Coliform	Pollution by human excreta causes high values of faecal coliform	Public Health; WQI	Downstream of outfall sewers and drains
3	pH	Chemical pollution alters pH from its normal value of 7	Corrosion or scale formation; WQI	Downstream of chemical factories
4	B.O.D.	Organic pollution exerts bio-chemical demand for oxygen	Aquatic life; WQI	Downstream of sewers, drains or polluted tributaries
5	C.O.D.	Pollution due to domestic and industrial effluent exerts chemical demand for oxygen	Aquatic life	Downstream of highly polluting industrial units
6.	Electrical conductivity	Pollution due to wastewater; Use of ground water containing high quantity of dissolved solids	Quality of water for drinking and agriculture	Downstream of large cities and estates of effluent producing industries
7	Heavy metals • Arsenic • Mercury • Lead • Chromium	Natural geological conditions Chlor-alkali plant based on mercury electrode technology Chrome Tanneries Other industrial wastes	Public health	Downstream of chemical industries using compounds or catalysts containing heavy metals
8	Pesticides	Agricultural runoff	Public health; Aquatic ecology	Near intensively cultivated areas
9	Fertilisers	Agricultural runoff	Groundwater contamination; Eutrophication in water bodies	Near intensively cultivated areas
10	Sodium Absorption Ratio	Use of water or wastewater containing high concentration of sodium compounds	Fertility of soil	Near areas that are intensively irrigated with groundwater or industrial effluent
11	Boron	Natural or (rarely) industrial effluent	Plant growth	Generally not reported
12	Selenium	Natural or from industrial effluent	Health of livestock	Generally not reported
13	Fluorides	Natural geological conditions	Teeth and skeleton of human beings	Affected areas have been delineated in most cases

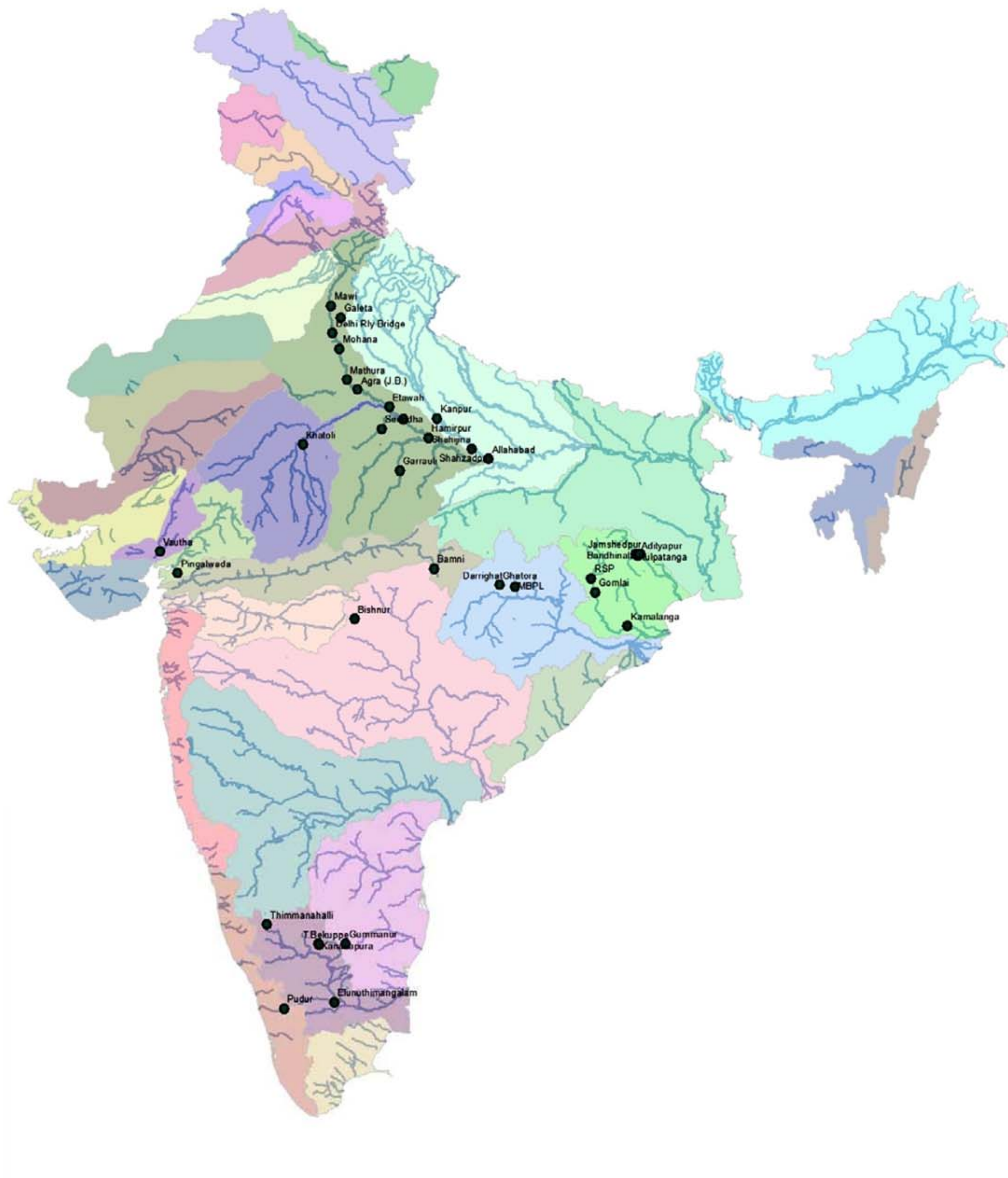
Sl No.	Parameter	Indication	Significance	Affected area
14	Nitrates	Naturally present in groundwater in some cases but mostly from nitrogenous fertilisers and industrial effluent	Adverse health effect on babies; Eutrophication of water bodies	In areas where nitrogenous fertilisers are extensively used
15	Iron	Natural geological conditions and, in some cases, from industrial effluent	Digestive disorders and deterioration of plumbing	In uplands where soil contains iron compounds and water has low pH
16	Ammonia	Industrial effluent; Pollution by urine	Fish are affected in particular; Odour nuisance	Near fertiliser plants and areas used for open urination
17	Phosphates	Pollution by large quantities of detergents	Eutrophication of water bodies; Depletion of oxygen in water	Downstream of urban settlements
18	Chlorides	Natural geological conditions; Sea water intrusion; Pollution by sewage and industrial effluent	Quality of drinking water is degraded; Agricultural production may be affected	Various areas may be affected depending upon the cause
19	Sulphates	Agricultural runoff and industrial effluent	Quality of drinking water is degraded	No specific area is affected
20	Turbidity	Soil erosion	Quality of drinking water	Near cultivated area and construction sites
21	Colour	Industrial effluent	Quality of drinking water	Downstream of industries, such as distillery, paper mill, printing & dyeing unit and tannery
22	Taste	Natural geological conditions; Industrial effluent	Quality of drinking water	Downstream of chemical and agro-based industries
23	Diversity Index	Aquatic ecological conditions; Domestic and industrial effluent	Bio-diversity may suffer	Downstream of outfall of sewers and industrial effluent and confluence with polluted tributaries
24	Saprobic Index	Aquatic ecological conditions; Water pollution	Robust aquatic life in conditions of symbiosis	- As above -

Annexure 5.2

Indian Standards for Drinking Water Quality (as per IS 10500)

S. No.	Parameter	Requirement desirable	Limit Remarks
1.	Colour	5	May be extended up to 50 if toxic substances are suspected
2.	Turbidity	10	May be relaxed up to 25 in the absence of alternate
3.	pH	6.5 to 8.5	May be relaxed up to 9.2 in the absence
4.	Total Hardness	300	May be extended up to 600
5.	Calcium as Ca	75	May be extended up to 200
6.	Magnesium as Mg	30	May be extended up to 100
7.	Copper as Cu	0.05	May be relaxed up to 1.5
8.	Iron	0.3	May be extended up to 1
9.	Manganese	0.1	May be extended up to 0.5
10.	Chlorides	250	May be extended up to 1000
11.	Sulphates	150	May be extended up to 400
12.	Nitrates	45	No relaxation
13.	Fluoride	0.6 to 1.2	If the limit is below 0.6 water should be rejected, Max. Limit is extended to 1.5
14.	Phenols	0.001	May be relaxed up to 0.002
15.	Mercury	0.001	No relaxation
16.	Cadmium	0.01	No relaxation
17.	Selenium	0.01	No relaxation
18.	Arsenic	0.05	No relaxation
19.	Cyanide	0.05	No relaxation
20.	Lead	0.1	No relaxation
21.	Zinc	5.0	May be extended up to 10.0
22.	Anionic detergents (MBAS)	0.2	May be relaxed up to 1
23.	Chromium as Cr+6	0.05	No relaxation
24.	Poly nuclear aromatic Hydrocarbons	--	--
25.	Mineral Oil	0.01	May be relaxed up to 0.03
26.	Residual free Chlorine	0.2	Applicable only when water is chlorinated
27.	Pesticides	Absent	--
28.	Radio active	--	--

Annexure 5.3



Stations having Biochemical Oxygen Demand Concentration above 3.0 mg/l in River water

Annexure 5.4

Summary of Notification on Uniform Water Quality Monitoring Protocol

In 2004, the Water Quality Assessment Authority was established by the Ministry of Environment & Forests. The Authority felt the need for notifying a protocol for water quality monitoring to ensure reliability of results of such monitoring. Accordingly, the said Ministry issued a Notification in 2005. The notification provided a uniform process for frequency and manner of sampling, parameters for analysis, analytical techniques, quality assurance, data analysis, reporting of results and such other matters, both for surface and ground water.

The order contained in the notification is applicable to all organisations, agencies or other bodies engaged in the activity of monitoring water quality. The protocol prescribes a monitoring network comprising baseline, trend and impact stations. The frequency and parameters for monitoring are also stated in the protocol for each kind of monitoring station. The frequency varies from quarterly to fortnightly. A list of 25 parameters is specifically selected to cover general parameters, nutrients, oxygen demand, specific ions, micro-pollutants, including pesticides and toxic metals.

The procedure for sampling, analytical techniques, preservation of samples, maintenance of records, protocol for quality assurance and accreditation of laboratories are part of the notification.

Unlike normal regulatory orders, the protocol contains relevant technical guidance for each stage of water quality monitoring.

CHAPTER 6

Energy–Water Linkage

Use of water, and consequently energy, makes our lives more comfortable in the short-term, but has a harmful impact in the long-term. We are not only degrading the quality of our water resources and drawing down aquifers, but also destroying valuable habitats. Further, our reliance on electricity to treat, move, pump, and heat the water we use, is resulting in mining non-renewable fossil fuels and contributing to climate change via greenhouse gas emissions. The energy-water nexus perpetuates wasteful use of natural resources. We are creating the challenges that are limiting our access to water and energy resources. Hence, the need for change.

While much of this change can take the form of water conservation in the home or adoption of more efficient practices in the agricultural and industrial sectors, new Government initiatives are needed to expedite the adoption and operation of these options. Technologies and management practices to reduce water and energy use are available in all sectors. Unless we start implementing these technologies through a more sustainable demand-side approach to resource management and use, we will continue to degrade vital resources and create even larger problems in the long-run. [1]

This chapter covers the dynamic give and take relationship between water and energy resources, e.g. the energy required for making water available for agriculture, industry and the like and water required for production of energy. Hence, the use of one resource i.e. water, is inextricably linked to use of the other i.e. energy – hence, the energy-water linkage [1].

Water and energy are both indispensable inputs to modern economies, and present systemic challenges to research and policy. Energy is the basic element of the biosphere and, defined as the ability to do work, embedded in all systems of production and consumption. Water is similarly embedded in production and consumption, and essential for all farms of life. Taken together, especially in the context of a dynamically changing climate which will affect supply and demand of both, close attention to water and energy encompasses a large part of the challenge of achieving sustainable development. It is not possible to optimize the operation of energy and water-supply utilities in isolation from each other or from considerations of climatic conditions. Many large-scale energy-conversion processes consume water, and most bulk water-supply processes require the expenditure of significant amounts of energy [17].

In a water use cycle, water is first collected, or extracted from a source. It is then transported to water treatment facilities and distributed to end users. What happens during end use depends primarily on whether the water is for agricultural or domestic use. Wastewater from urban uses is collected, treated, and discharged back to the environment, where it becomes a source for someone else. Energy is required at all stages of the water use cycle. Information is available about energy consumption by water and wastewater utilities as well as on water used for power generation. However, data are scattered and not comprehensive [9].

Each element of the water use cycle has unique energy intensities (kilowatt hours/million litres (kWh/ML)). Table 6.1 illustrates the considerable variability in both the range of intensities for each segment and the components of the water use cycle. End use energy demand was excluded since the focus is on the energy requirements in the remaining conveyance, treatment, distribution, and wastewater treatment processes. [9]

Table 6.1 : Range of Energy Intensities for Water Use Cycle Segments [9]

Water Use Cycle Segments	Range of Energy Intensity (kWh/ML)	
	Low	High
Water Supply and Conveyance	0	3699
Water Treatment	26	4227
Water Distribution	185	317
Wastewater Collection and Treatment	1100	1215
Wastewater Discharge	0	106
Recycled water treatment and Distribution	106	317

Residential water uses include personal hygiene (shower, bath, sink), dish and clothes washing, toilets, landscape irrigation, chilled water and ice in refrigerators, and swimming pools. Residential energy uses related to these activities include water treatment (filtering and softening), heating (natural gas or electric water heaters), hot water circulation loops, cooling (icemakers and chilled water systems for HVAC and chilled drinking water), and, in some cases, the groundwater pumping of private wells. In the commercial sector, the major water-related end uses that use electricity are cooling and water heating. Cooling towers for air conditioning are large water users. In the industrial sector, water-related energy use is very closely dependent upon specific processes. The high water consuming industries include power, paper and pulp, oil refinery etc. Huge amount of energy is also consumed in treating the effluents that are released from industries. [9]

6.1 Energy Consumption in Agriculture Water Supply

6.1.1 Energy Consumption in Agriculture Water Supply

Water is used in various sectors like agriculture, industry and domestic (residential/ commercial). In low and middle income countries, the water contribution per sector is: 82% agriculture, 10% industrial and 8% domestic, while in high income countries, the contributions are 30%, 59% and 11% respectively. In India, agricultural use of water is 83%, while 10% is used in industry and 7% for domestic purposes [3]. However, by 2050, the industrial demand for water would rise by 170%, allocating 30% of total available water to industrial sector, 59% to agriculture and 11% to domestic use [18].

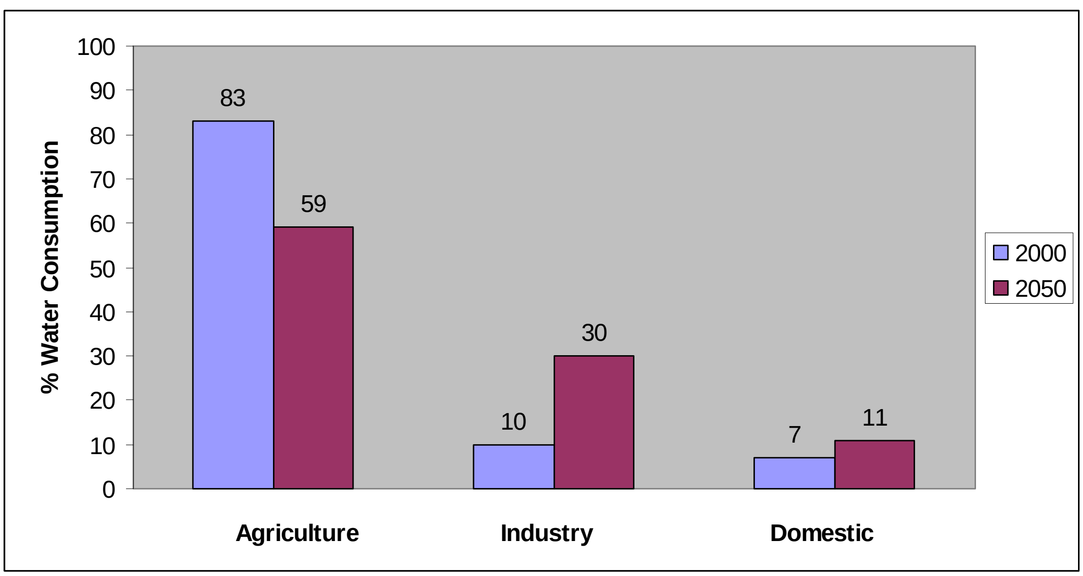


Figure 6.1: Projections of Water Consumption Sector-wise

Energy consumed in agriculture for water includes the energy consumed to convey water from water projects/rivers to the irrigation district, irrigation district surface water pumping, irrigation district ground water pumping, on-farm ground water and booster pumping. Irrigation was a key component of the Green Revolution that enabled many developing countries to produce enough food for the population. Additional water will be needed to produce food for 3 billion more people. But increasing competition for water and inefficient irrigation practices could constrain future food production [2]. Energy, in relation to irrigation, means energy for pumping water. Energy is needed for lifting water from wells, for providing pressure for sprinkler systems, for raising water to high point of a field so that it can be used for surface irrigation [10]. The energy required to pump surface water is 0.079kWh/m^3 while that for ground water is 0.185 kWh/m^3 [16]. It was estimated that 23 percent of the on-farm energy use for crop production in the U.S. was for on farm pumping. However, in India, the farm power availability is 1.35 KW/ha for a food grain productivity of 1723 kg/ha.

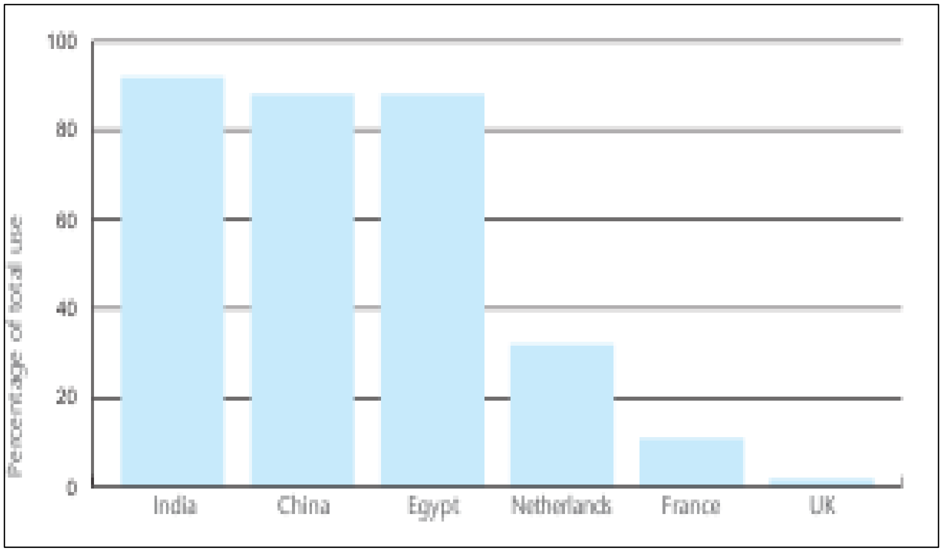


Figure 6.2 : Percentage of Total Water Used for Irrigation [2]

83% of the total water available in India is used in agriculture. Rice, wheat and sugarcane together constitute about 90% of India's crop production and are very high water-consuming crops. India has the highest water consumption rate among the top rice and wheat producing countries (China, US, Indonesia, etc.) as shown in figure 6.2. Also, agriculture based industries eg textiles, sugar and fertilizer are among the top producers of wastewater [2]. Electricity consumption in agriculture sector is increasing mainly because of greater irrigation demand for new crop varieties and subsidized electricity to this sector. Moreover, due importance is not being given to proper selection, installation, operation, and maintenance of pumping sets, as a result of which these do not operate at the desired level of efficiency, leading to huge waste of energy. [12].

Figure 6.3 shows the relation between the water footprint and the consumption pattern. The water footprint is significantly influenced by the fact that staple food in a State consists of rice or wheat, or the fact that there is a high or low level of oil and sugar consumption. The magnitude of the water footprint of a State is determined by the average virtual water content of the crops that are consumed in that State.

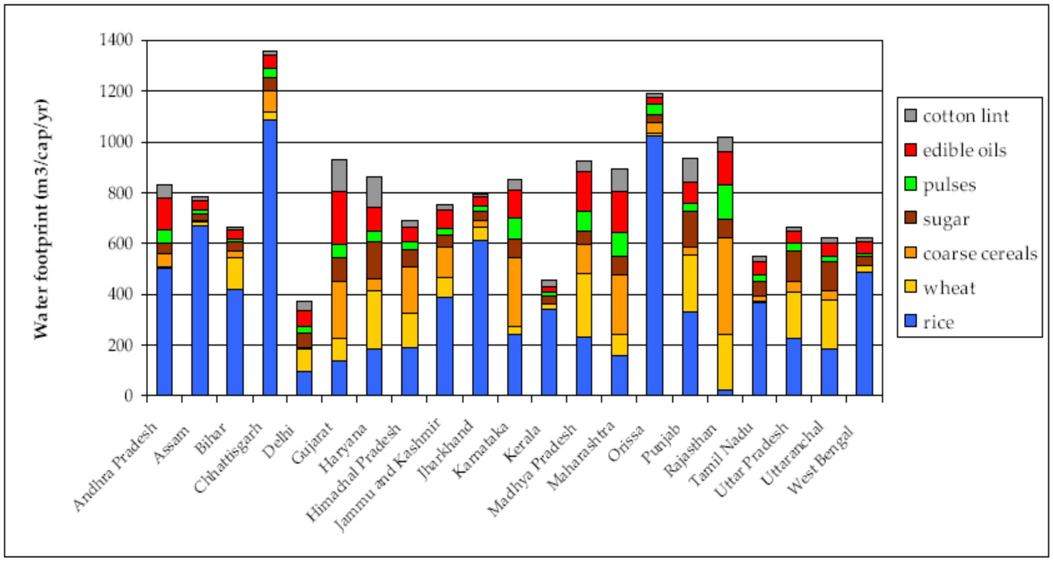


Figure 6.3 : Water Footprints Per Capita and the Contribution of the Different Crops for the Indian States during the Period 1997-2001 [18]

Besides the distinction between the blue, green and gray water footprint, the total water footprint can be divided into the water footprint of the individual crops.

6.1.2 Projections of Energy Consumption

- Agriculture's share of total water consumption is expected to decrease between 2000 and 2050. The total water demand for irrigation would be 690 BCM by 2025 and 735 BCM by 2050.
- India's demand for food grain will grow from 178 MM mt in 2000 to 241 MM mt in 2050.
- Production of water-intensive crops is expected to grow by 80% between 2000 and 2050
- The volume of water used for irrigation in India is expected to increase by 68.5 Tr liters between 2000 and 2025
- States with the highest production of rice/wheat are expected to face groundwater depletion of up to 75%, by 2050 [3]
- The share of mechanical and electrical power in agriculture increased from 40% in 1971/72 to 84% in 2003/04. The availability of farm power per unit area (kW/ha) is considered as one of the parameters for indicating the level of mechanization.
- Power availability for carrying out various agricultural operations increased from 0.3 kW/ha in 1971/72 to the tune of 1.4 kW/ha in 2003/04. Connected load in the agriculture sector in 2004 was estimated to be 51.84 GW, the number of consumers being 12.8 million.
- Electricity consumption in agriculture during 2003/04 was 87089 GWh, 24.13% of the total electricity consumption. There was an increase of 3.08% in the electricity sales to the agriculture sector in 2003/04 over 2002/03 (CEA 2005).

It is assumed that in irrigation, ground water used is 75% and surface water, 25% [16]. The energy required to pump ground water is taken as 0.185 kWh/m^3 and for surface water, it is 0.079 kWh/m^3, as already mentioned. Using these figures, the projections have been calculated, and summarized in Table 6.2. Figure 6.4 and Table 6.3(a) give projections of farm power and food supply demand in India.

Table 6.2 : Projections of Water and Energy Consumption for Irrigation

Year	2000	2025	2050
Water consumption (billion cubic meter)	542.5	690	735
Energy consumption for pumping ground water (GWh)	75.3	95.73	102
Energy consumption for pumping surface water (GWh)	10.7	13.62	14.51
Total energy consumption (GWh)	86.0	109.35	116.51

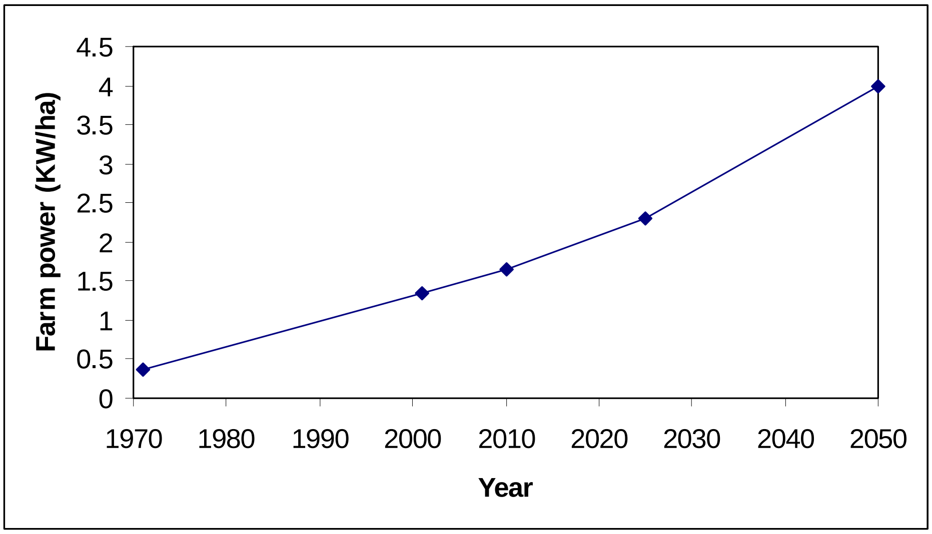


Figure 6.4 Projections for Farm Power Used

However, it may be noted that if ground water depletion continues, the energy demand will also go up proportionately to pump water from deep wells.

Table 6.3(a) : Demand for Food by Food Group, Million Tones, India [34]

Food Group	1999-2001	2015	2025	2050
	Million Tones			
Cereals	159	199	217	243
Potatoes	25	37	43	58
Fruits & Vegetables	108	160	192	257
Vegetable Oils	11	18	22	29
Sugar	29	40	45	54
Eggs	2	3	5	9
Chicken	1	4	8	18
Milk	66	104	132	196
Beef, Mutton and Pork	4	5	6	9

6.1.3 Benchmarks of Energy Consumption in Agricultural Water Supply

The global best and the Indian water footprints [43] for various crops were obtained to estimate the benchmark for the agricultural sector, Further, the best specific energy consumption for irrigation was estimated to be 0.16 Whi/m3, obtained by taking the figures in Table 6.3(a) and dividing the energy consumption by water consumption. The benchmark was obtained by multiplying this figure with the global best water consumption. Benchmarks for a few major crops are listed in Table 6.3(b).

Table 6.3(b) : Benchmarks of Energy Consumption

Crop	Water footprint for India (m^3/ton)	Globally best water footprint (m^3/ton)	Benchmark for energy consumption (Whr/ton)
Wheat	2104	566	90.56
Rice	2020	638	102.08
Sugar	1570	850	136.00

The benchmark water productivity is the one best achieved. The actual water productivity will depend on the climatic conditions, soil and the type of crop cultivated. However, benchmarks of water and energy consumption need to be targeted in a systematic manner for energy, water and food security. Adoption of various new scientific methods of irrigation, water efficient crops cultivation, genetic engineering of water efficient varieties and power efficient water pumps can achieve this target.

6.1.4 Recommendations relating to Water Supply in Agriculture for Energy Security and Optimization

New agricultural practices can save water and hence energy to a great extent. Hence, the focus should be on effective water utilization. For examples:

- Traditional water use in a sugar cane mill is about 21 m^3 per ton of processed cane (Macedo, 2005). New techniques have decreased water use to 0.92 m^3/ton of cane. The São Paolo State Plan on water resources estimated the water use in 1990 at 1.8 m^3 per ton of cane (Macedo, 2005).

- Sugar beet is a root crop cultivated in a temperate climate. Water consumption in traditional sugar beet plants ranges from 2.5 to 4.5 m^3/ton of beet (Vaccari et al., 2005). Modern plants sometimes do not even have a fresh water intake. Fornalek (1995), for example, shows that water use in a Polish plant was reduced from 105 m^3/ton in 1950 to 10 m^3/ton sugar in 1995.

Figure 6.5 : Sprinkler and Drip Irrigation [53]

By fine-tuning irrigation, farmers can improve crop water-use efficiency and reduce water use. This may include:

- Adding drop tubes to central pivot irrigation mechanism.

- Improving timing of irrigation: The goal in irrigation scheduling is to apply enough water to fully wet the plant's root zone while minimizing over watering and then allow the soil to dry out in between watering, to allow air to enter the soil and encourage root development, but not so much that the plant is stressed beyond what can be allowed, eliminating the excess amounts of water and energy for irrigation.

- Implementing Low-Energy Precision Application (LEPA) systems that discharge water just above the soil surface and reduce water losses from evaporation.

- Drip irrigation, which saves water and fertilizer, by allowing water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters. It is done with the help of narrow tubes which delivers water directly to the base of the plant. Although the initial cost is high, it has the advantages of high water application efficiency, minimized fertilizer usage and safe usage of recycled water, among others [1]. Table 6.4 shows the power savings in various crops due to drip irrigation.

Table 6.4 : Power Savings in Different Crops Due to Drip Irrigation [30]

Crop	kWhr/ha
Banana	1660
Cotton	258
Sugarcane	1250
Mango	371
Other Orchads	313
Other Crops	200

Table 6.5 gives the energy consumption for different irrigation methods for a given irrigation time of 8 hours per day.

Table 6.5 : Energy Consumption for Different Irrigation Methods [30]

	Flood Irrigation	Porous Pipe SSI	Drip / Sprinklers					Rain gun / Sprinklers			
	Low Flow	Low Flow / Low Pressure system	High Flow / High Pressure system								
Pressure requirement for different MIS kg/cm²	GL	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Pressure requirement for different MIS Bar (Mts.)		5	10	15	20	25	30	35	40	45	50
Total Head in Mts.	30	35	40	45	50	55	60	65	70	75	80
Irrigation hrs. / day	8	8	8	8	8	8	8	8	8	8	8
Total Water delivery(‘000L/ day)	547	469	411	365	328	299	274	253	235	219	205
Water Req./ Day / Hct. (‘000L)	100	42.5	50	50	50	50	50	50	50	50	50
Energy consumption in kW hr for Irrigating same area as Porous Pipe SSI	120	60	80	90	100	110	120	130	140	150	160

To sum up, for wide spaced orchard crop group, electricity savings with drip irrigation is estimated to be around 278 kWh/ha and about 100 kWh/ha, for close grown crops under drip. For close grown crops under sprinkler irrigation it may be around 120 kWhr/ha only. Some recent systems like porous pipe works on the principle of suction irrigation require very low head [30] and can be considered as a potential option for energy efficient irrigation system.

The recommendations are summarized as under:

- Initiate reliable methods of data collection for water and energy consumption in agriculture all over India
- Even though capital intensive, implement water efficient irrigation systems such as drip, sprinkler etc.
- Monitor irrigation practices to keep ground water level high to save power required for pumping. Never allow over withdrawal of ground water since it only increases energy consumption and does not increase water availability.
- Initiate and implement program for cultivating water efficient food, eg: soybean in place of basmati rice, beet in place of sugarcane
- Initiate local water storage practices so as to improve the water table and reduce energy required for conveyance and deep well withdrawal.
- Manufacture and sell only efficient motors and pumps in the market for agriculture. Allowing inefficient pumps is an unacceptable wastage of precious energy.
- Progressively reduce electricity subsidy and increase water cess to promote good practices for water and energy use.
- Promote research in agriculture for development of water efficient crop varieties.
- Reduce evaporation by converting it to evapotraspiration by covering ground with vegetation. Thus evaporation is utilized for conversion of solar energy to biomass.

6.2 Energy Consumption in Rural Water Supply

6.2.1 Energy Consumption in Rural Water Supply

As on 1.4.2007, figures show that out of a total of 15,07,349 rural habitations in India, 74.39%(11,21,366 habitations) are fully covered, and 14.64%(2,20,165 habitations) are partially covered. Further, current estimates show that out of the 2.17 lakh water quality affected habitations as on 1.4.2005, 70,000 habitations (approx.) have since been addressed for providing safe drinking water [14].

Supply and conveyance are the most energy-intensive portion of the water delivery chain. If the water source is groundwater, pumping requirements for supply of freshwater from aquifers vary with depth as given below:

142 kWh per million liters from a depth of 36m,

530 kWh per million liters from 122m.

Thus energy needs will increase in areas where groundwater levels are declining [5]. Further, ground water gets contaminated with deep strata minerals like arsenic and fluoride and removal of the same requires additional energy and treatment costs. As the energy required for treatment and delivery of water accounts for as much as 80% of its cost, an insufficient supply of affordable energy will have a negative impact on the price and availability of water.

The predominant consumer of electricity is pumping [20]. Table 6.6 gives the unit energy consumption for water supply from surface and ground water.

Table 6.6 : Summary of Unit Energy (Electric) Consumption for Water Supply from Surface Water and Ground Water [20]

Sector	Surface Water	Ground Water
kWh/Million gallons		
Domestic	-NA-	700
Public Supply (includes wide area distribution)	1406	1824
kWh/cubic meter		
Domestic	-NA-	0.185
Public Supply (includes wide area distribution)	0.371	0.482

Availability of the right quality and quantity of water throughout the year at affordable costs for the Indian population is the real challenge, considering the distribution of requirement.

6.2.2 Projections of Energy Consumption in 2022

"Provide clean drinking water for all by 2009 and ensure that there are no slip backs by the end of the Eleventh Plan" is one of the monitorable targets of the Eleventh Five Year Plan. Under Bharat Nirman, 55067 non-covered habitations, 2.8 lakh slipped back habitations and 2.17 lakh quality affected habitations are proposed to be covered. Department of Drinking Water Supply estimated that by April 2005, there were 2.31 lakh uncovered rural schools in the country, which had to be provided with water supply. Adding up the population figures, it comes out that 7.83 lakh extra inhabitants need to be supplied with water in the future. [38]

Table 6.7 shows the estimated energy requirement per day to supply all the rural inhabitants with water. Rural population is calculated from the projected figures of total Indian population, where it is 70%, 60% and 55% of the total population for the years 2000, 2025 and 2050 respectively [3]. The rural water consumption in India is assumed to be 43 liters per day per person, which may increase in the coming years, as the standard of living improves with time.

Table 6.7 : Water and Energy Consumption Projections for Rural India

Year	2000	2025	2050
Rural population (million)	721	840	743
Water demand (million m^3/day)	31	36.12	31.95
Energy requirement (GWh/day)	4.9	5.78	5.05

The supply of clean and adequate drinking water to rural population at affordable price and in an energy starved environment is a challenging task.

6.2.3 Benchmarks on Energy Consumption in Rural Water Supply

Water storage, recycle and reuse are resorted to for saving energy in rural water supply. Most large-scale reuse schemes are in Israel, South Africa, and the arid areas of USA, where alternative sources of water are limited. About 41 percent of recycled water projects are in Japan, 60% in California, USA, and 15% in Tunisia. These are used to combat water and energy deficiencies. Even in India, traditional practices like tanks in Tamilnadu or Bordi's of West Bengal encouraged water storage and conservation.

Considering the possible water reuse of 40% (global best), India can recycle 12.4 million m^3/day. Using the data from table 6.8, the corresponding saving of energy consumption by reuse and recycle is estimated at 0.395kWh/m^3. However, energy spent for reuse/recycle is estimated to be 0.2 kWh/m^3. Hence net saving of energy by recycle/reuse practice, for rural India would be 0.195kWh/m^3. Also considering 30% water is conserved by rainwater harvesting [50], corresponding energy saving is estimated to be 0.53kWh/m^3 and energy spent for pumping the conserved water is estimated to be 0.15 kWh/m^3. Hence net saving of energy by rainwater harvesting, would be 0.43 kWh/m^3. Therefore, the net potential energy saving from rain water harvesting and reuse practices for rural scenario in India is estimated to be 0.575 kWh/m^3. Thus, for rural water supply, a benchmark of water and energy consumption can be set as

Water consumption: 43 Lts per person per day as set by the Water Mission

Energy consumption for supply: 0.15 kWh/ m^3

6.2.4 Recommendations for Rural Water Supply for Energy Optimization

- Right price & location of water supply

The level of attention paid to water use efficiency is directly proportional to the prices charged for water servicing. Rising prices lead to increasing attention to water use and, in the long run, more efficient use of water. Addressing water and energy use efficiencies in the rural water supply system requires a complete revamp in view of the capacity to pay the rural population. Water should be made available at the lowest price but not for free at the door step. The traditional methods of fetching drinking water from a reasonable distance prevented misuse of water. Further, the community area for washing will enable water recycling. Hence, the policy of delivery of water, free of cost at the doorstep, needs review in view of definite misuse and over utilization of water.

- Rainwater harvesting, a must for rural water supply

Community based rainwater harvesting in rural areas of India - the paradigm of the past – is stronger today than ever before. Recognizing this fact, rain water is the only local source of water and harvesting is a sustainable solution. The average Indian population of an Indian village in November 2000 was approximately 1200. India's average rainfall is about 1170 mm, about 40% of which is runoff. Even if only half of this water can be captured through water harvesting technology, water supply can be improved hugely. An average Indian village needs 1.12 hectares of land to capture 6.57 million litres of water it will use in a year for cooking and drinking. If there is a drought and rainfall levels dip to half the normal, the land required would rise to 2.24 hectares. The amount of land needed to meet the drinking water needs of an average village will vary from 0.10 hectares in Arunachal Pradesh (average population 236) where villages are small and rainfall high to 8.46 hectares in villages near Delhi which are big (average population 4769) and rainfall is low. In Rajasthan, the land required will vary from 1.68 to 3.64 hectares in different meteorological regions and in Gujarat, it will vary from 1.72 to 3.30 hectares. And any more water the villagers may capture would, of course, go for irrigation.

India's total land area is more than 300 million hectares. Assuming that India's 587,000 villages can harvest the runoff from 200 million hectares of land, excluding inaccessible forest areas, high mountains and other uninhabited terrains, it would still gives every village, on average, access to 340 hectares or a rainfall endowment of 3.75 billion litres of water. This shows the enormous potential of rainwater harvesting [50].

In its broadest sense, it is a technology used for collecting and storing rainwater for human use from rooftops, land surfaces or rock catchments using simple techniques such as jars and pots as well as engineered techniques. Such a technique reduces energy consumption significantly as rainwater requires very little or no treatment before use; energy is also not spent in transporting the water to the consumption point. It reduces the rate of power consumption for pumping of groundwater. For every 1 m rise in water level, there is a saving of 0.4 KWH of electricity [16].

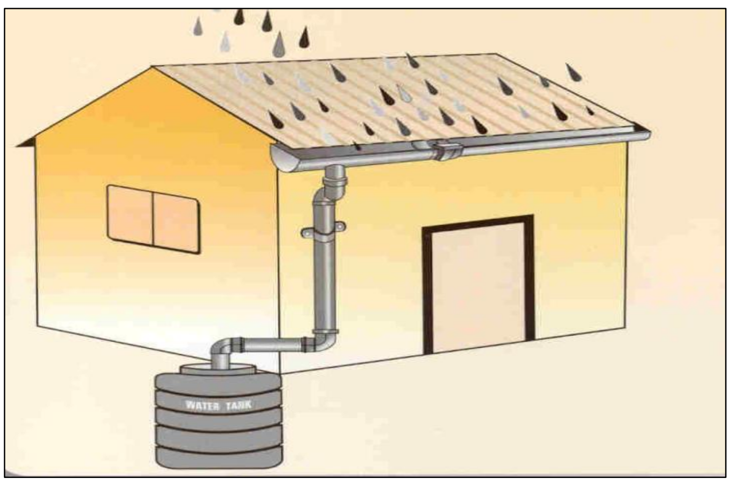


Figure 6.6 : Rainwater harvesting from a roof top

The present practice of Govt. taking responsibility for water supply by laying pipelines from rivers and tanks to the villages is energy-intensive and unviable. Hence, allocation of land for water collection from existing land, if separate land is not available for water harvesting, is more viable from the energy as well as the water quality point of view. Funds for the Water Mission should be spent on ensuring local water supply rather than desalination and purification of depleted water resources which will decline further, if not recharged.

- Wastewater treatment or recycling systems

Another major energy consumption source in rural water supply is water purification.

Rain water is pure and requires minimal treatment. Unhygienic disposal of human and animal waste, over utilization of water causing ingress of lower strata minerals like As and F and excessive use of fertilizers cause contamination. Prevention is better than cure and the same needs to be replicated for rural water supply.

Human waste needs to be treated before discharge and the Water Mission should focus on providing these facilities to keep rural water supply clean instead of providing water purification facilities. The technology of sewage water treatment with grey water recycle can reduce 40% of water demand. Hence treatment and recycle of sewage water at the generation point to prevent contamination of water bodies should be the second major priority for clean and energy efficient rural water supply. Animal waste can similarly be treated for extraction of energy and biofertiliser. Such a rural sanitation program will have wide positive effect on water supply and rural population health. Returns will be manifold compared to free water supply and purification facilities planned now.

Grey water for flushing toilets or recycle through purification has the potential of reducing 35% to 40% of annual water consumption corresponding to 6.2 GWh/day of energy saved and equivalent water produced. The production of same quantity of water by desalination and similar techniques will require 4 times more energy [31].

- Disinfection technologies:

Additional energy savings measures for new treatment techniques may be identified by a detailed investigation of new technologies. In addition, the regulations should ensure adequate measures to control concentration of impurities, not previously required to be controlled. For many treatment plants, the regulations are likely to require the use of relatively new treatment techniques e.g. zone, ultraviolet radiation, hydrogen peroxide, and chlorine dioxide or membrane filtration. As shown in Table 6.8, new treatment techniques require significantly higher use of electricity than the typical current treatment techniques. For example, reverse osmosis for desalination, consumes 3-14 kWh energy to produce 3780 lts of desalinated sea water, depending on the quality of water to be treated. Such consumption can be reduced with the development of better filtration systems and thinner membranes. For example, a new process uses the pressurized stream to pressurize the seawater entering the system. In this way, approximately, 95-99% of the 28.11 kW/m^3 of energy that would be lost is recovered [45].

Table 6.8 : Comparative Energy Use for Various Treatment Techniques [44]

Comparative Energy Use for Various Treatment Techniques	Energy Use (kWh/ML)
Ground Water Plant (Chlorination)	
Small	3
Large	3
Typical Surface water plant	
Small	38
Large	21
Ozone	
Pre-oxidation	31
Disinfection	105
UV Radiation(medium pressure)	
Bacteria	11
Viruses	11-48
Ultra filtration	68-103

Recommendations for energy efficient rural water supply are briefly as under:

- Rain water harvesting for each village by allocating land for collection and storage. This will reduce the major energy cost in transportation, contamination in deep well pumps, and make available adequate quantity of good quality water.
- Sanitation facilities and treatment of human and animal waste for ensuring clean and uncontaminated water. Reuse and recycle of water to reduce fresh water consumption and hence, the treatment costs. Use of grey water for flushing and local sewage treatment for ensuring that only clean water is let out.
- Use of local and energy efficient water treatment techniques e.g. sunlight ,UV and ozone rather than chlorine
- Use of efficient pumps and water efficient gadgets like flush and taps to reduce wastage.
- Discontinuation of free supply and treatment programs which increase contaminants in water for future generations.

We strongly recommend a thorough review of our Water Mission for rural water supply for providing a sustainable solution for the rural population. Rainwater harvesting and water recycle practices are the potential options for energy efficient rural water supply systems, leading to an annual energy saving of about 350 GWh. Further, such systems will offer affordable and adequate quantity of good quality water.

6.3 Energy Consumption in Urban Water Supply

6.3.1 Energy Consumption in Urban Water Supply

Water supply in urban areas is far from satisfactory. As on 31.3.2004, about 91% of the urban population had got access to water supply facilities. However, such access does not ensure adequacy, equitable distribution and the per capita availability is not as per norms in many areas. The average access to drinking water is highest in class I towns (73%), followed by class II towns (63%), class III towns (61%) and other towns (58%). Poor people in slums and squatter settlements are generally deprived of these basic amenities [14]. On the other hand, 6 to 18% of a city's energy demand is used to produce, treat and transport water. Table 6.10 gives the energy requirement for water use in various supply steps, for a typical urban area.

The energy requirements are typically 26 kWh/ML for water treatment, 317 kWh/ML for distribution and 661 kWh/ML for wastewater treatment. The energy used for the conveyance of water can vary widely depending on a city's proximity to the water source. e.g., Delhi and Chennai receive water from rivers that are 250 km and 450 km away, respectively.

Rapid expansion of urban population would inevitably exert greater pressure on water supply. Dams or reservoirs created for the cities are the traditional methods of water supply for urban areas. Increasing opposition to land acquisition from the rural population near cities would make such supplies more difficult. Hence, cities have to plan carefully and realistically for augmenting the supply to meet the growing needs. Growth of cities in future would be limited by water supply.

6.3.2 Projections of Energy Consumption

- As per the Indian standard code (IS: 1172: 1983), the per capita water supply norm is 135 lpcd. Based on this standard, the high and low water demand by 2050 is expected to be 50 million and 37 million liters per day (mld) of fresh water.
- Cities are reaching out to distant water sources, e.g., Delhi and Chennai receive water from rivers that are 250 Km and 450 Km away, respectively
- In 1991, the annual per capita availability of water was 2731 cubic meters. In 2020, this is expected to be just over 2000 cubic meters and by 2050, 1403 cubic meters [19].

For projecting the water and energy consumption in urban India, it is assumed that 75% of the water is supplied from ground water and 25% from surface water sources [16], urban population would be 30% (in 2000), 40% (in 2025) and 55% (in 2050) [3], of total projected population and the per capita demand is kept constant at 135 litres per day. The results are summarized in Table 6.9.

Table 6.9 : Projections of Water and Energy Demands in Urban India

Year	2000	2025	2050
Urban population (million)	310	560	910
Water consumption (million m^3/day)	41.9	75.6	150.2
Energy consumption (GWh/day)	6.65	12.0	23.9

The Table assumes that all the water comes from ground and surface water. But in States like Gujarat and Tamil Nadu, where both these sources are scarce, sea water desalination may be required to meet the increasing water demand. This method is highly energy intensive. The most efficient (reverse osmosis based) desalination plants consume about 5 kWh of energy per cubic meter of fresh water produced. [33]

6.3.3 Benchmarks on Energy Consumption in Urban Water Supply

The major energy requirement in urban water supply is conveyance, followed by distribution (317 KWh/ML) and purification treatment (26 KWh/ML). Waste water treatment can be an energy guzzler in future when all cities are expected to have sewage treatment facilities (661 KWh/ML).

Energy consumption for urban water supply depends on a number of parameters. Though energy costs for water treatment, distribution and waste water treatment can be considered constant for different cities, factors like the proximity of the city to the water source and the type of water supply processes (gravity fed or pressure supply), become critical for determining the energy consumption for a particular city. For example, the conveyance cost for Chennai which is 450km away [3] from the nearest water source will be much more than, say, that for Kolkata which receives its water from the Hooghly river, situated in the heart of the city. Another important factor is the method of distribution of the water. Gravity fed systems need to be used to a greater extent as it is more energy efficient than pressure systems used for water delivery. In New York, 95% of water supply is by gravity [31]. Hence, in India, water should be supplied by gravity wherever possible, as it will save an enormous amount of energy. Table 6.10 shows the benchmark for energy consumption in urban water supply system.

The benchmark energy consumption is derived from best practices all over world. Transportation of water depends on elevation and distance and can vary from city to city. The best energy consumption per km of pipeline (given below) is achieved by good pumping and design of transportation system. Water Treatment Energy consumption benchmark for water treatment is taken from the best plant in operation while, that for distribution, is from the gravity system practiced in New York.

Table 6.10 : Benchmarks for Urban Water Supply [30]

Water use	Energy consumption (kWh/(ML*km))
Conveyance	5
Water treatment	0.11
Distribution	1.35
Wastewater treatment	2.8

6.3.4 Recommendations for Urban Water Supply for Energy Optimization

6.3.4.1 Plan for Rainwater Harvesting and Storm Water Management

Conveyance is a major cost of energy in urban water supply system; Also, its availability is becoming more difficult because of greater local demands. Most cities have the capability to harvest about 20 to 30% of their water requirement. A few cities like Delhi are already doing so because of non availability of adequate quantity through municipal supply. Rainwater harvesting and storm water management are methods which can raise the groundwater levels and become potential local water sources.

We strongly recommend rain water harvesting in all cities. These can also become recreational water bodies within the city and a possible source of income.

6.3.4.2 Institute Energy Efficiency Programs for Water Distribution and Water Treatment Facilities

Use of advanced conveyance equipment's such as motors, pumps, valves, pipe materials, blowers and compressors, etc., may also result in significant energy savings. For example, for a 25 hp motor running 23 hours per day (2 hours at 100% speed: 8 hours at 75% speed: 8 hours at 67%: and 5 hours at 50%) a

Variable Frequency Drive (an electronic controller that adjusts the speed of an electric motor by modulating the power delivered to the motor) can reduce the energy use by 45%. At Rs 5 per kWh, this saves about Rs 2.5 lacs annually [44].

All water works need to be given Energy Consumption Norms per cum of supply. These should be monitored as is being done for Power Companies. A system should be initiated for efficiency improvement.

6.3.4.3 Provide Metering and Consumption Slab Based Pricing

Metering enables Water Utilities to monitor usage and identify leakage [23]. Evidence from the UK shows an instant drop of about 10% in consumption when meters are installed. In Hamburg, Germany, domestic water consumption for metered apartments (112 liter/capita/day) was 18% lower than for unmetered apartments (137 liter/capita/day). The Municipal Utility, Hamburger Wasserwerke GmbH, had installed more than 40,000 water meters in individual apartments of older houses from 1985. (All new apartments had to be metered by law). Earlier, there was only a single meter for the entire house in multi-apartment houses [51]. To promote efficient usage of water, differential pricing based on consumption slabs as is done for power needs to be put into operation.

All urban consumers should be supplied with metered water and a price based on consumption slabs should be fixed as is done for power consumer to discourage overdrawals.

6.3.4.4 Make Reusing of Grey Water Mandatory

“Grey water” from bath, laundry and utensil washing can be reused to flush WCs. This may provide savings of around a third of daily household water demand which reflects an energy saving of 2.21 GWh/day and equivalent water generation. Thus gray water recycle has a potential to augment capacity of urban water supply by 30 %.

In all Societies and Townships, grey water recycle should be made mandatory to reduce fresh water demand and sewage load. This should be implemented immediately for all new dwelling units and in a phased manner, for existing buildings. As in the case of solar and kitchen waste , an appropriate tax exemption may be given by the Municipal Corporations, keeping in view the large expenditure savings in providing sewage and raw water treatment facilities.

6.3.4.5 Introduce Distributed Waste water treatment

Recommendations for Waste Water Supply envisage a distribution system where sewage is treated close to the generation point, thus saving energy. The treatment can be done at the Society level or even the house hold level, using low energy using technologies.

Only clean water should be let out from the place of generation and incentives may be given for the same. Alternatively, a cess on water waste sent to sewage facilities may be introduced, based on generation.

6.3.4.6 Make Water Saving Devices Mandatory

Water saving devices to be encouraged would include, inter alia, low flush and composting toilets, dual flush toilets, which includes two buttons or handles to flush different levels of water. Dual flush toilets use (upto) 67% less water than conventional toilets which implies saving 4 litres of water in a single flush. Use of Faucet aerators, break water flow into fine droplets to maintain "wetting effectiveness" while using less water may be encouraged. An additional benefit is that these reduce splashing while washing hands and dishes. Simply installing a high-efficiency showerhead like a Flow point shower head, would save 2.175 kWh of energy over a conventional showerhead [52].

Water saving gadgets should be given the same treatment as energy saving CFL bulbs and all inefficient systems would have to be replaced in phased manner.

6.3.4.7 Promote Private Sector Participation (PSP)

Poor performance of Public Water Supply Agencies is one of the major reasons for lack of progress in urban water supply schemes. Private Sector Participation in urban water supply may be promoted through a proper policy framework. Private Sector Participation (PSP) in this sector, as in many other sectors of the economy, e.g. Telecom and Roads, would improve water supply by providing improved management skills and incentives [22]. The private sector will also promote innovations to reduce costs which will benefit the cities in future.

Table 6.11 : Measures for Urban Water Crises and Associated Potential Savings

Measure	Potential savings
Process changes and retrofits. E.g. Use of Variable Frequency Drives (VFD's)	$ 5374 annually @ $ 0.10/kWh
Reuse of Grey water	2.21 GWh/d*
Meter and Measure water use	18% of water saving (reduces the per capita consumption rate from 137 lpcd to 112 lpcd)
Behavior change and fixture retrofits. i.e. Use of Flow point showerheads	2.175 kWh compared to conventional shower head

** includes energy savings earned due to water transportation, treatment, distribution and wastewater treatment*

6.3.4.8 Recycle Waste Water

Waste water from cities can be treated and recycled for charging the aquifers or augmenting water supply through the natural cycle. Singapore is already practicing this. Our cities should plan for treatment and recycle. Technology for safe recycle need to be studied and implemented.

We recommend a multipronged approach to urban water supply issues with these eight recommendations. The degree of usage depends on local conditions which should be included in town planning.

6.4 Energy Consumption in Sewage Water Treatment

6.4.1 Energy Consumption in Sewage Water Treatment

Water and energy management are important and interrelated issues. Sewage treatment, involving the physical, chemical and biological processes to clean industrial and domestic wastewater, requires high energy. It takes approximately 0.634 gigawatt hours (GWh) of energy to treat 1billion liter of sewage. The actual energy used depends on the quality of sewage and the intensity of treatment required [7].

Typically, there are three stages of treatment:

- Primary: Solids are physically settled out.
- Secondary: Bacteria convert organic matter to a carbon-rich sludge.
- Tertiary: Further treatment may be used to remove more organic matter and/or disinfect the water.

As is to be expected, the unit electricity consumption decreases with the size of the plant due to economies of scale. Also unit electricity consumption is higher as the degree of treatment and complexity of the process increases. Advanced wastewater treatment with nitrification is 3 times energy intensive (due to additional pumping requirements) than the relatively simple trickling filter treatment. Variations in unit electricity consumption with size are illustrated in Figure 6.7.

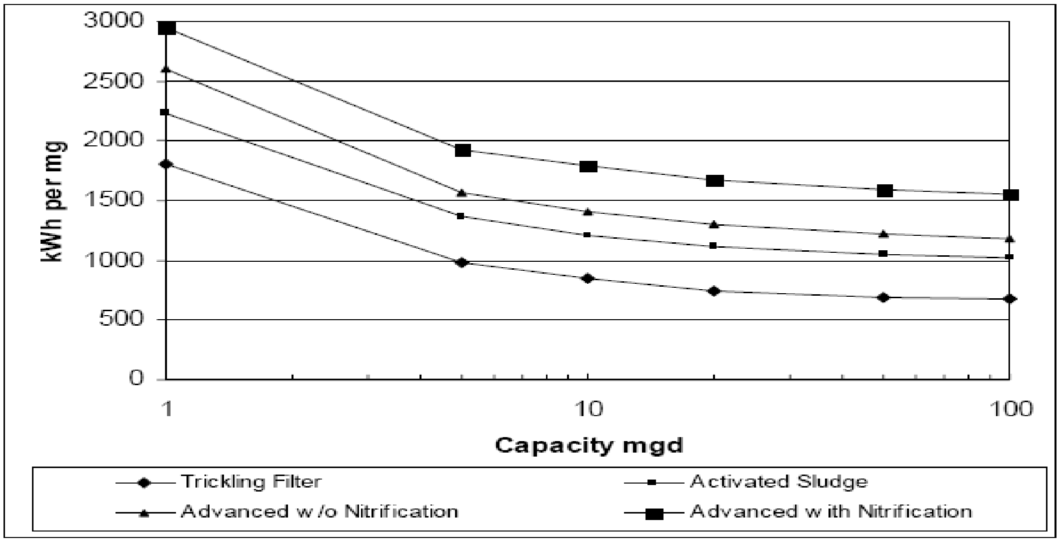


Figure 6.7: Variations in Unit Electricity Consumption with Size for Representative Wastewater Treatment Processes [20]

In a typical activated sludge facility, energy consumption distribution is: 50% aeration, 30% solid processing, 15% in-plant pumping and 5% for miscellaneous processes. Table 6.12 shows the energy requirement for different sewage treatment processes.

Table 6.12 : Unit Electricity Consumption for Wastewater Treatment by Size of Plant [20]

Treatment Plant Size (cubic meters per day)	Unit Electricity Consumption (kWh/m^3)			
	Trickling Filter	Activated Sludge	Advanced Wastewater Treatment	Advanced Wastewater Treatment (Nitrification)
3,758	0.479	0.591	0.686	0.78
18,925	0.258	0.362	0.416	0.509
37,850	0.225	0.318	0.372	0.473
75,700	0.198	0.294	0.344	0.443
189,250	0.182	0.278	0.321	0.423
378,500	0.177	0.272	0.314	0.412

Given the smaller size and potentially higher loadings, the unit electricity consumption in privately operated wastewater treatment facilities would be about 0.661 kWh/m^3. As these facilities typically discharge into surface water, it is likely that more aggressive wastewater treatment will be required over the next 20 years. This is likely to increase unit electricity consumption over the period by perhaps 5 to 10 percent.

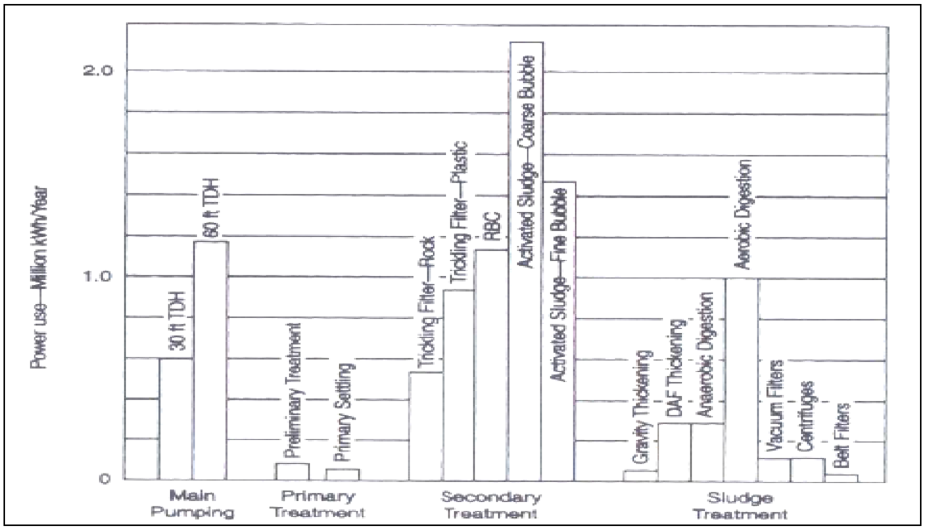


Figure 6.8 : Typical Energy Use Profile for 0.4m^3/sec (10mgd) Secondary Treatment Process [39]

Use of natural waste water systems such as ponds have lower energy consumption and value generation. (57) Availability of land is a major issue in implementing such technologies, but it would have good potential for the Indian environment in the long run.

6.4.2 Projections of Energy Consumption

In 2003, the volume of sewage generated was 26,254 MM l/day. Considering the population increase, this number would reach 33,437 MM l/day by 2022. By 2022, 45% of the total population will live in urban India. Hence, sewage contribution from the urban area will also increase and will require sewage treatment plants of higher capacities. The EPRI report projects, the baseline electricity consumption for wastewater treatment at about 21 billion kWh for the year 2000. This is expected to increase to about 26 billion kWh by 2020 and 30 billion kWh, by 2050.

Table 6.13 shows the projected sewage generated and the corresponding energy required for its treatment. The sewage generated is assumed to be 85% of the total water consumption and the energy calculations are made by considering that it takes 0.634 GWh of energy to treat 1 billion liter of sewage [7] as mentioned earlier.

Table 6.13 : Projected Energy Consumption for Sewage Treatment

Year	2000	2025	2050
Urban population (million)	310	560	910
Sewage generated (million m^3/day)	35.6	64.26	127.67
Energy consumption to treat sewage (GWh/day)	22.6	40.9	81.2

6.4.3 Benchmarks on Energy Consumption in Sewage Water Treatment

Quantities of all forms of energy consumed for collection, and treatment of municipal waste water were estimated by Smith. R, et al (1978). Heat energy was equated to electrical energy by a conversion factor of 10,500 BTU/kwh. Total energy consumption, expressed as kwh/mg of waste water treated, ranges from 2300 to 3700 kwh/mg. The use of high efficiency aeration devices, combined with good maintenance practices, appears to offer the best opportunity for conservation of energy within the plant [48]. The benchmark parameters are summarized in Tables 6.14 and 6.15.

Table 6.14 : Summary of Energy Benchmark Parameters and Energy Use Information for Secondary Wastewater Treatment Process and for Total Plant Operations [49]

Parameters	Range of Best Values Best
Energy/ kg BOD removed (kWh/ Kg BOD removed.)	0.9-5.7
Energy / ML treated (kWh/ML)	73-245
Oxygen Transfer Efficiency %	2.6-83
Electrical Use for total Plant Operations (kWh/ML)	258-509
% of total energy used for secondary treatment only	29-48

Table 6.15 : Energy Benchmark Parameters for Secondary Wastewater Treatment [49]

Secondary treatment process	Plant flow during data collection (MLD)	Energy used for secondary wastewater treatment (kWh/d)	Energy used for RAS, WAS & ML (%)	Energy used per Kg of BOD removed (kWh/ Kg BOD removed)	Energy used per ML treated (kWh/ ML)	Oxygen transfer Efficiency (%)	Electrical use for total plant operat-ions (avg kWh/ d)	Electrical use for total plant operations (avg kWh/ML)	% of total plant energy used for secondary WWT
RBC	0.5	1166	10	1.1	171	NA	1931	283	60
Bio-tower/ AAS	2.7	5007	8	0.9	134	17	15000	392	33
AAS	0.6	5708	6	4.2	641	3.8	10270	1131	56
AAS	3.0	9328	7	1.3	214	5.7	19433	446	47
AAS	0.4	2471	12	5.7	387	2.6	4290	667	58
AAS with N/D	5.1	24189	10	2.0	329	6.1	89813	1223	27
AAS with N/D	1.4	8107	4	4.9	398	5.2	NA	NA	NA
HPO-AS, PSA	1.5	12168	2	3.3	587	60	22124	1063	55
HPO-AS, PSA	5.2	14375	8	2.6	192	60	45716	604	31
HPO-AS, Cryo	16.6	46557	22	1.5	199	83	101650	373	49
TF	1.3	1397	NA		74		4892	258	29
AAS	1.3	2873	7		152		6779	358	42
AAS with N/D	1.3	4640	6		245		9631	509	48

Note:
RBC - rotating biological contactor. AAS - air activated sludge. AAS with N/D - air activated sludge with Nitrification and Denitrification. HPO-AS PSA - high purity oxygen activated sludge, oxygen produced by pressure swing adsorption. HPO-AS Cryo - high purity oxygen activated sludge, oxygen produced by cryogenic process. TF - Trickling Filters.

6.4.4 Recommendations for Sewage Water Treatment for Energy Optimization

All established and widely practiced sewage treatment techniques are energy intensive. Indian urban sewage treatment facilities are under development which need to be expedited. Hence for both energy and water security in urban areas, programs and policies addressing the specific issues need to be framed and implemented.

6.4.4.1 Implementation of Distributed Sewage Treatment

Implement distributed sewage treatment and where land is available, waste stabilization ponds can be explored. These are self sustainable and energy efficient natural systems and can be a potential source of revenue through promoting recreational activity. Planners need to assess such options in a long term perspective as is done for other infrastructure projects.

6.4.4.2 Extract Energy from Waste

There are mature, widely-practiced technologies for generating fuels from sewage treatment. Research has identified methods for exploiting sewage as an energy resource in future. In 2005 – 2006, the amount of renewable energy generated on water industry sites was 493 GWh - 6.4% of the total energy used to treat water and wastewater. Some of these technologies include sludge incineration and biogas production from sludge treatment. [7] These are briefly noticed hereunder:

- **Biogas**

Biogas production from sewage treatment, via a process called anaerobic digestion, is a well established means of generating energy. For each MGD processed by a plant with anaerobic digesters, the biogas available can generate energy upto 35 kW. The heating value of the gas produced from the anaerobic digesters is nominally 60 percent of that of natural gas (1000 BTU per cubic foot); however, with maximum digestion and proper cleanup, it can be increased to as much as 95 percent. For instance, the Point Loma Plant serves a 450-square-mile area in and around San Diego, California, and has a capacity of 910 million litres per day. The plant is energy-self-sufficient and sells excess energy in the form of electricity to the grid. The methane produced by the digesters from this plant, also fuels two internal-combustion reciprocating engines that run generators with a total capacity of 4.5 MW [47].

- **Process Modifications**

The County Sanitation Districts of Orange County (CSDOC) provides wastewater treatment for a population of about 2.1 million people. It operates two treatment plants, with a combined average wastewater flow of about 235 MGD. Application of Advanced Primary Treatment (APT) at both plants increased solids and BOD removal in the primaries. This resulted in an increase in biogas production, as the energy content of the solids recovered from the primaries is greater than that for solids recovered from secondary treatment. Increasing the amount of primary solids sent to the anaerobic digesters results in increased biogas production, equivalent to 3,000 KW. Hence, the reduced secondary treatment because of APT saved 1700 KW of energy. The annual saving estimated is about $ 1,200,000 [46].

- **Highly-efficient Submersible Mixers for Wastewater Pond Aeration**

Another area of interest is small scale treatment plants and the opportunities to increase energy efficiency at these sites. Small scale onsite treatment is an alternative when discharge to sewers is expensive or not possible. For residential rural households, septic tanks are often used, but another traditional on site method is the stabilization pond. Single wastewater treatment ponds have a low energy intensity compared to large advanced treatment plants, but these are sometimes compared to trickling filter plants (0.25 kWh m^{-3}) (EPA). Also, by creating an engineered wetland to process wastewater, DuPont estimates it saved roughly $9-12 million over conventional wastewater treatment.

6.4.4.3 Promote Innovation in Sewage Water Treatment

There are several novel technologies that produce energy or fuel as a by-product of sewage treatment, although further work is needed to improve performance, reliability and cost-effectiveness.

- **Conversion of bio-sludge to oil and gas**

Under carefully controlled conditions and extreme temperatures (450 – 1000^{o}C), sludge may undergo chemical reactions to produce fuels that may be used for energy production. Processes include gasification, producing syngas (similar to natural gas), and pyrolysis, producing bio-oil (similar to diesel oil).

- **Biomass crop**

In Northern Ireland, sewage sludge, equivalent to almost 3,000 tones dried solids, is applied as fertilizer to willow plantations. The trees are periodically coppiced and the wood used for fuel. Research into applying partially-treated, liquid sewage to biomass crops is also underway. Passage of the sewage through the soil, acts as a final polishing step for treatment, degrading organic matter, reducing nitrogen and phosphorus and producing a cleaner effluent. Little energy is required and capital and operational costs are low. However, it is not yet known how efficient this system will be at removing pollution and appropriate land must be available.

- **Hydrogen from Sewage**

There is a lot of interest in Hydrogen as a fuel because it can be produced from a wide range of materials and provides power with minimal air pollution. One source is organic wastes, such as high carbohydrate wastewater from breweries. Bacteria use organic matter to produce Hydrogen by fermentation. However, yields to date have been low, typically less than 15% of the maximum theoretically possible. Also, applications for Hydrogen, e.g. fuel cells, are not yet in widespread use.

- **Microbial Fuel Cells and anaerobic Membrane Bioreactor**

These devices offer the possibility of simultaneous sewage treatment and energy production to generate recyclable water quality, CH_4/CO_2 and inorganic residue as by-products. Bacteria use organic matter to produce electricity/biogas.

To sum up, our sewage treatment models need to be entirely different from those in the West, in view of our climatic conditions and population. We recommend planning and use of the most appropriate and known energy-efficient technologies as well as investment in research for developing India centric technologies.

6.5 Energy Consumption in Industrial Water and Effluent Treatment

6.5.1 Energy Consumption in Industrial Water Treatment

Industry is the second largest user of water after agriculture. However, the amount of water used varies widely from one type of industry to another. The largest single use of water by any industry is for cooling in thermal power generation. Industry uses water in various production processes and chemical reactions, as well as to make steam for direct drive power. Increasingly, Industry recycles and reuses this water over and over again. Water is used to make every product on the earth, and hence all businesses, in all sectors, depend on it some way. Some water experts use the term “virtual water” to describe the water embedded both in agricultural and manufactured products, as well as the water used in the growing or manufacturing process. When a country exports goods, it is exporting “virtual water”. A similar concept is “water footprint”. This looks at the total direct and indirect volume of freshwater that is used or consumed to produce the goods and services consumed by an individual or community or produced by a business.

Interestingly, many businesses have a supply-chain water footprint and/or an end-user footprint that is much larger than the operational water footprint. For example, the water it takes to grow and produce food products, and the water people need for personal washing and laundry [2].

FDI (Foreign Direct Investment) equity inflow in the industrial sector has grown from $1.93 Bn in 2004–2005 to $17.68 Bn in 2007–2008. Between 2006 and 2010, investment in infrastructure development is planned to be 7.7% of India's GDP. The manufacturing sector grew at an average of 8.6% between 2002 and 2007 and is expected to grow at 9.5% per annum in 2008-09. Thermal power plants (the most water-intensive industrial units), constituted 64.6% of the installed power capacity in India during 2008. [3]

The energy consumption for water use varies from industry to industry. Whereas thermal power, textiles, pulp and paper and iron and steel are highly water intensive sectors, industrial sectors like chlor-alkali, cement, copper and zinc and plastics require little water as shown in Table 6.16.

Table 6.16 : Water Use in Indian Industries [29]

Industrial Sector	Annual wastewater water discharge (million cubic meters)	Annual consumption (million cubic meters)	Proportion of water consumed in industry (%)
Thermal power plants	27000.9	35157.4	87.87
Engineering	1551.3	2019.9	5.05
Pulp and paper	695.7	905.8	2.26
Textiles	637.3	829.8	2.07
Steel	396.8	516.6	1.29
Sugar	149.7	194.9	0.49
Fertiliser	56.4	73.5	0.18
Others	241.3	314.2	0.78
Total	30729.2	40012.0	100.0

A major area of concern is the inefficient use of water by industry. The ratio of water consumption and economic value creation in Indian industry is poor. For every cubic meter of water used by the Indian industry, it generates US $7.5 industrial productivity as shown in Table 6.17.

Table 6.17 : Industrial Water Productivity of Different Countries [29]

Country	Industrial water use (billion cubic meters)	Industrial productivity (million US $)	Industrial water productivity (US $/cubic meter)
Argentina	2.6	77171.0	30.0
Brazil	9.9	231442.0	23.4
India	15.0	113041.0	7.5
Korea, Rep.	2.6	249268.0	95.6
Norway	1.4	47599.0	35.0
Sweden	0.8	74703.0	92.2
Thailand	1.3	64800.0	48.9
United Kingdom	0.7	330097.0	443.7

Water and energy requirements for some of these high water consuming industries are discussed in the subsequent sections. Power industry, which is the largest industrial user of water, has been discussed in a separate section.

6.5.1.1 Paper and Pulp Industry

In perhaps no other industrial process, the product that is being produced and water consumption are more intertwined than in the Paper industry. Most of the processes involve the use of large quantities of water; in fact, when leaving the head box of a paper machine, the stock solution is 99% water and 1% fibre. [28]

Wastewater treatment in the Paper and Pulp Industry, typically, includes (a) neutralization, screening, sedimentation, and floatation/hydrocycloning to remove suspended solids and (b) biological/secondary treatment to reduce the organic content in wastewater and destroy toxic organics. Chemical precipitation is also used. Fibres collected in primary treatment need to be recovered and recycled. A mechanical clarifier or a settling pond is used in primary treatment. Flocculation to assist in the removal of suspended solids is also sometimes necessary. Biological treatment systems, such as activated sludge, aerated lagoons, and anaerobic fermentation, can reduce BOD by more than 99% and achieve a COD reduction of 50% to 90%. Tertiary treatment may be performed to reduce toxicity, suspended solids, and colour [27].

6.5.1.2 The Chemical Industry

It has the potential to use more than 400 km^3 of water each year most of it for cooling purposes. Table 6.18 shows the water usage by unit operation for several industry segments. [28]

Table 6.18 : Water Usage by Chemical Industry Segment [28]

	Water used [kg/kg of product]			
Segment	**Cooling water**	**Process water**	**Steam**	**Total water use**
Ethylene	198	3.6	14.5	216.1
Phosphoric acid	135	4.2	1.3	140.5
Propylene	135	2.4	0.8	138.2
Polyethylene	82	0.5	0.4	82.9
Chlorine	70	3.0	1.8	74.8
Sulphuric acid	66	0.4	0.4	66.0

Sea water desalination Nirma Bhavnagar

Recycle plant

6.5.1.3 The Steel Industry

Water usage rates in a Steel plant can vary widely, from 0.63 to 27 m^3/tonne, depending upon the type of steel plant, water quality, environmental restrictions, cooling system design and various other factors.

A summary of water consumption rates by major processes is shown in Table 6.19. With the use of Best Available Technology (BAT), water consumption rates can be reduced to less than 1m^3/tonne in electric arc furnace steel plants (mini-mills) and to less than 5m^3/tonne in large integrated steel works. [28]

Table 6.19 : Water Usage Rates by Steel Making Processes [28]

Best available technology (BAT)	m^3/tonne
Blast furnace	1.5
Basic Oxygen Furnace	8.8
Direct Reduction	1.2
Electric Arc Furnace	1.0
Continuous Casting	4.2
Hot Strip Mill	13.0

6.5.2 Projections of Energy Consumption

- Production dependent industries are expected to grow in the coming years
- Industrial water consumption is expected to quadruple between 2000 and 2050
- By 2050, industrial water consumption will reach 18% of total annual water consumption, up from just 6% in 2000 [3]

Table 6.20 : Characteristics of Water and Energy Use by Sector in China [42]

Sector	Gross output/ direct use (yuan/m3)	Embodied Energy Intensity (MJ/yuan)	Embodied water intensity (MJ/1000 yuan)	Energy-water use ratio (MJ/m3)
Agriculture	9	1.9	356.8	5
Mining	100	4.6	7	656
Manufacturing	508	3	6.7	510
Chemicals	276	7.1	11.4	617
Building Materials & metals	357	6.5	10.6	620
Equipment	484	4.7	8.2	566
Electronics & instruments	605	4.5	9.8	456
Electricity & gas	156	18.5	12.9	1439
Refining & coking	399	20.1	7.2	2816
Water	12	6.6	94.6	69
Construction	562	4.7	8.8	538
Transport & telecom	302	3.7	8.4	439
Trade	286	2.5	8.1	309
Restaurants	172	2.1	9.7	214
Services	252	3	11.2	267
Average	87	3.7	8.5	433
Notes: Embodied energy and water intensities are calculated as unit energy or water per unit sect oral GDP				

6.5.3 Benchmarks on Energy Consumption in Industrial Water Treatment

In the 50 years from 1950 to 2000, world industrial water withdrawals climbed from 200 km^3/year to almost 800 km^3/year, while industrial water consumption increased from 20 to about 100 km^3/year. The relationship between industrial water withdrawal and industrial growth is not linear, as technological advances lead to water savings as well as water reuse in industry. Hence industrial water withdrawals in many developed countries have flattened off, while industrial water consumption (which is only a fraction of the total water withdrawal) continues to grow [25].

The benchmarks for different industries have been given in Table 6.21, which shows the water consumption of Indian industries and the corresponding water consumption of industries having globally best technologies. Hence these globally best figures can be considered as benchmarks for water consumption for Indian industries.

Table 6.21 : Water Consumption in Indian Industries Compared to the Globally Best [29]

Sector	Average water consumption in Indian industry	Globally best
Thermal power plant	On an average 80 m^3/ MWh(1)	Less than 10 m^3/MWh(2)
Textiles	200-250 m^3/ tonne cotton cloth(3)	Less than 100 m^3/ tonne cotton cloth(2)
Pulp & Paper	• Wood based mills: 150 - 200 m^3/ tonne(3) • Waste paper based mills: 75 -100 m^3/ tonne(3)	• Wood based mills: 50 - 75 m^3/ tonne(4) • Waste paper based mills: 10-25 m^3/ tonne(4)
Integrated Iron & steel plant	10-80 m^3/tonne of finished product	5 -10 m^3/ tonne of finished product; Best is around 25 m^3; less than 0.1 m^3 wastewater per tonne finished product(5)
Distilleries	75-200 m^3/ tonne alcohol produced(6)	Data not available
Fertiliser industry	• Nitrogenous fertiliser plant - 5.0 - 20.0 m^3/ tonne(3) • Straight phosphatic plant - 1.4 - 2.0 m^3/ tonne(3) • Complex fertiliser - 0.2 - 5.4 m^3/ tonne(3)	An effluent discharge of less than 1.5 m^3/ tonne product as P_2O_5(2)

Source: *1. No credible data available. Estimates done by CSE from wastewater discharge data from "Water Quality in India, Status and trends (1990-2001), CPCB, MoEF" and annual electricity generation data from "Annual Report (2001-2002) on the working of state electricity boards and electricity department, Planning Commission." 2. Pollution prevention and abatement handbook, World Bank. 3. Environmental management in selected industrial sectors - status and need, CPCB & MoEF, February, 2003. 4. Green Rating of Pulp and Paper Sector, CSE. 5. Integrated Pollution Prevention and Control (IPPC), Best available techniques reference document on the production of iron. 6. Environmental performance of Alcohol industry in UP, UPPCB, 2000-2001.*

6.5.4 Recommendations for Industrial Water Treatment for Energy Optimization

Industry is probably the least subsidized sector, and as such, has the greatest incentive to use resources efficiently. This will become even more important as fuel prices, and consequently energy costs, continue to rise and attempts are made to lower energy costs by reducing water use. In Newsprint and Kraft Pulp Mills, energy demand may be reduced by recovering heat from one process and redirecting it to another, e.g. heating water. The main drivers identified for improved water management are:

- Segregation of waste and stream specific wastewater treatment
- wastewater reductions and standards compliance
- environmental policy/regulations
- changes in water quality and availability

Consequently, reducing water consumption, development of water friendly and green processes and recycle, without affecting plant performance, can be considered a realistic and cost effective strategy. As a result, the industrial sector is the one sector that is making tangible progress towards more efficient use of water and water recycling, ultimately reducing its water intake, and in turn reducing energy use. Between 1981 and 1996 industrial water intake declined from 11,042 million cubic metres (MCM) to 7,508 MCM while production doubled [1].

Recommendations for water consumption optimization and related energy reduction in Industry are as under:

- Set norms for freshwater consumption and institute PAT scheme
- Encourage process improvement to reduce water and energy consumption by providing appropriate incentives for efficient equipments, (through subsidy if necessary) to make investment attractive.
- Power Plants would be the major water consumers in future. Appropriate planning should ensure that fresh water is not used for condenser cooling and only sea water/waste water is deployed. All new power plants should come under the new regime and the existing ones should shift in a phased manner.
- A mission mode approach is needed for the development of technologies for water free cooling in Power Plants without affecting efficiency adversely.
- Facilitating use of high energy efficiency water treatment equipments through proper incentives as return on investment are not high in view of low water costs.

Industrial Wastewater treatment facilities can reduce energy use by replacing/retrofitting existing equipment with high-efficiency and better-sized equipment, particularly as the equipment installed reaches the end of its useful life. Purchasing high efficiency pumps and motors can reduce wastewater treatment facility energy use, as pumps and aeration systems contribute 50 to 90% of the total energy use.

- **Recycle and reuse**

In textile industry, recycle and reuse of the water through various treatment processes can reduce overall energy consumption and cost. Producing recyclable water quality through wastewater treatment in textile industry would require 3.3 kwh/m^3. This in turn, would save Rs 20/m^3 of treated water recycled, based on the assumption that 80% of discharged effluent is treated and recycled to close the water cycle. It is also assumed that the cost of the water in the industrial belt would be around Rs 35/m^3 and the treatment cost would be around Rs 15/m^3.

- By reducing water consumption by 40%, BP Industries, Australia saved more than $ AUS 1.33 million [53].
- SAIL Steel plants, Tata Steel and IOCL refineries reduced water consumption manifold reducing water requirement and effluent generation as well as costs.

6.6 Water Consumption in Fossil Fuel/Nuclear Energy Generation

6.6.1 Water Consumption in Power Plants

As mentioned earlier, the largest single use of water by industry is in thermal power generation. In thermoelectric plants, 0.47 gal (1.8 L) of fresh water is evaporated per kWh of electricity consumed at the point of end use. In a typical thermoelectric power plant, heat is removed from the cycle with a condenser. In order to remove the heat, cooling water is used. The cooling water (and related heat) can be discharged into a river, a reservoir, or an ocean as shown in Figure 6.9. This practice is being replaced by evaporating a portion of the cooling tower water and transferring heat into the air by evaporating water. The reason for using cooling towers is to minimize the environmental impacts from withdrawing the abundant amount of water and quickly dumping it back into the stream [4].

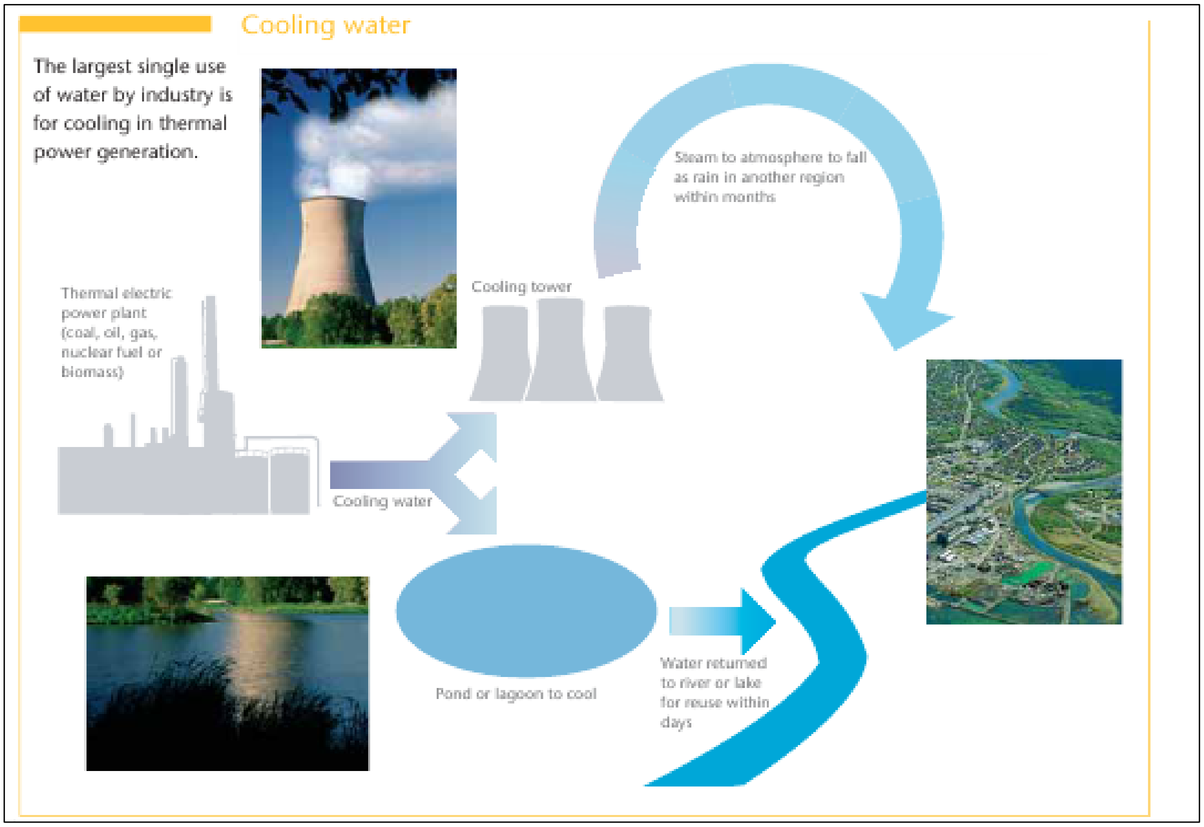


Figure 6.9 : Water Used For Cooling in Thermal Power Generation [2]

The specific water consumption of coal based power plants varies between 3.5-8 liters/kWh. In thermal power stations, by quality considerations and end use considerations, rank water as: Raw water, Clarified water, Drinking water, DM water, Service water, Ash water, Cooling water, or Circulating water, Fire water, etc. For all these, variants, raw water is the main source. Normally, raw water is sourced from a nearby river irrigation canal or a pond. For handling all these different type of water streams, a number of pumps and pumping stations are used. Table 6.22 presents the water consumption (in terms of raw water) for various purposes in a typical coal based super thermal power plant of capacity 2100 MW with ash water recycling facility. It can be seen that ash handling consumes the major quantity, to the tune of more than 40 percent, followed by the cooling towers (to compensate for evaporation losses). DM water consumption is the only minor quantity to the tune of only 2-2.5 percent in terms of raw water [13].

Table 6.22 : Water Consumption in a Coal Based Super Thermal Power Plant [13]

Area	Quantity m^3/hr with ash water recycling	Consumption (m^3/MW)	%
Ash Handling	4180	2	41.4
Cooling towers	32070	1.5	30.4
DM water	260	0.13	2.6
Drinking water (colony + plant)	640	0.32	6.3
Coal Handling	130	0.065	1.3
Fire fighting	476	0.37	4.7
Others	1334	0.66	13.2
Total	100090	5	100

Table 6.23 : Typical Range of Specific Water Consumption Figures of Different Power Plants [13]

Power Plant Type	Range (m^3/MW)
Gas based power plants	1.7-2.0
Total dry ash handling power plants	3.0-3.5
200 MW coal based thermal power plants with once trough system	3.0-3.5
200 MW coal based thermal power plants	4.5-5.0
500 MW coal based super thermal power plants	4.0-4.5
200 MW coal based power plants with ash water recycling	3.5-4.0
500 MW coal based super thermal power plants with ash water recycling	3.0-4.0
110 MW coal based oil power plants	7.0-8.0

Water requirement for a coal-based power plant is about 0.005-0.18 m^3/kwh while that for a natural gas plant is about 0.003 m^3/kwh. At Ramagundam Super Thermal Power Plant (RSTPP), the water requirement has been reduced from about 0.18 m/kWh to 0.15m^3/kwh by the installation of a Treatment Facility for the Ash Pond. At Chandrapur also a major part of treated effluent is utilized for ash slurry preparation, while a part of the ash pond overflow is discharged into the river [56].

6.6.2 Projections of Energy Consumption in Power Generation

- Annual per capita consumption of power is expected to grow from 704.2 kWh in 2008 to 1,000 kWh by 2012
- 75% of the total planned power capacity expansion is projected to come from thermal power

Table 6.24 gives the projections Water and related Energy use in the Power Sector. Data are available only till 2021, and those for the following years were obtained by extrapolation. Specific water consumption was taken as 5 liters/kWh, from which water consumption was calculated. For calculating energy consumption, specific energy was taken as 0.5MW/m^3 as mentioned in the earlier table. This is given in Table 6.24.

Table 6.24 : Projections of Water Consumption by the Power Sector

Year	Electrical energy requirement at power station (GWh)	Water consumption (million cubic meters)	Energy consumption (GW) X10^-3
2011	968659	4843.29	2421
2021	1914508	9572.54	4786
2031	3506459	17532.295	8766
2041	6928246	34641.230	17320
2051	13689193	68445.965	34223

Hence, the Power sector is going to consume a large quantity of water even though power consumption in India is low compared to that in other countries as shown in the Table 6.25.

Table 6.25 : Country Wise Electricity Consumption [31]

Country	Electricity consumption (GWh/day)
China	3444108
USA	4401698
EU	3635604
India	860723

6.6.3 Benchmarks on Water Consumption in Power Generation

Most of the Thermal Power Plants (TPPs) in India are in the Public Sector and are one of the highest consumers of water as compared to their global counterparts. On an average, for every 1000 Kwh power, Indian TPPs consume as much as 80 cubic meters of water. The major reason for this very high result is the widespread prevalence of 'once-through cooling systems' [29].

The benchmark fresh water consumption in the modern TPPs is less than 10 cubic meters for every 1000 Kwh. This is the benchmark that Indian TPP’s needs to target.

6.6.4 Recommendations for technologies and policies for water optimization

A number of technologies are in various stages of development with a potential for reducing the use of water per unit of energy (the water intensity) for power generation. These technologies will be deployed when they are economical, based on changes in water value and availability.

Some of the technologies available are as under:

- **Dry Cooling**

One approach to reducing water use in thermoelectric plants is replacing the evaporative cooling towers in closed-loop systems with dry cooling towers cooled only by air, with an impact however on plant efficiency. Evaporative closed-loop cooling provides cooling that approaches the dew point temperature. Dry cooling can approach only the ambient air temperature. Unless the relative humidity is 100 percent, air temperature is always higher than the dew point, so the outlet temperature of a dry-cooling system will always be higher than that for an evaporative system. As the cooling system outlet temperature increases, plant efficiency decreases. In other words, plant efficiency is higher for plants using evaporative cooling than for plants using dry cooling, especially in a hot, arid climate. So although these towers reduce water consumption, plant efficiency is low. In view of these factors, dry cooling is best suited to wet, cool climates. Wet cooling on an average consumes 40 liters/day/Kw of water. As dry cooling does not use water, this amount of and the associated cost of water treatment may be saved.

- **Hybrid Cooling:**

To counter some of the disadvantages of “dry” cooling, systems have been devised to pre-cool the incoming air by evaporating water, using generally either a pad or spray arrangement. This reduces the sink temperature, sometimes to temperatures approaching those of “wet” cooling. The major drawback, other than the high cost of these systems relative to “wet” cooling, is the high water consumption while running “wet”. In Sydney conditions, this can be as high as 160 litres/day/kW. Water savings are achievable only in situations where, due to load and ambient conditions, extended dry operation is possible [36]

- **Natural-Gas-Fired Combined-Cycle**

Gas turbines use (withdraw and consume) about half as much water as coal-fired plants and have been deployed in large numbers in recent years. Gas turbines in these plants provide two-thirds of the power generation. The hot exhaust from the gas turbine is used to generate steam, which drives a steam turbine to provide the balance generation. Water use is reduced because only the steam turbine requires condensate cooling. The gas fired combined cycle is the most efficient commercial technology with heat rates of only 5880 BTU/kWh (58% efficiency), but further improvements are expected in the near future.

- **Integrated Gasification Combined-Cycle (IGCC)**

Power plants are being developed that combine coal gasification with a combined cycle gas turbine. As with the natural-gas combined-cycle plants, water use is lower than for conventional thermoelectric plants although some water is consumed in converting coal to syngas [5].

- **Technology Development for Low Water Consumption**

A Mission Mode Project needs to be initiated to reduce water consumption by Power Generation plants. Appropriate technology development for dry ash disposal system, dry cooling towers, etc, need to be initiated urgently.

6.7 Water Consumption for Hydro Power

Hydroelectric power, an important component of electricity generation, varies greatly with the amount of water available, depending upon weather patterns and local hydrology, as well as on competing water uses, such as flood control, water supply, recreation, and in-stream flow needs (e.g., navigation and the aquatic environment). In addition to being a major source of base load generating capacity in some regions, hydroelectric power plays an important role in stabilizing the electrical transmission grid and in meeting peak loads, reserve requirements, and other ancillary electrical energy needs because it can respond very quickly to changing demand [5].

Water flow through hydroelectric turbines averages 12 billion m^3/day or nearly ten times the withdrawals of water from rivers. The United States Geological Survey (USGS) does not report it as water withdrawn because it remains in the river and, in fact, can be used many times by successive dams. However, reservoir operation can shift water releases in time relative to natural flows. When hydropower projects involve large storage reservoirs, evaporation of water from those reservoirs can be a significant consumptive use. However, water storage in hydropower reservoirs usually has multiple purposes; thus, hydroelectric power is not the only cause of these evaporative losses [5]. Figure 6.10 gives the net hydroelectric power generation of different countries.

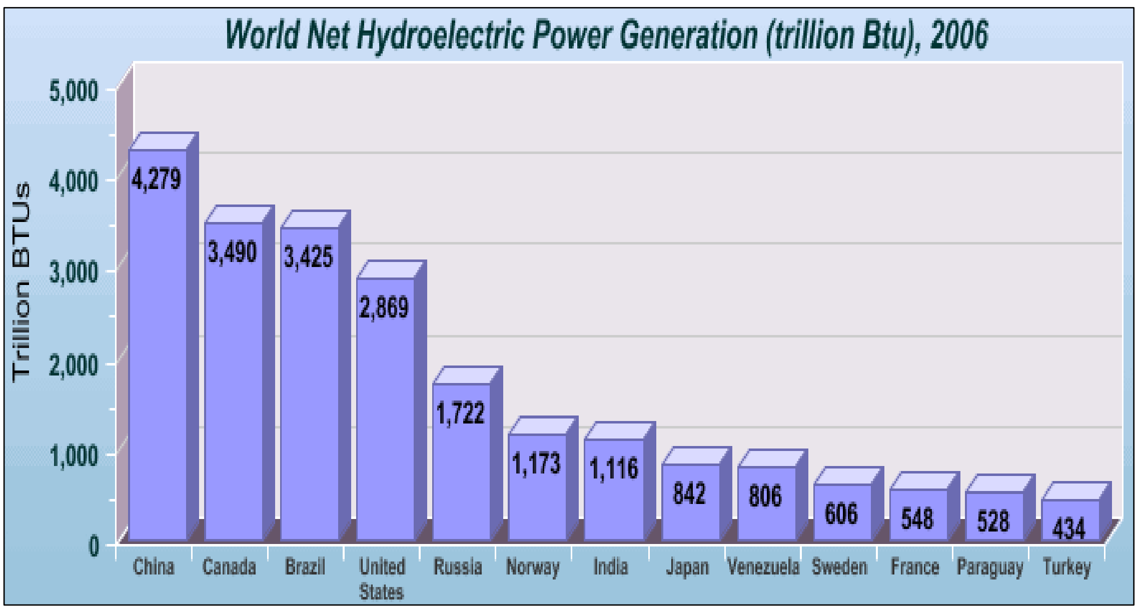


Figure 6.10 : Net Hydroelectric power generation in the world [15]

Hydroelectric potential in India is given in table below [56].

Basin/Rivers	**Probable Installed Capacity (MW)**
Indus Basin	33,832
Ganga Basin	20,711
Central Indian River system	4,152
Western Flowing Rivers of southern India	9,430
Eastern Flowing Rivers of southern India	14,511
Brahmaputra Basin	66,065
Total	1,48,701

The installed capacity as on today is 36878 MW. Almost 30% of water in major rivers except the Brahmputra pass through hydro power plants performing both doing duel work of irrigation and power generation.

6.8 Water Consumption in Other Power Generation Units Like Solar, Geothermal

Solar - Utilities are showing an increasing interest in deploying/ concentrating solar power plants to meet the requirements of State Renewable Electricity Standards. Dish systems, which already use air cooled engines, need only water for mirror cleaning. Troughs, linear Fresnel, and power towers use the heat of the sun to power conventional Rankine steam cycles. As with fossil and nuclear-power plants, water cooling is preferred to minimize cost and maximize cycle efficiency and most water is consumed for condenser cooling with less than 10% used for mirror cleaning. However, most large size solar thermal plants will be in the desert and arid areas and hence there are concerns about water shortages in solar plants. As mentioned in the Thermal plant review, direct or indirect dry cooling can eliminate over 90% of the water consumed in a water-cooled concentrating solar power plant. However, a combination of a reduction in power output and the added cost of the air cooling equipment might add roughly 2 to 10% to the cost of generating electricity, depending on the plant location and other factors. The use of hybrid parallel wet/dry coolers is estimated to reduce the energy cost penalty to below that of air cooling alone while saving about 80% of the water compared to a water-cooled plant [6].

Geothermal Electric Power – Geothermal power plants use the earth as their source of thermal energy. Some geothermal wells provide steam, while others provide hot water. Steam sources use steam Rankine cycle turbines much like coal and nuclear plants, but on a smaller scale. Over time, geothermal steam sources may decline, not because the heat of the resource has been consumed, but because the water/steam resource is being withdrawn faster than it is being recharged. For that reason, it is desirable to recharge the resource. Geothermal systems using hot water sources typically employ an air-cooled binary cycle, where the geothermal heat is used to evaporate an organic working fluid that drives an organic Rankine-cycle turbine. The organic working fluid is condensed in air cooled towers, although hybrid wet/dry cooling has been explored to improve performance in hot weather. In the dry cooled systems, all of the geothermal water is returned to the geothermal resource, so consumption is limited to other site needs.

Table 6.26 : Potential and Existing Capacity of Alternate Sources of Energy [16]

	Potential (MW)	Existing Capacity (MW)
Wind	45000	4400
Small Hydro (Upto 25 MW)	15000	1700
Solar (PV)	20 MW/ Sq. Km	Very Little
Biogas Plants	12 million	3.8 million
Urban/Industrial waste based plant	2700	Very Little

Amongst all renewable sources, solar PV and hydro do not require large volume of water. Rest consume water similar to thermal plants since they work on Rankine cycle.

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CHAPTER 7

Meeting the Water Challenges, 2025-2050

7.1 Introduction

The projected water demand for 2050 with 10 % improvement in irrigation efficiency and 46.5% increase in crop productivity is assessed at 735 BCM. In addition, there are demands from industrial, domestic and other sectors (373 BCM) raising the water demand bar to 1108 BCM against the total utilizable quantity of 1123BCM. We have also to take into account the growing ecosystem demands, as appreciation for the spiritual, recreational and aesthetic services provided by water is growing with development of economy. The environmental demands to maintain ‘C’ category status (moderate modification in the ecosystem that would not seriously modify biodiversity and habitat) are placed at 501 BCM (33 % of total renewable water resources) while for category ‘D’ (largely modified ecosystem), it is 353 BCM (Amarasinghe et al, 2007). Hence, our current water portfolio is heavily imbalanced. Besides, there is always some degree of risk, which gets multiplied, if droughts occur in succession because of monsoon failure. Basin-wise water supply and demand balance for 2025 and 2050 (Table-7.1) indicates that basins like the Indus are currently physically water-deficient and are surviving on groundwater overdraft, which is unsustainable. It is therefore imperative that we take serious note of the available water demand and supply management options.

Table 7.1 : Water Supply and Demand Balance in various River Basins in India (BCM)

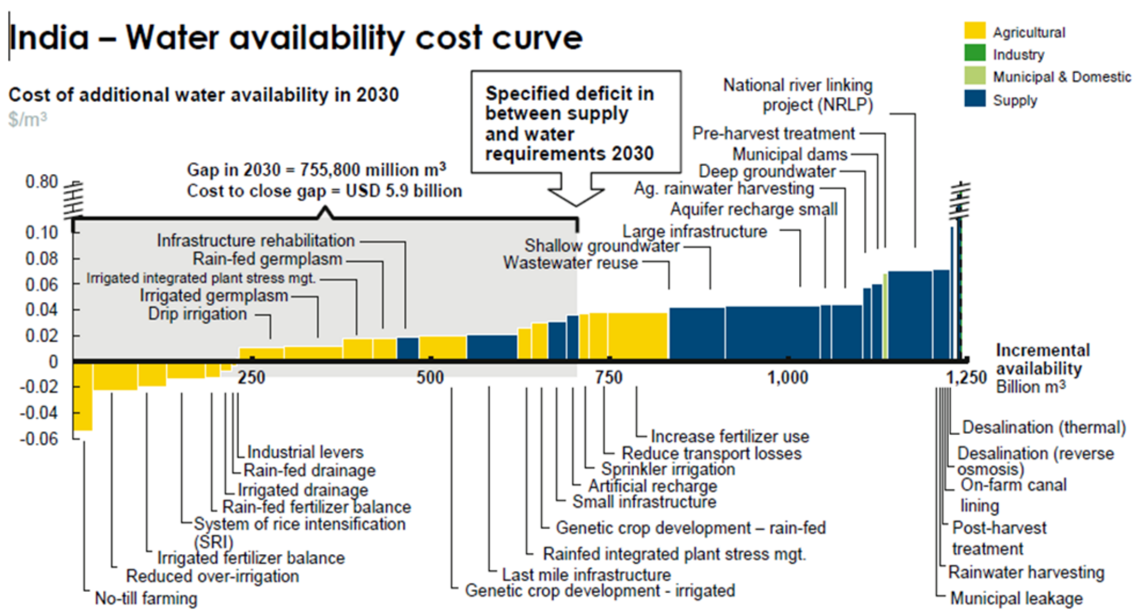
Basin	2025					2050				
	Total Sp	Irri	Ind& Dom	Total Dm	Bal	Total Sp	Irri	Ind& Dm	Total Dm	Bal
Indus	66	87	14	101	-35	72	85	20	105	-33
Ganga	339	280	98	378	-39	421	307	141	448	-27
B.Putra&Barak	40	12	19	31	9	59	15	27	42	17
Subarnarekha	6	5	3	8	-2	8	5	4	9	-1
Brahmani-Baitarani	11	8	4	12	-1	22	8	6	14	8
Mahanadi	46	31	11	42	4	66	34	15	49	17
Godavari	105	48	20	68	37	117	54	29	83	34
Krishna	83	56	21	77	6	84	62	30	92	-8
Pennar	12	8	3	11	1	12	8	4	12	0
Cauvery	31	26	9	35	-4	31	23	12	35	-4
Tapi	22	9	5	14	8	23	10	7	17	6
Narmada	45	18	8	26	19	45	19	12	31	14
Mahi	7	5	3	8	-1	7	6	4	10	-3
Sabarmati	5	8	3	11	-6	5	10	4	14	-9
WFR1	21	25	11	36	-15	26	31	16	47	-21
WRF2	51	11	14	25	26	54	10	21	31	23
EFR1	19	19	6	25	-6	22	19	8	27	-5
EFR2	26	33	9	42	-16	26	30	13	43	-17
Total	935	689	261	950	-15	1103	735	373	1108	-5

Sup-Supply, Dm-demand, Irri-irrigation demand, Ind.& Dom.-Industry, domestic and other demands. Bal- Water balance

The Business As Usual (BAU) scenario assumes that the current trends in population growth, urbanization, land and water productivity, irrigation efficiency, groundwater development etc, would continue in future. This scenario also assumes a substantially increased target for efficiency improvements; yet the total water demands are approaching the limits of potential utilizable water resources. However, there are some possibilities of shifting a few of the key drivers of water demand through technology interventions. These interventions would either augment the existing supplies or enable realisation of the production targets with reduced water diversions (Tyagi, 2009). It is imperative to examine the domains, capacities, associated costs of technological interventions, and review the alternative scenarios for taking optimal decisions. River basins in the country fall under various agro-climatic zones and are subjected to varying degrees of water stress, emphasizing the need for identifying the most appropriate mix of technological improvements for each region. The acceptability of the technology by the end users depends on the efficiency gains as well as the economic and financial viability. It may be relevant to mention that infrastructure development and implementation of water smart technologies are driven by public policies, not only in respect of direct investment by the State, but also for promoting public-private sector participation. Some of these issues affecting the sectors which follow water security programs are noticed briefly in the sections which follow.

7.2 Demand and Supply Measures to Meet the 2050 Water Challenge

Conceptually, there broad sets of options are available for meeting the growing water demand challenges: one is demand management, the other is supply management and the third is a mix of both these options (Figure 7.1). Agriculture sector is the dominant user of water and its current level of low productivity and irrigation system inefficiencies provide greater scope for minimizing water demand as compared to other sectors. The 2030 Water Resource Group (2009) reported that, of the estimated supply-demand gap of 755.8 BCM in 2030 in their study, nearly 80% (640 BCM) could be bridged through improvements in agriculture. The corresponding savings from the domestic and the industrial sectors were only 4.9 and 7.3 BCM, respectively. Though the gap in demand and supply estimated by this Group appears to be very much on the higher side, the Study highlights the potential of water management technologies in reducing demands. Hence, improvement in agricultural productivity holds the key for meeting the water challenge, 2025-2050.



Source : 2030 Water Resource Group (2009)

Figure 7.1 : India – Water Availability Cost Curve

7.3 Bridging the Water Availability through Demand Management in Agriculture

Demand management can be mediated through: (i) biological interventions like introduction of improved germplasm with higher yield potential or higher resistance to biotic and abiotic stress in both irrigated as well as rain-fed farming, (ii) improved plant nutrient management and (iii) improved water management technology. The seed has been a major factor in agricultural productivity enhancement all over the world. The water and nutrient inputs-responsive germplasm was significant in triggering the green revolution in India. Continuing efforts to capitalize on new advances in molecular biology would play on important role in sustaining and increasing productivity growth in future. Probably, development of germplasm, resistant to biotic and abiotic stresses, for irrigated and rain-fed conditions and tolerant of heat stress, which is likely to increase with impending climate changes, will be a critical element in increasing productivity and reducing irrigation water demand. Balanced fertilizer use, capturing interaction of water and fertilizers and enhanced fertilizer use is another group of technologies/practices that would reduce overall water demand in agriculture. The scope of this presentation precludes an elaborate discussion on the first two options. It would suffice to state that, while dealing with demand management, these two are assumed to be operating at the optimum level.

Agricultural production a land based activity, is spread over more than 140 million ha. While action for crop production takes place in the root zone in the soil, water has to traverse a large conveyance and distribution network and move over land of varying characteristics, before it becomes available to the plants. Hence, the efficiency in conveyance, distribution and application of water to the crop makes a substantial difference in water demand at the project head level. Even in case of rainfall, the watershed management authority would decide as to how much of it would be consumptively used as green water and what fraction will percolate down to the aquifers or flow into the rivers as runoff. Another point for consideration is that more than 60 % of water diverted to farms is consumptively used, offering limited scope for water reuse. On the other hand, the consumptive use fraction in domestic and industrial sector is less than 20% with higher possibilities for recirculation if quality aspects of the effluents are taken care of properly.

Agricultural productivity holds the key to water security

7.3.1 Agricultural Productivity - BAU and other Scenarios

There are several options for bringing about productivity shifts. Apart from water, two other important inputs which contribute to agricultural productivity are seeds and fertilizers. Under normal situations, contributions of these three production inputs are of the same order. As seed cost per unit area is generally the lowest, a preferred option always is to bring in productivity improvements. Such improvement through the water management route involves increase in the yield with a given quantity of water or getting the same yield with reduced water application. A third option could be increase in yield and reduction in water applied through appropriate changes in other inputs. Depending upon which resource is scarce, the yield per unit of water use (WP) or per unit of land (LP) is maximized. A few plausible scenarios, involving various land water productivities and irrigation system efficiencies, are discussed hereunder.

7.3.1.1 Crop Yield Growth Rates

The BAU scenario assumes an annual growth rate of 1.4% during 2010-2025 and 1.1% during 2025-2050, providing an average grain yield of 2.4 tons/ha in 2025 and 3.2 tons/ha in 2050. It may be added that the rate of growth of 3.4% during the 1980s, dropped to 2.1% during the 1990s. But recent growth rates for grain crops (Table-7.2) appear to be more encouraging, because except for wheat, the rate of increase for the period 2001 to 2009 is more than 1.9% (NRAA 2011). Decadal growth rate for fruits and vegetable is more than 7 %. Hence it is likely that in productivity growth might exceed the rates assumed in BAU. Further, significant gaps between the realized and the potential yields indicate a possibility of achieving higher growth rates in crop production.

Table 7.2 : Three Year Averages of Area, Production, and Productivity and Growth Rate of Food Grain 1984-86 to 2009-10

Period	Area Million ha	Production Million tons	Productivity Ton/ ha	Compound growth rate,%		
				Area	Production	Productivity
1984-86	128.62	149.45	1.16	-1.20	-0.64	0.43
1987-89	124.85	151.23	1.21	0.18	8.85	8.97
1990-92	125.49	171.94	1.37	-1.95	-0.78	1.48
1993-95	123.25	185.08	1.50	0.29	3.29	3.06
1996-98	122.81	190.71	1.56	1.17	3.23	1.99
1999-01	123.11	203.41	1.65	-1.66	-1.68	0.00
2002-04	120.03	200.27	1.66	0.27	0.08	-0.29
2005-07	121.77	208.08	1.70	1.53	4.66	2.99
2007-09	123.67	227.31	1.83	-0.20	3.75	3.92
2009-10*	-	218.20	-	-	-	-

**Single year figures*
Source: Agricultural Statistics at a Glance. 2009, DAC, Min of Agriculture, GOI

A review of the impact of increased crop yield on irrigation demands shows that the irrigation diversion requirement, namely 735 BCM for the BAU scenario, was estimated at two more yield levels. The new yields were assumed to reach 1.7 and 2.0 times the BAU yield of 2000 for which the irrigation diversions are shown in Table-7.3. If the assumed yield growths are realised, the irrigation diversion requirement would go down by 60 BCM (1.7 times yield increase) and 112 BCM (2.0 times yield increase) by 2050 respectively. In a fresh appraisal of India's water demand-2050 by Amarasinghe et al (2007), it was estimated that, if the water productivity increased from 1.13 kg/m^3 to1.27 kg/m^3, the BAU irrigation diversions could be reduced by 15% for the same level of crop production. The impacts of changes in water productivity (WP) and land productivity (LP), as shown in Figure 7.2, are quite steep, but in view of the recent advances in biological sciences and water technology, these targets appear to be within reach.

Table 7.3 : Effect of Crop Productivity on Irrigation Water Demands: 2025-2050

Year	Crop* Prod. tons/ha	Irrigation* Demand BCM	Crop@ Prod. tons/ha	Irrigation@ Demand BCM	Crop# Prod. tons/ha	Irrigation# Demand BCM
2000	2.6	621				
2010	3.0	642				
2025	3.6	690	4.2	628	4.4	600
2050	4.2	735	4.8	675	5.2	623

**BAU scenario, @and #-Irrigated crop yields by 2050 at 1.7 and 2.0 times the BAU yields in 2000*

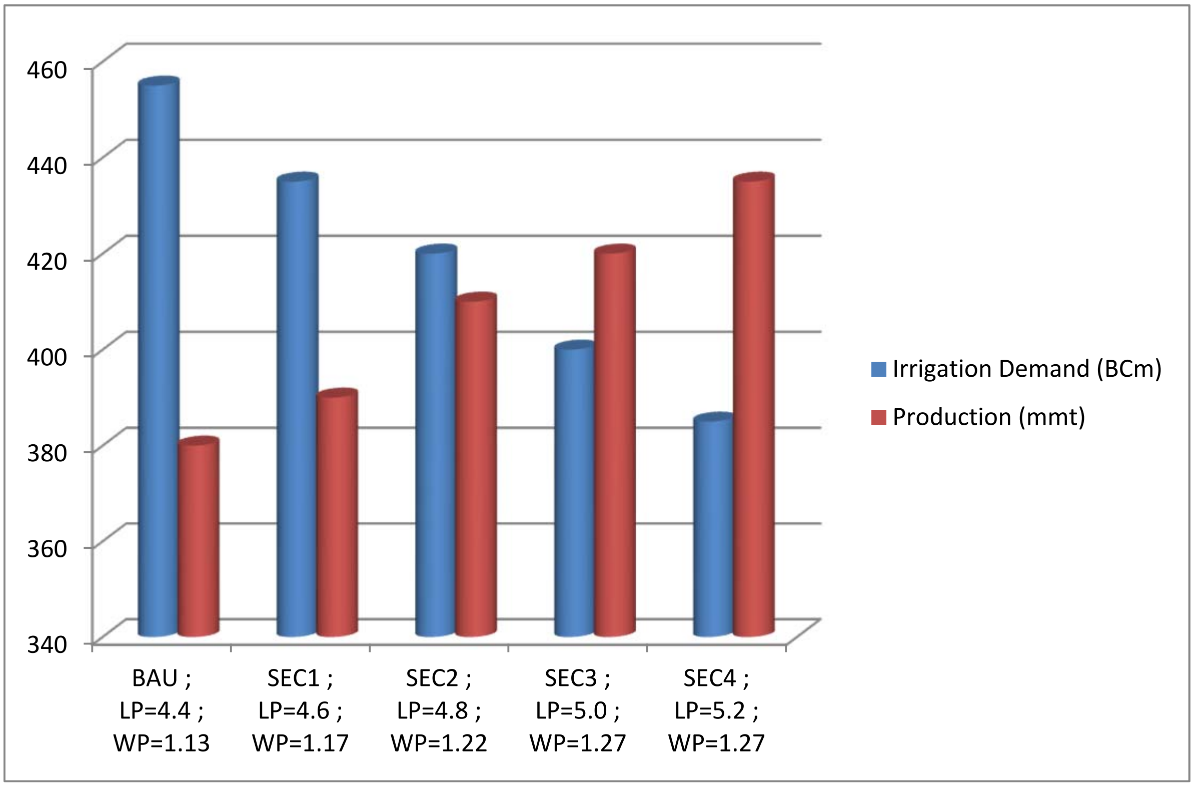


Figure 7.2 : Effect of Increase in Land and Water Productivity on Irrigation Demand in Crop Production (Amarasinghe, 2007)

Doubling of irrigated land productivity from the BAU level of 2000, will increase total production by 13% from the same irrigated area

7.3.1.2 Increasing Productivity through Irrigation Efficiency Route

Irrigation diversion requirement is greatly influenced by how water is conveyed from the source to the point of use and how it is applied to the crop. Technically, it is possible to improve the conveyance efficiency from the present range of 50 to 60% to 60-70% or even higher, at a cost of course. Change in conveyance efficiency does affect per unit area yields, but alters the water productivity at project level. Recent reports from the Directorate of Water Management of ICAR put currently operating project efficiencies between 30 and 38% (Singh and Kumar, 2011). The changes in BAU irrigation demand with surface irrigation efficiency at 50, 55 and 60% and groundwater irrigation efficiencies 70, 75 and 80% by 2050 (Figure 7.3) bring in significant changes in water demands.

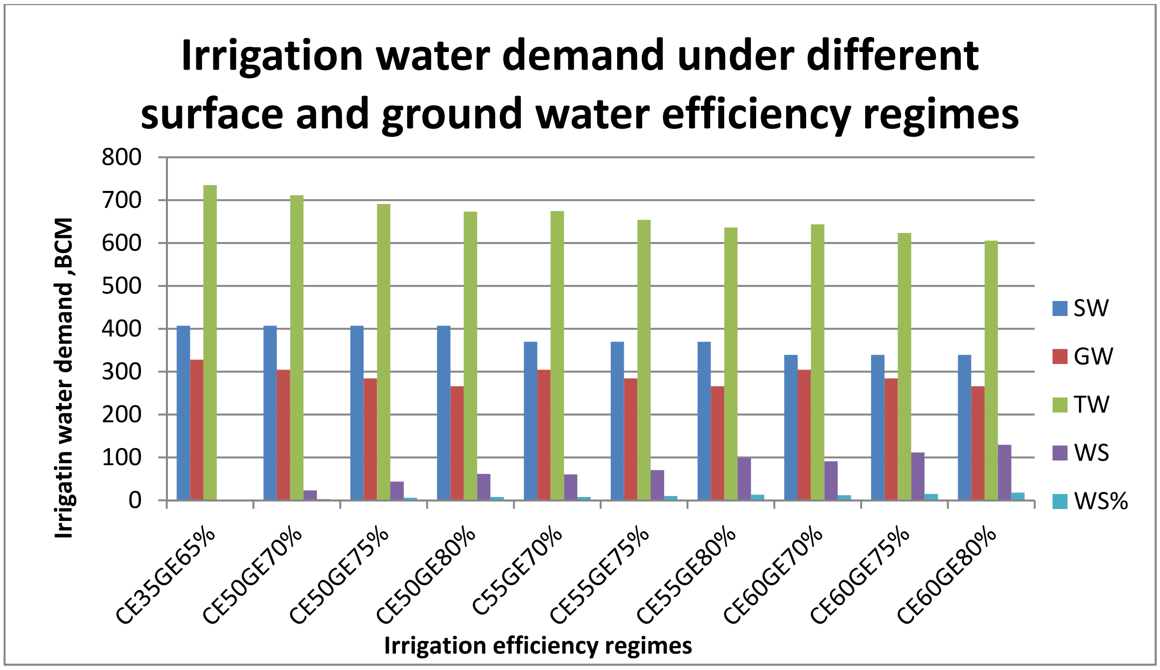


Figure 7.3 : Effect of Change in Irrigation Efficiencies on Irrigation Demands

A 5% increase in both canal irrigation efficiency (CE) and ground water efficiency (GE) would reduce irrigation demands by 60 BCM (8%), compared to BAU estimates without any reduction in crop yields and production per unit of irrigation diversion would go up. If efficiencies are raised by 10%, in case of canals and ground water, irrigation demands would come down by 18% (129.5BCM). Water so saved could be released for other uses e.g. meeting environmental demands. On the other hand, if efficiencies of the canal and ground water system fall short of the projected levels by 5%, the demand would escalate to 795 BCM, thereby decreasing water productivity

7.3.2 Ways to Improve Irrigation System Efficiencies

As indicated earlier, irrigation system efficiency is the product of conveyance and application efficiencies. It is true that water lost in conveyance or in application can be saved only through improvement in the respective subsystems. However, in a small range, it is possible to achieve the given system efficiency through alternate mix of technology interventions. Technical interventions required to achieve the canal and ground water irrigation system efficiencies are indicated in Table-7.4. The optimal mix of improvements would depend on their relative cost, but the values given here, do indicate the range of the required conveyance and distribution efficiencies and possible technical fixes. For example, if the target efficiency of ground water system is set at 80%, it will have to achieve conveyance and application efficiencies of the order of 90 %, which are possible only through piped conveyance and drip irrigation. This will obviously put limits on the area which can be brought under such irrigation efficiency regime as not only the cost of improvement, but also the suitability of water application system, will become a limitation. At a low efficiency target of 65 %, the management has recourse to a larger basket of options. Various technologies which help achieve water saving and higher yields at farm level are briefly discussed hereunder.

Table 7.4 : Required Conveyance and Application Efficiencies for Achieving Targeted Canal and Ground Water Irrigation Efficiencies at Basin Level, (%)

Target CE and GE	Conveyance Efficiency	Application Efficiency	Required technical interventions
CE-35	55-60	65-60	Partly lined channels, Laser leveling, bed planting, zero till
CE-50	65-70	80-75	Partly lined channels, Laser leveling, Zero till, SRI, Bed planting, Sprinkler, Drip
CE-55	70-75	85-75	Lined channels, Laser leveling, Zero till,SRI,Bed planting,Sprinkler,Drip
CE-60	75 -80	80-75	Lined channel Laser leveling , Zero till,SRI,Sprinkler,Drip
GE-65	75-80	85-80	Lined channel, Laser leveling, Zero till,Sprinkler,SRI,Bed planting, Drip
GE-70	85-90	90-85	Piped supply, Sprinkler and surface drip, Mulch
GE-75	90	85	Piped supply, Sprinkler and Surface drip, Mulch
GE-80	90	90	Piped supply and Sub surface drip

CE-Canal system efficiency, GE-Groundwater system efficiency

7.3.3 Laser Leveling

Laser leveling has the potential for making positive contributions to increasing the productivity and incomes of farmers. The manifold benefits of technology are realized in terms of water saving and increased water use efficiency, and reduced energy in pumping water (Tyagi1984). For example, seasonal irrigation requirement of rice-wheat in the Indo-Gangetic Plain (IGP) ranges between 1800 and 2250 mm (18000-22500m^3). At the least, 50 % of the irrigation requirements are met by ground water which has to be pumped for 50-70 hrs/ha/yr, from increasingly depleting groundwater reserves. Surface application being the dominant method of water application in rice-wheat system, laser leveling can achieve a high efficiency of 75% and reduce farm water diversion by 20-30%, apart from increasing crop yields (Ambast, et al, 2005). It is worth noting that introduction of laser leveling in surface application, which has wider applicability, can help achieve higher application efficiency comparable to the sprinkler method. In less than a decade, the number of laser leveling equipments in Punjab alone went up to 4000 indicating its effectiveness in achieving the desired objective.

Table 7.5 : Water and Energy Saving in Laser Leveled Irrigated Wheat Fields in Haryana

Item	Conventional surface irrigation	Laser leveled irrigated field
Leveling index, cm	More than 1.5	Less than 1.5
Seasonal irrigation depth, cm	30-35	20-25
Pumping time per irrigation, hrs/ha	15-17	9-11
Water productivity, kg/m^3	1.50	2.44

Source: Ambast et al, 2005

7.3.4 Micro Irrigation

Numerous studies show the potential of the micro irrigation system, including drip, for improving the overall productivity and profitability of several widely-spaced row crops, particularly fruits and vegetables. Current revolution in horticulture can be promoted further with micro-irrigation. It is worthwhile to note that horticultural crops have a higher productivity per unit area. For example, we produce only 4-5 t/ha of rice as against 22 t/ha of banana and 40 t/ha of pine apples. In terms of nutrition also, these crops outperform cereals. For example, supplying the total per capita per year $1.1x10^6$ kcal energy requirements, requires about 0.4 ha of land under paddy, 0.013 ha under banana and 0.15 ha under pineapples. Fruit crops are now playing a key role in contributing to the food and nutrition security of the country.

Micro irrigation provides triple benefits: reduction in irrigation requirements, fertilizer saving and increased crop yields. The return to investment on micro irrigation (with subsidy) could be as high 1:6, and even without subsidy, it may be more than 1:2. The area under micro irrigation (drip and sprinkler) in India is growing steadily and has the potential of being introduced in about 25 Mha.

7. 3.5 Some other Resource Conserving and Yield Enhancing Technologies

The third group of technologies was developed to increase mechanization and reduce cost of cultivation. Incidentally, measures like Zero-Till Farming (ZTL), System of rice intensification (SRI) not only increase productivity per unit area, but also reduce cost of cultivation, besides saving water. Reduced labour and fertilizer cost and decreased green house gas emissions are some of the other benefits of Zero-Till Farming (Lumpkin and Sayre, 2009 and Tandon and Singh, 2009).The benefits from increased production and reduced cost, more than compensate the cost of intervention. Water saving is an additional benefit at no cost.

7.3.6 Efficiency and Yield Enhancement Potential of Important On-farm Technologies

The total water saving potential of a technology application depends on an increase in efficiency from the base value and the extent of the area in which it can be implemented. For example, SRI is applicable only in rice; hence its usefulness is limited to rice cultivation. However, Zero tillage can be introduced in a large number of crops and would lead to higher savings. Introduction of technologies like Improved Germplasm or Balanced Fertilizer application has no direct water savings. But these increase land productivity and enable us to achieve food production target from a smaller area. Water saving and yield improvement potentials of various on-farm technologies are shown in Table-7.6.

Table 7.6 : Water Saving and Yield Improvement Potential of Different On-farm Technologies*

Technology	Water saving,%	Increase in yield,%
Minimum tillage	20-30	10-20
Laser land leveling	20-30	15-20
Drip irrigation	25-40	20-40
Sprinkler irrigation	20-30	10-20
System of rice intensification	10-30	20-30
Surface drainage	No direct saving	10-30
Biotic/Abiotic stress management	No direct saving	10-30
Balanced fertilizer use	No direct saving	20-30
Improved germplasm	No direct saving	10-20

**The savings and increase in yields are not cumulative and represent values above baselines/ conventional methods in different regions*

7.3.7 Farm Ponds for Improving Green Water Productivity in Rain-fed Agriculture

The debate going on in the country for the last two decades regarding irrigated agriculture vis-a-vis rain-fed agriculture is not very relevant. Data for the last 40 years show that productivity of solely rain-fed agriculture is hovering around 1 ton/ha, as against 2.5 ton/ha in irrigated agriculture. It is argued that substantial improvement in crop productivity can be brought about through better rainwater management. But results from across the country show that such improvement is brought about largely by rainwater harvesting in farm ponds and using the water so harvested for irrigation. Yield enhancement is hence achieved through supplementary irrigation and not otherwise.

It would be more logical to consider a continuity between rain-fed and irrigated agriculture in which the per unit area water availability to crops keeps on increasing and so does the crop yield up to certain level (Figure 7.4).

A Continuous Transition from a Green-Water Dominated Rainfed System to a Blue-Water Dominated Irrigation System.

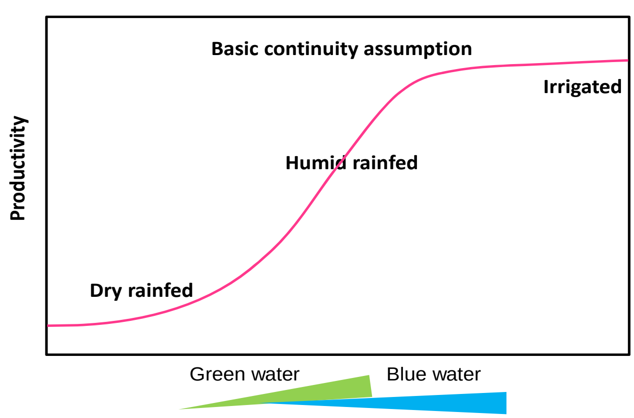


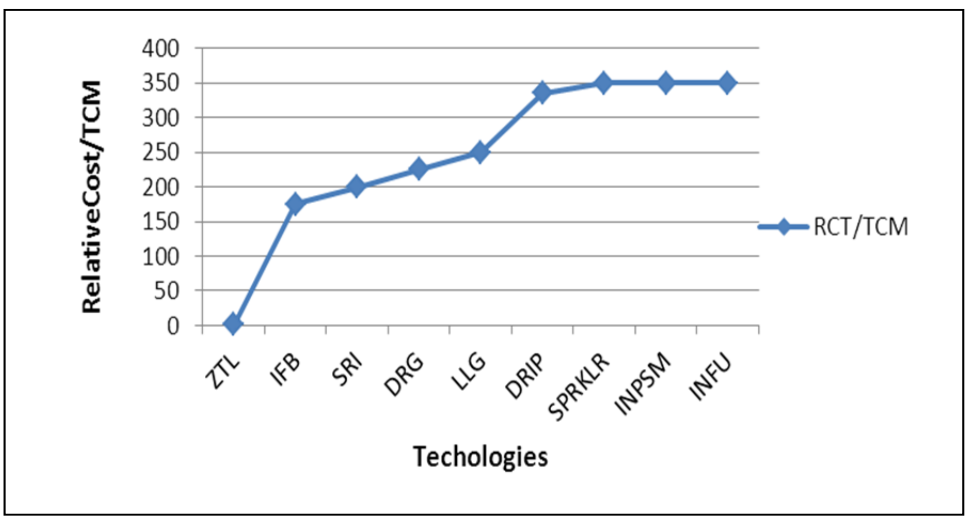
Figure 7.4 : Vision of the Green-to-Blue Water Continuum Based on the Assumption (Vidal, 2009)

Provide supplementary irrigation from on-farm rain-fed reservoirs to increase productivity in dry lands

It is estimated that, by 2050, India would need to develop additional 56 M-ha-m water out of which 48 M-ha-m would come from green water of which 15 M-ha-m would come from improved efficiency in rainwater management and the balance from increased storage in soil profile/farm ponds/large scale reservoirs. There are various technological options to increase green water, but there are some externalities as well, particularly for downstream users. Watershed management, with greater emphasis on supplementary irrigation from ponds, fitted with micro-irrigation systems, would transform subsistence rain-fed agriculture into profitable agriculture. Such efforts would be more rewarding in zones with an annual rainfall of about 600 to 1000 mm.

7.3.8 Relative Cost of Water Saving and Productivity Increasing Technologies

Cost differentials attached to various types of water savings are helpful in ranking and choosing various technologies for implementation. Incremental cost for saving a water unit, suggested by 2030 WRG (2009), is one of the tools for planning implementation of technologies. The cost curve, developed by them, indicates that incremental cost per unit of water saved may vary, from less than one Rupee to more than 100 Rupees per cubic meter saved/generated. On-farm agro-technologies/practices like Zero Tillage, Integrated Balanced Fertilizer Use or System of Rice Intensification, not only increase crop yields, but also reduce the overall cost of cultivation. Such interventions help in bridging the water demand - supply gap with no direct cost assigned to water savings (resulting from their implementation) and incremental costs are shown as negative. Some other technologies viz. Improved Irrigation Methods, save water through improved efficiency as well as increased yields (and consequent reduction in irrigated area requirement). Technologies like Improved Germplasm results only in increased yields with no direct water savings. But the potential of these technologies to bridge the demand supply gap is much larger. For example, 2030 Water Resource Group (2009) estimated that yield- increasing technologies might reduce water demand by 50 BCM as compared to 15 BCM only through agricultural efficiency improvement. The corresponding savings through efficiency improvement in municipal and industrial sectors would yield 2.2 and 0.7 BCM only respectively. The relative incremental costs of some of these technologies are shown in Figure 7.5. It must be appreciated that the cost curve is only a tool which can help in choosing a given and suitable technology or a combination of technologies to achieve the desired target water saving.



ZTL-Zero till, IFB-Irrigation-fertilizer balance, SRI- System of rice intensification, IRDRG- Irrigation – drainage, INPSM- Integrated plant stress management LLG-Laser leveling, INFU- Increased fertilizer use, TCM-Thousand cubic meters

Figure 7.5 : Relative Cost (RCT) of Generating Additional Water through Some Agricultural Water Demand Management Technologies

7.3.9 Basin Level Water Demand Balance and Suggested Action Programmes

In view of the fact that a matching gain in water supply to bridge the supply deficit to the extent of 80% could be had by demand management, adoption of this option should be given priority. The balance 20% gap between supply and demand should be addressed through wastewater reuse, cost effective storage development projects and limited regional river water transfers. Desalinization of sea water may be resorted to for augmenting drinking water supplies in coastal cities facing acute shortages.

It is emphasized that both the cost estimates as well as the quantity of water that can be saved/ made available, are only indicative. But these highlight the relative importance of various productivity-enhancing measures. There are large agro-climatic, hydro-geological and physiographic variations within and across river basins. These determine the crop choices and their productivity and consequently the techno-economic suitability of the technologies. Further, the river basins in the country are at different stages of development and varying levels of water stress. For example, the Luni and the WFR1 group of rivers are facing physical scarcity with little potential left for development. Such areas are not going to benefit from low value water intensive crops. Hence, introduction of high-value crops, mostly aromatic and medicinal plants, and arid horticultural crops with micro-irrigation, would be the right choice. On the other hand, in the Mahanadi basin, soil erosion control and rainwater harvesting in hilly areas would get priority. In the same basin in coastal Orissa, surface drainage and irrigation with shallow wells will be more beneficial. The grain crop-intensive Indus basin would have to reduce area under rice and wheat to curtail its water demands and introduce high tech precision agriculture. Based on these considerations, the priority of technological interventions for various groups of basins are indicated in Table-7.7. A few important targets for Technological Intervention for Managing Demand are shown in Table7.8.

Table 7.7 : Water Stress and High Priority Technological Interventions in Different Basins

River basins	Status of water stress status	Priority technological interventions
Luni and Westerly flowing rivers (WFR1)	Physical water scarcity, high degree of groundwater over exploitation.	Introduce : High value less water intensive crops, Micro irrigation, Virtual water import
Indus	High degree of development, high depletion ratios and high groundwater abstraction, The basins are now physically water stressed	Introduce: High value horticultural crops to partly replace rice-wheat limiting it to 50 % of planted area, Laser leveling, Zero tillage, SRI, Micro-irrigation, Reduced virtual water export
Pennar, Mahi, Sabarmati, WFR2, Krishna	High degree of development, high groundwater abstraction, Close to physical water scarcity	Introduce: Groundwater recharge, Watershed management, High value agriculture, SRI in Krishna
Ganga, Godavari, Subarnarekha,	Medium level of development, Economic water scarcity, Some reaches show depletion of groundwater	Introduce: Laser leveling, Zero tillage, Surface drainage-bed planting, SRI, Multiple water use, Brackish water aquaculture in coastal areas, virtual water export
Mahanadi, Baitarni,Brahamani,EFR1, Tapi, Narmada	Low level of development, Surplus water available for development	Introduce: Watershed development in hilly regions, Land surface modification to provide surface drainage, SRI, Aquaculture
Brahmaputra, Barak, Meghna	Very low level of development, Enough surface water	Introduce: Watershed management and horticulture in hilly regions, Land surface modification in plains to provide surface drainage, Aquaculture

Table 7.8 : Important 2025 Targets for Technological Interventions for Managing Demand

Technology	Major crops	Size of intervention	Remarks
Laser leveling	Field crops,	80 Mha	Yield increase,15-20 %, Cost-Rs.8-10x10^3/ha
Zero or minimum till	Rice, wheat and other grain crops	25 Mha	Saving in cost of cultivation-Rs2.5-3.0 x10^3/ha/yr
SRI	Rice	10 Mha(40 % irrigated rice	Reduction in cost of cultivation:11%
Sprinkler	Wheat, vegetables, plantation crops	20 Mha(20% irrigated land)	Yield increase,15-20%,Cost Rs 30-40x10^3/ha
Drip	Fruits and vegetables crops, cotton, sugarcane	20 Mha	Expected irrigation water saving-20-40 %,Cost- Rs 40-60x10^3/ha
Land surface modification-bed and furrow irrigation and drainage	Wheat, cotton, maize, sugarcane	20 Ma	Yield increase -5-15 %,Cost-Rs.5-10x10^3/ha
Sub surface drainage	Waterlogged and salt affected land	10 Mha	Yield improvement-20-30% Cost Rs. 14x10^3/ha*
Rain harvesting + Micro-irrigation	Medium to high rainfall un-irrigated farm land	20 Mha	Yield improvement by25-40% Cost Rs. 14x10^3/ha*
Piped /lined water conveyance from tube wells	Mostly sprinkler and drip irrigated areas	20 Mha	Cost Rs. 10x10^3/ha*
Biotic and Abiotic stress management	Most crops and areas	100 Mha	Yield increase:10-30%, Cost Rs. 500-1000/ha*
Improved germplasm	Most crops	100 Mha	Yield improvement of 20-30 % per yr. Premium on seed –Rs.500-1000/ha
Irrigation Scheduling	All crops	25 % of irrigated land:20 Mha	Gross water saving: 10-15%,Yield increase:5-20%,
Increased fertilizer use	All crops	20 % of cultivated land:30 Mha	Yield increase:25-50 %, Cost Rs. 2-3x10^3/ha*

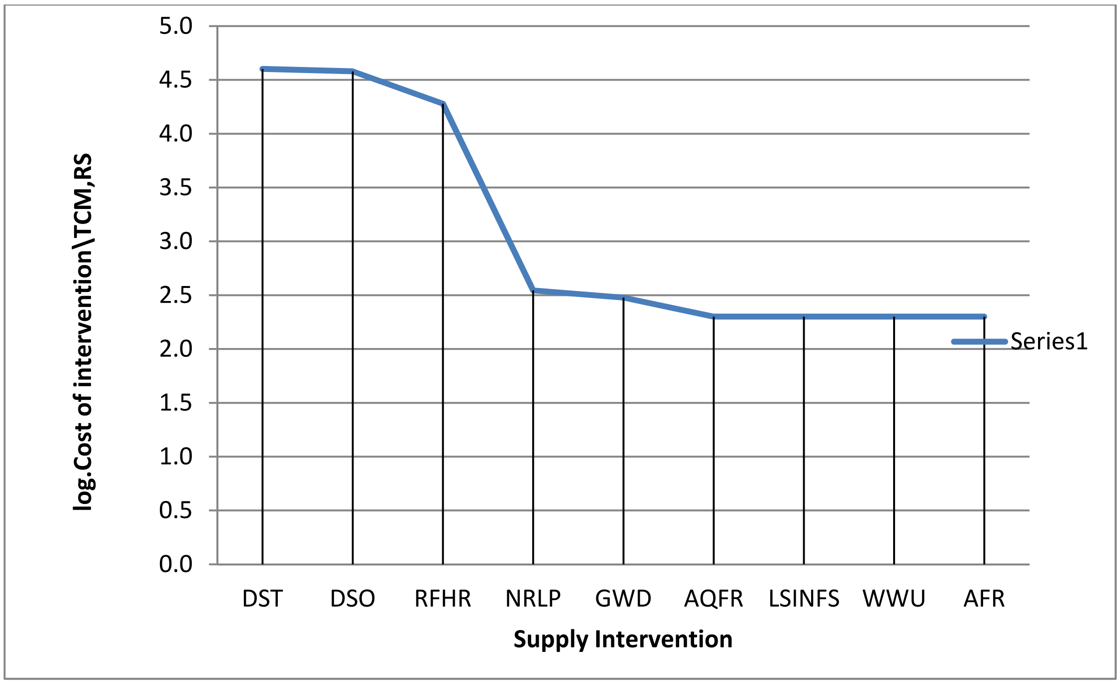
Source : 2030 Water Resources Group (2009).

7.4 Bridging Water Availability Gap through Supply Management

Increasing water availability through supply measures includes abstraction of more water from the rivers and aquifers, rainwater harvesting, inter-basin transfers, wastewater treatment and desalinization etc. Projections show that 45% of the estimated 1.64 billion population in 2050 AD would be living in urban agglomerates requiring 148 BCM of fresh water supply and generating waste water of more than100

BCM. This water could become either a valuable resource or a source of environmental pollution, depending upon the reuse options and the technology employed. As any major increase in urban water supply would come from diversion from agriculture and as agricultural use of wastewater also serves as a means of its use and treatment, it has to be a priority option.

The cost of creating water through these measures is adapted from 2030 WRG (2009) and is shown in Figure 7.6. Compared to water saving options, the cost of creation of new supplies is much higher. Even amongst the supply measures, the variation in unit cost is quite large. For example, wastewater reuse and deep aquifer development measures are much lower in cost than desalinization. Completing the surface storage projects as well as rainwater harvesting through watershed management project would be more cost effective.



DST-Desalination (thermal), DSO-Desalination (Osmosis), RFHR-Rainfall harvesting, NRLP-National river linking plan, GWD-Deep groundwater, AQFR-Aquifer recharge, LSINFS-Large scale infrastructure, WWU-Waste water use, AFR- Artificial recharge,

Figure 7.6 : Cost of Various Water Supply Enhancement Interventions (Rs/1000m^3)

7.4.1 Important 2025 Targets for Water Supply Increasing Interventions

Even though the supply measures face a steep marginal cost curve, with the ceiling price set by expensive technologies (2030WRG,2009), the task of ensuring water security for food, economic development and maintenance of ecosystem in a healthy state in a dependable manner, would require development of additional water resources. The Water Resource Group (2009) estimated that about 400 BCM of additional water could be developed through various supply enhancing measures. As regards agriculture, reclamation and reuse of domestic wastewater, aquifer recharge during monsoon, creation of new resources by completing the ongoing water development projects, should be the priority. Large scale rehabilitation of irrigation infrastructure could increase the irrigation potential by 5Mha. Completion of last mile irrigation infrastructure could bridge the gap between the potential created and the irrigation realized by 9 Mha. The wastewater, after treatment, is going to be a major source of new water supply. It may added that the consumptive use in domestic and industry sectors is less than 20%. The estimated diversion for these two sectors in 2025 being of the order of 260 BCM, an estimate close to 200 BCM would be a dependable target for committed water supply for reuse. Compared to other sectors, agriculture is better suited for using such waters. Drinking water scarcity in certain locations such as Chennai may justify investment in desalination. The National River Linking Project (NRLP) would get priority in view of the order passed of the Hon'ble Supreme Court of India on 27 February, 2012 and need to be taken up at the earliest. Brief details of the proposed NRLP are discussed in Chapter 8.

Table 7.9 : Suggested 2030 Targets for Interventions Increasing Water Supply

Intervention	Description	Size of intervention
Aquifer recharge	For>0.2 $x10^6m^3$ capacity-percolation tanks, For <0.2 $x10^6m^3$ capacity-Check dams, contour bunds	Saturate the catchments
Ground water development	Shallow and deep tube wells	350 Mham/yr to reach 80 % abstraction
Large scale infrastructure	Dams and reservoirs	Create an additional potential of 15 Mha
Large scale rehabilitation of irrigation works	Renovation, de-silting and setting up management infrastructure	Create additional potential of 5Mha
Last mile irrigation	Creation of command area and management structure, completion of last mile infrastructure	Rehabilitate the system to bridge the gap between potential created and utilized-9 Mha
Wastewater reuse	Treated domestic and industrial waste waters	50-70 BCM(20-25%) of domestic and industrial effluents
National river linking project	Water transfer from surplus to deficit river basins	Total potential: 173 BCM

7.5 The Emerging Directions for Development

A few interesting findings emerge from this analysis of water demand and supply scenarios and the possible options for meeting the 2025-2050 water challenge. It is evident that our water demands would escalate sharply while water supply would not match the growth in demand. Growth in agriculture, energy, industry and environment sectors have significant implications for water budgets in the river basins. It is observed that water demands for the year 2025 and 2050 would not be met by the current and projected water resources development plans in the Business As Usual mode. It is also noted that a major part of the solution, to the extent of 80%, lies in demand management, particularly through the productivity enhancement route in agriculture. Of course, demand management is subject to diffusion of knowledge, skills, and access to capital by millions of small and marginal Indian farmers which is, to say the least, a difficult and complex task.

However, the positive aspect is that a large basket of technologies is available to trigger productivity growth at reasonable cost. Further, the Government seems to have appreciated the significance of water availability for meeting India's food and nutrition security. Based on the premise that solutions to Water-2050 Challenge are within reach, the immediate objective is to design a pragmatic and implementable combination of programs and align it with the national development goals and plans. It is well known that development of various sectors is inter-linked and no sector can move forward in isolation. An obvious example is the energy and water nexus. Water is needed for energy generation but at the same time, the development process as well as use of water are dependent on energy availability for pumping irrigation water, performing field operations and processing, storing and transporting food. In a growing economy, public policies influence the direction and the extent of development by way of resource allocation, framing laws and rules for facilitating clearances and ensuring good governance. Various issues relating to availability of technology along with prioritization for their adoption, implementation challenges, and the need for aligning public policies and the institutions to meet the water challenge, are presented briefly hereunder.

7.6 Technology

7.6.1 Exploiting the Full Potential of Crop Genetics

The three main elements of crop production technology are: seed, nutrients and water. The vast diversity of the plant kingdom and the emergence of new tools to enhance the genetic potential, afford us an opportunity to have high yielding crop varieties which are resistant to biotic and abiotic stresses. Biotechnology also enables us to have the common crops fortified with additional nutrients for achieving the national goal of nutrient security along with food security. The increase in crop productivity through the seed route is not only large, but also the cheapest option, obviating the need for putting additional land under irrigation. Estimates show that improved germplasm in irrigated and rain-fed farming together has the potential of bridging 17% of the water demand–supply gap (2030 WRG, 2009).

7.6.2 Harnessing Synergy between Green and Blue Water

The contribution of green and blue waters to agricultural production is in the ratio of 2.5:1, yet green water seldom appears in the water balance equation and the entire planning revolves around blue water. It must be realized that blue water alone is incapable of ushering in the revolution we are hoping for during the next few decades. On the other hand, green water by itself, is also not in a position to ensure the productivity levels for achieving production targets of 2025. If the irrigated land productivity is frozen at current level, about 25 million ha additional land would have to be put under irrigation, with additional blue water, to meet the projected food and feed demands in 2025. The only way out lies in appreciating and realizing the importance of utilizing the synergy between blue and green waters and work towards establishing a smooth and continuous transition from green water dominated rainfed agriculture to partial and intensively irrigated agriculture. Essentially, these calls for harvesting and storing rainwater, not only in-Situ in the soil profile, but also in on-farm reservoirs as well as equipping these small reservoirs with micro-irrigation systems to achieve the desired area coverage.

7.6.3 Making Use of the Comparative Advantage in Crop Choices

River basins in the country have varying endowments, not only of water, but also of terrain, soil and climate, enabling them to produce certain crops with higher productivity. The crop choices should be determined by both water endowments and crop water foot prints. The technology and skills for growing crops are transferable from one region to other regions, through water transfers are difficult and costly. It is clear that for water- deficient basins like the Indus, it would not be correct ecologically to put extensive areas under high water-requiring crops for intra-basin grain transfer to water rich areas. Extensive crop diversity gives us an opportunity to shift to crops, which are less water-consuming, and at the same time, more remunerative. It is envisaged that, in future, the Ganga basin would replace the Indus basin for producing surplus food grains for food deficient basins. Concerted efforts in mission mode are required, to achieve this goal.

7.6.4 Wastewater as Irrigation Resource

As more than 50% of our population would live urban areas by 2050, wastewater is going to be an expanding and dependable source of water supply for reuse to the extent of 80-100 BCM. But looking at the health hazards that poor sanitation might create, it would be necessary to develop and enforce appropriate guidelines for disposal and use of such water.

7.6.5 Combating Water Pollution

In spite of the efforts made during the past few decades, pollution of both rivers and ground water has not declined and the long-term threat of what SIWI terms as 'Hydrocide' looms large (Falkenmark, 2005). The recent report of the Central Water Commission (2011) bears testimony to this state of affairs. It identified hot spots of water pollution which have grown in number and intensity. Such spots are linked largely to industrial hubs and metropolitan areas, though non-point source pollution from agriculture is also growing. The polluter Pays' principle works to some extent, if the polluters can be identified, but this is becoming increasingly difficult in case of water pollution. The "Polluter Pays" principle should be replaced by "Prevention Pays Off" or PPO principle. The PPO would essentially involve investment in treatment technology which comes at a cost.

7.6.6 Prioritization of Technologies for Implementation

The cost curve, relative costs and payback periods of various technologies provide the basis for ranking and choosing the technologies for execution. However, not all technologies are equally applicable to all the basins. For example, SRI has little relevance for the Luni basin and Laser Leveling will not be useful in Sikkim or Mizoram. Hence, for each basin, a prioritized list of interventions alongwith the scale of implementation needs to be drawn up. Some technologies like drip irrigation may be implemented across the basins

7.7 Implementation Challenges

Implementation of even sound technologies poses several challenges because of institutional barriers, presence of multiple agencies without specific division of responsibilities, lack of capacity and information. The challenges could be financial (lack of access to capital, high initial cost, high transaction cost), organizational (limited organizational capacity and fractured responsibility), social (low priority and lack of appreciation for the intended benefits) and political (price distortions due to subsidies or perceived negative impact in the locality). Motivating and enabling the millions of small and marginal farmers, to take advantage of the emerging opportunities, is the biggest challenge. Needless to say, the existing technology diffusion network and the financial commitments will have to be strengthened.

7.7.1 Incentivizing Technology Adoption

Availability of new technologies is not sufficient, by itself, to bring about development. Effective institutions and sustained policy support are equally important. Advanced production technologies in irrigated agriculture will get implemented better in a favourable policy environment. The capital cost of the technology is an important demand for technology adoption (Garido, 2005) and advanced technology comes at a cost. In such a situation, if the private sector is to bear the cost of the improvement, the technology would get implemented only if the financial returns from investment are attractive and competitive. Capital intensive technologies get implemented only when increase in variable costs of other inputs makes it attractive or a part of the capital cost is subsidized. Such subsidies should not be considered entirely as a dole to the farmers. It should be regarded as a mechanism to underwrite a certain fraction of the cost of the many social or pubic benefits, accruing from adoption of the technology. Micro irrigation has already come under the Accelerated Irrigation Benefit Programme (AIBP). This programme should be expanded to include other equally effective technologies e.g. laser leveling, subsurface drainage, zero tillage for incentivizing their adoption and it could be renamed as a Programme for Accelerated Benefits to Agriculture (PABA).

7.8 Some Important Policy Issues

7.8.1 Development Vs Management of Water Resources

In 2025, the country's water supply deficit would be more than 500 BCM. Demand management will, no doubt, play a significant role in reducing this supply gap provided the 500 million small and marginal farmers are enabled with technical knowledge and finances to adopt the new technology. But the balance water deficit would remain quite high. Further, the proposed food security programmes would require development of additional water resources. For several decades, the water sector was starved of public funds for financing water development projects. Though the contribution of ground water has been appreciated, water storage schemes have not been given their due. We should appreciate the hydrological reality that much of the groundwater was generated by the canal system feeding on water stored in reservoirs and diversions from rivers. It should be understood that we need both, a Sukhomajri as well as a Bhakra. It is not an either or situation and our policy should be to maximize water storage, be it behind dams, or in groundwater aquifers or in multipurpose local reservoirs.

7.8.2 Strategic Role of Ground Water and Water Banks

In arid basins like the Indus, the Sabarmati, the Mahi etc, development of ground water played a strategic role in minimizing the impact of drought on agriculture and domestic supply. But the massive development is unsustainable as it is based on mining. Lack of planning and inadequate legal framework and still weaker enforcement, has led to a new debate on this issue. Accelerated efforts are required to augment the valuable ground resource through induced recharge as well as for enforcement of safeguards meant for maintaining the aquifers in good health. We often talk of gene banks, seed bank and fodder bank, but seldom talk of water bank which enables the other banks to function. It is time that India starts thinking of water banks in a big way via the groundwater route.

7.8.3 Increased Funding for Water Resources Development and Private Participation

Surface water development, an entirely public funded programme, suffered from lack of funds in the last 2 / 3 decades resulting in languishing of projects, cost over runs and non fulfillment of targets. The need for increased investments in the water sector can hardly be overemphasized. Private participation in surface water development sector has not been possible so far because of the risks involved. However, a number of industrial hubs with huge water demands are now being established. Currently, the State makes the capital investment and the Industries pay the water charges. The time is now ripe to promote the PPP mode in the sector, as has been done in many other sectors. Details of the modalities can be worked out through mutual consultations, taking note of the upto-date experience in other sectors.

7.8.4 Strengthening Technology Research, Development and Incubation Hubs

Technology hubs need to be set up for development of new technologies and benchmarking of available technologies to provide a transparent picture of benefits to the private entrepreneurs. These hubs would also provide incubation facilities to inexpensive new technologies for attracting private participation. Hydro-hubs in Singapore and Irrigation Technology hubs in Israel could be the role models.

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CHAPTER 8

Inter-basin Transfer of Waters

8.1 Introduction

It would be recalled that the water demands by 2050 were estimated at 1108 BCM by this study. However, this is likely to increase in future because of the additional ecological needs to maintain the river systems in good health, increased variability of the flows due to climate change and the need to ensure more reliable water supply systems against successive monsoon failures. It is estimated that only about 1123 BCM would be utilizable through the current strategies and interventions, if large inter-basin transfers are not considered. As brought out in Chapter 7, conceptually, two groups of options are available to meet the growing water demand challenges: one is demand management and the other, supply management. The study projects that a major part of solution may lie in demand management through the productivity management route which is relatively less costly. Demand management is, however, a herculean task as it presumes diffusion of knowledge, skills, and access to capital by millions of small and marginal Indian farmers. Though supply side measures face a steep marginal cost curve with ceiling prices set by expensive technologies (2030 WRG 2009), the task of ensuring water security for food, economic development and sustainable maintenance of the ecosystem in a healthy state would require development of additional water resources. The Water Resources Group (2009) estimated that about 550 BCM of additional water could be developed through various supply enhancing measures. According to NWDA, 173 BCM through inter-basin water transfer projects can be developed. The revised draft National Water Policy (2012) highlights that planning, development and management of water resources need to be governed by national perspectives on an integrated and environmentally sound basis, keeping in view the human, social and economic needs. It recognises that limited availability of water in the context of increasing demands, the availability of water for utilization needs to be augmented. Apart from other strategies, the Policy stipulates that inter-basin transfers are not merely for increasing water availability for production but also for meeting basic human needs and achieving equity and social justice by transferring water from water surplus to water deficit regions. Inter-basin transfers of flood waters to recharge depleting ground waters in water stressed areas should be encouraged and implemented. Further, transfers from an open basin to a closed basin increase water use and need to be promoted.

8.2 National Perspective for Water Resources Development

Two main components of the National Perspective Plan for Water Resources Development prepared in 1980 by the Ministry of Water Resources, Govt. of India are as under:

(a) Himalayan Rivers Development

Himalayan Rivers Development envisages construction of storage reservoirs on the principal tributaries of the Ganga and the Brahmaputra in India, Nepal and Bhutan, along with inter-linking canal systems to transfer surplus flows of the eastern tributaries of the Ganga to the west, apart from linking the main Brahmaputra and its tributaries with the Ganga, augmentation of flow of Ganga at Farakka and linking the Ganga with Mahanadi, thus augmenting the flow of Mahanadi.

(b) Peninsular Rivers Development

This component has four major parts :

(i) Interlinking of the Mahanadi-Godavari-Krishna-Pennar-Cauvery rivers and building storages at potential sites in the basins of these rivers.

This is the major interlinking of the river systems where surpluses from the Mahanadi and the Godavari are intended to be transferred to the needy areas in the south.

(ii) Interlinking of the west flowing rivers, north of Mumbai and south of the Tapi.
This scheme envisages construction of as many optimal storages as possible on these streams and interlinking them to make available an appreciable quantum of water for transfer to areas where additional water is needed. It also projects water supply canal to the metropolitan areas of Mumbai; irrigation to the coastal areas in Maharashtra.

(iii) Interlinking of the Ken-Chambal Rivers
The scheme provides for a water grid for Madhya Pradesh, Rajasthan and Uttar Pradesh and Interlinking canals backed by as many storages as possible.

(iv) Diversion of other west flowing rivers

Heavy rainfall on the western side of the 'Western Ghats' runs down numerous streams which empty into the Arabian Sea. Construction of an interlinking canal system, backed up by adequate storages, would be planned to meet the requirements of Kerala as well as the needs of the drought affected areas in Karnataka and Tamilnadu.

8.2.1 Benefits

The National Perspective Plan would provide additional irrigation benefits to 35 Million hectares, 25 Million hectare from surface water and 10 Million hectare by increased use of ground water, over and above the ultimate irrigation potential of 140 Million hectare from Major, Medium and Minor projects. It would also increase installed capacity of hydropower by 34,000 Million MW and make available benefits of flood control, ensure better navigation, water supply and fisheries, reduction in salinity, augmentation of flow at Farakka, promote pollution control, ensure adequate ecological flow in the river system, etc.

8.3 Present Proposals on Interlinking of Rivers

In 1982, Govt. of India established the National Water Development Agency (NWDA) to study the feasibility of National Perspective Proposals for interlinking of rivers. Based on the studies carried out by NWDA, 30 inter-basin water transfer links have been identified. These links and their current status are shown in Figure-8.1.

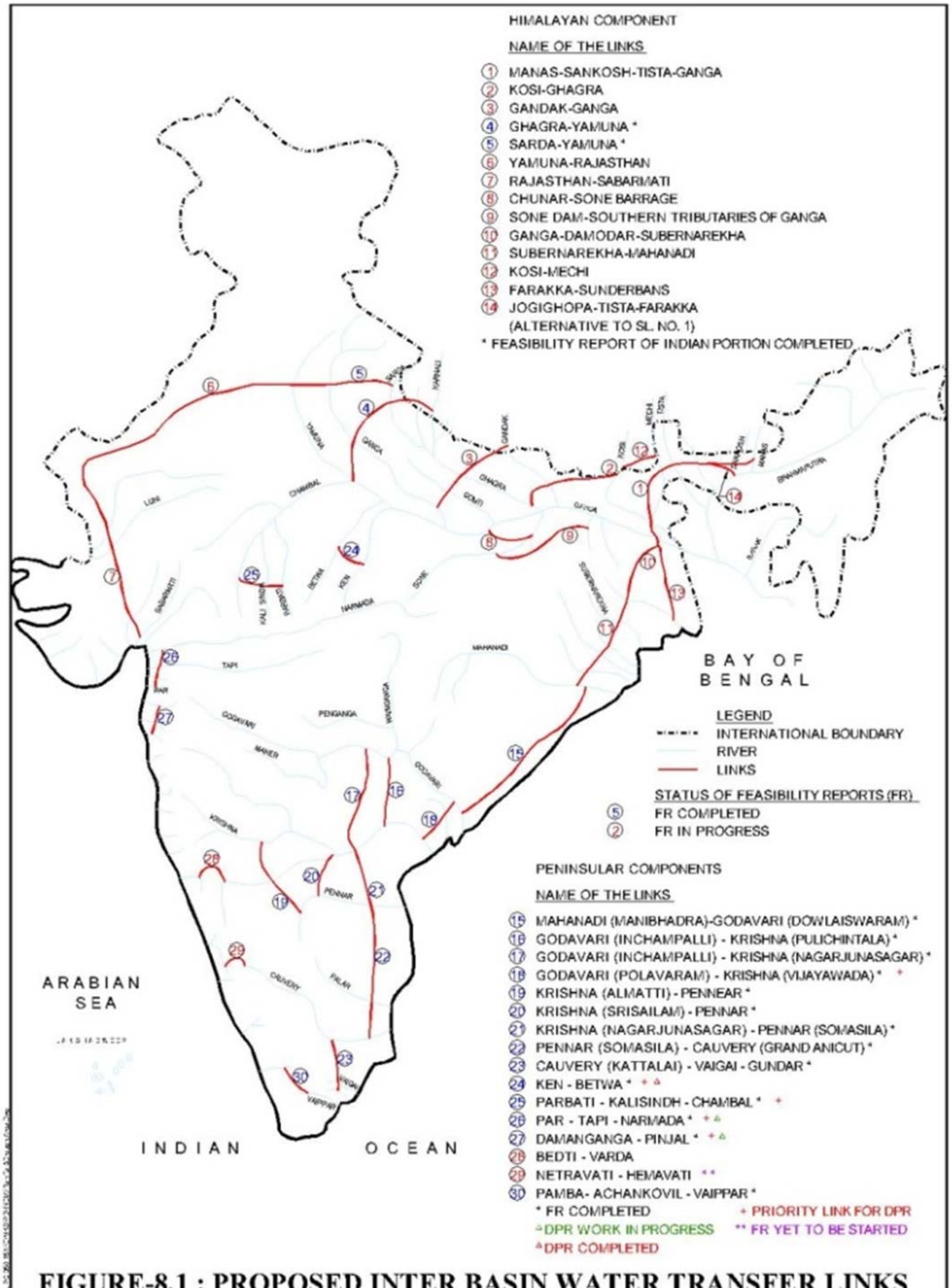

FIGURE-8.1 : PROPOSED INTER BASIN WATER TRANSFER LINKS UNDER STUDY

8.4 Task Force on Interlinking of Rivers

In response to a PIL filed in the Hon'ble Supreme Court of India in 2002 for Networking of Rivers, Govt. of India, in its Affidavit, mentioned that a Task Force will be formed to suggest modalities for consensus building on interlinking of rivers. Accordingly, a Task Force under the Chairmanship of Shri Suresh P Prabhu, Member of Parliament, Lok Sabha as Chairman was constituted in December 2002.

The Task Force was wound up in December 2004. The Action Plans and Recommendations submitted by the Task Force are briefly reviewed below.

(i) The Task Force got the Terms of Reference for preparation of Detailed Project Reports prepared by M/s Engineers India Ltd.

(ii) The Chairman held discussions with the Chief Ministers of various states for devising mechanism for bringing about consensus.

(iii) The Task Force suggested that the task might begin with the peninsular links.

The Top Priority links identified by the Task Force are :

(a)	The Ken-Betwa link	UP and MP
(b)	The Parbati-Kalisindh-Chambal link	MP and Rajasthan

(iv) A two tier institutional/organizational set up was proposed for implementation of the programme on Interlinking of Rivers along with a "National River Water Development Council" to act as the apex body of the proposed set up. A National Authority for Interlinking of Rivers was proposed as the first tier and the regional or branch offices or subsidiaries as the second tier of the organisational set up.

(v) The Task Force proposed that funding for the programme should be partly through public, public-private as well as private inputs. The requirements on a realistic basis will be available only after preparation of Detailed Project Reports of all the links. Based on NWDA studies, National Council of Applied Economic Research (NCAER) estimated the cost of river linking project at Rs. 4,44,331.20 crores which was lower than the rough estimate of Rs. 5,60,000 crores prepared earlier. NCAER was of the view that the programme would take 35-40 years for completion.

(vi) The Task Force was of the view that it was too early to pursue the matter at high political levels with the neighbouring countries.

8.5 Preparation of Detailed Project Reports for the River Links

After completion of Feasibility Reports, execution of inter basin water transfer schemes involves steps like Agreements amongst the States, preparation of DPRs, Techno-economic appraisal of DPRs, investment clearance, funding arrangements and construction.

The National Common Minimum Programme (NCMP) of the Government envisaged that the Government will make a comprehensive assessment of the feasibility of linking the rivers of the country, starting with the southern rivers, in a fully consultative manner. After a comprehensive assessment, the Govt. decided to pursue the matter, focusing on the peninsular component.

Five Peninsular links were identified as priority links, and their present status is as follows :

1.	Ken-Betwa	:	DPR Completed
2.	Parbati-Kalisindh Chambal	:	Consensus building under process
3.	Par-Tapi-Narmada	:	DPR is being prepared
4.	Damanganga-Pinjal	:	DPR is being prepared
5.	Godavari (Polavaram)-Krishna (Vijayawada)	:	State Government implementing the Link as per their own plan.

Efforts are being made by the NWDA and the MOWR to arrive at a consensus on other links.

8.6 Monitoring by the Supreme Court

As a sequel to the PIL filed on Networking of Rivers, the Hon'ble Supreme Court regularly monitors the progress of implementation of river linking projects. In its latest order, dated the 27th February 2012, the Hon'ble Supreme Court directed Ministry of Water Resources, Govt. of India to constitute forthwith a Committee to plan, construct and implement the program on interlinking of rivers for the benefit of the Nation. This Committee will be headed by the Hon'ble Union Minister of Water Resources and will have members from Central Govt. and the State Govts including Ministers from states concerned. The Committee may constitute Sub-Committee(s), considered necessary for carrying out the objectives of the program. It is also provided that all the Reports of the Expert bodies as well as the Status Reports, filed before the Court during the pendency of the petition, shall be placed before the Committee for its consideration. The Committee shall prepare its plans for implementation of the project after due analysis of the Reports and expert opinions.

The Hon'ble Supreme Court has directed that the Ken-Betwa link be taken up first for implementation. The Court observed that time is a very material factor for execution of the project and directed the Committee constituted to take firm steps, fix a definite time frame for completion of feasibility and other reports so as to ensure the completion of projects and accrual of the benefits within a reasonable time.

The Hon'ble Supreme Court has further directed that the decisions of this Committee, constituted under its order, shall take precedence over those of all other administrative bodies, created under the orders of the Court, or otherwise. In the event of default, liberty has been granted to the learned Amicus Curiae to file contempt petitions in the Court.

The Court hoped for speedy implementation of the project and issued a writ of Mandamus to the Central and the State Govts. concerned to comply with the directions contained in the judgement effectively and expeditiously and without default.

8.7 Conclusions

We consider that execution of such a large and complex infrastructure development programme is imperative in the national interest for resolving various contentious issues.

In the light of the importance given by the Central and the State Governments and the directions of the Hon'ble Supreme Court, it is necessary that the programme is executed after a comprehensive assessment of all relevant issues and carrying out necessary studies following the various criteria stipulated in Chapter 2 of this study on water availability. The entire programme needs to be broken down into pragmatic projects/programmes for facilitating implementation on the ground. It is estimated broadly that the cost of the programme would be of the order of Rs. 7,200 billion at 2012 price level, including the cost of development of hydropower potential of 34,000 MW, as a part of the River Linking Project.

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CHAPTER 9

Recommendations

This Research Study makes an effort to estimate the gap between supply and demand of water – a precious commodity over the medium term, upto 2025 and 2050, based on data available and taking cognizance of the uncertainties inherent in such estimations. It also draws on the research carried out on cost curves of various options for interventions covering the agriculture and industry sectors the municipal/rural livelihood demands, as well as the various water basins of the country.

The projected water demand for the country by 2050 is 1108 BCM. The estimated utilizable flow is 1123 BCM which would increase to 1300 BCM if the storages planned as well as those under construction are completed and the National River Linking Project is implemented. The requirements for ecosystems are estimated to be about 33% of the average annual flows i.e. around 600 BCM out of which 120 BCM (approx) would have to be released in the river system during the 8 dry months. The overall gap in demand and supplies would not exist and the dependability of the system would be greatly enhanced after implementation of the various interventions suggested as under:

A. Supply Management

Creation of Large Storages and Linkages

It is planned to create additional live storage capacity of 170 BCM by 2050. Completion of the storage projects under construction by 2025 would provide live storage of 63 BCM. The balance storage capacity of 107 BCM would be provided by 2050 by implementing various projects under consideration. In addition, the National River Linking Project will provide additional utilizable water of 173 BCM.

Large Scale Rehabilitation of Irrigation Works

Such an intervention would require renovation, desilting and setting up of management infrastructure for irrigation works, creating an additional potential of 5 mha.

Last Mile Irrigation Infrastructure

This will set up the command area management structure and rehabilitate the system to bridge the gap of 9 mha (approx) between the irrigation potential created and that utilized.

Small Scale Irrigation Infrastructure

Minor irrigation infrastructure projects, such as dams built closer to the community for using water during dry spells, will have a potential of irrigating 1.5 mha.

Aquifer Recharge

This would require construction of percolation tanks, check dams, contour bunds etc. to saturate the catchment area and increase abstraction efficiency to 90%, and recharge efficiency to 75%.

Rain Water Harvesting

This involves harvesting rain water in the watersheds and using it for micro-irrigation in rainfed cultivated areas. This will increase the yield of various crops by 25-40% and would be applicable in 20 mha of medium to high rainfall unirrigated farm land.

Use of Waste Water in Irrigation

Recycling and reusing waste water, in lands near urban areas for irrigation and other purposes, need to be ensured, through appropriate regulations, as necessary.

The investment cost on these supply enhancement interventions will be around Rs. 11200 billion at 2012 price-level, upto 2050.This cost also includes the cost of development of hydropower potential of 34000 MW, as a part of the River Linking Project.

B. Demand Management

Technology interventions identified for maximising productivity are listed below:

Laser Levelling

Conventional surface irrigation method in rice-wheat system involves surface application. Use of laser levelling equipment for quicker and better levelling of the fields will contribute to water saving and increase water use efficiencies, besides reducing energy used in pumping water. This intervention can be effectively used in 80 mha of land for field crops.

Zero or Minimum Tilling

This technology involves direct planting of the crops without any or minimum tillage of lands. It not only reduces water use by 20-30%, but also reduces cost of cultivation, increases yield by 10-20% and decreases greenhouse gas emission. This would be applicable in an approximate area of 25 mha for rice, wheat and other grain crops.

Sprinkler or Drip Irrigation

Use of sprinkler or drip irrigation saves 20-40% of water and increases yield by 10-40%; applicable to a large range of crops like wheat, vegetables, plantations, fruits, cotton and sugarcane, covering an area of 40mha.

System of Rice Intensification (SRI)

This envisages transplanting seedlings of lesser age with more spacing and less water application only at saturation size. This will increase the yield by 20-30%, reduce labour and fertilizer cost and decrease greenhouse gas emission; saving of water is about 10-30%.

Land Surface Modification, Bed and Furrow Irrigation and Drainage

Bed and furrow Irrigation permit growing of crops on beds with less water, reducing chances of plant submergence due to excessive rain. This will increase the yield of various crops like wheat, cotton, maize and sugarcane by 5-15%. This intervention can be effectively used for 20 mha farm land.

Biotic and Abiotic Stress Management

The objective is to encourage better management of plant stress by optimum use of pesticides and innovative crop protection technologies. There is no direct saving of water under this intervention but the yield of most crops increases by 10-30%. Applicable to 100 mha farm land.

Improved Germplasm

This would increase yield potential by using higher yielding seed varieties that are best adapted for specific conditions. There is no direct saving of water under this intervention but the yield of most crops increases by 20-30%. Would benefit 100 mha farm land.

Increased Fertilizer Use

This would involve increasing fertilizer use to reduce mineral exhaustion and improve yields in irrigated lands. The yield of all crops will increase by 25-50%. The intervention can be effectively used for 30 mha.

Irrigation Scheduling

The objective is to determine the exact amount of water for application to the field as well as the exact timing for application. The yield of all crops will increase by 5-20%, saving 10-15% of water.

Piped/lined Water Conveyance from Tubewells

This reduces the losses in the conveyance system. Use of piped/lined water conveyance from tubewells saves 20-40% water and increases yield by 10-40%. Applicable for a large range of crops like wheat, vegetables, fruits, cotton and sugarcane covering an area of 20 mha.

Subsurface Drainage

A subsurface drain is a perforated conduit of tile, pipe or tubing, installed below the ground surface to intercept, collect and/or convey drainage water. This intervention is applicable in an area of 10mha in waterlogged and salt affected lands. The yield would increase by 20-30%.

The investment on the above productivity enhancement interventions will be around Rs. 4000 billion if all the measures are simultaneously implemented in areas which are suitable for implementation of these measures. However, when any measure is implemented, it is likely that the scope for implementation of other measures will be reduced to varying extent. Hence, the investment cost for carrying out these measures on all India basis, depending upon location of the area; will be around 50% of the stand alone costs, which amounts to Rs. 2000 billion, up to 2025. The inter se priority for a particular intervention will be area specific and the cost curve (2030 WRG) can be used for determining inter se priority.

C. Water Security for Domestic, Industrial and Other Requirements

The requirement of 261 BCM by 2025 and 373 BCM by 2050 will be met by utilizing perennial ground water resources as well as from the storages created. As the requirements are dependent on concentration of human habitation and industrial activities, perennial sources of surface and ground waters need to be identified. Also, to ensure conservation, demand should be reduced as far as possible, leakages in the supply network should be minimised and recycling of waste water should be ensured for Agricultural/Horticultural uses. In some areas, desalination may be the only way to provide water security for domestic requirements.

D. Sustainability of Ecosystems

The total environmental demands to maintain category 'D' ecosystem is estimated as 353 BCM. Detailed study on the water needs for each river and their tributaries need to be conducted to ensure the specific quantum of flows required. A Scientific Panel consisting of Biologists, Ecologists, Geomorphologists and Hydrologists needs to be constituted to assess the water needs after taking care of the species composition in the riverine Wetlands. The Panel would define the capacity to support and maintain a balanced, integrated, adoptive ecosystem having the full range of elements (genes, species and assemblages) and processes expected in the natural habitat of a region. Till such results become available, provisions as under need be made in various reaches of the rivers for sustainability of the Aquatic Ecosystem.

"Minimum flow in any ten daily period to be not less than observed ten daily flow with 99% exceedance. Where ten daily flow data are not available, this may be taken as 0.5% of 75% dependable annual flow expressed in cubic meters per second".

E. Institutions

AIBP to be renamed as PABA

Availability of new technologies is not sufficient, by itself, to promote development. An effective institutional framework and sustained policy support are also required. The current Accelerated Irrigation Benefit Programme (AIBP) of the Govt. may be renamed as Programme for Accelerated benefits for Agriculture (PABA). The Programme may adopt the technologies discussed earlier for effective execution on the ground after providing suitable incentives as necessary.

Development of Water Technology Hubs

These hubs will be useful for benchmarking the available technologies to provide a clear picture of the benefits to private entrepreneurs. These will also provide incubation facilities to inexpensive new technologies for attracting private participation.

Engaging Local Users in Water Management

All stakeholders, including members of the public, need to be given full opportunities to share their views and influence the outcome of water projects impacting them. This will ensure efficient, effective, equitable and environmentally sustainable management practices.

Strengthening Technology Diffusion Network

The technology diffusion network needs to be strengthened. To start with, each Krishi Vigyan Kendras should have a water technologist.

The investment on these interventions will be around Rs. 200 billion upto 2025.

F. Policy

Climate Change

This study review impact of climate change on water availability and water demands. Climate change would have a direct impact on water demands and water availability. Mitigation and adaptation to climate change would require speedy action on implementation of supply and demand measures suggested at para A & B.

Private Participation

Private participation in development and management of water resources, specially in large industrial clusters, needs to be encouraged.

G. Investment

The total investment on the measures under para A to F would be around Rs. 13,400 billion (Rs. 6,200 billion up to 2025 and another Rs.7,200 billion upto 2050). This cost also includes the cost of development of hydropower potential of 34,000 MW as a part of the River Linking Project.

Water Resources Management

The Indian National Academy of Engineering (INAE), founded in 1987, comprises India's most distinguished engineers, engineer-scientists and technologists covering the entire spectrum of engineering disciplines. INAE functions as an apex body and promotes the practice of engineering & technology and the related sciences for their application to solving problems of national importance. The Academy provides a forum for futuristic planning for country's development requiring engineering and technological inputs and brings together specialists from such fields as may be necessary for comprehensive solutions to the needs of the country. INAE is an autonomous institution supported partly through grant-in-aid by Department of Science & Technology, Government of India. It is the only engineering Academy in India. INAE represents India at the International Council of Academies of Engineering and Technological Sciences (CAETS), USA and is one of the member Academies of CAETS.

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