1 A River Basin Perspective of Water Resources and Challenges

Anju Gaur and Priyanie Amerasinghe[†]

Introduction

The surface water resources potential in India is estimated to be around 1,869 km^3. Due to topographical constraints and spatio-temporal variations in resources, it is estimated that only about 1,123 km^3, (690 km^3 from surface water and 433 km^3 from groundwater) (Central Water Commission [CWC] 2010), can be used. According to the Food and Agriculture Organization (FAO), United Nations, the per capita availability of less than 2,000 m^3/year is defined as a water-stressed condition, and the per capita availability below 1,000 m^3/year is termed as a water-scarce condition. Due to a 3-fold increase in population during 1951–2010, the per capita availability of water in the country as a whole decreased from 5,177 m^3/year in 1951 to 1,588 m^3/year in 2010 (CWC 2010). This suggests that at a macro level, India is in a water-stressed state. The story at the local/regional level is far starker. Increasing shortages are felt at local levels which can spread to the regional level as the population continues to grow. India is divided into 20 river basins. Out of these, 14 basins are in a water-stressed condition (of which 10 are water-stressed, Table 1.1). The disparity among river basins is wide. The Brahmaputra-Barak basin has a total water availability of 11,782 m^3/per person. On the other hand in river basins, such as Sabarmati and east flowing rivers (Pennar and Kanyakumari), the availability of water is as low as 260 m^3 per person per year (Table 1.1).

The stress on water resources (both surface and groundwater) is increasing rapidly due to rising demands of various users and the deteriorating quality of water. In many regions in India the extraction of groundwater is more than the recharge (Chapter 7). The pollution of water resources caused by discharge of untreated municipal sewage and industrial effluents in rivers and the sea, and agro-chemicals penetration in groundwater has further exacerbated the availability of good quality water.

In short, the country's fragile resources are stressed and are depleting fast, both in quantity and quality.

Preserving the quality of water and managing multiple demands on it require an integrated water management strategy. The problem, however, is that water is a state subject and its management is spread across multiple organizations with hardly any coordination. This has posed difficulties in streamlining management issues. Another challenge in the management of water is that state boundaries do not coincide with the geographical boundary of the resource. Though the National Water Policy, 2002 recognizes that river basins should be the

[†] The authors are thankful to Jai Mansukhani for his help in preparing the database. The views expressed in this chapter are those of the authors alone and do not necessarily represent the official position of the World Bank.

TABLE 1.1 Surface and Groundwater Resources in River Basins in India

S.No.	*Name of the river basin*	*Population (million)*	*Catchment area (km^2)*	*Average annual surface water potential (km^3)*	*Estimated utilizable surface water (km^3)*	*Estimated replenishable groundwater resources (km^3)*	*Total utilizable water (km^3)*	*Surface storage potential, (km^3)*	*Total surface and groundwater storage (km^3)*	*Per capita water available (2010)*
1	Indus (up to the border)	59.01	321,289	73.31	46	26.49	72.49	19.14	45.63	1,242
2	Ganga	505.54	861,452	525.02	250	170.99	420.99	94.35	265.34	1,039
2.1	Brahmaputra, Barak, others	49.71	236,136	585.6	24	35.07	59.07	52.94	88.01	11,782
3	Godavari	76.02	312,812	110.54	76.3	40.65	116.95	41.89	82.54	1,454
4	Krishna	85.62	258,948	78.12	58	26.41	84.41	49.61	76.02	912
5	Cauvery	41.27	81,155	21.36	19	12.3	31.3	12.96	25.26	518
6	Subernarekha	13.23	29,200	12.37	6.81	1.82	8.63	3.93	5.75	935
7	Brahamani & Baitarni	13.80	39,033	28.48	18.3	4.05	22.35	13.72	17.77	2,063
8	Mahanadi	37.45	141,589	66.88	49.99	16.46	66.45	26.52	42.98	1,786
9	Pennar	13.67	55,213	6.32	6.86	4.93	11.79	4.82	9.75	462
10	Mahi	14.78	34,842	11.02	3.1	4.2	7.3	5.21	9.41	746
11	Sabarmati	14.80	21,674	3.81	1.93	3	4.93	1.56	4.56	257
12	Narmada	20.70	98,796	45.64	34.5	10.83	45.33	27.14	37.97	2,205
13	Tapi	20.85	65,145	14.88	14.5	8.27	22.77	12.26	20.53	714
14	West flowing rivers From Tapi to Tadri	36.33	52,900	87.41	11.94	8.7	20.64	16.42	25.12	2,406
15	West flowing rivers From Tadri to Kanyakumari	45.91	56,200	113.53	24.27	9	33.27	13.81	22.81	2,473
16	East flowing rivers between Mahanadi & Pennar	33.25		22.52	13.11	9	22.11	4.24	13.24	677
17	East flowing rivers between Pennar and Kanyakumari	63.29	100,100	16.46	16.73	9.2	25.93	1.38	10.58	260
18	West flowing rivers of Kutch, Saurashtra including Luni	31.10	321,900	15.1	14.98	11.23	26.21	9.59	20.82	486
19	Area of inland drainage in Rajasthan desert		60,000							0
20	Minor river basins draining into Bangladesh & Myanmar	2.11	36,300	31		18.8	18.8	0.31	19.11	14,679
	Total		3,184,684	1,869	690	431	1,122	411.81	843.21	1,588

Source: Central Water Commission and Central Ground Water Board.

basic hydrological unit for integrated planning and development of water resources, this has not happened so far.

This chapter presents an overview of the state of water resources in India. Though the strategies and policies to address various issues affecting the sector are discussed in later chapters, key strategic issues to bridge the gap between increasing demand and supply at the basin level are presented in this chapter.

Status of Water Resources Availability in India

The system of surface water resource in India comprises of 20 major river basins. Seven rivers and their tributaries feed these river basins (Figure 1.1). Of these 20 river basins, 13 are large comprising an aggregate catchment area of 2.6 million square km (Table 1.1). These 13 major river basins together are spread over about 81 per cent of the geographical area of the country. There are, however, substantial challenges and variations that these river basins face in their water availability.

These river basins depend on precipitation for water. Rainfall being the major component of precipitation is highly seasonal as most of the rain is concentrated during the monsoon season which lasts over 4–5 months (June to September/October). Further, there are huge geographical variations in the rainfall across the country. The western parts of Rajasthan get merely

Figure 1.1 Major River Basins in India

Source: Adapted from CWC (2010).

100 mm of rain during the year, while Cherrapunji in Meghalaya gets yearly rainfall of 11,000 mm. Hence, the annual average surface water that is available in the river basins varies a lot. Table 1.1 presents the estimated average annual surface water potential across various river basins.

There are huge variations in the extent of catchment areas of river basins and their surface water potential. The geographical coverage of the Ganga and Brahamputra-Barak river basins is the largest and covers about 34 per cent of the country served by all river basins. The Ganga and Brahamputra-Barak river basins account for 60 per cent of the average annual water resources potential. However, due to topographical constraints and spatio-temporal variability of the availability of water only 48 per cent of the total water potential in the Ganga basin and 4 per cent of the total water potential in the Brahmaputra basin is utilized. On the other hand, three river basins in southern India (Godavari, Krishna, and Cauvery) together represent 21 per cent area of the country area while they account for only 11 per cent of the surface water.

Table 1.1 also presents information on basin-wise utilizable surface water. The utilizable surface water as a percentage of the total water resource potential is far higher for southern river basins, such as Godavari, Krishna, Cauvery, Pennar, and east flowing rivers between Pennar and Kanyakumari river basins, than others. In the Pennar, Kanyakumari, and Tapi river basins, nearly all the water resource potential is utilizable. However, there is huge potential to tap the water resource in other river basins.

Surface Water Development through Storage

In order to address spatial and temporal variations across river basins and to increase water availability, water storage capacities have been developed along the rivers to meet the demand for water throughout the year. Surface water storages are categorized as major (live storage >10 km^3), medium (2–10 km^3), and minor projects (or irrigation tanks with culturable command area <2,000 ha). The total live storage in major and medium projects is 221 km^3 (from completed projects), which contributes 32 per cent to the total utilizable surface water. In addition, the storage capacity of 191 km^3 is either under construction or is being considered for development. Estimated total storage capacity of completed, ongoing, and contemplated projects, would be 412 km^3 which will take the total utilizable surface water to 881 km^3 from the present level of 690 km^3 for all river basins taken together.

The Krishna basin leads in terms of existing storage capacity (41.80 km^3), followed by the Godavari (25.12 km^3), and Narmada basins (16.98 km^3). In the southern river basins, where availability of water resource is a problem, including Krishna, Godavari, Cauvery, and west flowing rivers, water harvesting is prevalent through tanks. Indiscriminate increase in storage, however, affects the natural regenerative capacity of rivers. Certain amount of river flow is therefore necessary. In the Krishna basin, the surge in storage development since the 1960s resulted in a drastic reduction in river discharge and outflow into the sea from an average annual flow of 57.22 km^3 during 1950–60 to 24.94 km^3 during 1995–2005 (Gaur et al. 2007). The actual surface water usage during a normal year in the basin is 117 per cent of the storage capacity in the basin. The existing storage capacity in the west flowing rivers of Kutch, Saurashtra including Luni, Narmad, Brahmani, and Baitarni exceeds 50 per cent of their respective average annual natural flows. As a consequence, the overall flows reaching the sea from these rivers have reduced drastically. On the other hand, water rich basins, such as Brahmaputra and Barak have very low storage capacity, just about 9 per cent of the annual natural flow. In terms of planned storage capacity, the southern river basin of Pennar, which faces immense water shortages, leads in terms of planned storage development followed by the Tapi basin. This additional storage will, however, reduce the average annual natural flow of rivers in these basins by more than 70 per cent. On the one hand while it is necessary to tap the river flow by increasing storage capacity, it is important to balance the new development of storage in a way that the regenerative capacity of the river is not affected.

Status of Groundwater

The potential groundwater resource has two components—static (10,812 km^3) and dynamic reserves (433 km^3). Although static reserves are high, they cannot be exploited except in an emergency as they are non-replenishable. Only the usage of dynamic reserves, which are replenished seasonally, is permitted (Ministry of Water Resources 2002). The zone of fluctuation for the dynamic resource is about 450 m below the ground level in the alluvium soil aquifer in the Indo-Gangetic Valley, 100–150 m in the inland river basin, and 200 m in hard rock aquifers. The major source for dynamic recharge is rainfall, which contributes about 67 per cent of the recharge. The rest of the groundwater recharge happens from non-rainfall sources, such as leaky canals, tanks, and local water bodies (Central Ground Water Board 2004).

Table 1.1 gives the estimated replenishable groundwater resource by river basins. Though a detailed discussion on groundwater is presented in Chapter 7, the key points that emerge from the distribution of groundwater across the country are discussed here. Nearly half of the replenishable groundwater resource is located in the Ganga-Brahmaputra-Barak river basins. The Indus river basin accounts for another 25 per cent of the replenishable groundwater resource. Of the total utilizable water, groundwater comprise about a third except in Ganga-Brahmaputra-Barak, where it is about 42 per cent, and in Subernarekha, Brahmani, Baitarni, Mahanadi, and Narmada where it is 25 per cent or less. Unlike the availability of surface water, which is highly seasonal, groundwater is a steady source of water throughout the year. Of the total storage of water that is available throughout the year (comprising surface water storage plus the replenishable groundwater resource), groundwater constitutes nearly 50 per cent, though there are inequalities across river basins. In the Ganga river basin, the share of groundwater in the total water storage is about 64 per cent. In basins like Krishna, Mahanadi, Subernarekha, and Narmada the share is 35 per cent or less.

Groundwater Resources Development

At the national level, the net annual groundwater draft is about 231 km^3 which is 58 per cent of the dynamic reserves. Nearly 92 per cent of the groundwater draft is used for irrigation while the remaining is used for domestic and industrial use.

The groundwater resource has been exploited to the extent that many regions in the country are facing severe problems (Chapter 7). The overexploitation of groundwater has resulted in a number of problems, such as sea water ingression in coastal areas and groundwater pollution in different parts of the country.

The challenges for further development of groundwater systems are two-fold: (i) how to restrain groundwater use to sustainable levels in overexploited regions? and (ii) how to develop the large untapped groundwater potential, which exists in eastern India? The willingness to control the overexploitation of the groundwater resource by farmers by using efficient irrigation systems has remained weak. Subsidized electricity supply in most regions has further exacerbated the overexploitation of groundwater.

Water Demand at the River Basin Level

The demand for water will grow from 656 km^3 in 2010 to 1069 km^3 by 2050 (Thatte et al. 2009). Irrigation is the largest consumer of water, which accounted for 85 per cent of the water demand in 2010 (Table 1.2), followed by domestic use (6 per cent), energy development (3 per cent), and industries (6 per cent). The demand for water from non-irrigation sectors will grow rapidly over the next 40 years. The demand for water in the domestic sector will grow 2.6 times, energy 3.7 times, and industry 2.2 times during 2010–50 (Thatte et al. 2009).

The National Commission on Integrated Water Resources Development (NCIWRD) has estimated the multi-sector uses within basins (Table 1.3). Following the National Water Policy, 2002 criteria for allocation, priority was accorded to domestic use, followed by irrigation, industries, and other uses. For agriculture, NCIWRD assumed that the efficiency of surface irrigation systems would increase to 60 per cent from the present level of 35–40 per cent. The estimates indicate that 9 out of the 20 river basins do not have sufficient water for industry or other uses. Based on the availability of water according to priority of use, river basins like Indus and Sabarmati did not have any residual water left for industrial and other uses even in 2010. The situation will be worse in 2050 when Ganga and the basin fed by the east flowing rivers Mahanadi and Pennar will also face severe water availability problems. Estimates for 2010 indicate that at the basin level, d mestic water accounted for 9 to 46 per cent of the total water demand (based on Table 1.3). Even in water rich basins, such as the Barak, domestic water constitutes the major demand for water. Due to low storage capacity the availability for other uses cannot be enhanced. By

TABLE 1.2 Available Water Resources in India and Demand Projections by 2025 and 2050

Water Resources	*2010*	*Year* *2025*	*2050*
Estimated annual precipitation (including snowfall) (km^3)	4000		
Average annual potential in rivers, (km^3)	1869		
Estimated utilizable water (km^3)	1123		1379
Surface (km^3)	690		910
Ground (km^3)	433		469
Existing surface storage (km^3)	214	412	412
Population (million)	1150	1394	1750
Per capita actual water availability (m^3)	977	806	685
Per capita actual storage (m^3)	186	296	235
Irrigated area SW (M ha)	87	139	175
Water demand † (km^3)			
Domestic	43	62	111
Irrigation	557	611	807
Industry	37	67	81
Energy	19	33	70
Total	656	773	1069
Water regeneration (Mega Litre/day)	45133	68123	132253
(km^3)	16	25	48

Source: Central Water Commission, † Adapted from Thatte et al. (2009).

2050, domestic water will account for 12–55 per cent of the total water demand mainly due to an increase in population. Three more river basins of Ganga, Krishna, and Subernarekha will be added to the list of water scarce basins, taking the number of water-scarce basins to 12 by 2025. By 2050, the Indus basin may also become water-scarce while the Godavari basin may come closer to the water-scarce level.

By 2050 the level of water demand will reach closer to the utilizable level. Harnessing all of the 690 km^3 of utilizable surface water will be possible only if matching storage is built. As shown in Table 1.2, by 2025 the use of recycled water may be able to partially serve a basin's water demand through water conservation schemes but that will add only a tiny component to the overall water availability. Adopting various measures for exploring and tapping the remaining water resources, in addition to innovative water conservation and management techniques, would be necessary. Central Ground Water Board has estimated that it is possible to increase the groundwater availability by about 36 km^3, by taking up rainwater harvesting and artificial recharge over an area of 45 M ha utilizing surplus monsoon run-off. Trans-basin transfer of water, if taken to the full extent could further increase the utilizable quantity by approximately 220 km^3 (Planning Commission 2008).

CHALLENGES FOR WATER RESOURCE AVAILABILITY, MANAGEMENT, AND SUSTAINABILITY

There are a number of externalities associated with the water resource that affect its availability, management, and sustainability. Externalities, such as floods

Table 1.3 River Basin-wise Water Demand Projections for 2010, 2025, and 2050

S.No.	River basin	Total of surface and groundwater resources (km^3)	Estimated demand for Water in 2010 (km^3)					Balance available for industries and other uses (km^3)		
			Irrigation	Domestic	Total	Return Flow †	Net for irrigation and Dom.	2010	2025	2050
1	Indus	72.5	102.09	2.83	104.92	12.47	92.45	–19.95	–49.5	–71.81
2	a) Ganga	421	311.99	22.19	334.18	48.95	285.23	135.77	43.91	–24.25
2.1	b) Brahmaputra	50.55	12.91	1.31	14.22	2.34	11.88	38.67	34.87	32.07
2.2	Barak & others	8.52	1.61	1.42	3.03	1.3	1.73	6.79	6.44	5.65
3	Godavari	116.9	34.37	3.22	37.59	6.01	31.58	85.32	75.2	67.72
4	Krishna	84.4	42.85	4.28	47.13	7.71	39.42	44.98	32.32	22.94
5	Cauvery	31.3	16.13	1.98	18.11	3.2	14.91	16.39	11.59	8.01
6	Subarnarekha	8.6	3.45	0.61	4.06	0.83	3.23	5.37	4.31	3.47
7	Brahamani & Baitarni	22.35	7.15	0.51	7.66	1.12	6.54	15.81	13.7	12.11
8	Mahanadi	66.5	26.32	1.52	27.84	3.85	22.99	43.51	34.79	29.05
9	Pennar	11.83	5.81	0.64	6.45	1.09	5.36	6.47	4.72	3.33
10	Mahi	7.3	5.07	0.62	5.69	1	4.69	2.61	1.12	0.01
11	Sabarmati	4.9	7.01	0.87	7.88	1.4	6.48	-1.58	-3.68	-5.23
12	Narmada	45.3	11.26	0.83	12.09	1.79	10.3	35	31.69	29.24
13	Tapi	22.77	3.89	1.1	4.99	1.27	3.72	19.05	17.86	16.96
14	West flowing rivers from Tapi to Tadri	20.6	3.9	2.51	6.41	2.4	4.01	16.59	15.47	14.25
15	West flowing rivers from Tadri to Kanyakumari	33.3	5.99	1.94	7.93	2.15	5.78	27.52	25.67	24.27
16	East flowing rivers between Mahanadi and Pennar	22.1	21.01	1.43	22.44	3.25	19.2	2.9	–3.26	-7.84
17	East flowing rivers between Pennar and Kanyakumari	25.7	24.21	3.49	27.7	5.21	22.49	3.21	–4.01	-9.35
18	West flowing rivers of Kutch and Saurashtra including Luni	26.2	22.46	1.61	24.07	3.53	20.54	5.66	-1.02	-6.15
19	Area of inland drainage in Rajasthan		18.27	0.68	18.95	2.37	16.58	–16.58	–22.04	–26.52
20	Minor river basins draining into Myanmar (Burma) and Bangladesh	18.8	0.67	0.12	0.79	0.16	0.62	18.18	17.98	17.82
	Total	1,121.42	688.42	55.71	744.13	113.4	629.73	491.69	196.73	135.75

Source: † Adapted from Thatte et al. (2009) and Planning Commission (2007). Estimated by the National Commission for Integrated Water Resources Development (NCIWRD).
Note: † (80% of domestic + 10% of irrigation)

and droughts caused by extreme climatic factors, affect the livelihood and economy of a region. The quality of water and trans-boundary issues have an impact on the availability of this resource for consumption.

Extreme Climate Factors: Flood and Drought

Floods and droughts affect vast areas of the country that transcend geographical boundaries of states. One-sixth of the geographical area of the country (about 40 M ha) is drought-prone. Similarly, floods affect around 7.5 M ha of land each year. Despite such an impact of these calamities, experience in managing their impact has been poor. Managing the impact of droughts as well as floods requires a system of data collection, transmission, forecasting, and dissemination through an early warning system. However, a majority of the flood warning systems in India are not timely, primarily due to poor transmission. Delays cause enormous damage to property and lives every year. Moreover, models that are used for flood forecasting and its influence zones are not rigorous enough due to lack of integration of hydrology and the weather forecasting systems.

The lead time for flood forecasting can be improved through the use of hydraulic and hydrologic models which are linked to the weather forecasting system, the real time data acquisition system, and the reservoir operation system. It is possible to improve the current forecasting methods by using satellite based information for better estimates of rainfall and snowmelt. Attempts are being made to modernize site-specific forecasting systems with satellite based telemetry, which will improve overall basin-wise forecasting.

Water Quality

Poor water quality will further strain the availability of freshwater for various uses. The quality of water has become a serious problem in river basins. About 70 per cent of the surface water resources and large proportions of groundwater reserves have been contaminated due to indiscriminate discharge of wastewater from the industry, agriculture, and households sectors which contain biological as well as toxic organic and inorganic pollutants.

Water pollution across river basins varies in severity depending on the degree of urban development, agricultural and industrial practices, and systems for collecting and treating wastewater. The Central Pollution Control Board (CPCB) has identified some of the polluted river stretches and possible sources of pollution (Table 1.4).

Most of the polluted stretches of rivers are located in and around large urban areas. Municipal sewage contributes about 75 per cent and industrial pollution accounts for the rest of the point source pollution. Class-I and Class-II cities together generate an estimated 38,254 MLD of sewage (CPCB 2009). The treatment capacity of 11,787 MLD in 2009 was far behind the requirements. By 2050, the sewage generation from Class-I, II cities will increase by three-and-a-half times to 132,253 MLD, which will pose serious problems if concerted efforts to add wastewater treatment capacity are not undertaken.

Groundwater is also polluted due to point and non-point source pollution. In some areas, the groundwater is not of the desired quality due to geogenic elements. For example, occurrence of high fluoride content has been reported in 13 states. Other pollutants, such as arsenic in West Bengal, and iron in the north-eastern states, Orissa, and other parts of the country have also been reported. In the canal irrigated land of Haryana, Punjab, Delhi, Rajasthan, Gujarat, Uttar Pradesh, Karnataka, and Tamil Nadu, groundwater is affected due to salinization (the affected area comprises over 193,000 km^2 of land) (Thatte et al. 2009).

Efforts were made in the past to clean water resources through government intervention. The Ganga Action Plan implemented under the National River Conservation Plan (NRCP—1995/96) covers pollution abatement activities in 34 rivers and 160 towns in 20 states. Major interventions under the plan include interception and diversion of sewage into networked channels, construction of sewage treatment plants (STPs), low cost sanitation works, and river front development activities. Pollution abatement plans have been adopted for some rivers for implementation through a designated authority for the purpose (for example, the National Ganga River Basin Authority in 2009), where holistic approaches are being utilized. Though other formal or informal authorities are being set up for river pollution abatement activities, synergy between regulatory and implementing authorities is necessary for future water development programmes.

Table 1.4 Pollution in Selected Stretches of Rivers Basins

S. No.	*Name of the river basin*	*Polluted Stretch*	*Existing Class**	*Critical Parameters*	*Possible Causes of Pollution*
1	Indus (up to the border)	Satluj: Downstream of Ludhiana to Harike	D/E	BOD, DO	Domestic from Ludhiana and Jalandhar, and industrial from hosieries, tanneries, electroplating, and engineering
		Satluj: Downstream of Nangal	D/E	Ammonia	Waste from fertilizer, cholarlkali mills from Nangal
2	Ganga	Chambal River: Downstream of Nagda and Kota	D/E	BOD, DO	Domestic and industrial
		Gomti: Downstream of Lucknow	D/E	BOD, DO, Coliform	Domestic and industrial from distilleries
		Hindon: Sahranpur to confluence with Yamuna	D	DO, BOD, Toxicity	Domestic and industrial
		Kali: Downstream of Modinagar to confluence with Ganga	D/E	BOD, Coliform	Domestic and industrial
		Yamuna: Delhi confluence with Chambal	D/E		Domestic and industrial waste from Delhi, Mathura, and Agra
2.1	Brahmaputra, Barak, others	Downstream of Dhanbad	D/E	BOD, Toxicity	Industrial pollution from Dhanbad, Asansol, Haldia, and Brunpur
3	Godavari	Downstream of Nasik, Nanded		BOD	Industrial waste from sugar industries, distilleries, and food processing industries
4	Krishna	Karad to Sangli	D/E	BOD	Industrial waste from sugar industries and distilleries
5	Subernarekha	Hatia Dam to Bharagora	D/E	Ammonia	Domestic and industrial from Ranchi and Jamshedpur
6	Sabarmati	Starting from u/s of Ahmedabad to Vautha through Sabarmati Ashram	E	BOD, DO, Coliform	Domestic and industrial from Ahmedabad

Source: Central Pollution Control Board and Jain et al. (2007).
Notes: *As per CPCB (http://cpcb.nic.in/data2005.php last accessed on 20 September 2011) the existing classes for water quality are A (good) to E (very bad):

- D is best suited for wildlife and fisheries (pH 6.5–8.5, Dissolved Oxygen $\geq$ 4 mg/l, Free Ammonia $\leq$ 1.2)
- E is best suited for irrigation and controlled waste disposal (pH 6–6.5, EC $\leq$ 2250 Mmhos/cm, SAR $\leq$ 26 Boron $\leq$ 2 mg/l).

Trans-boundary Water Issues: International and Inter-state Scenarios

From a river basin perspective, water resource development and management has to address trans-boundary water allocation issues. Since water management is done through sector-wise administration by a number of government entities spread over 11 Central ministries, state governments, and local bodies water politics, rights, and conflicts are commonplace (discussed in detail in Chapters 3 and 4). Hence, the political economy drives the water agenda nationally and internationally.

Out of the 20 river basins, the two largest–the Indus and the Ganga-Brahmaputra-Barak basins are international river basins and the management of water resources is, therefore, driven by agreements or treaties between riparian countries. The remaining basins are mostly inter-state basins and a majority of them have commissions or boards to manage water issues. According to the Indian Constitution, water is a state subject and the role of the centre is limited only to the extent of managing the water resource in case inter-state river water disputes arise (Thatte et al. 2009). It may seem that the states have absolute rights over rivers and lakes but the Indian Easement Act, 1882 allows other users to claim prescriptive rights to the waters if customary usage of water can be established for a period of 20 years or more (D'souza 2006). In that sense, there are multiple rights holders—states, sectors, individuals, and communities—who hold various types of water rights. Multiplicity of rights poses problems for an integrated management of the water resource and hence its equitable availability. Rights related to water need an appropriate framework (this aspect has been discussed in Chapter 5) to reduce water conflicts between states, sectors, and people.

Programmes and Institutions Involved in the Sector

Growing demand across competing sectors, increasing occurrence of droughts, declining water quality, extreme weather conditions, inter-state river disputes, and inadequate institutional reforms and enforcement are some of the problems that the water sector in India faces today. The major areas that need attention are: management of existing water assets (used for irrigation and water supply systems) and water resources together with water sector institutional reforms. Towards this end, the Government of India has initiated a number of programmes and projects including the Accelerated Irrigation Benefits Programme, Hydrology Projects II, setting up of a Water Quality Assessment Authority, Command Area Development and Water Management Programme, National Project for Repair, Renovation and Restoration of Water Bodies, Flood Management, and setting up of River Basin Organizations. In addition, water resources restructuring projects are on in Andhra Pradesh, Maharashtra, Rajasthan, Uttar Pradesh, Madhya Pradesh, and Tamil Nadu which are aimed at modernizing irrigation systems. These programmes aim at a dressing the infrastructure gaps that exist and managing the water resource to enhance its quantity, quality, and sustainability.

Despite the conceptualization of a number of programmes, effective implementation has been challenging due to different priorities of implementing agencies, poor coordination among implementing departments, and low level of monitoring mechanisms. For example, from a functional point of view, the responsibility for ensuring adequate availability of water for agricultural use is divided among the Ministry of Water Resources (MoWR), which is responsible for major, medium, and minor irrigation programmes, the Department of Land Resources which is responsible for watershed management, the Department of Rural Development which is responsible for the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) which deals with water conservation issues, and the Department of Agriculture which addresses issues associated with water use efficiency (Figure 1.2). Requirements of rural drinking water, which are largely met through groundwater sources, are in the functional domain of the Department of Drinking Water Supply (DDWS) within the Ministry of Rural Development (MoRD). The development and management of groundwater involves other players and schemes that lie outside the purview of DDWS. Similarly, in the urban context, the Ministry of Urban Development (MoUD), states and its various departments and urban local bodies (ULBs), are involved in the supply of water within cities. In order to make these institutional arrangements effective, proper planning, convergence of various agencies, site-specific design, and monitoring using modern techniques, such as remote sensing have to be in place.

Given that water availability in India will be under tremendous stress in the future and many river basins will face severe water shortages rising demand and the deteriorating quality of water needs policies and strategies that manage the resource holistically.

Policies and Strategies

While the policies and strategies for the water sector and the institutional arrangements to deliver them have been discussed at length in various chapters in this

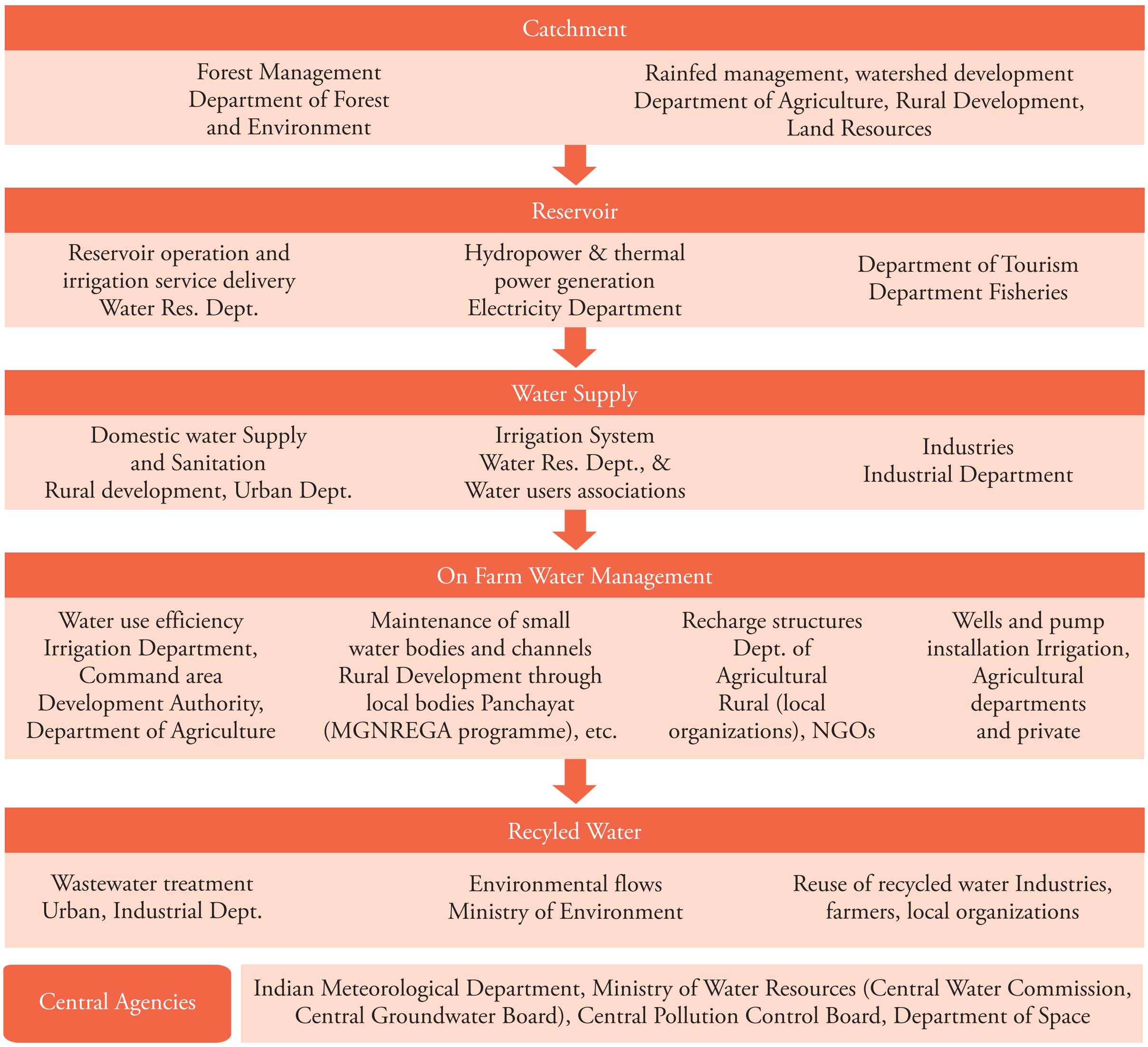

FIGURE 1.2 Existing Multi-disciplinary Approach for Water Resource Management in A River Basin

Source: Authors' own.

volume, a brief review of select policies and strategies is presented here.

Integrated Water Resources Management and River Basin Organization

In order to cater to multi-sectoral water demands and an optimum and judicious utilization of the available land and water resource, integrated water resource management (IWRM) is necessary. A basin authority, such as a river basin organization (RBO) is best suited to implement the principles of IWRM and for planning inter-state water allocation. The functions of an RBO should include assessing water availability, preparing comprehensive plans for the operational development of surface and groundwater systems, and promoting measures for prevention of water logging, water conservation, and ensuring water quality. The need for RBOs for inter-state water allocation and decision-making has been extensively discussed at the government, non-government, and political levels in the country. However, with the exception of the Brahmaputra and Barak Board and the Betwa River

Board, such basin authorities have not been realized. These boards were set up by the MoWR in 1980 for planning and for the integrated implementation of measures for the control of floods and bank erosion in the Brahmaputra Valley.[1] A few basin authorities, such as the Narmada Control Authority and the Upper Yamuna River Board are involved in the operation of the water system, but are not considered full-fledged basin authorities. While the Brahmaputra and Barak boards have comprehensive functions encompassing a whole range of inter-state and basin management functions, other river basin authorities, such as the Narmada Control Authority have limited functions relating only to the construction of a project. These boards were set up at the initiative of MoWR with not much support from states causing inefficiencies in their operations. If such boards are created with the support of the state, their functions will become more effective (see Box 1.1 for details about the Brahmaputra Board).

Recently, the Krishna Water Distribution Tribunal II suggested that a Krishna Basin Authority should be created along the lines of the Murray-Darling Basin Authority in Australia for the integrated management of the water resource (see Box 1.2).[2] The authority is proposed to be constituted by the Government of India and will be headed by a panel of experts representing environment, irrigation, agriculture, groundwater, geology, health, and ecology to protect the river basin area for its long-term sustainable productivity and ecology.

National Water Policy

The National Water Policy (NWP) was first formulated and adopted in September 1987 and later updated in 2002. It covers a comprehensive plan for India, and if adopted at a basin level, it can add value to water development programmes. We now discuss some of the highlights of this policy.

Box 1.1
The Brahmaputra Board

The Brahmaputra-Barak Basin

- One of the largest rivers in the world with a specific yield of 85 ha m/km^2 or 850 millimetre next to the Amazon river (87 ha m/km^2 or 870 millimetre).
- The basin extends over an area of 592,000 km^2 and falls in Tibet, India, Bhutan, Bangladesh, and Myanmar.
- The seven riparian states are Arunachal Pradesh, Assam, Meghalaya, Manipur Mizoram, Nagaland, and Tripura.
- The system serves a population of 50 million in India.
- Out of the total water potential of 585 km^3 within India, only 42 km^3 is available for beneficial use due to topographical constraints.
- Due to high yield, the basin is highly prone to floods with very low storage capacity of 2.3 km^3. Almost 50 km^3 of storage is under construction or consideration for development.
- In 1980, the Brahmaputra Board was set up under the Brahmaputra Board Act, 1980 to prepare a master plan for the control of floods in the Brahmaputra Valley giving due regard to the overall development and utilization of the water resources.
- Institutions involved in the Brahmaputra Barak Basin are the board, state representatives, the Central Water Commission, Central Electrical Authority, Geological Survey of India, and the Indian Meteorological Department.

Main Functions

The Board became effective in 1982. Its main functions are:

- Preparing a plan for flood control and utilization of water resources for various uses.
- Preparing a detailed report and estimates for proposed projects.
- Construction, maintenance, and operation of multi-purpose projects with the approval of the central government.

Source: Brahmaputra Board. Available at: http://brahmaputraboard.gov.in/organisation.htm

[1] Brahmaputra Board. Available at: http://brahmaputraboard.gov.in/organisation.htm last accessed on 20 September 2011.
[2] Murray–Darling Basin Authority. Available at: http://www.mdba.gov.au/last accessed on 20 September 2011.

Box 1.2
The Murray-Darling Basin Authority

The Murray-Darling Basin

- Possesses 23 river valleys covering 1 million square km, covering 14 per cent of Australia.
- The riparian five states and territories are New South Wales, Victoria, the Australian Capital Territory, Queensland, and South Australia.
- Provides one-third of Australia's food supply. It serves a population of 2 million inside the basin and 1.2 million outside the basin.
- The total average annual rainfall in the basin is 5,306 km^3: 94 per cent evaporates or transpires through plants, and 2 per cent drains into the ground, leaving only 4 per cent as runoff.
- The total volume of water storage capacity in the basin is around 350 km^3.
- First Murray-Darling Basin Commission was established in January 1988 under the Murray-Darling Basin Agreement to efficiently manage and equitably distribute River Murray water resources.
- The Water Amendment Act, 2008 (amendment to the Water Act, 2007) was introduced to transfer authority from the Murray-Darling Basin Commission to the Murray-Darling Basin Authority (MDBA), creating an independent, expert-based body that would manage the Basin holistically for the first time.
- Institutions involved are MDBA, basin states, the Australian Government Minister for Sustainability, Environment, Water, Population, and Communities.

Main Roles and Responsibilities

Since 2008, MDBA has been planning the integrated management of water resources of the Murray-Darling Basin. The Murray-Darling Basin Authority is an integral element of the Commonwealth Government's programme 'Water for the Future' which has four priorities: (i) tackling climate change, (ii) supporting healthy rivers, (iii) using water wisely, and (iv) securing water supplies.

In addition to the commission's former functions, the Authority's role includes:

- Preparing the Basin plan for adoption by the Minister for Sustainability, Environment, Water, Population, and Communities.
- Implementing and enforcing the Basin plan.
- Advising the minister on the accreditation of state water resource plans.
- Developing a water rights information service which facilitates water trading across the Murray-Darling Basin.
- Measuring and monitoring water resources in the Basin.
- Gathering information and undertaking research.
- Educating and engaging the community in the management of the Basin's resources.

Source: Murray–Darling Basin Authority. Available at: http://www.mdba.gov.au/

Information Systems

National Water Policy supports the development of a standardized national information system. MoWR's efforts towards developing a Water Resources Information System (WRIS), are a welcome development where central and state level information can be integrated to look at water issues from a river basin perspective. Efforts are being made under the Hydrology Project II to standardize databases and data are being used for proper planning and management practices. The information system can be further modernized with the use of satellite based telemetry and Light Detection and Ranging (LIDAR) based surveys. Though the use of satellite based telemetry and LIDAR is expensive, their benefits would outweigh the costs.

Water Resources Planning

NWP recognizes a drainage basin as the basic unit of planning, development, and management of the water resource and calls for appropriate measures to optimize the utilization of the water resource. Under Hydrology Project II, and other projects, efforts are being made to develop a decision support system for certain aspects within sub-basins in the states.

Groundwater Development

The development of groundwater is affected by policies and strategies from multiple sectors, including power and agriculture. Improved access to electricity in the eastern parts of India and incentives that have motivated head enders in canal irrigated area to use groundwater in place of canal water have contributed to substantial groundwater development, leading to overexploitation of groundwater in many regions. Some states, such as Gujarat, are implementing regulations to counter the overexploitation of groundwater.

A typical way by which overexploitation is addressed is by constructing groundwater recharge structures. However, this strategy needs careful evaluation. If overexploited areas in the upstream are supplemented with recharge structures, it may affect water availability (even for priority use, such as drinking) in the downstream projects. In closed or water-stressed river basins, water recharge structures should be implemented only after a proper analysis of the upstream and downstream implications and their effectiveness, particularly in southern India where infiltration potential for groundwater recharge is low.

Participatory Approaches to Water Resources Management

NWP recognizes the need for legal and institutional changes at various levels and participatory water resource management. Some reforms like establishing water users associations (WUAs) have been undertaken but their outcomes appear to be highly variable across the states (see Chapter 9). WUAs will need to be further strengthened and empowered. This may even require changes in the legislature. Currently, a majority of water-related schemes are introduced through gram panchayats and not WUAs. Clarity of roles and responsibilities between these two local bodies will strengthen implementation processes. Apart from WUAs for canal irrigation, water user groups of water bodies, such as tanks and groundwater also need appropriate policy frameworks for a more holistic management of water development processes within the basins.

Irrigation Projects

Managing irrigation water is necessary to conserve water in a sector that constitutes 85 per cent of the water demand and a large part of this demand is due to inefficient use. There are good examples of well-run irrigation projects. A case in point is the Parambikulam-Aliyar Project (PAP) in Tamil Nadu. This project has a planned operation system which encompasses a system of rotation of alternate canal system for alternate seasons, with opportunities for conjunctive use, fixed schedule, a gravity-based pipe conveyance system, and a drip irrigation system.

Water Quality

Water quality has become a major concern from a river basin perspective as upstream pollution has a downstream impact. Greater emphasis on the use of clean technologies and adopting context-specific technological options at different points along the waste streams is the way forward. In order to achieve this, from a regulation perspective, economic instruments (taxes and incentives), which are aimed at resource conservation, waste minimization, and reuse of wastes, would be necessary.

Monitoring of Projects

Ongoing and outcome monitoring is the key to measuring the success of projects and should be emphasized in all water development programmes. Modern technologies, such as management information systems to monitor the progress in implementation, mobile based technology, a global positioning system (GPS) based cameras, and satellite based imageries should be promoted to monitor the impact on land use. The reliability of data and quick assessment ability can help in good decision-making which is based on evidence.

Private Sector Participation

Although public-private partnerships (PPPs) for developing the water resource have been promulgated, the outcomes have not been as expected. This may be due to the fact that irrigation projects require large capital investments and given the low water charges, these may not appeal to a private investor (discussed in Chapter 14). An approach for promoting PPPs could be initiating collaboration by outsourcing services, such as irrigation system operations and maintenance, implementing efficient water management techniques, and agricultural extension projects with agreed output criteria for improved efficiency of the systems that clearly define irrigated areas and crop productivity.

These projects could be of a small size. An appropriate unit for the size is the command area, which can be easily monitored.

Research and Development

Research and development offers an array of tools and techniques for water resource modelling on a basin scale (discussed in Chapter 2). Opportunities that are available for developing models suitable for India with national and international collaboration should be explored as sophisticated modelling at a hydrological unit is necessary for integrated water resource management.

Conclusion

Given that India is likely to face severe water shortages in the future, measures to tap the water resource with prudent conservation measures will be required. Water shortages are likely to be exacerbated in some basins more than in the others due to pressures of demand, inadequate storage, deteriorating water quality, and rising disputes in inter-state water allocation.

Integrated water management strategies that look at water in a holistic manner are required. In its present state of governance, water is managed by various local, state, and central agencies. It is necessary to re-look at the management of this vital resource. The natural boundary of surface water is its hydrological boundary—the river basin. There are tremendous opportunities for improving water availability and security from a basin perspective, provided the resource is managed in a holistic and integrated manner at this level. To achieve integrated water resource management, administrative set ups, such RBOs consisting of multi-disciplinary units, are required for planning and implementation. The National Water Policy, 2002 encompasses vital initiatives for water resource management. However, their implementation requires strategic innovations to meet future demands. Modernizing information systems, having innovative resource planning, implementation, and monitoring of strategies, and focused evaluation systems using modern and advanced techniques supplemented by efficient governance mechanisms are the way forward. River basin level water development strategies will require revisiting policies and politics that affect the use of water which are sectoral. The sectoral nature of water use creates strategy silos such as energy, agriculture, remote sensing centres, and environment without giving due consideration to their inter-linkages.

References

Central Ground Water Board (2004), *Dynamic Groundwater Resources of India*, Ministry of Water Resources, Government of India, New Delhi.

Central Water Commission [CWC] (2010), 'Preliminary Consolidated Report on Effect of Climate Change on Water Resources', Government of India, available at: http://cwc.gov.in/main/downloads/Preliminary_Report_final.pdf last accessed on 20 September 2011.

———— (2010), 'Water and Related Statistics', Government of India, available at http://cwc.gov.in/main/downloads/ last accessed on 20 September 2011.

Central Pollution Control Board [CPCB] (2009), d'Status of Waste Supply, Wastewater

Generation, and Treatment in Class I Cities and Class II Towns of India', available at http://www.cpcb.nic.in/oldwebsite/Newsper cent20Letters/Latest/sewagepollution.html last accessed in August 2010.

D'souza, R. (2006), Interstate Disputes over Krishna Waters: Law, Science and Imperialism', Orient Longman, Hyderabad.

Gaur A., P.G. McCornick. H. Turral, and S. Acharya (2007), 'Implications of Drought and Water Regulation in the Krishna Basin, India', *International Journal of Water Resources Development*, Vol. 23, No. 4, pp. 583–94.

Jain S.K., P.K. Agarwal, and V.P. Singh (2007), *Hydrology and Water Resources of India*. Springer.

Ministry of Water Resources (2002), *National Water Policy 2002*, Ministry of Water Resources, Government of India, New Delhi, 1 April.

Planning Commission (2008), *Eleventh Five Year Plan (2007–12): Inclusive Growth*, Vols 1–3. Planning Commission, Oxford University Press, New Delhi.

———— (2007), *Report of the Steering Committee on Water resources for Eleventh Five Year Plan (2007–2012)*, Planning Commission, Government of India, New Delhi.

Thatte, C.D., A.C. Gupta, and M.L. Baweja (2009), *Water Resources Development in India*, Indian National Committee on Irrigation and Drainage, New Delhi.