RESEARCH
REPORT

83

Spatial Variation in Water Supply and Demand across River Basins of India

Upali A. Amarasinghe, Bharat R. Sharma, Noel Aloysius, Christopher Scott,
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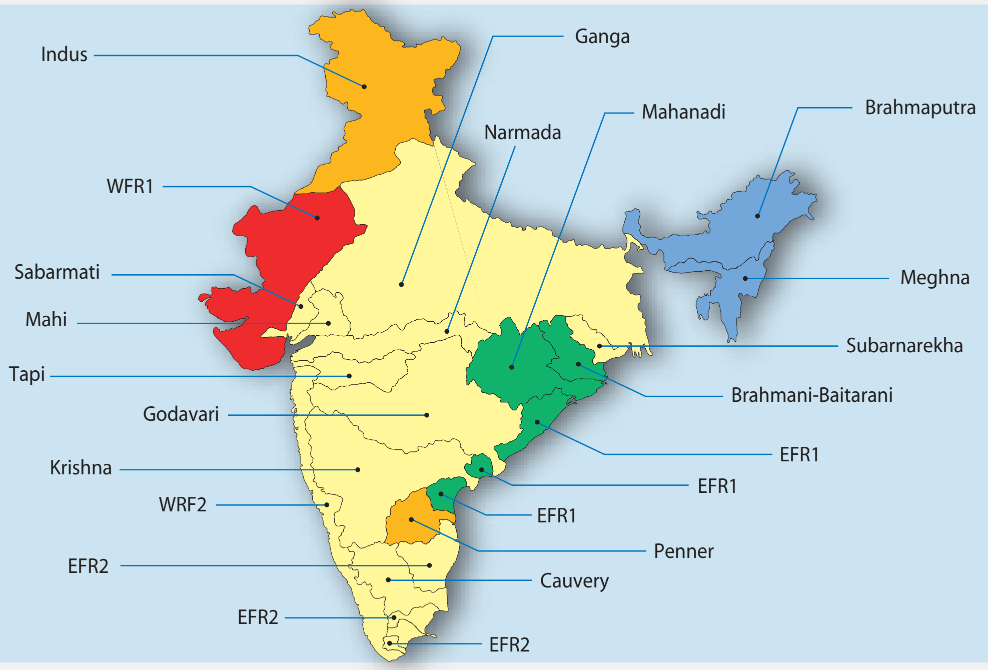

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Contents

Acronyms and Glossary

CI	Cropping intensity
CWC	Central Water Commission (India)
DD	Degree of development
DF	Depleted fraction
DWAF	Department of Water Affairs and Forestry (South Africa)
EFR	Environmental flow requirement
EFR1, EFR2	Easterly flowing small and medium-sized rivers-Group 1, -Group 2
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
GOI	Government of India
GWAR	Groundwater abstraction ratio
GWP	Global Water Partnership
ICAR	Indian Council of Agricultural Research
ICID	International Commission on Irrigation and Drainage
IFPRI	International Food Policy Research Institute
IRWR	Internally renewable water resources
IUCN	The World Conservation Union
IWMI	International Water Management Institute
IWP	India Water Partnership
IWRM	Integrated water resources management
NET	Net evapotranspiration
NIA	Net irrigated area
NSA	Net sown area
PUWR	Potentially utilizable water resources
RCPCD	Ratio of value of crop production to value of crop demand
SPSS	Statistical Package for Social Sciences
SWIM	System-Wide Initiative on Malaria
TRWR	Total renewable water resources
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USA	United States of America
WCD	World Commission on Dams
WFR1, WFR2	Westerly flowing rivers-Group 1, -Group 2
WRI	World Resources Institute

Cropping intensity:	Total annual crop area as a percentage of net sown area
Degree of development:	The extent of development of potentially utilizable water resources
Economic water scarcity:	Adequate water resources to meet additional needs, but inadequate economic, financial, and skilled human resources to tap the water resources
Gross sown area:	Net sown area × Cropping intensity
Groundwater abstraction ratio:	Ratio of groundwater withdrawals to groundwater availability
Internally renewable water resources:	Average annual flow of rivers and recharge of aquifers generated from endogenous precipitation
Net irrigated area:	Physical area equipped for irrigation
Net sown area:	Physical area sown under all crops
Physical water scarcity:	Inadequate water resources to tap for additional water needs of all sectors
Potentially utilizable water resources:	The part of the total renewable water resources that can be captured for use with all possible economic and physical means
Total renewable water resources:	Internally renewable water resources plus the flows generated externally

Summary

India is a large country with regional differences in per-capita water supply and demand. However, a comprehensive assessment of water accounting across river basins has not been available previously. Such an assessment is appropriate in the context of the increasing focus on integrated river basin management.

Attempts to describe the water situation in India at a national level are often misleading because of tremendous diversity in the water situation across the country. To overcome this and obtain a better understanding of water use in India, this report uses data disaggregated at the river basin level, to assess the water supply and demand across the river basins of India, classify river basins according to water scarcities and crop production surpluses or deficits, and discuss issues that are important for future water supply and demand projections.

India's land area can be divided into 19 major river basins. The per-capita water resource availability of these basins varies from a low of 240 m^3 in the Sabarmati basin to a high of 17,000 m^3 in the Brahmaputra basin, while water withdrawals vary from 243 m^3 in the Meghna basin to 1,670 m^3 in the Indus basin. Irrigation is by far the largest user of water in all the basins. The basins of the westerly flowing rivers of the Kutch and Saurashtra regions of Gujarat, and the Luni river—home to 6 percent of the Indian population—are classified as physically water-scarce and food-dependent. The second group of basins, the Indus and Pennar river basins—with 7 percent of India's population—are classified as physically water-scarce, but these basins have significant food surpluses. The grain surplus of the Indus basin alone is able to meet 85 percent of the grain demand from basins with grain production deficits. The water-scarcity problems of the third group of 11 river basins—home to 75 percent of the Indian population—are mixed, but almost all have significant deficits in crop production. The fourth and fifth groups of river basins are classified as "non-water-scarce and food-sufficient" and "non-water-scarce and food-surplus," respectively. These last two groups of basins are home to 12 percent of India's population.

Several factors influence India's future water supply and demand. These include spatial variation and future growth of the population, urbanization and income, and associated changes in dietary preferences, on the crop-consumption side; growth in crop yield, cropping intensity and groundwater use, and contribution to production from rain-fed agriculture, on the crop-production side; and future growth in other factors such as domestic, industrial and environmental water demand, and internal and international trade. These factors need to be carefully assessed in future water supply and demand projections.

Spatial Variation in Water Supply and Demand across River Basins of India

Upali A. Amarasinghe, Bharat R. Sharma, Noel Aloysius, Christopher Scott, Vladimir Smakhtin, and Charlotte de Fraiture of the International Water Management Institute.

Introduction

India, with a population of slightly more than one billion, is projected to become the most populated country in the coming decades (UN 1999). In 1995, about 75 percent of the Indian population was rural, but a substantial proportion of the population is expected to live in urban areas by 2025. There are conflicting views regarding the benefits of past agricultural development to all regions and sections of the rural poor in India. However, despite remarkable growth in agricultural production—which has resulted in national-level self-sufficiency in grains—poverty persists in many regions (CWC 2002; Dhawan 1988; Selvarajan et al. 2001; Bhattarai et al. 2003). A major part of the population remains malnourished and agriculture-related environmental degradation has caused irreversible damage to some ecosystems.

Continued irrigation expansion, combined with better inputs, played a vital role in India reaching a level of national food security. Providing water to irrigated grain production, which contributes two-thirds of the total grain production, was crucial in sustaining this level of agricultural production. Thus, most water-resources development schemes launched in the last few decades of the 20th century focused on meeting the water demands of irrigated agriculture. Estimates of irrigation withdrawals in India vary, but several studies indicate that it is more than 80 percent of total water withdrawals (Seckler et al. 1998; IWMI 2000a; Gleick 2000; WRI et al. 2000; FAO 2002a; Rosegrant et al. 2002). The water withdrawals for domestic and industrial sectors, as shares of the total water withdrawals in India, are quite small compared to those in other developing countries. Environmental water needs receive an even smaller share. Will this trend continue unchanged?

Already there are signs of change. The contribution from the agricultural sector to the gross domestic product (GDP) has been decreasing (from 38 percent in 1980 to 22.7 percent in 2001), while the contribution from domestic and industrial sectors to GDP has been increasing (Ministry of Agriculture 2002). The growth of the domestic and industrial sectors means an increasing demand for water by these sectors. Even with these new trends, India is still ranked as one of the lowest domestic and industrial water users in per-capita terms. For example, the combined annual domestic and industrial per-capita withdrawal in India (59 m^3 per person) is less than half of that of China (132 m^3 per person). However, with increasing urbanization and per-capita demand, the water demands of the domestic, industrial and other sectors are expected to increase rapidly (Seckler et al. 1998; IWMI 2000a; IWP 2000).

Similarly, the environmental sector is also receiving greater attention. Meeting the water needs of freshwater ecosystems has been discussed at length (WCD 2000). Meeting minimum environmental water requirements of rivers and aquifers is no longer an academic issue. More and more countries are including environmental water needs in their water management policies and development plans. Environmental water requirements are becoming even more important in water-stressed basins (Smakhtin et al. 2004). Because of the substantial variability in temporal river flow in India (Rao and Sinha 1991), environmental water demands during low-flow months may have to be met from already developed water resources. The impacts of such environmental water allocations on other water sectors need to be addressed in specific river basins.

In India, most of the rainfall occurs in a relatively short period of three to four months during the monsoon period. The average rainfall in the four months from June to September during the southwest monsoon is about 903 mm. During the remaining eight months, an average of only about 294 mm of rainfall is received (CWC 2002). Agrawal (1998) even contends that the total annual rainfall in much of the semi-arid tropics occurs within 100 hours of the year. Capturing and storing abundant rainfall during the southwest monsoon period for beneficial use during the rest of the year is an enormous task. This is especially true because of the wide spatial variation of rainfall in India. Water is abundant in locations where food production is low, while water is scarce in locations where most of the food is grown. Therefore, considering spatial variation of water availability is crucial to proper demand management.

Most of the recent water supply and demand projections in India have used data aggregated at national level (Rijsberman 2000; IWP 2000; IWMI 2000a) and results vary substantially from one study to another. The spatial variability of water supply and demand has not been adequately captured in earlier studies and this is a significant limitation hampering the projection of water needs.

Amarasinghe et al. (1999) and Barker et al. (2000) studied the spatial variation of water supply and demand and its effects on meeting the food demand in Sri Lanka and Mexico. The primary purpose of the current report is to analyze the spatial variation of water supply and demand across river basins in India. The study identifies basins that are water-scarce because of inadequate water availability to meet the effective demand. The study also identifies issues that are important for estimating the future water demand and for the formation of policy for future water-resources development and management.

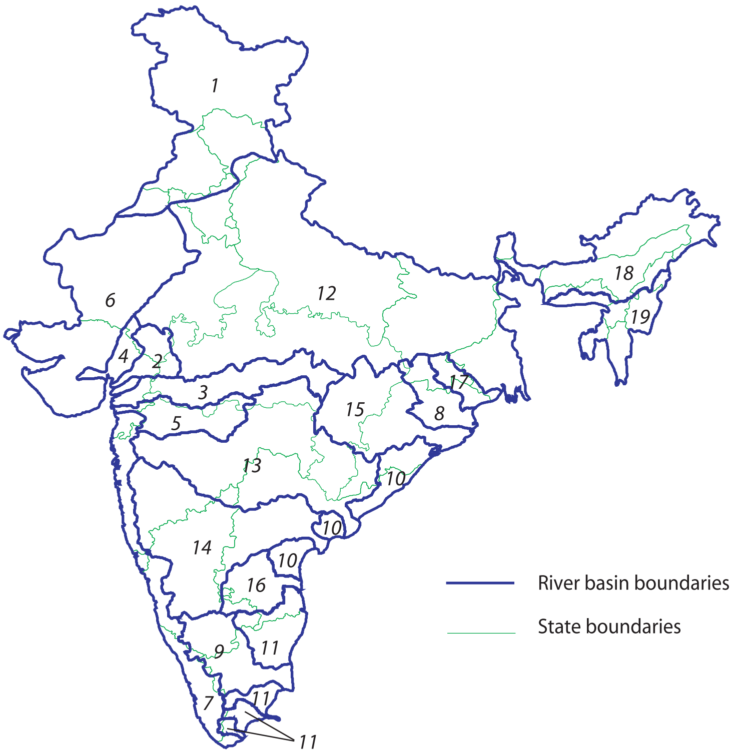
A river basin is an ideal analytical unit for studying water supply and demand. The water availability of Indian river basins has been comprehensively studied (CWC 2002) and, therefore, most of the data required for estimating water demand is already available at the administrative unit (state) level. Constitutionally, the development and management of water resources in India is an inter-state activity. Yet, substantial areas of different states cut across river basins, making water allocation a trans-state issue; disputes regarding water sharing between riparian states are on the increase. Thus, analyzing water supply and demand at river-basin level is an important step forward, and is even more topical in the context of today's increasing focus on integrated water resources management (IWRM) in river basins.

River Basins of India

Drainage Area

The water resources of India drain from 19 major drainage basins[1] (figure 1). The largest drainage area, Ganga–Brahmaputra–Meghna, covers 34 percent of the area of the country (table 1). This basin has three rivers—Ganga, Brahmaputra, and Meghna—that join before draining into the Bay of Bengal. The drainage areas of these three rivers are considered as three separate basins in this report. The Ganga, the largest river basin, covers a substantial area,

FIGURE 1.
The river basins of India.



River basins

1	Indus
2	Mahi
3	Narmada
4	Sabarmati
5	Tapi
6	Westerly flowing rivers-Group 1
7	Westerly flowing rivers-Group 2
8	Brahmani and Baitarani
9	Cauvery
10	Easterly flowing rivers-Group 1
11	Easterly flowing rivers-Group 2
12	Ganga
13	Godavari
14	Krishna
15	Mahanadi
16	Pennar
17	Subarnarekha
18	Brahmaputra
19	Meghna

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[1] Minor rivers draining to Myanmar and Bangladesh with a drainage area of 36,000 km^2 and total water resources of 31 km^3 are excluded from the present analysis as they contribute very little to India's total water demand.

TABLE 1.
Area and population of river basins in India.

	River basin	Catchment area[a]	Length of river	Population		
				Total[b]	Density	Rural (% of total)
		km²	km	millions	No./km²	%
	All basins	3,191		932	282	74
	17 basins[c]	2,955		888	301	73
Basins of the westerly flowing rivers	Indus	321	1,114 [d]	48.8	140	71
	Mahi	35	583	6.7	324	77
	Narmada	99	1,312	17.9	160	79
	Sabarmati	22	371	6	521	54
	Tapi	65	724	17.9	245	63
	WFR1	56	–	58.9	425	72
	WFR2	378	–	51.9	166	57
Basins of the easterly flowing rivers	Brahmani and Baitarani	52	1,164 [e]	16.7	204	87
	Cauvery	81	800	32.6	389	70
	EFR1	87	–	19.2	293	74
	EFR2	100	–	39	484	60
	Ganga	861	2,525	370.2	449	75
	Godavari	313	1,465	76.7	186	85
	Krishna	259	1,401	68.9	253	68
	Mahanadi	142	851	27.2	202	80
	Pennar	55	597	14.3	189	78
	Subarnarekha	29	395	15	347	76
	Brahmaputra	194	916	33.2	161	86
	Meghna	42	–	10	160	82

Notes: [a] Source: CWC (2002).

[b] Source: UN (1999).

[c] All the basins except Brahmaputra and Meghna.

[d] The length of the Indus river within Indian territory up to the border with Pakistan.

[e] The length of the Brahmani river itself is 799 km.

WFR1 = Westerly flowing rivers-Group 1: the westerly flowing rivers in the Kutch and Saurashtra regions of the state of Gujarat, and the Luni river.

WFR2 = Westerly flowing rivers-Group 2: the westerly flowing rivers south of the Tapi basin.

EFR1 = Easterly flowing rivers-Group 1: the easterly flowing small and medium-sized rivers between the Mahanadi and Pennar basins.

EFR2 = Easterly flowing rivers-Group 2: the easterly flowing small and medium-sized rivers between the Pennar basin and Kanyakumari at the southern tip of India.

with climate ranging from monsoonal in Uttar Pradesh, Madhya Pradesh, Bihar and West Bengal to arid in Haryana and Rajasthan in the west (Annex A table). There are four other large basins. The basin of the Indus river that flows in a southwesterly direction to Pakistan covers 10 percent of the total drainage area of India. The basins of the Godavari, Krishna and Mahanadi rivers draining to the sea in the east cover 22 percent of the total drainage area. Eight other medium-sized basins—of the Sabarmati, Mahi, Narmada and Tapi rivers flowing west and the Subarnarekha, Brahmani-Baitarani, Pennar and Cauvery rivers flowing east—cover 15 percent of the total drainage area. The remaining small river basins are divided into four major drainage areas. These are the basins of:

i. the westerly flowing rivers in the Kutch and Saurashtra regions of the state of Gujarat, and the Luni river (identified as Westerly flowing rivers-Group 1 or WFR1 in this report);

ii. the westerly flowing rivers south of the Tapi basin (Westerly flowing rivers-Group 2 or WFR2);

iii. the easterly flowing small and medium-sized rivers between the Mahanadi and Pennar basins (Easterly flowing rivers-Group 1 or EFR1); and,

iv. the easterly flowing small and medium-sized rivers between the Pennar basin and Kanyakumari at the southern tip of India (Easterly flowing rivers-Group 2 or EFR2).

Population

The population distribution is uneven across the basins (table 1). The Ganga basin, with only about a quarter of the total drainage area, has about 40 percent of the total population of India. The next five largest basins—Mahanadi, Brahmaputra, Krishna, Godavari, and Indus—cover 46 percent of the drainage area, but have only 30 percent of the population. About 75 percent of the people in all the river basins still live in rural areas and the livelihoods of most of them depend on agriculture. Thus, the development and management of available water resources are crucial factors in rural development and poverty alleviation in India.

Water Availability—Spatial Variation

Water Resources

The volume of the internally renewable water resources (IRWR) of India is 1,287 km^3 and the volume of the total renewable water resources (TRWR) is 1,887 km^3. The IRWR is the sum of internally generated surface runoff (1,236 km^3) and the volume of the groundwater resources (431 km^3) minus the overlap of groundwater and river flow (380 km^3). The overlap is the volume that is discharged from groundwater aquifers into rivers and it contributes to the base flow of the rivers (FAO 2003; CWC 2002). The TRWR is the sum of IRWR and the flow generated outside the national borders (600 km^3).

The aggregate figures show substantial water resources. For example, the TRWR of the Brahmaputra and Meghna basins is 633 km^3, but only 4 percent of it is potentially utilizable because of geographical restrictions. Thus, because of the uneven spatial and temporal distribution of rainfall and geographical restrictions, the volume of potentially utilizable surface water resources—the part of the water resources that can be captured for first-time use and subsequent reuse downstream with all possible physical and economic means—is only 37 percent of the TRWR, that is, about 690 km^3 (table 2; CWC 2002). The total volume of potentially utilizable water resources (PUWR), including groundwater, is only 55 percent of the TRWR, that is, about 1,033 km^3. In 1995, the per-capita volume of the potentially renewable water resources of India was 1,108 m^3. At the lower end, about 224 million people live with a per-capita volume of renewable water resources below 1,000 m^3.

TABLE 2.
Water resources of Indian river basins.

	River basin	Total renewable water resource (TRWR)[a]	Potentially utilizable water resources (PUWR)[a]			Water resources availability per capita	
			Surface water	Ground water[b]	Total	TRWR	PUWR
		km^3	km^3	km^3	km^3	m^3	m^3
	All basins	1,887	690	343	1,033	2,025	1,108
	17 basins[c]	1,253	666	308	975	1,411	1,098
Basins of westerly flowing rivers	Indus	73.3	46	14.3	60.3	1,501	1,235
	Mahi	11	3.1	3.5	6.6	1,649	990
	Narmada	45.6	34.5	9.4	43.9	2,542	2,448
	Sabarmati	3.8	1.9	2.9	4.8	631	797
	Tapi	14.9	14.5	6.7	21.2	831	1,183
	WFR1	15.1	15	9.1	24.1	257	409
	WFR2	200.9	36.2	15.6	51.8	3,871	998
Basins of easterly flowing rivers	Brahmani and Baitarani	28.5	18.3	3.4	21.7	1,703	1,296
	Cauvery	21.4	19	8.8	27.8	656	852
	EFR1	22.5	13.1	12.8	25.9	1,169	1,346
	EFR2	16.5	16.7	12.7	29.4	423	753
	Ganga	525	250	136.5	386.5	1,418	1,044
	Godavari	110.5	76.3	33.5	109.8	1,441	1,431
	Krishna	78.1	58	19.9	77.9	1,133	1,130
	Mahanadi	66.9	50	13.6	63.6	2,463	2,341
	Pennar	6.3	6.3	4.04	10.9	440	762
	Subarnarekha	12.4	6.8	1.7	8.5	829	568
	Brahmaputra	585.6	24.3	25.7	48	17,661	1,448
	Meghna	48.4	1.7	8.5	10.2	4,830	1,018

Notes: [a] Source: CWC (2002).

[b] Volume of potentially utilizable groundwater resources is the volume of groundwater replenished from normal natural recharge.

[c] All the basins except Brahmaputra and Meghna.

WFR1, WFR2, EFR1, EFR2 see Notes to table 1.

Water Withdrawals—Spatial Variation

India's aggregate water withdrawal in 1995 was estimated at about 650 km^3 (IWMI 2003). Of this, 91 percent was withdrawn for agriculture, 4 percent for the domestic sector, and 5 percent for the industrial sector.

Irrigation Withdrawal

Irrigation withdrawals vary substantially across basins, from 193 m^3 per person in the Brahmaputra basin to 1,617 m^3 per person in the Indus basin (table 3).

Irrigation withdrawal is estimated as:

$$\text{Irrigation withdrawal} = \left(\frac{\text{surface water irri. area}}{\text{surface water irri. efficiency}} + \frac{\text{groundwater irri. area}}{\text{groundwater irri. efficiency}} \right) \text{X} \left(\frac{\text{crop water}}{\text{requirement}} \right)$$

Irrigated (irri.) area is the primary factor in the spatial variation of irrigation withdrawal. The gross irrigated area (= net irrigated area × irrigation intensity) per person varies from 255 m^2 in the Brahmaputra basin to 1,996 m^2 in the Indus basin. Groundwater is the source of irrigation for about 57 percent of the irrigated area. Most of the groundwater development (about 70%) has been concentrated in the Indus basin, the basin of the westerly flowing rivers in Kutch and Saurashtra, and in the western parts of the Ganga basin.

Irrigation efficiency here is the field-scale application ratio, defined as the percentage of water withdrawals used for meeting the crop water requirement (Bos and Wolters 1989). It should be noted that the concept of efficiency here is valid only at the field scale. At the basin scale, the reuse of drainage water is also estimated. The field-scale irrigation efficiencies of surface water and groundwater are assumed to range from 27 to 50 percent and from 65 to 70 percent, respectively (personal communication, Central Water Commission, New Delhi). Thus, the overall field-scale efficiency in the basins depends on the surface-water and groundwater efficiencies and the percentage of the groundwater irrigated area. This is estimated to range from a low of 31 percent where most of the area is surface irrigated to a high of 62 percent where most of the area is irrigated with groundwater. Because of high field-scale application efficiencies, the irrigation requirement in groundwater irrigated areas is lower than that in surface-water irrigated areas. For example, in the absence of groundwater irrigation, the irrigation demand would be 37 and 43 percent higher in the Indus and Ganga basins, respectively.

Crop water requirement depends on several factors, including cropping pattern, crop-growth periods, crop coefficients (*kc*), potential evapotranspiration (Et^P), effective rainfall and percolation in paddy areas.

Crop water requirement (*CWR*) of the paddy crop is estimated as:

$$CWR^{Paddy} = Paddy\ Area \times \left(\sum_{j \in Growth\ periods} (Kc_j^{Paddy} \times Et_j^P - Effective\ rainfall_j) + deep\ percolation \right)$$

TABLE 3.
Irrigation withdrawals of river basins.

	River basin	Withdrawal per person	Net irrigated area (NIA)	Irrigation intensity	Groundwater irrigated area (% of NIA)	Grain crop irrigated area (% of NIA)	Overall irrigation efficiency	Potential annual evapo-transpiration (Et^P)	Annual 75% dependable rainfall (P75)	Crop water requirement (net evapotranspiration, NET)
		m^3	M ha	%	%	%	%	mm	mm	mm
	All basins	633	52.6	133	57	69	49	1,665	735	340
	17 basins[a]	653	51.5	134	58	69	52	1,726	635	373
Basins of westerly flowing rivers	Indus	1,617	5.5	177	56	74	43	1,345	296	288
	Mahi	703	0.49	118	66	47	54	1,968	449	417
	Narmada	636	1.26	106	41	67	48	1,825	664	362
	Sabarmati	573	0.36	122	90	38	60	1,947	384	443
	Tapi	381	0.64	120	64	47	55	1,890	455	452
	WFR1	649	4.38	122	95	41	62	1,934	344	429
	WFR2	219	1.26	126	67	50	53	1,631	1,657	296
Basins of easterly flowing rivers	Brahmani and Baitarani	475	0.83	121	54	88	48	1,608	873	233
	Cauvery	487	1.51	127	51	53	52	1,620	763	321
	EFR1	888	1.12	127	29	81	51	1,747	523	431
	EFR2	738	1.9	127	46	58	46	1,652	552	425
	Ganga	659	22.41	135	63	76	47	1,586	599	318
	Godavari	486	3.49	120	44	65	56	1,822	655	395
	Krishna	535	3.19	127	33	59	59	1,767	539	426
	Mahanadi	686	1.85	112	34	76	47	1,695	835	289
	Pennar	920	0.79	129	41	78	59	1,806	291	582
	Subarnarekha	374	0.55	124	43	88	45	1,502	912	232
	Brahmaputra	243	0.85	108	6	79	32	1,144	1,372	95
	Meghna	193	0.22	117	3	39	31	1,155	1,808	145

Notes: [a] All the basins except Brahmaputra and Meghna.
WFR1, WFR2, EFR1, EFR2 see Notes to table 1.

Sources: Net irrigated area, irrigation intensity and irrigation efficiency data are from CWC (2002), and the rest are authors' estimates.

and the crop water requirement of other crops is estimated as:

$$CWR^{Other\ crops} = \sum_{j \in other\ crops} Area_i \left(\sum_{j \in Growth\ periods} (Kc_j^i \ Et_j^P \ - \ Effective\ rainfall_j) \right)$$

The annual potential evapotranspiration ranges from 1,144 mm in the Brahmaputra basin to 1,968 mm in the Mahi basin, while the average for the country is 1,777 mm (IWMI 2000b). The aggregate of monthly, 75 percent dependable rainfall ranges from 296 mm in the Indus basin to 1,800 mm in the Meghna basin. The crop irrigation water requirement of the basins ranges from a high of 580 mm in the Pennar basin to a low of 95 mm in the Brahmaputra basin (table 3).

Domestic and Industrial Demand

In this report, we use the estimates of the National Planning Commission of India (GOI 1999) for domestic-sector and industrial withdrawals. Domestic withdrawals consist of two components: water withdrawals for human consumption plus domestic services, and water withdrawals for livestock. The human demand for drinking, cooking, bathing, recreation, etc., is 24 km^3 and accounts for 79 percent of domestic withdrawals. The drinking-water demand of livestock is estimated at 6.7 km^3 (CWC 2002). The spatial variation of domestic demand is mainly accounted for by differences in the distribution of urban and rural populations. Water demand in urban areas is higher due to water use for flushing latrines, gardening, fire-fighting, etc. The water withdrawal per person in urban areas (135 liters per day) is assumed to be more than three times those in rural areas (40 liters per day). The demand for livestock depends on the number of animals and consumptive use per head.

Water Scarcity—Spatial Dynamics

Water Accounting

Water accounts of river basins were constructed following the methodology of Molden (1997). Water accounting helps us to understand the sources and uses of water in a basin, and also the water scarcities and modes of improving water productivity. This report presents only the accounting of potentially utilizable water resources. Details of the accounts for river basins are given in table 4.

Unutilizable TRWR, part of the total water

TABLE 4.
Water accounts of river basins.

	River basin	Water account				
		Potentially utilizable water resources (PUWR)	Beneficial evaporation (% of PUWR)	Non-beneficial evaporation (% of PUWR)	Unutilizable return flows (% of PUWR)	Utilizable return flows (% of PUWR)
		km^3	%	%	%	%
	All basins	1,034	24	11	2.9	62.1
	17 basins[a]	974	26	11	3.0	60.5
Basins of westerly flowing rivers	Indus	60.3	48	25	5.2	22.1
	Mahi	6.6	39	19	3.7	37.9
	Narmada	43.9	12	6	1.3	81.2
	Sabarmati	4.8	46	12	5.9	36.2
	Tapi	21.2	17	10	1.9	70.4
	WFR1	24.1	98	19	5.4	9.9
	WFR2	51.8	11	8	2.1	79.2
Basins of easterly flowing rivers	Brahmani and Baitarani	21.7	12	10	2.1	76.0
	Cauvery	27.8	24	13	3.3	59.8
	EFR1	25.9	25	11	3.3	61.5
	EFR2	29.4	37	17	5.2	40.9
	Ganga	386.5	26	11	3.2	59.0
	Godavari	109.8	16	7	1.7	75.3
	Krishna	77.9	24	13	2.4	61.0
	Mahanadi	63.6	10	7	1.6	81.2
	Pennar	10.3	60	18	5.2	16.9
	Subarnarekha	8.5	21	13	4.4	61.8
	Brahmaputra	50.0	3	4	1.5	92.4
	Meghna	10.2	5	5	1.9	87.7

Notes: [a] All the basins except Brahmaputra and Meghna.
WFR1, WFR2, EFR1, EFR2 see Notes to table 1.

Source: Authors' estimates.

resources that cannot be captured for utilization, is 44 percent of the total TRWR, and thus PUWR is 56 percent of the total. The water resources developed are 42 percent of the PUWR of India (1995 data). However, this varies substantially across river basins. The Brahmaputra river basin has the smallest extent of development (only 11% of PUWR). The largest extent of development is in the drainage area of the westerly flowing rivers in Kutch and Saurashtra, and the Luni river (132%). This indicates that a substantial part of the water demand is met through groundwater mining.

Process evapotranspiration, non-process evapotranspiration, unutilizable outflow and utilizable flow are parts of the PUWR and are equal to 24 percent, 11 percent, 3 percent, and 62 percent of the PUWR, respectively (1995 data).

- *Process evapotranspiration* is the evaporation and transpiration from irrigation-sector withdrawals plus the evaporation from domestic- and industrial-sector withdrawals, and is low in most basins. This shows that substantial scope exists for increasing process evaporation by increasing recycling structures or through new infrastructure development.
- *Non-process evapotranspiration* is the evaporation and transpiration from homesteads, bare soil, swamps, reservoirs, canals, and rivers. The Indus basin has a high non-process evapotranspiration rate (25%). Most of the Indus basin PUWR is developed and a substantial part of it is withdrawn for irrigation. The Mahi and Tapi basins also have high non-process evapotranspiration rates for similar reasons.
- *Unutilizable outflow* is part of the return flow (from surface water and groundwater withdrawals) that is lost as outflow to the sea and committed or uncommitted flows to downstream countries. This part cannot be captured for further use in the basin.
- *Utilizable outflow* consists of two parts: (i) the part of the return flow that can be captured, with adequate infrastructure, for reuse; and (ii) the part of the PUWR that is not yet developed.

In the next section, water accounts of river basins are used, along with crop production and consumption, for assessing water scarcities and their impacts on overall crop production. First, we define primary water supply.

The *primary water supply* is the part of the PUWR that is controlled and becomes available to the supply system as first or primary inflow of unused water (Seckler et al. 1998). The total water withdrawal comprises the primary water supply and the portion that is recycled downstream. In most basins, the total water withdrawal is almost one-and-a-half times the primary water supply. The primary water supply and the total water withdrawals of India in 1995 were estimated at 428 km^3 and 645 km^3, respectively.

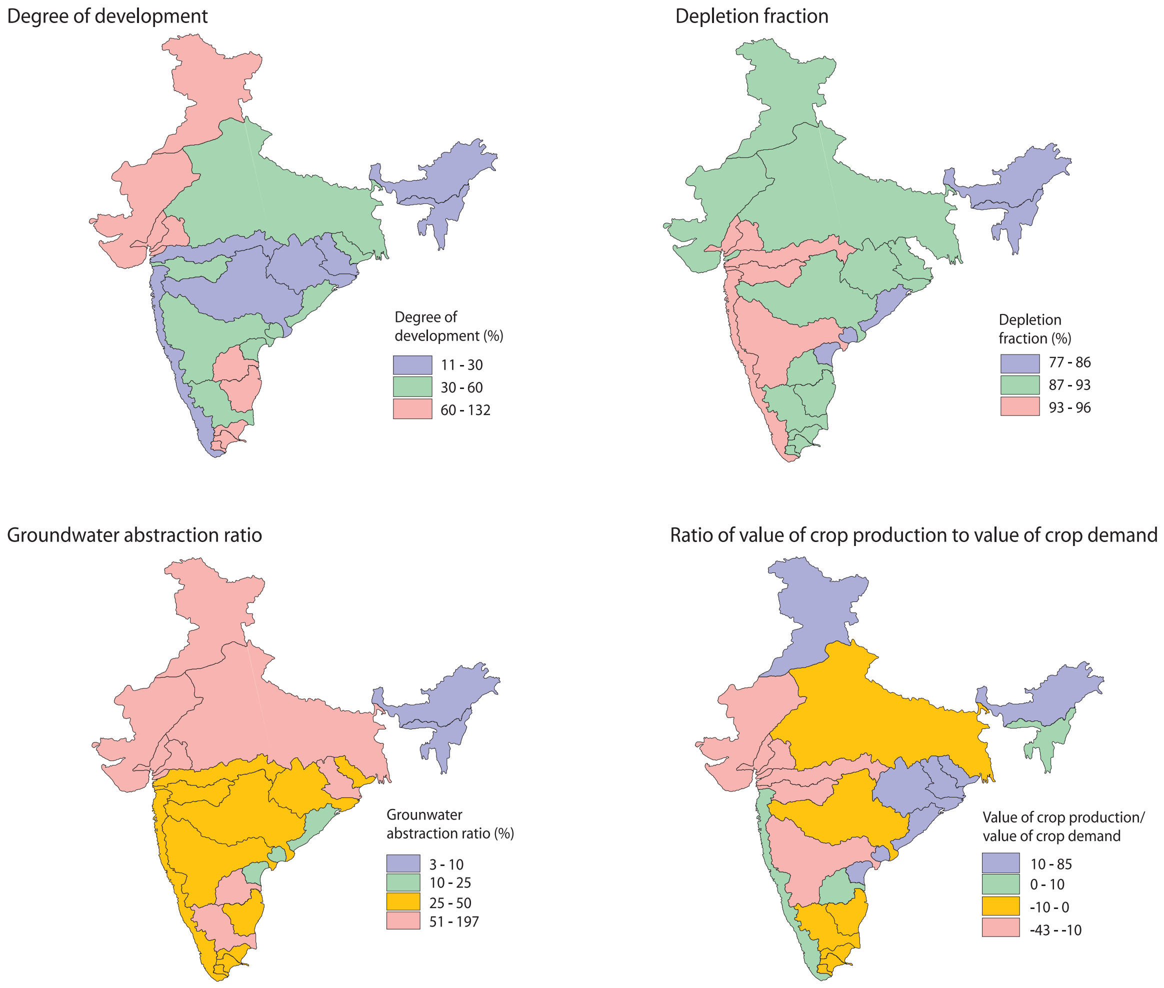
Water Scarcity and Agricultural Production

Four indicators (figure 2) are used in assessing the severity of water scarcity and crop production deficits.

Degree of development (DD), defined as the ratio of primary water supply to potentially utilizable water resources, shows the extent of water development in the basin. High values indicate physical scarcity and few opportunities for capturing potentially utilizable water resources (Seckler et al. 1998; IWMI 2000a) and the increasing cost of further development of water resources and its impact on environmental water needs in the basin (Wiberg and Strezepek 2000).

Depleted fraction (DF) is defined as the ratio of depletion (process, non-process and unutilizable outflows of return flows) to primary water supply, and shows the extent of depletion of the developed water resources. It shows the available utilizable outflow in the basin and opportunities for increasing depletion through recycling structures.

FIGURE 2.
Indicators of water scarcity and crop production for the river basins of India.



Degree of development

Depletion fraction

Groundwater abstraction ratio

Ratio of value of crop production to value of crop demand

Groundwater abstraction ratio (GWAR), defined as the ratio of groundwater withdrawals to groundwater availability, shows the degree of development of groundwater resources. The groundwater resources here include recharges from both natural rainfall and return flows. Groundwater resources are also not uniformly distributed in space and so the extraction of groundwater is also not uniformly distributed over the basin area. Therefore, an excessively high GWAR shows the existence of areas of unsustainable groundwater use.

Ratio of value of crop production to value of crop demand (RCPCD) shows the extent to which a basin is meeting its internal crop demand. The total production includes the production of crops cultivated under both irrigated and rain-fed conditions. The crop demand includes food demand, feed demand and waste, and the crop needed for seeds and other uses (FAO 2002b). The crops include rice, wheat, maize, other cereals, pulses, oil crops, roots and tubers, vegetables, sugar crops, fruits, and cotton. We have used export prices of crops to aggregate the crop production and demand (see Annex B for details). This indicates the degree of dependency on food from outside the basin or the degree of production surpluses available for transfer from the basin. This is important with respect to where food is grown in relation to water availability. Water management issues of water-scarce basins that are food-dependent are different from those of basins that are food-surplus. This also shows the large virtual water (Allan 1998) transfer embedded in the food items from food-surplus (but water-scarce) basins to food-deficit (but, may be, water-surplus) basins. Thus, this is an important indicator for assessing the status of water scarcity and virtual transfers across basins.

Values of these indicators for the basins are given in table 5. In summary, the degree of water development in India in 1995 was only 41 percent. However, the degree of development of several basins was over 60 percent. These basins are so physically water-scarce that even with increased water use efficiency they will not have adequate water resources to meet the water demands of all sectors (IWMI 2000a).

TABLE 5.
Indicators of water scarcity and food production surpluses or deficits for Indian water basins, 1995.

	River basin	DD	DF	GWAR	Crop production surplus/deficit as a percentage of consumption			Cluster
					Total	Grain	Non-grain	
		%	%	%	%	%	%	
	All basins	41	86	51	0.5	0.1	0.6	
	17 basins[a]	43	93	55	-0.2	0.1	-0.3	
Basins of westerly flowing rivers	Indus	84	93	70	66	226	-15	2
	Mahi	65	96	60	-27	-14	-33	3
	Narmada	20	94	30	-16	36	-42	3
	Sabarmati	67	95	91	-25	-45	-15	3
	Tapi	31	96	49	-29	-37	-26	3
	WFR1	132	92	194	-30	-32	-29	1
	WFR2	22	94	40	5	-56	37	3
Basins of easterly flowing rivers	Brahmani and Baitarani	26	92	55	61	15	85	5
	Cauvery	43	93	52	-8	-19	-3	3
	EFR1	45	86	24	46	35	52	5
	EFR2	64	92	46	-9	-10	-9	3
	Ganga	44	93	55	-9	-17	-5	3
	Godavari	27	92	36	-9	-6	-11	3
	Krishna	41	95	42	-11	-14	-9	3
	Mahanadi	21	89	26	90	57	106	5
	Pennar	91	91	64	1	19	-8	2
	Subarnarekha	42	91	50	23	5	33	3
	Brahmaputra	11	77	4	15	14	15	4
	Meghna	15	82	3	9	-41	34	4

Notes: DD = Degree of development; DF = Depleted fraction; GWAR = Groundwater abstraction ratio.

[a] All the basins except Brahmaputra and Meghna.

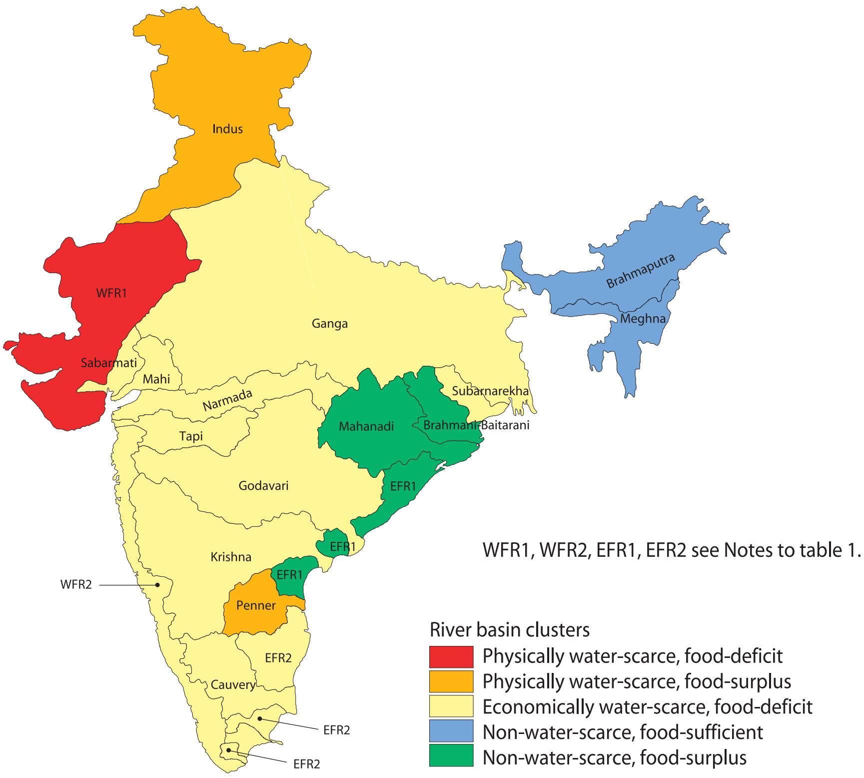
WFR1, WFR2, EFR1, EFR2 see Notes to table 1.

Most river basins are depleting well over 90 percent of the developed water resources. Most of the depletion is through the evapotranspiration of irrigation water diversions, indicating limited opportunities for increased recycling. The basins with high depletion fraction need to increase water productivity of the existing resources or develop new water resources for meeting future demand.

The GWAR varies from 3 to 194 percent across basins, and the average for India is 51 percent. The GWARs of the basins of the Indus, Pennar and Sabarmati rivers, the westerly flowing rivers of Kutch and Saurashtra and the Luni river are over 60 percent. These basins include most of the states of Punjab, Haryana, Gujarat and Rajasthan, where sustainable groundwater use is an emerging critical issue. In some parts of these states, groundwater tables are falling by 1–3 meters annually (Shah et al. 2000).

These four indicators are used to assess water scarcity and its relation to agriculture. K-mean clustering, a statistical technique, is used in grouping the basins into five clusters (SPSS 1998; see Annex C for a brief description). These clusters are shown in figure 3.

FIGURE 3.
River basin clusters according to water scarcity and food surplus or deficit.



WFR1, WFR2, EFR1, EFR2 see Notes to table 1.

Cluster 1: Physically water-scarce, food-deficit basins. Only the basin of the westerly flowing rivers of Kutch and Saurashtra and the Luni river is in this group. It is physically water-scarce, has high groundwater depletion and a high dependence on food from other basins. This group has 6 percent of the Indian population (about 60 million people) and produces about 4 percent of the grain and non-grain crops of the country. This basin has both grain and non-grain production deficits and so is described as a water-scarce and food-deficit basin. Such basins will invariably have to transfer water from the agriculture sector to other sectors to meet their future water needs. Low-value, water-intensive grain crop production will be badly affected by such water transfers. So, this basin will have its food dependency increased and is the most at risk in terms of water security.

Cluster 2: Physically water-scarce, food-surplus basins. There are two basins, the Indus and the Pennar, in this group. They have a high degree of development, high depletion ratios and high groundwater abstraction, but with significant crop production surpluses. Both basins have non-grain crop production deficits, but the grain production surpluses are more than enough to offset the non-grain crop production deficits. So, these basins are called water-scarce, food-surplus basins. This group has 7 percent of the Indian population (about 56 million), and produces 22 percent of the grain crop and 5 percent of the non-grain crop of the country. This shows that a large amount of virtual water embedded in food grain is being transferred from these water-deficit basins to food-deficit basins, which may be water-abundant. Estimates show that, in terms of water withdrawals needed to produce food, one tonne of non-rice cereal requires about 1,500 m^3 of water and one tonne of rice requires about 7,000 m^3 of water (Qadir et al. 2003). Water scarcity in the Indus basin became more pronounced after the large-scale introduction of groundwater-based rice cultivation to the basin (Prihar et al. 1993).

Water scarcities in this group are due to the over-development of water resources, especially for irrigation. The increasing demand from other sectors will have to be met by transferring water from the agriculture sector. Further water resources development in these basins will be unsustainable. Water transfers from the agriculture sector would adversely affect the production of grain crops and reduce surpluses that could be used to offset the deficits of food-importing basins.

Cluster 3: Economically water-scarce, food-deficit basins. A striking feature in this group is high crop production deficits. Eleven basins in this group have 75 percent of the Indian population, but produce only 62 percent of the grain crop and 72 percent of the non-grain crop of the country. The degree of development of this group of basins is 39 percent. Thus, basins in this group are called economically water-scarce, food-deficit basins. However, the extent of water scarcity of these basins is mixed. While some (basins of Sabarmati, Mahi, easterly flowing rivers between Pennar and Kanyakumari, Ganga, and Cauvery) are already physically water-scarce, or near to it, others have adequate water resources to meet future water demands. Groundwater depletion is a problem in some basins, but overall it is not as severe as in Clusters 1 and 2. As of 1995, the food-deficit basins in this group depended for their food mostly on the Indus basin in the water-scarce, food-surplus group. But the Indus is physically water-scarce and will have smaller food surpluses in the future. Therefore, most basins in this group will either have to substantially increase water-related investments, thus becoming economically water-scarce (Seckler et al. 1998) or will have to increase food imports. Among the other options, increasing water productivity, which is very low at present (see the discussion on reallocation of agriculture withdrawals in the next section), could eliminate a major part of the food deficit.

Indeed, on the basis of either grain production surpluses or non-grain production surpluses, three basins—the Subarnarekha, the Narmada, and the basin of easterly flowing rivers between Pennar and Kanyakumari—seem to have been misclassified into this group. The Subarnarekha basin has grain and non-grain production surpluses. The Narmada has substantial grain production surpluses, but its non-grain production deficits are large and it has an overall crop production deficit. The non-grain crop production surpluses in the basin of easterly flowing rivers between Pennar and Kanyakumari are large enough to offset its grain production deficits. These three basins have 7.7 percent of the total population, and produce 8 percent of the grain crop and 7 percent of the non-grain crop of India.

Cluster 4: Non-water-scarce, food-sufficient basins. Two basins—the Brahmaputra and the

Meghna—fall into this category. These basins have only 5 percent of the Indian population and contribute only 4 and 6 percent, respectively, of the grain and non-grain crop production. The basins in this category have a low degree of development (only 4 percent of PUWR), low depletion fractions, low groundwater use, and some crop production surpluses. In the Meghna basin, significant non-grain crop production surpluses offset the production deficits of grain crops. The low degree of development of these basins indicates that a significant portion of the potentially utilizable water resources (both surface water and groundwater) remains untapped and could perhaps be used for increasing crop production surpluses. There has been a significant improvement in groundwater utilization in Assam through the shallow-well development component of the government-sponsored *On-farm Improvement in the Eastern Region* scheme. Yet, in these basins, availability of cultivable land, not the water resource, is the major constraint.

Cluster 5: Non-water-scarce, food-surplus basins. Three basins—the basin of the easterly flowing rivers between Mahanadi and Pennar, and those of Brahmani–Baitarani and Mahanadi—are in this group. Seven percent of the Indian population lives in these basins, which contribute 8 percent and 13 percent of the grain and non-grain crop production of the country, respectively. Although these basins have a high depleted fraction, they have a relatively low degree of development and a low GWAR. Also, these basins have significant production surpluses. The water-scarcity issues in these basins are not serious. As in the previous group, water resources of basins in this group could be further tapped to increase food production.

Overall, 88 percent of the Indian population lives in river basins that experience either some form of water scarcity or food deficit, or both. These river basins contribute 88 percent of the country's grain production and 81 percent of the non-grain crop production. India is self-sufficient in grain crops due to surplus production in the basins of the Indus, Narmada, Mahanadi and a few easterly flowing rivers. The production surplus of the Indus basin alone offsets 85 percent of the production deficits of 15 other river basins. However, the Indus basin is physically water-scarce, with most of the surface water and groundwater resources being fully utilized. Of this, the irrigation sector dominates (97 percent) the water withdrawals. This situation will certainly change in the future. Increasing demand from the domestic and industrial sectors, and the concerns of environmental degradation will reduce the share of water withdrawals used for irrigation. Unless there is a substantial increase in water productivity, the production surplus of the Indus basin will decrease (Hira and Khera 2000). The reduction of grain production in the Indus basin will have a significant impact on the availability of food surpluses to meet the future demands of food-deficit river basins. How the river basins will manage their utilizable water resources will have a significant bearing on the national food self-sufficiency scenario. The question "How much more irrigation in the future?" that global research programs, such as the Comprehensive Assessment of Water Management in Agriculture (IWMI 2003), try to answer is highly relevant for India. The issues that are critical for estimating future water needs are the focus of our discussion in the next section.

Issues for Future Water Supply and Demand Estimation

The spatial dynamics of water scarcity give rise to various issues that are important in estimating the future water needs of India. In this section, we discuss some important issues that have policy implications for future water development and management.

Growth in Population and Urbanization

The *population growth* pattern will be an important factor in future water-resources development and management. The population of India increased at an annual rate of about 2 percent over the 1990s. By 2025, India will have to feed another 207 million people under a medium growth scenario and 92 million people under a low growth scenario (UN 1999; Viasria and Viasria 1996). Based on the current agricultural requirement (633 m^3 water withdrawal per person), India will need at least an additional 252 km^3 of water withdrawals by 2025, a 44 percent increase on the current level.

Urbanization: India's urban population is expected to increase from 27 percent of the population in the mid-1990s to 45 percent by 2025. Commensurate with this increase, the demand for water in the domestic sector could more than double (IWP 2000). Due to rapid urbanization, a similar increase in demand could also be expected from the industrial sector (Seckler et al. 1998; IMWI 2000a).

The *food consumption pattern* changes with urbanization and increasing income. Past trends show that India's consumption of milk and milk products, and sugar has increased substantially (Food balance sheets, FAO 2002b; Delgado et al. 1999). Increase in milk consumption means increase in fodder for feed and that is water-intensive (though wastewater is increasingly used for fodder production). Consumption of meat products has increased in developing countries (Bhalla and Hazell 1997); for example, the share of meat products in the daily calorie supply in China increased from 6 percent in the 1970s to 19 percent in the late 1990s. However, the share of meat products in the daily food consumption in India is very low (less than 1 percent of the total calorie supply in 1995). Meanwhile, animal husbandry in India is mainly non-commercial with crop residues being used to feed animals; however, with increasing income and urbanization, animal husbandry is likely to become more commercialized with crop or crop products used as feed. For example, in China the quantity of feed grains consumed annually (mainly maize) increased by 600 percent from just 18 million tonnes in 1965 to 111 million tonnes in 1995. Because of its huge base population, any significant increase in the consumption of animal products in India will also have a significant impact on the feed grain requirement. Whether and where these additional feed grains are to be produced locally will have a significant bearing on the future food and irrigation requirements.

Thus, the magnitude of population growth and urbanization are very important factors in the assessment of the future water requirement. Most of the water-scarce and food-deficit basins with high populations had high population growth rates in the past and will have high growth rates in the future.

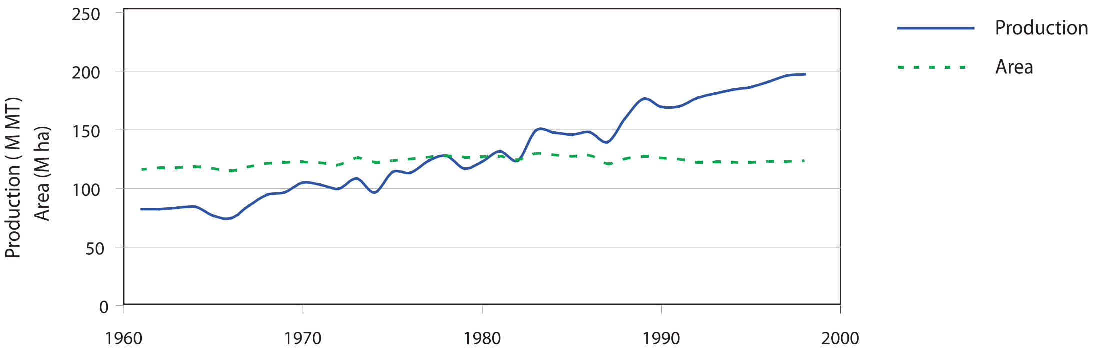
Because of the priority expected for services of the domestic and industrial sectors, the physically water-scarce basins will have to transfer water from the agriculture sector to the domestic and industrial sectors. This is especially applicable to basins in the physically water-scarce, food-deficit and the physically water-scarce, food-surplus groups, and a few based in the economically water-scarce, food-deficit group, such as the Sabarmati, the Mahi, the basin of easterly flowing rivers south of Pennar, and water-scarce pockets of other basins such as the Ganga and the Cauvery. Unless there is a significant increase in productivity, the surplus of crop production in basins such as the Indus and Pennar in the physically water-scarce, food-surplus group may decrease, and deficits of crop production in water-scarce basins in the physically water-scarce, food-deficit group and the economically water-scarce, food-deficit group may increase. Issues that are critical for increasing crop production are the focus of our next discussion.

Irrigation Expansion

Crop production in India has increased substantially since the 1960s (figure 4). Increases in cropping intensity and crop yields have contributed to production growth. Though the extent of its contribution is still a debatable issue, irrigation expansion, both in surface water and groundwater, is thought to have contributed significantly to crop intensification and yield increase (WCD 2000; Dhawan 1988; Bhattarai et al. 2003; Evenson and Rosegrant 1998). Before we explain the implications of irrigation on future crop production, we briefly look at the role of irrigation expansion in increasing the cropping intensity and crop yields.

Increase in *cropping intensity* contributed the most to the increase in gross sown area (= net sown area × cropping intensity) over the period 1965–1995. Although the cultivable area of all crops in India stagnated at around 142 million hectares during this period, the gross sown area increased by 16 percent. Expansion and intensification of cropping on irrigated land were the major factors in the increase in overall cropping intensity (Annex D table). Decomposition of cropping intensity (see Annex D for details) shows that the *expansion and intensification of cropping in irrigated lands have contributed to three-quarters of the increase in cropping intensity in India*.

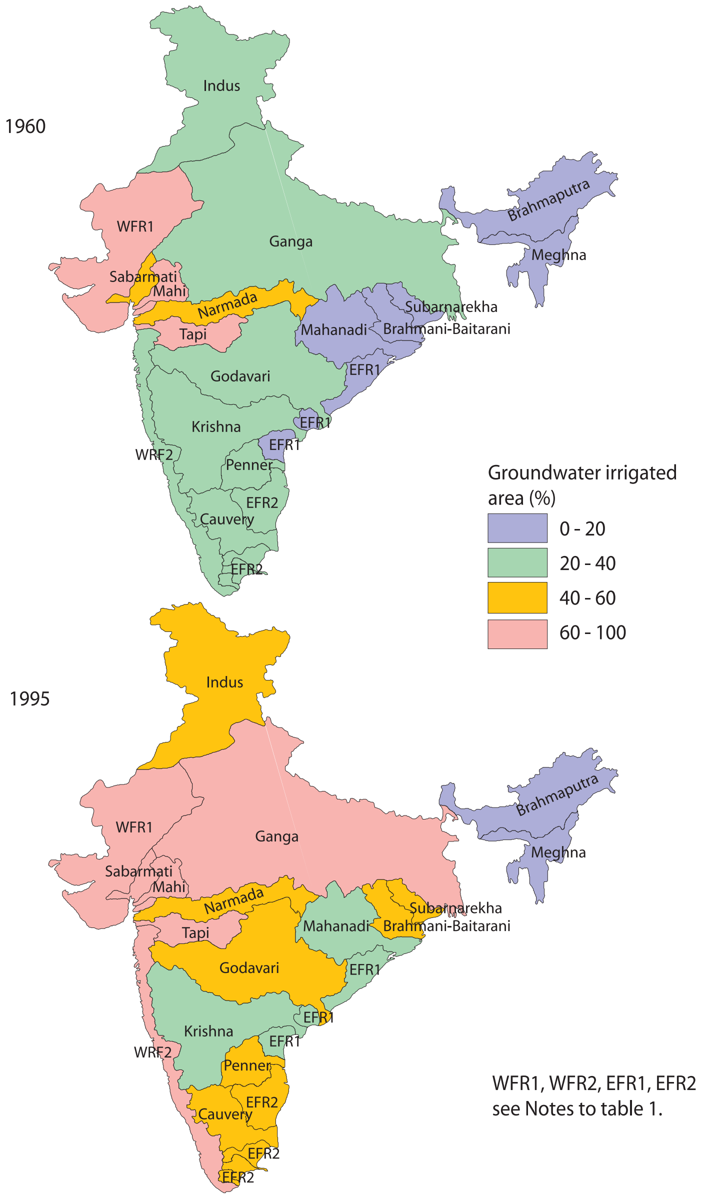
FIGURE 4.
Area and production of grain crops.



Most cropping intensity increases have occurred in water-stressed basins, demonstrating the importance of irrigation expansion. The crucial issue to address is how far irrigation can contribute to the increase in cropping intensity of river basins or how much cropping intensity increase can be realized in the absence of new irrigation development. This is even more important when the contribution of groundwater to irrigation expansion is taken into consideration.

Groundwater irrigation in India increased from about 40 percent of the net irrigated area in the early 1960s to 57 percent in 1995. Most of the expansion in groundwater irrigation occurred in river basins of Clusters 1 and 2, and in a few basins of Cluster 3 (figure 5). These basins have moderate to high GWARs, which means that some regions of these basins already have groundwater overdraft. The unprecedented growth in groundwater development in the 1970s in the western states such as Punjab and Haryana led to increased food production, but the rate of growth of food production in these states is decreasing. However, in the absence of large-scale surface-water resources developments, the trend in groundwater development is expected to continue. This will be a source of livelihood for many poor people in the rural sector. For example, Shah (2001) contends that groundwater expansion in the eastern Ganga plains would be a partial solution to enhancing food production, moderating floods and reducing poverty. Given the unsustainable water use in some locations, where and to what extent groundwater development can be continued in these basins are important issues to be dealt with (Sharma 2000).

FIGURE 5.
Net groundwater irrigated area as a percentage of net irrigated area in 1960 and 1995.

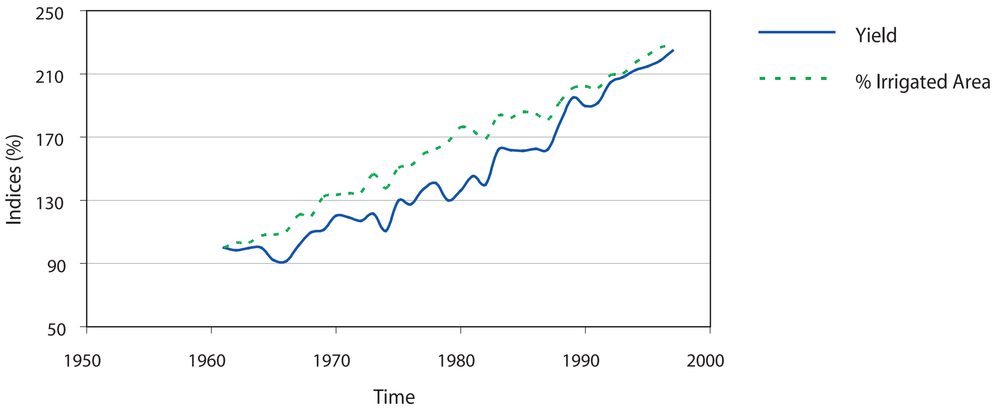


WFR1, WFR2, EFR1, EFR2
see Notes to table 1.

Increase in crop yield: estimates of the contribution of irrigation to the growth of agricultural productivity in India vary (CWC 2002; Dhawan 1988; Bhattarai et al. 2003). However, statistics at the national level clearly show the association between irrigation expansion and crop yield (figure 6).

The average yield of grain crops increased at a compound growth rate of 2.32 percent annually between 1965 and 1995 (Ministry of Agriculture 2002). The ratio of irrigated grain area to total grain area has increased at an annual rate of 2.48 percent. The association between irrigation and average yield seemed much stronger after the mid-1980s. Part of the reason for this is that most of the other inputs that contributed to yield growth, such as fertilizer and high-yielding varieties, have nearly reached their full potential impacts. Of the different sources of irrigation, groundwater has contributed the most to average yield growth. Across river basins, there is a strong correlation between the net groundwater irrigated area and the growth in grain yield (Shah 2000).

FIGURE 6.
Indices of average grain yield and irrigated grain area as a percentage of the total grain area.



Source: GOI (2000).

Thus, the crucial issue that every river basin has to address is the potential for increasing the irrigated yield in the absence of, or with little, increase in irrigated area. And where and to what extent groundwater irrigation expansion occurs would also be a crucial factor in increasing crop productivity. This is especially true for river basins in the first three clusters with high ratios of groundwater abstraction.

Environmental Flow Requirement

The environmental water demand or environmental flow requirement (EFR) of river basins has been attracting increasing attention (e.g., Naiman et al. 2002; Sharma et al. 2004). The most straightforward practices of environmental water allocation focus on keeping some minimum flow in a river downstream of the major abstractions. However, even these practices have limited application in India, where the increasing demands of irrigation and domestic and industrial sectors are met without considering the needs of freshwater ecosystems. This is the typical situation in most developing countries, where research on estimating ecosystem water requirements is at an early stage. A global study recently conducted by the International Water Management Institute (IWMI), the World Resources Institute (WRI) and Kassel University provides preliminary estimates of the environmental flow requirements for all major river basins in the world and discusses the directions for future research (Smakhtin et al. 2004). The estimates provided by the study are coarse and represent, effectively, one desirable scenario of environmental water allocation in the world. This scenario corresponds to the maintenance of all freshwater ecosystems in a "fair" condition. Aquatic ecosystems in this condition are normally characterized by disturbed dynamics of the biota, with the loss of some sensitive species or the occurrence of alien species, or both (e.g., DWAF 1997). Multiple disturbances associated with the need for socioeconomic development, such as dams, diversions and transfers, habitat modification and water quality degradation, may have occurred in rivers in this condition. The "fair" condition should be seen as the most modest goal of ecosystem management (e.g., DWAF 1997). "Above" this are ecosystems in "good" and "excellent" conditions, while ecosystems "below" the "fair" condition have become severely degraded and have lost their ecological integrity. Having ecosystems in the latter condition cannot be considered as a water management goal.

The EFR estimates of Smakhtin et al. (2004) are assumed to be related to the hydrological variability of river flow. The hypothesis is that river basins with highly variable hydrological regimes may require a smaller proportion of surface runoff to be set aside as EFR, because aquatic life in such rivers is adapted to prolonged periods of little or no flow. On the contrary, river basins with more stable, less variable hydrological regimes require a higher proportion of surface runoff as EFR, because their aquatic life is more sensitive to flow reductions and changes.

Most Indian rivers have monsoon-driven hydrological regimes, where 60–80 percent of the flow comes during 3–4 wet months. Such rivers fall into the category of highly variable flow regimes. The EFR for most Indian rivers, estimated by the authors on the basis of information calculated by Smakhtin et al. (2004), ranges from 20 to 27 percent of the renewable water resources (which are represented by the long-term, mean, annual natural river discharge or volume; table 6). As discussed in the previous section, only a portion of the surface runoff is utilizable with all possible storage and conveyance structures. The question then is whether the unutilizable part of the river runoff is adequate for meeting the EFR. If the unutilizable river runoff is not adequate, then part of the potentially utilizable water resources has to be kept in rivers to meet the EFR.

According to the above criteria, in most Indian drainage basins the unutilizable portion of surface runoff is more than adequate to meet the estimated EFR. The EFR of only a few basins—such as the Pennar, the basin of westerly flowing rivers in Kutch and Saurashtra and the Luni river, the Cauvery and the basin of easterly flowing rivers between Pennar and Kanyakumari—exceed the unutilizable runoff and hence the degree of development of these basins is affected (last column in table 6). The degree of development (DD) is the ratio of primary water supplies to potentially utilizable water resources. In cases where the difference between unutilizable water and EFR is negative, the utilizable resources are reduced accordingly and the DD may go above 100 percent (table 6). In several locations in these basins—along the sea-coast of Gujarat, Tamilnadu, Karnataka and Andhra Pradesh—intrusion of seawater inland has been reported due to inadequate EFR and excessive abstraction of groundwater in the coastal regions.

The EFR estimates built into our assessment are only preliminary. They have been based only on aggregated annual hydrological information, simulated at the coarse spatial scale. They ignore the temporal (seasonal) variability of the EFR and water resources in general. The EFR also does not explicitly include ecological information on Indian freshwater ecosystems and social aspects associated with river water use and conservation. These estimates need modification through more detailed, basin-specific assessments of the EFR, using the time series of monthly flows. It is also important to understand that environmental allocations of less than 20 percent of the flow are most likely to degrade a river beyond the limits of possible rehabilitation. Another factor not yet considered in the assessment is that a reduction in river flows decreases the ability of a river to cope with pollution loads. These loads are known to be high in many Indian basins.

TABLE 6.
Impact of the environmental flow requirement (EFR) on water resources utilization.

	River basin	EFR scenario (EFR necessary to maintain rivers in fair condition)		Unutilizable renewable water resources	Unutilizable water resources minus EFR	DD when EFR considered
		Vol.	% of TRWR	(TRWR – PUWR)		
		km^3	%	km^3	km^3	%
	All basins	476.3	25	1197.2	721	42
	17 basins[a]	303.9	24	587.2	283.2	42
Basins of westerly flowing rivers	Indus	18.5	25	27.3	8.8	84
	Mahi	2.6	23	7.9	5.3	65
	Narmada	10.6	23	11.1	0.5	20
	Sabarmati	0.9	23	1.9	1	67
	Tapi	3.5	23	0.4	-3.1	36
	WFR1	3.1	21	0.1	-3	151
	WFR2	54	27	164.7	110.6	22
Basins of easterly flowing rivers	Brahmani and Baitarani	6.9	24	10.2	3.3	26
	Cauvery	5.3	25	2.4	-2.9	48
	EFR1	6.1	27	9.4	3.3	45
	EFR2	4.4	27	0	-4.4	76
	Ganga	121.8	23	275	153.2	44
	Godavari	26.4	24	34.2	7.8	27
	Krishna	19.1	24	20.1	1	41
	Mahanadi	16	24	16.9	0.9	21
	Pennar	1.7	27	0	-1.7	108
	Subarnarekha	3	24	5.6	2.6	42
	Brahmaputra	159.3	27	563.3	404	11
	Meghna	13.2	27	46.7	33.5	15

Notes: TRWR = Total renewable water resources.
PUWR = Potentially utilizable water resources.
DD = Degree of development.
[a] All the basins except Brahmaputra and Meghna.
WFR1, WFR2, EFR1, EFR2 see Notes to table 1.

Source: Authors' estimates.

Reallocation of Agricultural Withdrawals

The water productivity of irrigated grain crops varies substantially across river basins and is also substantially different from that of non-grain crops. The water productivity of irrigated grain crops (US\$0.13 per m^3 of evaporation and transpiration) is only a third of the water productivity of irrigated non-grain crops (US\$0.35 per m^3 of evaporation and transpiration).

The difference in water productivities between grain and non-grain crops is substantial in all river basins, except in the physically water-scarce basins. This shows that substantial increases in the value of crop production could be achieved in several basins by a slight reallocation of irrigation water withdrawals from grain to non-grain crops. To illustrate this we consider two scenarios of water reallocation. Table 7 shows the gains in the value of total production and changes in the value of production surpluses or deficits for the two scenarios. Here reallocation scenarios are applied to all basins except those in the physically water-scarce, food-deficit and physically water-scarce, food-surplus groups.

TABLE 7.
Production surpluses or deficits under different water reallocation scenarios.

Crop	Water productivity	Reallocation factor	Water diversion	Irrigated area	Total production surplus/deficit (% of consumption)
	US$/$m^3$	%	km^3	M ha	%
Grain	0.13	0	408	48	0.1
Non-grain	0.36		144	15	0.6
Total			552	63	0.4
Grain	0.13	5	392	46	-1.9
Non-grain	0.36		160	17	6.7
Total			552	63	3.8
Grain	0.13	10	376	44	-3.9
Non-grain	0.36		176	19	12.8
Total			552	63	7.2

Scenario 1: Five percent reallocation. If 5 percent of the water withdrawal to grain crops is reallocated to non-grain crops, the value of crop production surplus would increase from 0.4 percent to 3.8 percent. Under this scenario, there would be a 1.9 percent deficit in the value of grain crop production. However, the surplus in value of production of non-grain crops would be enough to offset the deficit in value of production of grain crops. Efforts to adopt this scenario are being made in the states of Punjab and Uttar Pradesh through World Bank assisted *Agricultural Diversification* projects. The major thrust is to replace water-intensive rice and other grain crops with high-value vegetables, oilseeds and other horticultural crops like strawberry, olives, and medicinal and aromatic plants in water-scarce basins, and increase water-intensive grain crops in water-surplus basins.

Scenario 2: Ten percent reallocation. In this scenario, 10 percent of the irrigation water withdrawal is reallocated to non-grain crops.

The result is a substantial surplus in the value of crop production: the value of the deficit of grain crop production increases to 3.9 percent, while the value of the surplus of non-grain crop production increases to 13 percent. Another useful concept of "multiple uses of water resources" is also being tried in irrigation systems where water from a canal or tube-well source is first stored in a reservoir and then used for the field irrigation of high-value crops. An integrated farming system with components of grain crops, vegetable or horticultural crops, and aquaculture may enhance water productivity by about five times, compared to grain crops alone or growing grain and non-grain crops with the same amount of water (Samra et al. 2003).

Though such scenarios are very optimistic in terms of the value of total crop production, they also need to be assessed in terms of costs and benefits to society. India is a large country and its grain and non-grain crop production is ranked among the three largest in the world, along with the USA and China. Therefore, substantial production deficits or production surpluses of grain or non-grain crops would have a significant impact on world food prices. Such scenarios would affect both producers and consumers. India cannot afford to be in such a situation for several reasons: (i) the livelihoods of more than 250 million people are directly dependent on agriculture (FAO 2002b), (ii) more than 400 million people were poor and undernourished in the late 1990s (FAO 2002c), and (iii) the staple diet of Indians is grain. Therefore, such water reallocation scenarios resulting in large shifts from grain to non-grain crop production need careful planning, so that production surpluses will not only help the Indian producers with better prices, but also help poor people to buy food at affordable prices.

Policy Issues and Conclusion

Irrigation still dominates water withdrawals in India. Thus, the discussion here is centered on water development and management issues, which are important in addressing the question, "How much more irrigation is required in the future to meet the food demand of the nation?"

The future additional water requirement of each river basin depends on several factors, including the following.

- How the productivity of water consumed could be increased from present levels.
- The potential for improvements in rain-fed agriculture.
- The additional water demand of domestic and industrial sectors, which compete directly with the irrigation sector for scarce water resources.
- The potential for exploiting groundwater resources.
- The contribution of saline, alkaline or other poor-quality waters to increased agricultural output.
- The part of the environmental water requirement that has to be met from utilizable water resources.
- The potential for transferring food between basins and the potential for increasing international trade.
- The potential contribution of water transfers or interlinking of river basins to the water supply of the basin.

Increasing the Productivity of Water Consumed

In most Indian basins the productivity of water consumed is low. Substantial room exists for the improvement of productivity. Possible avenues for increasing productivity are discussed by Molden (1997), Molden et al. (2001) and Kijne et al. (2003). Briefly, these possible avenues are:

- changing or improving crop varieties, thus providing increased yields for the level of water consumed, or increased (or constant) yields for fewer units of water consumed;
- substituting crops that consume less water for those that consume more;
- practicing deficit, supplemental or precision irrigation techniques;
- sustainable use of saline or poor-quality waters;
- improving agronomic practices (land preparation, fertilization, etc.);
- improving water management to provide reliable water supplies; and,
- optimizing non-water inputs.

Improvements in the above areas would result in net water savings or improvements in production, thereby reducing the requirement for the development of additional irrigation water resources.

In 1995, more than a third of the primary water supply in India was lost as non-beneficial depletion. Most of this loss was from irrigation water withdrawals. Non-beneficial evaporation can be reduced by efficient irrigation practices (such as precision irrigation techniques), adjustments of crop planting to match periods of less evaporative demand, reducing water or polluted water flowing to sinks, and increasing water reuse. Also, as part of the return flow cannot be captured for further use with the available infrastructure, reusing these flows through gravity or pump diversions would reduce the unutilized return flows. It should be noted, however, that significant non-process depletion, for example, through native vegetation and tree cover in irrigated areas, may maintain environmental quality.

Potential for Rain-fed Production Increases

Almost two-thirds of the crop area in India is rain-fed (1995 data). However, because of low yields, the rain-fed area contributes to only 40 percent of the total production. For example, had rain-fed grain yield been higher by 0.50 tonnes per hectare (in 1995, it was only 0.99 tonnes per hectare), the total grain production would be 20 percent higher. The true potential for increasing rain-fed productivity would be a significant factor in estimating future irrigation needs. Supplemental irrigation through rainwater harvesting and improved agronomic management in rain-fed areas shows high potential for increasing rain-fed productivity (Singh 1998). Yet the increase in evapotranspiration from rain-fed areas affects the flow regimes, and the impact of these on downstream storage and ecosystem requirements needs thorough assessment.

Increasing Domestic and Industrial Water Demand

Domestic water demand is given higher priority than irrigation in the National Water Policy of 2002. Industrial demand tends to be a de facto higher priority than irrigation because of the ability of industries to pay more for water access. These two sectors, especially in water-scarce regions and during water-scarce periods, compete for water resources available for irrigation. Thus, the share of present irrigation water withdrawals that will be allocated to meet additional domestic and industrial demands is a key factor in deciding the future irrigation withdrawals of a basin.

Potential for Groundwater Development

Most river basins in the economically water-scarce, food-deficit and non-water-scarce, food-surplus clusters have high potential for further groundwater exploitation. For example, only about half of the groundwater is exploited in the Ganga basin and only a third in the Godavari basin (1995 data). Most of the groundwater development has been in the western areas of these river basins, although there is evidence that groundwater development is fast spreading into eastern parts of the basins (Shah 2001). Groundwater contributes to 57 percent of India's irrigated area, but its contribution to the total irrigation volume is only 44 percent. Because of easy access to groundwater resources and the reliability of supply, the quantity of groundwater irrigation required from groundwater is much less than that required from surface water. Moreover, productivity per cubic meter of groundwater is 1.2 to 3.0 times higher than the productivity of irrigation from canals or other surface water resources. Therefore, the potential expansion of groundwater irrigation is a major factor in the equation determining how much more surface irrigation is needed.

Environmental Water Needs

The pilot, low-confidence estimates of the environmental flow requirement (EFR) of Indian rivers presented in this paper will need to be thoroughly refined. While hydrological variability is an important determinant of ecosystem integrity, other factors—including biophysical and social aspects, water quality, institutional context, technical and political feasibility of allocating water to ecosystems in each basin or state—need to be taken into account in determining the EFR (Dyson et al. 2003). Detailed studies of the EFR in specific basins represent an important prerequisite for achieving sustainable water resources development in India. The portion of the potentially utilizable river runoff that should be allocated to meet environmental needs is a crucial policy issue for future water resources development.

Trade

Two factors—national self-sufficiency targets and food transfers between basins—are important in determining the future basin-wise water requirements. Because of food production surpluses in the Indus basin, India is self-sufficient in food. Food deficits resulting from the reduction of grain production surpluses in the Indus basin could be met either by increasing the food trade between basins or by importing food.

To increase *inter-basin trading in food*, the grain production of basins should be increased. This is possible in basins where water productivity of grain crops is high (e.g., Ganga, Narmada and Subarnarekha) or where water is not a constraint to grain crop production increases (e.g., Mahanadi). Increasing crop production is not dependent on water availability alone; land availability is also a factor. For example, parts of the state of Bihar in the Ganga basin have surplus groundwater, but only about 3 million hectares of the sown area in the state is under rain-fed cultivation and only part of that may be irrigated with tube-well water. Moreover, the per-capita land availability is extremely low. A thorough assessment of all these factors is necessary before selecting a basin for increased production and making a decision on the magnitude of the targeted production increase.

Increasing the *international trade* in commodities is the other option for reducing food deficits (Allan 1999). The water productivity of grain crops in some basins is quite low. A slight reallocation of water withdrawals from grain crops to non-grain crops would result in significant surpluses in non-grain crop production and the value of these surpluses would be adequate to meet the value of production deficits in grain crops. Thus, in principle, the export earnings of non-grain crop production surpluses would be adequate to pay for the importation of grain crops, for which most of the present water withdrawals are diverted (Qadir et al. 2003). To what extent this can be done depends on the effect of substantial production surpluses or deficits on world market prices, and on the poor farmers and consumers in India.

Water Transfers between Basins

The potential for water transfers between river basins is an option being pursued in India to alleviate water scarcity in some basins. The move to link major rivers in the north with river basins in the south and west is gaining momentum (MoWR 2003). The major objective here is to transfer water from water-abundant rivers in basins such as the Ganga, Brahmaputra and Godavari to water-scarce central, western and southern basins. As in most other water development programs, besides the huge capital costs involved, there are major concerns about the linking of rivers in relation to: (i) the adverse impacts on biodiversity and freshwater ecosystems downstream, (ii) the displacement of millions of people from potential storage locations, and (iii) decisions made to link rivers based on the assumption that this would provide water to millions of people in water-scarce regions (Shankari 2004). In most cases, linking rivers means diverting water from the potentially utilizable water resources (PUWR). Which basins have excess PUWR for transfer to other basins, after meeting the additional future demand of all other sectors in the basin? Which basins can divert unutilizable renewable water resources to water-scarce regions? These issues need further research to understand the benefits and costs of a water transfer program.

At an institutional level, inter-state water allocation within a basin and inter-basin transfers remain a key policy challenge in India. Several river basin tribunals (e.g., Cauvery and Krishna) are engaged in acrimonious, often politically motivated disputes for which the Supreme Court and even the Prime Minister may become the arbiters of last resort. How these disputes will be addressed and whether the tensions will be eased or heightened will be a key determinant of successful water management in India.

Conclusion

The availability of and the demand for water resources in India show substantial spatial and temporal variations. Analyses of water supply and demand across river basins indicate that some basins are physically water-scarce due to inadequate availability of water in the basin, while others are physically water-scarce due to excessive development in the basin. Water scarcity in some basins is exacerbated by unsustainable groundwater use and these basins are characterized by high dependency on other basins for food.

This study has shown that 88 percent of the Indian population lives in river basins with some form of water scarcity or food production deficit, or both. The physically water-scarce Indus basin alone meets more than 85 percent of the food demand from other basins with grain production deficits. Because of India’s large population, significant shifts in production surpluses or deficits in water-scarce basins would have serious consequences not only for India, but also for other countries dependent on food imports. Several factors could influence India’s future water supply and demand, including the following:

- spatial variation and future growth of population, urbanization and income, and associated changes in dietary preferences, on the crop consumption side;
- growth in crop yield, cropping intensity and groundwater use, and contribution to production from rain-fed agriculture, on the crop production side; and,
- future growth in other factors such as domestic, industrial and environmental water demand, and internal and international trade.

These factors need to be carefully assessed in future water supply and demand projections.

ANNEX A TABLE.

Areas (percentages) of Indian states in the different river basins.

State	River basin																		
	Indus	Mahi	Narmada	Pennar	Sabarmati	WFR1	WFR2	Brahmani andBaitarni	Cauvery	EFR1	EFR2	Ganga	Godavari	Krishna	Mahanadi	Subarnarekha	Tapi	Bramhaputra	Meghna
Andhra Pradesh	0	0	0	17	0	0	0	0	0	20	5.1	0	28	29	0	0	0	0	0
Arunanchal Pradesh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0
Assam	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	9.8
Bihar	0	0	0	0	0	0	0	8.9	0	0	0	84	0	0	0.1	7.4	0	0	0
Goa	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0
Gujarat	0	6.5	5.9	0	12	69	4	0	0	0	0	0	0	0	0	0	2.1	0	0
Haryana	30	0	0	0	0	0	0	0	0	0	0	70	0	0	0	0	0	0	0
Himachal Pradesh	90	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0
Jammu and Kashmir	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Karnataka	0	0	0	4	0	0	14	0	17	0	2.8	0	3	59	0	0	0	0	0
Kerala	0	0	0	0	0	0	93	0	5.7	0	1	0	0	0	0	0	0	0	0
Madhya Pradesh	0	1.9	20	0	0	0	0	0.3	0	0	0	46.7	14	0	16	0	1.5	0	0
Maharashtra	0	0	1	0	0	0	12	0	0	0	0	0	47	22	0	0	18	0	0
Manipur	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
Meghalaya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38	62
Mizoram	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
Nagaland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	69	31
Orissa	0	0	0	0	0	0	0	23	0	15	0	0	11	0	45	6.2	0	0	0

(Continued)

ANNEX A TABLE *(Continued).*

State	River basin																		
	Indus	Mahi	Narmada	Pennar	Sabarmati	WFR1	WFR2	Brahmani andBaitarni	Cauvery	EFR1	EFR2	Ganga	Godavari	Krishna	Mahanadi	Subarnarekha	Tapi	Bramhaputra	Meghna
Punjab	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rajasthan	5.3	4.6	0	0	1	54	0	0	0	0	0	34.2	0	0	0	0	0	0	0
Sikkim	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0
Tamil Nadu	0	0	0	0	0	0	6.1	0	37	0	56	0	0	0	0	0	0	0	0
Tripura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
Uttar Pradesh	0.2	0	0	0	0	0	0	0	0	0	0	99.8	0	0	0	0	0	0	0
West Bengal	0	0	0	0	0	0	0	0	0	0	0	81	0	0	0	7.6	0	11	0
Others	1	0	0	0	0	0.4	5.2	0	1.4	0	3	90	0	0	0	0	0	0	0

Note: WFR1, WFR2, EFR1, EFR2 see Notes to table 1.

Source: GOI (1999).

Annex B

Estimating the Value of Crop Production and Demand

The grain crops in the analysis include rice, wheat, maize, other cereals (millet, sorghum, barley, etc.) and pulses. Non-grain crops comprise six crop categories: roots and tubers, oil crops, fruits, sugar, vegetables, and cotton.

First, we define:

p_{ijk} Indian export prices of the jth crop or crop product in the ith crop category in the kth year

e_{ijk} India's export quantity of the jth crop in the ith crop category in the kth year

P_{ik} India's production of the ith crop category in the kth year

D_{ik} India's demand of the ith crop category in the kth year (demand includes food demand, feed demand, and seeds, waste and other uses).

The three-year weighted average export price of the of the ith crop category is defined as:

$$p_i = \tfrac{1}{3} \sum_{k=1994}^{1996} \frac{\displaystyle\sum_{j = \text{all crops in crop or crop products in } i^{th} \text{ crop category}} e_{ijk} \times p_{ijk}}{\displaystyle\sum_{j = \text{all crops in or crop products in } i^{th} \text{ crop category}} e_{jkc}}$$

The total value of grain production P^{Grains} or grain demand (D^{Grains}) in 1995 is defined as:

$$P_{1995}^{Grains} = \sum_{i=1}^{5} p_i \times \frac{1}{3} \sum_{k=1994}^{1996} P_{ik} \quad \text{and} \quad D_{1995}^{Grains} = \sum_{i=1}^{5} p_i \times \frac{1}{3} \sum_{k=1994}^{1996} D_{ik}$$

$i = 1$(= Rice), 2(= Wheat), 3(= Maize), 4(= Other cereals), 5(= Pulses)

The total values of non-grain crop production and non-grain crop demand in 1995 are defined as:

$$P_{1995}^{Non\text{-}Grains} = \sum_{i=1}^{6} p_i \times \frac{1}{3} \sum_{k=1994}^{1996} P_{ik} \quad \text{and} \quad D_{1995}^{Non\text{-}Grains} = \sum_{i=1}^{6} p_i \times \frac{1}{3} \sum_{k=1994}^{1996} D_{ik}$$

$i = 1$(= Oil crops), 2(= Vegetables), 3(= Roots and tubers), 4(= Sugar crops), 5(= Fruits), 6(= Cotton)

Annex C

K-Mean Clustering

K-mean clustering is a statistical technique used for identifying *k* homogenous groups of observations using certain characteristics (Chatfield and Collins 1980). The groups are identified so that the members are closer to the mean of their group than to the mean of any other group. The methodology of k-mean clustering is as follows.

1. Initialize the procedure by separating the members into *k* clusters either randomly or using some information about the members.
2. Estimate the Euclidean distance between each member and means of *k* clusters, and regroup the members to the nearest clusters. The Euclidean distance between points *x* and *y* in *n* dimensional space is defined as:

$$\left(\sum_{i=1}^{n} (x_i - y_i)^2 \right)^{1/2}$$

3. Re-compute the mean of each cluster and repeat the second step.
4. Repeat the third and second procedures until there are no changes in cluster membership.

Annex D

Contributions to Cropping Intensity Increase

The decomposition of cropping intensity into different factors is shown below. First, we define:

CI	Overall cropping intensity
NSA	Net sown area
NIA	Net irrigated area
CI^{I}	Cropping intensity in irrigated area
CI^{R}	Cropping intensity in rain-fed area

Then, the gross sown area at time t_0 can be written as:

$$CI_{t_0} \times NSA_{t_0} = NIA_{t_0} \times CI_{t_0}^{I} + (NSA_{t_0} - NIA_{t_0}) \times CI_{t_0}^{R}$$

The gross sown area at time $t = t_0 + \Delta t$ can be written as:

$$(CI_{t_0} + \Delta CI) \times (NSA_{t_0} + \Delta NSA) = (NIA_{t_0} + \Delta NIA) \times (CI_{t_0}^{I} + \Delta CI^{I}) + ((NSA_{t_0} + \Delta NSA) - (NIA_{t_0} + \Delta NIA)) \times (CI_{t_0}^{R} + \Delta CI^{R})$$

By subtracting the first equation from the second we get:

$$\Delta CI \times (NSA_{t_0} + \Delta NSA) + CI_{t_0} \times \Delta NSA = CI_{t_0} \times \Delta NIA + NIA_{t_0} \times \Delta CI^{I} + \Delta CI^{I} \Delta NIA + (NSA_{t_0} - NIA_{t_0}) \times \Delta CI^{R} + CI_{t_0}^{R} \times \Delta NSA + (\Delta NSA - \Delta NIA) \times \Delta CI^{R}$$

This can be further simplified to:

$$\Delta CI \times (NSA_{t_0} + \Delta NSA) = (CI_{t_0}) \Delta NIA + (NIA_{t_0}) \times \Delta CI^{I} + \Delta CI^{I} \Delta NIA + (NSA_{t_0} - NIA_{t_0}) \times \Delta CI^{R} - (CI_{t_0} - CI_{t_0}^{R}) \times \Delta NSA + (\Delta NSA - \Delta NIA) \times \Delta CI^{R}$$

The six components on the right-hand side can be interpreted respectively as the:

1. positive contribution due to changes in net irrigated area expansion only;
2. positive contribution due to growth in irrigation intensity only;
3. positive contribution due to both irrigation intensity increase and net irrigated area expansion;
4. positive contribution due to intensity increase only in the existing rain-fed area;

5. negative contribution from expanding net sown area with existing rain-fed cropping intensity;
6. positive or negative contribution from converting rain-fed area into irrigation had there been only rain-fed intensity increase (a negative contribution could occur if the rain-fed cropping intensity at time $t + \Delta t$ is still less than the average cropping intensity at time t).

The percentage contributions of the six components to the total cropping intensity are given in Annex D table.

ANNEX D TABLE.
Contributions to change (%) in overall cropping intensity (CI).

	River basin	CI		Estimated contribution of the change in factor to CI change (% of total)					
		1995	Change (1995–1960)	NIA	Irrigated CI (CI^{Ir})	NIA x CI^{Ir}	Rain-fed CI	NSA (CI^{Rf})	CI^{Rf} x NSA
	All basins	132	16	57	8	10	30	0	-5
Basins of westerly flowing rivers	Indus	168	43	39	33	16	14	2	-4
	Mahi	119	12	68	2	8	25	-1	-2
	Narmada	124	15	63	1	5	38	-1	-6
	Sabarmati	115	11	80	3	12	8	0	-3
	Tapi	119	16	41	1	3	58	0	-3
	WFR1	117	4	85	4	9	3	-1	0
	WFR2	123	41	22	-3	-2	57	3	23
Basins of easterly flowing rivers	Brahmani and Baitarani	148	35	34	0	0	80	0	-15
	Cauvery	119	12	37	-2	0	70	0	-5
	EFR1	133	11	63	-5	-3	61	-1	-14
	EFR2	121	9	63	-16	-4	87	-5	-25
	Ganga	141	16	59	11	16	21	-1	-7
	Godavari	123	15	56	1	1	49	0	-7
	Krishna	118	13	60	5	6	38	0	-8
	Mahanadi	140	13	64	-3	-5	54	0	-10
	Pennar	121	1	78	-22	-2	49	0	-1
	Subarnarekha	148	25	45	10	11	49	0	-16
	Brahmaputra	144	29	12	34	7	36	-2	12
	Meghna	146	44	6	7	16	39	-14	46

Note: WFR1, WFR2, EFR1, EFR2 see Notes to table 1.

Source: Authors' estimates.

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