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123

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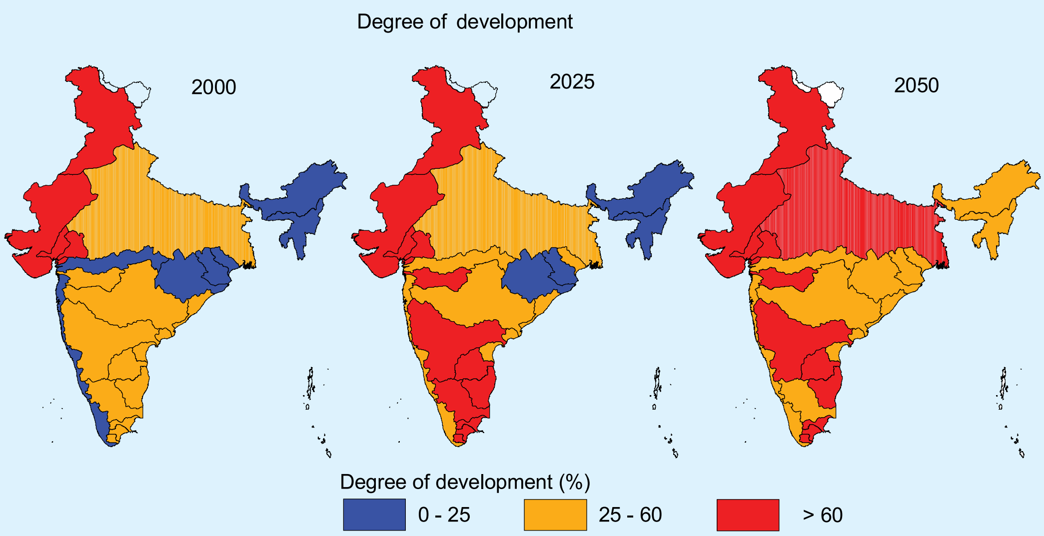
Business-as-Usual Scenario and Deviations

Upali A. Amarasinghe, Tushaar Shah, Hugh Turral and B. K. Anand



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Cover map generated by Upali Amarasinghe shows the degree of development of Indian river basins under the business-as-usual scenario water supply and demand. The degrees of development in different years are authors' estimates given in this report.

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Contents

Abbreviations and Acronyms

BAU	Business-as-usual
Bm^3	Billion cubic meters
CWC	Central Water Commission
EFR	Environmental flow requirement
EMC	Environmental management class
EWD	Environmental water demand
FAI	Fertilizer Association of India
FAO	Food and Agriculture Organization of the United Nations
FCF	Feed conversion factor
GCA	Gross cropped area
GDP	Gross domestic product
GIA	Gross irrigated area
GWE	Groundwater efficiency
GOI	Government of India
IFPRI	International Food Policy Research Institute
IWMI	International Water Management Institute
kcal	Kilocalories
lpcd	Liters per capita per day
MAI	Moisture availability index
MAR	Mean annual runoff
MFR	Minimum flow requirement
Mha	Million hectares
Mmt	Million metric tonnes
NCIWRD	National Commission for Integrated Water Resources Development
NGWIA	Net groundwater irrigated area
NIA	Net irrigated area
NSA	Net surface irrigated area
NSSO	National Sample Survey Organization
PODIUMSIM	Policy Dialogue Model Simulation
WTO	World Trade Organization

Summary

With a rapidly expanding economy many changes are taking place in India today. Some of these changes will have substantial implications on India's water future. Land use, cropping and water use patterns are changing, partly as responses to changing demographic and consumption patterns, and partly as responses to changing investment scenarios and economic growth. This report attempts to capture the trends of key drivers of water demand in the recent past, and assess their implications on future water demand. The business-as-usual (BAU) scenario in this report assumes the continuation of current trends and projects India's water future to 2025–2050.

The BAU scenario projects the total water demand to increase by 22% and 32% by 2025 and 2050, respectively, from the present level of 680 billion cubic meters (Bm^3). The industrial and domestic sectors will account for 85% of the additional demand by 2050. Groundwater dominates irrigation growth of the BAU scenario and will share 60% of the area and 51% of the total irrigation by 2050. This, along with higher irrigation efficiencies, will decrease the water demand for irrigation over the period 2025–2050.

Irrigation water withdrawals under the BAU scenario are sufficient to meet most of the future food demand. The BAU projects a small production surplus of grain crops, and a small production deficit of non-grains crops. Overall, the BAU scenario projects a small deficit of crop production of all crops by 2050. Although the BAU scenario is optimistic in meeting the future food demand, its water use patterns will lead to a severe regional water crisis by 2050. Many river basins will reach closure, will be physically water-scarce and will have regions with severely overexploited groundwater resources.

Assessment of possible deviations from the BAU scenario shows rather optimistic and pessimistic scenarios. While higher growth of both urban population and feed demand for the livestock population will increase water demand, the productivity growth, higher groundwater irrigated area and efficiency growth will reduce irrigation demand significantly. In order to reach the benefits of the latter scenarios, India requires investments in interventions in recharging groundwater, spreading water saving technologies and increasing crop productivity growth.

India's Water Future to 2025–2050: Business-as-Usual Scenario and Deviations

Upali A. Amarasinghe, Tushaar Shah, Hugh Turral and B. K. Anand

Introduction

For many reasons, India has occupied a center stage in global food and water supply and demand projections. First, with a population of over a billion, India is the second most populous country in the world. By the middle of this century it needs to feed an extra population of 500 million. Second, India has had a huge economy and a remarkable economic growth in the last decade. With the booming economy, people's expenditure patterns are changing; so do their lifestyles. Rapid urbanization is also adding fuel to these changes. As a result, food consumption patterns are changing—changes a traditional country like India would not have imagined a few decades ago. The changing food consumption patterns are so significant that they have a considerable impact on the needs of future food and water demand. Third, and perhaps the most critical, is that India has significant spatial mismatches of the population and water resources (Amarasinghe et al. 2005). Less water is available in places where more people live and much of the food is grown. Some river basins are already experiencing physical water scarcities. A few others face problems of unsustainable groundwater use. Thus, how India meets its increasing food and water demand was the major focus of many recent food and water demand projections at the global scale (IWMI 2000; Rijsberman 2000; Rosegrant et al. 2002; Seckler et al. 1998) and the national scale (Bhalla et al. 1999; Dyson and Hanchate 2000; GOI 1999).

Food and water demand projections of India—which are experiencing rapid economic and demographic changes—need regular updating. For the base year, many recent projection studies used information relevant to the period from the late 1980s through the early 1990s. One such study, considered a blueprint for water resources management and planning of India, is the 1998 water demand projections of the National Commission for Integrated Water Resources Development (NCIWRD) (GOI 1999). For the base year, the NCIWRD projections used data relevant to 1993–1994, and the trends relevant to the 1980s for future projections. However, many unforeseen changes, which affected the demand projections, took place in the last decade. In particular, the changes due to economic liberalization in India in the early 1990s are only visible now. Due to these changes, some food and water demand drivers, which are endogenous to India, such as food consumption and land use patterns, and exogenous to India, such as the world food trade, are fast changing. Therefore, in this context, many of the past food and water demand projections need to be reassessed.

This report revisits India's water future assessment to 2025 and 2050. It incorporates the recent changes in food- and water-related drivers in the supply and demand assessment. The assessment uses the PODIUMSIM model methodology for projecting India's water future. The

PODIUMSIM, the Policy Dialogue Model, is a tool for simulating the alternative scenarios of water future with respect to the variation of food and water demand drivers (http://podium.iwmi.org/podium/). This analysis benefits from using the latest data on a) demography from the 2001 census (GOI 2003), b) food consumption patterns from the latest consumption and expenditure surveys (NSSO 2001), and c) land use and production patterns from the recent surveys on agriculture (GOI 2004). The major objectives of this report are to:

- project the water future of India and assess the implications of the water demand projections on water scarcity at the river-basin level; and
- assess the sensitivity of food and water demand projections with respect to the changes in the key demand drivers.

Specifically, this report estimates water demand of irrigation, domestic and industrial sectors in 2025 and 2050. First, it assesses the BAU scenario water demand. The BAU scenario assumes continuation of recent trends of key water demand determinants. We also assess several deviations from BAU, with respect to the changes in key demand drivers.

The rest of the report is organized into four sections. The next section, *Data and Methodology*, presents a description of the methodology and data used for simulating water demand. The section, *Business-as-Usual Scenario to 2025-2050*, gives water future of India to 2025 and 2050. The BAU scenario is mainly based on the recent trends of the food and water demand drivers. In the section, *Other Scenarios: Deviations from BAU*, we provide alternative scenarios with respect to changes in the demand drivers. The report concludes with a discussion of policy implications.

Data and Methodology

Methodology

The PODIUMSIM model, which simulates water future scenarios of this report, has four major components: crop demand, crop production, water demand and water accounting (see Annex 1 for details of the model). These components are assessed at various temporal and spatial scales (Table 1).

TABLE 1. Spatial and temporal scales of different components.

Component	PODIUMSIM model	
	Spatial scale	Temporal scale
Crop demand	National (rural/urban)	Annually
Crop production	River basin	Seasonally
Water demand		
Irrigation	River basin	Monthly
Domestic	River basin	Annually
Industrial	River basin	Annually
Environment	River basin	Annually/Monthly
Water accounting	River basin	Annually

The crop demand component assesses the future demand of 11 crops or crop categories at the state or national level. The crops include grain crops: rice (milled equivalent), wheat, maize, other cereals and pulses, and the non-grain crops: oil crops (including vegetable oils as oil crop equivalent), roots and tubers (dry equivalent), vegetables, fruits, sugar (processed) and cotton (lint). The major drivers of this component are the rural and urban population, the nutritional intakes (calorie supply) from grains, non-grains and animal products, per capita consumption of different crop categories and the feed conversion ratios. These ratios indicate the quantity of feed use by livestock for producing 1,000 kilocalories (kcal) from animal products.

The crop production component assesses the outputs of irrigation and rain-fed crops, where area and yields under irrigated and rain-fed conditions are the main drivers. This component shows, first, the production surplus or deficit in river basins, and then the aggregate at the national level. The production surplus or deficit at the national level shows the quantity available for export or the quantity required to import, respectively.

The water demand component assesses the river-basin water requirements for the irrigation, domestic, livestock, industrial and environmental sectors. The crop water requirement is first estimated at the district level for the 11 crop categories and the other irrigated crops, which mainly include fodder. The district estimates are then aggregated to determine the river-basin-level estimates. The major parameters of the irrigation crop requirements are the crop irrigated area, crop calendar, crop coefficients, potential evapotranspiration and the 75% exceedence probability of rainfall. The crop water requirements in the surface water and groundwater irrigated areas divided by the respective project irrigation efficiencies give the irrigation demand. The population and the per capita domestic water demand drivers estimate the change in domestic water demand. The total livestock population and the per head water requirement norms estimate the livestock water demand.

The model accounts for the potentially available water resources of different river basins with respect to consumptive use, return flows of different sectors, the non-beneficial use and the outflows.

Data

We use the year 2000 as the base year for our future projections. The database for 2000 and the past trends of different drivers are derived using the data of various internal and external publications (see Annex 1).

The river-basin-wise data in this report are derived by aggregating the information of the districts falling within the area of the river basins. In general, most of the information, except that on water supply, is collected and is available at the level of the administrative boundaries. In this report, these data are available at the district level. When districts overlap with two or more river basins (Figure 1), the district population is divided according to the geographical area of the river basins, and the crop area is divided according to the net sown area of the districts falling in different river basins. The net sown area of river basins is estimated using the land use map of India (IWMI 2005).

FIGURE 1. District and river basin boundaries of India.

Business-as-Usual Scenario to 2025–2050: Story Line

First, we assess the directions of key drivers of the BAU scenario. We begin the story line of BAU with a quote from the Prime Minister of India, Dr. Manmohan Singh (Prime Minister's address to the Economic Summit 2005):

…It is certainly within the realm of possibility that an appropriate combination of policies can raise the economic growth beyond 8% easily. In fact, we should be targeting 10% growth rate in 2–3 years' time. In my view, this is eminently feasible, if we have the expected increase in savings rate and arising out of a young population, if we manage to make a quantum leap in the growth rate of our agriculture...

The BAU scenario in this report is mainly based on the recent trends of key drivers. But it also incorporates some of the rather optimistic economic growth assumptions that the Prime Minister has envisaged. It assumes that the contribution from the agriculture sector to the gross domestic product will be further reduced. But the benefits of higher economic growth filter down to every sphere, and the government and the private sector will invest to arrest the declining growth of agricultural productivity to some extent. The quantum leap as the Prime Minister suggested could be possible, but it certainly would be a deviation from the trends of the BAU scenario. In a later section, we will assess the implication of this deviation on the water demand.

We assume that the consumption pattern shifts will continue with further urbanization and increasing income. We also assume that the groundwater expansion, which played a major role in helping the livelihoods of many rural poor, will continue. But, the emerging groundwater markets, scarcity of the resource, the increasing cost of pumping, and the spread of micro-irrigation technologies will make groundwater use more efficient. The BAU scenario assumes that unsustainable groundwater development patterns emerge in other regions, as we see today in the states of Punjab, Haryana, Rajasthan and Tamil Nadu.

Now we give a brief description of past trends and future directions of the key drivers of the BAU scenario at the national level. Recent trends, both temporal and spatial, across districts and states are the basis for the magnitude of the changes of these drivers at the regional level. First, we present the trends of crop demand drivers (Table 2).

TABLE 2. Past trends and projections of growth of the crop demand drivers.

Drivers	Past trends			Projections	
	1979-1981	1989-1991	1999-2000	2025	2050
Demography					
Population (million)	689	851	1,007	1,389	1,583
Urban population (%)	23	25	28	37	51
Economic growth					
GDP growth ($1995 prices[1])	228	319	463	1,765	6,735
Nutritional intake					
Total calorie supply (kcal/person/day)	2,083	2,365	2,495	2,775	3,000
Contribution of grain crops (%)	71	69	65	57	48
Contribution from non-grain crops (%)	23	24	28	33	36
Contribution from animal products (%)	6	7	8	12	16
Food consumption/person (kg/yr)					
Grains	163	177	172	166	152
Rice	68	78	76	74	69
Wheat	46	54	58	58	58
Maize	7	8	10	8	4
Other coarse cereals	29	23	17	15	9
Pulses	13	14	11	12	12
Non-grain crops					
Oil crops (oil crop equivalent)	22	28	41	64	73
Roots and tubers	5	5	6	8	12
Vegetables	52	55	69	102	114
Fruits	29	34	40	49	67
Sugar	23	23	25	28	33
Animal products					
Milk	40	55	66	88	100
Poultry meat	0.2	0.4	1	7	13
Eggs	0.7	1.2	1.4	7	33
Freshwater fish	1	2	3	6	7
Meat (beef/pork/mutton)	3	4	4	6	7
Cotton	1.2	1.6	2.1	2.8	3.8
Feed conversion ratio (kg of feed grains per 1,000 kcal of animal products)					
Conversion ratio	0.07	0.06	0.12	0.27	0.40

[1]In this report, $ means US$.

Demographic Change

India's population is increasing but will stabilize in the middle of this century. During the third and fourth quarters of the twentieth century, India's population had increased annually by 2.3% and 1.9%, respectively. In a background study to this report, Mahmood and Kundu (2006) projected that the total population would increase at 1.3% and 0.52% in the first and second quarters, respectively, of this century. The population growth is expected to stabilize in the early 2050s. According to this study, urbanization will also continue to expand, and slightly over half of India's population will live in the urban areas by 2050. The BAU scenario assumes the projections of population growth in Mahmood and Kundu 2006 for estimating food and water demand (Table 2).

Regionally, the population of several large states will peak well before 2050. The population of some states, such as Tamil Nadu, Andhra Pradesh, Kerala, Karnataka, Gujarat and Punjab will have declining trends in the 2030s and 2040s. Many of the states with a declining population before the 2050s are in the south and east, and they have a high urbanization growth. These states are located in river basins which presently experience regional water scarcities. We expect that the migration from agriculture to employment in the nonagriculture sector will be highest in these states. In fact, Sharma and Bhaduri (2006) have shown that the odds of rural youth moving out of agriculture are high in areas where water scarcities are more, and where nonagricultural employment opportunities in the neighborhoods are high.

Income Growth

The economic growth in India shows contrasting patterns before and after the economic liberalization. India's per capita Gross Domestic Product (GDP) increased at 1.9% annually in the pre-liberalized economy (1961–1990) and at 3.8% annually thereafter. Since 1991, the annual per capita GDP growth has been steady and has fluctuated from 3% to 6% with an average of 3.8%. The International Food Policy Research Institute (IFPRI), using the IMPACT model, projects India's total GDP (in 1995 constant prices) to increase at 5.5% between 1995 and 2020 (Rosegrant et al. 2001).

The BAU scenario assumes that India's per capita income will increase at 5.5% annually over the next 50-year period. At this rate, the GDP will increase at 6.8% annually from 2000 to 2025, and at 6% annually from 2025 to 2050. Indeed, to maintain such an average growth rate, India's GDP growth requires spurts of over 8% in some periods as suggested by the Prime Minister.

The per capita GDP will increase from $463 ($1.00=Indian Rupees 33.45 in 1995 prices) in 2000 to about $1,765 by 2025 and to about $6,735 by 2050. We also assume that the contribution from the industrial and the service sectors to the overall economic growth will continue to increase. By 2050, the GDP of the industrial sector will contribute to about 40% of the total GDP.

Consumption Patterns

India's nutritional intake patterns are changing fast. The consumption of food grains, once the dominant calorie supply provider, is decreasing in both rural and urban areas. On the other hand, the consumption of non-grain crops, such as vegetables, fruits and oil crops, and animal products such as milk, poultry and eggs, is increasing (Amarasinghe et al. 2007a; Dyson and Hanchate 2000).

We expect that the high income growth and urbanization will continue to contribute to further changes in the consumption patterns. Based on income growth and urbanization, Amarasinghe et al. (2007a), in a background study to this report, have projected that the total nutritional intake will continue to increase, but that the share of grain products in the consumption basket will reduce further. As much as 54% of the total calorie supply will be from the non-grain products by 2050, compared to the present 36%. As a result of changing consumption patterns, per capita consumption of rice, maize and other coarse cereals will decrease by 9%, 60% and 47%, respectively, in 2000–2050. On the other hand, per capita consumption of oil crops (including vegetable oil), vegetables, fruits and sugar will increase by 78%, 65%, 68% and 32%, respectively.

We also assume, as did Rao (2005), that the differences in urban and rural consumption patterns will still exist, but that the gap will be narrower by 2050. As a result of these growths, the rural nutritional poverty will also decrease substantially.

The increased projections of the consumption of animal products will have a significant impact on feed grain demand. The feed grain conversion factor, the quantity of grains, primarily maize, required for producing 1,000 kcal of animal products, was only 0.12 kg/1,000 kcal in 2000. Based on recent trends, Amarasinghe et al. (2007a) projected that the feed conversion ratio would increase to about 0.40 kg/1,000 kcal by 2050, which is the level of feed grain conversion ratio of some of the present upper- to middle-income developing countries, such as China.

National Food Self-Sufficiency

The BAU scenario assumes that the national self-sufficiency for individual crops will no longer be a concrete goal. Some crops are expected to have production deficits, as at present. But, at the national level, increase in income from high-value crops is sufficient to pay for imports to cover any deficit in other crops (see Annex 2).

Crop diversification, which started spreading in the last decade, will continue at a faster pace. The share of grain area, both in the gross cropped and gross irrigated area, is decreasing. Farmers will shift cropping patterns to grow more cash crops, which best suit the available land and water resources and the prevailing market conditions. As a result, the share of grain area, both in the gross cropped and the irrigated area will further decrease (Table 2). In the future, income from high-value non-grain crops is expected to contribute significantly to the livelihood security of the rural population.

Crop Area Growth

The BAU scenario assumes that the net sown area will remain the same, at the present level of 142 million hectares (Mha) (Table 3). But irrigation expansion, a major thrust of the growth in the crop area in the past decade, is likely to continue and irrigation coverage is expected to increase from 41% to 55% over the period 2000–2050.

TABLE 3. Past trends and projections of crop production drivers.

Drivers	Past trends			Projections	
	1979-1981	1989-1991	1999-2000	2025	2050
Crop area (million ha)					
Net sown area	141	142	141	142	142
Net irrigated area	38	46	55	74	81
Net groundwater area	18	25	34	43	50
Net canal and tank area	20	22	21	31	31
Gross irrigated area (GIA)	49	62	76	111	117
Gross crop area (GCA)	172	183	189	208	210
Grain crop area - % of GCA	74	69	65	58	57
Grain irrigated area - % of GIA	77	71	71	56	54
Crop yield (tons/ha)					
Average grain yield	1.0	1.4	1.7	2.4	3.1
Irrigated grain yield[i]	1.5	2.1	2.6	3.6	4.4
Rain-fed grain yield[i]	0.6	0.8	1.0	1.3	1.8

[i]Irrigated and rain-fed yields in 1979-1981 and 1990-1991 are estimated using the ratio of irrigated and rain-fed yields to the average yield in 1999-2001.

The BAU scenario assumes groundwater irrigation to be a major driver of irrigation expansion in the future. Some of these new groundwater areas would extract the water that is recharged from the surface irrigation return flows. But many of the new groundwater irrigated areas would exploit the water recharged from the rainfall. And by 2025, the gross groundwater irrigated area will increase to 60 Mha and, by 2050, this will increase to 70 Mha (see Annex 3). Indeed, the BAU scenario growth of the net groundwater irrigated area is very much below the trends during the past few years. Our assumption is influenced by the current potential of groundwater irrigation coverage. However, with artificial recharge, groundwater irrigation potential could increase more in the future. In a later section, we will assess the sensitivity of the BAU water demand projections due to various groundwater irrigation growth scenarios.

To some degree, a departure from the recent trends, the BAU scenario assumes that the surface irrigation coverage will also increase. The projects that are under construction now will contribute to this increase. The IXth Five-Year Plan (2002–2007) alone envisages adding 10 Mha to the surface irrigation potential (GOI 2004). The net canal irrigated area coverage is expected to increase, from 17 to 27 Mha over the period 2000–2025, and then remain so between 2025 and 2050. A major part of the rest of the net sown area—what is presently classified as rain-fed—receives supplemental irrigation in the periods of water stress, which are crucial to crop growth.

The BAU scenario also projects the supremacy of the grain crop in the irrigated agriculture to diminish, where irrigation coverage of grain crops will decrease from the present 71% to about 56% and 54% by 2025 and 2050, respectively (see Annexes 2 and 3 for detailed estimations).

Crop Yield Growth

The growth of grain yield has been declining in recent decades—at 3.6% annually in the 1980s and 2.1% annually in the 1990s. The BAU scenario assumes that the declining trends will continue, but not at such a steep trend as was seen in the last two decades. The BAU scenario assumes that, in the first and second quarters of this century, the annual growth of grain yield would decline to 1.4% and 1.0%, respectively (see Annex 3 for details).

In spite of the decreasing trends in the past, and also the bleak assumptions in the BAU scenario, we believe that substantial scope exists for increasing yield beyond this limit. It is clear that there is a significant gap between the highest and the lowest actual yields, and between the actual and the potential yields (Aggarwal et al. 2000). The investments in the future, both private and public, that the Prime Minister mentioned, will focus on small-scale infrastructure and technologies that may greatly enhance the crop yields. The micro-irrigation technologies offer opportunities for significant yield growth (Kumar et al. 2006a; Narayanamoorthy 2006; INCID 1998). The expanding groundwater use could also contribute significantly to increasing irrigated yield. And at critical periods of water stress, supplementary irrigation, through water harvesting, can substantially boost rain-fed yields (Sharma et al. 2006). Moreover, farmers will have an incentive to increase crop productivity to benefit from the increasing internal and external food trade. Later, we will assess the implications of rather optimistic scenarios of crop yield growth, than assumed in the BAU, on crop production and water demand.

Irrigation Efficiency

The information available so far suggests that irrigation efficiency in surface water projects has not improved much and also that many groundwater irrigation areas have relatively higher efficiencies. As the resources become scarce and also expensive, water saving technologies spread fast. As a result, the efficiency of groundwater irrigation would increase further. The BAU scenario assumes that the efficiency of groundwater irrigation would increase to 75% by 2050 from the present level of 65% (Table 4). Irrigation efficiency in surface irrigation projects would also increase to about 50% from the present level of 30–40%.

Domestic Water Demand

With increasing household income and increasing contribution from the service and industrial sectors, the water demand in the domestic and industrial sectors could increase substantially. We assume that the average domestic water demand would increase from 85 liters per capita per day (lpcd) in 2000, to 125 and 170 lpcd by 2025 and 2050, respectively (see Annex 4 for more details). The BAU scenario approach differs from the approach adopted by the NCIWRD, which assumes norms where the rural domestic water demand in 2025 and 2050 are estimated at 70 and 150 lpcd, respectively, and the urban water demand at 200 and 220 lpcd, respectively. They also assume 100% coverage for both the rural and the urban sectors. At this rate, the average per capita water demands in 2025 and 2050 are estimated to be 126 and 191 lpcd, respectively.

The domestic water demand includes livestock water demand. We assume 25 liters per head of the cattle and buffalo population. The livestock population is projected at the rate of calorie supply of animal products. We estimate the livestock water demand to increase from 2.3 Bm^3 in 2000 to 2.8 and 3.2 Bm^3 by 2025 and 2050, respectively (Table 4).

Industrial Water Demand

In a rapidly booming economy, we expect the contribution of the industrial sector to increase very much, and the industrial water demand to increase accordingly. However, the dearth of information on the types of industries, their growth, water use and the extent of recycling is a constraint for future projection in the context of increasing economic growth. The NCIWRD, based on a small sample of industries and their water use, projected that industrial water demand would increase from 30 Bm^3 in 2000, to about 101 and 151 Bm^3 by 2025 and 2050, respectively.

However, an analysis using the global trends shows that, with the present economic growth rates, the industrial water demand increases slightly more, to 92 and 161 Bm^3, by 2025 and 2050, respectively (see Annex 4 for more details).

Environmental Water Demand (EWD)

As a result of increasing economic activities, the quality and quantity of water in some rivers are at a threateningly low level. However, with increasing campaigns by NGOs and civil societies, people's awareness of the environmental water-related problems is increasing. As a result, the water demand for the environment could increase rapidly. At the least, we believe that a minimum flow requirement (MFR) provision will be established in most river basins. We use the MFR estimates of Smakhtin and Anputhas (2006) as a guide for assessing the BAU scenario of the EWD

The MFR of Smakhtin and Anputhas (2006) depends on the hydrological variability and the environmental management class (EMC) that the

TABLE 4. Growth of other water demand drivers.

Drivers	2000	Projections	
		2025	2050
Project irrigation efficiency (%)			
Surface water	30-45	35-50	42-60
Groundwater	55-65	70	75
Domestic water demand			
Human water demand (m^3/person/year)	31	42	61
Livestock water demand (Bm^3)	2.3	2.8	3.2
Industrial water demand (m³/person/year)	42	66	102
EWD			
Minimum river flow - % of mean annual runoff	-	6-45	6-45

river ought to maintain. We estimate environmental flow requirement (EFR) using the guidelines for the EMC C, which is classified as for a “moderately disturbed” river. In EMC C, the habitats and the biota of the rivers have already been disturbed, but the basic ecosystem functions are intact. The management perspective is to preserve the ecosystem to such an extent that multiple disturbances associated with the socioeconomic development are possible. This management class, in general, proposes an MFR in the range of 12 to 30% of the mean annual runoff. In particular, the MFR of the Brahmaputra River Basin is estimated as 46%, and of the Mahi River as 7%. We use these guidelines for estimating the EWD to be released from the potentially utilizable water resources (see Annex 5 for details).

Although maintaining MFR is the least desirable policy option, no such maintenance was practiced in the past. Therefore, we assume MFR is not maintained in the BAU scenario. Later, we will assess the implications of maintaining MFR on meeting the water demand of other sectors, especially in the water-scarce basins.

Business–as-Usual Scenario Projections

Water Demand

The total water demand of the BAU scenario is projected to increase 22% by 2025 and 32% by 2050 (Table 5). The domestic and industrial sectors account for a substantial part of the additional water demand, 8% and 11%, respectively, of the total water demand by 2025, and 11% and 18%, respectively, by 2050. Moreover, the domestic and industrial sectors will account for 54% of the additional water demand by 2025, and for more than 85% by 2050.

The BAU scenario envisages significant water transfers from the irrigation sector to other sectors by 2050. The combination of higher irrigation efficiencies and large groundwater irrigated areas decreases the demand for surface water irrigation between 2025 and 2050. While the total irrigation demand decreases by 38 Bm^3 the demand for surface water irrigation is estimated to decrease by 46 Bm^3. This surplus irrigation water is projected to be available for the other two sectors.

TABLE 5. The BAU scenario water demand projections.

Sector	2000		2025		2050	
	Total Bm^3	% from groundwater	Total Bm^3	% from groundwater	Total Bm^3	% from groundwater
Irrigation	605	45	675	45	637	51
Domestic[a]	34	50	66	45	101	50
Industrial[b]	42	30	92	30	161	30
Total	680	44	833	43	900	47

[a] Domestic withdrawals include those for livestock water demand.

[b] Industrial withdrawals include cooling needs for power generation.

In fact, the water transfers from irrigation to other sectors is not a new phenomenon in India's water-scarce regions although the quantum of water transfers involved is small and the context in which water is transferred is different at present. The first priority in India's water policy is to meet domestic water demand. In water-scarce basins, and especially in water-stress periods, curtailing water withdrawals to the irrigation sector is not uncommon for meeting the drinking water demand of the domestic and livestock sectors. So, at present, it is not the water surplus in the irrigation sector, but the water demand in water-scarce regions in water-stress periods that determines the water transfers to other sectors.

Production Surpluses or Deficits

The BAU water withdrawals are sufficient to meet most of the food needs by 2050 (Table 6). In 2050, the total grain production is estimated to be 2.0% more than the estimated demand of 377 million metric tons (Mmt). The total production of non-grain crops, estimated in terms of the average export prices of 1999–2001, was 9.4% less than the production of non-grain crop demand in 2000. And the production deficit of non-grain crops is projected to decrease to 6.3% by 2050. Due to production deficits of non-grain crops, the total value of production is projected to be less than the demand of all crops—about 4.0% by 2025 and 2050.

Among the grain crops, substantial production deficits are projected for other cereals and pulses (Table 7). The production deficit of other cereals is primarily due to increased demand of maize for livestock feeding. The maize demand is projected to increase from 5 Mmt in 2000 to 107 Mmt by 2050. However, the production surpluses of rice and wheat offset the deficits of other crops to maintain overall grain production surpluses by 2050 (Table 7). Among the non-grain crops, oil crops are expected to have substantial production deficits.

BAU Projections: Comparisons

The BAU projection is first compared with the projection of the NCIWRD's high demand scenario (GOI 1999). We select the high-demand scenario for comparison, as it is claimed to be the basis for the justification for the National River Linking Project. Figure 2 shows the incremental demand of the irrigation, domestic and industrial sectors of the two projections. The striking difference between the two projections is the irrigation demand in 2050, where both projections to 2025 are similar but the projections deviate significantly by 2050. While the BAU scenario projects a decreasing irrigation demand between 2025 and 2050, the NCIWRD projects an additional demand of 250 Bm^3 by 2050.

TABLE 6. Crop demand and production surpluses or deficits.

Crop category	Demand			Production surpluses (+) or deficits (-) as a % of demand		
	2000	2025	2050	2000	2025	2050
Food grains (Mmt)	173	230	241			
Feed grains (Mmt)	8	38	111			
Total grains (Mmt)	201	291	377	2.8	0.2	2.0
Grains (billion $)[1]	52	73	90	3.3	0.4	3.4
Non-grains (billion $)[1]	106	198	284	-9.4	-5.4	-6.3
Total (billion $)[1]	158	272	374	-5.2	-3.9	-4.0

[1] The value is expressed in terms of average of the export prices in 1999, 2000 and 2001.

TABLE 7. Production, demand and production surpluses or deficits of different crops.

Crop	Production			Demand			Production surpluses or deficits - % of demand		
	2000 Mmt	2025 Mmt	2050 Mmt	2000 Mmt	2025 Mmt	2050 Mmt	2000	2025	2050
Rice	89	117	143	82	109	117	8	7	22
Wheat	72	108	145	67	91	102	8	18	41
Other cereals	32	49	78	37	73	137	-16	-33	-43
Pulses	13	18	19	14	18	21	-5	-3	-7
Grains	207	292	385	201	291	377	3	1	2
Oil crops	31	73	97	48	103	133	-35	-30	-27
Roots/tubers	7	14	26	7	13	24	-3	10	7
Vegetables	74	150	227	75	150	189	-1	0	20
Fruits	46	83	106	47	78	123	-1	6	-14
Sugar	30	46	60	26	42	55	14	9	10
Cotton	2	4	6	2	4	6	-12	-2	-3

Sources: 2000 data are from the FAOSTAT database (FAO 2005a); the 2025 and 2050 data are estimated by the author.

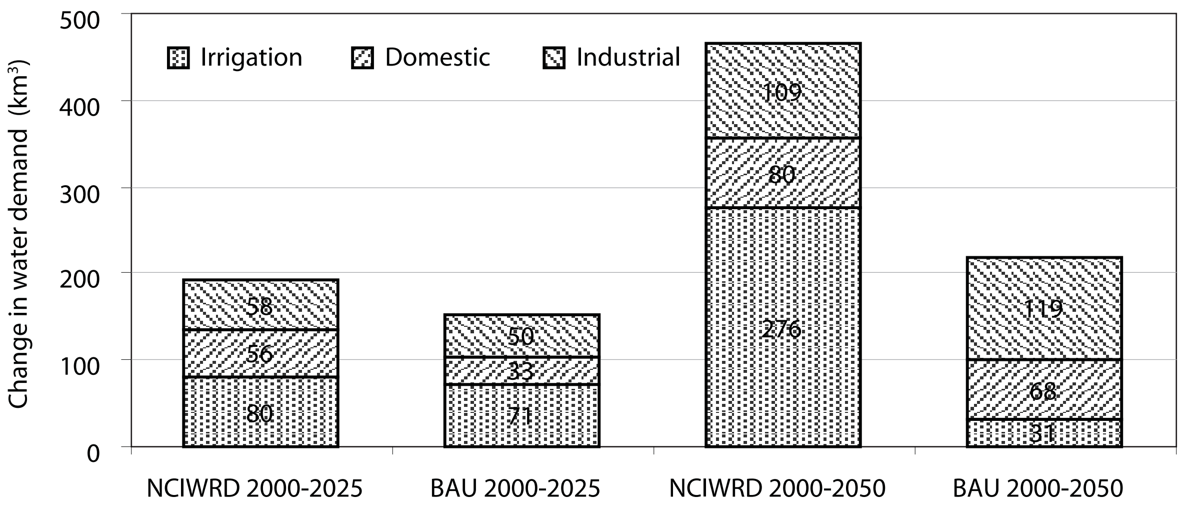

FIGURE 2. Difference of water demand projections—the BAU and NCIWRD high-growth scenarios.

The differences in incremental irrigation demand in 2050 are due to several factors. First, the BAU scenario, based on recent trends, projects a decreasing food grain demand and an increasing feed grain demand. The NCIWRD projects a significant growth in food grain consumption. Both projections target nutritional security, but the BAU scenario projects a diversified diet whereas the NCIWRD assumes a grain-dominating diet. The BAU scenario projects a 3,000 kcal/person/day average calorie supply by 2050. However, the average calorie supply based on the NCIWRD assumptions could well be over 4,000 kcal/per person/day. The latter is not realistic, at least according to global consumption patterns, where even the developed countries, with substantial animal products in the diet, consume about 3,600 kcal/person/day.

Second, the Commission has assumed the self-sufficiency of grains, and has projected that much of the additional grain requirement for meeting self-sufficiency is to be produced under irrigation conditions. For this, the Commission estimates 104 Mha of grain irrigated area, while the BAU scenario projects only 79 Mha of such area.

Third, the BAU scenario assumed rapid expansion of groundwater irrigation whereas a major part of the NCIWRD's projection is for surface irrigation. The Commission assumed the ratio of surface water to groundwater as 55:45, while the BAU scenario projected a ratio of 40:60. Combined with the area differences, the assumption of irrigation efficiencies has contributed to the water demand differences. But, if proper attention is not paid, the BAU scenario may lead to a water crisis at the regional level. We will discuss these in detail in the next section.

We also compare the BAU scenario projections of this report and those of the IMPACT-Water model (Rosegrant et al. 2002). Although, the total water demand projections to 2025 of the two scenarios are similar (IMPACT-Water projects 822 Bm^3 by 2025), we find that the assumptions that lead to demand estimations and the sectoral demand projections themselves are different.

The IMPACT-Water model projects 76 Mha of potential irrigated area for India by 2025. However, the gross area has already reached 76 Mha, the base-year value for the BAU scenario of this report. The IMPACT-Water model also projects the cereal irrigated area to increase to 48 Mha by 2025. But India's irrigated cereal area is already above this level, and this report's base-year grain irrigated area was 54 Mha. The IMPACT-Water model assumptions of key drivers did not fully capture the recent trends in groundwater development, thus resulting in significant deviations of irrigated crop area projections. As a result, the irrigation demand of the two projections varies.

BAU Scenario and Regional Water Crisis

The BAU scenario assumed groundwater irrigation to be a key driver of future expansion of the irrigated area. Expanding groundwater irrigation, on the one hand, contributes to increasing gross irrigated area, crop yield and crop production. Uncontrolled pumping, on the other hand, contributes to physical water scarcities and groundwater-depletion-related environmental issues in some basins. Figure 3 shows how the degree of development, the groundwater abstraction ratio and the depletion fraction[1] of the potentially utilizable water resources (PUWR) will change over the period 2000–2050.

Many river basins will be physically water-scarce by 2050. That is, these river basins will not have adequate freshwater resources for meeting the future development without affecting the environment or other water users. The degree of development of 10 river basins, home to 75% of the total population, will be well over 60% by 2050. These water-scarce basins would have developed much of the potentially utilizable water resources by the second quarter of this century. The water reallocation between different sectors in these basins would be a common exercise to meet the increasing demand. Indeed, the BAU scenario projects the transfer of surface irrigation resources to domestic and industrial water uses.

Increased groundwater irrigation would have severe detrimental effects on many basins. Groundwater abstraction ratios of many basins are significantly high. Given the current level of recharge, groundwater use patterns of these basins are not sustainable. Indeed, patterns of the BAU scenario growth could lead to regional water crises.

The depletion ratios show where the water crises are severe. Several basins would deplete more than 60% of the PUWR by 2050, and face

[1]PODIUMSIM water accounting framework, based on Molden 1997, estimates degree of development, groundwater abstraction ratio and depletion fraction. The degree of development is the ratio of primary withdrawals to PUWR. The groundwater abstraction ratio is the ratio of total groundwater withdrawals to total recharge from the rainfall and the return flows. The depletion fraction is the process and non-process evaporation as a fraction of the PUWR, where process evaporation is evapotranspiration from irrigation and transpiration from domestic and industrial sectors, and non-process evaporation is evaporation from the swamps, homesteads, canals and reservoir surfaces.

severe water scarcities under the BAU scenario. The solutions for such problems in these river basins are a) to increase crop productivity for every unit of water used at present, b) to increase potential groundwater supply through artificial recharge methods, c) to concentrate on economic activities where the value of water is very high, or d) to get water transfers from the water-rich basins.

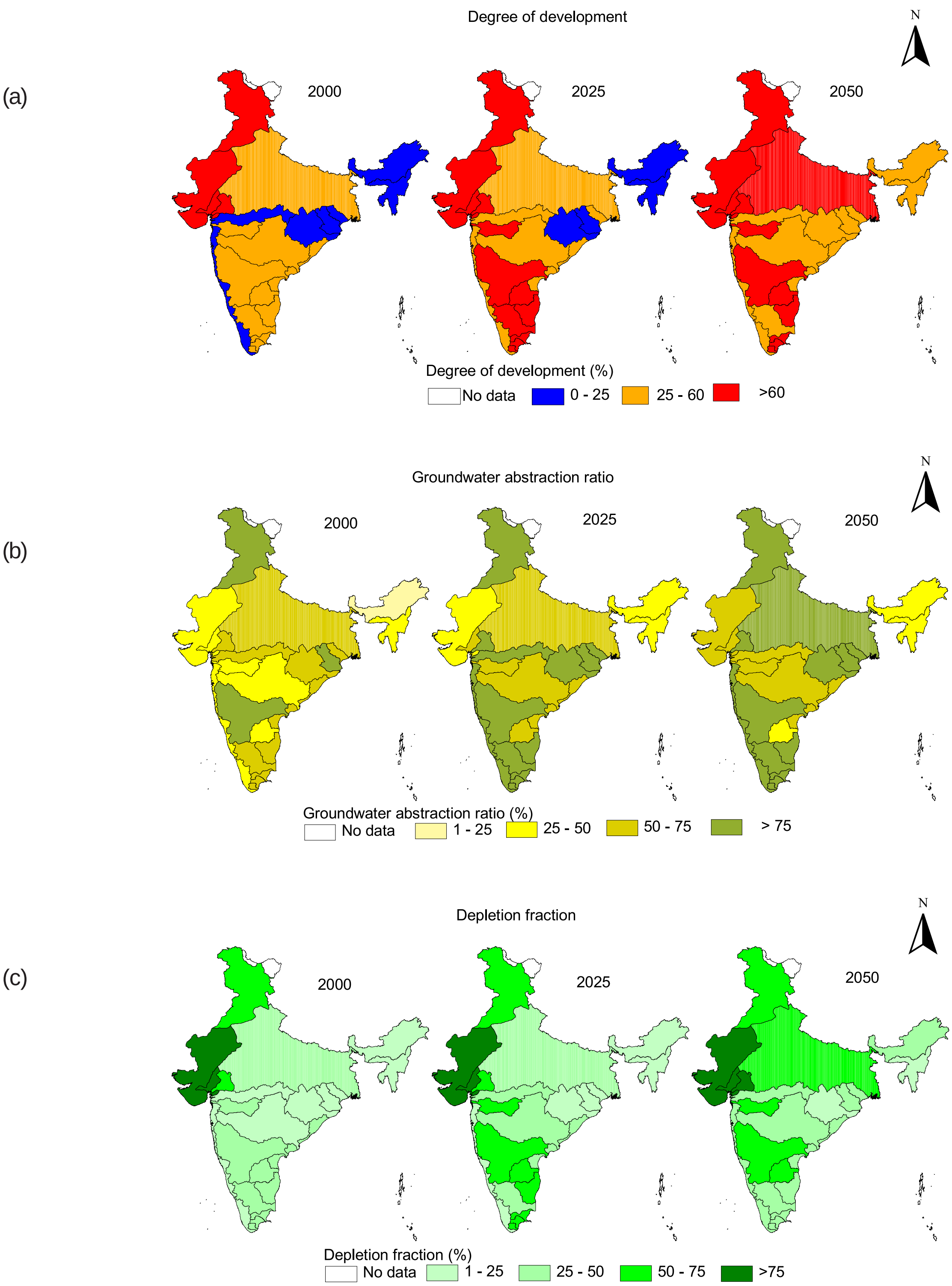

FIGURE 3. (a) Degree of development, (b) groundwater abstraction ratio, and (c) the depletion fraction in 2000, 2025 and 2050.

Water Supply with EWD

The EWD has often received scant attention in most demand projections. The NCIWRD projections have a provision of 10 Bm^3—1% of total demand; Rosegrant et al. (2002) have allocated 6–15% of the mean annual runoff; and other studies (Seckler et al. 1998; IWMI 2000) have highlighted the impacts of environment by setting a threshold for the withdrawal limits. We update the EFR demand of Indian river basins, based on the guidelines of Smakhtin and Anputhas (2006). However, even this analysis, based on annual EFR estimates, has some limitations. Ideally, environmental flow assessments should be conducted on a monthly basis, where maintaining minimum flows is most important for the lean months. But annual values can also illustrate the implications of water availability for human use if the EFR gets first priority. This is especially true for water-scarce peninsular basins.

First, the unutilizable surface water resources of a river basin meet part of the EFR. The remaining part has to be met from the utilizable water resources. For instance, it is estimated that only 22 Bm^3 of the vast renewable surface water resources of the Brahmaputra River Basin are potentially utilizable for human use. The remaining part, 607 Bm^3 of unutilizable water supply, can easily meet the EFR of the Brahmaputra River Basin. On the other hand, the major part of the renewable surface water resources of the Cauvery River Basin is estimated to be potentially utilizable for human use. In Cauvery, only half of the EFR can be met from the unutilizable water resources. So, the full EFR requirement in the Cauvery River Basin cannot be met without tapping the utilizable water resources. Table 8 shows the part of the environmental flow demands of the river basins that cannot be met from the unutilizable water resources.

TABLE 8. The EWD to be met from the potentially utilizable surface flows.

River basin	Potentially utilizable surface water resources[1] (PUSWR) Bm^3	Unutilizable surface water resources[2] Bm^3	Environmental water demand (EWD)[3] Bm^3	EWD to be met from PUSWR[4] Bm^3
Brahmaputra	22	607	287	0
Cauvery	19	2	4	2
Ganga	250	275	152	0
Godavari	76	34	18	0
Krishna	58	20	14	0
Mahanadi	50	17	12	0
Mahi	3	8	1	0
Narmada	35	11	6	0
Pennar	6	0	1	1
Sabarmati	2	2	0.5	0
Subarnarekha	7	6	2	0
Tapi	15	0.4	2	2

[1] PUWR is from CWC 2004.
[2] Unutilizable water resources = TRWR-PUSWR.
[3] EWD is from Annex 5.
[4] max (EWD - Unutilizable water resources, 0).

The estimated unutilizable part of the renewable water resources that, in general, is utilized by the fisheries, ecosystems and navigation, in many basins is higher than the estimated EWD. Only three basins—those of Cauvery, Pennar and Tapi—require to allocate EWD from the PUWR. However, we caution the interpretation of this result here. As mentioned earlier, the EWD estimates of this report are made on an annual basis. However, the flows of Indian rivers, especially those in the peninsular basins, which are dominated by the monsoonal rainfall pattern, vary significantly between months. If the demand is estimated on a monthly basis, the EWD of some basins could be more, and the PUWR will have to meet part of this demand. As a result, if EWD gets priority, then the effective water supply available for other sectors could diminish in many basins.

Other Scenarios: Deviations from BAU

The assumptions of future growth of many of the drivers in this analysis are sensitive to the final water demand projections. Furthermore, in the BAU scenario, we have assessed the long-term outlook up to 2050. However, as was the case in the 1990s, there can be many turning points of these key drivers between now and 2050. These can change the BAU projections. Therefore, in this context, we present a few alternative scenarios to the BAU, where we assess the implications of food and water demand with respect to the deviations from the assumption of key food and water demand drivers in BAU.

Urban Population Growth

India's urbanization scenarios of different projection studies vary widely. The census estimates of 2001 show that most of the previous urban population projections are higher than the census estimates. Based on this trend, Kundu (2006) estimated that the urban population is likely to increase to 45% of the total by 2050. The NCIWRD assumed an increase of 60%, and the UN population projections indicate an increase of 50% in the urban population by 2050 (UN 2004).

Figure 4 shows the sensitivity of the urbanization driver on the food and water demand, where urbanization increases by 45%, 51% (BAU scenario) and 60% of the urban population by 2050. While the food grain demand decreases with increasing urban population, the demand for non-grain crops increases. As a result, the production surplus of grain crops and the production deficits of both non-grain crops and all crops increase. However, the changes of overall production deficits are not significantly high.

To estimate the implications on water demand, we assume that the additional production requirement under higher urbanization scenarios will have to be met only under irrigation conditions. We use the BAU scenario water productivities in 2050, which are 0.17 and 0.60 $/m^3 of irrigation diverted for grain and non-grain crops, respectively, to estimate the additional irrigation demand. For example, decreasing grain demand with increasing urbanization to 60% can save 5.7 Bm^3. But increasing non-gain consumption will require another 9.6 Bm^3. So the net effect is an additional irrigation requirement of 3.9 Bm^3.

Higher urban growth will also have an impact on the domestic-sector water demand. We estimate that the domestic demand will go up from 101 Bm^3 under the BAU scenario to 107 Bm^3, if urban population increases to 60%. So, the overall effect of the higher urban growth scenario is an additional water requirement of 10 Bm^3, which is about 5% of the additional water demand projected under the BAU scenario.

Feed Conversion Factor Growth

Figure 5 shows that the feed conversion factor is an extremely sensitive driver for crop demand projection. As maize is the dominant feed at present, we confine our analysis to grain crops. First, we assume the same level of grain production under the BAU scenario, and then compare it with the demand under different feed grain conversion factors (FCF). The BAU scenario is that FCF=0.4. If the FCF is doubled from the level of the BAU scenarios by 2050, then the grain deficits would increase to 22% of the total demand or to about 108 Mmt.

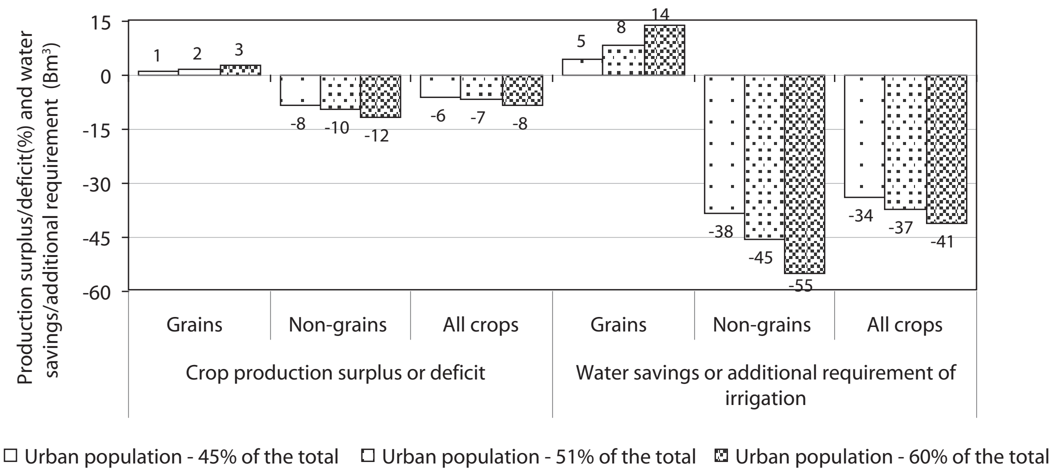

FIGURE 4. Implications on food and water demand under varying levels of urbanization growth. *Source:* Authors'estimates using PODIUMSIM methodology.

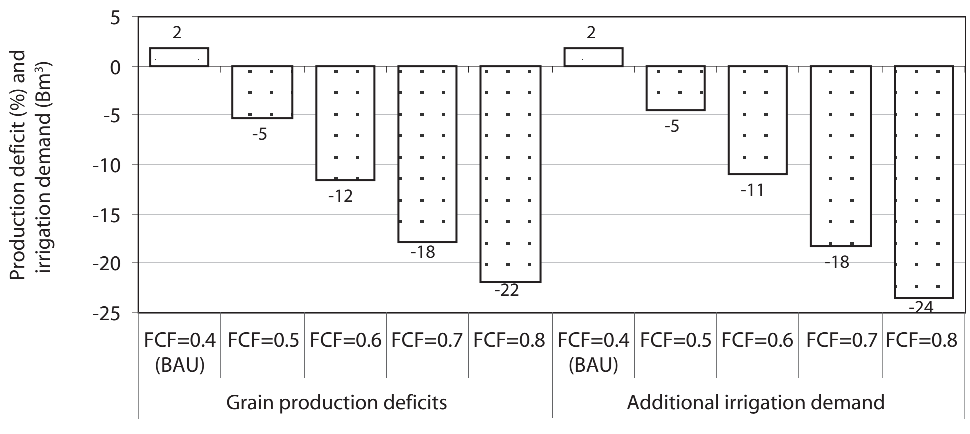

FIGURE 5. Grain production deficits or additional irrigation demand under different feed conversion factors. *Source:* Authors'estimates using PODIUMSIM.

So, could the feed grain conversion factors in India increase beyond the BAU scenario level? First, we note that the feed grain conversion factors vary significantly between countries. And the conversion factors are high in countries where livestock is a commercial industry and stall-feeding is common. For example, in the USA, Australia, Brazil and France, feed grain conversion factors are 1.54, 1.06, 0.75 and 0.81 kg/1,000 kcal, respectively.[2] Countries with more pasturelands, such as the UK and New Zealand, have lower feed grain conversion ratios (0.46 kg/1,000 kcal). In China, the corresponding ratio is 0.34 kg/1,000 kcal. However, with a large livestock population, India's feed grain conversion factor in 2000 was only 0.11 kg/1,000 kcal. The trends of the last decade show that the land under permanent pastures and the area under fodder are decreasing, and this trend is expected to continue with increasing nonagricultural income activities (Pandey 1995). Therefore, it is inevitable that the demand for commercial feed would increase.

How will commercial feeding shape up in India in the coming decades? The answer to this depends, first, on the extent to which India can increase the milk productivity of its cattle, the extent of animal draft in agriculture for labor, and the increase in poultry products in the daily diet. At present, milk is the major calorie provider of animal products. In the future, the contribution of poultry products is expected to increase (Amarasinghe et al. 2007a). In India, production and consumption of meat, especially beef and pork, have been very low for religious reasons. And this trend will most likely continue in the future too. So, as in the past, the greater part of the cattle and buffalo population in India is looked after for milk production.

Among the major milk producers, India has one of the lowest milk productivities, amounting to only one-tenth and one-fifth of milk productivity of the USA and New Zealand, respectively (Hemme et al. 2003). While the cattle stock of the USA was about 74 million, the stock of cattle and buffalos in India counted over 300 million. Indeed, a major part the bovine population in India is non-milking, and some are providing animal draft. Regardless of whether they milk or not, they still need feed, fodder and space for grazing.

The demand for pastureland and fodder and also for commercial feeding will depend very much on the number as well as the shape (hybrid to local) of the cattle population, and how it will increase milk productivity. According to Pandey (1995), while the non-milk cattle population in India has been decreasing, the cross-bred population has been increasing. In spite of these changes, there still exists much scope for improving the milk productivity failing which India would require a large cattle population for meeting its internal milk demand and, in turn, would face a severe shortage of fodder. This feed shortage will have to be met from commercial feeding.

A major part of the additional grain requirement for commercial feeding projected in the BAU scenario is from maize. To estimate the implications on water demand due to the additional feed requirements, we assume that all additional feed requirements with a high feed grain conversion factor will be for maize, and will be produced in irrigated areas. We estimate implications on water demand in the right-hand section of the graph in Figure 5 using the irrigation water productivity of maize in 2050, which is 4.55 kg/m^3. If the feed grain conversion factor increases to 0.8, then the additional maize requirement will increase by 108 Mmt or 22% of the total demand, and water requirement by 23.6 Bm^3 (Figure 5).

Crop Yield Growth

The BAU scenario assumed a rather modest growth in crop yield, but it resulted in only a slight deficit in crop production. Figure 6 shows how this deficit changes with higher yield growth. In the alternative scenarios, we assumed a slightly higher growth of rain-fed and irrigated yields. The BAU scenario projects the average grain yield to increase to 3.2 tons per hectare (tons/ha) by 2050. The three

[2]Feed grain conversion factors of different countries are estimated from the FAOSTAT database (FAO 2005a).

alternative scenarios correspond, respectively, to 3.5, 4.0 and 4.2 tons/ha of average grain yield increase by 2050. We assume a similar increase in the growth rates of the non-grain crop yields. The growth of crop yields in all scenarios, except the last, is lower than those recorded between 1990 and 2000. In the last scenario we assume the growth between 1990 and 2000.

Alternative scenarios suggest that crop production and the production surpluses can be increased considerably with a slightly higher yield growth. Alternatively, with higher yield growth, the requirement for additional irrigated crop area and irrigation water can decrease. According to the BAU scenario, India has an overall deficit of crop production, and hence needs to import 18 Bm^3 of virtual water, i.e., water consumed by crops or crop products. However, scenario 2, with a slightly higher yield growth, which is equivalent to the present growth of crop yields, could record a production surplus, which is equivalent to 64 Bm^3 of consumptive water use. India can either export this production surplus, or save an equivalent amount of water by reducing the additional requirement of irrigated crop area and irrigation. This saving is equivalent to 10% of the total consumptive water use demand, or 15% of the irrigation consumptive water use demand in 2050.

If India can maintain the present growth of crop yield, i.e., scenario 3, the excess of crop production is estimated to be over 45% of the total demand. The equivalent crop consumptive water use in this scenario is 74 Bm^3. This is equal to 23% of the total crop consumptive water use under the BAU scenario, which projects only a 22% increase in consumptive water use over the period 2000–2050. This shows that, by maintaining the present level of yield growth, India may require little or no increase in additional irrigation water withdrawals.

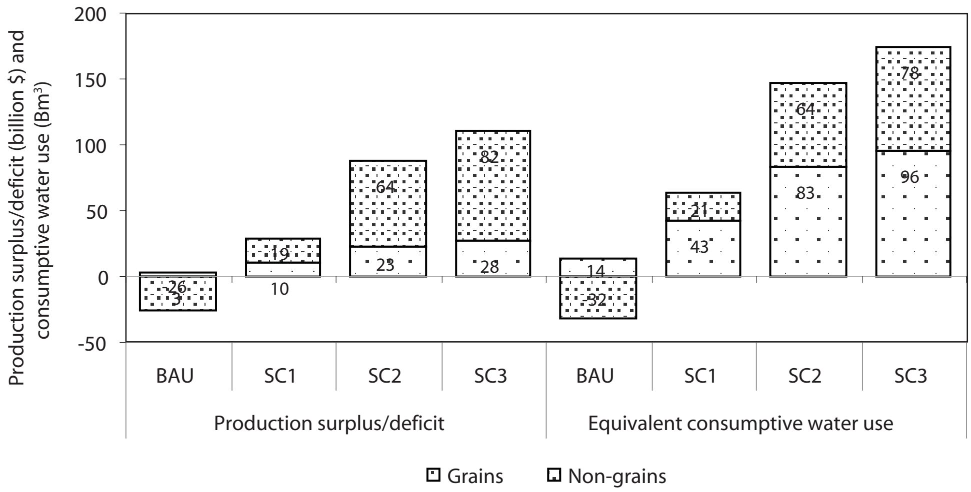

FIGURE 6. Production surplus/deficit and equivalent consumptive water use under different yield growth scenarios. *Source:* Authors'estimates using PODIUMSIM.

Groundwater Area Growth

During the last decade, barring the drop in 1999 due to low rainfall, the net groundwater irrigated area increased linearly, adding more than a million hectares every year. This trend, in spite of little or no growth in canal irrigation, is likely to continue, possibly at a decreasing growth rate. Although the extent of growth is debatable, the contribution of groundwater, if it does increase, on the gross irrigated area (GIA) and on the gross cropped area (GCA) is very significant. Figure 7 shows the likely growth of GIA and GCA under different growth patterns of net groundwater irrigated area (NGWIA). Scenario 2, the BAU scenario in this report, assumes that NGWIA would increase to 50 Mha. Scenario 1 assumes a slightly lower growth, and scenarios 3 and 4 assume a slightly higher growth—55 and 60 Mha, respectively.

The BAU scenario (scenario 2) projects NGWIA to increase to 50 Mha and, as a result, GIA is expected to expand to 116 Mha. At the other extreme, scenario 4 projects the NGWIA to increase to 60 Mha and, as a result, the GIA to increase to 131. The gross groundwater coverage under this scenario could be 86 Mha. Certainly, such growth is significantly higher than the ultimate groundwater potential of 65 Mha projected at present (GOI 1999) or 70–80 Mha projected by Sanghal (1987). So, it is not clear whether scenario 4 projections can be realizable under the present groundwater recharge scenario. However, if high groundwater irrigation scenarios can be realizable with intensive artificial groundwater recharge programs, then their impact on crop productivity and crop production growth will be considerable. Studies show that the productivity under groundwater irrigation is two to three times higher than that under canal irrigation, and a small life-saving irrigation of 3 to 5 centimeters of groundwater would considerably increase the yields over rain-fed yields (Kumar et al. 2006b; Palanisami et al. 2006; Shah et al. 2001). We assess the implications of crop production and irrigation water demand if groundwater is the source for all the additional gross irrigated area of the BAU scenario.

First, we note that surface irrigation covers only 14 Mha of the total increase of 40 Mha of gross irrigated area over the period 2000–2050. We assess the implication of crop production: a) if the 14 Mha are also irrigated from groundwater, and b) if the groundwater irrigated crop yields are 2 to 3 times higher than the surface-water irrigated yields. We estimate that the value of crop production under the above scenario could be as high as $230 or $236 billion, and would increase by another 7 to 10%.

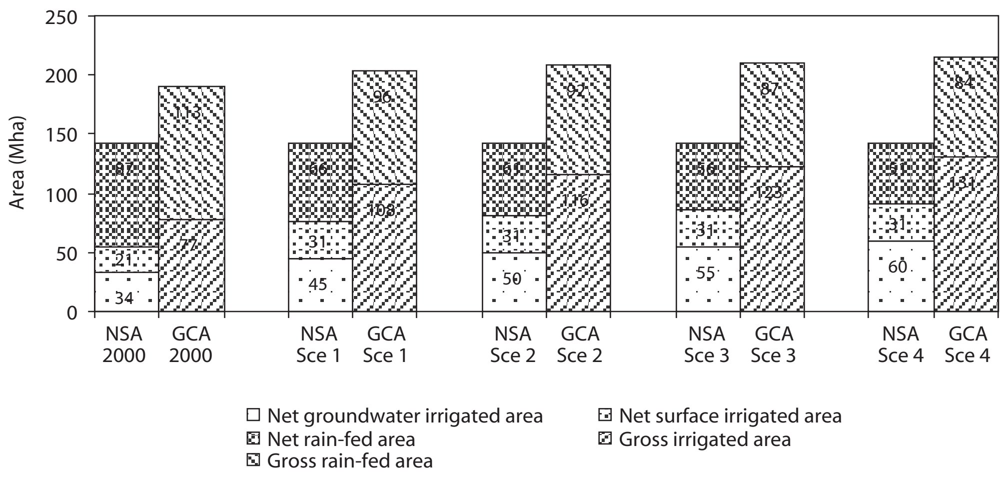

FIGURE 7. Gross crop and gross irrigated areas under different groundwater development scenarios.
Source: Authors'estimates.

Second, we note that depths of water application in surface water and groundwater irrigation in the BAU scenario in 2050 are 0.416 and 0.796 m/ha, respectively. If groundwater irrigates all the additional irrigated area, then the groundwater demand would increase by 58 Bm^3, but the total water demand would decrease by 53 Bm^3 or 7% of the BAU irrigation water demand. This indicates that complete groundwater irrigation of the additional irrigated area, coupled with efficiency increase, would require even a lower demand than the present level of water use.

Yet, we add a word of caution here. Although such a scenario requires less irrigation it leads to an even more unsustainable groundwater use in many regions than projected in the BAU scenario. Unless intensive groundwater recharge programs are in place, a complete groundwater irrigation scenario should be avoided in many parts of river basins. The other solution is to manage the growing demand by increasing the efficiency of groundwater irrigation. If the micro-irrigation technologies, commonly used with groundwater irrigation, spread, then the efficiency of groundwater irrigation could increase and the groundwater withdrawals could further decrease. We assess the sensitivity of irrigation efficiencies on water demand in the next section.

Efficiency of Groundwater Irrigation

The BAU scenario assumed that the efficiency of groundwater irrigation would increase from 65 to 75% over the next 50 years. Figure 8 shows how water demand decreases with increasing groundwater efficiency under different scenarios of efficiency of surface water irrigation.

The first bar shows the water withdrawals in 2000, where the efficiencies of groundwater and surface water irrigation were 65% and 35%, respectively. The first set of alternative scenarios assumes a 50% efficiency of surface water irrigation and the second set a 60% efficiency of higher surface water irrigation. If the groundwater efficiency can be increased by another 10% over the BAU scenario, i.e., to 85%, the total water demand could go down by 6 to 15% depending on the scenarios of the same or higher efficiency of surface water irrigation.

Can India increase its overall groundwater efficiency to 85%? The short answer is, it could, and perhaps for some crops, but it requires a substantial investment in micro-irrigation technologies. Recent studies show that efficiency in many groundwater irrigation systems is as high as 85 to 90% (Kumar et al. 2006a; Palanisami et al. 2006; Narayanamoorthy 2006). And, most of

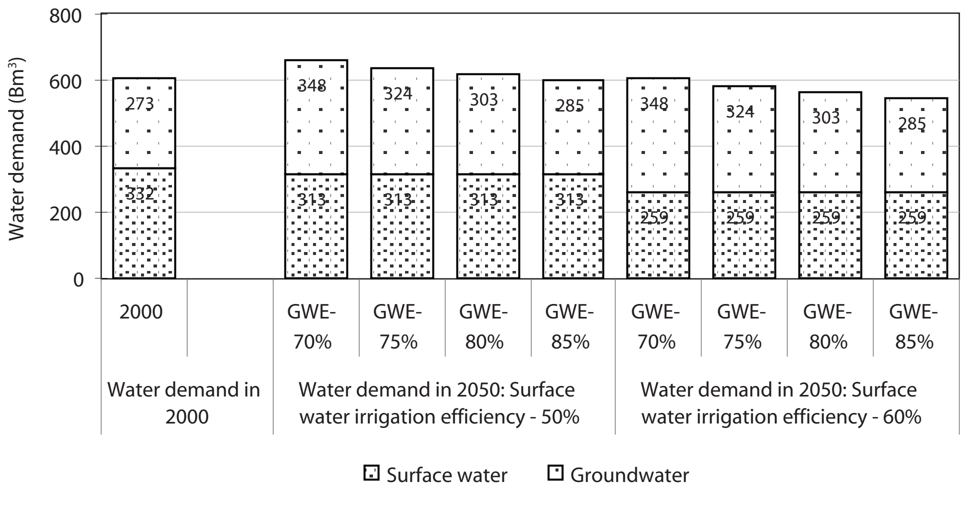

FIGURE 8. Water demand under different surface water and groundwater irrigation efficiency scenarios.
Source: Authors'estimates.

these high-performing systems are using water saving technologies at present.

Can India increase the efficiency of surface water irrigation to 60%? This could also be possible in many surface-water irrigated areas, but it requires significant institutional and physical interventions. A recent study of the cost and benefit assessment of intermediate water storage structures, each called a "*diggi,*" in Rajasthan, shows that they assist in increasing the efficiency of surface water irrigation of canal command areas (Amarasinghe et al. 2007b). Diggis operate in the warabandi system, where water deliveries from the main canals to distributaries, to minors, to watercourse and then to farms take place in rotations. Diggis store water deliveries to a farm in their turn of water supply, and then pump out to irrigate crops through sprinkler micro-irrigation systems. With diggis, farmers irrigate a 30% larger area from the same water resources than they did without diggis. However, to what extent the diggi type interventions work in nonrotational water delivery systems is not known as yet.

Summary and Policy Implications

This report projected India's food and water future to 2025 and 2050 and assessed their sensitivities with respect to key water demand drivers. Trends observed in the last decade were the basis for the assumptions of the key food and water demand drivers, which form the BAU scenario.

On the water demand and supply, the BAU scenario projects:

- the total water demand to increase from 680 in 2000 to 833 Bm^3 by 2025, and to 900 Bm^3 by 2050 (22% and 32%, respectively), and the demand estimates for the 3 years are 66%, 81% and 87%, respectively, of the PUWR;
- the degree of development, the ratio of primary water withdrawals to PUWR, to increase from 37% in 2000 to 52% and 61% by 2025 and 2050, respectively;
- that nine river basins, comprising 75% of the total population, will be physically water-scarce by 2050 (i.e., the degree of development will be greater than 60%);
- the industrial and the domestic sectors to account for 54% and 85% of the additional demand by 2025 and 2050, respectively;
- the groundwater withdrawal to increase from 303 Bm^3 in 2000 to 365 and 423 Bm^3 by 2025 and 2050, respectively, and the groundwater ratio to increase from 60% to 74% and 84%, respectively; and
- that ten river basins, home to 80% of the total population, will see their groundwater tables declining considerably by 2050 (i.e., groundwater abstraction ratio will be greater than 75%).

On the food demand, the BAU scenario projects:

- the non-grain products to provide more than 50% of the nutritional intake by 2050;
- the feed grain demand to increase rapidly, from a mere 8 Mmt in 2000 to 38 and 111 Mmt by 2025 ad 2050, respectively;
- the food grain demand to increase slowly, from 178 Mmt in 2000 to 230 and 241 Mmt in 2025 and 2050, respectively;
- the per capita grain availability to increase from 200 kg in 2000 to 210 and 238 kg/person in 2025 and 2050, respectively; and
- the total grain demand to increase from 201 Mmt in 2000 to 291 and 377 Mmt by 2025 and 2050, respectively.

On the food supply side, the BAU scenario projects:

- overall production surpluses of grain crops, but substantial imports of maize and pulses and exports of rice and wheat. The maize import is primarily for livestock feeding;
- production deficits of non-grains and substantial imports of oil crops (edible oil);
- overall production deficits of all crops to increase from 5% of the total demand in 2000 to 9% by 2050; and
- the gross irrigated area to increase from 76 to 117 Mha during the 2000–2050 period, and the share of groundwater irrigation coverage to increase from 43 to 70 Mha over the same period.

The BAU projection is significantly different from the demand projections of the NCIWRD. The NCIWRD assumes surface irrigation to dominate future irrigation, whereas the BAU projects groundwater to dominate future irrigation. The NCIWRD projections assume the ratio of surface-water irrigated area to groundwater irrigated area in 2050 to be 55:45, whereas the BAU scenario suggests a corresponding ratio of 40:60. With higher irrigation efficiencies in groundwater irrigation the BAU scenario irrigation demand is much lower than the NCIWRD projections.

The projections of the BAU scenario are mainly based on the extrapolations of the trends of the recent years. The projections to 2050 are far ahead, and there is every possibility that the unexpected changes in demand drivers could significantly alter the BAU demand directions. The deviations explored in this report show both optimistic and pessimistic scenarios. Proper policies could offer significant opportunities to lessen the variability of the demand drivers and the negative impacts due to changes in some drivers.

A growth in urban population higher than foreseen in the BAU scenario leads to a very modest impact on irrigation demand. But it can have a substantial impact on domestic water demand and on investments related to meet this increase. If the urban population increases to 60% of the total population by 2050, as against 51% in the BAU scenario, the total irrigation and domestic water demand could increase by another 10 Bm^3, which is only 2% of the total water demand, but close to one-third of the additional water demand. With more people in the urban sector, the pressure for surface water supply will increase.

Rapidly growing feed demand is also a concern. Much depends on how animals are fed, i.e., with irrigated or rain-fed cereals, crop residues or grazing. If the amount of cereals used per kilo of livestock product doubles, irrigation demand could increase by 22 Bm^3. Meeting huge feed deficits consistently via international trade or meeting large unexpected irrigation demands could also be problematic for a country like India. However, there is ample scope for reducing the feed demand by improving the milk productivity. A combination of investments in extension and research, introduction of hybrid high-productive livestock, control of the unproductive cattle population growth, etc., could help reduce the demand for commercial feed.

Crop productivity growth offers the greatest scope for meeting increasing demand for food and feed, while at the same time offering opportunities to increase the income of the rural poor. Alternative scenarios show that if India can maintain the present growth level of crop yields, its irrigation requirement can be reduced by 10% as compared to the BAU scenario assumption. The investments of research and extension, and revising the policies for pro-productivity growth could offer a way out of the present predicament that India is in, in terms of the declining crop yield growth. Past trends show that irrigation was a key input for increasing crop yields. To what extent crop yields can be increased without additional irrigation in India, especially in the water-scarce regions, is subject to debate. Further research is required to identify regions with low and high crop yields, and low and high potential for increasing water use efficiency. Investment in research and extension and other physical interventions should be provided for increasing both yield and water use efficiency in different regions.

Groundwater irrigation expansion is a key driver of agricultural production and water demand growth. Investments in small-scale structures that can enhance groundwater recharge in locations where there are no adverse impacts of downstream users, and abstraction of groundwater in areas where it is abundantly available are necessary policy measures. In fact, this needs to be a high priority area of research and investment in the short to the medium term.

With groundwater as the dominant source of irrigation in the future, micro-irrigation technologies could offer significant opportunities for increasing water use efficiency, and reducing overabstraction. Indeed, the BAU scenario assumes a significant growth in groundwater efficiency. Spreading water saving technologies through investment promotions could be the key here.

A major part of the additional water demand in the industrial and domestic sectors of the BAU scenario would have to be met from surface water supply. By 2050, the BAU scenario estimates an additional water requirement of 117 Bm^3 for the two sectors. This growth is equivalent to 20 Bm^3 every decade over the next 50 years. The BAU scenario projects that a part of this requirement is to be met from the excess surface irrigation supply. But it still requires adding new water supplies, equivalent to or more than the water in the Aswan Dam. Does this mean large-scale water transfers between basins? The answer to this could be 'yes' and the large-scale water transfers could be justifiable on the grounds that the burgeoning industrial sector could demand, and is willing to pay for, a more reliable surface water supply for its production processes. But, the extent of these water transfers depends on the extent to which India can improve its crop water productivity.

By how much can India increase its crop water productivity over the next 50 years? We do not know the answer to this question now, but we know, and conclude this report by discussing, the impact of improving water productivity on the future water needs. Amarasinghe et al. (2007a) showed that a modest increase (1% annually) in water productivity (quantity per consumptive water use) could eliminate the additional consumptive water demand for grains. With a 1.3% annual increase it could eliminate the consumptive water demand of all crops. India's crop water productivity is very low at present and varies widely across regions and over different land use patterns. There is much scope for increasing the water productivity of all grain and other crops. If this can be realized, the water requirement of the other sectors can be met from the existing water resources.

The scenario analysis in this report has not considered the implications of climate change on the water demand drivers. It is claimed that climate change could seriously affect water availability for many regions, especially for the Indo-Gangetic Plain that benefits from the Himalayan glaziers, change the onset and the magnitude of rainfall patterns, and affect agriculture in the coastal areas with saltwater intrusions due to higher sea level, etc. However, to what extent these will affect the key water demand drivers over the first half of this century is not clear as yet. This is another area where investments for research and extension are highly desirable.

Annexes

Annex 1. Data Requirements and PODIUMSIM Components

Table A1 shows the data requirements and the sources of data collected for the analysis in this report.

TABLE A1. Types and sources of data used for the water supply and demand analysis.

Data	Sources	Reference
Urban and rural population	2001 Census records and the projections of Mahmood and Kundu (2006)	GOI 2003; Mahmood and Kundu 2006
Crop consumption (calorie supply, food and feed consumption of different crops)	Nutritional intakes and per capita consumption data of the FAOSTAT database of the FAO and the various rounds of National Sample Survey Organization (NSSO) reports	FAO 2005a; NSSO 1996; 2001
Land use statistics, crop area and crop yield	Crop production data of the FAOSTAT database and the various issues of agricultural statistics at a glance, fertilizer statistics, crop yield estimation surveys of principal crops	FAO 2005a; GOI 2002, 2004; FAI 2003a, 2003b, 2003c, 2003d
Rainfall, potential evapotranspiration and land use map	International Water Management Institute's Climate and Water Atlas	IWMI 2001; 2005
Crop calendar, crop coefficients	AQUASTAT database of the FAO and FAO Irrigation and Drainage Paper No. 56	FAO 2005b; 1998
Basin runoff	Central Water Commission of India	CWC 2004; FAO 2003

PODIUMSIM Components

The four major components of the PODIUMSIM, the policy dialogue model used for simulating scenarios, are briefly presented here. For more details we refer to http://podium.iwmi.org/podium.

Crop Demand

The crop demand module estimates the total demand of 12 crop categories. The total demand includes the demand for food, feed and seeds and other uses. The crops include rice (milled equivalent), wheat, maize, other coarse cereals, pulses, oil crops (including vegetable oils), roots and tubers, vegetables, fruits, sugar and cotton. We refer to Amarasinghe et al. 2007a for details of the crop demand estimation component.

Crop Production

The crop production module estimates the crop production of the 12 crop categories at the subnational level. The unit of analysis can be a river basin or an administrative unit. First, the model determined the net and gross sown and irrigated area of each unit. Next, the cropping patterns of the 12 crop categories and the crop yield growth are specified. Besides the 12 crops in the crop demand module, the specified cropping patterns include fodder and other irrigated crops. The model estimates the crop production for the 12 crop categories and the value of production for grain and non-grain crops. The value of production is based on the average export prices of the base year of the model (in this report the average of 1999, 2000 and 2001 export prices). We refer to Amarasinghe et al. 2005 for more details of the crop production estimation component.

Irrigation Water Demand

The PODIUMSIM model estimates the monthly irrigation water requirements during cropping periods for different seasons. First, the model specifies the months of the crop-growth periods using the starting date (month and day) of the season and the length of the growth periods. Next, it estimates the crop water requirement for each growth period using effective rainfall, potential evapotranspiration (ETp) and crop coefficients. Seasonal irrigation water demand is estimated using the estimates of the crop water requirements, the extent of groundwater irrigated area in the basins, and the project irrigation efficiencies of surface water and groundwater irrigation (see Amarasinghe et al. 2005 for details).

Domestic and Industrial Water Demand

The domestic water demand includes the human and livestock water demand. The human water demand is based on the norms of 150 liters per capita per day (lpcd) in the rural areas and 200 lpcd in the urban areas. The livestock water demand is based on the cattle and buffalo population and the norm of 25 liters per day per head of water demand. The growth of industrial water requirement is taken as the driver of estimating the industrial water demand.

Environmental Water Demand

The EWD component estimates the part of minimum flow requirement (MFR) of a river that has to be met from the potentially utilizable water resources. First, we observe that all or part of the minimum flow requirement in each month can be met from the unutilizable part of the total renewable surface water resources (RSWR) or mean runoff. From this we estimate the minimum flow requirement that cannot be met from unutilizable RSWR. Ideally, this portion of the MFR cannot be available for other users in the basin. But in most river basins, this cannot be met due to the increasing pressure from other sectors. Therefore, the model keeps this portion of the potentially utilizable water resources (PUWR) as a driver for determining the future environmental flow requirement scenarios.

Accounting of Utilizable Water Resources

The PODIUMSIM model estimates water accounts of the potentially utilizable water resources of a river basin (Figure A1). At any given time, only a part of the potentially utilizable water resources is developed and is used by the different sectors.

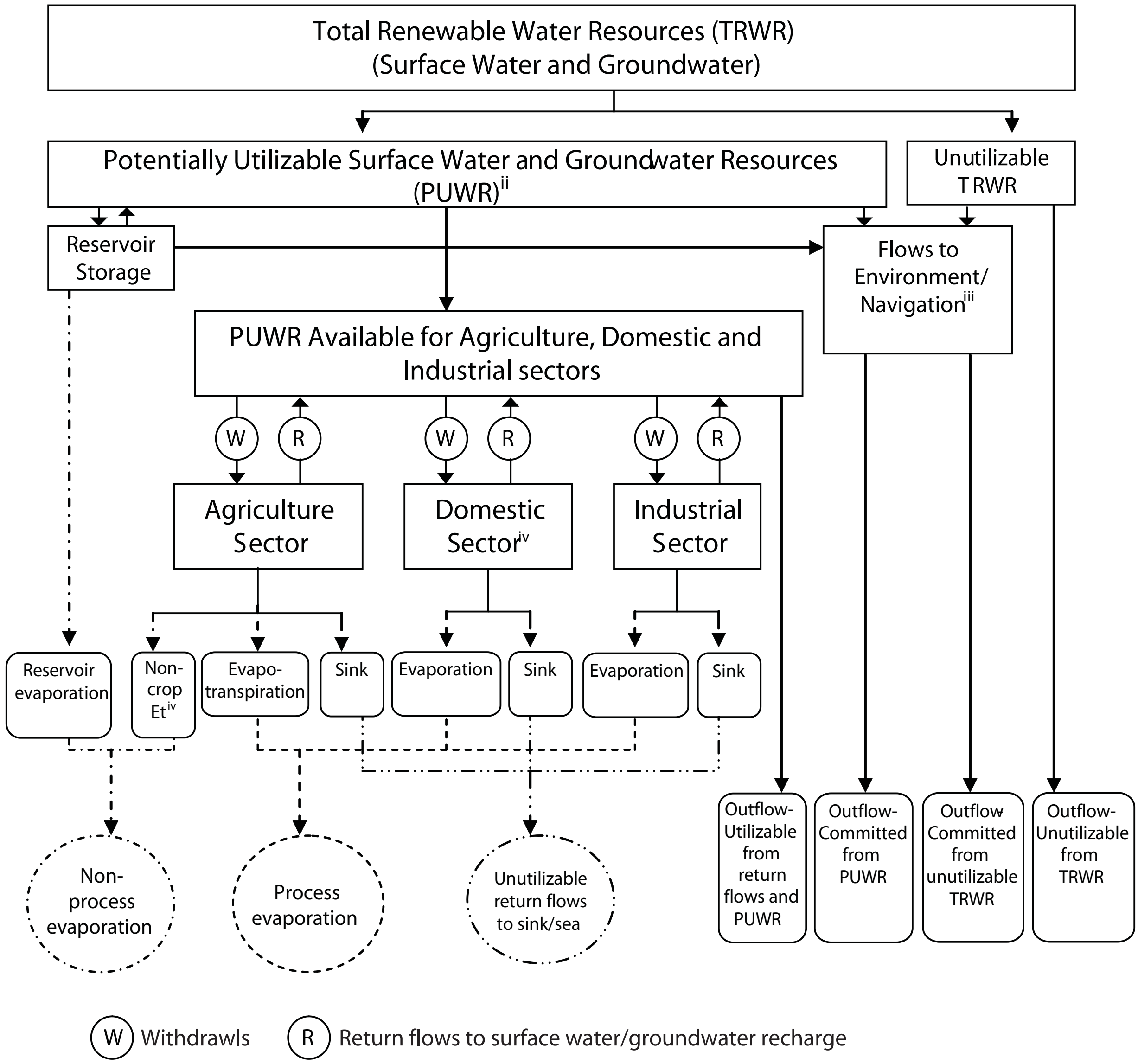

FIGURE A1. Flow diagram of water accounting.

Of the water diversions to the agricultural, domestic and industrial sectors, the model estimates:

- process evaporation (evapotranspiration in the irrigation and consumptive use in the domestic and industrial sectors);
- balance flows, i.e., the difference between the withdrawals and the process evaporation;
- return flows to surface water supply and recharge to groundwater supply;
- non-process evaporation, i.e., flows to swamps in irrigation;
- unutilizable flows to the sea or a sink; and
- utilizable flows to the sea from the surface return flows and groundwater recharge.

The three indicators of the extent of water development in the basin, the degree of development, the depletion fraction and the groundwater abstraction ratio, are given by

$$\textit{Degree of development} = \frac{\textit{Primary water supply}}{\textit{PUWR - Environmental flows from PUWR}}$$

$$\textit{Depletion fraction} = \frac{\textit{Total depletion}}{\textit{Primary water supply}}$$

$$\textit{Groundwater abstraction ratio} = \frac{\textit{Total groundwater withdrawals}}{\textit{Total available groundwater supply}}$$

where, the primary water supply is defined as

$$\begin{aligned}\textit{Primary water supply} = {} & \textit{Process evaporation + non-process evaporation +} \\ & \textit{unutilizable flows to the sea + utilizable return flows to the sea}\end{aligned}$$

and the total depletion of the primary water supply is

$$\begin{aligned}\textit{Total depletion} = {} & \textit{Process evaporation + non-process evaporation +} \\ & \textit{unutilizable flows to the sea}\end{aligned}$$

Annex 2. Economic Growth, National Food Security and Crop Diversification

Some water-rich countries like Japan, Brazil and South Korea import a substantial part of their food demand and hence trade virtual water—the water embedded in food imports or exports (Allan 1998; de Fraiture et al. 2004; Kumar and Singh 2005). The upper-, middle- or high-income countries can continue to follow this trend as they have vibrant industrial and service sectors to pay for their food imports. Theoretically, virtual water trade helps water-scarce countries. These countries can divert water to higher-value crops or other uses, and pay for the import of water-intensive food crops. In contrast, India, even with severe regional water scarcities, has maintained national food security for the last two decades. The domestic agricultural support policies, which were designed to favor the large agriculturally dependent rural masses, had helped India to maintain national self-sufficiency in the past. However, the emphasis on self-sufficiency for all crops is changing.

The post-World Trade Organization (WTO) negotiations saw a considerable increase in India's food trade. The new WTO agreements of agriculture require the member countries to relax the protectionist domestic policies, reduce export subsidies and increase market access. As a result of increased market access, imports of pulses and edible oil have increased considerably. Between 1991 and 2001, the net import of pulses and edible oil increased by 52% and 1,460%, respectively (Table A2). Despite these large import increases, the net export of grains and non-grain crops or crop products has also shown a considerable increase. The net export of grains, mainly rice and wheat, in 2001, accounted for 24% of the net agricultural imports vis-à-vis no contribution in 1991. The value of the net export of non-grain crop products also increased over this period. The emerging picture is that self-sufficiency of each crop is not a goal anymore. The exports of high-value crops are paying for the import needs of other crops. And, according to many researchers, Indian farmers will gain by increasing this food trade.

TABLE A2. Net export of agricultural commodities in 1991 and 2001.

Commodity	Net exports 1991		Net exports 2001	
	Quantity (1,000 mt)	Value[1] (million $)	Quantity (1,000 mt)	Value[1] (million $)
Rice (Basmati)	373	129	742	449
Rice (other)	163	23	2,145	432
Wheat	-224	-42	1,921	202
Pulses	-496	-79	-755	-205
Other cereals	-124	-27	-5	-5
Total grains	-308	4	4,047	873
Edible oil	-271	-55	-4,232	-1,518
Total non-grains		1,280		2,729
Total agriculture		1,284		3,602

[1]Values in 2001 dollars ($1.00= INRs 45.00).

Source: GOI 2004.

India has great potential for increasing the production of high-value crops. In fact, crop diversification is already picking up to realize this potential (Joshi et al. 2006). During the last decade, the GCA and irrigated area increased from 183 and 62 Mha, respectively, in 1990, to about 189 and 76 Mha in 2000. But the share of grain crops, both the total and irrigated, has been decreasing in the last two decades (Figure A2). This trend is expected to continue, not only to take advantage of the increasing food trade with other countries but also to meet the increasing internal demand due to changing consumption patterns. With the recent trends, the BAU scenario projects the share of the irrigated and total grain area to decrease from the present 65% and 71%, respectively, to about 54% and 57%, respectively, by 2050.

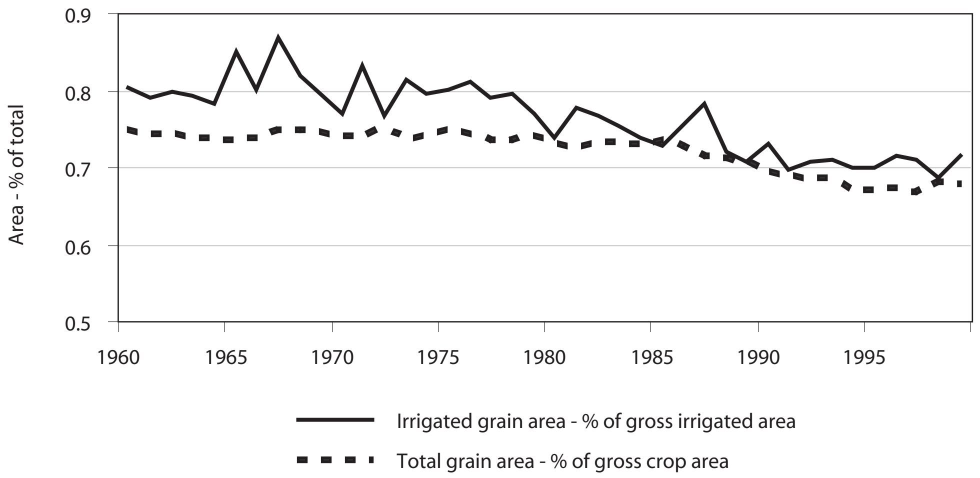

FIGURE A2. Total and irrigated grain area as a percent of gross cropped and irrigated area. *Source:* GOI 2004.

Annex 3. Crop Area and Yield Growth

Crop Area Growth

Much of the growth of India's cropped area in recent years has been due to irrigation expansion. The net sown area has stagnated at around 141–142 Mha in the last two decades. But the GCA, 171 Mha in 1980, has increased by 11 Mha in the 1980s, and by another 6 Mha in the 1990s. Over the same periods, the gross irrigated area has increased by 13 and 14 Mha, respectively. Clearly, irrigation expansion has contributed to almost all the increase in crop area in the last two decades. However, in light of the decreasing growth of the surface-water irrigated area, many have expressed concern on the sustainability of the growth of the gross irrigated area. So, given the current trends of irrigated area expansion, how far will the crop area expand?

Groundwater has contributed to the growth of virtually all the net irrigated area (NIA) in recent years. Expanded rapidly in the last few decades, the growth of groundwater irrigation has three distinct phases (Figure A3). The growth in the pre-green-revolution period was low. But, with the increased return flows of surface irrigation, net groundwater irrigated area (NGWIA) grew rapidly during the green-revolution period. The growth has picked up in the post-green-revolution period, and the NGWIA surpassed the net surface irrigated area (NSIA) in the mid-1980s. Today, it is virtually the only source of growth of the NIA, which has increased from 25 Mha in 1961 to about 55 Mha by 2000.

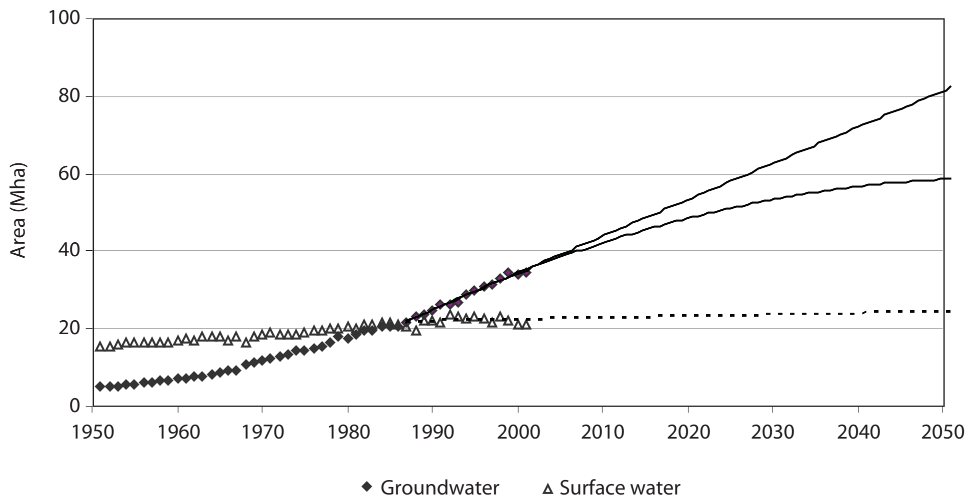

FIGURE A3. Net growth of surface water and groundwater irrigated area. *Source:* GOI 2004.

The NSIA has recorded no appreciable growth since 1985. However, the NGWIA has continued to expand, and the 14 Mha of additional NGWIA have contributed to virtually all the NIA growth in the 1990s. A popular belief is that the expansion of groundwater irrigation was only possible due to the recharge from the surface-water irrigation return flows. But, Bhaduri et al. (2006) have shown that surface-water irrigation recharge was not a necessary condition for the boom in groundwater irrigation in the last decade or so. Indeed, we have seen in subsection *BAU Scenario and Regional Water Crisis* (p.13) that, as a result of this boom in groundwater area, substantial overabstraction issues had surfaced in some river basins. However, in spite of these issues in some basins, the overall trend of groundwater irrigation expansion will continue, perhaps at a reduced growth rate.

If increased at the present linear growth rate, the NGWIA could reach at least 80 Mha, and at a slightly reduced quadratic rate it could increase to 60 Mha. And this means, gross groundwater irrigated area could increase at least to 80 or 110 Mha, depending on the quadratic or linear growth rate of the NGWIA. However, these estimates are well above the estimated groundwater potential of 64 Mha (GOI 1999). Therefore, we take a rather conservative view of groundwater expansion under the BAU scenario. We assume that the NGWIA would increase to about 43 Mha by 2025 and to about 50 Mha by 2050. And most of this increase will be at the expense of existing rain-fed lands. In addition, we assume that the ongoing major and medium irrigation projects will add another 10 Mha to the net surface irrigated area. How will this growth in NGWIA and NSIA influence the growth of gross irrigated and gross cropped areas?

We use the district-level data of 2000 to assess the contribution of surface water and groundwater irrigation to the variation of GIA and GCA. Our explanatory variables are net groundwater irrigated area (NGWIA), net surface irrigated area (NSIA), net tank irrigated area (NTIA) and net rain-fed area (NRFA). We also take moisture availability index (MAI) as an indicator of soil-moisture availability. The MAI is the ratio of 75% dependability rainfall and the potential evapotranspiration (Hargreaves and Samani 1986). The regression estimates are given in Table A3.1.

TABLE A3.1. Coefficients of gross cropped and gross irrigated area regression models.

Independent variables	GIA	GCA
	(n=421)[a]	(n=421)[a]
Net groundwater irrigated area	1.47[b] (0.02)	1.76[b] (0.06)
Net surface-water irrigated area	1.39[b] (0.01)	1.75[b] (0.05)
Net tank irrigated area	0.58[b] (0.13)	0.39 (0.19)
Net rain-fed area	-0.05[b] (0.01)	1.08[b] (0.02)
MAI	-	-0.09[b] (0.02)
MAI*MAI	-	0.03[b] (0.01)
Constant	0.01 (0.01)	0.02 (0.01)
R^2	92%	96%

[a] Number of districts in the regression analysis.

[b] Statistically significant at 0.05 level.

Using the elasticities of the explanatory variables we project that the GIA and GSA would increase to 102 and 203 Mha, respectively, by 2025, and to 117 and 208 Mha by 2050. The irrigation coverage will increase to 50% of the GCA by 2025, and 56% by 2050.

Crop Yield Growth

The abysmally low crop yields have been a bane to India's agricultural growth in the past. Grain crops always had a preeminent position in the Indian agriculture and, as a result, India is one of the three largest grain producers in the world today. However, in spite of India's prominent place in the world's grain production, the grain yield is one of the lowest among the largest producers. The grain yield was 0.7 tons/ha in 1961, and increased to only 1.7 tons/ha by 2000. Over the same period, one of the two other largest producers, the USA, has increased its grain yield by almost 4 tons/ha, from 2.5 tons/ha in 1961; and the other, China, with a similar level of grain yields in 1961 as in India, has increased its present yields to 4 tons/ha. In fact, China's grain yield is more than two and a half times the increase attained by India over the last four decades. Can India, in 50 years from now, increase the grain yield at least to a level where China is now? If so, India will have more than enough grains for all domestic requirements by 2050.

To reach the yield level of China in 50 years, India needs to increase its grain yield by 1.8% annually. But the past trends show that yield growth rates of most of the crops are decreasing (Table A3.2). The grain yield increased by 3.4% annually in the 1980s and the growth dropped to 2.1% annually in the 1990s. A similar reduction of yield growth can be seen in all crop types. If the present decreasing trends continue, India's grain yield will reach about 2.4 tons/ha by 2025 and by about 3.1 tons/ha by 2050. That is, the average grain yield is expected to increase by 1.5% annually between 2000 and 2025, and by 1.0% annually between 2025 and 2050. We assume this growth of grain yield for the BAU scenario. What does this growth reduction mean to yield growths of different crops? Indeed, this depends on the growth rates of irrigated and rain-fed yields. But the time series of the irrigated and rain-fed yields of different crops are not available for an assessment of the past trends. Therefore, to estimate the growth of irrigated and rain-fed yields we made two assumptions. First, we assumed that the grain yield increased 3.4% annually in the 1980s but that it increased only 2.1% in the 1990s. We also assumed that the ratio of rain-fed yield to irrigated yield will remain the same over the corresponding period.

TABLE A3.2. Crop area and yield growth.

	Unit	Grains	Rice (milled)	Wheat	Maize	Other cereals	Pulses
Crop area							
2000	Mha	123.1[a]	44.8	26.9	6.5	23.2	21.6
2025	Mha	122.0[a]	45.0	26.0	10.0	19.0	22.0
2050	Mha	120.0[a]	46.0	27.0	17.0	10.0	20.0
Crop irrigated area as a % of total crop area							
2000	%	44[b]	54	86	22	6	13
2025	%	49[b]	56	96	41	13	13
2050	%	52[b]	56	97	30	27	14
Average crop yield growth							
1980-1990	%	3.4	3.5	3.7	3.2	1.8	2.1
1990-2000	%	2.1	1.3	2.0	2.2	1.4	1.4
2000-2025	%	1.4	1.1	1.7	1.8	1.1	1.2
2025-2050	%	1.1	0.9	1.3	1.5	0.17	1.0
Average crop yield							
2000	tons/ha	1.67	1.98	2.76	1.83	0.82	0.60
2025	tons/ha	2.40	2.61	4.16	2.87	1.09	0.81
2050	tons/ha	3.20	3.10	5.36	3.81	1.30	0.97
Rain-fed yield as a % of irrigated yield							
2000	%	0.37	0.53	0.34	0.58	0.60	0.72
Irrigated crop yield							
2000	tons/ha	2.60	2.54	3.00	2.72	1.29	0.79
2025	tons/ha	3.55	3.31	4.26	3.56	1.68	1.06
2050	tons/ha	4.43	3.91	5.45	4.90	1.84	1.27
Rain-fed crop yield							
2000	tons/ha	0.96	1.33	1.03	1.58	0.78	0.57
2025	tons/ha	1.29	1.74	1.46	2.08	1.01	0.77
2050	tons/ha	1.80	2.05	1.87	2.85	1.11	0.92

Sources: 1990, 2000 data are from GOI 2004, FAO 2005a. Projections for 2025 and 2050 are authors' estimates.

[a] Grain crop area is 65%, 58% and 57% of the gross crop area of the respective years.

[b] Irrigated grain crop area is 43%, 49% and 52% of the gross irrigated area of the respective years.

Annex 4. Domestic and Industrial Demand

Rapid economic growth and urbanization are strong determinants of increasing domestic and industrial water demand (Figure A4). We use a Cobb-Douglas regression function to assess how economic growth and urbanization influence the per capita water demand increase. The coefficient of Cobb-Douglas equation (column 2 in Table A4) shows that urbanization contributes to most of the difference in the increase in the domestic water demand. A 1% increase in gross domestic product per person would have a 0.17% increase in the domestic water demand per person. A similar increase in urbanization would result in a 0.68% increase in per capita domestic water demand. With a 5.5% annual growth of the per capita GDP, and with more than half the population living in urban areas, India’s per capita domestic and industrial water demand per person could more than double by 2050 (Table A4).

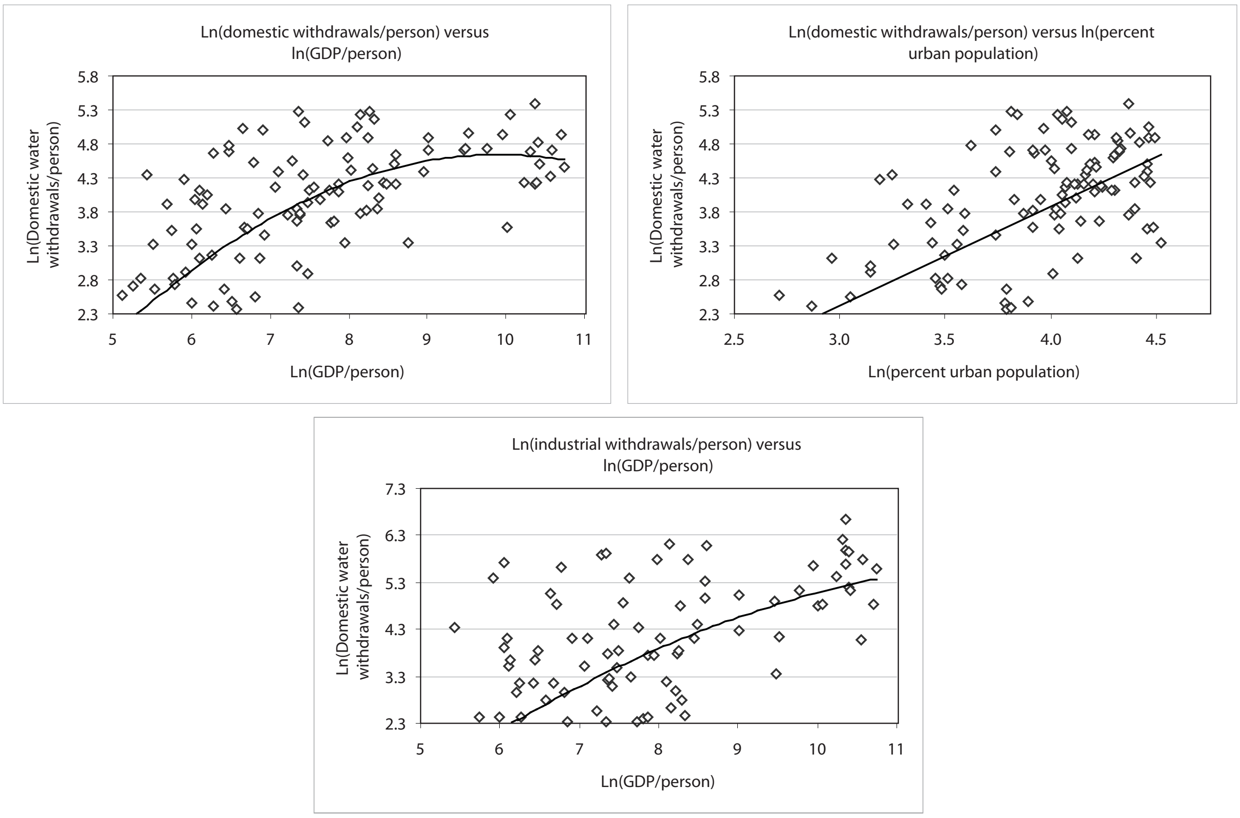

FIGURE A4. Ln (domestic water withdrawals/person) and ln (industrial water withdrawals/person) versus ln (GDP/person) and ln (percent urban population) of different countries in 2000. *Source:* WRI 2005.

TABLE A4. Coefficient of the regression equation for and the natural log transformation of per capita domestic and industrial water withdrawals.

Variable	Ln (dom) model (n=110)[a]	Ln (ind) model (n=84)[b]	GDP, Urban population and domestic and industrial demand projection for India		
			2000	2025	2050
GDP per person	0.17 (0.06)[c]	0.38 (0.81)[c]	$463	$1,765	$6,730
Urban population - % of total	0.68 (0.21)[c]	-	28%	38%	53%
Constant	0.04 (0.66)	1.14 (0.66)			
R^2	0.34	0.20			
	Domestic withdrawals/person/ year (m^3)		31	46	62
	Industrial withdrawals/person/ year (m^3)		42	66	102

[a] Sample includes countries with per capita water supply above 10 m^3/person/year.

[b] Sample includes countries with per capita water supply between 10 and 800 m^3/person/year.

[c] Statistically significant at 0.05 level.

Annex 5. Environmental Water Demand

The per capita domestic water demand in India is likely to increase from the estimated 85 lpcd or 31 m^3/person/year in 2000 to about 125 and 170 lpcd or 46 and 62 m^3/person/year by 2025 and 2050, respectively. This increase includes a substantial water supply coverage increase for both urban and rural areas. The water supply coverage in urban India in 2000 was 69% of the total number of households, and has increased 2.0 and 3.6% annually during the last two decades (GOI 2004). And it is most likely that most of the urban population will be covered with drinking water supply by 2050. Under the norms suggested by the NCIWRD, 150 and 220 lpcd for the rural and the urban areas, the rural water supply coverage could also increase to about 76% by 2050. In 2001, the rural water supply coverage was only 23%.

Under the BAU scenario, the total industrial water demand[3] is likely to increase from 42 m^3 per person in 2000 to 66 and 102 m^3 per person by 2025 and 2050, respectively.

This report uses the guidelines of Smakhtin and Anputhas (2006) for estimating the EWD. According to them, the EFR estimates depend on the natural hydrological variability of flow, and the environmental class that the river ought to maintain. They defined six EMCs ranging from a river that is in natural condition (class A) to slightly, moderately, largely, seriously and critically modified (classes B to F). The classes D to F describe the development states of the river basins with a largely intact biodiversity and habitat to a level where the basic ecosystem functions are destroyed so that the changes to the river ecosystem are irreversible. Table A5 shows the EWD under different classes for the 12 river basins. These river basins account for 78% of India's total renewable water resources (TRWR).

The total environmental requirements of the 12 basins vary from 70% of the annual runoff in class A to 13% of the runoff in class F. Class A water demand of the 12 rivers is even more than the present estimate of the total unutilizable water resources. Given the present development scenarios, no river could be maintained at such a pristine condition, and meeting this level of EWD is all but impracticable. The total requirement to maintain rivers at class B is 731 Bm^3. Although this level of demand is within the total unutilizable water resources of the basins, a few individual rivers still require a substantial part of the utilizable water resources to meet the environmental demand. This report uses the EMC C for assessing the sensitivity of meeting the EWD on the utilizable water supply for other sectors.

[3]Industrial water demand, which includes industries and cooling demand for power generation, in 1997/1998 was 39 Bm^3, or 42 m^3/person. In the absence of recent data, we use this level of per capita water use for projecting future industrial demand.

TABLE A5. Environmental water demand of Indian river basins.

River basin	Natural MAR[a] (Bm^3)	EWD – % of MAR					
		A	B	C	D	E	F
Brahmaputra	629.1	78	60	46	35	27	21
Cauvery	21.4	62	36	20	11	6	3
Ganga	525.0	68	44	29	20	15	12
Godavari	110.5	59	32	16	7	4	2
Krishna	78.1	63	36	18	8	4	2
Mahanadi	66.9	61	35	19	10	6	4
Mahi	11.0	42	17	7	2	1	0
Narmada	45.6	56	29	14	7	4	3
Pennar	6.3	53	28	14	7	4	2
Sabarmati	3.8	50	24	12	7	3	2
Subarnarekha	12.4	55	30	15	7	3	2
Tapi	14.9	53	30	17	9	5	3
Total environmental water demand (Bm^3)		1,065	731	501	353	260	202
Total - % TRWR		70	48	33	23	17	13

[a] Mean annual runoff in Bm^3.

Glossary

Total Renewable Water Resources (TRWR): Internally renewable water resources plus the flows generated externally

Potentially Utilizable Water Resources (PUWR): The part of the TRWR that can be captured and used with available physical and economic means

Primary Water Supply: Water withdrawn for the first time from PUWR

Process Evaporation: Evaporation and transpiration from the intended purposes

Non-process Evaporation: Evaporation and transpiration from the unintended processes

Degree of Development: Ratio of primary water supply to PUWR

Depletion Fraction: Ratio of sum of the process and non-process evaporation to primary water supply

Groundwater Abstraction Ratio: Ratio of total groundwater withdrawals to groundwater availability through recharge from rainfall and return flows

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