India's Water Supply and Demand from 2025-2050: Business- as- Usual Scenario and Issues

[1]*Upali A. Amarasinghe*, [1]*Tushaar Shah* and [2]*B.K.Anand*
[1]*International Water Management Institute, New Delhi, India*
[2]*Consultant, Bangalore, India*

Introduction

For many reasons, India and China have had a central place in global food and water supply and demand projections. First, constituting more than one-third of the world's population, they are the two most populous countries in the world. And, by the middle of this century they need to feed 700 million more people. Second, both countries have huge economies. Their economic growth in the recent decades—since the 1970s in China and since the 1980s in India—has been remarkable. With booming economies, people's expenditure patterns are changing and 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 future food and water demands. Third, and perhaps the most critical, is that both countries have significant spatial mismatches between their populations and their water resources; less water is available in places where more people live and much of the food is grown. Thus, the manner in which India and China meet their increasing food and water demands have been the major focus of many recent food and water demand projections both at the global scale (IWMI 2000; Rijsberman 2000; Rosegrant et al. 2002; Seckler et al.1998) and at the national scale (Bhalla and Hazelle 1999; Dyson and Hanchate 2000; GOI 1999).

On account of the rapid economic and demographic changes, the food and water demand projections of India and China need regular updating. For the base year, many recent projection studies used information relevant to the late 1980s and up to the early 1990s. One such study is the 1998 water demand projections of the National Commission of Integrated Water Resources Development (NCIWRD)—(GOI 1999), which considered a blueprint for water resources management and planning in India. For the base year, the NCIWRD projections used data relevant to 1993-1994, while future projections were derived from trends relevant to the 1980s. However, many changes over the past decade, which were unforeseen at the time of the study, have affected the demand projections. In particular, for example, changes due to the economic liberalization of the early 1990s in India are only visible now. Today, India has an unprecedented economic growth (there has been an annual economic growth of 8 % to 9 % in the last few years). This kind of growth has rapidly changed, certain food and water demand drivers that are endogenous to India, such as food consumption and land use patterns, and that are exogenous to India, such as world food trade. Therefore, in this context, many of the past food and water demand projections need to be reassessed. This paper revisits India's water future assessment from 2025 - 2050. It incorporates the recent changes in food- and water-related drivers in the supply and demand assessment and also analyzes the sensitivity of future projections to changes in these demand drivers. This paper uses the PODIUMSIM model for projecting India's water future. The PODIUMSIM (the Policy Dialogue Model) methodology is a tool for simulating alternative scenarios of water future with respect to variations in the food and water demand drivers (see Annex 1 for more details). This analysis has the benefit of using the latest data on demography, by using the 2001 census (GOI 2003); on food consumption patterns from the latest consumption and expenditure surveys (GOI 2001); and on land use and production patterns from recent agriculture surveys (GOI 2004a 2004b). The major objectives of this paper are to:

- assess the current status of food and water supply and demand in Indian river basins;
- project the water future of India and assess the implications of the water demand projections on river basins; and
- assess the sensitivity of food and water demand projections to changes in the key demand drivers.

The rest of the paper is organized into four sections. The next (second) section presents the methodology and descriptions of the data used for simulating water demand in this paper. The third section describes the current situation of food and water accounting in India and her river basins. The fourth section relates the projected water future of India during the period 2025 to 2050. The BAU scenario, which describes the business-as-usual scenario water future, is mainly based on the recent trends of the food and water demand drivers. The final projection of water future is very sensitive to many of these drivers. Therefore, in the fifth section, we assess the sensitivity of the water future projections with respect to changes in the demand drivers. We conclude the paper with a discussion of policy implications.

Data and Methodology

Methodology

The PODIUMSIM simulates the water future scenarios of this paper. The model explores the technical, social and economic aspects of alternative scenarios of future water demand and supply at the sub-national level (see Annex 1 for details of the model). The sub-national units could either be the administrative boundaries such as states or hydro-ecological regions, or the hydrological boundaries such as river basins. The river basins are the units of assessment for this paper.

The PODIUMSIM model has four major components: crop demand, crop production, water demand, and water accounting. The four components are assessed at various temporal and spatial scales (Table 1).

Table 1. Spatial and temporal scale improvements 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 12 crops or crop categories. They include grain crops: rice (milled equivalent), wheat, maize, other cereals, and pulses; and non-grain crops: oil crops (including vegetable oils as an 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, the per capita consumption of different crop categories, and the feed conversion ratio (which indicate the quantity of feed used for producing 1,000 kcal of calorie supply).

The crop production component assesses the irrigation and rain-fed crop outputs of the 12 crop categories. The crop area and the yields under irrigated and rain-fed conditions are the main drivers of this component. The production component shows, first, the production surplus or deficit in the river basins, and then the aggregate at the national level. The production surplus or deficit at the national level shows the available quantity for export, stocks or import requirements.

The water demand component assesses the river basin water requirements for irrigation, and domestic, livestock, industrial and environmental sectors. The crop water requirement is first estimated at the district level for the 12 crop categories and the other irrigated crops, which mainly include fodder. The district estimates are then aggregated to estimate 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 rainfall. The crop water requirements in the surface water and groundwater irrigated areas divided by the respective project irrigation efficiencies indicate the irrigation demand. The population and per capita domestic water demand drivers can provide an estimate as to the domestic water demand change, while the total livestock population and average per head water requirement can indicate the approximate livestock water demand.

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

Data

We use the year 2000 as the base year for our future projections. The 2000 database and the past trends of different drivers are derived using the data of various internal and external publications (Table 2).

Table 2. Types and sources of data used for the analysis.

Data	Sources	Reference
Urban and rural population	2001 Census records andthe projections of Mahmood and Kundu 2006	GOI 2003; Mahmood and Kundu 2006
Crop consumption (calorie supply, food and feed consumption of different crops) (NSSO) reports	Nutritional intakes and per capita consumption data of FAOSTAT database of the Food and Agriculture Organization (FAO) and the various rounds of National Sample Survey Organization	FAO 2005a GOI 1996 GOI 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 and Crop Yield Estimation Surveys of Principal Crops	FAO 2005a; GOI 2004, FAI 2003a, FAI 2003b, FAI 2003c, FAI 2003d
Rainfall, potential evapotransiration and land use map	International Water Management Institute World Water and Climate Atlas	IWMI 2001 IWMI 2005
Crop calendar, crop coefficients	AQUASTAT database of the FAO and FAO Irrigation and Drainage Paper No. 56	FAO 2005b; FAO 1998
Basin runoff	Central Water Commission of India	CWC 2004FAO 2003

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

Figure 1. State and land use cover map of India overlaid on major river basins.

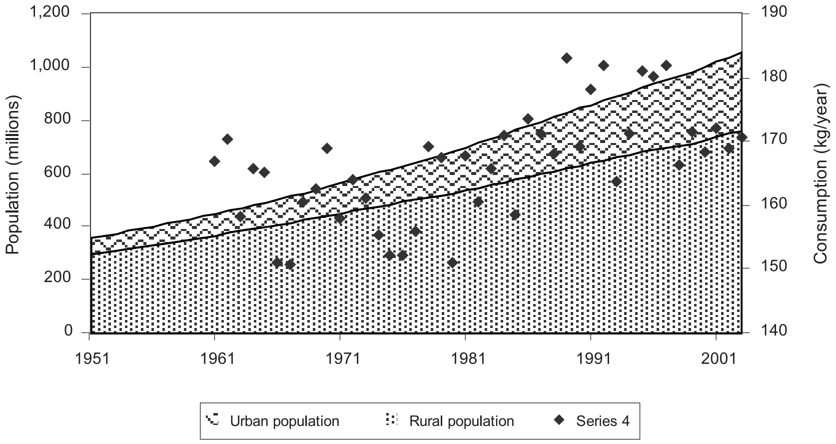
Food and Water Accounts—Past Trends and Current Status

Food Demand

The growth of food grain demand in India has been decreasing in recent years. The grain demand increased 3.1 % annually in the 1980s and the total population increased at 2.2 % during the same period. Decreasing trends of food grain consumption per person (Figure 2) however, led to a 1.3% annual decline in the growth of total grain demand in the 1990s, even though the population growth during this period was similar to the 1980s i.e. increased annually at 2.1 %.

Three factors contribute to the decline in food grain demand. First, the per capita grain consumption in both the rural and the urban population itself is decreasing. The rural and urban food grain consumption in the 1900s has been declining at an annual rate of 0.9 and 0.4% respectively, (GOI 1996 and 2001). Although the decline in rural food grain consumption is expected to continue, the rate of urban consumption is likely to stabilize soon (Amarasinghe et al. 2006; Dyson and Hanchate 2000). The rural-urban consumption differential and the rapid urban population growth are the second and third factors, contributing to the declining food grain demand.

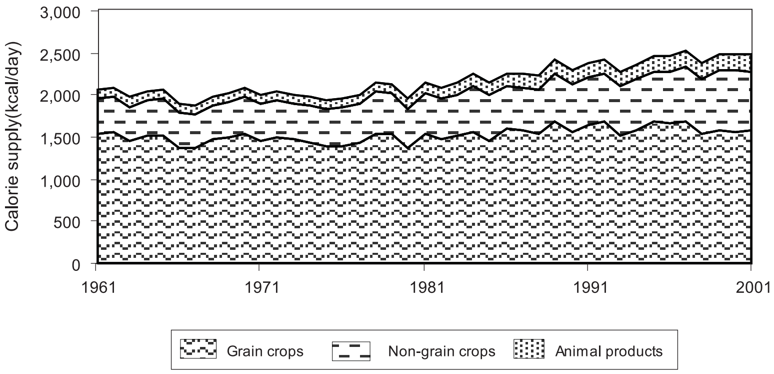
Figure 2. Growth of population and per capita food grain consumption in India.



Source: FAO 2005
UN 2005

In spite of the declining intake of food grains in the diet, the average nutrition supply per person in India has increased steadily over the last decade (Figure 3). Increased consumption of non-grain crops such as vegetables and fruits, and animal products such as milk, poultry and eggs has contributed to most of the increase in total calorie supply. Increasing income and rapid urbanization are expected to Further increase the nutritional supply per person in the future (Dyson and Hanchate 2000; Amarasinghe et al. 2006).

Figure 3. The calorie supply per person from grain crop, non-grain crop and animal products.

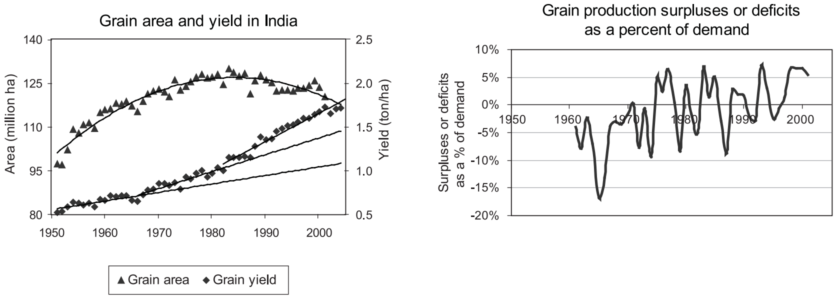


Source: FAO 2005

Food Production

Today, India is self-sufficient in most of her food requirements. Grain production, which has consistently outpaced grain demand over the last three decades, increased to 207 million metric tons (Mmt) by 2000. Area expansion and yield growth were both contributing factors to such production increases until the mid-1980s. Such increases have led, India, after a long period of food grain deficits, to record grain production surpluses in the mid-1970s (Figure 4). Although grain area growth stopped after the mid-1980s, growth in yield has been pushing India to record consistent grain surpluses even after the 1980s (Figure 4).

Figure 4. Grain area and yield and the production surpluses or deficits in India.



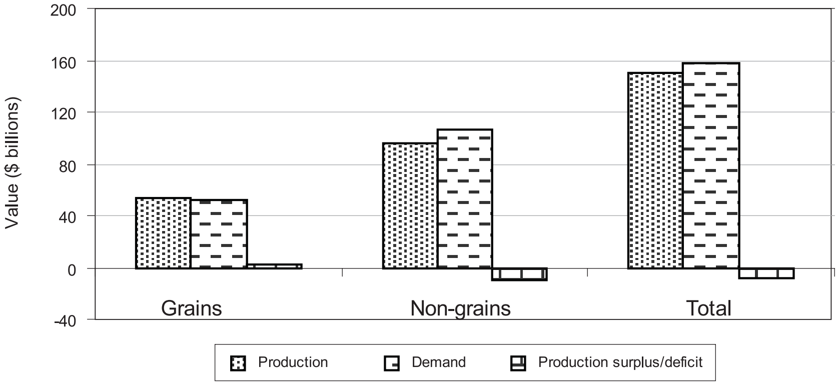
Source: FAO 2005

Although in the past, grain had a preeminent place in Indian agricultural production, this influence is slowly changing. The share of the value of grain production[1] has decreased over time, and is only 36 % now. Though the production value of non-grain crops, including oil crops, roots and tubers, vegetables, fruits, sugar and cotton is much higher(US$95 billion in 2000) than that of grain crops—non-grain crops recorded a production deficit of 9 % of total consumption in the year 2000 (Figure 5). India imports a substantial part of its edible oil requirements at present. However, overall, India is more or less self-sufficient in all crops, recording only a 3 % production deficit in the year 2000. As regards grain crops, India has been importing a substantial quantity of pulses in recent years, and exporting surplus rice and wheat.

---

[1] The value of total crop production under the PODIUMSIM methodology is estimated using the average export prices/kg of different crops in 1999, 2000 and 2001 (FAOSTAT 2005a). The average export prices of rice, wheat, maize, other cereals, pulses, oil crops (including vegetable oils), roots and tubers (dry equivalent), vegetables, fruits, sugar (refined) and cotton (lint), respectively, are US$/mt 375, 107, 176, 203, 199, 559, 1,631, 285, 776, 268 and 1,110

Figure 5. Value of crop production and demand and production surpluses or deficits of India.



Although India is self-sufficient in her food requirements, significant production surpluses and deficits exist in different river basins. Although food security is indeed a national issue, regional imbalances are important in the context of increasing water scarcities and virtual water trade is an important factor in terms of water use. Virtual water trade is the transfer of water, embedded in commodities, through trade, and could also become an instrument for mitigating the water scarcities of different regions or countries (Allan 1998; de Fraiture et al. 2004; Kumar and Singh 2005). The regions with water surpluses, in general, could benefit from virtual water trade, although the practices in reality so far suggest the opposite. The Indus Basin is a clear case of where the impact of virtual water trade has transformed what was perhaps a water-deficit basin in to a water-surplus one. The Indus meets more than 80 % of the grain production deficits of other basins, which are also classified as physically water-scarce. But with increasing demand from other sectors, this picture could change in the future. At present, this imbalance of the virtual water trade between basins is partly due to low productivities in the production-deficit basins and the scarcity of land is also a contributing factor. But by improving low productivities in the water-surplus areas, the virtual water trade could indeed ease regional water scarcities.

Water Supply

India's water availability varies substantially across the regions, and over time. Of the total rainfall of about 4,000 BCM, 1,260 BCM are estimated to be available as the internally renewable water resources (IRWR[2]). Adding the inflows from, and subtracting the flows out to other countries, India records 1,953 BCM of rainfall as the total renewable water resource

---

[2] The total renewable water resources consist of the internally renewable water resources and net inflows to the country. The internally renewable water resource is the average annual flow of rivers and recharge of aquifers generated from the endogenous precipitation .The commission's estimate of TRWR, based on the Central Water Commission reports, is about 1,953 BCM (GOI 1999; CWC 1998).

(TRWR)—(GOI 1999; CWC 2004; FAO 2003). In 1950, India recorded 5,400 m^3 of water per person, and was ranked 126 out of 154 countries in the world in terms of per capita water availability (Gardener-Outlaw and Englemen 2006). Today (2000), per capita water availability has decreased to 1,900 m^3/person, although, at the national level, this figure is a sufficiently high value of total renewable water resource availability. Despite a considerable spatial variation of rainfall, many river basins record significantly lower per capita water availability in terms of the TRWR (Amarasinghe et al. 2005).

In spite of the large TRWR, potentially utilizable water resources (PUWR) in India are only a fraction of the TRWR. The Brahmaputra and Megna basins cannot physically store their massive water resources (677 BCM or 35% of India’s TRWR), and therefore due mainly to such physical constraints, only 18 % of the TRWR is potentially utilizable there. Most other basins, especially those in the peninsular, receive their IRWR from the 2 to 3 months of monsoonal rains. As a result, some basins have a very low PUWR. In fact, each of as many as eight basins had a per capita PUWR less than 1,000 m^3 of water person in the year 2000, a level indicating severe regional water scarcity according to Falkenmark et al. (1989). Overall, the PUWR of surface water and groundwater that can be diverted to various human and other uses are estimated as 1,030 BCM (CWC 2004).

Water Withdrawals

Irrigation is still the largest consumptive water use sector in India. Irrigation contributed to 90% of the total withdrawals of 680 BCM in 2000. The domestic and industrial sectors contributed 5 % each.

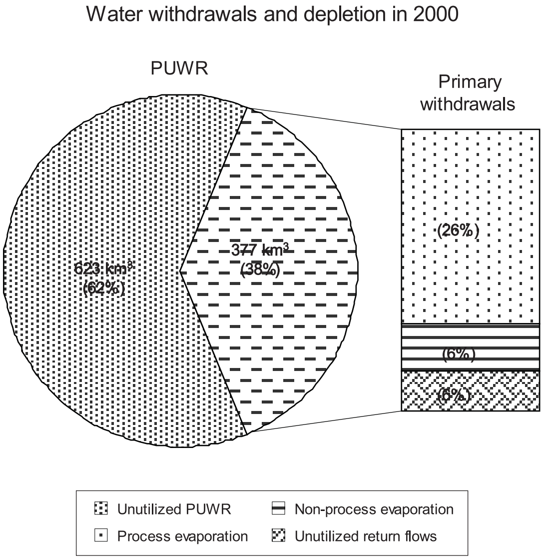
Groundwater irrigation, which expanded rapidly in the last few decades, forms a major part of the water withdrawals in many river basins. At present, more than 60 % of the total irrigated area is groundwater irrigated. However, with relatively higher project efficiencies than surface irrigation, groundwater contributed to only 45 % of the total irrigation withdrawals. Still, due to over-abstraction, some basins are facing severe regional water table depletions (Amarasinghe et al. 2005).

Water Accounting

The PODIUMSIM model uses the water accounting framework of Molden (1997) to show how water in different river basins is depleted through various processes. The *process evaporation*—the evapotranspiration from irrigation and the transpiration from the domestic and industrial sectors, accounts for 26 % of the total PUWR (Figure 6). The *non-process evaporation*—the evaporation from swamps, homesteads, canals and reservoir surfaces—constitutes another 6 % of the PUWR. The *outflows*, the return-flows of the water diverted (6%) and the unutilized PUWR (62%) account for the remainder of the PUWR.

In 2000, the ‘degree of development’, the ratio of primary withdrawals to the PUWR, of all basins was 38 %. A higher degree of development indicates: a) physical water scarcity, i.e., whether adequate quantities of water are available for meeting future development without affecting the environment or other water users; and, b) the increasing costs of further water development. When the degree of development exceeds 60 %, the basins are classified to be physically water-scarce (Seckler et al. 1998; IWMI 2000).

Figure 6. Water accounts of the potentially utilizable water resources of all river basins in India.



Indeed, several river basins in India are already physically water-scarce, which include the Indus, Western Flowing Rivers Group 1(WFR1), Mahi and Sabarmati. The Indus Basin is physically water-scarce but it produces a substantial part of the nation's grain requirement. The Western Flowing Rivers, Group 1 (WFR1), Mahi and Sabarmati basins are physically water-scarce and are also recording deficits in crop production. Many river basins in India also experience unsustainable regional groundwater use. The groundwater abstraction ratios—the ratios of total groundwater withdrawals to the total recharge from rainfall and return flows—of many basins are significantly high. This indicates that certain regions experience unsustainable groundwater depletions.

Business-as-Usual Scenario from 2025-2050: Storyline

We begin the Business-as-Usual (BAU) scenario storyline 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 paper is, indeed, based on this rather optimistic economic growth assumption. It assumes that the contribution from the agriculture sector to the gross domestic product will further reduce, but that the benefits of higher economic growth will filter down to every sphere, and the government and the private sector will invest in accelerating the growth of agricultural productivity to make that quantum leap as suggested by the Prime Minister.

The BAU scenario assumes that the shifts in consumption pattern will continue with further urbanization and increasing income. The average Indian diet, in the future, will have more calorie supply from non-grain products, such as non-grain crops and animal products. Although food grain consumption decreases, the demand for feed grain, primarily maize, will increase with a higher intake of animal products in the diet.

The BAU scenario also assumes that groundwater expansion, which played a major role in contributing to 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.

Table 3 shows the growth rates assumed for the key drivers that influence future water demand. Recent trends, both temporal and spatial, across districts and states, are the basis for the magnitude of change in these drivers. Here we give a brief description of the future directions of the key drivers.

Demographic Change

India’s population is increasing but will stabilize in the middle of this century. The BAU scenario assumes that the population will increase at 1.3 % over the period 2000-2025, and at 0.52 % between 2025 and 2050. The population growth is expected to stabilize in the early 2050s, although several large states will have peaked in their population growth well before the year 2050, and certain states will even record declining trends as early as the 2030s and 2040s. Urbanization will also continue to expand, and slightly over half of India’s population will live in urban areas by 2050 (Mahmood and Kundu 2006).

Many of the states with a declining population before the 2050s are in the south and east, and also have a high urbanization growth. These states are located in river basins, which are experiencing regional water scarcities at present, and are also expected to record the highest rate of migration from agriculture to employment in the nonagriculture sector. 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 pronounced, and where nonagricultural employment opportunities in the neighborhood are high. For the purpose of the BAU scenario, we assume that this demographic pattern will continue.

Income Growth

The economic growth in India shows contrasting patterns before and after 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 % thereafter. Since 1991, the per capita GDP growth has been steady and has fluctuated from 3 % to 6 % annually. 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).

Table 3. Growth in food and water demand drivers.

Water demand drivers	2000	2025 projection	2050 projection
Demography			
Population (million)	1,007	1,389	1,583
Urban population (%)	28	37	51
Economic growth			
GDP growth (US$1995 prices)	463	1,765	6,735
Nutritional intake			
Total calorie supply (Kilo calories per person per day (kcal/pc/day)	2,495	2,775	3,000
Contribution of grain crops (%)	65	57	48
Contribution from non-grain crops (%)	28	33	36
Contribution from animal products (%)	8	12	16
Food consumption/per capita (kg/yr)			
Grains	172	166	152
Rice	76	74	79
Wheat	58	58	58
Maize	10	8	4
Other coarse cereals	17	15	9
Pulses	11	12	12
Oil crops (oil crop equivalent)	41	64	73
Roots and tubers	6	8	12
Vegetables	69	102	114
Fruits	40	49	67
Sugar	26	28	33
Cotton	2.1	2.8	3.8
Feed conversion ratio (kg of feed grainsper 1,000 kcal of animal products)			
Conversion ratio	0.12	0.27	0.40
Crop area (Million ha)			
Net sown area	142	142	142
Net irrigated area	55	74	81
Net groundwater area	34	43	50
Net canal and tank area	21	31	31
Gross irrigated area (GIA)	76	111	117
Gross crop area (GCA)	189	208	210
Grain crop area - % of GCA	65	58	57
Grain irrigated area - % of GIA	43	49	52
Crop yield (tons/ha)			
Average grain yield	1.7	2.4	3.1
Irrigated grain yield	2.6	3.6	4.4
Rain-fed grain yield	1.0	1.3	1.8
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 (BCM)	2.3	2.8	3.2
Industrial water demand (m^3/person/year)	42	66	102
Environmental water demandMinimum river flow - % of mean annual runoff	-	6-45	6-45

We assume that India’s per capita income will increase at 5.5 % annually over the next 50-year period. The per capita GDP will increase from US$463 (in 1995 prices) in 2000 to about US$1,765 by 2025 and to about US$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 industrial sector GDP will contribute to about 40 % of the total GDP.

Consumption Patterns

India’s nutritional intake patterns are fast changing. The consumption of food grains, which provide a major part of the daily nutritional intake, is decreasing in both the rural and the 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. 2006; Dyson and Hanchate 2000).

We expect high income growth and urbanization will continue to contribute to further changes in the food consumption patterns. The total nutritional intake will continue to increase, but the share of grain products in the consumption basket will diminish further. As much as 54 % of the total calorie supply will be derived from non-grain products by the year 2050, compared to the 36 % at present (see Amarasinghe et al. 2006 for a detailed estimation). We also assume, as did Rao (2005) that the differences in urban and rural consumption patterns will still exist, but the gap will be much narrower by 2050. As a result of these factors, rural nutrition impoverishment will also reduce substantially.

Projections on the increase of animal products consumption will have a significant impact on the 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. (2006) projected that the feed conversion ratio would increase to about 0.40 kg/1,000kcal by 2050, which is the ratio for certain upper to middle income developing countries, such as China, at present.

National Food Security

The BAU scenario assumes that national self-sufficiency in individual crops will no longer be a concrete goal. Crop diversification, which started spreading in the last decade, will continue at a faster pace. 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 crop area and the irrigated area will diminish.

Some crops are expected to have production deficits, as at present. But, at the national level, the increase in income from high-value crops is sufficient to pay for the imports needed to cover any deficit in other crops.

Crop Area Growth

The BAU scenario assumes that the net sown area will remain the same, that being at the present level of 142 million hectares (Mha). But irrigation expansion is likely to continue and will remain a major contributor to growth in the gross irrigated and crop areas.

Groundwater irrigation has spread to the rain-fed areas, some of which do not have substantial surface irrigation return flows. And by 2025, gross groundwater irrigated area would increase to 60 Mha, and by 2050 this will increase to 70 Mha. Indeed, the BAU scenario for growth in the net groundwater irrigated area has been very much below the trend level during the past few years. Our assumption in this regard 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 assess the sensitivity of the BAU water demand projections to various groundwater irrigation growth scenarios.

The surface irrigation coverage in the BAU scenario will also increase. The projects that are under construction now will contribute to this increase. The IXth 5- 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. The same surface irrigation coverage is assumed for the period between 2025 and 2050. A major part of the rest of the net sown area—what is at present classified as rain-fed—receives supplemental irrigation during periods of water stress, which is crucial to crop growth.

The BAU scenario projects that the irrigation coverage will continue to increase to approximately 55 % of the total crop area by 2050, from its present level of 41 %. We also assume that the supremacy of the grain crop in irrigated agriculture will diminish and the irrigation coverage of grain crops will decrease from the present level of 71 % to approximately 56 and 54 % by 2025 and 2050, respectively (see Annex 2 for detailed estimations).

Crop Yield Growth

The grain crop yield growth has been declining in recent decades—3.6 % in the 1980s and 2.1 % in the 1990s. The BAU scenario assumes that the declining trends will continue, but not at such a steep trend as is seen in the last two decades. The growth of grain yield would decline to 1.4 and 1.0 % annually in the first and second quarters, respectively, of this century. With these growth rates, average grain yields will increase from the year 200 level of 1.7 tons/ha to 2.4 tons/ha by 2025, and 3.2 tons/ha by 2050.

In spite of decreasing trends in the past, and also the bleak assumptions of the BAU scenario, we, however, believe that there is substantial scope for increasing the yield beyond this limit. It is clear that there is a significant gap between the highest and lowest actual yields, and further between the actual and potential yields (Agrawal et al. 2000). The investments, both private and public, that the Prime Minister mentioned, in the future will focus on small-scale infrastructure and technologies that will greatly enhance crop yields. Micro irrigation technologies offer opportunities for significant yield growth (Kumar et al. 2006; Narayanmoorthy 2006; INCID 1998). The expanding groundwater use could also contribute significantly to increasing the irrigated yield. And supplementary irrigation, through water harvesting, at critical periods of water stress, 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 assess the sensitivity of crop production to the assumptions of yield growth under the BAU.

Irrigation Efficiency

The information available to date, suggests that surface project irrigation efficiency has not improved much, while many groundwater irrigation areas have relatively higher efficiencies. As resources become scarce and also expensive, water saving technologies spread fast, resulting in further improvements in groundwater irrigation efficiency. The BAU scenario assumes that groundwater efficiency would increase to 75 % by 2050 from its present level of 65 %. Surface project irrigation efficiency is also assumed to increase from its present level of 30-40 % to about 50 % in 2050.

Domestic Water Demand

With increasing household income and increasing contributions 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. The BAU scenario approach differs from the approach adopted by the NCIWRD commission. They assumed norms where the rural domestic water demand in 2025 and 2050 are assessed at 70 and 150 lpcd, respectively, and the urban water demand at 200 and 220 lpcd, for 2025 and 2050 respectively. They also assumed 100 % coverage of domestic water supply for both the rural and the urban sectors. At this rate, the average per capita water demand in 2025 and 2050 is estimated to be 126 and 191 lpcd, respectively.

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

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 also increase accordingly. However, the dearth of information—the types of industries, their growth, water use and the extent of recycling—is a constraint for future projections in the context of increasing economic growth. The NCIWRD commission, based on a small sample of industries and their water use, projected that industrial water demand would increase from 30 BCM in 2000, to about 101 and 151 BCM by 2025 and 2050, respectively.

However, an analysis using the global trends show that, with the present economic growth rates, the per capita industrial water demand could increase from 42 m^3/person in 2000, to about 66 and 102 m^3/person by 2025 and 2050, respectively or the total industrial water demand to increase to 92 and 161 BCM by 2025 and 2050, respectively. The BAU scenario too assumes these growth rates.

Environmental Water Demand

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, awareness of water-related environmental 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 environmental water demand.

The MFR of Smakhtin and Anputhas (2006) depends on the hydrological variability and the environmental management class that the river ought to maintain. We estimate Environmental Flow Requirement (EFR) using the guidelines for the environmental management class C, which is classified as for a 'moderately disturbed' river. In class C, the habitats and the biota of the rivers have already been disturbed, but the basic ecosystem functions are intact. And the management perspective for Class C 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 Brashmaputra River basin's MFR is estimated as 46 %, and for the Mahi River it is 7 %. We use these guidelines for estimating the environmental water demand to be released from the potentially utilizable water resources.

Business-as-Usual Scenario Projections

Water Demand

The total water demand of the BAU scenario is projected to increase to 22 % by 2025, and 32 % by 2050 (Table 4). A major part of the additional water demand is for the domestic and industrial sectors. The water demands of the domestic and industrial sectors will account for 8 % and 11 % of the total water demand by 2025. And these shares will increase to 11 % and 18 %, respectively, by 2050. Moreover, the domestic and industrial sectors will account for 54 % of the additional water demand by 2025, and more than 85 % by 2050.

Table 4. BAU scenario water demand projections.

Sector	2000		2025		2050	
	Total	% from groundwater	Total	% from groundwater	Total	% from groundwater
	BCM	%	BCM	%	BCM	%
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

Notes: [a]Domestic withdrawals include those for livestock water demand
[b]Industrial withdrawals include cooling needs for power generation

The BAU scenario projects significant water transfers from the irrigation sector to other sectors by 2050. The combination of higher irrigation efficiencies and large groundwater irrigated areas would result in a decrease of the irrigation water demand between 2025 and 2050. While the total irrigation demand would decrease by 38 BCM, the surface irrigation demand is estimated to decrease by 46 BCM. This surplus irrigation water is projected to be available for the domestic and industrial sectors.

Production Surpluses or Deficits

The total grain production under the BAU scenario in 2050 is estimated to be more than the total grain demand (Table 5). In 2050, the total grain production is estimated to be 2.0 % more than the estimated grain demand of 377 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 non-grain crop demand of 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 crop production is projected to be less than the demand of all crops i.e., approximately 4.0 % by 2025 and 2050.

Table 5. 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 (BUS$)[1]	52	73	90	3.3%	0.4%	3.4%
Non-grains (BUS$)[1]	106	198	284	-9.4%	-5.4%	-6.3%
Total (BUS$)[1]	158	272	374	-5.2%	-3.9%	-4.0%

Notes: [1] The value is in billion US$ and is expressed in terms of the average of export prices in 1999, 2000 and 2001. Totals include other components (seeds, waste etc) grain availability.

Among the grain crops, substantial production deficits are projected for other cereals and pulses (Table 6). The production deficit of other cereals is primarily due to the increase in demand of maize for livestock feeding – total maize demand is projected to increase from 5 Mmt in 2000 to 107 Mmt by 2050. However, the deficits of other crops are offset by production surpluses of

Table 6. Production, demand and production surpluses or deficits of different crops.

Crop	Production			Demand			Production surpluses or deficits - % of demand		
	2000	2025	2050	2000	2025	2050	2000	2025	2050
	Mmt	Mmt	Mmt	Mmt	Mmt	Mmt	%	%	%
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	206	292	385	200	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

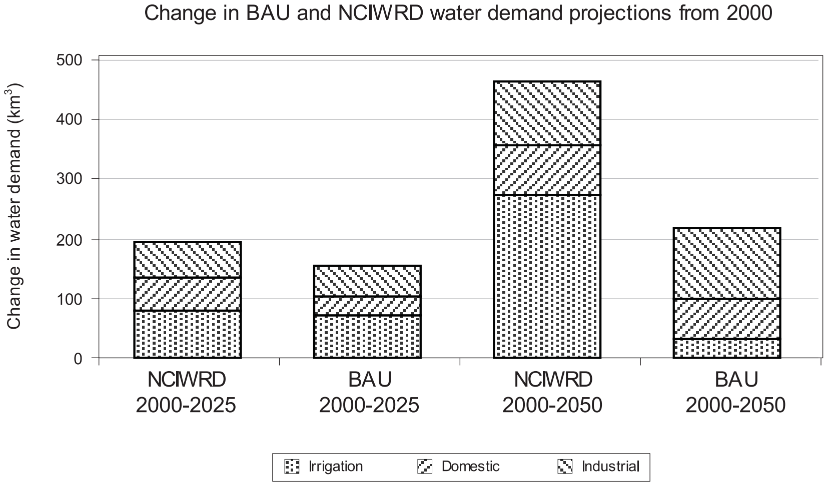
Sources: 2000 data are from the FAOSTAT database (FAO 2005a); the 2025 and 2050 data are estimated by the author.

rice and wheat to maintain overall grain production surpluses by 2050 (Table 5). Among non-grain crops, oil crops are expected to have substantial production deficits.

BAU Projections: Comparisons

The BAU projections are first compared with the projection of the NCIWRD commission (GOI 1999). Figure 7 shows the incremental water demand of irrigation, domestic and the industrial sectors projected for the time frames of 2000 to 2025 and 2000 to 2050. The striking difference between the projections for the two time frames is the irrigation demand. In both time frames, the projections up to 2025 have a similar irrigation demand increase, but the projections deviate significantly by 2050. While the BAU scenario projects a decreasing irrigation demand between 2025 and 2050, the NCIWRD commission projects an additional demand of 250 BCM by 2050.

Figure 7. Difference of water demand projections—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 commission projects a significant growth in food grain consumption. Both projections target nutrition security, but the BAU scenario projects a diversified diet, whereas the NCIWRD assumes a grain-dominated diet. The BAU scenario projects a 3,000 kcal per person per day average calorie supply by 2050, while the average calorie supply based on the NCIWRD assumptions could well be over 4,000 kcal per person per day by 2050. The latter is not a realistic goal to attain, at least according to present global consumption patterns, where even developed countries, with substantial animal products in the diet, consume about 3,600 kcal per day per person. Second, the commission has assumed self-sufficiency in grains, and has projected that much of the additional grain requirement for meeting self-sufficiency is to be produced under irrigation conditions. For this, they estimated 104 Mha of grain irrigated area, while the BAU scenario projected a grain irrigated area of only

79 Mha. Third, the BAU scenario assumes a rapid groundwater irrigation expansion, whereas a major part of the NCIWRD commission’s projection is for surface irrigation. The commission assumed the surface water to groundwater ratio to be 55:45, while the BAU scenario projected a ratio of 40:60. Combined with area differences, the assumption of irrigation efficiencies has contributed to water demand differences.

We also compared the BAU scenario projections of this paper and those of the IMPACT ((International Model for Policy Analysis Commodities and Trade)-Water model (Rosegrant et al. 2002). Although, the total water demand projections for 2025 of the two scenarios are similar (IMPACT-Water model projects 822 BCM by 2025), we find that the assumptions leading to demand estimations and the sectoral demand projections themselves are different.

The IMPACT model projects 76 Mha of potential irrigated area for India by 2025. However, the gross area has already reached 76 Mha as per the base year (2000) data for the BAU scenario of this paper. 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 in 2000, which is this paper’s base year, the grain irrigated area was 54 Mha. The IMPACT - Water model has erred in its assumptions as regards key drivers by failing to consider the recent trends in groundwater development, which has in turn resulted in significant deviations between the IMPACT-Water model and BAU scenario projections irrigated crop area. As a result, the irrigation demand under the two projections is also at variance.

BAU Scenario and Regional Water Crisis

The BAU scenario assumed that groundwater irrigation would continue to increase, but at a reduced pace. Uncontrolled groundwater pumping, on the one hand, contributes to increasing gross irrigated area, crop yield and crop production and, on the other, contributes to physical water scarcities and groundwater-depletion- related environmental issues in certain basins. Figure 8 shows how the degree of development, the groundwater abstraction ratio, and the depletion fraction[3] of the PUWR change over the period 2000-2050.

Many river basins will be physically water-scarce by 2050. The degree of development of 10 river basins, comprising 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. And the different sectors in these basins would share a common water reallocation to meet the increasing demand. Indeed, the BAU scenario projects transfer of surface irrigation resources to domestic and industrial water use.

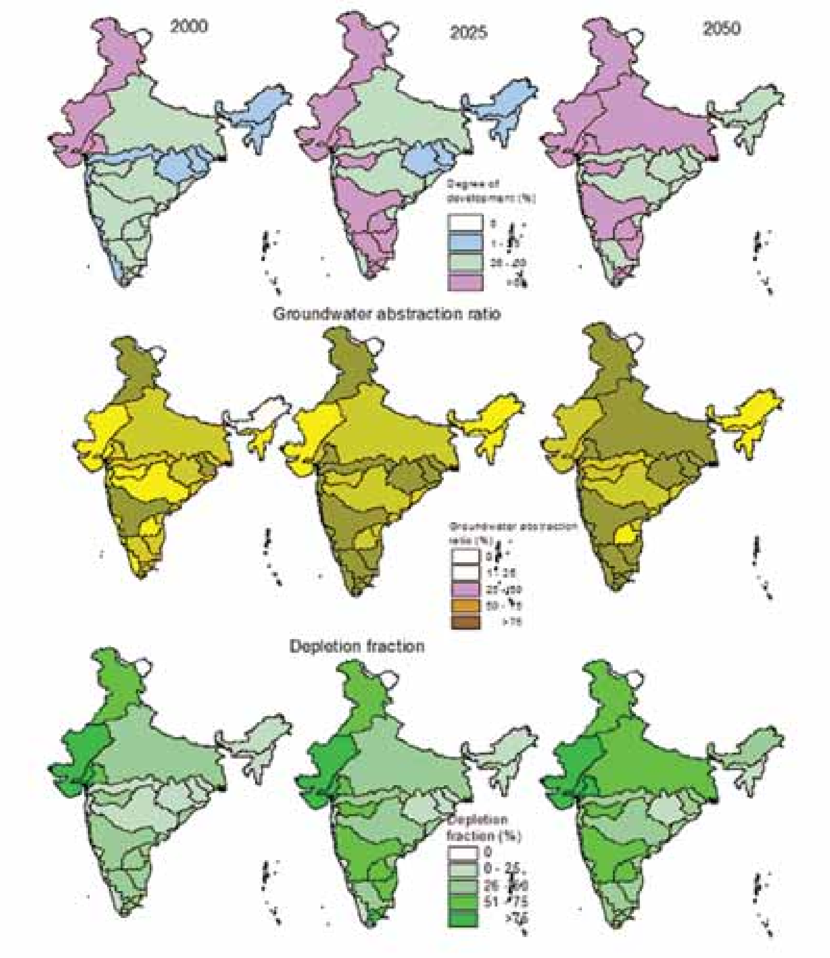
Increased groundwater irrigation would have severe detrimental effects on many basins. Groundwater abstraction ratios of many basins are significantly high. Given the current level of recharge, patterns of groundwater use for these basins are not sustainable. Indeed, the growth patterns under the BAU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

---

[3] Depletion faction in this paper is defined as process and non-process evaporation as a fraction of the PUWR.

The depletion ratios show where the water crises are severe. Several basins would deplete more than 60 % of the PUWR by 2050, and face severe water scarcities under the BAU scenario. The solutions for these river basins are: a) to increase crop productivity for every unit of water they use 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; and d) to get water transfers from the water-rich basins.

Figure 8. Degree of development, groundwater abstraction ratio and the depletion fraction in 2000, 2025 and 2050.



Water Supply with Environmental Water Demand

Environmental water demand often received scant attention in most demand projections and the absence of a clear methodology was a major constraint in this respect. The primary emphasis of meeting the water needs of other sectors is also to blame for this situation. The NCIWRD commission projections have a provision of 10 BCM—1 % of total demand;

Rosergrant et el. (2002) have allocated 6-15 % of the mean annual runoff; and other studies (Seckler et al. 1998; IWMI 2000) have highlighted environmental impacts by setting a threshold for the withdrawal limits. We updated the EFR demand of Indian river basins based on the guidelines of Smakhtin and Anputhas (2006).

Table 7 shows the environmental flow demands of the river basins, and the available water resources for other sectors if part of the environmental demand is to be met from the PUWR.

Table 7. Environmental water demand to be met from the potentially utilizable surface flows.

River basin	Potentially utilizable surface water resources[1] (PUSWR)	Non-utilizable surface water resources[2]	Environmental water demand (EWD)	EWD to meet from PUSWR[3]
	BCM	BCM	BCM	BCM
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
Subernarekha	7	6	2	0
Tapi	15	0.4	2	2

Notes: [1]PUWR is from CWC 2004
[2]Non-utilizable water resources – TRWR-PUSWR
[3]The difference between the third and fourth column

The estimated unutilized part of the water resources in many basins is higher than the estimated environmental flow demand. Only three basins—those of Cauvery, Pennar and Tapi—require environmental water demand allocations from the PUWR. However, we caution the interpretation of this result here. The environmental water demand of this paper is estimated at an annual basis, but the flows of Indian rivers vary significantly between months. If the demand is estimated at a monthly basis, the environmental water demand of certain basins could increase, and the PUWR will have to meet part of this demand. As a result, the effective water supply available for other sectors could diminish in many basins.

Sensitivity Analysis

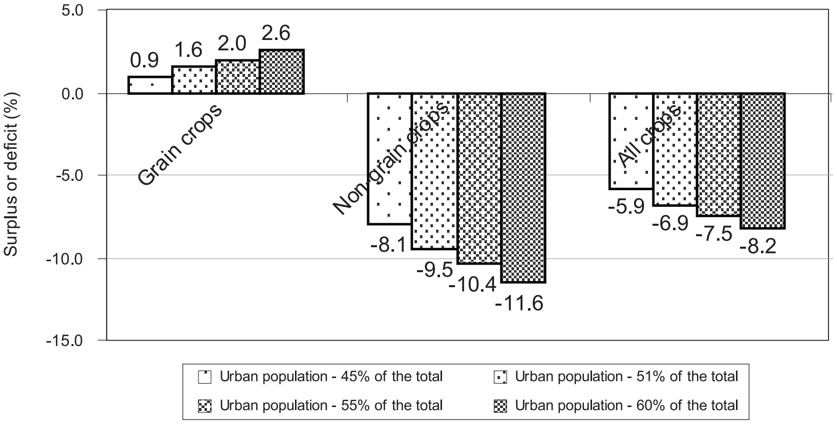
The growth assumptions on many of the drivers under the PODIUMSIM model are sensitive to the final water demand projections. This section assesses the sensitivity of four key drivers—two on the food demand and two on the water demand.

Urban Population Growth

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

Figure 7 shows the sensitivity of future food demand to urbanization. We assume four urbanization scenarios—increases where urban population constitutes 45 %, 51 % (BAU scenario), 50 % and 60% in 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, the production deficit of the non-grain crops, and the production deficit of all crops increase. However, the changes of overall production deficits are not significantly high compared to the urban population growth.

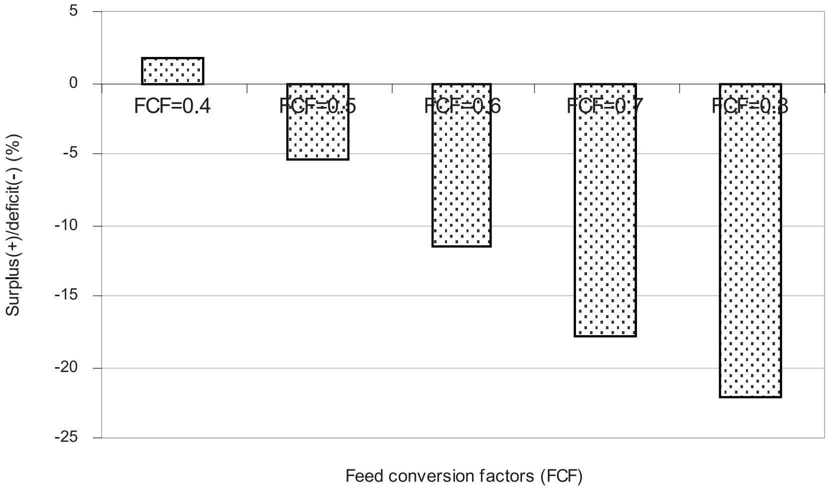
Figure 9. Crop production surpluses or deficits under varying levels of urbanization growth.



Feed Conversion Factor Growth

Figure 8 shows that the feed conversion factor, the quantity of crops used for producing 1,000 kcal of animal products in calorie supply, 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 conversion factors (FCF). The BAU scenario is that FCF=0.4. If the FCF is double the level of projected by the BAU scenarios for 2050, then the grain deficits would increase to 22 % of the total demand or to about 108 Mmt. Indeed, such a deficit will be a significant burden for a country like India.

Figure 10. Grain production surpluses as a percentage of total demand under different feed conversion factors.



So, could the feed conversion factors in India increase beyond the BAU scenario level? First, we note that feed conversion factors vary significantly between countries, and that they are high in countries where livestock is a commercial industry and stall feeding is common. For example, in the USA, Australia, Brazil and France, food conversion factors are 1.54, 1.06, 0.75 and 0.81 kg/1,000 kcal, respectively.[4] Countries with larger areas of pastureland, such as the UK and New Zealand, have lower feed conversion ratios (0.46 kg/1,000 kcal). In China, the ratio is 0.34 kg/1,000 kcal. However, with a large livestock population, India's conversion factor in the year 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 the increase in 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 its milk productivity in cattle, the extent of animal draught power in agriculture used for labor, and the increase in poultry products in the daily diet. At present, milk is the major calorie provider of animal products, and, in the future, the contribution of poultry products is expected to increase (Amarasinghe et al. 2006). Meat consumption and production, especially beef and pork, in India have been very low due to religious reasons, and this trend will most likely continue in the future too. So, as in the past, much of the cattle and buffalo population in India will be solely utilized for milk production

Among the major milk producers, India has one of the lowest milk productivity; only one-tenth of the milk productivity of the USA, and one fifth of the productivity of New Zealand

---

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

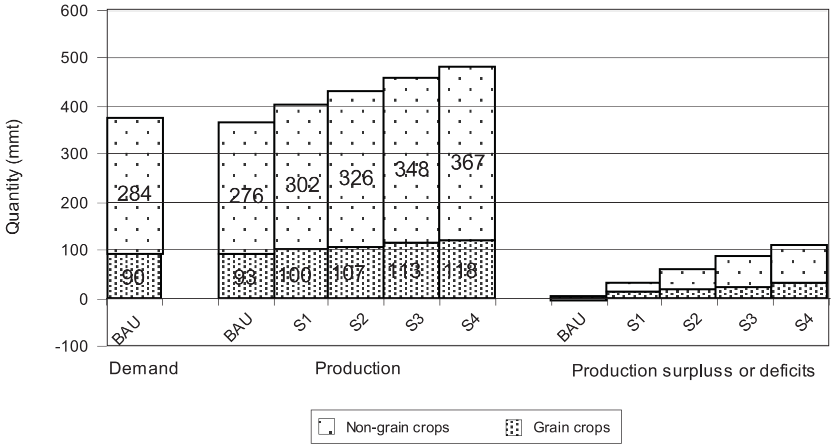
(Hemma et al. 2003). While the USA had a cattle stock of approximately 74 million, India had more than 300 million cattle and buffalos. Indeed, a major part the bovine population in India is non-milk cattle and some are draught animals. Regardless of whether they milk or not, these animals still need feed, fodder or 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 large scope for improving milk productivity, failing which, India could require a large cattle population for meeting its internal milk demand, and in turn could face a severe shortage in meeting the fodder demand. And this feed shortage will have to be met by commercial feeding.

Crop Yield Growth

The BAU scenario assumed a rather modest growth in crop yield. Thus, under the BAU scenario, the value of overall crop production has a deficit of 4 % of the value of the total crop demand. Figure 9 shows how this deficit changes with higher yield growth. In the alternative scenarios we assumed a slightly higher growth of rain-fed and irrigated yield. While the BAU scenario projects the average grain yield to increase to 3.2 tons/ha by 2050, the four alternative scenarios correspond, respectively, to 3.5, 3.75, 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. In all scenarios we allow for the production deficits in individual crops, and in this paper these mainly include maize, pulses and oil crops. The growth of crop yields in all scenarios, except the last is lower than the growth recorded between 1990 and 2000. In the last scenario we assume the growth to be similar to what was recorded between 1990 and 2000.

Figure 11. Crop production surpluses or deficits under varying levels of yield growth.

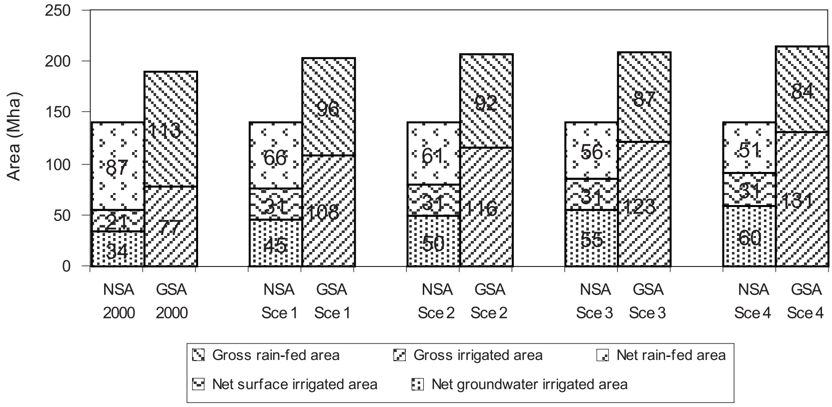


In all the alternative scenarios, both the grain and the non-grain crops record production surpluses. Alternative scenarios, thus, suggest that crop production and the production surpluses can be increased considerably with a slightly higher yield growth.

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 one million hectares every year. And 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 impact of groundwater, if it does increase, on the gross irrigated area (GIA) and on the gross crop area (GCA) is very significant. Figure 10 shows the likely growth of GIA and GCA under different net groundwater irrigated area (NGWIA) growth patterns. Scenario 2, the BAU scenario in this paper, assumes that (NGWIA) would increase to 50 Mha. Scenario 1 assumes a slightly lower growth of 43 Mha, while scenarios 3 and 4 assume a slightly higher growth of 55 and 60 Mha, respectively.

Figure 12. Gross irrigated and crop areas under different groundwater development scenarios.



The BAU scenario projects the GIA to expand to 116 Mha. On the other extreme, scenario 4 projects the NGWIA to increase to 60 Mha and as a result the GIA to increase to 131 Mha. The gross groundwater coverage under this scenario could be 86 Mha. Certainly, such a growth is significantly higher than the ultimate groundwater potential of 65 Mha that is projected at present (GOI 1999), and could not be realistic under the present groundwater recharge scenarios.

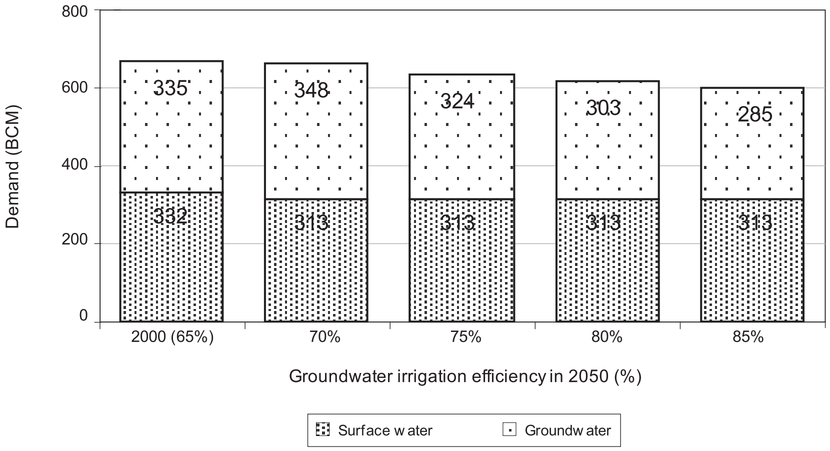
However, if the high groundwater irrigation scenarios are realizable, their impact on crop productivity and crop production growth will be considerable. Studies show that productivity under groundwater irrigation is two to three times higher than the level of productivity under canal irrigation, and, that a small life-saving irrigation of 3 to 5 centimeters of groundwater would considerably increase crop yields over rain-fed yields (Kumar et al. 2006b; Palanisamy et al. 2006, Shah et al 2001).

The higher groundwater irrigation scenarios have a significant impact on water withdrawals too. In general, groundwater irrigation efficiency is 30 % to 50 % higher than canal irrigation efficiency. In 2000, the average water withdrawal for one hectare of canal irrigation was 1.1m, and 0.6 m for one hectare of groundwater irrigation. If the micro irrigation technologies that are commonly used with groundwater irrigation spread, groundwater irrigation efficiency could increase, resulting in a further decrease in groundwater withdrawals. We assess the sensitivity of water demand to irrigation efficiencies in the next section.

Groundwater Irrigation Efficiency

The BAU scenario assumed that groundwater irrigation efficiency would increase from 65 % to 75 % over the next 50 years. Figure 11 shows how water demand decreases with increasing groundwater efficiency.

Figure 13. Irrigation water demand under different groundwater irrigation efficiency scenarios.



The first bar shows the water withdrawals in 2000. The groundwater efficiency in that year was 65 %. The rest of the bars in the graph show the 2050 water demand at varying levels of groundwater efficiency. All the alternative scenarios assume the same surface irrigation efficiency (about 50%), and they show a reduction in the total water demand. If groundwater efficiency can be increased to 80 %, the total water demand could decline by 10 % from its present level.

Can India increase its overall groundwater efficiency to 80 %? The short answer is, it could, but it requires substantial investment in micro irrigation technologies. Recent studies show that groundwater efficiency in many irrigation systems is as high as 85 % to 90 % (Kumar et al.; Palanisamy et al. 2006; Naranyanmoorthy 2006). And, most of these high-performing systems are using water saving technologies at present.

Summary and Policy Implications

This paper projected India’s food and water future in 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 ‘Business-as-Usual’ scenario.

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

- the total water demand to increase from 680 BCM to 833 BCM by 2025, and to 900 BCM by 2050;
- the total water withdrawals as a % of PUWR to increase from 37 % in 2000, to 81 % and 87 % by 2025 and 2050, respectively;
- the degree of development, primary water withdrawals as a % of PUWR, to increase from 37 % to 52 % and 61 % by 2025 and 2050, respectively;
- the industrial and the domestic sectors to account for 54 % and 85 % of the additional demand by 2025 and 2050, respectively;
- groundwater withdrawal to increase from 303 BCM in 2000 to 365 BCM and 423 BCM by 2025 and 2050, respectively, and the groundwater abstraction ratio to increase from 60 % to 74 % and 84 %, respectively.

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 Mmt and 111 Mmt by 2025 ad 2050, respectively;
- the food grain demand to increase slowly, from 178 Mmt in 2000 to 230 Mmt and 241 Mmt in 2025 and 2050, respectively;
- the per capita grain availability to increase from 200 kg/person in 2000, to 210 kg and 238 kg/person in 2025 and 2050, respectively;
- the total grain demand to increase from 201 Mmt in 2000 to 291 Mmt and 377 Mmt by 2025 and 2050, respectively.

On the food supply side, the BAU scenario projects:

- overall production surpluses in grain crops, but substantial imports of maize and pulses, and exports of rice and wheat. The maize import is primarily for livestock feeding. The production deficit of maize is projected to be 22 and 57 Mmt by 2025 and 2050 respectively.
- production deficits in non-grain crops and substantial imports of oil crops (edible oil);

- overall production deficits of all crops to increase from 5 % of the total crop demand in 2000 to 9 % by 2050;
- the gross irrigated area to increase from 76 Mha to 117 Mha during the 2000-2050 period, and the share of groundwater irrigation coverage to increase from 43 Mha to 70 Mha over the same period.

The projections of the BAU scenario are mainly based on the extrapolations of the trends of recent years. Thus, the projections to 2050 are too far ahead, and there is every possibility that the unexpected changes in demand drivers could significantly alter the BAU demand directions. We selected a few water demand drivers that could change sharply and bring in these unexpected changes in the projection. At the same time, proper policies could offer significant opportunities to lessen the variability of the demand drivers or the impacts of the changes.

The urban population could increase at a much higher rate than the assumed level in BAU, but this will not significantly impact food production surpluses, although it can have a considerable impact on the domestic water demand. The investments required to increase the domestic water supply coverage could drastically change under such a scenario. If the urban population increases to 60 % of the total population by 2050, as against 51 % in the BAU scenario, the total domestic water demand could increase from 101 BCM to 107 BCM.

Increasing feed deficits with higher feed conversion ratios is also a concern. If the feed conversion ratio doubles, then the feed grain deficits will be more than double. As we have discussed earlier, there is ample scope for reducing the feed demand by improving milk productivity. A combination of investments in extension and research, introduction of hybrid highly-productive livestock, control of the unproductive cattle population growth, etc., could help reduce the demand for commercial feed. In the absence of these, feed deficits can increase more than 100 Mmt. Meeting such huge feed deficits consistently via international trade could also be problematic for a country like India.

Crop productivity growth offers the best solution for meeting the increasing demand for food and feed, and increasing the income of the rural poor. The sensitivity analysis in this paper suggests that the crop yield of 0.5 % over and above the BAU scenario could propel crop production to significantly higher levels. And the investments in research and extension, and revising the policies for pro-productivity growth could offer a way out of the predicament that India is in, at present, in terms of the declining crop yield growth.

Groundwater irrigation expansion is a key driver of agricultural production and water demand growth. Water demand projection of the BAU depends very much on the extent of net groundwater area expansion. Investment in small-scale structures that can enhance groundwater recharge in locations where there are no adverse impacts on downstream users, and abstraction of groundwater in areas where it is abundantly available, are a few other policy options.

As groundwater will be the dominant source of irrigation in the future, micro irrigation technologies could offer significant opportunities for increasing efficiency in water use, and thereby reduce over abstraction. Indeed the BAU scenario assumes a significant growth in groundwater efficiency. Spreading water saving technologies through investment promotions could be the key here.

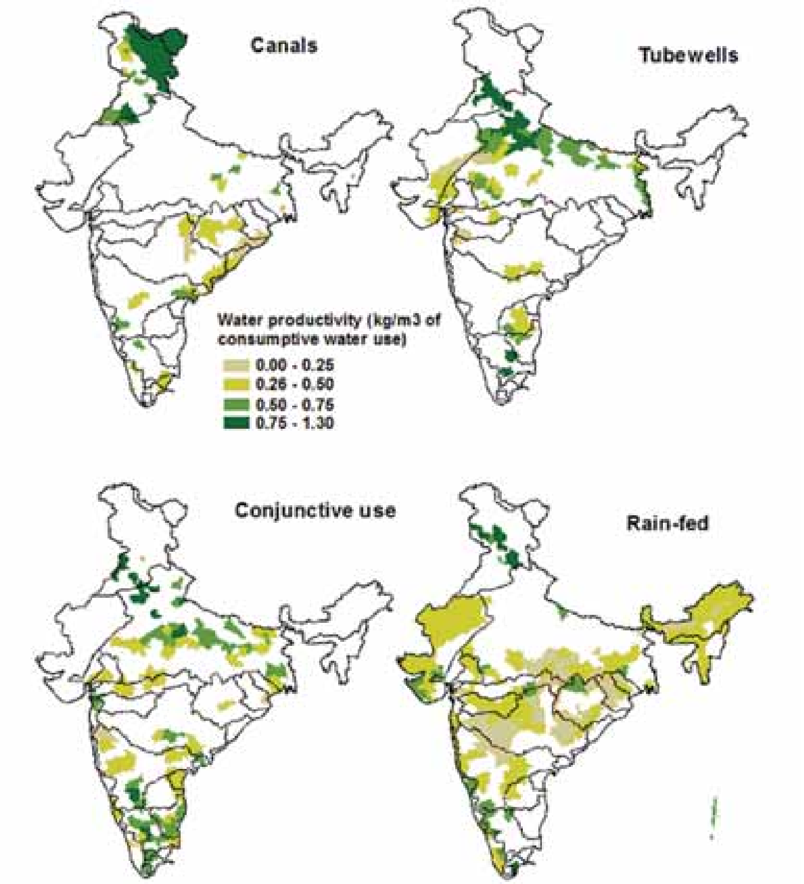
The BAU scenario projections are not overly pessimistic, but, they still call for substantial investments for meeting future water demand. Growth of the agriculture sector water demand would mainly depend on groundwater development and efficiency enhancements, which requires investments in increasing groundwater recharge, spreading water saving technologies, and enhancing efficiency and crop productivity. However, 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 117 BCM as the additional water requirement for the two sectors. This growth is equivalent to 20 BCM 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 would be needed? The answer to this could be yes, and the large-scale water transfers could only be justifiable on the ground that the burgeoning industrial sector could demand, and is willing, to pay for a more reliable surface water supply for their 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 her crop water productivity over the next 50 years? At the moment we don’t know the answer to this question, but we do know, as seen in the concluding discussion of this paper, that improving water productivity will have a significant impact on future water needs. Amarasinghe et al. (2006) showed that a modest increase (1% annually) in water productivity (quantity per consumptive water use) could eliminate the additional consumptive water demand for grains. And, 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. Figure 12 shows these variations across districts dominated by surface irrigation, groundwater irrigation, conjunctive irrigation and rain-fed irrigation.[5] This shows that the crop productivity of many districts is well below the average crop water productivity, and that there is substantial scope for increasing water productivity in all crops, be they grain and or other. If this increase can be realized, the water requirement of the other sectors can be met by existing water resources.

---

[5] Rain-fed-dominated districts are those with a gross irrigated area (GIA) less than 25 % of the gross crop area. Of the remaining districts, canal-irrigation dominated ones are those with a gross canal irrigated area greater than 50 % of the GIA. Tubewell-dominated districts are those with a gross tubewell-irrigated area greater than 50 % of the GIA. The remaining districts are classified as those having a conjunctive use.

Figure 14. Water productivity of grain crops in districts dominated by canal, tubewell and conjuctive irrigation and rain-fed agriculture.



Annex 1

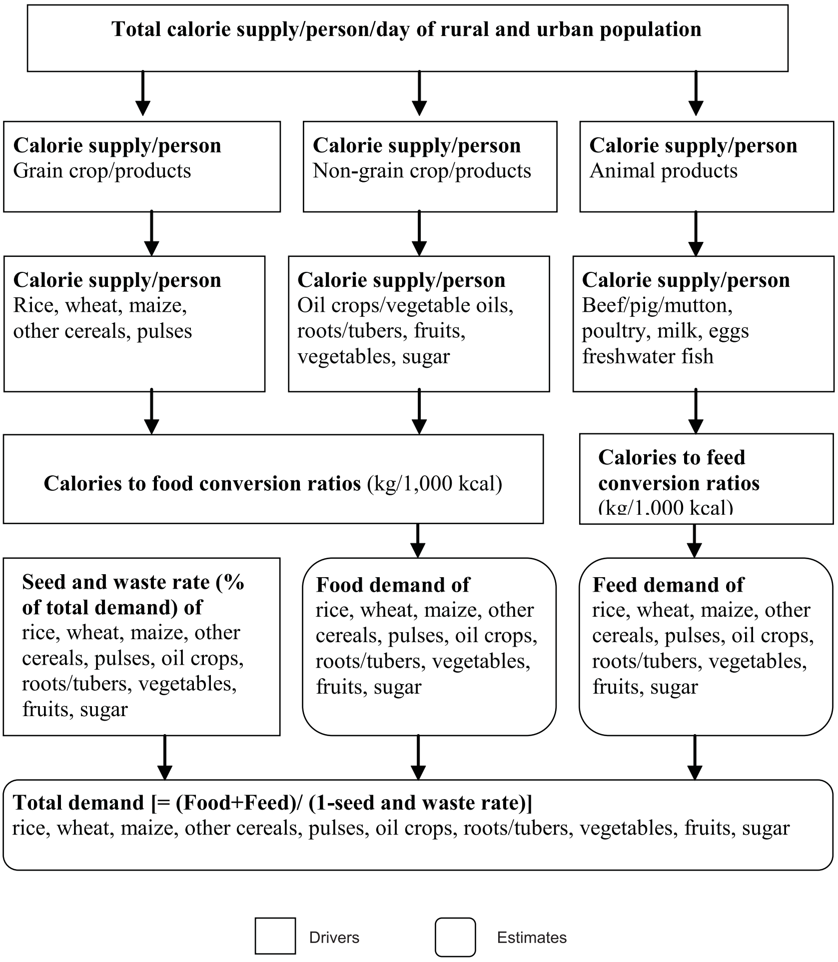
PODIUMSIM Components

The four major components of the PODIUMSIM (the policy dialogue model used for simulating scenarios) are briefly presented here. For more details, please refer to www.iwmi.org/applications/podium.

Crop Demand

The crop demand module estimates the total demand of 11 crop categories. The total demand includes the demand for food, feed and seeds and other uses. And 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. The crop demand component is given in Annex 1, Figure 1.

Annex 1, Figure 1. Flow chart: Crop demand estimation module.

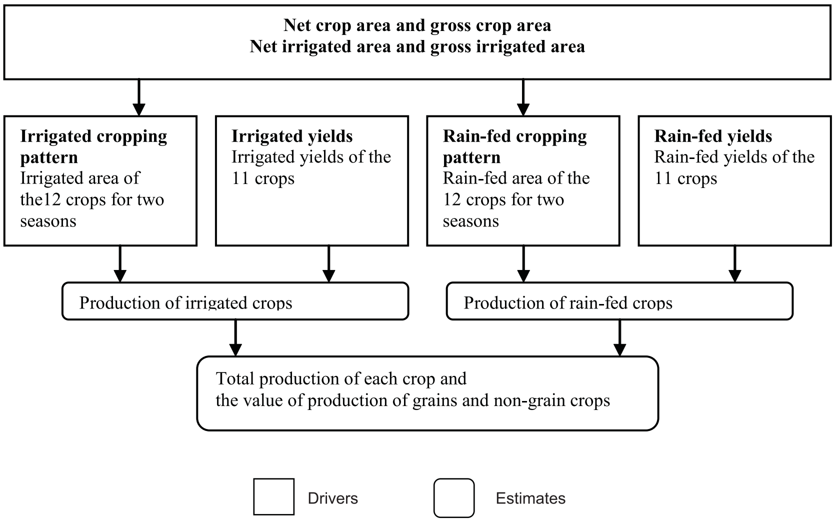


The primary objective of crop demand components is to estimate the crop requirement to achieve a certain nutritional level for the population. First, the model sets the level of daily nutritional intake per person for the urban and the rural sectors. Second, the composition of the calorie supply from grain products, non-grain crop products and animal products of the rural and the urban sectors is determined. The next step is to estimate the food and feed requirements. The food demand of different crops is obtained by multiplying the calorie intake by the food conversion factors. The food conversion factor is the quantity (kg) of food required to generate 1,000 kcal of calorie supply. The feed demand is estimated by multiplying the feed conversion ratios with the animal products' calorie supply. The feed conversion ratio is defined as the quantity (kg) of a crop used for generating 1,000 kcal of animal products in the diet. The final step is to estimate the quantity of crop allocated for seeds, waste and other uses. This is given in the model as the ratio of seed and waste to the total crop requirement. In conclusion, the total food and feed demand, and ratio of seed and waste are used to estimate the total crop demand.

Crop Production

The crop production module estimates the irrigated and rain-fed crop production of the 11 crop categories at the subnational level (Annex 1, Figure 2). 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 11 crop categories and their crop yield growth are specified. Besides the 11 crops in the crop demand module, the specified irrigated cropping patterns include fodder and other irrigated crops. The model estimates the crop production for the 11 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 paper the average export prices are those of 1999, 2000 and 2001).

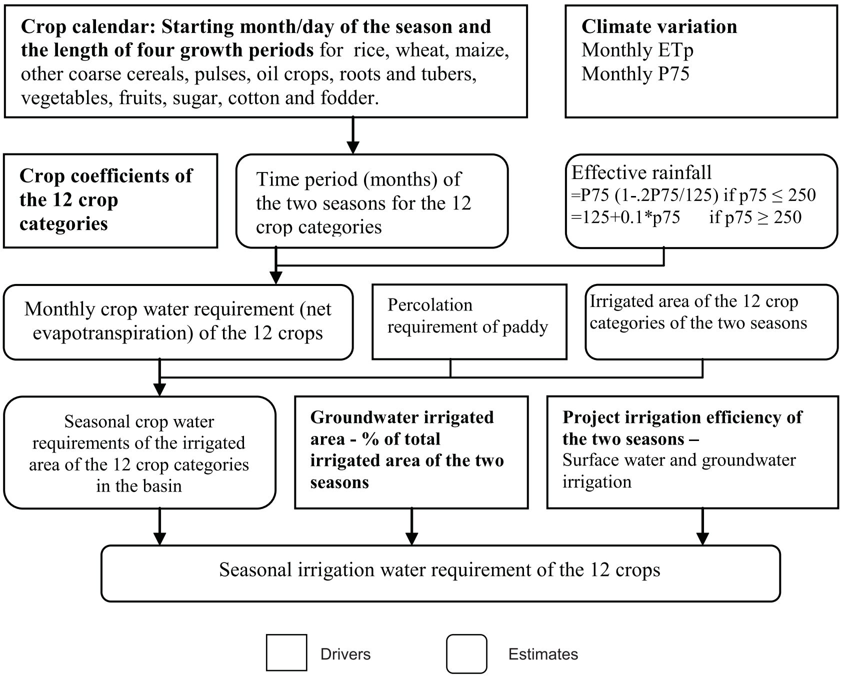
Annex1, Figure 2. Flow chart: Crop production estimation module.



Irrigation Water Demand

The PODIUMSIM model estimates the monthly irrigation water requirements during cropping periods for different seasons (Annex 1, Figure 3). 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 determined 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 www.iwmi.org/applications/podium for more details).

Annex1, Figure 3. Flow chart for irrigation water demand estimation.



Domestic and Industrial Water Demand

The domestic water demand includes the human and livestock water demands. 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 uses the norm of 25 liters per day per head water demand. The growth of industrial water requirement is taken as the driver for estimating the industrial water demand.

Environmental Water Demand

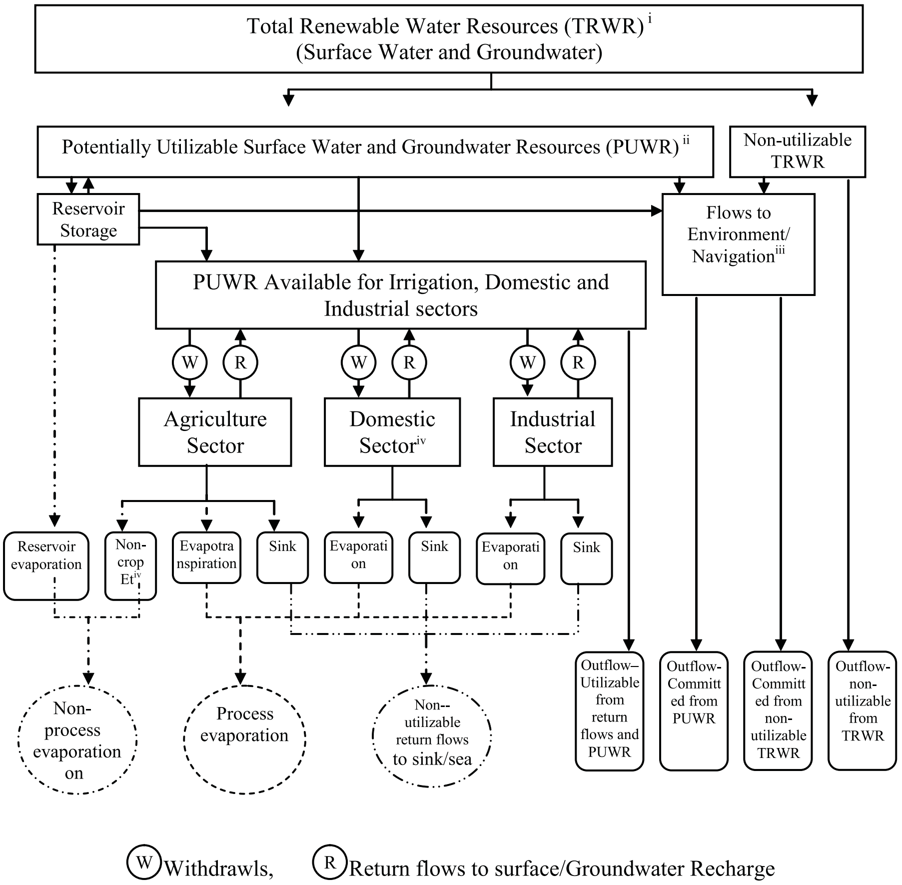
The environmental water demand component estimates the part of minimum flow requirement (MFR) of a river that has to be met from the potentially utilizable water resources (PUWR). First, we observe only a part of the minimum flow requirement in each month can be met from the non-utilizable part of the total renewable surface water resources (RSWR) or mean runoff. From this we estimate the minimum flow requirement that cannot be met from non-utilizable IRWR, and has to be met from the PUWR. Ideally, this portion of the MFR should not be made available for other users in the basin. But in most river basins, this cannot be implemented due to the increasing pressure from other sectors. Therefore, the model keeps this portion of the 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 (Annex 1, Figure 4). At any given time, only a part of the potentially utilizable water resources is developed and is used by the different sectors. Of the water diversions to the agricultural, domestic and industrial sectors, the model estimates:

- Process evaporation (evapotranspiration in the irrigation sector 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;
- Non-utilizable flows to the sea or a sink; and
- Utilizable flows to the sea from the surface water return flows and groundwater recharge.

Annex 1, Figure 4. Flow diagram of water accounting.



i. TRWR – Total renewable water resources

ii. PUWR – Potentially utilizable water resources

iii. Parts of the environment and navigation flows are met from non-utilizable TRWR and the other parts are met by PUWR

iv. Domestic sector includes livestock sector water needs

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

$$Degree\ of\ \ development = \frac{primary\ water\ \sup ply}{PUWR - environmental\ \ flows\ \ from\ PUWR}$$

$$Depletion\ \ fraction = \frac{total\ depletion}{primary\ water\ \sup pply}$$

$$Groundwater\ abstraction\ ratio = \frac{Total\ ground\ water\ withdrawals}{Total\ available\ groundwater\ \sup ply}$$

where, the primary water supply is defined as

$$\begin{aligned}\Pr imary\ water\ \sup ply = \Pr ocess\ evaporation + non\ \ process\ evaporation + \\ un\ utilizable\ \ flows\ to\ sea + utilizable\ returnflows\ to\ sea\end{aligned}$$

and

the total depletion of the primary water supply is

$$\begin{aligned}Total\ depletion = \Pr ocess\ evaporation + non\ \ process\ evaporation + \\ + un\ utilizable\ \ flows\ to\ sea\end{aligned}$$

References

Agarwal, P.K.; Talukdar, K.K.; Mall R.K. 2000. *Potential yields of rice-wheat systems in the Indo-Gangetic plains of India*. Rice-Wheat Consortium Paper Series 10. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Allan, J.A. 1998. Virtual water: Strategic resources. global solutions to regional deficits. *Groundwater* 36: 545-546.

Amarasinghe, U.A.; Sharma, B.R.; Aloysius, N.; Scott, C.; Smakhtin, V.; de Fraiture, C. 2005. *Spatial variation of water supply and demand across river basins of India.* Research Report 83. Colombo, Sri Lanka: International Water Management Institute.

Amarasinghe, U. A.; Shah, T.; Singh, O. 2006. Changing consumption patterns: Implications for food and water demand in India. Draft prepared for the IWMI-CPWF project on ‘Strategic Analysis of National River Linking Project of India’.

Bhaduri, A.; Amarasinghe, U.A.; Shah, T. 2006. *Groundwater irrigation India: Ananlysis and prognostics.* Draft prepared for the IWMI-CPWF project on ‘Strategic Analysis of National River Linking Project of India’.

Bhalla, G. S.; Hazell, P.; Kerr, J. 1999. *Prospects of India’s cereal supply and demand to 2020.* Food, Agriculture and the Environment Discussion Paper 29. Washington, D.C., USA: International Food Policy Research Institute (IFPRI).

CWC (Central Water Commission). 2004. *Water and related statistics.* New Delhi, India: Water Planning and Projects Wing, Central Water Commission.

de Fraiture, C.; Molden D.; Rosegrant, M.; Cai, X.; Amarasinghe, U. 2004. *Does international cereal trade save water? The Impact of Virtual Water Trade on Global Water Use*. Comprehensive Assessment Research Report No 5. Colombo, Sri Lanka: International Water Management Institute.

Dyson, T.; Hanchate, A. 2000. India’s demographic and food prospects: State level analysis. *Economic and Political Weekly* 11: 4021-4036 (November).

FAI (Fertilizer Association of India). 2003a. *Fertilizer and agriculture statistics, northern region 2002-2003.* New Delhi, India: The Fertilizer Association of India.

FAI. 2003b. *Fertilizer and agriculture statistics, western region 2002-2003.* Mumbai, India: The Fertilizer Association of India.

FAI. 2003c. *Fertilizer and agriculture statistics, eastern region 2002-2003*. New Delhi, India: The Fertilizer Association of India.

FAI. 2003d. *Fertilizer and agriculture statistics, southern region 2002-2003*. New Delhi, India: The Fertilizer Association of India.

Falkenmark, M.; Lundqvist, J.; Widstrand, C. 1989. Macro-scale water scarcity requires micro-scale approaches: Aspect of vulnerability in semi-arid development. *Natural Resources Forum* 13 (4): 258-267.

FAO (Food and Agriculture Organization). 1998. *Crop evaporation guidelines for computing crop water requirements.* FAO Irrigation and Drainage Paper No. 56. Rome, Italy: Food and Agriculture Organization.

FAO. 2003. *Review of world water resources by country.* Water Reports No. 23. Rome, Italy: Food and Agriculture Organization.

FAO. 2005a *FAOSATAT data base.* Rome, Italy: Food and Agriculture Organization

FAO. 2005b. *AQUASTAT data base*. Rome, Italy: Food and Agriculture Organization.

Gardener-Outlaw, T.; Engleman, R. 1997. *Sustaining Water, Erasing Scarcity. A Second Update.* Washington, D.C., USA: Population Action International.

GOI (Government of India) 1999. *Integrated water resources development. A plan for action.* Report of the Commission for Integrated Water Resource Development Volume I. New Delhi, India: Ministry of Water Resources.

GOI. 1996. *Key results on households consumer expenditure in 1993-94, 50th round.* Report No. 401. New Delhi, India: National Sample Survey Organization, Ministry of Statistics, Government of India.

GOI. 2002. *Consolidated results of crop estimation survey on principal crops 2001-2002.* New Delhi, India: National Sample Survey Organization, Ministry of Statistics, Government of India.

GOI (Government of India) 2003. *Final Population Totals – India (India, State, District, Sub-district, Town, Ward-in-town & Village).* New Delhi, India: Office of the Registrar General & Census Commissioner, India.

GOI. 2004. *Agricultural statistics at a glance 2004.* New Delhi, India: Ministry of Agriculture, Government of India.

Hargraves, G. H.; Samani, Z. A. 1986. *World water for agriculture.* Logon, Utah, USA: International Irrigation Center, Department of Agricultural and Irrigation Engineering, Utah State University.

Hemme, T. Garcia, O.; Saha, A. 2003. *Review of milk production in with a particular emphasis on small-scale producers*. PPLPI Working Paper No. 2. Rome, Italy: FAO.

INCID (Indian Committee on Irrigation and Drainage) 1998. *Sprinkler irrigation in India.* New Delhi, India: Indian Committee on Irrigation and Drainage.

IWMI (International Water Management Institute). 2000. *World water supply and demand 1995 to 2025 (draft)*. www.cgiar.org/iwmi/pubs/WWVison/WWSDOpen.htm

IWMI. 2001. *IWMI climate and water atlas.* Colombo, Sri Lanka: IWMI CD-ROM.

IWMI. 2005. *Land use land cover (LUCL-MODIS 500m, 2000),* www.iwmidsp.org

Joshi, P.K.; Birthal, P.S.; Minot, N. 2006. *Sources of agriculture growth in India. Role of diversification towards high-value crops.* MTID Discussion Paper No. 98. Washington, D.C., USA: International Food Policy Research Institute.

Kumar, D.; Singh, O.P. 2005. *Virtual water in global food and water policy making: Is there a need for rethinking?* IWMI-Tata Water Policy Research Highlights,

Kumar, M.D.; Samad, M.; Amarasinghe, U.A.; Singh, O.P. 2006. Water saving technologies: How far can they contribute to water productivity enhancement in Indian agriculture? Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Kumar, M.D.; Singhe, O.P.; Samad, M.; Purihit, C.; Didyla, D. 2006. Water productivity of irrigated agriculture in India. Potential areas of improvement. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Kundu, A. 2006. Estimating urban population and its size class distribution at regional level in the context of demand for water: Methodological issues. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Mahmood, A.; Kundu, A. 2006. Demographic projections for India 2006-2051: Regional variations. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Molden, D.J. 1997. *Accounting for water use and productivity.* SWIM Paper 1. Colombo, Sri Lanka: International Water Management Institute.

Narayanamoorthy, A. 2006. Potential for drip and sprinkler irrigation in India. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

NSSO (National Sample Survey Organization). 2001. *Key results on households consumer expenditure in 1999-2000 55th round.* Report No. 461. New Delhi, India: Department of Statistics, Government of India.

Palanisami, K.P.; Senthivel, K.; Ranganathan, C.R.; Ramesh, T. 2006. Water productivity at different scales under canal, tank and tubewell irrigation systems. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Pandey, U.K. 1995. The Livestock Economy of India: A Profile. *Journal of Indian Agricultural Economics.* 50. (3): 264-282.

Rao, H.C.H. 2005. *Agriculture, food security, poverty and environment.* New Delhi, India: Oxford University Press.

Rosegrant, M. W.; Paisner, M.S.; Meger, S.; Witcover, J. 2001. *Global food projections to 2020.* Washington, D.C., USA: International Food Policy Research Institute.

Rosegrant, M.W.; Cai, X.; Cline, S.A. 2002. *World water and food 2025. Dealing with scarcity.* Washington, D.C., USA: International Food Policy Research Institute.

Rijsberman, F.R. 2000. *World water scenarios: Analysis.* London, UK: Earthscan Publications.

Seckler, D.; Amarasinghe, U.A.; Molden, D.; de Silva, R.; Barker, R. 1998. *World water demand and supply 1995 to 2025: Scenarios and issues.* Research Report No. 19. Colombo, Sri Lanka: International Water Management Institute.

Shah, T.; Roy, A.D.; Qureshi, A.S.; Wang, J. 2001. Sustaining Asia's groundwater boom: An overview of issues and evidence. Draft paper prepared for the International Conference on Freshwater in Bonn.

Sharma, B. 2006. The 'tipping point' in Indian agriculture. Understanding the withdrawal of Indian rural youth. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Sharma, B.; Rao, K.V.; Vittal, K.P.R. 2006. Realizing the rain-fed agriculture potential in India. Draft prepared for the IWMI-CPWF project on 'Strategic Analysis of National River Linking Project of India'.

Smakhtin, V.; Anputhas, M. 2006. *An assessment of environmental flow requirements of Indian river basins.* Research Report 107. Colombo, Sri Lanka: International Water Management Institute.

UN (The United Nations). 2004. *World population prospects, the 2004 revision.* New York, USA: UN Department for Policy Coordination and Sustainable Development.

WRI (World Resources Institute). 2005. *Earth trends*. Searchable database http://earthtrends.wri.org. Washington, D.C.