India's Water Demand Scenarios to 2025 and 2050: A Fresh Look

[1]Upali A. Amarasinghe, [2]Peter G. McCornick and [3]Tushaar Shah
[1]International Water Management Institute (IWMI), NewDelhi, India
[2]International Water Management Institute (IWMI), Colombo, Sri Lanka
[3]International Water Management Institute (IWMI), Anand, India

Introduction

India is a vast country and its water supply varies significantly across regions and river basins. Water is plenty in the northeast (Brahmaputhra and Meghna basins), but few people live there, and land availability and food production is low. In the northwest most of the water resources are diverted for crop production to the extent that this region supplies food to the deficit regions of the country making it the largest provider of virtual water, that is water embedded in food, in the county (Amarasinghe et al. 2005). Water is scarce in the south and west of the country as the naturally drier areas come under increasing demand, and the aquifers have low storage capacity.

Much of the runoff in the peninsular river basins is from the highly variable monsoon, which means it occurs during the 2 to 3 months of monsoonal rains. Thus, the regional water availability vis-à-vis changing water demand patterns and the determinants of these changing growth patterns are particularly important factors for medium to long-term water investment strategies in general in India, and in particular in the water-scarce peninsular river basins.

This report examines the implications of future water supply demand of India under business as usual (BaU) scenario trends of key water demand drivers and also under possible divergences. The assumptions of the growth of key drivers in the BaU scenario (Annex 1) in this paper significantly differ from the assumptions of the scenarios of the NCIWRD (discussed in detail in Paper 2). The BaU scenario considers the year 2000 data as the base year and the trends in the 1990s for its demand projections whereas the NCIWRD scenarios considered 1993/94 data for the base year and the trends in 1980s for determining the key drivers. This report, which is primarily, based on the studies by Amarasinghe et al. 2007a and 2007b,

- gives an overview of the business as usual (BaU) scenario food and water demand up to 2025/2050 in India;
- discusses the past trends of key determinants or 'drivers' of water and food demand; and

- assesses the deviations of BaU scenario projection with respect to possible deviations of the assumptions of key drivers.

The projections of food and water demand of different scenarios use the methodology of the PODIUMSIM model. The PODIUMSIM model is a tool for simulating the alternative scenarios of water futures with respect to the variation of food and water demand drivers (www.iwmi.cgiar.org/tools/PDF/PODIUMSIM.pdf).

The report is organized into three sections. It first presents an overview of the BaU scenario water demand, which is followed by a discussion of the deviation of BaU water and food demand projections with respect to the assumptions of key drivers. The final section considers development issues, which have significant investment implications for meeting India's future water demand.

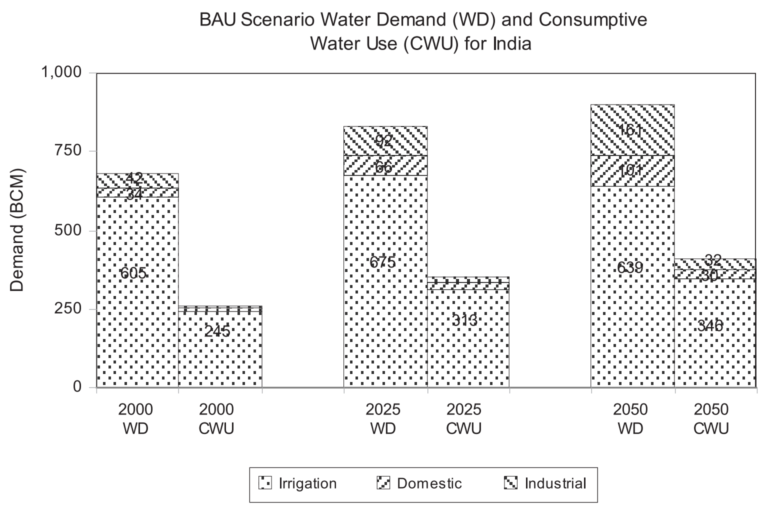
BaU Scenario – Overview

Total Water Demand

India's water demand patterns are fast changing. The water withdrawal for the agriculture, domestic use and industry, the three most consumptive water use sectors, in 1960 was 277 billion cubic meters (bcm) (Shiklomanov 1999). This has since increased to about 680 bcm in 2000. The BaU scenario, based on the PODIUMSIM analysis, projects that the total water demand will increase by another 150 bcm, or 22 % by 2025; and a further 69 bcm or 8 % by 2050 (Amarasinghe et al. 2007a) (Annex 1 for details of the assumptions on key drivers and comparison with other different scenarios of water demand projections).

However, the dominance of agriculture in the water demand is projected to change over time (Figure 1). Although agriculture is still the largest water use sector, the share of it in the

Figure 1. Water demand and consumptive water use of the agriculture, domestic and industrial sector of India.



total water demand is expected to decrease. Irrigation has accounted for 98 % of the total withdrawals in 1950, and 89 % in 2000. BaU trends projects a further decline – 81 % in 2025, and 71 % in 2050. However, the irrigation demand will increase in absolute terms between 2000 and 2025, and will decrease between 2025 and 2050. The decrease in demand during 2025 to 2050 is due to various factors including expansion of groundwater use, spread of micro irrigation technologies, higher irrigation efficiencies and decreased demand for grain crop, especially rice.

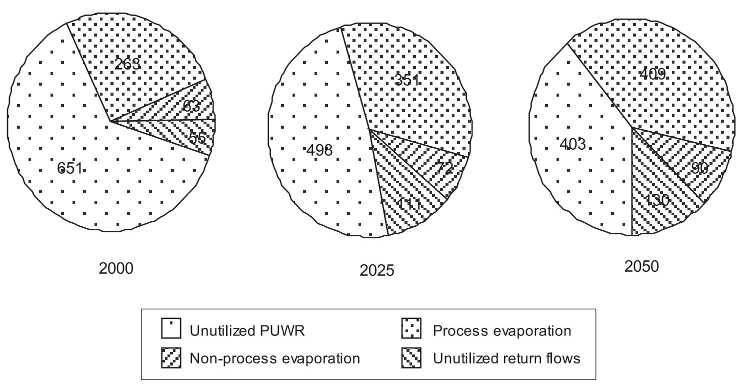
The domestic and industrial sector water demands, unlike in the agriculture sector, are increasing rapidly. The shares of the domestic and industrial sectors of the total water withdrawals are projected to increase, from 5 and 6 %, respectively in 2000, to 8 % and 11 % by 2025, and 11 % and 18 % by 2050 (Figure 1). Rapid growth of the industries and services, which is associated with recent economic expansion and urbanization are the major causes for this increasing demand. In fact, unlike in the past, the total additional water demand of the domestic and industrial sectors is projected to exceed the additional irrigation demand, and accounts for 54 % growth between 2000 and 2025, and 85 % of growth between 2025 and 2050.

Water Accounting

In spite of the large water withdrawals, India has very low consumptive water use or process depletion. The process depletions, the water depleted through evaporation and transpiration in the process for which the water is diverted, was only 39 % of the total withdrawals in 2000 (authors' estimates based on PODIUMSIM model). In irrigation, the average process evaporation at the project level is estimated as only 41 %. However, all the water lost at the project scale, is not lost at the basin scale. The return flows to surface and groundwater systems in one location are again reused in downstream locations. This results in basin water use efficiency being higher than the system efficiency.

Figure 2 shows the aggregate water accounting at the national level. The water accounting of the BaU scenario, estimated according to Molden's water accounting framework (Molden 1997), was assessed at the river basin level. The process depletion from all basins in 2000 was 69 % of the primary water withdrawals, but was only 39 % of the total water withdrawals. This indicates that much of the return flows of the primary water withdrawals are reused as surface or groundwater downstream. The primary water withdrawals as a percentage

Figure 2. Water accounting of potentially utilizable water resources (in billion cubic meters) of all river basins in India.

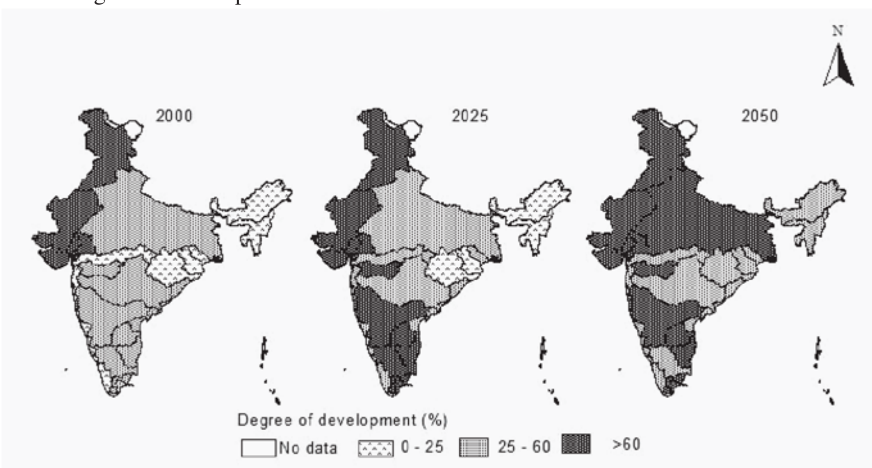


of potentially utilizable water resources, called the *degree of development*, in 2000 was only 37 % (authors' estimates based on PODIUMSIM model). This ratio is estimated to increase to 52 % and 61 % by 2025 and 2050, respectively (Amarasinghe et al. 2007b). When the degree of development exceeds 60 %, the basins or countries are classified as physically water-scarce (Seckler et al. 1998; IWMI 2000). High physical water scarcity indicates severe physical and economic constraints for further development of the water resources. In physically water-scarce river basins, there are not enough utilizable water resources left for further development without affecting the environment and the other riverine water users. It also indicates progressively high cost of developing the remaining water resources.

Although the degree of development at the national level and also of few relatively large river basins are low at present, several other river basins are already physically water-scarce due to water supply and demand mismatches (Figure 3). In other words, they have a high degree of development. This situation is expected to worsen in the future. Four basins, the Indus, Sabramati, Mahi and west flowing rivers of Kutch and Saurashtra, with 11 % of the total population, were physically water- scarce in 2000. A further 11 basins are projected to reach this status by 2050, and as a result three-quarters of the total population will live in such basins.

Many basins will require substantial additional water resources to meet the future demand by 2025. These basins are economically water-scarce where the additional water requirements by 2025 exceed 25 % of the primary water withdrawals at the 2000 level. The economic water-scarce basins require substantial investments if these additional water demands are to be met.

Figure 3. Degree of development of Indian river basins.

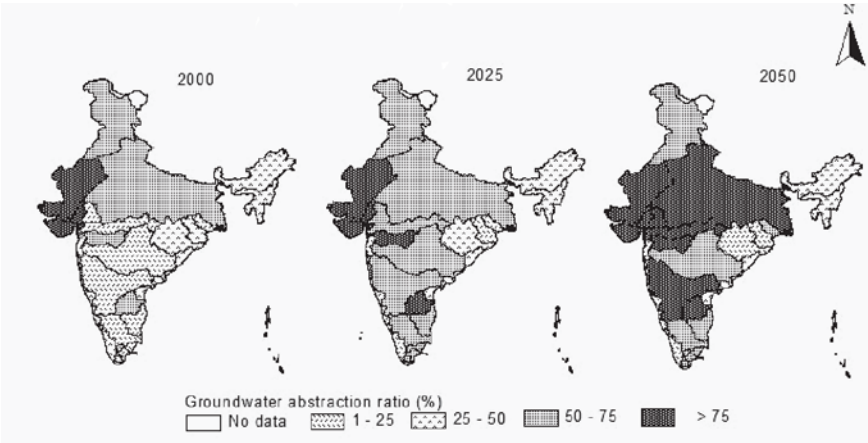


Groundwater Use

Groundwater development was the main driver of irrigation expansion in the 1980s and 1990s. This reliance of groundwater is projected to continue further. India abstracted about 300 bcm of groundwater in 2000 of which 91 % was for the agriculture sector (authors' estimates based on PODIUMSIM model). Amarasinghe et al. 2007b projects that total groundwater withdrawal will further increase, 11 % by 2025, and 7 % more by 2050.

As the reliance of groundwater, especially for irrigation, increases, many basins will have severe groundwater depletion. According to the BaU scenario, many basins will have groundwater abstraction more than 75 % of their utilizable groundwater resources by 2050. Figure 4 shows the groundwater abstraction ratio - the ratio between total groundwater withdrawals and the total utilizable groundwater resources. The utilizable groundwater resource is defined as the available groundwater through natural recharge from rainfall and the artificial recharge from the return flows of various uses. As the water use patterns are not uniform within basins, many regions of these basins will have unsustainable water use patterns, and even economically profitable cropping patterns may become hydrologically unsustainable (e.g., rice-wheat in the western IG basin).

Figure 4. Groundwater abstraction ratio of Indian river basins.



Crop Production Surplus or Deficits

We also present the production surplus or deficit estimates, the difference between the production and consumption demand of major crop or crop categories resulting under the BaU scenario water use patterns. The consumption demand estimates here are based on the food consumption demand estimates of the rural and urban population and the feed demand for the livestock sector at the state level (Amarasinghe et al. 2007b). The food production estimates are based on the cropping patterns and crop productivity growth assumptions at the state and district level (Amarasinghe et al. 2007a). Despite the complicating water picture described above, India has substantial rice and wheat surpluses in 2000 and will continue to be so in the future. Past trends show per capita consumption of rice in both the rural and urban areas are decreasing and consumption of wheat is stabilizing. With these changing consumption patterns and with rather optimistic crop productivity growth assumptions, BaU scenario projects production surpluses for rice and wheat to increase substantially by 2025 and even more by 2050 (Table 1). However, the present production deficits for other cereals (maize and other coarse cereals) are projected to get significantly worse over the same time frame primarily due to rapidly increasing maize demand for livestock feeding. The maize demand is projected to increase from 5 mmt in 2000, to 107 mmt by 2050. However, the production

Table 1. Production, demand and production surpluses or deficits of different crops.

Crop	Production			Demand			Production surpluses/ deficits as % 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
Total- 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
Grains (BUS$)[1]	54	74	93	52	73	90	3	0.4	3
Non-grains (BUS$)[1]	96	187	266	106	198	284	-9	-5	-6
Total (BUS$)[1]	150	261	359	158	272	374	-5	-4	-4

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

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

surpluses of rice and wheat offset the deficits of other cereal crops to maintain overall grain production surpluses by 2050.

Among the non-grain crops, oil crops and fruits will have substantial production deficits by 2050. Fruits record a production deficit by 2050, where increasing demand will far outweigh the production. However, this situation may change if the conversion of wastelands to orchards will significantly increase. 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 in 2000. However, with increasing sophistication of the market demand and resulting crop diversification, this deficit is projected to decrease to 6 % by 2050. The total value of the production of all crops is projected to have a slight deficit, about 4.0 % by 2025 and 2050.

Key Determinants of Water Demand - Sensitivity

Trends in the 1990s were used as a guide for determining the future growth of the key drivers of BaU. However, slight changes in many of these key drivers will have significant changes in the demand projections. Here, we highlight three drivers which could have a significant bearing on the water demand and also for decisions on future investments in the water sector.

Groundwater Irrigation Growth

Until mid-1980s, surface irrigation was the major source of irrigation in Indian Agriculture, and the groundwater development was considered to have been within the canal commands. But, since mid 1980s, groundwater is the major source of irrigation for many regions and districts, and in some cases spreading to areas even outside the canal commands (Bhaduri et al. in this volume, Shah et al. 2001). In fact, groundwater irrigation has contributed to virtually all of the net irrigated area (NIA) growth since mid 1980s. BaU scenario projects this trend to continue, and assumes that

- the on-going major to medium irrigation projects will also add another 10 million ha (mha) of net surface irrigated area (NSIA) by 2025, and growth of NIA after 2025 is primarily groundwater driven; but
- the groundwater irrigated area expansion will slow down due to excessive depletion in some basins and net groundwater irrigated area (NGWIA) is assumed to increase from 37 mha in 2000 to 50 mha by 2050; and
- as a result, the gross irrigated area increases from 77 Mha in 2000 to 117 Mha by 2050.

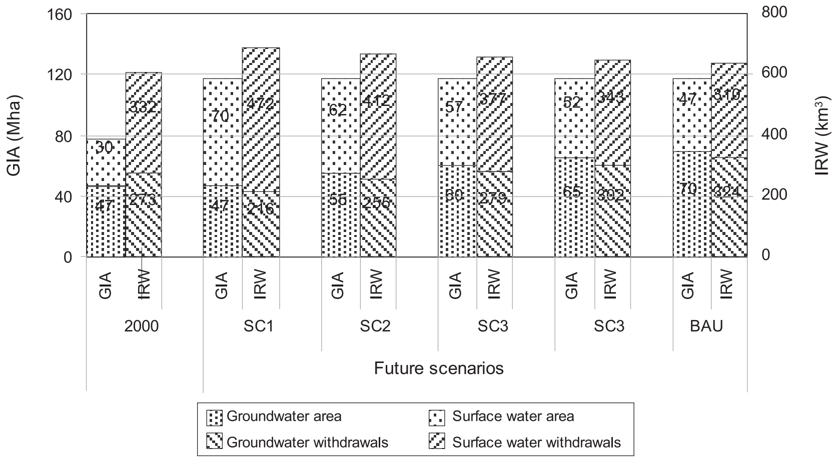
But, the crucial question is how far can groundwater irrigation expand in India beyond the 2000 level? If NGWIA increases to 50 Mha (as assumed in the BaU scenario), because of the increased cropping intensity the gross groundwater irrigated area (GGWIA) is estimated to increases to about 70 Mha. But according to the Central Ground Water Board the estimated gross groundwater irrigation potential stands at only 65 Mha, and according to Sanghal (1987) the groundwater coverage is estimated as 80 Mha. A recent study (Thenkabail et al. 2006), using remote sense imageries, estimates that NIA of India is already 100 Mha, in contrast with the 56 Mha reported by official statistics. The same study also determined that a greater portion of the irrigated area is supplied by groundwater, and the gross irrigated area is close to 133 Mha. So, the assumption on the growth of groundwater irrigation still could deviate substantially than that assumed under BaU scenario.

First, we assess the implications of these deviations on the total irrigation demand using four alternative scenarios (SC1-SC4) of slower growth of the groundwater irrigated area (Figure 5). SC1 relates to no further expansion of the ground water irrigated area from the level of 2000 and SC2, SC3 and SC4 relate to the increase of gross groundwater irrigated area to 55 Mha, 60 Mha or 65 Mha, respectively. In each case, we assumed gross irrigated area (117 Mha) and the efficiencies of surface water and groundwater irrigation remain the same.

Deviations SC1 and SC2 from the BaU scenario require substantial increases in withdrawals of surface water (140 km^3 under SC1 and 80 km^3 under SC2), but lower withdrawals of groundwater (57 km^3 under 18 km^3 under SC2) from the 2000 level (Overall water requirement under SC1 and SC2 will increase by 14 % and 10 %, respectively. While such growth in irrigation scenarios can be a big relief for over exploited groundwater basins, it requires substantial investments in surface water development for meeting the projected food demand.

On the other hand, deviations SC3 and SC4 from the BaU scenario would result in an increase in both surface and groundwater irrigation withdrawals (43 km^3 and 6 km^3 in SC3 and 11 km^3 and 29 km^3 in SC4, respectively) from the 2000 level. These two scenarios, while still

Figure 5. Gross irrigated area (GIA) and irrigation withdrawals (IRW).



Source: Authors' estimates using PODIUMSIM

require developing more surface water resources will also increase the pressure on already overexploited groundwater resources in water-scarce basins.

What are the implications of keeping the groundwater irrigation withdrawals at the level of abstraction in 2000? With the projected irrigation efficiencies in the BaU scenario, the groundwater irrigated area can then be increased by another 12 Mha from the 2000 level. This requires doubling the gross surface irrigated area to 58 Mha, and increasing surface irrigation withdrawals by 54 km^3 to meet the projected crop production under the BaU scenario.

The above analysis shows that deviations in the form of slower growth of groundwater irrigation than assumed in the BaU scenario would require substantial investments in developing surface water resources. However, if only the groundwater irrigation potential projected by the Central Groundwater Board is used in irrigation, then India would be using only two-thirds of its available groundwater resources. However, even under this scenario, many river basins will still have severe regional overexploitation.

It is important to note that all these scenarios assumed a reasonable increase in the efficiency of both groundwater and surface water use for irrigation. We assess the implication of deviations from assumed efficiencies next.

Growth in Irrigation Efficiency

The BaU scenario assumes a modest growth of surface and groundwater project efficiency. First, from the information available, the project efficiency of surface irrigation systems has not improved much over the years. But it is clear, however, that the nonagricultural sector water demand, especially for surface water, is increasing at a faster rate, and the irrigated agriculture will have to produce more with less water. So, it is imperative that project surface irrigation efficiency increases, from the present level of about 30-40 %, to meet this growing demand. That said, in some basins, increasing the project efficiency in certain systems will negatively affect other water users downstream. The return flows of many low efficiency surface irrigation systems are either a source for more productive groundwater agriculture or to meet the environmental water needs in the downstream. As discussed earlier, the overall efficiency of these basins, where return flows are recycled and reused, is already high. Thus, increasing surface efficiency for that saved water to be consumed by other upstream users could only adversely affect the downstream water users. The BaU scenario assumes that surface project irrigation efficiency increase to about 45 % by 2025, and 50 % by 2050. Clearly such efforts should be targeted at locations where both the project and the basin level efficiencies are relatively low, and careful consideration needs to be given as to how to improve the management of these schemes that are at stubbornly low levels to date.

Second, the water saving technologies and the institutional interventions for increasing the efficiency of groundwater are spreading. Decreasing public investments in major and medium irrigation, food and livelihood security for the agriculture dependent rural households coupled with low energy prices and free electricity supply have contributed to the recent groundwater boom. As a result, the depth to the groundwater table in many locations is increasing at an alarming rate, and the physical or the economic water scarcities are emerging in many locations. At the same time, the energy prices are escalating, and providing free electricity for the agriculture sector is becoming a huge burden to the state coffers, and the solvency of the power companies. Using diesel for pumping long hours is not a viable proposition any more for the small and marginal farmers. Innovations such as informal water markets, regulating electricity supply to agriculture through separate power lines, and water saving technologies are being promoted to address the problems in the groundwater irrigated agriculture. All these measures have been shown to increase the water use efficiency. For example, drip and sprinkler irrigation are generally 15-20 % more efficient than the flood irrigation. The BaU scenario assumes that this trend towards higher efficiency technologies will continue, and the overall groundwater efficiency would increase from about 65 % in 2000 to 75 % by 2050.

However, with increasing scarcity and escalating energy prices, farmers may increasingly opt for micro-irrigation techniques, such as sprinklers and drip, for enhancing water use efficiency. Efficiency of a well managed sprinkler and drip system can be as high as 80-95 % (Narayanmoorthy 2007). If the overall groundwater irrigation efficiency can be increased to 80 %, 5 % over the BaU scenario, the total irrigation water demand in 2050 could go down by 32 BCM; and with 5 % more groundwater irrigation efficiency growth, the total irrigation demand could decrease another 20 BCM. This reduction in groundwater pumping could reduce the over abstraction to a great extent in many water-scarce basins, although the actual consumption of water would remain the same as projected under the BaU.

Crop Productivity Growth

Until now, India's growth in crop yields has been stubbornly low in comparison with that of other countries with major irrigated agriculture sector. For example, grain crops always had a preeminent position in Indian agriculture, and, as a result, the country is one of the three largest grain producers in the world today. But India also has one of the lowest yield growth among all grain producers. Between 1960 and 2000, average grain yields increased only by 1.0 ton/ha in India, from 0.7 tonnes/ha in 1961, while China increased its grain yields by 3 tonnes over the same time period; and the USA increased its yield by almost 4 tonnes/ha. Compounding the low yields, the rate of growth also has been decreasing in the last decade, from an all time high of 3.8 % annually for grains in the 1980s to 2.0 % in the 1990s. Recent policy decisions of the government of India suggest that there will be more investments for research and development for increasing crop productivity in the coming decades. Therefore, although the BaU scenario does not anticipate a complete reversal of the declining trends of crop productivity, it expects a reduction in the rate of decline of the growth rates. In fact, this rather optimistic assumption of growth in crop yield is a key component of BaU scenario food and water demand projections.

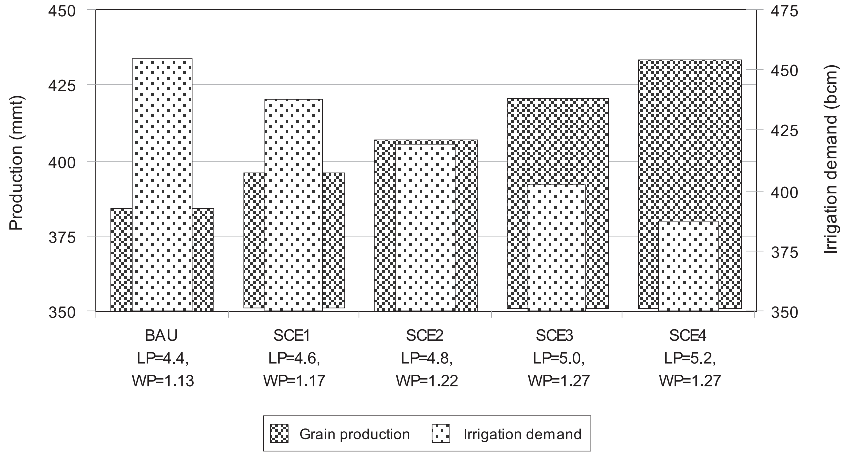
In spite of these decreasing trends, this analysis assumes that a substantial scope exists for increasing the yield beyond the current level. A significant gap exists in many locations between the highest and the lowest actual yields, and between the actual and the potential yields. The future investments, both private and public sector, focus on small-scale infrastructure and technologies that enhance the crop yields. Breeding of rice hybrids and improved varieties of other crops (improving harvest index), reducing losses through pests and diseases and post-harvest losses, expanding groundwater use and micro irrigation technologies offer significant opportunities for the irrigated yield growth. And the supplementary irrigation, through water harvesting (Sharma et al. in this volume), at critical periods of water stress, can substantially boost rain-fed yields. Moreover, farmers will have an incentive to increase crop productivity to benefit from the increasing internal and external food trade. Thus, the BaU scenario crop productivity growth rate assumptions are somewhat optimistic than the assumptions recent trends indicate. Even these assumptions to some extent are conservative according to some, as they argue that a second green revolution is well overdue. If that happened it could dramatically change this yield growth scenario.

BaU scenario in this paper projects the decreasing trend of yield growth to continue, albeit at a slower rate. The grain yield growth is expected to be 1.5 % annually between 2000 and 2025, and 1.0 % annually between 2025 and 2050. BaU scenario assumes a similar growth pattern for non-grain crops.

Irrigated agriculture is estimated to contribute three-quarters of the crop production by 2050. Thus, a small increase in the irrigated yield from the BaU scenario can significantly increase the crop output from the same irrigated area or reduce the irrigation demand to maintain the same production levels. For example, the BaU scenario expects the irrigated grain yield to increase from 2.6 to 4.43 tonnes/ha between 2000 and 2050. But our analysis shows that crop yield growth assumptions indeed are very sensitive to the total crop production and irrigation water demand projections. Figure 6 shows grain production and irrigation demand under different land productivity (LP in tonnes/ha) and water productivity (WP in kg/m^3 of consumptive water use) growth assumptions. SCE1-SCE4 assume that land or water productivity increase annually at 0.08 to 0.30 % higher than the assumed growth in the BaU scenario.

If irrigated land productivity can be doubled by 2050, as indicated in SCE4, then the grain production can be increased by 13 % from the same irrigated area. On the other hand, if water productivity is doubled, the crop production can be maintained at the BaU scenario level with 15 % less irrigation withdrawals. Is this a realistic goal to achieve? One could argue that, given the significant productivity variations that exist in similar agro-climatic zones (Molden et al. 1998), doubling water productivity in 50 years is not an impossible target to achieve. The SCE4 has the average grain yields of China in 2000. Can India reach the China's yield levels in 50 years from now? If it can, future grain production requires much less irrigation water than they use now.

Figure 6. Grain production and irrigation demand under different assumptions of land and water productivity growth.



Source: Authors estimates based on PODIUMSIM analysis.

Rain-fed Crop Production

Although the above discussion mostly focused on irrigation, a brief description of the potential improvements in the rain-fed agriculture is required here. Rain-fed agriculture, water harvesting and the related yield improvements are discussed in detail in two later papers. We discuss here only the rain-fed agriculture contribution to the BaU scenario. Another key assumption of the BaU scenario is that India’s net sown area will remain the same in the period 2000-2050. This assumption implies that the existing rain-fed area is either replaced by the new irrigated area or taken over for the nonagricultural purposes. Over the period 2000-2050, the rain-fed crop area under the BaU scenario is projected to decrease from 60-44 % of the gross cropped area. How will then rain-fed agriculture contribute to overall crop production?

In 2000, grain area under rain-fed agriculture was 57 % of the total grain area, and contributed to 33 % of the crop production. Abysmally low rain-fed yield was the main reason for low contribution. India’s grain yield, only 0.97 tonnes/ha in 2000, is one of the lowest among the countries with significant rain-fed areas. It is only 20 %, 32 % and 37 % of the rain-fed yield of the USA, China and Argentina, respectively. Given these differences, it seems that a substantial scope exists for improvements in the rain-fed yield in the future. Indeed, in Paper 10, Bharat et al. show that with proper application of inputs and a small dose of supplemental irrigation in the water stress crop periods the yields of many rain-fed crops can even double.

The BaU scenario assumes that the rain-fed yield will increase to 1.3 tonnes/ha in 2025, and 1.8 tonnes/ha by 2050. That is the BaU assumes that rain-fed yield will increase by 80 % over the 50-year period from 2000. By 2050, the rain-fed area will consist of 34 % of the total grain area, but contributes to 28 % of the total grain production. This contribution can be increased further with the higher growth in rain-fed yield. The results of that obviously is lower requirement for irrigated area expansion and hence irrigation. In Paper 10, Bharat et al. show that local water harvesting, in extremely non-arid or non-wet areas, could indeed provide the small supplemental irrigation that is required for the rain-fed yield increase. However, in Paper 14, Dinesh et al. show that water harvesting potential is very low in water- scarce areas due to physical and institutional constraints. Further research is required to identify the high potential rain-fed areas where water harvesting is feasible for providing the small supplemental irrigation.

Conclusion

This report discussed the implications of future food and water demand under the business as usual scenario trends. For most determinants, the BaU scenario assumes the growth patterns of the recent years for future projection. For the yield growth, based slightly optimistic assertion of agriculture investments, we assume somewhat higher growth rates than the recent trends.

On the water demand side the BaU scenario projects that:

- India's total water demand, for the irrigation, industrial and domestic sectors, increases 22 % and 32 %, respectively by 2025 and 2050, from the estimated withdrawals of 680 bcm in 2000;
- industrial and domestic sectors account for 54 % and 85 % of the additional water demand by 2025 and 2050, respectively;
- groundwater use will contribute to a major share of the future irrigation water withdrawals;
- and on the supply side several basins will reach physical water-scarce condition by 2050, where the remaining utilizable water supply cannot be developed further without making a severe impact on the environment and riverrine water users down stream; and
- groundwater abstraction to increase significantly and many basins will have unsustainable water use regions, where the total available groundwater through recharge from natural rainfall and return flows in some regions are not adequate for meeting the increasing demand.

The agriculture water demand projections have accounted for the expected changes in consumption patterns. The BaU projections show that on the food demand side,

- India's preeminence in food grains in the diet is changing, and food grain consumption will continue to decrease from 471 grams/person/day in 2000 to 454 and 417 grams/person/day, respectively by 2025 and 2050;
- non-grain crop products including vegetables, fruits and vegetable oil, and animal products, primarily from dairy and eggs, will provide a major part of the nutritional intake by 2050; and
- due to increasing animal product consumption, the feed grain demand will increase significantly from a mere 8 mmt in 2000 to about 38 and 111 mmt by 2025 and 2050.

And, on the food supply side,

- there will be production deficits of maize and pulses, but the production surpluses of rice and wheat offset this deficit, and will have grain production surpluses over the demand;

- oil crops and fruits will have production deficits by 2050; but
- crop diversification will help decrease the overall value of crop production deficits from 9 % of the demand in 2000 to about 4 % by 2050.

The sensitivity analysis shows that changes in the ground water irrigated area, groundwater efficiency and crop productivity could significantly alter the BaU food and water demand projections. A slight crop productivity growth, in both irrigated and rain-fed agriculture, beyond the BaU assumption could result in a significant

- reduction in water needs for meeting the projected food demands; or
- increase in food production from the projected level of BaU irrigation withdrawals.

In fact crop water productivity growth is by far the best option for meeting future food demand while reducing the pressure on water resources. It is imperative that India should invest in increasing research and extension for increasing their crop productivity from the dismal levels at present.

Groundwater expansion is also an influential driver on future water demand. Given the present investment patterns, groundwater will continue to play a major role in irrigation expansion in the short to medium terms. Groundwater expansion not only reduces the withdrawal requirement, but could also lead to higher crop productivity and economic benefits. However, overexploitation in different river basins could be a serious constraint for sustaining groundwater expansion in the future. India should invest in artificial recharge programs for increasing the groundwater stocks where opportunities exist to capture water from under developed basins or sub-basins and recharge into appropriate aquifers as long as it does not create adverse impacts in the down stream water users.

India should also introduce physical and institutional interventions including micro irrigation techniques, regulating the electricity supply and introducing efficient water markets, for reducing the uncontrolled pumping in many river basins. Depending on the extent of the success of these programs groundwater expansion will continue to expand and benefit the irrigation users.

It is also important to note that it may be inevitable that India will have to find adequate surface water resource for meeting the increasing domestic and industrial water requirements. The additional surface water resource required for these two sectors exceed the estimated surface water reallocation from the irrigation sector. This requirement may increase beyond the BaU scenario estimates with a higher growth in Indian economy.

Annex 1.

Assumption of Key Drivers in the BaU Scenario

The assessment of BaU scenario uses the methodology of PODIUMSIM model Policy Dialogue Model Simulation for projecting India's water future. The PODIUMSIM is a tool for simulating the alternative scenarios of food and water future with respect to the variation of food and water demand drivers. The model has four major components, which can assess food and water demand at various temporal and spatial scales: crop demand (annual and state/river basins/ national), crop production (seasonal and districts/state/river basins), water demand (monthly and districts/state/river basins) and water accounting (annual and river basins) (for more details see www.iwmi.org/applications/podium). Annex Table 1 gives the key drivers of the BaU scenario and few other comparable scenarios projecting India's water futures.

Changing consumption patterns is a key driver for estimating food demand in the BaU scenario. The BaU scenario projects that significant increase in contribution from non-grain food crops and animal products increase the total nutritional intake, whereas the NCIWRD scenario projects increasing dependency on food grains. According to the BaU trends, expanding groundwater irrigation and changing cropping patterns are key drivers for projecting the irrigation demand, whereas the NCIWRD scenario projects significant increases in surface irrigation of grain crops, with a substantial rice area. Changes in cropping patterns and irrigation efficiencies reduce the irrigation demand under BaU scenario between 2025 and 2050. However, due to high demand for irrigating grain crops, total irrigation demand under the NCIWRD scenario increases significantly over the same time period. Increase in domestic and industrial water demand is more than 85% of the additional water demand between 2000 and 2050 under the BaU scenario, while it is only 48 % under the NCIWRD scenario.

Seckler et al. 1998; IWMI 2000; and Rosegrant et al. 2002 scenarios only projected food and water demand to 2025. Both scenarios assumed lower population projections and higher demand for food grains than the BaU. The overall water demand projection of Rosegrant et al. scenario, after adjustment for the differences of population projects, is similar to that of BaU, while Seckler et al. 1998 scenario project higher total water demand.

Annex Table 1. Summary of the key drivers and water demand projections of BaU and other scenarios for India.

Drivers	Unit	2000[i]	BaU scenario projections[ii]		NCIWRD high demand scenario[ii]		Seckler et al.[ii]	Roasgrant et al.[ii]
			2025	2050	2025	2050	2025	2025
Population	Million	1,007	1,389	1,583	1,383	1,581	1,273	1,352
- % urban population	%	28	37	51	45	61	43	43
Total calorie supply/person/day	Kcal	2,495	2,775	3,000	-	-	2,812	-
- % of food grains	%	65	57	48	-	-	58	-
- % from non-grain food crops	%	28	33	36	-	-	32	-
- % from animal products	%	8	12	16	-	-	11	-
Food grain demand/person/year	Kg	172	166	152	210	284	188	183
Total grain demand/person/year	Kg	200	210	238	231	312	215	215
Net sown area	Mha	142	142	142	144	145	-	-
Net irrigated area	Mha	55	74	81	67[iii]	93[iii]	-	-
- from groundwater	Mha	34	43	50	34[iv]	42[iv]	-	-
Gross irrigated area	Mha	76	105	117	98	146	90	76
Irrigated area of grains	Mha	54	59	63	69	102	61	51
Rain-fed area of grains	Mha	69	62	57	70	57	61	69
Total grain availability/person/year	Kg	208	213	240	242	312	216	206
Net irrigation requirement	Km^3	245	313	346	359[iv]	536[iv]	323	332
Irrigation efficiency- surface water	%	30-45	35-50	42-60	50	60	-	-
Irrigation efficiency- groundwater	%	55-65	70	75	72	75	-	-
Total irrigation demand	Km^3	605	675	637	611	807	702	741
- from groundwater	Km^3	272	304	325	245	344	-	-
Irrigation for grain crops	Km^3	417	398	351	428	565	-	-
Domestic water demand/person	m^3/day	33	45	64	45	70	31	31
Industrial water demand/person	m^3/day	42	66	102	48	51	55	
Total water demand	Km^3	680	833	900	773	1,069	811	822

Notes: [i] Data for 2000 is from various publications of Government of India;
[ii] BaU, NCIWRD, Seckler et al. and Rosegrant et al. Information is compiled from GOI 1999, Amarasinghe et al. 2007b, IWMI 2001, and Rosegrant et al. 2002, respectively.
[iii] Estimated with cropping intensities- 141 % in 2025 and 155 % in 2050; [iv] Estimated with percent from groundwater irrigation- 50 % in 2025 and 43.7 % in 2050.

References

Amarasinghe, U. A.; Shah, T.; Turral, H. 2006. India's Water Futures to 2025-2050: Business as Usual Scenario and Issues. Draft prepared for the IWMI-CPWF project on 'Strategic Analyses of National River Linking Project of India'.

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. P. 2007a. *Changing consumption patterns: implications for food and water demand in India.* IWMI Research Report 119, Colombo, Sri Lanka: International Water Management Institute.

Amarasinghe, U. A.; Shah, T.; Turral, H.; Anand, B.K. 2007b. *India's water futures to 2025-2050: BAU scenario and deviations.* IWMI Research Report 123, Colombo, Sri Lanka: International Water Management Institute.

Bhaduri, A.; Amarasinghe, U.A.; Shah, T. (2006). Groundwater irrigation India: Analysis and Prognostics. Draft prepared for the IWMI-CPWF project on 'Strategic Analyses of National River Linking Project of India'.

FAO. 2005. FAOSATAT Data Base. Rome: Food and Agriculture Organization.

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

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

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

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 Analyses 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 Analyses 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 Analyses 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.

Molden, D.; Sakthivadivel, R.; Perry, C. J.; de Fraiture, C.; Kloezen, W. K. 1998. *Indicators for comparing performance of irrigated agricultural systems.* Research Report 20. 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 Analyses of National River Linking Project of India'.

Pandey, U.K. 1995. The Livestock Economy of India: A Profile. *Journal of Indian Agricultural Economics.* Vol 50, No. 3. pp 264-282.

Rosegrant, M.; Cai, X.; Cline, S. 2002. World Water and Food to 2025. Dealing with Scarcity. Washington D.C.: International Food Policy Research Institute.

Shah, T.; Roy, A.D.; Qureshi, A.S.; Wang, J. 2001. Sustaining Asia's Groundwater Boom: An Overview of Issues ad Evidence. Draft paper prepared for the International Conference on Freshwater in Bonn

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

Shiklomonav, I. 1999. World Water Resources and their Use. http://webworld.unesco.org/water/ihp/db/shiklomanov/

Thenkabail, P. S.; Biradar, C. M.; Turral, H.; Noojipady, P.; Li, Y. J.; Vithanage, J.; Dheeravath, V.; Velpuri, M.; Schull, M.; Cai, X. L.; Dutta, R. 2006. *An irrigated area map of the world (1999) derived from remote sensing.* Research Report 105. Colombo, Sri Lanka: International Water Management Institute.

UN. 2004. World population prospects, the 2004 revision. New York: UN Department for Policy Coordination and Sustainable Development.

WRI. 2005. Earth trends. Searchable database http://earthtrends.wri.org. Washington, D.C.