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Seeking calm water: Exploring policy options for India's water future

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Abstract

This paper seeks to identify some promising policy options which could be part of a strategic and holistic effort to address India's future water challenges. Significant increases in agricultural water productivity would be a major factor in reducing the need for developing new water sources. Crop diversification, appropriately targeted to account for the present agricultural systems and available water resources, will increase productivity. Furthermore, much more emphasis needs to be placed on effective management of the groundwater resources through renewed efforts to enhance artificial recharge and conservation. Also, efforts should be revived to improve the existing surface irrigation systems. In particular, systems could be reconfigured to provide a more reliable water supply and allow effective community level management, where appropriate. Finally, while some of the increasing demands from domestic and industrial users will be met by the development of groundwater and reallocation of water from the agricultural sector, this will not be sufficient. Given that such conditions are emerging in states with high economic growth and relatively water scarce basins, this will require the further development of water resources. In some cases, these conditions along with the demand for reliable water for high value crops, will be part of the justification for inter-basin transfers.

Keywords: India; River basins; Water crisis; Groundwater; Recharge; Diversification; Water productivity.

1. Introduction

The best course for managing and further developing India's water resources is a hotly debated subject, with some of the more contentious arguments centered on the large-scale inter-basin transfers planned as part of the National River Linking Project (NRLP). As part of a broader study[1] to examine the NRLP and potential alternatives, this paper seeks to identify some of the more promising policy options which could be part of a strategic and holistic effort to address India's future water challenges.

Accounting for the characteristics of recent water resources development and management, the paper considers the future water needs should the country continue along this Business-as-Usual (BAU) path. There are a number of policy options which could be considered to replace, complement and/or supplement elements of the NRLP. Suggestions include: increased emphasis on recharging groundwater to offset the over-abstraction; adoption of water saving technologies for increasing water use efficiency;[2] formal or informal water markets; provision of a more reliable, yet rationed, rural electricity supply to reduce uncontrolled groundwater abstraction; and increasing research and extension for enhancing agricultural water productivity.

As in many countries, agriculture is the largest user of water in India, and as such has and will continue to be a

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[1] This study first assesses scenarios and issues of India's future water needs to 2025–2050 and then explores potential options of water development and management, including that of NRLP, for meeting the water futures. The water futures assessment included various studies on changing regional demographic, economic and food consumption patterns and implications on water demand; economic growth, world trade, virtual trade of water and implications on water demand; future of irrigation; potential for harvesting rainwater and improving rainfed agriculture; potential groundwater recharge; opportunities for improving water productivity, spreading water savings technologies; water demand in the domestic, industrial and environmental sectors and on the potentially utilizable water supplies in India's river basins. Draft publications of these and other ongoing studies are available in http://nrlp.iwmi.org.

[2] However, in many cases while such technologies may reduce the amount of water pumped, it may not result in water savings at the basin scale.

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major driver of water resources management and development in the country. The dominance of food grains and the prominence of surface irrigation in India's agricultural production are gradually changing. In fact, groundwater is already the dominant water source for agriculture, and recent trends show that agriculture is diversifying to cater to the changing domestic consumption patterns and increasing export opportunities. Groundwater irrigation is continuing to expand to meet the increasing demand for water in agriculture. Generally, the agricultural diversification takes place for higher value crops and livestock, which in most cases requires more expensive inputs, and necessitates a relatively reliable water supply. Until now, the inherent reliability of groundwater has made it the source of choice.

The unplanned development of the resource, and the difficulty of managing it thereafter, means that an increasing number of aquifers are over-exploited, bringing high social and environmental costs, and jeopardizing the reliability of the supply. Groundwater resources within many river basins will soon reach this critical stage with continuing groundwater use expansion (Amarasinghe *et al.*, 2007). Without appropriate management strategies and interventions, these unsustainable practices may lead to serious crises in the near future for some regions and most certainly within the next four to five decades for others. We discuss the magnitude of the water crisis in the next section.

However, there are a number of policy options which could avert such a crisis. Artificial groundwater recharge, increasing efficiency of groundwater use and reducing uncontrolled groundwater pumping can sustain the groundwater expansion. Among others, increasing productivity and diversifying with proper cropping patterns can also offer a significant leverage. These options will be discussed in detail in the third section. However, we are also mindful of the fact that some of these options require further research before becoming concrete policy recommendations.

In spite of these options, there are situations where major inter-basin transfers may still be inevitable, especially over the long term. The justification and necessary support for such investments is unlikely to come from the development of new irrigated areas, at least not as a significant part of the investments, but more likely from a combination of: increased domestic and industrial water demand, providing a reliable water supply for high-value crops, the growing pressure on groundwater systems, escalating energy prices, and from increased efforts to account for environmental needs. These issues will be discussed in the final section.

2. Pending water crisis

India already withdraws about 273 cubic kilometers (km^3) of groundwater per annum, which is estimated to be around 60% of the sustainable yield (Amarasinghe *et al.*, 2007). Given that the majority of the groundwater is abstracted for agriculture and has been developed by the private sector.

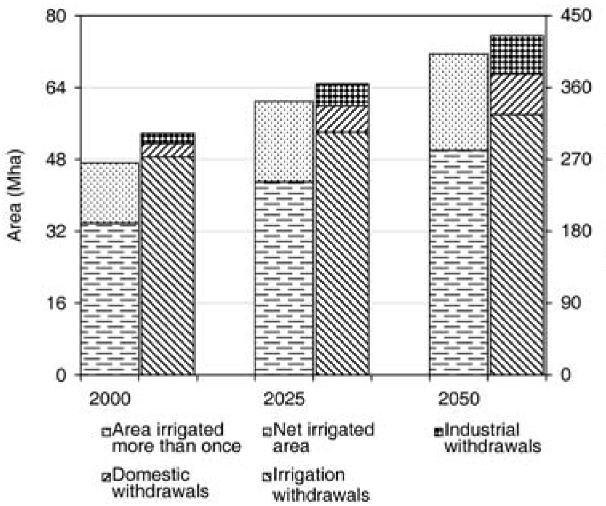

Figure 1. Groundwater irrigated area and withdrawal projections. *Source*: Irrigated area data of 2000 are from GOI (2005).

It is anticipated that groundwater will continue to be the major source for future growth in irrigated areas.

Projections based on the most recent trends estimate that a further 14 million hectares (Mha) of land will be brought under irrigation by 2025 (see Figure 1), and an additional 10 Mha by 2050 (Amarasinghe *et al.*, 2007). Consequently, the Business-as-Usual scenario[3] projects that 31 km^3 of additional groundwater withdrawals will occur by 2025, and a further 22 km^3 by 2050. The result will be that by 2025 and 2050 India would be withdrawing 60 and 72% of the sustainable groundwater supply, respectively, accounting for both natural and return flow recharge. With this, several river basins would become water scarce and the rate of use in large regions, especially in water stressed basins would be unsustainable. In fact, 8 basins will withdraw more than 75% of their available groundwater supply (Figure 2), and these 8 basins account for 80% of the total groundwater withdrawals in India.

On the other hand, if groundwater withdrawals are to remain at the 2000 level, then the additional surface withdrawal requirement will need to increase further by 65 km^3 by 2025, in part because surface water systems are less efficient than groundwater-based systems. The peninsular basins, some of which are already water scarce, will require more than half of the total additional surface water withdrawals projected for the country, which is more than 35 km^3. Given the past investment trends and the slow growth of canal irrigation in recent decades, it is difficult to envisage adding this quantity of surface water in the next 25 years. Furthermore, such demands cannot be met in the peninsular rivers without diverting water from elsewhere.

In either case, whether it is through rapid expansion or an unexpected slowdown of further groundwater use, a major crisis in the water sector is pending unless immediate

[3] See Annex 1 for a brief detail of the key drivers of the BAU scenario and Amarasinghe *et al.* (2007) for more details.

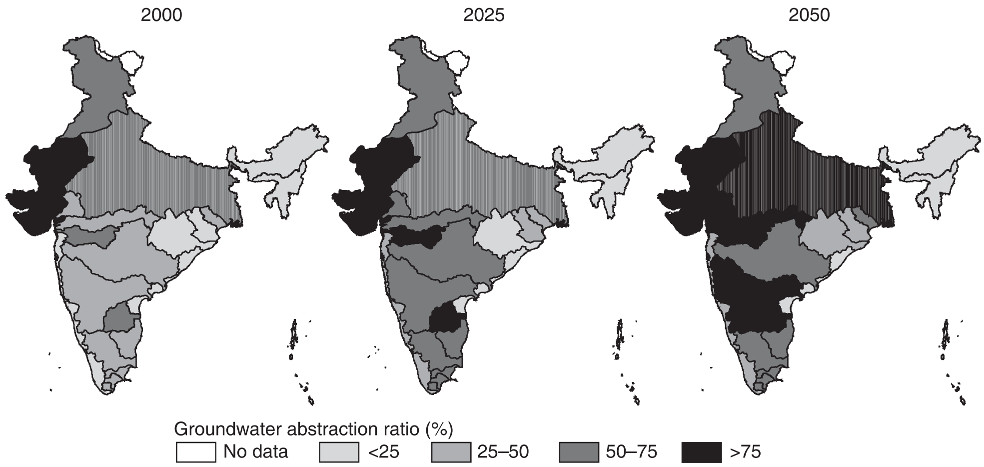

Figure 2. Groundwater abstraction ratio of Indian river basins.
Source: Amarasinghe *et al.* (2007).

solutions are sought. Next, we discuss some policy options that can avert a crisis in the short- to medium-term.

3. Policy options

From an overall economic investment perspective, groundwater has been a much cheaper option than the development of surface water. This is mainly because most of the good sites for large dams have already been developed. At present, the development of one hectare of surface irrigated area costs more than three times the cost required for developing one hectare of groundwater irrigated area (GOI, 2006). But the cost of groundwater abstraction is also increasing due to falling groundwater tables and rising energy prices. In the past, groundwater development has generally been undertaken by the private sector with users sharing a significant part of the cost. And groundwater irrigation generates higher crop production and livelihood benefits, provided that adequate groundwater stocks are available to ensure reliability. Therefore, further development of the resource and maintaining livelihood benefits requires major investments in recharge and perhaps even large-scale transfers of water to where the recharge is required.

3.1. Sustaining groundwater irrigation

Artificial groundwater recharge could enhance the groundwater stocks, have positive impacts, and generate various social and environmental benefits. As has been practiced in some developed countries, India can start to actively manage its aquifers. At present, it depletes its groundwater stocks before the monsoon months and then recharges these with the monsoon runoff (Shah, 2007). Existing small tanks and ponds, numbering more than 500,000 throughout India, which are already augmenting the natural groundwater recharge, can be modified to further increase recharge, while meeting the drinking water demand for human beings and livestock (Sakthivadivel, 2007). Also, new small tanks and ponds need to be designed and constructed with a view towards optimizing groundwater recharge, where appropriate. Rainwater harvesting programs, such as *johads* in the Alwar District in Rajasthan (Sakthivadivel, 2007) and also groundwater recharge movements in Saurashtra and Kutch (Shah, 2000; Shah and Desai, 2002), have proven to rejuvenate the groundwater resources available for irrigation.

However, some interventions, such as rainwater harvesting in the upstream catchments, have been shown to reduce the inflows to existing reservoirs downstream (Kumar *et al*., 2006a), and can incur more costs than the benefits they generate. Also, the underlying hydrogeology dictates whether recharge will result in improved supplies of groundwater in a form which can be appropriately utilized. Therefore, we need to know more about the negative impacts on downstream users before embarking on large-scale groundwater recharging and rainwater harvesting programs, especially in water scarce river basins.

The existing knowledge on surface water and groundwater interaction across river basins in India is generally site-specific and not sufficient to identify the locations where such negative impacts can occur, nor in fact to determine where and how to improve groundwater recharge. Further research is required to identify the locations where artificial groundwater recharge can harness water; the quantity of water that can be harnessed and the extent to which it meets the additional demand; and the net social benefits that these programs generate.

Increasing groundwater irrigation efficiency by an additional 5% from the level assumed under the BAU scenario (70%) can reduce the additional groundwater demand in 2025 by about 20 km^3 or two-thirds, assuming that these measures result in savings at the basin scale. Recent research shows that modern irrigation technologies

— sprinklers and drip irrigation — are operating at 70–85% efficiency in some irrigation systems in India (Kumar *et al*., 2006b; Narayanamoorthy, 2006). Modern irrigation technologies also improve the uniform distribution of the irrigation water, reduce non-beneficial transpiration, and, in general, have higher productivity than the traditional flood irrigation methods. However, adoption of these technologies in India has been very slow and adopted mainly for a few crops, such as fruits and vegetables, in the groundwater irrigated areas (Narayanamoorthy, 2006; Kumar *et al*., 2006b). Recent innovations in low-cost micro irrigation technologies could accelerate the spread of these technologies in India (Shah *et al.*, 2004; Verma *et al.*, 2004). However, further research and extension are needed to determine the potential of such technologies, their net economic benefits and practical modalities to scale them up where appropriate. It is also imperative that it be determined these interventions would result in actual water savings, and not merely transferring water from other users further downstream in the basin, as has been the case elsewhere.

Reducing uncontrolled groundwater pumping could mitigate over-abstraction in many basins. In 2000, India withdrew about 273 km^3 of groundwater to meet only 151 km^3 of crop consumptive water-use demand. Part of the remaining water is available for reuse through return flows and the other part is lost to the system as non-beneficial depletion. However, proper policy and institutional interventions can reduce over-abstraction and non-beneficial depletion even when traditional irrigation methods are utilized. Raising the price of electricity and hence the cost of groundwater in formal or informal water markets (Somanathan and Ravindranath, 2006; Banerji *et al*., 2006), and regulating and/or providing a reliable rural electricity supply (Shah and Verma, 2008) have been shown to have some effect on controlling unnecessary pumping and increasing water-use efficiency. Replicating these interventions, with adjustments to satisfy local socioeconomy, could help arrest the uncontrolled groundwater pumping in many water-stressed river basins.

3.2. Improving crop productivity

Improving crop productivity presents the greatest opportunity for reducing additional irrigation requirements. If water productivity stagnates at 2000 levels, India will require 1,029 km^3 by 2050 to meet the agricultural consumptive water use demand. In effect this is the same as the estimates of total potentially usable water resources of India, and simply unattainable. Therefore, it is imperative that the productivity of water[4] be continuously increased.

In comparison with other countries, India's grain crop water productivity — 0.64 and 0.34 kg/m^3 of consumptive water use (CWU) for irrigated and rainfed areas, respectively — is stubbornly low. The water productivity of non-grain crops under irrigated and rainfed conditions is also low, and varies significantly across districts (Table 1).

By increasing grain crop water productivity by 1.0% per annum, the respective CWU could be maintained at present day levels while meeting the increased demands for grain. Increasing the productivity a little further, to 1.4% annually, would even account for the CWU demand for all crops (Amarasinghe *et al*., 2007). These scenarios demonstrate a significant opportunity to avoid a future agriculture-driven, water crisis. The latter scenario is equivalent to doubling the yield over the next 50 years, which given the past trends in India, is setting a very high goal. On the other hand, given the remarkable achievements of other countries over the last few decades, India does have that potential.

India's research and technological capacities are increasing. Knowledge generation in the research of new commodities, remote sensing, geographic information systems, and advances in water management systems are second to none in developing countries. India also has a sound agricultural research system spread across all regions. Thus, the immediate focus should be on combining these rich resources with proper extension systems to promote rapid growth in crop productivity. India needs to effectively use the advances in research and technology to identify opportunities for high productivity and also high potential zones for different crop and livestock production systems. As the value of water is increasing, agricultural production systems should be promoted in zones where they have a high value for each drop of consumptive water use and where there is adequate water supply for irrigation, such as in the lower part of the Ganga Basin. The recent trends of agricultural diversification, which are associated with changing consumption patterns, should also facilitate this revolution.

3.3. Agricultural diversification

Agricultural diversification, if properly planned, could also help reduce additional irrigation demand. The BAU scenario projections, as discussed in the previous two chapters, show that the increasing consumption of animal products is transforming the demand and production patterns of cereals (Table 2). Over the period (2000–2025), maize, primarily for livestock feeding, will contribute to more than one-third of the total grain demand increase (45%). Between 2025 and 2050, this contribution is expected to be 83% of the total grain demand increase. Also, food demand for high value non-grain crops, such as oilseeds, vegetables and fruits, is increasing. The share of the value of non-grain crop production is expected to increase, from 51% in 2000, to 63 and 69% by 2025 and 2050, respectively.

[4] Improving water productivity means obtaining more crops or income or livelihood and ecological benefits for every drop of water used or depleted. Crop water productivity of grains in this paper is the ratio of grain crop production to consumptive water use. Consumptive water use in rainfed areas is only the effective rainfall. In irrigated areas, it is the actual evapotranspiration, i.e., the sum of effective rainfall and net irrigation requirement.

Table 1. Irrigated, rainfed and total water productivity of grain and non-grain crops

State	Water productivity (WP) of grain and non-grain crops								
	Irrigation			Rainfed			Total		
	Grain area as a fraction of total	WP of grains	WP of non-grains	Grain area as a fraction of total	WP of grains	WP of non-grains	Grain area as a fraction of total	WP of grains	WP of non-grains
	#	$*/m³	$/m³	#	$/m³	$/m³	#	$/m³	$/m³
Andhra Pradesh	0.76	0.17	0.41	0.45	0.11	0.72	0.59	0.16	0.56
Assam	0.99	0.22	0.19	0.78	0.10	0.72	0.79	0.11	0.72
Bihar	0.93	0.13	1.66	0.86	0.14	1.43	0.90	0.13	1.55
Chhattisgarh	0.95	0.10	1.47	0.91	0.10	0.50	0.92	0.10	0.69
Gujarat	0.37	0.08	0.23	0.45	0.12	0.57	0.42	0.10	0.31
Haryana	0.76	0.17	0.16	0.84	0.12	1.37	0.77	0.17	0.19
Himachal Pradesh	0.89	0.13	2.28	0.85	0.13	1.99	0.86	0.13	2.03
Jammu and Kashmir	0.81	0.13	1.34	0.88	0.14	4.10	0.85	0.14	2.43
Jharkhand	0.71	0.11	2.18	0.91	0.11	0.83	0.89	0.11	1.17
Karnataka	0.60	0.15	0.34	0.69	0.12	0.63	0.66	0.13	0.44
Kerala	0.50	0.16	0.39	0.09	0.16	0.83	0.17	0.16	0.78
Madhya Pradesh	0.87	0.07	0.36	0.56	0.10	0.40	0.64	0.09	0.39
Maharashtra	0.56	0.07	0.51	0.67	0.08	0.21	0.65	0.07	0.34
Orissa	0.83	0.11	1.44	0.75	0.07	0.72	0.77	0.09	0.89
Punjab	0.87	0.25	0.24	0.57	0.13	4.21	0.86	0.24	0.39
Rajasthan	0.59	0.07	0.20	0.84	0.07	0.36	0.75	0.07	0.24
Tamil Nadu	0.64	0.20	0.49	0.55	0.22	1.09	0.60	0.20	0.64
Uttar Pradesh	0.83	0.15	0.26	0.80	0.14	2.12	0.82	0.14	0.44
Uttaranchal	0.73	0.20	0.25	0.91	0.11	1.26	0.83	0.15	0.35
West Bengal	0.85	0.21	1.23	0.66	0.17	1.17	0.73	0.19	1.18
India	0.76	0.15	0.36	0.68	0.11	0.69	0.71	0.13	0.50

Source: Authors' estimates are based on PODIUMSim methodology.
* Values of crop production, estimated using the average (1999–2000) of the unit export prices of crops in the FAOSTAT Database (FAO, 2005) are used to make comparisons between the grain and non-grain crops.

Table 2. The demand and production of grain and non-grain crops with their irrigation requirements and withdrawals

Crop	Crop demand[i] (million tons)			Crop production: Total[i] (million tons)			Crop production: Share from irrigation (%)			Irrigated crop area (million ha)			Irrigation requirement[ii] (net evapotranspiration) (km³)			Irrigation withdrawals (km³)		
	2000	2025	2050	2000	2025	2050	2000	2025	2050	2000	2025	2050	2000	2025	2050	2000	2025	2050
Grain crops																		
Rice	82	109	117	89	117	143	69	70	71	24.1	25.0	26.0	74	73	72	261	239	207
Wheat	67	91	102	72	108	145	95	99	99	23.0	25.0	26.3	64	72	76	132	135	122
Maize	16	50	121	12	28	65	32	51	38	1.4	4.0	5.1	1	3	3	3	5	6
Other cereals	21	23	16	19	21	13	14	19	38	2.2	2.4	2.7	5	5	6	10	9	9
Total cereals	187	273	357	193	274	365	71	76	75	50.8	56.4	60.1	144	153	158	406	388	344
Pulses	14	18	21	13	18	19	17	17	18	2.8	2.9	2.8	6	6	5	11	10	8
Non-grain crops																		
Oilcrops	48	103	133	31	73	97	31	56	68	6.1	18.7	25.2	13	37	49	25	66	76
Vegetables	75	150	189	74	149	227	44	64	69	1.7	3.3	3.8	3	5	6	6	10	10
Fruits	47	78	123	46	83	106	46	60	63	1.7	3.0	4.0	5	9	12	10	16	18
Sugar	26	42	55	30	46	60	94	93	100	4.2	5.1	6.6	41	48	60	80	87	95
Cotton	2	4	6	2	4	6	50	65	71	3.0	5.9	7.9	16	28	38	31	50	59
Other crops	—	—	—	—	—	—	—	—	—	5.6	11.3	7.3	18	26	18	36	48	28
Total grains	52[i]	73[i]	90[i]	54[i]	74[i]	93[i]	67	72	72	53.6	59.3	62.9	149	159	163	417	398	352
Total non-grains	106[i]	198[i]	284[i]	96[i]	187[i]	266[i]	51	65	71	22.3	47.2	54.8	95	154	183	188	277	286
Total	158[i]	271[i]	374[i]	150[i]	261[i]	359[i]	57	67	71	76	107	118	245	313	346	605	675	638

Notes: [i] Total demand and production for grain and non-grain crops are estimated using the average 1990–2000 export prices.
[ii] Irrigation requirement or net evaporation is the difference between evapotranspiration and effective rainfall.
Source: Authors' estimates based on PODIUMSim methodology.

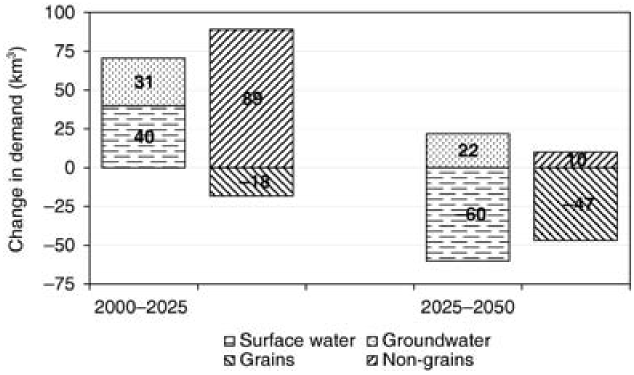

Figure 3. Change in surface water and groundwater and grain and non-grain crops irrigation demand.
Source: Authors' estimates.

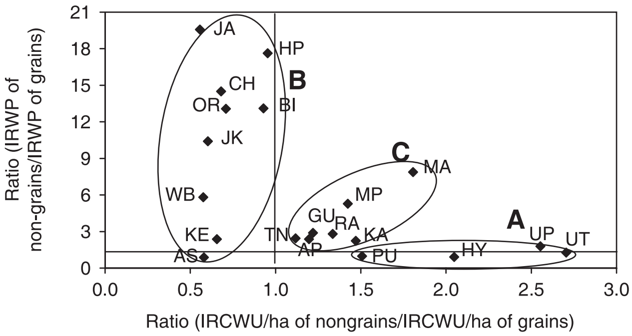

Figure 4. Consumptive water use and water productivity differences between grain and non-grain crops in irrigated areas of different states. *Note*: Irrigated water productivity (IRWP) is measured in $/m³ and Irrigation consumptive water use (IRCWU) is measured in m³/ha. See footnote 5 for key to states.

As a result of the changing consumption patterns, food production patterns will change. The production of irrigated non-grain crops, as compared with irrigated grain crops, will increase much faster. According to the BAU scenario, as much as half the irrigated area will be under non-grain crops by 2050, compared to only 29% in 2000; 71% of the crop production (grains and non-grain crops) will be produced under irrigation by 2050, compared to 67% in 2025 and 57% in 2000. Major implications of this agricultural diversification are:

- consumptive water use demand of grain crops, in comparison to non-grain crops, increases very slowly;
- with increasing reliance on groundwater and increasing water-use efficiency of groundwater, the irrigation demand for grain crops will decrease from the 2000 levels (Figure 3), and
- almost all additional irrigation demand will be for non-grain crops, and much of that will be from groundwater (Figure 3).

Most of the non-grain crops, usually produced for urban markets or for exports, can bring in high returns. However, in order to reap these benefits, high-value crops require the timely application of expensive inputs. A reliable irrigation supply is a critical prerequisite for timely input application, and also an input by itself in water-stressed crop growth periods. More recently, groundwater has been the major source of this reliable irrigation supply in the context of diversifying agricultural production. It is likely that this trend will continue, at least into the near future. Therefore, an immediate challenge is to identify the cost-effective physical and institutional interventions for sustaining the groundwater irrigation growth.

Agricultural diversification could also be promoted in conjunction with improvement in water productivity. Figure 4 shows a glimpse of where this can be done at the state level. For the case of irrigated crops, the X-axis in figure 4 is the ratio between CWU (m^3/ha) of non-grain and grain crops, and the Y-axis is the ratio between water productivity ($/$m^3$ of CWU) for non-grain and grain crops.

For the irrigated conditions there are three distinct clusters[5] (Figure 4). The states in cluster A, i.e., Punjab, Haryana, Uttar Pradesh and Uttaranchal, are those areas where irrigation is dominant and yields of grain crops are generally high. As a result, the states of Punjab and Haryana have significant production surpluses of grains. At present, they account for as much as 85% of the grain production deficits in other states and share most of the virtual water export within India (Amarasinghe *et al.*, 2007; Verma *et al.*, 2008). However, virtual water export is also the primary reason for water scarcities in these states. Can crop diversification to non-grain crops be a solution to water scarcities in these states? We find that the CWU/ha for non-grain crops in these areas is significantly higher than for grain crops, but have lower productivity in terms of value per cubic meter of water. The difference between the water productivities of irrigated grain and non-grain crops is relatively small. Crop diversification in states in this cluster, according to the current cropping patterns, may yield little or no benefit. These states can continue to grow grains, increase the yields and trade the production surplus to other states, or export virtual water, as has been the case in the past. The benefit of that per every cubic meter of water depleted could be as high as the benefits that non-grain crops generate.

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[5] We use the threshold value of 1 of the ratios in the X-axis and Y axis to group states into three clusters. Punjab (PU) and Haryana (HY), with WP ratio more than 1 and CWU ratio less than 1, are in cluster A. Jharkhand (JA), Himachal Pradesh (HP), Chhattisgarh (CH), Orissa (OR), Bihar (BI), Jammu and Kashmir (JK), West Bengal (WB) and Kerala (KE) have CWU ratio less than 1 and WP ratio more than 1. They form cluster B. Andhra Pradesh (AP), Tamil Nadu (TN), Gujarat (GU), Rajasthan (RA), Madhya Pradesh (MP) and Maharashtra (MA), with both ratios more than 1, form cluster C. There are few exceptions. Uttar Pradesh and Uttaranchal have CWU ratio more than 1, but their WP ratio is higher than CWU ratio, therefore we included them in cluster A. Both CWU and WP ratio of Assam is less than 1, but WP ratio is higher than the CWU ratio. Therefore Assam is included in cluster B.

The states in cluster B are generally rich in water availability, but import a substantial part of their grain requirements and hence virtual water. This is primarily due to constraints such as limited land availability and lack of proper infrastructure facilities (Kumar and Singh, 2005; Verma *et al.*, 2008). These states also have significantly high irrigated area under grain crops and a substantial part of that is rice. However, the rice crop has low yields and higher CWU than the irrigated non-grain crops in the state. Thus, this group has the highest potential for improvements in water productivity in irrigated grain crops or diversifying to non-grain crops. Many states in this group are also relatively water abundant and, due to recurrent floods, rice is the only crop that can be grown in the Kharif (wet) season. Therefore, they can continue to grow water-intensive grain crops and increase water productivity through growth in yield. On the other hand, due to limited land resources many small to medium landholders are poor in these states. So, crop diversification, especially in the Rabi (dry) season, can also generate substantial benefits to these farmers. The states in cluster B should have a combined strategy — increase the yields of grain crops while diversifying cropping patterns in small to medium landholdings with low productivity. The production surpluses of non-grain crops in this cluster can meet the production deficits of the states in cluster A. To facilitate this process, states in cluster C should invest in eliminating some major bottlenecks, which include lack of procurement facilities and inadequate access to markets, roads and farm power supply.

In cluster C, states like Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra, Madhya Pradesh and Gujarat, and Rajasthan, are relatively water scarce compared to those in cluster B. Irrigated, non-grain crops in these states consume more water than the grain crops, but generate significantly more benefits. Crop diversification can benefit these states the most and should be promoted as a medium-term solution to meet increasing agricultural water demand and increasing demand for non-grain food crops and feed grains. In fact, the recent trends of decreasing irrigated rice area in Andhra Pradesh and Tamil Nadu are indicators of crop diversification in these water scarce states.

Rainfed non-grain crops in all states have significantly higher water productivity than rainfed grain crops (Figure 5), and many areas will benefit from crop diversification. On the other hand, major rainfed states also have very low productivity compared to irrigated crops. These states have significant scope for increasing crop yields. A small quantity of supplemental irrigation in the critical period of crop growth could even double the rainfed yield (Sharma *et al.*, 2006).

Recognizing that the above analysis is constrained by the fact that the analysis was done at the state level, it demonstrates that there is scope for improvement in productivity and crop diversification. An analysis of smaller spatial units, such as districts or sub-basins, incorporating water with other factors such as climate, land use patterns,

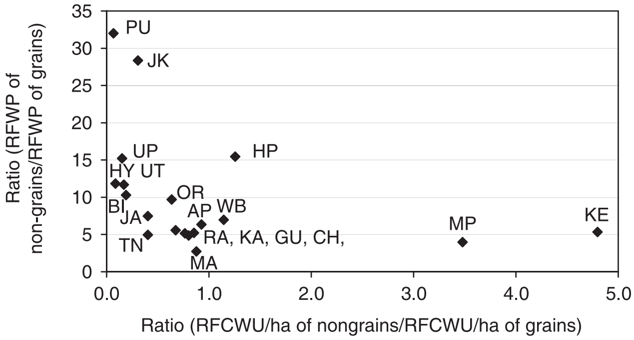

Figure 5. Consumptive water use/ha and water productivity differences between grain and non-grain crops in rainfed areas of different states. *Note*: Rainfed Water Productivity (RFWP) is measured in $/m^3 and Rainfed Consumptive Water Use (RFCWU) is measured in m^3/ha. See footnote 5 for key to states.

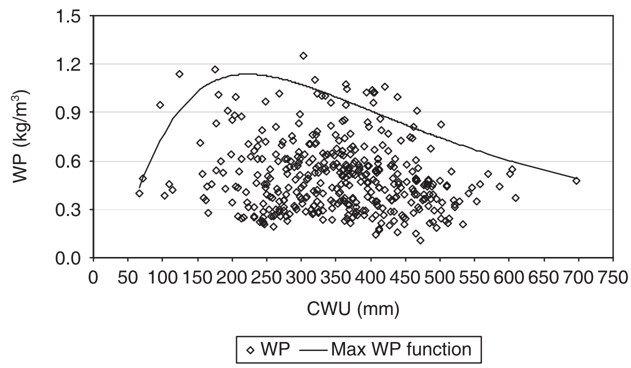

Figure 6. Variation of water productivity (WP) and consumptive water use of grain crops across districts.

land size and other non-water inputs should provide a better picture of where these improvements can de done and what interventions are required. Analysis of water productivity of grain crops (Amarasinghe and Sharma, 2008) shows a significant gap between the actual and the maximum attainable water productivities at similar levels of consumptive water use (CWU) (Figure 6). Providing a small supplemental irrigation is a key input for regions with low CWU, i.e., for mainly rainfed areas. Reducing the gap between actual and maximum attainable yield with better management of water, non-water and technological inputs offers the greatest opportunity in moderate to high CWU irrigated areas. Practicing deficit irrigation with little or no decrease in crop yield is a solution for land abundant, high CWU regions. Agriculture diversification to high-value non-grain crops or livestock production should increase the value of productivity production in areas where land availability is a major constraint.

3.4. *Relaxing national self sufficiency requirement*

In the past, the national self sufficiency of food grains was the major thrust for India's water development strategy. The

BAU scenario discussed in this paper also leads to national food self sufficiency with overall production surpluses of grains (Table 2). It projects that the production surpluses of rice and wheat would offset the production deficits of maize. However, relaxing the self sufficiency of food grains, especially rice, will have significant windfall on the irrigation water demand. For example, if the surplus production of rice in 2050 is reduced by 10–20 million tons, equivalent to only 3–5% of the total grain demand, it reduces irrigation demand[6] by 20–40 km^3, equivalent to 3–6% of the total irrigation demand. This savings can either be used to reduce the production deficits of maize, for other high-value crop production or in other sectors.

How realistic is the national self-sufficiency assumption in projecting India's grain and water futures? The grain self-sufficiency would be a reasonable goal, if the production of grain crops, or for that matter the total agriculture production, is a significant part of the total economy. However, over the period 1961–2000, the contribution of the agriculture sector to the gross domestic product has decreased from 46 to 25%. And at the present rate of decline — 2.9% annually in the 1990s — the share of agriculture to GDP would reach single digits in the next three to four decades. Moreover, the value of grain production, in comparison with the total agriculture production, is very small and is also declining. Besides these, the food grain demand is declining as well. Thus, although it was a constraint for the Indian economy to import part of the grain demand now, it will be insignificant for a trillion dollar economy in a few years. However, we should also be mindful that large import of grains from countries such as India and China could also have a destabilizing effect on the world's food market. The current increases in world food prices, as a result of a large demand for imports, or due to demand for bio-fuel etc., could also hurt the very consumers that the imports are expected to help. Yet, in spite of the price increase concerns, India's food trade, especially for maize is expected to increase in the future.

4. Contingencies for large-scale inter-basin water transfers

As discussed elsewhere in this paper, there are a number of policy options which could serve to replace, supplement or complement aspects of the NRLP while addressing India's future water needs for food production and the other sectors. However, there are situations where major inter-basin transfers will be inevitable, especially over the long term. The justification and necessary support for such investments is unlikely to come from the development of new irrigated areas, at least not as a significant part of the investments, but more likely from a combination of: increased domestic and industrial water demand, providing a reliable water supply for high-value crops, growing pressure on the groundwater systems, escalating energy prices, and increased efforts to account for environmental needs. In each case, the characteristics and timing of such developments will depend on socioeconomic, environmental, and agricultural conditions within the given basin and locality.

4.1. Domestic and industrial water demand

The demand for water in the domestic and industrial sectors, according to the BAU scenario, will increase several-fold over the period 2000–2050 (Figure 7). Domestic water demand is projected to increase by 204% over the period 2000–2050, and the industrial water demand will increase by 234% over the same period. It is expected that these sectors will generally secure their water from surface water sources, and given the expected increasing affluence of both sectors, the users will be able to pay for a reliable and high quality surface water resource. Some of this may come from reallocating water from the agriculture sector. However, the increasing demand for surface water of both the sectors (118 km^3 over the period 2000–2050) is expected to outpace the reallocation from the irrigation sector. Over this period, surface irrigation demand is expected to decrease by 20 km^3, according to the BAU scenario, but this would still require that a further 100 km^3 of surface water supply be developed for the domestic and industrial sectors. A substantial part of this additional surface water supply is projected for states that are already on the physical water scarcity threshold. These states are Andhra Pradesh, Tamil Nadu, Gujarat, Maharashtra and Karnataka, where water availability for further development is a severe constraint or the cost of further development is prohibitively expensive if it has to be conveyed from distant locations. So these states, even under the BAU growth patterns, may require some intra- or inter-basin water transfers to meet the demands of domestic and industrial sectors. In addition, groundwater depletion in most of these states is already high, and further development of this resource for irrigation will exacerbate this situation, and increase the tension between agriculture and other sectors.

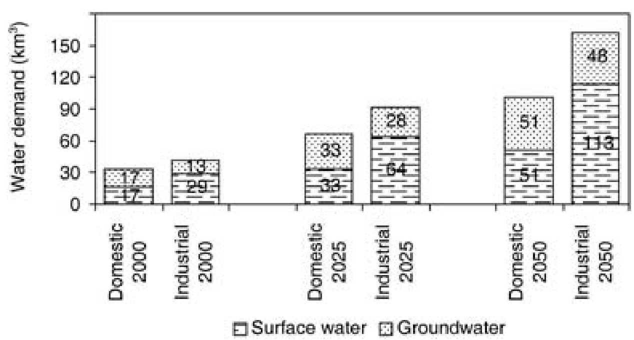

Figure 7. Domestic and Industrial water demand projections of India. *Source*: Authors' estimates.

[6] Estimated using the water productivity of irrigated rice (0.49 kg/m^3).

It is also likely that India's industrial and service sectors could shift gears and grow much faster than envisaged in the BAU scenario. The BAU scenario assumed that the per capita gross domestic product (GDP) will, on average, grow at 5.5% annually, and the contribution from the industrial and service sectors will further increase. Given the present economic growth patterns (9 to 10% GDP growth) these assumptions are conservative. Many of the well-to-do states, with better industrial infrastructure now, will inevitably contribute more to a scenario of high industrial and service sector growth. And many of the water scarce rich states may be willing to pay water rich poor states to meet their future water requirements, thus creating the conditions to both finance and develop large inter-basin water transfers, similar to the situation with the Lesotho Water Highlands Project (Shah *et al.*, 2007).

4.2. Agricultural diversification

It is imperative that India diversify its agriculture to meet future food demands. Much of the diversification will be towards high-value agricultural products. Returns from surface irrigation systems at present are very low because much of the command areas grow food grains, while high-value crops are grown outside the command areas using groundwater. Crop diversification could change the chronic low productivity of these systems, but only if a reliable water supply can be secured. There are already movements towards growing high-value crops with a reliable water supply for urban markets or export. Income from high-value agriculture has significantly increased in Southern and Western India. Should this gather momentum, these areas may be willing to invest for inter-basin water transfers. However, if low productivity of these surface irrigation systems persists, further irrigation sources will need to be developed, including inter-basin water transfers. To meet the demands for high-value crops, the latter would be a significantly more expensive solution, both in terms of economics and water resources.

4.3. Rising cost of energy

Irrigation expansion in India in the last two decades was primarily due to small-scale lift irrigation systems using mostly groundwater, but also surface water. These systems are highly flexible and provide a reliable irrigation supply on demand. Yet, this mode of irrigation development is, in most cases, highly energy intensive. So far, the energy supplies of many states are highly subsidized. But the cost of energy, whether it is in the form of electricity or diesel, has been rapidly increasing in recent times. States can no longer continue to provide subsidies on electricity as they are an impediment to economic growth in other sectors. As energy prices increase, the farmers may opt for direct surface water for irrigation or reduce their pumping costs by groundwater recharge. Thus, rising energy costs could be another condition from the agriculture sector that supports, to some extent, the development of large-scale inter-basin water transfers. Conceivably there could also be an indirect argument for inter-basin water transfers where concurrent development of hydropower could provide increased supplies of electricity. However, from an economic perspective, this new source of power would be better utilized in the industrial and service sectors.

5. Conclusion

Increasing agricultural water productivity offers one of the greatest opportunities to reduce the demand for additional irrigation demand. By doubling the water productivity over the next five decades, no additional irrigation water would be required, at least on-balance. To achieve this will require major investments in research, development, extension on better management of other inputs, and infrastructure particularly to improve the reliability of water supply.

Crop diversification offers opportunities to increase the value produced by the same amount of water, which would be particularly important in the water scarce basins in peninsular India. Crop diversification in already high water productivity areas, such as in the north and northwest, shall need further understanding as the water productivity is already high for grain crops. In the water abundant east there is considerable scope to increase the productivity of grain crops, yet crop diversification would help the poor small farmers increase their returns from their land.

Based on recent trends, groundwater will continue to be the source of choice for further development of irrigation for the foreseeable future. However, in an increasing number of basins, aquifers are becoming over-exploited. Continuing along this business-as-usual (BAU) pathway means that India is heading for an increasing number of regional water crises. Depending on the specific conditions, artificial recharge could significantly enhance groundwater supplies. Such interventions should include renewed efforts for small-scale water recharge systems, but also carefully consider large-scale facilities, including components of inter-basin water transfer projects. The implementation of any large-scale programs or interventions must determine, among other things, the hydrogeological suitability, the likely negative implications on downstream water users, and the relative economic viability. Increasing groundwater irrigation efficiency and other demand management strategies will also be helpful in reducing the over-abstraction of groundwater.

It is acknowledged that the interactions between surface water and groundwater resources will be different for a given basin and the dynamics will very much depend on how these resources are developed. The important point to emphasize is that the policy environment for water resources management in India must take into account the present realities, and allow not only for the realistic future demands, but also for the real constraints of the availability of the resource. Specifically, much more emphasis needs to be placed on the effective management of groundwater resources through enhancing the supply by artificial recharge and conservation. Also, revived efforts to improve the existing surface irrigation systems, in particular to reconfigure the systems to provide more reliable water supply and allow effective community level management, are necessary where appropriate. To achieve this requires a level of study and investigation beyond that which has yet to be done in most situations.

Further development of groundwater, water savings and the reallocation of water from the agricultural sector will not be sufficient to meet the water requirements of other sectors. The increasing capacity and willingness of the domestic and industrial sectors to pay for a clean and reliable water supply would increase the pressure for further development of surface water resources. Such conditions are likely to emerge soon in states with high economic growth, particularly in the basins that are water scarce. Most of these are located in peninsular India, and meeting the additional surface water demand in these basins may require large intra- or inter-basin water transfers.

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Annex 1. Assumption of key drivers in the BAU Scenario

The assessment of the BAU scenario uses the methodology of the PODIUMSIM model (Policy Dialogue Model Simulation) for projecting India's water future. The

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

Drivers	Unit	2000[i]	BAU scenario projections[ii]		NCIWRD high demand scenario[ii]		Seckler *et al.*[ii]	Rosegrant *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	—
— % from 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
Rainfed 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 are from various publications of Government of India; ii. BAU, NCIWRD, Seckler *et al*. and Rosegrant *et al.*, information are 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.

PODIUMSIM is a tool for simulating alternative scenarios of food and water future with respect to the variation of food and water demand drivers. The model has four major scenarios, 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/states/river basins), water demand (monthly and districts/states/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 a few other comparable scenarios projecting India's water futures.

Changing consumption patterns is a key driver of estimating food demand in the BAU scenario. The BAU scenario projects that a significant increase in contribution from non-grain food crops and animal products increases 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 of projecting the irrigation demand, whereas the NCIWRD scenario projects significant increases in surface irrigation of grain crops, with substantial rice area. Changes in cropping patterns and irrigation efficiencies reduce the irrigation demand under the 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.* (IWMI, 2001) and Rosegrant *et al.* (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 the Rosegrant *et al.* scenario, after being adjusted for the differences of population projections, is similar to that of BAU, while the Seckler *et al.* scenario projects higher total water demand.