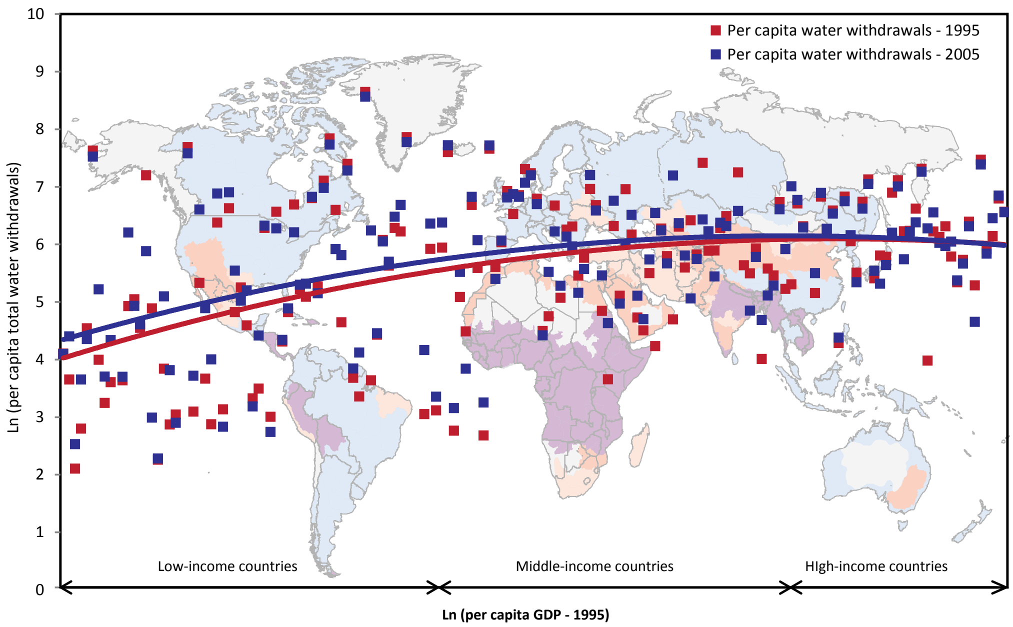
IWMI Research Report

156

Global Water Demand Projections: Past, Present and Future

Upali A. Amarasinghe and Vladimir Smakhtin



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Global Water Demand Projections: Past, Present and Future

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Front cover image: The graph shows the per capita gross domestic product (GDP) in 1995 and water withdrawals in 1995 and 2005 (FAO 2012a, 2012b). The X-axis shows countries with increasing per capita GDP in 1995. The world map in the background shows the water scarcity outlook to 2050 (Molden 2007). Countries experiencing physical and economic water scarcity are indicated in orange and purple, respectively.

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Summary

Water demand projections (WDPs) are widely used for future water resource planning. Accurate WDPs can reduce waste or scarcity associated with overdevelopment or underdevelopment, respectively, of water resources. Considering that the projection period of some WDPs have now passed, this paper examines how closely such past projected withdrawals match current water withdrawals to identify lessons that can be learned and strengthen future studies on WDPs. Six WDPs conducted before 1990 and seven conducted after 1990 are analyzed in detail. The review shows that the pre-1990 WDPs, which considered population as the main driver of change, overpredicted current water use by 20 to 130%. Unrealistic assumptions on the norms of water use in different sectors were the main reasons for large discrepancies. The post-1990 WDPs had sophisticated modeling frameworks. They integrated many exogenous and endogenous drivers of food and water supply and demand, with refined estimation procedures for domestic and industrial sectors. Yet, the post-1990 WDPs of the 'business as usual' (BAU) scenarios show substantial underestimation globally, and large deviations for sectors and countries, from the current water-use patterns; the sustainable water use scenarios are even more downward biased. The average per capita domestic water withdrawals at present already exceed projections made by the BAU scenario for 2025. Still, many low-income countries have fairly low levels of withdrawals. The demand projections for the industrial sector are no better; the relatively large differences are in the low-income countries. BAU projections for the agriculture sector are mostly under- or over-estimated (-11% to 3%). For India, the underestimation ranges from 20 to 90 billion cubic meters (Bm^3) or 3 to 14% of the total water withdrawals. For China, they over-estimated the demand by 37-54 Bm^3 or 7 to 11% of the total withdrawals. The projections for many small countries also differ substantially compared to their current water withdrawals. Moreover, there is no analysis that assesses the accuracy of projections. Overall, the value of long-term country-level projections in global WDPs is inadequate for local water resource planning. The accuracy and value of global WDPs could be increased, if past trends, spatial variation across and within countries, and influence of rapidly changing key exogenous and endogenous drivers of water demand in different sectors are taken into account. For individual countries, short-term projections and sensitivity analysis can be more useful.

Global Water Demand Projections: Past, Present and Future

Upali A. Amarasinghe and Vladimir Smakhtin

Introduction

Water demand projections (WDPs) are widely used for future water resource planning because water development projects usually take long periods of time to complete. Accurate WDPs, in principle, can optimize water development efforts. Better planning can alleviate water-related conflicts, reduce environmental degradation, target investments in water infrastructure and help design better adaptation measures. This naturally explains the continuing interest of WDPs and their widespread application to guide development efforts.

Studies on water supply and demand revealed emerging hot spots – from environmentally unsustainable water-use patterns (Tilman et al. 2001; Arnell 2004; Smakhtin et al. 2004; Milly et al. 2005; Alcamo et al. 2007) to physically water-scarce regions, where the water resources available are not sufficient to meet the increasing demand (Seckler et al. 1998; IWMI 2000; Cosgrove and Rijsberman 2000; Alcamo et al. 2003a; Vörösmarty et al. 2005; Kummu et al. 2010) or the population is at risk of facing severe water scarcity by the middle of this century (Molden 2007).

The 'business as usual' (BAU) scenario in WDPs, which assumes status quo, shows a grim future for water resources availability, with no substantial changes to the present water-use pattern; some other scenarios show pathways to sustainable water resources development.

Water development projects, when completed, should ideally meet the actual demand. However, global drivers of change are at work continuously and, as a rule, it is difficult to quantify demand accurately. The challenge for WDPs is to anticipate change. Understanding the drivers that influence the WDPs the most and how they change over time may offer valuable lessons for future studies. The drivers of change range from endogenous (demographic change, economic growth and lifestyle changes) to exogenous drivers (e.g., virtual water flows) (Allen 1998; Oki et al. 2004; Islam et al. 2007; Chapagain and Hoekstra 2008) and climate change (Cosgrove and Rijsberman 2000; Vörösmarty and Sahagian 2000; Arnell 2004; Alcamo et al. 2007; Elliot et al. 2014).

The world has seen many WDPs by now. They range from scenarios showing large physically water-scarce areas to sustainable water visions with a better outlook of water supply and demand. To what extent these short- to long-term (or bleak to optimistic) projections will materialize in the future is difficult to say. However, the extent to which they follow the current water-use patterns provides clear evidence for their use in future water resource planning. Assessing past projections against current actual conditions may be seen as a learning process for improved water resource planning.

Gleick (2003) presented a review of the pre-1990 WDPs to 2000. The main objective of this paper is to expand the review to recent WDPs, in order to determine the factors that are critical for achieving accurate WDPs or to identify what contributed to deviations from the present water-use pattern. The paper aims to specifically address the following:

- Assess the difference between projected and actual present water withdrawals, globally, and in different sectors and countries.
- Assess what contributes to these differences.
- Propose regional drivers which are sensitive to WDPs and require careful consideration in the future.

Data and Sources

Sources of WDPs

WDPs conducted after 1990 (post-1990 WDPs) used sophisticated modeling frameworks, which was not typical in pre-1990 WDPs. Thus, WDPs with the base year before and after 1990 provide a good comparison for improved methods and increased accuracy. This study primarily collects data and information of WDPs from the published literature and secondary sources.

Extrapolation of population trends is the main feature of pre-1990 global WDPs, as shown in studies by Nikitopoulos (1967), L'vovich (1974), Kalinin and Shiklomanov (1974), Falkenmark and Lindh (1974), De Mare (1976) and WRI (1990). Most of these studies projected the water demand outlook to 2000, showing the increase from the base years of 1960 to 1970. Population was always the main sole driver of change. The norms of water use determined the demand for different sectors. Gleick (2003) used these publications for the review of pre-1990 WDPs to 2000.

Moreover, although population growth is still a key driver, post 1990-WDPs considered other drivers of change: Regional variation of economic growth, changes in demography, lifestyles and consumption patterns, and technological advances in improving water-use efficiencies. They also accounted for the variation of climatic factors and their impact on water use.

The post-1990 WDPs used in this study include: the Russian State Hydrological Institute (Shiklomanov 2000; Shiklomanov and Balonishnikova 2003); World Water Vision (WWV) (Cosgrove and Rijsberman 2000; Rijsberman 2000); International Food Policy Research Institute (IFPRI) (Rosegrant et al. 2002); International Water Management Institute (IWMI) (Seckler et al. 1998); Gleick (Gleick 1998); and Alcamo (Alcamo et al. 2003a). The base year of all post-1990 WDPs was 1995, except for Seckler et al. (1998), where the base year was 1990. Shiklomanov 2000, Shiklomanov and Balonishnikova 2003, and Rosegrant et al. 2002 made WDPs for the year 2010 too, and all other WDPs provided the outlook to 2025.

Shiklomanov (1997, 2000) were influential assessments of water resources in the post-1990 period. It contributed to the 'Comprehensive assessment of the freshwater resources of the world' by the United Nations Commission on Sustainable Development (UN 1997); submitted scenarios to projections of the World Water Council at its Second World Water Forum (Rijsberman 2000); and provided estimates of water withdrawals and consumption patterns for the base year for many other studies on WDPs, including Shiklomanov and Balonishnikova (2003).

IWMI estimated water demand for 119 countries, with 93% of the global water use. Unlike many other projections, the effect of return flows from different sectors and their reuse were explicitly accounted for. It estimated crop water requirements using climatic data from each country.

IFPRI considered 16 agricultural commodities of 36 countries or regions for the estimation of food supply and demand, as well as 69 river basins, countries and regions for agricultural and non-agricultural water demand.

The most recent projections used in this paper are the scenarios of the Comprehensive Assessment of Water Management in Agriculture (CA), developed by IWMI and partners (Molden 2007). The base year of the CA WDPs is 2000, and it only presented the long-term outlook to 2050.

Analytical Approach and Methods

Various WDPs show a different number of countries in the analysis and use various demographic projections (Table 1). In order to make a meaningful comparison, this paper standardizes WDPs in relation to population estimates of the United Nations 2010 revision (UN 2011) – referred to as 'revised' water withdrawals under projections in Table 1. The BAU scenarios (also 'Conventional water use' of Shiklomanov [2000]), in essence, assume that current water-use patterns will continue. The 'sustainable water use, development or vision scenario' (SUS) assumes many departures from the BAU scenario: they emphasize water treatment and reuse, technology use, water saving and designing the path to a sustainable water future.

First, the paper compares all WDPs in 2000 and 2010 with the trends in actual water withdrawals estimated from 1995 and 2005. The AQUASTAT database of the Food and Agriculture Organization of the United Nations (FAO 2012a) has compiled water withdrawals for individual countries from national sources; data of 1995 and 2005 are available for 166 countries, comprising 98% of the global population. Gleick (2000) provides missing data for 1995 for a few countries. Linear interpolation and extrapolation of water withdrawals in 1995 and 2005 provide the estimate for 2000 and 2010, respectively.

TABLE 1. Summary of global water demand projections.

WDP	Source	Scenario[1]	Baseline		Projection[2]		
			Year	Withdrawals (Bm^3)	Year	Withdrawals (original) (Bm^3)	Withdrawals (revised) (Bm^3)
WDP01	Nikitopoulos 1967	BAU	1960	3,029	2000	6,730	6,521
WDP02	L'vovich 1974	BAU	1970	3,029	2000	12,270	8,074
WDP03		Rational use	1970	3,029	2000	6,825	6,622
WDP04	Kalinin and Shiklomanov 1974	BAU	1970	3,029	2000	5,970	5,793
WDP05	Falkenmark and Lindh 1974	Without reuse	1970	3,029	2000	6,030	8,131
WDP06	Falkenmark and Lindh 1974	With reuse	1970	3,029	2000	8,380	5,851
WDP07	De Mare 1976	BAU	1970	3,029	2000	5,605	5,439
WDP08	Falkenmark and Lindh 1974	Without reuse	1970	3,029	2015	10,840	9,683
WDP09	Falkenmark and Lindh 1974	With reuse	1970	3,029	2015	7,885	7,043
WDP10	Belyaev 1990	BAU	1980	4,410	2000	4,350	4,221
WDP11	**WRI** (WRI 1990)		1980	5,285	2000	4,660	4,522
WDP12	**IWMI** (Seckler et al. 1998)	BAU	1990	4,892	2025	4,561	4,695
WDP13		High irrigation efficiency	1990	4,892	2025	3,631	3,720
WDP14	Gleick 1998	SUS vision	1995	5,735	2025	4,270	4,338
WDP15	Alcamo et al. 2003a	BAU	1995	3,572	2025	4,091	4,156
WDP16	Raskin et al. 1997	BAU	1995	4,892	2050	6,081	5,614
WDP17		Policy reform	1995	4,892	2050	3,899	3,600
WDP18	**IFPRI** (Rosegrant et al. 2002)	BAU	1995	3,906	2010	4,356	4,421
WDP19		BAU	1995	3,906	2025	4,772	4,832
WDP20		Water crisis	1995	3,906	2025	5,231	5,297
WDP21		SUS water use	1995	3,906	2025	3,743	3,790
WDP22	Shiklomanov 2000	BAU	1995	3,577	2000	3,717	3,682
WDP23		BAU	1995	3,577	2010	4,089	3,964
WDP24		BAU	1995	3,577	2025	4,867	4,945
WDP25	Shiklomanov and Balonishnikova 2003	SUS development	1995	3,577	2000	3,650	3,616
WDP26		SUS development	1995	3,577	2010	3,771	3,656
WDP27		SUS development	1995	3,577	2025	3,619	3,677
WDP28	**WWV** (Cosgrove and Rijsberman 2000)	BAU	1995	3,600	2025	3,980	3,980
WDP29		SUS vision	1995	3,600	2025	3,456	3,456
WDP30	**CA** (Molden 2007)	Rainfed - high yield	2000	3,529	2050	5,117	4,453
WDP31		Rainfed - low yield	2000	3,529	2050	5,122	4,458
WDP32		Irrigation - area expansion	2000	3,529	2050	6,082	5,418
WDP33		Irrigation - yield increment	2000	3,529	2050	5,422	4,758
WDP34		Trade scenario	2000	3,529	2050	4,722	4,058
WDP35		CA - most plausible	2000	3,529	2050	4,937	4,273

Notes: [1] WDPs used different population projections. The revised projections show the adjustments in relation to the United Nations 2010 population revisions (UN 2011).

Income growth is a key determinant of projected water demand. World Bank (2012) used per capita gross national product (GNP) to categorize countries into three income groups. Using this criteria, this paper used per capita gross domestic product (GDP) to categorize countries into three income groups: (a) low-income - less than USD 1,000/person; (b) middle-income - USD 1,000-12,000/person; and high-income - more than USD 12,000/person. The World Development Indicators of the World Bank (World Bank 2012) is the source for obtaining GDP and other socioeconomic data.

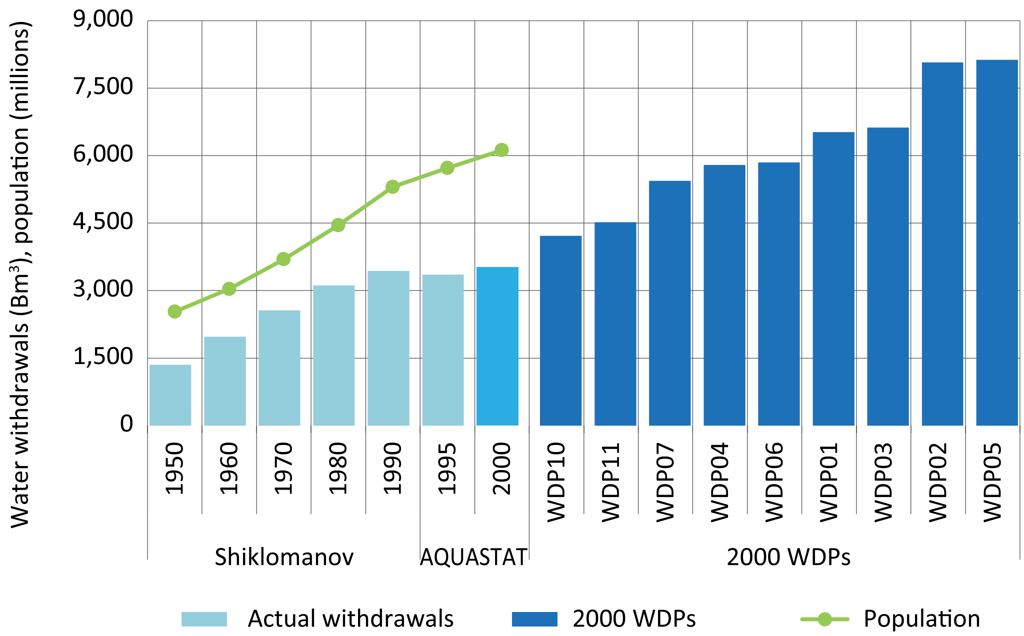
Global WDPs: Results

Pre-1990 Projections

Most Pre-1990 WDPs (WDP01-WDP11) exceeded the actual water withdrawals of 2000 significantly (Figure 1). The base year for WDP10 and WDP11 was 1980. All other projections used either 1960 or 1970 as the base year. All projections used population growth as the main driver of change. It is those unrealistic assumptions of norms of water needs that made WDPs 20-130% higher than the withdrawals in 2000, which was about 3,521[1] Bm^3.

Unrealistic assumptions made on domestic and industrial water use were norms rather than exceptions in pre-1990 WDPs. In the domestic sector, the assumed water withdrawals varied from 73 m^3/person/year to 183 m^3/person/year, whereas the actual withdrawals (based on data

FIGURE 1. Population growth and pre-1990 water demand projections.



Sources: Estimates of water withdrawals on or before 1995 are from Shiklomanov 1997; and FAO 2012a. Population data are from the United Nations 2010 population revisions (UN 2011).

[1] Total water withdrawals in 2000 is the interpolation of water withdrawals from the AQUASTAT database reported for 1995 and 2005, which are 3,285 Bm^3 and 3,757 Bm^3, respectively (FAO 2012a).

from FAO's AQUASTAT database in 2000) were about 71 m^3/person. Importantly, 86 countries, with 70% of the world's population, use much less than 73 m^3/person/year.

In the industrial sector, the assumed levels varied from 183 to 1,200 m^3/person/year under the BAU scenario, whereas 75% of the world's population had lower industrial water withdrawals than even the minimum norms assumed. By 2000, average industrial water withdrawals were only 115 m^3/person. Yet, the assumption of about 143 m^3/person, even with reuse included in some scenarios, is still substantially higher than the norm.

For example, WDP01 of Nikitopoulos (1967) assumed prevailing water use in the late 1960s in the USA when making future projections. The figures assumed for water withdrawals in the domestic, industrial and agriculture sectors were 183, 183 and 700 m^3/person, respectively. However, water withdrawals in the domestic, industrial and agriculture sectors, based on data from FAO's AQUASTAT database in 2000, were 71, 115 and 412 m^3/person, respectively. The total water withdrawals under WDP01 in 2000 was 83% more than the actual demand in that year.

The total water withdrawals under WDP02 of L'vovich (1974), under the BAU scenario, are twice that of WDP01 of Nikitopoulos (1967). Their 'rational water use' scenario (WDP03) assumed less conservative norms, and also took into account water recycled and reused. Despite that, total water withdrawals under WDP02 were still on par with that of WDP01.

In 2000, domestic water demand of many developing countries was nowhere near as the level assumed by WDP04 of Kalinin and Shiklomanov (1974), and WDP07 of De Mare (1976). They assumed 200-300 liters/person/day (lpd) or 73-109 m^3/person/year. Similarly, the assumption of the North American standard of 1,200 m^3/person/year for industrial water use is also high. Even the industrialized high-income countries failed to realize that level of industrial water withdrawals by 2000. Total water withdrawals to 2000 under WDP04 and WDP07 were 65% and 54% larger than the actual withdrawals, respectively.

WDP05 of Falkenmark and Lindh (1974) have followed a slightly different approach. They assumed separate per capita domestic consumption demand for urban and rural populations. Yet, the assumed norms of 400 and 200 lpd (or 146 and 73 m^3/person/year) are even higher than the assumptions of Kalinin and Shiklomanov (1974). By assuming that 90% of industrial wastewater is recycled, this study used a lower industrial water demand of 143 m^3/person/year. However, more than 75% of all the countries had lower industrial water withdrawals per cubic meter per person in 2005 than this norm. The total water withdrawals to 2000 under WDP05 exceeded the actual withdrawal by 100%, and the projection to 2015 seemed to be missing the actual trends by a significant margin.

WDP10 of Belyaev (1990) (cited in WRI 1990) and WDP11 of WRI (1990) are the closest projections made to the actual demand. The main reason for this is that these studies used data of a recent base year (1990), and refined drivers of change based on past projections. These drivers included irrigated area and water-use norms in other sectors.

Comparison of pre-1990 WDPs with actual water use provides a few valuable lessons:

- Population growth is a necessary driver, but is not sufficient for making accurate projections; many other drivers determine water demand of different sectors of different countries.
- Assumption of constant norms of water use per person across sectors and countries is not correct; water demand, which depends on many factors including economic growth, varies substantially, especially across developing countries.
- Short-term projections are better; projections made to the distant future may only illustrate a development path based on some idealistic assumptions, which many countries cannot follow given the level of economic development at present.
- Taking into account the effects of food consumption patterns, cropping patterns and climatic factors (which vary substantially across countries) when estimating the demand for irrigation is crucial.

Post-1990 Projections

Post-1990 WDPs, typically, have two sets of scenarios: the BAU scenario and sustainable water use scenario (SUS), the latter showing the paths for sustainable water resources development and management. This review includes projections made by the Russian State Hydrological Institute (Shiklomanov 2000; Shiklomanov and Balonishnikova 2003); WWV (Cosgrove and Rijsberman 2000; Rijsberman 2000); IFPRI (Rosegrant et al. 2002); IWMI (Seckler et al. 1998); Gleick (Gleick 1998); Alcamo (Alcamo et al. 2003a); and CA (Molden 2007). All WDPs assessed the long-term outlook to 2025 or 2050; the scenarios by IFPRI and Shiklomanov also provide short-term projections to 2000 or 2010.

Post-1990 WDPs used different approaches from those of pre-1990 WDPs. Table 2 summarizes the main characteristics of these differences, which include a detailed assessment of water requirements of three sectors, assumption of recycling and reuse, and modeling to integrate return flows and reuse between sectors.

Generally, post-1990 WDPs, under the BAU scenario, have substantially lower projections than pre-1990 WDPs. For example, the lowest of the pre-1990 WDP BAU projections to 2000 was 20% above the present water use, whereas the largest of the post-1990 projections is 4% below the present water use.

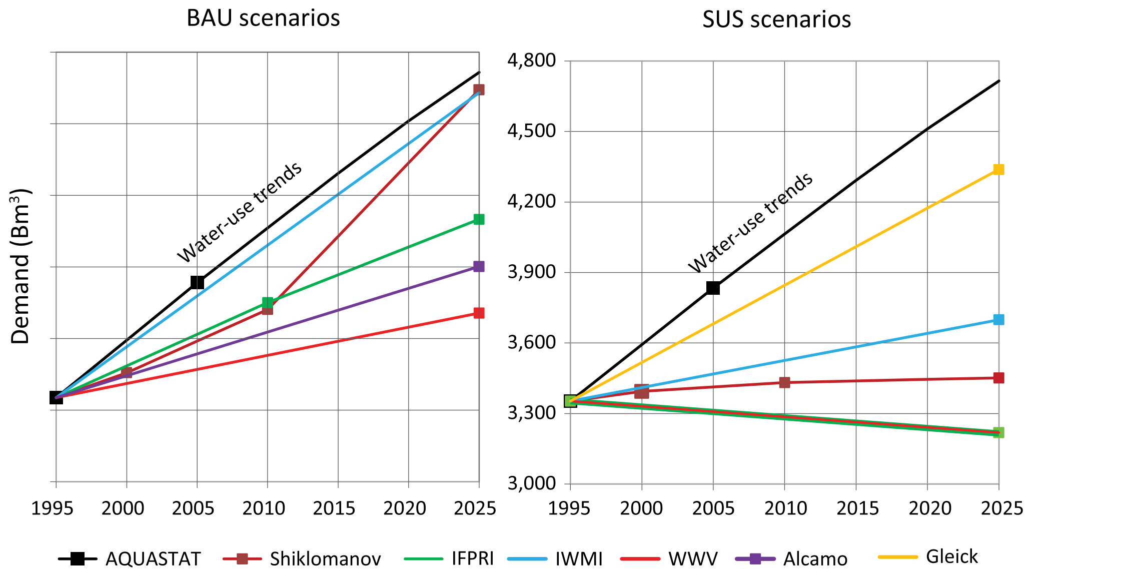
Figure 2 shows the water-use trends based on data from FAO's AQUASTAT database, and the BAU and SUS projections of different WDPs. Even after standardizing for differences in the population projections (in Table 1), total water withdrawal estimates for the base year are different from the AQUASTAT data. The studies by Shiklomanov, IFPRI and WWV show large differences. Therefore, the projections need further adjustments. The WDPs in Figure 2 show these adjustments, which are the products of the percentage increase in demand of the original scenarios and the AQUASTAT baseline withdrawals in 1995, i.e., adjusted projection = initial projection/1995 baseline estimate of WDP × 1995 AQUASTAT estimate.

Most post-1990 WDPs have a lower projection than the short-term trend of present actual water use, which are shown by AQUASTAT 1995 to 2010 (Figure 2, first block). The long-term trends are indicated by the 2015-2025 withdrawals. AQUASTAT 2000 withdrawals are the interpolation of 1995 and 2000 estimates. AQUASTAT estimates of 2010 to 2025 are the

TABLE 2. Approaches used in the pre-1990 and post-1990 WDPs.

Pre-1990 WDPs	Post-1990 WDPs
• Population growth is the main driver.	• Population growth is a main driver, but not the only one.
• Assumed constant norms of water use for the domestic sector; some with different norms for rural and urban populations.	• Econometric modeling to estimate per capita water demand with economic growth and demographic change as drivers.
• Assumed constant norms of water use for the industrial sector; some assumed reuse.	• Econometric modeling with economic growth, types of industries and output, and demographic change as drivers to estimate per capita water demand; technological advancement, and reuse and recycling as drivers to estimate total water demand.
• Assumed constant norms for per capita irrigation demand.	• Econometric modeling with changing lifestyles and consumption patterns, economic growth and demographic change as drivers to estimate food demand. • Land-use patterns, water availability, yield growth, rainfed potential and trade to estimate production and irrigated area demand. • Climatic factors, soils and cropping patterns to estimate irrigation requirements. • Water-use patterns (surface water, groundwater), technology (drip, sprinkler) and irrigation efficiency as drivers to estimate irrigation demand.
• Aggregate water demand of different sectors.	• Modeling framework to incorporate return flows and reuse of different sectors to estimate total water demand.

FIGURE 2. Post-1990 WDPs under the BAU and SUS scenarios.



Sources: AQUASTAT data for 1995 and 2005 are from FAO 2012a; AQUASTAT 2000 and 2015-2025 data are authors' estimates. BAU scenario and SUS values are based on Table 1 (with further adjustments as noted above).

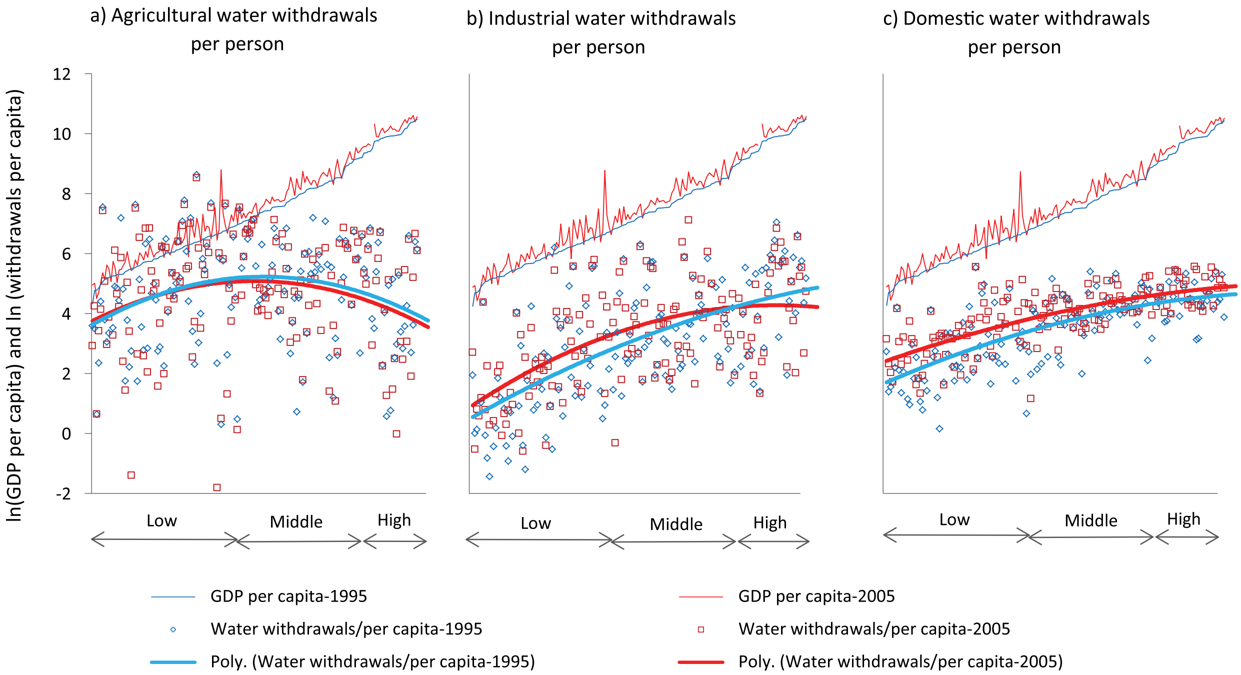
extrapolation using the population projection of a given period with the per capita water withdrawals of the preceding period. Although these estimates are not the actual values, they reflect the possible trends under the BAU scenario with the two actual withdrawals in 1995 and 2005.

All SUS projections to 2015, except for WDP14 of Gleick (1998), are even less than the present total withdrawals. If these projections are to realize by 2025, there should be a sharp change in water-use patterns in all the sectors, especially in the agriculture sector. However, this is highly unlikely given the present low level and slow change in water withdrawals in many developing countries (Figure 3). Many low- to middle-income countries have lower water withdrawals now than the developed countries. There is a tendency for per capita water withdrawals to increase with economic growth. However, the changes over the decade 1995-2005 was slow.

The fact that population projections used in both pre- and post-1990 WDPs are similar mean that other key drivers of water demand used in the two periods are substantially different. Yet, most post-1990 WDPs under the BAU scenario were also not able to adequately capture the general trends of other critical drivers. For example:

- WDP22 and WDP23, the BAU scenarios of Shiklomanov (2000) for 2000 and 2010, are 4% and 8% lower than the trends of AQUASTAT, respectively. However, in the next 15 years, WDP24 (BAU scenario to 2025) makes a sharp course correction, with significantly higher growth rates in total water withdrawals. However, for a BAU scenario, such changes in growth during the middle of the projection period are rather unrealistic. Therefore, the claim that 40% of the global population in 2025 would live under a situation of catastrophically high pressure on water resources, where water use exceeds 40% of the available supply, may not be realistic too.
- WDP28, WWV BAU scenario (Cosgrove and Rijsberman 2000), assumed virtually no increase in irrigated area after 1995. However, the net irrigated area (NIA) (i.e., area equipped for irrigation at least in one season) has increased 14% between 1995 and 2005, and by a further 3% by 2010 (FAO 2012b). This BAU scenario also projected

FIGURE 3. Per capita GDP, and water withdrawals in the (a) agriculture, (b) industrial, and (c) domestic sectors in 1995 and 2005.



Sources: GDP data are from World Bank 2012; Water withdrawals of different sectors are from FAO 2012a.

Notes: the X-axis of the three figures shows countries with increasing per capita GDP in 1995. 'Poly.' in the legend shows the trend with a quadratic polynomial fit.

irrigation withdrawals to increase by 11% by 2010, but it increased about 14% by 2005 according to FAO's AQUASTAT database (FAO 2012a).

- Similarly, the WWV BAU scenario (Cosgrove and Rijsberman 2000) projected industrial and domestic water withdrawals to increase by 7% and 47%, respectively, between 2000 and 2025; however, actual withdrawals have already increased by 7% and 48% by 2005. This BAU scenario also assumed a 20% to 50% reduction in domestic withdrawals in developed countries, and a significant increase in the water-use efficiency in irrigation and industrial water use, globally. Given the present trends (Figure 3), it is likely that the water-use efficiency in all sectors will increase, and water use in the domestic and industrial sectors of the high-income countries will decrease. However, it is highly unlikely that the decrease in all the countries will be as rapid as suggested in the scenarios of Cosgrove and Rijsberman (2000).
- WDP12, the IWMI BAU scenario (Seckler et al. 1998), assumed that per capita irrigated area and irrigation efficiency remain constant over the projection period. It is true that, globally, actual per capita NIA remained constant at 0.046-0.047 ha since 1990 (FAO 2012b). This is the main reason why the projections of this BAU scenario are close to, and only 2% lower than, the actual withdrawal estimates of 2010. However, as will be shown later, there are significant differences between countries.
- The WDP18 and WDP19 IFPRI BAU scenarios (Rosegrant et al. 2002) assume the continuation of present policies and trends in water investments, pricing and management. These scenarios project total water demand to increase by 12% between 1995 and 2010. However, this is lower than the present trends in water use. The main reason for this is the low demand for irrigation, which is projected to increase by only 4%. The IFPRI BAU scenarios assumed some growth in irrigated

crop area, but projected hardly any increase in irrigation consumption. This is difficult to achieve without a major shift in cropping patterns, from high to low water-consuming crops or to different regions. For example, IFPRI projected the world's total rice area to increase by only 1 million hectares (Mha) between 1995 and 2010, and then decrease by 3 Mha by 2025. However, the total rice area increased by 10 Mha by 2010, and much of that increase was due to the use of irrigation (IRRI 2012).

In the domestic sector, providing at least the basic water needs for humans (50 liters/day, or 20 m^3/year) (Gleick 1996) for drinking, cooking, washing and bathing is a norm (WDP12 [IWMI] and WDP14 [Gleick 1998] scenarios). Beyond this minimum, economic growth and urbanization are the main drivers of domestic water demand. Water pricing, technological development and water reuse, especially in the industrial sector, would reduce the overall demand for water.

All SUS assumed increasing water-use efficiency, especially in the irrigation and industrial sectors.

- The WDP25 to WDP27 scenarios (Shiklomanov and Balonishnikova 2003) assumed that there were progressive tendencies of increasing water-use efficiency, and showed that water demand will stabilize by 2025 with a 26% lower demand under the BAU scenario. Given the mismatches between BAU scenarios and actual trends in water use, it is highly unlikely that water demand under the SUS scenarios will stabilize by 2025.
- The WDP13 IWMI scenario (Seckler et al. 1998) assumed an increased irrigation efficiency subject to a 70% ceiling, which allow adequate flows for use in other sectors, and projects a 32% lower total demand in 2025 than under the BAU scenario. This ceiling premised that there will be adequate flows to meet the demand of all the sectors, and is thus closer to a SUS demand scenario. The high irrigation efficiency scenario projects a 25% increase in total water demand compared to a 57% increase under the BAU scenario.

  IWMI claimed that the actual water demand could be between the BAU and high irrigation efficiency scenarios. However, the actual growth in water demand seemed to be closely following the BAU scenario. The main reason for this is the detailed analysis of the changes of drivers and assessment of water demand for each country, rather than using estimates of the drivers for regions or of analogues.
- The WDP21 scenario of IFPRI (Rosegrant et al. 2002), which is similar to the WDP29 WWV SUS scenario, assumes that increased water-use efficiency and water pricing would drastically reduce water consumption in all the sectors, leading to a 20% lower overall consumption than under the BAU scenario.
- The WDP14 scenario (Gleick 1998) used a slightly different approach - the disaggregated end-use approach: (a) setting an explicit set of criteria and limits for sustainable water use for different sectors and regions, and (b) examining how to reach those limits. In the domestic sector, Gleick (1998) assumed water requirements of at least 50 lpd to meet the basic human needs for all people, and improving water-use efficiency to bring down the high domestic water use to a level of 300 lpd. In the agriculture sector, the assumption was that changes in dietary patterns would provide a calorie supply of 2,500 kilocalories (kcal)/ person/day, and about 3,500 lpd to grow food to obtain the calorie supply. In the industrial sector, the assumption was that there was a significant improvement in water-use efficiency, and no increase in total water use. Besides these, Gleick (1998) assumed significant changes in policies, open trade and technological improvements to support the realization of the scenario. Among all the scenarios, the SUS scenario of Gleick (1998) followed the actual trends in water use far better than those suggested by many other BAU scenarios.

A few scenarios had an outlook to 2025. IWMI (2000) generated three scenarios (basic, TEC and VAL, as in the WWV scenarios) to contribute to the World Water Vision. The assumptions underlying the main drivers were similar to the WWV scenarios. Thus, the projected values are much lower than in the IWMI scenarios discussed earlier.

WDP15 (Alcamo et al. 2003a) presented a BAU scenario to 2025 using the WaterGAP 2 (Water – a Global Assessment and Prognosis) model (for details of the model, see Alcamo et al. 2003b). The model assesses the current water resources of river basins, and water use by domestic, industrial and irrigation sectors, and integrates both these factors to assess the influence of changes in various drivers on future water supply and demand. The WaterGAP model, under similar assumptions as those made in the WWV scenario, projects a 16% increase in total water withdrawals, which is slightly higher than the WWV scenario but smaller than all the other scenarios (Figure 2).

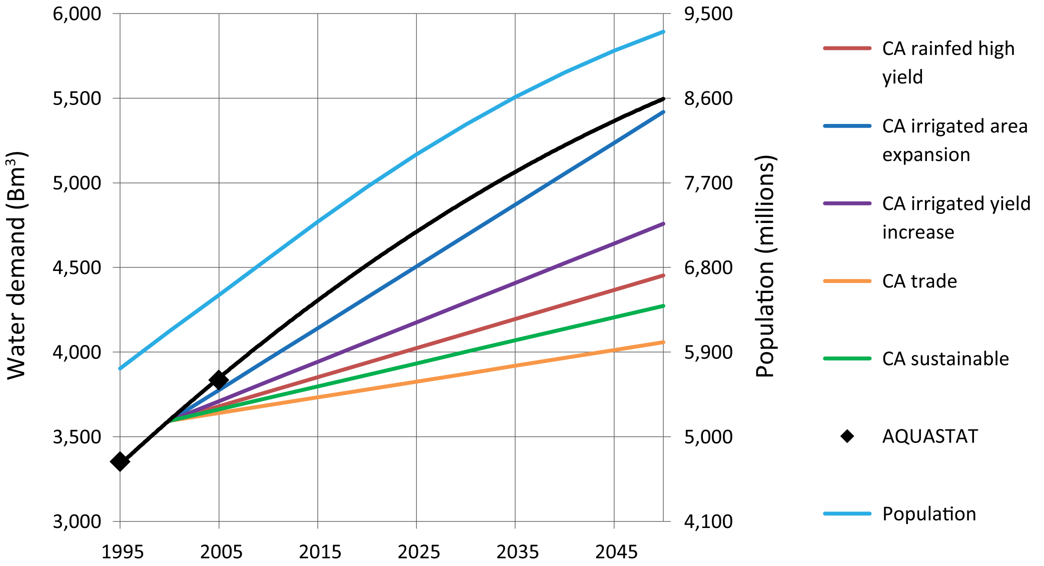
The CA scenarios of agricultural water demand mainly show the changes in the outlook from 2000 to 2050. Figure 4 shows water demand projections, including demand from the domestic and industrial sectors: Improvements in irrigated or rainfed yields, expansion of irrigated area (similar to the BAU scenario), increased trade and sustainable water use (the most plausible). All CA scenarios show an increase in water withdrawals from the base year 2000, but the irrigated area expansion scenario shows the closest to withdrawals in 2005 and 2010. The short time period of the projection has helped the CA irrigation scenario to better extrapolate the current trends.

The **'CA irrigated area expansion'** scenario (Figure 4, dark blue line) seemed to follow the actual trends in water use very closely.

The **'CA trade'** scenario (Figure 4, yellow line) seemed very optimistic. The actual water withdrawals in 2010 were already at the level that they projected for 2050. Per capita water demand in 2050 is only 74% of that in 2005. Such a reduction may not be realistic, given that per capita water demand decreased by only 1% between 1995 and 2005, and a large number of low- and middle-income countries still have significantly lower per capita withdrawals.

The **'CA sustainable'** scenario (Figure 4, green line) is identified as the most plausible scenario of CA, where per capita water demand in 2050 is 87% of the present withdrawals. Yet,

FIGURE 4. CA scenarios of agricultural water demand.



Sources: Based on Table 1 (with further adjustments for baseline differences as indicated in Figure 2).

Note: Trends in water use after 2005, projected by AQUASTAT, mainly reflect the population growth with per capita withdrawals of the preceding period, which were used to estimate withdrawals of the current period after 2005.

such a reduction requires significant increases in water productivity in all sectors, especially in agricultural water use over and above the 'CA rainfed high yield' and 'CA irrigated yield increase' scenarios, and also in the low-income countries. Figure 3 shows that the path envisaged in the plausible scenario has already missed the present trends or requires a significant bending of the demand curve now. In other words, it requires stopping further water development and increasing water productivity considerably. This means a large reduction of water use from the agriculture sector in some countries, as the water demand of the domestic and industrial sectors is rapidly increasing in those countries. This is also unlikely to happen, at least in the near future.

The above WDPs show that global scenarios, assessing even the short-term outlook, have differences in projections. Most BAU projections follow vastly lower trajectories than the present trends of water withdrawals. A major shortcoming here is that the WDPs have no sensitivity analyses with respect to key drivers, so it is not possible to gauge the accuracy of these projections.

The trajectories of the BAU projections of IWMI, Shiklomanov and IFPRI are the nearest to the actual trends in water use. However, they also have a progressively increasing gap: 2-7% lower than the actual withdrawals by 2010, and possibly 13-15% lower than the trends in water use by 2025. The accuracy of these WDPs for different sectors and countries will be discussed in later sections. Yet, it is useful to highlight a few features from the post-1990 WDPs that are valuable for studies on future projections. The short-term projections have better accuracy and provide a valuable input into local planning. Also, it is important to:

- conduct a detailed assessment of past trends in food demand and supply, which indicate the future trajectories of key exogenous or endogenous drivers of water demand estimation; and
- have realistic assumptions for future growth of the key drivers of water demand and supply, as they are important for estimating:
  - demand for irrigation, which will still be the dominant water use sector, at least in the short- to medium-term;
  - water demand and supply of large countries with huge spatial variation of resources and key drivers; and
  - domestic and industrial demand of countries with vastly different levels of economic growth.

Despite the level of accuracy, the post-1990 WDPs show a frightening future outlook. The present water-use patterns, assessed by many WDPs, are rather bleak. Many large regions and river basins are already physically water scarce and have unsustainable water use. The BAU projections only show an exacerbating situation. Given the current water-use trends, it is difficult to anticipate the time at which the demand curve bends to meet the sustainable WDP scenarios to 2025. This requires further detailed assessment of differences in water demand of different sectors and countries. This can facilitate refining the present methodology and improving WDPs in the future.

Sectoral WDPs

Water-use Patterns

Most WDPs seemed to have overlooked changing water-use patterns of different sectors. The current trends show that, between 1995 and 2010 (Figure 5, AQUASTAT data), the share of water withdrawals from the:

- agriculture sector decreased, albeit slowly by 3%;
- domestic sector increased by 4%; and
- industrial sector decreased by 1%.

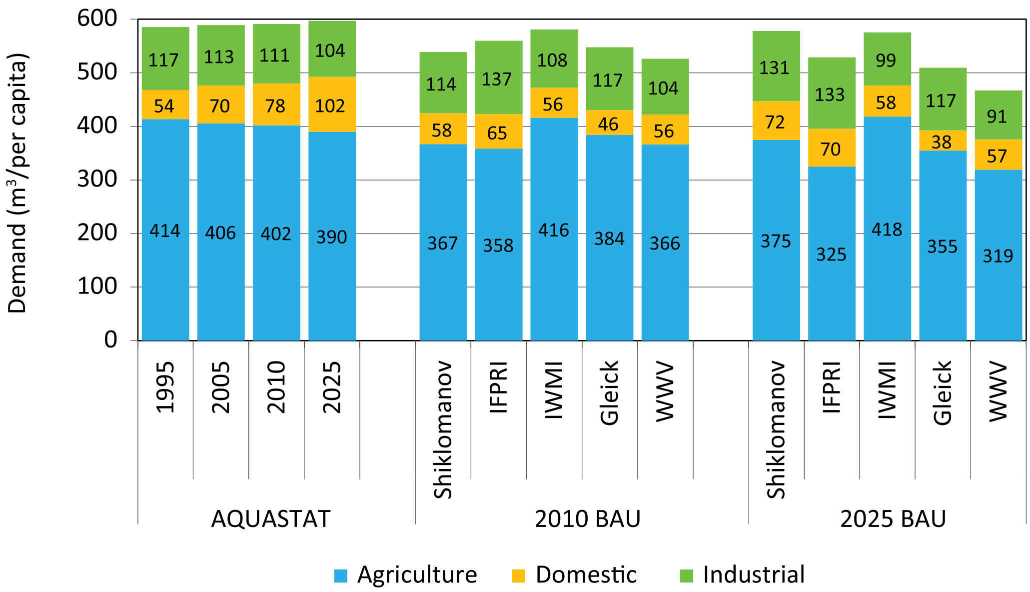
However, even the BAU scenarios of most WDPs are significantly different from the current pattern of water use (Figure 5, 2010 BAU scenarios). With the assumption of increased efficiency, SUS projected lower withdrawals for the agriculture and industrial sectors. It is sufficient to say that the projections for different sectors under sustainable use scenarios are far off from the present trends.

In spite of the changing patterns of the three sectors, total per capita withdrawals show very little change globally; only an increase of 1 m^3/person between 1995 and 2010. However, BAU WDPs predicted reductions of 6 to 49 m^3/person (IWMI to WWV). They contributed to the large deviations between the WDPs and actual trends of total water withdrawals in 2010. This indicates two things: even the BAU scenarios used vastly different assumptions between them on the key drivers of water demand; and the assumptions led to substantial departures from the past trends which, in fact, BAU scenarios would expect to extrapolate.

Domestic Sector WDPs

The post-1990 BAU WDPs predicted substantially lower water demand for the domestic sector (Figure 5). This sector has the lowest share of total water withdrawals now - only 12% globally, but the highest growth in per capita water withdrawals (26% between 1995 and 2005). At present, the average withdrawal (70-78 m^3/person) exceeds even those projected for 2025 by 4 to 50%.

FIGURE 5. Per capita actual (1995-2010) and projected (2025) water withdrawals.



Sources: FAO 2012a; Shiklomanov and Balonishnikova 2003; Rosegrant et al. 2002; Seckler et al. 1998; Gleick 1998; Cosgrove and Rijsberman 2000.

Note: AQUASTAT data for 1995 and 2005 are actual estimates, and 2010 and 2025 are extrapolated trends.

Further disaggregation shows that per capita domestic water demand has increased in all income groups: 77% in the low-income group, and 11% and 17% in the middle- and high-income groups, respectively (Table 3). In spite of these increases, low-income countries still have very low domestic water withdrawals - only 43 m^3/person in 2005, which is nearly half that of the middle-income countries and only 27% of the high-income countries. The average figures mask large variations that exist across countries (Figure 6).

The box plot in Figure 6 shows the distribution of domestic and industrial water withdrawals in each income category; the median is shown by the horizontal line inside each box and the box depicts the interquartile range.

TABLE 3. Population, GDP and water withdrawals in 1995 and 2005.

Factor	All countries[1] (n=160)		Income group[2] Low-income (n=70)		Middle-income (n=64)		High-income (n=26)	
Year	1995	2005	1995	2005	1995	2005	1995	2005
Population (millions)	5,610	6,376	3,562	4,128	1,224	1,366	823	882
Percentage of urban population (%)	45	50	32	37	66	69	75	78
GDP/person (USD)	4,371	5,179	471	822	2,930	3,664	23,598	28,192
Percentage from agriculture sector (%)	4	4	21	15	7	6	2	1
Percentage from industrial sector (%)	29	29	37	41	34	34	28	26
Percentage from service sector (%)	67	68	42	44	58	59	71	73
Water withdrawals/person (m^3)[3]								
- Total	586	589	477	509	607	598	1,023	952
- Agriculture sector	414	406	411	413	419	406	419	371
- Industrial sector	117	113	42	52	103	98	465	422
- Domestic sector	54	70	24	43	85	95	138	159

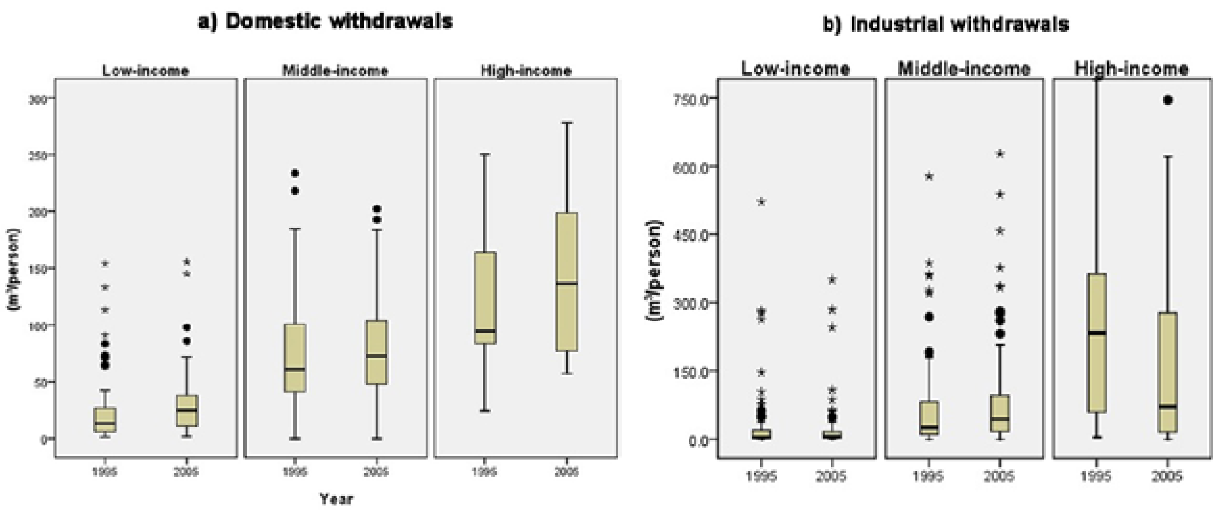
Source: Water withdrawals are from the AQUASTAT database (FAO 2012a); Population and GDP are from the World Development Indicators (World Bank 2012).

Notes: [1] This includes 160 countries, comprising 99.3% of the world's total population.

[2] Income grouping is based on 1995 per capita GDP.

[3] Weighted averages.

Figure 6. Per capita (a) domestic withdrawals, and (b) industrial withdrawals in 1995 and 2005 across different income groups.



In 2005, the median per capita domestic water withdrawals of low-income groups was only 25 m^3/person (Figure 6(a)); and 80% of the countries in this group have per capita domestic withdrawals below the average. Similar skewed distributions exist in other income groups too.

Due to these skewed distributions of access to water, income growth and urbanization, there will be further increases in domestic water demand, especially in the low- and middle-income countries, which Seckler et al. (1998) used in econometric models to estimate per capita domestic and industrial demand. Equation (1), the Cobb-Douglas regression on domestic water demand per person (*DOMWDPC*) across countries with the share of urban population *(%URBPOP*) and per capita GDP (*GDPPC*) as explanatory variables, confirms these trends.

global models; yet, they are very important to ensure accuracy and value of WDPs for use in planning for two reasons. First, very often, the priority of national water policies is to secure domestic water supply. This also has strong links with water supply, sanitation and health aspects, and the Millennium Development Goals. Thus, the present level of water supply and the priorities of countries are very important parameters to consider. Second, a large number of low- and middle-income countries, which include a major part of the world's population, have very low domestic withdrawals at present. With economic growth and urbanization, these countries demand more access to domestic water supply (Equation 1). Thus, the demand drivers of individual countries under BAU scenarios require detailed examination.

$$Ln(DOMWDPC) = -4.3^{**} + 0.27^{*} \times I_{year} + 1.2^{**} \times LN(GDPPC) - 0.05^{**} \times Ln(GDPPC)^2 + 0.55^{**} \times Ln(\%URBPOP),\ R^2 = 0.55 \quad (1)$$

where: I_{Year} is a dummy variable taking the value 0 in 1995 and 1 in 2005. Values within parenthesis show the standard errors; ** indicates that estimates are statistically significant at 0.005 level (in fact, the significance level of the five coefficients are 0.0, 0.004, 0.0, 0.001 and 0.0, respectively; the scatter plot of residuals shows no undue influence from outliers, and the normal probability plot shows no significant departure from the assumption of normal errors).

This shows that a 1% increase in per capita GDP in 2005 will increase the domestic demand by 1.2%; or in absolute terms, a USD 100 increase in average per capita GDP will increase the domestic demand by 1.1 m^3 from the average withdrawals of all countries. A similar increase in GDP will increase domestic demand of low- and middle-income countries by 4.3 and 1.9 m^3/person, respectively, from their averages, but only 0.4 m^3/person in high-income countries.

However, the statistically significant dummy variable for time in Equation (1) shows that other factors have also contributed to increasing domestic water demand. These factors are mostly country-specific and are difficult to capture in

Given this backdrop, the projections under sustainable water use scenarios could be highly unrealistic, as they are even more downward biased than the BAU projections. Future studies should identify countries according to the present level of development, and develop realistic scenarios for those which are ready to move towards sustainable development.

Industrial Sector WDPs

In the Industrial sector, the BAU scenarios have mixed projections: some are optimistic about increasing water-use efficiency and others are not. In fact, the current trends show a significant reduction in per capita industrial water use. Two factors contributed to this trend. First, high-income countries dominate industrial water withdrawals at present: they account for 51% of the total water withdrawn by the industries; but only have 14% of the world's population. Second, per capita industrial withdrawals of high-income countries have been decreasing recently.

Technological advances and stringent policies led to high-income countries increasing water treatment and reuse in the industrial sector. In fact, many high-income countries have reduced industrial water withdrawals; both the mean and median have decreased significantly between 1995 and 2005 (Table 3; Figure 6(b)). However, the same is not true for other countries, where industrial water withdrawals are very low to begin with.

In 2005, the average per capita industrial water withdrawals was only 54 m^3/person in the low-income countries, whereas it was 422 m^3/person in the high-income countries. Again, the average values hide vast variations between countries (Figure 6(b)). The median industrial water withdrawals of the low-income countries is only 6 m^3/person, and 86% of the countries have lower withdrawals than the average. Also, the middle-income countries did not fare better in this count.

A vibrant industrial sector is critical for rapid economic growth. The double-digit growth of industrial outputs of rapidly growing economies of developing countries, such as China, India, Brazil and South Africa, are good examples. Many other developing countries aspire to follow a similar path, and access to adequate water will be crucial for sustaining this process. Industries are already looking at sustainable water security for their growth. Perhaps, past WDPs missed this reality, which future projections should take cognizance.

Agriculture Sector WDPs

The agriculture sector is by far the highest water user in many countries; it accounted for 71% of the total water withdrawals globally, and 81% in low-income countries in 1995. Many BAU scenarios were highly optimistic about the increase in irrigation efficiency. They project drastic reductions in average per capita irrigation demand: 11% by Shiklomanov and WWV, 13% by IFPRI and 7% by Gleick. However, IWMI's BAU scenario was less optimistic about the increase in irrigation efficiency. It assumed constant per capita net irrigated area and agricultural demand as in 1995.

Yet, actual per capita agriculture sector withdrawals decreased only by 4% between 1995 and 2005. The high-income countries are the major contributor to this overall decrease, where per capita withdrawals decreased by 12% from 419 to 371 m^3/person. On the other hand, agriculture is still a major component of economic growth in low-income countries. It directly contributes to 15% of the overall GDP at present, compared to only 1% by the high-income countries. This contribution could be much higher in the low-income countries, if the forward and backward linkages of the industrial and service sectors are also taken into account.

Accurate demand projections for the agriculture sector are important for water resources planning in developing countries. However, it is also the most complex sector to make demand projections. Many factors contribute to agricultural demand, including national self-sufficiency, household food security, rural livelihood security, economic growth, cropping patterns, climate, soils, access to water, water management technologies, water reuse, etc. Many of these factors vary between and within countries. It is not clear as to what extent the global WDPs have accounted for these critical factors.

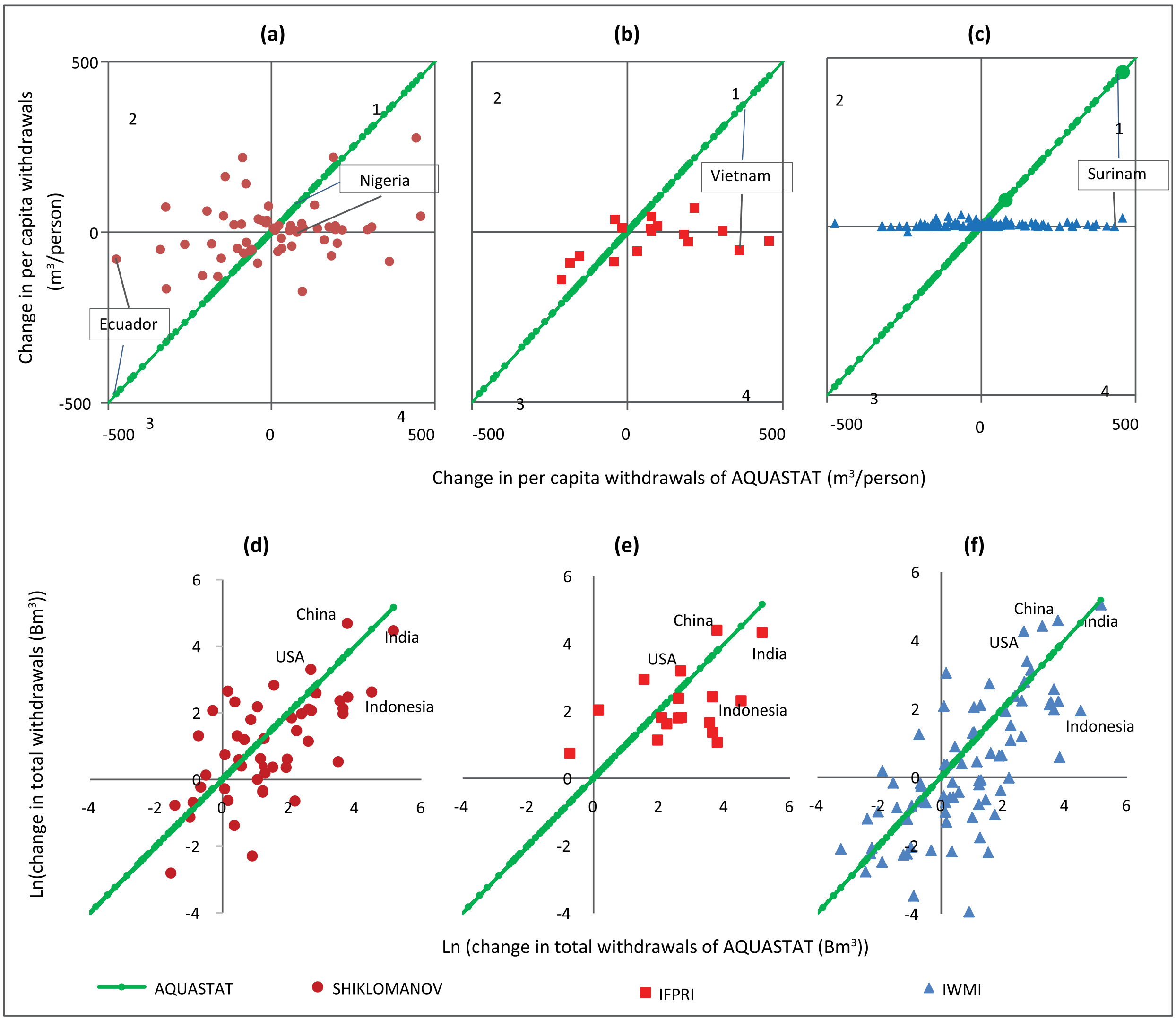
WDPs for Countries

Global estimates of WDPs of many large and small countries are quite different from the present patterns of water withdrawals. Figures 7(a), 7(b) and 7(c) compare the changes in per capita water withdrawals from 1995 to 2010 of Shiklomanov, IFPRI and IWMI BAU scenarios (on the Y-axis), respectively, with those of the AQUASTAT database (on the X-axis). Figures 7(d), 7(e) and 7(f) show the changes in total withdrawals of the three scenarios with those of the AQUASTAT database; in these figures, the axes are depicted in natural log scale to show the deviation of small as well as large countries.

The diagonal line (green) shows the changes in withdrawals according to the AQUASTAT database. The points close to the diagonal line in the first and third quadrant of figures 7(a) to 7(f) show that the projected water demand of the scenarios and water withdrawals in the AQUASTAT database closely follow each other. The points that are below or above the diagonal line show an under- and over-estimated projection; all three scenarios have many countries in this category. The countries in the second and fourth quadrant show WDPs that are completely opposite to the current trends.

Over- or under-estimation of the demand in small countries have little influence on the overall results of the global WDPs. Nevertheless, the projections depict a distorted picture of those

FIGURE 7. Changes in total per capita and total water withdrawals from 1995 to 2010 for the Shiklomanov, IWMI and IFPRI BAU scenarios.



Sources: AQUASTAT database (FAO 2012a); Shiklomanov (Shiklomanov 2000; Shiklomanov and Balonishnikova 2003); IFPRI (Rosegrant et al. 2002); IWMI (Seckler et al. 1998).

Notes: AQUASTAT has data for 160 countries, and the BAU scenarios of Shiklomanov, IFPRI and IWMI have 63, 21 and 118 countries, respectively.

countries and have no value in national policy planning. For example, Surinam (first quadrant, Figure 7(c)) is a small country with a population of only 0.5 million in 2005. The country's per capita water withdrawals has increased to 288 m^3/person between 1995 and 2005, whereas IWMI's BAU scenario assumed no growth. The total water withdrawals in the country has increased by only 0.21 Bm^3. Although this is a significant increase in relation to the country, it is negligible (0.1%) in the context of the changes in total water withdrawals globally. A similar situation exists in Ecuador (third quadrant, Figure 7(a)), where projections are over-estimated.

On the other hand, deviation of large countries can significantly influence global WDPs. China, India, Indonesia and the USA are good examples: these four countries include 45% of the world's population and 47% of the total water withdrawals. These countries alone contributed to 47% of the change in global water withdrawals between 1995 and 2010. Yet, figures 7(d), 7(e) and 7(f) show that there are significant under- or over-estimations of water demand of these countries under the BAU scenarios of IWMI, IFPRI and Shiklomanov, of which the latter, as shown before, was the nearest global projection to actual withdrawals in 2010.

For these four countries, the change in total demand between 1995 and 2010 under the IWMI BAU scenario is just 6 Bm^3 more than the change in trends according to the AQUASTAT database; this looks impressive in terms of aggregate projection, given the size of the total withdrawals of these countries. However, the IWMI BAU scenario over-estimated the total water demand of China and USA by 110 Bm^3, and underestimated the total demand for India and Indonesia by 104 Bm^3. Similarly, although the global projection to 2010 made by the IWMI BAU scenario is within 2% of the actual change, it over- or under-estimated the change in demand by more than 100% in 40 countries, and by more than 50% in another 48 countries. This projection is hardly impressive where the individual countries are concerned.

The IFPRI and Shiklomanov BAU scenarios have over-estimated the aggregate change in demand of China and the USA by 105 Bm^3 and 135 Bm^3, respectively, and underestimated the aggregate change in demand of India and Indonesia by 86 Bm^3 and 100 Bm^3, respectively. Once again, the projected aggregate change of the four countries is relatively close to the change in trends, but the projections of individual countries are far off.

What contributed to these deviations is critical for future projection exercises. Since agricultural demand dominates the total demand in many countries, the focus of the analysis here is on four key drivers of agricultural water demand:

- Net irrigated area or area equipped for irrigation.
- Irrigated area of water-intensive crops.
- Efficiency of irrigation water use.
- Crop yields.

The differences in key drivers of water demand from the projections made for China and India are shown in Box 1 and Box 2, respectively.

Significant discrepancies also exist between projections and actual water demand trends in many other countries:

- The USA has 5% of the world's total population, but accounted for 12% of the total irrigation withdrawals in 2010. All WDPs have projected a significantly higher per capita irrigation demand for the USA. Yet, actual NIA and irrigation withdrawals have hardly changed since 1995. In fact, per capita water withdrawals of the USA have decreased by 211 m^3 between 1995 and 2010.
- Nigeria has the largest population in Africa, which was about 158 million people in 2005; its per capita water withdrawals have increased by 75 m^3/person in a decade, from only a tiny 33 m^3/person in 1995. However, all the BAU scenarios projected a growth of less than 10 m^3/person. Total water withdrawals of the country have increased by 8 Bm^3 since 1995. Although this increase is still low (only 2%) in comparison to the global increase, it is a significant increase for Nigeria, given its large population and low GDP. It is likely to increase further with economic growth, and water withdrawals

should follow a significantly higher trajectory than that projected by all the scenarios.

- Egypt had a population of about 81 million people by 2010; it has reduced its per capita water withdrawals from 948 to 906 m^3/person, and 88% of that was for irrigation. However, due to population growth, the total water withdrawals have increased to 15 Bm^3 since 1995. With increasing water scarcities, Egypt will have to tread the same path of reducing per capita irrigation withdrawals, and meeting the increasing demand from the other sectors. While Shiklomanov and IFPRI over-estimated the decrease in demand in Egypt, the IWMI scenario had underestimated the decrease by assuming similar per capita irrigation demand.

Box 1. China.

China, with 1.37 billion people, had 20% of the world's population in 2010, and accounted for 14% of the total water withdrawals. Between 1995 and 2010, per capita water withdrawals had decreased slightly by 6 m^3/person and total water withdrawals had increased by 43 Bm^3. However, all BAU scenarios have over-estimated the total demand (figures 7(d), 7(e) and 7(f)), mainly due to higher irrigation demand projections.

- All WDPs assumed significantly lower growth of per capita NIA (by at least 11%) and total NIA (by 10 Mha) than the actual growth, but projected similar or higher per capita irrigation withdrawals. This means that all WDPs assumed lower growth of irrigation efficiency.
- The projection of rice yield made by the IFPRI BAU scenario exceeds that of the current trends by 11%; higher yield means smaller rice area. However, the projected rice area is similar to the current trends.
- The IFPRI BAU scenario projected 6% lower wheat yield; and projected the wheat area to remain at the same level as in 1995. However, the actual wheat area has declined by 4 Mha.

However, between 1995 and 2010:

- NIA has increased 15 Mha (or 29%); and
- total irrigation withdrawals have decreased by about 10%.

Water scarcity is a major issue in northern China (Molden 2007). China's water governance policy has stringent laws that require improvements in irrigation water-use efficiency (Gao 2012). It heavily emphasized the modernization of irrigation schemes and increasing the use of water-saving technologies, leading to increases in water-use efficiency in the last decades. Many WDPs have not expected such drastic changes in China.

It is not clear whether the Chinese policymakers heeded to the bleak water resources situation assessed by the global WDPs. However, they clearly responded to pending water scarcities, especially for irrigation, by increasing water-use efficiency; responded to water scarcities in the south-north water transfer from the Yangtze to the Yellow River Basin; and in the process increased storage capacity by 45 Bm^3 after 2005 (FAO 2012a). Although it is not clear how these factors will affect future water-use patterns, future WDPs should take these into account in order to make accurate global projections.

Many other low- and middle-income countries increased their irrigation withdrawals significantly between 1995 and 2005: 24% by Tanzania, 10% by Bangladesh, 4.5% by Vietnam and 5.4% by Thailand. However, the projections made by the BAU scenarios show either much lower or no growth in the level of withdrawals.

The important point here is that it is not the small or large countries that matter for the WDPs; what matters are the projections of water demands, and the demand of a particular sector that has a significant influence on the development of individual countries. Given the current water-use patterns, it is highly unlikely that low- and middle-income countries will reduce their water consumption to fall in line with the projections of the BAU scenarios, let alone the sustainable use scenarios, at least in the short-term (2010-2025).

Box 2. India.

With 1.2 billion people, India accounted for 17% of the world's population in 2010 and an identical share of total water withdrawals. Between 1995 and 2010, per capita total water withdrawals increased to 32 m^3 and irrigation withdrawals increased to 25 m^3.

However, the BAU scenarios of IFPRI and Shiklomanov projected a decrease of 40-58 m^3/person of total water withdrawals, while IWMI projected a slight increase of 4 m^3/person. As a result, projections of total demand are far off from the actual trends (figures 7(d), 7(e) and 7(f)). The main reason for such large differences is the inaccurate irrigation demand projections. The following are among the main irrigation drivers:

- NIA is 20% lower than the actual level under the IFPRI and Shiklomanov BAU scenarios; and 1% lower under the IWMI BAU scenario. Total NIA growth, even under the IWMI scenario, is at least 7 Mha less than the actual NIA. All BAU scenarios were highly optimistic about increasing irrigation efficiency. However, between 1995 and 2010, India's NIA has increased by 21% and irrigation withdrawals increased by 35%, indicating hardly any increase in overall irrigation efficiency.
- Rice is the major irrigated crop. The IFPRI BAU scenario was rather pessimistic about growth in the rice area; in fact, it projected a 1 Mha less rice area by 2010, but was more optimistic about yield growth - 1.3% annual growth versus the actual of 0.6%.

It is clear that Indian policymakers have not relied much on WDPs for water development planning. Contrary to the projections of global WDP studies, the gross irrigated area has increased by 15 Mha between 1995 and 2010 (GoI 2012), irrigation withdrawals by 154 Bm^3, and total water withdrawals by 174 Bm^3. Environmental impacts, such as severe groundwater depletion, due to irrigation expansion seemed to have received less priority now (Amarasinghe et al. 2007).

India has rapidly growing services and industrial sectors. Yet, per capita water withdrawals by the domestic and industrial sectors are very low. The sub-national water demand assessments show that these two sectors will have the biggest growth in water demand in the future (GoI 1999; Amarasinghe et al. 2007). It is likely that overall water demand in India will increase in the short-term. Also, it is highly unlikely that India will bend its demand curve to meet the sustainable water development path, at least in the short- to medium-term.

Conclusions

Review of the global WDPs shows that the current water withdrawals follow a higher rate of growth than that of most post-1990 demand projections. BAU scenarios generally expect to extrapolate the past trends of key drivers. However, many subjective assumptions on demand drivers seemed to have confounded the BAU projections. The sustainable use scenarios have even lower demand growth patterns, and the assumptions on major drivers are even more conservative than those of the BAU scenarios.

Post-1990 global WDPs to 2010 under the BAU scenarios are 4-13% less than current water withdrawals. Water demand is either under- or over-projected for many countries. A major lacuna of all the studies is the absence of a sensitivity analysis. It is difficult to find which drivers are the most important for different countries and how sensitive they are for projections. Future studies should fill this gap of information separately for each of the countries, so that projections can be guiding tools for local water resource planning. Notwithstanding the above deviation, the post-1990 WDPs are a significant improvement to the pre-1990 WDPs, which over-projected global water demand by 20-130%.

The domestic sector has the lowest overall demand at present, especially in the low-income countries. All WDPs have underestimated the change in demand of the domestic sector by 15 to 97%. With rapid economic growth and urbanization, people demand much more than the basic daily requirement. The level of demand also depends on many other factors, including the ability to pay, reliability of the supply and climatic factors. The WDPs need to capture these details in order to make accurate projections.

The demand projections for the industrial sector also varied significantly. Some scenarios projected 30-58% more and some projected 50% less than the actual change in demand. The optimistic assumptions made on advancing technology, and water treatment and reuse may have contributed to these variations. However, many low- and middle-income countries have very low water withdrawals in the industrial sector at present; they may want to increase this sufficiently before they plan reuse, as suggested by the current water-use patterns. Only the most advanced countries with high industrial water withdrawals have a decreasing trajectory of per capita industrial demand. Even the BAU scenarios missed this reality.

Agriculture is the largest water use sector in most countries. One of the major weaknesses of global WDPs is their inability to accurately project the irrigation demands. Having said that, the irrigation sector is also the most complex for making demand projections. Many drivers, both endogenous and exogenous to the countries, affect irrigation demand. They vary significantly between and within countries. This is the reason why actual water use in many countries differs significantly from those projected by the global WDPs. Ideally, the demand projections should take these factors into account. Otherwise, global WDPs have little or no value for local water resource planning, regardless of the size of the country or the magnitude of water use.

The review presented in this paper seemed to depict a rather negative picture of all global water demand projections. Indeed, it shows that even with sophisticated modeling tools, it is extremely difficult to make water demand projections even for the medium-term of 10-15 years. Post-1990 WDPs incorporated significantly more drivers of water demand, yet they are also significantly incorrect in predicting the current water-use patterns. The difficulty of making accurate projections lies in tracing the trends of key demand drivers for each country. Clearly, detailed country-level and sub-national studies for large countries should assess the changing demand patterns.

In spite of the inaccuracies, global water supply and demand studies still have many benefits. First, they can incorporate details of water flows between countries through food trade, which could be a critical factor in mitigating water demand in already water-scarce regions. Second, they highlight the hot spots: Regions or basins with physical or economic water scarcity or unsustainable water use, and sound urgent need for action and change. Third, they develop a methodology, which can be used by local and national policy and governance institutions, and researchers. Fourth, the results include key information for global change. This is especially important due to climate change, where many change agents are global but the impacts are local. Water falls into this category.

Reviews of past WDPs offer many valuable lessons for future projection studies. The latest is the new global projection study, 'Water futures and solutions: World water scenarios', which is a collaborative initiative of the International Institute for Applied Systems Analysis (IIASA); International Water Association (IWA); Ministry of Land, Infrastructure and Transport, Republic of Korea; United Nations

Educational, Scientific and Cultural Organization (UNESCO); and the World Water Council (WWC). The main objective of this initiative is to produce "a new generation of global, science-based and stakeholder-informed water scenarios that are relevant and useful to the stakeholders and are fully consistent with global scenarios being developed in other sectors and disciplines, particularly those of the Intergovernmental Panel on Climate Change (IPCC)." The IPCC scenarios add further complexity to this projection study; it should, therefore, take into account the strengths and weaknesses of the past WDPs developed a decade ago. The global projections are good as long as the local projections are accurate and offer value for local water resource planning, because water development and management, and the impacts that can occur are mostly local.

The review in this paper offers a few possible lessons for future global water demand projection studies.

1. Short-term WDPs — five- to ten-year duration — could provide an accurate future outlook, and they have more value for country-level water resource planning. Long-term projections, especially under sustainable use scenarios, provide good input to countries that already have substantial overdevelopment and scarcity issues.

2. Assuming constant norms of per capita water use for countries or sectors is not recommended, because they depend on many exogenous factors including economic growth, lifestyles, access to technology, financial affordability, social and environmental constraints, and climatic conditions.

3. Detailed trend analyses of land and water use, and climatic patterns are necessary. They offer the critical and important insights necessary for making realistic assumptions on growth rates of key drivers, especially for assessing agricultural water demand.

4. Detailed sub-national analyses of food demand and supply, and cropping patterns are imperative for determining credible WDPs in medium to large countries, and offer value for irrigation planning even in small countries. This is very important because irrigation constitutes a large portion of total water withdrawals of many large and small developing countries.

5. Detailed analysis is also necessary for assessing the domestic per capita water demand for individual countries. At present, a large number of low- and middle-income countries have meager domestic water withdrawals. Also, many factors, other than economic growth and urbanization, seemed to influence domestic water demand.

6. Detailed analysis of the industrial sector is also needed. Majority of the developing countries have very low industrial water withdrawals. Large and small industries are clamoring for sustainable water security. Also, a vibrant Industrial sector is a vital arm of economic growth and vice versa.

7. No less important are the other sectors of water use. This review did not include the water demand for the hydro and thermal power sectors, minimum flows for the environmental sector, or water for navigation. Some of these have low consumptive water use. However, explicit water allocation to these sectors may lead to higher overall consumption, and stiffer competition for water from other sectors.

8. The sensitivity analyses of projections, especially with respect to key drivers, are important for countries for making well-informed and calculated planning decisions.

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